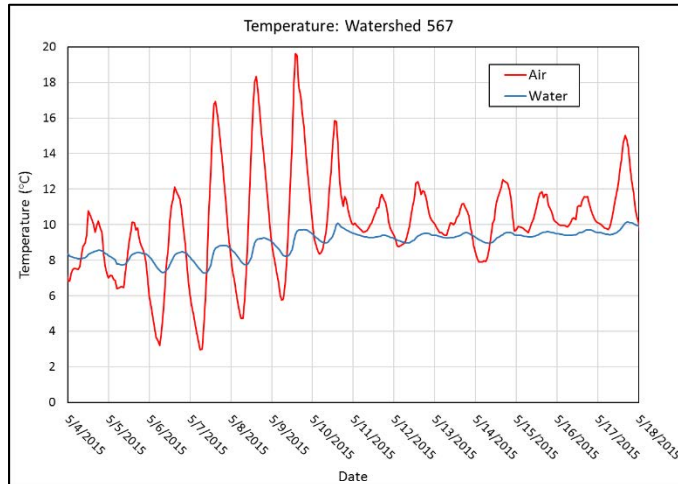


# Status and Trends Monitoring of Riparian and Aquatic Habitat in the Olympic Experimental State Forest

Monitoring Protocols

**November 2022  
Revision**



**This protocol compendium was originally published in March 2017. Since then, many of the chapters have been revised, as listed in this table, for improved clarity or to reflect changes in methodology made to increase efficiency and accuracy of monitoring. The revision history of each protocol is summarized at the beginning of each chapter.**

<b>Chapter</b>	<b>Last revision date</b>
Introduction	March 2017
1. Site Establishment	March 2017
2. Channel Morphology	March 2017
3. Stream Shade	June 2018
4. Channel Substrate	June 2022
5. In-stream Large Wood	June 2022
6. Habitat Units, Valley and Channel Classification	June 2019
7. Stream Temperature	June 2019
8. Stream Discharge	November 2022
9. Stream Discharge Data Management and Analysis	November 2022
10. Riparian Microclimate	March 2017
11. Riparian Vegetation	March 2017
12. Riparian Down Wood	August 2022
Glossary	March 2017

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# Acknowledgements

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## Acronyms and Abbreviations

**7-DADmax:** 7Day Average Daily Maximum Temperature

**BFD:** Bankfull Depth

**BFW:** Bankfull Width

**DEM:** Digital Elevation Model

**EPA:** Environmental Protection Agency

**ESA:** Endangered Species Act

**HCP:** Habitat Conservation Plan

**GIS:** Geographic Information Systems

**GPS:** Global Positioning System

**LED:** Light-Emitting Diode

**LEW:** Left Edge of Water

**LiDAR:** Light Detection and Ranging

**LWD:** Large Woody Debris

**OESF:** Olympic Experimental State Forest

**ONP:** Olympic National Park

**PNW:** USDA Forest Service Pacific Northwest Research Station

**PVC:** Polyvinyl Chloride

**REW:** Right Edge of Water

**RP:** Reference Point

**TFW:** Timber, Fish, and Wildlife Agreement for Washington State Forest Practices

**USGS:** United States Geological Survey

**WADNR:** Washington Department of Natural Resources

**WADOE:** Washington Department of Ecology



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## Executive Summary

Presented here are the monitoring protocols for the project Status and Trends Monitoring of Riparian and Aquatic Habitat in the Olympic Experimental State Forest (OESF). This long-term study documents changes in riparian and stream conditions within the OESF – 270,000 acres (110,000 ha) of state trust lands managed by the Washington State Department of Natural Resources (WADNR).

The procedures and analyses described in this document will yield the empirical data needed to address key uncertainties regarding the integration of timber production and habitat conservation across landscapes and assess progress toward achieving the conservation objectives stated in the State Trust Lands Habitat Conservation Plan (HCP). The HCP calls for the provision of habitat for viable salmonid populations and riparian-obligate species. The OESF watersheds are managed under an experimental “integrated management” approach which includes riparian buffers with varied-width and blending forest management and habitat conservation at stand and landscape level. In a broader framework, the OESF as part of the USDA Forest Service Experimental Forest and Range Network, provides opportunities for research and education to improve our understanding of Pacific Northwest ecosystems and natural resource management. Riparian status and trends monitoring provides a basis for ancillary research and collaboration with universities, regulatory agencies, various stakeholder groups including tribes, conservation groups, and the timber industry.

The working hypothesis for riparian management within the OESF is that current stream and riparian protections allow natural disturbance and ecological succession to improve aquatic and riparian habitat over time. The expected improvement trend is from the degraded habitat conditions prior to adoption of the 1997 HCP towards a range of habitat conditions reflective of the region’s natural variability.

Key indicators of stream and riparian habitat are monitored at 50 watersheds representative of the OESF and four reference watersheds in Olympic National Park. The monitored watersheds are those of small, fish-bearing streams and range in size from 0.04 to 3 square miles (0.2-7.9 km<sup>2</sup>).

Detailed monitoring protocols are developed for nine habitat attributes: stream temperature, channel morphology, stream shade, channel substrate, in-stream-large wood, habitat units and channel classification, stream discharge, riparian microclimate, and riparian vegetation. They describe field and data management procedures for all habitat measurements required by the project. The standardized protocols and robust quality assurance and quality control procedures in this document are essential to ensure the accuracy and repeatability of measurements needed to characterize site conditions and temporal trends over the duration of the project.

Detection of trends in the monitored indicators will require several years of observation due to many factors, including high inter-annual variability and the rate of response to site and watershed-scale changes. Monitoring is expected to continue for at least 10 years, at which time the project’s value to WADNR will be assessed.

## ■ Introduction

Project results will be used to evaluate the effectiveness of HCP conservation strategies, test the habitat projections in the Environmental Impact Statement for the OESF Forest Land Plan, and assess fish response to forest management – contributing to the validation monitoring required by the HCP. In concert with information on OESF land management activities, the results will also facilitate inferences about management impacts on habitat, thus contributing to the adaptive management required by the HCP.

More information about this monitoring project, including study plan, progress reports and first habitat status report are available on WADNR website at <http://www.dnr.wa.gov/programs-and-services/forest-resources/olympic-experimental-forest/ongoing-research-and-monitoring>

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■ Introduction

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# Introduction

This document includes monitoring protocols for the project Status and Trends Monitoring of Aquatic and Riparian Habitat in the Olympic Experimental State Forest (OESF). It describes detailed field and data management procedures for all habitat measurements required by the study.

Standardized environmental monitoring protocols are necessary to characterize the conditions of multiple study sites, describe temporal trends, compare information among different projects, and ensure repeatability of measurements amid changing project staff (Bain and Stevenson 1999, McMahon et al. 1996).

## Monitoring Protocols

### PURPOSE

The purpose of the monitoring protocols is to describe: (1) field and office procedures for sampling aquatic and riparian habitat indicators identified in the project study plan (Minkova et. al 2012); (2) quality assurance and quality control steps; and (3) data management procedures necessary to document and report the status and trends of habitat indicators in the monitored watersheds.

### ORGANIZATION AND CONTENT

This document includes 11 monitoring protocols, organized as stand-alone chapters with their own tables of contents, appendices, and lists of references. One protocol describes field procedures for site establishment. Nine protocols focus on the monitored habitat attributes: stream temperature, channel morphology, stream shade, channel substrate, in-stream large wood, habitat units and valley and channel classification, stream discharge, riparian microclimate, and riparian vegetation. Because of the multiple steps and complexity of stream discharge data management and analyses, the office procedures for this indicator are described in a separate protocol.

Each protocol includes a title page describing the revision history and the literature sources it is based on. This is followed by a description of the protocol's monitoring design, a list of the equipment and supplies needed for sampling, detailed field procedures, procedures for calculating metrics, and a section on data management. Given the longevity of the project (at least 10 years), turnover among seasonal field technicians, and the participation of multiple researchers from different organizations, it is critical to develop robust quality assurance (QA) and quality control (QC) procedures. QA/QC procedures for field data collection and data management are described separately in each protocol.

### PROTOCOL DEVELOPMENT AND FUTURE UPDATES

The monitoring protocols were written by the project's research team and six protocols were peer-reviewed by two external specialists from the USDA Forest Service Pacific Northwest Research Station (PNW RS) as early drafts: Stream Temperature, Channel Morphology, Stream Shade, Channel Coarse Substrate, In-stream Large Wood, and Habitat Units, Valley and Channel Classification.

The field and data management protocols published in this document are expected to be updated as technology advances, new knowledge is gained, and field procedures are refined. To ensure high-quality and consistent data collection over time, all changes to the published protocols will be approved by the project manager or the researcher overseeing protocol implementation. Updated protocols will be assigned new version numbers and publication dates. Owing to sampling dependencies among protocols (e.g. channel substrate and morphology sampling are conducted together), field procedure updates may necessitate changes in other, dependent protocols. Specific dependencies are described in the protocols.

### ***Study Goal and Objectives***

The project is organized as an extensive, long-term monitoring study of habitat attributes in watersheds representative of the OESF. These watersheds are managed by the Washington State Department of Natural Resources (WADNR) with the dual objectives of producing revenue (primarily through timber harvest) and ecological values (such as biological diversity and long-term site productivity). The riparian conservation strategy described in the State Trust Lands Habitat Conservation Plan (HCP) aims to provide habitat for viable salmonid populations and other riparian-obligate species (WADNR 1997).

The study will test the hypothesis that current stream protection such as riparian buffers, protection of unstable slopes, and road improvements allows the natural processes of disturbance and succession to improve riparian and aquatic habitat over time. The improvement is relative to the habitat conditions before the adoption of the 1997 state lands HCP (WADNR 1997).

This monitoring project tracks habitat conditions across the OESF as WADNR implements the OESF Forest Land Plan (WADNR 2016b). Specific monitoring objectives include assessing the habitat projections in the Environmental Impact Statement for the OESF Forest Land Plan (WADNR 2016a) and testing assumptions about ecological relationships among in-stream, riparian, and upland conditions, thus providing information that will help improve WADNR's forest management planning. When integrated with information on management activities in the OESF, the monitoring data will help researchers make inferences about management effects on habitat, contributing to the effectiveness monitoring and adaptive management required by the HCP (WADNR 1997). Additionally, monitoring data will be used to characterize habitat conditions to study fish response to managed landscapes, contributing to the OESF riparian validation monitoring (Martens 2016). The project's findings are expected to provide valuable information relevant to tribal, private, and federal land managers in the Pacific Northwest who face the challenge of managing forests for multiple uses.

The monitoring project started in 2012 and is planned to continue for at least 10 years. A study plan (Minkova et al. 2012), annual progress reports (Minkova and Vorwerk 2013, Minkova and Vorwerk 2014, Minkova and Devine 2015), a quality control report (Devine and Minkova 2016) and the first habitat status report (Minkova and Devine 2016) are available on the WADNR website at <http://www.dnr.wa.gov/programs-and-services/forest-resources/olympic-experimental-forest/ongoing-research-and-monitoring>.

## Spatial Design of the Study

### STUDY AREA

The OESF includes 110,000 ha (270,000 ac) of state trust lands on the Olympic Peninsula in Washington State. The OESF ranges in elevation from 0 m to 1,050 m (3,500 ft) and is characterized by steep, erodible terrain. The regional climate is strongly influenced by the Pacific Ocean. The area receives heavy precipitation, ranging from 203 cm to 355 cm (80–140 in) per year, with the majority falling as winter rain. Small fish-bearing and headwater streams are abundant within a dense network of streams and rivers exceeding 4,000 km (2,500 mi) in length.

The Sitka spruce (*Picea sitchensis*) vegetation zone dominates along the coast from 0 to 150 m (500 ft), while a majority of the OESF falls within the western hemlock (*Tsuga heterophylla*) zone, with western red cedar (*Thuja plicata*) found in the wetter areas (Franklin and Dyrness 1988). The Pacific silver-fir (*Abies amabilis*) zone extends higher in elevation from 550 to 1,300 m (1,800 to 4,300 ft). Douglas-fir (*Pseudotsuga menziensis*) is a seral component in all zones; red alder (*Alnus rubra*) is common in riparian zones and recently disturbed areas at lower elevations (below 550 m). The entire area is characterized by a very high tree-growth rate. Old growth forest, which once dominated the landscape, is still present on 11 percent of the OESF. About half of the OESF is dominated by young (0- to 50-year-old) stands.

Riparian areas in the OESF provide habitat for a diversity of fish taxa, including nine resident anadromous salmonid species: sockeye salmon (*Oncorhynchus nerka*), pink salmon (*O. gorbuscha*), chum salmon (*O. keta*), Chinook salmon (*O. tshawytscha*), coho salmon (*O. kisutch*), steelhead trout (*O. mykiss*), coastal cutthroat trout (*O. clarkii clarkii*), bull trout (*Salvelinus confluentus*), and mountain whitefish (*Prosopium williamsoni*). In addition, 17 species of non-game fish, including dace (*Cyprinidae spp.*), lampreys (*Lampetra spp.*), minnows (*Phoxinus spp.*), suckers (*Catostomus spp.*), and sculpins (*Cottus spp.*), may also be found in the OESF (WADNR 2013). Bull trout and the Lake Ozette sockeye are the only fish species on the peninsula listed as threatened under the Endangered Species Act (ESA). Multiple other aquatic, riparian obligate, and terrestrial species depend on riparian and aquatic systems in the OESF, including the federally listed northern spotted owl (*Strix occidentalis caurina*) and marbled murrelet (*Brachyramphus marmoratus*).

Windthrow caused by ocean winds is the most prevalent natural disturbance in the OESF. Moist conditions generally limit wildfire occurrence in the region. However, wildfire frequency and extent are expected to increase on the Olympic Peninsula under recent climate change projections (Halofsky et al. 2011). Soil erosion, landslides, floods, and debris flows are common hillslope-and stream channel-scale disturbance processes.

WADNR manages state trust lands in the OESF for revenue production (primarily from timber harvest) and ecological values (primarily habitat conservation) through an approach called “integrated management.” This is an experimental management approach based on the principle that a forested landscape can be managed by blending active management (such as tree planting, thinning, and stand-replacement harvest) with habitat conservation (such as provision for salmonid and spotted owl habitat)

across the landscape. Integrated management is rooted in the concept of disturbance ecology, which recognizes a natural mosaic of successional stages that shift in time through disturbances. This approach differs from the more common conservation-biology approach that divides forested areas into large blocks, each managed for a single purpose such as late-successional habitat in late-successional reserves or timber production in the forest matrix. A notable element of the integrated management approach in the OESF is the ability to vary the width of the riparian buffers based on the overall health of a watershed. Implementation of this approach is described in detail in the OESF Forest Land Plan (WADNR 2016b).

The current sustainable harvest level for the OESF is 576 million board feet per decade (WADNR 2007). An average of 1,475 ac (596 ha) of state trusts lands in the OESF (0.55% of the land base) have been harvested annually since the adoption of the HCP in 1997 (WADNR 1997). The main harvest methods on state lands in the OESF are variable retention harvest, commercial thinning, and variable density thinning. OESF conservation goals, described in the HCP, focus on restoring levels of habitat capable of supporting viable salmonid populations, spotted owls, and marbled murrelets with the expectation that this will also provide habitat for other native fish and wildlife species (WADNR 1997).

### LOCATION OF THE MONITORED WATERSHEDS

The Type 3 watershed<sup>1</sup> (watersheds around the smallest fish-bearing streams) was selected as the sampling unit for the study because it is the smallest hydrologically complete unit, Type 3 watersheds are relevant to both the riparian ecological processes that provide salmonid habitat (such as sediment production and transport, wood production and transport to streams, and the hydrologic cycle) and to WADNR management activities in the OESF (primarily timber harvest and road management). The Type 3 watershed is also the spatial unit used for the environmental impact analyses of the OESF Forest Land Plan (WADNR 2013).

A sample size of 50 OESF Type 3 watersheds was selected based on previous studies that determined  $n=50$  to be sufficient to provide enough statistical power to detect relatively small trends (1–2% per year) in habitat indicators within a decade (Larsen et al. 2004; Reeves et al. 2004). The 50 sample watersheds were selected to represent the entire population of Type 3 watersheds in the OESF in terms of ecological conditions and management history of the forest (Figure i-1). Refer to the study plan (Minkova et al. 2012) for a description of the watershed selection process and to Minkova and Vorwerk (2014) for a description of modifications of the process following a statistical review of the spatial design.

In addition to the 50 watersheds on the OESF, four reference watersheds are monitored in the adjacent Olympic National Park (ONP). They are Type 3 watersheds that drain into Queets, Bogachiel, Hoh and South Fork Hoh rivers (Figure i-1). The reference watersheds were selected to be ecologically similar to the OESF watersheds and readily accessible by established hiking trails. The purpose of the reference

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<sup>1</sup> The smallest fish-bearing stream as identified through biological criteria (fish presence) or physical criteria (a stream  $\geq 0.7$  m [2 ft] wide with a  $\leq 16\%$  gradient for watersheds up to 20 ha [50 ac] or with a gradient between 16% and 20% for watersheds larger than 20 ha [50 ac]). Type 3 streams can be considered loosely equivalent to Strahler's 3<sup>rd</sup> order streams.



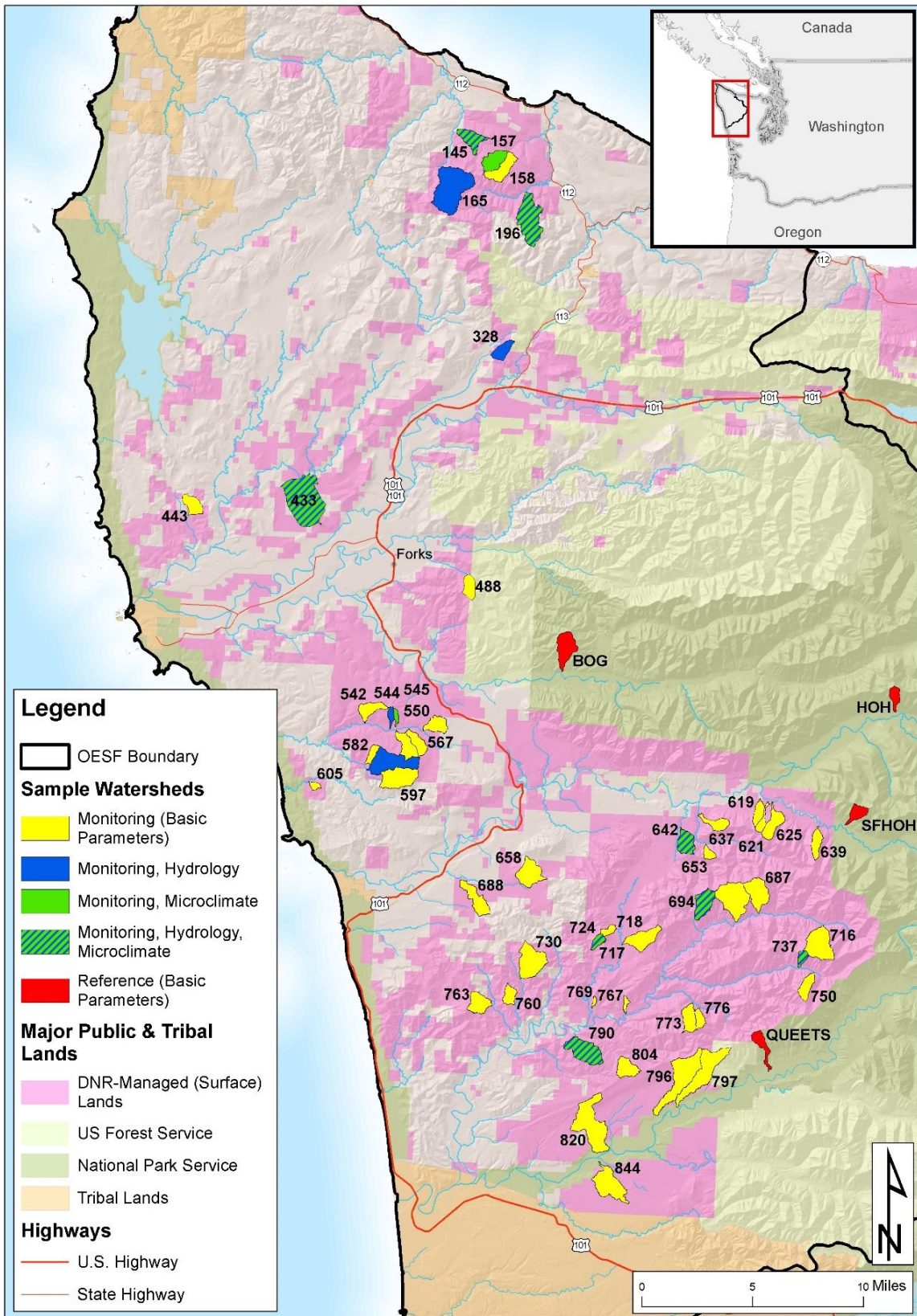


Figure i-1. Map of the study area. Fifty monitored watersheds are located in the Olympic Experimental State Forest (OESF); four reference watersheds are located in Olympic National Park.

## ■ Introduction

sites is to: 1) inform about habitat complexity in unmanaged (pristine) watersheds under natural disturbance regimes, and 2) help assess natural background variation that may impede detection of the OESF watersheds' response to management.

All sample watersheds were selected for monitoring using a stratified random design. Watersheds identified as prospective sample sites were screened remotely in the office and visited to determine their suitability. Refer to the two establishment reports (Minkova and Vorwerk 2013, 2014) for description of the process.

### **LOCATION OF THE SAMPLE SITES**

The aquatic and riparian habitat conditions of each watershed are monitored at the most downstream section of the Type 3 stream and the adjacent riparian area (refer to Figure 1-1 in the Site Establishment Protocol). Channels transmit the impacts of land use disturbances from headwater areas down through drainage networks (Reid 1993), so the conditions in a waterway's most downstream reach should represent the response to changes throughout the watershed. For example, the most downstream reach is expected to have greater variation in stream morphology as a result of sediment delivery, debris inputs, and peak flow compared to upstream reaches within the watershed (Montgomery and McDonald 2002).

In addition to field monitoring at the sample reach, potential watershed-level disturbances such as land management (e.g., timber harvest, road management, and road use) and natural disturbances (e.g., windthrow and landslides) are monitored remotely within each of the 54 watersheds (Minkova et al. 2012). Data on these stressors are collected retrospectively and prospectively using remote-sensing tools and operational records, with the objective of linking reach-level habitat data to watershed-wide changes using analytical approaches such as regression analysis and multi-model-based inference.

### **LAYOUT OF A SAMPLE REACH**

The length of a sample reach is 20 times the channel width, or at least 100 m. This is a useful scale over which to relate stream morphology to channel processes, response potential, and habitat characteristics (Montgomery and Buffington 1997). Each sample reach includes a permanent benchmark (reference point) and six permanent cross sections installed at five equally spaced intervals (refer to Figure 1-2 in the Site Establishment Protocol).

In all 54 watersheds, eight habitat indicators are sampled at the reach scale: 1) channel morphology (gradient, confinement, depth, width, and sinuosity); 2) channel substrate; 3) in-stream large wood, 4) valley and channel classification; 5) habitat units (such as pools); 6) stream shade; 7) water temperature; and 8) riparian vegetation. In addition, stream discharge is monitored in 14 OESF watersheds and riparian microclimate is monitored in 10 OESF watersheds.

## Temporal Design of the Study

### SAMPLING APPROACH

The temporal component of the sampling design influences the study's capacity to detect long-term trends across a variety of habitat attributes. The sampling frequency of each habitat attribute was chosen to balance the need for enough sites to characterize habitat status across the OESF with the need for enough visits per site to characterize habitat trends over time. This balance between the spatial and temporal sampling effort is a result of finite resources available for sampling in each field season.

The temporal sampling strategy for each habitat attribute is also a function of the temporal variability of the attribute. Whereas some habitat attributes have low inter-annual variability and measurement variability (i.e., measurement error) and do not require frequent sampling to detect trends, other attributes have high inter-annual or measurement variability and therefore require more frequent sampling to detect underlying trends. Therefore, in developing the temporal sampling design, we relied heavily on an analysis of temporal and measurement variability of 33 of the metrics monitored under this project (Devine and Minkova 2016).

### SAMPLING FREQUENCIES

Based on our understanding of the range in temporal variability among habitat attributes, and given our current level of resources for field work, we selected three levels of sampling intensity for this study:

- **High-frequency field sampling.** This approach is for attributes that must be measured manually by a field crew and that have a relatively high level of temporal or measurement variability.
- **Low-frequency field sampling.** This approach is for attributes that must be measured manually by a field crew and that have a relatively low level of both temporal and measurement variability.
- **Continuous sampling.** This sampling is limited to habitat attributes that meet two criteria: (1) the attribute changes at a frequency of minutes or hours and thus necessitates continuous sampling, and (2) it is possible to sample the attribute by using automated sensors.

#### *High-frequency field sampling*

Some manually sampled habitat attributes, such as channel width and depth, habitat units, substrate, and in-stream large wood, are expected to change relatively rapidly as a result of natural stream flows and sediment delivery (Montgomery and Buffington 1997) or potentially anthropogenic disturbances such as road management and timber harvest. Additionally, attributes such as substrate and erosion have an inherently high level of measurement variability (Devine and Minkova 2016). For these reasons, this group of attributes is sampled relatively frequently.

There are several potential sampling strategies for monitoring regional ecological trends with finite sampling resources, each strategy balancing spatial and temporal sampling intensities in different ways (Urquhart et al. 1998). In our case, we have the resources to measure the high-frequency habitat attributes in approximately 28 to 30 of the 54 sample reaches each year. We selected a temporal sampling design

for these attributes that uses a combination of annually sampled “sentinel” reaches and a 3-year rotating panel of the remaining reaches for a total of 28 to 29 reaches sampled per year (Table i-1). The 16 sentinel reaches include the 4 reference reaches plus 12 OESF reaches selected to represent all of the strata that were originally used in the study plan during selection of the 50 OESF sample reaches. The remaining 38 OESF reaches are sampled on a 3-year panel rotation, with 13, 13, and 12 sites sampled in each of the three years. This combined sampling strategy is designed to capture the attributes’ inter-annual variability using the sentinel sites, while sampling the rotating panel sites at an interval that is still frequent enough—at 3 years—to identify long-term trends. This sampling design will be implemented starting in 2017, as all of these attributes had been measured at least once in every reach by 2016.

**Table i-1. Temporal sampling design for status and trends monitoring of riparian and aquatic habitat attributes in the OESF. Values in the table represent the number of watersheds/reaches in which a habitat attribute is monitored in the specified year.**

Attribute	2013-2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
<i>High-frequency field sampling (16 annual sentinel reaches plus a 3-year rotating panel of 13/13/12 reaches)</i>												
Channel width, depth, floodplain width	42	12	45	29	29	28	29	29	28	29	29	28
Channel substrate	42	12	45	29	29	28	29	29	28	29	29	28
Channel erosion	41	13	47	29	29	28	29	29	28	29	29	28
In-stream large wood	41	13	45	29	29	28	29	29	28	29	29	28
Habitat unit survey	40	14	40	29	29	28	29	29	28	29	29	28
<i>Low-frequency field sampling (5-year sample rotation, divided among 2 or 5 years)</i>												
Channel gradient, azimuth	42	12	0	0	0	27	27	0	0	0	27	27
Channel sinuosity	39	12	0	0	0	27	27	0	0	0	27	27
Stream shade	35	8	13	7	10	11	11	11	11	10	11	11
Riparian vegetation	10	31	6	7	10	11	11	11	11	10	11	11
<i>Continuous sampling (using electronic data loggers)</i>												
Stream temperature	54	54	54	54	54	54	54	54	54	54	54	54
Riparian microclimate	10	10	10	*	*	*	*	*	*	*	*	*
Stream discharge	14	14	10	10	10	10	10	10	10	10	10	10

\* Sampling of microclimate beyond 2016 will be based on results of 2014-2016 sampling.



### ***Low-frequency field sampling***

Habitat attributes expected to change more slowly over time—channel gradient and azimuth, channel sinuosity, stream shade, and riparian vegetation—are measured at five-year intervals after the initial measurement is completed at all sites. For example, data collected thus far indicate that channel gradient and stream shade can be measured with a relatively high degree of precision and change little from one year to the next (Devine and Minkova 2016; Minkova and Devine 2016). For practical reasons, these low-frequency sampling efforts are spread over 2 years (for channel gradient, azimuth, and sinuosity) or 5 years (for stream shade and riparian vegetation).

The sampling schedule for both low-frequency and high-frequency habitat attributes may be adjusted as a result of: (1) new insights on temporal and spatial variability of attributes as more data are accumulated, (2) a major natural disturbance in the study area, or (3) changes to the funding levels for the program. If a major natural disturbance occurs (e.g., a debris flow, landslide, or earthquake), the affected reaches will be re-sampled as soon as possible for all habitat attributes regardless of the original sample schedule. Every sample reach will be visited at least once per year to download stream temperature data loggers, and during that visit field personnel will perform a reconnaissance of the sample reach and immediate vicinity to determine if any major disturbance has occurred since the last visit.

### ***Continuous sampling***

In this project, continuously sampled habitat attributes are stream temperature, riparian microclimate, and water level (for hydrologic monitoring). These three attributes are monitored continuously year-round using electronic data loggers. Stream temperature data loggers, installed in all 54 watersheds, record every 60 minutes; for the western Olympics, this interval provides a less than one percent probability of missing the maximum and minimum daily temperatures (Dunham et al. 2005). Temperature data loggers are downloaded at least once per year. Microclimate data loggers record air temperature and humidity every 120 minutes in 10 OESF watersheds, and are downloaded at least twice per year. Microclimate conditions are quantified by sampling for three full years at the beginning of the project (2014-2016). Based on the results of this sampling, a determination will be made when to conduct additional microclimate sampling in same watersheds.

For hydrologic monitoring, gage station data loggers record water level every 15 minutes year-round in 10 OESF watersheds. Additionally, manual stream discharge measurements are made periodically at each sample reach to create a relationship between water level and discharge, thereby allowing discharge to be calculated from each water level reading. Manual stream discharge measurements are made 8-10 times during the first year of monitoring and 4-6 times in subsequent years, unless there is a significant change in the stream channel. Such a change necessitates 8-10 discharge measurements to reestablish the water level-discharge relationship. In addition to these measurements, annual stream channel cross-section and gage stability surveys are required for hydrologic monitoring.

## IMPLEMENTATION

All monitoring sites in OESF and reference watersheds were established from 2012 to 2014. The first round of field sampling was completed for most attributes from 2013 to 2015 (Minkova and Devine 2016). Installation of the continuously recording electronic data loggers measuring stream temperature, riparian microclimate, and water level (used to calculate stream discharge) was completed in 2012 and 2013.

This long-term monitoring project will continue for at least 10 years, when the first robust habitat trend results are expected and at which point the project's value for WADNR will be reassessed. Many years of monitoring will be required to detect any trends in habitat attributes because: (1) some metrics respond slowly to watershed-scale environmental change; (2) some metrics have high inter-annual variability; and (3) some metrics have high measurement variability. Similar monitoring projects (e.g. Watershed Condition Status and Trends Monitoring for the Northwest Forest Plan [Lanigan et al. 2012]) report habitat trends every five years. Trends in OESF watersheds also will be reported every five years.

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# Site Establishment

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**Version:** 1.2

## *Revision History:*

Protocol Version	Purpose / Changes	Author(s)	Reviewer(s)	Date
1.0	Initial draft	Teodora Minkova, Mitchell Vorwerk, Ellis Cropper		10/23/2014
1.1	Final draft with field and data management procedures updated from 2014 and 2015 field seasons	Teodora Minkova, Mitchell Vorwerk, Ellis Cropper	Alex Foster	06/10/2016
1.2	Final technical review and edit	Teodora Minkova Mitchell Vorwerk, Ellis Cropper	Paul Dunnette, Warren Devine, Alex Foster	12/18/2016

## *Based on the Following Protocols:*

This protocol is based on two protocols prepared for the Washington Department of Natural Resources under the Timber, Fish, and Wildlife Agreement (TFW): TFW Monitoring Program methods manual for stream segment identification (Pleus and Schuett-Hames 1998a) and TFW Monitoring Program methods manual for reference point survey (Pleus and Schuett-Hames 1998b).

## *Reasons to Adopt the Above Protocols:*

TFW protocols were created for long term-monitoring projects that are implemented over several years by seasonal field crews with various levels of experience. Consequently, the protocols are detailed, well-illustrated, and thorough in addressing unusual circumstances encountered in the field. The field procedures have been tested in western Washington watersheds and are similar to protocols from other regional aquatic monitoring efforts in the Pacific Northwest.

## *Purpose and Content:*

The purpose of this monitoring protocol is to describe the site establishment procedures and data management necessary to repeatedly locate the sampling points used in this long-term monitoring project. The protocol details the field procedures for identifying the start of a sample reach and establishing permanent cross sections, a reference point (benchmark), and a photo point.

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## Monitoring Design

Long-term monitoring requires repeated visits to sample sites, often by different crews and at long time intervals. Establishment of a permanent, monumented reference point (benchmark) and permanent cross-sections in each sample reach ensures that data collection will occur at the same locations during every visit.

The field procedures described in this protocol are implemented in 50 sample watersheds in the Olympic Experimental State Forest (OESF) and four reference watersheds in Olympic National Park (ONP). Refer to Figure i-1 in the Introduction chapter for a map of the sample watersheds.

All sample reaches in the OESF were established in 2013 and 2014. The ONP reference sites were established in 2015. Reach locations are not expected to change unless a major disturbance necessitates relocating a monitoring site.

## Equipment and Supplies

The following equipment and supplies are needed for the establishment of a monitoring site:

- Ruggedized field tablet or paper field forms
- Panasonic™ Lumix Camera and battery charger
- Resource-grade GPS (e.g. Trimble™ Pro XT or Trimble™ Pro XH) with receiver, external antennae, and batteries
- Field calculator
- Chalk
- 5-ft metal u-bar fence post
- Rebars, 2-ft length ,0.5 in diameter (12-13 per sample reach)
- Wooden stakes, 2-ft length (ONP) (14 per sample reach)
- Orange plastic mushroom rebar caps (12-13 per sample reach)
- Rectangle aluminum tags and wires (12-17 per sample reach)
- Nails
- Blue spray paint
- Pink plastic flagging
- Red biodegradable flagging (ONP)
- Permanent marker
- 4 lb sledge hammer
- HDX fence post driver (optional: a 4 lb hammer usually works just as well and may even be safer)

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- Sighting compass (e.g. Silva Ranger<sup>®</sup>)
- 50-meter tapes (2)
- Chaining pins (2)
- Spring clips (4)
- Stadia rod
- Installation field form

### PRE-FIELD SETUP

Check the batteries for the ruggedized field tablet and Panasonic<sup>™</sup> Lumix camera. Paint the rebars blue with spray paint (optional). Adjust current declination on compass.

## Field Procedures

### IDENTIFYING THE START OF THE SAMPLE REACH

First, measure the 100-year floodplain of the mainstem (i.e. larger stream) receiving flow from the Type 3 stream selected for the sample reach. Sample reaches must start beyond the floodplain of the mainstem to avoid water mixing and other disturbances caused by high flows (Figure 1-1).

Establish the bankfull stage of the mainstem at its confluence with the Type 3 stream. Bankfull stage represents the dominant discharge associated with channel-forming events (refer to the Channel Morphology protocol for a description of bankfull stage indicators). Stand at the deepest point of the mainstem at the confluence holding a stadia rod vertically with the rod bottom end placed on the stream bed. Find the bankfull stage on the stadia rod, double the measurement, and mark this value with flagging on the stadia rod. Use a 50-meter tape or clinometer to project a straight, horizontal line from the mark on the stadia rod toward the Type 3 stream and perpendicular to the mainstem channel. The point where the imaginary line touches the water surface of the Type 3 stream is the extent of the 100-year floodplain of the mainstem.

The start of the sample reach can be moved upstream to avoid side channels, undercut banks, channel bends, log jams that could be dangerous to field crews or monitoring equipment, or other irregularities. Refer to the *Special Circumstances* section below. If no surface water is present, establish the reach start where steady flow begins (not just standing water).

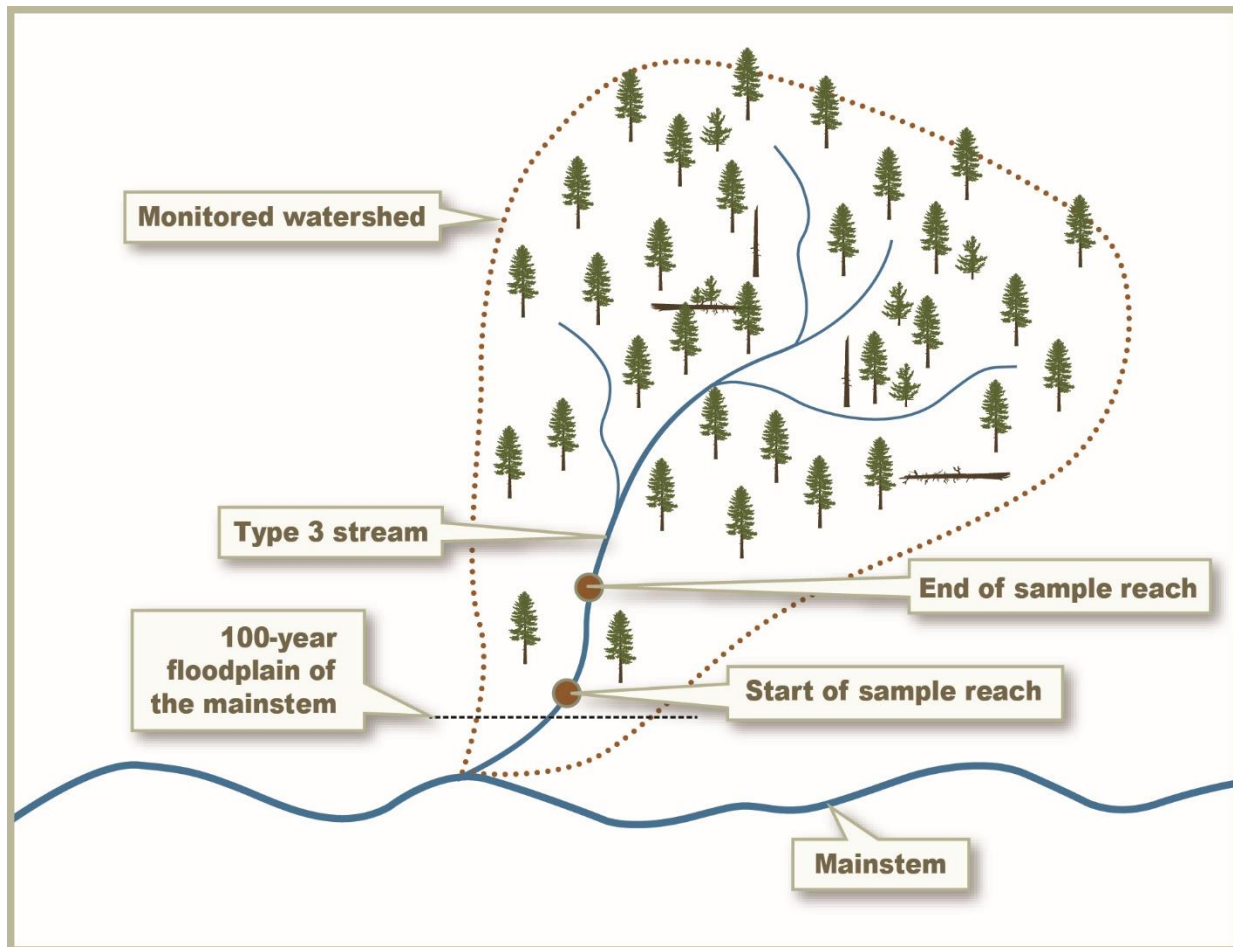


Figure 1-1. Schematic of a sample reach in a monitored watershed.

## DETERMINING SAMPLE REACH LENGTH AND ESTABLISHING PERMANENT CROSS SECTIONS

The length of a sample reach is determined as 20 times the bankfull width at the start point (cross section A). If the width is less than 5 m, the reach length is 100 m. Each sample reach includes six permanent cross sections installed at five equally spaced intervals (Figure 1-2). The cross sections are delineated by permanent rebar monuments placed on each stream bank.

First, establish cross section A, which serves as a permanent marker for the reach start.

Find stable locations on each bank, well outside the bankfull stage, that create a cross section perpendicular to the stream.

Use the 4 lb sledge hammer to pound the rebar into the ground, a log, a root, or a rock until only 6-8 inches of rebar is visible. Make sure the rebar is secure; if it is loose, find a different position on the same perpendicular line. Once the rebar is installed, spray it with blue paint (or use a pre-painted rebar) and place

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an orange plastic mushroom cap on top. Mark the rebar with pink flagging and an aluminum tag affixed with stainless wire. Label the top of the orange cap, both sides of the flagging, and both sides of the aluminum tag with the corresponding letter for the cross section (i.e. A, B, C, D, E, or F).

Use a 50-meter tape to measure the distance to the nearest 0.01 m (1 cm) between the left and right monuments (rebars) at each cross-section and the azimuth from the left monument to the right monument. Record the measurements in the installation field form. This information can be used to locate/re-install a lost monument in the future.

Next, measure the bankfull width at cross section A, following the procedures detailed in the Channel Morphology protocol.

To mitigate for potential irregular bankfull width, also measure the bankfull width at 2 m and 4 m upstream of the cross section. Measure to the nearest 0.01 m (1 cm), and record the measurements in the field form. To calculate the sample reach length, average the three measurements and multiply the result by 20.

Round to the nearest 5 m to allow easy calculation of the cross-section intervals, then divide that number by five to attain the cross-section interval for the sample reach. For a 100 m sample reach, the cross-section interval is 20 m.

To find the location of the next cross-section (B), one technician holds the zero end of the 50-meter tape at the thalweg (deepest path of flowing water in the main channel) of cross section A. The other technician carries the reel end of the tape upstream, following the thalweg. Keep the tape at the water surface along the thalweg while measuring. If a sharp bend in the channel is encountered, hook the tape on a rock or stick in the bend to ensure that the tape follows the thalweg and accurately measures the interval distance. After reaching the predetermined interval distance, establish cross section B as described above. Repeat for all cross sections. Sample reach layout is illustrated in Figure 1-2.

Collect the GPS coordinates of the sample reach start and end (cross sections A and F) and record multiple GPS waypoints throughout the reach along the thalweg. The spatial data will permit GIS mapping of the reach.

### ***Special Circumstances***

#### **Reference Sites in Olympic National Park**

For sites in Olympic National Park (ONP), sample reach cross sections are monumented by wooden stakes instead of rebars. The corresponding letter for each cross section (i.e. A, B, C, D, E, or F) is written on the appropriate stake with a permanent marker. Each monument is also marked with red biodegradable flagging and labeled with the study permit number, ONP coordinator, and expected year of removal (e.g. “OLYM-361, Pat Crain, Down in 2022”). Stakes should be labeled before installation, when they are dry and clean. Plastic flagging, rebars, and orange plastic mushroom caps are not allowed in the park.

### Undercut Banks and Obstructions

When establishing a cross section, try to avoid severe undercut banks, channel bends, large logjams that could be dangerous, or other obstructions that may occur at the intended cross section location. These obstacles can make it difficult to establish and measure the cross section accurately. If one of these obstructions is encountered, move the cross section to the nearest suitable location (upstream or downstream); measure and note the offset in the field form (e.g. “cross section B was moved 2.1 m upstream to avoid a severe undercut”).

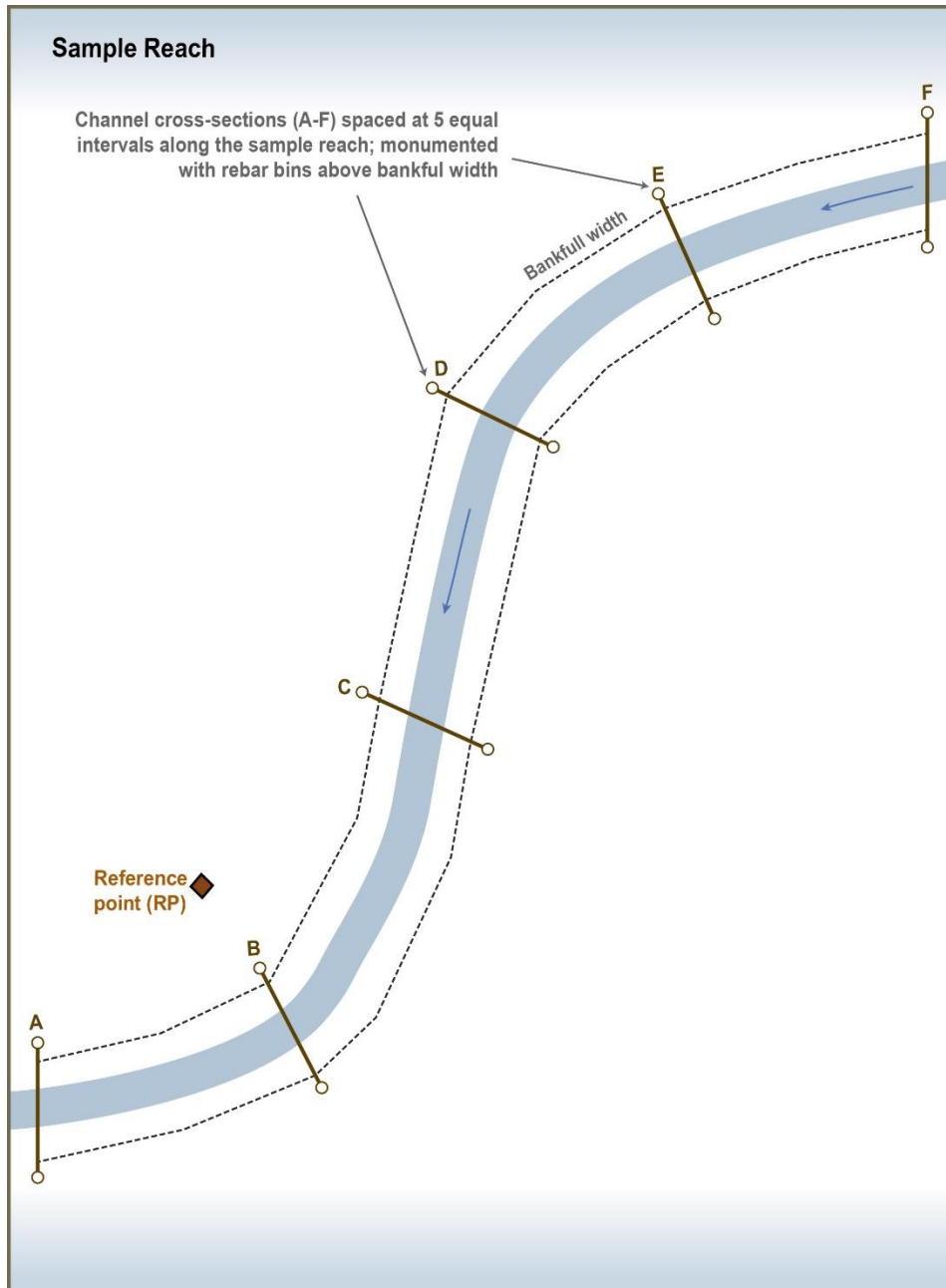


Figure 1-2. Layout of a sample reach.

## ■ Site Establishment

Avoid offsetting by more than 2 m. The sample reach should never be shortened from its calculated length. If it is not possible to install cross section F at its intended location, move the cross section upstream. Record any offsets in the field form.

### Side Channels (dry or wetted)

Avoid side channels by moving the cross-section upstream or downstream. If this is not possible, install the cross section monuments beyond the side channel. When measuring a cross section that intersects a side channel, determine the bankfull stage of the side channel along the cross section line, measure the channel's bankfull width, and add this value to the main channel bankfull width.

## ESTABLISHING A REFERENCE POINT

A reference point (RP) is established near each sample reach to assist in locating sampling points along the reach (e.g. reach start and data loggers). The RP will be used as a permanent benchmark that serves as a vertical and horizontal control point used for all monitoring conducted at a sample site.

The RP is typically placed between the start of the sample reach and the temperature data loggers, in a location that provides a clear view of both (Figure 1-3). The location should be near the channel but on stable substrate (non-erodible slope) outside of the 100-year floodplain of the sample reach (refer to the Channel Morphology protocol for the procedure to identify the 100-year floodplain).

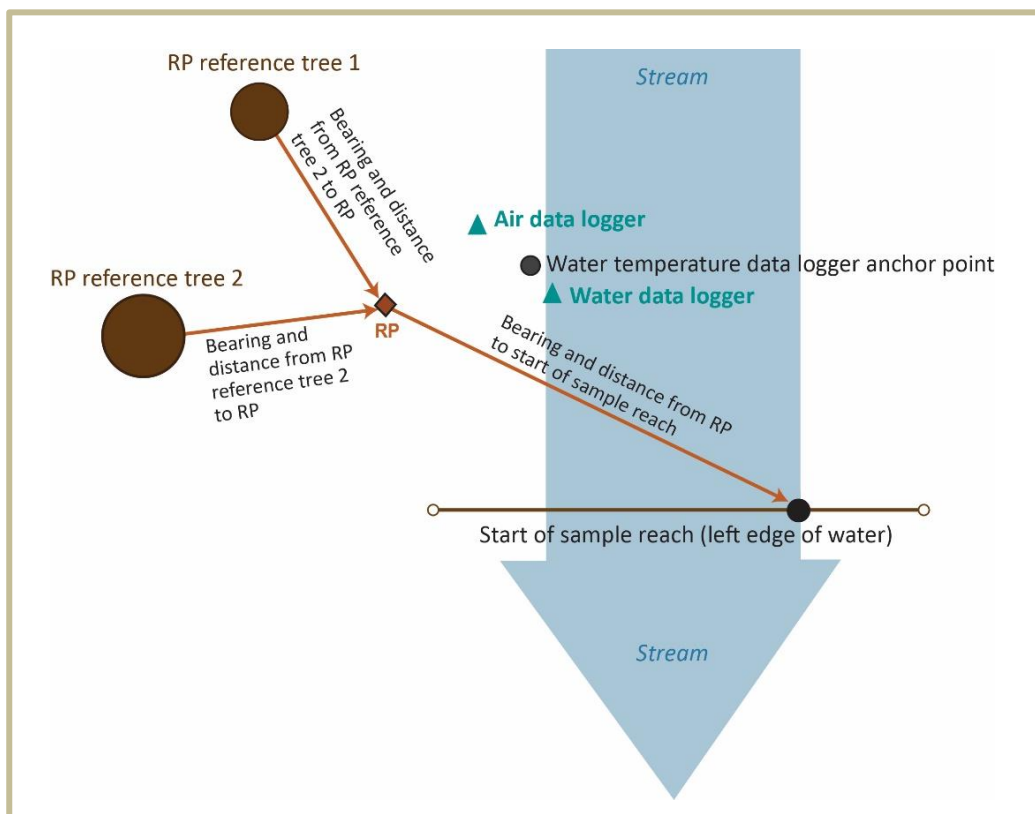


Figure 1-3. Typical layout of the sample reach start, RP, reference trees, and temperature loggers.



Monument the RP with rebar pounded into the root of a live tree, a solid piece of LWD, or directly into the ground until only 6-8 inches of rebar is visible. Once installed, spray it with blue paint (or use a pre-painted rebar) and place an orange plastic mushroom cap on top. Mark the rebar with pink flagging and an aluminum tag affixed with stainless or copper wire. Write “RP” on the top of the orange cap, and label the flagging and both sides of the aluminum tag with the watershed number. Measure the distance (within 0.01 m [1 cm]) and azimuth from the RP to the start of the sample reach at the left edge of water (LEW) (Figure 1-3) and enter the data in the field form together with a short description of the RP location.

Identify two live, vigorous trees near the RP that can be used to find the RP location via triangulation if the RP is lost. Mark these “reference trees” with pink flagging and blue spray paint. Nail an aluminum tag to the trunk of each tree at breast height (1.4 m) on the side facing the RP. Label each tag with the distance and azimuth to the RP (for example: Ref. Tree #1 RP at 7.8 m @ 320°). Record the distance, azimuth, species, and DBH of each reference tree in the field form.

Take a photo of the RP from about 2 m to the north, including the reference trees in the image, if possible (Figure 1-4). Record the photo number in the field form.

Collect the GPS coordinates of the RP and record them in the field form.

The procedure for establishing an RP and reference trees at the ONP reference sites is the same as described above except that blue paint and pink plastic flagging are not used. Instead, use red biodegradable flagging as a marker. Label all aluminum tags and flagging for the RP and reference trees with the study permit number, the name of the ONP coordinator, and the expected year of removal (e.g. “OLYM-361, Pat Crain, Down in 2022”).



**Figure 1-4. Typical reference point and two marked reference trees.**

## MEASURING THE REFERENCE POINT ELEVATION

The elevation of each RP is measured once during the study. These known elevations will be used as benchmarks for determining the absolute elevation of cross sections or other elements of sample reaches. However, for most analyses, a relative RP elevation of “0” will be used.

Measure the RP elevation with survey-grade GPS or derive it from LiDAR (light detection and ranging) data. LiDAR may be a better option in some areas, such as incised valleys with dense canopy where it is difficult to obtain a satellite signal. Refer to Appendix 1A for step-by-step directions for recording elevation with a GPS unit.

## ESTABLISHING A PERMANENT PHOTO POINT

A permanent photo point establishes location for collecting repeated photographs of the same stretch of the sample reach over time. The photos will be used to illustrate stream dynamics over time, to clarify questionable data points, and to track vegetation succession.

Each photo point includes a metal T or U fence post used to position the camera and a target placed across the stream from the post.

As the situation warrants, a photo point target can be one of the following:

- A plastic mushroom cap on a cross section monument (already installed).
- A plastic mushroom cap on a specially installed photo point target rebar.
- Four aluminum tags in an X-shape nailed to a live tree or piece of LWD.
- A bullseye drawn on a recording gage with a permanent marker.
- A recording gage cap.
- A bullseye drawn on a wooden stake with a permanent marker (ONP).

Find a stable location close to the RP, with a good view of the stream, preferably oriented upstream. If the watershed contains a gage station, it should be visible in the photo point photo. If there is an interesting feature (e.g. large erosion patch, log jam, large precarious tree) nearby, try to select a position for the fence post that will include the feature in the photo.

Pound in the fence post using the 4 lb. hammer until only ~1.25 m of post is visible. If it is too difficult to pound in the post with the hammer, use the fence post driver. Mark the fence post with pink flagging labeled “Photo Point [Watershed ID]”. Install the target on the opposite bank near the stream. Mark the target with pink flagging labeled “Photo Point Target [Watershed ID]”.

Measure the distance (within 0.01m [1 cm]) and bearing from the RP to top of u-bar fence post. Measure the distance (0.01m) and bearing from the top of the fence post to the photo point target. Measure the distance (0.01m) and bearing from the RP to the left edge of water (LEW) at the cross section. Label the fence post flagging with the distance and bearing from the photo point to the photo point target (e.g. “Photo Point Target is cross section B monument cap 2.53m @ 156°”).

Record the photo point location and all measurements in the field form. For ONP sites, use wooden stakes marked with red biodegradable flagging for both the photo point and the photo point target. Using a permanent marker, write the study permit number, the name of the ONP coordinator, and the expected year of removal (e.g. “OLYM-361, Pat Crain, Down in 2022”) on the stake and bioflagging marking the photo point. Draw a bullseye on the stake serving as the photo point target, and write the permit number, coordinator name, and removal year on the bioflagging marking the target.

## TAKING A PICTURE AT THE PHOTO POINT

Set the camera's display to "grid view." Rest the camera on top of the fence post, zoom in all the way, and center the image on the photo point target. Holding the camera steady zoom out to the full extent and take the photo (Figure 1-5). Record the photo number in the field form.

At the ONP reference sites, take the photo at 1.5 m above the base of the wooden stake marking the photo point. Conveniently, when a stadia rod is set at its lowest height, the top of the rod is at 1.5 m.



**Figure 1-5. Taking a photo from a permanent photo point. The photo target is drawn on the PVC of the gage station across the stream.**

## Time and Cost Estimates for Implementing the Field Procedures

The estimated time for site establishment is about two to three hours per sample reach for an experienced two-member field crew. This estimate does not include travel time to sites.

Table 1-1 shows the cost estimates for the equipment unique to site establishment protocol implementation. Many of the items listed in the *Equipment and Supplies* section above are shared with the Channel Morphology protocol (e.g., ruggedized field tablet and the camera). Their costs are detailed in that protocol and not included here.

The survey-grade GPS unit for measuring the elevation at the RP and collecting the stream sinuosity points is borrowed from the WADNR Engineering Division.

**Table 1-1. Cost Estimates for the Equipment Used in the Site Establishment Field Protocol**

Equipment/Supplies	Amount per watershed	Individual cost	Amount for the project (54 sites)	Cost for the project*
2-ft rebar, 0.5 in diameter	13	\$1.80	650	\$1,170
Rebar caps, mushroom orange	13	\$10 (box of 25)	650 (26 boxes)	\$260
5-ft metal u-bar fence post	1	\$3.50	50	\$175
Nails, aluminum tags, wires		\$35 (box of 300)	2	\$70
Plastic flagging		\$2	25 rolls	\$50
Biodegradable flagging		\$5	2 rolls	\$10
2-ft wooden stakes	14	\$20 (pack of 12)	56 (5 packs)	\$100
Spray paint		\$7	10 cans	\$70
4-lb sledge hammer		\$20	1	\$20

\*Initial installation only, replacements are not included.

## Quality Assurance and Quality Control

The quality assurance for the site establishment field protocol includes staff training and the use of standardized protocols. The quality control for the field procedures includes field checks on 10% of the field measurements. The field checks are performed by the project researchers and/or assigned field crew. The QA/QC procedures for data management are described in the Data Management section below.

### TRAINING

All personnel conducting field protocols will be trained in a consistent manner to ensure that the surveys are conducted properly and in standardized fashion. The training is conducted or, for returning personnel, reviewed, annually before the start of the field season. At least one member of the field crew should be experienced with the field procedures.

### STANDARD PROTOCOLS

The standard procedures described in this protocol will be followed for the duration of the project. Any deviations from the procedures should be documented, and the reasons for deviation should be described and discussed with the project manager or the researcher overseeing the protocol implementation. Changes to the published protocols must be approved by the project manager or the researcher overseeing the protocol implementation. Revised protocols will be assigned new version numbers and publication dates.

## Data Management

### DATA FLOW

Site establishment data and metadata are recorded in the field using paper field forms (2013-2014 field seasons) or a ruggedized field tablet (2015 field season onward). In the office, data are then transferred to a database for long-term storage. The steps below detail the process.

#### *Data flow for paper field forms*

1. **Fill out field forms.** The Site Description section of the Stream Morphology, Substrate, Shade datasheet is used to record the data and metadata associated with site establishment at each sample reach.
2. **Scan and store field forms.** After returning from the field each week, the field forms are scanned and stored on the WADNR network drive; the original paper forms are archived by the OESF Data Management Specialist at the WADNR Forest Resources Division.
3. **Enter data.** All site establishment data collected on paper field forms are entered in the Stream Geomorphology Database by the OESF Data Management Specialist on a weekly basis. After data from a field form is entered, the Specialist writes “Entered” on the form followed by his or her initials and the date.
4. **Quality control.** Entered field form data are verified by comparing the data on the field form to the data in the database. This process is performed by someone other than the person who originally entered the data. After the data are verified, the person who verified it writes “Verified” on the field form followed by his or her initials and the date.

#### *Data flow for electronically collected data*

1. **Fill out forms on electronic field data recorder.** Field personnel collect all site establishment data using the Tablet Database, which is a customized database created in Microsoft Access and saved on the ruggedized field tablet.
2. **Store field data.** At the end of each day in the field, a copy of the Tablet Database, containing all data collected to date, is transferred to the OESF Data Management Specialist via cloud storage or email. If internet access is not available, the field crew makes a daily backup copy of the database on a laptop or other storage device and then transfers the data to the Data Management Specialist at the end of the work week. The Specialist stores these Tablet Database copies in a temporary location on the WADNR network drive (J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\07\_Data management\\_All new data and photos\) until they are processed and the data are transferred to a database for long-term storage.
3. **Quality control.** Because data are recorded electronically, and thus never transcribed, transcription errors do not exist. However, there is still a possibility of data entry errors in the field. In particular, if metadata (e.g., the date of a field visit or a watershed ID) are recorded incorrectly in the field, this could cause errors during the process of importing data from the Tablet Database to other databases for long-term storage (next step; see below). For this reason, metadata are examined for accuracy prior to importing data to the long-term storage databases.



4. **Import data to database.** On a weekly basis, the OESF Data Management Specialist imports all new data from the Tablet Database to databases for long-term storage, such as the Stream Geomorphology Database. This is accomplished using a set of queries stored in another database called “Distribute\_Tablet\_Data.accdb”.
5. **Verify transfer of data.** After data have been imported, the OESF Data Management Specialist verifies that no records have been missed, using the record count queries built into the Distribute\_Tablet\_Data database.

### **Photographs**

1. **Transfer photos to data manager for storage.** All digital photographs taken in the field are transferred to the OESF Data Management Specialist at the end of each work week. The Specialist stores the uncatalogued photos on the DNR server at:  
J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\07\_Data management\\_All new data and photos\
2. **Rename and archive photos.** The OESF Data Management Specialist renames each photo point photo using the following naming convention: PT\_<WatershedID>\_<Date taken>\_<Original photo name> (for example: PT\_797\_20140715\_P1000851.JPG). The photos are then moved to long-term storage in the following directory:  
J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\03\_Photos and videos\04\_Stream\_survey\Photo\_Points\

### **GPS Data**

1. **Transfer data to data manager for storage.** All GPS data recorded in the field are transferred to the OESF Data Management Specialist at the end of each work week. The Specialist stores the data on the WADNR server at:  
J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\07\_Data management\\_All new data and photos\
2. **Differentially correct GPS data.** All GPS data are differentially corrected using Pathfinder Office. Instructions are located here:  
J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\02\_Spatial data\04\_GIS Instructions\Differential Correction & Draw Linework in ArcMap-ArcView.docx  
After differential correction is completed, the original, uncorrected GPS files from the field are stored here:  
J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\02\_Spatial data\01\_GPS Field Data\
3. **Transfer corrected data to long-term storage.** Differentially corrected GPS data are added to the latest “SERP” feature class, which is located here:  
J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\02\_Spatial data\07\_Map\_Data\OESF Map Data.gdb

## DATA STORAGE

### *Paper Field Forms*

The paper field forms are archived at the WADNR Forest Resources Division. The designated data steward is Teodora Minkova, WADNR. Scanned copies of these forms are saved in the Adobe portable document format (.pdf) in the following directory:

```
J:\hcp\monitoring_research\tminkova\01_OESF_R&M Program\01_Rip S&T Mon\01_FIELD
DATA\01_Stream survey\Data\Data archive\Field forms\
```

### *Tablet Databases*

The original Tablet Databases, which are transferred to the OESF Data Management Specialist on a daily or weekly basis, are stored on the WADNR network drive after the field data they contain have been transferred to the Stream Geomorphology Database. The long-term storage location for the Tablet Databases is:

```
J:\hcp\monitoring_research\tminkova\01_OESF_R&M Program\01_Rip S&T Mon\01_FIELD
DATA\01_Stream survey\Data\Data archive\Processed tablet databases\
```

### *Long-Term Data Storage*

The ultimate location of the site establishment data is the Stream Geomorphology Database, located on the WADNR network drive at:

```
J:\hcp\monitoring_research\tminkova\01_OESF_R&M Program\01_Rip S&T Mon\01_FIELD
DATA\01_Stream survey\Data\Stream_Geomorphology_Database.acddb
```

Within the Stream Geomorphology Database, site establishment data are stored in three related tables: the Installation Table, the Site Visit Table, and the Visit Detail Table. The Installation Table contains data for which only one value exists, such as the location of the photo point or the sample reach length. The Site Visit Table contains data that change over time (e.g. hiking trail condition, photo point photo name), and therefore must be recorded each time the site is visited. The Visit Detail Table contains data that change every day (e.g. weather conditions, time of day that the visit began) and thus may differ on each day of a multi-day site visit.

The Installation Table and the Site Visit Table are connected by a one-to-many relationship. One record exists in the Installation Table for each sample reach, but each record in that table is related to multiple records in the Site Visit Table because each sample reach has had multiple visits. Each record in the Visit Detail table represents one day of one site visit. Because a single visit can contain multiple days, the Site Visit Table is related to the Visit Detail Table through a one-to-many relationship. In the diagram below, the arrows point to the “many” side of each one-to-many relationship.

**Installation Table → Site Visit Table → Visit Detail Table**

The database fields in the three tables are described in Tables 1-2, 1-3, and 1-4.

**Table 1-2. Installation Table in the Stream Geomorphology database.**

Field	Field description
BasinID	Watershed identifier
PhotoPt_Description	Narrative description of where the photo point is located.
PhotoPt_Dist_RP	Photo point distance (m) from the reference point.
PhotoPt_Az_RP	Photo point azimuth (degrees) from the reference point.
PhotoPt_Post	A check-box to indicate if the post was installed.
Photo_Target_Desc	Narrative description of the photo target.
Photo_Target_Dist	Photo target distance (m) from the photo point.
Photo_Target_Az	Photo target azimuth (degrees) from the photo point.
GPS_LEW_collected	A check-box to indicate if coordinates were recorded by GPS at the start and end LEWs.
GPS_Unit	The type of GPS used.
GPS_Date	The date the coordinates were recorded.
LEWdist_from_RP	The distance (m) of the start LEW from the reference point.
LEWaz_from_RP	The azimuth (degrees) of the start LEW from the reference point.
BFW_0m	Bankfull width (m) at the 0-m location.
BFW_2m	Bankfull width (m) at 2 m upstream.
BFW_4m	Bankfull width (m) at 4 m upstream.
Average_BFW	Average of the three bankfull widths (m).
Reach_Length	Sample reach length (m).
CrossSection_Interval	Interval between sample reach cross sections (m).

**Table 1-3. Site Visit table in the Stream Geomorphology database.**

Field	Field description
Site_Visit_ID(Auto)	A unique ID for each site visit.
BasinID	Watershed identifier
Trail_Condition	Narrative describing the condition of the hiking trail.
Site_Condition	Narrative describing the condition of the site.
Tributaries	Are tributaries present along the sample reach (Yes/No).
Trib_Side	The side of the sample reach on which tributaries are located (Left/Right/Both).
Trib_Location	The location of the tributaries, relative to the cross-sections.
Photo_Name	The camera's filename of the photo point photograph.
To-Do_Notes	Tasks or maintenance needed at the sample reach.
Remarks	Any other remarks recorded during the site visit.
Fish_Pres_Notes	Were fish observed during the site visit?
Weather	Weather conditions during the site visit. (This is an old field, from when the weather was recorded only once per visit. Now, weather is recorded each day in the Visit Detail Table.)



**Table 1-4. Visit Detail table in the Stream Geomorphology database.**

Field	Field description
Detail_ID(Auto)	A unique ID for each day of each site visit.
Site_Visit_ID	A unique ID for each site visit (because a visit may consist of multiple days). This ID is used to relate this table to the Site Visit Table.
Survey_Date	The date.
Start_Time	The time that work began on that date.
End_Time	The time that work ended on that date.
Field_Crew	The initials of the field crew members present on that date (this is an old field, from when datasheets recorded only the field crew once per site visit).
Field_Crew_tablet	The initials of the field crew members present on that date (this is a field created when we began using the tablet to collect data; it accommodates difference crew members on each date).
Camera_Num	The camera ID for the camera used on that date.
Weather	The weather on that date.

## DATA QUALITY CONTROL

Prior to data analysis, all data in the data tables are assessed to identify potentially erroneous values. The first step is to examine individual fields, one at a time. For categorical data fields (e.g. GPS\_Unit) and date or time fields, every field is assessed to identify any records exhibiting the following:

1. Missing values.
2. Illogical values. In some cases, where the data collector is free to enter values rather than selecting values from a predefined list, illogical values may be recorded (e.g. a survey time of 3:00 AM).

For numerical fields, each is assessed for the following:

1. Missing values.
2. Outlier values (e.g. a bankfull width was recorded in cm instead of m).

The next step in quality control assessment is to examine values in the context of other fields. For example, if the three bankfull widths are 3.2, 3.5, and 26 meters, then there is most likely a decimal error in the third value.

When missing values are discovered, it is generally not possible to “fill in the blank” from the office. The fact that data are missing should be recorded, in brackets, in the Remarks field, with the initials of the person who performed the quality control check (e.g., [Trail\_Condition was not recorded. –WD]).

Illogical or outlier values can sometimes be corrected in the office. For example, AM and PM might have been switched or a decimal place error can be corrected. When data are corrected, this must be noted in the

## ■ Site Establishment

remarks field, in brackets, with the initials of the person who performed the quality control check. For example: [BFW\_4m was recorded as 36 m. This was clearly incorrect and changed to 3.6 which is logical given the other two widths. –WD].

In many cases, clearly erroneous outlier values cannot be corrected in the office and should be edited so as not to affect the results of analysis. In such cases, the value should be removed from the field and transferred to the Remarks field with an explanation, in brackets, with the initials of the person who performed the quality control check. For example: [BFW\_4m was recorded as 74.8 m. This was clearly incorrect and removed from the dataset. –WD]).

## References

- Pleus, A. E. and D. Schuett-Hames. 1998a. TFW Monitoring Program methods manual for stream segment identification. Prepared for the Washington Department of Natural Resources under the Timber, Fish, and Wildlife Agreement. TFW-AM9-98-001. DNR #103. May.
- Pleus, A. E. and D. Schuett-Hames. 1998b. TFW Monitoring Program methods manual for reference point survey. Prepared for the Washington Department of Natural Resources under the Timber, Fish, and Wildlife Agreement. TFW-AM9-98-002. DNR #104. May.

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## ***Appendix 1A. Directions for recording reference point elevation with Trimble Recon survey-grade GPS unit***

1. Power on the Trimble Recon and Trimble Receiver and attach all cables and antenna
2. Open ArcPad
3. File Folder-> open map -> map\_settings.saved (to access all layers in a pre-saved map)
4. File Folder -> New -> Shapefile
5. Type: "Point Z", CodePage: OEM- United States. Then click the "+", click "ok", click "ok" again
6. Name the file: [date]-b[watershed ID]-RP (e.g. 20150125-b433-RP)
7. Select folder: "none", Type: "Shapefile", Location: "Storage Card"
8. Click "Save", Click "no" for creating a QuickForm.
9. Double check in the Layers whether the file was created and is editable.
10. GPS Preferences-> Protocol: Trimble GPSCorrect ->Capture: check the box for "enable averaging" with "30 points & 5 vertices". ->GPS Height: Antenna Height: \_\_m (while wearing the backpack have your partner measure the height from the ground to the bottom of the antenna mount). Check the box for "Use Height In Datum Transform".
11. GPSCorrect Settings->Logging settings->click the Antenna height wrench->Make sure the correct type of antenna is listed. Measure Height To: "Bottom of antenna mount"
12. GPSCorrect Settings->Real-time Settings -> "Use uncorrected GPS"
13. Activate the GPS Receiver. See GPS cursor on the map, check the satellite reception. Once there are at least 4 satellites with good geometry a point can be collected.
14. Stand at the base of the RP, with the antenna directly over it.
15. Click on the satellite icon to start averaging (percentages will show up on the top of the screen).
16. Name the field: "b[watershed ID]-RP (e.g. b433-RP)"
17. When averaging reaches 100%, click "ok" and the collected point should now be visible on the map. Watch the screen for a while and make sure that the Trimble still agrees with the location of the collected point. Also, make sure that the point looks reasonable in comparison to other points that have been collected in the stream.

■ Site Establishment

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# Channel Morphology

**Authors:** Teodora Minkova, Mitchell Vorwerk, Ellis Cropper

**Version:** 1.4

## Revision History:

Protocol Version	Purpose / Changes	Author(s)	Reviewer(s)	Date
1.0	Initial draft presented to project staff	Teodora Minkova	Alex Foster	04/01/2013
1.1	Draft submitted to external review	Teodora Minkova	Rebecca Flitcroft, Ashley Steel	04/16/2013
1.2	Final draft incorporating external reviews, sampling procedures from 2013 field season, and data mgmt. procedures	Teodora Minkova, Mitchell Vorwerk, Ellis Cropper		04/20/2014
1.3	Final draft with field and data management procedures updated from 2014 and 2015 field seasons	Teodora Minkova, Mitchell Vorwerk, Ellis Cropper	Alex Foster	06/10/2016
1.4	Final technical review and edit	Teodora Minkova, Mitchell Vorwerk, Ellis Cropper	Paul Dunnette, Warren Devine, Alex Foster	12/18/2016

## Based on the Following Protocols:

The general monitoring design follows the Field Protocol Manual for Aquatic and Riparian Effectiveness Monitoring Program (AREMP) for the Northwest Forest Plan (Lanigan et al. 2010). Details on some of the field procedures are adapted from the Illustrated Guide to Field Technique for Stream Channel Reference Sites (Harrelson et al. 1994) and the Timber, Fish, and Wildlife (TFW) Method Manual for the Reference Point Survey (Pleus and Schuett-Hames 1998).

## Reasons to Adopt the Above Protocols:

The AREMP protocols (Lanigan et al. 2010) have higher consistency scores and are better at describing environmental heterogeneity than other regional protocols (Roper et al. 2010). The AREMP conceptual framework (Reeves et al. 2004) has been adopted in the study plan for this monitoring project.

The TFW protocols and Harrelson et al. (1994) are widely used in the Pacific Northwest because of their detailed and well-described field procedures.

## Purpose and Content:

The purpose of this monitoring protocol is to describe the sampling and data management necessary to document and report the shape, size, and slope of the stream channels and how they change over time. The protocol details the field procedures for sampling channel width, depth, gradient, sinuosity, confinement, and bank erosion; the quality assurance and quality control steps; and the data management procedures.) Classifications for valley and channel types and geomorphological units (e.g., pools, riffles) are described in the protocol Habitat Units and Valley and Channel Classification.



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## Introduction

Channel morphology (i.e., shape, dimensions, and slope) reflects the stream-reach and watershed-level ecological process and provides a basis for interpreting the potential responses of the stream to perturbations such as sediment delivery and peak flows (Montgomery and Buffington 1993).

Channel morphology influences the distribution and abundance of aquatic plants and animals by governing the characteristics of water flow and the capacity of streams to store sediment and transform organic matter (Bisson et al. 2006). Geomorphic characteristics such as channel width, confinement and gradient are used in models to identify fish habitat, which enable land managers to prioritize habitat conservation, maintenance, and restoration.

Channel morphology changes as a result of water discharge, sediment deposition, and delivery of large wood (Montgomery and Buffington 1997). Forestry practices such as logging and road management can affect channel shape, size, and gradient directly through sediment and wood delivery to the streams or indirectly by modifying watershed vegetation and road density, which alter flow regimes (Grant et al. 2008).

In the environmental impact analysis for the Olympic Experimental Forest (OESF) Forest Land Plan (WADNR 2016), stream gradient and confinement were used to identify stream reaches (the smallest analysis unit) and to assign reach-scale sensitivity ratings for in-stream large wood, fine sediment, coarse sediment, and peak flow. Channel width was used in the stream shade model (to locate the channel edge and define a non-forested area immediately above the stream) and in the microclimate model (to locate the channel edge and assign a starting point for the equations that represent the microclimate gradients). Finally, the models utilized in the environmental impact analysis for fish used channel width and gradient to identify fish habitat (chinook spawning, coho summer rearing, coho winter rearing, and steelhead rearing habitat).

## Monitoring Design

### SPATIAL SAMPLING DESIGN

All channel morphology attributes described in this protocol are measured in each of the 50 sample watersheds in the OESF and in the four reference sample watersheds in Olympic National Park (ONP). Refer to the Introduction chapter for a map of the sample watersheds.

Some channel morphology measurements are taken at the permanent cross-sections (e.g., channel depth, channel width, and valley width). Others are measured as a continuous survey over the entire sample reach (e.g. sinuosity, gradient, and bank erosion) (Figure 2-1).

### TEMPORAL SAMPLING DESIGN

Sampling should occur when flows are at relatively low levels, such as during summer and early fall. Sampling should not be performed when streams are near bankfull stage or higher because under such conditions it becomes difficult or impossible to accurately identified bankfull markers.

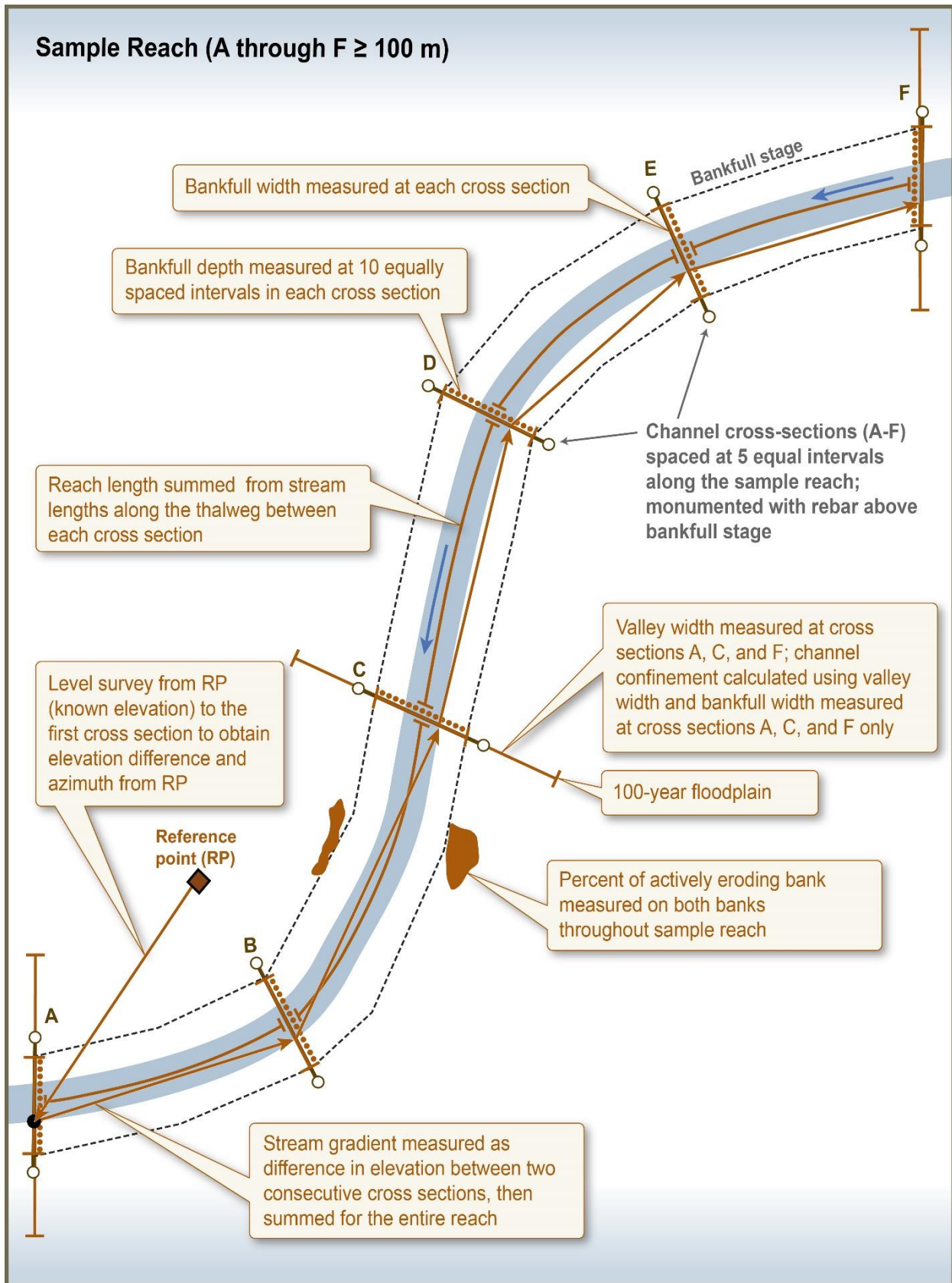


Figure 2-1. Location of channel morphology attribute sampling within the sample reach

## Equipment and Supplies

The following equipment and supplies are needed for implementing the field procedures of the Channel Morphology Protocol:

- Stadia rod
- 50-meter tapes (2)
- Chaining pins (2)
- Spring clamps (5)
- Pink flagging
- Chalk
- Compass
- Clinometer
- Auto level with tripod (e.g., Topcon™ AT-B4)
- Resource-grade GPS (e.g., Trimble™ Pro XT or Trimble Pro XH) with receiver, external antennae, and batteries
- Field calculator
- Ruggedized field tablet or paper field forms
- Panasonic™ Lumix camera
- Custom plumb-line (for bankfull depth sampling)

For replacement of lost or damaged cross section monuments:

- 2-ft rebar
- 4 lb hammer
- Orange plastic mushroom rebar caps
- Rectangle aluminum tags and wires
- Blue spray paint
- Pink plastic flagging
- Permanent markers

### PRE-FIELD SET UP

Calibrate and check the auto level using the Reticle Cross-Line (line of sight) directions found in the Topcon™ Instruction Manual for AT-B2/B3/B4 (refer to step by step instructions in Appendix 2C). Auto level calibration and checks are done once at the beginning of each field season and whenever damage is suspected.

Load the Trimble™ GPS unit with appropriate layers (e.g., watershed outline, roads, streams, previously collected data points).

Charge all batteries: field tablet, GPS units, and Panasonic™ Lumix camera.

## Field Procedures

### MEASUREMENT OF BANKFULL WIDTH

Bankfull width is the horizontal distance between the bankfull stage indicators on each side of a stream, measured directly across the channel. Bankfull stage represents the dominant discharge associated with channel-forming events. The recurrence interval of these events varies among channels and regions, but is generally between 0.5 and 2.0 years (Williams 1978).

In this study, bankfull width (BFW) is measured at each permanent cross-section (Figure 2-1).

First, extend a 50-meter tape between the rebars monumenting the cross sections (Figure 2-2). Attach the zero end of the tape to the left monument (rebar) with a spring clamp, extend the tape tautly across the channel, and attach the tape to the right monument with another clamp. Make sure the tape forms a straight line over the cross section, and clear any vegetation that may obstruct the tape. This is the “upper” tape.

Next, determine the bankfull stage on both banks using the indicators described and illustrated in Appendix 2A. Insert chaining pins into the ground to mark the left and right bankfull stages (LBF and RBF, respectively) directly below the upper tape.

*Recommended tip: hang a plumb-line from the upper tape to correctly line up the chaining pins. This device can easily be fashioned with a spring clamp, ~3 m of cordage, and a small weight. A stadia rod may be used instead, but this can be inaccurate, especially if the monuments are placed very high above the stream.*

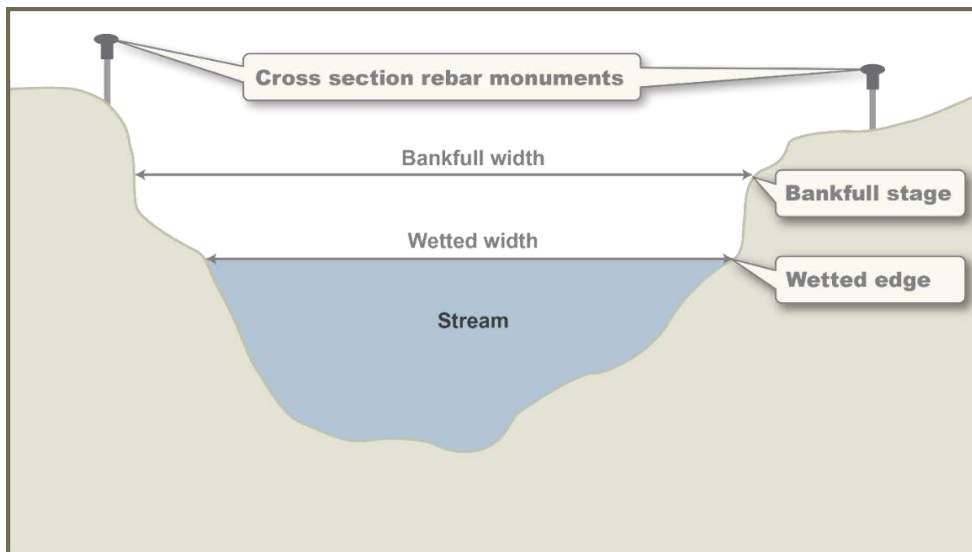


Figure 2-2. Sample reach cross section.

Attach the zero end of a second 50-meter tape to the left chaining pin with a spring clamp, extend the tape tautly across the channel, and attach the tape to the right pin with another clamp. This is the “lower” tape. Make sure the upper and lower tapes are pulled tight and aligned; adjust the lower tape, if necessary. Aligning the lower tape with the permanent cross section line allows repeatable measurements over time.

Ensure that the lower tape is unobstructed by vegetation, logs, or boulders. Prune vegetation if necessary or stretch the lower tape separately on both sides of the boulder or log.

If a side channel is within the cross section, measure the side channel’s bankfull width using the upper tape and add the width to the main channel width (see *Special Circumstances*, below, for further instructions). A side channel exists when both of the following criteria are met:

1. There is an island or bar in the stream which is higher than bankfull stage and has bankfull indicators present (see Appendix 2A for indicators)
2. The portion of the island/bar that is above bankfull stage has a length at least twice that of the stream’s estimated BFW (average of BFW measurements already made, or, if none have been made yet, measure BFW above and below the island and average)

A side channel does not need to have water present in it, but it must have bankfull indicators.

Measure the BFW on the lower tape and record the measurement in the appropriate field on the field tablet (nearest 1 cm). When measuring the BFW of the main channel or side channels, do not include the width of bars or islands that are *above* the bankfull stage, but do include the width of bars or islands that are *below* the bankfull stage (Figure 2-3).

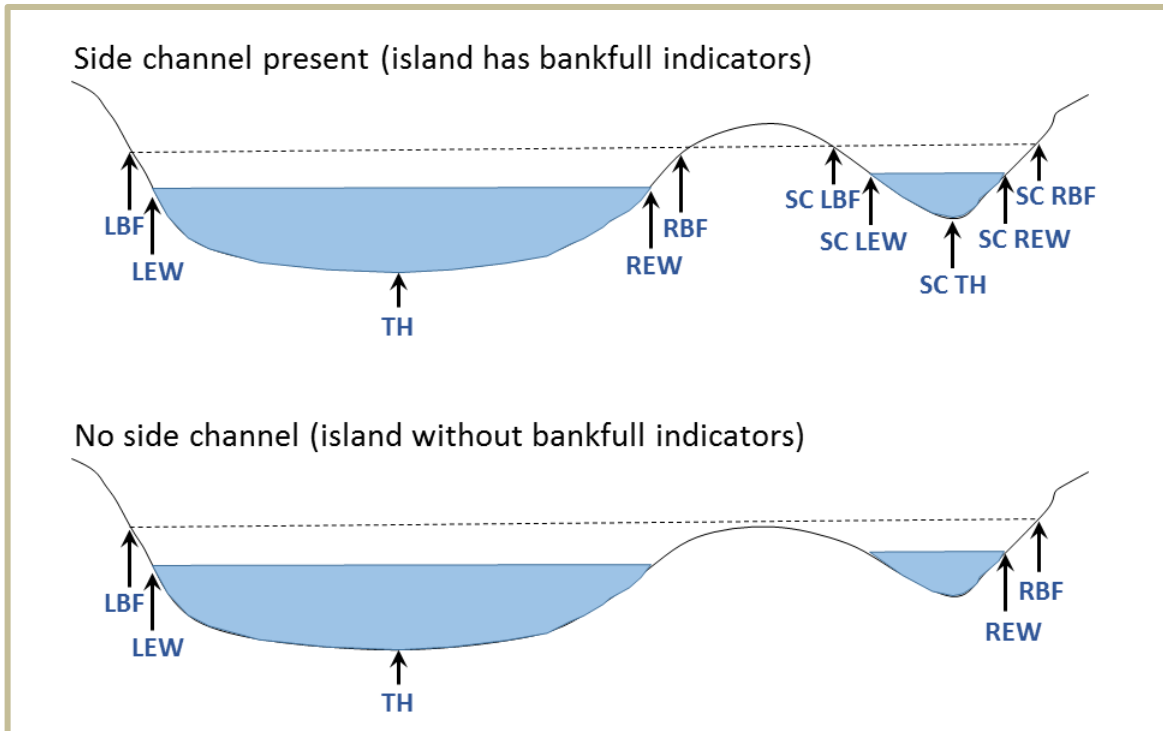


Figure 2-3. Two similar cross-sections, one with a side channel and one without. In the top diagram, the presence of bankfull indicators on the island resulted in the designation of a side channel. In the lower diagram, the island is a gravel bar with no bankfull indicators. The dashed line represents a tape stretched from opposing bankfull locations. LBF=left bankfull; LEW=left edge of water; TH=thalweg; REW=right edge of water; RBF=right bankfull; SC=side channel.

## MEASUREMENT OF BANKFULL DEPTH

Bankfull depth is the average flow depth across the channel at bankfull stage.

In this study, bankfull depth is not measured directly. Rather, an auto level is used to read heights (in cm) on a graduated stadia rod at 10 equal intervals (11 stations) along each cross section (Figure 2-4). The stations include the bankfull stages (LBF, RBF) and nine points on the stream bed. Bankfull depths are later calculated by subtracting the bankfull heights from the stream bed heights. In addition, stadia rod heights are measured at several other key points along the cross section: the left monument (LM), right monument (RM), left edge of water (LEW), right edge of water (REW), and thalweg (TH).

Bankfull depth sampling occurs after the bankfull width is measured and in concert with channel substrate sampling (refer to the Channel Substrate Protocol). Sampling stations are located using the lower and upper tapes extended across the channel for the BFW protocol.



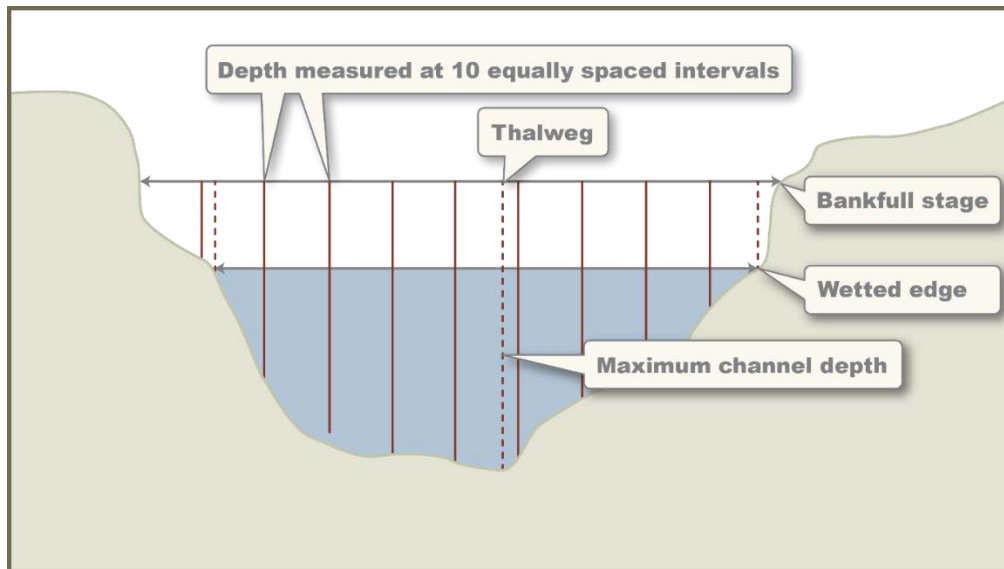


Figure 2-4. Bankfull depth sampling.

### ***Auto Level Set-up and Operation***

Set up the auto level and tripod in a stable location that is high enough to take stadia rod height measurements above both cross section monuments and provides a clear view of the entire cross section (Figure 2-5). Choose a location as close as possible to the cross section to facilitate clear communication between the auto level operator and the crew member holding the stadia rod. Before attaching the auto level to the tripod, secure the tripod feet in the ground or substrate and adjust the legs to make the tripod plate nearly level. Place the auto level on the tripod plate and tighten the centering screw.

Next, level the auto level by adjusting the leveling foot screws to center the bubble in the center circle. Periodically check the bubble's position throughout the survey; if the instrument goes out of level (i.e., the bubble leaves the circle), the survey may need to be restarted.

To take measurements, aim the telescope at the stadia rod, focus using the focusing knob, identify the center reticle (line) in the sight, and note the height where the center line (reticle) intersects the rod (see Topcon instruction manual for further details). Heights should be measured to the nearest 0.5 cm. Record only the numbers viewed at the center line, not at the upper or lower lines.



Figure 2-5. Sampling bankfull depth using a stadia rod and auto level.

### *Survey*

Before starting the survey, enter the cross section BFW in the field tablet database, which will automatically calculate the sampling interval and produce a list of 21 sampling stations (distances in cm) along the lower tape. Stadia rod heights are measured at 11 of the stations (equally spaced, top row of the list), and channel substrate is sampled at every station (top and bottom rows). Be sure to measure heights before disturbing the substrate (see Channel Substrate Protocol).

One crew member takes auto level measurements, enters data in the field tablet, and reads the distances to the other crew member, who positions the stadia rod at each sampling station. The rod should always be plumb, not leaning, when measurements are taken. If sampling occurs in the rain, use an umbrella to shield the field tablet touch screen.

All sampling stations are based on the lower tape. Thus, stations for the LM, RM and other points outside the bankfull width are determined using their distances from the LBF or RBF, measured with the upper tape. Stations to the left of the LBF are negative values, and stations to the right of the RBF exceed the BFW.

Begin measurements at the LM. Hold the stadia rod at the base (ground level) of the monument, record the height in the field tablet database “Fore.” (foresight) field, and select LM in the “Location” field.

Use the upper tape to determine the distance from the LBF to the LM and record this distance in the “Station” field as a negative number, because it extends past zero on the lower tape. An exception is when undercut banks at the bankfull stage extend beyond the monuments.

Next, measure the LBF height. Hold the stadia rod at the correct bankfull height, even if an obstruction or undercut bank prevents attaching the lower tape and/or placing the stadia rod at the true bankfull stage (see *Special Circumstances*, below). The recorded distance for the LBF should always be zero.

Move to the next predetermined station, place the stadia rod base on the stream bed, and take a height measurement. Record the distance and height in the appropriate field tablet fields. Continue on to collect and record stream bed heights and distances for each of the listed stations. Also identify, measure, and record distances and stadia rod heights for the LEW, TH, REW, RBF, and RM. Calculate the RM station distance by finding the distance from RBF to the RM (using the upper tape) and adding this value to the BFW.

Record LM, LBF, LEW, TH, REW, RBF, or RM in the “Location” fields corresponding to the stations for these key points. A given cross section will only have one value for LM, LBF, LEW, TH, REW, RBF, or RM in the Location field. This remains true even if a side channel is present; in that case, follow the Location data entry protocol described below in the Side Channels subsection of the Special Circumstances section.

The LEW and REW are the points where water meets the left and right banks. Measure LEW and REW heights with the stadia rod base held at the water surface. Unless there is a tributary or a qualifying side channel, it is not necessary to record more than one LEW and one REW per cross section, even in the Remarks section (see the lower diagram in Figure 2-3: there is a gravel bar present but there is no need to record a LEW2 or REW2).

The TH is measured by probing with the stadia rod to find the deepest point along the cross section. Be careful not to move/remove rocks in deep sections of the channel during the substrate survey so an accurate TH measurement can be made and so that the 100 year floodplain can be correctly measured after the cross section survey.

If channel gradient and azimuths are measured during the field visit, mark the LEW with chalk, to easily identify the location later.

Before ending the survey, do two QC checks to ensure that the auto level has not moved. First, check that the leveling bubble is still centered in the circle. If the bubble has moved out of the circle, take an auto level reading back to the LM or another clearly defined QC point. If the two measurements differ by more than 1.0 cm, you will have to re-level the instrument and retake all the measurements.

### ***Special Circumstances***

- **Unable to pin the lower tape at the correct bankfull stage.** Move up or down as necessary - it is ideal, but not imperative, that the lower tape be pinned exactly at both bankfull stages. It is most

important to make sure that the lower tape is in line with the upper tape, that the correct bankfull height is identified along that line, and that the zero end of the tape begins at the correct distance.

- **Undercut LEW or REW** (see Figure 2-6 for illustrations of each scenario described below)
  - A. *LEW/REW distance.* Using the stadia rod in a horizontal position, measure the distance to the true wetted edge under the cut bank. Record in the field tablet “Remarks” field that “LEW (or REW) is undercut xx cm”. Next, hold the stadia rod vertically against the bank edge and note the distance where the rod intersects the lower tape. To calculate an undercut LEW, subtract the undercut distance from the bank edge distance. For an undercut REW, add the undercut distance to the bank edge distance. Record the distance in the LEW or REW “Station” field. Note that the LEW station will be a negative number if it extends beyond bankfull; likewise, the REW will be a larger number than the bankfull width if it extends beyond bankfull.
  - B. *Impossible to do more stream bed measurements.* Measure the stream bed height with the vertical stadia rod pressed against the bank (keeping it plumb). Record the height and lower tape distance and note “start of undercut” in the “Remarks” field.
  - C. *LEW/REW height.* Measure wetted edge heights with the vertical stadia rod pressed against the bank, keeping it plumb. Remember to suspend and hold the stadia rod base at the water’s surface.
  - D. *LBF/RBF height.* To measure the bankfull height, place the vertical stadia rod at the LBF/RBF, pressing against the bank (keeping it plumb), suspend and hold the bottom of the rod at bankfull height. If the bankfull stage is undercut, suspend the stadia rod base at the lower tape, which should be at bankfull height.

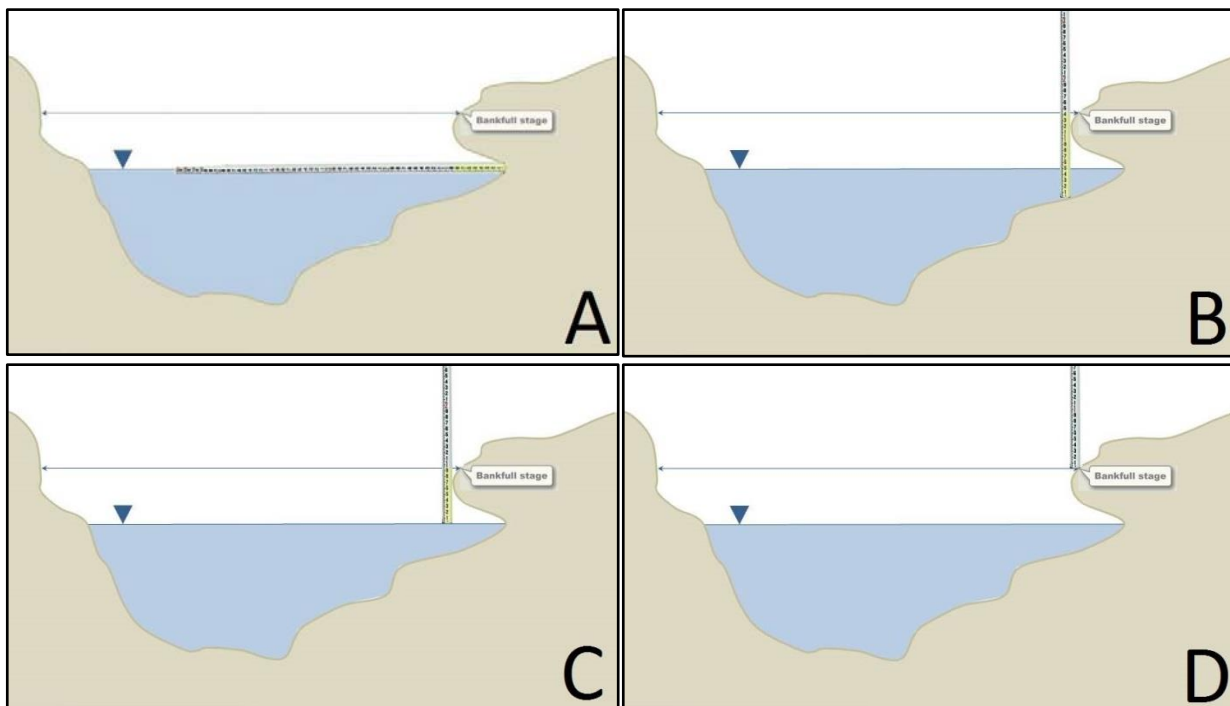


Figure 2-6. Taking measurements when banks are undercut. A) Measure length of wetted undercut; B) Measure stream bed height; C) Measure height of wetted edge; D) Measure bankfull height.

- **Undercut LBF or RBF.** Follow the same procedure for measuring undercut LEW or REW distances and heights, substituting the undercut LBF/RBF. Note that the bankfull stage and wetted edge can both be undercut on one or both sides of the cross section.
- **Vertical bank.** Measure and record heights for the LBF/RBF, LEW/REW, and stream bed. The tape distances may be the same.
- **Large boulders/logs.** If a large obstruction extends above the water surface and interferes with one or more height measurements, take measurements from the stream bed before the obstruction (stream left), from the top of the obstruction, and after the obstruction (stream right). Record the distances (stations) along the lower tape for each height measurement. Resume measuring at the regular intervals as soon as possible.

- **Side channels.**

***Determining the side channel measurement stations***

If a side channel intersects the cross section, identify the side channel's bankfull stage indicators and determine its BFW using the upper tape. Add the side channel BFW to the main channel BFW and record the sum on the tablet in the cross-section's Bankfull Width field. The tablet will then display the stations; however, these stations will not be usable when a side channel exists because they do not account for the island's width. So, instead of using the displayed measurement stations, manually calculate the sampling interval by dividing the entire BFW (i.e., sum of both channels) by 20. It may be helpful to write in a field notebook a list of sampling stations that includes both the distances along the lower tape (used in sampling) and the distances relative to the main channel LBF (recorded in the field tablet). Wetted width is calculated similarly to BFW: separately measure the wetted width of the main channel and the side channel, add the two, and enter the sum in the Wetted Width field for the cross section.

Following the same process as described for cross-sections without a side channel, measure stadia rod heights at the calculated station interval across the main channel and side channel(s). This interval is designed to produce a total of 21 equally spaced stations across the combined main and side channels. For the main channel, also make stadia rod measurements as you normally would at LBF, LEW, TH, REW, and RBF. For the side channel, measure at these same five locations; if the side channel is dry, omit its LEW and REW locations. Because all station distances are based on the main channel's LBF station distance of 0 cm, station distances left of the main channel LBF will be negative, and station distances right of the main channel RBF will exceed the RBF. The lower tape will need to be moved from the main channel to the side channel after the main channel is measured.

***Recording data***

When recording data for a cross section with a side channel(s), record LBF, LEW, TH, REW, and RBF in the Location field *only* for the main channel. For each side channel, record SC in the Location field for all side channel stations beginning with the side channel's LBF and ending with the side channel's RBF (Table 2-1 and Figure 2-7). For the side channel's LBF, LEW, TH, REW, and RBF, record these abbreviations in the Remarks field, prefaced by SC (e.g., SC LBF).



Table 2-1. Example of how to record locations and remarks when a side channel is present (see Figure 2-7). Note that this example shows fewer stations than would be recorded in an actual measurement; also, foresight and particle fields are not shown.

Station (cm)	Location	Remarks
-55	LM	
0	LBF	
23	LEW	
75		
150		
205	TH	
225		
300		
368	REW	
407	RBF	
521	SC	SC LBF
563	SC	SC LEW
602	SC	SC TH
651	SC	SC REW
678	SC	SC RBF
749	RM	

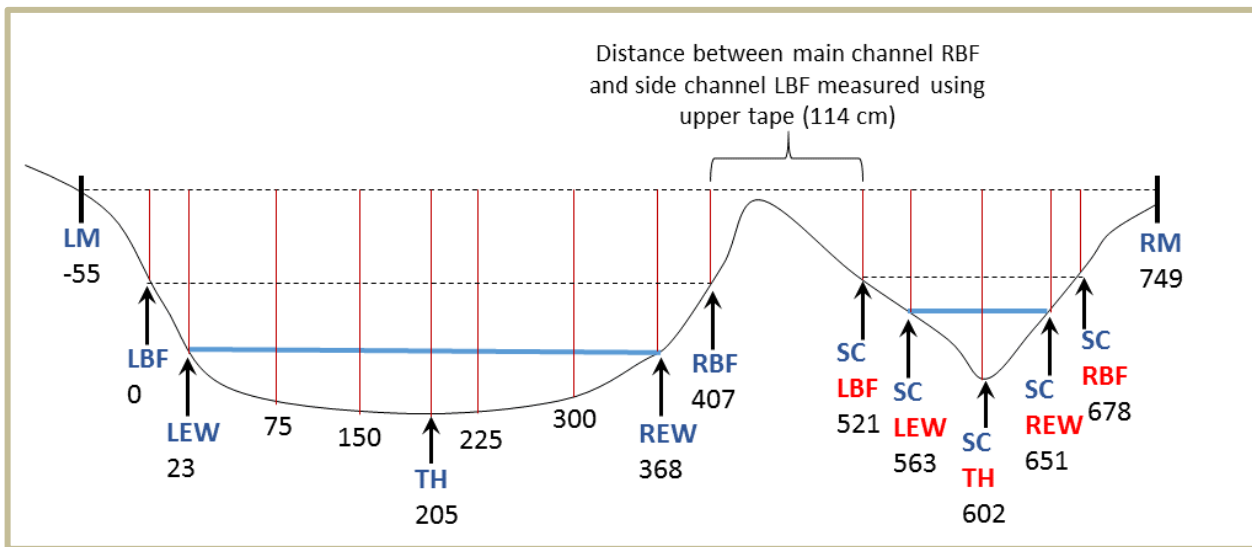


Figure 2-7. Example of a cross-section with a side channel to the right of the main channel. Dashed lines represent the upper and lower tapes; vertical red lines represent measurement stations; blue text is entered in the Location field, red text is entered in the Remarks field, and numbers represent the station distance (cm) (see Table 2-1).

- **Tributaries.** If a tributary intersects the cross section, three stadia rod measurement stations should be associated with the tributary: the left and right edges of water and the thalweg (i.e., the deepest point in the tributary). On the field tablet, record “TR” in the Location field for these three stations. Then, in the Remarks field, record like for side-channels, that is prefaced with a “TR” such as TR LEW, TR REW, and TR TH. The tape distances for the tributary’s stations are based on the lower tape, with 0 cm at the main channel’s LBF, as usual. Unlike side-channels, do not add the tributary width to the main channel bankfull width or take additional cross-section height measurements beyond the three mentioned here: TR LEW, TR REW, and TR TH.

## MEASUREMENT OF BANK EROSION

Streambank erosion is a natural process, however, the rate of erosion can change because of effects associated with forest management. Increased erosion and resulting sediment influx to streams can negatively affect habitat for fish and other aquatic organisms (Chamberlain et al. 1991).

In this study, the metric “percent actively eroding bank” is used to quantify the amount of erosion within a sample reach. To qualify as “actively eroding,” an area of the bank (a “patch”) needs to meet all of the following criteria:

- It is above but in contact with the bankfull stage.
- It is at least 2 m in length and 0.5 m in height above the bankfull stage.
- It has exposed soils with active sloughing or tension cracks (e.g., banks crumbling or falling into the stream).
- It is not stabilized by rooted vegetation, although it may be covered with forest organic matter or superficial non-rooted vegetation like moss and algae. Note that undercut banks that are stabilized by tree roots (soil near the roots is missing and/or not crumbling or falling into the stream) are not counted as active erosion even if their height is > 0.5 m above the bankfull stage. Undercut banks at or below the bankfull stage usually are well-supported by roots.

Measure the height above bankfull stage and the length of all qualifying erosion patches using the stadia rod and a 50-meter tape (nearest 0.1 m). (Figure 2-8). If the patch is long and varies in height, average several height measurements. Measure all qualifying erosion patches on both banks between cross sections A-B, B-C, C-D, D-E, and E-F. Split up an erosion patch into two measurements if it intersects a cross section.





**Figure 2-8. Field crew measuring active erosion height and length.**

Note the cause of erosion ( e.g., road, uprooted tree, cut bank caused by stream, elk or human trail, logjam, etc.) if it is obvious. Enter any additional comments in the “Remarks” field. Photograph each patch of active erosion and include the stadia rod or 50-meter tape (for long sections) in the photos. Record the photo number in the appropriate field on the field tablet.

“Percent actively eroding bank” is calculated at the office by dividing the total sample reach stream bank distance defined as “actively eroding” (both banks) by the total streambank distance (twice the reach length).

## **MEASUREMENT OF CHANNEL CONFINEMENT**

Channel confinement is defined as the ratio of flood plain width to channel bankfull width. Confinement values provide information on the ability of the channel to migrate within the floodplain under the present hydrologic regime (Dunne and Leopold 1978). The floodplain width, often called the channel migration zone, is the width of the stream at maximum flood flows that have a recurrence interval of 100 years (WADNR 2004). In this study, floodplain width is measured as channel width at an elevation of twice the maximum bankfull depth of the channel.

Channel confinement is calculated from measurements of floodplain and bankfull width taken at the beginning, middle, and end of each sample reach (at cross sections A, C, and F) (Figure 2-1).

At cross section A, first measure the maximum bankfull depth standing at the thalweg (Figure 2-4). The field tablet database automatically calculates the floodplain height using the following equation:

$$[\text{TH} - ((\text{LBF} + \text{RBF}) / 2)] \times 2 = \text{FP height}$$

where TH is the thalweg, LBF is the left bankfull stage, RBF is the right bankfull stage, and FP is the floodplain.

Next, tie flagging to the stadia rod at the FP height. Hold the rod vertically at the thalweg. If a third crew member is not available to hold the stadia rod, prop up the rod with a camera tripod and spring clamps. At the flagged height, extend a 50-meter tape out level across the channel cross section and adjacent floodplains until you reach a terrace, hillside, or large barrier on each side of the channel. Measure up and over small gravel bars, logs or other nonpermanent barriers unlikely to impede floodwaters at FP height.

The total distance across the channel and valley is the 100-year floodplain width. Record the width to the nearest 0.01 m. Repeat the measurement at the other two cross sections.

The reach confinement ratio, commonly called the entrenchment ratio describes the degree to which the stream is vertically incised within its floodplain. This dimensionless rating describes the relationship of bankfull mean depth to stream discharge (Dunne and Leopold 1978). A widening and degrading stream over time (increase in confinement ratio) can result from several intertwined factors including higher or more frequent flood or peak discharges that exceed a stream's floodplain capacity for conveyance.

The confinement ratio is calculated:

$$\text{FP width} / \text{mean BFW} = \text{reach confinement ratio}$$

Where FP is the floodplain and BFW is the bankfull width.

The confinement ratios are then used to assign the sample reaches into three categories:

- Unconfined: floodplain width  $\geq 4$  bankfull widths (ratio 2.2+)
- Moderately confined: floodplain width  $\geq 2$  and  $< 4$  bankfull widths (ratio 1.4 - 2.2)
- Confined: floodplain width  $< 2$  bankfull widths (ratio 1.0 - 1.4)

Further explanation of channel confinement can be found in WADNR (2004).

## MEASUREMENT OF WATER SURFACE GRADIENT

The elevation of the Reference Point (RP) is measured once during the study (refer to the Monitoring Site Establishment protocol). The measurement provides a known elevation in each watershed that will be used as a benchmark for determining the absolute elevation of cross section features or other elements of the sample reach. However, for most analyses, a relative RP elevation of "0" will be used.

### **Stream gradient survey**

Stream gradient, also called channel slope, is the elevational difference (rise) between two points in a stream divided by the distance between them (run), measured along the water surface (rise / run = % slope). In this study, we measure the water surface gradient using auto level and stadia rod (Figure 2-9).

The difference in elevation is measured between the RP and the first cross section (A), then between consecutive cross sections heading upstream. It is most efficient to conduct the survey in concert with bankfull depth sampling, which establishes the elevation of the rebar monuments relative to the RP. Stream gradient surveys do not have to be done at the same frequency as bankfull depth surveys, because changes in stream gradients can be calculated from the data gathered during bankfull depth surveys, provided that monuments have not been lost or moved. As a rule of thumb, if any monuments have been found severely disturbed or are missing, then gradient cannot be calculated by bankfull depth surveys alone and must instead be determined via a full gradient survey of the sample reach.

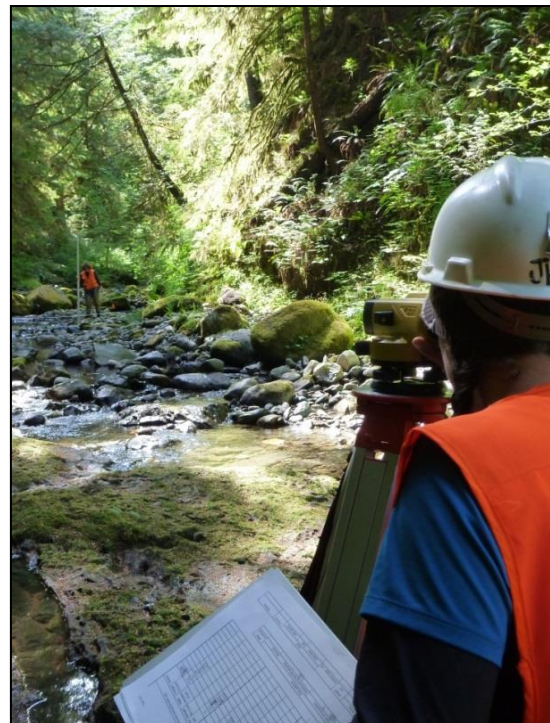
#### **Auto level set up**

Set up the auto level on the tripod in a stable location that provides the height and visibility necessary to take a stadia rod height reading at the next cross section (or an intermediate point) and, if necessary, back to the previous cross section. The ideal auto level position allows readings at as many cross sections as possible to reduce the number of measurements and minimize cumulative error. If necessary, remove brush and branches to provide a clear view between cross sections. See *Measurement of Bankfull Depth*, above, for more detailed instructions on setting up, leveling, and operating the auto level. Stream gradient heights are recorded to the nearest 0.5 cm.

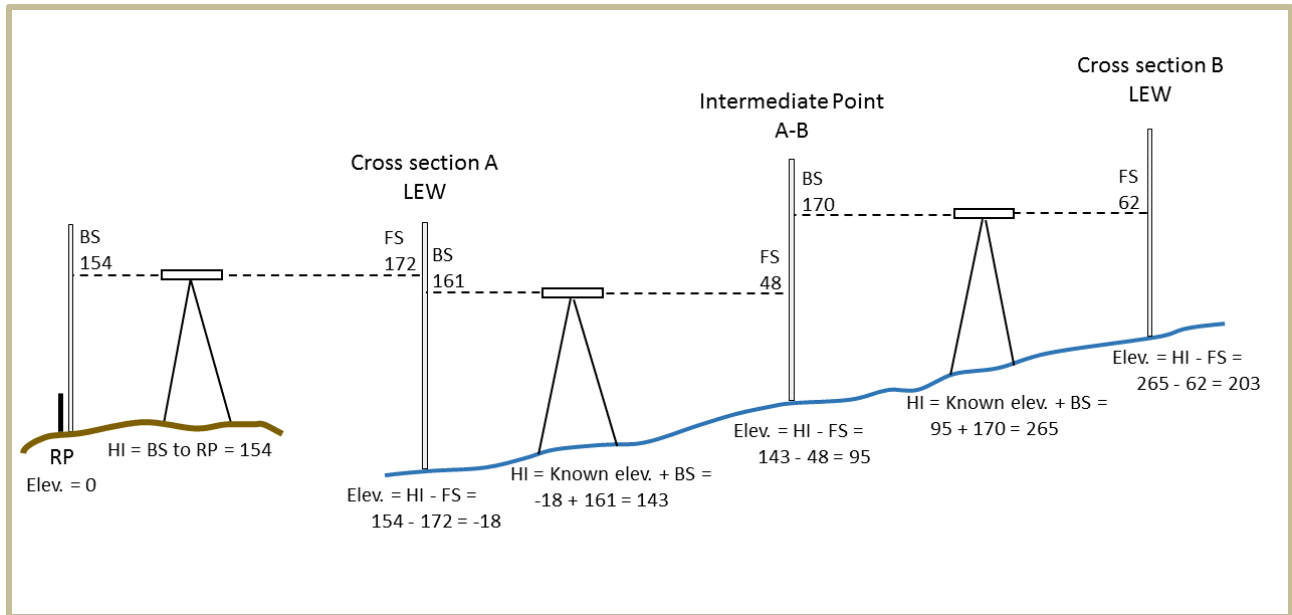
#### **Gradient Survey**

In the gradient survey, a process called differential leveling is used to measure the elevational differences between stream reach cross sections (Figure 2-10).

First, use the auto level and stadia rod to measure the difference in elevation between the RP (known elevation) and the beginning of the sample reach (cross section A). Hold the stadia rod at the base (ground level) of the RP and take a height reading with the auto level. Record the height in both the “Backsight (BS)” and “Height of Instrument (HI)” in the tablet field for cross section A. Also, note “BS to RP” in the “Remarks” section of the field form.



**Figure 2-9. Using an auto level and stadia rod to measure stream gradient.**



**Figure 2-10.** Example of a portion of a stream gradient survey, from the reference point (RP) to cross-section B, where an intermediate point was necessary. Calculations are performed sequentially, from left to right; all values are in centimeters. The elevation of the RP is zero for these calculations. BS—back-sight; FS—fore-sight; HI—height of instrument; LEW—left edge of water.

Hold the stadia rod at the LEW of cross section A. The LEW should have already been marked with chalk during the bankfull depth survey. The bottom of the stadia rod must be held at the water surface, not the channel bottom. Measure the height with the auto level, and record the value in the “Foresight” in the field tablet database field for cross section A. Do not change the position of the auto level between the two measurements and make sure the leveling bubble is still centered when you turn the telescope toward the stadia rod at the LEW.

Next, move the auto level upstream to a point with clear views of both the stadia rod at the LEW of cross section A and the LEW of cross section B. Do not move the stadia rod from its position at cross section A. Take a height reading at the LEW of cross section A from the new auto level position and record the value in the field form as back-sight (“BS”). Leave the auto level in place, move the stadia rod to the LEW of cross section B (exact position marked with chalk), take a height reading at this location, and record the measurement as foresight (“FS”) in the field tablet. The HI in this case is the difference between FS and BS.

Repeat this procedure for all of the intervals between cross sections (B-C, C-D, D-E, E-F). If possible, take readings of multiple cross section LEWs from the same auto level location; this will reduce the number of BS measurements and minimize error introduced by changes in auto level height.

If a steep stream gradient or thick vegetation blocks the view to the next cross section, sight to an intermediate point (IP, also called a turning point [TP]). Select a stable point between the two cross sections (e.g., a large rock) and hold the stadia rod plumb at this IP. Measure the height of the IP and record it as an (A-B) Intermediate Foresight. Mark the exact location of the IP with chalk so it can be measured accurately



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for the next BS. Move the auto level to a stable point between the IP and the next cross section, then take a foresight height reading at the cross section LEW and a backsight height reading at the IP (Figure 2-10).

*Helpful tip:* Although the field tablet has fields to record all gradient measurements, schematic field notes (Figure 2-11) should also be recorded to help technicians understand differential leveling, reduce errors in the field, and assist in future data verification.

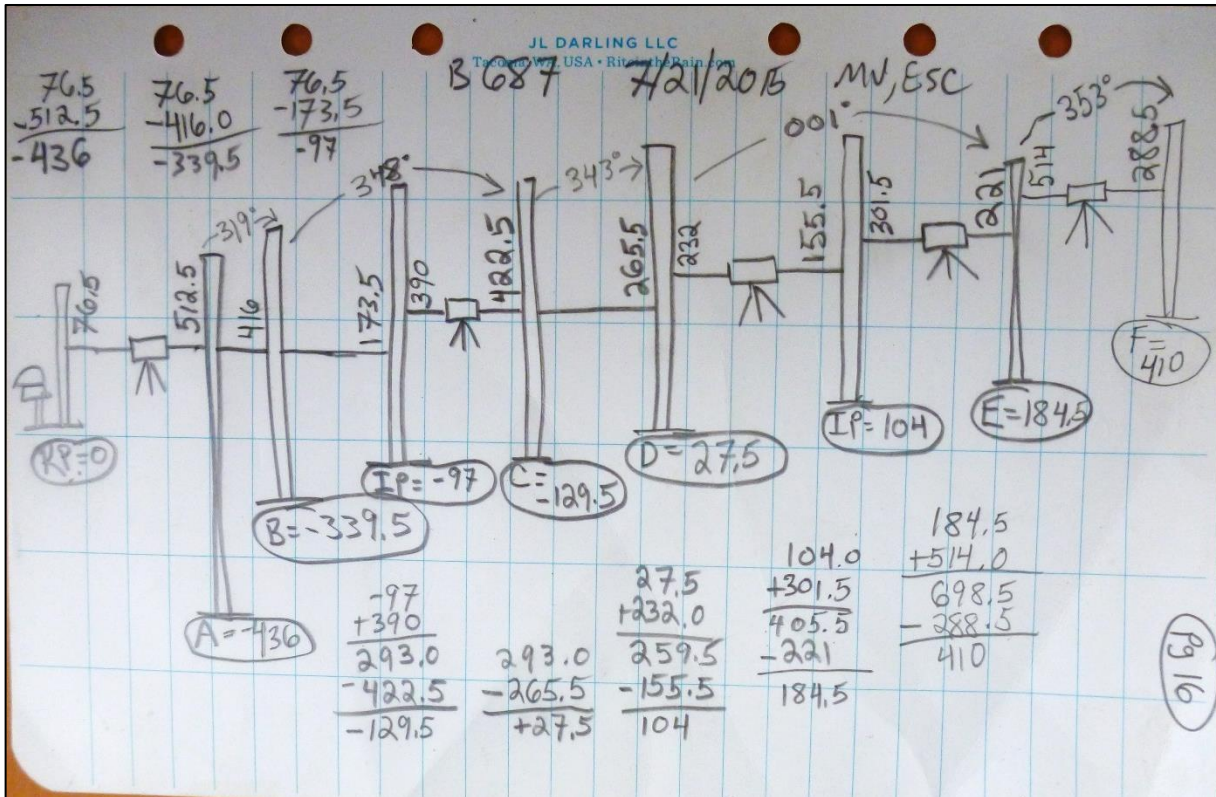


Figure 2-11. Example of field notes illustrating differential leveling.

**AZIMUTH SURVEY**

Azimuths are recorded between cross sections to assist in creating a map of the sample reach. The survey should begin at cross section A and proceed upstream. If the survey starts at cross section F, be sure to record back azimuth readings.

One crew member holds the stadia rod, adorned with bright flagging, at the upstream cross section LEW and the other crew member uses a compass to measure the azimuth from the downstream cross section LEW to the rod. All LEWs should have been marked with chalk during the Bankfull Depth survey.

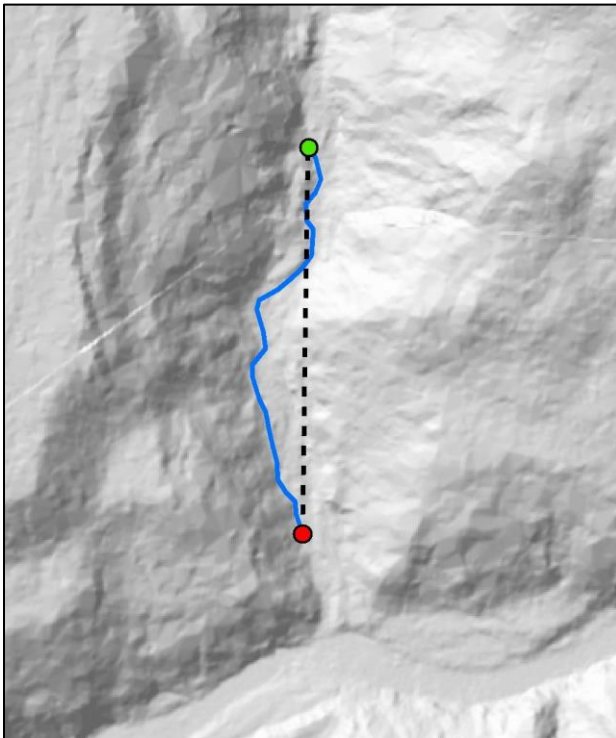
Enter the azimuths in the field tablet database “Gradients and Azimuth” tab.

## MEASUREMENT OF CHANNEL SINUOSITY

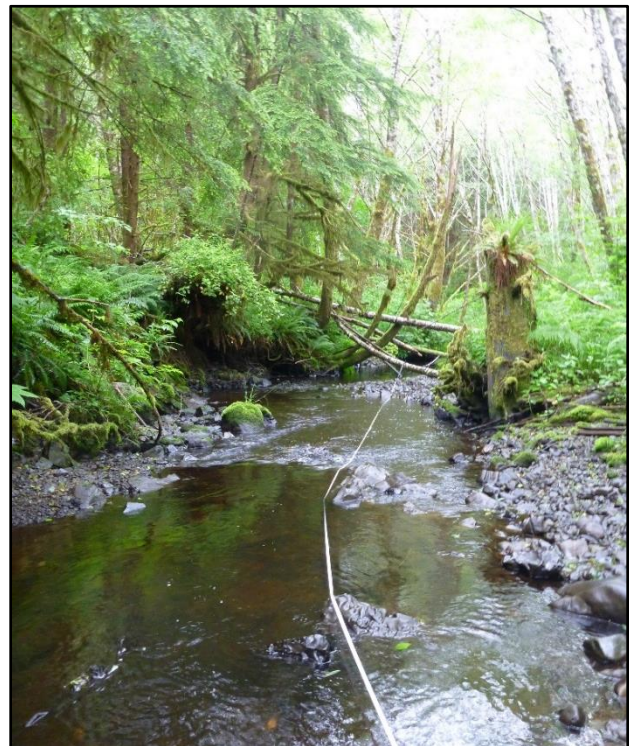
Channel sinuosity describes a stream or river channel's tendency to meander across its floodplain. Changes in channel sinuosity may indicate a change in sediment supply or transport capacity (Grant et al 2008). Aerial photography, generally used to determine landscape-scale channel patterns, may record some finer-scale shifts in sinuosity over time. However, field measurements are needed for small streams in forested watersheds. Channel sinuosity is defined as the ratio of the sample reach length measured along the thalweg to the straight-line distance between the beginning and end of the sample reach (WADNR 2004) (Figure 2-12).

Use a survey-grade GPS unit (Trimble™ Recon) to record the coordinates at the beginning and end of the sample reach. See step-by-step instructions in Appendix 2B.

Sample reach length is measured to the nearest 0.1 m by extending a 50-meter tape along the thalweg at the water surface between consecutive cross sections (Figure 2-13). This is done during establishment of the permanent cross sections (refer to Site Establishment protocol). Sinuosity values are calculated in the office.



**Figure 2-12.** Channel sinuosity measured as a ratio of the sample reach thalweg length (blue line) to the straight line distance (dashed black line) between the reach ends. In this example, the ratio is 1.12.



**Figure 2-13.** Measuring sample reach length along the thalweg.

## ***Time and Cost Estimates for Implementing the Field Procedures***

The estimated time for sampling the channel morphology attributes is about five hours per sample reach for an experienced two-member field crew if all stream morphology protocols are implemented.

Table 2-2 shows the cost estimates for all equipment needed to carry out the field procedures. Many of the listed items are used in other protocols, but their costs are not included in the other protocols' estimates.

The survey-grade GPS unit for measuring the elevation at the RP and collecting the stream sinuosity points is borrowed from the WADNR Engineering Division or can be rented.

**Table 2-2. Cost Estimates for the Equipment Used in the Channel Morphology Protocol**

<b>Equipment/Supplies</b>	<b>Amount</b>	<b>Individual cost</b>	<b>Cost for the project</b>
Ruggedized field tablet	1	\$1,400	\$1,400
Panasonic™ Lumix camera	1	\$200	\$200
Stadia rod	1	\$220	\$220
Topcon auto level with tripod	1	\$650	\$650
50-meter tapes	2	\$35	\$70
Clinometer	2	\$180	\$360
Compass	2	\$50	\$100
Orange flags with 18" wire	Box of 100	\$10	\$10
Chaining pins	Box of 11	\$25	\$25
Spring clamps	8	\$5	\$40
Miscellaneous hardware			\$100

## ***Procedures for Calculating Metrics***

All metrics are calculated in the office following the procedures in Table 2-3

Table 2-3. Procedures for calculating metrics.

<b>Metric</b>	<b>Calculation Procedure</b>
<b>Mean bankfull width</b>	Mean of the bankfull widths at the six cross sections.
<b>Mean bankfull depth</b>	<p>Mean of the mean bankfull depths at the six cross sections.</p> <p>At each cross section, mean bankfull depth is calculated as the mean of the bankfull depths at each of the 11 stations.</p> <p>At each station, bankfull depth is calculated as the difference between the distance-prorated mean of the two bankfull heights and the height of the streambed at that station.</p>
<b>Mean maximum bankfull depth (thalweg depth)</b>	<p>Mean of the six maximum bankfull depth measurements from the six cross sections.</p> <p>Maximum bankfull depth at each cross section is calculated as the difference between the distance-prorated mean of the two bankfull heights and the height of the thalweg at that cross section.</p>
<b>Bankfull width-to-depth ratio</b>	<p>Mean of the bankfull width-to-depth ratios from the six cross sections.</p> <p>For each cross section, the width-to-depth ratio is calculated as the bankfull width divided by the mean bankfull depth at that cross section.</p>
<b>Percent slope of the sample reach water surface</b>	Cumulative difference in water surface heights (cross-sections A through F) divided by total reach length.
<b>Sinuosity of the sample reach</b>	Ratio of the sample reach length to the straight-line distance between the beginning and end of the sample reach.
<b>Channel confinement category</b>	<p>Assigned based on the ratio of the mean 100-year floodplain width to the mean bankfull width.</p> <p>Mean of the 100-year floodplain widths at three cross sections (A, C, and F)</p> <p>The three categories are defined as:            Unconfined: floodplain width <math>\geq 4</math> bankfull widths.            Moderately confined: floodplain width <math>\geq 2</math> and <math>&lt; 4</math> bankfull widths.            Confined: floodplain width <math>&lt; 2</math> bankfull widths</p>
<b>Percent of actively eroding stream bank</b>	Sum of the streambank distance that is actively eroding along both sides of the sample reach, divided by twice the sample reach length, then multiplied by 100.

## Quality Assurance and Quality Control

The quality assurance for the channel morphology field protocol includes field instruments calibration, staff training and the use of standardized protocols. The quality control for the field procedures includes annual field checks. The QA/QC procedures for data management are described in the Data Management section below.



## CALIBRATION OF THE AUTOLEVEL

The auto level is calibrated and checked at the beginning of each field season or whenever damage is suspected using the Reticle Cross-Line (line of sight) directions found in the Topcon Instruction Manual for AT-B2/B3/B4 (see Appendix 2C for step-by-step calibration procedure).

## TRAINING

All personnel conducting field protocols will be trained in a consistent manner to ensure that the surveys are conducted properly and in standardized fashion. The training is conducted or, for returning personnel, reviewed, annually before the start of the field season. At least one member of the field crew should be experienced with the field procedures.

## STANDARD PROTOCOLS

The standard procedures described in this protocol will be followed for the duration of the project. Any deviations from the procedures should be documented, and the reasons for deviation should be described and discussed with the project manager or the researcher overseeing the protocol implementation.

Changes to the published protocols must be approved by the project manager or the researcher overseeing the protocol implementation. Revised protocols will be assigned new version numbers and publication dates.

## FIELD CHECKS

The researcher overseeing the protocol implementation or a different field crew will conduct spot checks on 10% of the field measurements every year.

## Data Management

### DATA FLOW

All channel morphology data are recorded in the field using paper field forms (2013-2014 field seasons) or a field tablet (2015 season onward). In the office, data are then transferred to a database for long-term storage. The steps below detail the process.

#### *Data flow for paper field forms*

1. **Fill out field forms.** Channel Morphology field forms are used to record the data and metadata at each sample reach.
2. **Scan and store field forms.** After returning from the field each week, the field forms are scanned and stored on the WADNR network drive; the original paper forms are archived by the OESF Data Management Specialist at the WADNR Forest Resources Division (see *Data Storage* section below).
3. **Enter data.** All channel morphology data collected on paper field forms are entered in the Stream Geomorphology Database by the OESF Data Management Specialist on a weekly basis. After data

from a field form is entered, the Specialist writes “Entered” on the form followed by their initials and the date.

4. **Quality control.** Entered field form data are verified by comparing the data on the field form to the data in the database. This process is performed by someone other than the person who originally entered the data. After the data are verified, the person who verified it writes “Verified” on the form followed by his or her initials and the date.

### ***Data flow for electronically collected data***

1. **Fill out forms on electronic field data recorder.** Field personnel record all channel morphology data using the Tablet Database, a customized database created in Microsoft Access and saved on the field tablet.
2. **Store field data.** At the end of each day in the field, a copy of the Tablet Database, containing all data collected to date, is transferred to the OESF Data Management Specialist via cloud storage or email. If internet access is not available, the field crew makes a daily backup copy of the database on a laptop or other storage device and then transfers the data to the Specialist at the end of the work week. The Specialist stores these Tablet Database copies in a temporary location on the WADNR network drive (J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\07\_Data management\\_All new data and photos\) until they are processed and the data are transferred to a database for long-term storage:
3. **Quality control.** Because data are recorded electronically, and thus never transcribed, transcription errors do not exist. However, there is still a possibility of data entry errors in the field. In particular, if metadata (e.g., the date of a field visit or a watershed ID) are recorded incorrectly in the field, this could cause errors during the process of importing data from the Tablet Database to the Stream Geomorphology Database (next step; see below). For this reason, metadata are examined for accuracy prior to importing data to the Stream Geomorphology Database.
4. **Import data to database.** On a weekly basis, the OESF Data Management Specialist imports all new data from the Tablet Database to the Stream Geomorphology Database. This is accomplished using a set of queries stored in a third database:  
J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\07\_Data management\Stream\_Survey\Database\Distribute\_Tablet\_Data.accdb
5. **Verify transfer of data.** After data have been imported, the OESF Data Management Specialist verifies that no records have been missed, using the record count queries built into the Distribute\_Tablet\_Data database.

### ***Photographs***

1. **Transfer photos to data manager for storage.** All digital photographs taken in the field are transferred to the OESF Data Management Specialist at the end of each week. The Specialist stores the uncatalogued photos on the WADNR server at:  
J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\07\_Data management\\_All new data and photos\
2. **Rename and archive photos.** The OESF Data Management Specialist renames each photo using the following naming convention: <Photo type>\_<BasinID>\_<Date taken>\_<Original photo name> (for

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example: ER\_797\_20140715\_P1000851.JPG). The photos are then moved to long-term storage in the following directory: J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\03\_Photos and videos\04\_Stream\_survey\

## DATA STORAGE

### *Paper Field Forms*

The paper field forms are archived at the WADNR Forest Resources Division. The designated data steward is Teodora Minkova, WADNR. Scanned copies of these forms are saved in the Adobe portable document format (.pdf) in the following directory: J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD DATA\01\_Stream survey\Data\Data archive\Field forms\

### *Tablet Databases*

The original Tablet Databases, which are transferred to the OESF Data Management Specialist on a daily or weekly basis, are stored on the WADNR network drive after the field data they contain have been transferred to the Stream Geomorphology Database. The storage location for these databases is:

J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD DATA\01\_Stream survey\Data\Data archive\Processed tablet databases\

### *Long-Term Data Storage*

The ultimate location of the channel morphology data is the Stream Geomorphology Database, located on the WADNR network drive at: J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD DATA\01\_Stream survey\Data\Stream\_Geomorphology\_Database.accdb

Within the Stream Geomorphology Database, channel morphology data are stored in five related tables: the Cross Section Table, the Depth Table, the Substrate Table, the Erosion Table, and the Gradient Table (Figure 2-14). The Cross Section, Erosion, and Gradient tables are all related to metadata via one-to-many relationships with the Visit Detail Table. Based on these relationships, one visit date can be related to multiple records in each of the other three tables (the full structure of the metadata is described in detail in the Site Establishment protocol). The Cross Section Table is related to the Depth and Substrate tables via one-to-many relationships: each cross section is related to multiple depth and substrate records.

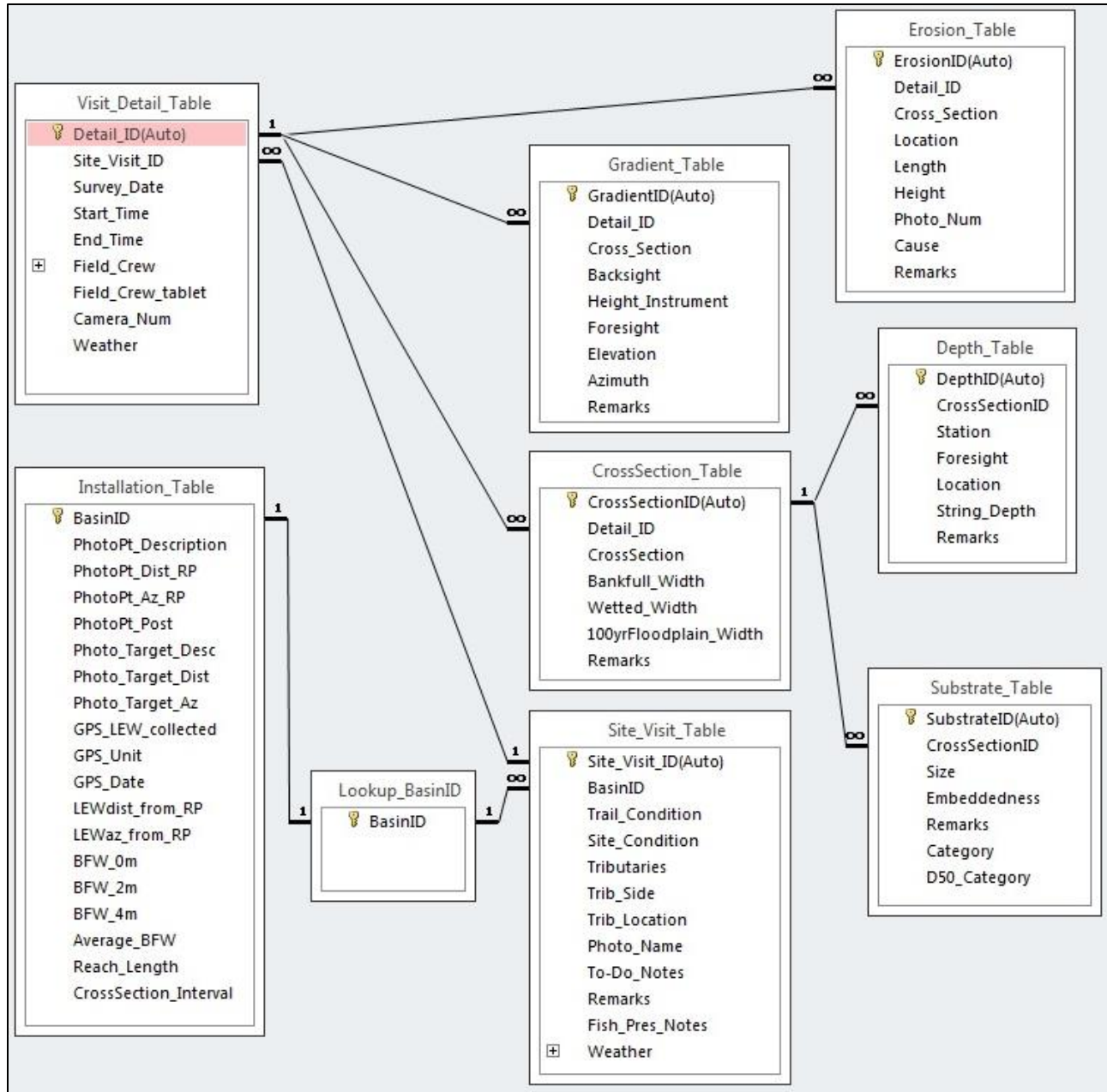


Figure 2-14. The structure of the Stream Geomorphology Database.

The database fields in the five tables containing channel morphology data are described in tables 2-4, 2-5, 2-6, 2-7, and 2-8.

**Table 2-4. The Cross Section table in the Stream Geomorphology Database.**

Field	Field description
CrossSectionID(Auto)	A unique identifier for each cross section.
Detail_ID	Relates the cross section to the appropriate metadata in the Visit Detail Table.
CrossSection	Cross section letter (A-F).
Bankfull_Width	Bankfull width (m).
Wetted_Width	Wetted width (m).
100yrFloodplain_Width	The width of the 100-year floodplain (m), measured for cross sections A, C, and F.
Remarks	Remarks regarding the cross section.

**Table 2-5. The Erosion table in the Stream Geomorphology Database.**

Field	Field description
ErosionID(Auto)	A unique identifier for each erosion patch.
Detail_ID	Relates the erosion patch to the appropriate metadata in the Visit Detail Table.
Cross_Section	Cross sections directly above and below the erosion patch (e.g., A-B, B-C, C-D, etc.)
Location	Left or right bank (LB, RB).
Length	Length of erosion patch (m).
Height	Height of erosion patch (m).
Photo_num	Photo number/name for the photograph(s) of the erosion patch.
Cause	Cause of erosion.
Remarks	Remarks regarding the erosion patch.

**Table 2-6. The Gradient table in the Stream Geomorphology Database.**

Field	Field description
GradientID(Auto)	A unique identifier for each gradient measurement.
Detail_ID	Relates the gradient measurement to the appropriate metadata in the Visit Detail Table.
Cross_Section	Cross section name.
Backsight	Backsight reading (+cm).
Height_Instrument	Height of the instrument (cm), relative to the reference point.
Foresight	Foresight reading (-cm).
Elevation	Calculated elevation value (cm).
Azimuth	Azimuth (degrees), taken from lower station.
Remarks	Remarks regarding the gradient measurement.

**Table 2-7. The Depth table in the Stream Geomorphology Database.**

Field	Field description
DepthID(Auto)	A unique identifier for each depth measurement.
CrossSectionID	Relates the depth measurement to the appropriate cross section in the Cross Section Table.
Station	The measurement location along the cross section (cm).
Foresight	The autolevel depth reading (-cm).
Location	Indicates whether the station was located at a monument, bankfull stage, edge of water, or thalweg (LM/LBF/LEW/TH/REW/RBF/RM).
String_Depth	Depth, measured by the string method (cm). This method was not used after 2013, and thus the field does not appear on the data entry forms after that year.
Remarks	Remarks regarding the depth measurement.

**Table 2-8. The Substrate table in the Stream Geomorphology Database.**

Field	Field description
SubstrateID(Auto)	A unique identifier for each substrate measurement.
CrossSectionID	Relates the substrate measurement to the appropriate cross section in the Cross Section Table.
Size	Particle size (mm).
Embeddedness	Particle embeddedness (%).
Remarks	Remarks regarding the substrate measurement.
Category	Particle size category (e.g., cobble, boulder).
D50_Category	Particle size category (mm) used for calculating D50 and other metrics. This differs from the Size field in that the Size field may contain actual diameter measurements, especially for larger particles, rather than a size category.

## DATA QUALITY CONTROL

Prior to data analysis, all fields in the data tables are assessed to identify potentially erroneous values. The first step is to examine individual fields, one at a time. For categorical data fields (e.g., cross section) and date or time fields, every field is assessed to identify any records exhibiting the following:

- Missing values.
- Illogical values. In some cases, where the data collector is free to enter values rather than selecting values from a predefined list, illogical values may be recorded (e.g., a survey time of 3:00 AM).

For numerical fields, each is assessed for the following:

- Missing values.
- Outlier values (e.g., a stream width was recorded in cm instead of m).

## ■ Channel Morphology

The next step in quality control assessment is to examine derived values and values in the context of other fields. An example of a derived value is the lengths of all erosion patches in a sample reach added together. If the sum of patch lengths is greater than twice the length of the sample reach, then the data should be examined to determine if one of the patch lengths was recorded incorrectly. An example of checking a value in the context of another field is the comparison of wetted width with bankfull width. If wetted width is greater than bankfull width, and there is no record of undercutting, then there may be an error in the data.

When missing values are discovered, it is generally not possible to “fill in the blank” from the office. The fact that data are missing should be recorded, in brackets, in the Remarks field, with the initials of the person who performed the quality control check (e.g., [Location was not recorded. –WD]).

Illogical or outlier values can sometimes be corrected in the office. For example, AM and PM might have been switched or a decimal place error can be corrected. When data are corrected, this must be noted in the remarks field, in brackets, with the initials of the person who performed the quality control check. For example: [Height was recorded as 250 m. This was clearly incorrect and changed to 2.5 m which is logical given nearby erosion heights. –WD].

In many cases, clearly erroneous outlier values cannot be corrected in the office and should be edited so as not to affect the results of analysis. In such cases, the value should be removed from the field and transferred to the Remarks field with an explanation, in brackets, with the initials of the person who performed the quality control check. For example: [Erosion height was recorded as 74.8 m. This value was clearly incorrect and removed from the dataset. –WD]).



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## ■ Channel Morphology

Williams, G.P. 1978. Bank-full discharge of rivers: *Water Resources Research*. 14(6): 1141-1154.

## Appendix 2A. Indicators of Bankfull Stage

From Streamkeepers of Clallam County. 2012. Field procedures. 14<sup>th</sup> Edition.

<http://www.clallam.net/streamkeepers/assets/applets/Bankfull.pdf> [accessed 12-14-2016]

### BANKFULL: WHAT IT IS AND HOW TO LOCATE IT

#### WHY BANKFULL?

Several procedures in this manual require you to locate what is known as the "bankfull channel edge," or more simply as "bankfull." This is an important concept in understanding the workings of a stream.

#### HOW DOES A "BANKFULL" GET CREATED?

Most lower portions of streams in our area are alluvial, meaning that they create their own channels by moving sediment from the surrounding hillslopes and from the stream channel itself. Major episodes of such movement occur during floods and are called "channel-forming events." These events determine the size of the channel needed to convey the water. In a period of relatively stable climate and land-cover, a stream system will develop equilibrium between its flows and the size of the channel, whereby the channel is large enough to contain the stream under most flow conditions. When flows are greater than this capacity, the stream overflows its banks and flooding occurs.

In such streams, the channel is usually big enough to contain a high-flow event that recurs on an average of every 1.5 years (which we call the "1.5-year flood"). Such a frequency of inundation is frequent enough that perennial vegetation can't grow there, either because its roots are too wet or its seedlings get swept away. So usually, what you'll see if you look at the cross-section of a stream channel is a sort of "bowl" that contains the stream most of the time, inside which no perennial vegetation grows, and a place over the top of this bowl where the water can flow during a high-water event greater than a 1.5-year flood. This "floodplain" may be on one or both banks, depending on the site.

#### WHAT ARE INDICATORS OF BANKFULL?

Most stream systems are in a continual cycle of change, and every site is unique; thus, no single indicator of bankfull can always get you the "right answer." There are several indicators which can help to identify the bankfull channel

edge, and you should consider all that are present at a given site:

1. **Bank slope:** In stream channels with natural (undiked) riparian areas and a low, flat floodplain, the bankfull edge is located at the edge of this plain. Often the floodplain will slope down very gradually and then more abruptly. This abrupt slope-break is usually a good indicator. However, you may find such a slope-break on only one bank, or none at all, for instance if the channel has cut down into the streambed. Or the slope-break may be impossible to find on a bank that is slumping or undercut.
2. **Vegetation:** The bankfull edge is often indicated by a demarcation line between lower areas that are either bare or have aquatic and annual vegetation, and higher areas with perennial vegetation such as ferns, shrubs, and trees. (Keep in mind, though, that the vegetation line is always in transition, retreating during wetter periods and advancing during dryer ones. So except for ferns, you should rely most heavily on perennial vegetation which is more than 6 feet high.) One particular confusion arises from willow or alder trees growing within the bankfull channel, because the channel has migrated into them, or they fell into the stream and managed to reestablish themselves. Therefore, when you look at vegetation, you should also look at soils...
3. **Soils:** Look for a transition as you move up the bank, from cobble/gravel to sand/silt to soil. Above bankfull level, you should find old leaf litter forming into soil with organic matter. (Beware: this may be covered by flood deposits, so you may have to dig down.)
4. **Point bars and bank undercuts:** Often on the inside of meander bends, the stream will build up a bar of sediment from the eddy current created by the bend; the top of such a bar is the minimum height of bankfull. Similarly, on the outside of such bends, the stream will often undercut the bank and expose root mats. If you reach up

**BANKFULL**

beneath this mat, you can estimate the upper extent of the undercut. This would also be the minimum height of bankfull.

5. **Lines on boulders/bedrock:** If you're in a steep channel with no clear floodplain, look for the highest mineral-stain line or the lowest line of lichen or moss on stable rock.
6. **Adjacent indicators:** If the indicators are unclear where you're looking, try looking up- or downstream to see if there is a clear bankfull line from which you can extrapolate.

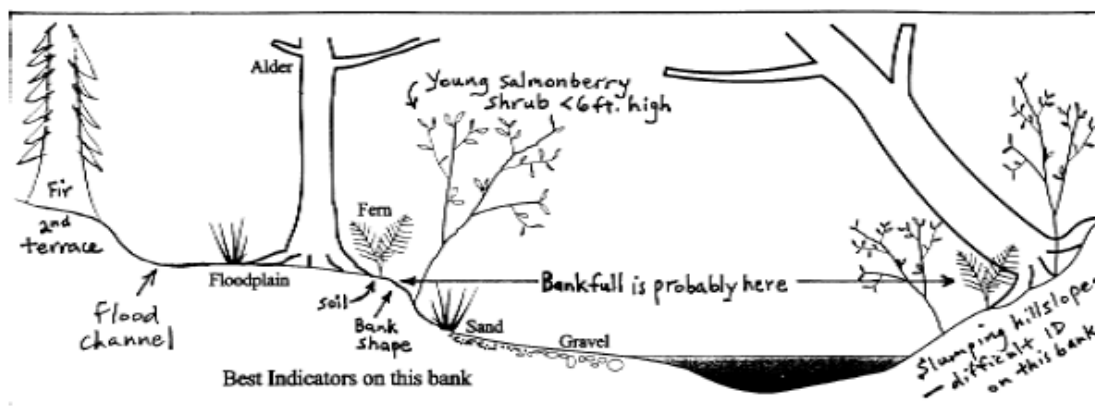
**HOW SHOULD I LOCATE BANKFULL?**

The following method was found by the TFW program to maximize data precision and minimize bias toward over- or under-estimation of bankfull elevation:

1. Start on the bank with the best bankfull indicators.
  - a) Move up the bank from the channel, observing the indicators listed above. When you reach a point at which you're

no longer 100% sure that you're below bankfull, mark that level with a flag or stick.

- b) Then walk up to what is clearly dry land, and walk around, observing indicators and moving back toward the bankfull edge. When you're no longer 100% confident that you're above bankfull, mark that point.
  - c) Reassess the indicators and your confidence levels, and consult with your fellow samplers, and make adjustments as needed.
  - d) The bankfull channel edge is at the elevation point midway between these two points.
2. Now follow the same procedure on the other bank. If it is not possible to accurately identify the bankfull level on that bank (which often happens on the outside bank of a meander bend), locate it using a level line from the bankfull point on the first bank.



**Typical bankfull ID situation, adapted from Pleus and Schuett-Hames, 1998.**

(Also referenced for this section: Harrelson et al., 1994.)

## **Appendix 2B. Directions for recording sinuosity points with Trimble™ Recon survey-grade GPS unit**

Record sinuosity points at the beginning and end of the sample reach: the left edge of water at cross sections A and F.

1. Power on the Trimble Recon and Trimble Receiver and attach all cables and antennas.
2. Open ArcPad.
3. File Folder-> open map -> map\_settings.saved (to access all layers in a pre-saved map).
4. File Folder -> New -> Shapefile.
5. Type: "Point", CodePage: OEM- United States. Then click the "+", click "ok", click "ok" again.
6. Name the file: [date]-b[basinID]-SIN (e.g. 20150125-b433-SIN).
7. Select folder: "none", Type: "Shapefile", Location: "Storage Card".
8. Click "Save", Click "no" for creating a QuickForm.
9. Double check in the Layers whether the file was created and is editable.
10. GPS Preferences-> Protocol: Trimble GPSCorrect ->Capture: check the box for "enable averaging" with "30 points & 5 vertices".
11. GPSCorrect Settings->Logging settings->click the Antenna height wrench->Make sure the correct type of antenna is listed.
12. GPSCorrect Settings->Real-time Settings -> "Use uncorrected GPS".
13. Activate the GPS Receiver. See GPS cursor on the map, and check the satellite reception. Once there are at least four satellites with good geometry, a point can be collected.
14. Stand at the LEW of cross section A, with the antenna directly over it.
15. Click on the satellite icon to start averaging (percentages will show up at the top of the screen).
16. Name the field: "b[basin ID]-Start-SIN (e.g. b433-Start-SIN).
17. When averaging reaches 100%, click "ok" and the collected point should now be visible on the map.  
Watch the screen for a while and make sure that the Trimble still agrees with the location of the collected point. Make sure that the point looks reasonable in comparison to where other GPS points collected in the stream.
18. Stand at the LEW of cross section F, with the antenna directly over it.
19. Click on the satellite icon to start averaging (percentages will show up on the top of the screen).
20. Name the field: "b[basin ID]-End-SIN (e.g., b433-End-SIN).
21. When averaging reaches 100%, click "ok" and the collected point should now be visible on the map.  
Watch the screen for a while and make sure that the Trimble still agrees with the location of the collected point. Make sure that the point looks reasonable in comparison to where other GPS points were collected in the stream.

■ Channel Morphology

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## Appendix 2C. Auto Level Checks/Calibration and Adjustments

Source: TOPCON Instruction Manual, Automatic Level, AT-B2/B3/B4. 2010.

[http://geoshack.com/wp-content/uploads/2011/06/AT-B2\\_B3\\_B4\\_rm1.pdf](http://geoshack.com/wp-content/uploads/2011/06/AT-B2_B3_B4_rm1.pdf)

Auto level calibration and checks should be performed once at the start of each field season and whenever damage is observed or suspected.

See TOPCON Instruction Manual for part diagrams/descriptions.

- 1) Circular Level Check
  - a. Adjust the leveling foot screws to center the bubble in the circular level.
  - b. Turn the auto level 180 degrees. If the bubble remains within the circular level (the circle), no adjustment is needed. If the bubble shifts out of the circle, adjust as follows:
    - i. Compensate for one-half of the shift by adjusting the leveling foot screws.
    - ii. Compensate for the remaining half-shift using the circular level adjusting screws. Adjust the screws using the hexagonal wrench.
    - iii. After the adjustments, turn the auto level 180 degrees and check the circular level. If the bubble remains within the circle, the adjustment is complete.
  
- 2) Automatic Compensator Check
  - a. Center the bubble in the circular level.
  - b. Look through the eyepiece and identify the horizontal cross-line. While turning the leveling screw nearest the sighting axis 1/8 of a turn to the right or left, check the movement of the cross-line. If the automatic compensator mechanism is working properly, the cross-line should bounce, then immediately return to its original position. Alternatively, the compensator can be checked by monitoring the cross-line's behavior after tapping the tripod legs or the auto level's main body while sighting on a clear target. The cross-line should quickly return to its original position after the disturbance.
  
- 3) Reticle Cross-Line (Line of Sight) Calibration
  - a. Set up the auto level halfway between two points (A and B) that are 30 to 50 meters apart. Take readings on the stadia rod while the rod is positioned at each point ( $a_1$  and  $b_1$ ).
  - b. Set up the auto level at a point 2 meters from point A (still between A and B). Take a reading on the stadia rod at Point A ( $a_2$ ), and then at Point B ( $b_2$ ). Leave the auto level telescope sighted on Point B after the second reading.
  - c. Calculate  $b_2' = a_2 - (a_1 - b_1)$ . If  $b_2' = b_2$ , the horizontal cross-line is normal and no adjustment is necessary. If  $b_2'$  and  $b_2$  are different, adjust the cross line as follows:
    - i. Unscrew and remove the adjusting screw cover.
    - ii. Use the adjusting pin (see "Standard Equipment" section of TOPCON manual) to eliminate the difference between  $b_2'$  and  $b_2$ . If the horizontal line needs to be lowered (when  $b_2'$  is higher), carefully loosen the adjusting screw slightly using the adjusting pin. To raise the horizontal line, tighten the adjusting screw.



## ■ Channel Morphology

- i. Repeat the adjustment procedure described in (i) and (ii) until the difference between  $b_2'$  and  $b_2$  is “small.” (TOPCON does not define “small”.)

# Stream Shade

*Authors:* Jeffrey Ricklefs, Teodora Minkova, Mitchell Vorwerk, Ellis Cropper

*Version:* 1.5

## *Revision History:*

<b>Protocol Version</b>	<b>Purpose / Changes</b>	<b>Author(s)</b>	<b>Reviewer(s)</b>	<b>Date</b>
1.0	Initial draft presented to project staff	Jeffrey Ricklefs	Teodora Minkova	04/02/2013
1.1	Draft submitted to external review	Jeffrey Ricklefs	Rebecca Flitcroft	04/16/2013
1.2	Draft incorporating external reviews, sampling procedures from 2013 field season, and data mgmt. procedures	Jeff Ricklefs, Teodora Minkova		05/20/2014
1.3	Final draft with field and data management procedures updated from 2014 and 2015 field seasons	Jeff Ricklefs, Teodora Minkova, Mitchell Vorwerk, Ellis Cropper	Alex Foster	06/11/2016
1.4	Final technical review and edit	Jeff Ricklefs, Teodora Minkova, Mitchell Vorwerk, Ellis Cropper	Paul Dunnette, Warren Devine, Alex Foster	12/18/2016
1.5	Addition about new photo point location when cross-section monuments have to be re-established (p. 3-9)	Warren Devine and Paul Dunnette	Teodora Minkova	06/21/2018

## *Based on the Following Protocols:*

Solar input protocols from Bonneville Power Administration (BPA) Columbia Habitat Monitoring Program (CHaMP) (Bouwes et al. 2011).

## *Reasons to Adopt the Above Protocols:*

The CHaMP sample framework is similar in scale to that of the Olympic Experimental State Forest (OESF) monitoring project. CHaMP provides an established protocol and detailed sampling procedures.

## *Purpose and Content:*

The purpose of this monitoring protocol is to describe the sampling and data management necessary to document and report the status and multi-year trends of stream shade in the monitored watersheds. It details the field procedures for taking canopy photos, the field quality assurance and quality control steps, and the data management procedures.

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## **Introduction**

Stream shade, the extent to which a stream channel is shielded from incoming sunlight, is one of the primary factors influencing stream temperature (Brown 1969). Stream temperature, in turn, affects aquatic organisms directly, because all organisms have a temperature range outside of which they cannot exist, and indirectly, by regulating stream oxygen and nutrient levels. Shade can strongly influence stream structure (e.g. organic substrate, algal biomass) and function (e.g. primary production) (Gregory et al. 1991, Naiman and Decamps 1997).

In the environmental impact analysis for the Olympic Experimental State Forest (OESF) Forest Land Plan, stream shade was recognized as an important indicator for fish habitat quality, riparian areas, and water quality (WADNR 2016). Because empirical stream shade data were not available at the time of the analysis, they were modeled using riparian vegetation inventory data and projected sun paths over streams.

## **Monitoring Design**

### **SPATIAL SAMPLING DESIGN**

Stream shade is measured in all 50 OESF sample reaches and the four reference sample reaches in Olympic National Park (ONP). Refer to the Introduction chapter for a map of the sample watersheds.

One stream shade measurement is taken at each of the permanent cross sections of the sample reach (Figure 3-1). The six measurements are then averaged to calculate the mean percent stream shade for the reach.

### **TEMPORAL SAMPLING DESIGN**

The sampling window is typically between June 1 and September 15, coincident with the leaf-out period of regional deciduous vegetation, but may vary from year to year as a result of climatic factors influencing vegetation. In case of major disturbance at the sample site (e.g., timber harvest, windthrow, or debris flow), photos are retaken during the next available sampling window.

Repeated photos at each sample reach should be taken within two weeks of the date when the initial shade photos were taken at that reach. This minimizes the seasonal effects of phenology (specifically the emergence and falling of leaves) and the sun's position over the horizon.

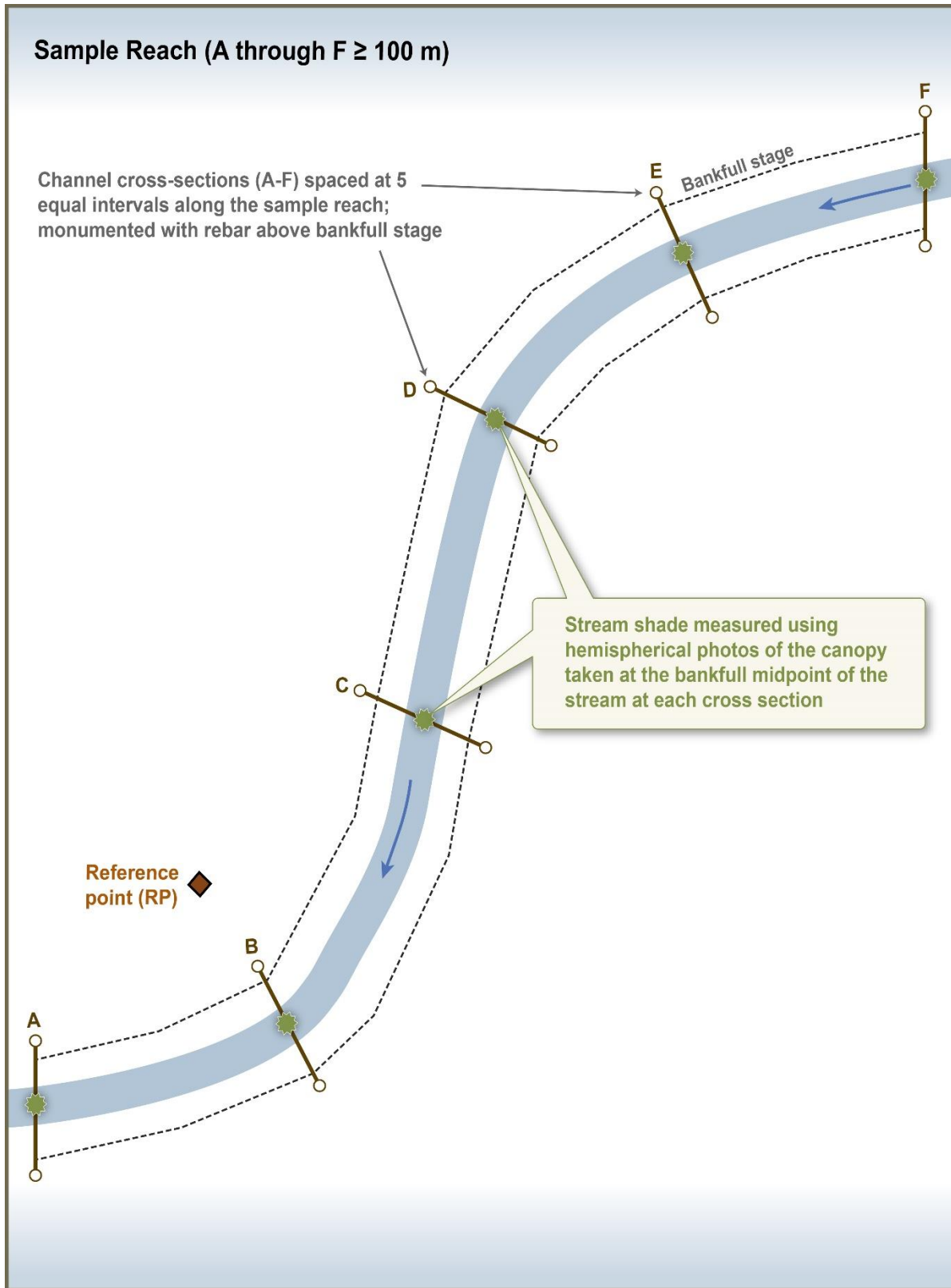


Figure 3-1. Location of stream shade sampling within a sample reach.

## Equipment and Supplies

The following equipment and supplies are needed for implementing the stream shade protocol field procedures:

- Nikon™ Coolpix 4500 digital camera
- Nikon™ FC-E8 fisheye converter (7.2 mm f/2.4, approximately 183° FOV)
- Pelican™ 1400 case, to transport and protect camera equipment in transit to sampling locations
- SimpleTech™ 512 MB CompactFlash Memory Card
- Nikon™ EN-EL1 camera battery or equivalent (two per camera. One in use, and another as backup)
- Nikon™ battery charger or equivalent
- Hemisfer software, version 2.16 or later
- Slik™ sprint 150 aluminum tripod w/ SBH-150DQ Ball Head
- Camera plate and Slik™ DQ-L Quick release adapter set
- StreamLight™ Stylus LED penlight (to indicate north on the photo)
- Compass
- Two 50-m measuring tapes
- Two chaining pins and four spring clamps
- Stadia rod
- Fixed-length plumb-line for setting camera tripod height (5 oz. plumb-line point, 24 gauge stainless steel cable, and cable ferrules)
- Ruggedized field tablet or paper field forms
- Data on the location of the initial set of photos in each watershed. This information is on the field tablet or it can be printed out.
- Camera operator's manual (optional)
  - The Nikon Guide to Digital Photography with the Coolpix 4500 Digital Camera
  - <http://www.nikonusa.com/pdf/manuals/coolpix/CP4500man.pdf>


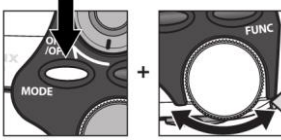

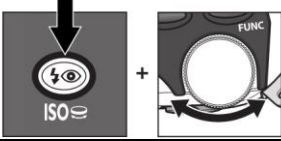


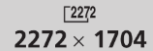
## Field Procedures

In this study, stream shade is measured using hemispherical canopy photos taken with a digital camera with a fish-eye lens.

### PRE-FIELD SET-UP

Ensure that the camera batteries are fully charged, previous data has been downloaded from the compact flash card, and the 9v battery for the LED indicator is functioning. Ensure time and date are correctly set on camera. Camera settings should match the ones in Table 3-1.

Table 3-1. Camera settings for Nikon Coolpix 4500.

Parameter	Setting Symbol	Setting Name
<b>Main Screen</b>		
Mode		Programmed Auto (set via MODE button and dial) 
ISO (a.k.a. "Sensitivity")		Must first set mode to "P" (Programmed Auto); then set ISO to <b>100</b> (set via dedicated button held down while turning dial) 
Self-timer		On (set via dedicated button) 
<b>Shooting Menu (camera must first be set to "P" (Programmed Auto) mode and also must be in shooting mode)</b>		
White balance	<b>A-WB Auto</b>	Auto
Metering	n/a	Controlled by setting Lens parameter to "Fisheye1"
Continuous	<b>S Single</b>	Single
Best shot selector	<b>Off</b>	Off
Image adjustment	<b>O Normal</b>	Normal
Saturation control	<b>0 Normal</b>	Normal
Image quality	<b>FINE</b>	Fine (1:4 JPEG compression)
Image size		2272 x 1704
Image sharpening	<b>Diamond Normal</b>	Normal
Lens	<b>Fisheye1</b> (Creates circular image)	Fisheye 1; sets the following three items automatically: <ul style="list-style-type: none"> <li>• Zoom fixed at widest angle</li> <li>• Focus fixed at infinity</li> <li>• Metering fixed at center-weighted</li> </ul>
Exposure options	<b>Off</b>	Off
Focus options	n/a	Controlled by setting Lens parameter to "Fisheye1"
Zoom options	n/a	Controlled by setting Lens parameter to "Fisheye1"
Speedlight options	<b>Internal Off</b>	Internal off
Auto bracketing	<b>OFF Off</b>	Off
Noise reduction	<b>OFF Off</b>	Off



## FIELD SAMPLING

Hemispherical canopy photos are taken at the midpoint between bankfull stages of the six permanently marked cross sections within each sample reach (Figure 3-1).

Although stream shade photography can be done as an independent survey, it is best combined with channel morphology and/or channel substrate sampling because the measuring tapes extended across the channel for these protocols can be used to position the camera at the cross section midpoint.

For optimal image quality, overcast flat lighting is preferred. Photos taken in direct sunlight or with a very bright sky can be washed out or include sun flares and glare. This can be partially corrected (see below). Photos are not to be taken in the rain.

### *Initial Photos*

When assessing stream shade trends, it is important that repeated photos are taken at the exact same location (horizontally and vertically). Canopy closure can vary greatly over fine spatial scales; thus, even minor changes in the position of the camera can introduce large differences in shade values. Therefore, when the initial stream shade photo is taken at a cross section, multiple measurements are taken to quantify the camera's location relative to the stream bed and monuments. This location is then replicated during the repeat photos.

Sampling starts at cross section A. First, two 50-meter tapes are extended across the stream channel to measure bankfull width and the distance between the bankfull midpoint and the left monument.

Attach the zero end of one tape (upper tape) to the left monument (rebar) with a spring clamp, extend the tape tautly across the channel, and attach the tape to the right monument with another clamp. Make sure that the tape is not obstructed by vegetation; prune if necessary. Identify bankfull stage at the cross section (using the indicators described in Appendix 3A of the Channel Morphology Protocol) and mark its position on both stream banks with chaining pins. Attach the zero end of the second tape (lower tape) to the chaining pin marking bankfull stage on the left side with a spring clamp, extend the tape tautly across the channel, and attach the tape to the chaining pin marking bankfull stage on the right side with another clamp. The lower tape should be aligned with the upper tape, and unobstructed by vegetation, logs, or boulders.

*Recommended tip: hang a plumb-line from the upper tape or use the stadia rod to correctly line up the chaining pins with the upper tape.*

Using the stadia rod or plumb-line, identify the distance along the upper tape that corresponds to the midpoint of the bankfull width (BFW/2) on the lower tape and record the bankfull midpoint's distance from the left and right monuments. Use the compass to measure the azimuth from each cross section monument to the camera and record the measurements in the field tablet.

Connect the plumb-line to the base of the camera tripod and set up the tripod with the plumb-line aligned with the bankfull midpoint. If debris, large boulders, or other obstacles prevent positioning the tripod at the

## ■ Stream Shade

midpoint, reposition the tripod upstream or downstream, as necessary, while keeping it as close as possible to the bankfull midpoint along the cross section line. Record the offset on the field tablet shade data entry form as a distance and azimuth from the true bankfull midpoint.

Mount the camera to the tripod (Figure 3-2). Switch on the LED penlight and insert it into the hole at the edge of the camera plate. Be sure that the front of the camera (not the screen-side) is facing the LED.

Adjust the tripod height so the plumb-bob point is just touching the stream bed (not the water surface). At this height, the top of the fisheye lens is 1.4 m (4.5 ft) above the stream bed and the camera plate edge is 1.25 m above the stream bed. Line up the compass housing with a corner of the camera plate, such that the compass bottom is flush with the plate edge opposite the LED. Rotate the camera plate until the orienting arrow shows that the camera is facing true north. With this alignment, the LED will indicate true north in the photograph. Level the camera plate and camera using the two-axis bubble levels.



**Figure 3-2. Camera positioned for a stream shade photo at the bankfull midpoint of a reach cross section.**

Take down the upper tape and any equipment (e.g., auto level) above the height of the camera that could appear in the photo. Prune any vegetation within 1.0 m of the lens. Before taking the photo, check that the camera is still at the correct height, leveled, and aimed toward true north and make sure the fisheye lens is clean and free of fog/water droplets.

To prevent glare, avoid taking the photograph with the lens positioned in direct sunlight. If possible, wait for the sun to be obscured by vegetation or clouds. If necessary, block the sunlight with a stick or the stadia rod, but try to affect the photo as little as possible. If a stick/stadia rod was used to shade the camera lens, note this in the field tablet “Remarks” field.

Turn on the camera and enable the self-timer. Press the shutter release to start the timer (10 seconds), then duck below the camera plate to avoid appearing in the photo. Remain below the camera plate until the light on the camera bottom stops blinking, indicating that the photo was taken.

Review the photo on the camera screen to make sure that the image is in focus, with no major lens flare, equipment or people in the photo (Figure 3-3). To view the photo and the photo number, press the play button above the screen twice. The number will appear in the right upper corner of the screen (XXXX.JPG).

If necessary, re-take the photo without deleting unsuccessful images. Return to the main screen by pressing the play button above the screen.

Record the picture number and time of photo in the appropriate field tablet database field.

Repeat the above steps at the remaining five cross-sections.



**Figure 3-3. Example of a hemispherical canopy photograph.**

### **Repeat Photos**

Photos that are taken subsequent to the initial set of photos in each basin (i.e., “repeat photos” taken in a subsequent year) should be taken in the same location and at the same height above the stream bed as the initial photos. For the repeat photos, the camera is positioned at the original bankfull midpoint, which can be found using the measurements recorded when the initial photo was taken. Extend a 50-meter tape from the left monument to the right monument and locate the original bankfull midpoint using its previously recorded distance from the left monument. This distance, along with other data from the previous photo visit (e.g. azimuth from each monument to the camera), is accessible on the field tablet database via the “Shade Photos” data entry option. Alternatively, it can be printed prior to going to the field.

If repeat stream shade sampling occurs in concert with channel morphology measurements, be sure to position the camera at the original bankfull midpoint (located using the upper tape), rather than at the new bankfull midpoint.

If the original bankfull midpoint cannot be located due to displaced monuments, or if the channel has migrated outside the original cross section, then re-establish the monuments along the channel and follow the protocol for locating the bankfull midpoint at the cross section (see *Initial Photos* section). Refer to the *Monitoring Site Establishment* protocol for cross section re-establishment procedures.

Connect the plumb-line to the base of the camera tripod and set up the tripod with the plumb-line aligned with the original bankfull midpoint. If in-channel debris, large boulders, or other obstacles prevent

## ■ Stream Shade

positioning the tripod at the midpoint, position the tripod upstream or downstream, as necessary, while keeping it as close as possible to the midpoint at the cross section. Record any offset on the field tablet as the distance and azimuth from the original bankfull midpoint position.

Mount the camera to the tripod camera plate (Figure 3-2). Switch on the LED penlight and insert into the hole at the edge of the plate. Be sure that the front of the camera (not the screen-side) is facing the LED.

Adjust the tripod height so the plumb-bob point is just touching the stream bed (not the water surface). At this height, the top of fisheye lens is 1.4 m (4.5 ft) above the stream bed.

Line up the compass housing with a corner of the camera plate, such that the compass bottom is flush with the plate edge opposite the LED. Rotate the camera plate until the orienting arrow shows that the camera is facing true north. With this alignment, the LED will indicate true north in the photograph.

Level the camera plate and camera using the two-axis bubble levels.

Take down the upper tape and any equipment (e.g., auto level) above the height of the camera that could appear in the photo. Prune any vegetation (salmonberry, devils club, vine maple, etc.) within 0.5 m of the lens. Before taking the photo, check that the camera is still at the correct height, leveled, and aimed toward true north and make sure the fisheye lens is clean and free of fog/water droplets.

To prevent glare, avoid taking the photograph if the lens is positioned in direct sunlight. If possible, wait for the sun to be obscured by vegetation or clouds. If necessary, block the sunlight with a stick or the stadia rod, but try to affect the photo as little as possible. If a stick or the stadia rod was used to shade the camera lens, note this in the “Remarks” field.

Turn on the camera and enable the self-timer. Press the shutter release to start the timer (10 seconds) then duck below the camera plate to avoid appearing in the photo. Remain below the camera plate until the light on the camera bottom stops blinking, indicating the photo has been taken.

Review the photo on the camera screen to make sure the image – is in focus, with no major lens flare, equipment or people in the photo. (Figure 3-3). To view the photo and the picture number, press the play button above the screen twice and the picture number will appear in the right upper corner of the screen (XXXX.JPG). If necessary, re-take the photo without deleting unsuccessful images. Return to the main screen by pressing the play button above the screen.

Record the picture number and time of photo in the field form.

Repeat the above steps at the remaining five cross-sections.

## Time and Cost Estimates for Implementing the Field Procedures

The estimated time for sampling stream shade in a sample reach is about two hours for an experienced two-member field crew (about 20 minutes per photo). This time estimate doesn't include the travel to the site.

Table 3-2 shows the cost estimates for the equipment unique to implementing the field procedures of the Stream Shade protocol. Many of the items listed in the *Equipment and Supplies* section above, such as the field tablet and stadia rod, are shared with other protocols. Their costs are detailed in the Channel Morphology protocol and not included here.

**Table 3-2. Cost Estimates for the Equipment Used in the Stream Shade Field Protocol**

Equipment/Supplies	Quantity	Individual cost
Nikon Coolpix 4500 (refurbished)	1	\$150
Nikon FC E8 Fisheye lens	1	\$100
Slik sprint 150 aluminum tripod w/ SBH-150DQ Ball Head	1	\$60
Slik DQ-L Quick release adapter set	1	\$50
Pelican 1150 Case	1	\$30
SimpleTech 512MB CompactFlash Memory Card	1	\$90

## Procedures for Calculating Metrics

### IMAGE PROCESSING

After photos have been renamed and moved to the archival folder, image processing is performed using Hemisfer software (Schleppi 2016). Hemisfer is capable of batch processing, although all settings must be carefully adjusted prior to running the batch. Settings chosen (April 2016) are shown in Table 3-3. If the decision is made in the future to process photos using any other software, then all photos must be re-analyzed using that software to ensure consistency in analysis.



**Table 3-3. Hemisfer settings chosen for image analysis.**

Parameter class	Parameter	Setting	Reason for setting
Image registration	Center x	1142	Determined by carefully examining images and fitting a circle to the perimeter of the hemispherical photograph.
	Center y	870	
	Radius	800	
	North, Declination, Slope, Aspect	0	We do not need to adjust these settings for the current analysis.
	Rings	1	For this analysis, we are not using multiple rings.
	Width	90	90 degrees represents the full hemisphere.
	Sectors	1	We are not using separate sectors in this analysis.
Site	All parameters	Leave either blank or zero.	We do not use these settings for our analysis.
Lens	Lens	Nikon FC-E8	This is the lens used for our photographs.
Colours	Red, Green, Blue	Red=0; Green=0; Blue=100	In the literature, the blue band is widely regarded as the best choice for image analysis.
Threshold	Minimum, maximum	Minimum=64; Maximum=255	Default setting.
	Gamma	1.0	This setting was used in previous DNR analyses (2007) and it seems to produce the most reasonable threshold values in the current set of photos.
	Threshold	Automatic detection	Permits batch processing by calculating a specific threshold value for each photo in the batch.
	Threshold method	Nobis & Hunziker (2005)	Regarded in the literature as the best method currently available.
Results	Level of detail	Full results	This gives detailed output, including the total count of pixels and the total count of white and black pixels.

## CALCULATING METRICS

From the results file produced by Hemisfer, calculate the percent shade as the count of black pixels in the image divided by the total number of pixels (always 2,010,553 when using the above settings), multiplied by 100.

For each photograph, percent shade, along with image processing metadata, are stored in two tables in the Shade Database (the database is described in the Data Management section below). Percent shade is stored in the Analysis Output Table, and image processing metadata are stored in the Analysis Parameter Table.

## Quality Assurance and Quality Control

Quality assurance includes staff training, use of standardized protocols, and annual field checks. The QA/QC procedures for data management are described in the Data Management section below.

## TRAINING

All personnel conducting field protocols will be trained in a consistent manner to ensure that the surveys are conducted properly and in standardized fashion. The training is conducted or, for returning personnel, reviewed, annually before the start of the field season. At least one member of the field crew should be experienced with the field procedures.

## STANDARD PROTOCOLS

The standard procedures described in this protocol are followed for the duration of the project. Any deviations from the procedures should be documented, and the reasons for deviation described and discussed with the project manager or the researcher overseeing the protocol implementation.

Changes to the published protocols are approved by the project manager or by the researcher overseeing the protocol implementation. Revised protocols are assigned new version numbers and publication dates.

## FIELD QUALITY CONTROL

The researcher overseeing the protocol implementation or a different field crew will conduct spot checks on 10% of the field measurements every year.

## Data Management

### DATA FLOW

The shade data collected in the field consist of digital photographs. Shade metadata are recorded in the field using paper field forms (2013-2014 field seasons) or a field tablet (2015 field season onward). In the office, digital photographs are stored on the network drive and metadata are transferred to a database for long-term storage. The steps below detail these processes.

#### Photographs

1. **Transfer photos to data manager for storage** All shade photos taken in the field are transferred to the OESF Data Management Specialist at the end of each field week. The Specialist temporarily stores the uncatalogued shade photos on the WADNR server at:  
J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\07\_Data management\\_All new data and photos\
2. **Rename photos** The OESF Data Management Specialist renames each photo using the following naming convention: SH\_<WatershedID><cross section>\_<Date taken>\_<Original photo name> (for example: SH\_797A\_20140715\_P1000851.JPG).
3. **Archive photos** The renamed photos are moved to long-term storage in the following directory:  
J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\03\_Photos and videos\05\_Shade\Photo archive\



### ***Metadata recorded on paper field forms***

1. **Fill out field forms** The Stream Morphology, Substrate, and Shade field forms are used to record the shade photo metadata at each sample reach.
2. **Scan and store field forms** After returning from the field each week, the field forms are scanned and stored on the WADNR network drive; the original paper forms are archived by the OESF Data Management Specialist at the WADNR Forest Resources Division.
3. **Enter data** All shade metadata collected on paper field forms is entered in the Shade Database by the OESF Data Management Specialist on a weekly basis. After each field form is entered, the person who entered it writes on it the word “Entered” followed by their initials and the date.
4. **Quality control** Entered field form data are verified by comparing the data on the field form to the data in the database. This process is performed by someone other than the person who originally entered the data. After the data are verified, the person who verified it writes on the field form the word “Verified” followed by their initials and the date.

### ***Metadata collected electronically***

1. **Fill out forms on electronic field data recorder** Field personnel record all shade metadata using the “Tablet Database”, which is a customized database created in Microsoft Access and saved on the field tablet.
2. **Store field metadata** At the end of each day in the field, a copy of the Tablet Database, containing all metadata and data collected to date, is transferred to the OESF Data Management Specialist via cloud storage or email. If internet access is not available, the field crew makes a daily backup copy of the database on a laptop or other storage device and then transfers the data to the Specialist at the end of the work week. The Specialist stores these Tablet Database copies in a temporary location on the WADNR network drive (J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\07\_Data management\\_All new data and photos\) until they are processed and the data are transferred to a database for long-term storage.
3. **Quality control** Because the metadata are recorded electronically, and thus never transcribed, transcription errors do not exist. However, there is still a possibility of data entry errors in the field. For this reason, metadata are examined for accuracy before they are imported to the Shade Database.
4. **Import data to database** On a weekly basis, the OESF Data Management Specialist imports all new metadata from the Tablet Database to the Shade Database. This is accomplished using a set of queries stored in a third database: J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD DATA\01\_Stream survey\Data\ Distribute\_Tablet\_Data.accdb
5. **Verify transfer of data** After data have been imported, the OESF Data Management Specialist verifies that no records have been missed, using the record count queries built into the Distribute\_Tablet\_Data database.

## DATA STORAGE

### *Paper Field Forms*

The paper field forms are archived at the Washington Department of Natural Resources (WADNR) Forest Resources Division. The designated data steward is Teodora Minkova, WADNR. Scanned copies of these forms are saved in the Adobe portable document format (.pdf) in the following directory:

J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD  
DATA\01\_Stream survey\Data\Data archive\Field forms\

### *Tablet Databases*

The original Tablet Databases, which are transferred to the OESF Data Management Specialist on a daily or weekly basis, are stored on the WADNR network drive after the metadata they contain have been transferred to the Shade Database. The storage location for these databases is:

J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD  
DATA\01\_Stream survey\Data\Data archive\Processed tablet databases\

### *Long-term Data Storage*

Shade photos are archived at: J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\03\_Photos and videos\05\_Shade\Photo archive\

Shade photo metadata, as well as all metadata and data produced during image analysis, are stored in the Shade Database, located on the WADNR network drive at:

J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD  
DATA\01\_Stream survey\Data\Shade\_Database.accdb

Within the Shade Database, data and metadata are stored in four related tables: the Form Header Table, the Field Data Table, the Analysis Output Table, and the Analysis Parameter Table (Figure 3-4). The Form Header Table is related to the Field Data Table through a one-to-many relationship: one record in the Form Header Table (i.e., a watershed visit) is related to multiple records in the Field Data Table (i.e., multiple photographs).

Each record in the Field Data Table (i.e., each photograph) is related to a record in the Analysis Output Table (i.e., analysis results from that photograph). This relationship is facilitated by a query that constructs each photo name from metadata in the Field Data Table and then links that name to the actual photo name in the Analysis Output Table. This one-to-one relationship is possible because every photo has a unique name. Records in the Analysis Output Table are related to records in the Analysis Parameter Table, which contain all of the metadata associated with image analysis. The fields in the four tables of the Shade Database are listed below (Tables 3-4 through 3-7).

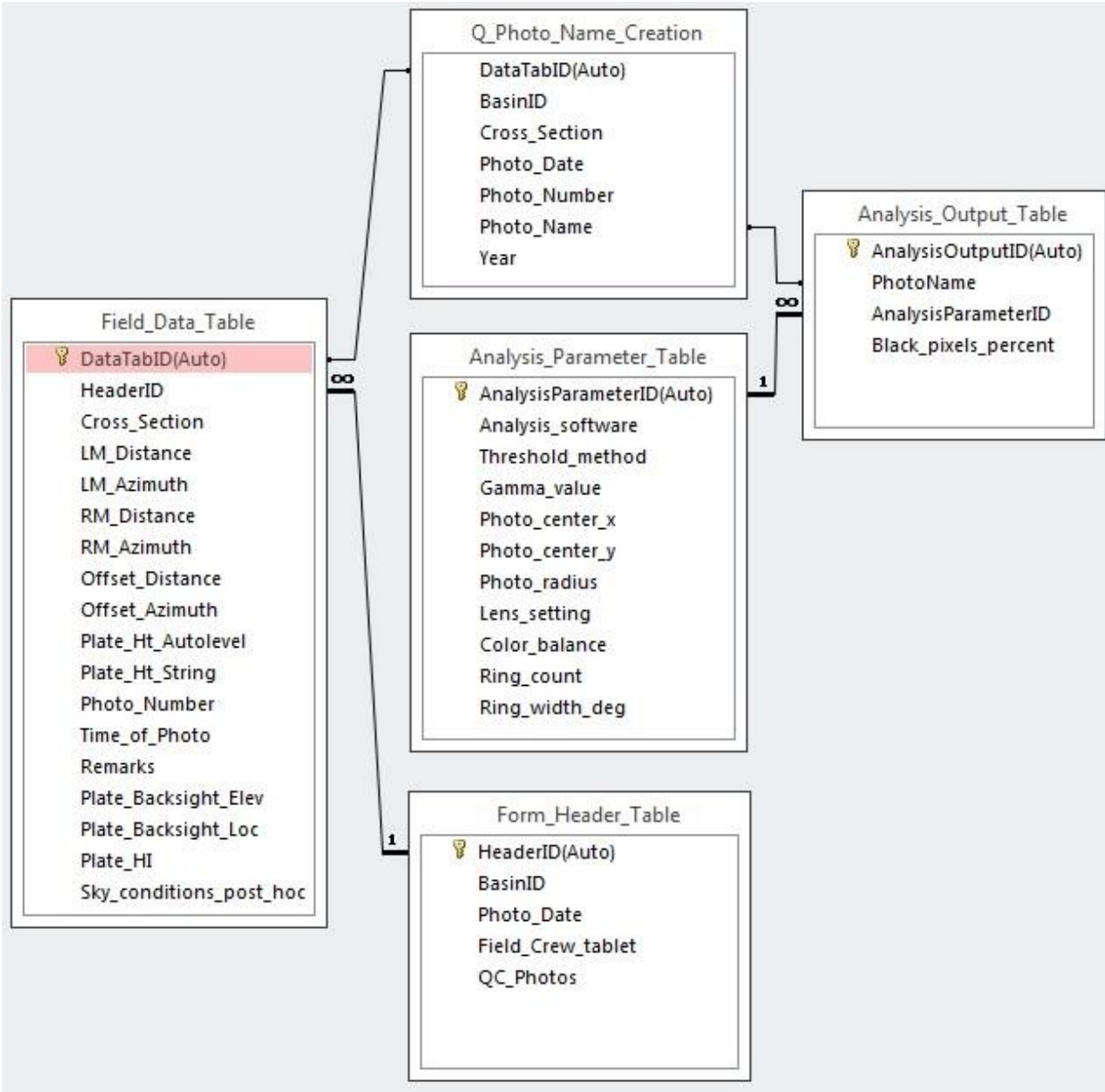


Figure 3-4. Structure of the Shade Database.

Table 3-4. Form Header Table from the Shade Database.

Field	Field description
HeaderID(Auto)	Unique ID for each record in this table.
BasinID	Watershed identifier.
Photo_Date	Date of the photo.
Field_Crew_tablet	Initials of the field crew.
QC_Photos	Indicates that the photos were taken for the purpose of quality control.

**Table 3-5. Field Data Table from the Shade Database.**

Field	Field description
DataTabID(Auto)	Unique identifier for each record in the table.
HeaderID	Links record to the appropriate record in the Form Header Table.
Cross_Section	The cross section at which the photo was taken.
LM_Distance	Camera distance from left monument (m).
LM_Azimuth	Azimuth from the left monument to the camera (degrees).
RM_Distance	Camera distance from right monument (m).
RM_Azimuth	Azimuth from the right monument to the camera (degrees).
Offset_Distance	Distance from middle (m).
Offset_Azimuth	Azimuth from middle (degrees).
Plate_Ht_Autolevel	Height of tripod plate, measured using auto level (cm).
Plate_Ht_String	Height of tripod plate, measured using string method (cm).
Photo_Number	The photo number assigned by the camera.
Time_of_Photo	The time the photo was taken (PDT).
Remarks	Remarks recorded in the field.
Plate_Back sight_Elev	Elevation of plate (cm), measured to a monument of known elevation. (This variable was recorded for only 33 photos.)
Plate_Back sight_Loc	The monument that the plate backsight elevation referenced. (This variable was recorded for only 32 photos.)
Plate_HI	Plate height of instrument (cm). (This variable was recorded for only 13 photos.)
Sky_conditions_post_hoc	The sky conditions (clear, partly cloudy, or overcast), as determined by examining the photo in the office.

**Table 3-6. Analysis Output Table from the Shade Database.**

Field	Field description
AnalysisOutputID(Auto)	A unique identifier for each record in the table.
PhotoName	The name of the photo, taken from the file itself.
AnalysisParameterID	ID linking each record to the software and settings that were used during image analysis.
Black_pixels_percent	Percent of all pixels that are black; this value represents percent shade.

**Table 3-7. Analysis Parameter Table from the Shade Database.**

Field	Field description
AnalysisParameterID(Auto)	A unique identifier for each record in the table.
Analysis_software	The software package or packages used in the image analysis, including version number.
Threshold_method	The method used to calculate the threshold value.
Gamma_value	The gamma value used during the threshold calculation.
Photo_center_x	The x coordinate (measured in pixels), within the full rectangular photo, of the center of the round hemispherical image.
Photo_center_y	The y coordinate (measured in pixels), within the full rectangular photo, of the center of the round hemispherical image.
Photo_radius	The radius of the round hemispherical image (measured in pixels).
Lens_setting	The lens type.
Color_balance	The color balance (red, green, blue, each ranging from -100 to 100) used in the analysis (e.g., OR OG 100B).
Ring_count	The number of rings used in the analysis.
Ring_width	The width of the rings, measured in degrees.

## DATA QUALITY CONTROL

### *Quality control for metadata*

Prior to data analysis, all fields in the data tables are assessed to identify potentially erroneous values. The first step is to examine individual fields, one at a time. For categorical data fields (e.g., cross section) and date or time fields, every field is assessed to identify any records exhibiting the following:

1. Missing values.
2. Illogical values. In some cases, where the data collector is free to enter values rather than selecting values from a predefined list, illogical values may be recorded (e.g., a survey time of 3:00 AM).

For numerical fields, each is assessed for the following:

1. Missing values.
2. Outlier values (e.g., an LM\_Distance was recorded in cm instead of m).

When missing values are discovered, it is generally not possible to “fill in the blank” from the office. The fact that data are missing should be recorded, in brackets, in the “Remarks” field, with the initials of the person who performed the quality control check (e.g., [LM\_Distance was not recorded. –WD]).

Illogical or outlier values can sometimes be corrected in the office. For example, AM and PM might have been switched or a decimal place error can be corrected. When data are corrected, this must be noted in the

remarks field, in brackets, with the initials of the person who performed the quality control check. For example: [LM\_Distance was recorded as 550 m. This was clearly incorrect and changed to 5.5 m which is logical given RM\_Distance. –WD].

In many cases, clearly erroneous outlier values cannot be corrected in the office and should be edited so as not to affect the results of analysis. In such cases, the value should be removed from the field and transferred to the Remarks field with an explanation, in brackets, with the initials of the person who performed the quality control check. For example: [Black\_pixels\_percent was recorded as 145.3; this value was clearly incorrect and removed from the dataset. –WD]).

### ***Quality control for photographs***

All photographs are reviewed to ensure there are no abnormalities that will affect the results of image analysis. Potential photo quality issues include:

1. Issues with camera settings such as focus or exposure. Blurry photos cannot be analyzed because the boundary between dark and light areas is unclear. Overexposed photos cannot be analyzed because shaded portions appear as light.
2. Obstructed photos. In some cases, understory plants, such as shrubs, obstruct significant portions of the image because they are close to the camera. If analyzed, these photos would produce a misleading result.

If a photo is unusable, then it is placed in a separate folder so that it will never be mistakenly analyzed:

J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\03\_Photos and videos\05\_Shade\Unusable photos\

A minimum of four photos from each sample reach and date are required for analysis. If more than two of the six photos from a given sample reach and date are unusable, then the photos from that reach and date are not analyzed.

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## Appendix 3A. Image Processing Software Options

Prior to processing any of the images in this study, several potential options for image processing software were considered. The choice of image processing software was independent of the process of locating and taking the photographs. Although Hemisfer was selected for image analysis (as of April 2016), the information in this Appendix may be of future use as a reference.

### Option 1: SideLook and Gap Light Analyzer

This option requires two software packages to perform two separate steps of the analysis. First, SideLook 1.1.01 (<http://www.appleco.ch>) is used to establish an image threshold to distinguish sky from non-sky. Second, Gap Light Analyzer 2.0 (<http://www.caryinstitute.org/science-program/our-scientists/dr-charles-d-canham/gap-light-analyzer-gla>) is used to measure canopy openness. Option 1 is not currently feasible because the software packages are not maintained or updated and they will not run on the operating systems that WADNR uses.

*More on SideLook:* SideLook is imaging software for the analysis of vegetation structure with true-color photographs. Sidelook is available for a nominal cost, and WADNR has a license. Sidelook implements an automatic threshold algorithm for edge detection (Nobis and Hunziker 2005) to distinguish sky from non-sky, and allows for processing of individual color channels (red, green, or blue). Processing of only the blue channel is recommended by several authors (Lee and others 1983; Frazer and others 1999, 2001). SideLook does not permit batch analysis and must run images individually. Note: Sidelook has not been updated since 2005 and is not likely to run on WADNR computers again, unless the authors of the software update it.

*More on Gap Light Analyzer (GLA):* GLA is Imaging software used to extract forest canopy structure and gap light transmission indices from true-color hemispherical photographs. GLA is free and offers a variety of customizations. GLA allows the user to specify topographic masks to compensate for topographic vs. vegetative shading, compensates for lens distortion using standard or customized equations, enables processing of images by color channel (red, green, or blue), and generates 22 canopy structure and light transmission metrics in 3 general categories: openness, effective LAI (leaf area index), and irradiance. Note: GLA has not been updated since 1999 and will not run on the current operating systems that WADNR uses.

### Option 2: Hemisfer 2.16

Hemisfer 2.16 ([http://www.wsl.ch/dienstleistungen/produkte/software/hemisfer/index\\_EN](http://www.wsl.ch/dienstleistungen/produkte/software/hemisfer/index_EN)) is a canopy image analysis program designed by the Swiss Federal Institute for Forest, Snow and Landscape Research. The software is available for a nominal cost, and WADNR has a license. Hemisfer offers many of the same capabilities as GLA, such as automated image thresholding using the same algorithm as SideLook. Hemisfer offers the advantage of batch processing. Batch processing, however, assumes all images are oriented and registered in an identical manner. Hemisfer is maintained and updated; the author of the software, Patrick Schleppi, is responsive to comments and questions.

### Option 3: HemiView

HemiView (<http://dynamax.com/products/leaf-canopy-and-image-analysis/hemiview-hemispheric-image-analysis-system>) is a commercially available canopy image analysis program developed by Delta T-Devices and sold

■ Stream Shade

by Dynamax. The software is sold as part of an integrated package that includes the camera, lens, tripod, mount, and software. The items are stocked as a kit and are not sold separately.

# Channel Substrate

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**Version:** 1.5

## **Revision History:**

<b>Protocol Version</b>	<b>Purpose / Changes</b>	<b>Author(s)</b>	<b>Reviewer(s)</b>	<b>Date</b>
1.0	Initial draft presented to project staff	Scott Horton	Teodora Minkova	03/28/2013
1.1	Draft submitted to external review	Scott Horton	Rebecca Flitcroft	04/16/2013
1.2	Final draft incorporating external reviews, sampling procedures from 2013 field season, and data mgmt. procedures	Scott Horton, Teodora Minkova	Mitchell Vorwerk	05/20/2014
1.3	Final draft with field and data management procedures updated from 2014 and 2015 field seasons	Scott Horton, Mitchell Vorwerk, Teodora Minkova	Ellis Cropper Alex Foster	06/10/2016
1.4	Final technical review and edit	Scott Horton, Mitchell Vorwerk, Teodora Minkova	Paul Dunnette, Warren Devine, Alex Foster	12/18/2016
1.5	Added pool tail fines protocol; removed embeddedness from the protocol.	Warren Devine, Kyle Martens	Kyle Martens, Teodora Minkova, Alex Foster	6/1/2022

## **Based on the Following Protocols:**

The general monitoring design follows the Field Protocol Manual for Aquatic and Riparian Effectiveness Monitoring Program (AREMP) for the Northwest Forest Plan (Lanigan et al. 2010). Details on some field procedures and adaptations are taken from Peck et al. (2006), which describes the U.S. Environmental Protection Agency's wadeable stream monitoring program (EMAP), and from Archer et al. (2012), with the multi-federal agency PACFISH/INFISH Biological Opinion Monitoring Program (PIBO).

## **Reasons to Adopt the Above Protocols:**

The EMAP protocol (Peck et al. 2006) employs the methods of Wolman (1954), as adapted by Kaufman and Robison (1998). These methods have been widely used because they are easy to learn and apply to obtain objective, repeatable measures (Peck et al. 2006) and provide unbiased estimates of surface substrate composition (Kaufman et al. 1999). The EMAP and PIBO protocols use sampling methods that are applicable to this study's site and cross-sectional transect layout and have the best-performing measures of substrate characteristics (Roper et al. 2010).

## **Purpose and Content:**

The purpose of this monitoring protocol is to describe the sampling and data management necessary to document and report the status and multi-year trends of channel substrate in the monitored watersheds. It details the field procedures for sampling substrate composition, the field quality assurance and quality control steps, and the data management procedures.

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## Introduction

Channel substrate refers to the mineral and organic materials that form the bottom or bed of a stream. Substrate composition determines the roughness of stream channels, which influences channel hydraulics (water depth, width, velocity) and consequently stream habitat. Substrate provides micro-conditions needed by many aquatic species (Bain 1999). For example, specific substrates are needed for spawning because eggs adhere to some surfaces; interstitial water flow through substrate maintains high oxygen levels around buried eggs. Certain-size substrate provides living space and cover for macroinvertebrates, amphibians, and fish (Hicks et al. 1991, Mellina and Hinch 2009, Roni et al. 2006).

Substrate composition and stability can be used as indicators of forest management impacts on sediment and hydrologic regimes.

In the environmental impact analysis for the Olympic Experimental State Forest (OESF) Forest Land Plan, fine sediment delivery (small soil particles such as sand, silt, and clay) was recognized as an important indicator of management effects on fish habitat and riparian areas (WADNR 2013). Because empirical sediment delivery data were not available at the time of the analysis, they were modeled using road inventory data and traffic impact scores based on road surface type, road proximity to streams, and projected traffic levels.

In this protocol, channel substrate is sampled by using two different procedures designed for two different objectives (Lanigan et al. 2010; Archer et al. 2012). Cross-section substrate surveys are used to characterize the reach-scale substrate composition. Pool tail fines are surveyed to assess the amount of fine sediments accumulated in possible spawning locations.

## Monitoring Design

### SPATIAL SAMPLING DESIGN

Channel substrate sampling is conducted in each of the 50 sample watersheds in Olympic Experimental State Forest (OESF) and in the reference watersheds. Refer to the Introduction chapter for a map of the sample watersheds.

Channel substrate particle size is sampled using two procedures: (1) at the six permanent cross sections established under the Monitoring Site Establishment Protocol (Figure 4-1), and (2) at pool tails. During cross section sampling, substrate particles are sampled at 21 stations spaced at equal intervals at each cross section (a minimum of 126 particles per sample reach). During pool tail sampling, fines are counted in 150 locations at each of the three largest scour pools per sample reach, for a total of 450 locations per reach.

### TEMPORAL SAMPLING DESIGN

Channel substrate is sampled during low flow conditions in the late spring or summer. Accuracy of substrate sampling is compromised if it is performed during high flows.

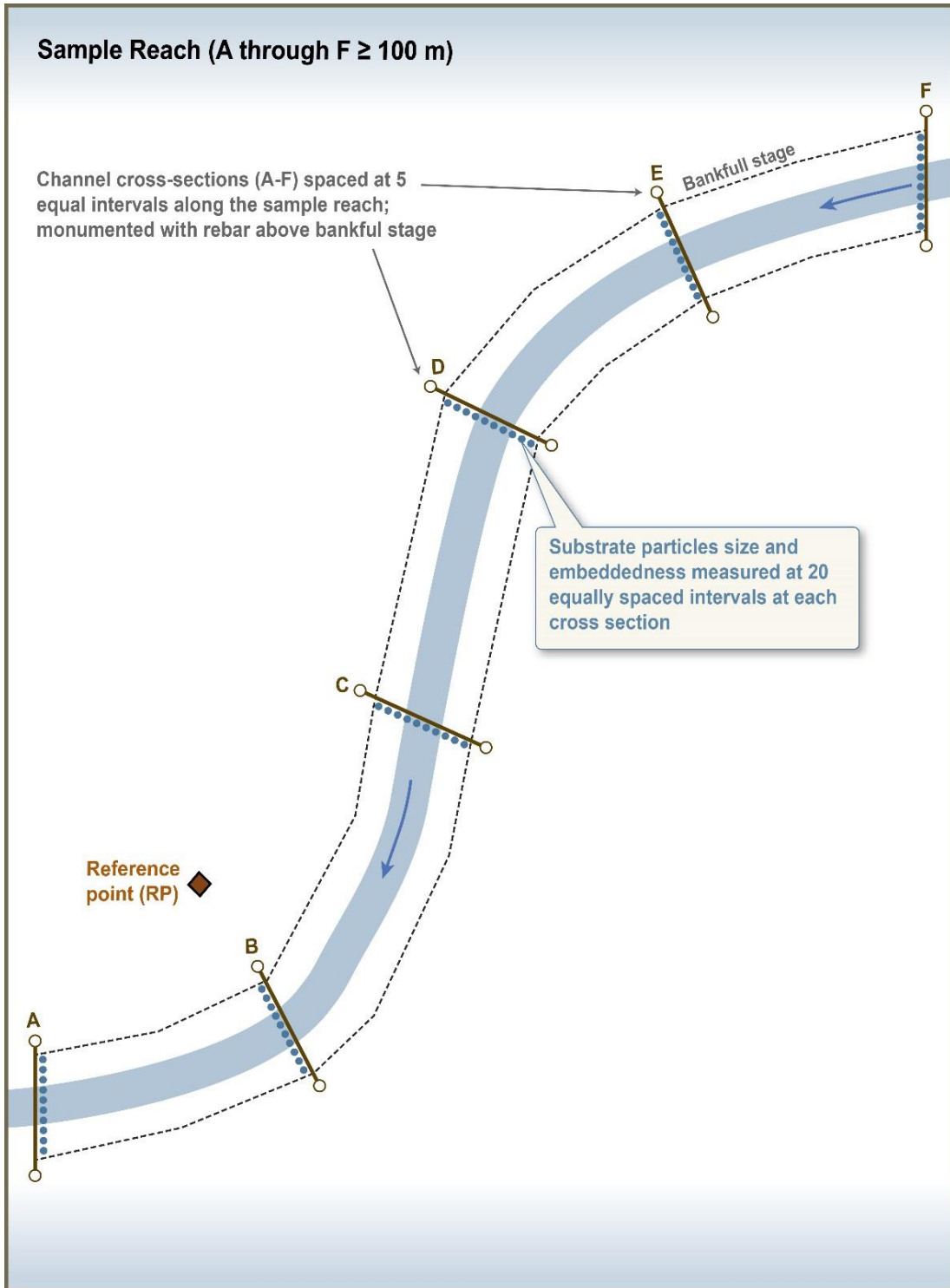


Figure 4-1. Locations of cross-section channel substrate sampling within a sample reach.

## Equipment and Supplies

- Gravelometer
- Stadia rod
- Two 50-meter tapes
- Two chaining pins and four spring clamps
- Sample grid of 5-cm squares, with 49 evenly distributed intersections (see Bunte et al. 2012).
- Plexiglas or plastic underwater viewer
- Ruggedized field tablet or paper field forms

## Field Procedures

### CROSS-SECTION SAMPLING

Cross-section substrate data are collected in conjunction with bankfull depth sampling (refer to the Channel Morphology Protocol). Thus, the substrate sampling described here includes a partial description of bankfull depth sampling as well.

As part of the cross-section surveys, two fixed, 50-meter tapes are used to measure distances and locate sampling stations at each cross section. One tape is extended from the left monument (LM) to the right monument (RM) and attached to the monuments with spring clamps (upper tape). The other tape is extended from the left bankfull stage (LBF) to the right bankfull stage (RBF) and secured to the banks using chaining pins and spring clamps (lower tape). The stadia rod or a plumb-line hung from the upper tape should be used to align the chaining pins and lower tape directly below the upper tape.

Before starting the bankfull depth/cross-section substrate surveys, enter the cross section BFW in the field tablet database, which automatically calculates the sampling interval and produces a list of 21 sampling stations (distances) along the lower tape (Figure 4-2).

One crew member takes auto level measurements for bankfull depth sampling (i.e., stadia rod heights), enters data in the field tablet, and reads the station distances to the stadia rod operator, who positions the rod on the stream bed at each sampling station. Stadia rod heights for bankfull depth sampling are collected at 11 of the 21 stations; be sure to collect heights before disturbing the substrate at these locations.

Substrate sampling begins at the LBF, which is assigned a station distance of zero. Without looking, pick up the substrate particle immediately at the base of the stadia rod. The accuracy of data collected using this sampling approach, called the pebble count technique, depends on unbiased selection of particles so be sure to place the rod at the predetermined station and avoid looking at the substrate. Be careful not to be biased toward larger pieces; substrate size classes are as small as 2 mm.

The size of a particle is determined along its intermediate axis, which controls whether the particle will fit through an opening of a certain size. This is the particle's median dimension (consider it the "width"), not the longest (length) or shortest (thickness) dimension. (Figure 4-3).



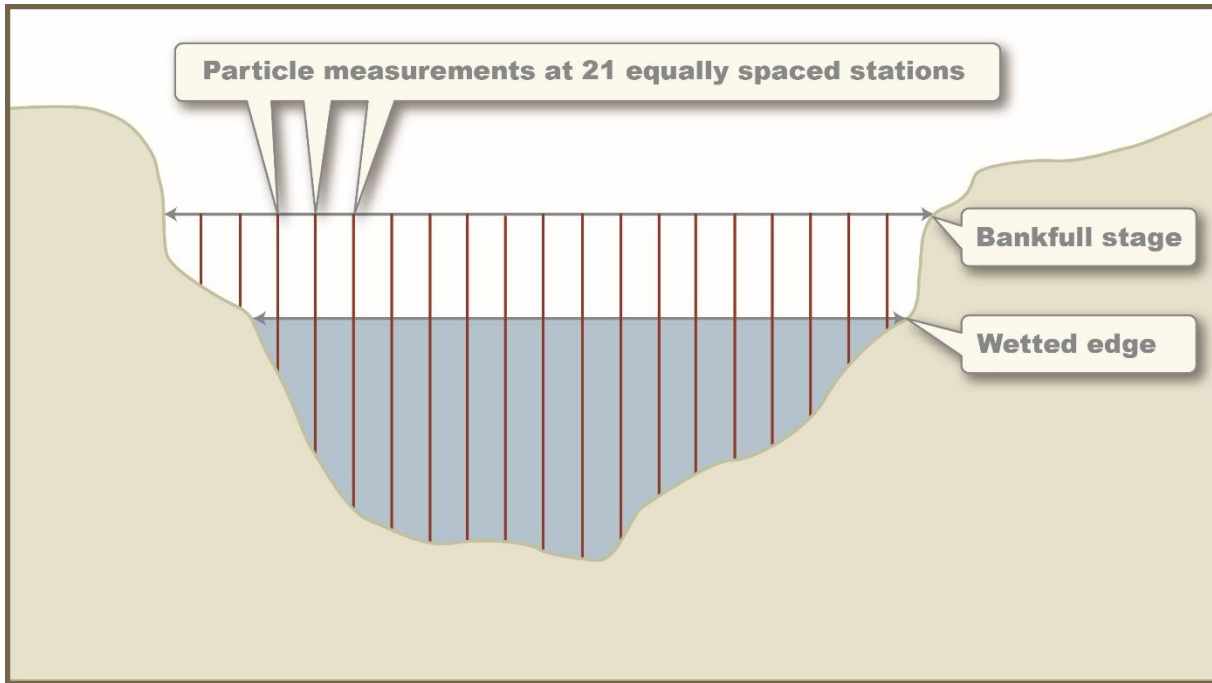


Figure 4-2. Profile view of channel substrate measurement locations.

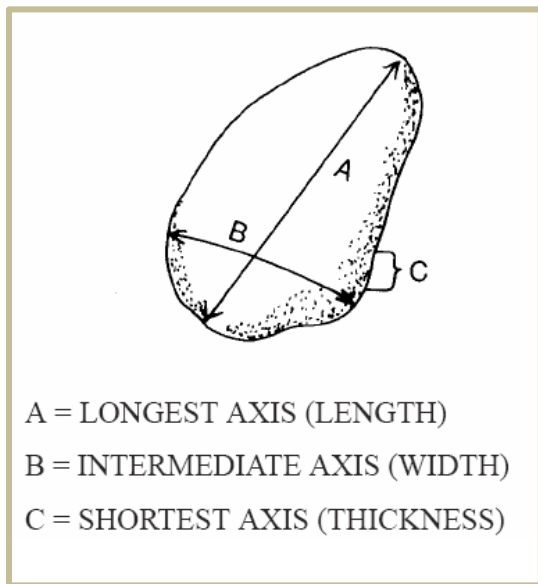


Figure 4-3. Measurement axes of a substrate particle (Harrelson et al. 1994).

A gravelometer is used to measure particles with intermediate axes up to 300 mm (Figure 4-4). Fit the selected particle through the smallest opening possible in the gravelometer (size of openings ranges from 2 to 180 mm) and record the opening size (i.e., the particle's size class) in the field tablet substrate "Size" field. If a particle intermediate axis is between 180 and 300 mm, measure it with the scale on the side of the gravelometer to determine its size class (Table 4-1). If the particle intermediate axis exceeds 300 mm, measure it with the stadia rod, a ruler, or a tape measure. Be sure to measure large and embedded particles even if they cannot be moved. For these, measure the smaller of the two exposed or estimate the intermediate axis of largely buried substrate.

Particles smaller than 2 mm (smallest opening of the gravelometer) are recorded as "Sand/silt/clay" (Table 4-1). Particles in size classes from 2.8 to 180 mm are recorded in



**Figure 4-4. Sampling channel substrate using the stadia rod and gravelometer.**

classes named according to gravelometer opening size. Particles between 181 mm and 250 mm are recorded as “Large cobble”. Particles between 251 mm and 3999 mm are recorded as “Boulder”. Substrate larger than 3999 mm is classified and recorded as “Bedrock”. Exposed bedrock also is recorded as “Bedrock” and no measurements are taken.

Woody debris, such as logs, bark and twigs, are recorded as “wood” only if it is not possible to get a substrate particle under the wood (Lanigan et al. 2010). Moss, live plants, or thick layers of organic debris are recorded as “organic” only if a substrate particle cannot be dug out from under the organic matter. Do not measure wood or organic particles.

**Table 4-1. Values measured and recorded for various particle size classes.**

Measurement method	Observed value (mm) based on gravelometer opening or manual measurement	Particle size class (mm) or descriptor recorded
Gravelometer opening	≤ 2	“Sand/silt/clay”
	2.8	2.8
	4	4
	5.6	5.6
	8	8
	11	11
	16	16
	22.6	22.6
	32	32
	45	45
	64	64
	90	90
Side of gravelometer (measured manually)	181 to 250	“Large cobble”
	251 to 3999	“Boulder”
Side of gravelometer, stadia rod, ruler, or tape measure (measured manually)	4000 and larger	“Bedrock”
None	Woody debris such as logs, bark, and twigs (if not possible to get a substrate particle from beneath)	“Wood”
	Moss, live plants, thick layers of organic debris (if not possible to get a substrate particle from beneath)	“Organic”

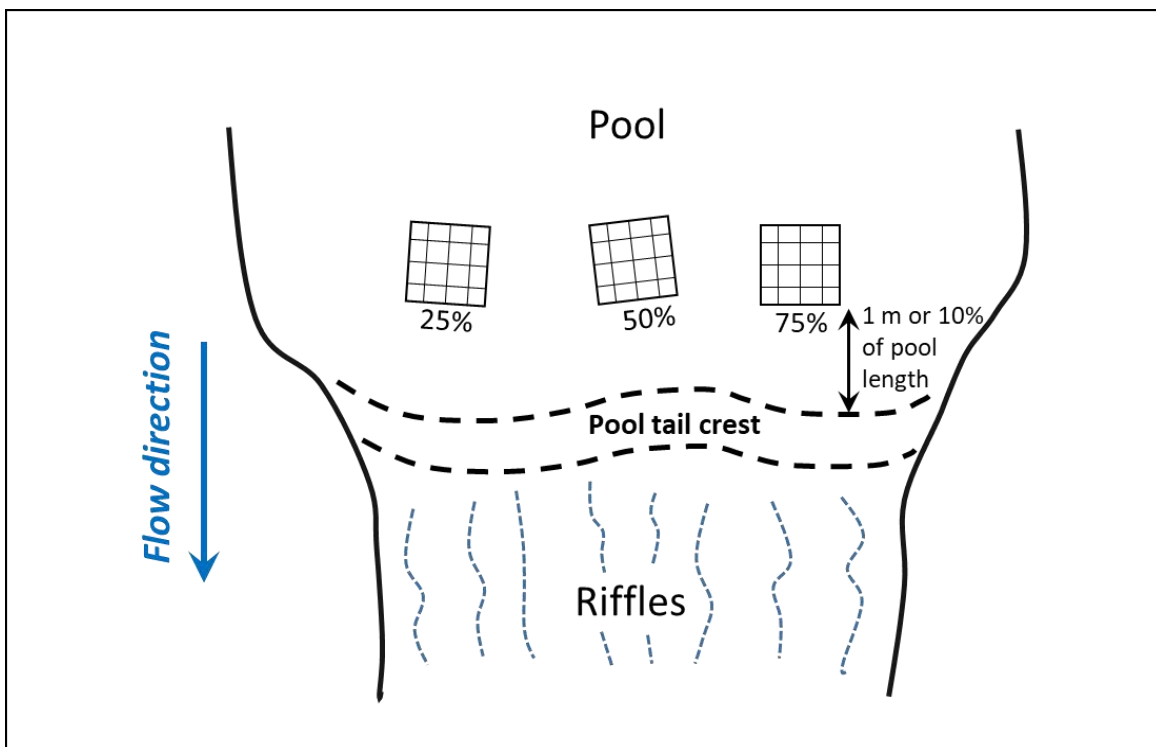
## POOL TAIL FINES SAMPLING

During a stream survey, pool tail fines sampling should be done after the habitat unit survey has been completed (page 6-1).

Begin the survey by identifying the three longest scour pools in the sample reach; these are the pools that will be sampled. To identify these pools, go to the *Pool Tail Fines* data form on the field tablet. Make sure the current survey is selected at the top, and then look at the habitat unit list at the bottom of the screen to identify the three longest scour pools in the reach. Note that it is OK if a portion of one of the three longest pools extends either above or below the end of the reach. If there are fewer than 3 scour pools in a reach, then sample all the scour pools present.

Go to the nearest of the three pools to be sampled; this pool will be known as Pool 1 on the tablet data form. Pool tail fines will be sampled by using the following procedure:

1. Sampling is based on the wetted channel, though in some cases it is possible that portions of the sample grid may be on dry sediments.
2. Identify the pool's tail crest. Sampling will be done within the pool at the *lesser* of 1 meter or 10% of the pool length upstream from the pool's tail crest (Figure 4-5).



**Figure 4-5. Diagram of the placement of three sampling grid locations, at distances of 25%, 50%, and 75% across the wetted channel. This example shows riffles below the pool, though riffles are not always present.**

3. To sample fines, the sampling grid will be placed successively in three different locations in each pool: center the sampling grid at 25%, 50%, and 75% of the distance across the wetted channel (visually estimated), making sure that the grid is parallel to and following the shape of the pool tail crest. Grid overlap is OK in narrow streams.
4. The grid (described below) has 49 intersections; include the top right corner of the grid frame to make 50 total “intersections”. After the grid is placed in each location, view the 50 intersections with the help of the underwater viewer. At each grid location, record the total number of intersections that:
  - a. are underlain with fine sediment <2 mm diameter. For reference, the elastic strings are 2 mm wide.
  - b. are underlain with fine sediment <6 mm diameter. For reference, a 6-mm-wide piece of tape is on the frame of the sampling grid.
  - c. are non-measurable. This includes intersections underlain by boulders larger than 50 cm (20 inches) diameter, vegetation, wood, or other organic materials. Do not move any of these non-measurable materials during this assessment.

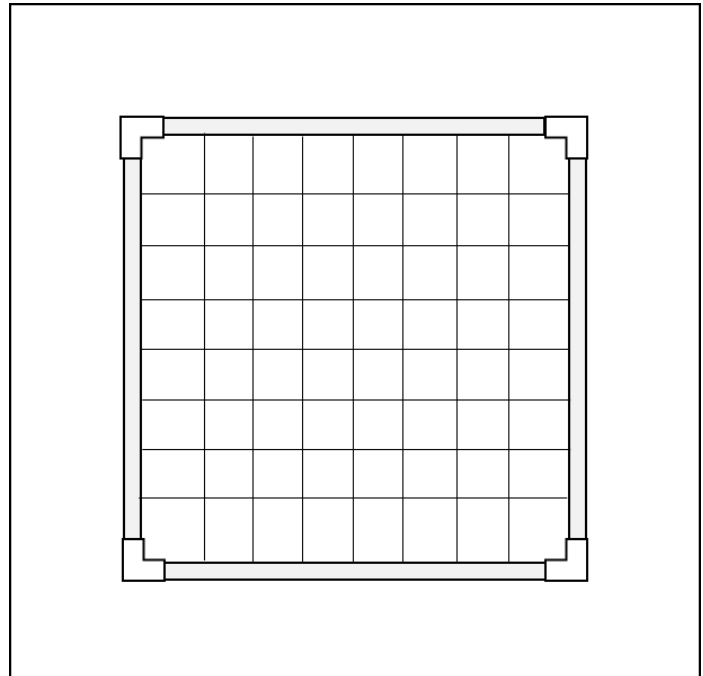
*Note:*

- The number of fines <6 mm *cannot* be less than the number of fines <2 mm.
- The number of fines <6 mm plus non-measurable intersections must be  $\leq 50$ .

After sampling of Pool 1 is complete, continue walking along the reach to the other two of the three largest pools, and repeat steps 1-4 at those pools.

*Sampling grid*

The sampling grid is constructed by using a square frame built from PVC pipe, with an inside diameter of 40-60 cm (Figure 4-6). Stretched across the square are 14 wires or elastic bands, with 7 running in each of 2 perpendicular directions (Bunte et al. 2012). This results in 49 intersections. The top right corner of the frame is considered the 50<sup>th</sup> intersection. Each of the squares within the grid are 5 × 5 cm in size.



**Figure 4-6. Diagram of the sampling grid. The frame is square and the bands or wires stretched across the frame create a total of 49 intersections.**

## Procedures for Calculating Metrics

Substrate data collected at each sample reach are condensed to site-level summaries that describe particular aspects of physical habitat (Kaufman et al. 1999). An initial list of metrics for substrate indicators is presented in Table 4-2. Data are often summarized by condensing the particle size classes from Table 4-1 into substrate type classes, as shown in Table 4-3. Numerous other metrics can be calculated from the substrate data (see Kaufman et al. [1999] for discussion of the conceptual basis and operational details for calculating summary metrics).

**Table 4-2. Indicators, metrics, and measurements for channel substrate analysis (modified from Kaufman et al. 1999).**

<b>Indicator</b>	<b>Metric (calculated at the reach scale)</b>	<b>Measurement</b>
Substrate composition (cross-section surveyes)	D <sub>50</sub> (median particle size)	Derived by ordering the particle size classes (Table 4-1), calculating the cumulative percentage of particles in each class, and identifying the class containing the median value. Wood, organics, and bedrock are not included in the D <sub>50</sub> calculation.
	Substrate percentage by size class	Percentage of particles in each substrate type class (Table 4-3).
	Percent fines	Percentage of particles in the ≤ 2 mm size class.
	Percent boulders	Percentage of particles in the 251–3999 mm size class.
Pool tail fines	Percent fines <2 mm	Subtract the total number of non-measurable intersections from 450: this is the number of measurable locations in the sample reach. Next, divide the total number of intersections with fines <2 mm by the number of measurable locations. Multiple the result by 100 to calculate this metric.
	Percent fines <6 mm	Subtract the total number of non-measurable intersections from 450: this is the number of measurable locations in the sample reach. Next, divide the total number of intersections with fines <6 mm by the number of measurable locations. Multiple the result by 100 to calculate this metric.

**Table 4-3. Classification of substrate types by size**

Substrate type	Particle size (mm)
Fines (sand, silt, clay)	≤ 2
Fine gravel	>2 – 16
Coarse gravel	>16 – 64
Cobbles	>64 - 250
Boulders	> 250 - 3999
Bedrock	≥4000

## Time and Cost Estimates for Implementing Field Procedures

The estimated time needed to sample channel substrate is 10 minutes per cross section or 60 minutes per sample reach for an experienced two-member crew. If the measuring tapes have to be set at each cross section, the additional field time is 60 min per sample reach. These two estimates do not include time spent traveling to the site, setting up the tapes at a cross section, or measuring channel morphology attributes. The pool tail fines sampling procedure is estimated to take 20-30 minutes.

Table 4-4 shows the cost estimates for specialty equipment unique to implementing the field procedures of the channel substrate protocol. Many of the items listed in the *Equipment and Supplies* section above are shared with other protocols, such as the field tablet, measuring tapes, and stadia rod. Their costs are detailed in the Channel Morphology protocol and not included here.

**Table 4-4. Cost estimates for the equipment used in the channel substrate protocol**

Equipment/Supplies	Amount	Individual cost
Gravelometer	1	\$75
Sampling grid	1	\$30
Underwater viewer	1	\$40

## Quality Assurance and Quality Control

The quality assurance for the channel substrate field protocol includes staff training and the use of standardized protocols. The quality control for the field procedures includes annual field checks. The QA/QC procedures for data management are described in the Data Management section below.

## TRAINING

All personnel conducting field protocols will be trained in a consistent manner to ensure that the surveys are conducted properly and in standardized fashion. The training is conducted or, for returning personnel, reviewed, annually before the start of the field season. At least one member of the field crew should be experienced with the field procedures.

## STANDARD PROTOCOLS

The standard procedures described in this protocol will be followed for the duration of the project. Any deviations from the procedures should be documented, and the reasons for deviation should be described and discussed with the project manager or the researcher overseeing the protocol implementation. Changes to the published protocols must be approved by the project manager or the researcher overseeing the protocol implementation. Revised protocols will be assigned new version numbers and publication dates.

## FIELD CHECKS

The researcher overseeing the protocol implementation or a different field crew will conduct spot checks on 10% of the field measurements every year.

## Data Management

The management procedures for channel substrate data are integrated within the overall channel morphology data management procedures. Therefore, this section summarizes procedures used for both channel substrate data and channel morphology data.

## DATA FLOW

All channel morphology data (including substrate data) are recorded in the field using paper field forms (2013-2014 field seasons) or a ruggedized field tablet (2015 field season onward). In the office, data are then transferred to a database for long-term storage. The steps below detail the process.

### *Data flow for paper field forms*

1. **Fill out field forms** Channel Morphology field forms are used to record the substrate data and metadata at each sample reach.
2. **Scan and store field forms** After returning from the field each week, the field forms are scanned and stored on the WADNR network drive; the original paper forms are archived by the OESF Data Management Specialist at the WADNR Forest Resources Division.
3. **Enter data** All channel morphology data (including substrate data) collected on paper field forms is entered in the Stream Geomorphology Database by the OESF Data Management Specialist on a weekly basis. After data from a field form is entered, the Specialist writes “Entered” on the form followed by his or her initials and the date.
4. **Quality control** Entered field form data are verified by comparing the data on the field form to the data in the database. This process is performed by someone other than the person who originally



entered the data. After the data are verified, the Specialist writes “Verified” on the form followed by his or her initials and the date.

### ***Data flow for electronically collected data***

1. **Fill out forms on electronic field data recorder** Field personnel record all channel morphology data (including substrate data) using the “Tablet Database,” a customized database created in Microsoft Access and saved on the field tablet.
2. **Store field data** At the end of each day in the field, a copy of the Tablet Database, containing all data collected to date, is transferred to the OESF Data Management Specialist via cloud storage or email. If internet access is not available, the field crew makes a daily backup copy of the database on a laptop or other storage device and then transfers the data to the Specialist at the end of the work week. The Specialist stores these Tablet Database copies in a temporary location on the WADNR network drive (J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\07\_Data management\\_All new data and photos )until they are processed and the data are transferred to a database for long-term storage.
3. **Quality control** Because data are recorded electronically, and thus never transcribed, transcription errors do not exist. However, there is still a possibility of data entry errors in the field. In particular, if metadata (e.g., the date of a field visit or a basin ID) are recorded incorrectly in the field, this could cause errors during the process of importing data from the Tablet Database to the Stream Geomorphology Database (next step; see below). For this reason, metadata are examined for accuracy prior to importing data to the Stream Geomorphology Database.
4. **Import data to database** On a weekly basis, the OESF Data Management Specialist imports all new data from the Tablet Database to the Stream Geomorphology Database. This is accomplished using a set of queries stored in a third database: J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD DATA\01\_Stream survey\Data\Distribute\_Tablet\_Data.accdb
5. **Verify transfer of data** After data have been imported, the OESF Data Management Specialist verifies that no records have been missed, using the record count queries built into the Distribute\_Tablet\_Data database.

## **DATA STORAGE**

### ***Paper Field Forms***

The paper field forms are archived at the Forest Resources Division of Washington Department of Natural Resources. The designated data steward is Teodora Minkova, WADNR. Scanned copies of these forms are saved in the Adobe portable document format (.pdf) in the following directory:

J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD DATA\01\_Stream survey\Data\Data archive\Field forms\

**Tablet Databases**

The original Tablet Databases, which are transferred to the OESF Data Management Specialist on a daily or weekly basis, are stored on the WADNR network drive after the field data they contain have been transferred to the Stream Geomorphology Database. The storage location for these databases is:

J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD DATA\01\_Stream survey\Data\Data archive\Processed tablet databases\

**Long-term Data Storage**

The ultimate location of the channel morphology and substrate data is the Stream Geomorphology Database, located on the WADNR network drive at: J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD DATA\01\_Stream survey\Data\Stream\_Geomorphology\_Database.accdb

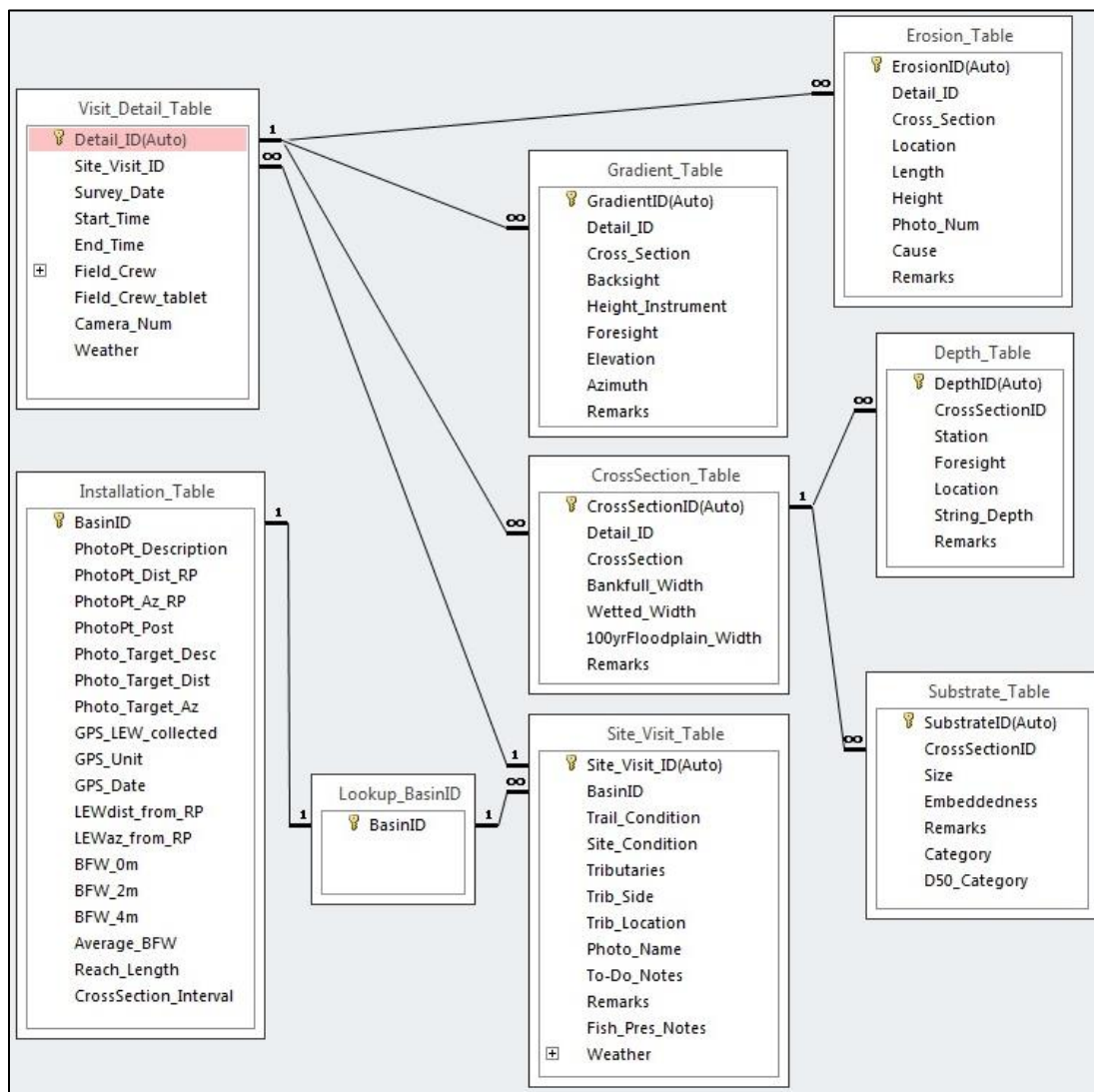
Within the Stream Geomorphology Database, data are stored in a series of related tables (Figure 4-7). The Cross Section Table is related to metadata via a one-to-many relationship with the Visit Detail Table: multiple cross-sections (e.g., from the same survey date and sample reach) are typically related to a single metadata record in the Visit Detail Table. The Cross Section Table is also related to the Substrate Table via a one-to-many relationship: each cross section is related to multiple substrate records. The database fields relevant to substrate data are described in Tables 4-5 and 4-6.

**Table 4-5. Cross Section Table from the Stream Geomorphology Database.**

Field	Field description
CrossSectionID(Auto)	A unique identifier for each cross section.
Detail_ID	Relates the cross section to the appropriate metadata in the Visit Detail Table.
CrossSection	Cross section letter (A-F).
Bankfull_Width	Bankfull width (m).
Wetted_Width	Wetted width (m).
100yrFloodplain_Width	The width of the 100-year floodplain (m), measured for cross sections A, C, and F.
Remarks	Remarks regarding the cross section.

**Table 4-6. Substrate Table from the Stream Geomorphology Database.**

Field	Field description
SubstrateID(Auto)	A unique identifier for each substrate measurement.
CrossSectionID	Relates the substrate measurement to the appropriate cross section in the Cross Section Table.
Size	Particle size (mm).
Embeddedness	Particle embeddedness (%). [Not collected after 2020.]
Remarks	Remarks regarding the substrate measurement.
Category	Particle size class (e.g., cobble, boulder).
D50_Category	Particle size class (mm) used for calculating D50 and other metrics. This differs from the Size field in that the Size field may contain actual diameter measurements, especially for larger particles, rather than a size class.



**Figure 4-7. The structure of the Stream Geomorphology Database.**

## DATA QUALITY CONTROL

Prior to data analysis, all fields in the data tables are assessed to identify potentially erroneous values. The first step is to examine individual fields, one at a time. For categorical data fields (e.g., cross section) and date or time fields, every field is assessed to identify any records exhibiting the following:

1. Missing values.
2. Illogical values. In some cases, where the data collector is free to enter values rather than selecting values from a predefined list, illogical values may be recorded (e.g., a survey time of 3:00 AM).

For numerical fields, each is assessed for the following:

1. Missing values.
2. Outlier values (e.g., a particle diameter was recorded in cm instead of mm).

The next step in quality control assessment is to examine whether all aspects of the data are within a reasonable range. For example, if one cross section has 40 substrate measurements, it is likely that an error has occurred somewhere.

When missing values are discovered, it is generally not possible to “fill in the blank” from the office. The fact that data are missing should be recorded, in brackets, in the “Remarks” field, with the initials of the person who performed the quality control check.

Illogical or outlier values can sometimes be corrected in the office. For example, AM and PM might have been switched or a decimal place error can be corrected. When data are corrected, this must be noted in the remarks field, in brackets, with the initials of the person who performed the quality control check.

In many cases, clearly erroneous outlier values cannot be corrected in the office and should be edited so as not to affect the results of analysis. In such cases, the value should be removed and transferred to the “Remarks” field with an explanation, in brackets, with the initials of the person who performed the quality control check. For example: [Erosion height was recorded as 74.8 m. This value was clearly incorrect and removed from the dataset. –WD]).

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[https://www.fs.fed.us/biology/nsaec/assets/archeretal\\_2012\\_pibo\\_stream\\_sampling\\_protocol.pdf](https://www.fs.fed.us/biology/nsaec/assets/archeretal_2012_pibo_stream_sampling_protocol.pdf)
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## ■ Channel Substrate

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## Appendix 4A. *Embeddedness Procedure (Discontinued after 2020)*

NOTE: After the 2020 field season, measurement of substrate embeddedness was discontinued. The primary reason for this was the difficulty in precisely and consistently evaluating the embeddedness of individual particles. Upon reviewing the embeddedness data collected from 2013 through 2020, it was clear that there were dramatic variations in embeddedness associated with different field crews. This, combined with our personal experience measuring embeddedness, led us to decide that the embeddedness protocol was unsuitable for long-term monitoring. The discontinued protocol is provided below:

### EMBEDDEDNESS

Embeddedness is estimated for particles measuring 45 mm or more. Embeddedness is the fraction of particle surface area surrounded or covered by fine sediment ( $\leq 2$  mm). Embeddedness is estimated in increments of 10%. The following factors are considered:

- The proportion of a particle's surface area, including the underside, which is obviously covered with sand, silt, or clay.
- The difficulty associated with removing a particle from the streambed and the size of the particles around it. Particles  $>2$  mm do not contribute to embeddedness.
- Staining or "biofouling" is usually caused by the accumulation of periphyton on the exposed wetted surface. The biofouled area thus has a different coloration. The surface area without biofouling is generally not exposed to flowing water and is the portion used to estimate embeddedness. However, use this last factor with caution as particles  $>2$  mm that touch the selected particle can also prevent biofouling.

For particles classified as "sand/silt/clay", embeddedness is recorded as 100%. For bedrock, embeddedness is recorded as 0%. No embeddedness is recorded for wood or organic material.

Record the percentage embeddedness of each particle in the field tablet database "Embed." field.



# In-stream Large Wood

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Version: 1.7

## Revision History:

Version number	Purpose / Changes	Author(s)	Reviewer(s)	Date
1.0	Initial draft presented to project staff	Alex Foster	Peter Bisson, Teodora Minkova	03/19/2013
1.1	Draft submitted to external review	Alex Foster	Rebecca Flitcroft	04/16/2013
1.2	Draft incorporating external reviews, sampling procedures from 2013 field season	Alex Foster, Teodora Minkova	Mitchell Vorwerk	05/20/2014
1.3	Final draft incorporating sampling procedures from 2014-2015 field season, and data mgmt. procedures	Alex Foster, Mitchell Vorwerk, Teodora Minkova	Ellis Cropper, Kyle Martens	05/10/2016
1.4	Final technical review and edit	Alex Foster, Mitchell Vorwerk, Teodora Minkova	Paul Dunnette, Warren Devine, Alex Foster	12/18/2016
1.5	Change in wood decay classification	Paul Dunnette	Alex Foster, Teodora Minkova	06/21/2018
1.6	Added process for recording pool-forming pieces and jams to link these pieces to pool habitat units.	Warren Devine	Teodora Minkova	6/13/2019
1.7	Added piece diameter measurement for jam pieces. Made numerous other minor updates and clarifications.	Warren Devine	Teodora Minkova, Kyle Martens, Alex Foster	6/2/2022

## Based on the Following Protocols:

This protocol is adapted from the Level 2 large woody debris (LWD) survey, of the *TFW Monitoring Program Method Manual for the LWD Survey* by Schuett-Hames et al. (1999). Refer to the original document if clarification is needed.

## Reasons to Adopt the Above Protocols:

Due to its rigorous wood classification, measurement, and counting methodologies, Schuett-Hames et al. (1999) had the lowest repeat survey variation in a comparison of several stream survey methods being implemented in the Pacific Northwest (Roper et al. 2010).

## Purpose and Content:

This protocol details the field procedures for classifying and measuring pieces of large wood in the sample reaches, the field quality assurance and quality control steps, and the data management and analysis procedures necessary to document and report the status and trends of in-stream large wood across the Olympic Experimental State Forest.

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## Introduction

In-stream large wood—or large woody debris (LWD)—refers to logs, pieces of logs, root wads, or large chunks of wood that have fallen into stream channels. In-stream large wood has many roles in aquatic systems: it traps and retains sediment, changes water velocity and diverts stream flows, changes channel shape and gradient, releases nutrients as it decomposes, and provides habitat and cover for aquatic organisms (Bisson et al. 1987, Cummins 1974).

The type and level of ecological function provided by LWD depends on the size, species, location, and distribution of the wood pieces. LWD functionality also depends on stream characteristics such as size and gradient. For example, logs of the same size may not provide the same level of ecological function in a large stream as they do in a small one. The condition and location of LWD vary considerably in time and space and reflect past and present recruitment rates and the rates of LWD transport through the channel (Schuett-Hames et al. 1999). Owing to all these factors, comprehensive and repeated LWD surveys are required to assess the status of and changes in riparian and aquatic habitat over time.

In the environmental impact analysis for the Olympic Experimental Forest (OESF) Forest Land Plan, LWD recruitment was recognized as an important indicator for fish habitat and riparian areas (WADNR 2013).

## ***Monitoring Design***

### **SPATIAL SAMPLING DESIGN**

The LWD survey is conducted at each of the 50 sample watersheds in the OESF and in the reference watersheds. Refer to the Project Background chapter for a map of the sample watersheds.

LWD pieces are classified and measured during a continuous survey of the sample reach.

### **TEMPORAL SAMPLING DESIGN**

The ideal time to sample in-stream wood in the OESF is late spring through early fall, when stream flow is relatively low. To prevent unnecessary disturbance and mortality to salmon, avoid working in the channel during spawning or when there are eggs in the gravel.

## ***Equipment and Supplies***

The following field equipment and supplies are needed for LWD surveys:

- Stadia rod or reel tape, to measure LWD piece length
- Log calipers (in metric units)
- Ruggedized field tablet with electronic data entry form and paper field forms (as backup to tablet)
- Railroad chalk

## ***Field Procedures***

### **LARGE WOODY DEBRIS IDENTIFICATION CRITERIA**

Data are collected for all *qualifying* LWD pieces within the sample reach.

#### ***Logs and Rootwads***

LWD pieces that qualify for sampling are classified as either: (1) logs, or (2) rootwads less than 2 m long.

## ■ In-Stream Large Wood

- **Logs** must have a minimum diameter of 10 cm for at least 2 m of length to qualify for sampling. Logs may or may not have root systems still attached (Figure 5-1).
- **Rootwads** are pieces that are *less than 2 meters in length* that still qualify for sampling (Figure 5-2). To qualify, rootwads must have:
  1. An identifiable root system and bole (i.e., stem or tree trunk),
  2. A total length that is less than 2 meters, and
  3. A minimum diameter of 20 cm above the root swell (see *Diameter and Length*, below, for measurement details).

In addition, each LWD piece (whether a log or rootwad) must meet the following criteria to qualify:

1. It is completely dead. No live (green) needles or leaves or other signs of life are evident at the time of the survey.
2. At least 10 cm of its qualifying dimensions is within or directly above the bankfull stage of the channel (Figure 5-3; refer to Appendix 5A for indicators of bankfull stage).
3. Its root system, if it has one, is detached from its original position (i.e., it is not rooted and has the ability to move along the length of the channel and become “debris”).

LWD pieces are to be sampled separately if they are broken on the long axis; each broken piece should be sampled only if it qualifies. Branches still attached to the bole are not included in the survey (even if they are of qualifying diameter and length). See *Diameter and Length*, below, for instructions on measuring logs or rootwads with multiple boles.

If a portion of a LWD piece is buried and its full length and midpoint diameter (see *Diameter and Length*, below) cannot be determined, measure only the exposed section(s). Some probing/surface debris removal is acceptable, if necessary, to obtain a better length or diameter measurement.

### **Log Jams**

Accumulations of LWD pieces (logs and rootwads) that form a log jam are measured in a different way than individual pieces. A log jam is defined as an accumulation of 10 or more *qualifying* LWD pieces with each piece touching at least one other piece in the accumulation.

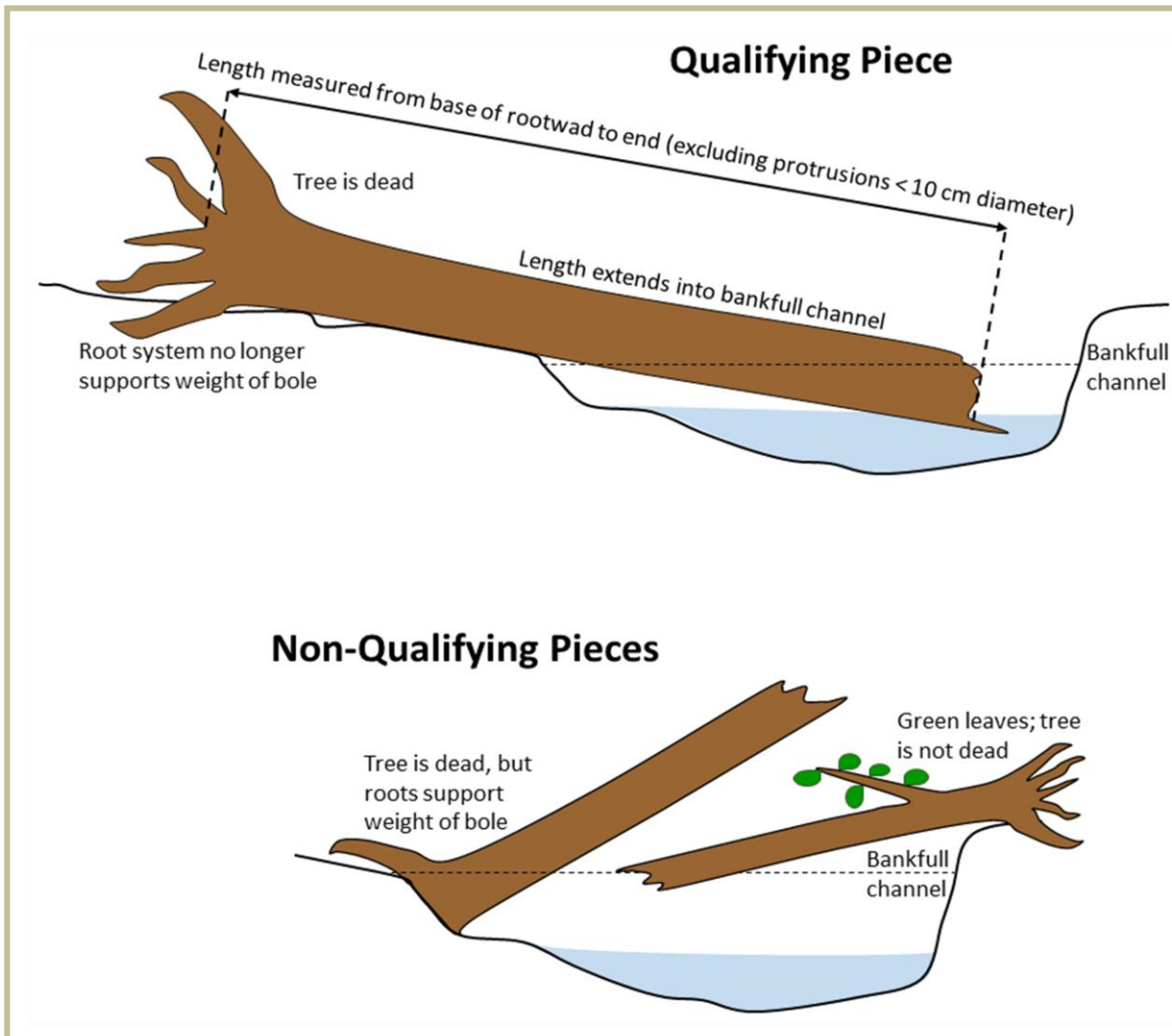


Figure 5-1. Criteria for determining whether individual pieces of wood qualify for measurement (modified from Schuett-Hames et al. 1999).

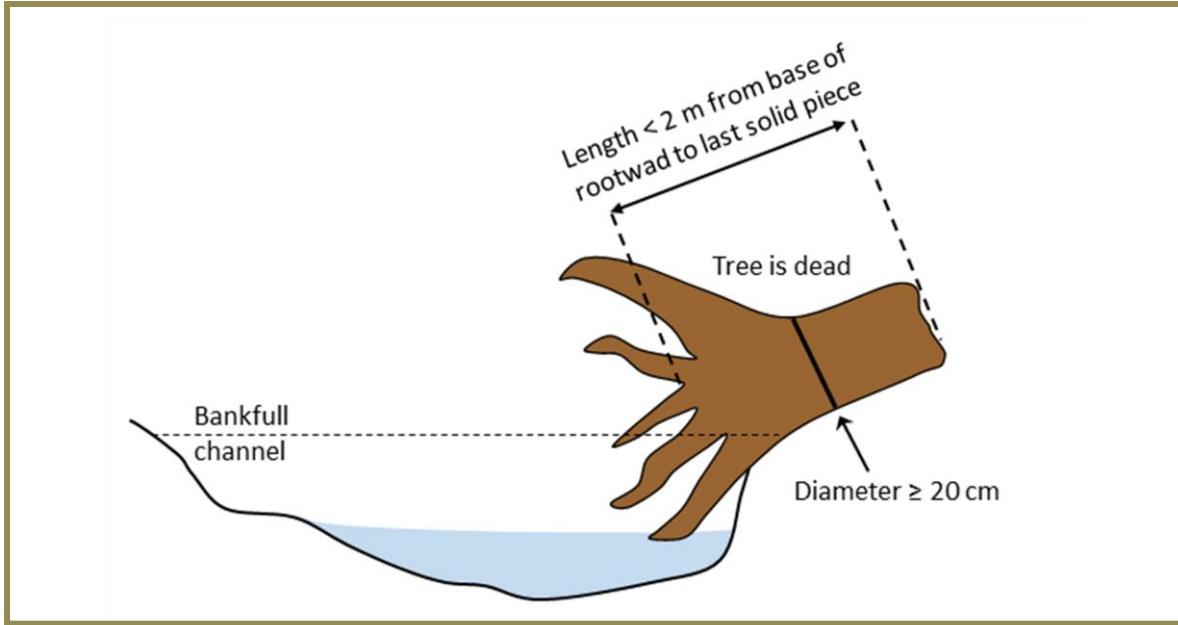


Figure 5-2. Criteria for determining whether a rootwad qualifies for measurement (modified from Schuett-Hames et al. 1999).

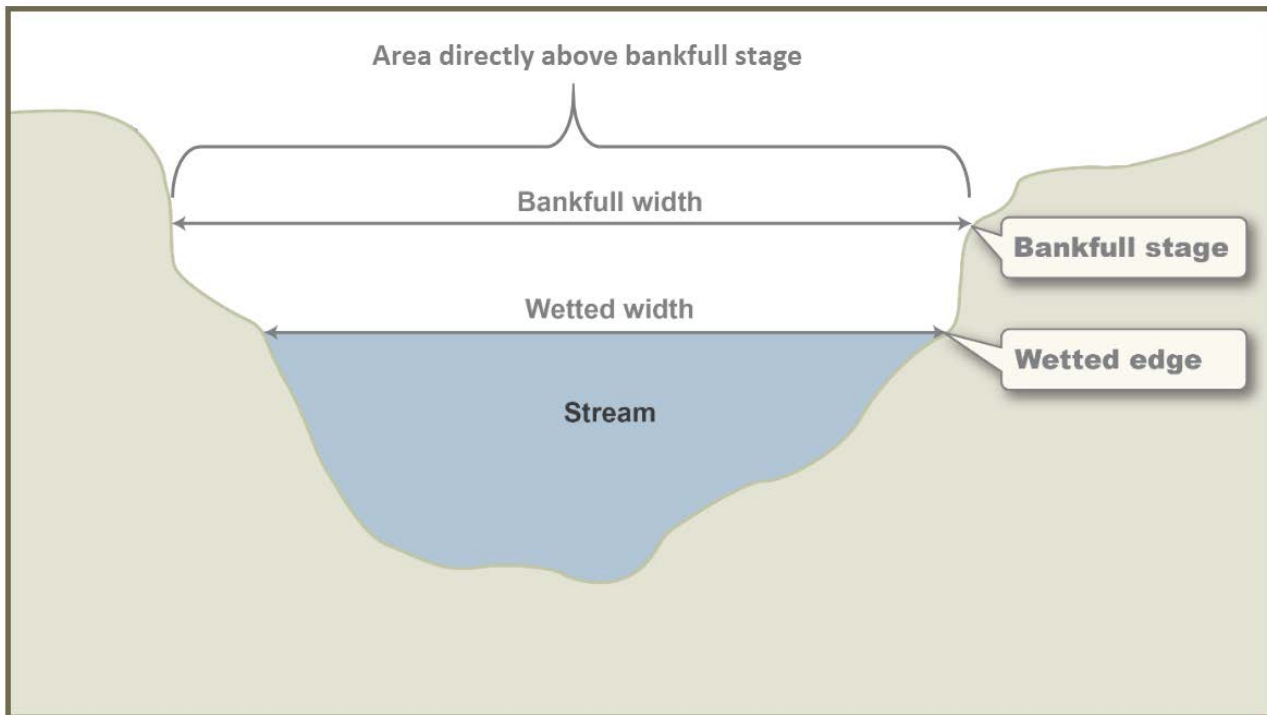


Figure 5-3. Sample reach cross section, showing bankfull stage and the area above bankfull stage.

## SAMPLING OF INDIVIDUAL LOGS AND ROOTWADS

Moving upstream from cross section A, one crew member records the data, while the other crew member identifies and examines LWD pieces and measures their diameter with a caliper and their length with a reel tape or stadia rod.

Qualifying LWD pieces extending below or above the sample reach (i.e., below cross-section A or above cross-section F) are sampled if at least 10 cm of the qualifying dimensions enters the reach. Pieces in side channels are included in the survey, but note in the “Remarks” field when a piece is located in a side channel.

### Location

Record the location of each LWD piece using one of the following categories (Figure 5-3):

**W (Wetted):** At least 10 cm of its length is within the wetted portion of the channel.

**B (Bankfull):** At least 10 cm of its length is within the bankfull stage of the channel (refer to Appendix 5A for indicators of bankfull stage).

**S (Suspended):** At least 10 cm of its length is directly above the bankfull stage of the channel.

Assess location categories in the sequence listed above (W, B, S) and record the *first* category for which the piece qualifies.

### Diameter and Length

For logs, measure diameter at the midpoint of its length using calipers (preferred) or a diameter tape (Figure 5-4). Record diameters to the nearest 1 cm. For rootwads, measure diameter just above the tapered portion at the base of the tree (Figure 5-2). When measuring diameter, the beam of the caliper should always be horizontal (Figure 5-4a) unless obstacles make that impossible. The jaws of the caliper should always be perpendicular to the long axis of the log or rootwad. If the log or rootwad is too large for the calipers (i.e., >80 cm), use a reel tape or stadia rod to estimate its diameter.



**a**



**b**

**Figure 5-4. Measuring diameter (a) and length (b) of in-stream large wood.**



Sometimes logs are forked. In such instances, use the guidance in Figure 5-5 to determine where to measure diameter and whether to measure diameter twice (treating it as two logs) or once.

The following lengths are measured for each qualifying piece (whether log or rootwad):

- the length of the portion within or above the bankfull channel (this is the **W**, **B**, or **S** portion, as defined above), and
- the length outside of the bankfull channel. For some pieces, the entire piece is within the bankfull channel, so this value will be 0.

Measure these lengths to the nearest 0.1 m using a reel tape or stadia rod (Figure 5-4b). Include the piece's rootwad, if one is present, in both log and rootwad length measurements (Figures 5-1, 5-2, 5-5). Measure length to where the main mass of the piece ends; do not include jagged, splintered ends or other protrusions that are less than 10 cm diameter (Figures 5-1, 5-5).

### ***Tree Species Category***

Categorize each LWD piece as one of the following:

**C** (Coniferous species)

**D** (Deciduous species)

**U** (Unknown species)

Characteristics used to categorize LWD species include bark color and texture, wood color and firmness, bole shape, branching pattern, and diameter. Local riparian tree species composition and tree size also may serve as guides. Nearly all deciduous LWD pieces are alder. Nearly all large, older pieces are coniferous.

### ***Stability***

Describe the stability of each LWD piece using one of the following categories:

**U** (Unstable): The piece could become mobile at high flows. If you are not certain, kick or push the piece to see if it wiggles, rocks, or feels unstable.

**S** (Stable): The piece does not move or seem unstable when it is kicked or pushed. An example of this is a very large log with a mass that makes it stable.

### ***Decay Class***

Determine the decay class of each LWD piece on a scale of 1 to 4, where 1 is minimally decayed (died very recently) and 4 is very decayed (advanced stages of rotting). Refer to Table 5-1 for a summary of class characteristics and to Table 5-2 for a decision key. The summary of class characteristics is also on the tablet.

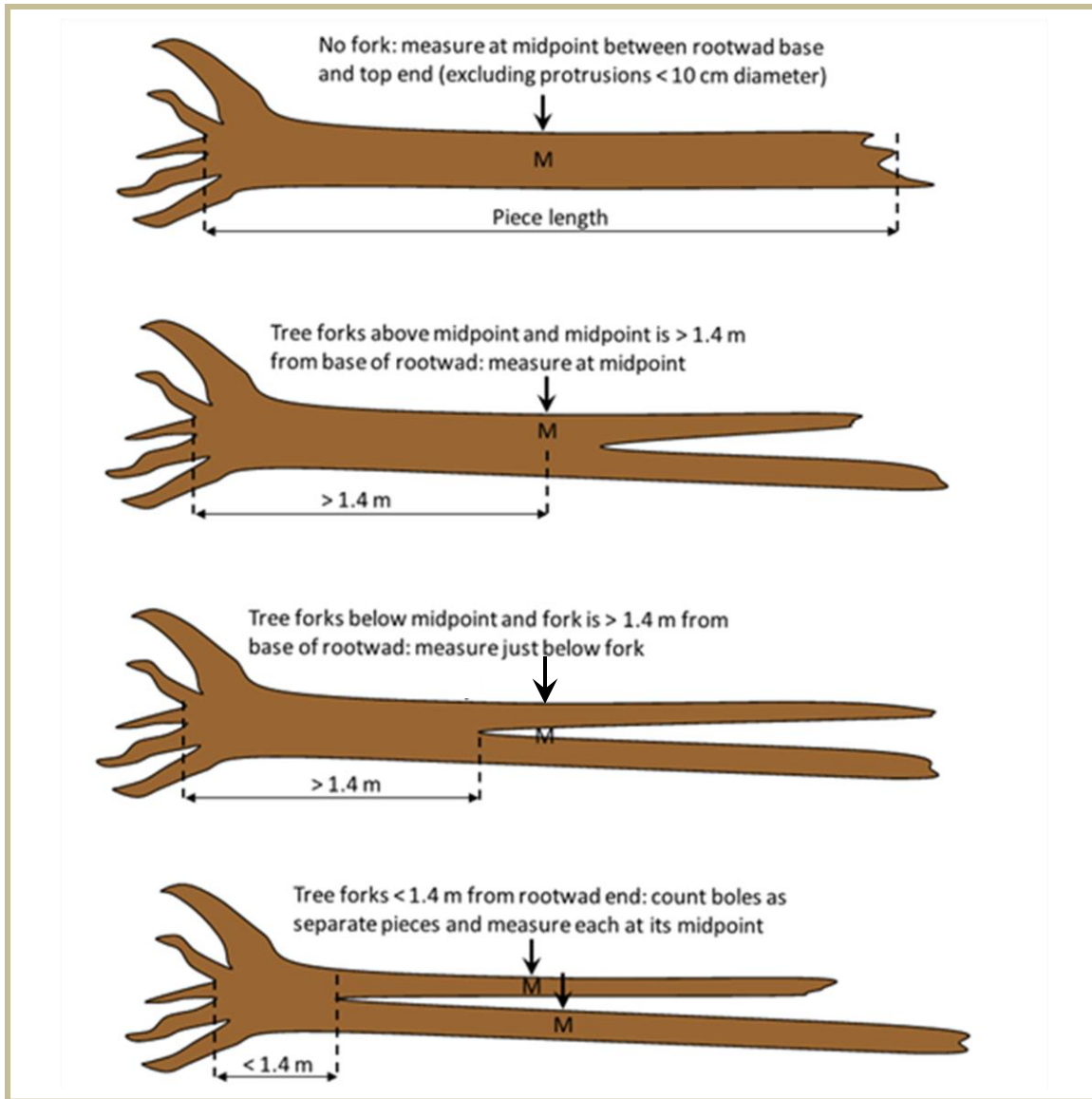


Figure 5-5. Examples of diameter measurement locations, indicated by vertical arrows, for LWD pieces with single or multiple boles. “M” indicates the midpoint of the each piece. Note that roots may or may not be present on LWD pieces.

Table 5-1. Decay class characteristics

	Class 1	Class 2	Class 3	Class 4
Structural Integrity	Piece is predominantly firm/hard, with few, if any, soft spots and no surface deterioration. Sapwood and heartwood are sound.	Piece may be predominantly firm/hard or softening. Any decay/deterioration is confined to the surface (< ~3 cm depth). Heartwood is sound.	Typical piece has soft sapwood, with relatively deep decay/deterioration (> ~3 cm). Rotten parts can be readily pulled from the piece, but heartwood is sound. Firm pieces lacking decay but with an irregular shape also may qualify (see Shape and Texture).	Sapwood and heartwood are rotten and deteriorating (fibrous, crumbly, or powdery). Piece can be readily pulled apart and may lack structure (cannot support its own weight). Note that pieces this degraded are not common in streams.
Bark	Bark is intact (> ~75% coverage and adheres tightly to bole; can't be readily stripped by hand).	Bark is partial (loose and/or < ~75% coverage) or absent due to effects of minor decay and/or aquatic processes.	Bark is absent due to effects of moderate decay and/or aquatic processes.	Bark is absent due to effects of severe decay.
Branches	Piece may have 2nd-order branches.	Piece may have 1st-order branches or branch stubs.	Piece lacks branches.	Piece lacks branches.
Shape and Texture	Piece has original (round) shape and exposed wood has a smooth, even surface. No holes or openings.	Piece has generally retained its original (round) shape, but wood surface may be rough and/or uneven. Few holes or openings.	Piece may have an irregular or largely original shape. Wood surface is uneven and rough due to effects of moderate decay and/or aquatic processes. May have abundant holes or openings.	Piece has an irregular shape with an uneven surface and holes or openings caused by significant decay.

**Sediment-Storing Function**

Assess whether each LWD piece contributes directly to storage of coarse or fine sediment (Figure 5-6). If a sediment deposit would not exist without the presence of the LWD piece, and would likely mobilize if the piece were removed, the piece qualifies as “sediment storing.” Record **Y** for yes or **N** for no.

**Pool-Forming Function**

If a piece was flagged as forming a pool habitat unit during the habitat unit survey, then record the pool habitat unit ID number written on the flag in the “Pool H.U. ID” field on the data form. Note that in some cases multiple pieces of wood will form the same pool and thus more than one LWD piece entry may have the same Habitat Unit ID Number.

**Table 5-2. Decision key for classifying in-stream large wood pieces in 4 decay classes**

1A.	Piece is predominantly firm/hard	[2]
1B.	Piece has many soft sections caused by decay	[3]
2A.	Piece has intact bark (> ~75% coverage, and can't be readily stripped by hand)	Class 1
2B.	Piece lacks intact bark	[4]
3A.	Soft sections are shallow (< ~3 cm) and confined to surface sapwood	[4]
3B.	Soft sections are deep (> ~3 cm); rotten pieces can be readily pulled from the sapwood	Class 3
4A.	Piece has partial bark (loose and/or < ~75% coverage)	Class 2
4B.	Bark is absent	[5]
5A.	Piece has generally retained its original shape. May have an uneven surface, but with few holes or openings	Class 2
5B.	Piece has an irregular shape with an uneven surface and many holes and openings	[6]
6A.	Heartwood is sound	Class 3
6B.	Heartwood is rotten	Class 4

**Figure 5-6. Examples of sediment-storing wood pieces.**

### SAMPLING OF LOG JAMS

Owing to the difficulty and potential danger involved with maneuvering around a log jam, detailed data are not collected on the LWD pieces associated with a jam. Only diameter (nearest 1 cm) is measured for jam pieces. The same qualifying criteria is used for pieces in jams as was used earlier for individual pieces.

Within a sample reach, assign each jam a consecutive number, beginning with 1, and record this number on the field tablet for the LWD pieces in that jam. For each LWD piece in the jam, record diameter and check the appropriate box if the piece is a rootwad.

When measuring the pieces in a jam, it may be helpful to mark pieces with chalk to help keep track of which pieces have been measured, especially on large, complex, or mossy jams. If some pieces in a jam are unstable or high above the channel and cannot be measured safely, diameters may be visually estimated.

**Pool-Forming Function**

If a jam was determined to be pool-forming and flagged with a habitat unit number during the habitat survey (e.g. “HU 3275”), then enter the habitat unit number in the field “Pool H.U. Number”. In some cases, a single jam may form more than one pool, and thus there may be more than one Habitat Unit Number entered in the “Pool Habitat Unit Number” field (e.g., “3255, 3256”). Note that habitat unit number(s) only needs to be entered once per jam on the tablet.

**Procedures for Calculating Metrics**

All metrics are calculated in the office following the procedures in Table 5-3.

**Table 5-3. Procedures for calculating LWD metrics.**

Metric	Calculation procedure
Total pieces/100 m (excluding pieces in jams)	Count of total pieces (logs and rootwads) in sample reach, adjusted to 100-m length. Pieces in jams are not included.
Total pieces/100 m (including pieces in jams)	Count of total pieces (logs and rootwads) in sample reach, adjusted to 100-m length. Pieces in jams <i>are</i> included.
Percentage of pieces per species class	Percentage of pieces in each species class (conifer, deciduous, or unknown).
Percentage of pieces per decay class	Percentage of pieces in each decay class (1-5).
Piece mean diameter	Mean diameter of all pieces in the sample reach.
Total piece volume per 100 m (excluding pieces in jams)	$Length * \pi * (Diameter/2)^2$ , where both length and diameter are in meters, summed for all pieces except those in jams and adjusted to a 100-m sample reach length.
Pool-forming pieces per 100 m	Count of pool-forming pieces per sample reach, adjusted to 100-m sample reach length.
Sediment-storing pieces per 100 m	Count of sediment-storing pieces in sample reach, adjusted to 100-m sample reach length.
Piece stability	Percentage of pieces in each stability class.
Number of jams per 100 m	Count of jams per sample reach, adjusted to a 100-m sample reach length.
Number of pieces in jams per 100 m	Total count of pieces tallied in all jams in each sample reach, adjusted to a 100-m sample reach length.

**Time and Cost Estimates for Implementing Field Procedures**

The time for sampling in-stream large wood varies greatly depending on the amount of wood in the stream, the length of the sample reach, and the amount of brush that impedes movement and visual estimates. The

estimated time ranges from one to two hours (typically 1 to 1.5 hours) per sample reach for an experienced two-member crew. This time estimate does not include the travel to the site.

Table 5-4 shows the cost estimates for the equipment unique to implementing the field procedures of the in-stream large wood protocol. Many of the items listed in the *Equipment and Supplies* section above are shared with other protocols, such as the field tablet and stadia rod. Their cost is detailed in the Channel Morphology protocol and not included here.

**Table 5-4. Cost estimates for the equipment used in the In-stream Large Wood Field Protocol.**

Equipment/Supplies	Amount	Cost
Metric log calipers	1	\$150
Railroad chalk	1 box (144 pieces)	\$30

## Quality Assurance and Quality Control

The quality assurance for the in-stream large wood field protocol includes staff training and use of standardized protocols. The quality control for the field procedures includes annual field checks.

The QA/QC procedures for data management are described in the Data Management section below.

### TRAINING

All personnel conducting field protocols will be trained in a consistent manner to ensure that the surveys are conducted properly and in standardized fashion. The training is conducted (or reviewed for returning personnel) annually before the start of the field season. At least one member of the field crew should be experienced with the field procedures.

### STANDARD PROTOCOLS

The standard procedures described in this protocol are followed for the duration of the project. Any deviations from the procedures should be documented, and the reasons for deviation described and discussed with the project manager or the researcher overseeing the protocol implementation.

Changes to the published protocols must be approved by the project manager or by the researcher overseeing the protocol implementation. Revised protocols are assigned new version numbers and publication dates.

### FIELD CHECKS

The field crew checks the data entry form for missing records or unusual numbers on site at the end the field survey.

The researcher overseeing the protocol implementation or a different field crew will conduct spot checks on 10% of the field measurements every year.



## Data Management

### DATA FLOW

All LWD data are recorded in the field using paper field forms (2013-2014 field seasons or in case of tablet PC malfunction) or the ruggedized field tablet (2015 field season onward). In the office, data are then transferred to a database for long-term storage. The steps below detail the process.

#### *Data flow for paper field forms*

1. **Fill out field forms** Two types of field forms, an individual-piece form and a log jam form, are used to record data and metadata at each sample reach.
2. **Scan and store field forms** After returning from the field each week, the field forms are scanned and stored on the WADNR network drive; the original paper forms are archived by the OESF Data Management Specialist at the WADNR Forest Resources Division.
3. **Enter data** All LWD data collected on paper field forms are entered in the Habitat\_LWD\_Database by the OESF Data Management Specialist on a weekly basis. After data from a field form is entered, the Specialist writes “Entered” followed by his or her initials and the date.
4. **Quality control** Entered field form data are verified by comparing the data on the field form to the data in the database. This process is performed by someone other than the person who originally entered the data. After the data are verified, the person who verified it writes “Verified” on the form followed by his or her initials and the date.

#### *Data flow for electronically collected data*

1. **Fill out forms on electronic field data recorder** Field personnel record all LWD data using the Tablet Database, which is a customized database created in Microsoft Access and saved on the field tablet.
2. **Store field data** At the end of each day in the field, a copy of the Tablet Database, containing all data collected to date, is transferred to the OESF Data Management Specialist via cloud storage or email. If internet access is not available, the field crew makes a daily backup copy of the database on a laptop or other storage device and then transfers the data to the Specialist at the end of the work week. The Specialist stores these Tablet Database copies in a temporary location on the WADNR network drive (J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\07\_Data management\\_All new data and photos) until they are processed and the data are transferred to a database for long-term storage.
3. **Quality control** Because data are recorded electronically, and thus never transcribed, transcription errors do not exist. However, there is still a possibility of data entry errors in the field. In particular, if metadata (e.g., the date of a field visit or a watershed ID) are recorded incorrectly in the field, this could cause errors during the process of importing data from the Tablet Database to the Habitat\_LWD\_Database (next step; see below). For this reason, metadata are examined for accuracy prior to importing data to the Habitat\_LWD\_Database.
4. **Import data to database** On a weekly basis, the OESF Data Management Specialist imports all new data from the Tablet Database to the Habitat\_LWD\_Database. This is accomplished using a set of queries stored in a third database: J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M



Program\01\_Rip S&T Mon\01\_FIELD DATA\01\_Stream survey\Data\  
Distribute\_Tablet\_Data.accdb

5. **Verify transfer of data** After data have been imported, the OESF Data Management Specialist verifies that no records have been missed, using the record count queries built into the Distribute\_Tablet\_Data database.

### **Photographs**

1. **Transfer photos to data manager for storage** All digital photographs taken in the field are transferred to the OESF Data Management Specialist at the end of each week. The Specialist temporarily stores the uncatalogued photos on the WADNR server at:  
J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\07\_Data management\\_All new data and photos\
2. **Rename and archive photos** The OESF Data Management Specialist renames each photo using the following naming convention: <Photo type>\_<BasinID>\_<Date taken>\_<Original photo name> (for example: ER\_797\_20140715\_P1000851.JPG). The photos are then moved to long-term storage in the following directory: J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\03\_Photos and videos\04\_Stream\_survey\LWD\

## **DATA STORAGE**

### **Paper Field Forms**

The paper field forms are archived at the WADNR Forest Resources Division. The designated data steward is Teodora Minkova, WADNR. Scanned copies of these forms are saved in the Adobe portable document format (.pdf) in the following directory: J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD DATA\01\_Stream survey\Data\Data archive\Field forms\

### **Tablet Databases**

The original Tablet Databases, which are transferred to the OESF Data Management Specialist on a daily or weekly basis, are stored on the WADNR network drive after the field data they contain have been transferred to the Habitat\_LWD\_Database. The storage location for these databases is:

J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD DATA\01\_Stream survey\Data\Data archive\Processed tablet databases\

### **Long-term Data Storage**

The ultimate location of the LWD data is the Habitat\_LWD\_Database, located on the WADNR network drive at: J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD DATA\01\_Stream survey\Data\Habitat\_LWD\_Database.accdb

Within the Habitat\_LWD\_Database, the LWD data are stored in three related tables: the LWD Survey Table, the LWD Data Table, and the LWD Jams Data Table (Figure 5-7). The LWD Survey Table contains the metadata from each survey. The LWD Data Table contains records on individual LWD pieces, and the LWD

Jams Data Table contains data on log jams. The fields in the three database tables are described in Tables 5-5, 5-6, and 5-7. The LWD\_Survey\_Table is related to the other two tables through one-to-many relationships: a single record in the LWD Survey Table may be related to any number of records in the other tables.

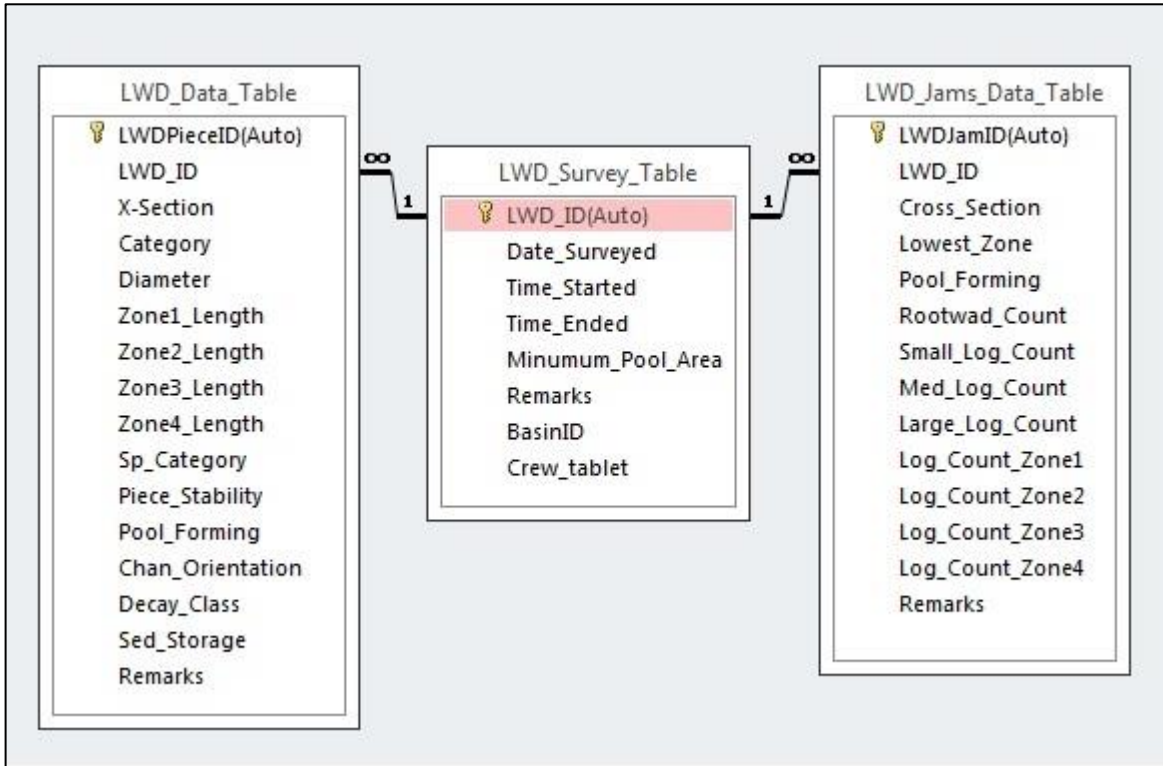


Figure 5-7. The structure of the LWD portion of the Habitat\_LWD\_Database

Table 5-5. Fields in the LWD Survey Table.

Field	Field description
LWD_ID(Auto)	Unique identifier for each record in the table.
Date_Surveyed	The date of the LWD survey.
Time_Started	The time of day that the survey began.
Time_Ended	The time of day that the survey ended.
Minimum_Pool_Area	The minimum pool area for classifying pool-forming LWD pieces.
Remarks	Remarks.
BasinID	The watershed identifier.
Crew_tablet	The initials of the crew members.

**Table 5-6. Fields in the LWD Data Table.**

<b>Field</b>	<b>Field description</b>
LWDPieceID(Auto)	Unique identifier for each record in the table.
LWD_ID	A value that links the record to the appropriate metadata in the LWD Survey Table.
X-Section	The downstream cross section, relative to the LWD piece's location.
Category	Left or right bank.
Diameter	Piece midpoint diameter (cm).
Location	Location of the piece (wetted, bankfull, suspended).
TotalLength	Total length of the piece (m).
Zone1_Length	[Field used through 2015 only] Length of the piece in zone 1 (m).
Zone2_Length	[Field used through 2015 only] Length of the piece in zone 2 (m).
Zone3_Length	[Field used through 2015 only] Length of the piece in zone 3 (m).
Zone4_Length	[Field used through 2015 only] Length of the piece in zone 4 (m).
Sp_Category	Species category (deciduous, conifer, or unknown).
Piece_Stability	Piece stability (stable, unstable) [Through 2015, five fields were used (stable, unstable, buried, pinned, rooted)].
Pool_Forming	Is the piece pool-forming? (Yes/No).
Chan_Orientation	[Field used through 2015 only] Orientation of the piece, relative to the channel (A, B, C, or D).
Decay_Class	Decay class (1, 2, 3, 4, or 5).
Sed_Storage	Is the piece sediment-storing? (Yes/No).
Remarks	Remarks.

**Table 5-7. Fields in the LWD Jams Data Table.**

<b>Field</b>	<b>Field description</b>
LWDJamID(Auto)	Unique identifier for each record in the table.
LWD_ID	A value that links the record to the appropriate metadata in the LWD Survey Table.
Cross_Section	The downstream cross section, relative to the LWD piece's location.
Lowest_Zone	[Field used through 2015 only] Lowest zone of the jam (1, 2, or 3).
Pool_Forming	Is the jam pool forming? (Yes/No)
Rootwad_Count	Count of rootwads in jam.
Small_Log_Count	Count of small logs in jam.
Medium_Log_Count	Count of medium logs in jam.
Large_Log_Count	Count of large logs in jam.
Log_Count_Zone1	[Field used through 2015 only] Count of logs in zone 1.
Log_Count_Zone2	[Field used through 2015 only] Count of logs in zone 2.
Log_Count_Zone3	[Field used through 2015 only] Count of logs in zone 3.
Log_Count_Zone4	[Field used through 2015 only] Count of logs in zone 4.
Remarks	Remarks.

## DATA QUALITY CONTROL

Prior to data analysis, all fields in the data tables are assessed to identify potentially erroneous values. The first step is to examine individual fields, one at a time. For categorical data fields (e.g., cross section) and date or time fields, every field is assessed to identify any records exhibiting the following:

1. Missing values.
2. Illogical values. In some cases, where the data collector is free to enter values rather than selecting values from a predefined list, illogical values may be recorded (e.g., a survey time of 3:00 AM).

For numerical fields, each is assessed for the following:

1. Missing values.
2. Outlier values (e.g., a log diameter was recorded in m instead of cm).

The next step in quality control assessment is to examine derived values and values in the context of other fields. An example of a derived value is the sum of log counts for a particular log jam. If the sum of log counts is less than 10, then the data should be examined more closely because this value does not meet the minimum requirement for a log jam. An example of checking a value in the context of another field is comparing the sum of the log counts with the sum of log counts by size (plus rootwads). These two sums should be equal; if they are not, then there may be an error in the data.

When missing values are discovered, it is generally not possible to “fill in the blank” from the office. The fact that data are missing should be recorded, in brackets, in the “Remarks” field, with the initials of the person who performed the quality control check (e.g., [Lowest\_Zone was not recorded. –WD]).

Illogical or outlier values can sometimes be corrected in the office. For example, AM and PM might have been switched or a decimal place error can be corrected. When data are corrected, this must be noted in the “Remarks” field, in brackets, with the initials of the person who performed the quality control check. For example: [Diameter was recorded as .55. This was clearly incorrect and changed to 55. –WD].

In many cases, clearly erroneous outlier values cannot be corrected in the office and should be edited so as not to affect the results of analysis. In such cases, the value should be removed from the field and transferred to the “Remarks” field with an explanation, in brackets, with the initials of the person who performed the quality control check. For example: [Log\_Count\_Zone2 was recorded as 455. This was clearly incorrect and removed from the dataset. –WD]).

## References

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## Appendix 5A. Indicators of Bankfull Stage

From Streamkeepers of Clallam County. 2012. Field procedures. 14th Edition.

<http://www.clallam.net/streamkeepers/assets/applets/Bankfull.pdf> [accessed 12-14-2016]

### BANKFULL: WHAT IT IS AND HOW TO LOCATE IT

#### WHY BANKFULL?

Several procedures in this manual require you to locate what is known as the "bankfull channel edge," or more simply as "bankfull." This is an important concept in understanding the workings of a stream.

#### HOW DOES A "BANKFULL" GET CREATED?

Most lower portions of streams in our area are alluvial, meaning that they create their own channels by moving sediment from the surrounding hillslopes and from the stream channel itself. Major episodes of such movement occur during floods and are called "channel-forming events." These events determine the size of the channel needed to convey the water. In a period of relatively stable climate and land-cover, a stream system will develop equilibrium between its flows and the size of the channel, whereby the channel is large enough to contain the stream under most flow conditions. When flows are greater than this capacity, the stream overflows its banks and flooding occurs.

In such streams, the channel is usually big enough to contain a high-flow event that recurs on an average of every 1.5 years (which we call the "1.5-year flood"). Such a frequency of inundation is frequent enough that perennial vegetation can't grow there, either because its roots are too wet or its seedlings get swept away. So usually, what you'll see if you look at the cross-section of a stream channel is a sort of "bowl" that contains the stream most of the time, inside which no perennial vegetation grows, and a place over the top of this bowl where the water can flow during a high-water event greater than a 1.5-year flood. This "floodplain" may be on one or both banks, depending on the site.

#### WHAT ARE INDICATORS OF BANKFULL?

Most stream systems are in a continual cycle of change, and every site is unique; thus, no single indicator of bankfull can always get you the "right answer." There are several indicators which can help to identify the bankfull channel

edge, and you should consider all that are present at a given site:

1. **Bank slope:** In stream channels with natural (undiked) riparian areas and a low, flat floodplain, the bankfull edge is located at the edge of this plain. Often the floodplain will slope down very gradually and then more abruptly. This abrupt slope-break is usually a good indicator. However, you may find such a slope-break on only one bank, or none at all, for instance if the channel has cut down into the streambed. Or the slope-break may be impossible to find on a bank that is slumping or undercut.
2. **Vegetation:** The bankfull edge is often indicated by a demarcation line between lower areas that are either bare or have aquatic and annual vegetation, and higher areas with perennial vegetation such as ferns, shrubs, and trees. (Keep in mind, though, that the vegetation line is always in transition, retreating during wetter periods and advancing during dryer ones. So except for ferns, you should rely most heavily on perennial vegetation which is more than 6 feet high.) One particular confusion arises from willow or alder trees growing within the bankfull channel, because the channel has migrated into them, or they fell into the stream and managed to reestablish themselves. Therefore, when you look at vegetation, you should also look at soils...
3. **Soils:** Look for a transition as you move up the bank, from cobble/gravel to sand/silt to soil. Above bankfull level, you should find old leaf litter forming into soil with organic matter. (Beware: this may be covered by flood deposits, so you may have to dig down.)
4. **Point bars and bank undercuts:** Often on the inside of meander bends, the stream will build up a bar of sediment from the eddy current created by the bend; the top of such a bar is the minimum height of bankfull. Similarly, on the outside of such bends, the stream will often undercut the bank and expose root mats. If you reach up



**BANKFULL**

beneath this mat, you can estimate the upper extent of the undercut. This would also be the minimum height of bankfull.

5. **Lines on boulders/bedrock:** If you're in a steep channel with no clear floodplain, look for the highest mineral-stain line or the lowest line of lichen or moss on stable rock.
6. **Adjacent indicators:** If the indicators are unclear where you're looking, try looking up- or downstream to see if there is a clear bankfull line from which you can extrapolate.

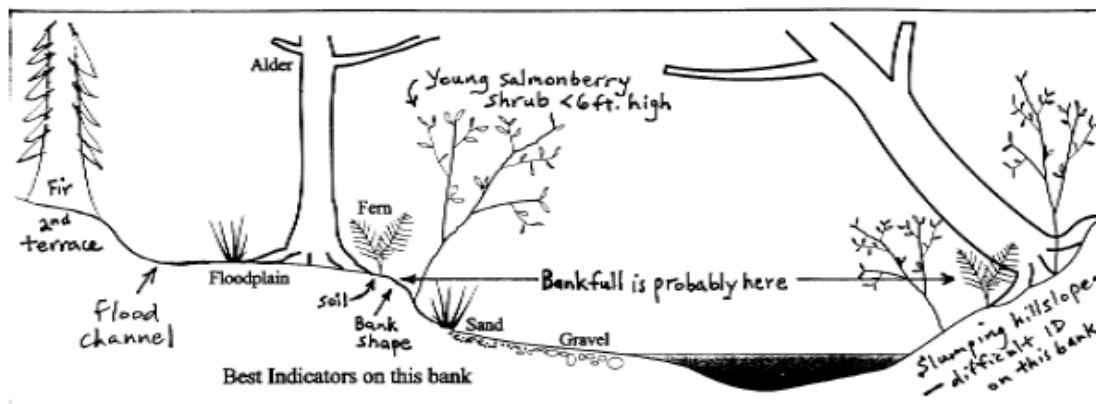
**HOW SHOULD I LOCATE BANKFULL?**

The following method was found by the TFW program to maximize data precision and minimize bias toward over- or under-estimation of bankfull elevation:

1. Start on the bank with the best bankfull indicators.
  - a) Move up the bank from the channel, observing the indicators listed above. When you reach a point at which you're

no longer 100% sure that you're below bankfull, mark that level with a flag or stick.

- b) Then walk up to what is clearly dry land, and walk around, observing indicators and moving back toward the bankfull edge. When you're no longer 100% confident that you're above bankfull, mark that point.
  - c) Reassess the indicators and your confidence levels, and consult with your fellow samplers, and make adjustments as needed.
  - d) The bankfull channel edge is at the elevation point midway between these two points.
2. Now follow the same procedure on the other bank. If it is not possible to accurately identify the bankfull level on that bank (which often happens on the outside bank of a meander bend), locate it using a level line from the bankfull point on the first bank.



**Typical bankfull ID situation, adapted from Pleus and Schuett-Hames, 1998.**

(Also referenced for this section: Harrelson et al., 1994.)

## Appendix 5B. Field Procedures Dropped from Original Monitoring Protocol in 2015

Following the 2015 field season, the field procedures were simplified. Procedures dropped from the original field protocol include:

- Identifying channel zones.
- Classifying LWD pieces by zone.
- Measuring the portion of each piece within each zone.
- Counting log jam LWD pieces by lowest zone.
- Estimating individual LWD piece orientation within the channel.

The dropped field procedures are included in this appendix for historical reference or in case they are used again in the future.

Procedures modified from the original field protocol include:

- Reporting individual LWD piece location in three categories (within wetted portion of the channel, within bankfull stage, or suspended above the bankfull stage).
- Measuring the length of the portion of each piece within the bankfull channel and measuring the length of the portion outside of the bankfull channel.
- Estimating the stability of individual LWD piece in two categories (unstable or stable) instead of the previous five categories (rooted, buried, pinned, unstable, and stable).

The first round of LWD sampling in all watersheds was conducted using the original, more detailed procedures. The original field procedures were changed as a result of a field quality control analysis (Devine and Minkova 2016) and consultation with other researchers. The quality control report showed low precision of piece length measurements and piece count calculated by zone vs. the same metrics calculated for the total number of pieces. This difference was due to the smaller sample size in each zone. Review of available literature and consultation with researchers led to the conclusion that data on LWD pieces classified by zone and piece orientation in the channel are rarely used in analyses.

Starting in 2018, the decay classification criteria were changed and classes were reduced from 5 to 4 in order to improve the repeatability of measurements taken by different field teams and to better account for the effect of aquatic processes on in-stream wood. A decision key and new classification table were added.

### CHANNEL ZONE IDENTIFICATION

Four zones are used to identify LWD locations in the channel (Figure 5B-1). To be counted in the survey, a piece of LWD must extend into zone 1, 2, or 3 a minimum of 10 cm.

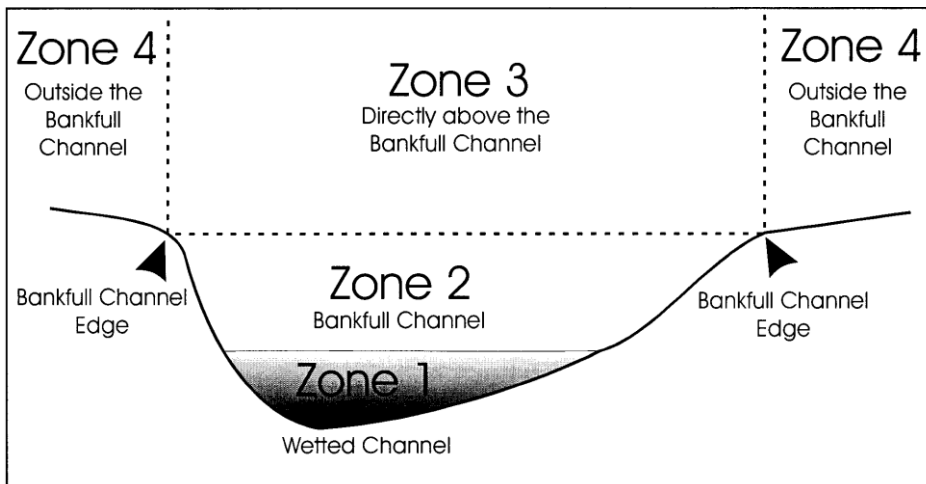


Figure 5B-1. Criteria for channel zone identification (from Schuett-Hames et al. 1999).

**Zone 1:** Located underwater at the time of the survey, regardless of whether the water is flowing or stagnant. Zone 1 is flow-dependent and future surveys should be taken at similar flows to produce comparable zone 1 data for trend monitoring.

**Zone 2:** Located above the water surface but below bankfull stage (an “imaginary” line connecting the right and left bankfull). Zone 2 is also flow-dependent and future surveys should be taken at similar flows to produce comparable zone 2 data for trend monitoring.

**Zone 3:** Located directly above Zone 2. Count LWD in zone 3 only if it is between the left and right bankfull and above bankfull stage. LWD in this zone is usually suspended above the stream and will likely fall into the stream in the future.

**Zone 4:** Located outside of zones 1, 2 and 3 on each bank of the stream. This zone typically includes LWD located in floodplains, terraces, and riparian areas. LWD pieces that are located only in zone 4 are typically not counted, except LWD in zone 4 that is associated with a jam and thus may become active if the jam moves.

### MEASURING THE LENGTH OF INDIVIDUAL LOGS AND ROOTWADS BY ZONE

Record the total length of each piece, separated by zone, to the nearest 0.1 m (e.g. 3.1 m in zone 1, 2.4 m in zone 2, 1.1 m in zone 3, and 0.5 m in zone 4) (Figure 5B-2). For logs that traverse multiple zones, it can be helpful to first mark each zone transition with chalk, then come back to measure the length of each marked zone.

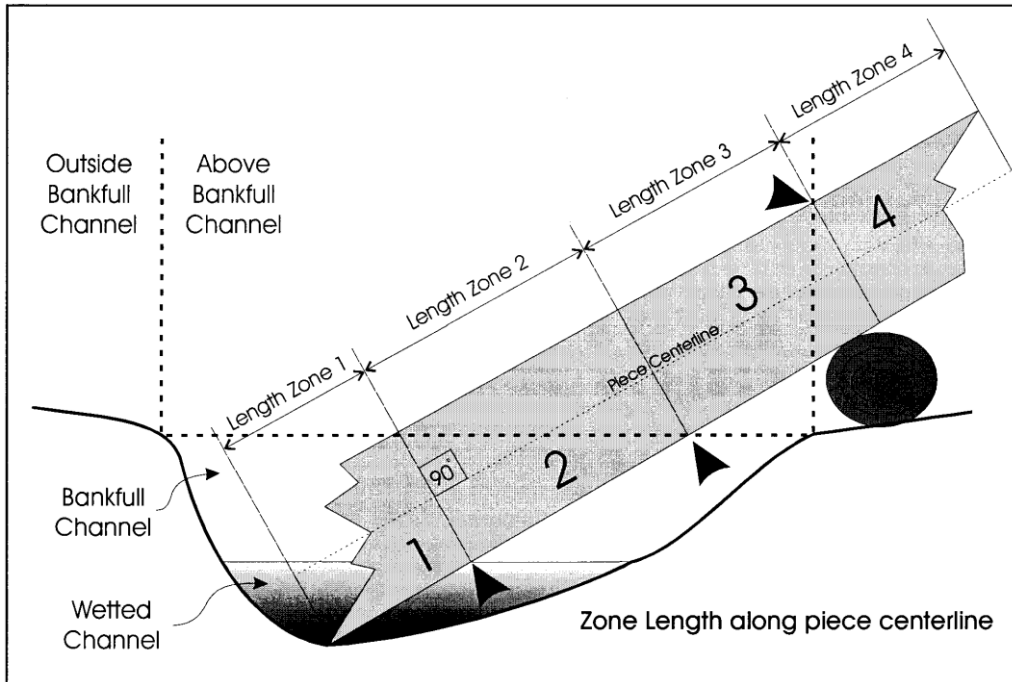


Figure 5B-2. Recording piece length by channel zones (from Schuett-Hames et al. 1999).

### ESTIMATING THE ORIENTATION OF INDIVIDUAL LOGS AND ROOTWADS

Identify the piece orientation (horizontal direction within the channel) in one of four categories (Figure 5B-3). These categories are estimated and assume that directly upstream is 0 degrees and directly downstream is 180 degrees.

**A** for parallel to flow: A piece with its length axis either 337.5-22.5 degrees or 157.5-202.5 degrees. The direction of the root system or small-diameter end does not matter.

**B** for perpendicular to flow: a piece with its length axis between 67.5 and 112.5 degrees or 247.5 and 292.5 degrees. The direction of the root system or small-diameter end does not matter.

**C** for downstream: A piece with its length axis at any other angle (than Parallel (A) and Perpendicular (B)) and its small-diameter end downstream from its large-diameter or rootwad end.

**D** for upstream: A piece with its length axis at any other angle (than Parallel (A) and Perpendicular (B)) and its small-diameter end upstream from its large diameter or rootwad end.

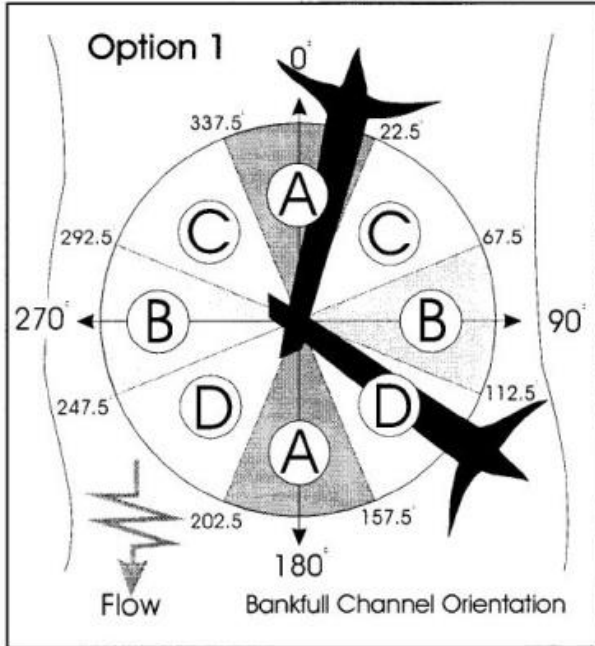


Figure 5B-3. Orientation of logs and rootwads in a stream (from Schuett-Hames et al. 1999).

### COUNTING THE LWD PIECES IN A LOG JAM BY ZONE

Using the zone descriptions described in the “Channel Zone Identification” section above, identify the lowest zone that each qualifying piece is located in. Zone 1 is the lowest zone, zone 2 is the second-lowest, and zone 3 is the third-lowest zone. The piece must have a minimum of 10 cm of length in the lowest zone to be categorized in that zone.

## Appendix 5C. Wood Decay Classifications Implemented during 2013-2017

### WOOD DECAY CLASSIFICATION USED DURING THE 2013-2015 FIELD SEASONS

Classify the decay logs and rootwads on a scale from 1-5 where 1 is not decayed (died very recently) and 5 is very decayed (advanced stages of rotting). Refer to Table 5C-1 as a guide to evaluating decay class. Use a “poke test” for assisting with determining decay class - poke the piece with the log calipers or stadia rod to gauge how soft it is. The poke test is used in combination with all the other factors to determine the final decay class.

**Table 5C-1. A five-class decay system from evaluating in-stream large wood (from WADNR 2002)**

Decay class	Bark	Twigs (diameter <3cm)	Wood texture	Shape	Wood color
1	Intact	Present	Intact/ Firm	Round	Original
2	Intact	Absent	Intact to softening	Round	Original
3	Trace	Absent	Hard, large pieces	Round	Original to faded
4	Absent	Absent	Small, soft, blocky pieces	Round to oval	Light brown to reddish brown
5	Absent	Absent	Soft and powdery	Oval / Irregular	Light brown to dark brown

### WOOD DECAY CLASSIFICATION USED DURING THE 2016-2017 FIELD SEASONS

Classify the decay class of each LWD piece on a scale of 1 to 5, where 1 is not decayed (died very recently) and 5 is very decayed (advanced stages of rotting). Refer to Table 5C-2 as a guide. Also, a “poke test” may be used to help determine decay class. Poke the LWD piece with the calipers or stadia rod to gauge how soft it is. The poke test is used in combination with the other factors to determine the decay class.

**Table 5C-2. A five-class system for evaluating wood decay (from USDA Forest Service 2005 and WADNR 2002)**

Decay class	Bark	Twigs (diam. <3 cm)	Structural integrity	Texture of rotten portions	Shape	Wood color
1	Intact	Present	Sound, freshly fallen, intact logs	Intact/firm; no rot	Round	Original
2	Intact	Absent	Sound	Mostly intact; sapwood partially soft, but can't be pulled apart by hand	Round	Original
3	Trace	Absent	Heartwood sound; piece supports its own weight	Hard, large pieces; sapwood can be pulled apart by hand	Round	Original to faded
4	Absent	Absent	Heartwood rotten; piece does not support its own weight, but maintains its shape	Soft, small, blocky pieces	Round to oval	Light brown to reddish brown
5	Absent	Absent	None, piece no longer maintains its shape	Soft; powdery when dry	Oval/ Irregular	Light brown to dark brown



# Habitat Units and Valley and Channel Classification

*Authors:* Teodora Minkova, Mitchell Vorwerk

*Version:* 1.6

## *Revision History:*

Protocol Version	Purpose / Changes	Author(s)	Reviewer(s)	Date
1.0	Initial draft presented to project staff	Teodora Minkova	Peter Bisson, Alex Foster	04/02/2013
1.1	Draft submitted to external review	Teodora Minkova	Rebecca Flitcroft	04/16/2013
1.2	Final draft incorporating external reviews, sampling procedures from 2013 field season, and data mgmt. procedures	Teodora Minkova, Mitchell Vorwerk		05/20/2014
1.3	Final draft with field and data management procedures updated from 2014 and 2015 field seasons	Teodora Minkova, Mitchell Vorwerk	Ellis Cropper, Alex Foster	06/10/2016
1.4	Final technical review and edit	Teodora Minkova, Mitchell Vorwerk	Paul Dunnette, Warren Devine	12/18/2016
1.5	Added protocol on pool-forming wood pieces	Kyle Martens, Paul Dunnette	Teodora Minkova, Warren Devine	06/21/2018
1.6	Edits regarding data entry	Warren Devine	Teodora Minkova	06/13/2019

## *Based on the Following Protocols:*

Habitat unit classification is adapted from Bisson et al. (2006) and Pleus et al. (1999). Stream valley and channel classification follows Bisson et al. (2006) and Montgomery and Buffington (1993 and 1997).

## *Reasons to Adopt the Above Protocols:*

The selected classification methods are widely used in broad-scale monitoring programs in the Pacific Northwest, including the Northwest Forest Plan Aquatic and Riparian Effectiveness Monitoring Program (Lanigan et al. 2010), the Washington Department of Natural Resources Timber, Fish, and Wildlife Monitoring Program (Pleus et al. 1999), and the Columbia Habitat Monitoring Program (CHaMP) (Bouwes et al. 2011).

The reach-level assessments following these classifications are rapid, repeatable, and ecologically relevant. They rely on aspects of channel form that reflect channel processes such as sediment delivery.

## *Purpose and Content:*

The purpose of this monitoring protocol is to describe the sampling and data management necessary to document and report stream channel and valley segment types and the status and multi-year trends of habitat units in the monitored watersheds. It details the field procedures for sampling habitat units and classifying channel reaches and valley segments, the field quality assurance and quality control steps, and the data management procedures.

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## ***Introduction***

Classification of stream valleys, channels, and habitat units provides a foundation for interpreting channel morphology, assessing channel conditions, describing microhabitat of fish and other aquatic organisms, and understanding stream response to natural and anthropogenic influences (Montgomery and Buffington 1993; Bisson et al. 2006).

Understanding stream response to disturbance depends on established systems and procedures for stream classification and assessment that facilitate accurate, repeatable reach descriptions and provide information on the processes that govern channel structure (Bisson et al. 2006).

Valley, channel, and habitat unit classification also allows for comparisons among drainages and/or extrapolation of results to other areas with similar features.

## ***Monitoring Design***

### **SPATIAL SAMPLING DESIGN**

Valley, channel, and habitat unit classification is conducted in each of the 50 sample watersheds in the Olympic Experimental State Forest (OESF) and in the four reference watersheds in Olympic National Park (ONP). Refer to the Introduction chapter for a map of the watersheds.

Sample reaches in the watersheds are a minimum of 20 channel widths in length, a ratio that provides the scale necessary to relate stream morphology to channel processes, habitat characteristics, and potential response to disturbance (Montgomery and Buffington 1997).

The entire length of the sample reach is considered for classifying the channel type and valley segment. Habitat units are delineated, classified, and measured from reach start (cross section A) to end (cross section F).

### **TEMPORAL SAMPLING DESIGN**

Valley and channel classification and habitat unit surveys should be conducted during low flow periods in late summer or early fall when discharge conditions are stable and habitat units are most defined. At higher flows, habitat units tend to “run together,” making delineation and repeat surveys difficult or impossible. Refer to Appendix 6-A for guidance when to discontinue the habitat unit surveys due to high stream flow. At the other end of the spectrum, do not survey during very low flow when the surface flow is not continuous throughout the reach length. Pre-survey reconnaissance should be done to determine flow conditions.

To prevent unnecessary disturbance and mortality to salmon, avoid working in the channel during spawning or when there are eggs in the gravel.

## Equipment and Supplies

The following equipment and supplies are needed for classifying the stream valley, channel, and habitat units and for measuring each habitat unit:

- Stadia rod
- 50-meter tape
- Clinometer
- Ruggedized field tablet PC (and paper field forms as backup to the tablet).
- Field Guide for Identifying Stream Channel Types and Habitat Units (Minkova and Vorwerk 2015)

## Field Procedures

### CLASSIFICATION OF VALLEY SEGMENTS

Valleys are areas of the landscape between higher terrain features, where runoff and sediment transport occur through downslope convergence (Armantrout 1998). Valley segments, hierarchically nested subdivisions of the drainage network, are classified as alluvial, bedrock, or colluvial based on valley fill, channel transport capacity, and sediment transport processes and supply (Bisson et al. 2006, Frissel et al. 1986). Their position within the hierarchy of watershed spatial scales is shown in Figure 6-1.

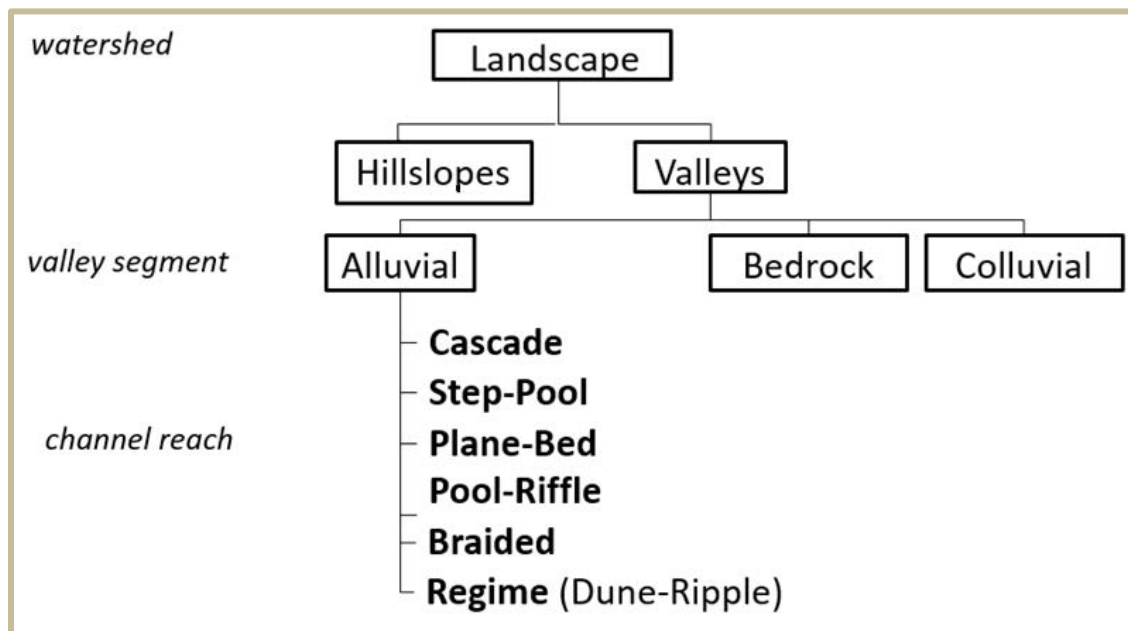


Figure 6-1. Hierarchical subdivision of watersheds into valley segments and stream reaches (adapted from Montgomery and Buffington 1993).

Valley types are classified in the field. The classification is based on multiple characteristics of the sample reach and surrounding slopes such as substrate, gradient, and confinement. Therefore, the valley type should be identified after completion of the Channel Morphology protocol, the Channel Substrate protocol, and the habitat unit survey described in this chapter.

Consider the entire length of the sample reach when classifying the valley segment. Identify the valley segment type (Alluvial, Bedrock, or Colluvial) using the guidance below, and enter the type in the field tablet database Habitat Unit data entry form or on a paper form.

### ***Valley Segment Descriptions (from Bisson et al. 2006):***

**Alluvial valleys:** Alluvial valleys are filled primarily with alluvium (sediment transported along the valley floor by stream flow). The sediment transport capacity of an alluvial valley is usually insufficient for a stream to scour down to bedrock, resulting in an accumulation of valley fill primarily of fluvial origin. Alluvial valleys are the most common type of valley segment in many landscapes and usually contain streams of greatest interest to aquatic ecologists. They range from confined, a condition in which the hillslopes narrowly constrain the valley floor with little or no floodplain development, to unconfined, with a well-developed floodplain. A variety of stream reach types may be associated with alluvial valleys, depending on the degree of confinement, gradient, local geology and sediment supply, and discharge regime.

**Bedrock valleys:** Bedrock valleys have little valley fill material but instead are dominated by bedrock. They usually possess confined channels lacking an alluvial bed.

**Colluvial valleys:** Colluvial valleys are filled primarily with colluvium (unconsolidated sediments and organic matter), which slowly accumulates at the base of hillslopes over time. In colluvial valleys, fluvial (waterborne) transport is relatively ineffective at removing materials deposited on the valley floor. Consequently, sediment and organic matter gradually accumulate in headwater valleys until they are periodically flushed by debris flows in steep terrain, or excavated by periodic hydrologic expansion of the alluvial channel network in low-gradient landscapes.

## **CLASSIFICATION OF CHANNEL REACHES**

Repeating series of specific channel unit types (e.g., pool-riffle-gravel bar sequences) and certain channel characteristics (e.g., slope, substrate size, and width-depth ratio) are the defining features of channel reaches (Bisson et al. 2006). For example, bedrock reaches are often the result of debris flows or a lack of roughness elements that trap sediment. Whereas, channels in colluvial valleys may have signs of scour and deposition but flows are often intermittent and sufficient for sediment transport only at certain times. Further downstream where perennial flow dominates, alluvial valleys can host a range of alluvial reach types (Bisson et al. 2006). Montgomery and Buffington (1993) recognized six alluvial reach types (Figure 6-1 and Table 6-1).

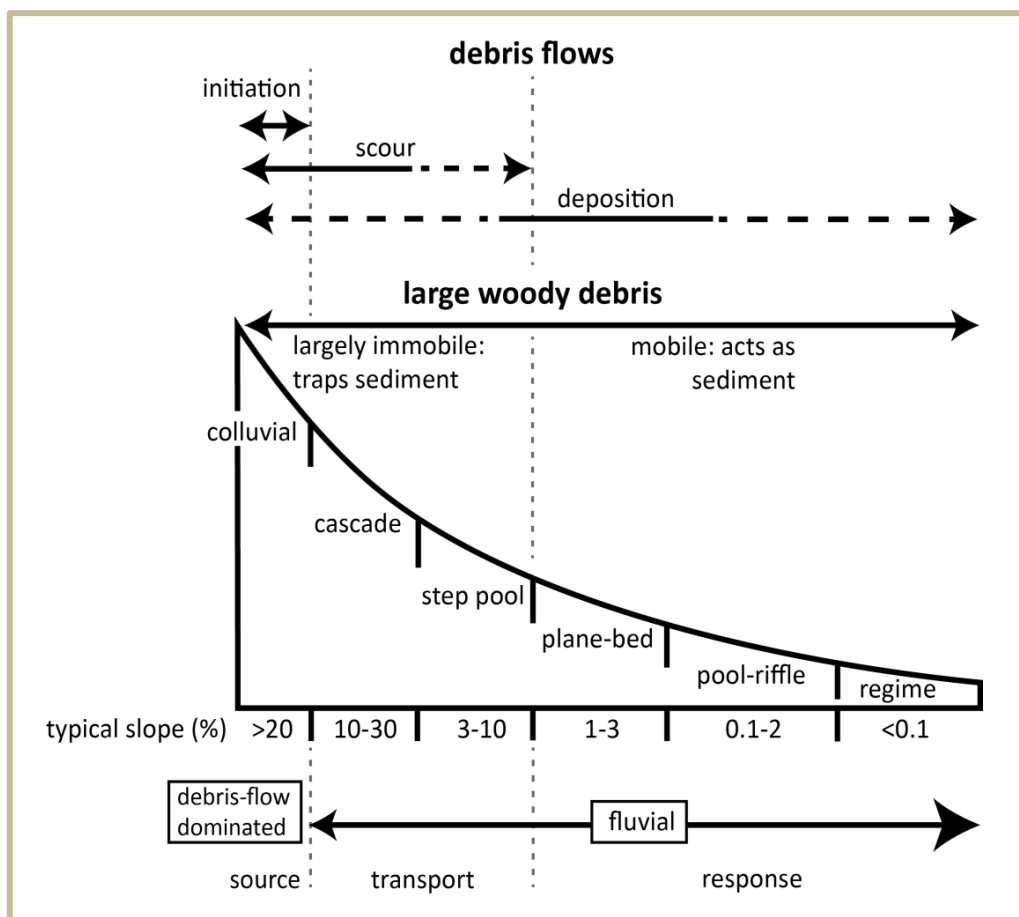
	Colluvial	Bedrock	Cascade	Step-pool	Plane-bed	Pool-riffle	Dune-ripple	Braided
Predominant bed material	variable	bedrock	boulder	cobble/boulder	gravel/cobble	gravel	sand	variable (sand to boulder)
Bedform	variable	variable	chaotic	vertically oscillatory bedforms	none	laterally oscillatory bedforms	multilayered	laterally oscillatory bedforms
Dominant roughness elements	banks, boulders, large wood	streambed, banks	boulders, banks	(steps, pools) boulders, large wood, banks	boulders and cobbles, banks	(bars, pools) boulders and cobbles, large wood, sinuosity, banks	sinuosity, bedforms (dunes, ripples, bars), banks, large wood	pools), boulders and cobbles
Dominant sediment sources	hillslope, debris flows	fluvial, hillslope, debris flows	fluvial, hillslope, debris flows	fluvial, hillslope, debris flows	fluvial, bank erosion, debris flows	fluvial, bank erosion, inactive channels, debris flows	fluvial, bank erosion, inactive channels	fluvial, bank erosion, debris flows, glaciers
Typical slope* (%)	>20	variable	>7.5	3-7.5	1.5-3	<1.5	<0.1	<2.5
Typical confinement	strongly confined	strongly confined	strongly confined	moderately confined	variable	unconfined	unconfined	variable
Pool spacing (channel widths)	variable	variable	<1	1-4	none	5-7	5-7	variable
Bankfull recurrence interval (years)	variable	variable	variable	variable	1-2	1-2	1-2	variable

Table 6-1. Characteristics of different channel types (Bisson et al. 2006; modified from Montgomery and Buffington 1997). Continuous slope ranges from Buffington et al. (2003) but may vary regionally.

Channel types are classified in the field. The classification is based on multiple characteristics of the sample reach and surrounding slopes such as substrate, gradient, confinement, and habitat units. Therefore, the channel type should be identified after completion of the Channel Morphology and Channel Substrate protocols and the habitat unit survey described in this chapter.

Consider the entire length of the sample reach when classifying the channel type. Identify the channel type using the diagnostic characteristics in Figure 6-2 and Table 6-1, the schematic and photo references in the protocol field guide (Minkova and Vorwerk 2015), and the descriptions below.

Record the channel type (Cascade, Step-pool, Plane-bed, Pool-riffle, Braided, or Regime) in the field tablet database Habitat Unit data entry form.



**Figure 6-2. Idealized longitudinal profile from hillslope down through the channel network, showing the general distribution of channel types and controls on channel processes (from Montgomery and Buffington 1997).**



***Channel Reach Descriptions (from Bisson et al. 2006):***

**Cascade reaches:** This reach type is characteristic of the steepest alluvial channels, with gradient typically ranging from 4 to 25% [defined as >7.5% in this study]. A few small, turbulent pools may be present in cascade reaches, but the majority of flowing water tumbles over and around boulders and large wood. The boulders are supplied from adjacent hillslopes or from periodic debris-flow deposition. Waterfalls (“hydraulic jumps”) of various sizes are abundant in cascade reaches. The large size of particles relative to water depth effectively prevents substrata mobilization during typical flows. Although cascade reaches may experience debris flows, sediment movement is predominantly fluvial. The cascading nature of water movement in this reach type is usually sufficient to remove all but the largest particles of sediment (cobbles and boulders) and organic matter. What little fine sediment and organic matter occurs in cascade reaches remains trapped behind boulders and logs, or it is stored in a few pockets where reduced velocity and turbulence permit deposition. The rapid flushing of fine sediment from cascade reaches during moderate to high flows suggests that transport from this reach type is limited by the supply of sediment recruited from upstream sources.

**Step-pool reaches:** Step-pool reaches, with typical gradients of 2-8% [defined as 3-7.5% in this study], possess discrete channel-spanning accumulations of boulders and logs that form a series of steps alternating with pools containing finer substrata. Step-pool reaches tend to be straight and have high gradients, coarse substrata (cobbles and boulders), and small width to depth ratios. Pools and alternating bands of channel-spanning flow obstructions typically occur at a spacing of every 1–4 channel widths in step-pool reaches, although step spacing increases with decreasing channel slope (Grant et al. 1990). A low supply of sediment, steep gradient, infrequent flows capable of mobilizing coarse streambed material, and heterogeneous sediment composition appear to favor the development of this reach type. The capacity of step-pool reaches to temporarily store fine sediment and organic matter generally exceeds the sediment storage capacity of cascade reaches. Flow thresholds necessary to transport sediment and mobilize channel substrata are complex in step-pool reaches. Large bed-forming structures (boulders and large wood) are relatively stable and move only during extreme flows. During high flows, fine sediment and organic matter in pools is transported over the large, stable bed-forming steps.

**Plane-bed reaches:** Plane-bed stream reaches, with gradients typically 1-4% [defined as 1.5-3% in this study] lack a stepped longitudinal profile and instead are characterized by long, relatively straight channels of uniform depth. They are usually intermediate in gradient and relative submergence (the ratio of bankfull flow [see note below on bankfull flow] depth to median particle size) between steep, boulder-dominated cascade and step-pool reaches, and the more shallow gradient pool-riffle reaches. At low to moderate flows, plane-bed stream reaches may possess large boulders extending above the water surface, forming mid-channel eddies. However, the absence of channel-spanning structures or significant constrictions by stream banks inhibits pool development. Particles in the surface layer of plane-bed reaches typically are larger than those in subsurface layers and form an armor layer over underlying finer materials (Montgomery and Buffington 1997). This armor layer prevents transport of fine sediments except during periods when flow is sufficient to mobilize armoring particles.

**Pool-riffle reaches:** This reach type is most commonly associated with small to midsized streams and is a very prevalent type of reach in alluvial valleys of low to moderate gradient (1-2%) [defined as <1.5% in this study]. Pool-riffle reaches tend to possess lower gradients than the three previous reach types and

are characterized by an undulating streambed that forms riffles and pools associated with gravel bars. Also, unlike most cascade, step-pool, and plane-bed reaches, the channel shape of pool-riffle reaches are often sinuous and contain a predictable and often regular sequence of pools, riffles, and bars in the channel. Pools are topographic depressions in the stream bottom and bars form the high points of the channel. Riffles are located at crossover areas from pools to bars. At low streamflow, the water meanders around bars and through pools and riffles that alternate from one side of the stream to the other. Pool-riffle reaches form naturally in alluvial channels of fine to moderate substrata coarseness (Leopold et al. 1964, Yang 1971) with single pool-riffle-bar sequences found every 5–7 channel widths (Keller and Melhorn 1978). Large wood, if present, anchors the location of pools and creates upstream sediment terraces that form riffles and bars (Bisson et al. 1987; Lisle 1986). Streams rich in large wood tend to have erratic and complex channel morphologies (Bryant 1980). Channel substrata in pool-riffle reaches are mobilized annually during freshets. At bankfull flows, pools and riffles are inundated to such an extent that the channel appears to have a uniform gradient, but local pool-riffle-bar features emerge as flows recede. Movement of bed materials at bankfull flow is sporadic and discontinuous (Montgomery and Buffington 1997). As portions of the surface armor layer are mobilized, finer sediment underneath is flushed, creating pulses of scour and deposition. This process contributes to the patchy nature of pool-riffle reaches, whose streambeds are among the most spatially heterogeneous of all reach types (Buffington and Montgomery 1999).

**Regime (dune-ripple) reaches:** Regime stream reaches consist of low gradient (<1%) [defined as <0.1% in this study], meandering channels with predominantly sand substrata. This reach type generally occurs in higher order channels within unconstrained valley segments and exhibits less turbulence than reach types with high gradients. Shallow and deep water areas are present and point bars may be present at meander bends. As current velocity increases over the fine-grained substrata of regime reaches, the stream bed is molded into a predictable succession of bedforms, from small ripples to a series of large dune-like elevations and depressions. Sediment movement occurs at all flows and is strongly correlated with discharge. A well-developed floodplain typically is present. The low gradient, continuous transport of sediment, and presence of ripples and dunes distinguish this reach type from pool-riffle reaches.

**Braided reaches:** Braided reaches possess multithread channels with low to moderate gradients (<3%) [defined as <2.5% in this study] and are characterized by large width–depth ratios and numerous bars scattered throughout the channel. Individual braid threads typically have pool-riffle morphology, with pools commonly formed at the confluence of two braids. Bed material varies from sand to cobble and boulder, depending on channel gradient and local sediment supply. Braiding results from high sediment loads or channel widening caused by destabilized banks. Braided channels commonly occur in glacial outwash zones and other locations overwhelmed by high sediment supply (e.g., downstream of massive landslides or volcanic eruptions) or in places with weak, erodible banks (e.g., river corridors that have lost vegetative root strength because of riparian cattle grazing or riparian clear cutting or in semiarid regions where riparian vegetation is naturally sparse) (Buffington et al. 2003). In braided reaches, the location of bars changes frequently and the channel containing the main flow can often move laterally over short periods of time.

[Bankfull flow: refer to Chapter 5, In-Stream Large Wood, Appendix 5A, Indicators of Bankfull Stage for a more in-depth discussion of bankfull flow.]

## HABITAT UNIT SURVEYS

Habitat units, also called channel geomorphic units or channel units, are “relatively homogenous areas of the channel that differ in depth, velocity and substrata characteristics from adjoining areas” (Bisson et al. 2006). They are the next hierarchically nested subdivision on the drainage network after stream reach.

This protocol uses a modified three-tier classification for fast water units and a two-tier classification for slow water units (scour pools and dammed pools) with the addition of backwater pools (Figure 6-3). Backwater pools are important elements of fish habitat in small streams and relatively easy to identify in the field.

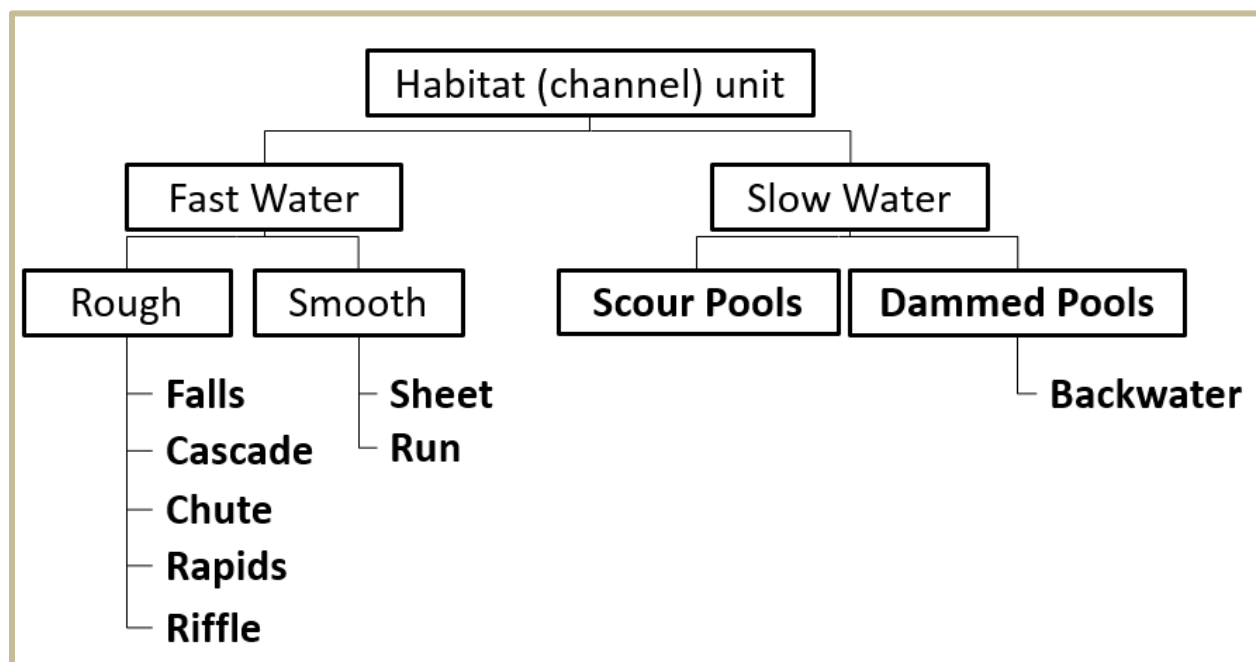


Figure 6-3. Hierarchical subdivision of habitat (channel) units in streams (modified from Bisson et al. 2006).

Habitat unit surveys should be conducted during low flow periods (late summer/early fall) because habitat units are often indistinguishable at high discharges. Habitat unit dimensions and hydraulic properties vary considerably with discharge, so repeated surveys should occur under similar flow conditions.

*Optional: To ensure that habitat unit surveys are conducted under similar flow conditions each year and to permit post hoc comparisons between repeat surveys, consider taking a discharge measurement at the time of sampling.*

Habitat unit surveys require a two-person field crew. One crew member (the “recorder”) holds the measuring tape, flags the pool-forming piece(s) of wood (if any), and enters data into the Field tablet. The

other crew member (the “observer”) pulls the zero end of the meter tape to the end of the habitat unit; identifies the unit type and boundary; and measures wetted widths, pool depths, and fall/step heights.

Starting from the beginning of the sample reach (cross section A), the crew walks the reach and classifies and measures all habitat units. Include the units that are intersected by the first and last cross-sections (i.e., start below the beginning of the sample reach and/or end beyond the end of the sample reach).

Habitat unit identification is a two-step process. The first step is to identify the unit type. For this study, please refer to the photo and schematic references in the *Field Guide for Identifying Stream Channel Types and Habitat Units* (Minkova and Vorwerk 2015), which includes hydraulic and geomorphic indicators such as water velocity, water depth, gradient, and bed roughness. Unit types are listed in Figure 6-3.

The second step is to identify the boundary where one unit ends and another begins. At first, the location of habitat unit boundaries can seem unclear, but as survey crews become familiar with what to look for, as identified in Minkova and Vorwerk (2015), consistency will develop.

An area of the stream should be counted as a habitat unit if:

- 1) The overall physical characteristics are clearly different from those of adjacent units, and
- 2) The length is equal to or greater than the average wetted width of the sample reach (Bisson et al. 2006). Exceptions to this rule are steps and falls, which have no minimum length. Backwater pool length must be at least half the average wetted width of the sample reach.

Stream areas that do not meet the minimum length requirements are lumped with the most similar adjacent unit.

Lumping multiple habitat units into one broader unit (e.g., a string of run-pool-riffle-run might be lumped into one run unit) is allowed if both crew members agree that this is the best way to capture the character of the stream. This can be the case where habitat units are not distinct enough to count using criteria 1 or 2 above. In practice, it is often helpful to use the stream’s average wetted width as a guide to help determine whether to lump or split. Calibration during training is essential to achieve sampling consistency across space and time (see the section on QA/QC below).

It can often be difficult to distinguish between cascades and rapids or between rapids and riffles. When identifying unit types, consider substrate, longitudinal profile, and gradient (i.e., % slope). Use the criteria below as an addendum to the habitat unit guide to help make the tough calls.

**Cascades:**  $\geq 6\%$  slope, stepped longitudinal profile, large substrate (boulders and large cobble).

**Rapids:** 3-5% slope, somewhat planar longitudinal profile, coarse substrate (cobble, small boulders often submerged – causing eddies).

**Riffles:**  $< 3\%$  slope, fine to moderate substrate (gravel, cobble).

A unit is identified as “subsurface flow” where the main channel becomes dry across its entire width. On small streams, short sections of subsurface flow (intermittency) are common during base flow sample

periods, however if a sample reach is subsurface for more than 10% of its longitudinal profile, the habitat unit survey should not be done.

### **Measuring Gradient**

To take a gradient measurement with a clinometer, crew members should first determine where their eye levels correspond to their partner. One crew member stands at the upstream end of the habitat unit and the other stands at the downstream end – both with their feet at the water surface level. One crew member looks through the clinometer, aligns the horizontal crosshair with the predetermined height on his or her partner, and reads the % slope scale (right side) corresponding to that height. Include all gradients taken with a clinometer in the field tablet database “Remarks” field. Gradients can be measured only when a habitat unit is fairly straight. If the unit is on a stream bend, the gradient will be inaccurate.

### **Habitat unit measurement**

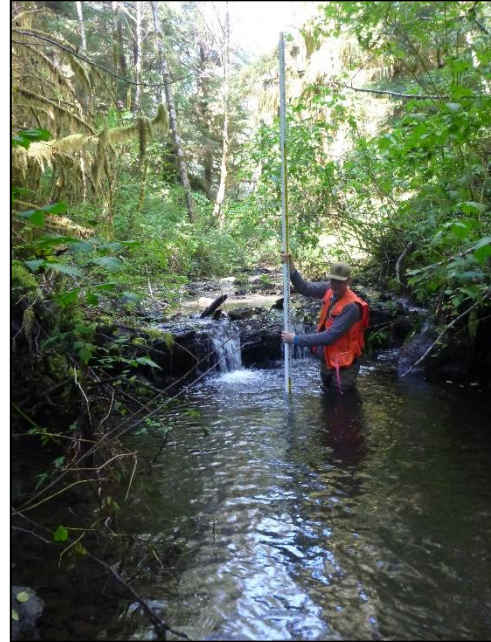
Starting at cross section A, measure the length of each habitat unit along the thalweg at water surface level (nearest 0.1 m). If the first habitat unit is intersected by cross section A, measure that habitat unit’s entire length and enter that value into the field tablet database. Note the distance where the unit crosses the reach start, and record the measurement in the “Remarks” field (e.g., “this unit extends 0.5 m below the sample reach”). The survey will progress upstream until the last habitat unit at cross section F. If the last habitat unit extends beyond the reach, record the entire unit length and then note the unit distance outside the sample reach in the “Remarks” field (e.g., “this unit extends 0.5 m above the sample reach”).

Use the measuring rod (or meter tape or stadia rod) to collect a minimum of three representative wetted widths per habitat unit (Figure 6-4a). Additional width measurements are recommended for long or complex units. Record each habitat unit’s type, length (nearest 0.1 m), and wetted widths (nearest 0.01 m) in the field tablet database. A subsurface section has a “0” wetted width. Record any notes or photo numbers in the “Remarks” field.

If habitat units in the main channel are not arranged linearly and thus overlap, visualize a diagonal dividing line between the units and measure the lengths from the mid-point of that line. Where habitat types occur side-by-side (e.g., a qualifying scour pool next to a riffle), measure and record the length of the dominant unit type and note the type and width of the adjacent unit in the “Remarks” field. Be sure to record the entire wetted width in sections where habitat types occur side-by-side.

If the stream splits into two channels, identify the main channel and side channel based on flow (main channel has higher flow). Identify and measure habitat units within the main channel. For instructions on determining whether a side channel exists and measuring habitat units in the side channel, see the *Side Channels* section, below.



**a****b**

**Figure 6-4. Measuring habitat unit wetted width (a) and maximum pool depth (b).**

### Measuring Falls

A water fall (i.e., falls) is a vertical or nearly vertical habitat unit  $\geq 0.5$  m in height. Measure the height of the falls from the water surface of the lower unit (usually a pool) up to the crest (where the water begins to fall). Record the length (nearest 0.1 m) and a minimum of one width.

Falls should also be labeled as either classic or complex in the field tablet “Remarks” field. A classic falls is a well-defined falls over a sheer drop. A complex falls has a series of drops, breaks, or channels (Armantrout 1998).

### Measuring Steps

Steps are abrupt, discrete breaks in channel gradient resulting from elevation changes  $< 0.5$  m. Steps are not habitat units per se; they are usually much shorter than the channel width and can separate sequential units of the same type.

Measure the height of the step from the water surface of the lower unit up to the crest of the upper unit (where the water begins to fall). Record the length (nearest 0.1 m) and a minimum of one width.

### Measuring Pools

*Maximum depth:* Probe the pool with the stadia rod to find the maximum pool depth (i.e., largest vertical measurement from stream bed to water surface). Record the depth in the field tablet database (nearest 0.01 m).

*Pool tail crest:* Use the stadia rod to find and measure the maximum depth along the pool tail crest (the tail crest is the peak instream bed elevation on the downstream end of the pool) (Figure 6-5). For dammed pools, measure the tail crest depth along the top of the obstruction if all flow is going over the obstruction. If no water is flowing over, the tail crest for the dammed pool will be 0 cm (Pleus et al 1999). Record the pool tail crest depth (nearest 0.01 m) in the field tablet database.

Subtract the pool tail crest depth from the maximum pool depth to determine the residual depth. To qualify as a pool, a unit must meet a minimum residual depth, based on the mean reach bankfull width (see Table 6-2). For example, for sample reaches with bankfull widths < 2.5 m, the residual pool depth of a unit must be at least 10 cm.

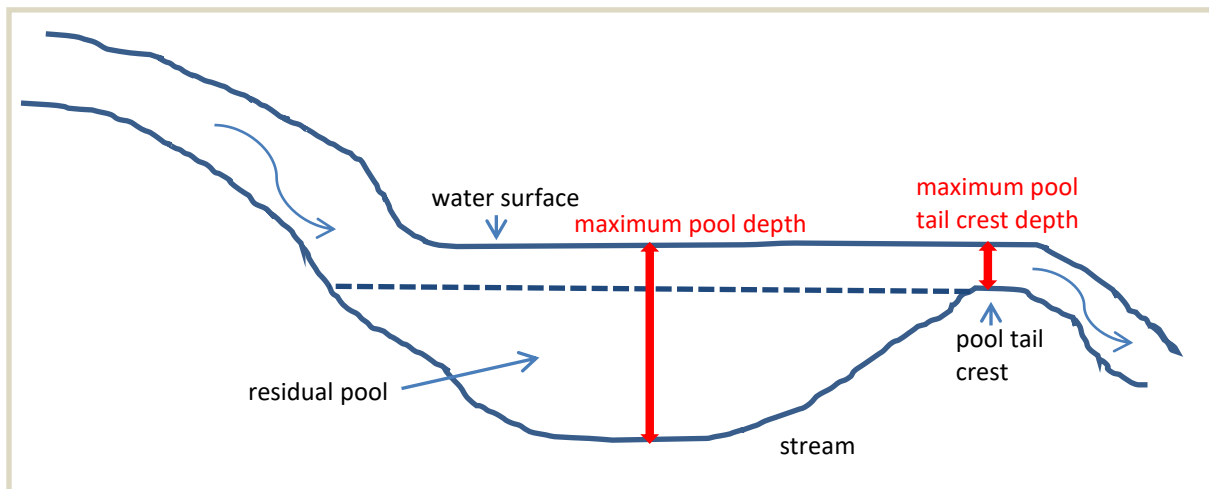


Figure 6-5. Side profile illustration of a pool and the points of measurements.

Table 6-2. Minimum residual pool depth criteria by reach mean bankfull width (from Pleus et al. 1999)

Mean reach Bankfull Width (m)	Minimum Residual Pool Depth (m)
0 to < 2.5	0.10
≥ 2.5 to < 5.0	0.20
≥ 5.0 to < 10	0.25
≥ 10.0 to < 15	0.30
≥ 15.0 to < 20	0.35

*Pool-forming wood:* Look for piece(s) of large woody debris (LWD) that contribute directly to the pool’s formation (see In-stream Large Wood protocol for LWD identification criteria). Pool-forming wood may create dammed pools by blocking flow or enhance the scour of pools by changing channel hydraulics. Water may spill over a wood step, creating a plunge pool downstream, or be redirected down under woody debris, leading to stream bed scour. Flag the piece(s) of pool-forming wood and write the habitat unit number (from the tablet) on the flagging (e.g. “HU 5”). This label will be used later in the in-stream wood survey. In the tablet data entry form, check the check-box to indicate the piece is “large-



wood formed”. If using paper datasheets, write “LWF” in the Remarks field for the pool that is large-wood formed.

Note that LWD pieces flagged during the habitat survey will not necessarily match the pieces designated as “pool-forming” during the in-stream wood survey because the habitat and LWD protocols define pools differently. (For the LWD survey, pools do not need to meet minimum length or residual depth requirements. Rather, they are defined using only a minimum surface area based on bankfull width; see LWD protocol.)

## Side channels

A side channel exists when both of the following criteria are met:

1. There is a stable island or bar in the stream that is higher than bankfull stage and has bankfull indicators present (see Appendix 3A for indicators).
2. The portion of the island/bar that is above bankfull stage has a length at least twice that of the stream’s estimated bankfull width (BFW). Use the average BFW calculated during Channel Morphology sampling. If no measurements have been taken, use the average BFW upstream and downstream of the island/bar.

If any there is a continuous surface flow in the side channel, the channel should be typed for habitat units.

Label each side channel habitat unit as “SideChannel” in the field tablet database “Habitat Unit” field. Measure the unit’s length and wetted widths as usual and enter them in the database. Note in the “Remarks” section the type for each habitat unit, the stream side of the side channel, and the approximate distance from the nearest cross-section to the points of divergence and convergence. For example: *[habitat unit type]-side channel on stream [left or right]. Side channel diverges 6 m [upstream or downstream] of cross section [A, B, C, D, E, or F] and converges 4 m [upstream or downstream] of cross section [A, B, C, D, E, or F]*”.

## Time and Cost Estimates for Implementing the Field Procedures

The estimated time for classifying valley segment, channel reach, and habitat units and for measuring the habitat units along a 100-m reach is approximately one hour for an experienced two-member crew. Habitat unit classifications should be made by the same “observer” throughout the survey. However, consultation and discussion with the other crew member is highly encouraged. This estimate does not include travel time.

All items listed in the *Equipment and Supplies* section are shared with other protocols, and their costs are detailed in the Channel Morphology protocol.

## Procedures for Calculating Metrics

All metrics are calculated in the office following the procedures in Table 6-3.

**Table 6-3. Procedures for Calculating Metrics**

Metric	Calculation Procedure
Units/100 m	Total number of habitat units per sample reach, adjusted to a 100-m length.
Pools/100 m	Total number of pools (scour pool, dammed pool, backwater pool) per sample reach, adjusted to a 100-m length.
Number of habitat units/100 m, by type	For each habitat unit type, the number of units per sample reach is calculated and adjusted to a 100-m length.
Percentage of sample reach allocated to each habitat unit type	Summed length of sample reach allocated to a given habitat type, divided by total reach length, multiplied by 100.
Mean residual pool depth	For each pool, residual pool depth is calculated as the maximum depth minus the tail-crest depth. Residual pool depth is then averaged across all pools.

## Quality Assurance and Quality Control

The quality assurance for the Habitat Units and Valley and Channel Classification protocol includes staff training and the use of standardized protocols. The quality control for the field procedures includes annual field checks.

The QA/QC procedures for data management are described in the Data Management section below.

### TRAINING

All personnel conducting field protocols will be trained in a consistent manner to ensure that the surveys are conducted properly and in standardized fashion. The training is conducted or, in case of returning personnel, reviewed, annually before the start of the field season. At least one member of the field crew should be experienced with the field procedures.

One of the most important tasks for the classification procedures is to calibrate the observers so they are consistently identifying the features. One member of the crew, the observer, is assigned to make the final call if there is disagreement on the classification result.

### STANDARD PROTOCOLS

The standard procedures described in this protocol are followed for the duration of the project. Any deviations from the procedures should be documented, and the reasons for deviation described and discussed with the project manager or the researcher overseeing the protocol implementation.

Changes to the published protocols are approved by the project manager or by the researcher overseeing the protocol implementation. Revised protocols are assigned new version numbers and publication dates.

## FIELD CHECKS

The researcher overseeing the protocol implementation or a different field crew will conduct spot checks on 10% of the field measurements every year.

## Data Management

### DATA FLOW

All habitat unit data are recorded in the field using paper field forms (2013-2014 field seasons) or a ruggedized field tablet (2015 field season onward). In the office, data are then transferred to a database for long-term storage. The steps below detail the process.

#### *Data flow for paper field forms*

1. **Fill out field forms** Paper field forms are used to record data and metadata at each sample reach.
2. **Scan and store field forms** After returning from the field each week, the field forms are scanned and stored on the WADNR network drive; the original paper forms are archived by the OESF Data Management Specialist at the Washington Department of Natural Resources Forest Resources Division.
3. **Enter data** All habitat unit data collected on paper field forms are entered in the “Habitat\_LWD\_Database” by the OESF Data Management Specialist on a weekly basis. After each field form is entered, the Specialist writes “Entered” on the form, followed by his or her initials and the date.
4. **Quality control** Entered field form data are verified by comparing the data on the field form to the data in the database. This process is performed by someone other than the person who originally entered the data. After the data are verified, the person who verified it writes “Verified” on the field form, followed by his or her initials and the date.

#### *Data flow for electronically collected data*

1. **Fill out forms on electronic field data recorder** Field personnel record all habitat unit data using the “Tablet Database”, which is a customized database created in Microsoft Access and saved on the field tablet.
2. **Store field data** At the end of each day in the field, a copy of the Tablet Database, containing all data collected to date, is transferred to the OESF Data Management Specialist via cloud storage or email. If internet access is not available, the field crew makes a daily backup copy of the database on a laptop or other storage device and then transfers the data to the Data Management Specialist after returning to the Natural Resources Building at the end of the week. The OESF Data Management Specialist stores these Tablet Database copies in a temporary location on the WADNR network drive (J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip

S&T Mon\07\_Data management\\_All new data and photos\) until they are processed and the data are transferred to a database for long-term storage.

3. **Quality control** Because data are recorded electronically, and thus never transcribed, transcription errors do not exist. However, there is still a possibility of data entry errors in the field. In particular, if metadata (e.g., the date of a field visit or a watershed ID) are recorded incorrectly in the field, this could cause errors during the process of importing data from the Tablet Database to the Habitat\_LWD\_Database (next step; see below). For this reason, metadata are examined for accuracy prior to importing data to the Habitat\_LWD\_Database.
4. **Import data to database** On a weekly basis, the OESF Data Management Specialist imports all new data from the Tablet Database to the Habitat\_LWD\_Database. This is accomplished using a set of queries stored in a third database: J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD DATA\01\_Stream survey\Data\Distribute\_Tablet\_Data.accdb
5. **Verify transfer of data** After data have been imported, the OESF Data Management Specialist verifies that no records have been missed, using the record count queries built into the Distribute\_Tablet\_Data database.

### ***Photographs***

1. **Transfer photos to data manager for storage** All digital photographs taken in the field are transferred to the OESF Data Management Specialist at the end of each week. The Specialist temporarily stores the uncatalogued photos on the WADNR server at:  
J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\07\_Data management\\_All new data and photos\
2. **Rename and archive photos** The OESF Data Management Specialist renames each photo using the following naming convention: <Photo type>\_<WatershedID>\_<Date taken>\_<Original photo name> (for example: ER\_797\_20140715\_P1000851.JPG). The photos are then moved to long-term storage in the following directory: J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\03\_Photos and videos\04\_Stream\_survey\

## **DATA STORAGE**

### ***Paper field forms***

The paper field forms are archived at the Washington Department of Natural Resources Forest Resources Division. The designated data steward is Teodora Minkova, WADNR. Scanned copies of these forms are saved in the Adobe portable document format (.pdf) in the following directory:

J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD DATA\01\_Stream survey\Data\Data archive\Field forms\

**Tablet databases**

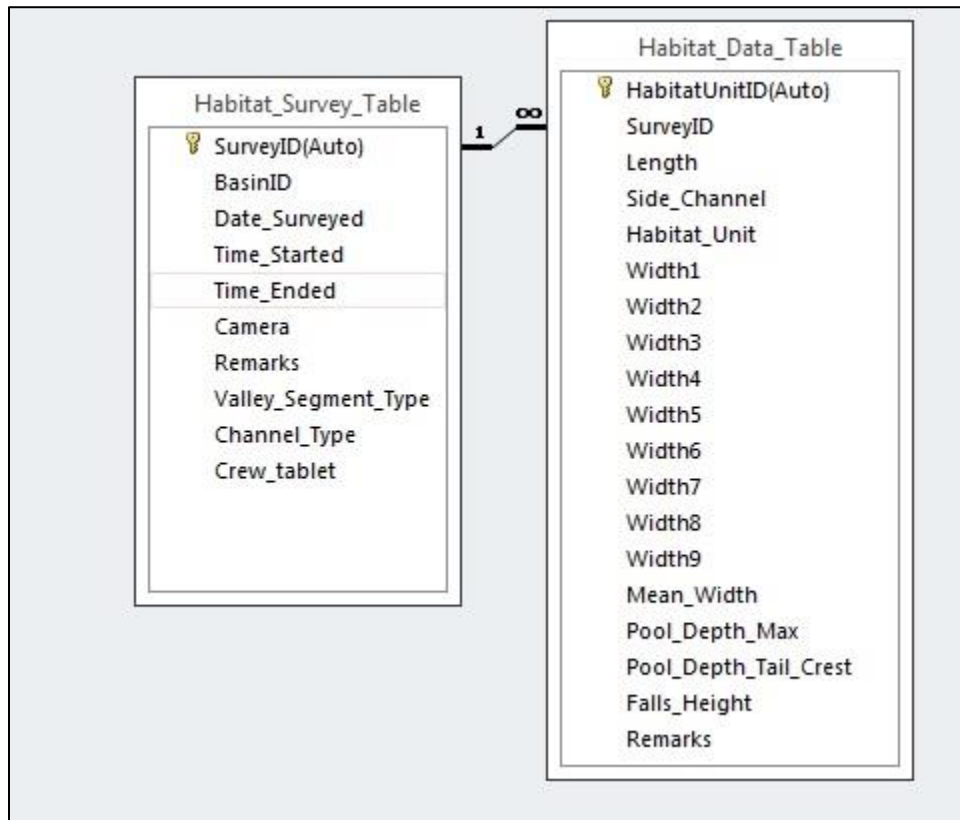
The original Tablet Databases, which are transferred to the OESF Data Management Specialist on a daily or weekly basis, are stored on the WADNR network drive after the field data they contain have been transferred to the Habitat\_LWD\_Database. The storage location for these databases is:

J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD DATA\01\_Stream survey\Data\Data archive\Processed tablet databases\

**Long-term data storage**

The ultimate location of the habitat unit data is the Habitat\_LWD\_Database, located on the WADNR network drive at: J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD DATA\01\_Stream survey\Data\Habitat\_LWD\_Database.accdb

Within the Habitat\_LWD\_Database, the habitat data are stored in two related tables: the Habitat Survey Table and the Habitat Data Table (Figure 6-6). The Habitat Survey Table contains the metadata from each survey, and the Habitat Data Table contains the habitat unit data. The Habitat Survey Table is related to the Habitat Data Table through a one-to-many relationships: a single record in the Survey Table is related to multiple records in the Data Table. The fields in the two habitat unit database tables are described in Tables 6-3 and 6-4.



**Figure 6-6. The structure of the habitat portion of the Habitat\_LWD Database.**

**Table 6-3. Fields in the Habitat Survey table in the Habitat\_LWD database.**

Field	Field description
SurveyID(Auto)	A unique identifier for each record in the table.
BasinID	Watershed identifier.
Date_Surveyed	The date of the habitat unit survey.
Time_Started	The time of day that the survey began.
Time_Ended	The time of day that the survey ended.
Camera	The ID of the camera that was used.
Remarks	Remarks.
Valley_Segment_Type	The valley segment type.
Channel_Type	The channel type.
Crew_tablet	The initials of the crew members.

**Table 6-4. Fields in the Habitat Data table in the Habitat\_LWD database.**

Field	Field description
HabitatUnitID(Auto)	Unique identifier for each record in the table.
SurveyID	A value that links the record to the appropriate metadata in the LWD Survey Table.
Length	Length of the habitat unit (m).
Side_Channel	If the unit occurs on a side channel, then a “Y” is recorded in this field.
Habitat_Unit	Habitat unit type.
Width1	Width of unit (m).
Width2	Width of unit (m).
Width3	Width of unit (m).
Width4	Width of unit (m).
Width5	Width of unit (m).
Width6	Width of unit (m). (More than five widths are measured only on rare occasions.)
Width7	Width of unit (m). (More than five widths are measured only on rare occasions.)
Width8	Width of unit (m). (More than five widths are measured only on rare occasions.)
Width9	Width of unit (m). (More than five widths are measured only on rare occasions.)
Mean_Width	Mean width of the habitat unit (m). (This field is automatically calculated.)
Pool_Depth_Max	Maximum pool depth (cm).
Pool_Depth_Tail_Crest	Pool depth at tail crest (cm).
Falls_Height	Falls height (m).
Remarks	Remarks.

## DATA QUALITY CONTROL

Prior to data analysis, all fields in the data tables are assessed to identify potentially erroneous values. The first step is to examine individual fields, one at a time. For categorical data fields (e.g., habitat unit type) and date or time fields, every field is assessed to identify any records exhibiting the following:

1. Missing values.
2. Illogical values.

In some cases, where the data collector is free to enter values rather than selecting values from a predefined list, illogical values may be recorded (e.g., a survey time of 3:00 AM).

For numerical fields, each is assessed for the following:

1. Missing values.
2. Outlier values (e.g., a stream width was recorded in cm instead of m).

The next step in quality control assessment is to examine derived values and values in the context of other fields. An example of a derived value is the lengths of all habitat units in a sample reach added together. If the sum of habitat unit lengths is significantly less than the length of the sample reach, then the data should be examined to determine if one of the habitat unit lengths was recorded incorrectly. An example of checking a value in the context of another field is the comparison of a maximum pool depth with the tail crest of the same pool. If the tail crest is significantly greater than the maximum pool depth, there may be an error in the data.

When missing values are discovered, it is generally not possible to “fill in the blank” from the office. The fact that data are missing should be recorded, in brackets, in the “Remarks” field, with the initials of the person who performed the quality control check (e.g., [Pool\_Depth\_Max was not recorded. –WD]).

Illogical or outlier values can sometimes be corrected in the office. For example, AM and PM might have been switched or a decimal place error can be corrected. When data are corrected, this must be noted in the remarks field, in brackets, with the initials of the person who performed the quality control check. For example: [Width2 was recorded as 50 m. This was clearly incorrect and changed to 5.0 which is logical given the other widths for that unit. –WD].

In many cases, clearly erroneous outlier values cannot be corrected in the office and should be edited so as not to affect the results of analysis. In such cases, the value should be removed from the field and transferred to the “Remarks” field with an explanation, in brackets, with the initials of the person who performed the quality control check. For example: [Width2 was recorded as 74.8 m. This was clearly incorrect and removed from the dataset. –WD]).



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■ Habitat Units and Valley and Channel Classification

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## Appendix 6A. Habitat Units Identification at High Flows

The habitat units' classification and dimensions are affected by the water level in the stream (Figure 6A-1). To ensure consistent measurements over time and reduce the variability introduced by the water flow, this protocol requires sampling during low flows in the summer and fall when the conditions are stable and the habitat units are most defined. Below are additional details on determining when to discontinue field surveys and, in case habitat units data are already collected, what data to reject during the QC process.



**Figure 6A-1. Sample reach in watershed 790 at low flow (a) and high flow (b). The gage heights readings from the USGS Calawah River station are 2.54 feet and 6.66 feet, respectively.**

## ■ Habitat Units and Valley and Channel Classification

The determination is a two-step process: 1) screening of online data prior to the field and 2) if necessary, field assessment of site conditions.

### **Step 1. Check online data**

Check the latest data from USGS Calawah River flow monitoring station. The Calawah River is non-glacial and flow of this river is believed to be relatively representative of the current flow conditions of our monitored streams. Visit [https://waterdata.usgs.gov/wa/nwis/uv?site\\_no=12043000](https://waterdata.usgs.gov/wa/nwis/uv?site_no=12043000) and look at the most recent value for the parameter Gage height, which can be viewed in graphical or tabular format.

If the last Calawah gage height reading is 3.0 feet or less, conditions are expected to be suitable for surveying habitat units.

If the last Calawah gage height reading is above 4.0 feet, do not survey habitat units. If data have been collected during this flow it should be rejected.

If the last gage height reading is between 3.0 feet and 4.0 feet, visit the site and do the field assessment described in Step 2.

*Our analyses showed similar flow patterns between the four USGS monitoring stations on the western Olympic Peninsula, therefore it is sufficient to use only one for online screening. If the precipitation event differs considerably between southern and northern part of the study area, check the gage height of the USGS Hoko River monitoring station ([http://waterdata.usgs.gov/wa/nwis/uv?site\\_no=12043300](http://waterdata.usgs.gov/wa/nwis/uv?site_no=12043300)) prior to visiting the sample reaches in the Clallam landscape.*

*Our analyses showed less than a 12-hour delay between high peak flows in the sample reaches and the Calawah River gage station; therefore, the latest gage height reading from that station is an appropriate screening tool.*

### **Step 2. Field assessment of the sample reach**

Walk a portion of the sample reach and observe the flow and safety conditions. Do not survey for habitat units if any of the following conditions are met:

- The conditions are not safe (e.g. high water velocity, mobilized wood pieces).
- The demarcation lines between fast and slow water habitat units are not clearly visible (e.g. between pool-riffle and pool).
- The water flow conditions look very different from the previous habitat unit survey. This may be determined by reviewing the habitat unit data and pictures from previous surveys.

If in doubt, or if you feel that you do not have sufficient experience with the study to make the decision as to whether to sample, ask a project researcher for advice. Record any field observations regarding flow level in the Notes section on the field tablet.



# Stream Temperature

**Authors:** Alex Foster, Warren Devine, Mitchell Vorwerk

**Version:** 1.5

## Revision History:

Protocol Version	Purpose / Changes	Author(s)	Reviewer(s)	Publication Date
1.0	Initial draft presented to project staff	Alex Foster	Peter Bisson, Teodora Minkova	04/02/2013
1.1	Draft submitted to external review	Alex Foster	Rebecca Flitcroft, Ashley Steel	04/16/2013
1.2	Draft incorporating external reviews, sampling procedures from 2013 field season, and data mgmt. procedures	Alex Foster, Warren Devine, Mitchell Vorwerk	Teodora Minkova, Ellis Cropper	12/03/2015
1.3	Final draft with field and data management procedures updated from 2014 and 2015 field seasons	Alex Foster, Warren Devine, Mitchell Vorwerk	Teodora Minkova	05/11/2016
1.4	Final technical review and edit	Alex Foster, Warren Devine, Mitchell Vorwerk	Paul Dunnette, Warren Devine, Alex Foster	12/18/2016
1.5	Added Appendix D	Warren Devine	Teodora Minkova	6/13/2019

## Based on the Following Protocols:

This protocol is based on two published protocols: Washington State Department of Ecology’s (WADOE) *Standard Operating Procedures for Continuous Temperature Monitoring of Fresh Water Rivers and Streams Conducted in a Total Maximum Daily Load (TMDL) Project for Stream Temperature, version 3.0* (Bilhimer et al. 2013) and USDA Forest Service’s *Measuring Stream Temperature with Digital Data Loggers: A User’s Guide* (Dunham et al. 2005).

## Reasons to Adopt the Above Protocols:

WADOE already has three active, long-term monitoring sites established in the Olympic Experimental State Forest (OESF) and once had seven additional sites in the area. Thus, data-sharing between agencies would be mutually beneficial. The active WADOE sites in the OESF are included in a national network for stream temperature monitoring maintained by the U.S. Forest Service Rocky Mountain Research Station ([http://www.fs.fed.us/rm/boise/AWAE/projects/stream\\_temperature.shtml](http://www.fs.fed.us/rm/boise/AWAE/projects/stream_temperature.shtml)).

WADOE metrics are the same as those used by most other regional water monitoring efforts, and the field procedures have been proven in western Washington streams. Dunham et al. (2005) provides further information about sampling interval specifications, logger accuracy testing, and data analysis. WADOE uses Dunham et al. (2005) as a reference for its protocols.

## Purpose and Content:

The purpose of this monitoring protocol is to describe the sampling and data management necessary to document and report the status and multi-year trends of stream temperature in the monitored watersheds. It

## ■ Stream Temperature

details the field procedures for deployment, maintenance, and downloading of temperature data loggers (thermistors), the field quality assurance and quality control steps, and the data management procedures.



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## ***Introduction***

All aquatic life forms have a temperature range within which they can survive. Temperature changes can affect stress, mortality, and life histories of all aquatic species (i.e., invertebrates, fish, and amphibians) (Hauer and Hill 2006). Federal endangered species listings of trout and salmon cite increasing stream temperatures as a limiting factor for population recovery. As such, increases in stream temperature can affect embryonic development; juvenile growth; adult migration; competition with non-native species; and the relative risk and severity of disease (Sullivan et al. 2000).

Stream temperature is a function of multiple energy transfer processes, including solar and long-wave input, air convection, stream bed conduction, groundwater flux, hyporheic flux, evaporation, and condensation. Solar radiation, as a function of the amount of surface area of unshaded water, is a primary contributor to daily maximum summer stream temperature. This process responds directly to riparian tree canopy removal resulting from logging, windthrow, wildfires, or mass wasting (Poole and Berman 2001, Moore et al. 2005).

In the environmental impact analysis for the Olympic Experimental State Forest (OESF) Forest Land Plan, stream temperature was recognized as an important indicator for fish habitat quality, riparian area function, and water quality (WADNR 2013). Because comprehensive stream temperature data was not available at the time of the analysis, stream shade was used as a surrogate.

## ***Monitoring Design***

### **SPATIAL SAMPLING DESIGN**

Stream temperature is measured in each of the 50 sample reaches in the OESF and the four reference sample reaches in Olympic National Park (ONP). Refer to the Project Background chapter for a map of the sample watersheds. One water temperature data logger and one air temperature data logger are installed at each sample site (Figure 7-1). The water and air data loggers are always paired and installed in close proximity to each other. The air and water temperature digital records are compared to determine whether the water temperature data logger was de-watered (i.e., exposed to air) at any point during its deployment.

### **TEMPORAL SAMPLING DESIGN**

#### ***Sampling Interval***

Both air and water temperature data loggers are deployed year-round and set to record temperature every 60 minutes. For the western Olympics, this interval provides a less than one percent probability of missing the maximum and minimum daily temperatures (Dunham et al. 2005). At this interval, the data loggers' memory limits and battery life will allow continuous recording for up to 5 years.

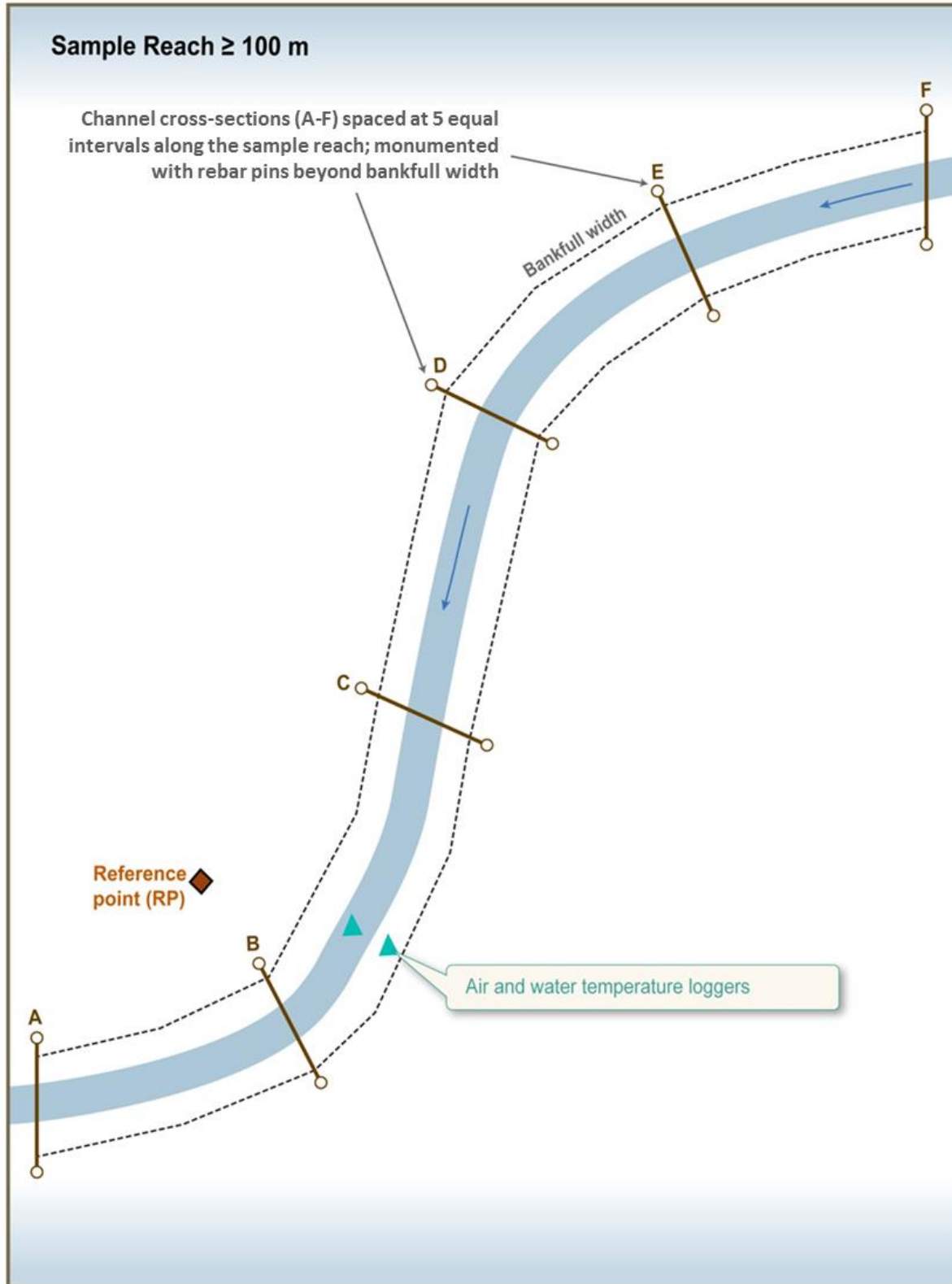


Figure 7-1. Typical location of water and air temperature data loggers within a sample reach. Water and air loggers are always installed close together, though not necessarily between cross-sections B and C.

### **Download Schedule**

Data will be downloaded and the loggers inspected at least once a year and preferably twice annually: in spring to check for dewatering, winter damage, and loss of loggers due to high flows; and in the fall to collect summer temperatures and check the status of installations to reduce the risk of damage or loss during upcoming winter high flows. It is most efficient to download data and inspect loggers when the sample sites are visited for other monitoring purposes.

## **Equipment and Supplies**

The following equipment and supplies are needed for initial data logger installation, replacement of lost or damaged loggers, and data download:

- Onset<sup>®</sup> HOBO TidbiT v2 thermistors
- Onset<sup>®</sup> HOBOWare Pro software
- Onset<sup>®</sup> HOBO Waterproof Shuttle (optical data shuttle for data download)
- Ruggedized field tablet with data logger location photos and descriptions of observations from previous visits (optional) or Rite in the Rain<sup>™</sup> field forms
- Pre-drilled 1.5 inch diameter (43 mm) #80 PVC pipe cut to 6 cm long housings
- Size No. 72 tar-coated nylon braided cordage
- 8 in (20 cm) nylon cable (zip) ties
- 10 gauge copper wire
- Pre-drilled 8 oz (240 ml) #5 white plastic cup shade devices
- Wire cutter/pliers
- Pre-assembled anchor brick with soldered copper wire loop for cord tether installations
- Pre-assembled PVC capped enclosures and tools for epoxy mount installations
- Adjustable, prefabricated, or 1-inch open end wrench (for installing/removing caps on epoxy mount installations)
- No. 10 hot dipped galvanized nails (can also be used for epoxy mount cap removal)
- 4 lb hammer
- Blue spray paint and blue flagging for marking logger locations
- Leatherman pliers or knife (needed to cut/remove the cable ties)
- Lighter (used to melt the tips of the cordage to prevent fraying)

## TESTING TEMPERATURE LOGGER ACCURACY

While the data loggers (Onset<sup>®</sup> HOBO TidbiT v2 thermistors) cannot be adjusted following factory calibration, they should be tested in a controlled environment to determine whether they are recording within their specifications before deployment. The testing process is described on the Onset<sup>®</sup> website (<http://www.onsetcomp.com/support/tech-notes/quick-temp-accuracy-check-ice-bath>) and is summarized here. Testing multiple data loggers at once saves time and can reveal loggers that may be unsuitable for deployment. The data loggers should be launched prior to testing and set to record at a 1-to-5-minute interval.

To test the loggers, place crushed ice in an ice chest large enough to hold the loggers being tested. Crushing the ice will help maintain a consistent, uniform temperature. Fill the ice chest with water to just below the level of the ice and stir. String the loggers together and submerge them in the ice water. Place a certified thermometer in the ice water to monitor temperature. To minimize temperature gradients, place the ice chest in a refrigerator. The ice will melt slowly, so the actual temperature should settle around 0 °C if the ice bath was prepared correctly.

Leave the loggers in the ice bath for a minimum of one hour, though immersion in the bath for several hours is preferable because it allows the loggers to fully acclimate. The test should provide enough data to allow for comparisons to temperatures recorded by the thermometer and to the manufacturer's specifications on temperature drift and accuracy (the accuracy standard is  $\pm 0.2$  °C). Check and record the water temperature when the data loggers are removed from the ice bath. Record the date, time, and results in a spreadsheet for each data logger.

If data recorded by a logger do not fall within the temperature accuracy standard or have high variability (drift) compared to other loggers, the logger should not be deployed but should be retested.

## LAUNCHING THE TEMPERATURE LOGGERS

Set the clock on the computer used to launch the loggers to Pacific Standard Time (PST) through the use of the atomic clock (e.g., <http://www.time.gov/timezone.cgi?Pacific/d/-8/java>). This ensures that all loggers will record data at exactly the same times.

Program all the loggers for a common delayed launch time that starts after the planned field deployment time and date (usually 12:00 a.m. PST if deployed the day before).

## *Field Procedures*

### SAMPLING SITE SELECTION

Stream temperature loggers should be deployed in the lower half of the sample reach, within the active channel and close to the permanently marked reference point. Look for a suitable anchor location to securely attach the data logger (see details below). The location should be shielded from direct sunlight and provide protection from high flows. Avoid locations just downstream of tributaries, backwater areas, riparian

## ■ Stream Temperature

wetlands, and potential hillslope groundwater seeps because these features may seasonally bias the recorded temperatures. Consider locations upstream of these features.

Loggers should be deployed deep enough to prevent exposure to air (dewatering) during low-flow periods but far enough above the stream bed to avoid recording temperatures affected by groundwater inflow. In small streams, deployment ~10 cm (4 in) above the stream bed is ideal. In reaches where loggers are deployed using cord tether installations (see below), this is facilitated by attaching the logger to an anchor weight (brick).

In small streams, placing the data logger in a pool will often ensure it does not dewater during base flow. However, pools are turbulent during high flows, so care should be taken concerning the anchoring location (see below). In larger streams, a deep riffle or glide may be the preferred location. If necessary, place cobbles or boulders around and on top of the data logger to protect it from high flows.

## DEPLOYMENT OPTIONS

### *Housing and Assemblies for Water Temperature Data Loggers*

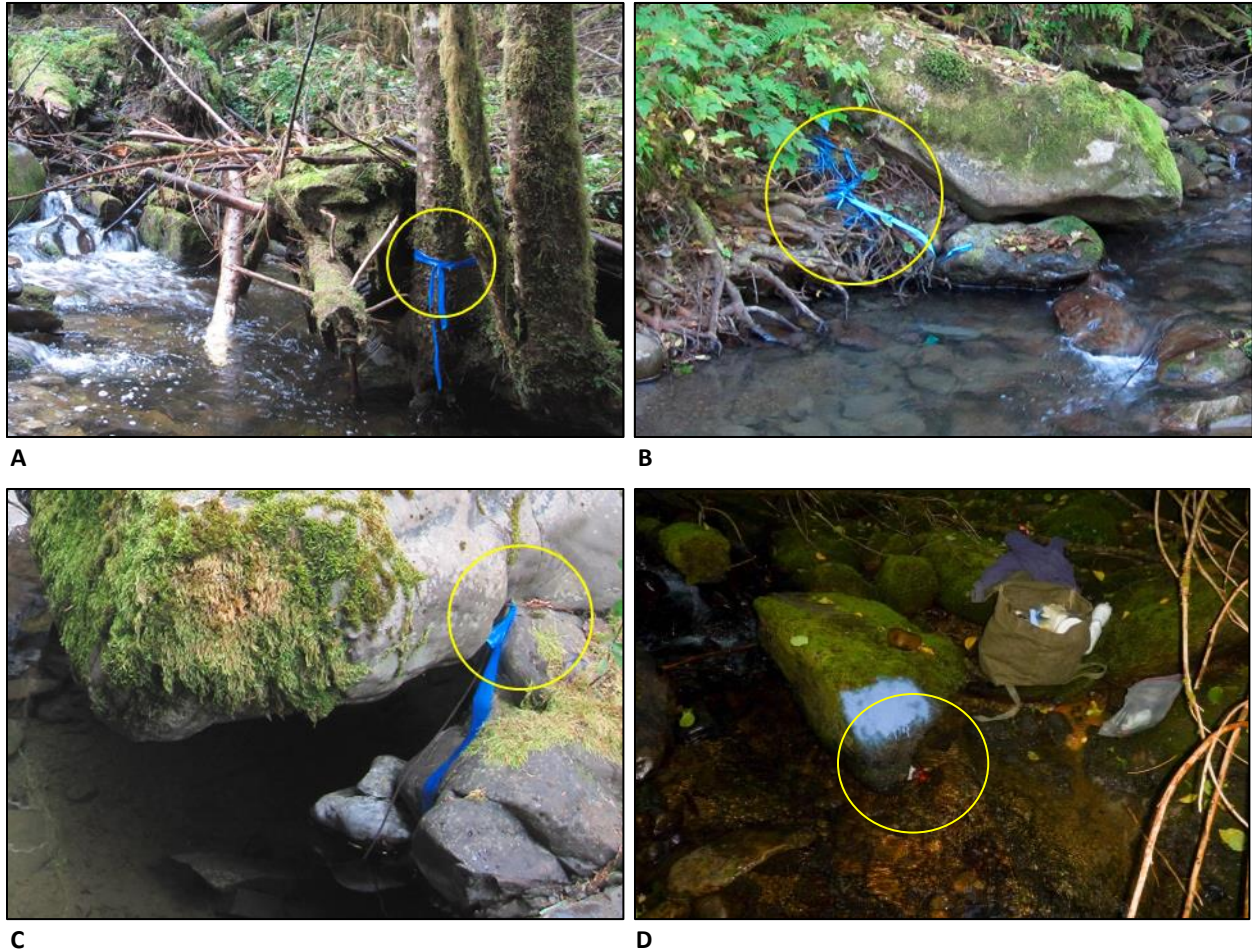
In small and/or low-gradient streams, loggers are deployed inside a PVC housing attached to a brick and tied to an anchor point in or along the stream with a nylon cord (*cord tether installations*; Figures 7-2B, 7-3C). The camouflaged (i.e., painted green) housing protects and hides the logger and minimizes indirect solar radiation. In streams where high gradient and/or stronger currents increase the probability of logger loss or damage, loggers are often encased in a different PVC housing that is affixed to a boulder below the water surface using epoxy (*epoxy mount installations*; Figures 7-2C, 7-3D).

For cord tether installations, affix the logger within the PVC housing by threading a nylon cable (zip) tie through the hole in the logger casing (Figure 7-2A) and two holes drilled on opposite sides of the PVC (Figure 7-2B). Use another cable tie to attach the housing to a soldered copper wire wrapped around a brick, which will keep the assembly submerged and minimize movement. Due to corrosion and possible logger loss, do not use steel or aluminum cable, wire, or fasteners. A tar-coated, nylon braided cord is used to attach the assembly to the selected anchor (see below).



**Figure 7-2. Assemble a temperature logger (A) in a PVC cover using nylon cable ties (for cord tether installations) (B) or a PVC cover (for epoxy mount installations) (C).**





**Figure 7-3. Examples of anchor points for water temperature data loggers: (A) Live tree root; (B) tree trunk; (C) copper wire wrapped around the connection point of two boulders; (D) PVC enclosure mounted under water on the downstream side of a boulder.**

### ***Anchors for Water Temperature Data Loggers***

Water temperature loggers are anchored to streamside or in-stream structures such as live tree roots, boulders, and woody debris (Figure 7-3). In order of preference these are: 1) Large boulders for epoxy mount installations (Figure 7-3D); 2) Live tree root at least 7 cm (2.5 in) in diameter (cord tether; Figure 7-3A); 3) Tree trunk close to the water's surface (cord tether; Figure 7-3B); 4) Copper wire wrapped around the connection point of two boulders ("wedged rock") that is close to the water's surface (cord tether; Figure 7-3C); 5) Rebar driven into large, non-mobile, and solid woody debris (cord tether); and 6) Rebar driven into stream bed or stream bank (cord tether).

Please note that for options 2-6, the anchor point should be as close to the water's surface as possible during low flow installation.



## ■ Stream Temperature

- **For epoxy mount installation:** Place the data logger into a pre-assembled PVC enclosure (Figure 7-2C) that is attached to the downstream side of a boulder using epoxy following methods described in Isaak et al. (2013) and Isaak and Horan (2011). Also attach the logger to the PVC enclosure using a nylon cable tie. This installation is preferred for high-energy stream locations where cord tether installations are inadequate to prevent logger loss.
- **For tree root/trunk installation (cord tether):** Attach the data logger assembly (logger, PVC, brick) to the root or trunk using a tar-coated, nylon braided cord. Tie a figure-eight knot at each end of the nylon cord (Figure 7-4). The cord should be long enough to keep the logger submerged in high flows but short enough to prevent it from “bouncing” and twisting the cord in high flows. Melt the ends of the cord to prevent fraying. Wrap the cord around the root, pull one knotted end through the loop on the opposite end of the cord, and securely attach the PVC cover to the other figure-eight loop (Figure 7-4) at the end of the anchored nylon cord using two nylon cable ties. Then, attach the brick anchor to one of the cable ties on the PVC assembly using another nylon cable tie (Figure 7-2B). Place the entire assembly in the water with large cobble (200+ mm) placed on top and around it.
- **For “wedged rock” installation (cord tether):** Loop the 10 gauge copper wire around the boulder connection point and “twist tie” off the copper wire. Pull on the wire loop to test the security of the anchor. If the boulders and anchor seem stable and secure, , attach the nylon cord to the copper wire loop using, figure-eight knots, as described for the tree root/trunk installation (Figure 7-4).

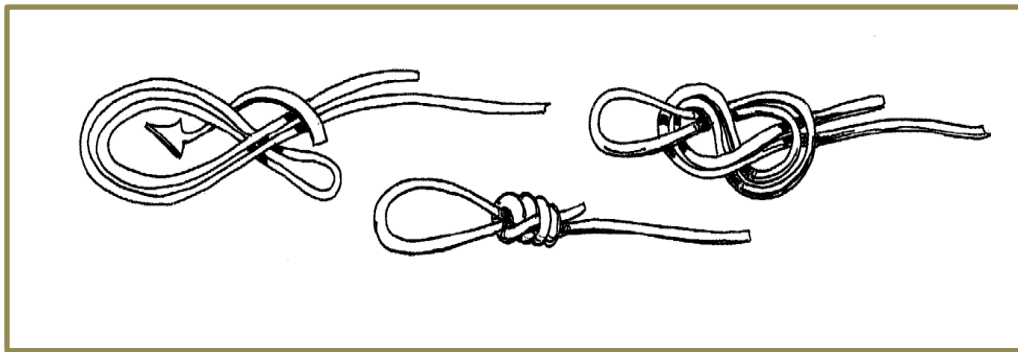
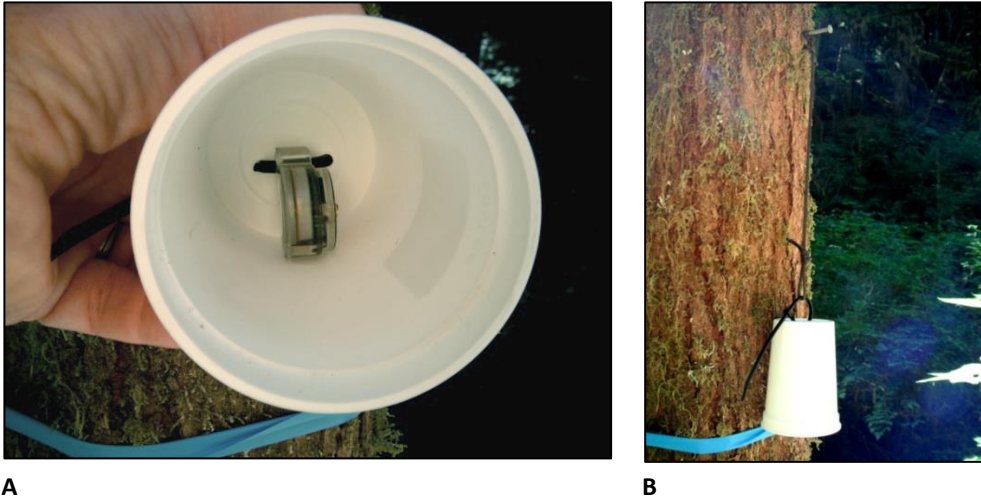


Figure 7-4. Figure-eight knot.

### ***Housing and Attachment for Air Temperature Data Loggers***

Affix the air temperature logger inside an 8 oz (240 ml) #5 white plastic cup to protect the logger from direct sun radiation. Use a nylon cable tie to attach both the cup and the data logger to a surgeon’s loop tied on the end of a nylon cord (Figure 7-5). Optional: each cup should have a sticker label with contact information. If no labels are available, contact information can be written on the outside of the cup with a sharpie marker.

Air temperature loggers should be located close to water temperature data loggers. Attach the air temperature assembly to a branch or nail on the north side of a live conifer tree with full canopy (Lundquist and Huggett 2008). Place the assembly not more than 2.5 m above the stream channel but at least one meter above the ground and within 5 m of the water logger. Branches lower on the bole of the tree will provide better shading year-round.



**A** **B**  
Figure 7-5. Housing (A) and attachment (B) of air temperature logger.

### ***Marking and Referencing the Location of Temperature Data Loggers***

Mark all temperature sampling locations with blue flagging and blue paint. Measure and record the slope distance and azimuth from the top of the RP rebar to the water data logger anchor point (Figure 7-6). Measure and record the slope distance and azimuth from the water temperature data logger anchor point to the air temperature data logger. Take photos of the locations of both loggers. Record the locations and photo numbers on the installation field form (Appendix 7B).

If a logger needs to be moved or is missing and needs to be replaced, take the appropriate action and enter new remarks and notes on the field form (Appendix 7A). Installation in a new location should be recorded in the installation field form (Appendix 7B). Reflag and paint the new location and take a picture of the station.

## Stream Temperature

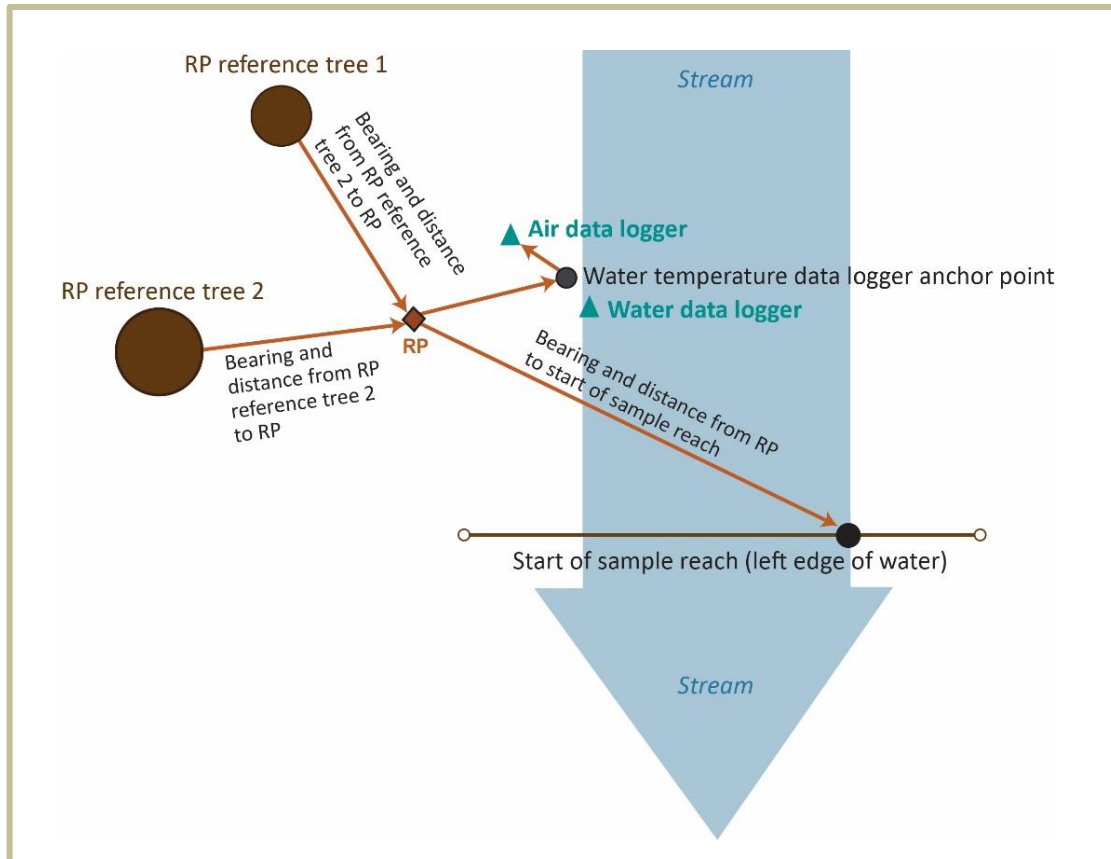


Figure 7-6. Illustration referencing the location of the water temperature data logger anchor point and the air temperature data logger relative to the Reference Point (RP).

## DOWNLOADING PROCEDURES

The full, detailed description of field visit procedures, including downloads and typical maintenance is given in Appendix 7D.

Data from the data loggers are downloaded using an Onset<sup>®</sup> HOBO Waterproof Shuttle and ruggedized field tablet or laptop (weather permitting). The HOBOWare Pro software must be installed on the tablet or laptop before going to the field. For additional information on these electronic devices, such as technical specifications and manufacturer's procedures, see the manuals located on the Onset website:

<https://www.onsetcomp.com/support/manuals>.

## ***Time and Cost Estimates for Implementing the Field Procedures***

Tables 7-2 and 7-3 show the time and cost estimates for implementing the field procedures of the stream temperature protocol.

**Table 7-2. Time Estimates for Implementing the Stream Temperature Field Protocol\***

<b>Procedure</b>	<b>Estimated time per thermistor</b>	<b>Estimated time for all sites</b>
Calibration	10 min	17 h
Installation	20 min	36 h
Download	10 min	18 h

\*Does not include travel time to sites

**Table 7-3. Cost Estimates for the Equipment Used in the Stream Temperature Field Protocol**

<b>Equipment/Supplies</b>	<b>Cost per thermistor</b>	<b>Cost for the project</b>
Onset TidbiT v2 thermistor	\$120	\$12960
Onset data shuttle	–	\$185
Onset HOBOWare Pro software	–	\$80
Miscellaneous hardware	–	\$500

## ***Procedures for Calculating Metrics***

All metrics are calculated in the office following the procedures in Table 7-4.

**Table 7-4. Procedures for calculating metrics**

Metric	Calculation Procedure
Daily maximum and minimum temperatures.	Maximum and minimum temperatures during each 24-hour period beginning at midnight.
Daily temperature range.	Maximum minus minimum temperature for each 24-hour period beginning at midnight.
Mean daily temperature and standard deviation.	Mean of all temperature readings during each 24-hour period beginning at midnight. Standard deviation for temperature readings during each 24-hour period beginning at midnight.
Residuals of measurements for the date.	Sum of the differences between each measurement and the mean for that date, for a selected 24-hour period beginning at midnight.
7-day moving mean of daily maximum measurements and standard deviation.	Sum of daily maximum temperatures for seven consecutive days, divided by seven. Standard deviation of daily maximum for seven consecutive days.
7-day moving mean of daily range and standard deviation.	Sum of daily temperature range for seven consecutive days, divided by seven. Standard deviation of daily temperature range for seven consecutive days.
7-day moving mean of daily 7-day minimum measurements and standard deviation.	Sum of daily minimum temperatures for seven consecutive days, divided by seven. Standard deviation of daily minimum for seven consecutive days.
Minimum and maximum water temperature values and date for the year during the recorded period.	Minimum and maximum values for the year and the date of their occurrence.
Mean water temperature for the year during the recorded period and standard deviation.	Mean of all values for a selected year; standard deviation of all values for a selected year.
Correlation coefficient between water and air temperature.	Pearson's <i>r</i> , calculated using paired air and water temperature readings (i.e., recorded at the same time in the same watershed) within the time period of interest (e.g., season or year).

## Quality Assurance and Quality Control

The field quality assurance (QA) for the stream temperature protocol includes staff training and use of standardized protocols. The field quality control (QC) for the field procedures includes checks to evaluate performance and tests of data logger accuracy.

The QA/QC procedures for data management are described in the Data Management section below.

## TRAINING

All personnel conducting field protocols will be trained in a consistent manner to ensure that the surveys are conducted properly and in standardized fashion. The training is conducted or, in case of returning personnel, reviewed, annually before the start of the field season. At least one member of the field crew should be experienced with the field procedures.

## STANDARD PROTOCOLS

The standard procedures described in this protocol are followed for the duration of the project. Any deviations from the procedures should be documented, and the reasons for deviation described and discussed with the project manager or the researcher overseeing the protocol implementation.

Changes to the published protocols are approved by the project manager or by the researcher overseeing the protocol implementation. Revised protocols will be assigned new version numbers and publication dates.

## TESTING DATA LOGGERS

The accuracy of each data logger should be tested prior to deployment and again after it has been retrieved from the field. Calibration procedures are described in the Equipment and Supplies section above, under the heading *Testing Temperature Logger Accuracy*. The manufacturer-reported accuracy level for the Onset<sup>®</sup> HOBO TidbiT v2 data logger thermistor is  $\pm 0.2^{\circ}\text{C}$ .

## Data Management

### DATA FLOW

Field data are collected in two formats: (1) field notes on paper data forms or tablet PC, and (2) electronic downloads of Onset<sup>®</sup> HOBO TidbiT data loggers. Additionally, photographs taken in the field are archived to document data logger locations, conditions, and data collection methods. This section contains a description of the steps used to process these data from their raw field formats through the quality control stage; the flowcharts in Figures 7-7 and 7-8 provide an overview of the process. Details on long-term data storage and archiving appear in the following section, titled *Data Storage*.

#### *Data flow for paper field forms*

1. **Fill out field forms** The Stream Temperature Monitoring Field Form (Appendix 7A) is used to record all activities related to data loggers: installations, retrievals, downloads, changes in location, reports of missing loggers, or observations such as dewatering events. If a data logger is moved to a new location, a separate installation form is filled out (Appendix 7B).
2. **Scan and store field forms** After returning from the field each week, the field forms are scanned and stored on the WADNR network drive (see *Data Storage* section below); the original paper forms are archived at the Forest WADNR Resources Division.
3. **Enter data** All of the information collected on paper field forms is entered in the stream temperature database by the OESF Data Management Specialist on a weekly basis. The Specialist initials and

dates the bottom of every field sheet entered. The database is then used to facilitate field work planning by producing updated lists of which watersheds need to be visited and of any data logger maintenance needs.

4. **Quality control** Entered field form data are verified by comparing them with the original field forms. The person who verifies the data initials and dates the bottom of each field sheet and writes the word “verified”.

### **Data flow for data logger downloads**

1. **Download data loggers** Temperature data are downloaded from the Onset<sup>®</sup> HOBO TidbiT data loggers in the form of “.hobo” files, a proprietary file format that can be opened only using HOBOWare<sup>®</sup> Pro software (Onset Computer Corp.). TidbiT data loggers are downloaded at least once per year using an optical shuttle (the files on the shuttle are later transferred to a computer), or can be downloaded directly to a tablet field computer or laptop. Each downloaded file is automatically named with the data logger’s serial number (e.g., “10186954.hobo”) unless it has been manually renamed at some point by DNR personnel. At each download, the field crew fills out the Stream Temperature Monitoring Field Form (Appendix 7A) to record each download’s metadata.
2. **Store raw data files** After returning to the office, a member of the field crew transfers all downloaded .hobo files to a temporary location on the WADNR network drive:

J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\07\_Data management\\_All new data and photos\

3. **Export files** Using HOBOWare<sup>®</sup> Pro software, the data from all of the .hobo files are batch exported to comma-separated-variable (.csv) format files. (*Note:* steps 3 through 5 of this procedure are also described in detail within the Stream Temperature database. From the main menu, click the button titled “Data Import Form”)
4. **Combine files** To facilitate the process of importing the data to the database, all .csv files are merged into a single .csv file using the R script “Temp\_Combine\_Files.R”.
5. **Import data to database** Using the buttons on the Data Import Form in the Stream Temperature Database, the data in the merged .csv file are imported to the database.
6. **Quality control** A series of quality control inspections are performed (Figure 7-8). The results of the quality control inspections are recorded in the database, and the data are assigned a data quality level based on the completion of various quality control steps (Table 7-5). After an initial series of automated data quality checks, data are assigned the “Level 1: Provisional” quality level. After completion of all quality control steps, data are assigned the highest quality level, “Level 2: Published”. At this level, every record in the dataset is flagged as one of the following: accepted, rejected, estimated, or missing. Data are now ready for analysis and sharing.



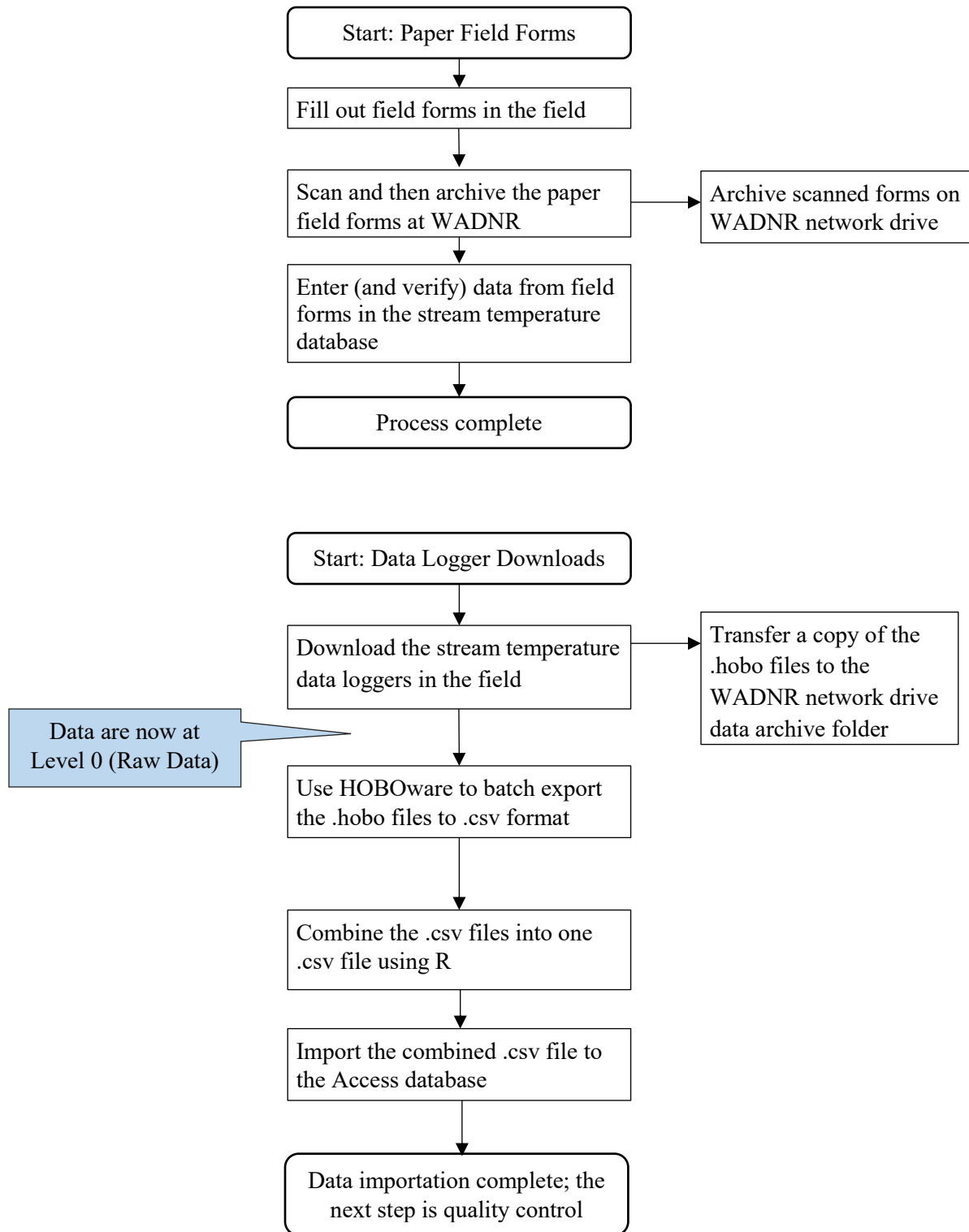


Figure 7-7. Data flow for field forms and data logger downloads.

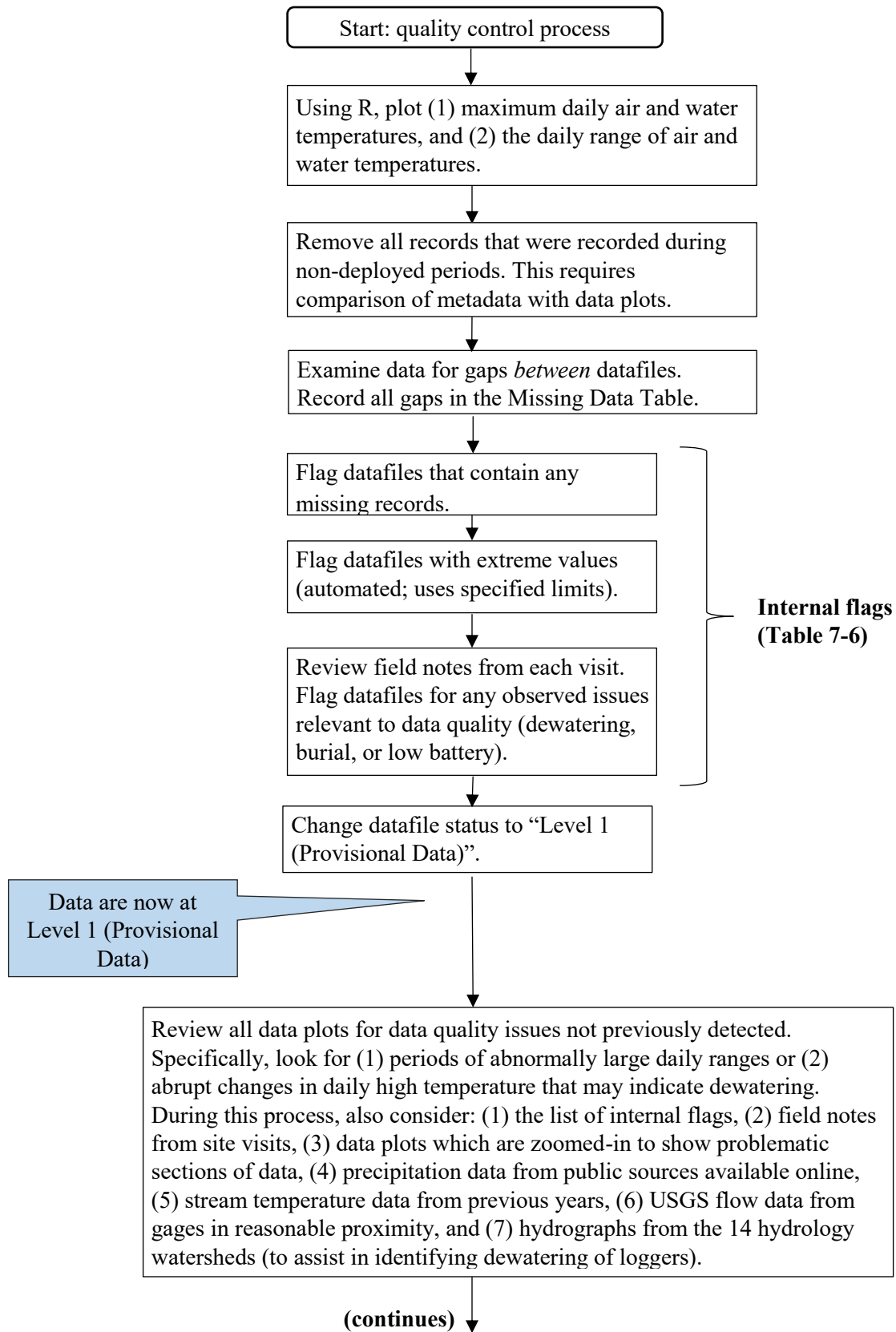


Figure 7-8. Quality control process for stream temperature data.

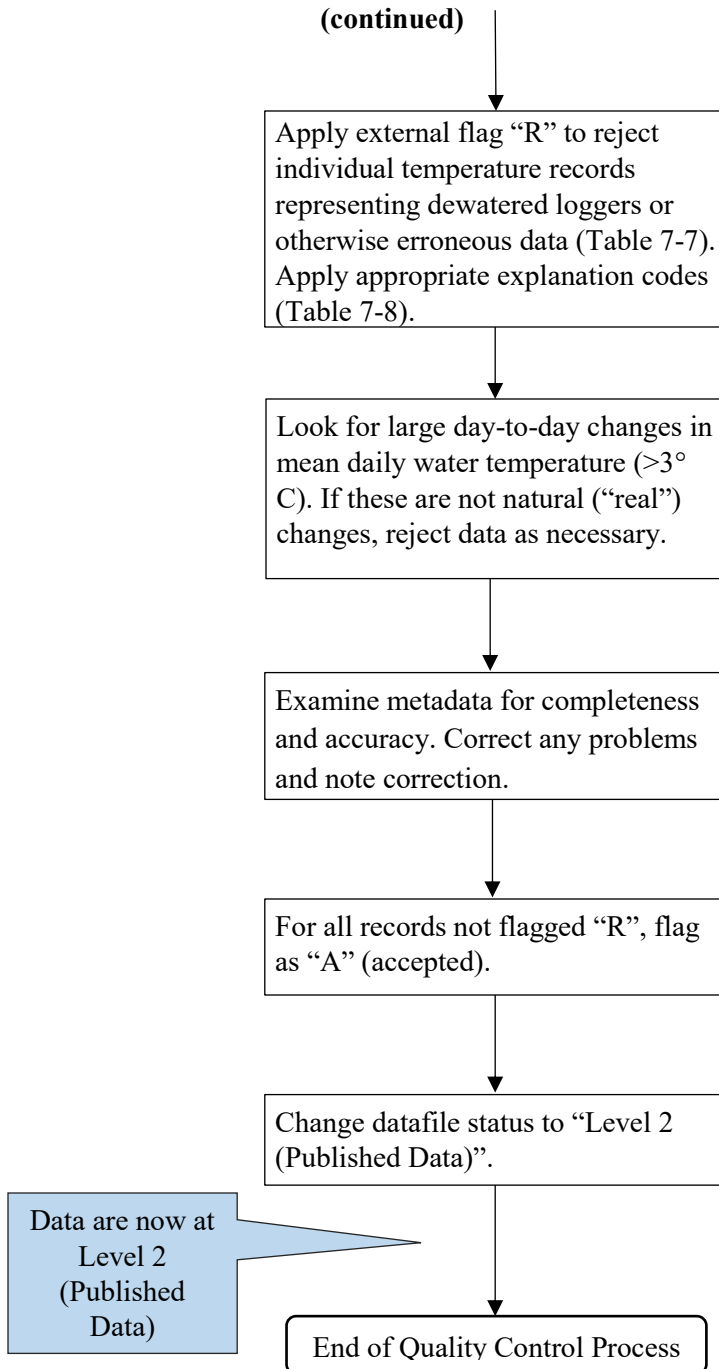


Figure 7-8. continued.

**Table 7-5. Data quality levels for monitoring data collected using electronic data loggers on the OESF.**

Data Quality Level	Description
0: Raw	Unprocessed data. No QC checks have been applied, and no flagging has been added. These data are archived as raw files produced by data loggers.
1: Provisional	Data have been imported to a database. Checks for completeness (e.g., data gaps within or between datafiles) as well as automated QC checks have been performed, and datafiles have been flagged at the file level if any quality checks are not passed successfully.
2: Published	All QC checks, both automated and manual, have been completed, and any potential problems in the data have been evaluated and resolved. Flags for any problematic data points are applied at the individual-record level. All metadata is verified as complete and accurate. Data at this level are unlikely to change in the future.

**Table 7-6. Internal data quality flags. These are used for quality control and data management purposes only; they are not released with published data.**

Internal Flag	Description
Extreme	File contains extreme value(s) above or below a specified threshold.
Dewatered	File contains data from a dewatered logger.
Buried	File contains data from a logger buried in sediment.
Missing_data	File contains missing data anywhere between its first and last records. This flag is not used for gaps that occur between datafiles.
Battery	Battery low (for TidbiT loggers, the minimum acceptable value is 2.7 V).

**Table 7-7. External data quality flags. These flags are associated with individual data records rather than datafiles. They reflect the final conclusions after all of our quality control checks are completed.**

External Flag	Description
A	Accepted. Data record passed all QC checks necessary to attain “Level 2: Published” status.
R	Rejected. Data record failed Quality Control and should not be used in analysis.

**Table 7-8. Explanation codes to identify reasons for data rejection. If an individual data record is flagged as R, it must also be coded with one of these explanation codes in the Level 2 (Published) data.**

Explanation Code	Description
D	Dewatered. Stream temperature logger was determined to have been dewatered at the time data were recorded.
B	Buried. Stream temperature logger was determined to have been buried in sediment at the time the data were recorded.
X	Extreme value. An extreme value, not associated with a dewatering or burial event, was determined to be an erroneous measurement.

### **Photographs**

All digital photographs taken to document stream temperature monitoring will be stored on the WADNR server at: J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\03\_Photos and videos\03\_Temperature\

Typically each watershed will have two photograph files: one each for air and water data loggers. Each photograph file will be labeled with the watershed number and the type of logger that the photo is documenting (AT for air temperature and WT for water temperature) using the following format:

<Type>\_<WatershedID>\_<Date taken>\_<Original photo number> (for example:

WT\_584\_20130623\_P1010238.jpg).

## DATA STORAGE

### *Raw Data Archives*

The raw data consist of paper field forms and electronic data files. The paper field forms are archived at the Washington Department of Natural Resources Forest Resources Division. The designated data steward is Teodora Minkova, WADNR. Scanned copies of these forms are saved in the Adobe portable document format (.pdf) in the following directory:

```
J:\hcp\monitoring_research\tminkova\01_OESF_R&M Program\01_Rip S&T Mon\01_FIELD  
DATA\03_Temperature\Data\Archived data\Field_Forms\
```

After the data have been batch exported to .csv format using HOBOWare Pro, the electronic .hobo datafiles are saved on the WADNR network drive at:

```
J:\hcp\monitoring_research\tminkova\01_OESF_R&M Program\01_Rip S&T Mon\01_FIELD  
DATA\03_Temperature\Data\Archived data\Downloads_Hobo\
```

At the end of each field season, all of the archived data files from that season should be checked for completeness as well as accuracy of file names. These files will be archived together with a report containing all metadata. The metadata report will be produced by Microsoft Access, and will include the following information for each data file:

- Watershed number
- Narrative description of logger location
- Distance and azimuth of water temperature data logger from the site reference point
- Distance and azimuth of air temperature logger from water temperature data logger
- Latitude and Longitude (with datum)
- Data logger type (Manufacturer and model; e.g., Onset<sup>®</sup> HOBO TidbiT v2)
- Data logger serial number
- Download date
- Date range (record begin and end date and time)
- Person who downloaded the data

### *Stream Temperature Database*

All of the temperature monitoring data, including data collected on field forms and by data loggers, is stored in a Microsoft Access database (.accdb) on the WADNR network drive (Olympia, WA) at:

```
J:\hcp\monitoring_research\tminkova\01_OESF_R&M Program\01_Rip S&T Mon\01_FIELD  
DATA\03_Temperature\Data\Temperature_Database.accdb
```

In addition to providing long-term storage of data, this database is used to produce reports and lists needed to facilitate field work, to create data summaries, and to prepare and export datasets for analysis by statistical software.

Within the stream temperature database, data are organized into a series of tables (illustrated in Figure 7-9 and detailed in Appendix 7C), based on the type of data, its structure, and its intended use. The primary tables in the database are:

1. **Logger Location Table:** This table contains information about each monitoring location, including the date it was initially established as well as details on the logger's current location, such as distance and azimuth from a reference point and type of anchor. Data come from entries recorded on field forms when loggers are installed, and from field forms that are filled out when loggers are moved to a new location within a watershed (Appendix 7A and Appendix 7B).
2. **Logger Download Table:** This table is used to document each data logger download; it includes the downloaded file name, date and time of download, field crew, and logger type and serial number. The source of the data in this table is the Stream Temperature Monitoring Field Form.
3. **Logger Maintenance Table:** This table is used to document data logger maintenance activities other than downloads. These activities are installation, retrieval, movement of a logger to a new location within a watershed, observation of a logger's condition, or the discovery of a missing logger. Fields in this table include date and time of visit, field crew, logger type and serial number, and photo information. The source of the data in this table is the Stream Temperature Monitoring Field Form.
4. **Data Quality Table:** This table contains information describing the quality of each downloaded data file. It documents any potential problems with the logged temperature data (e.g., dewatering or data gaps) and also is used to record the data quality level. The table is filled out during the quality control process.
5. **Temperature Data Table:** This is the table in which all of the downloaded water and air temperature data are stored. The table also contains external flags indicating the status of every record (accepted or rejected). Before data are added to this table, the source datafile is already documented in the Logger Download Table.
6. **Thermometer Temperature Table:** This table stores all of the thermometer readings that were taken manually in the field as part of an earlier, discontinued quality control process. This table includes the location, date, and time of each thermometer record. Data are entered from the temperature records on the field forms. The source of the data in this table is the Stream Temperature Monitoring Field Form.
7. **Missing Data Table:** This table is used to record gaps in the data stream that occur between datafiles. Unlike gaps within datafiles, which are associated with specific files, gaps between datafiles are not associated with the files but rather with a logger location (e.g., watershed 584 water logger). Entries in this table are recorded manually during the quality control process.



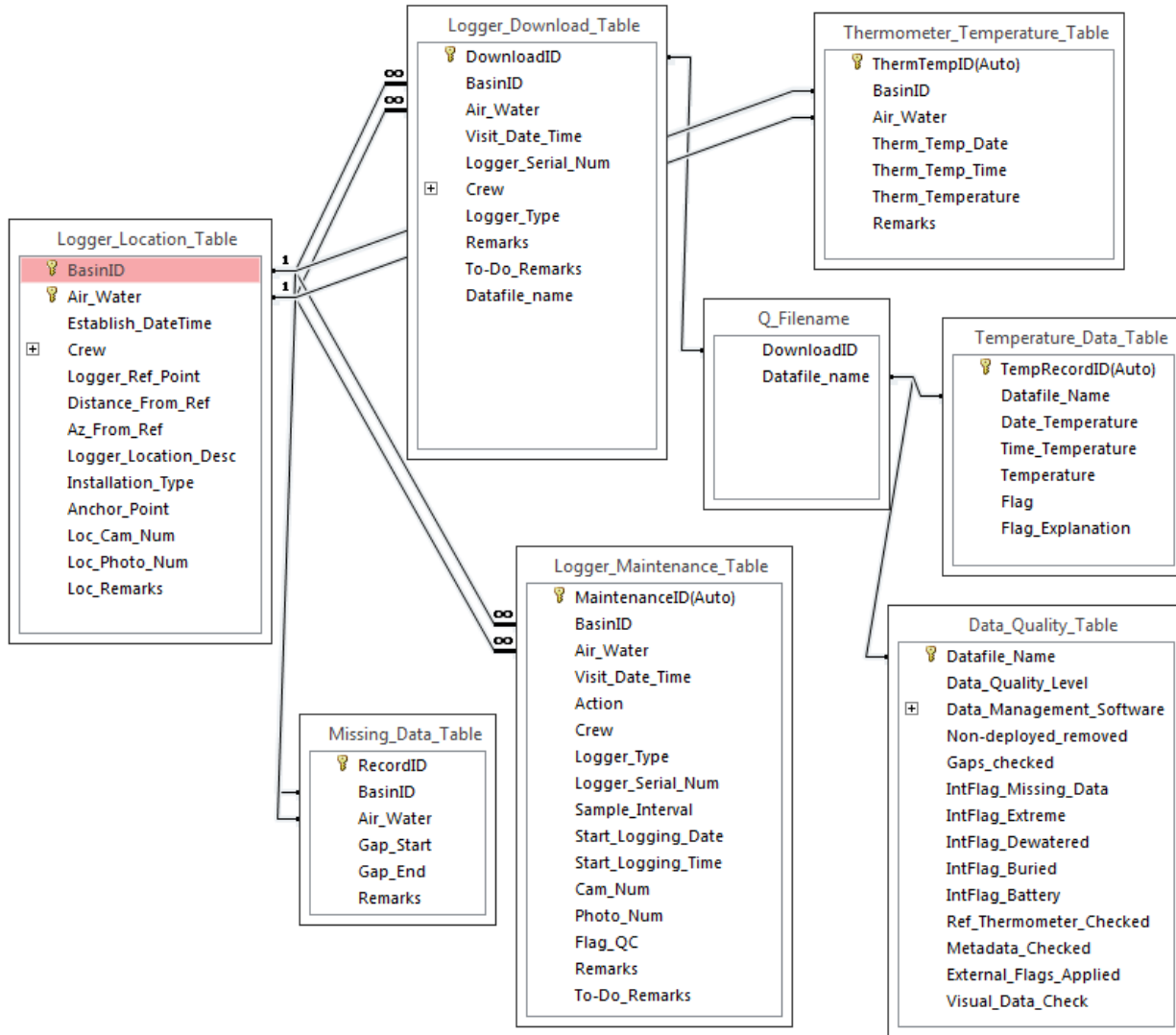


Figure 7-9. Primary tables and relationships in the Stream Temperature Database.

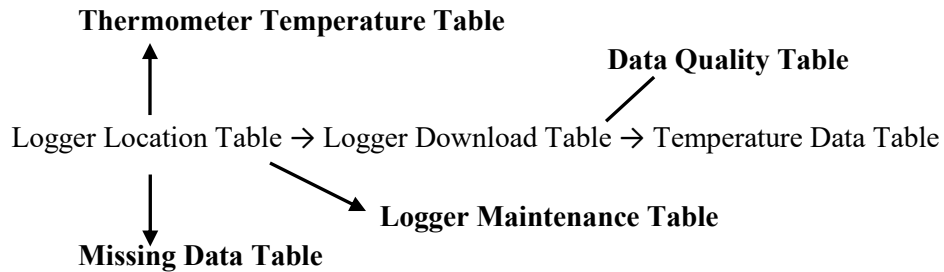
These tables are linked to one another through a series of relationships. The core of the database consists of three related tables:

**Logger Location Table → Logger Download Table → Temperature Data Table**

The first two tables are connected through a one-to-many relationship, with the arrow above pointing toward the “many” side. Each of the 108 logger locations is related to multiple download records in the Logger Download table. The Logger Download Table is related to the Temperature Data Table through a query that builds the datafile name from various fields within the Logger Download Table. Each logger download record is then related to many records in the Temperature Data Table that bear the same filename. This structure associates every temperature record with all of the metadata from the download, such as logger type

and serial number, crew, and date of site visit. Every hourly temperature record is also associated with the logger location information in the Logger Location Table.

In addition to these three core tables, there are four other related tables in the database, shown here in bold type:



The Data Quality Table is related to the Logger Download Table in a one-to-one relationship (via a query): each download record in the Logger Download Table is associated with a record in the Data Quality Table that contains the quality control information associated with all of the data within that datafile. The Logger Location Table is related to the Logger Maintenance Table in a one-to-many relationship. Each logger location is associated with multiple maintenance visits, each of which is documented by a record in the Logger Maintenance Table.

The Thermometer Temperature Table is related to the Logger Location Table (in a one-to-many relationship) because it contains manual temperature measurements taken at the air and water logger locations. (Because the manual temperature measurements were typically made at a point in time between two datafiles, the manual temperature measurements are not directly associated with individual datafiles or loggers.) The Missing Data Table is related to the Logger Location Table through a one-to-many relationship because it documents all occurrences of missing data at a given logger location (i.e., gaps in the data stream between datafiles).

## DATA PRODUCTS

The stream temperature database contains various queries designed to facilitate field work planning, to perform data quality control checks, to create data summaries, and to export data for statistical analysis by other software. Often, these queries are used to create reports. Examples of database products include:

### Field Work Planning:

- A report containing a list of watersheds that have not yet been visited during the current field season, showing the last time each of the data loggers was downloaded.
- A report containing a “to do” list based on the “to do” items that were noted on field forms during the field season.
- A report of all water data loggers that became dewatered during the past season, and the date range of when they were dewatered.

## ■ Stream Temperature

### **Data Management:**

- A query that lists any missing metadata for each of the datafiles.
- A query to produce the metadata report that is required for annual archiving of logger data files.

### **Data Summaries:**

- Summaries of basic water temperature metrics listed in Table 7-1 of this protocol, such as mean daily stream temperature, daily temperature range, and daily maximum and minimum temperatures, by watershed.
- A list of all occurrences when stream temperature exceeded a threshold value during the past summer (excluding dewatering events). The database can also create a temperature versus time plot of all such events.

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## Appendix 7C. Tables in the Stream Temperature Database

Logger Location Table		
Field	Field description	Selectable choices
BasinID	Watershed number, or name (in the case of the reference watersheds).	Select watershed ID from a list of watersheds.
Air_Water	Logger function: either 'Air' or 'Water'.	Air / Water
Establish_DateTime	Date and time on which logging initially began in this watershed.	
Crew	Crew who established the current logger location.	Select one or more from personnel list
Logger_Ref_Point	Reference point: usually watershed reference point (RP) is ref. for Water, and Water is ref for Air.	Watershed RP / Water Logger Location / <enter other value>
Distance_From_Ref	Current logger location's distance from reference point (meters).	
Az_From_Ref	Current logger location's azimuth from reference point (degrees).	
Logger_Location_Desc	Description of the current logger location.	
Installation_Type	For water loggers: record current type of installation.	Epoxy mount / cord tether
Anchor_Point	Type of anchor point currently used.	
Loc_Cam_Num	ID number of camera used to photograph current logger location.	
Loc_Photo_Num	Photo number for the photo of the current logger location (hyperlinked to the photo file in .jpg format).	
Loc_Remarks	Notes on the logger location.	

Logger Download Table		
Field	Field description	Selectable choices
DownloadID	Auto numbered record ID	
BasinID	Watershed number, or name (in the case of the reference watersheds).	Select watershed ID from a list of watersheds.
Air_Water	Logger function: either 'Air' or 'Water'.	Air / Water
Visit_Date_Time	Date and time of visit (PST).	
Crew	Field crew members.	Select one or more from personnel list.
Logger_Type	Default logger type is set to "Tidbit (UTBI-001; Onset)".	Currently Tidbit is only option.
Logger_Serial_Num	Serial number of data logger.	
Remarks	Comments that do not require any further action (e.g., "Installed epoxy mount on underside of boulder in same pool as it was previously located").	
To-Do_Remarks	Issues that need to be addressed either in the office or field; used to create "to do" list.	
Datafile_name	Datefile name, updated from the query that constructs the name. It is included here because it simplifies some of the quality control forms.	

Logger Maintenance Table		
Field	Field description	Selectable choices
MaintenanceID(Auto)	Auto numbered to provide every record with a unique ID.	
BasinID	Watershed number, or name (in the case of the reference watersheds).	Select watershed ID from list of watersheds
Air_Water	Logger function: either 'Air' or 'Water'.	Air / Water
Visit_Date_Time	Date and time of visit (Pacific Standard Time).	
Action	Type of action taken.	Install / Retrieve / Report Missing / Move / Observe Condition
Crew	Field crew members.	Select one or more from personnel list.
Logger_Type	Default logger type is set to "Tidbit (UTBI-001; Onset)".	Currently Tidbit is the only option.
Logger_Serial_Num	Serial number of data logger.	
Sample_Interval	Sample interval length in minutes.	60 / 80 / <enter other value>
Start_Logging_Date	Date on which logger is set to start recording (if using delayed start).	
Start_Logging_Time	Time at which logger is set to start recording (if using delayed start) (Pacific Standard Time).	
Cam_Number	ID number of camera used.	
Photo_Number	Photo number of photo taken to document action (hyperlinked to the photo file in .jpg format).	
Remarks	Comments that do not require any further action (e.g., "Installed epoxy mount on underside of boulder in same pool as it was previously located").	
To-Do_Remarks	Issues that need to be addressed either in the office or field; used to create "to do" list.	

<b>Data Quality Table</b>		
<b>Field</b>	<b>Field description</b>	<b>Selectable choices</b>
Datafile_name	Name of download file.	A list of datafile names is automatically created from the names in the Logger Download Table.
Data_Quality_Level	Data Quality Level.	Level 0 (Raw Data) / Level 1 (Provisional) / Level 2 (Published)
Data_Management_Software	Program(s) used to inspect, clean, and prepare the data prior to importing it into the stream temperature database.	HOBOWare Pro / Excel / R / <enter other program>
Non-deployed_removed	Data recorded during non-deployed status have been removed.	No / Yes
Gaps_checked	Gaps between datafiles checked and recorded in Missing Data Table.	No / Yes
IntFlag_Missing_Data	Records missing within the datafile.	No / Yes
IntFlag_Extreme	Extreme values present in the datafile. Extreme values are defined for water loggers as <-1 degree C or >20 degrees C.	No / Yes
IntFlag_Dewatered	Remarks indicate logger was dewatered.	No / Yes
IntFlag_Buried	Remarks indicate logger was buried.	No / Yes
IntFlag_Battery	Flag is battery went below 2.7 V for any period of time during data collection.	No / Yes
Ref_Thermometer_Checked	Have all reference thermometer readings been checked against the logger data?	No / Yes
Metadata_Checked	Were metadata checked for completeness and accuracy?	No / Yes
External_Flags_Applied	Were all records flagged with an external flag?	No / Yes
Visual_Data_Check	Was a plot of the data (daily max. temperature vs. time and daily range vs. time) visually inspected for potential data problems?	No / Yes

Temperature Data Table		
Field	Field description	Selectable choices
TempRecordID(Auto)	Auto numbered to provide every temperature record with a unique ID.	
Datafile_Name	Name of datafile.	
Date_Temperature	Date of temperature record.	
Time_Temperature	Time of day of temperature record (Pacific Standard Time).	
Temperature	Recorded temperature (°C).	
Flag	External flag applied to every record (accepted, missing, rejected, or estimated).	A / R
Flag_Explanation	Explanation of why record was rejected, applied to R records (dewatered, buried, extreme value).	D / B / X

Thermometer Temperature Table		
Field	Field description	Selectable choices
ThermTempID(Auto)	Auto numbered to provide each temperature record with a unique ID.	
BasinID	Watershed number, or name (in the case of the reference watersheds).	
Air_Water	Logger function: either 'Air' or 'Water'.	Air / Water
Therm_Temp_Date	Date of reading.	
Therm_Temp_Time	Time of reading (Pacific Standard Time).	
Therm_Temperature	Water or air temperature, measured by thermometer (degrees °C).	
Remarks	Remarks.	



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<b>Missing Data Table</b>		
<b>Field</b>	<b>Field description</b>	<b>Selectable choices</b>
RecordID	Auto numbered to provide each record with a unique ID.	
BasinID	Watershed number, or name (in the case of the reference watersheds).	
Air_Water	Logger function: either 'Air' or 'Water'.	Air / Water
Gap_Start	Date/time of the first missing record in the data gap.	
Gap_End	Date/time of the last missing record in the data gap.	
Remarks	Remarks.	

## Appendix 7D. Field Procedures for Data Logger Download and Maintenance

### EQUIPMENT LIST

- Onset TidbiT v2 data loggers (spares, with voltages of 2.96 v or higher)
- Onset HOBO Pro v2 Temp/RH data loggers (spares, with battery voltage at 100%)
- Field Tablet with Onset HOBOWare Pro software installed
- Tablet charger
- Photos of temperature logger locations from past two years (saved on tablet)
- List of all previous download records (86+ pages; printed version and electronic version saved on tablet)
- Onset HOBO Waterproof Shuttle
- Shuttle adapter (“coupler”) for Tidbit data loggers (black piece on end of shuttle)
- Shuttle adapter (“coupler”) for HOBO Pro Temp/RH data loggers (black piece on end of shuttle)
- Cable for shuttle (mini-USB to USB cable)
- USB 3.0 to 2.0 adapter to fit tablet, to connect tablet to the shuttle USB cable
- Field datasheets on Rite-in-Rain paper (see Appendix 7A; use version of datasheet at the link in Appendix)
- Camera & charger
- Collapsible shovel
- PVC housings (pre-drilled 1.5 inch diameter (43 mm) #80 PVC pipe cut to 6 cm long (see fig. 7.2B))
- Bricks (bring 2 or 3 in truck, carry 1 per basin; see fig. 7.2B)
- Spool of nylon cord (size No. 72 tar-coated nylon braided cordage)
- Cable ties (“zip ties”) - 8 inch (20 cm)
- Copper wire, 10 gauge (spool)
- Plastic cup shade devices for air loggers (pre-drilled 8 oz (240 ml) #5 white) (see fig. 7.5)
- Wire cutter/pliers
- Adjustable, prefabricated, or 1-inch open end wrench (for installing/removing caps on epoxy mount installations)
- Nails (No. 10 hot dipped galvanized; can also be used for epoxy mount cap removal)
- Blue spray paint
- Blue flagging
- Multi-tool or knife
- Lighter (used to melt the tips of the cordage to prevent fraying)

### FIELD PROCEDURES

#### *Finding the temperature logger locations*

- Loggers are installed within the stream sample reach. In each sample reach is a pair of loggers (water and air temperature) located near one another. Logger locations are both marked with blue paint and flagging. Be aware that in a few cases loggers had to be moved in the past so you might see traces of blue paint from a former location.

## ■ Stream Temperature

- Whenever conditions permit, the temperature loggers are located near the basin reference point (“RP”), which should be on the Garmin GPS. However, often loggers are installed farther up the sample reach at is the nearest suitable location.
- If the RP is not on the GPS for some reason, or if you don’t see it, then look along the reach for the blue flagging and paint, beginning at the lower end of the reach (cross-section A).
- Read the past field notes (in the 86+ page document) to learn more about a particular logger’s location. Often loggers had to be moved, owing to changing streambed conditions, so pay attention to the most recent location description and photos.
- If you still can’t find a logger, use the logger location photos saved on the tablet. These usually show the specific location, and landmarks (boulders, trees, logs) can be seen in the photos.


### *Document condition*

- All logger downloads, maintenance, replacements, etc. are documented on a paper field form. If doing more than one thing to a logger (i.e., more than just a download), use multiple lines on the field form.
- Before you move, extract, or do anything with the water logger, document its location/condition as found by taking a picture or two of the water logger as you found it, from a distance of 4 to 6 feet away. If the logger is well submerged and not visible from above the surface, then just take a photo of the area where it is submerged. Some loggers will be buried in sediment; in that case, a photo of the burial location is fine. These photos are very helpful in determining the cause of anomalies in the temperature data. Note photo number on the field sheet.
- Record notes on the field sheet if there is anything noteworthy about how you found a logger. For example, “Logger found out of water, 6 inches above water surface.” Or “Logger was found buried 4 inches deep in gravelly sediment” or “Logger found under large cobbles and silt.”
- No photos are needed of air temperature loggers, unless the logger or plastic cup is damaged. If it has, just take a picture of its condition as you found it.

### *Extracting and downloading loggers*

To extract the logger for download, cut the cable ties or, in the case of epoxy mount enclosures, unscrew the cap, using a nail or other object if necessary. For tethered loggers, check the cord and housing for damage or abrasion and replace it if necessary. Gently clean the temperature logger optical contacts with a soft, wet cloth or soft, bristled brush to remove any biofouling or sediment that may affect the logger’s ability to communicate during the downloading process. Be careful to not scratch the logger optic communication area.

1. Connect shuttle to tablet via the adapter and the USB-to-mini-USB cable.
2. Insert the cleaned and dried-off data logger securely into the adapter/coupler so that the logger LEDs face the shuttle. Because the communication is optical, do the next step out of direct sunlight on sunny days.
3. Open the HOBOWare Pro application.
4. Press down the black plastic lever on the shuttle so that it momentarily touches the shuttle body.
5. The amber LED blinks momentarily; in a few seconds the green LED should glow steadily to indicate that the logger is ready to communicate with HOBOWare. (If the red LED blinks instead, the logger was not found. Make sure the logger and coupler are aligned and seated properly, and that there is no dirt or strong sunlight interfering with communications.)

6. Click the Readout icon  on the toolbar or select Readout from the Device menu. Because the logger is logging, and we don't want to stop it, click the "DON'T STOP" button in the window that pops up.
7. A progress bar displays while the data is being read out. Once the readout is complete, save the file on the tablet in a location of your choice (desktop works fine). Leave the file name as it is. If a Plot window pops up, hit "Cancel".
8. From the Device menu, choose "Status...". In the Current Readings portion of the Status window, the loggers battery voltage is listed. Record this on the datasheet. If a TidbiT's battery is 2.94 v or lower, it must be replaced (see below). NOTE: Replace TidbiT air temperature loggers with HOBO Pro Temp/RH loggers; replace water temperature loggers with TidbiT data loggers.
9. It is now OK to disconnect the logger. Its occasionally flashing LED indicates that it is still logging.
10. Fill out a line on the field form to document the logger download.
11. Re-install the logger into its assembly using cable ties, and return the assembly to its location. (If epoxy-mounted, return logger to mount.)

### ***Replacing missing or low-battery loggers***

**Missing loggers:** In some cases water temperature loggers will have been lost during winter high flows. Often you will see a frayed or broken cord where this has happened. If the logger has been lost, walk down the stream to the confluence and back to see if you can find the brick/logger assembly anywhere in the streambed. If you find the lost logger, download it and then repair/replace the assembly and re-attach it to its anchor point. If you cannot find the lost logger, build a new assembly with a new (launched) logger and attach it to the anchor point. It is unlikely that an air temperature logger will be lost, but if it is, it will also need to be replaced with a new assembly on the north side of the same tree it was previously on. On the field sheet, when you replace a missing logger, you will need to enter two rows: one for Not Found and one for Install (with the new logger's serial number and other info).

**Low-battery:** When you are checking the logger's battery voltage, if a TidbiT's voltage is 2.94 volts or lower, the logger should be replaced. For the logger you are removing, tie a flag to it labeled "low battery" so it won't get mixed up with the other spares, and bring it back to the office. Replace the low-voltage logger with a new (launched) logger and re-install as usual. On the field sheet, when you download and replace a low-voltage logger, you will need to enter three rows: one for Download, one for Retrieve, and one for Install (with the new logger's serial number and other info).

### ***Repositioning loggers***

If the water logger was found well-submerged in water and does not appear to have moved from the location in which it was installed, then it should be re-installed where found, after it is downloaded. If the water logger appears to have moved from its original location during winter high flows, then replace it in the stream using the guidance from the Sampling Site Selection subsection of the Field Procedures section in the Stream Temperature Protocol. In general, loggers are installed in deep pools so that during very low summer stream flows, they will not become dewatered. Often, a logger is protected by several large cobbles laid around and on top of them. However, it is important that water circulates around the loggers. Thus, loggers should not be positioned so that they would be likely to become buried in the streambed sediment.

■ Stream Temperature

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# Stream Discharge

*Authors:* Rachel LovellFord, Ellis Cropper, Jeff Ricklefs, and Jeff Keck

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*Revision History:*

Version number	Purpose / Changes	Author(s)	Reviewer(s)	Publication Date
1.0	Initial draft presented to project staff	Jeff Ricklefs	Teodora Minkova, Alex Foster	04/02/2013
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1.2	Initial draft including detailed field procedures	Rachel LovellFord, Jeff Ricklefs, Ellis Cropper	Teodora Minkova, Jeff Ricklefs	10/10/2013
1.3	Final draft including detailed field procedures	Rachel LovellFord, Ellis Cropper, Jeff Ricklefs	Teodora Minkova	05/16/2016
1.4	Final technical review and edit	Rachel LovellFord, Ellis Cropper, Jeff Ricklefs	Paul Dunnette, Warren Devine, Alex Foster	12/18/2016
1.5	Minor edits and addition of channel geometry survey procedures and field notebook forms	Jeff Keck	Warren Devine	11/17/2022

*Based on the Following Protocols (in order of importance):*

Turnipseed, D., Sauer, V. 2010. Discharge measurements at gaging stations: U.S. Geological Survey Techniques and Methods book 3, chap. A8, 87 p.

Le Coz, J., Renard, B., Bonnifait, L., Branger, F., Le Boursicaud, R. 2014, Combining hydraulic knowledge and uncertain gaugings in the estimation of hydrometric rating curves: A Bayesian Approach, Journal of Hydrology, Vol. 509, pp.573-587

Benson M.A., Dalrymple, T., 1967. General field and office procedures for indirect discharge measurements, Techniques of Water-Resources Investigations of the United States Geological Survey, bk. 3, ch. A1

Dalrymple, T., Benson, M.A. 1968. Measurement of peak discharge by the slope-area method: U.S. Geological Survey Techniques of Water-Resources Investigations, bk 3, ch. A2, 12 p.

Kenney, T.A. 2010. Levels at gaging stations: U.S. Geological Survey Techniques and Methods 3-A19, 60 p.

Butkus, S. 2007. Quality Assurance Monitoring Plan Streamflow Gaging Network. Environmental Assessment Program, Washington State Department of Ecology, Olympia, WA. Pub. No. 05-03-204. [www.ecy.wa.gov/biblio/0503204.html](http://www.ecy.wa.gov/biblio/0503204.html)

Bouwes, N., J. Moberg, N. Weber, B. Bouwes, S. Bennett, C. Beasley, C.E. Jordan, P. Nelle, M. Polino, S. Rentmeester, B. Semmens, C. Volk, M.B. Ward, and J. White. 2011. Scientific protocol for salmonid habitat surveys within the Columbia Habitat Monitoring Program. Prepared by the Integrated Status and Effectiveness Monitoring Program and published by Terraqua, Inc., Wauconda, WA. 118 p.

Pleus, A. 1999. Method Manual for Wadeable Stream Discharge Measurement. NW Indian Fisheries Commission; Timber, Fish, & Wildlife Monitoring Program. TFW-AM9-99-009.

Adams, K. 2010. Quality Assurance Monitoring Plan; Ambient Biological Monitoring in Rivers and Streams: Benthic Macroinvertebrates and Periphyton. Washington State Department of Ecology. Publication No. 10-03-109

***Reasons to Adopt the Above Protocols:***

Turnipseed and Sauer (2010), Kenney (2010), Benson and Dalrymple (1967) and Dalrymple and Benson (1968) describe USGS stream flow measurement protocols. The USGS stream flow protocols are generally regarded as both high quality and well-reviewed. Le Coz et al. (2014) is a newer, widely applied method for combining direct observations with indirect, hydraulics-based flow measurements and was published in the *Journal of Hydrology*, a reputable, peer-reviewed journal. Direct and indirect flow measurements described in this protocol follow USGS protocols where feasible, given the remote nature of the project sites and limited budget. Bouwes et al. (2011) provides additional insight and specifications from a long-running monitoring program with similar budget and monitoring goals. Butkus (2007) also offers guidance on measurements and management of gaging stations.

***Purpose and Content:***

This protocol details the field procedures and field quality assurance steps necessary to document and report the status and trends of stream discharge across the Olympic Experimental State Forest (OESF). Described herein are methods for measuring discharge, installation and configuration of water level sensors to record stage height at set intervals, installation of staff gages, and the general maintenance and tracking of the accuracy of the gaging stations (water level sensors plus staff gage). A separate protocol chapter titled *Stream Discharge Data Management and Analysis* describes data management, rating curve development, hydrograph creation, and data quality control procedures.



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## Introduction

Stream discharge, or stream flow, is the flow rate of water in a stream channel. Stream flow quantity and timing are critical components of water supply, water quality, and the ecological integrity of river systems (Poff et al. 1997). Stream discharge is an important determinant of aquatic habitat conditions because it affects channel morphology, concentrations of chemical elements such as dissolved oxygen, and distribution of habitat elements such as in-stream large wood. The life histories of many aquatic species are dependent on stream flow regimes. For example, adult salmon distribution (Mitchell and Cunjak 2007) and juvenile coho survival and growth (Hartman and Scrivener 1990; Holtby and Hartman 1982) are strongly influenced by stream flow.

Timber harvests may, in some situations, influence stream flow dynamics for a period of 10 to 20 years after harvest in coastal Pacific Northwest watersheds (Moore and Wondzell 2005). In small headwater watersheds, harvesting has been observed to increase peak flows (periods of maximum discharge usually associated with storm events) and to reduce the severity of summer low flows (Moore and Wondzell 2005). Logging roads may intercept overland and surface runoff thus effectually increasing the drainage network, leading to increased peak flows (Negishi et al. 2008; Wemple et al. 1996; Wemple and Jones 2003). Prior to modern ecological forestry with riparian conservation measures, extensive clearcutting was shown to increase peak discharges by as much as 50% in small watersheds and as much as 100% in large watersheds (Jones and Grant 1996).

In the environmental impact analysis for the Olympic Experimental State Forest (OESF) Forest Land Plan, peak flow was recognized as important indicator for fish habitat and riparian areas (WADNR 2016). Because empirical data on peak flows was not available at the time of the analyses, this indicator was assessed via analysis of the proportion of hydrologically immature forests in a watershed.

## Monitoring Design

### MONITORING APPROACH

For this project, stream flow is measured through permanent gaging stations installed in a subset<sup>1</sup> of the Status and Trends Monitoring watersheds; each station consists of a sensor that records water level every 15 minutes, and a staff gage. The water level sensor consists of paired pressure transducers, one measuring pressure within the water in which it is submerged and the other measuring only atmospheric pressure (atmospheric pressure must be subtracted from the submerged sensor to convert pressure measured within the water to water level). At each permanent gage location, stream discharge and water level is manually measured in the field repeatedly throughout the year. Channel slope and the geometry of the flow controls (parts of the channel that control the water level) are surveyed at least once per year and after any large storm that significantly alters channel conditions. The manually recorded discharge water level measurements are

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<sup>1</sup> The number of gaging stations has varied over time, between 10 and 14, as changes in the stream channel sometimes cause a sample reach to become unsuitable for monitoring. In such cases the gaging station is moved to a different watershed.

used to build an empirical relation between the discharge and the water level (a direct measurement rating curve). Using established hydraulics formula, the discharge, channel geometry and slope measurements are used to develop a hydraulics-based rating curve (an indirect measurement rating curve). The empirically derived rating curve and channel geometry-based rating curve are combined to create a final rating curve using the BaRatin method (Le Coz et al. 2014). Continuous discharge over time (i.e., a hydrograph) is then calculated using the combined rating curve to convert the time series of water level data to discharge. The hydrograph then is used to characterize channel flow regimes which influence aquatic and riparian habitat conditions within the OESF.

### ***Spatial Sampling Design***

Stream gaging stations were originally established in 14 of the 50 DNR-managed watersheds sampled in the OESF as part of the Status and Trends Monitoring of Riparian and Aquatic Habitat (Figure 8-1). Monitoring at four of these gaging stations was discontinued in 2016 because constant migration of the stream channels made it infeasible to maintain either an observational or channel hydraulics-based rating curve. The alternative—construction of weir-based gaging stations—is beyond the scope of the project.

In the summer and fall of 2019, the pressure sensors from the discontinued watersheds were installed in 4 new watersheds. In contrast to the 10 existing monitoring watersheds, the 4 new watersheds are predominantly (>80%) composed of mature forest that has never been harvested. Any harvest that has taken place in these four watersheds has been near the periphery rather than in the riparian or lower portions of the watersheds. Flow observations in these four “reference” watersheds will be used for comparison with the 10 DNR-managed watersheds for paired-watershed-style analyses. The study design, and specifically the selection of the original set of 14 hydrology watersheds, is described in the 2013 establishment report (Minkova and Vorwerk 2014).

The 10 DNR-managed hydrology watersheds were selected to include a range of watershed sizes, watershed slope, precipitation type, and underlying geology. The 4 reference hydrology watersheds were selected to capture—to the extent possible—the geologic, watershed size, and watershed slope variability. In each watershed, the gaging station is located within the sample reach, near the outlet of the watershed (refer to Figures 1-1 and 1-2 in the Establishment report (Minkova and Vorwerk 2014) for location and layout of the sample reaches).

### **TEMPORAL SAMPLING DESIGN**

During the first water year (the 12-month period from October 1 to September 30) that the gaging station is in operation, a minimum of 8 to 10 discharge measurements that span a range of flow magnitudes is collected (Table 8-1). This observation-based rating curve (refer to the *Stream Discharge Data Management and Analysis* Protocol for details on rating curves) is most accurate when the range of flow magnitudes is as great as possible. The observation-based rating curve accurately predicts discharge for values within the range of measured events. While extrapolation of discharge beyond the highest measured flow should be done with great caution, the accuracy of such extrapolation can be increased with the addition of a hydraulics-based rating curve.

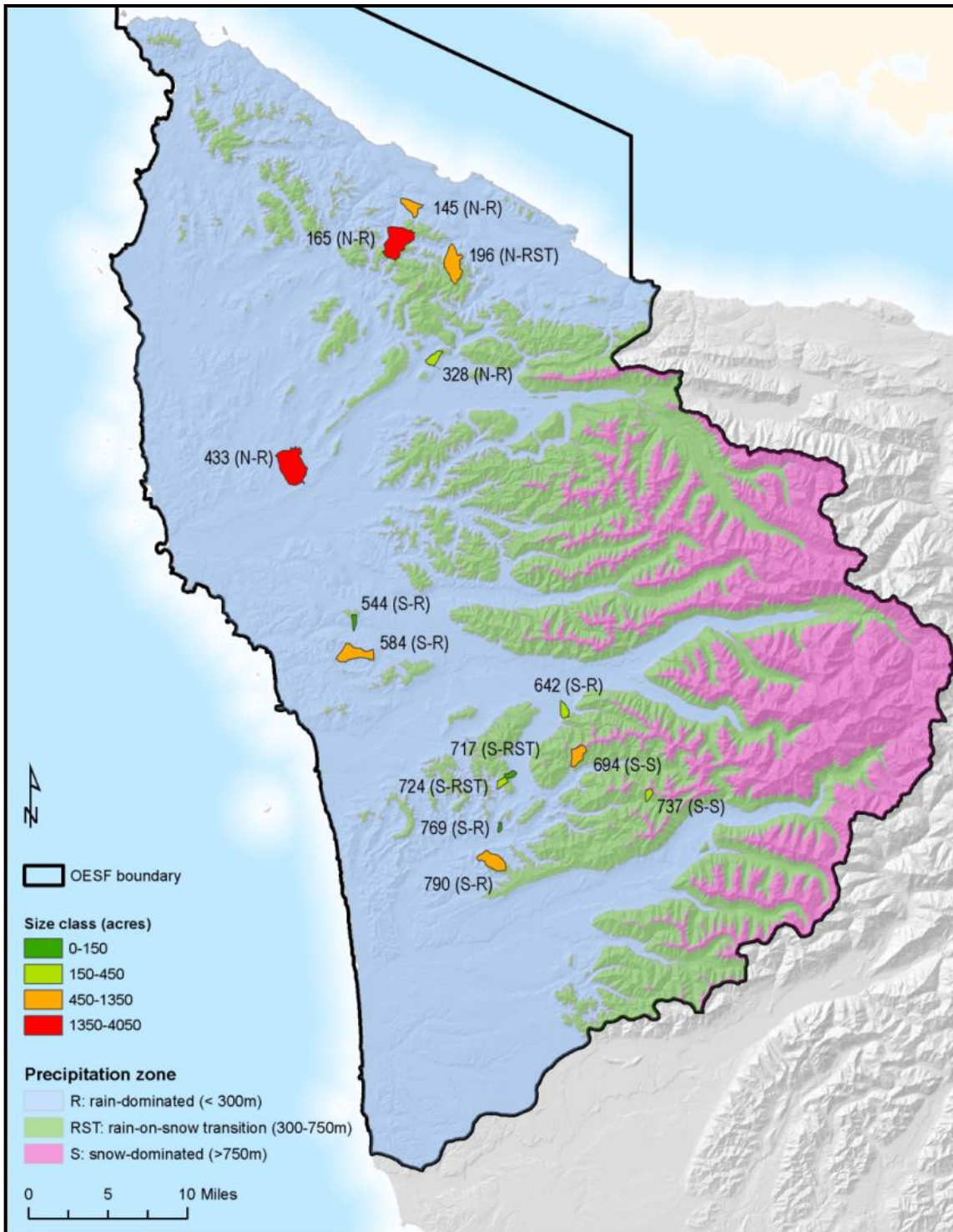


Figure 8-1. The 14 watersheds selected for discharge monitoring, classified by precipitation zone, rainfall intensity, and size. In 2016, monitoring was discontinued in watersheds 328, 433, 717, and 769.

**Table 8-1. Calendar of field activities to maintain gaging stations and collected associated data.**

<i>Time of activity</i>	<i>Discharge Measurements</i>	<i>Gage/Equipment Calibration, Cleaning, and Maintenance</i>	<i>Cross-section and Gage Stability Survey</i>
<b>At Installation</b>	8-10 measurements at various flows within the first water year, 4-6 in following years to maintain curve. Repeat 8-10 measurements if a new rating curve must be constructed.  NOTE: These visits are also used to check on the condition of gaging stations. Sites should be visited after large storm events and a minimum of 4 times a year.		Perform initial survey
<b>January</b>			
<b>February</b>			
<b>March</b>			
<b>April</b>			
<b>May</b>			
<b>June</b>			
<b>July</b>		Clean housing and repair/repaint staff and recording gage housing.	Additional surveys should be completed annually and following major storm events.
<b>August</b>			
<b>September</b>			
<b>October</b>			
<b>November</b>			
<b>December</b>			

After a reliable rating curve has been established, it is regularly updated and verified with additional flow measurements. In general, the physical structure of a stream’s channel changes over time. The channel hydraulics can be altered by sediment deposition, erosion, or changes to the channel’s slope due to sediment supply. These changes in channel geometry and structure alter the stage/flow relationship and therefore the rating curve itself. As a result, discharge measurements should be made throughout the water year. In particular, measurements should be taken immediately following large flow events to verify the validity of the rating curve. If there is evidence that the rating curve has shifted, follow-up measurements should be done as soon as possible to establish a new rating curve using another 8 to 10 measurements that span a range of flow magnitudes.

## ***Equipment and Supplies***

### ***For measurement of instantaneous discharge***

- Field notebook, blank notebook pages printed on Rite-in-the-Rain paper, and pencils
- Distance measuring device, preferably 50-m fiberglass tape (sufficient to span channel cross section)
- Spring clips and surveyor chaining pins, or other tape anchors
- Flow meter (Hach FH 950®)
- Metric top setting wading rod

- Calculator - It is recommended that calculations be completed in the field so measurements can be retaken if an error is detected
- Stadia rod and level (for non-fixed staff gage sites)
- Digital camera
- Small bucket for instrument calibration

#### ***For retrieval of data from water level sensor***

- Field notebook and blank notebook forms
- Solinst DataGrabber® and/or field laptop with downloading cables with Solinst software installed
- Download cables for field laptop
- Replacement 9 Volt batteries for shuttle device
- Stadia rod and level
- Digital camera

#### ***For channel slope and geometry work***

- Stadia rod
- Auto level and tripod
- Field notebook and blank data forms
- 50 m tape
- Digital camera
- Spring clips
- Rebar (for permanent marking of the original cross section and for the gage reference point)
- Epoxy
- Medallion

#### ***For installation, repair and configuration of water level and staff gages***

- Notebook for drawing of schematic of installation
- Solinst LT Levellogger Edge, M5/F15 (water level pressure transducer)
- Solinst Direct Read Cable Assembly (15ft) for the Levellogger
- Solinst LT Barologger Edge, M1.5/F5 (barometric pressure transducer)
- Solinst Direct Read Cable Assembly (5ft) for the Levellogger
- Solinst Well Cap Assembly (2") for the Levellogger
- Solinst Direct Read Comm. Package (USB) for the Levellogger
- Rickly® 1m USGS approved staff gage plate 1cm gradient
- Hach FH950® Portable Velocity Meter with 5' Cable
- Metric top setting wading rod
- Backpacks for transport of supplies
- Digital camera
- Survey equipment for initial relationship to the benchmark for the monitored sample reach
- Construction Tools:
  - 50 m fiberglass measuring tape
  - Metal tape measure—metric
  - SECO® 7.6m metric SVR Level .5cm gradient (with labeled centimeters)
  - Ratchet wrench set
  - Heavy Duty Scissors
  - Cordless drill (with impact and regular drive settings)



- Drill hex bit set for hose clamps
  - Drill bits (for multiple sizes and materials)
  - Standard and irrigation trenching shovel
  - Wax pencils (for underwater use)
  - 12" High tension hacksaw
  - 15" Handsaw
  - 4 lb sledge hammer, 15" handle
  - Pliers, Needle Nose and Slip Joint
  - 2 ft standard box level
- Construction Supplies:
    - 2" diameter PVC: straight sections, sweeping and regular elbows (45° and 90°), straight couplers, and end caps
    - 2" X 4" pressure treated wood; length determined for each site
    - Washers; ¼" x 2" stainless steel fender washers and ¼" regular washers
    - ¼"x 4' All-Thread rod (Cut to needed lengths)
    - PC Concrete Epoxy
    - ¼" x 3", 1½", 1" stainless steel hex bolts
    - ¼" Stainless steel locking nuts
    - 2" hose clamp
    - Cement-60 lb bag; 1 bag per in-bank installation
    - PVC glue-all purpose
    - 2" two-hole straps
    - String to use for threading instruments-150 m
    - Rebar (1/2" and 3/4" in 2' and 3' lengths)
    - Screws Stainless Steel Square drive; (1½"-3")size dependent on site and materials
    - Rock anchor screws hex head; ¼", length dependent on site and materials
    - Rebar wire
    - Zip ties; approximately 6 per station
    - Electrical tape
    - Fiberglass screen ; standard window screening approximately 3 ft x 1 ft section
    - U-Post 13 gage 5'

***Notebook sheets (see the appendices at the end of this chapter)***

- **8A:** Site Visit Tracking Field Form
- **8B:** Stream Gage Download Field Form
- **8C:** Stream Gage Installation Field Form
- **8D (a)-(e):** Stream Discharge Field Forms (by method: Hach FH950, MMB, NBO, and Slope-Area)
- **8E:** Elevation Survey for Cross-section Stability Field Form



## Field Procedures

Where feasible, the U.S. Geological Survey (USGS) gaging protocol (Turnipseed and Sauer 2010) has been followed and should be referred to for more detailed information and guidance.

### REGULAR SITE VISITS

*Procedures are adapted from Butkus (2007)*

Use the field forms Site Visit Tracking (Appendix 8A) and Stream Gage Download (Appendix 8B). Step-by-step instructions for operating the flow meter and downloading data from the gages are provided in Appendices 8F and 8H, respectively.

A regular site visit begins with recording the date, time and level water surface relative to the staff gage. Then stream flow is measured. Any gage maintenance issues or changes to the channel can be noted in the stream flow measurement note sheet. At the conclusion of the stream flow measurement, the water surface level relative to the staff gage is again recorded. Next, the pressure sensor data is downloaded and the channel geometry is surveyed. The pressure sensor download and channel geometry survey protocols are described below. Also during a regular site visit, the field crew takes a photo of the channel from the permanently established photo point, as well as upstream and downstream photos of the discharge measurement cross section.

### INSTALLATION AND CONFIGURATION OF WATER LEVEL SENSORS

Use the *Stream Gage Installation Field Form* (Appendix 8C).

This section describes the process of siting, constructing, and installing the water level sensors. The water level sensors are Solinst Levelogger and Solinst Barologger pressure transducers. For specific information on these instruments, refer to Appendices 8H and 8I.

#### **Step 1: Select site for gaging station**

Gaging stations must be installed in stream channel locations that are suitable for accurate recording gage and staff gage measurements and also for nearby discharge measurements. Although it is rare to find all of these site conditions together, it is important to spend as much time as possible scouting for the best gage sites.

Rantz (1982) identifies the following characteristics for an *ideal* gaging station installation:

- 1) The general course of the stream is straight for about 100 m (approx. 300 ft) upstream and downstream from the gage site.
- 2) The total flow is confined to one channel at low stages, and minimal flow bypasses the site as subsurface flow.
- 3) The streambed is not subject to scour and fill and is free of aquatic growth.
- 4) Banks are permanent, high enough to contain floods, and are free of brush.

- 5) Unchanging natural channel controls are present in the form of a bedrock outcrop or other stable riffle for low flow and a channel constriction for high flow or a falls or cascade that is unsubmerged at all stages.
- 6) A pool is present upstream from the channel control at extremely low stages to ensure a recording of stage at extremely low flow, and to avoid high velocities at the streamward end of gaging station intakes during periods of high flow.
- 7) The gage site is far enough upstream from the confluence with another stream or from tidal effect to avoid any variable influence the other stream or the tide may have on the stage at the gage site.
- 8) A satisfactory reach for measuring discharge at all stages is available within reasonable proximity of the gage site (Low and high flows do not need to be measured at the same stream cross section).
- 9) The site is readily accessible for ease in installation and operation of the gaging station.
- 10) The gage can be fixed permanently at a cross section and will not be shifted by high flows or debris.

When investigating sites, consider these additional questions relevant to the project and the limitations of instrumentation and access:

- 1) Can the channel be waded at high flows?
- 2) Is site access of minimal, average, or maximum difficulty for the study area?
- 3) Are there natural features that can safely anchor a gage during high flow events?
- 4) Does the installation site represent flow conditions experienced within a majority of the reach?

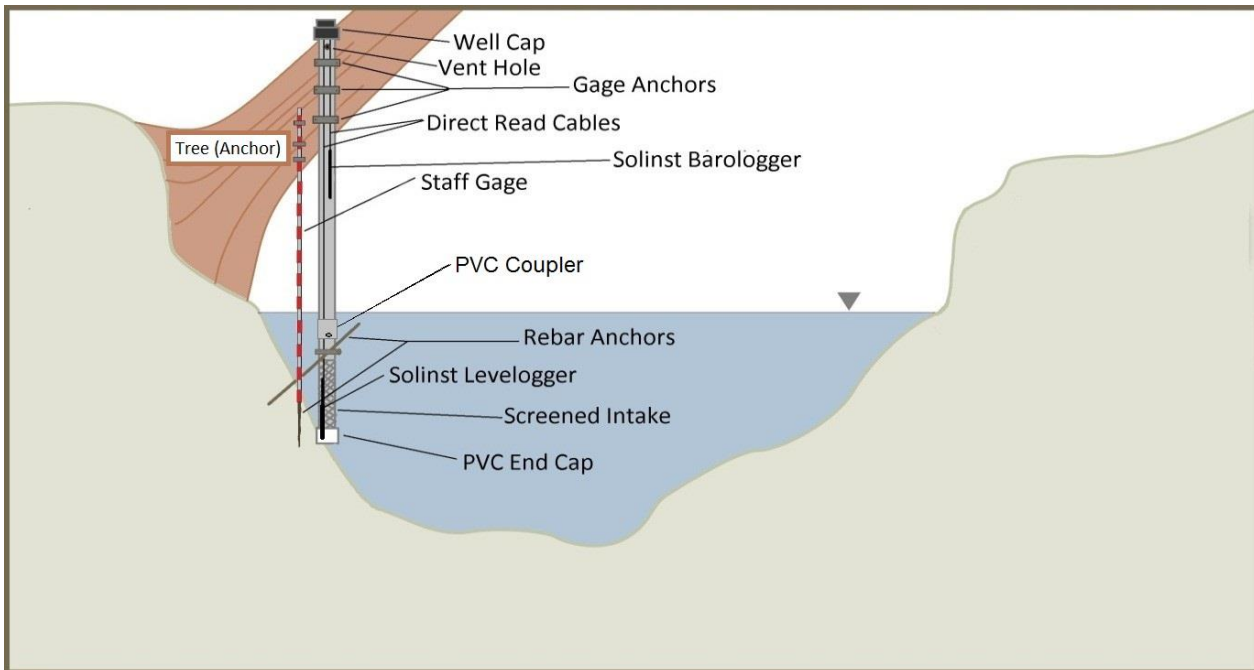
### ***Step 2: Choose configuration for water level sensor housing***

Each gaging station consists of an anchored staff gage and a continuously recording water-level gage (Figure 8-2).

All water level sensors are protected in a housing made of schedule 40 conduit (grey) PVC. These installations are attached to bankside trees, rocks, or other semi-permanent structures and, as a last resort, bankside sediment. Note that available anchors may limit the ability to gage a site. It is crucial that 1) the gage does not move during any flow event in order to maintain the gage's datum and 2) the housing does not restrict the sensor's access to the water surface in the housing. Although this can be difficult to achieve, especially for long-term installations, time spent on identifying a proper cross section and on securing the gages will pay off later in data quality. There are three general designs for the gage housing configuration; the simplest possible design appropriate for the site is the preferred option. Often this will be a vertical installation, though site characteristics may require a more stable installation configuration.

The three installation configurations to be used are (Figure 8-3):

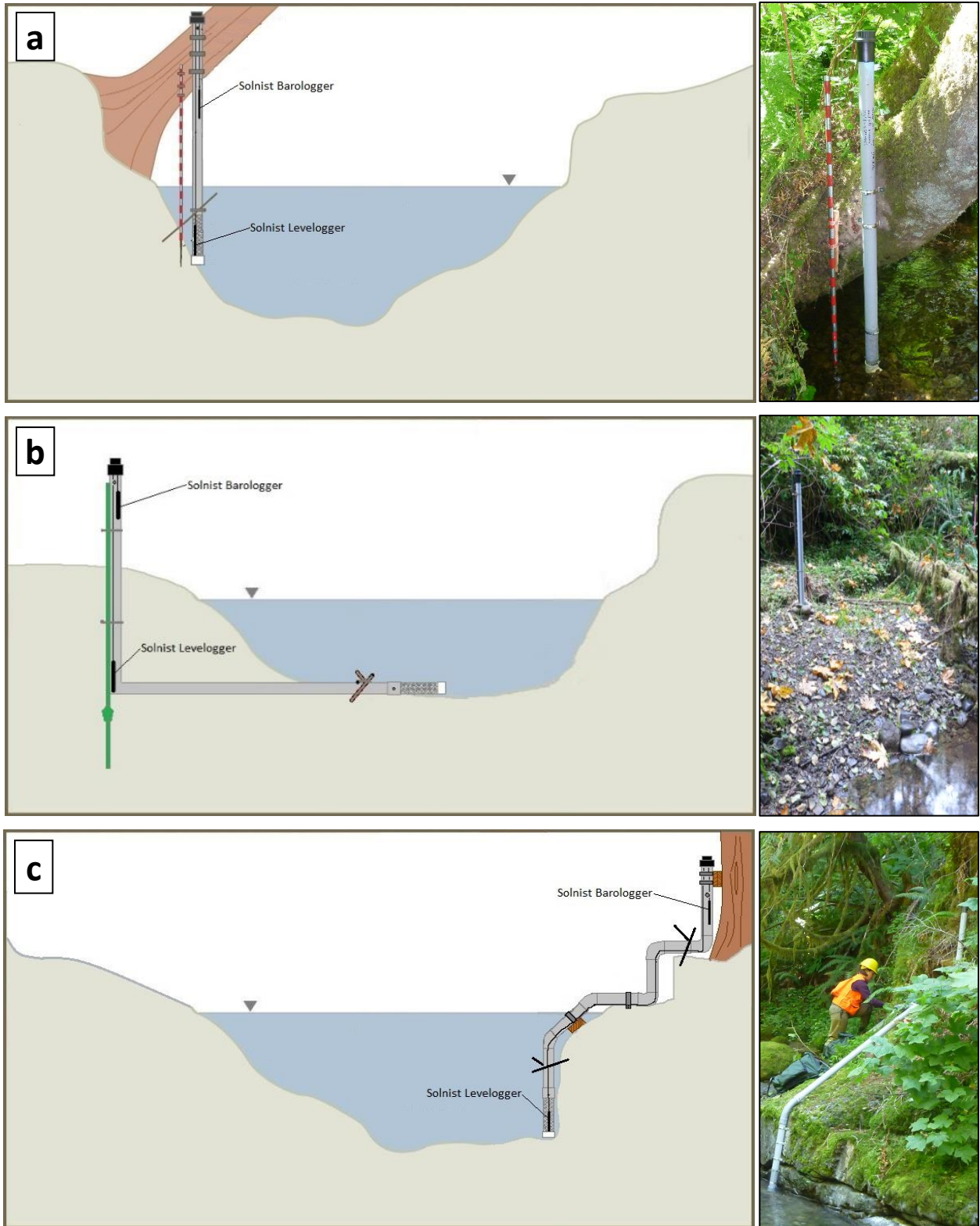
- a) **Vertical Installation:** This is the simplest installation. Vertical installations require a tree or other anchor near the bank. Consider the project duration (10+ years) and likely stability of the anchor during high flow events when choosing an installation site.



**Figure 8-2. Schematic layout of stream gaging station, including staff gage and continuously recording water level gage.**

- b) **In-bank Installation:** As opposed to the vertical installation, the in-bank option requires excavating a trench that is as deep as the channel thalweg and located far enough from the channel to reach a stable anchor. When choosing a site for this installation, consider future erosion or deposition that would influence the intake for the water level sensor housing. Also consider that this installation relies on sediment as its main anchor; this may make it very prone to failure/movement.
- c) **Over-bank Installation:** This is the most complicated installation method because this setup requires more engineering and planning than the other two installation methods. Used primarily on bedrock, the anchors used in this setup may provide the most stable installation. Depending on the angles used, this option may require feeding instrument cables through the installation before it is glued together. If this is done, consider how the instrument will be replaced if it or the cable needs to be removed for maintenance. A string tied to the end of the cable before the cable is pulled up through the housing will allow the cable and instrument to be easily returned to the original configuration.

Once an installation configuration is selected, make sketches and notes on the *Stream Gage Installation Field Form* (Appendix 8C) to plan the project. Estimate the necessary length of PVC pipe, making sure to consider length added by the angle and coupler components. Make note of the anchor types and hardware you plan to use for the installation. Because of the wet, warm environment these gages will endure, be cautious when using wood for the installation.



**Figure 8-3. Schematics and pictures of the three types of water level sensor installations: (a) vertical, (b) in-bank, and (c) over-bank.**

### Step 3: Design and prepare water level sensor housing

Design and construction of the water level sensor housing will likely be an iterative process. Assume there will be difficulties with the installation and try to plan accordingly so you have extra materials and any tools needed to work around these problems. Key considerations when constructing the gage housing are:



Figure 8-4. Solinst® locking well cap.

*Well cap:* The locking cap, which is part of the Solinst® water level sensor system, consists of three parts (Figure 8-4): one which attaches to the PVC stilling well, a separate hanger for the Direct Read Cables, and a locking lid. The cables must be threaded through the hanger before the extra cable is contained.

*Casing:* The main casing of the well is constructed of 2-in diameter PVC pipe. The pipe must be arranged in a way that will allow the free surface of the water to fluctuate inside the well. Additionally, the casing must protect the instruments, not be able to move or shift, and be arranged so as to reduce clogging of the intake screen.

*Screen:* The bottom part of the gage housing provides the main intake for the gage when the housing works as a stilling well. It is constructed out of a removable section of PVC pipe, drilled with many holes, and covered with a screen secured by three or four hose clamps (Figure 8-5). The end is sealed with a 2-inch diameter PVC cap, which is glued on. This screen section is attached to the main casing using a 3-inch stainless steel bolt and a PVC coupler. The bolt passes through the coupler and the screen section when assembled.

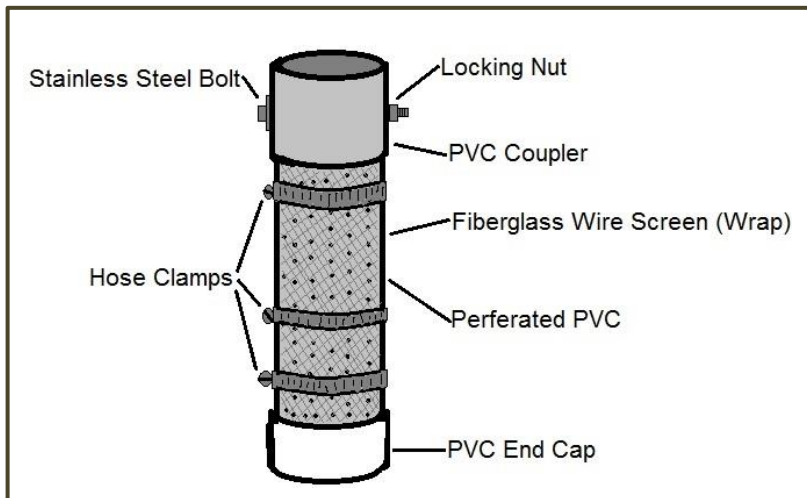


Figure 8-5. Schematic of the gage intake section.

*Vent hole:* The gage housing will ultimately be composed of one to several sections of PVC pipe that will be glued together. Each section of the casing should contain multiple drilled holes above the 100 year flood mark to allow equilibrium of the free water surface.



*Anchors:* Potential anchors include two-hole straps and wood screws, rebar and rebar wire, concrete, epoxy and All-Thread fully threaded rod, rock anchors, hose clamps, and streamside materials (trees and rocks) that are estimated to be stable enough to withstand most flow levels for a minimum of 10 years.

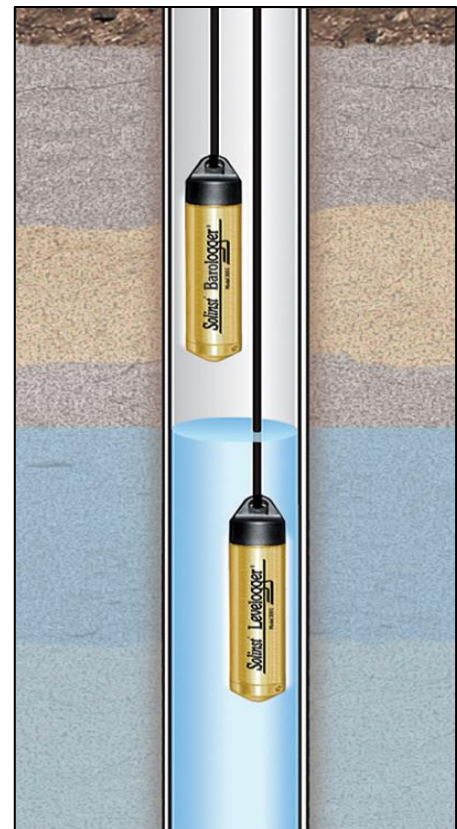
*Access/re-installation:* The gage housing will need to be cleaned and/or the water level sensor may need to be replaced. Often, the simplest way to facilitate this work will be to make the intake portion (Figure 8-5) of the gage housing (i.e., the section containing the water level pressure transducer) easily removable. Consider this when planning the installation. Note that you will need to be able to return the sensor to its original location and that measurements of relative instrument depth will need to be made before and after any intentional movement of the gage (see QA/QC section, below).

*Installation tip:* Each gage should be fabricated off-site and brought to the gaging location in sections and reassembled on-site.

Once the housing configuration has been determined, gather necessary supplies and cut PVC pipe to size; avoid cutting PVC in the stream. If possible, test the housing in place to verify that it will fit before you glue it together. If you cannot lift the entire unit into place, test the housing in sections starting with the intake portion. If you have a particularly complicated housing arrangement, make sure to run a string through the housing as you put it together; you will use this to pull the sensor into position once the housing is constructed.

#### **Step 4: Configure Solinst® Direct Read cable and well cap**

When using the Solinst® water level sensor system, there are two sensors in the housing, 1) a water level sensor (Solinst Levelogger) and 2) a barometric pressure sensor (Solinst Barologger) (Figure 8-6). Each of these sensors will be connected to an optical port located at the well cap. The elevation of these two sensors is dependent on the length of the cable, which connects the optical port to the sensor. Once the cables have been fed through the well cap, determine the cable length needed to locate the Levelogger approximately 1 cm above the bottom of the stilling well/gage housing. The Barologger needs to rest above the anticipated 100-year flood elevation. Control the height of the data loggers inside the housing by shortening the Direct Read cable. This can be done by wrapping the cable carefully around a small section of 1-in diameter PVC pipe, using nylon cable zip ties to zip-tie each end through a hole drilled in PVC, and then covering the entire wrap with electrical tape (Figure 8-7). It is helpful to wrap the cable to the approximate length before installation, and then



**Figure 8-6. Arrangement of Solinst® Levelogger and Barologger in a simple vertical installation.**



**Figure 8-7. Shortening the cable.**

make final adjustments to the length once the cable has been installed.

Protect the cable from damage by sanding sharp edges of the 1" diameter PVC pipe and covering them with electrical tape. When finished, record the final cable lengths for both sensors as measured from the top of the hangar plate to the lower tip of each sensor.

### ***Step 5: Assemble gage housing and gage***

When the housing configuration has been tested, assemble the pieces and secure it into position. Draw a sketch using the *Stream Gage Installation Field Form* (Appendix 8C),

and take photos of the final installation and anchors. Be sure to record measurements of the various pieces and anchors used. Remember that once you glue PVC pieces together, you will have to cut new pieces if you want to change them. Each of the different configurations will require different consideration when seating the gage:

- 1) Vertical installation: Make sure that the cable is firmly attached to the 1" diameter PVC pipe that holds the cable up. Make repeat, careful soundings with the sensor to verify that the cable will be long enough to keep the sensor in the water during low flow, but not so long that the sensor touches the bottom of the inside of the well.
- 2) In-bank installation: This installation is similar to the vertical installation. Before filling in the trench that the housing is placed in, double-check that the intake (the horizontal piece of the housing) is level. This is to ensure that the logger will be properly submerged at all flow levels and no pooling will occur in the elbow, which would cause the logger to record artificially high water levels.
- 3) Over-bank installation: When assembling the housing, leave the screen section off of the installation until the Levelogger has been moved into position. Once the housing is complete, snake the assembled gage through the housing using the string that was put in place during housing construction. Once the Levelogger has been moved into position, complete the housing assembly.

### ***Step 6: Setup of water level sensors***

Using Solinst® Levelogger Software, set the water level sensor, which consists of the paired Levelogger and Barologger, to record a water level every 15 minutes by selecting a linear sample rate of 15 minutes and “future start” them to start recording at the same time (starting at :00, :15, :30, or :45 past the hour). Set the units to meters for the Levelogger and kPa for the Barologger. Also set both sensors to record until full by selecting the slate memory mode. See Appendix 8H for step-by-step computer directions.

### ***Step 7: QA/QC and Maintenance***

*Annual cleaning of screening/housing:* Every year, the gage housing needs to be cleaned and checked for stability. This requires removing the screen section of the gage from the housing and either flushing it out or



replacing the components. At this point, check the Barologger and Levelogger for biofouling. For complex housing setups that require the Levelogger to be removed for inspection, tie a string around the end of the sensor before it is pulled up or removed. Re-snaking the sensor through the housing without the assistance of a string may prove difficult when the housing is fully assembled.

*Sensor accuracy check:* Before the sensors are deployed, place them in a container of water, all at exactly the same depth, for at least one day, recording every hour. Check sensor data for any deviation from the measured water level (after barometric compensation). Any sensors reading outside the manufacturer's acceptable error range ( $\pm 0.3$  cm) should be returned to the manufacturer for re-calibration or replacement. For more details, see the list of manuals in Appendix 8I.

### **Step 8: Download and reading of water level sensor**

The water level sensor (Solinst Levelogger and Barologger) should be downloaded whenever the gaging station is visited and recorded on the *Stream Gage Download Field Form* (Appendix 8B). Details on the operation of these sensors, as well as step-by-step directions for how to download the sensors, the barometric compensation process, where to store the data, and the file naming conventions can be found in Appendix 8H. Review and processing of the water level data is addressed in *Stream Discharge Data Management and Analysis Protocol*. The storage capacity of the sensors is 40,000 readings, which is more than 13 months at a 15-minute recording interval.

## **INSTALLATION AND CONFIGURATION OF STAFF GAGE AND CROSS SECTION**

Use the field forms *Stream Gage Installation* (Appendix 8C).

The staff gage (Figure 8-8) is used as a calibration reference for the water level sensor as well as a real-world measurement of water depth. Essentially, this staff gage acts as a controlled check on the water level sensor's calibration. The difference between the staff gage water height and the height reported by the water level sensor should remain constant in time and across all water levels.



**Figure 8-8. Staff gage installed alongside water level sensor housing.**

It is crucial to the stream gaging effort that the staff gage be stable and reliable. The staff gage stability is measured using surveying methods (see section *Elevation Survey Data Collection for Cross-section and Gage Stability*).

A cross-section, separate from those used for measuring bankfull depth in the stream morphology protocol, is monumented at the gaging station to facilitate repeated surveys of the cross-section profile over time. These surveys will be used to identify any changes in stream channel morphology at the gaging station. Such changes can significantly affect the stage-discharge relationship and thus necessitate modification of the rating curve or creation of a new rating curve.

### ***Step 1: Locate a stable vertical surface or permanent measurement point***

Ideal sites for the staff gage are the same as those for the vertical installations of water level sensor housing. Additionally, the staff gage should be within the same pool or behind the same channel control as the water level sensor. If no vertical installation is possible, a reliable measurement point should be located. This can be either a measurement from the stream bottom (e.g. a stake driven into the stream bed but be aware of potential scour and fill of the channel) or a measurement down to the stream surface from above (for example, a measurement from a bridge deck). A permanent staff gage installation is preferable however.

### ***Step 2: Attach to anchor and establish location***

Attach the staff gage to a stable anchor that will reliably hold the staff gage level. At least two attachment points must be used and the staff gage must be kept as level as possible. Ensure no vertical movement of the staff gage by securing multiple bolts through the staff gage plate into the anchor. Using the field form in Appendix 8C, record details of the gage installation; including a sketch of the staff gage with measurements and a photo of the installed gage.

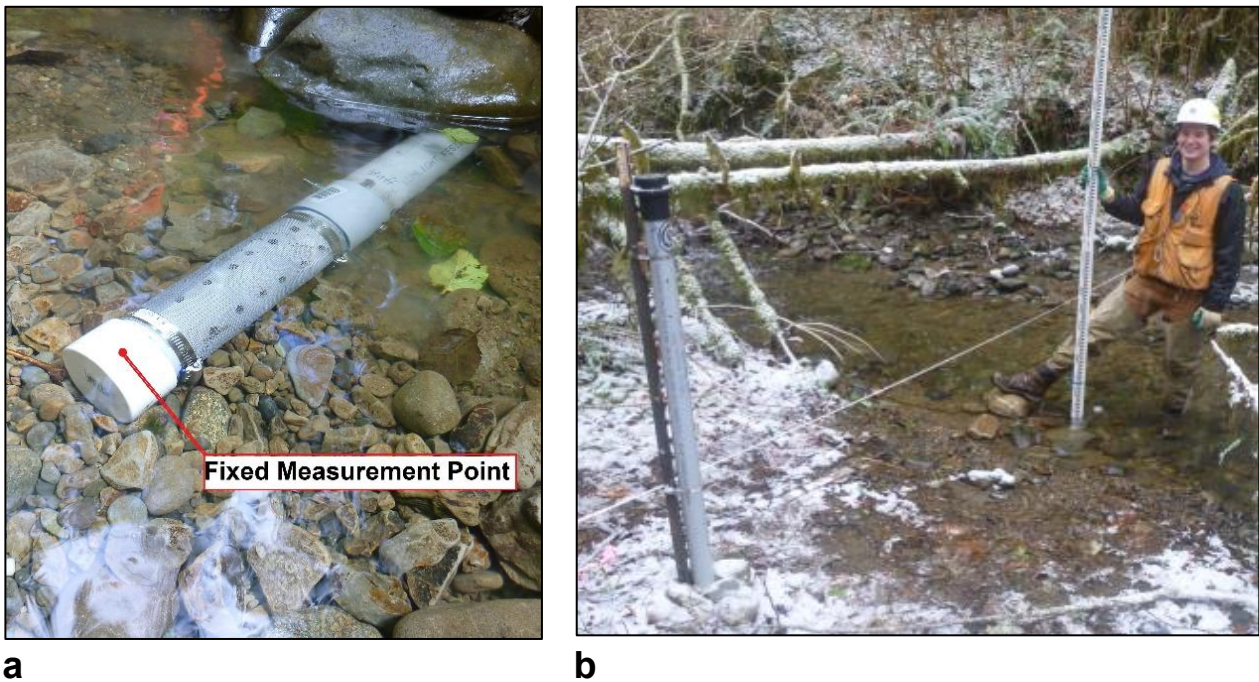
For an unfixed staff gage it is important to establish a location that will not change and is easy to locate for future visits. The top of the white endcap of the recording gage housing is a reliable, and easy to find location to measure from (Figure 8-9). Markings on the recording gage housing using permanent markers or paint pens have been found to wear away.

### ***Step 3: Read the staff gage***

Record stage height using the staff gage each time a discharge measurement is taken (at the start and the end of the discharge measurement) or the water level sensor is downloaded. If the water height is fluctuating as you attempt to read the staff gage or there is water pile up on the upstream side, estimate the average of the fluctuation or the mean of the pile up across the staff gage surface.

### ***Step 4: Install gaging station cross section***

Establish cross section benchmarks at the gaging station so repeated measurements can be taken at the same cross section. The cross sections of all gaging stations in this project are marked with rebar topped by orange mushroom caps, installed above the stream bankfull stage.



**Figure 8-9.** Example of a fixed-point for staff gage measurements when no anchor for a vertical installation of a staff gage is available: a) end cap of a recording gage housing is used as fixed measurement point; b) taking a measurement with unfixed staff gage.

## DISCHARGE MEASUREMENTS

*Protocol adapted from Butkus (2007) and Pleus (1999)*

Use the Stream Discharge Field Forms (Appendix 8Da-e) or Discharge Field Sheets.

Building and maintaining a rating curve that accurately predicts discharge based on water level requires measurement of a wide range of water levels and discharge rates over time.

In this project, instantaneous discharge is measured using the velocity-area method, which involves wading along a transect across the stream and measuring discharge using a top-set wading rod and flow meter (such as the Hach FH 950<sup>®</sup>) (refer to Appendix 8F). An alternative method, which may be used when flows are too high to safely use a wading rod, is the slope-area method; this method involves surveying a reach of the gaged stream and calculating discharge using Manning’s equation (Dalrymple 1967, Bradley 2012). Refer to Appendix 8G for guidance.

Another application of the velocity-area method—measuring stream flow using a neutrally buoyant object—was tested in this project but was rejected because of low data precision. The field form for this method is included in Appendix 8D in case the method is used in the future; however, this method must be



quantitatively compared to the preferred method (i.e., using a top-set wading rod and flow meter) before it is used again.

All velocity-area discharge calculations will be done using the USGS mid-section method (Turnipseed and Sauer 2010). Explicit instructions for each discharge measurement method are included in this protocol and/or in its appendices.

Because the velocity-area method (with a top-set wading rod and flow meter) is the standard method used for discharge measurements in this study, detailed notes on its application are outlined here:

### ***Step 1: Select a discharge measurement site***

For the discharge measurement, selection of a suitable site is very important and cannot be over-emphasized. Site selection is, in most cases, the most important factor in developing accurate flow information. The limitations of a poor measurement site cannot be overcome by the quality of equipment or the ability of the individual taking the measurement (Turnipseed and Sauer 2010).

An ideal site for making a discharge measurement should have the following characteristics (the following list is a modified version of Butkus et al. 2007):

- 1) The discharge measurement site should be close enough to the gaging station to ensure that the gaging station and discharge measurement site are receiving the same flow.
- 2) The stream course should be relatively straight and free-flowing both upstream and downstream of the discharge measurement site. The site should be free of excessive turbulence.
- 3) The stream channel should be free of vegetative growth and be relatively stable (free of major seasonal scouring or deposition of bed material).
- 4) Flow velocities exceed 0.15 m/s (0.5 ft/s) and depths are greater than 0.15 m (0.5 ft).
- 5) The stream bed should be relatively uniform with only minor irregularities (no large cobble or boulders). When obstructions are present at an otherwise suitable site, it is acceptable to remove them. Place the obstructions downstream of the site so that they do not affect flow conditions at the measurement site. Examples of obstructions include small organic debris, such as leaves, twigs and branches, and larger sediment particles such as cobble and boulders with less than 50 percent of their mass embedded in the channel bed surface. Avoid channel bed disturbances that cause continuous movement of smaller sediment particles downstream while removing obstructions or taking measurements.
- 6) During low flow conditions (typically July-October) the stream channel should be confined to a single course. Temporary damming along shallow margins of the measurement site is acceptable to divert flow into deeper sections where the water level would not otherwise completely cover a velocity sensor.
- 7) The stream bank should be stable and able to contain the maximum measurable stream flow. Avoid areas with flow diversions, side channels, undercut banks, or other obstructions.

Note that it will be difficult to locate areas that include all of these features, but it is important to spend time finding a suitable location. It is recommended that you locate and mark typical high water and low water

discharge measurement sites at each sample reach so they can be used for future discharge measurements if locations remain acceptable.

As described above, it may be necessary to slightly modify the streambed in order to obtain more accurate measurements. If such modifications are necessary, ensure that the modification will not affect stage height at the recording gage and that the discharge measurement site is not located near any permanent cross sections used in other project monitoring protocols.

If the streambed at the discharge measurement site has been modified, the flow should be allowed to stabilize before starting discharge measurements. Do not alter the measurement site after measurements have begun because this will change the flow characteristics and affect data accuracy.

### ***Step 2: Establish the measurement transect***

Extend a measuring tape across the wetted portion of the stream channel (from left to right, determined facing downstream) perpendicular to the main direction of flow; this is typically perpendicular to the banks (Figure 8-10). Anchor the ends of the tape just past the wetted edges using spring clamps and surveyor chaining pins. Anchor the tape using rocks or roots, if the pins cannot be placed. Previously established discharge measurement sites can be used. Make sure the tape is taut, and above the water surface.



**Figure 8-10. Discharge measurement transect with measuring tape anchored above wetted surface.**

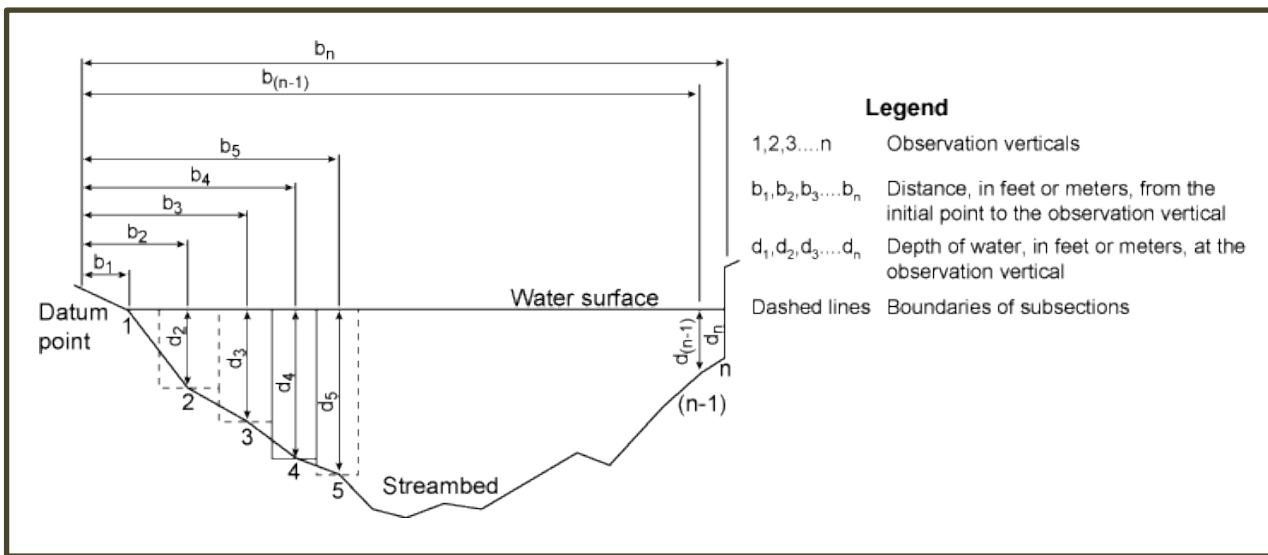
### ***Step 3: Assemble and test the flow meter system***

Assemble and test the flow meter system to ensure that it is working properly based on manufacturer specifications. This includes the flow sensor unit (probe/rotor assembly), the sensor cable, the data

indicator/logger/meter, and the wading rod. If it is the first measurement of the day, be sure to calibrate the instrument in still water. See instrument manuals and directions in the appendices regarding the setup, calibration, and troubleshooting for specific flow meters (refer to Appendices 8F, 8H, and 8I).

**Step 4: Establishing measurement stations**

For most wadeable streams, at least 15 measurement stations are required to ensure an accurate reading (Figure 8-11). To calculate the sampling interval, measure the wetted width at the transect and divide by the selected number of measurement stations. Intervals should be no smaller than 10 cm, even if this results in fewer than 15 stations (Peck et al. 1996). It is desirable to use more than the minimum number of stations where the stream channel morphology is variable or the water is turbulent.



**Figure 8-11. A stream cross-section showing depth observation verticals (d), measurements of the distance from the initial vertical to the observed vertical (b) and boundaries of each station subsection (dashed lines). Total discharge is the sum of discharge within each rectangle (adapted from Turnipseed and Sauer 2010).**

Locate the first measurement station one interval distance from the left wetted edge. If water depth at this distance is inadequate for measurement due to instrument limitations, move the station to the required depth. Note if the bank gradually slopes out to the first station or if the bank edge is vertical; record this on the field form.

The second and subsequent measurement stations can be calculated by adding the interval distance to the previous measurement station. However, stations should be spaced equally throughout the transect only if discharge is evenly distributed across the stream. Measurement stations should be closer together in portions of the transect where flow is concentrated and/or where velocity or bottom irregularities are the greatest. In these sections, stations should represent average depth and velocity conditions within an area (observation station, referred hereafter as simply the “station”) defined as half the distance from the last station plus half the distance to the next station (Figure 8-11). Adjust station locations so that station boundaries fall

wherever noticeable breaks or discontinuities in velocity and depth occur. Ideally, each cell should account for less than 10% of the total discharge. The discharge in some stations may be greater than 10% in small streams where the measurement stations are already at the minimum 10 cm interval, but this does affect the quality of the measurement.

The number of stations can be reduced depending upon the width, depth, and uniformity of the stream channel. Uniform flow has little vertical or horizontal variation in flow direction. These flow conditions are generally found in shallow stream reaches with a flat channel bed, small substrate, and little or no surface turbulence.

### **Step 5: Record wetted edge locations, station number, and tape distance**

Station 1 is the start of the measurement transect at the left bank wetted channel edge. Note this as “LEW” in the *Notes* column and record the tape distance in the *Distance Along Tape* column of the “Station 1” row.

*Distance from Left Edge of Water* is recorded as zero in the station 1 row.

Next, record each station's location along the transect tape in the *Distance Along Tape* column and distance from the wetted edge in the *Distance from Left Edge of Water* column to the nearest 0.01 m. Record the ending wetted channel edge bank and location (“REW”) in the row following your final velocity station measurement (refer to Appendix 8Da).

### **Step 6: Record water level, as shown on the staff gage, before and after discharge measurement**

In addition to the water level sensor, gaging stations are equipped with either a permanent staff gage (Figure 8-8) or a fixed point where water level can be measured using a stadia rod (Figure 8-9). To track any water level change during discharge measurement, read the water height on the gage or a stadia rod before and after measurement (i.e., prior to starting measurements, and after all cells have been measured) and record the heights in the header of the field form (nearest 0.001 m). If water height is difficult to determine due to fluctuation caused by turbulence, estimate the average across the staff gage or stadia rod surface.

### **Step 7: Measure and record water depth and velocity at each observation station.**

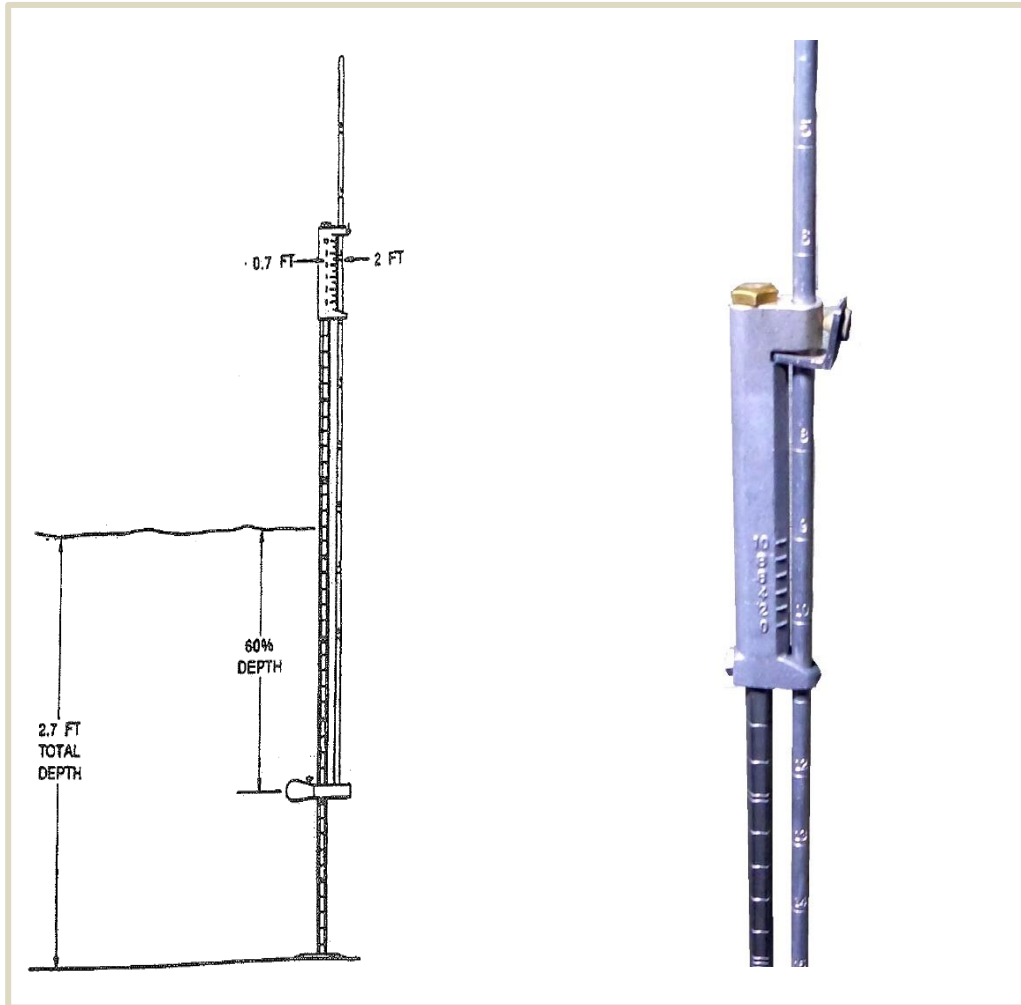
Before taking flow velocity measurements, select: a) the number of measurements to be taken at the station, and b) the averaging time for each measurement.

A velocity meter such as the Hach FH 950<sup>®</sup> flow meter (Figure 8-12) or Marsh McBirney<sup>®</sup> and a top-set



**Figure 8-12. Hach FH 950<sup>®</sup> flow meter.**





**Figure 8-13. Top setting wading rod set to measure velocity at six-tenths water depth (left) (Adams 2010). Top-set wading rod set to measure at a depth of 100 cm (right).**

wading rod (Figure 8-13) are used in each of these tasks, as described below.

*Measuring depth at a station:* Station depth is the distance from the surface of the channel bed to the water surface, as measured with the wading rod held level. Measure the water depth at a given measurement station using the wading rod and record it in the *Depth of Water* column to the nearest centimeter.

When high velocities cause water to pile up on the upstream side of the wading rod, read the water depth on the rod as the average between the stacked water level on the upstream side and the depression level on the downstream side. Note that, for the first station, the distance from the edge of water is zero and in many cases the depth may also be zero. For the last station, the distance from the starting edge of water will equal the wetted width, and the depth may also be zero.

If the bank at the edge of water is vertical, measure the depth of the water at the edge and enter it into the field form and flow meter. When using the Hach FH950 flow meter you are prompted to select an edge factor on a vertical edge (Hach User's Manual):

- Vertical edge: 0.8 to 0.9
- Brick sides with vegetation: 0.7
- Rough walls with heavy vegetation: 0.6 to 0.5

Note in the notes section of the field form the type of edge (vertical or sloped) and the edge factor (if it is a vertical edge).

*Considerations for the number of velocity readings taken in the water column at each station (from Butkus (2007):* "In most natural stream conditions, a logarithmic relationship exists between velocities through the depth strata of the water column. Typically, velocity increases in the upper portion of the water column and decreases near the bottom." In order to capture the average vertical velocity within a segment, use one of the following methods, depending on measurement conditions:

- 1) Six-tenths method: Use the six-tenths method in stream segments that are less than 0.76 m in depth. In this technique, a single station velocity is taken with the sensor unit positioned at 0.6 (i.e., 60%) of the total water depth from the water surface, which approximates the average velocity within that column of water. Velocity sampled at six-tenths of the depth represents the average velocity through the depth strata up to 0.76 m. In cases when stage is fluctuating rapidly and the measurement must be made quickly, it is acceptable to use only the six-tenths method at any depth.
- 2) Two-point method: Employ the two-point method in streams with depths greater than 0.76 m. This method can also be used when there are minor but noticeable flow field disruptors (for example, a single rock in an otherwise smooth streambed). Velocities are sampled at two-tenths and eight-tenths of the depth, and the results are averaged."

#### *Using a Top Setting Wading Rod:*

Top setting wading rods (Figure 8-13) are designed to automatically calculate 0.6 x the depth of the water, or 60% of the water's depth. This value can be calculated by lining up markings on the suspension rod with those along the top of the depth rod (or Vernier) based on the station's total water depth (Figure 8-11). For example, for a station depth (or sounding) of 100 cm, the "10" on the suspension rod is lined up with the "0" on the depth rod handle, resulting in the sensor position at the 40 cm water depth mark on the guide rod shaft, or 0.6 x the water depth from the water surface. This position from the streambed can be calculated manually by multiplying the station depth by 0.6 (e.g.,  $100 \times 0.6 = 60$ ) and then subtracting that value from the water depth.

The top setting wading rod can also be used to easily position the sensor for a 0.2 or 0.8 velocity reading. The 0.2 x depth is determined by multiplying the total depth by 2 and adjusting the rod to the calculated value. The 0.8 x depth is determined by dividing the total measured depth by 2.

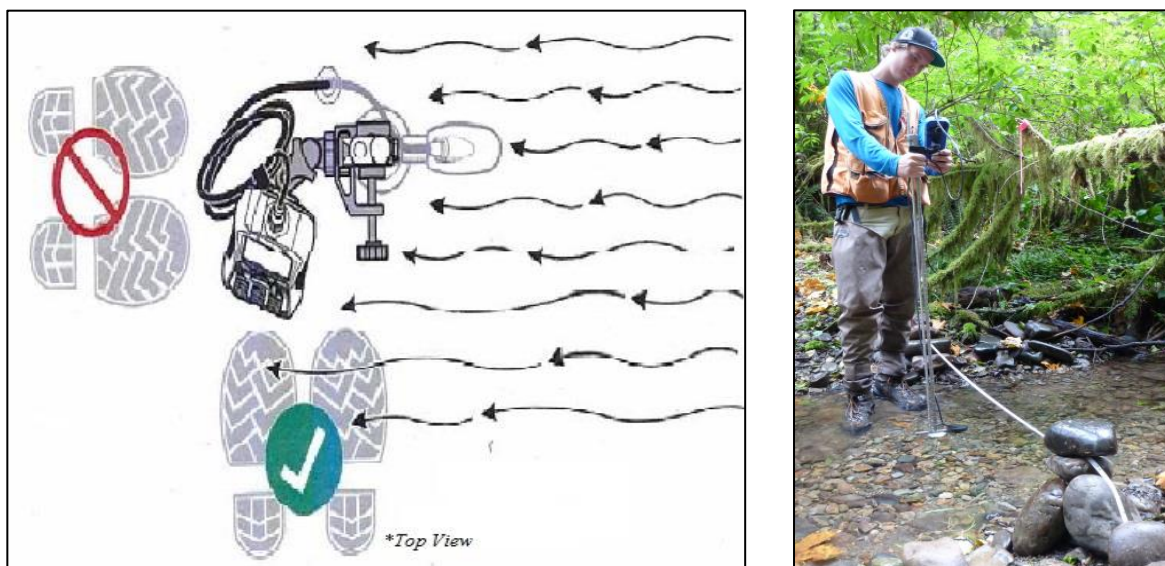
#### *Selecting an Appropriate Velocity Averaging Time:*

Revised from Butkus (2007): Stream velocities in natural conditions tend to "pulse" or speed up and slow down over time at the same stage. These fluctuations compound the effects of horizontal and vertical velocity variability at fixed locations in the stream. Take 40-second velocity samples to address variations in velocity

over time at each measurement point. In the case of mechanical instruments, take two 20-second samples. Measure 40-second velocity samples at each measurement point except in situations when stage is fluctuating significantly or when very low velocities are sampled with mechanical instruments. In circumstances when stage is fluctuating, take single 20-second velocity samples to complete the discharge measurement quickly and to obtain a stage that reasonably represents the measured discharge. When using mechanical equipment, increase the sample time to 60 seconds when velocity is less than 0.15 meters per second.

#### *Measuring Velocity:*

Before taking measurements, be sure that the operator is not interfering with the flow field and that the flow meter has adjusted to the speed of the current. To avoid affecting stream flow, the flow meter operator should stand 0.5 m (1.5 ft) downstream and to the side of the meter while facing the stream bank (stand perpendicular to the flow, on the downstream side of the tape extended across the transect) (Figure 8-14). In slower streams, the movement of the flow meter operator can greatly affect stream flow. Allow the stream to return to its normal flow pattern (~10-15 seconds) before a measurement is taken.



**Figure 8-14 Proper positioning of the flow meter operator (Hach FH950 User Manual: Edition Three, 2013); performing a velocity-area measurements with the Hach FH950®.**

To take a velocity measurement, hold the top setting wading rod in a vertical position and aim the velocity sensor upstream at a 90 degree angle, even if local flow eddies are hitting the sensor at oblique angles.

Measure the station's average velocity at an appropriate time interval and depth and record the measurement in the *Velocity 1* column to the nearest 0.01 m/second. If additional measurements are taken at various depths, record them in the order they appear within the methods section. Make sure to circle the appropriate method(s) (0.2/0.6/0.8) in the *Method* column on the *Stream Discharge Field Form* (Appendix 8Da).

Note that negative velocity readings are possible. For example, this can occur in local flow eddies near edges or behind boulders. When a negative value is recorded, make a clear note on the field form confirming the negative value.

*Discharge Measurement At High Flow:*

When a stream at high flow cannot be safely waded, an indirect discharge measurement method known as the slope-area method can be used (Appendix 8G). The measurement consists of surveying high water elevations, or markers of high water, at locations measured pre- or post-event. If the survey is taking place during a flood event, survey the water level at previously measured and marked locations. After the flood, these locations can be measured. It is suggested that the computer program SAC-GUI (USGS) be used to estimate these high flow levels. For more details on the implementation of this method, see the USGS documentation in Appendix 8G and the SAC-GUI manual (Dalrymple 1967; Bradley 2012). Use the field forms in Appendix 8Dd and 8De.

**Step 8: Document discharge information on field form**

When the measurement is complete, record the reported or calculated total discharge on the appropriate field form in Appendix 8D and determine the qualitative rating of the measurement (see below).

**Qualitative Rating of the Discharge Measurement (from Turnipseed and Sauer (2010), page 79)**

Every discharge measurement should be evaluated for accuracy using the qualitative method. Historically, this has been the preferred method, and the hydrographer should make this evaluation immediately after making the measurement. The evaluation should be based on the hydrographer's opinion of the accuracy of the measurement – not on how well, or how poorly, the measurement plots on the stage-discharge relation. It is difficult to provide written guidelines for making a qualitative evaluation of accuracy. A good qualitative evaluation depends mostly on the experience and training of the hydrographer. Several of the factors that should be considered by the hydrographer are as follows:

*Measuring section.*—Consider factors such as the uniformity of depths, the smoothness of the streambed, the streambed material (that is, smooth sand; small, firm gravel; large rocks; soft muck; and so forth), the ability to accurately measure the depth, the approach conditions, presence of bridge piers, and other conditions that would affect measurement accuracy.

*Velocity conditions.*—Consider smoothness of velocity, uniformity of velocity, very slow velocity, very high velocity, turbulence, obstructions that may affect the vertical velocity distribution, use of one-point or two-point method, length of averaging time (40 or more seconds versus half-counts), and other factors that affect accuracy of velocity measurements.

*Equipment.*—Consider the type of current meter used, the type of depth-sounding equipment, and the condition of the equipment.

*Spacing of measurement stations.*—Use about 25 to 30 verticals for a discharge measurement, spaced so that no more than 5 percent of the total discharge is contained in each subsection. Although this is

frequently difficult to attain, except in unusual cases, no more than 10 percent of the total discharge should be in a subsection. Otherwise, the accuracy will be negatively affected.

*Rapidly changing stage.*— Although discussed in previous sections of this chapter, this condition should also be considered when assessing the accuracy of the measurement. Using the shortcut methods previously described will result in less accurate measurements of discharge.

*Ice measurements.*— Making discharge measurements under ice cover is usually more difficult, and sometimes less accurate, than making open-water discharge measurements. Presence of slush ice, layered ice, and anchor ice will have adverse effects on accurate measurement of depth and velocity. Velocity distribution will be affected if the water surface is in contact with the ice. Freezing of water in the meter cups and pivot chamber may affect performance of the equipment.

*Wind.*— Wind can affect the accuracy of a discharge measurement by obscuring the angle of the current, or by creating waves that make it difficult to sense the water surface prior to making depth soundings. Wind can also affect the vertical-velocity distribution, particularly near the surface, and can cause vertical and (or) horizontal movement of the current meter while making a boat measurement, introducing possible error in velocity measurements.

The qualitative method of assessing the accuracy of a discharge measurement requires that the hydrographer consider all of the above items and their cumulative effect on the measurement accuracy.

The discharge measurement field form has space for describing (1) the streambed at the discharge measurement transect, (2) the flow, (3) the weather, and (4) any other flow conditions that relate to the accuracy. These descriptions, along with the type of equipment, number of verticals, velocity measurement method, and other measurement conditions, should provide the basis for rating the measurement (and associated estimated percent error) as excellent (2 percent), good (5 percent), fair (8 percent), or poor (more than 8 percent).

For instance, a measurement might be rated as excellent (2 percent) if (1) the streambed at the measurement location is smooth, firm, and uniform; (2) the velocity is smooth and evenly distributed; (3) the equipment is in good condition; (4) the two-point velocity measurement method was used; and (5) weather conditions are good (no wind or ice). On the other hand, if several of these factors make it difficult to accurately measure depth and (or) velocity, the measurement might be rated fair (8 percent), or even poor (more than 8 percent).

As stated previously, it is not possible to provide absolute guidelines for making the qualitative evaluation of accuracy. As a general rule, the accuracy of most discharge measurements will be about 5 percent, or qualitatively a “good” measurement. This is sometimes used as the base-line accuracy, with accuracy upgraded to “excellent” when measuring conditions are substantially better than average, and accuracy downgraded to “fair” or “poor” when conditions are substantially worse than average. The qualitative-accuracy evaluation is based on the hydrographer’s judgment.



### Step 9: Quality assurance and quality control of discharge measurement

Perform instrument self-tests before each discharge measurement. Calibration tests of flow meters (0 m/s) should be performed daily before any measurements are taken. Record calibration checks and instrument self-tests on the field form. Make duplicate measurements during each field session (minimum of once per week). Randomly choose a single site and repeat the measurement. The repeat can be made in the same location and with the same tape, but locate the measurements at different increments along the transect. This duplicate measurement will be used to estimate measurement errors associated with discharge measurements at different flow levels. A discharge measurement should not be duplicated if the stage level is changing at the time of the field visit.

Butkus (2007) states: “The objective of duplicating measurements is to document the random variability inherent in the measurement procedure. The relative percent difference (RPD) is calculated and compared to the measurement quality objective of 5% (Equation 1). In addition, the cross-sectional areas and the average velocities of the two measurements should be within five percent. The following formula will be used to evaluate duplicate measurements:”

$$RPD = \frac{|R1-R2|}{R1+R2} \times 200 \quad (\text{Equation 1; from Butkus (2007)})$$

R1=Result for the first measurement  
R2=Result for the second measurement

## GAGE SURVEY

This section was developed at the DNR but also borrows from Butkus (2007), Kenney (2010), and Le Coz et al. (2014). Use the *Elevation Survey for Cross-Section Stability* Field Form (Appendix 8E).

### Gage Survey

The gage survey determines the elevation of the staff gage and pressure sensors. It is repeated at least once per year. The purpose of tracking the elevation of the staff gage and pressure sensors is to make sure that changes in the rating curve attributed to changes in channel geometry are not actually caused by a moving gage.

Elevation of the gage is tracked relative to a Reference Point (RP) installed in close proximity to the gage at stable location or the base of rebar stakes at the ends of the cross section. The RP at many sites is designated by a metal medallion epoxied to bedrock or a large boulder (Figure 8-15). Other sites use the top of a 1 meter long 1.5 cm diameter rebar stake.



**Figure 8-15. Reference Point installed on large stable boulder near recording gage.**

Back in the office the gage survey and cross section surveys are assessed for the following characteristics:

**Changes in the elevation of the gage:** If the vertical location of the recording gage or pressure sensors has changed, then the gage data must be adjusted accordingly. Adjustments to the pressure sensors or staff gage data should only be made if the gage’s elevation has changed by at least 0.5 cm. Refer to the *Stream Discharge Data Management and Analysis Protocol* for guidance on these adjustments.

**Changes in the area or shape of the cross-section:** Plot the current cross-section against previous surveys and note if there have been any significant changes in shape or cross-sectional area at the same flow depth (+/- 10% as a general rule). Changes in the cross-section’s shape can be quantified by its hydraulic radius (cross-sectional area divided by the wetted perimeter at bankfull stage).

**Differences in the reported instrument water height:** Compare the water surface elevation to the staff gage reading and the recording gage reading (after barometric compensation). This number should remain constant across time, though measurements during storm events may not necessarily be constant because of a lag between the channel water surface elevation and the elevation of the water in the pressure sensor housing.

## Time and Cost Estimates for Implementing the Field Procedures

Following are the time and cost estimates for implementing the field procedures of the stream discharge protocol (Tables 8-2 and 8-3). These estimates do not include data management.

**Table 8-2. Time Estimates for Implementing the Stream Discharge Field Protocol by a two-member field crew (not including travel time to sites).**

Procedure	Estimated time per gaging station	Estimated time per gaging station per year (assuming 12 visits)	Estimated time for 10 sites per year
Discharge measurement and downloading water level sensors	3 h	36 h	360 h
Installation of gaging station (including planning, purchasing of assembly materials and fabricating sections of the gaging station off site, and field installation)	24 h	-	240 h (one-time activity unless a station is moved)
Testing of the water level sensors off site	-	-	10 h



**Table 8-3. Cost Estimates for the Equipment Used in the Stream Discharge Field Protocol for 14 sites**

Equipment/Supplies	Cost per unit	Number of units	Cost for the project
Solinst Levellogger Edge 3001 LT M5 F15	\$504	16*	\$8064
Solinst Barologger Edge 3001 LT M1.5 F5	\$267	16	\$4272
Solinst Direct Read Cable Assembly 15 ft	\$84	16	\$1344
Solinst Direct Read Cable Assembly 5 ft	\$78	16	\$1248
Well Cap 2"	\$26	16	\$416
Direct Read Comm. USB Package	\$397	1	\$397
Solinst DataGrabber with cables	\$400	1	\$400
FH950 HACH Velocity Meter with cable	\$4330	1	\$4330
Top Setting Wading Rod (metric)	\$1004	1	\$1004
Construction Tools (drills, pliers, shovel, wrench set, etc.)	–	-	\$500
Construction Supplies (PVC, cement, wires, epoxy, rebar, fiberglass screen, etc.)	–	-	\$1000

\* Extras purchased in case of theft or damage.

## Quality Assurance and Quality Control

Upon completion of a Water Year, compile a “Final Record Packet,” for each stream gaging station. Each packet consists of a complete annual hydrograph, copies of discharge measurements with total discharge, notes on adjustments to the channel controls, copies of the rating curve(s), and any modeling notes used to estimate flow at stages above (or below) those actually measured. This packet, along with the database, is used in the review of the gaging station record. The researcher leading the hydrologic monitoring reviews each flow measurement to ensure that there is no evidence of errors made during data collection or discharge calculation.

Directions on the process for acquiring this data and the QA/QC procedures for data management are described in the *Stream Discharge Data Management and Analysis Protocol*.

## TRAINING

Discharge measurements and gaging station installation and maintenance requires a dedicated hydrologic technician. All personnel conducting field protocols will be trained in a consistent manner to ensure that the surveys are conducted properly and in standardized fashion. The training is conducted or, for returning personnel, reviewed, annually before the start of the field season. At least one member of the field crew should be experienced with the field procedures.

## STANDARD PROTOCOLS

The standard procedures described in this protocol are followed for the duration of the project. Any deviations from the procedures should be documented, and the reasons for deviation described and discussed with the project manager or the researcher overseeing the protocol implementation.

Changes to the published protocols are approved by the project manager or by the researcher overseeing the protocol implementation. Revised protocols are assigned new version numbers and publication dates.

Pacific Standard Time (PST) should be used for all field procedures, year-round. During Pacific Daylight Time (PDT), March through November, one hour should be subtracted to arrive at standard time. The letters PST should be appended to all times in field notes to ensure consistency.

## CALIBRATION AND TESTING OF THE INSTRUMENTS

The calibration procedures for the flow meter are in Appendix 8F; a link to the manual is provided in Appendix 8I. Also see Step 9 (Quality assurance and quality control of discharge measurement) in the *Discharge Measurements* section, above. The water level sensors are factory calibrated, but this calibration is checked using the process described in Step 7 of the *Installation and Configuration of Water Level Sensors* section above.

## FIELD CHECKS

Field forms will be checked for errors immediately after data collection (i.e., in the field) so measurements can be repeated, if needed.

## FIELD SAFETY

Discharge monitoring will include field activities during all seasons, including periods of high discharge/flood conditions. It is recommended that field staff use personal floatation devices (PFD) when measuring discharge during moderate to high flow conditions. As a general rule of thumb, wear a PFD when entering water flowing faster than 1 m/s or above your mid-calf (~ 0.3 m deep). Do not enter water moving faster than 2.0 m/s or higher than your waist. Use your best judgment to determine if conditions are safe. When wearing chest waders in or near moving water, be sure to have your wading belt buckled and tight at all times.

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## Appendix 8A. Site Visit Tracking Field Form

Discharge Task Tracking Checklist	
Start Date:	
End Date:	
Staff:	

*Fill in the following sheet with the date and any notes regarding maintenance.*			
Site	Discharge Measurement	Staff Gage	Recording Gage Download
145			
165			
196			
328			
433			
544			
584			
642			
694			
717			
724			
737			
769			
790			

Notes:

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## Appendix 8B. Stream Gage Download Field Form

Stream Gage Download Form		
Site ID:		Date:
Crew:		Time (PST or PDT):
Download Equipment: Leveloader or Laptop: _____		
Camera Number:		Photo Point Picture:
Levelogger		
SN:		
Real-time depth (m):		Real-time Temperature (C):
Real-time battery:		Sync Time?:
Restart gage?	Time Interval:	Restart date and time:
Barologger		
SN:		
Real-time atmospheric pressure(kPa):		Real-time Temperature (C):
Real-time battery:		Sync Time?:
Restart gage?	Time Interval:	Restart date and time:
Staff Gage		
Staff Gage Depth (m; nearest 0.001):		
Office Processing		
Enter date of data entry and initials		Download File Name
Barologger:		
Levelogger:		
Compensated Levelogger:		

Notes/ Any problems with data/loggers/gage housing and plan for fixing:



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# Appendix 8C. Stream Gage Installation Field Form

## Stream Gage Installation Field Sheet

Date/Time (PDT or PST):	Basin #:	Crew:
	Camera #:	GPS #
Site Access different from main site accesss?		

**Installation: Plan**                      \*tie flagging at location of planned install\*

Install Type:	vertical	along bank	in-bank	other /combo:
---------------	----------	------------	---------	---------------

Draw Gaging Equipment Layout (w/ stream section control, significant structures, etc. *Birdseye View*):

Draw Detailed Installation Plan( w/ estimated measurements, *Elevation View*):

**Installation: Site**

Describe Stream Characteristics (Significant Structures, Strength of Flow, Section Controls, etc.):

Bankfull Width:	Length of Straight:	Gradient of Straight:
-----------------	---------------------	-----------------------

Manning's n at cross section: * see roughness guide	channel bed	right bank		left bank	Notes:

Bank Composition (Clay, Loose Gravel, Dirt, Bedrock, etc.):

### Installation: Final Design and Location of Recording Gag

Date/Time (PDT or PST) (if different from Plan date and time):

Distance and Bearing from RP:			
GPS of Stream Gage:	N:	W:	Point #:

\*DO NOT GLUE HOUSING UNTIL RECORDING GAGES HAVE BEEN INSTALLED\*

Detailed Schematic of Gage Housing (Exact Measurement of sections, Degrees of Angles, etc, Elevation View):

### Installation: Anchoring for Recording and Staff Gages

Describe Type of Anchor (Tree, Rebar, poured concrete, etc.):

Tree Species:  DBH:

Describe Anchor Connection and Materials Used ( Directly to tree, Bracket, plummets tape, etc):

Describe Staff Gage Anchor (If different):

Tree Species:  DBH:

Describe Staff Gage Anchor Connection and Materials Used( Directly to tree, Bracket, plummets tape, etc):

Is staff gage stable?:	Yes	No	Is staff gage level from all directions?:	Yes	No
Depth of water on Staff Gage:			Time of Staff Gage Reading:		

### Installation: Recording Gage Instrument Setup

\*Label With Teodora Minkova's Contact Information: 360-902-1175, DNR Riparian Monitoring, and Site Number\*

Levellogger Serial number:	Barologger Serial number:
Start Date/ Time:	Start Date/ Time:
Water Level (cm; Levellogger):	Atmospheric Pressure (kPa, Barologger):
Time of Water Level Reading:	Time of Atmospheric Reading:
Levellogger Sampling Interval:	Barologger Sampling Interval:
Averaging? Y or N; sec:	Averaging? Y or N; sec:

Length from Tip of Sensor to Well Cap Top:	Barologger:	Length of PVC (Used for Wrap):
	Levellogger:	

Describe marking used to show if gage has shifted over time:

## Installation: Photos

Upstream Photo:	Downstream Photo:
Construction Photo(s):	
Final Recording Gage Photo(s):	Final Staff Gage Photo(s):
Final Recording Gage Anchor Photo(s):	Final Staff Gage Anchor Photo(s):

## General Notes:

Base Values of Manning's n (modified from United States Geological Survey Water-supply Paper 2339)			
Bed Material	Median Size of Bed Material (mm)	Straight Uniform Channel <sup>1</sup>	Smooth Channel (minimum value) <sup>2</sup>
Sand	0.2	0.012	--
	0.3	0.017	--
	0.4	0.02	--
	0.5	0.022	--
	0.6	0.023	--
	0.8	0.025	--
	1	0.026	--
Rock Cut	--	--	0.025
Firm Soil	--	0.025 to 0.032	0.02
Coarse Sand	1 to 2	0.026 to 0.035	--
Fine Gravel	--	--	0.024
Gravel	2 to 64	0.028 to 0.035	--
Coarse Gravel	--	--	0.026
Cobble	64 to 256	0.030 to 0.050	--
Boulder	>256	0.040 to 0.070	--

1 Benson and Dalrymple-No data.  
2 For indicated material; Chow (1959)

Manning's n for Channels (Chow, 1959).			
Type of Channel and Description	Minimum	Normal	Maximum
Natural streams - minor streams (top width at floodstage < 100 ft)			
<b>1. Main Channels</b>			
a. clean, straight, full stage, no rifts or deep pools	0.025	0.03	0.033
b. same as above, but more stones and weeds	0.03	0.035	0.04
c. clean, winding, some pools and shoals	0.033	0.04	0.045
d. same as above, but some weeds and stones	0.035	0.045	0.05
e. same as above, lower stages, more ineffective slopes and sections	0.04	0.048	0.055
f. same as "d" with more stones	0.045	0.05	0.06
g. sluggish reaches, weedy, deep pools	0.05	0.07	0.08
h. very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.1	0.15
<b>2. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages</b>			
a. bottom: gravels, cobbles, and few boulders	0.03	0.04	0.05
b. bottom: cobbles with large boulders	0.04	0.05	0.07
<b>3. Floodplains</b>			
a. Pasture, no brush			
1. short grass	0.025	0.03	0.035
2. high grass	0.03	0.035	0.05
b. Cultivated areas			
1. no crop	0.02	0.03	0.04
2. mature row crops	0.025	0.035	0.045
3. mature field crops	0.03	0.04	0.05
c. Brush			
1. scattered brush, heavy weeds	0.035	0.05	0.07
2. light brush and trees, in winter	0.035	0.05	0.06
3. light brush and trees, in summer	0.04	0.06	0.08
4. medium to dense brush, in winter	0.045	0.07	0.11
5. medium to dense brush, in summer	0.07	0.1	0.16
d. Trees			
1. dense willows, summer, straight	0.11	0.15	0.2
2. cleared land with tree stumps, no sprouts	0.03	0.04	0.05
3. same as above, but with heavy growth of sprouts	0.05	0.06	0.08
4. heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.08	0.1	0.12
5. same as 4. with flood stage reaching branches	0.1	0.12	0.16

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## Appendix 8D (a). Stream Discharge Field Forms: Velocity Area Method Using Flow Meter Hach FH 950

Stream Discharge Field Sheet-FH950							
Date:		Site:		Crew: Meter:		Recorder:	
Start Time (PST):				Start Staff Gage Level (closest 0.1 cm):			
End Time (PST):				End Staff Gage Level (closest 0.1 cm):			
Calibration Check (0 m/s):		YES    NO		Weather: Sunny    Cloudy    Drizzle    Rain    Windy			
Camera #:		Photos: Upstream:		Downstream:		Photopoint:	
* <b>Discharge Measurement Rating:</b> Excellent (2%)    Good (5%)    Fair (8%)    Poor (>8%)							
* Consider the quality of the cross-section, the uniformity of the velocity, equipment and method used, Spacing of each station and % discharge at each station, change in flow height and other factors such as weather.							
Station #	Distance Along Tape (m)	Distance from Left Edge of Water	Depth of Water (cm)	Method	Velocity 1	Velocity 2	Notes
		<i>Estimate to the closest 0.01 m</i>	<i>Estimate to the closest 1 cm</i>		<i>20 or 40 second averaging</i>	<i>20 or 40 second averaging</i>	<i>LEW, REW, stone affecting flow, vertical/ sloped edge, edge factor, etc.</i>
1				0.2 / 0.6 / 0.8			
2				0.2 / 0.6 / 0.8			
3				0.2 / 0.6 / 0.8			
4				0.2 / 0.6 / 0.8			
5				0.2 / 0.6 / 0.8			
6				0.2 / 0.6 / 0.8			
7				0.2 / 0.6 / 0.8			
8				0.2 / 0.6 / 0.8			
9				0.2 / 0.6 / 0.8			
10				0.2 / 0.6 / 0.8			
11				0.2 / 0.6 / 0.8			
12				0.2 / 0.6 / 0.8			
13				0.2 / 0.6 / 0.8			
14				0.2 / 0.6 / 0.8			
15				0.2 / 0.6 / 0.8			
16				0.2 / 0.6 / 0.8			
17				0.2 / 0.6 / 0.8			
18				0.2 / 0.6 / 0.8			
19				0.2 / 0.6 / 0.8			
20				0.2 / 0.6 / 0.8			
21				0.2 / 0.6 / 0.8			
22				0.2 / 0.6 / 0.8			
23				0.2 / 0.6 / 0.8			
24				0.2 / 0.6 / 0.8			
25				0.2 / 0.6 / 0.8			
26				0.2 / 0.6 / 0.8			
27				0.2 / 0.6 / 0.8			
28				0.2 / 0.6 / 0.9			
29				0.2 / 0.6 / 0.10			
Total Q:		Q units:		Meters/Sec or Meters/Min			
Max V:		Max units:		Meters/Sec or Meters/Min			
Station > 5% of Q?		YES    NO		Station > 10% of Q?		YES    NO	
Notes/Other photos:							

## Appendix 8D (b). Stream Discharge Field Forms: Velocity Area Method Using Marsh-McBirney Flow Meter

Stream Discharge Field Form: Velocity-Area Method Using Marsh McBirney							
Date:		Site:		Crew:			
Start Time (PST or PDT):			Start Staff Gage Level (closest 0.001 m):				
End Time (PST or PDT):			End Staff Gage Level (closest 0.001 m):				
Instrument Serial Number:				Weather: Sunny Cloudy Drizzle Rain Windy			
Calibration Check (0 m/s)?							
Camera #:		Photos: Upstream		Downstream		Other	
Station #	Distance Along Tape (m)	Distance from Left Edge of Water	Depth of Water (cm)	Method	Velocity 1	Velocity 2	Notes
		<i>Estimate to the closest 0.01 m</i>	<i>Estimate to the closest 1 cm</i>		<i>20 or 40 second averaging</i>	<i>20 or 40 second averaging</i>	<i>Right bank, left bank, stone affecting flow, roughness</i>
0				0.2 / 0.6 / 0.8			
1				0.2 / 0.6 / 0.8			
2				0.2 / 0.6 / 0.8			
3				0.2 / 0.6 / 0.8			
4				0.2 / 0.6 / 0.8			
5				0.2 / 0.6 / 0.8			
6				0.2 / 0.6 / 0.8			
7				0.2 / 0.6 / 0.8			
8				0.2 / 0.6 / 0.8			
9				0.2 / 0.6 / 0.8			
10				0.2 / 0.6 / 0.8			
11				0.2 / 0.6 / 0.8			
12				0.2 / 0.6 / 0.8			
13				0.2 / 0.6 / 0.8			
14				0.2 / 0.6 / 0.8			
15				0.2 / 0.6 / 0.8			
16				0.2 / 0.6 / 0.8			
17				0.2 / 0.6 / 0.8			
18				0.2 / 0.6 / 0.8			
19				0.2 / 0.6 / 0.8			
20				0.2 / 0.6 / 0.8			
21				0.2 / 0.6 / 0.8			
22				0.2 / 0.6 / 0.8			
23				0.2 / 0.6 / 0.8			
24				0.2 / 0.6 / 0.8			
25				0.2 / 0.6 / 0.8			
26				0.2 / 0.6 / 0.8			
27				0.2 / 0.6 / 0.8			
28				0.2 / 0.6 / 0.8			
29				0.2 / 0.6 / 0.8			
30				0.2 / 0.6 / 0.8			
<b>Discharge Measurement Rating:</b> Excellent (2%) Good (5%) Fair (8%) Poor (>8%)							
* Consider the quality of the cross-section, the uniformity of the velocity, equipment and method used, Spacing of each station and % discharge at each station, change in flow height and other factors such as weather.							
Comments on Control/ General Notes:							



## Appendix 8D (c). Stream Discharge Field Forms: Naturally Buoyant Method

Stream Discharge Field Form: Neutrally-Buoyant Method						
Date:		Site:		Crew:		
Start Time (PST or PDT):			Start Staff Gage Level (closest 0.001 m):			
End Time (PST or PDT):			End Staff Gage Level (closest 0.001 m):			
Weather: Sunny Cloudy Drizzle Rain Windy		Slope (%):		Object used: whiffle ball stick other:		
Camera #:		Photos: Upstream		Downstream		Other
<b>Area Calculation</b>						
Cross-Section	Depth (cm)	LB	2	3	4	RB
<b>Upper</b>	Depth (cm)					
	Distance from LB (m)					
	Manning's #					
<b>Middle</b>	Depth (cm)					
	Distance from LB (m)					
	Manning's #					
<b>Lower</b>	Depth (cm)					
	Distance from LB (m)					
	Manning's #					
<b>Length of Test Section (m)</b>						
	<b>Time (sec)</b>					
<b>Right Bank</b>						
<b>Center</b>						
<b>Left Bank</b>						
<b>Average Time (sec)</b>						
<b>Discharge Measurement Rating:</b> Excellent (2%) Good (5%) Fair (8%) Poor (>8%)						
* Consider the quality of the cross-section, the uniformity of the velocity, equipment and method used, Spacing of each station and % discharge at each station, change in flow height and other factors such as weather.						
Notes:						

# Appendix 8D (d). Stream Discharge Field Forms: Slope Area Method

Stream Discharge Field Sheet- Slope Area Method									
Date:		Site:			Crew:				
GPS #:		Weather: Sunny Cloudy Drizzle Rain Windy							
Start Time (PST or PDT):				Start Staff Gage Level (closest 0.001 m):					
End Time (PST or PDT):				End Staff Gage Level (closest 0.001 m):					
Photopoint Photo: Camera #				Photo #					
Reach Length:		Established Crosssections Used:							
Tributaries in Reach?: Yes No		Trib Notes:							
Control Point: Tree Other?:		Marked With?:							
Distance and Bearing Control Point to Basin RP:									
GPS Coordinates of Control Point: N:					W:				
X-Section 1 (Furthest Downstream)									
Previously Established X- Section?: Yes No					X-Section #:				
Seq. #	Distance	Bearing	Elevatio	Point ID	Mannings	Point Quality	Backsite	BS Height	Notes/photos:
1				X1-1		E   G   F   P			
2				X1-2		E   G   F   P			
3				X1-3		E   G   F   P			
4				X1-4		E   G   F   P			
5				X1-5		E   G   F   P			
6				X1-6		E   G   F   P			
7				X1-7		E   G   F   P			
8				X1-8		E   G   F   P			
9				X1-9		E   G   F   P			
10				X1-10		E   G   F   P			
Highwater Marks									
Seq. #	Distance	Bearing	Elevatio	Point ID	Mannings	HWM Quality	Backsite	BS Height	Notes/Photos:
1R				RH-1		E   G   F   P			
1L				LH-1		E   G   F   P			
2R				RH-2		E   G   F   P			
2L				LH-2		E   G   F   P			
3R				RH-3		E   G   F   P			
3L				LH-3		E   G   F   P			
4R				RH-4		E   G   F   P			
4L				LH-4		E   G   F   P			
5R				RH-5		E   G   F   P			
5L				LH-5		E   G   F   P			
6R				RH-6		E   G   F   P			
6L				RH-6		E   G   F   P			

Notes:

**X-Section 2 (Middle)**

Previously Established X- Section?: Yes No					X-Section #:				
Seq. #	Distance	Bearing	Elevatio	Point ID	Mannings	Point Quality	Backsite	BS Height	Notes/photos:
11				X2-1		E   G   F   P			
12				X2-2		E   G   F   P			
13				X2-3		E   G   F   P			
14				X2-4		E   G   F   P			
15				X2-5		E   G   F   P			
16				X2-6		E   G   F   P			
17				X2-7		E   G   F   P			
18				X2-8		E   G   F   P			
19				X2-9		E   G   F   P			
20				X2-10		E   G   F   P			

**Highwater Marks**

Seq. #	Distance	Bearing	Elevatio	Point ID	Mannings	HWM Quality	Backsite	BS Height	Notes/photos:
7R				RH-7		E   G   F   P			
7L				LH-7		E   G   F   P			
8R				RH-8		E   G   F   P			
8L				LH-8		E   G   F   P			
9R				RH-9		E   G   F   P			
9L				LH-9		E   G   F   P			
10R				RH-10		E   G   F   P			
10L				LH-10		E   G   F   P			
11R				RH-11		E   G   F   P			
11L				LH-11		E   G   F   P			
12R				RH-12		E   G   F   P			
12L				RH-12		E   G   F   P			

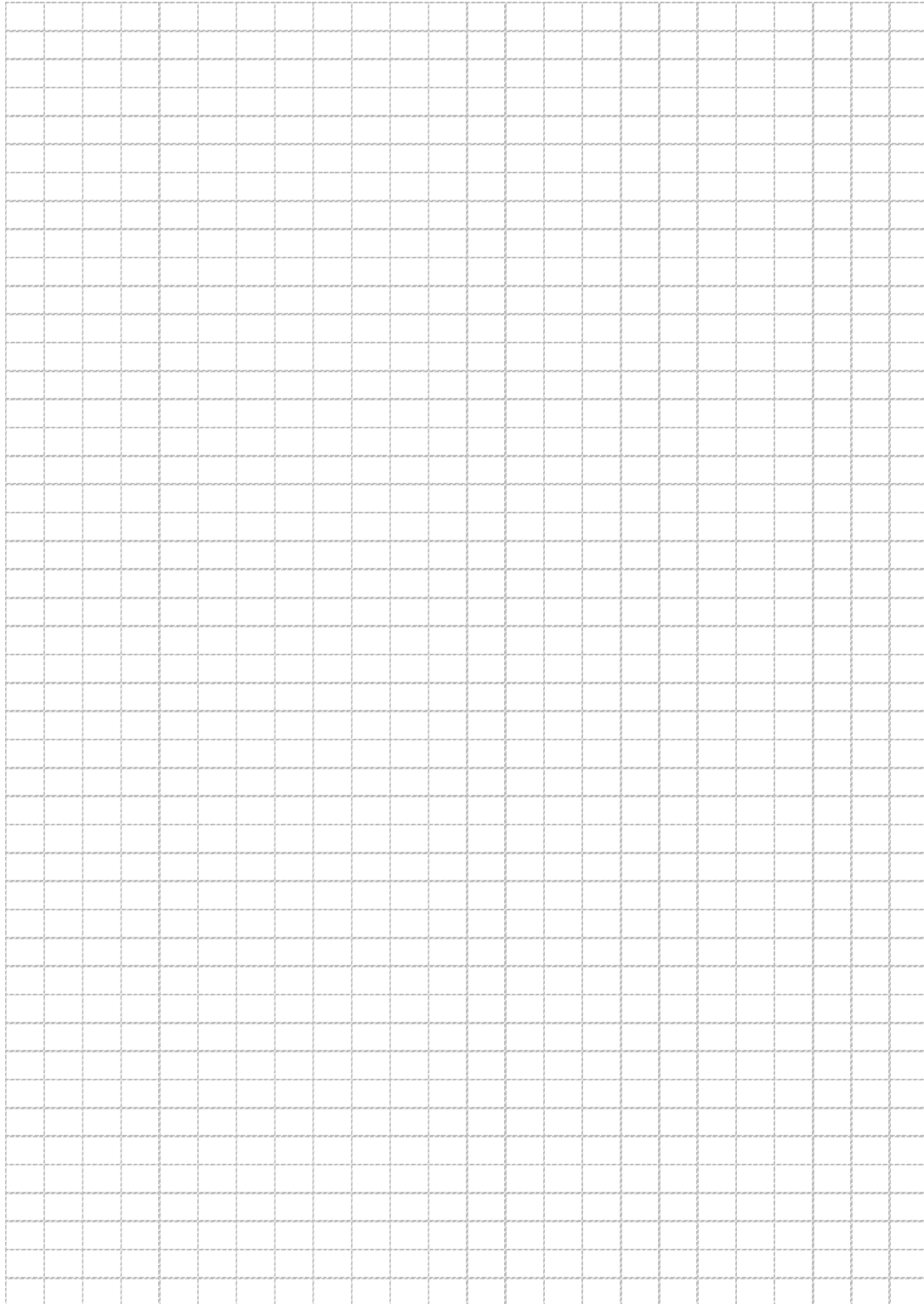
**X-Section 3 (Furthest Upstream)**

Previously Established X- Section?: Yes No					X-Section #:				
Seq. #	Distance	Bearing	Elevatio	Point ID	Mannings	Point Quality	Backsite	BS Height	Notes/photos:
21				X3-1		E   G   F   P			
22				X3-2		E   G   F   P			
23				X3-3		E   G   F   P			
24				X3-4		E   G   F   P			
25				X3-5		E   G   F   P			
26				X3-6		E   G   F   P			
27				X3-7		E   G   F   P			
28				X3-8		E   G   F   P			
29				X3-9		E   G   F   P			
30				X3-10		E   G   F   P			

Notes:



Plan View (number each point and label codes on additional sheet)





# Appendix 8E. Elevation Survey for Cross-Section Stability Field Form

## GAGE STATION AND CROSS SECTION STABILITY SURVEY

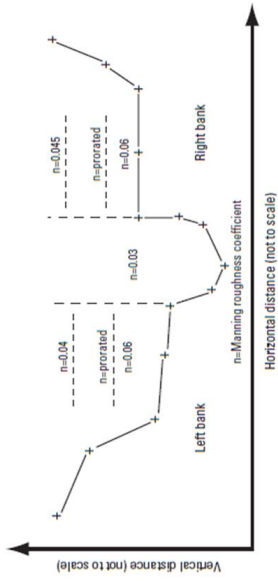
Gage Station description	Basin #	Field crew:	
	Date:	Survey start time:	Survey end time:
	Remarks on site condition (e.g. recent disturbance, lost RP, management activity):		Weather: heavy rain, light rain, cloudy, sunny, foggy, windy, snow, snowing
	Photo point marked with:	Monument LB: yes no	Start of Survey Staff Gage Reading (m):
	Photo target:	Monument RB: yes no	End of Survey Staff Gage Reading (m):
	Picture #:		
	Camera #:		
	Gage x-section location (LB monument) from 2 points:		
	1) Nearest x-section's LB monument:	Distance (m):	Azimuth:
	2) Backsite Location:	Distance (m):	Azimuth:

Notes/sketches:





Cross section sketch with Manning's Coefficient; label significant points and banks.



**Cross Section Stability Survey Ancillary Data Sheet - page 1**

Site: \_\_\_\_\_ Camera Number: \_\_\_\_\_  
 Date and Time: \_\_\_\_\_ Photo Range: \_\_\_\_\_  
 Staff: \_\_\_\_\_

Directions: Along with the survey data, be sure to note the following information:

Manning's n

Note changes in the roughness and estimate Manning's n at every subsection; including overbank/floodplain areas

Sketches

- 1) Draw a plan view of the entire reach
- 2) Draw side-views for each cross-section; note right and left banks along with significant changes in slope, channel roughness, obstructions, or irregularities in the flow field

Notes

- 1) General comments on weather and location
- 2) Details about cross-section and features of channel

Pictures Take many pictures of the cross-sections and channel features, including Manning's n features, so that you can verify conditions when back in the office.

Points to gather:

Floodplain elevation points; extended out to next break in grade after main channel (100 yr FP)

Major points of inflection in the channel used to estimate channel area and hydraulic radius

Changes in channel roughness (Manning's n)

RGT: The top of the recording gage sensor housing,

RGB: The bottom point of the recording gage sensor housing (describe in notes and with a photo)

SGT: One point on the top of the staff gage (if present) or on the staff gage data point

SGB: One point on the bottom of the staff gage or fixed point used for staff measurement (if present)

RP: Benchmark

WSE: Water surface at the time of survey on both right and left bank

Staff Gage Reading: Record the staff gage reading at the same time the survey is completed.

Note that the survey should start on the left bank and move right.

Enter the final, processed elevations into the Access database following field work.

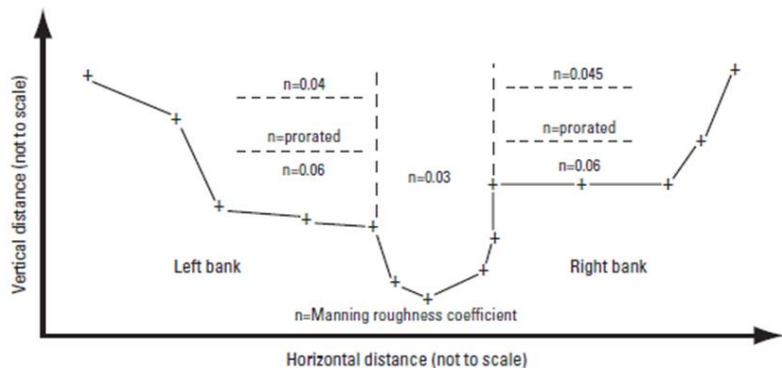
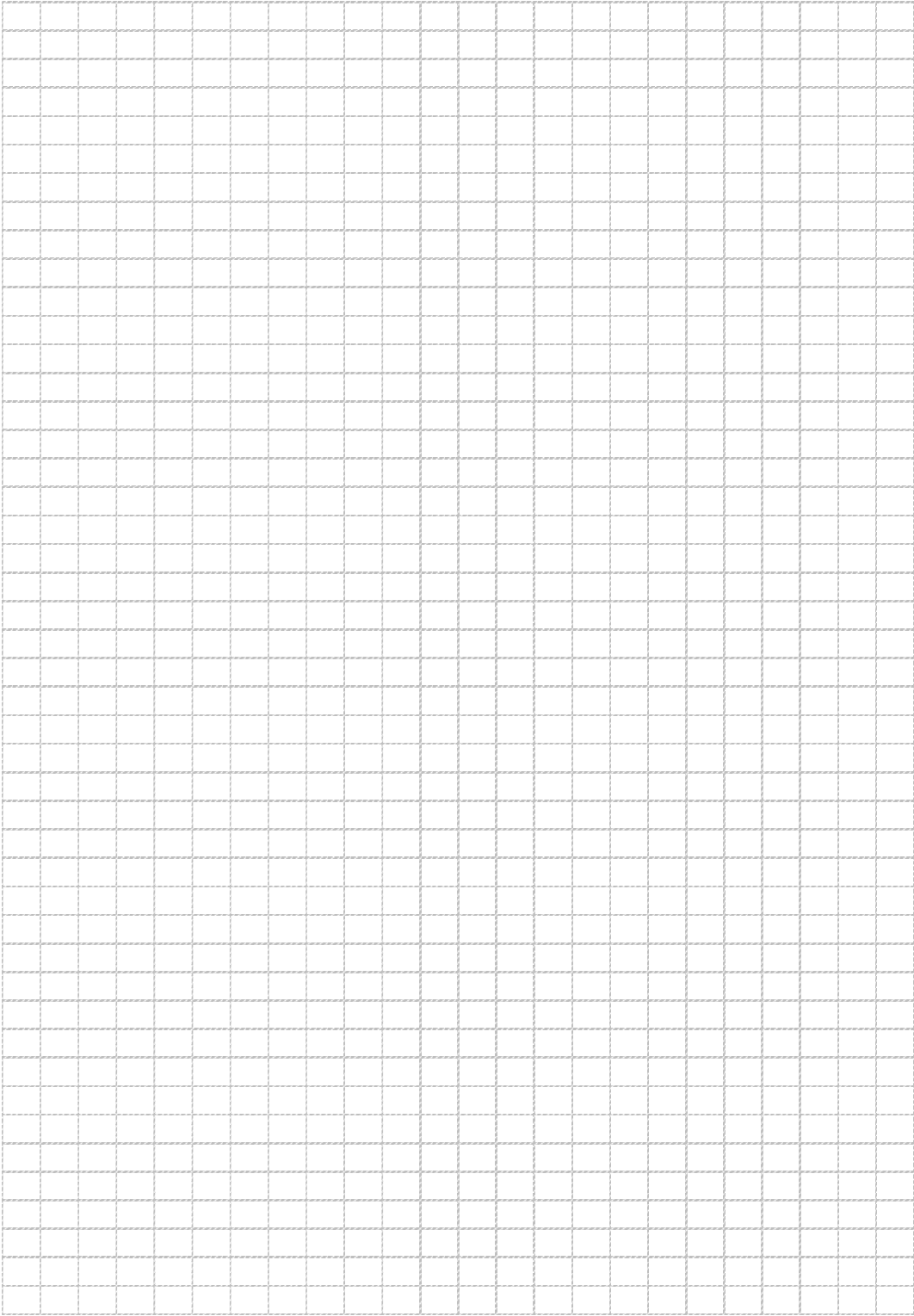


Figure 1: Example of cross-section sketch with notation method for Manning's n

Notes:

Side View of Cross Section and Plan View of Relationship between RP and Gages



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## **Appendix 8F. Directions for Using Flow Meter Hach FH950**

**Manual at:** [https://www.hachflow.com/pdf/FH950\\_User\\_Manual.pdf](https://www.hachflow.com/pdf/FH950_User_Manual.pdf)

### **Directions for setting up the instrument**

**Step 1:** Connect sensor. Upon startup of the meter, it will run a self-test, which takes several seconds. Note whether this test is passed or not. If not passed, return to the manufacturer for repairs.

**Step 2:** Perform a velocity calibration once per day. Using a non-metallic bucket of still water at least 16 cm (6 in) deep, place the sensor in the center of the bucket so that it doesn't touch the sidewall or bottom of bucket. After the water has stilled, go to "Setup->Velocity Calibration" and follow the directions on the screen. Observe the velocity reading, and wait for it to stabilize. When it's stable, select "Zero Velocity", then select "OK" to finish.

**Step 3:** After velocity calibration, verify that the settings of the instrument are correct. Under Setup->Filter Parameters->Main Filter->Fixed Period Avg., and set the value to 40 seconds.

**Step 4:** Go to Setup->Units->Metric, and select the following: velocity (cm/s), flow (m<sup>3</sup>/minute), depth (cm), and area (cm<sup>3</sup>).

**Step 5:** Go to Setup->Flow Calculation, and verify that "Mid-section" is selected.

**Step 6:** Under Setup->Station Entry, select "Non-fixed" and then "Top" to permit changing the distance between stations.

**Step 7:** Under Setup->Measurement Resolution, select "0.001". Setup is now complete.

### **Directions for taking a discharge measurement**

**Step 1:** In main menu, select, "Profiler."

**Step 2:** Enter the operator name (initials of person using instrument).

**Step 3:** Select the type of cross section you will be measuring, "Stream." If you need to change the Fixed Point Averaging (FPA) time, you can also do that at this screen under "Setup."

**Step 4:** Enter name for stream (11 characters) in the format, "site number\_YMMMDD" (e.g., 790\_171227). If an additional measurement is taken at this site on the same day, add "b, c, d..." to the end of the file name.

**Step 5:** Leave the stage reference blank.

**Step 6:** In the "Station" menu, select "Edge/Obstruction." Choose the starting edge (left whenever possible).

**Step 7:** Enter the "Distance to Vertical," or the distance from your first station to the starting edge.

**Step 8:** Select "Set Depth" and enter the actual depth. If you are at an edge, the depth is automatically zero. If you have a sheer edge, your next station should be as close to the edge as possible.

**Step 9:** Enter the "Edge Factor," which is a roughness estimator/multiplier. The scale ranges from 0.50 (very rough) to 1.0 (totally smooth). The roughness factor is relevant only for right angled cross sections. It is used as a factor in the calculation of the discharge proportion of edge areas. For example:

- Smooth edge with no vegetation (e.g., concrete, steel, cement) - 0.8 to 0.9
- Brick sides with vegetation— 0.7
- Rough walls with heavy vegetation—0.6 to 0.5

**Step 10:** Select “Measure Velocity.” If you are at an edge, you will not have this option as the velocity is assumed to be zero. You will next be prompted to select the number of points at which you will measure velocity at this station. See the discharge guidelines above for a discussion of when to collect more than one point. Generally, you will collect a single point at 0.6 times the water depth.

**Step 11:** Select the measurement point (ex. 0.6). Obey the instrument prompts and adjust the sensor to the correct depth.

**Step 12:** Once the sensor is adjusted and it has had a few moments to adjust to the new station velocity, select, “Capture.” Once you push this button, the instrument will begin collecting data.

**Step 13:** Once the instrument has finished reading, if you believe the value to be accurate, select “Verify” to see the result. Then return to the main menu and select “Next” to go to the next station.

**Step 14:** Repeat steps until you reach the opposite edge where you will repeat the edge reading.

**Step 15:** When all of the measurements have been completed, select “Channel Summary” to view the results. If any of the sections contain >5% of the total discharge, you will have the opportunity to add additional stations within these sections. NOTE: If the stations are already at the minimum distance apart (10 cm), do not take additional readings.

**Step 16:** To insert a new station, navigate back to the station before the location you would like to add a measurement to. For example, if you want to add a measurement between stations 3 and 4, navigate to station 3 and push “OK” to display the station settings. Select “Ins” and push “OK.”

**Step 17:** To delete a station, navigate to the desired station and select “Del” and “OK.”

**Step 18:** Be sure to select “Save Data and Exit” when you finish the measurements. Enter the file name as “<site number>\_MMDD”.

### **Directions for transferring data from the Hach FH950 to the field laptop:**

**Step 1:** Connect the Hach FH950 to the field laptop using the USB cable. The laptop will treat the instrument like a USB storage device, though it is read-only.

**Step 2:** Transfer the files to a directory location specified by the OESF Data Manager. The files should be stored in a subdirectory labeled with the type of data and date. Make sure the number of files is what you expect it to be.

**Step 3:** To delete files off of the meter (please do this once the files are saved on the network AND backed up in a location of your choosing), you must use the handheld device. Select “Main Menu->Diagnostics->Delete Files,” and follow the prompts.



## Appendix 8G. Slope-Area Method Guidance

Base Values of Manning's n (modified from United States Geological Survey Water-supply Paper 2339)			
Bed Material	Median Size of Bed Material	Straight Uniform Channel <sup>1</sup>	Smooth Channel (minimum)
Sand	0.2	0.012	--
	0.3	0.017	--
	0.4	0.02	--
	0.5	0.022	--
	0.6	0.023	--
	0.8	0.025	--
	1	0.026	--
Rock Cut	--	--	0.025
Firm Soil	--	0.025 to 0.032	0.02
Coarse Sand	1 to 2	0.026 to 0.035	--
Fine Gravel	--	--	0.024
Gravel	2 to 64	0.028 to 0.035	--
Coarse Gravel	--	--	0.026
Cobble	64 to 256	0.030 to 0.050	--
Boulder	>256	0.040 to 0.070	--

<sup>1</sup> Benson and Dalrymple-No data.  
<sup>2</sup> For indicated material; Chow (1959)

Manning's n for Channels (Chow, 1959).			
Type of Channel and Description	Minimum	Normal	Maximum
Natural streams - minor streams (top width at floodstage < 100 ft)			
<b>1. Main Channels</b>			
a. clean, straight, full stage, no rifts or deep pools	0.025	0.03	0.033
b. same as above, but more stones and weeds	0.03	0.035	0.04
c. clean, winding, some pools and shoals	0.033	0.04	0.045
d. same as above, but some weeds and stones	0.035	0.045	0.05
e. same as above, lower stages, more ineffective slopes and sections	0.04	0.048	0.055
f. same as "d" with more stones	0.045	0.05	0.06
g. sluggish reaches, weedy, deep pools	0.05	0.07	0.08
h. very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.1	0.15
<b>2. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages</b>			
a. bottom: gravels, cobbles, and few boulders	0.03	0.04	0.05
b. bottom: cobbles with large boulders	0.04	0.05	0.07
<b>3. Floodplains</b>			
a. Pasture, no brush			
1. short grass	0.025	0.03	0.035
2. high grass	0.03	0.035	0.05
b. Cultivated areas			
1. no crop	0.02	0.03	0.04
2. mature row crops	0.025	0.035	0.045
3. mature field crops	0.03	0.04	0.05
c. Brush			
1. scattered brush, heavy weeds	0.035	0.05	0.07
2. light brush and trees, in winter	0.035	0.05	0.06
3. light brush and trees, in summer	0.04	0.06	0.08
4. medium to dense brush, in winter	0.045	0.07	0.11
5. medium to dense brush, in summer	0.07	0.1	0.16
d. Trees			
1. dense willows, summer, straight	0.11	0.15	0.2
2. cleared land with tree stumps, no sprouts	0.03	0.04	0.05
3. same as above, but with heavy growth of sprouts	0.05	0.06	0.08
4. heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.08	0.1	0.12
5. same as 4. with flood stage reaching branches	0.1	0.12	0.16

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## **Appendix 8H. Solinst® Leveloader, Levelogger, and Barologger Setup and Retrieval of data from Levelogger Water Level Sensor**

This section includes specific computer commands for the setup and downloading of data using a laptop and the Solinst Leveloader data transfer device. The choice of how frequently to download data is not necessarily limited by the storage capacity of the water level sensor. Most units are capable of storing many months' worth of data. Instead, a greater concern is equipment failure. Infrequent data retrieval could result in the loss of considerable amounts of data. If the equipment has failed, it would be better to know sooner than later.


### **Directions for setting up the Levelogger and Barologger sensors using a computer**


**Step 1:** Connect logger to the computer using either the Direct Read cable or Base Station.

**Step 2:** Select the “Datalogger Settings” tab, then select the “Retrieve Datalogger Settings” button in the upper, left-hand corner.



**Step 3:** Under the “Datalogger Sampling Mode,” choose the “Linear” tab and then set the “Sampling Rate” to 15 minutes.

**Step 4:** Under “Datalogger Memory Mode,” select “Slate” 

**Step 5:** Under “Start/Stop Datalogger,” check the “Future Start,” box and set for the desired start time; then select “Start Now.” 

### **Directions for setting up the Leveloader**

**Step 1:** Connect the Leveloader to the computer.

**Step 2:** Open the Solinst program, select the “Leveloader” tab on the upper right hand side of the window.


**Step 3:** Select the “Retrieve Leveloader Settings” button 

**Step 4:** Set the computer time to Pacific Standard time; then select “Synchronize” button on the bottom left side of the screen.

**Step 5:** Under “Levelogger Default File Settings,” name the “Settings Title” with the type of logger and the interval (ex. Level\_15min).

**Step 6:** Under “Levelogger Type,” select the Sensor type (LT-Edge or LT-Edge-Baro).

**Step 7:** Under “Logger Sampling Mode,” select the “Linear” tab and set the “Sampling Rate” to 15 minutes.

**Step 8:** Once settings are finalized, select “Apply Leveloader Settings,” to transfer the settings file to the Leveloader. 

**Step 9:** Disconnect the Leveloader from the computer.

### **Directions for setting up a levelogger or barologger sensor with the leveloader**

**Step 1:** Connect the leveloader to the logger using the “Direct Read” or “Direct Connect” cable.

**Step 2:** Select “Connect to Logger” on the Leveloader Gold Menu

**Step 3:** On the Levelogger Menu select “Load Settings File”

**Step 4:** In the Load Settings Files Menu find the appropriate settings file (ex. If you are starting a Barologger and want 15min logging intervals select the “Baro\_15min” settings file). Once a settings file is selected it will load onto the logger and a confirmation message will appear. The Leveloader will then direct you back to the Levelogger Menu.

### **Directions for double checking the settings file loaded on the logger**

**Step 4a:** Select “Edit Levelogger” from the Levelogger Menu.

**Step 4b:** From the Edit levelogger Menu select “Edit Sample Rate”. Observe the units and time duration to insure it is what you intended to be selected. Return to the “Edit Levelogger Menu” by selecting “Submit”.

**Step 4c:** From the Edit levelogger Menu select “Edit Unit”. Insure the unit of measurement selected for depth is meters, Pressure is kPa and temperature is degrees Celsius. When the desired units are shown select “OK” return to the Edit Levelogger menu.

**Step 4d:** Once logger setting are reviewed select “Menu” to return to the Levelogger menu.

**Step 5:** Select “Restart Levelogger” on the Levelogger Menu.

**Step 6:** Select “Future Start Logging” on the Restart Levelogger menu.

**Step 7:** If prompted to, stop the logger by pressing the up and down buttons on the instrument at the same time. Remember to save the data on the logger before restarting.

**Step 8:** Input the preferred start time and select “Submit”. Once selected a confirmation message will appear informing you that the logger has been restarted.

\* Save the data on the logger to the computer before restarting the water level sensor\*

## **Directions for downloading the Levellogger and Barologger sensors using a Leveloader**

**Step 1:** Open the locking well cap and remove direct read cable caps.

**Step 2:** Before connecting the cable to the Leveloader first screw it onto the direct read cable, then connect it to the Leveloader.

**Step 3:** Turn on the Leveloader and select “connect to Logger”

**Step 4:** Select “Real Time-View Only” and enter the real time depth or barometric pressure and temperature in the field form. Then select “Menu” to return back to the main menu.

*Note: You cannot tell if it is the Barologger or Levellogger until this point. Check the units used to identify which logger it is. If it is the Levellogger the units will be in meters and be generally around 10.00m. If it is the Barologger the units will be in Kilopascals and generally be around 100kPa.*

**Step 5:** Select “Data from Levellogger”

**Step 5a:** Write down the serial number located at the top of the screen (ex. #202xxxx) in the “SN:” section of the field form.

**Step 5b:** Check the download intervals under the “Time” header. There should be a download every 15 minutes. Enter the download interval into the “Time Interval” section of the field form

**Step 5c:** Check the battery percentage in the upper right hand side of the screen and enter it into the “Real-Time battery” section of the field form.

**Step 5d:** Finally, select “Save Log” to save all the data off the logger. Once the log has been saved it will automatically return you to the Levellogger menu.

**Step 6:** Select “Edit Levellogger” (*note: it says “Edit Levellogger” whether you are connect to the Levellogger or the Barologger*). Stop the Leveloader by pressing the Up and Down arrows at the same time. Next, sync the time by pressing “Edit” while the cursor is on the “Time (sync to loader)” tab. Press the “Menu” button to return back to the main menu. Write “Yes” under in the “Sync Time?” section of the field form.

**Step 7:** At the very bottom of the main menu select “Restart Levellogger” (*note: this is on the next page so if you don't immediately see it just keep going down on the main menu*)

**Step 7a:** select “Future Start Logging” and press “OK” at the scary warning screen (unless you haven't downloaded the data off the logger)

**Step 7b:** Enter the start time as the next even :15 minute interval (X:00:00, X:15:00, X:30:00, or X:45:00). Move the cursor to the number you want to edit by selecting the ”NXT” tab. Then using the up and down arrows select the number you want to enter. The date format is YY:MM:DD

**Step 7c:** Select “Submit” when you have successfully entered the date and time you would like the logger to start on. Enter the date and time you selected into the field form under “Restart date and time”

**Step 8:** Disconnect the cable from the Leveloader, then the direct read cable and reconnect it on the logger you have not downloaded yet and repeat steps 2-7.

### **Directions for downloading the Levelogger and Barologger sensors using a computer**

**Step 1:** Connect the sensor to a computer using the base station.

**Step 2:** Open The Solinst software and select the “Data Control” tab.

**Step 3:** Select the “Download Data” icon 

**Step 4:** Save the data into the appropriate folder. “Desktop\Hydrologic Databases\Recording Gage Data”, then select the “Recording\_Gage\_Site\_Site\_Number” folder for the desired watershed and put the files into the “SiteNumber\_Levelogger\_Barologger\_files” folder. Save the file using the naming convention “YYMMDD\_SiteNumber\_LL or BL”.


**Step 5:** Copy paste the Barologger or Levelogger data file from the desktop folder into the appropriate network folder: “\\snarf\div\_lm\ecosystem\monitoring\_research\tminkova\OESF\_Projects\10\_Rip S&T Mon\01\_FIELD DATA\06\_Hydrology\Hydrologic Databases\Recording Gage Data”, then select the “Recording\_Gage\_Site\_Site\_Number” folder for the desired watershed and paste the files into the “SiteNumber\_Levelogger\_Barologger\_files” folder.

### **Directions for downloading the Leveloader data onto a computer**

**Step 1:** Connect Leveloader to laptop using the micro USB cable.

**Step 2:** Select “Data to PC” on the Leveloader’s main menu.

**Step 3:** On the laptop, open the Solinst software. When the application opens select the “Leveloader” tab on the top right side of the window.

**Step 4:** On the laptop, select the “Retrieve Leveloader Settings” icon. Make sure you have selected the correct Com Port. 

**Step 5:** Check the boxes of only the Barologger and Levelogger combination you wish to download. Then

click the “Download Data” icon. 

**Step 6:** download the files onto the laptop into their appropriate folders. “Desktop\Hydrologic Databases\Recording Gage Data”, then select the “Recording\_Gage\_Site\_Site\_Number” folder for the desired watershed and put the files into the “SiteNumber\_Levelogger\_Barologger\_files” folder. Save the file using the naming convention “YYMMDD\_SiteNumber\_LL or BL”

**Step 7:** When the files have downloaded select “Finish and Open all”. View the files and look for any irregularities.

**Step 8:** Repeat steps 5-7 for all loggers.

**Step 9:** Once all the loggers have been downloaded copy paste each Barologger and Levellogger pair into the appropriate network folder:

“\\snarf\div\_lm\ecosystem\monitoring\_research\tminkova\OESF\_Projects\10\_Rip S&T Mon\01\_FIELD DATA\06\_Hydrology\Hydrologic Databases\Recording Gage Data”, then select the

“Recording\_Gage\_Site\_Site\_Number” folder for the desired watershed and paste the files into the


“SiteNumber\_Levellogger\_Barologger\_files” folder.

### **Directions for Levellogger barometric compensation**

**Step 1:** On the laptop, open the Solinst software and select the Data Wizard tab.

**Step 2:** Select “Basic: Barometric Compensation (only)” and click next (at the bottom right of window)

**Step 3:** Click the Open File icon and navigate to the desired Levellogger and Barologger pair you wish to

compensate. 

**Step 4:** Highlight the Barologger and Levellogger files you wish to compensate by clicking on them. Then click next.

**Step 5:** Once the files have been compensated click the Open button and look for any irregularities in the data.

**Step 6:** Export the data by clicking the Export Data icon and selecting Export Data. 

**Step 7:** Navigate to the appropriate folder: “Desktop\Hydrologic Databases\Recording Gage Data” folder for the desired watershed and paste the files into the “Recording\_Gage\_Site\_Site\_Number” folder. Use the naming convention “YYMMDD\_SiteNumber\_LL\_Comp\_Exp”.

**Step 8:** Repeat steps 2-7 for all Barologger and Levellogger file combinations.

**Step 9:** Once all the loggers have been Compensated copy paste each compensated Levellogger file into the appropriate network folder:

“\\snarf\div\_lm\ecosystem\monitoring\_research\tminkova\OESF\_Projects\10\_Rip S&T Mon\01\_FIELD DATA\06\_Hydrology\Hydrologic Databases\Recording Gage Data”, and paste the files into the appropriate

“Recording\_Gage\_Site\_Site\_Number” folder.

**Step 10:** Open the data using Excel and Re-save the file as an .xlsx file.



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## ***Appendix 8I. List of Instrument Manuals***

Solinst Levellogger Series - Quick Start Guide

<http://www.solinst.com/products/dataloggers-and-telemetry/3001-levellogger-series/operating-instructions/quick-start-guide/3001-quick-start-guide.pdf>

Solinst Levellogger Series - Software Version 4, November 5, 2013

<http://www.solinst.com/products/dataloggers-and-telemetry/3001-levellogger-series/operating-instructions/user-guide/3001-user-guide.pdf>

Solinst Levellogger Series – Technical Specifications and Setup

<http://www.solinst.com/products/data/3001.pdf>

Solinst DataGrabber – User Guide

<https://www.solinst.com/products/dataloggers-and-telemetry/3001-levellogger-series/datagrabber/operating-instructions/3001-datagrabber-115003.pdf>

HAC FH950 Flow Meter – Technical Specifications

[http://www.hachflow.com/pdf/FH950\\_ds.pdf](http://www.hachflow.com/pdf/FH950_ds.pdf)

HAC FH950 Flow Meter – User Manual

[https://www.hachflow.com/pdf/FH950\\_User\\_Manual.pdf](https://www.hachflow.com/pdf/FH950_User_Manual.pdf)

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# Stream Discharge Data Management and Analysis

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*Version:* 1.4

## *Revision History:*

Version number	Purpose / Changes	Author(s)	Reviewer(s)	Date
1.0	Initial draft presented to project staff	Rachel LovellFord	Teodora Minkova Jeffrey Ricklefs	06/23/2014
1.1	Draft submitted for second review	Rachel LovellFord Warren Devine	Teodora Minkova Ellis Cropper	12/15/2014
1.2	Final draft protocol	Warren Devine	Teodora Minkova	6/06/2016
1.3	Final technical review and edit	Warren Devine	Warren Devine, Alex Foster	12/18/2016
1.4	Addition of new protocols for creating the rating curve and hydrograph	Jeff Keck	Warren Devine	11/17/2022

## *Based on the Following Protocols:*

Sauer, V.B. 2002. Standards for the analysis and processing of surface-water data and information using electronic methods: U.S. Geological Survey Water-Resources Investigations Report 01–4044, 91 p.

Le Coz, J., Renard, B., Bonnifait, L., Branger, F., Le Boursicaud, R. 2014, Combining hydraulic knowledge and uncertain gaugings in the estimation of hydrometric rating curves: A Bayesian Approach, *Journal of Hydrology*. 509:573-587.

Bouwes, N., J. Moberg, N. Weber, B. Bouwes, S. Bennett, C. Beasley, C.E. Jordan, P. Nelle, M. Polino, S. Rentmeester, B. Semmens, C. Volk, M.B. Ward, and J. White. 2011. Scientific protocol for salmonid habitat surveys within the Columbia Habitat Monitoring Program. Prepared by the Integrated Status and Effectiveness Monitoring Program and published by Terraqua, Inc., Wauconda, WA. 118 p.

## *Reasons to Adopt the Above Protocols:*

Data management in this protocol is based on the United States Geological Survey (USGS) standards for the analysis and processing of surface-water data and information (Sauer 2002). Analysis is based largely on Le Coz et al. (2014), which is a newer, widely applied method for combining direct observations with indirect, hydraulics-based flow measurements and was published in the *Journal of Hydrology*, a reputable, peer-reviewed journal. Bouwes et al. (2011) provides additional insight and specifications from a long-running monitoring program with similar budget and monitoring goals.

## *Purpose and content:*

This protocol details the data management, quality assurance, and analytical steps necessary to document and report the status and trends of stream discharge at gaged stream watersheds within the Olympic Experimental

## ■ Stream Discharge Data Management and Analysis

State Forest (OESF). The protocol ultimately describes the process of computing a time series of streamflow data (i.e., a time series hydrograph) using data collected using the *Stream Discharge Field Protocol*.

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## Introduction

This chapter describes activities associated with management and analysis of hydrology data collected as described in Chapter 8 (*Stream Discharge*). The first four sections of this chapter focus on the four classes of hydrology data: gaging station metadata, recording gage data, discharge data, and stream channel data.

The gaging station metadata consist of information describing the gaging station, including its installation, elevation relative to a local datum, instruments, and maintenance history. The recording gage dataset contains stream water level data, recorded every 15 minutes year-round, at every gaging station. The discharge dataset contains stream flow measurements, collected during field visits. Finally, the stream channel data consist of cross-section profile, control, and channel slope data.

The next two sections of this chapter cover data quality control practices and archiving of data. The final sections cover processes that must be performed by a professional hydrologist: adjustments of data and rating curve and hydrograph development.

This document frequently references the Microsoft Access database in which the hydrology data are stored (hereafter called the “hydrology database”) (Figure 9-1). All hydrology data collected in the field is ultimately archived in this Access database, though data are collected in various electronic formats and on paper field data forms. Within the hydrology database, tables are used to store all data. Data and metadata are generally stored in separate tables that are related to one another via common fields (Appendix 9A-1). The hydrology database is stored at:

[J:\hcp\monitoring\\_research\tminkova\01\\_OESF\\_R&M Program\01\\_Rip S&T Mon\01\\_FIELD DATA\02\\_Hydrology\Data\Hydro\\_Database.accdB](J:\hcp\monitoring_research\tminkova\01_OESF_R&M Program\01_Rip S&T Mon\01_FIELD DATA\02_Hydrology\Data\Hydro_Database.accdB).

### Key Terms Used in This Chapter

**Elevation survey:** A periodic leveling check (survey) at a gaging station to ensure that gages are accurately set to the established gage datum.

**Gage datum:** A horizontal surface used as a zero point for measurement of stage or gage height. On a staff gage, the datum is the zero reading.

**Gaging station:** A particular site on a stream where systematic observations of gage height or discharge are obtained.

**Local site datum:** A gage datum that is maintained independently of any national geodetic datum.

**Rating curve (stage-discharge curve):** A graph showing the relation between the gage height, usually plotted as ordinate, and the amount of water flowing in a channel, expressed as volume per unit of time, plotted as abscissa.

**Stage:** The height of a water surface above an established datum plane.

**Staff gage:** A graduated scale that is semi-permanently installed in a stream channel to indicate the height of the water.

**Stream discharge:** Also called flow, discharge is the amount of water that passes a given point in a given amount of time. Discharge is the product of the cross-sectional area multiplied by the velocity of the water.

**Water level sensor:** Also known as a submersible pressure transducer, a water level sensor measures the depth of water in which it is submerged.

*Based on: Langbein and Iseri (1960) and Kenney (2010)*

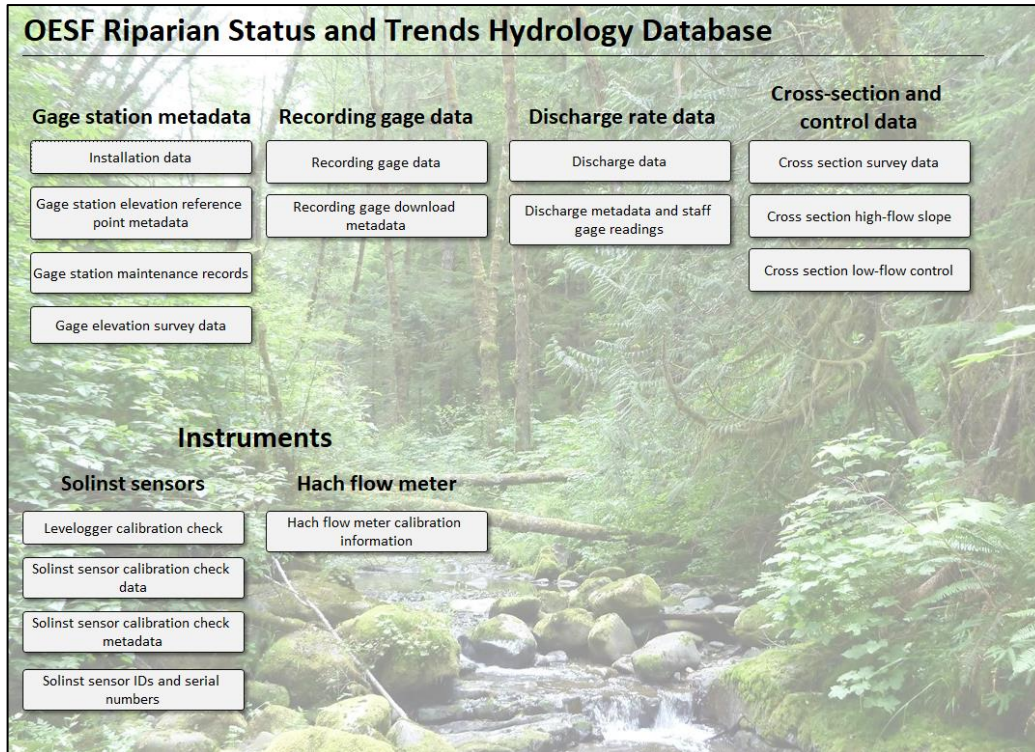


Figure 9-1. Main menu of the hydrology database.

## Gaging Station Metadata

Gaging station metadata consists of information on: (1) the details of a gaging station’s installation and design, (2) gaging station maintenance, and (3) gaging station elevational stability. All of these data are stored in four tables that are opened by the four buttons under the Gaging Station Metadata heading in the hydrology database. Data are added to this dataset when a new gaging station is installed or when all or a portion of a gaging station is replaced.

### GAGING STATION INSTALLATION DATA

During the installation of a new gaging station, or during replacement of instruments at a gaging station, a series of field forms are filled out to document the details of the work (see *Chapter 8: Stream Discharge*). The data from these forms are added to the hydrology database’s **Installation Table** (accessed via the Installation Data button). This form contains 59 different fields to document information such as site characteristics, details of the staff gage and recording gage installations, photo numbers, and general site notes.

At each gaging station is a permanently installed reference point that is used during all surveys, including surveys of the channel cross-section and surveys to verify that instruments remain at a constant elevation. Metadata for each of these reference points are in the **RP Table**. This table is accessed via the button labeled Gaging Station Elevation Reference Point Metadata.

## GAGING STATION MAINTENANCE TRACKING

Occasionally, maintenance on the various components of the gaging stations is necessary. Some maintenance activities are performed regularly, but others occur on an irregular basis, as problems are noted in the field. Field maintenance records, as well as observations of maintenance needs (or observations that maintenance is not needed), are stored in the **Maintenance Table**, accessed via the Gaging Station Maintenance Records button.

## GAGING STATION ELEVATION STABILITY

Periodically, the semi-permanently installed recording gage and staff gage at each station are surveyed to assess whether their elevations, relative to the gaging station reference point, have remained constant over time. Data from these surveys are stored in the **Elev Stability Table**, accessed via the Gage Elevation Survey Data button in the hydrology database.

## DATA FLOW

1. **Fill out field forms** For each of the datasets described above, data and metadata are recorded on field forms or in a field notebook, as the work is performed.
2. **Scan and store field forms** After returning from the field each week, all of the field forms are scanned and stored on the DNR network drive; the original paper forms are archived at the Forest Resources Division of Washington Department of Natural Resources.
3. **Enter data** All of the information collected on paper field forms is entered in the hydrology database tables.

## Recording Gage Data

In each of the watersheds selected for hydrologic monitoring, a gaging station records stream depth every 15 minutes, year-round. Each gaging station collects stream depth data using two instruments: a Solinst Levellogger and a Solinst Barologger. The Levellogger is a submersible pressure transducer that logs the depth of the water in which it is submerged. The Barologger logs atmospheric pressure at the same time interval so that the Levellogger's data can later be compensated for variation in atmospheric pressure. This compensation process is performed using Solinst software developed specifically for those instruments; it takes place after the downloaded data files have been transferred to an office computer or a field laptop. The processes of downloading and compensating the data are described in detail in Chapter 8. At the time of each download, field personnel record pertinent metadata as well as a staff gage reading.

## THE RECORDING GAGE DATASET

The compensated stream depth data produced by the recording gages (refer to the *Stream Discharge Field Methods* protocol) are stored in the hydrology database in the **Gage Sensor Data Table**, accessed via the Recording Gage Data button. This table contains fields that include the date and time of reading, water level (nearest 0.0001 m), and water temperature.

## RECORDING GAGE DOWNLOAD METADATA

Each time a recording gage is downloaded in the field, field personnel document this activity by recording metadata on a field form or in a notebook. The metadata includes the data and time, the download equipment used, and any other relevant observations. This metadata is stored in the **Gage Table**, accessed via the Recording Gage Download Metadata button.

## DATA FLOW

### *Field forms*

1. **Fill out field form** Download metadata are recorded in a field notebook or on a field form.
2. **Scan and store field forms** After returning from the field each week, the field forms are scanned and stored on the DNR network drive; the original paper forms are archived at the Forest Resources Division of Washington Department of Natural Resources.
3. **Enter data** All of the metadata collected on paper field forms is entered in the hydrology database, in the **Gage Table**.

### *Electronic data*

1. **Download and process data files** The *Stream Discharge Field Methods* protocol provides a detailed, step-by-step description of how the data are downloaded from the recording gage instruments (Levelogger and Barologger) and then processed in the office to compensate the water level readings for barometric pressure. The result is one comma-separated variable (.csv) file per watershed per download.
2. **Store data files** In the DNR office, the raw downloaded files and the processed (compensated) .csv files are stored on the DNR network drive in the directory:  
J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\07\_Data management\\_All new data and photos\
3. **Import data to database** The compensated data are added to the hydrology database's **Gage Sensor Data Table**.

## Discharge Data

Stream discharge is measured 6 to 10 times per year in each of the hydrology watersheds. The discharge data are used to produce, verify, and potentially update a rating curve for each gaging station. At each discharge measurement in a given watershed, a stream discharge value and channel metrics are calculated by the flow meter. In addition to this, metadata are recorded.

## THE DISCHARGE DATASET

Stream discharge is measured using an electronic flow meter (currently the Hach FH 950<sup>®</sup> velocity meter is used), although two alternative measurement methods may be used under certain conditions, as described in detail in Chapter 8. Regardless of the method used, all discharge data are added to the hydrology database and stored in the **Discharge Data Table**, accessed via the button labeled Discharge Data.

There is another table, the **Discharge Detail Table**, that contains additional details about some of the discharge measurements collected between 2015 and 2019. This table includes flow measurements from individual stations, not just the overall discharge rate for the stream. The data in this table are unlikely to be used often, and are retained in the database primarily for archival purposes.

## DISCHARGE METADATA

Metadata associated with discharge readings, including staff gage readings, are stored in the **Discharge Metadata Table**, accessed via the button labeled Discharge Metadata and Staff Gage Readings. The **Discharge Metadata Table** contains information that includes the date and time of the discharge measurement, instrument type, weather conditions, a quality rating of the discharge measurement, staff gage readings, and any notes made about the condition of the channel.

## DATA FLOW

### Field forms

1. **Fill out field form** The field form titled *Stream Discharge Field Sheet*, or a field notebook, is used to record the metadata associated with each discharge measurement. There is a different version of this field sheet for each discharge measurement method, but all versions include the same metadata. This field form is also used to record stream discharge measurements produced by the Hach flow meter. In the event that a duplicate discharge measurement is taken for quality control purposes, a second copy of the field form is filled out.
2. **Scan and store field forms** After returning from the field each week, the field forms are scanned and stored on the DNR network drive; the original paper forms are archived at the Forest Resources Division of Washington Department of Natural Resources.
3. **Enter metadata** All of the metadata collected on the paper field form are entered in the **Discharge Metadata Table** in the hydrology database. When entering a duplicate measurement (i.e., two separate discharge measurements taken at the same stream on the same day), check the Duplicate box in the table.
4. **Enter data** Enter discharge data into the **Discharge Data Table** in the hydrology database.

### Electronic data

The current recommended practice is to write down the discharge data on a field form or in a notebook (see process above); if this is done, it is not necessary to use the following steps. These steps apply only if you wish to save an electronic copy of the data from the Hach flow meter.

1. **Download and convert data files** Chapter 8 provides detailed instructions on how to transfer the data files, in “.TSV” format, from the Hach flow meter to a field laptop and save the file as a Microsoft Excel workbook (one workbook is created per discharge measurement).
2. **Store data files** In the DNR office, the Excel files containing the discharge measurements, and the original .TSV raw data files, are stored on the DNR network drive. The raw .TSV data files are stored in the directory: J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD DATA\02\_Hydrology\Data\Archived\_data\Discharge\_data\Raw\_data\



The data files converted to Excel format are stored in the directory:

J:\hcf\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD  
DATA\02\_Hydrology\Data\Archived\_data\Discharge\_data\Excel\_format\

## Cross-Section, Control, and Slope Data

The stream channel cross-section is surveyed at least once per year and after any exceptionally high flow events. Data on the low-flow control and high-flow channel slope are collected at the same time (see *Chapter 8: Stream Discharge*). These data are important in the development and assessment of the rating curve (described below).

### CROSS-SECTION, CONTROL, AND SLOPE DATASETS

The data produced by the cross-section stability survey are stored in the **Cross Section Table**. Prior to 2015, the raw cross-section survey data recorded in the field were not entered in the database; instead, summary values (i.e., cross-sectional area and hydraulic radius) were calculated externally. The results of these calculations were recorded in the **Elev Stability Table**. This approach was problematic for two reasons: 1) errors were common during these complex calculations, and the source of the errors can only be detected by manually reconstructing the calculations, and 2) the raw data were not preserved. Beginning in 2015, a new approach was adopted: the raw data recorded in the field are now entered directly into the database, without performing any manual calculations first. Using this approach, all data are preserved and calculations can subsequently be performed using the desired software.

The **Cross Section Table** contains the raw cross-section profile data. These data enable the user to evaluate exactly how the cross-sectional profile changes over time (i.e., between surveys); it also can be used to calculate summary values such as cross-sectional area and hydraulic radius. All of these metrics are important in determining whether a new rating curve must be developed for a given gaging station.

Two other tables contain data on low-flow controls and the high-flow channel slope: the **Cross Section Low Flow Control Table** and the **Cross Section High Flow Slope Table**. Data in these tables are used in rating curve development and evaluation.

### DATA FLOW

1. **Fill out field form** The field form titled *Gaging station and Cross Section Stability Survey*, or a field notebook, is used to record all data and metadata associated with each survey visit.
2. **Scan and store field forms** After returning from the field each week, the field forms are scanned and stored on the DNR network drive; the original paper forms are archived at the Forest Resources Division of Washington Department of Natural Resources.
3. **Enter data and metadata** All of the data and metadata collected on the paper field form are entered in the hydrology database in the **Cross Section Table** and in the **Cross Section Low Flow Control Table** and the **Cross Section High Flow Slope Table**.

## Quality Assurance and Quality Control

### INTRODUCTION

A variety of steps are taken for QA/QC purposes. These are:

1. Data verification. Verification processes are established for all manually entered and imported data, including data that are collected for the purposes of quality control.
2. Recording gage - staff gage consistency. Although this check cannot identify the source of error, it provides a useful check on the consistency of the recording gage data over time and across a range of stage values.
3. Recording gage sensor calibration check. Sensors are evaluated in a controlled environment to measure any instrument drift that may have occurred.
4. Flow meter calibration. This is a factory check of the Hach flow meter's sensor calibration.

### DATA VERIFICATION

#### *Data entered from field forms*

After data from each field form have been entered in the hydrology database (a process described in the Data Flow subsections throughout this chapter), the original paper field forms are initialed and dated to indicate that the data have been entered.

After a data entry session is completed, the entered data should be compared against the original field sheet to verify accuracy of the data entry. To view the entered data, the user should access the appropriate data table by clicking its button on the database navigation menu. Corrections to the entered data should be made as necessary. The fact that the data were verified should then be noted, along with the user's initials and date, on each paper field form. Thus, the original paper forms will each have documentation of both data entry and data verification.

#### *Imported electronic data*

After electronic data have been downloaded from the instrument and imported to the hydrology database, this action should be noted, along with the user's initials and date, on the paper field form associated with that downloaded data file (i.e., the form containing the metadata). The imported electronic datasets are verified in different ways, as described below.

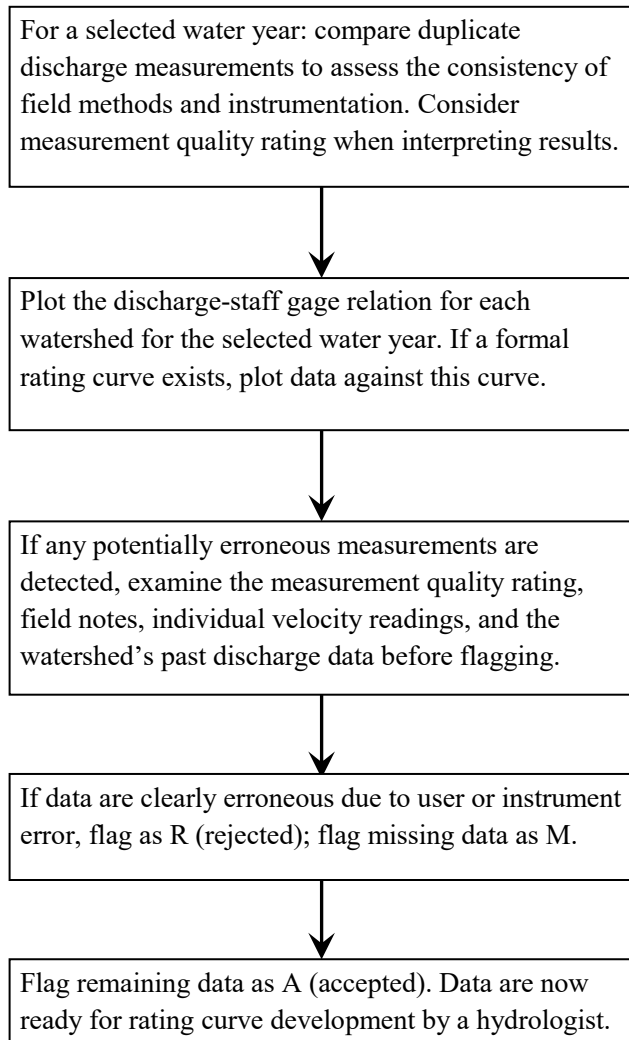
#### **Discharge Data**

Quality control is performed on discharge data one water year at a time. The two primary processes for assessing data quality are comparing duplicate discharge measurements (i.e., two consecutive measurements made on the same stream cross-section) and examining the relationship between discharge and staff gage readings (Figure 9-2).

Duplicate readings are compared to assess the precision of field methodology and instrumentation. The measurement rating quality and any field notes should be examined if duplicate measurements differ by more



than 5 percent. If duplicate measurements commonly differ by more than 5 percent, then field methods should be re-examined.



**Figure 9-2. Data quality control process for discharge data.**

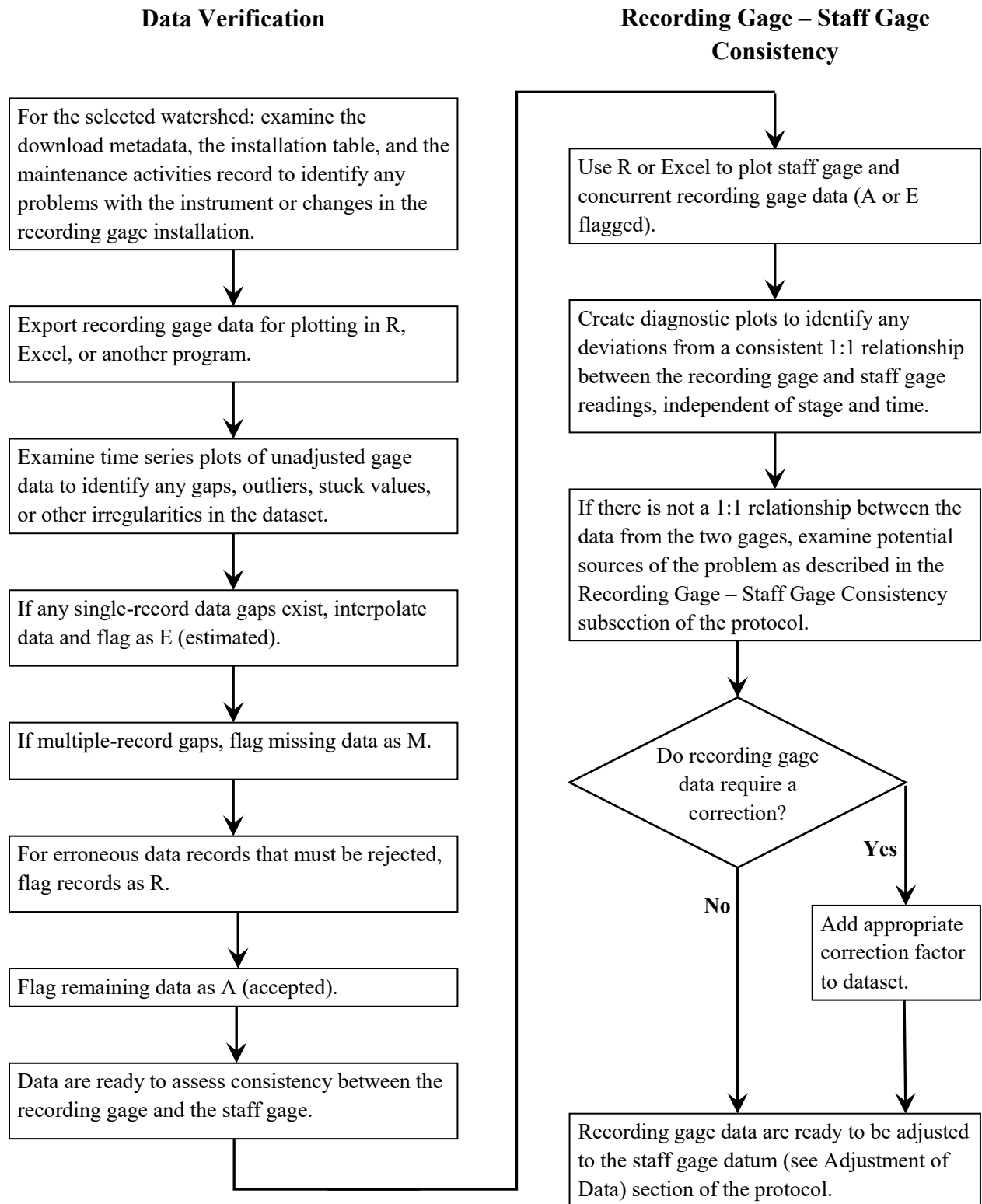
### Recording Gage Data

The quality control process for the recording gage data is described in this section and in the following section titled “Recording Gage – Staff Gage Consistency” (Figure 9-3). The first step in performing a quality

The other process for quality checking the discharge dataset is to plot discharge measurements against staff gage readings. There are two options for performing this check:

1. If a rating curve has been developed previously, the data can be plotted against this curve. Discrepancies between the data and the curve may reflect an error or malfunction during discharge data collection, a change in the stream cross-section since the development of the curve, or a shift in gage elevation. Because of these multiple sources of potential error, this quality control approach may be effective only for detecting large amounts of error in a discharge reading.
2. If no rating curve exists, or if the cross-section is known to have changed since the last rating curve was created, then the discharge data can be plotted as an informal rating curve to examine consistency of the data and check for outliers.

If graphing reveals any potentially erroneous measurements, then the user should carefully consider the measurement quality rating, field notes, individual velocity readings, and the watershed’s past discharge data before proceeding with flagging. Only data that are clearly erroneous due to user error or equipment malfunction should be rejected (flagged “R” in the **Discharge Data Table**).



**Figure 9-3. Data quality control process for recording gage stage data. This process is performed separately for each watershed, and consists of two stages: data verification and the recording gage – staff gage consistency check.**

control check of the recording gage data is to examine the gage download metadata, installation metadata, and maintenance activity records to identify any instrument problems or other issues that were noted in the field.

After reviewing the metadata, quality control is performed on the recording gage data by examining a time series plot of the data from each watershed. For this quality control process, data do not need to be adjusted to any specific datum. The data must be plotted in a program with graphical capabilities such as R or Excel (R Core Team 2013).

In examining the plotted recording gage data, look for any data continuity issues or unexpected values that do not appear to represent normal patterns in stream stage. These may appear as “stuck” values or as abrupt changes in stage. If it is unclear whether a pattern is natural or a result of an instrument malfunction, then the gage plot can be compared with data from another watershed’s recording gage or with the nearest USGS hydrograph for the same time period.

Any recording gage records that are determined to be erroneous due to instrument malfunction or other reasons should be flagged “R” as rejected in the **Gage Sensor Data Table**. In cases where there is a single-record gap, the gap may be filled by averaging the values of the records immediately before and after it. These estimated values should be flagged “E” as estimated in the **Gage Sensor Data Table**. Records with missing data values should be flagged “M”. After the quality control process is completed; all unflagged records should be flagged “A” as accepted.

## RECORDING GAGE – STAFF GAGE CONSISTENCY

### *Introduction*

This assessment is a review of the relation between all of the staff gage readings and the corresponding recording gage readings (i.e., readings from the same watershed and time) collected during a specified time period. This assessment can be performed on raw, unadjusted data or it can be performed on adjusted datasets. However, for data quality control purposes, we assume that the user is working with raw, unadjusted data.

Ideally, changes in values on the recording gage and the staff gage should have a linear, 1:1 relationship: for any change in stage measured on the staff gage, there should be an identical change measured by the recording gage. This 1:1 relationship should not change over time, nor should it vary based on stage.

This quality control assessment is designed to evaluate consistency between gage readings, but it cannot conclusively identify the cause of inconsistencies, which may arise from sensor drift, elevational movement of the gages, or other sources. It also is important to note that this assessment will not reveal *all* potential gage errors. For example, if both the staff gage and recording gage move in the same direction relative to the original gage datum (e.g., if they are mounted on the same tree and that tree moves), then this assessment will not reveal any problem in the data. Thus, the assessment is not a substitute for analysis of staff and recording gage elevation survey data and recording gage sensor calibration checks.

Three types of plots should be evaluated for each watershed. The first is a time series plot showing staff gage readings, recording gage sensor readings, and the difference between the staff gage and recording gage readings. This plot will show whether the difference between the gages is consistent over time. Second, a plot should be produced showing the staff gage readings versus the recording gage readings for each watershed. This will indicate whether the gage readings have a 1:1 relation and whether the gages' relation is linear. The third plot should show, for each watershed, the difference between the two gages versus the staff gage reading. This plot will help reveal any stage-dependent differences between the two gages. This quality control assessment is important for identifying at least two potential data quality issues:

1. A non-linear relation between the staff and recording gages. For example, if the recording gage responds differently at high stage values than at low stage values.
2. Deviation from a 1:1 slope between the two gages. An increase of 1.0 cm in the staff gage reading should be accompanied by an increase of 1.0 cm in the recording gage reading.

Because the staff gage data are expected to be highly reliable, with error limited only to gage movement and user error, issues detected in the relation between the staff gage and recording gage readings are most likely a result of error associated with the recording gage. This error also may be the cumulative effect of multiple problems. Potential gage problems include:

1. *Elevational movement of a gage.* Examine the gage elevation survey results. This type of error is addressed in the Adjustment of Data section.
2. *Recording gage sensor calibration.* Examine the results of the periodic calibration check to determine if sensor drift is influencing the data. This type of error is addressed in the below subsection titled Recording Gage Sensor Calibration Check.
3. *Problems within the recording gage housing.* If the recording gage readings are lagging behind the staff gage readings, or if the sensitivity of the recording gage seems to be diminished, the recording gage housing may require maintenance. This issue can only be diagnosed by an evaluation in the field.
4. *Recording gage clock error.* If there a time series plot of recording gage and staff gage data show a temporal offset, then there may be an issue with clock settings (including daylight saving time). Address this by checking the sensor clock settings and by comparing data among multiple sensors.

## RECORDING GAGE SENSOR CALIBRATION CHECK

### *Introduction*

On a periodic basis, the recording gage sensors from every gaging station are transported to the office for a calibration check (refer to the *Stream Discharge Field Methods* protocol). Sensors are all submerged in water to a common depth, and then the reading from each sensor is compared to the measured depth of the water. This section describes the data involved in this process. The application of the sensor calibration is in the Recording Gage Data Adjustment section of this protocol.

### *The calibration dataset*

After the calibration check in which all sensors are submerged to a common depth, data from the loggers are downloaded and the readings are compensated for atmospheric pressure using Solinst software. The resulting data files are in Microsoft Excel format. The data from these files are copied and pasted into the **Sensor Calibration Check Data Table**. Calibration metadata are entered directly in the **Sensor Calibration Metadata Table**.

The **Sensor Calibration Check Data Table** contains the following fields:

1. Sensor calibration ID number (used to relate data to metadata).
2. Sensor ID number (watershed number has been used thus far).
3. Date and time of measurement.
4. Water depth reading.
5. Temperature.

The **Sensor Calibration Metadata Table** contains the following fields:

1. Sensor calibration ID number (used to relate metadata to data).
2. Water year for which the calibration was performed.
3. Beginning and end date and time of the calibration.
4. Water depth at the beginning and end of the calibration.

### *Data products*

The results of the sensor calibration check appear in a report titled **Levellogger Calibration Summary**, accessed within the hydrology database. This report contains, for each calibration of each sensor:

1. The mean water depth reading from the sensor during the calibration period.
2. The standard deviation of the water depth readings from the sensor during the calibration period.
3. The range in the water depth readings during the calibration period.
4. The actual, measured depth of the water during the calibration period.
5. The difference between the sensor reading and the actual depth of the water during the calibration period.

## **FLOW METER CALIBRATION**

The Hach flow meter sensor is shipped to the factory periodically for calibration. Data produced during this calibration are stored in the database in the **Instrument Calibration Table**.

## **Data Archives**

### **STORAGE OF ELECTRONIC DATA AND PAPER FIELD FORMS**

Original completed field forms will be archived with the OESF Research and Monitoring Manager, at the Natural Resources Building in Olympia, WA. The original paper field forms will be placed in a binder organized either by site or by year and will be stored in the Forest Resources Division. It is crucial that the

raw data, both field forms and electronic data files, retain their integrity and not be modified. Any new information added to field forms or data files after returning from the field must be clearly identified as not part of the original data.

All electronic data files downloaded from field instruments will be stored on a server of Washington Department of Natural Resources in the appropriate subdirectories within:

J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD  
DATA\02\_Hydrology\Data\

All scanned field forms will be stored in Adobe pdf format in the appropriate subdirectory within the same directory. The hydrology database itself is located at:

J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD  
DATA\02\_Hydrology\Data\Hydro\_Database.accdb

## Adjustment of Data

### INTRODUCTION

Adjustment of the hydrology data is a prerequisite for data analysis and should be done by a professional hydrologist. It is important to note that none of these adjustments are changes in the original field-collected data; rather they are adjustments done to separate versions of the data used for analysis. There are four types of data adjustments necessary prior to data analysis. These adjustments are:

1. **Adjustment for staff gage replacement (required for all watersheds where a staff gage has been replaced).** For example, ten staff gages were replaced between December 2014 and January 2015. Because the replacement staff gages could not be installed at exactly the same elevation as the original staff gages, the pre-replacement staff gage data had to be adjusted to the post-replacement staff gage datum.
2. **Adjustment of staff and recording gage data to watershed datum (required for all watersheds).** For analysis, all staff gage and recording gage data from a given watershed must be adjusted to the same watershed-specific datum.
3. **Adjustment of cross-section survey data to detect cross section changes (required for all watersheds).** To evaluate changes in the cross-section profile over time, multiple cross-section surveys are plotted together on the same graph. Before the cross-sections can be plotted, the data must be adjusted so that they are all in the same datum.
4. **Adjustment for a shift in staff or recording gage elevation (required for watersheds in which gage elevation changed).** If the staff gage elevation changes over time as a result of any type of disturbance, then the data must be adjusted to account for the change.

The procedures described here assume that the applicable quality control processes described in the Data Quality Control section have already been performed on the data.

## **ADJUSTMENT FOR STAFF GAGE REPLACEMENT**

Over time, staff gages may need to be replaced owing to normal wear-and-tear or damage during a flood. When a staff gage is replaced, it is rarely possible to install the new gage at exactly the same elevation as the old gage. For this reason, the all staff gage readings taken prior to the replacement must be adjusted so that the readings are comparable to the readings taken on the new staff gage.

To adjust the staff gage readings, the adjustment factors must be determined using information recorded in the field at the time of gage replacement. This is done by taking a reading on the old gage, replacing it, and then taking a reading on the new gage. Assuming no change in stage during the replacement process, the difference between these two readings is the adjustment factor that should be applied to all readings prior to the gage replacement. These adjustment factors, and the dates of gage replacements, are stored in a table called **SG Adjustment Values Table**.

## **ADJUSTMENT OF STAFF AND RECORDING GAGE DATA TO WATERSHED DATUM**

Prior to any analysis, each watershed must have a defined datum to which all staff and recording gage data are adjusted. There are various options for establishing this watershed-specific datum, but the most logical option is to use the gaging station reference point.

## **ADJUSTMENT OF CROSS-SECTION SURVEY DATA TO DETECT CROSS-SECTION CHANGES**

To evaluate changes in the cross-section profile over time in a given watershed, profiles from multiple cross-section surveys are plotted together on the same graph. However, simply plotting the unadjusted survey data together on the same graph is not effective due to frequent measurement errors between the reference point and the gaging station cross-section. For example, the left and right monuments in a given watershed should have elevations that don't change over time. This is not the case; the same monument often has different elevations in different surveys, presumably due to measurement error between the reference point and the cross-section. Thus, if the monument elevations indicate error, we would also expect measurement error in the entire profile. To plot the profiles without the measurement error that occurred between the reference point and the cross-section, we chose to adjust the survey data using the elevations of the left monument. For example, if our most reliable survey (the one with the fewest obvious errors) reported a left monument elevation of -200 cm and the next survey reported an elevation of -190 cm, then we would adjust all of the cross-section profile data from the second survey by -10 cm.

## **ADJUSTMENT FOR A SHIFT IN STAFF OR RECORDING GAGE ELEVATION**

The gage elevation survey is performed periodically to determine the elevation of the gages relative to the watershed's gaging station reference point. If a staff or recording gage is found to have changed elevation over time, then a portion of the readings must be adjusted to compensate for that movement, therefore making all data points, before and after the movement, comparable. The adjustment is made to the data collected *prior* to the elevation change, and, if the change is determined to have occurred gradually over time, the data collected during the gradual change are adjusted as well, on a prorated basis.



The procedure for identifying the need for data adjustment and for adjusting data is given below. This procedure is the same for either type of gage but must be applied separately to each gage if both gages in the same watershed are found to have changed elevation.

1. Use the **Gage Elevation and Cross-Section Survey** reports to determine whether the staff or recording gage elevation changed over time. In the reports, gage elevation change is calculated between the earliest and most recent elevation surveys and between the two most recent elevation surveys. A threshold of 1 cm is used as the minimum amount of movement that can be used to make an adjustment, though each situation should be examined on an individual basis to determine whether gage elevation changed enough to warrant adjustment.
2. If, for a given watershed, the reports show no change in gage elevation, then no data adjustment is necessary. If the reports show that a gage's elevation changed, then that gage's data must be adjusted. In that case, proceed to the next step.
3. Determine whether the specific date of the gage's elevation change is known. For example, the gage might have moved during a specific flood event or as a result of instrument maintenance (see the **Maintenance Table**). There are two possible outcomes:
  - a. *The date of the staff gage movement is known.* This scenario is based on the assumption that the gage only moved on a specific date and not before or after that date. In this case, calculate the change in elevation as the difference between the gage's elevation according to the surveys prior to and after the gage elevation change. Adjust all data prior to the change by the amount of change. For example, if the gage moved 5 cm lower in elevation, then add 5 cm to every reading prior to the change.
  - b. *There is no known date of staff gage movement.* In this case, make the assumption that the staff gage moved at a constant rate between the two surveys that indicate the change in elevation. Prorate the adjustment throughout this time period (Sauer 2002, p. 22). Thus, the adjustment factor for each record between the two surveys is calculated by multiplying the total gage movement for that interval by the fraction of the interval that has elapsed (see example of this calculation below).

## Creating the Rating Curve and Hydrograph

### INTRODUCTION

Discharge is not easily measured but the elevation of the water surface is. Hence, most flow gauging stations use a pressure sensor to record flow height every 15 to 60 minutes and the record (time series) of flow height, is then converted to a time series of flow using a rating curve. A rating curve, or stage-discharge relationship, is an empirical formula that predicts discharge at a given channel location as a function of the elevation of the water surface (stage). Rating curves typically rely on graphical or statistical methods to fit the following power function to a scatter plot of repeat measurements of flow and stage (gaugings; Rantz et al. 1982):

$$Q = k(h - a)^c \quad 1$$

Where  $Q$  is discharge,  $h$  is stage,  $k$  is a scaling coefficient,  $a$  is the zero-flow elevation above the gauge datum and  $c$  is specific to the shape and type of hydraulic control. While this method has created reliable rating curves for many stable channel reaches, it is not easily adapted to unstable channels that frequently aggrade or scour (Guerrero et al. 2012). The channels monitored in the OESF are steep, low-order channels where supply and transport capacity of bedload frequently change and cause the geometry of the channels to change as well. Observation-based, empirical rating curves are difficult to apply because the stage-discharge relation tends to change before enough observations can be collected to create a reliable rating curve.

Rating curves can also be created using hydraulic characteristics of the channel (Kean and Smith 2010); however, because many of the parameters in a hydraulics-based rating curve are estimated and may change with flow depth, they are not necessarily any more accurate than an empirical rating curve. New methods for creating a rating curve combine hydraulics-based rating curves with empirical rating curves. This combined rating curve approach permits the creation of rating curves with fewer observations. Furthermore, it provides a method for estimating rating curve uncertainty. Rating curves developed for the OESF gauges use the Bayesian rating curve framework (BaRatin) method described by Le Coz et al. (2014). The BaRatin method uses Bayes theorem and the maximum likelihood method for fitting a distribution to observations to combine channel hydraulics with gaugings to develop a rating curve and estimate rating curve uncertainty. This section summarizes key concepts needed to understand and implement the BaRatin method, describes an example application and includes a standard-operation-procedure (SOP) of how to implement the method on the small, unstable channels typical in the OESF. For a full description and explanation of the BaRatin method please read Le Coz et al. (2014) and documentation by Istrea (2020).

### CONSTRUCTION OF THE RATING CURVE

The BaRatin method for constructing a rating curve involves three components: A channel hydraulics survey, gaugings and software or code that will implement the BaRatin method. Presently, we implement the BaRatin method using the BaratinAGE software. The BaratinAGE software is freely available on request from the authors at: <https://riverhydraulics.inrae.fr/en/tools/measurement-software/baratin-method/> .

**Example: Bayes Theorem and application to assess the accuracy of DNR stream typing**

Bayes theorem is a convenient method for utilizing previous or *prior* estimates of the probability of an event occurring to determine the probability of the event occurring given the occurrence of some other related event. It is written as follows:

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)}$$

Where  $P(A|B)$  is the probability that A is true given that B is true,  $P(B|A)$  is the probability that B is true given that A is true,  $P(A)$  is the probability that A is true and  $P(B)$  is the probability that B is true.

In Washington, streams are often assigned a type based on physical characteristics (channel width, slope, presence of pools and wood) without actually seeing a fish. Large, lowland streams are typed as Type 1 or 2. Excluding the large, lowland streams, and considering only the smaller, upland channels, streams are typed as Type 3, 4 or 5. Type 3 has fish. Type 4 and 5 are perennial and seasonal channels that do not have fish (Washington State Legislature, 2020). Bayes Theorem can be used to estimate the probability that a small, upland stream in which fish have been recently observed is correctly typed as Type 3 in the Washington State Stream Type database. In the stream type database, Type 3 streams account for roughly 20% of all channels that are either Type 3, 4 or 5. If we assume that 90% Type 3 classifications are correct and that 80% of Type 4 or 5 channel classifications are correct, the probability that a small mountainous stream that is observed to have fish in the field is correctly recorded as Type 3 in the stream type database is:

$$P(B|A) = P(\text{stream has fish} | \text{stream recorded as Type 3}) = 0.9$$

$$P(A) = 0.2$$

$$P(B) = .2 * .9 + .8 * .2 = 0.34$$

$$P(A|B) = P(\text{stream recorded as Type 3} | \text{stream has fish}) = \frac{0.9 * 0.2}{0.34} = 0.53$$

If you are walking along a small, upland channel and you observe fish, there is a 53% chance it is typed correctly in the Stream Type database.

In the application of rating curves, Bayes Theorem is used to determine the probability that coefficients of the rating curve are correct given a set of gaugings:

$$P(\text{rating curve coefficients} | \text{gaugings}) = \frac{P(\text{gaugings} | \text{rating curve coefficients})P(\text{rating curve coefficients})}{P(\text{gaugings})} \quad 2$$

Since rating curve parameters are continuous variables, rather than discrete (like the Type 3, 4 and 5 values of the Stream Database), the result of equation 2 is a likelihood or probability density (probability per unit length) rather than a probability. Solving equation 2 for a range of rating curve parameter values produces a probability density function (pdf) that can be used to determine probability (and rating curve confidence intervals). Note that because there are at least 3 parameters in the rating curve, the probability density function is multidimensional. Since  $P(\text{gaugings})$  is just a normalizing constant it isn't needed to determine the maximum likelihood of the pdf (Istrea 2020) and in the BaRatin method, equation 2 is written as:

$$p(\boldsymbol{\theta}, \sigma_f | \tilde{\mathbf{H}}, \tilde{\mathbf{Q}}) \propto p(\tilde{\mathbf{Q}} | \boldsymbol{\theta}, \sigma_f, \tilde{\mathbf{H}})p(\boldsymbol{\theta}, \sigma_f) \quad 3$$

Where  $\boldsymbol{\theta}$  is the set of parameter values. If the rating curve is defined by equation 1,  $\boldsymbol{\theta} = [k, a, c]$ .  $\sigma_f$  is the standard deviation of the remnant error of the rating curve. Where remnant error is variability in the true discharge from the rating curve predicted discharge; the rating curve is a simplified model that doesn't account for changes in hydraulics during the rising and falling limb of the hydrograph (Le Coz et al. 2014), changes in relative roughness due to flow depth (Ferguson 2007) and other unknown controls on the water stage.  $\tilde{\mathbf{H}}$  is the set of stage measurements and  $\tilde{\mathbf{Q}}$  is the set of discharge measurements and together make of the gaugings,  $p(\boldsymbol{\theta}, \sigma_f | \tilde{\mathbf{H}}, \tilde{\mathbf{Q}})$  is the likelihood that  $\boldsymbol{\theta}$  and  $\sigma_f$  are correct given the gaugings.  $p(\tilde{\mathbf{Q}} | \boldsymbol{\theta}, \sigma_f, \tilde{\mathbf{H}})$  is the likelihood that a given set of  $\boldsymbol{\theta}$  predict  $\tilde{\mathbf{Q}}$  give  $\tilde{\mathbf{H}}$  and  $\sigma_f$ .  $p(\boldsymbol{\theta}, \sigma_f)$  is the likelihood that  $\boldsymbol{\theta}$  and  $\sigma_f$  are correct given a prior estimate (probability density function) of the true value of  $\boldsymbol{\theta}$  determined from the channel hydraulics survey.

In words, Equation 3 states that given a set of gaugings, the likelihood of the rating curve parameters and remnant error is proportional to the likelihood of the gaugings given the parameters multiplied by the likelihood of the parameters. In the BaRatin method, the hydrographer solves equation 3 for a range of parameter values based on the channel hydraulics survey. From that range of likelihoods, a pdf is created, and the maximum likelihood and corresponding set of parameter values and remnant error is determined. In the following sections, each part of equation 3 is broken down and discussed in terms of the measurements recorded by the hydrographer.

### Rating curve parameter likelihood given the gaugings

The likelihood that a rating curve parameter set  $\boldsymbol{\theta}$  predicts  $\tilde{\mathbf{Q}}$  for a give set of  $\sigma_f$  and  $\tilde{\mathbf{H}}$  is computed as:

$$p(\tilde{\mathbf{Q}} | \boldsymbol{\theta}, \sigma_f, \tilde{\mathbf{H}}) = \prod_{i=1}^N P_N \left( (\tilde{Q}_i | f(\tilde{H}_i), \boldsymbol{\theta}, \sqrt{\sigma_f^2 + u_{Q_i}^2}) \right) \quad 4$$

Where  $\tilde{Q}_i$  and  $\tilde{H}_i$  are discharge and stage observation  $i$  of  $N$  observations in the gauging dataset.  $u_{Q_i}$  is the standard deviation of the discharge measurement error. The term  $\sqrt{\sigma_f^2 + u_{Q_i}^2}$  is the combined standard deviation of the remnant error and discharge measurement error. Both of these terms are defined by the hydrographer in BaRatinAge.

An illustration of the likelihood that a rating curve using equation 1 predicts 10 gaugings ( $N=10$ ) is illustrated in Figure 9-4. In this application, equation 1 is parameterized for a 2 meter wide channel that has a slope of 2% and Manning's roughness of 0.05. For each gauging ( $\tilde{Q}_i, \tilde{H}_i$ ) a Gaussian distribution with a mean  $Q_i = k(H_i - a)^c$  where  $a, b$  and  $c$  are define by  $\theta$  and standard deviation  $\sqrt{\sigma_f^2 + u_{Q_i}^2}$  is used to determine the likelihood of  $\tilde{Q}_i$  given the rating curve. Note that at each gauging, the mean of the distribution is set by the predicted mean (the rating curve) and the standard deviation is set by the  $\sqrt{\sigma_f^2 + u_{Q_i}^2}$  term. The product of each gauging likelihood is the likelihood of the rating curve parameters and remnant error. It can be thought of as the likelihood that rating curve predicts the set of discharge observations. Figure 9-4 shows an example of how the likelihood is computed for a single rating curve with parameters  $k, a$  and  $c$  equal to 5, 0.2 and 1.67 respectively. The 95% confidence intervals of  $k, a$  and  $c$  are 0.05, 1.32, 0.05 are respectively, As an example, we can compute the likelihood for the 8<sup>th</sup> and 10<sup>th</sup> gaugings. The likelihood the parameters based on the 8<sup>th</sup> gauging is 0.0052 and the likely hood of the 10<sup>th</sup> gauging is 0.0015. The combined likelihood of the rating curve for the 8<sup>th</sup> and 10<sup>th</sup> gauging is  $0.0052 \cdot 0.0015$ .

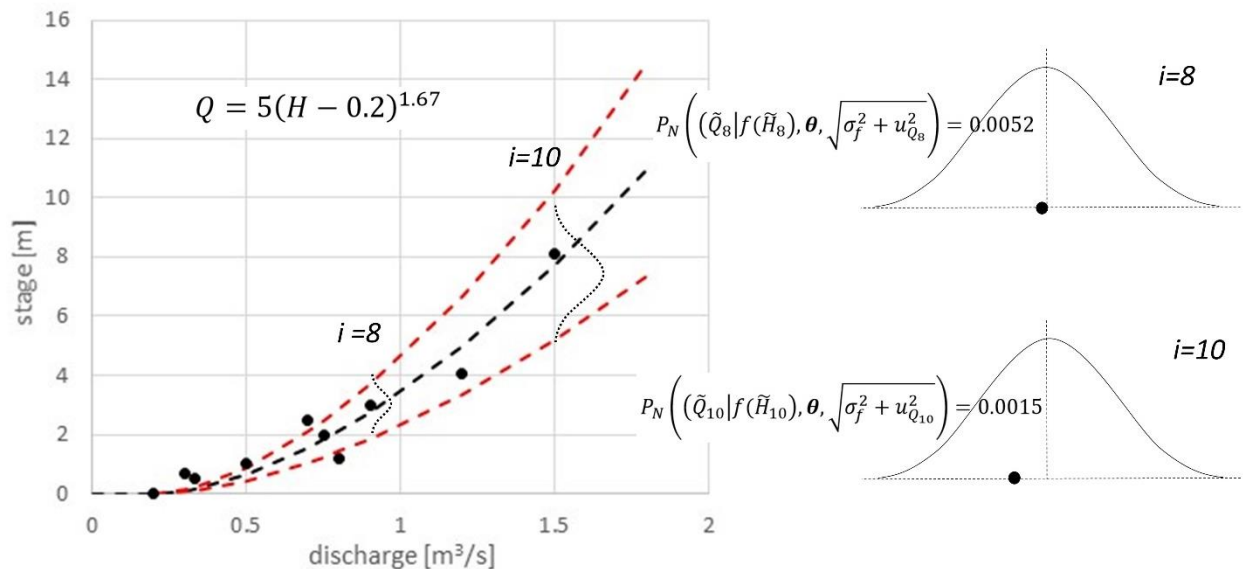


Figure 9-4. Illustration of the likelihood that a set of rating curve coefficients matches the predicted mean of the data.

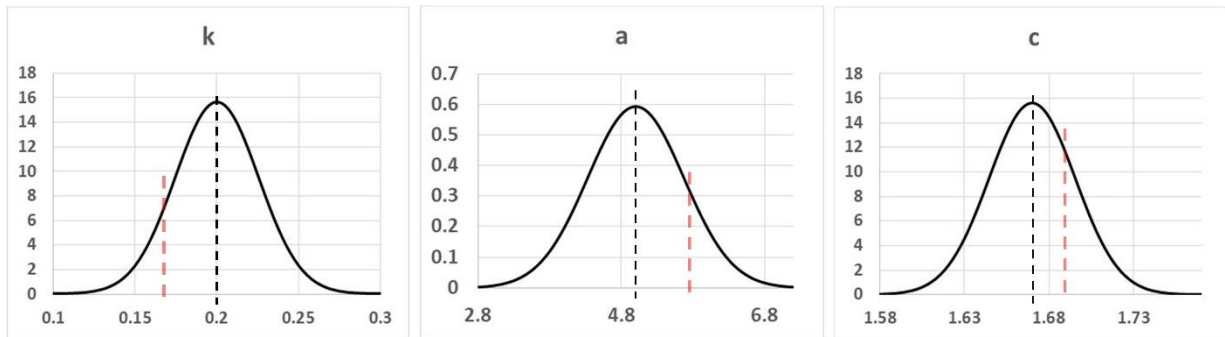
**Rating curve parameter likelihood given the a prior pdf**

The likelihood of the rating curve parameters based on a prior estimate of the rating curve parameter and remnant-error probability distribution functions are determined as:

$$p(\theta, \sigma_f) = p(\sigma_f) \prod_{i=1}^{N_{par}} p(\theta_i) \tag{eq. 5}$$

Where  $N_{par}$  is the number of parameters in  $\theta$ ,  $\theta_i$  is parameter  $i$  and  $p(\theta_i)$  is the likelihood of parameter  $i$ .  $p(\sigma_f)$  is likelihood of the remnant error. Again, the prior pdfs of parameter values are based on the channel hydraulics survey. An example of how these pdfs are created is shown in the section *Example workflow for using the BaRatin method*.

Figure 9-5 shows prior pdfs for parameters k, a and c equal to 5,0.2 and 1.67 respectively. The pdfs are normal distributions with mean equal to the parameter values and the standard deviations derived from approximated uncertainty, where uncertainty is 95% confidence interval for the parameter value. Since these pdfs are independent of the gaugings, they can be used to determine the likelihood that any new parameter value used to fit Equation 1 to the gaugings is correct.



**Figure 9-5. Illustration of prior pdf of rating curve parameters used to determine  $p(\theta, \sigma_f)$**

The same single rating curve and its 95% confidence intervals are shown in Figure 9-6 as plotted by BaRatinAGE. The rating curve parameters that fit the gaugings while retaining information about the hydraulics rating curve are determined by solving for Equation 3 using a Markov Chain Monte Carlo sampling scheme. The MCMC procedure picks different combinations of parameters, evaluates equation 3, and jumps to the new set of parameter values if the new set of parameters has a higher likelihood than the last set of parameters. Over 10,000 parameters sets are tested and in this way, the posterior pdf, informed by both the gaugings and the prior estimate of the rating curve parameter pdf (hydraulics rating curve) is created. From the posterior pdf, the parameter set that yields the maximum likelihood is selected (max-parameter set) as the best fit parameter set and the 95% confidence interval of the parameter is determined (Figure 9-7). One of the outputs of BaRatinAGE is a visualization of the pdfs of the prior and the posterior rating curve parameters k, a, and c (Figure 9-8). If the mean and standard deviation of the prior and posterior pdfs are vastly different, the number or location of the hydraulic controls may be wrong. Details on correctly assessing the hydraulic controls are discussed in the section *Example workflow for using the BaRatin method*.

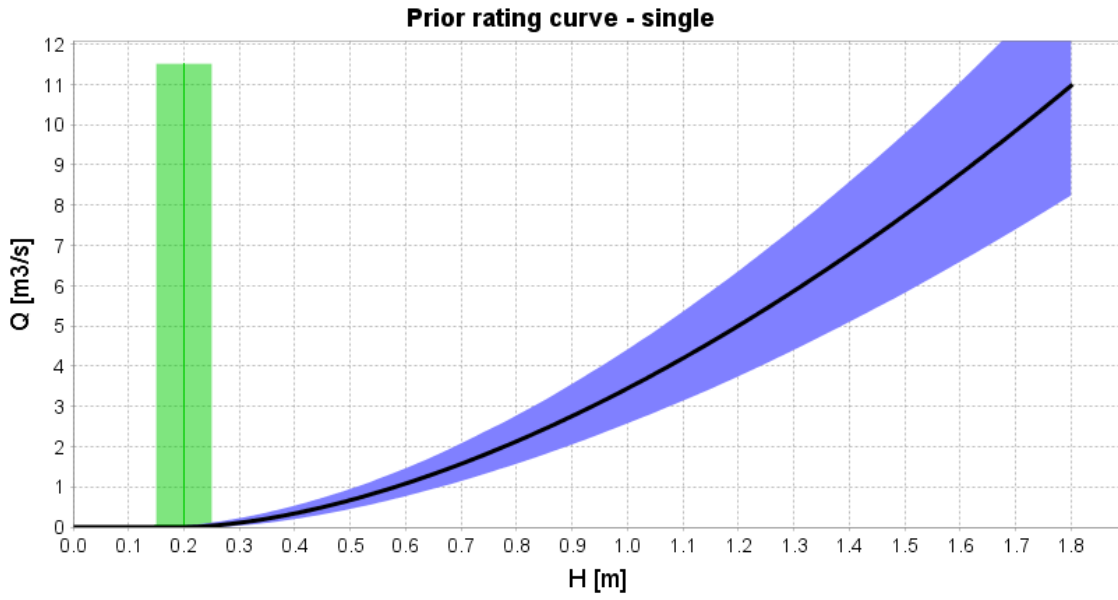


Figure 9-6. Prior rating curve, a hydraulics based rating curve (same as Figure 9-4, but now plotted using function in BaRatin). Blue area is the 95% confidence interval of rating curve parameters.

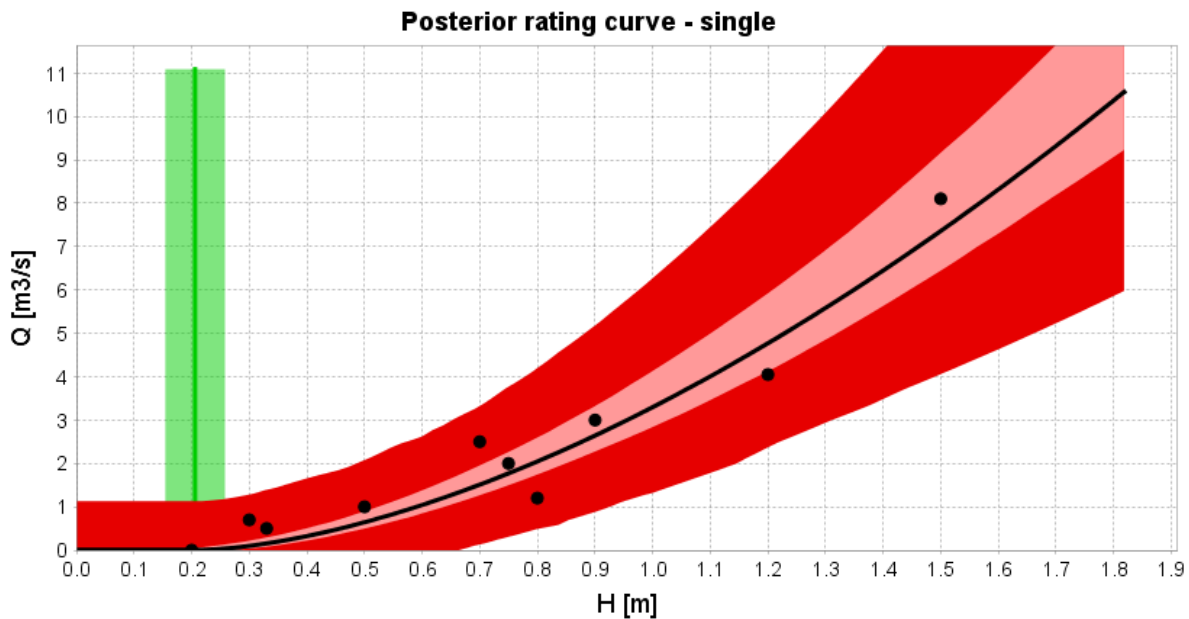


Figure 9-7. Posterior rating curve and 95% confidence interval of the parameters (light red) Dark red is 95% confidence interval including the remnant error, which is estimated based on the spread of the gaugings.



*Example: Assess likelihood of two rating curve parameter sets and if the MCMC algorithm will hop to the second set*

Given parameter sets  $\theta_1 = [0.2, 5.0, 1.67]$  and  $\theta_2 = [0.165, 5.2, 1.71]$  and the likelihood values determined from a set of gaugings for each parameter set,  $p(\tilde{Q}|\theta_1, \sigma_f, \tilde{H})$  and  $p(\tilde{Q}|\theta_2, \sigma_f, \tilde{H})$ , determine the prior likelihood of each parameter set. See BayesianRatingCurveAndHydrograph\_Box2.xlsx for example likelihood calculations. Is the change in value of parameter set 2 high enough for the MCMC sampler to jump to the sample 2 location or will it jump again from sample 1?

$\tilde{Q}$ [m <sup>3</sup> /s]	$\tilde{H}$ [m]	$p(\tilde{Q} \theta_1, \sigma_f, \tilde{H})$	$p(\tilde{Q} \theta_2, \sigma_f, \tilde{H})$
0.001	0.21	16.73251	0.000741
0.2	0.3	0.001422	7.828145
0.12	0.33	4.656126	0.379532
1	0.5	0.141713	1.154806
2.5	0.7	0.016107	0.149715
2	0.75	0.988013	0.942356
1.2	0.8	0.08627	0.037421
3	0.9	0.656229	0.645032
4.05	1.2	0.254059	0.149703
8.1	1.5	0.250898	0.226961
9	1.8	0.121975	0.07419

From equation 4, the combined likelihood of each parameter set is:

$$p(\tilde{Q}|\theta_1, \sigma_f, \tilde{H}) = 16.7*0.0014*4.66*0.15*0.016*0.99*0.086*0.66*0.25*0.25*0.12 = 1.1e-7$$

$$p(\tilde{Q}|\theta_2, \sigma_f, \tilde{H}) = 0.0074*7.82*0.38*1.15*0.15*0.94*0.04*0.64*0.15*0.23*0.07 = 2.18e-8$$

**Conclusion:** The likelihood of the first parameter set is higher than the second set so the MCMC calibration algorithm does not jump to the second parameter set.

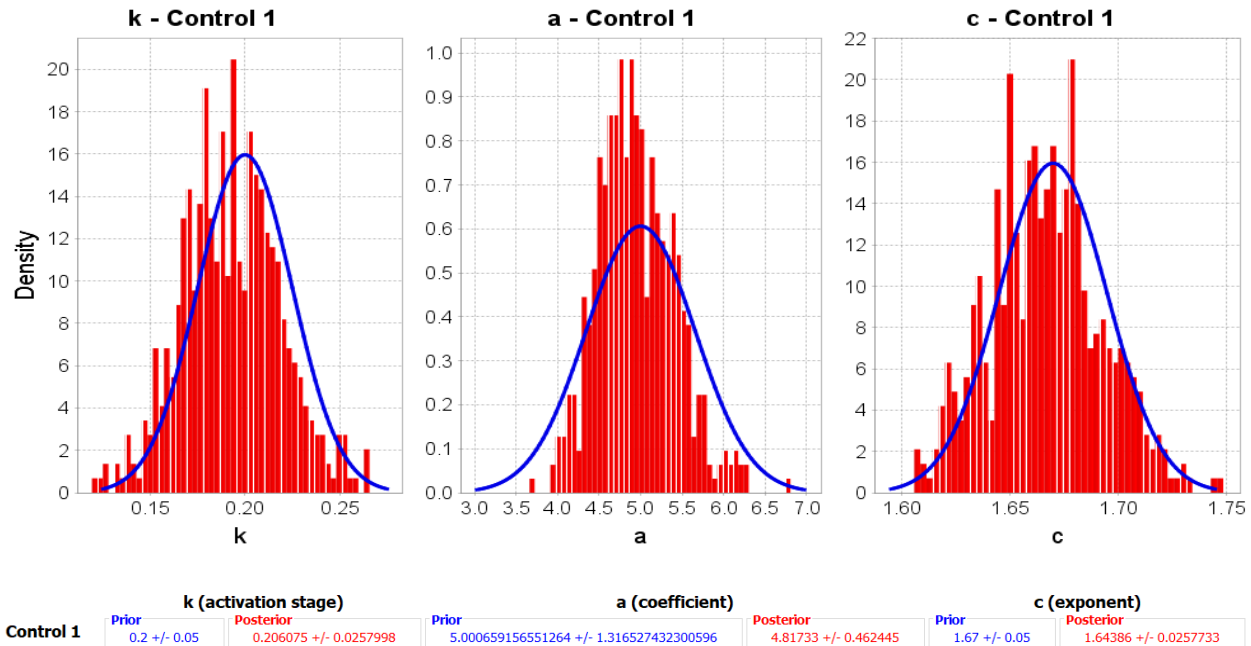


Figure 9-8. Visualization of the pdfs of the prior and the posterior rating curve parameters k, a, and c.

### Compound rating curves

At most of the small streams monitored in the OESF, the stage-discharge relationship is better described by two more power functions that apply to different stage ranges. For this scenario, a compound rating curve is needed. BaRatinAGE has a Graphical User Interface (GUI) where the user can select the stage range and control type to create a compound rating curve based on the hydraulics survey. The rating curve becomes the following:

$$Q = \sum_{r=1}^{N_{range}} \left( \mathbf{1}_{[K_{r-1}; K_r]}(h) \times \sum_{j=1}^{N_{control}} M(r, j) \times a_j (h - b_j)^{c_j} \right)$$

BaratinAGE solves for the coefficients of the compound rating curve using the same method used for a single rating curve described above; however, unlike the single rating curve, where  $\theta$  has only three rating curve parameter, the number of parameters in  $\theta$  for a compound rating curve is equal to three times the number of rating curves. An example of how to specify the compound rating curve from the channel hydraulics survey using BaRatinAGE is included in the section *Example workflow for using the BaRatin method*.

### EXAMPLE WORKFLOW FOR USING THE BARATIN METHOD

The workflow for implementing the BaRatin method can be summarized as three steps.

1. *Prior rating curve – channel hydraulics survey*: Survey the channel hydraulics, generalize the channel as a set of equivalent, geometric hydraulic controls. Using the BaRatinAGE GUI, specify the type (channel or section), geometry, roughness and stage-range of each control.
2. *Additional information about the rating curve parameters – gaugings*: Collect (ideally) 6 to 10 gaugings over a range of flow rates controlled by the surveyed channel geometry. Estimate the 95% confidence interval of the stage and discharge measurements. Organize the stage-discharge measurements into a single csv file readable by BaRatinAGE and load them into BaRatinAGE.
3. *Posterior rating curve and maximum likelihood parameters* : Using the prior pdf of rating curve parameters and the gaugings, run BaRatinAge to determine the rating curve parameters that have the maximum likelihood of predicting both the hydraulics rating curve and the gaugings.

These three steps are detailed below using Green Cove creek. Green Creek Cove creek drains a large marsh located on the Northwest side of Olympia. Near the outlet of the stream, it is 4- to 6-meters wide at bankfull flow, has a slope between 1 to 2 percent and is pool-riffle channel morphology. The cross-section location used for developing a rating curve is shown in Figures 9-9 and 9-10.

### **Step 1. Prior rating curve – channel hydraulics survey**

To determine the prior pdf, the cross-section and low flow control are surveyed at the gauge. Details on what to survey and record during the channel hydraulics survey are listed in the *Channel Hydraulics Survey* section. Once the survey is completed, the channel is conceptualized as a set of equivalent, geometrically defined, flow controls. An example conceptualization for Green Cove creek is shown in Figure 9-11. At the Green Cove creek cross section, all controls were channel controls (open-channel-flow-controls); even at low flow, there was no section (weir) control. The first control was defined active for flow depths less than approximately 15 centimeters, when relative roughness is high and the slope of the water surface matches the bed slope (~0.014). The next control was for flow depths between 15 and 35 cm, where relative roughness is lower and the flow is confined to the main channel (no flood plain or overbank flow). Measured water surface slope under influence of the 2<sup>nd</sup> control was about 1%. The third and fourth controls were a flood plain and over bank flow controls and were added following two flow measurements recorded on 2019/12/20. Water surface slope during the two high flow measurements was only 0.005. At this location, once the flow depth was high enough to inundate the flood plain and interact with the channel wall vegetation, control 3 was activated and control 2 no longer influenced the water surface height. The slope of the water surface decreased rather than remain parallel the channel bed due to a backwater effect associated with the flood plain, which narrows in width in the downstream direction. The backwater effect may have also been caused by increased interaction with vegetation along the channel banks of the flood plain. Except for control 3, all other controls were deactivated once control 4 was activated (Table 1).

Before the high flow measurement shown in Figure 9-9, there were no observations of flow conditions at depths that activated the third and fourth controls and it was assumed that control 2 maintained influence over the flow at all flow depths and that the water surface slope remained constant at 1%. Observation of the high flow rates revealed that the original conceptualization of flow controls was wrong, highlighting the importance of both the gaugings and hydraulics survey for accurately describing the rating curve.





**Figure 9-9.** Looking upstream at the creek cross-section during 0.25 year event. Gauge location at the middle of the straight section of the channel, where flow is close to uniform and a reach is clearly defined. During this flow, control 2 is active and control 3 is beginning to become active.



**Figure 9-10.** Looking upstream during a ~2 to 5 year flow event in the creek. During this flow, water has inundated the left flood plain and is flowing on the right flood plain. As a consequence of flow on the left flood plain, a back water effect occurs, reducing the water surface slope. During this flow, control 3 now controls flow rates and the profile of the water surface. Control 4 is just becoming active.

Water surface slope, channel width and roughness measurements (back computed from flow observations) are listed in Table 1. The resultant hydraulics based rating curve is shown in Figure 9-12.

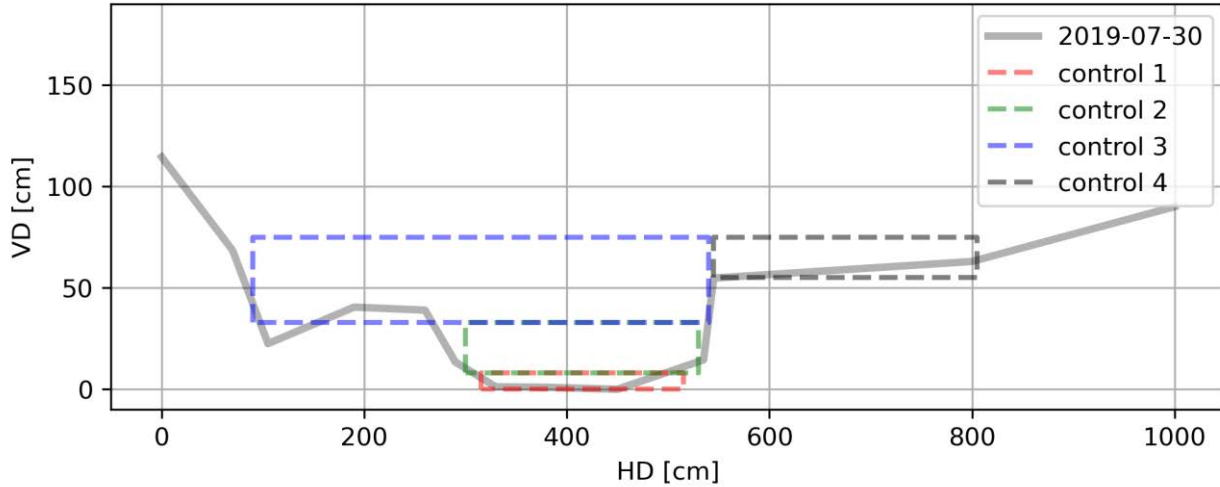
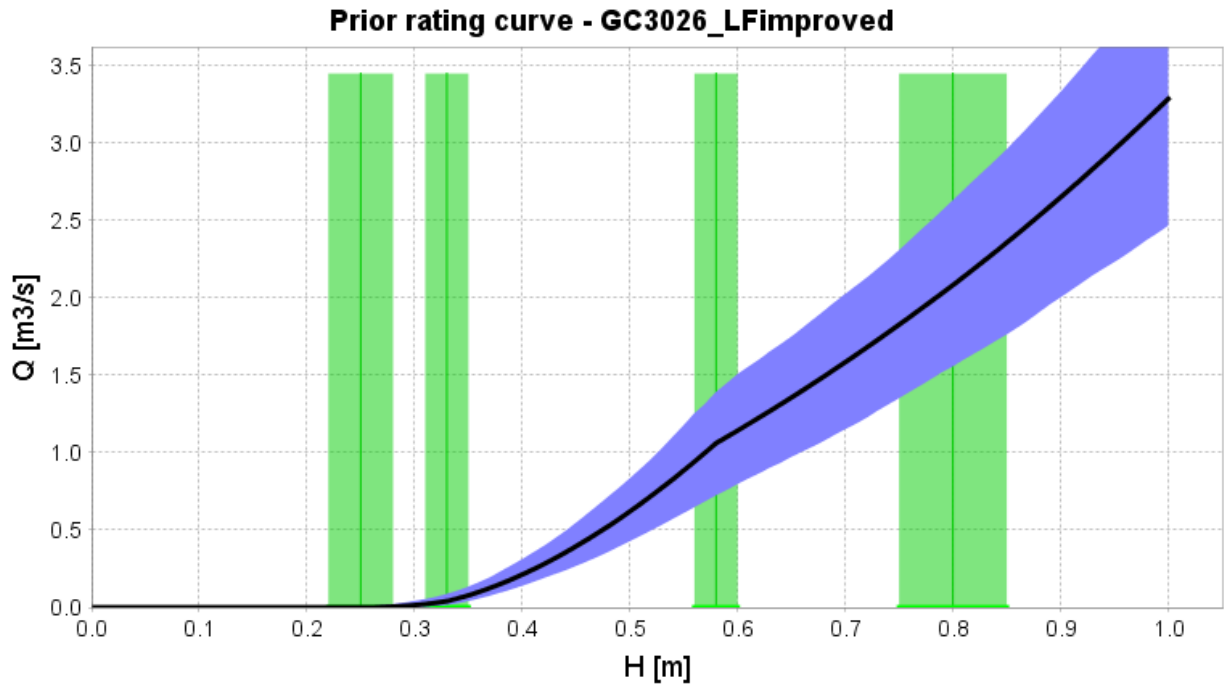


Figure 9-11. The surveyed cross section and the equivalent hydraulic controls.

Table 1. Upper box shows stage activation range for each control as shown in BaRatinAGE. The parameters of each control are  $K_s$ : Strickler coefficient ( $1/n$ ),  $B_p$ : parabola width,  $H_p$ : Parabola depth,  $B_w$ : width rectangular channel,  $S$ : slope,  $c$ : exponent,  $k$ : activation stage. For each parameter, the 95% confidence interval ( $2 \cdot \sigma$ ) is listed

		Control 1		Control 2		Control 3		Control 4					
Segment 1	<input checked="" type="checkbox"/>												
Segment 2	<input type="checkbox"/>		<input checked="" type="checkbox"/>										
Segment 3	<input type="checkbox"/>		<input type="checkbox"/>	<input checked="" type="checkbox"/>									
Segment 4	<input type="checkbox"/>		<input type="checkbox"/>		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>							
$K_s$	+/-	$B_p$	+/-	$H_p$	+/-	$B_w$	+/-	$S$	+/-	$c$	+/-	$k$	+/-
12.0	3.0	2.3	0.05	0.15	0.03	-	-	0.07	0.0025	2.17	0.05	0.25	0.03
33.3	11.1	-	-	-	-	2.5	0.1	0.01	0.0025	1.67	0.05	0.33	0.02
14.3	4.1	-	-	-	-	4.1	0.1	0.005	0.0025	1.67	0.05	0.58	0.02
2.85	0.41	-	-	-	-	3.0	1	0.007	0.0025	1.67	0.05	0.8	0.05



**Figure 9-12. Channel geometry hydraulics-based rating curve used to determine the prior pdf of the hydrograph parameter values.**

### ***Step 2 Additional information about the rating curve parameters – gaugings***

Eight gaugings were recorded during the period that the cross-section geometry shown in Figure 9-11 controlled channel hydraulics and stage (Figure 9-13). Several low flow measurements, a few mid-range measurements and one measurement during a 2 to 5 year flow. Stage measurements were assumed to have an uncertainty of 1 to 2 mm. Based on repeat flow measurements, flow measurement uncertainty was estimated as 5%. The gaugings and their uncertainty were entered into the `Gagings_field_entry.xlsx` form and the converted to a `gaugings csv` file in the format necessary for BaRatin following the Rating Curve and Hydrograph Construction SOP (Appendix 9B).



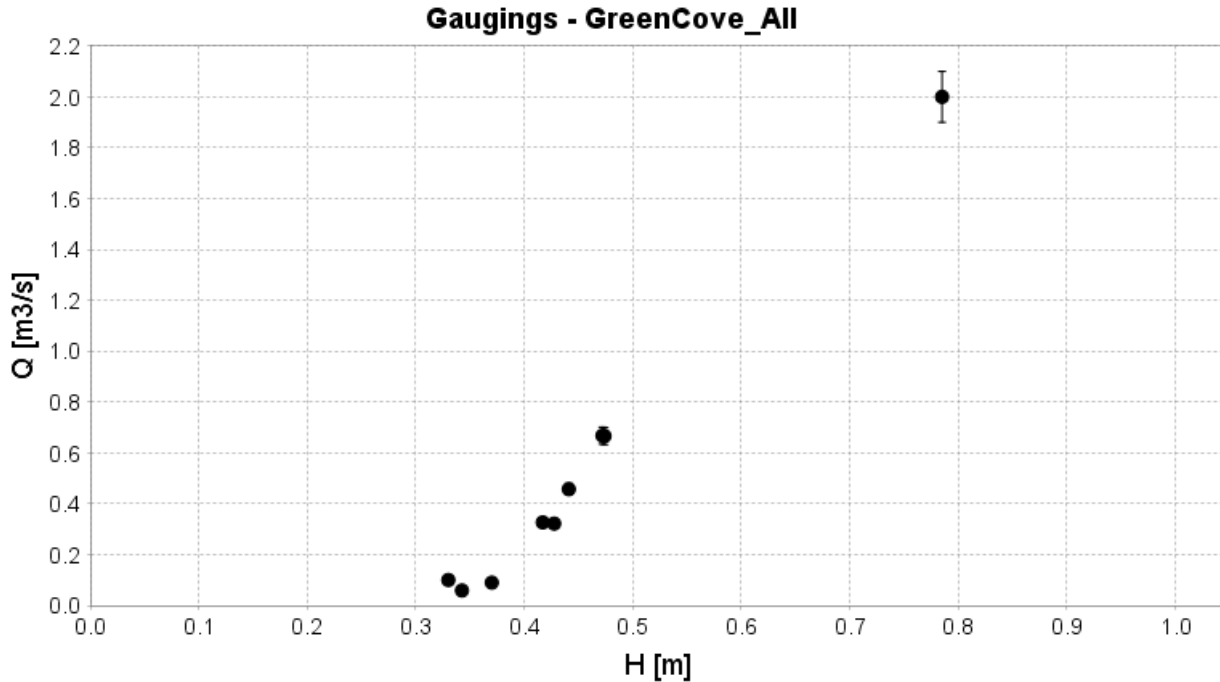


Figure 9-13. Plot of the observed stage and flow and uncertainty of the flow measurement.

**Step 3 Posterior rating curve and maximum likelihood parameters**

With geometric data from the channel hydraulics survey and the gaugings, the posterior rating curve is created by entering the channel geometry information shown in Table 1, loading the gaugings, into BaRatinAGE and then running the posterior rating curve function. See BaRatinAGE online support for directions on operating the GUI. The resulting rating curve is shown in Figure 9-14. Note that the posterior rating curve still has 4 controls, but the stage activation and parameters of each control have been adjusted to incorporate information brought by the gaugings.



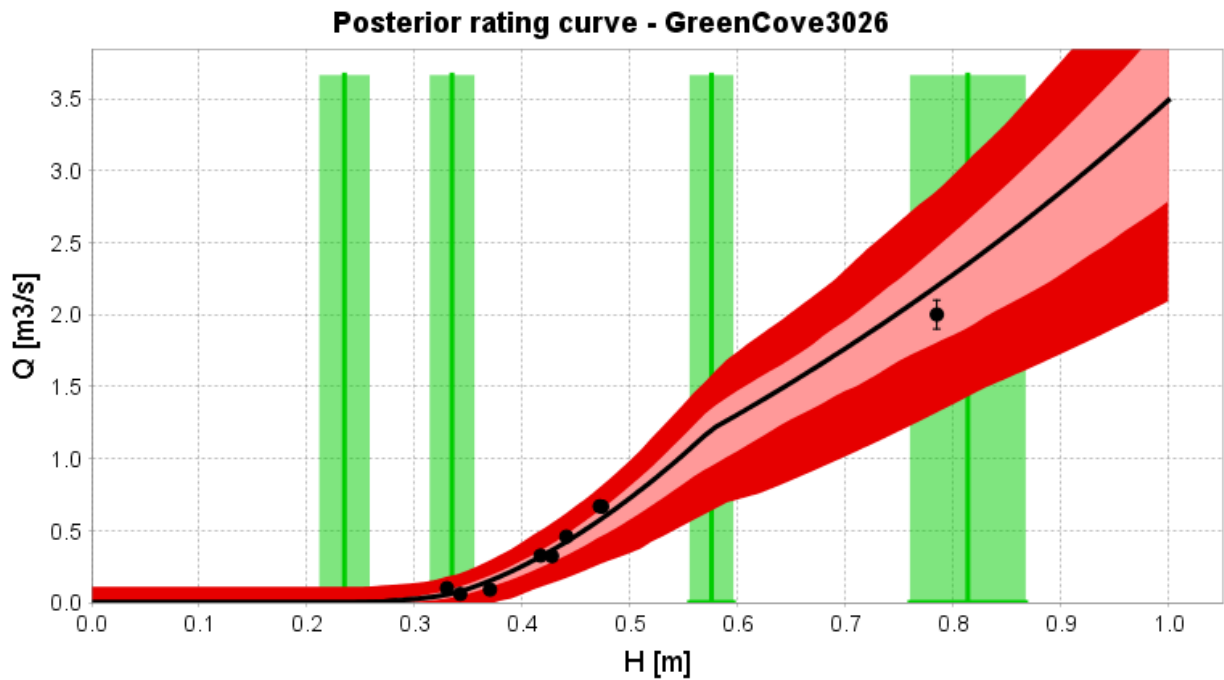


Figure 9-14. Final rating curve that incorporates both the gaugings and the hydraulics defined rating curve

## CHANNEL HYDRAULICS SURVEY

The channel hydraulics survey consists of a topographic survey of the channel and flow geometry. Results of the channel hydraulics survey are used to develop a hydraulics-based rating curve. It involves surveying parts of the channel that control the elevation of the water surface at low, moderate and high stream flow rates. It also requires a survey of the water surface slope (approximation for friction slope) at low, moderate and high flows. The survey information is used to back-compute channel roughness (Manning's  $n$ ). Channel hydraulics surveys are repeated at least once per year but are needed any time the geometry of a channel changes. At present, the channel geometry survey is completed using an autolevel and two fiber glass tapes. Future surveys will hopefully use a total station. The channel geometry survey consist of three separate parts: the (1) channel cross section survey, (2) low-flow control survey and (3) water surface slope survey. An example channel hydraulics survey setup in the field is shown in Figure 9-15. Methods and the goal of each component are described below.

### *Channel cross section*

The channel cross section is always measured at a designated cross-section so that changes in the section-control (open-channel-flow-control) channel geometry can be tracked. As such, the cross section is located to capture topographic changes representative of the channel geometry that controls the water surface at mid to high flow rates at the gauge. The left and right ends of the cross section are marked with a rebar stake. To begin the survey, a fiber glass tape is stretched between the two rebar stakes. Beginning at the left rebar



**Figure 9-15. Channel hydraulics survey during summer low flow. The low flow control at is located about 5 meters downstream of the cross section. The reach extends roughly 10 meters up and downstream of the cross section. The channel is bedrock and rarely aggrades so the channel geometry and gauge survey are generally repeated only once a year. Other, less stable channels require surveys following most large flow events.**

stake, the vertical distance relative to the auto level and horizontal distance along the tape are recorded at all slope breaks and the following stream locations: left bankfull water surface (LBF), left water surface (LWS), thalweg (TH), right water surface (RWS), right bankfull water surface (RBF). In addition to tracking changes in the channel geometry, the goal of the survey is to get enough information about the channel geometry so that cross-section can be approximated as some combination of rectangular, triangular and/or parabolic channel shapes. Fine detail, such as individual cobbles, are not needed in the survey but features such as flood plains and terraces should be included in the survey. Results of the survey are entered into the StageControls.xlsx spreadsheet. Multiple cross-section surveys are used to track changes and the timing of the changes of the geometry of the open-channel-flow-control part of the channel geometry. An example summary plot is shown in Figure 9-16.

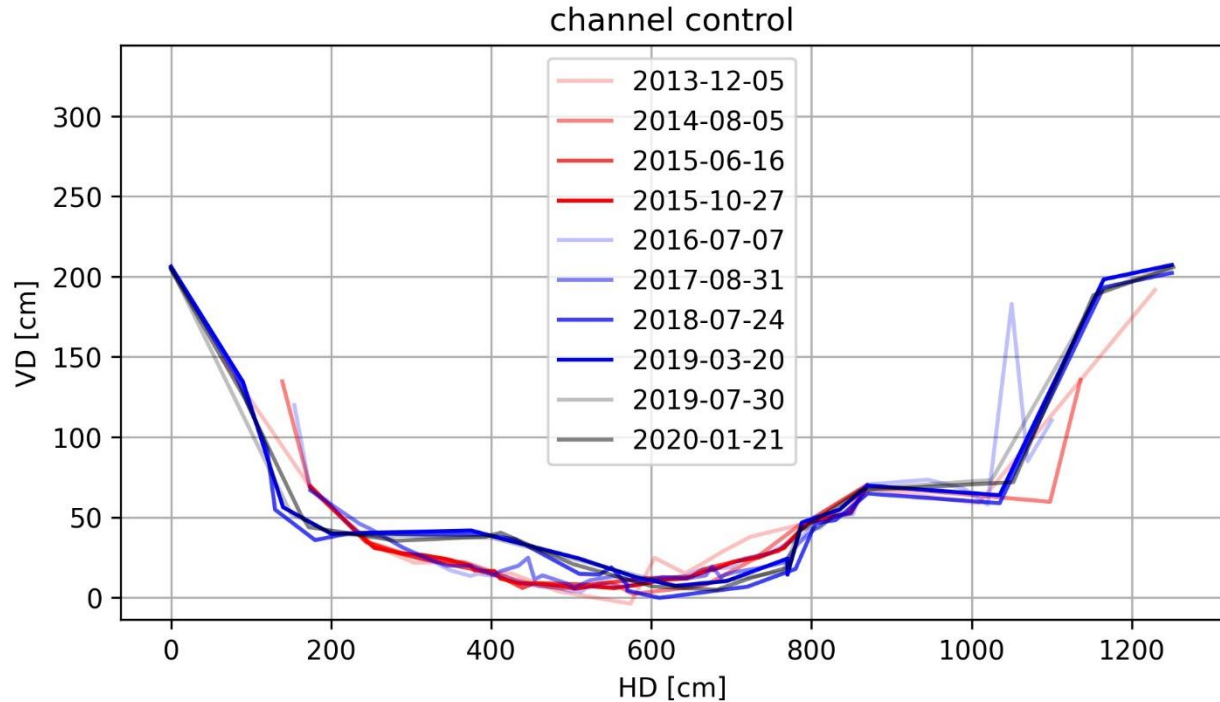


Figure 9-16. Example plot of repeat cross-sections showing how the geometry changes with time.

### **Low-flow control:**

Cobbles that act as roughness elements during mid to high flow rates act as a natural weir during low flows. The objective of the low-flow control survey is to capture the geometry of the natural weir that controls the elevation of the water surface at the gauge during low flows. Just like the channel cross section survey, the low-flow control survey is used to approximate low flow control as a known weir shape. It may be a single or combination of rectangular, triangular or parabolic weirs for which a specific stage discharge relation can be computed. Unlike the channel cross section survey, the location of the low flow control can change following a large storm. Thus, the survey location of the low flow control generally changes each survey. The survey begins by noting the distance between the cross section and the low flow control and taking a photo of the relative location. A fiberglass tape is stretched from the left edge (looking down stream) to the right edge of the low flow control. The location of the left edge of the low flow control relative to the cross section tape is noted so that the two surveys can be plotted using the same horizontal datum. The horizontal distance relative to the tape and vertical distance relative to the auto level are recorded at all major slope breaks. Like channel cross-section, the channel control plots are summarized in a single plot to track changes in the geometry of the low-flow control (Figure 9-17).



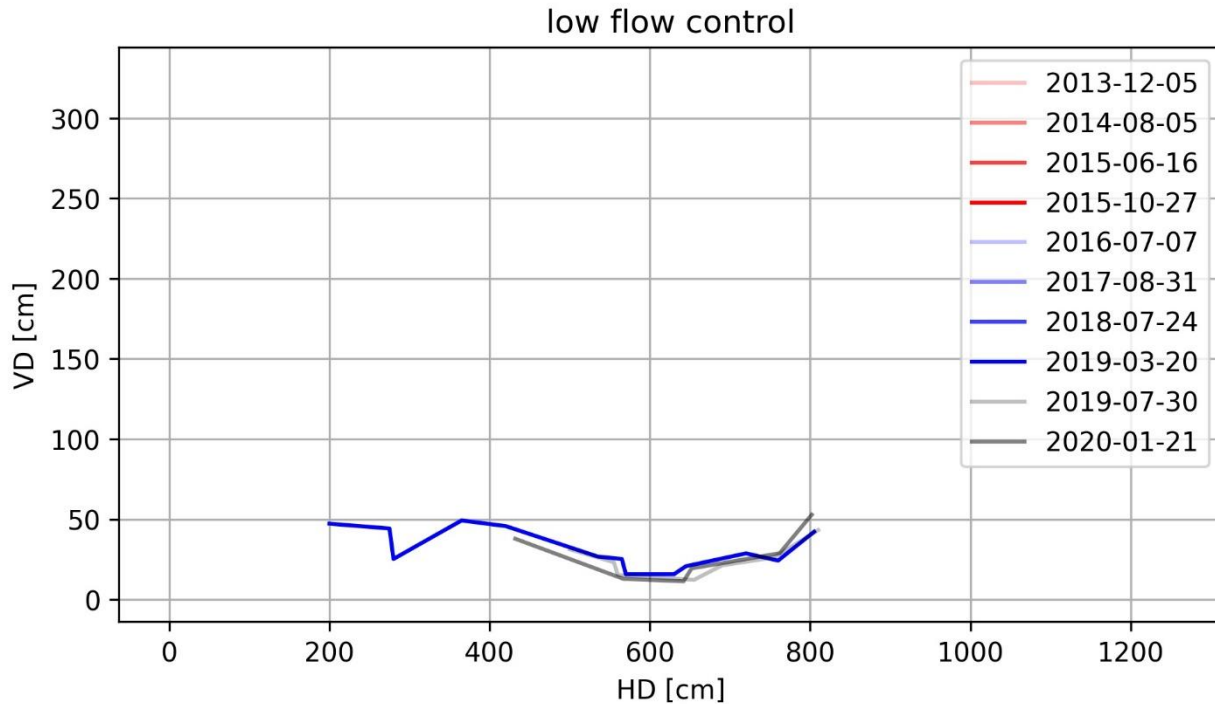
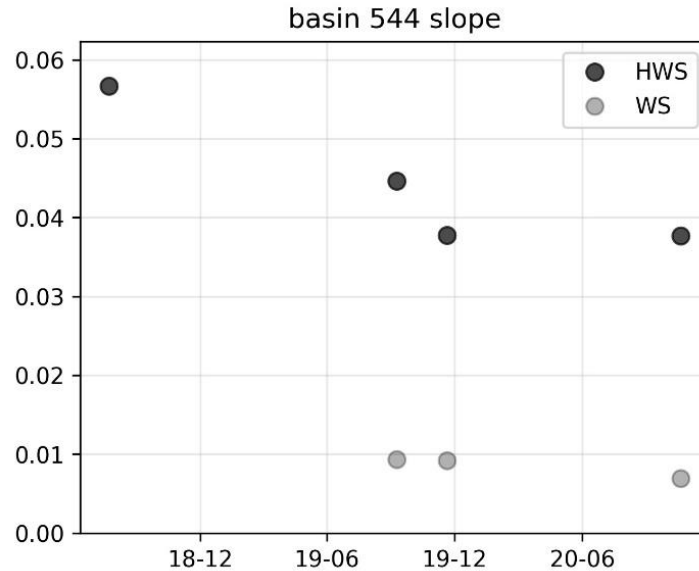


Figure 9-17. Example plot of repeat surveys of the low-flow control. Over the measurement period (3/20/2019 to 1/21/2020, the low flow control lowered by about 5 cm.

**Water surface slope:**

Most open equations for channel and weir flow are a function of the slope of the energy grade line or friction slope. Under gradually varied flow, the energy grade line can be approximated by the water surface slope (Sturm 2010) and when flow is uniform, the water surface slope can be approximated by the channel slope. In most OESF channels, flow is gradually varied, and the slope of the water surface must be measured or approximated from field indicators. The water surface slope is measured along a transect that extends from the upstream end to the downstream end of the channel reach that the gauge is located in. The channel reach is defined as the segment of the stream channel in which flow is uniform to gradually varied. The elevation and distance along the channel centerline are recorded at the upstream end of the reach, the cross section and the downstream end of the reach. Each elevation measurement includes a measurement at the thalweg, water surface and estimated left and right bankfull water surfaces. The left and right bankfull water surfaces are estimated based on the elevation of scour and debris indicators left by the previous high flow. If no indicators of the last high flow are present, then bankfull flow indicators such as the vegetation line are used. Slope measurements are entered into the ChannelSlope\_field\_entry.xlsx spreadsheet. Slope may change with flow rate or changes in channel geometry. After multiple slope measurements have been measured, the appropriate slope can be selected for each control in the BaRatin rating curve by looking at summary plots of slope relative to flow rate and time (Figure 9-18).



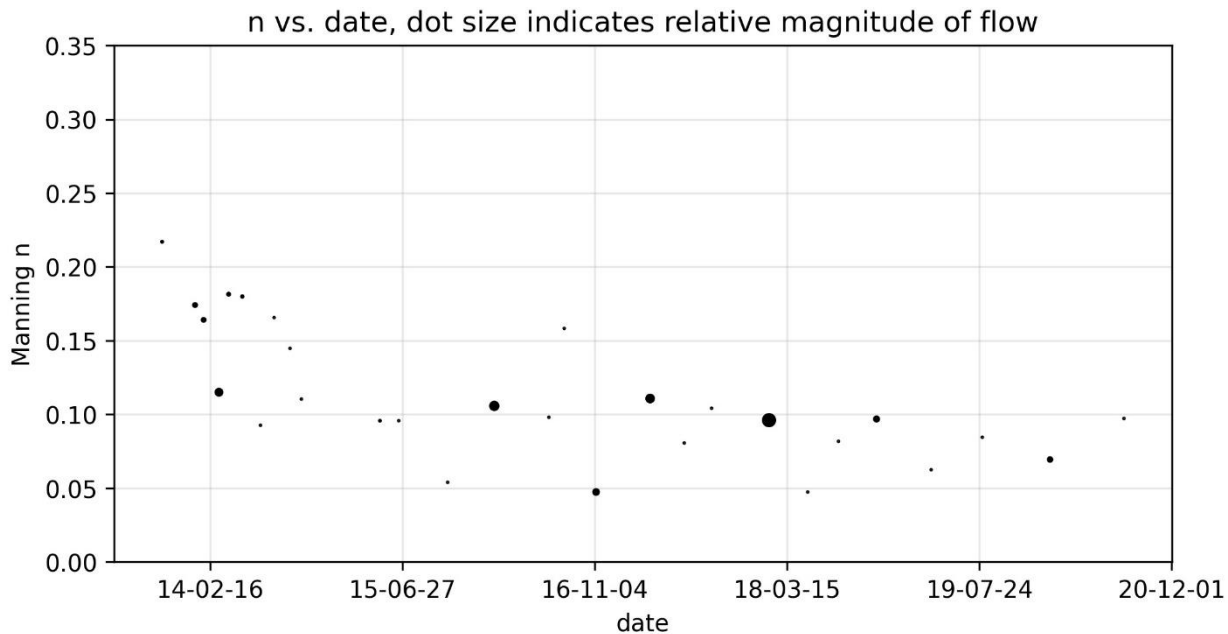
**Figure 9-18.** Example slope measurements for the high-water-surface (HWS) and the water surface at the time of the survey (WS).

### **Channel roughness (flow resistance):**

The hydraulics based rating curve is sensitive to channel roughness. Channel roughness, or flow resistance, is determined two ways: (1) back-compute from hydraulic radius, slope and flow using Manning's equation and information collected during the cross-section survey and flow measurement or (2) compute using the Rickenmann and Recking, (2011) form of the Ferguson (2007) flow resistance equation. Using method 2, only flow depth and an estimate of the 65<sup>th</sup> percentile grain size (D65) are needed. The D65 grain size can be determined from a cumulative distribution of the grains in the gauge channel reach created from a pebble count of 100 grains following Kondolf and Piegay (2016). Roughness on the flood plain and banks of the channel are determined visually using Arcement and Schneider (1989). After multiple flow roughness measurements have been determined, they can be plotted as a function of date and flow magnitude at the time of the measurement (Figure 9-19). From this plot, appropriate flow resistance values can be selected for each control in the BaRatin rating curve.

## **DETERMINE PERIODS OF RATING CURVE STATIONARITY**

A rating curve is only applicable to a single channel geometry. The rating curve becomes invalid following a large storm that causes channel aggradation or scour because channel slope, geometry, roughness and/or flood plain elevation change. Rating curves that must frequently be updated for new channel hydraulic conditions are known as non-stationary rating curves. The OESF flow gauges are located on steep (> 1%), upland channels where sediment supply and flow rates are especially variable and the rating curves are especially non-stationary.



**Figure 9-19. Example plot of back computed flow resistance as a function of time and flow magnitude (dot size). Note that larger flows generally have lower flow resistance.**

To determine periods of rating curve stationarity (periods of time that a single rating curve accurately predicts the stage-discharge relation), we use specific gauge analysis. Specific gauge analysis is a commonly used method for utilizing gaugings to determine periods of rating curve stationarity (Blench 1969; Anderson & Konrad 2019; Pfeiffer et al., 2019). It is a simple procedure in which the stage predicted for a given flow by the single rating curve is compared to the observed stage (the stage residual). Trends in the stage residual, which is different in the observed stage and the predicted stage for the observed discharge rate, are tracked through time. Periods of consistent stage residual values indicate periods of rating curve stationarity. Since the uncertainty of the OESF rating curves is generally higher at higher flow ranges, stage residuals of bankfull flows and smaller should be given more weight when evaluating periods of stationarity. An example plot of stage residuals before and after specific-gauge analysis is shown in Figures 9-20 and 9-21.

### CREATING THE HYDROGRAPH

Once periods of rating curve stationarity have been determined and a rating curve has been created for each period, the next step is to convert the time series of flow depth to a time series of flow. In python, the set of rating curves are loaded into an instance of the class Hydrometric Station and converted to a hydrograph following the steps listed in Appendix 9B.

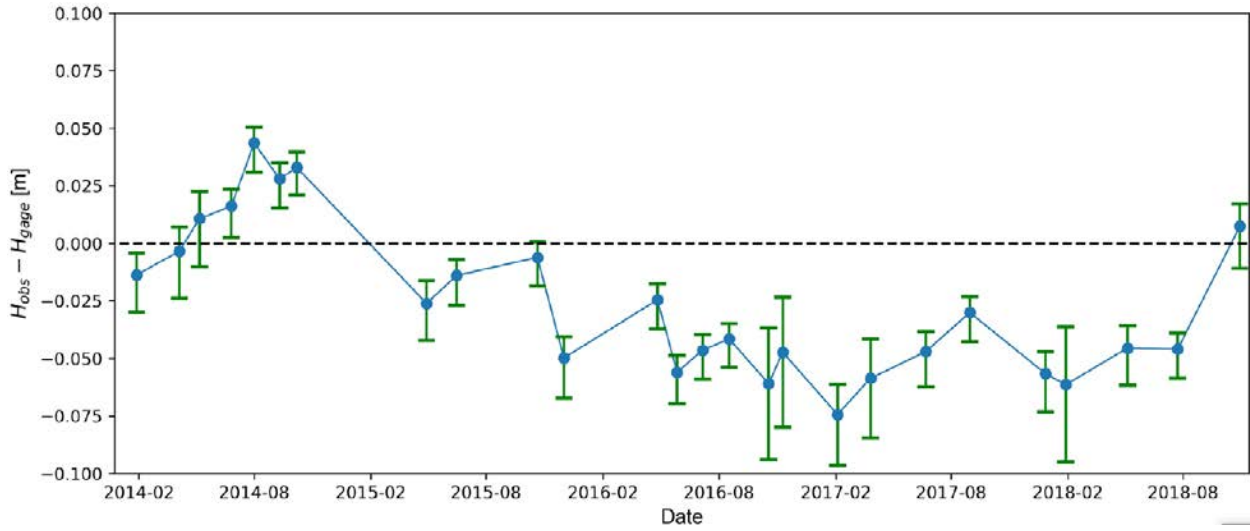


Figure 9-20. Stage residuals ( $H_{obs}-H_{gage}$ ) comparing observed flow and stage to a single rating curve.

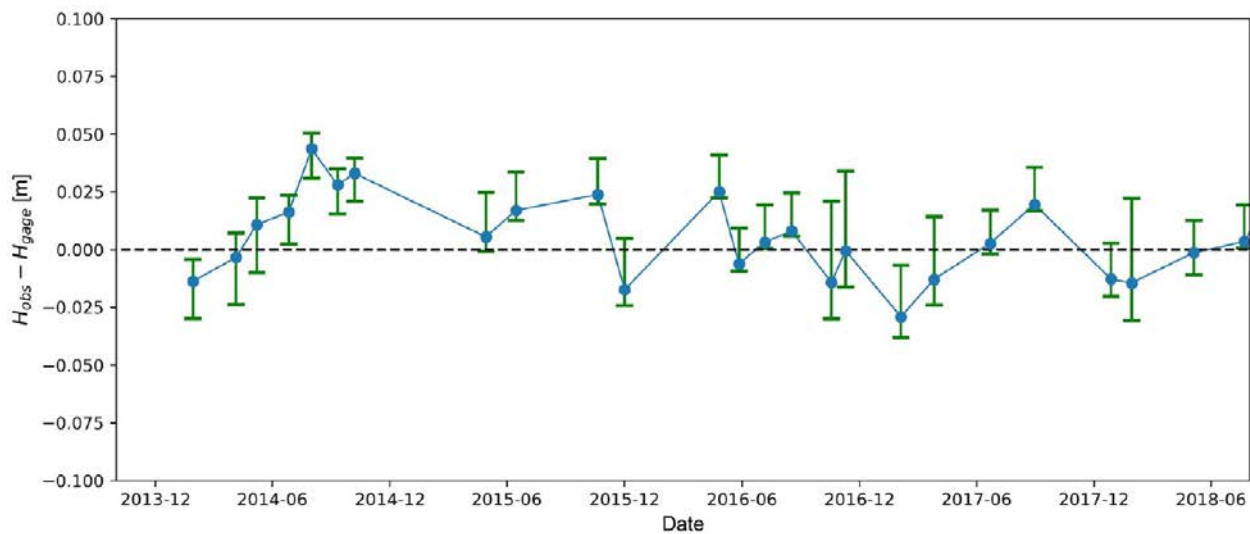


Figure 9-21. Stage residuals after several a rating curve was developed for each period of stationarity.

## HYDROGRAPH METRICS

The following metrics can be used to characterize the hydrograph and evaluate the “health” or condition of the flow-regime relative to other gauged watersheds:

- **Annual minimum 7-day mean flow:** Minimum consecutive 7-day mean flow rate, determined for each water-year



## ■ Stream Discharge Data Management and Analysis

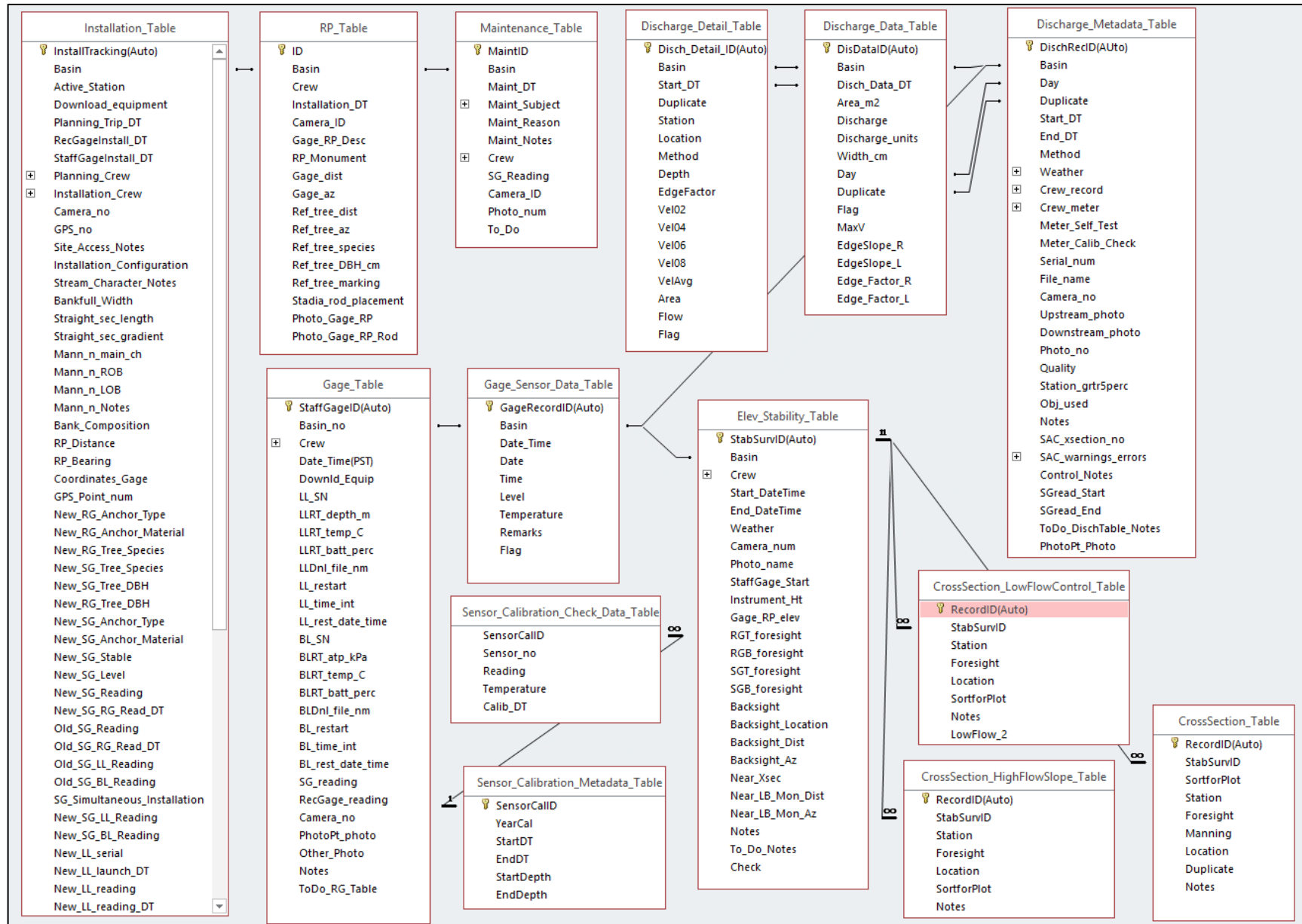
- **Seasonal minimum 7-day mean flow:** Minimum consecutive 7-day mean flow rate, determined for each water-year of each season
- **Annual peak flow:** Maximum instantaneous flow rate, determined for each water-year
- **Seasonal peak flow:** Maximum instantaneous flow rate, determined for each water-year of each season.
- **Runoff ratio:** ratio of cumulative precipitation to cumulative runoff
- **Aridity index:** ratio of potential evapotranspiration to actual evapotranspiration (precipitation - runoff)

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## Appendix 9A: Hydrology Database Structure





## Appendix 9B: Rating Curve and Hydrograph Construction SOP

### Field data entry: Excel

- (1) Convert Hach pressure sensor data to a single .csv file in LevelLogger software
  - a. Save file in an appropriately name folder at:
    - i. e.g., D:\DNR\OESFHydrologyMonitoring\Data\StageDischarge
- (2) Append new pressure sensor data to pressure sensor csv
  - a. *StageRecordAppend* function
- (3) If channel survey was conducted, enter channel slope information into *ChannelSlope\_field\_entry.xlsx*
- (4) Enter flow observation data into *Gagings\_field\_entry.xlsx*
  - a. From raw Hack flow meter files and/or notes get time of measurement,
  - b. enter pressure sensor reading at time of measurement
  - c. Use cell formulas to compute channel roughness and assign uncertainty
  - d. Look up stage at time of flow measurement and enter time into spreadsheet
    - i. *python: LookUpStage* function
- (5) Convert each sheet in *Gagings\_field\_entry.xlsx* to b“basin number”\_obsAll.csv
  - a. *ExtractRatingData* function
- (6) If channel survey was conducted, Enter cross section and low flow control data into *StageControls.xlsx*

### Visualize gauge hydraulics and stability: HydrometricStation Python module

- (1) Channel slope plots - Plot times series of channel slope by slope type for each gauge
  - a. *VisualizeSlope*
- (2) Channel hydraulic controls plots – plot cross-section and low flow control plots.
  - a. For each gauge, plot one plot with all surveys, and a plot for each survey
  - b. *XsecPlots*
- (3) Channel roughness plots – plot time series of roughness, with points colored by stage height
  - a. *visualize\_channel\_roughness*
- (4) Sensor stability plots – plot a time series of the vertical offset (ws+pressure depth) to the pressure sensor
  - a. *GageStabilityPlots*

### Rating curve construction: BaRatin rating curve software, HydrometricStation Python module

- (1) Load gagings output from HydrometricStation into BaRatin
- (2) First year rating curve
  - a. Use Equivalent Geometry conceptual model illustration, channel slope plots, channel roughness plots to create the prior rating curve.
  - b. Load the gagings for the first year and create the posterior rating curve
- (3) Specific gauge analysis
  - a. Load rating curve into HydrometricStation instance for gauge
  - b. Check if predicted depth is equal to observed
  - c. For each period the predicted depth varies from observed, and that sufficient hydraulic and observational data exists, create a separate rating curve and note the date range that each rating curve applies to the channel (period of applicability)
  - d. Repeat a, b and c until entire flow record has a predicted depth minus observed depth that is close to zero.
- (4) Export each rating curve as a csv file
- (5) Enter rating curve name and period of applicability in “rating\_parameters.py”

## ■ Stream Discharge Data Management and Analysis

### *Hydrograph construction*

- (1) Create final hydrograph
  - a. Load stage time series using load\_rating\_curves method
  - b. Convert stage to flow using stage\_to\_flow method
  - c. Save hydrographs using save\_hydrograph method



# Riparian Microclimate

*Authors:* Richard Bigley, Paul Dunnette, Ellis Cropper, Warren Devine

*Version:* 1.3

## *Revision History:*

Version number	Purpose / Changes	Author(s)	Reviewer(s)	Date
1.0	Initial draft	Richard Bigley, Ellis Cropper		03/03/2014
1.1	Draft presented to project staff for review	Richard Bigley, Ellis Cropper	Teodora Minkova	07/03/2014
1.2	Final draft incorporating internal reviews, sampling procedures from 2013-2015 field seasons, and data mgmt. procedures	Richard Bigley, Ellis Cropper, Warren Devine	Teodora Minkova	11/22/2016
1.3	Final technical review and edit	Richard Bigley, Paul Dunnette, Ellis Cropper, Warren Devine	Alex Foster	12/18/2016

## *Based on the Following Protocols:*

In this protocol, the spatial monitoring design along the riparian gradient is adapted from Brosofske et al. (1997) and Anderson et al. (2007). Sampling generally follows Moore et al. (2005).

## *Reasons to Adopt the Above Protocols:*

Brosofske et al. (1997) and Anderson et al. (2007) provided a general sense of the contours of the microclimate gradient. Moore et al. (2005) and Anderson et al. (2007) provided insight as to sampling intensity required to detect differences.

## *Purpose and Content:*

This protocol details the field procedures for deployment, maintenance, and downloading of microclimate data loggers, the field quality assurance and quality control steps, and the data management and analysis procedures necessary to document and report the status and trends of riparian microclimate across the Olympic Experimental State Forest (OESF).

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## Introduction

The goal of the Olympic Experimental State Forest (OESF) riparian conservation strategy is to provide habitat for salmonids and other species dependent on in-stream and riparian environments. The strategy is implemented by establishing riparian management areas designed to maintain a stream's key physical and biological functions.

Maintenance of aquatic and riparian ecosystem function hinges in part on preservation of riparian microclimate – a suite of variables including moisture, temperature, light, and wind speed that affect species adapted to conditions found in or near streams. Riparian microclimate moderates environmental fluctuation to maintain in-stream temperatures and provides habitat for riparian-associated wildlife. The high productivity, complex habitat, and moist conditions of riparian areas support the highest biodiversity in forested landscapes (Olson et al. 2007). Numerous invertebrate taxa, many small mammals, and all western Washington amphibians depend on the cool, moist conditions in stream corridors.

Research has demonstrated that stream microhabitats can be strongly influenced by adjacent land use. Nonetheless, it is assumed that riparian buffers ameliorate edge effects created by upslope forest harvest (Brosnoff et al. 1997). The effects of partial cuts or thinning treatments within riparian areas are poorly understood and believed to be short-lived, owing to vegetation response to increased light after disturbance (Guenther et al. 2012). However, studies have shown strong near-stream gradients and increased diurnal variation in relative humidity in the riparian zones of forest stands that were selectively harvested with no buffer (Danehy and Kirpes 2000, Moore et al. 2005, Anderson et al. 2007, Guenther et al. 2012).

The environmental impact analysis for the OESF Forest Land Plan found that planned increases in timber harvesting could negatively affect riparian microclimate in managed stands. Presently, management effects on riparian microclimate are characterized as “medium impact” in nearly half of the OESF watersheds analyzed (WADNR 2016).

## Monitoring Design

### SPATIAL SAMPLING DESIGN

Riparian microclimate (i.e., air temperature and humidity) is monitored in 10 of the 50 OESF sample watersheds. At each sample site, five microclimate monitoring stations are installed systematically along each of two, 60-m transects, perpendicular to the stream (Figures 10-1 and 10-2). The transects bisect permanent 30 x 60-m vegetation plots established adjacent to two of the six channel cross sections installed at each sample reach (see *Riparian Vegetation Monitoring Protocol*). The two transects are located at separate, randomly selected cross sections, on opposite sides of the stream.

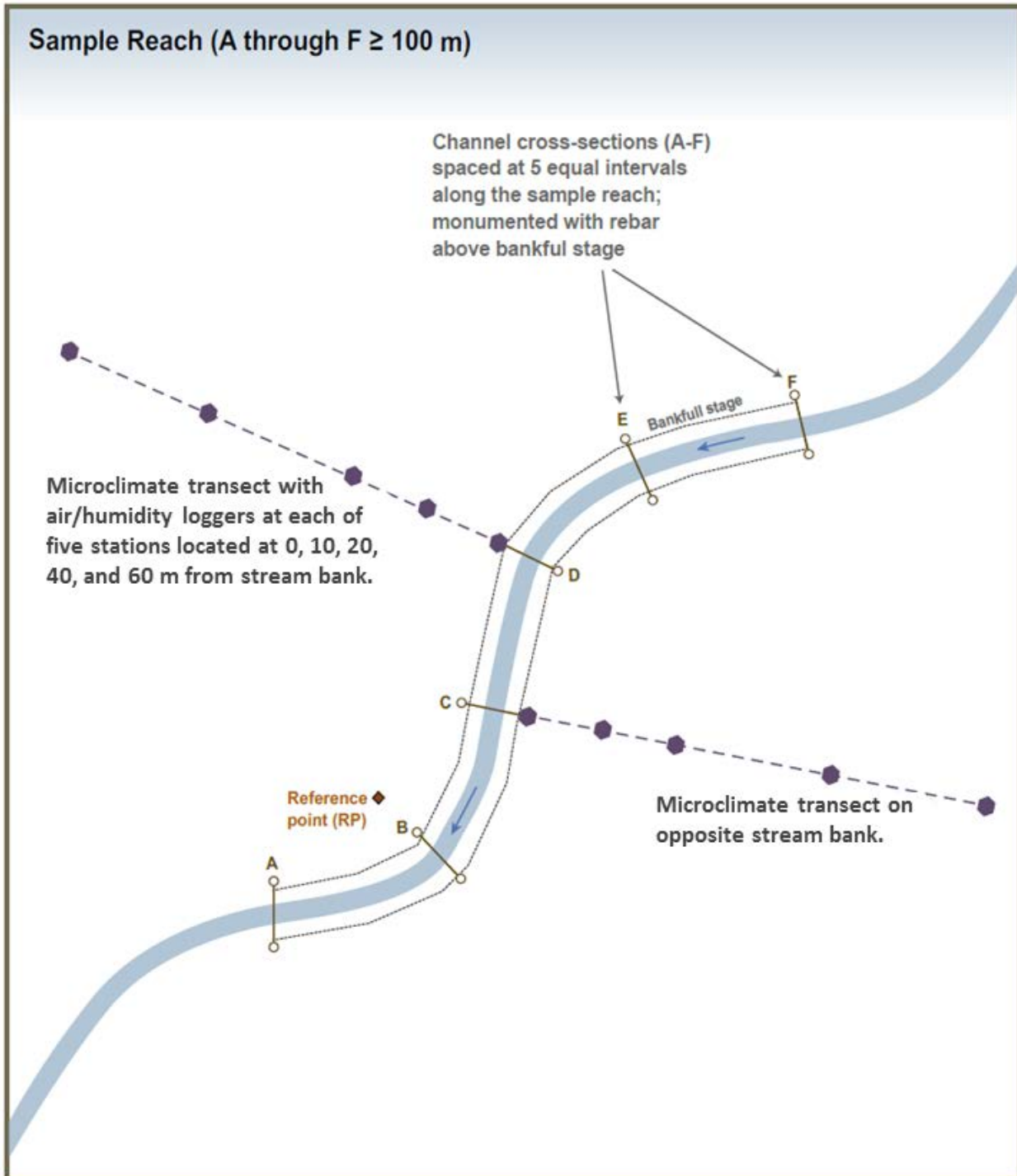


Figure 10-1. Location of microclimate transects within the sample reach.

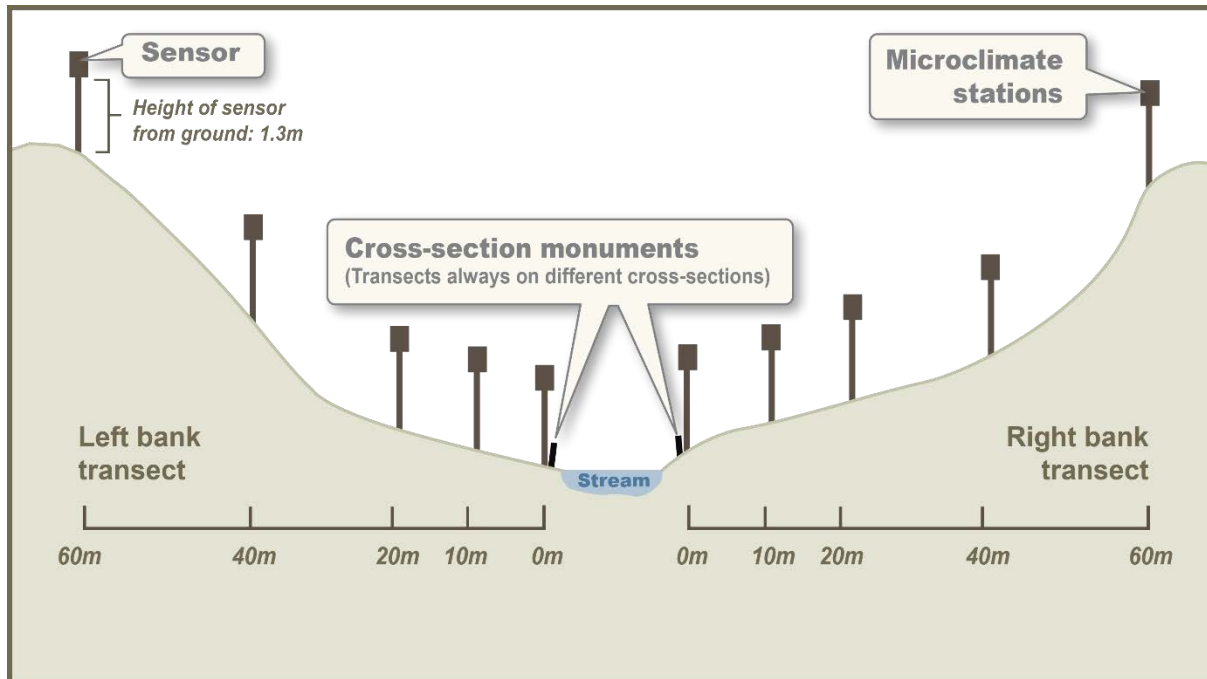


Figure 10-2. Location of microclimate monitoring stations in cross-section at a sample reach.

Site stratification followed the variables and methods used in selecting watersheds for hydrologic monitoring in this project (see Minkova and Vorwerk 2014). The stratification method aims to capture the full range of hydrologic conditions within the OESF by distinguishing different hydrologic regimes.

## TEMPORAL SAMPLING DESIGN

### *Sampling Interval*

Both air temperature and humidity data loggers are deployed year-round and set to record temperature every 120 minutes. At this interval, the data loggers' memory limits and battery life will allow continuous recording for up to 4-5 years.

### *Download Schedule*

Data will be downloaded and the loggers inspected twice annually: in spring (May-June) and fall (October-November). It is most efficient to download data and inspect loggers when the sample sites are visited for other monitoring activities.

## Equipment and Supplies

The following equipment and supplies are needed for initial microclimate monitoring station installation, data logger download, and replacement of lost or damaged loggers:

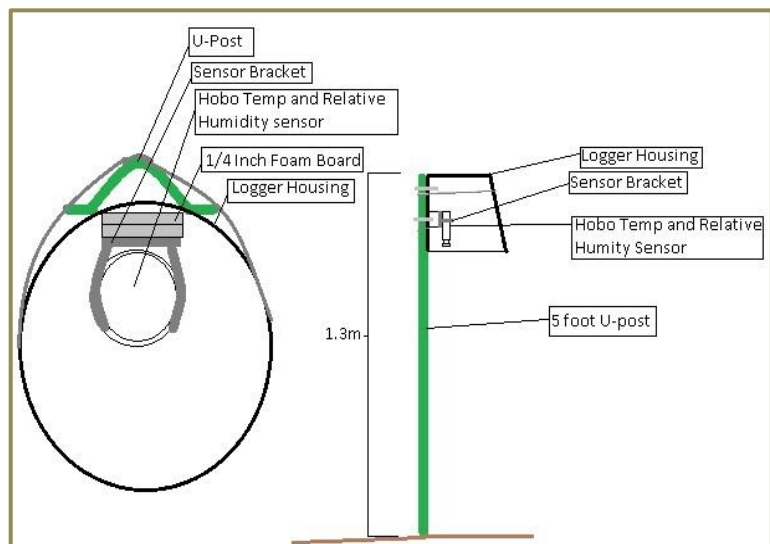
- Onset® HOBOWare Pro software
- Onset® HOBO Pro v2 U23-001 Temp/RH Data Loggers
- Onset® HOBO Waterproof Shuttle (optical data shuttle for data download)
- 3-liter plastic paint-mixing buckets
- Onset® logger-specific mounting brackets
- 8 in nylon cable ties
- ¼ in foam boards
- Multitool/knife
- Hot glue gun and glue
- 5 ft U-post
- 4 lb hammer or post driver
- Laser range finder
- Compass set to current declination
- Brush-clearing tools (machete, brush ax, loppers, saw)

## PRE-FIELD SET UP

### Preparing the Microclimate Housing Assembly

Each microclimate station includes a 5-ft U-post, a housing, and a HOBO® Pro v2 logger, which measures air temperature and relative humidity. The housing protects the logger from direct sunlight and precipitation.

The housing is composed of an upside-down 3-liter paint-mixing bucket equipped with a bracket to hold the logger (Figure 10-3). Two pieces of ¼ in foam board are attached between the bucket and the bracket. When the bracket is attached to the U-post, make sure the logger bottom is immediately above the bottom of the housing. The assembly is glued together and secured to the U-post with two nylon cable (zip) ties – one at the base and one near the top. Insert the logger into the bracket with the vented membrane (narrow end) pointed toward the ground (Figure 10-4). An instructional video showing the housing construction method is



**Figure 10-3. Diagram of a microclimate monitoring station. View from below the microclimate housing (left), side view of microclimate housing (right).**





Figure 10-4. Part of a microclimate transect (left) and microclimate data logger and housing (right).

available on the network drive at: [J:\hcp\monitoring\\_research\tminkova\01\\_OESF\\_R&M\\_Program\01\\_Rip S&T Mon\03\\_Photos and videos\01\\_Implementing Field Protocols\Microclimate\STRONG - A microclimate housing instructional video.MTS](J:\hcp\monitoring_research\tminkova\01_OESF_R&M_Program\01_Rip_S&T_Mon\03_Photos_and_videos\01_Implementing_Field_Protocols\Microclimate\STRONG - A_microclimate_housing_instructional_video.MTS).

### ***Launching and Testing the Loggers***

First, make sure the HOBOWare Pro software used to interact with HOBO data loggers has been downloaded on the computer. That software will be used to launch the logger and process data.

Set the clock on the computer used to launch the loggers to Pacific Standard Time (PST) through the use of the atomic clock (e.g., <http://www.time.gov/timezone.cgi?Pacific/d/-8/java>). This ensures that all loggers will record data at exactly the same times.

Before programming for field deployment, test all loggers to confirm that they are calibrated similarly. Do this by first programming them to record temperature and relative humidity at a short logging interval (e.g., five minutes) and launching them all at a common, delayed launch time. Follow the manufacturer's programming and launching procedures described in the manual, which is available at: [http://www.onsetcomp.com/files/manual\\_pdfs/10694-N%20MAN-U23.pdf](http://www.onsetcomp.com/files/manual_pdfs/10694-N%20MAN-U23.pdf). Put all loggers in a common indoor environment for at least 4 hours, then move them to a common outdoor environment for an additional 4 hours. Ensure that all loggers are exposed to exactly the same conditions, including shade/sunlight. After the outdoor period, download all loggers. Compare indoor data from all loggers to ensure that temperature among loggers is within a 0.21°C range and that relative humidity values are within 3.5 percentage points



(these standards are from the manual). Repeat this comparison with the data recorded outdoors. The purpose of the test is to identify any loggers giving outlier values. Such loggers should be returned to the factory for re-calibration.

After this test, loggers must then be re-programmed for field deployment. Program all the loggers for a common delayed launch time that starts after the planned field deployment time and date (usually 12:00 a.m. PST if deployed the day before. Program the loggers to measure and record temperature and relative humidity at 2-hour intervals.

## Field Procedures

### MICROCLIMATE TRANSECT ESTABLISHMENT

At each sample reach, two microclimate transects are established adjacent to separate, randomly selected channel cross section monuments, on opposite sides of the stream (Figure 10-1). The transects project 60 m into the forest along the center line of riparian vegetation plots (see *Riparian Vegetation Monitoring Protocol* for additional details).

The six channel cross sections that define OESF sample reaches are marked by rebar topped with orange mushroom caps (i.e., monuments) labeled with the cross section identifier (A-F).

#### Transect Installation

Microclimate transects should start ~1-5 m upslope of the randomly selected cross-section monument (A-F, left or right bank, determined facing downstream) and extend upslope at an angle perpendicular to the stream. The reason for starting the microclimate transect slightly upslope from the monument is to avoid placing the first microclimate station in a location where it could be lost in a flood event. In some cases, the cross-section monument is high enough above the stream that the location is safe from floods, but in other cases the transect starting point may need to be located as much as 5 m upslope from the monument.

If a vegetation plot has already been established at the cross section, use the previously recorded center line azimuth (also called the “plot azimuth”; see *Riparian Vegetation Monitoring* protocol) to locate microclimate monitoring station installation locations. If a vegetation plot has not been established at the cross section, use a compass to determine the stream azimuth. Then, calculate and record the azimuth perpendicular to the stream (add/subtract 90 degrees); this upslope azimuth will define the transect (as well as the vegetation plot center line).

Microclimate monitoring stations are installed at 0, 10, 20, 40, and 60 m along this transect. Distances are horizontal distance, meaning measurements on sloping terrain must be taken using a range finder that can calculate horizontal distance. A measuring tape can be used on relatively flat terrain.

### **Installation of Microclimate Monitoring Stations**

At each microclimate monitoring location, a metal post (U-post) and housing assembly (see Pre-field Set-up) are installed to hold and protect the data logger. To install the U-post, position the open side so it is facing north and use a hammer or post driver to pound the post into the ground until the wings are buried and the top of the post is 1.3 m above the forest floor. If needed, adjust the post location (move it parallel to the stream, so that it maintains the same distance from the stream) to ensure it is lodged in stable ground. Record the azimuth and distance of any offset from the original location.

Attach the microclimate housing assembly (see Pre-field Set-up) to the open (north-facing) side of the U-post, using nylon cable (“zip”) ties. Insert the HOBO® Pro v2 logger into the bracket. The bracket should allow the logger to hang parallel to the side of the housing and the logger tip (the smaller end with a vented membrane) should be nearly flush with the bottom of the housing.

Topographic and forest structure characteristics will be documented as possible contributors to spatial variation in microclimate. The horizontal distance and azimuth from the cross-section monument to the 0-m station is measured. Additionally, the vertical distance from the base of the cross-section monument to the base of the 0-m station post is measured using the rangefinder and recorded (see *Installation Field Form* in Appendix A). For the 10-, 20-, 40-, and 60-m stations, measure the vertical distance between the base of that station’s post and the base of the preceding post (e.g., for the 10-m station, measure the vertical distance between its base and the base of the 0-m post). Vertical distances may be positive or negative, depending on topography.

### **DOWNLOADING PROCEDURES**

Microclimate data loggers (Onset HOBO Pro v2) should be downloaded and inspected twice annually: in the Spring (May-June) and Fall (October-November).

Microclimate loggers can be downloaded directly to a laptop (weather permitting) or to an optical data shuttle (HOBO Waterproof Shuttle; preferred). Record metadata in the *Microclimate Field Form* (Appendix 10B).

To retrieve the logger for download, reach inside the housing and slip the logger out of its bracket. Clean the logger communications window (clear face) with a cloth and connect the logger to the data shuttle or laptop. Follow the manufacturer’s download procedures ([http://www.onsetcomp.com/files/manual\\_pdfs/10694-N%20MAN-U23.pdf](http://www.onsetcomp.com/files/manual_pdfs/10694-N%20MAN-U23.pdf)). The download takes only a couple of minutes.

Record the logger serial number and logger name (Watershed #\_Stream Bank (Right/Left)\_Station (0, 10, 20, 40, 60 m) on the *Microclimate Field Form* (Appendix 10B). Inspect the logger, housing, and U-post and note any damage on the form (e.g., bear bites can perforate the logger membrane that protects the sensors). If necessary, re-attach the housing to the U-post with nylon cable ties. If logger damage is severe (e.g., perforated membrane), the logger should be replaced. When installing a new logger, record the serial numbers of both loggers, the station (0-60 m), and the reason for replacement. Be sure to clearly communicate the change to the project Data Management Specialist.

## Time and Cost Estimates for Implementing the Field Procedures

A skilled crew of two people can install a microclimate transect, including posts and housing installations, in two hours. Programming of loggers and manufacture of the housings is done in mass and takes about eight hours. This time estimate doesn't include the travel to the site.

Table 10-1 shows the cost estimates for the equipment unique to implementing the field procedures of the microclimate protocol. Some of the items listed in the *Equipment and Supplies* section above, such as the laser rangefinder, are shared with the vegetation protocol. Their costs are detailed in that protocol and not included here.

**Table 10-1. Cost Estimates for the equipment used in the riparian microclimate protocol.**

Equipment/Supplies	Amount per watershed	Individual cost	Amount for the project (10 sites)	Cost for the project*
Onset® HOBO Pro v2 U23-001 Temp/RH Data Loggers	10	\$170	100	\$17,000
Onset® HOBO waterproof shuttle	n/a	\$249	1	\$249
Onset® HOBO Pro v2 clamp kit	10	\$5	100	\$500
HOBOWare Pro software	n/a	\$99	1	\$99
5-ft metal u-bar fence post	10	\$3.50	100	\$350
Data Logger solar shield	10	\$1	100	\$100
Cable ties	50	\$0.02	500	\$10

## Procedures for Calculating Metrics

- For air temperature, the daily minimum, maximum, mean, and range are calculated for each data logger (Table 10-2). Values also will be summarized by month and season.
- For absolute humidity ( $\text{g/m}^3$ ), the daily minimum is derived for each data logger. Values will be summarized by month and season.
- Vapor pressure deficit (kPa) may be calculated as well, if required by the objectives of the analysis. Vapor pressure deficit is calculated, similarly to absolute humidity, from simultaneous temperature and relative humidity readings.
- Temperature and humidity gradients will be calculated across each of the transects (i.e., 0- to 60-m horizontal distances from the stream).
- Three forms of analyses will be conducted with respect to overstory density, canopy cover, and microclimate response variables:
  - Influence of stand basal area on microclimate (temperature and humidity) will be assessed using overstory vegetation data collected in three zones (0-20, 20-40, 40-60 m from stream).

- Influence of canopy cover on microclimate (temperature and humidity) will be assessed using hemispherical canopy photos.
- Between-watershed differences will be evaluated statistically by evaluating data stratified into near-stream, mid-slope, and upslope zones.

**Table 10-2. Microclimate metrics and calculations.**

<b>Metric</b>	<b>Calculation procedure</b>
Temperature: daily mean, min, max, and range.	Daily mean, minimum, maximum, and range (max minus min); calculated for each logger.
Absolute humidity (g/m <sup>3</sup> )	Calculated from simultaneous relative humidity and temperature readings for each logger. Absolute humidity is calculated using the following equation where <i>rh</i> =relative humidity and <i>T</i> =temperature:  $Absolute\ Humidity\ (grams/m^3) = \frac{6.112 \times e^{\left[\frac{17.67 \times T}{T+243.5}\right]} \times rh \times 2.1674}{273.15 + T}$
Absolute humidity: daily min.	Daily minimum of absolute humidity; calculated for each logger.

## Quality Control and Quality Assurance

Quality assurance includes staff training, use of standardized protocols, and periodic field checks. The QA/QC procedures for data management are described in the Data Management section, below.

### TRAINING

All personnel conducting field protocols will be trained in a consistent manner to ensure that the work is conducted properly and in standardized fashion. The training is conducted or, for returning personnel, reviewed, annually before the start of the field season.

### STANDARD PROTOCOLS

The standard procedures described in this protocol are followed for the duration of the project. Any deviations from the procedures should be documented, and the reasons for deviation described and discussed with the project manager or the researcher overseeing the protocol implementation.

Changes to the published protocols are approved by the project manager or by the researcher overseeing the protocol implementation. Revised protocols are assigned new version numbers and publication dates.

Pacific Standard Time (PST) should be used for all field procedures, year-round. Field personnel should be particularly aware of this during Pacific Daylight Time (PDT) from March through November. The letters PST should be appended to all times in field notes to ensure accuracy.

## TESTING DATA LOGGERS

The accuracy of each data logger should be tested prior to deployment and again after it has been retrieved from the field. Calibration procedures are described in the Equipment and Supplies section above, under the heading *Launching and Testing the Loggers*. The manufacturer-reported accuracy level for the Onset<sup>®</sup> HOBO Pro v2 U23-001 Temp/RH Data Loggers is  $\pm 0.21^{\circ}\text{C}$  from  $0^{\circ}$  to  $50^{\circ}\text{C}$ .

## DATA QUALITY CONTROL

All microclimate data (i.e., every data point recorded during this project) are plotted and evaluated graphically to identify any suspect data points that could indicate instrument malfunction or other errors. This is typically done using the software R. Temperature and humidity data are plotted separately. Typically, all temperature or humidity data points from each transect's loggers (n=5) are plotted together on one graph, for one calendar month at a time. Each graph is then reviewed by two people (a scientist and the Data Management Specialist).

Field notes are extremely valuable for detecting and diagnosing problems with data quality. All field notes should be examined during the quality control phase, and used in conjunction with the quality control plots.

## *Data Management*

### DATA FLOW

Field data are collected in two formats: (1) paper field forms used to record metadata, and (2) electronic downloads of HOBO Pro v2 U23-001 data loggers. Additionally, photographs are taken in the field to document data logger damage or other irregularities. This section of the protocol describes the steps used to process these data from their raw field formats through the quality control stage. Details on long-term data storage and archiving appear in the following section on Data Storage.

#### *Paper field forms*

1. **Fill out field forms** The Microclimate Field Form (Appendix 10B) is used to record all activities related to data loggers, such as data downloads and logger replacements. Information recorded includes the logger location, date, time, crew, serial number, and notes.
2. **Scan and store field forms** After returning from the field each week, the field forms are scanned and stored on the WADNR network drive; the original paper forms are archived at the Washington Department of Natural Resources Forest Resources Division.
3. **Enter data** All of the information collected on microclimate field forms will be entered in the stream temperature database by the OESF Data Management Specialist on a weekly basis.

#### *Data logger downloads*

1. **Download data loggers** Temperature and relative humidity data are downloaded from the HOBO data loggers in the form of “.hobo” files, a proprietary file format that can only be opened using

HOBOWare® software (Onset Computer Corp.). Data loggers are downloaded using an optical shuttle (the files on the shuttle are later transferred to a computer), or can be downloaded directly to a laptop. Each downloaded file contains the data logger’s serial number embedded within the file. This serial number is important for matching data files with monitoring locations.

2. **Store raw data files** In the WADNR office, a member of the field crew transfers all downloaded .hobo files to a temporary location on the WADNR network drive:  
J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\07\_Data management\\_All new data and photos\
3. **Export files** Using HOBOWare® software, the data from all of the .hobo files are batch exported to comma separated variable format (.csv).
4. **Import data to database** Using R, the data from all .csv files are merged into a single file which is then imported into the Microsoft Access microclimate database.
5. **Quality control** Data are inspected as described in the Quality Control section above. The results of the quality control inspections are recorded in the database, and the data are assigned a data quality level based on the completion of various quality control steps. Data begin as “Level 0: Raw Data”. After an initial series of automated data quality checks, data are assigned the “Level 1: Provisional” quality level. After completion of all quality control steps, data are assigned the highest quality level, “Level 2: Published”. At this level, every record in the dataset is flagged as one of the following: accepted, rejected, estimated, or missing. Data are now ready for analysis and sharing.

## DATA STORAGE

### *Paper Field Forms*

The paper field forms are archived at the Washington Department of Natural Resources (WADNR) Forest Resources Division. Scanned copies of these forms are saved in the Adobe portable document format (.pdf) within the following directory: J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD DATA\

### *Long-term Data Storage*

All microclimate data, as well as metadata, are stored in the Microclimate database, which is a Microsoft Access database designed specifically for this project. The database is located on the WADNR network drive at: J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD DATA\

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## Appendix 10A. Riparian Microclimate Installation Field Form

<b>Date:</b>		<b>Watershed:</b>		<b>Crew:</b>	
<b>Transect #1</b>		<b>Transect azimuth (bet. 0- and 60-m stations) (deg.):</b>			
<b>Crossection:</b>		<b>Bank:</b>		<b>Recording Interval: 2hr</b>	
<b>Azimuth from x-sec. monument to 0-m station:</b>					
<b>Dist. from x-sec. monument to 0-m station:</b>					
<b>Distance(m):</b>	<b>Serial #:</b>	<b>Logger Name:</b>		<b>Elevation difference (+ or -) measured at base of each post:</b>	
0				(monument to 0-m station)	
10				(from 0-m to 10-m station)	
20				(from 10-m to 20-m station)	
40				(from 20-m to 40-m station)	
60				(from 40-m to 60-m station)	
<b>Transect #2</b>					
		<b>Transect azimuth (bet. 0- and 60-m stations) (deg.):</b>			
<b>Crossection:</b>		<b>Bank:</b>		<b>Recording Interval: 2hr</b>	
<b>Azimuth from x-sec. monument to 0-m station:</b>					
<b>Dist. from x-sec. monument to 0-m station:</b>					
<b>Distance(m):</b>	<b>Serial #:</b>	<b>Logger Name:</b>		<b>Elevation difference (+ or -) measured at base of each post:</b>	
0				(monument to 0-m station)	
10				(from 0-m to 10-m station)	
20				(from 10-m to 20-m station)	
40				(from 20-m to 40-m station)	
60				(from 40-m to 60-m station)	
<b>Camera #:</b>		<b>Photos #:</b>			
<b>General Notes:</b>					

■ Riparian Microclimate

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## Appendix 10B. Riparian Microclimate Download Field Form

Microclimate Download Form						
<b>Date:</b>		<b>Basin #:</b>		<b>Crew:</b>		<b>Recording Interval: 2 hr</b>
<b>Start time:</b>		<b>End time:</b>		<b>Camera #:</b>		
<b>Transect #1</b>						
<b>X-section:</b>			<b>Streamside:</b>		<b>Notes, picture #, etc:</b>	
<b>Distance (m)</b>	<b>Serial #</b>		<b>Logger Name</b>			
0						
10						
20						
40						
60						
<b>Transect #2</b>						
<b>X-section:</b>			<b>Streamside:</b>		<b>Notes, picture #, etc:</b>	
<b>Distance (m)</b>	<b>Serial #</b>		<b>Logger Name</b>			
0						
10						
20						
40						
60						

■ Riparian Microclimate

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# Riparian Vegetation

*Authors:* Richard Bigley, Paul Dunnette, Warren Devine

*Version:* 1.3

## *Revision History:*

Version number	Purpose / Changes	Author(s)	Reviewer(s)	Date
1.0	Initial draft	Richard Bigley		03/03/2014
1.1	Draft presented to project staff for review	Richard Bigley	Teodora Minkova	07/03/2014
1.2	Final draft incorporating internal reviews	Richard Bigley, Warren Devine		11/22/2016
1.3	Final technical review and edit	Richard Bigley, Paul Dunnette, Warren Devine	Teodora Minkova, Alex Foster	12/18/2016

## *Based on the Following Protocols:*

This protocol is based generally on the approach used by Allen (1993) and Curtis and Marshall (2005) for the detection of forest change through time. Plot sizes were adjusted to match the area of stream influence.

## *Reasons to Adopt the Above Protocols:*

Established measurement protocols and large plot sizes were required to detect changes in tree growth and mortality through time.

## *Purpose and Content:*

The purpose of this monitoring protocol is to describe the sampling and data management necessary to document and report multi-year trends in riparian forest canopy cover and vegetation structure and composition in the monitored watersheds. The protocol details the field procedures for establishing permanent plots, sampling understory and overstory vegetation, and taking canopy photos; the field quality assurance and quality control steps; and data management procedures. These procedures will help reduce sampling errors and ensure consistency in plot establishment, sampling, and data collection through time.

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## Introduction

Understanding forest structure dynamics resulting from competition, forest decay, and disturbance is vital to assessing riparian forest influence on stream temperature (by influencing shade), near-stream microclimate, and litter, sediment and woody debris inputs to streams – all central indicators of stream habitat condition.

When watersheds are disturbed, restoration of aquatic community-level resilience reflects a successional process driven by riparian vegetative recovery (Kauffman et al 1997). Modern riparian management practices designed to protect riparian areas from the effects of timber harvesting are known to differ in their effectiveness. Their capacity to maintain water quality, aquatic and riparian biodiversity, and ecosystem functions and services varies with the extent of near-stream vegetation removal (Cristan et al. 2016).

In the Olympic Experimental State Forest (OESF), most riparian areas have been previously clear-cut to the stream edge. The resulting vegetation is a mixture of natural regeneration and plantation establishment. Changes in vegetation structure are key to interpretation of watershed recovery from past disturbance.

The Washington Department of Natural Resources (WADNR) riparian conservation strategy assumes that as riparian forests recover from past disturbance, so too does riparian function. In the environmental impact analysis for the OESF Forest Land Plan, riparian vegetation height, composition, and mortality rate were key drivers in predicting stream habitat condition recovery (WADNR 2016). Streamside vegetation dictated stream temperature, inputs of litter and woody debris, and microclimate.

## Monitoring Design

### SPATIAL SAMPLING DESIGN

Riparian vegetation is monitored in all 50 OESF sample watersheds and the four reference sample watersheds in Olympic National Park (ONP). Refer to the Introduction chapter for a map of the sample sites. The vegetation conditions sampled represent the common forest types on the OESF. The Sitka spruce (*Picea sitchensis*) vegetation zone dominates along the coast, while a majority of the OESF falls within the western hemlock (*Tsuga heterophylla*) vegetation zone.

Vegetation monitoring occurs within two fixed-area plots established adjacent to two of the six systematically defined channel cross sections installed at each sample reach. The 0.18-ha plots are located at separate, randomly selected cross sections on opposite sides of the stream. Trees are tagged and measured throughout each plot, hemispherical canopy photos are taken at five photo points spaced systematically along the plot center line, and understory canopy cover and tree seedling recruitment are sampled within five circular 50-m<sup>2</sup> subplots offset from the photo points (see Figure 11-1).



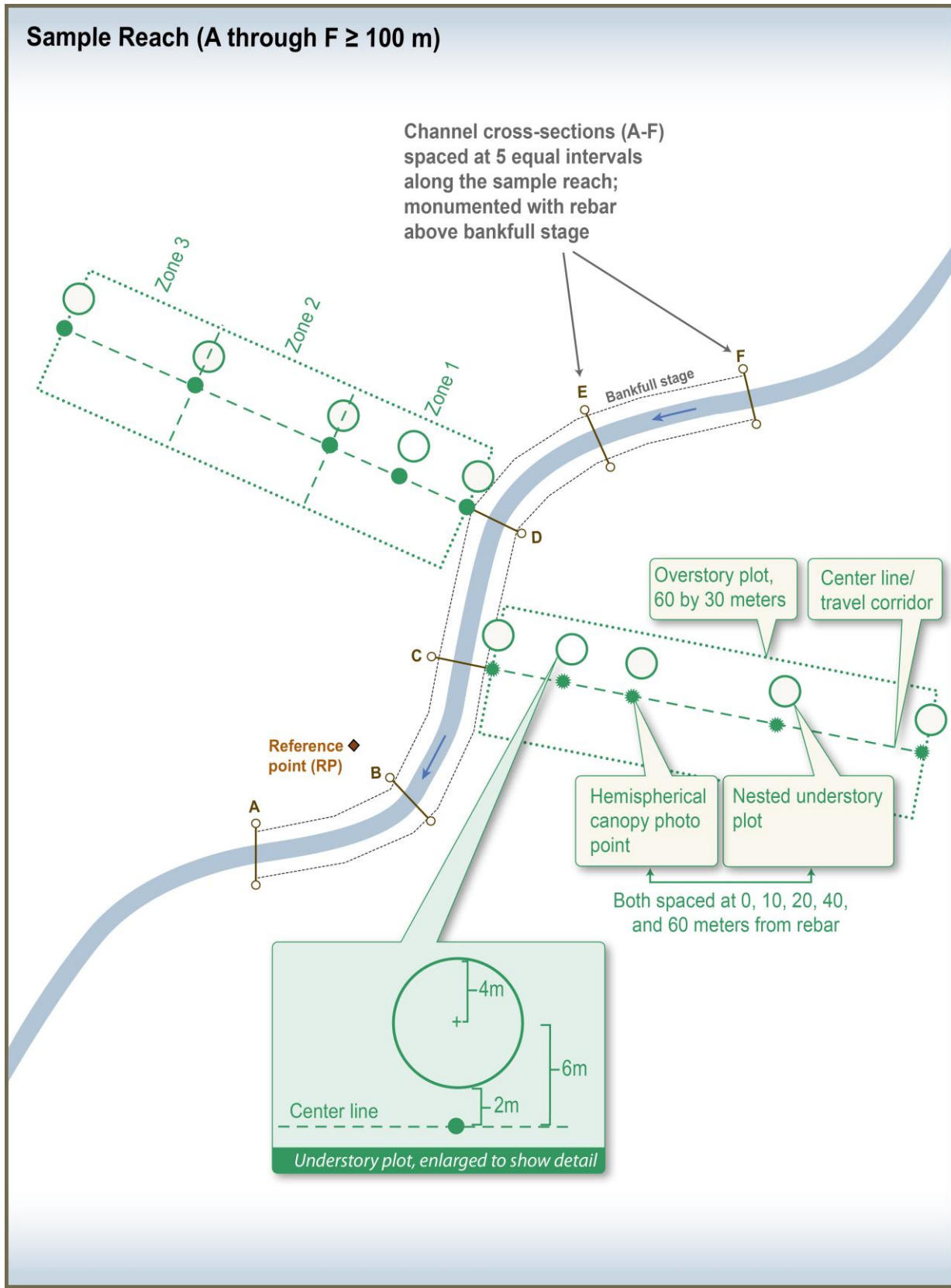


Figure 11-1. Location of riparian vegetation sampling plots within the sample reach.

## TEMPORAL SAMPLING DESIGN

Riparian overstory and understory vegetation are sampled in the summer, every 3 to 5 years. Hemispherical canopy photos are taken annually, between June 1 and September 15, coincident with the leaf-out period of regional vegetation. Complementary remote sensing data are updated as they become available.

## Equipment and Supplies

- Red/white striped plastic flagging (for OESF sites)
- Blue or red biodegradable flagging (for ONP sites)
- Permanent markers (i.e., black sharpies)
- Hammers (to drive nails into trees and rebar/stakes into the ground)
- Sighting compass (e.g., Silva Ranger©) set to current declination
- Laser range finder or Haglöf Vertex Hypsometer
- Diameter (DBH) tapes
- 50-meter tape
- 30-meter logger's tape
- Aluminum tree tags (numbered)
- Aluminum nails
- 2-ft rebar (for OESF sites)
- Orange plastic mushroom rebar caps (for OESF sites)
- Wood stakes (for ONP sites)
- Nikon™ Coolpix 4500 digital camera
- Nikon™ FC-E8 fisheye converter (7.2 mm f/2.4, approximately 183° FOV)
- Pelican™ 1400 case, to transport and protect camera equipment in transit to sampling locations
- SimpleTech™ 512 MB CompactFlash Memory Card
- Nikon™ EN-EL1 camera battery or equivalent (Two; one in use, another as backup)
- Nikon™ battery charger or equivalent
- Slik™ sprint 150 aluminum tripod w/ SBH-150DQ Ball Head
- Camera plate and Slik™ DQ-L Quick release adapter set
- StreamLight™ Stylus LED penlight (to indicate north in the photo)
- Plant field guide (e.g., Pojar and MacKinnon 1994)

## Field Procedures

### PRE-FIELD SET UP

Crews should know the channel cross section (designated A-F) and stream bank (left or right) selected for vegetation plot establishment and sampling. If plots were previously established and/or sampled, obtain a list of the azimuths used to delineate the plot boundaries and center lines.

If using Haglöf Vertex Hypsometer, calibrate daily and bring spare batteries.

Make sure that the canopy photo camera (Nikon™ Coolpix 4500) batteries are fully charged, previous data has been downloaded from the compact flash card, and the 9-volt battery for the LED penlight is functioning. Ensure that the time and date are correctly set on the camera. The camera settings should match the ones in Table 11-1.

## **PLOT ESTABLISHMENT**

### ***Sample Site Location and Assessment***

In OESF sample reaches, six channel cross sections are delineated by rebar topped with orange mushroom caps (i.e., monuments) labeled with the cross section identifier (A-F). Flagged wood stakes mark ONP reach cross sections.

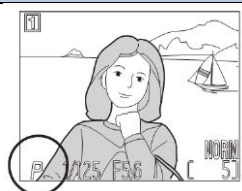
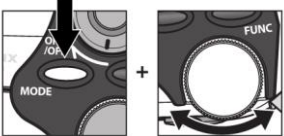

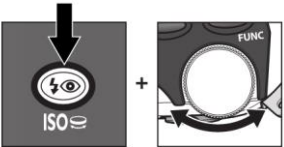





The 60 m x 30 m overstory vegetation plots start ~1-5 m upslope from randomly selected cross-section monuments (A-F, left or right bank, determined facing downstream) and extend into the adjacent forest at an angle perpendicular to the stream. The reason that plots start upslope from the cross-section monument is that the 30-m wide base of the plot must not overlap the stream; due to a stream's meandering, this may require starting the plot as much as 5 m upslope from monument. Rebar monuments (or wood stakes in ONP) are installed at 0, 10, 20, 40, and 60 m to delineate the plot center line and define locations for hemispherical canopy photos and understory vegetation sampling (see Figure 11-1). Plot dimensions are horizontal distance, meaning measurements on sloping terrain must be taken using a range finder. A measuring tape can be used on relatively flat terrain.

After locating the channel cross section monument selected for plot establishment, use a compass to determine the azimuths that will be used to delineate the plot boundaries. Measure and record the azimuth of the stream at the cross section; this azimuth and its back-azimuth ("stream azimuths") will define the upstream and downstream plot boundaries. Then, calculate and record the azimuth perpendicular to the stream (add/subtract 90 degrees); this azimuth ("plot azimuth") will define the plot center line.

Before starting plot establishment, use the azimuths to assess whether the selected location is suitable for plot establishment and sampling. A plot should be moved to an alternative, randomly chosen cross section if: 1) the slope cannot be traversed safely; 2) the plot would intersect a road, another perennial stream, or its riparian zone, or 3) there is a sharp stream bend in the sample reach.

To verify suitability of the plot, measure 15 m along the stream azimuths (both upstream and downstream) from streamside plot center (just upslope from the monument at the plot azimuth); if this line intersects the stream channel, adjust the azimuths slightly and/or move the plot edge up the hillslope (but not more than 5 m). Next, from the streamside plot center, walk 60 m along the plot azimuth to verify that the entire plot can be traversed safely and that no roads or other perennial streams or their riparian zones are in the plot. Move the plot to a different cross section only if it cannot be situated to meet these criteria. In that scenario, randomly select another stream cross section for the vegetation plot.

Table 11-1. Camera settings for taking hemispherical canopy photos with the Nikon Coolpix 4500.

Parameter	Setting Symbol	Setting Name
<b>Main Screen</b>		
Mode		Programmed Auto (set via MODE button and dial) 
ISO (a.k.a. "Sensitivity")		Must first set mode to "P" (Programmed Auto); then set ISO to <b>100</b> (set via dedicated button held down while turning dial) 
Self-timer		On (set via dedicated button) 
<b>Shooting Menu (camera must first be set to "P" (Programmed Auto) mode and also must be in shooting mode)</b>		
White balance	<b>A-WB Auto</b>	Auto
Metering	n/a	Controlled by setting Lens parameter to "Fisheye1"
Continuous	<b>S Single</b>	Single
Best shot selector	<b>Off</b>	Off
Image adjustment	<b>Normal</b>	Normal
Saturation control	<b>0 Normal</b>	Normal
Image quality	<b>FINE</b>	Fine (1:4 JPEG compression)
Image size	 <b>2272 x 1704</b>	2272 x 1704
Image sharpening	<b>Normal</b>	Normal
Lens	 <b>Fisheye1</b> (Creates circular image)	Fisheye 1; sets the following three items automatically: <ul style="list-style-type: none"> <li>• Zoom fixed at widest angle</li> <li>• Focus fixed at infinity</li> <li>• Metering fixed at center-weighted</li> </ul>
Exposure options	<b>Off</b>	Off
Focus options	n/a	Controlled by setting Lens parameter to "Fisheye1"
Zoom options	n/a	Controlled by setting Lens parameter to "Fisheye1"
Speedlight options	 <b>Internal Off</b>	Internal off
Auto bracketing	<b>OFF Off</b>	Off
Noise reduction	<b>OFF Off</b>	Off

### **Plot Installation**

Once it is clear that a vegetation plot can be established, install a rebar monument at plot center, ~1-5 m upslope from the cross section monument along the plot azimuth. Use the hammer to pound the plot center monument into stable ground or a root. Leave ~15 cm (6 in) of rebar above ground, and place an orange mushroom cap on top. Make sure the rebar is secure; if it is loose, find a new location close to plot center. If the monument must be offset, record the azimuth and distance from true plot center on the data sheet and on the flagging tied to the rebar.

Use a permanent marker to label the mushroom cap with “Veg” and the plot distance (0, 10, 20, 40, 60 m). Also attach red/white striped flagging labeled with the watershed number, “Vegetation”, the plot azimuth, and the corresponding letter for the cross section (A-F). At ONP reaches, plot center markers must be wood stakes with biodegradable flagging.

After establishing the plot center monument near the cross section (i.e., at 0 m), use a compass and the range finder to locate plot center at 10, 20, 40, and 60 m upslope from the starting point (following the plot azimuth). Clear vegetation along the plot center line to facilitate travel and accurate horizontal distance measurements. Install flagged monuments and hang flagging at eye level at each designated distance along the center line, as described above.

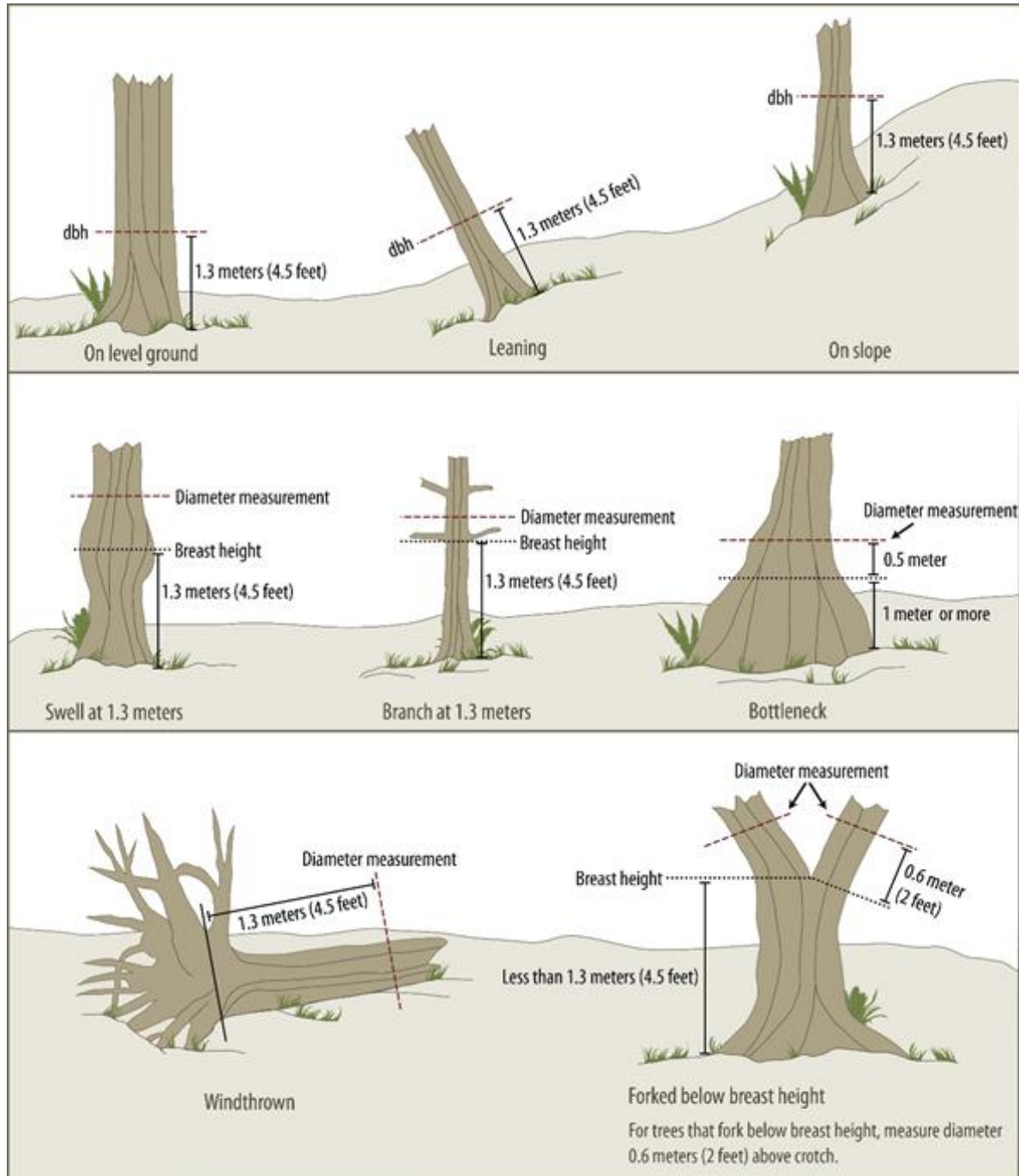
From the plot center monuments at 0, 20, 40, and 60 m, measure 15 m along the stream azimuths on the upstream and downstream sides and place flagging at or above eye level to mark the plot boundaries and delineate three zones (Zone 1: 0-20 m; Zone 2: 20-40 m; Zone 3: 40-60 m; Figure 11-1). Write the zone number on the flagging at plot center and at the plot edges.

### **TREE SAMPLING AND TAGGING**

Tag and measure all qualifying trees. A qualifying tree is a tree that meets one of the following criteria:

1. Live tree >12.5 cm diameter at breast height (DBH; 1.3 m above the forest floor).
2. Dead tree >12.5 cm DBH and ≥6.0 m in height.
3. Dead tree >12.5 cm DBH and < 6.0 m in height with an intact top.

Begin tagging and measuring trees on the upstream side of plot center (defined by the monuments), working your way away from the stream along plot center from Zone 1 to Zone 3 (see Figure 11-1). On the upstream side of the plot, tags should be placed on the stream-facing side of trees. Then, work your way back toward the stream from Zone 3 to Zone 1 on the downstream side of plot center, tagging trees on the side away from the stream. Keep careful track of plot and zone boundaries. A tree is considered within the plot only if its entire circumference at breast height is within the boundaries. Assign a tree to a zone if >50% of its circumference falls within the zone.



Adapted from Curtis and Marshall 2005

**Figure 11-2. Location of tree diameter measurements. Adopted and redrawn from Curtis and Marshall 2005.**

Nail a numbered tag to each qualifying tree at breast height. To determine breast height, carefully follow the examples in Figure 11-2. Be aware that, on steep slopes, tags facing the stream may be much higher than 1.3 m above the base of the tree's *downhill* side (see "On slope" example in Figure 11-2). The nail should be hammered into the tree only so far that it cannot be pulled out with one's fingers; it is important to leave



much of the nail protruding from the tree to allow for growth. Angle nail ~5-10 degrees below horizontal to ensure that the tag rides the nail head and will not be consumed as the tree grows.

When measuring DBH, wrap the diameter tape around the tree immediately above the nail. Make sure the tape is perpendicular to the main axis of the bole, even if the tree is leaning. Press the tape flat against the tree, and measure the diameter to the nearest 0.1 cm (Curtis and Marshall 2005). If the tree is covered by a thick layer of moss or lichens at breast height, peel these off before measuring diameter. Consistent, repeated measurement at the same point on the tree bole is vital for tracking growth over time (Curtis and Marshall 2005). Measure and tag trees only if it is safe to do so.

Record tag number, tree species, DBH, whether the tree is alive or dead, and zone number for all qualifying trees (see Appendix 11A for field sheet). Species codes for common OESF taxa include: PISI (Sitka spruce); TSHE (Western hemlock); THPL (Western red cedar); ALRU (Red alder); PSME (Douglas-fir); ABAM (Pacific silver fir); and ACMA (Big leaf maple). More tree species codes can be found at: [http://plants.usda.gov/dl\\_state.html](http://plants.usda.gov/dl_state.html).

### ***Special Circumstances (see Figure 11-2)***

- **Forked trees.** Trees that fork above 1.3 m are considered single trees. Measure the diameter immediately below any swelling related to the fork but as close as possible to breast height (1.3 m). If the open crotch of the fork starts below 1.3 m, measure both boles 60 cm above the beginning of the fork (Curtis and Marshall 2005). If all forks are <12.5 cm in diameter, skip the entire tree. If all forks are >12.5 cm in diameter, measure each fork as a separate tree. If fork sizes are mixed, measure only forks >12.5 cm in diameter and do not measure the forks <12.5 cm in diameter. Identify forked trees on the data sheet as “fork stem.” If the forks appear to be trees that have grown together, follow the same guidelines but write “fused” on the data sheet.
- **Bole irregularities at DBH (limbs, scars, burls).** If tree diameter cannot be measured at 1.3 m due to a limb, burl, scar, or other bole form irregularity, measure diameter immediately above the irregularity – where it ceases to affect the stem – and record the height at which diameter was measured on the field sheet. If the irregularity extends far up the bole, but stem form below 1.3 m is unaffected, measure diameter below the irregularity but as close as possible to 1.3 m. Do not measure tree diameter below 1 m on the stem. If bole irregularities (e.g., lightning scars) extend over most of the bole length, making adjustment impractical and/or misleading, measure the tree at normal DBH height.

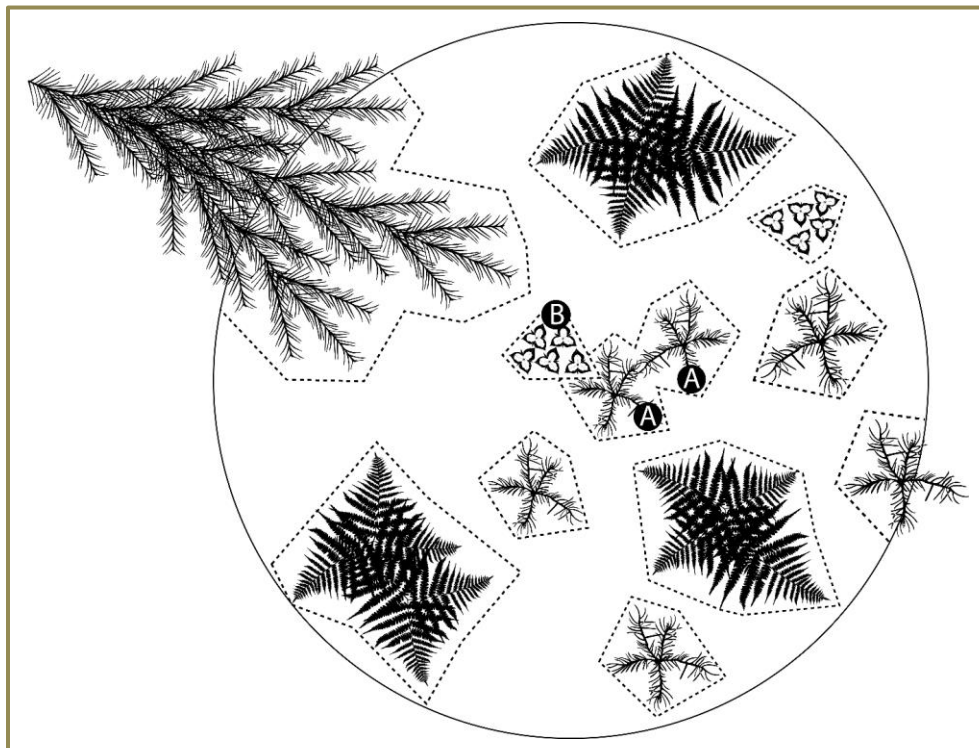
## **UNDERSTORY VEGETATION AND TREE SEEDLING SAMPLING**

Understory vegetation percent cover is sampled within a 4-m-radius nested subplot offset from each plot center monument (at 0, 10, 20, 40, 60 m along the transect). From each monument, measure 6 m along the stream azimuth (i.e., perpendicular to the plot center line) on the upstream side and flag the location. This is the center of the circular understory vegetation subplot. To help define the subplot, place flagging at three or four locations 4 m from the subplot center. The understory field sheet appears in Appendix 11A.



Before sampling, scan the area within the subplot and make a list of the plant species present, identifying them by the USDA symbol (as identified in the latest version of the USDA Plants Database (<http://plants.usda.gov/java>)). Shrubs (woody plants), forbs (herbaceous flowering plants), and graminoids (grasses and sedges) should all be sampled. If there is uncertainty regarding a species, place a sample in a plastic bag for later identification. Label the bag with the watershed number, cross section identifier (A-F), and nested subplot identifier (0, 10, 20, 40, 60 m).

Estimate percent canopy cover for species within this circular subplot, one at a time (Figure 11-3). To estimate percent cover, mentally draw a convex, straight-line polygon around the outer portions of the crown of a plant, or around the crowns of closely spaced plants of the same species (Figure 11-3). Project this polygon to the ground; this is the canopy cover of the plant. Measure or estimate the diameter of the polygons and use these determinations and the count of individual plants to estimate cover of that species for the entire plot. If the entire plot cannot be viewed at once, determine cover by quarter wedges (i.e., 0 to 100% cover per wedge), sum the four wedges, and divide the sum by four to get the plot average. Do not subtract for small spaces between leaves or small gaps between branches. For each species, record cover as a percentage of the subplot in 1% increments. Estimate each species' cover regardless of whether it is overlapped by other species. For each species, cover will range from 1 to 100%. Summing total percent cover of all species can exceed 100%, due to species overlap. Periodically cross-check individual species cover estimates (i.e., “calibrate”) to ensure consistency among technicians.



**Figure 11-3. Polygon method to determine plant species cover. When multiple plants of the same species have overlapping polygons, construct polygons as shown in (A). For plants of different species, construct polygons separately for each species, even where those polygons overlap (B).**

Also determine the number of seedlings and saplings of each tree species within each subplot. Count trees <10 cm DBH and record by species and height class: 1) < 30 cm; 2) 30 cm-136 cm; 3)  $\geq 137$  cm. If the number exceeds 29 per species, simply record 30 to indicate that the number exceeded the counting threshold.

## HEMISPHERICAL CANOPY PHOTOS

### *Timing of Canopy Photos*

Hemispherical canopy photos are taken between June 1 and September 15, coincident with the leaf-out period of regional vegetation. Photos for each sample site should be taken within two weeks of the date when the previous canopy photos were taken at that site. This minimizes the seasonal effects of phenology (specifically the emergence and falling of leaves) and the sun's position over the horizon.

For optimal image quality, overcast flat lighting is preferred. Photos taken in direct sunlight or with a very bright sky can be washed out or include sun flares and glare. This can be partially corrected (see below). Photos are not to be taken in the rain.

### *Location of Canopy Photos*

When assessing canopy cover trends, it is important that repeated photos are taken at the exact same location (horizontally and vertically). Canopy closure can vary greatly over fine spatial scales; thus, even minor changes in the position of the camera can introduce large differences in canopy cover values. Therefore, the camera should be positioned at the same location each time a hemispherical photo is taken. In this study, photos are taken at rebar/wood stake monuments placed at 0, 10, 20, 40, and 60 m along the center line of the vegetation plots established perpendicular to each study reach (see Plot Establishment, above, for details).

Locate the vegetation plots, and walk upslope from the cross section monuments (perpendicular to the stream) to determine if plot center monuments have been installed. If monuments have not been installed, place them as you take canopy photos, following the instructions in the Plot Establishment section. Make sure to carefully follow the designated plot azimuths and distances.

### *Taking Canopy Photos*

After locating or installing a plot center monument, position the camera tripod directly over the monument. If an obstacle makes it impossible to position the tripod above the monument, reposition the tripod as close as possible to plot center and record the distance (nearest 0.01 m) and azimuth from the monument.

Mount the camera to the tripod, then switch on the LED penlight and insert it into the hole at the edge of the camera plate. Be sure that the front of the camera (not the screen-side) is facing the LED. Adjust the tripod height so the camera lens is 1.3 m above the forest floor next to the monument (measure with a stadia rod, transect tape, or diameter tape). Line up the compass housing with a corner of the camera plate, such that the compass bottom is flush with the plate edge opposite the LED. Rotate the camera plate until the orienting

arrow shows that the camera is facing true north. With this alignment, the LED will indicate true north in the photograph. Level the camera plate and camera using the two-axis bubble levels.

Pull back any vegetation within 1.0 m of the lens. Before taking the photo, check that the camera is still at the correct height, leveled, and aimed toward true north and make sure the fisheye lens is clean and free of fog/water droplets. To prevent glare, avoid taking the photograph with the lens positioned in direct sunlight. If possible, wait for the sun to be obscured by vegetation or clouds. If necessary, block the sunlight with a stick, but try to affect the photo as little as possible. If a stick was used to shade the camera lens, note this on the data sheet.

Turn on the camera and enable the self-timer. Press the shutter release to start the timer (10 seconds), then duck below the camera plate to avoid appearing in the photo. Remain below the camera plate until the light on the camera bottom stops blinking, indicating that the photo was taken. Review the photo on the camera screen to make sure that the image is in focus, with no major lens flare or field crew members in the photo. To view the photo and the photo number, press the play button above the screen twice. The number will appear in the right upper corner of the screen (XXXX.JPG).

If necessary, re-take the photo without deleting unsuccessful images. Return to the main screen by pressing the play button above the screen. Record the photo number, stream cross section (A-F), stream bank (right or left), and plot distance (0, 10, 20, 40, 60 m) on the data sheet.

Repeat the above steps at each sample site vegetation monument (total of 10 photos per watershed).

## **Quality Assurance and Quality Control**

Quality assurance includes staff training, use of standardized protocols, and periodic field checks. The QA/QC procedures for data management are described in the Data Management section below.

### **TRAINING**

All personnel conducting field protocols will be trained in a consistent manner to ensure that the surveys are conducted properly and in standardized fashion. The training is conducted or, for returning personnel, reviewed, annually before the start of the field season. At least one member of the field crew should be experienced with the field procedures and have proven plant identification skills.

Before field sampling begins, and at least once at each sample site, crew members will cross-check understory vegetation percent cover determinations (i.e., “calibrate”) to ensure consistency among technicians.

### **STANDARD PROTOCOLS**

The standard procedures described in this protocol are followed for the duration of the project. Any deviations from the procedures should be documented, and the reasons for deviation described and discussed with the project manager or the researcher overseeing the protocol implementation.

Changes to the published protocols are approved by the project manager or by the researcher overseeing the protocol implementation. Revised protocols are assigned new version numbers and publication dates.

## FIELD QUALITY CONTROL

The researcher overseeing the protocol implementation or a different field crew will conduct spot checks on 10% of the field measurements every year.

## Time Estimates for Implementing the Field Procedures

Two skilled crew members can install one 30 x 60-m vegetation plot in 2 hours (4 hours per watershed). A two-member crew can tag and measure trees, sample the understory, and take canopy photos in one vegetation plot in 4 hours (8 hours per watershed). This is an average time estimate; actual time spent varies greatly by watershed, depending on riparian conditions. The time estimate doesn't include the travel to the site.

## Procedures for Calculating Metrics

A variety of metrics will be reported for riparian vegetation. Examples of the metrics appear in Table 11-2.

**Table 11-2. Riparian vegetation metrics and calculation procedures.**

<i>Metric (calculated for each watershed)</i>	<i>Calculation procedure</i>
Overstory basal area per hectare	Use all measured living trees. Sum basal area by plot and convert to a per-hectare basis by dividing by 0.18 for each plot.
Overstory basal area per zone	Use all measured living trees. Sum basal area by zone within each plot and convert to a per-hectare basis by dividing by 0.06 for each zone.
Overstory trees per hectare	Use all measured living trees. Count trees and convert to a per-hectare basis by dividing by 0.18 for each plot.
Overstory hardwood basal area per hectare	Use all measured living hardwood trees. Sum basal area by plot and convert to a per-hectare basis by dividing by 0.18 for each plot.
Overstory hardwood basal area per zone	Use all measured living hardwood trees. Sum basal area by zone within each plot and convert to a per-hectare basis by dividing by 0.06 for each zone.
Overstory conifer basal area per hectare	Use all measured living conifer trees. Sum basal area by plot and convert to a per-hectare basis by dividing by 0.18 for each plot.
Overstory hardwood basal area per zone	Use all measured living conifer trees. Sum basal area by zone within each plot and convert to a per-hectare basis by dividing by 0.06 for each zone.
Understory cover	Sum cover and report for each growth form.

## Data Management

### DATA FLOW

Data are collected in the field using paper field forms. Owing to the large number of different field personnel participating in riparian vegetation data collection, this is the most practical method of recording data at present. This section contains a description of the steps used to process this data from its field format through the quality control stage; flowcharts provide an overview of the process. Details on long-term data storage and archiving appear in the following section, titled Data Storage.

#### *Data flow for paper field forms*

1. **Fill out field forms** For overstory data, the field forms contain information at the plot level identifying the watershed ID, cross-section, and bank. At the individual tree level, the fields are: zone, tag number, dbh, species, live/dead status, and notes. For understory data, plot-level fields include watershed ID, cross-section, bank, and plot ID. For each plot, the following fields appear on the field sheet: species, percent cover, and notes.
2. **Scan and store field forms** After returning from the field each week, the field forms are scanned and stored on the WADNR network drive at: J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\07\_Data management\\_All new data and photos\  
The original paper field forms are archived at the Washington Department of Natural Resources Forest Resources Division.
3. **Enter data** All of the information collected on paper field forms is entered into an Excel spreadsheet by personnel involved in its collection. This approach has been favored by personnel in the past (rather than entering data directly into the Access database) because they were familiar with Excel; this approach creates no additional work for the OESF Data Manager.
4. **Data verification** Entered field form data are verified by comparing it to the original field forms.
5. **Import data to database** The OESF Data Manager imports the data from Excel to the Access database used for long-term storage of riparian vegetation data.
6. **Quality control** A series of quality control checks are performed by the OESF Data Manager (Figure 11-4). After the quality control has been completed, data status is set to “Published”.

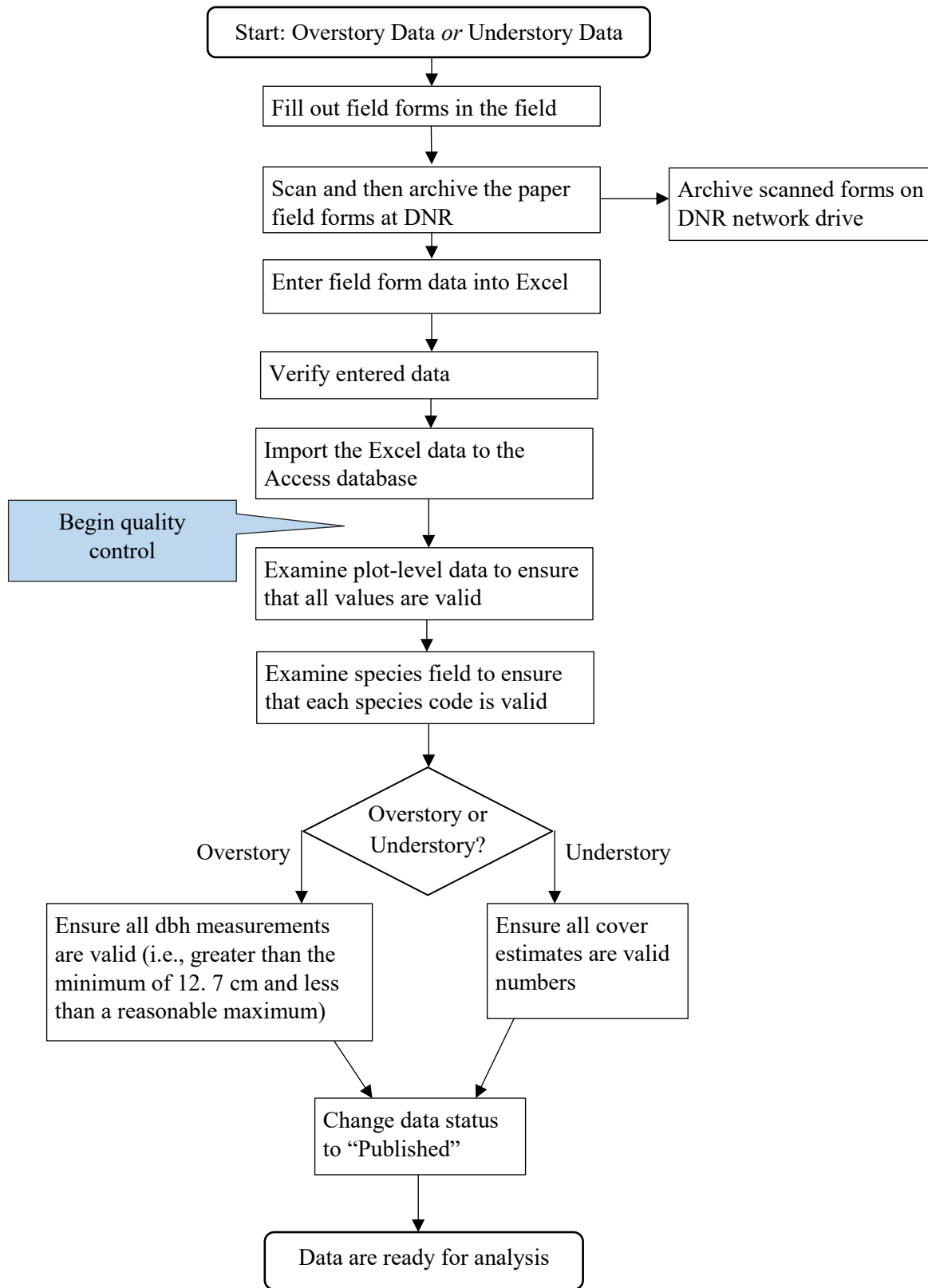


Figure 11-4. Flow chart describing the riparian vegetation data quality control process.

### *Data flow for hemispherical photos*

1. **Download hemispherical photos at the office** All hemispherical photographs will be stored on the WADNR server at: J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD DATA\06\_Riparian vegetation\Hemispherical\_photos\
2. **Rename photos** Each photograph file is renamed using the following format: VC\_<Watershed ID><Transect>\_<Station>m\_<Date taken>\_<Original filename> (for example: VC\_773E\_40m\_20160926\_DSCN6260.JPG).

## **DATA STORAGE**

### *Raw Data Archives*

The raw field data consist of paper field forms (overstory and understory data) and digital photographs. The paper field forms are archived at the Washington Department of Natural Resources Forest Resources Division. Scanned copies of these forms are saved in the Adobe portable document format (.pdf) in the following directory: J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD DATA\06\_Riparian vegetation\Data\Field sheets (blank)\

All hemispherical photographs, renamed but unedited, will be stored on the DNR server at: J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD DATA\06\_Riparian vegetation\Hemispherical\_photos\Labeled photos for analysis\

### *Riparian Vegetation Database*

All of the riparian vegetation data collected on field forms, as well as the results of the hemispherical photo analysis, will be stored in a single Microsoft Access database (.accdb) on the WADNR network drive (Olympia, WA) at: J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD DATA\06\_Riparian vegetation\Data\

In addition to providing long-term storage of data, this database is used to create data summaries and to prepare and export datasets for analysis by statistical software.

Within the riparian vegetation database, data are organized into a series of tables (illustrated in Figure 11-5 and described in detail in Appendix 11B). The primary tables in the database are:

1. **Understory Plot Table:** This table contains information about each understory plot: basin ID, stream bank, cross-section, and sample plot location (i.e., station or transect distance).
2. **Understory Visit Table:** This table contains the date on which each understory plot was assessed and any notes associated with the field visit.
3. **Understory Measurement Table:** This table contains the understory plot data: species, cover (%), and data status (i.e., whether data is published/ready for analysis).
4. **Tree Plot Table:** This table contains information on each overstory plot: basin ID, bank, and cross-section.



5. **Tree ID Table:** In this table is stored data on each tree that will not change over time: species, tag number, and zone.
6. **Tree Measurement Table:** This table contains data collected during each field measurement visit: measurement date, dbh, tree status (live or dead), notes, and data status. It also contains a field indicating whether the measurement was performed as part of a QC check and a field containing the tree species recorded during the QC check. The latter field exists because the species recorded during a QC check sometimes differs from the species originally recorded (in the Tree ID Table).

These six tables are linked to one another through a series of relationships (Figure 11-5). The Tree Plot table is related to the Tree ID table via a one-to-many relationship because there are many trees on each plot. Similarly, the Tree ID Table is linked to the Tree Measurement Table through a one-to-many relationship because there are multiple measurements taken on each tree.

The Tree Plot Table is related to the Understory Plot Table because the understory plots are nested within the overstory plots, an arrangement that may be relevant during data analysis. The Understory Plot Table is related to the Understory Visit Table via a one-to-many relationship: there are multiple visits at each plot. Finally, the Understory Visit Table is related to the Understory Measurement Table via a one-to-many relationship because there are many measurements (i.e., understory species and associated cover values) recorded for each visit at each plot.

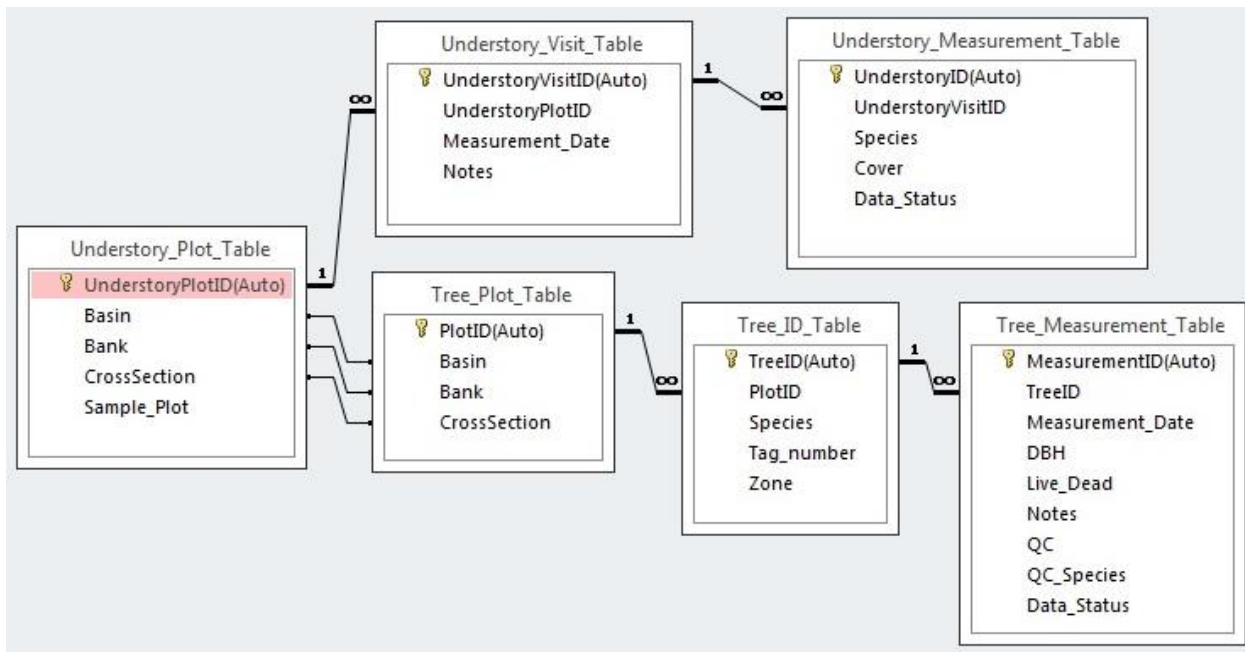


Figure 11-5. The primary tables and relationships in the riparian vegetation database.

## DATA PRODUCTS

The stream temperature database contains various queries that create data summaries and prepare the data for statistical analysis by other software. These are accessed via the main database menu. Examples of data products include:

### Data summaries:

- A report containing a list of all tree species found on the overstory plots, as well as the frequency and average diameter of each species.
- A report summarizing all understory species found on the understory plots.
- A report listing, for each overstory plot, trees per hectare and basal area per hectare.

### Data for analysis:

- A dataset containing all overstory data, except for that collected for QC purposes.
- A dataset containing all understory data.

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## Appendix 11A. Riparian Vegetation Field Sheets

### Plot Establishment and Canopy Photo Field Sheet

<b>Olympic Experimental State Forest (OESF) Stand Dynamics Vegetation Plot Data</b>				
<b>Plot Establishment/Layout</b>				
Basin:	Date:	Azimuth to plot center (at 0 m) from cross-sec monument:	Distance to plot center (at 0 m) from cross-sec monument:	
Cross-Sec:	Stream Azimuth:			
Bank:	Plot (Upslope) Azimuth:			
Crew:	Plot (Horizontal) Azimuth:			
Weather / Visit notes:				
Site and Plot Establishment notes:				
<b>Canopy Photos</b>				
Date of photos:			Photo location (lens at 1.3 m above stake or offset?)	Photo notes (e.g., stick used to block sun)
Photo	Photo number	Time (PST)		
0 m				
10 m				
20 m				
40 m				
60 m				









## Appendix 11B. Tables in the Riparian Vegetation Database

Understory Plot Table	
Field	Field description
UnderstoryPlotID(Auto)	Unique identifier for each record.
Basin	Watershed identifier.
Bank	The stream bank on which the plot is located.
CrossSection	The cross section where the plot is located.
Sample_Plot	The sample plot identifier, based on distance from beginning of transect.

Understory Visit Table	
Field	Field description
UnderstoryVisitID(Auto)	Unique identifier for each record.
UnderstoryPlotID	Relates records to a record in the Understory Plot Table.
Measurement_Date	Date of measurement.
Notes	Notes recorded in the field.

Understory Measurement Table	
Field	Field description
UnderstoryID(Auto)	Unique identifier for each record.
UnderstoryVisitID	Relates records to a record in the Understory Visit Table.
Species	Plant species.
Cover	Percentage of the plot covered by that species.
Data_Status	Indicates whether data have passed the QC procedure (in which case status is changed to "Published").

Tree Plot Table	
Field	Field description
PlotID(Auto)	Unique identifier for each plot.
Basin	Watershed identifier.
Bank	The stream bank on which the plot is located.
CrossSection	The cross section where the plot is located.

■ Riparian Vegetation

Tree ID Table	
Field	Field description
TreeID(Auto)	Unique identifier for each record.
PlotID	Links records to the appropriate record in the Tree Plot Table.
Species	Tree species.
Tag_number	Tree tag number.
Zone	The zone in which the tree is located.

Tree Measurement Table	
Field	Field description
MeasurementID(Auto)	Unique identifier for each record.
TreeID	Links records to the unique tree identifier in the Tree ID Table.
Measurement_Date	Date of the measurement
DBH	Diameter at breast height (cm).
Live_Dead	Tree status at the time of measurement.
Notes	Notes recorded during the measurement visit.
QC	Is the measurement for the purpose of a quality control check? (Y/N)
QC_Species	The species recorded during the QC measurement.
Data_Status	Indicates whether data have passed the QC procedure (in which case status is changed to "Published").

# Riparian Down Wood

*Authors:* Warren Devine

*Version:* 1.2

## *Revision History:*

Version number	Purpose / Changes	Author(s)	Reviewer(s)	Date
1.0	Initial draft presented to project staff for review	Warren Devine	Teodora Minkova, Kyle Martens, Alex Foster	7/19/2022
1.1	Draft with comments and edits from project staff and additions and edits made in response to these comments.	Warren Devine	Teodora Minkova, Kyle Martens, Alex Foster	7/25/2022
1.2	Revised draft after testing protocol in the field	Warren Devine	n/a	8/5/2022

## *Based on the Following Protocols:*

The sampling approach is based on the line-intersect sampling guidelines of Marshall et al. (2000) and Harmon and Sexton (1996). The layout of clustered transects is based on the approach used by the USDA Forest Service Forest Inventory and Analysis program (Waddell 2002; Woodall and Monleon 2007). The riparian down wood sampling approach of Anderson and Meleason (2009) was also reviewed during protocol development.

## *Reasons to Adopt the Above Protocols:*

Line-intersect sampling is an efficient approach for measuring down wood. The clustered transect layout maximizes total transect length within and around the previously installed forest overstory plots, while avoiding any potential bias associated with sampling on a slope.<sup>1</sup> The clustered transect layout also optimizes efficiency of field work relative to many other transect designs (Woodall and Monleon 2007).

## *Purpose and Content:*

The purpose of this monitoring protocol is to describe the sampling and data management necessary to assess riparian down wood conditions in Type-3 watersheds in the OESF as part of status and trends monitoring. The protocol details the field procedures and data management, including quality assurance and quality control.

<sup>1</sup> To avoid slope-related bias, transect orientation is independent of stream orientation and therefore independent of the stream valley slope.

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## Introduction

Understanding the recruitment processes associated with large woody debris (here, “down wood”) in riparian and aquatic habitats is a key component of the status and trends monitoring program. Previous chapters of this compendium of protocols describe monitoring of instream wood (Chapter 5) and of the riparian forest overstory (Chapter 11). The present chapter describes the down wood monitoring protocol which will provide data to: (1) describe the down wood habitat component of the riparian forest, and (2) link riparian forest dynamics to recruitment of instream wood.

Down wood is an important component of the habitat for many riparian-obligate species, including vertebrates, invertebrates, and vascular and non-vascular plants. By assessing the relationships between the riparian forest condition and down wood, we will be able to relate forest composition and disturbance history to down wood. Then, these findings can be used to estimate recruitment of instream wood from the riparian forest. In Pacific coastal forests, instream wood is recruited primarily through mortality of riparian trees, bank erosion, and debris flows and mass wasting (Benda and Bigelow 2014). The relative contribution of each of these sources is influenced by watershed terrain (e.g., stream valley slope and channel confinement) and riparian forest condition (Naiman et al. 2002). Recruitment by tree mortality most often results from competition-induced mortality or windthrow: dead trees (i.e., snags) or living trees in the riparian zone fall and may end up within the stream channel. The role of bank erosion in wood recruitment is strongly influenced by channel confinement and stream size; for large, low-gradient, meandering streams, bank erosion may be the primary mechanism of wood recruitment from the riparian forest (Martin and Benda 2001; Naiman et al. 2002). Debris flows and landslides occur relatively infrequently but are highly impactful in the magnitude of their wood contribution. By contrast, wood recruitment from bank erosion and mortality of trees in the riparian forest is gradual but occurs continuously.

This protocol assesses down wood in the near-stream riparian zone, specifically, the zone from 0 to 20 meters from the stream, measured laterally from the channel. This zone was selected for two primary reasons. First, the riparian forest overstory has already been sampled in this zone, and by measuring down wood within the same zone, relationships between the forest overstory and down wood can be assessed directly.<sup>2</sup> Second, the first 20 meters of the riparian forest is the source of the majority of wood that is recruited into streams via tree mortality. Instream wood recruitment from the riparian forest decreases rapidly with distance from stream (Naiman et al. 2002). In small streams in old-growth and mature forests of the Coast and Cascade Ranges, 100% of hardwood pieces recruited to a stream originated within 25 meters of the stream, as did 87% of conifer pieces (McDade et al. 1990). However, these riparian forests were all older than 80 years; recruitment distances are shorter in younger forests (Meleason et al. 2002).

Through these surveys of riparian down wood, we will be able to answer the following questions:

- How does the amount, size, and species of riparian down wood relate to the forest overstory condition, including management history?

---

<sup>2</sup> The riparian forest overstory in two other zones (20-40 and 40-60 meters from the stream) also was sampled; however, the forest from 20 to 60 meters from the stream has less of a riparian character (Devine et al. 2022) and is substantially less likely to contribute wood to the stream channel (Naiman et al. 2002). For these reasons, we focus down wood sampling on the 0-20 m zone.



## ■ Riparian Down Wood

- Is the amount, size, and species of riparian down wood correlated with instream wood?
- Based on relationships between riparian overstory condition and down wood, what is the projected future recruitment of instream wood from the riparian forest?

## *Monitoring Design*

### **SPATIAL SAMPLING DESIGN**

Riparian down wood will be sampled at each of the locations where riparian forest overstory plots have been established (n=118, as of 2022). At each sample reach, a riparian overstory plot was established beginning several meters<sup>3</sup> upslope of one randomly selected cross-section monument on each stream bank, for a total of two plots per reach (see Chapter 11 of this protocol for details). In rare instances, topography or roads prevented establishment of plots in this arrangement, so two plots were located on the same side of a reach or only one plot was established at a sample reach. Appendix 12A contains a list of all overstory plot locations.

### **TEMPORAL SAMPLING DESIGN**

Down wood sampling will occur no more often than once every 10 years, owing to an anticipated slow rate of change in down wood and the fact that this sampling procedure will require a significant number of person-days. An exception to the 10-year interval will be made in the case of a major natural disturbance to the riparian forest such as a windthrow or landslide. Similarly, down wood surveys will be repeated within two years of any timber harvest within or adjacent to the riparian overstory plot.

## *Equipment and Supplies*

- This protocol with the list of plot locations (Appendix Table 12A)
- Datasheets (in Appendix 12B)
- Tablet with Avenza Status and Trends map, to navigate to sites
- Printed driving and hiking directions to Status and Trends sites
- Clipboard
- Red/white striped plastic flagging
- Chaining pins (two, plus spares)
- 50-meter reel tape
- Two sighting compasses (e.g., Silva Ranger©) set to current declination
- Laser range finder capable of measuring horizontal distance
- Log caliper (metric; to 80 cm)
- Diameter tape (metric)
- Clinometer

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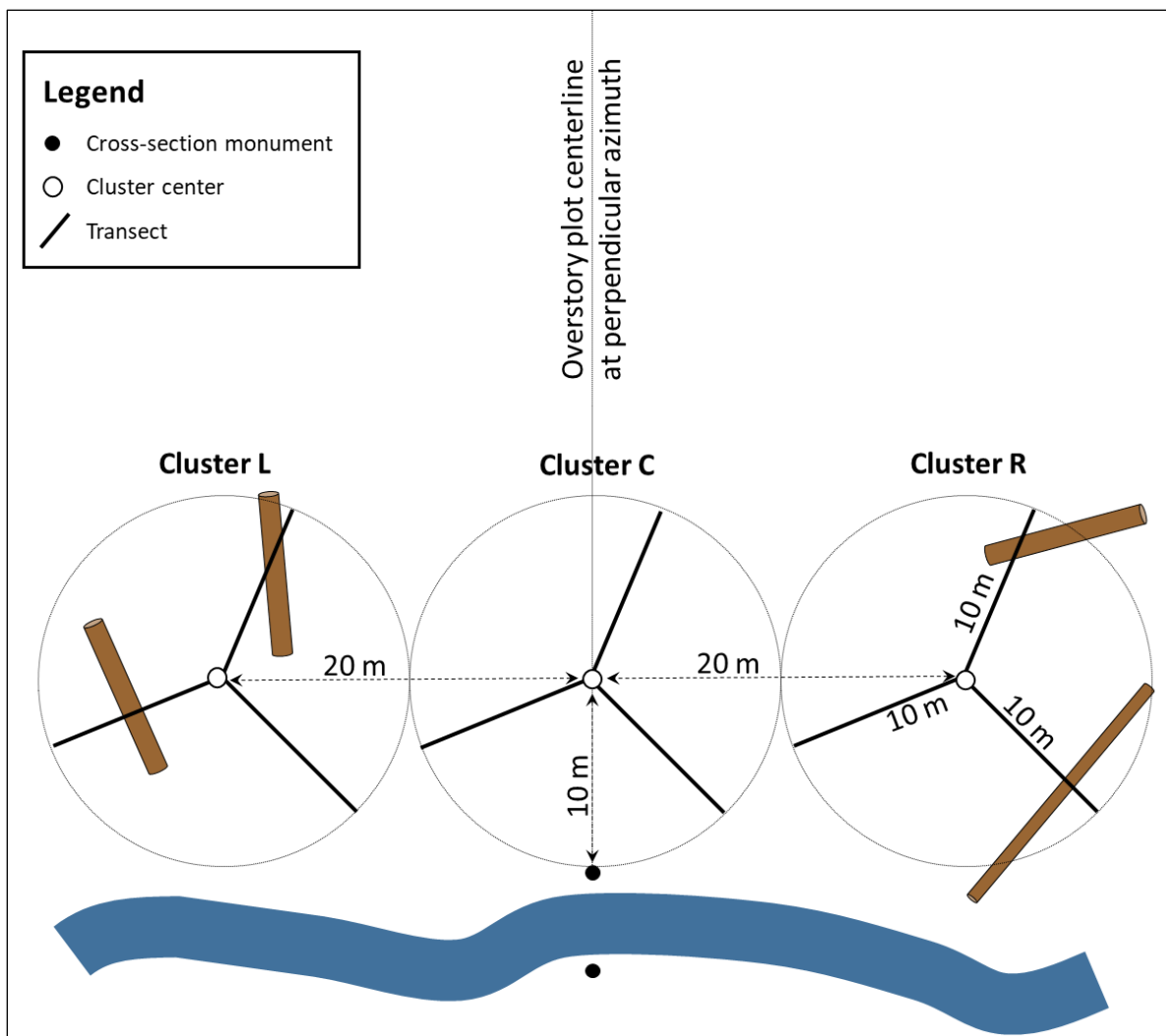
<sup>3</sup> The overstory plots often began 2 to 5 meters upslope from the cross-section monument, but in some cases began more than 10 meters upslope from the monument.

## Field Procedures

### OVERVIEW

At each sample reach, a series of 10-meter-long transects will be used to sample down wood. These transects will be located at the same cross-section and stream side locations as already-established forest overstory plots (Appendix Table 12A). At most of the sample reaches, there are two overstory plots, one on each side of the reach. At each overstory plot location, nine transects will be arranged in three clusters of three transects each, for a total of 18 transects per reach (Figure 12-1).

Of these three transect clusters, the center cluster is located on the centerline of the forest overstory plot. This overstory plot centerline originates at one of the reach cross-section monuments and extends upslope, perpendicular to the reach. The three transect clusters are identified as “L”, “C” and “R”, indicating their positions as left, center, right, respectively, when one stands at the monument, facing the



**Figure 12-1.** Schematic of the down wood transect layout for one overstory plot location. At most sample reaches, there are two overstory plots, and this layout will be duplicated for each, for a total of 18 transects.

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centerline, with their back to the stream. The locations of the down wood transects will not be permanently monumented in the field; the center of each transect cluster will be temporarily flagged during the surveys and flags will be removed when the survey is completed.

### SAMPLING PROCEDURE

#### 1. *Navigate to the listed cross section monument.*

The down wood transects will be installed near the same randomly selected cross-section monuments as the forest overstory plots. At most of the sample reaches, there are two overstory plots. After arriving at a sample reach, use the list of overstory plot locations in Appendix Table 12A to identify which cross section and stream bank to go to. At each sample reach, there are six evenly spaced stream cross sections, identified sequentially as A-F, with A furthest downstream. Each cross section is monumented with a rebar or wood stake on each side of the stream. On state and national forest land, these are rebar stakes capped with an orange mushroom cap. In Olympic National Park, stakes are wooden and may be flagged with biodegradable flagging.

#### 2. *Identify the location of the cross-section monument.*

After arriving at the listed cross section and bank, find the monument itself. Sometimes a monument is hard to locate due to vegetation, particularly if it is a wooden stake. If you cannot find the monument, then use the monument on the other side of the stream to identify where it is or most likely was (monuments are located in stable soil near the bankfull channel, but far enough above it to not be disturbed during a flood). Once you find the monument itself or the location where it likely once was, temporarily tie a piece of red/white flagging above it to mark this location.<sup>4</sup> If both cross-section monuments are missing, find the monuments upstream and downstream (e.g., if you are looking for C, then find B and D), and estimate where the point is half way between these.

#### 3. *Navigate from the monument location to cluster C center.*

Use a compass to sight the “perpendicular azimuth” from Table 12A, and measure 10.0 meters in that direction from the monument location, to cluster C center. (Be aware that occasionally the azimuth in the table may be 180 degrees off.) If the slope of the ground is gradual (i.e., easily walkable / less than 20% slope), use the reel tape to measure the distance; if it is steeper than 20%, then use the range finder in “Horizontal Distance” mode. Temporarily hang a red/white flag to mark cluster C center.

*Note:* You will usually encounter rebar stakes or fence posts marking the centerline of the overstory plot (often labeled with distances of 0, 10, 20, 40, or 60 meters). These stakes or posts should *not* be used as the cluster C center because those distances are not measured from the cross-section monument; however, you *can* use them to identify the perpendicular azimuth (instead of using a compass).

---

<sup>4</sup> Replacement of missing monuments is done during the stream survey and is beyond the scope of the down wood protocol.

#### 4. *Transect sampling.*

Three 10-meter transects will radiate out from cluster center at azimuths of 30, 150, and 270 degrees (Figure 12-1). Begin with the 30-degree transect.

- a. Lay out transect:** One person will hold the metal end of the reel tape at cluster C center while the other person, holding the reel near the ground, walks 10 meters at a 30-degree azimuth. If the slope is gradual (i.e., easily walkable / less than 20%), use the distance on the reel tape to find the transect length of 10.0 m; if the slope is steeper, then use the range finder in “Horizontal Distance” mode to find 10.0 m. Note that if you use the range finder to measure 10.0 meters horizontal distance, then the transect length on the tape will always be greater than 10.0 meters because the tape represents slope distance rather than horizontal distance. In this case, put a chaining pin in the ground beside the tape where the range finder says is 10.0 m. The pin may be at, for example, 10.5 m on the tape.

The tape should be as straight as possible. If desired, a chaining pin can be put through the metal end clip and staked into the ground.

- b. Collect data:** One person walks along the transect tape and identifies each piece of dead down wood that intersects the tape:
- Dead down wood is fallen wood that is not supported by its own roots. It must be dead. Stumps are not measured because they are rooted.
  - Each piece must be a minimum of 10 cm diameter; there is no piece length requirement.
  - The central axis (e.g., pith) of a piece must be above ground level. It may be suspended above the ground, either level or at an angle, or lying on the ground. If it is only slightly leaning (less than 45 degrees), then don't count it.
  - The transect must intersect the central axis of piece, not just a corner.
  - If the transect passes through a curved or a branched piece more than once, then record each intersection as a separate piece on the datasheet (Marshall et al. 2000).
  - If a single piece intersects more than one of the transects, count it each time (Marshall et al. 2000).
  - Do not sample pieces that have clearly been transported there by the stream itself, such as pieces that are in a log jam or pieces along the edge of the stream channel. Also, stream-transported pieces will have signs of being worn down during transport. If uncertain whether a piece was stream-transported, assume that it was *not* transported by the stream. A sampled piece may extend into or above the stream channel, but the goal is to sample wood recruited from the local riparian forest, not wood transported from elsewhere by the stream.

For each qualifying piece of wood that intersects the transect tape, use the datasheet (Appendix B) to record the transect azimuth, the piece diameter at the point of intersection (to nearest cm), species class (“C” for conifer; “H” for hardwood), and decay class (“S” for sound and “R” for rotted):

- Always measure diameter holding the bar of the caliper perpendicular to the log (not perpendicular to the tape), with the jaws pointing down.
- If you are unsure of species class, use your best judgement to pick one, based on the characteristics of other down wood at the site.

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- An indicator of sound vs. rotted wood is that rotted wood can be pulled apart by hand (not the bark, but the wood itself).

c. **Repeat for the next two transects:** Repeat steps **a** and **b** for the next transect (150 deg.) then for the third transect (270 deg.). For a cluster, all three transects are entered on the same half-page datasheet.

### 5. *Navigate from cluster C center to cluster L center and then sample cluster L.*

Cluster L center will be located 20.0 meters from cluster C center and, as with all cluster centers, will be 10.0 meters from the stream channel (Figure 12-2). Use a reel tape or rangefinder (for slopes >20%) to measure 20.0 meters from cluster C center toward cluster L center, at an azimuth 90 degrees different from the perpendicular azimuth. As you walk toward cluster L, estimate your distance from the stream as you go, with the objective of placing cluster L center 10 meters from the stream. When you are 20.0 m from cluster C center and also an estimated 10 m from the stream, temporarily flag this location.

Next, verify that this temporarily flagged location is indeed 10.0 m from the stream channel. Do this by measuring the distance to the nearest edge of the stream channel (or to the edge of any stream-transported wood). If it is more or less than 10.0 m, then shift the temporarily flagged location of cluster L center so

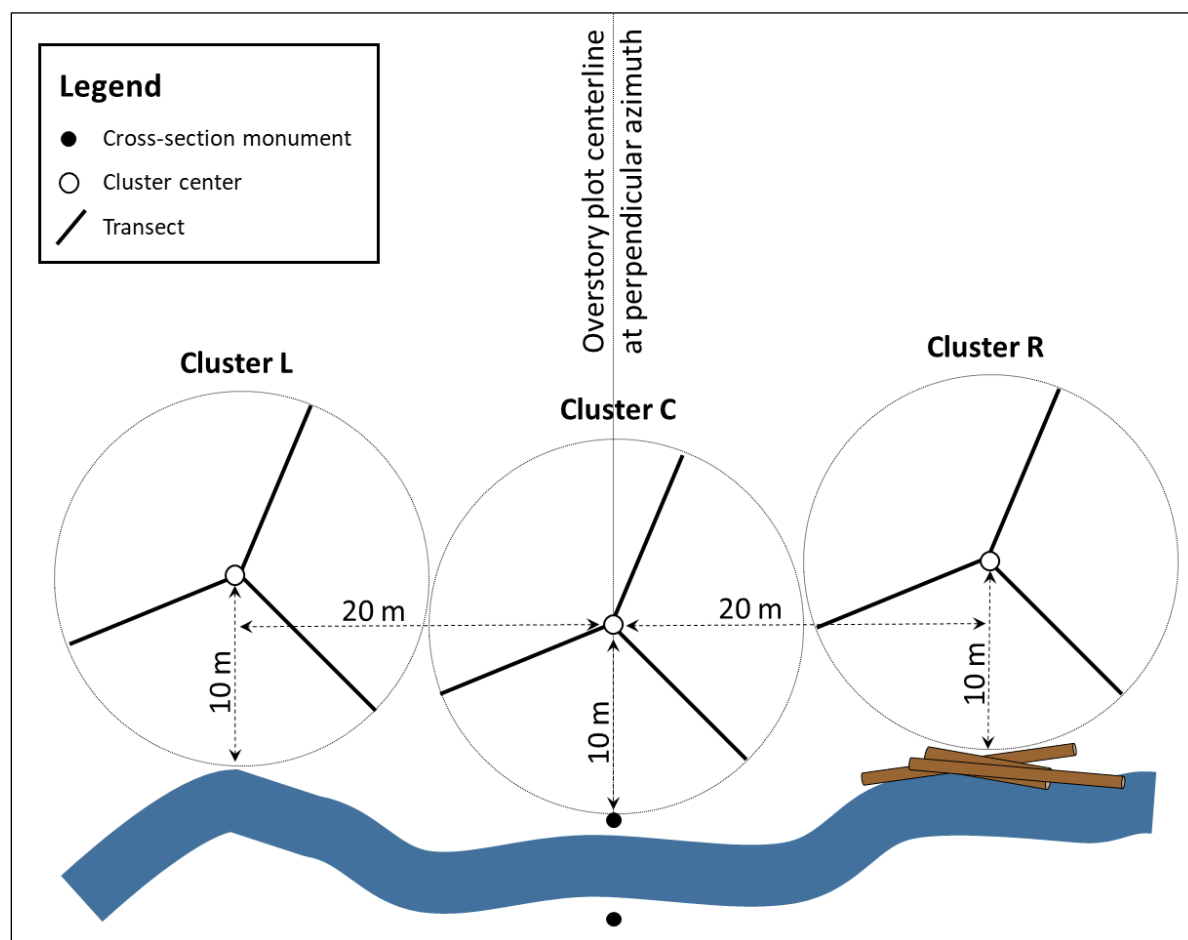


Figure 12-2. Example of transect layout where cluster L and cluster R centers have been shifted away from the stream so that the centers are a full 10 m from the channel (cluster L) or from stream-transported wood (cluster R). Clusters are always shifted along the same azimuth as the plot centerline.

that it is 10.0 m from the nearest edge of the stream (or any stream-transported wood). Figure 12-2 shows two examples of cluster centers that had to be shifted.

Note that you may encounter other cross-section monuments while establishing clusters L and R; ignore these as they are not relevant to this sampling.

Now, repeat step 4 above for cluster L, recording data on new half-page datasheet.

#### **6. *Identify cluster R center and sample cluster R.***

Return to cluster C center. Now, repeat the same process from step 5, except this time heading right instead of left (oriented with your back to the stream) to find cluster R center.

Now, repeat step 4 above for cluster R, recording data on a new half-page datasheet.

#### **7. *Repeat steps 1-6 for the other overstory plot location at the sample reach*** (note that watersheds NF9 and 750 have only one overstory plot instead of two).

## **Quality Assurance and Quality Control**

Quality assurance includes staff training, use of standardized protocols, and periodic field checks. The QA/QC procedures for data management are described in the Data Management section below.

### **TRAINING**

All personnel conducting field protocols will be trained in a consistent manner to ensure that the surveys are conducted properly and in standardized fashion. The training is conducted or, for returning personnel, reviewed, annually before the start of the field season.

### **STANDARD PROTOCOLS**

The standard procedures described in this protocol are followed for the duration of the project. Any deviations from the procedures should be documented, and the reasons for deviation described and discussed with the project manager or the researcher overseeing the protocol implementation.

Changes to the published protocols are approved by the project manager or by the researcher overseeing the protocol implementation. Revised protocols are assigned new version numbers and publication dates.

### **FIELD QUALITY CONTROL**

The researcher overseeing the protocol implementation or a different field crew will conduct spot checks on 10% of the field measurements every year.

## Time Estimates for Implementing the Field Procedures

Including driving and hiking time, and assuming the crew is based in Forks, typically a crew of two people can complete two sites (i.e., 4 plots; 12 transect clusters) in a 10-hour work day.

## Procedures for Calculating Metrics

A variety of down wood metrics will be calculated. Examples of the metrics appear in Table 12-1.

**Table 12-1. Riparian down wood metrics and calculation procedures. Metrics are calculated separately for each overstory plot location (i.e., calculated from nine transects).**

<b>Metric</b>	<b>Calculation procedure</b>
Volume of down wood (m3/ha)	Equation 7 from Harmon and Sexton (1996), converted to a per-hectare basis.
Volume of down wood by diameter class (m3/ha)	Equation 7 from Harmon and Sexton (1996).
Volume of down wood by species class (m3/ha)	Equation 7 from Harmon and Sexton (1996).
Volume of down wood by species and diameter class (m3/ha)	Equation 7 from Harmon and Sexton (1996).
Volume of down wood by decay class (m3/ha)	Equation 7 from Harmon and Sexton (1996).
Volume of down wood by decay class and diameter class (m3/ha)	Equation 7 from Harmon and Sexton (1996).
Cover of down wood (%)	Equations from Marshall et al. (2000).
Cover of down wood by diameter class (%)	Equations from Marshall et al. (2000).
Cover of down wood by species class (%)	Equations from Marshall et al. (2000).
Cover of down wood by species and diameter class (%)	Equations from Marshall et al. (2000).
Cover of down wood by decay class (%)	Equations from Marshall et al. (2000).
Cover of down wood by decay class and diameter class (%)	Equations from Marshall et al. (2000).

## Data Management

### DATA FLOW

Data are collected in the field using paper field forms (Appendix 12B). This section contains a description of the steps used to process this data from its field format through the quality control stage; flowcharts provide an overview of the process. Details on long-term data storage and archiving appear in the following section, titled Data Storage.



**Data flow for paper field forms**

1. **Fill out field forms** Completed as data are collected.
2. **Scan and store field forms** After returning from the field each week, the field forms are scanned and stored on the WADNR network drive at:  
 J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\07\_Data management\\_All new data and photos\  
 The original paper field forms are archived at the Washington Department of Natural Resources Forest Resources Division.
3. **Enter data** All of the information collected on paper field forms is entered into an Excel spreadsheet by personnel involved in its collection. This approach has been favored by personnel in the past (rather than entering data directly into the Access database) because they were familiar with Excel.
4. **Data verification** Entered field form data are verified by comparing it to the original field forms.
5. **Import data to database** The data are imported from Excel to the Access database used for long-term storage of riparian vegetation and down wood data.
6. **Quality control** A series of quality control checks are performed (Figure 12-3). After the quality control has been completed, data status is set to “Published”.

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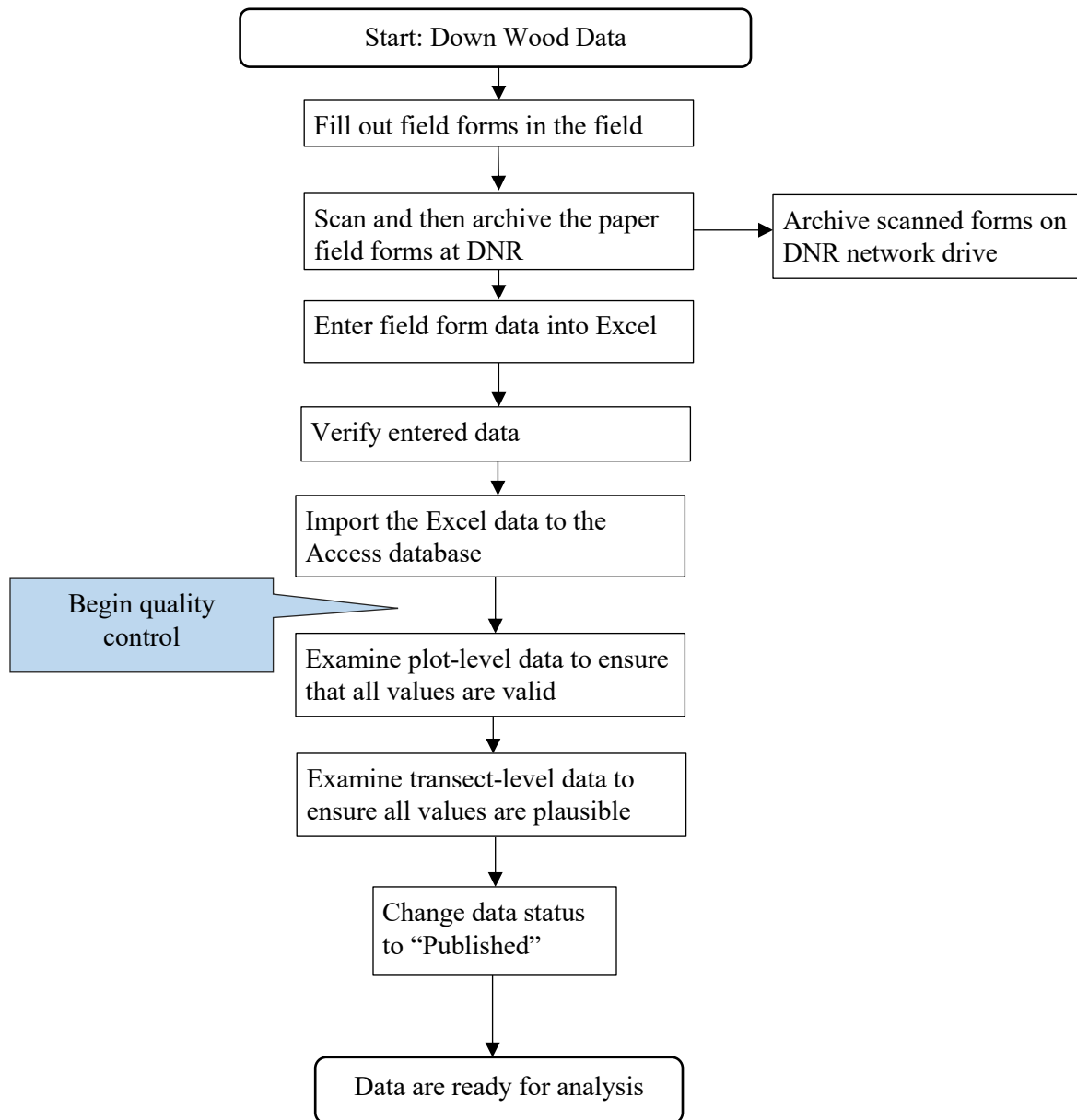


Figure 12-3. Flow chart describing the down wood data quality control process.

## DATA STORAGE

### *Raw Data Archives*

The raw field data consist of paper field forms. The paper field forms are archived at the Washington Department of Natural Resources Forest Resources Division. Scanned copies of these forms are saved in the Adobe portable document format (.pdf) in the following directory:

J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_Field data\06\_Riparian vegetation\Data\Data archive\Field sheet scans (data in database)\

### ***Database***

All of the down wood data collected on field forms will be stored in a single Microsoft Access database on the WADNR network drive (Olympia, WA) at: J:\hcp\monitoring\_research\tminkova\01\_OESF\_R&M Program\01\_Rip S&T Mon\01\_FIELD DATA\06\_Riparian vegetation\Data\Riparian\_Vegetation.accdb

In addition to providing long-term storage of data, this database is used to create data summaries and to prepare and export datasets for analysis by statistical software.

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## Appendix 12A. Riparian Overstory Plot Information

**Table 12A.** Location and descriptive information for riparian overstory plots established at permanently installed sample reaches in status and trends watersheds.

**Note:** data in this table are current as of 19 July 2022.

Watershed	Bank	Cross-section	Perpendicular azimuth (deg.)	Plot centerline monuments	Plot establishment / measurement year
145	Left	A	228	Fence posts	2014
145	Right	C	49	Fence posts	2014
157	Left	E	331	Fence posts	2014
157	Right	F	172	Fence posts	2014
158	Right	B	no data	unknown	2015
158	Left	E	no data	unknown	2015
165	Left	E	228	unknown	2015
165	Right	F	37	unknown	2015
196	Right	C	90	Fence posts	2014
196	Left	E	261	Fence posts	2014
328	Right	B	44	Stakes	2016
328	Left	C	197	unknown	2016
433	Left	C	180	Fence posts	2014
433	Left	E	211	Fence posts	2014
443	Left	A	168	unknown	2015
443	Right	D	306	unknown	2015
488	Right	C	77	Stakes	2015
488	Left	E	261	Stakes	2015
542	Left	B	68	Centerline ends only	2015
542	Right	D	269	Centerline ends only	2015
544	Right	B	244	Stakes	2015
544	Left	E	94	Stakes	2015
545	Left	A	91	Fence posts	2014
545	Right	F	291	Fence posts	2014
550	Right	A	314	Centerline ends only	2015
550	Left	E	135	Centerline ends only	2015
566	Left	A	76	Stakes	2017
566	Right	E	238	Stakes	2017
567	Right	C	95	Centerline ends only	2015
567	Left	E	250	Centerline ends only	2015

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568	Right	B	74	Stakes	2015
568	Left	C	257	Stakes	2015
582	Left	A	147	Centerline ends only	2015
582	Right	E	11	Centerline ends only	2015
584	Left	B	160	Centerline ends only	2015
584	Right	F	329	Centerline ends only	2015
597	Right	C	341	Centerline ends only	2015
597	Left	D	176	Centerline ends only	2015
605	Left	B	235	Centerline ends only	2015
605	Right	F	60	Centerline ends only	2015
619	Right	B	121	Centerline ends only	2015
619	Left	D	220	unknown	2015
621	Right	B	91	Centerline ends only	2015
621	Left	F	276	Centerline ends only	2015
625	Left	B	203	Centerline ends only	2015
625	Right	C	81	Centerline ends only	2015
637	Left	A	170	Centerline ends only	2015
637	Right	D	20	Centerline ends only	2015
639	Right	E	144	unknown	2015
639	Left	F	285	unknown	2015
642	Left	D	263	Fence posts	2014
642	Right	F	94	Fence posts	2014
653	Left	A	265	Centerline ends only	2015
653	Right	C	90	Centerline ends only	2015
658	Left	B	169	Stakes	2015
658	Right	F	320	Stakes	2015
687	Left	A	42	unknown	2015
687	Right	D	279	unknown	2015
688	Right	A	92	Stakes	2015
688	Left	B	226	Stakes	2015
690	Right	B	263	unknown	2015
690	Left	D	103	unknown	2015
694	Right	C	326	Fence posts	2014
694	Left	E	127	Fence posts	2014
717	Right	B	212	Stakes	2015
717	Left	C	41	Stakes	2015

718	Right	B	278	unknown	2015
718	Left	D	100	unknown	2015
724	Left	C	124	Fence posts	2014
724	Right	F	354	Fence posts	2014
730	Right	D	250	unknown	2015
730	Left	F	44	unknown	2015
737	Left	D	86	Fence posts	2014
737	Right	E	257	Fence posts	2014
744	Left	E	32	Stakes	2017
744	Right	E	202	Stakes	2017
750	Left	C	285	unknown	2016
760	Right	A	198	Stakes	2016
760	Left	F	34	Stakes	2016
763	Right	A	215	Centerline ends only	2015
763	Left	C	13	Centerline ends only	2015
767	Right	C	268	Stakes	2015
767	Left	E	75	Stakes	2015
769	Right	C	269	Stakes	2015
769	Left	E	31	Stakes	2015
773	Right	E	140	Stakes	2016
773	Left	F	288	Stakes	2016
790	Left	A	286	Fence posts	2014
790	Right	D	106	Fence posts	2014
796	Left	B	89	Stakes	2016
796	Right	F	260	Stakes	2016
797	Right	A	290	unknown	2016
797	Left	D	100	Stakes	2017
804	Left	E	210	Centerline ends only	2015
804	Right	F	28	Centerline ends only	2015
820	Right	B	240	Stakes	2016
820	Left	E	90	Stakes	2016
844	Left	A	277	unknown	2015
844	Right	C	67	unknown	2015
BOG	Left	A	125	Stakes	2017
BOG	Right	C	300	Stakes	2017



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HOH	Right	E	210	Stakes	2017
HOH	Left	F	5	Stakes	2017
NF4	Right	A	330	Stakes	2018
NF4	Left	C	115	Stakes	2018
NF5	Left	A	260	Stakes	2018
NF5	Right	F	60	Stakes	2018
NF6	Right	B	310	Stakes	2018
NF6	Right	E	350	Stakes	2018
NF7	Left	A	270	Stakes	2018
NF7	Right	E	110	Stakes	2018
NF8	Left	B	291	Stakes	2018
NF8	Right	E	112	Stakes	2018
NF9	Left	B	320	unknown	2018
QUE	Right	A	250	unknown	2016
QUE	Left	B	70	unknown	2016
SFH	Left	C	128	Stakes	2016
SFH	Right	F	311	Stakes	2016

***Appendix 12B. Field Data Sheet***

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Watershed:			Cross section:			Date:				
Crew:			Bank:			Remarks:				
Cluster L/C/R	Azimuth 30/150/270	Diam. (to 1 cm)	<u>C</u> onifer/ <u>H</u> ardwood	<u>S</u> ound/ <u>R</u> otted		Cluster L/C/R	Azimuth 30/150/270	Diam. (to 1 cm)	<u>C</u> onifer/ <u>H</u> ardwood	<u>S</u> ound/ <u>R</u> otted

Watershed:			Cross section:			Date:				
Crew:			Bank:			Remarks:				
Cluster L/C/R	Azimuth 30/150/270	Diam. (to 1 cm)	<u>C</u> onifer/ <u>H</u> ardwood	<u>S</u> ound/ <u>R</u> otted		Cluster L/C/R	Azimuth 30/150/270	Diam. (to 1 cm)	<u>C</u> onifer/ <u>H</u> ardwood	<u>S</u> ound/ <u>R</u> otted

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# Glossary

**Adapted from Armantrout 1998 unless otherwise indicated.**

*Active channel* – A streambank transition zone that marks a change from vegetative species able to survive extended periods of inundation like herbs and moss to permanent woody vegetation.

*Alluvial* – Relating to the process of sediment transport and sorting, chiefly by water.

*Bankfull depth* – Average flow depth across the channel at bankfull stage.

*Bankfull discharge* - The dominant channel forming flow with a recurrence interval seldom outside the 1 to 2 year range.

*Bankfull stage* – Bankfull stage is delineated by the elevation point of incipient flooding, indicated by deposits of sand or silt at the active scour mark, a break in stream bank slope, perennial vegetation limit, rock discoloration, and root exposure.

*Bankfull width* – Channel width between bankfull stage indicators, often congruent with the active channel.

*Canopy* – The continuous cover of branches and foliage formed collectively by the crowns of adjacent trees and other woody growth.

*Channel confinement* – The degree to which stream channel migration is limited in its lateral movement by valley walls or relic terraces. It is expressed as the ratio of the width of the floodplain to the channel's bankfull width.

*Channel control* – Natural or artificial channel feature(s) downstream of a gage station that influence the stage-discharge relationship at the gage station.

*Colluvial* – Relating to the process through which sediment is transported chiefly by gravity and is unsorted.

*D<sub>50</sub>* – Median particle size of a distribution.

*Diameter at breast height (DBH)* – The diameter of a tree, measured 1.37 m (4.5 ft) above the ground on the uphill side of the tree.

*Diel* – Pertaining to a 24-hour period or a regular occurrence in every 24-hour period.

*Discharge* – Rate at which a volume of water flows past a point per unit of time.

*Fines* – Particulate material less than 2 mm in diameter, including sand, silt, clay, and fine organic material.

## ■ Glossary

*Floodplain width* – The stream width at a discharge level defined as twice the maximum bankfull depth.

*Floodplain, 100-year* – Area adjoining a water body that becomes inundated during periods of overbank flooding that happens an average of once every 100 years.

*Gaging station* – Particular location on a stream, canal, lake, or reservoir where systematic measurements of streamflow or quantity of water are made.

*Geographic information system (GIS)* – A computer system that stores and manipulates spatial data, and can produce a variety of maps and analyses.

*Habitat attribute*– Single element of the habitat or area (such as stream temperature or pools) where an organism lives or occurs (synonymous with *habitat component*).

*Habitat metric* – Quantitative characteristics that describes the biological, chemical, and physical components of an ecosystem (for example mean daily stream temperature or residual pool depth) (synonymous with *habitat parameter and habitat variable*). A variety of metrics can be derived from original measurements.

*Hemispherical canopy photography* – A method for indirectly characterizing the forest canopy using a camera equipped with a hemispherical (or “fish-eye”) lens which is aimed directly upward.

*Hydrograph* – Graph that shows the rate of flow (discharge) versus time past a specific point in a channel.

*In-stream large wood (large woody debris)* – Wood in the active channel with pieces larger than 10 cm in diameter and 2 m in length.

*Log jam or jam* – Wholly or partially submerged accumulation of woody debris from winds, water currents, or logging activities that partially or completely blocks a stream channel and obstructs streamflow.

*Monitored Watersheds* – For this project, the drainage around the smallest fish-bearing (Type 3) stream identified for sampling through GIS and subsequent field reconnaissance.

*Outlet* – Terminus or mouth of a stream where it flows into a larger water body.

*Rating curve* - A relationship between water level and streamflow (discharge) that is specific to each gaging station.

*Reach* - A length of uniform channel with respect to discharge, depth, area, and slope.

*Riparian zone* – A narrow band of moist soils and distinctive vegetation along the banks of lakes, rivers, and streams.

*Sample Reach* – A portion of a stream where field sampling takes place.

*Signal-to-Noise Ratio* – The ratio of the variation in a measured parameter (“signal”) to the variation in that parameter among repeated measurements (“noise”) (Kaufman et al. 1999).

*Sinuosity* – An index ( $K$ ) of a stream’s meander as a function of stream length. In this project, channel sinuosity is calculated as the ratio of sample reach length measured along the thalweg (using a reel tape) to the straight-line distance between the beginning and the end of the sample reach (measured with resource-grade GPS).

*Thalweg* – Path of a stream that follows the deepest part of the channel.

*Type 3 Watershed* – The drainage around the smallest fish-bearing (Type 3) stream (WADNR 1997).

*Type 3 Stream* – smallest fish-bearing stream as identified through biological criterion (fish presence) or through physical criteria (a stream  $\geq 2$  ft (0.7 m) wide and  $\leq 16\%$  gradient for watersheds up to 50 ac (20 ha) or with a gradient between 16% and 20% for watersheds larger than 50 ac). Type 3 streams can be considered loosely equivalent to Strahler’s 3<sup>rd</sup> order streams (WADNR 1997).

*Wetted width* – Width of a water surface at the time of a survey, measured perpendicular to the direction of flow. The average wetted width is often derived from multiple channel widths measured along a reach.

## *Literature Cited*

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