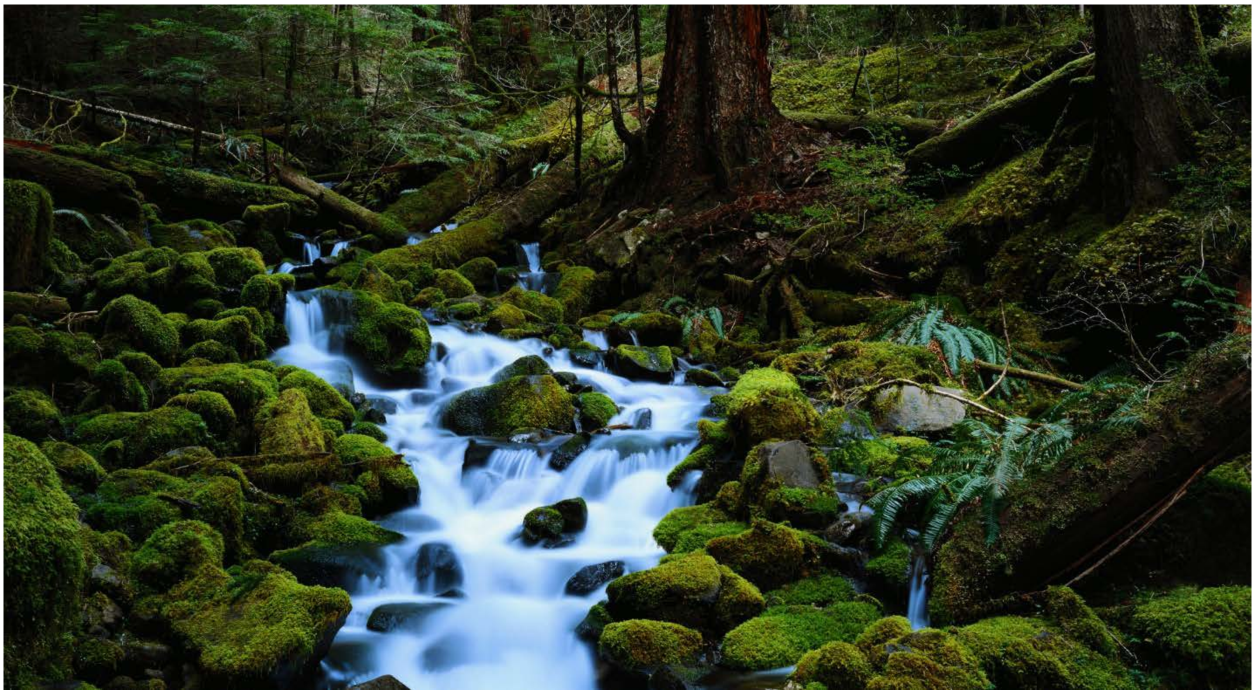
Evaluation of physical features that define fish habitat in forested landscapes across Washington State



Study plan prepared for the Washington Forest Practices Board

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Submitted by

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Summary

Fish habitat in forested watersheds is influenced by many factors including gradient, channel condition, nutrients, flow, barriers to migration, history of anthropogenic and natural disturbance, and fish population size. The Washington Forest Practices Board has selected criteria to be used in determining potential habitat breaks (PHBs) between fish (Type F) and non-fish bearing waters (Type N) across the state. These criteria are based upon data collected during a single Washington Department of Natural Resources (DNR) protocol electrofishing survey and include gradient, bankfull width, and vertical and non-vertical barriers to migration. To evaluate which physical criteria best define the end of fish (EOF) habitat (the uppermost stream segments that actually or potentially are inhabited by fish at any time of the year), detailed information is needed on the uppermost fish location and associated habitat in small streams across Washington State. While some data on habitat conditions at EOF are available (e.g., from existing water type modification forms submitted to DNR), these data were found to be insufficient to determine PHBs that defined EOF locations and associated habitat.

The purpose of the proposed study is to determine which combinations of gradient, channel width, barriers to migration, and other physical habitat and geomorphic conditions can be used to most accurately define PHBs and EOF habitat across Washington State. Additionally, this study is intended to provide insight into how EOF habitat and PHBs proposed by the Washington Forest Practice Board may vary across ecoregions, seasons, and years. We recommend the study be conducted across three years and three seasons (spring, summer, and fall) at 35 sites in each of seven forested EPA Level III ecoregions in Washington State. A total of 245 randomly selected sites from approved water type modification forms on the DNR hydro layer will be surveyed repeatedly every year for three years. Upstream fish distribution limits (i.e., EOF locations) will be determined during each season at each site following DNR protocols for electrofishing surveys. Once the uppermost fish is located during each sampling event, the EOF location will be flagged, GPS coordinates will be recorded, and a longitudinal profile habitat survey will be conducted to characterize habitat and geomorphic conditions 100 m downstream and 200 m upstream of the EOF location. During each of the three years, a random sample of one-third of all sites (82 sites)

will be revisited seasonally and DNR protocol electrofishing surveys repeated to determine how much the EOF location changes intra- and inter-annually. If the EOF location changes during any subsequent survey, a longitudinal profile survey will be conducted to append upstream or downstream, depending on the direction of change in the EOF point. This will ensure that there are habitat data 200 m above and 100 m below EOF locations for all seasons and years. Data will be analyzed to determine the combinations of gradient, channel width, and other geomorphic features that best define PHBs, EOF habitat, and whether these vary by ecoregion and season. The results of this study will be used to evaluate the effectiveness of PHB criteria in determining the regulatory break between fish (Type F) and non-fish bearing (Type N) waters.

Table of Contents

List of Acronyms

BFW	Bankfull Width
DNR	Department of Natural Resources
eDNA	Environmental DNA
EOF	End of Fish (Upstream extent of fish occupancy)
F/N Break	Regulatory break between fish and non-fish bearing waters
FHAM	Fish Habitat Assessment Method
GIS	Geographic Information System
PHB	Potential Habitat Break(s)
Type F	Fish Bearing Streams
Type N	Non-Fish Bearing Streams
WTM	Water Type Modification
WTMF	Water Type Modification Form

Introduction

Washington State forest practices are regulated by the Forest Practices Act established by the legislature, with rules established by the Washington Forest Practices Board (Board). The goals of the rules include protecting public resources (water quality, fish, and wildlife) and maintaining an economically viable timber industry. Rules pertaining to aquatic and riparian habitats are specifically included in the Forest Practices Habitat Conservation Plan, which provides coverage for approximately 9.3 million acres of forestland in Washington (6.1 million acres west of the Cascade Crest and 3.2 million acres in eastern Washington). Specific prescriptions (rules) are applied in waters containing fish to protect fish and their habitats.

The Board is responsible for rule-making and overseeing the implementation of forest practice rules. The evaluation of the effectiveness of these rules is directed by the Adaptive Management Program of the Washington Department of Natural Resources. Water typing is an important part of applying contemporary forest practice rules since prescriptions in riparian areas are based in part on whether streams are used by fish. Streams identified as having fish habitat are classified as Type F waters, defined in the interim water typing rule WAC 222-16-031, and have specific riparian buffer prescriptions and fish passage requirements. Fish habitat is defined in WAC 222-16-010 as "…habitat, which is used by fish at any life stage at any time of the year including potential habitat likely to be used by fish, which could be recovered by restoration or management and includes off-channel habitat." Currently, the interim rule delineates Type F waters through the use of either default physical criteria (e.g., 2 feet defined channel within the bankfull width and greater than 20 percent slope) or protocol surveys (e.g., electrofishing).

The Forest Practice Rules require forest land owners to determine, in the field, the type of any regulated waters as identified within proposed harvest areas prior to submitting a forest practices application/notification. Landowners are encouraged to submit a Water Type Modification Form (WTMF) to the DNR to make permanent changes to the water type maps. Thousands of WTMF have been submitted to DNR to modify water body types and modify the location of the break between Type F and Type N waters. The process for submitting and getting water type approved is outlined includes the following steps:

1. Proponent conducts a "protocol electrofishing survey"
2. Proponent submits a WTMF
3. DNR and reviewers concur/don't concur
    a. If DNR and reviewers concur, the water type modification is approved
    b. If DNR and reviewers don't concur, a site visit is organized to adjust and agree upon the F/N break

The Board is currently in the process of establishing a permanent water typing rule. Ultimately, the rule must be implementable, repeatable, and enforceable by practitioners and regulators involved in the water typing system. An important part of the permanent rule will be guidance on a specific protocol to determine the regulatory break between Type F and Type N waters. The Board is considering the use of a fish habitat assessment method that incorporates potential habitat breaks (PHBs) to identify features that can be used to locate the starting location for a survey of fish use. These PHBs are based upon changes in gradient, stream size, and the presence of vertical and non-vertical barriers to migration (e.g., obstacles).

Over the past 20 years, protocol electrofishing surveys have been conducted under WAC 222-16-031 with guidance provided by Board Manual Section 13 to determine the upper extent (EOF) of Type F waters. These fish presence surveys have incorporated additional stream length (defined in WAC 222-16-010) to capture habitat that was "likely to be used by fish" upstream of the detected uppermost fish during a protocol survey. Throughout Washington, the uppermost-fish detected is most often a salmonid. In over 90% of cases the uppermost fish is a cutthroat trout *Oncorhynchus clarki* (D. Collins, Washington Department of Natural Resources, unpublished data). Other salmonid species that have been recorded at uppermost fish locations across Washington include rainbow trout *O. mykiss*, brook trout *Salvelinus fontinalis* (an invasive non-native that has become established in many Washington streams), and (rarely) bull trout *S. confluentus*. In headwater reaches that are accessible to anadromous fishes, coho salmon *O. kisutch* juveniles have been reported on occasion as the uppermost fish during protocol survey seasons (March 1st through July 15th). Of the non-salmonid species recorded at uppermost fish sites in western Washington, sculpins *Cottus* spp. were most prevalent, followed by brook lamprey *Lampetra* spp., and less commonly dace *Rhinichthys* spp., three-spine stickleback

Gasterosteus aculeatus, and Olympic mudminnow *Novumbra hubbsi*. The only uppermost non-salmonid fish species recorded in east-side Washington streams were sculpins.

Many factors determine the limits of distribution of fishes, including barriers to migration, stream gradient, flow/channel size, and food resources. Understanding the current science on these four factors is important prior to discussing how they can be used to most accurately define the upstream limits of fish distribution in forested streams of Washington State.

Barriers to Migration

Natural stream habitat breaks that might obstruct or completely block upstream fish movement to apparently suitable habitat include: vertical drops, steep cascades, bedrock sheets, and trench/chutes (Hawkins et al. 1993; Figure 1).

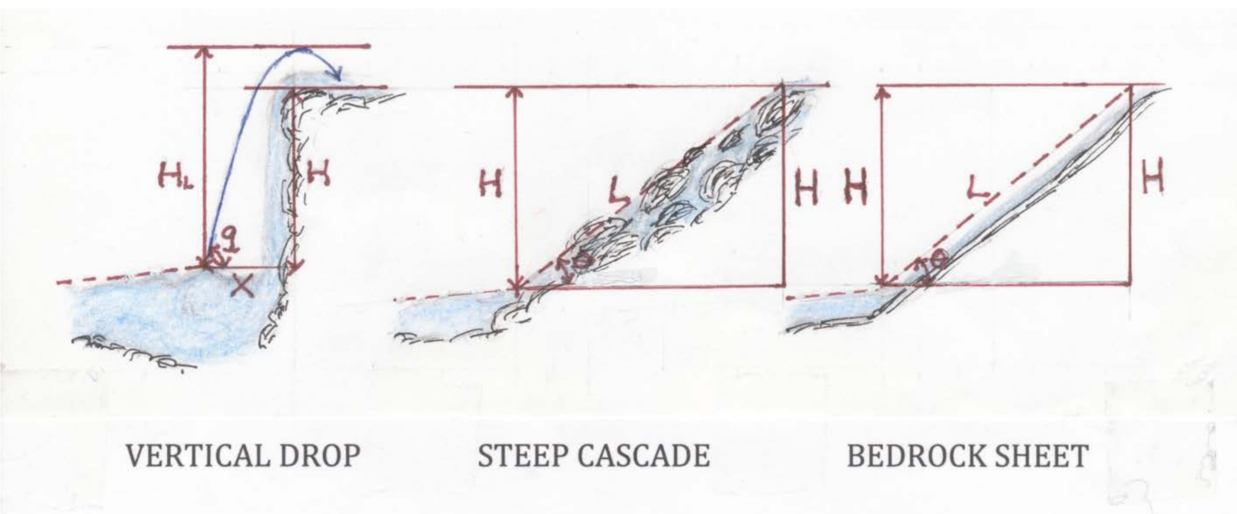

Figure 1. Three types of habitat that could pose obstacles or barriers to upstream movement of headwater fishes.

The ability of fishes to pass such obstacles is associated with their swimming and leaping abilities. The swimming ability of fishes is typically described in terms of cruising, prolonged, and burst speed, which are measured in units of body lengths per second (Watts 1974; Beamish 1978; Webb 1984; Bell 1991; Hammer 1995). Cruising speed is the speed a fish can sustain essentially indefinitely without fatigue or stress, usually 2–4 body lengths per second. Cruising speed is used during normal migration or movements through gentle currents or low gradient reaches. Prolonged speed (also called sustained speed) is the speed a fish can maintain for a period of several minutes to less than an hour before fatiguing; typically 4–7 body lengths per second. Prolonged swimming speed is used when a fish is confronted with more robust currents or moderate gradients. Burst speed is the speed a fish can maintain for only a few seconds without fatigue, typically 8–12 body lengths per second. Fish typically accelerate to burst speed when necessary to ascend the short, swiftest, steepest sections of a stream, to leap obstacles, or avoid predators.

Swimming ability is influenced by environmental factors such as temperature, ontogeny, and condition. Body form can also affect swimming ability, with more fusiform body shapes being advantageous for stronger burst speeds in fishes such as cutthroat and rainbow trout (Bisson et al. 1988; Hawkins and Quinn 1996) rather than other fishes.

When leaping obstacles, fish come out of the water at burst velocity and move in a parabolic trajectory (Powers and Orsborn 1985). Relationships for the height attained in the leap, and the horizontal distance traversed to the point of maximum height are often used to assess barriers. Depth at the point of takeoff is important for enabling fish to reach burst velocity. Stuart (1962) found water depth of at least 1.25 times the height of an obstacle to be required for successful upstream barrier passage. More recently, however, Kondratieff and Myrick (2006) reported that small brook trout (size range 100-150 mm) could jump vertical waterfalls as high as 4.7 times their body length from plunge pools only 0.78 times the obstacle height, and larger brook trout (size ranges 150-200 mm and 200 mm+) could jump waterfalls with heights 3 to 4 times their body length if the plunge pool depth was at least 0.54 times the obstacle height.

To successfully ascend 4.7 body lengths in height, a back-calculation from the Powers and Orsborn (1985) trajectory equation yields a burst speed of 22 body lengths per second (11.7 feet per second) for the 100-150 mm body-length brook trout reported by Kondratieff and Myrick (2006). If it is assumed that other salmonids (e.g., cutthroat, rainbow trout or coho salmon) could perform as well as brook trout in the size range typically found at uppermost fish locations in Washington (Sedell et al. 1982; Fransen et al. 1998; Liquori 2000; Latterell et al. 2003; Peterson et al. 2013), then a burst speed of 22 body lengths per second (11.7 feet per second) would allow the largest fishes in the size range typical of headwater-dwelling salmonids (160 mm) to leap a vertical obstacle 2.6 feet high, whereas a vertical obstacle of 3 feet high would be impassable.

When leaping is not required, fishes may ascend steep cascades and other high-velocity habitat units (Hawkins et al. 1993) by seeking pockets of slow water interspersed in areas with turbulent flow (e.g., boundary layers near rocks or logs). The average water velocity measured in cascade habitat units in small western Washington streams by Bisson et al. (1988) was only 24.8 ± 3.2 cm/s, or about 0.8 ft/s. Average water depth in these same cascades was 10.0 ± 1.4 cm, or about 4 inches. It is possible that fish may ascend streams during periods of elevated flow by moving along the channel margins where water velocities are reduced relative to mid-stream and small falls and boulder cascades are partially or completely submerged.

Although studies examining fish migration through potential non-vertical obstacles are rare, a small number of studies have examined brook trout movement through steep cascades and reported fish ascending cascades of more than 20% gradient (Moore et al. 1985; Adams et al. 2000; Björkelid 2005). For example, Adams et al. (2000) reported that adult brook trout ascended cascades with slopes of 13% that extended for more than 67 m, and 22% for more than 14 m as well as adult brook trout ascending a waterfall 1.2m high. Similarly, Björkelid (2005) reported invasive brook trout colonizing 18 headwater streams in Sweden and found they ascended stream segments of 22% measured with a clinometer and 31% measured with GIS.

Gradient

In Washington streams, fish (not necessarily the uppermost fish) have been observed in headwater segments with overall slopes as steep as 31% (S. Conroy, formerly Washington Trout [now Wild Fish Conservancy], unpublished data), 35% (J. Silver, Hoh Indian Tribe, unpublished data; D. Collins, Washington Department of Natural Resources, unpublished data), and in reach gradients of 25% and steeper in Oregon streams (C. Andrus, Oregon Department of Forestry, unpublished data; Connolly and Hall 1999). This range of channel steepness is consistent with other observations in western North America (e.g., Fausch 1989; Ziller 1992; Kruse et al. 1997; Watson and Hillman 1997; Dunham et al. 1999; Hastings et al. 2005; Bryant et al. 2004, 2007) and Europe (Huet 1959). In the "trout zones" of European rivers (headwaters), brown trout *Salmo trutta* predominate and reach gradients may be 10 to 25% or steeper (Huet 1959; Watson 1993). In Washington, it is important to note that fish presence in streams steeper than 15% accounted for only 10% of reported occurrences in forested streams (Cole et al. 2006; J. T. Light, Plum Creek Timber, unpublished data). However, these observations clearly establish that fish habitat in headwater streams extends into steep step-pool and cascade reach types (Montgomery and Buffington 1993).

In steep step-pool and cascade reaches, habitat use by fishes may be different from the pool-riffle reaches further downstream. For example, in streams of low to moderate gradient and well-developed pool-riffle sequences (Montgomery and Buffington 1993; 1997), gravels are usually relatively abundant. In steep, typically boulder-bed reaches where the uppermost fish are often found, pool-riffle sequences are generally absent, gravels are less abundant, and gravels that are present are confined to small patches around wood or rock; these patterns are distinctly different from lower gradient streams (Heede 1972; Kondolf et al. 1991). Often the water surface slopes where fish occur in step-pool habitats have much lower local gradients than the overall reach gradient and may range from only 0.4 to 4%, even where overall reach gradients may be as high as 35% (Kondolf et al. 1991; Figure 2).

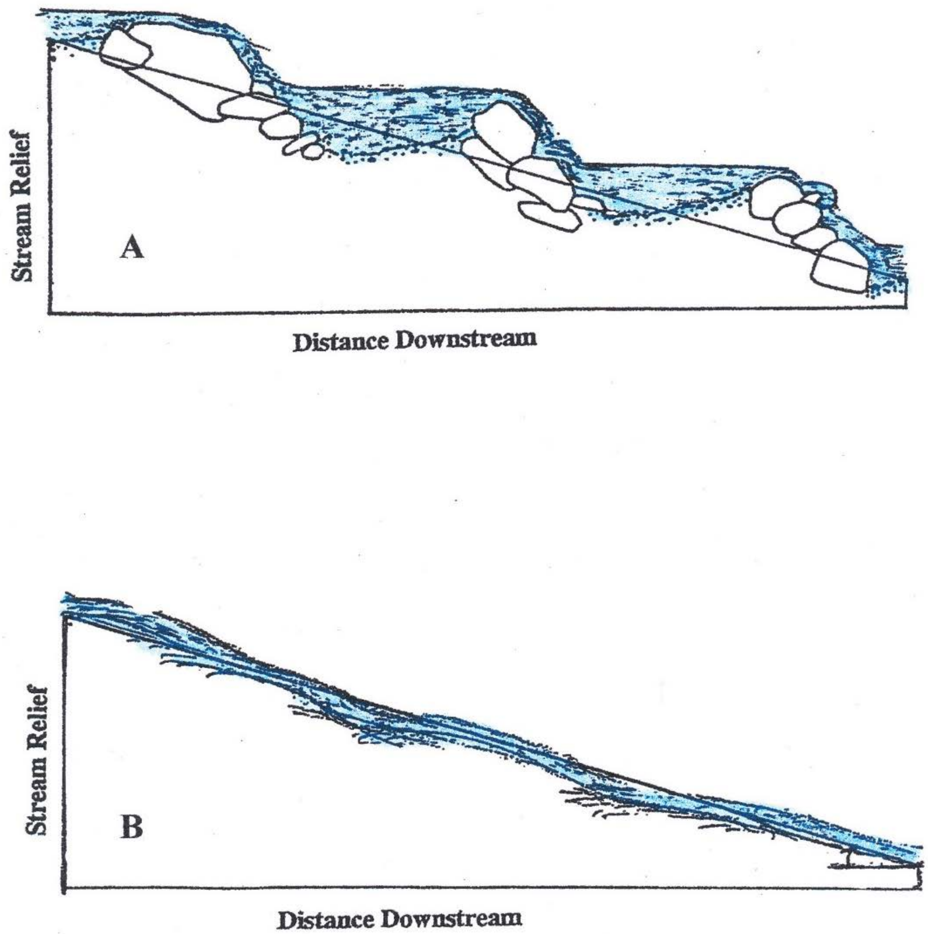

Figure 2. Two very different profiles of a headwater reach with the same overall reach gradient. Illustration (A) demonstrates how roughening elements create local gradients that are lower than the overall reach gradient, while reaches without such features (B) do not.

Flow and Channel Size

Bankfull width (BFW) is used to define the stage of discharge at which a stream does its habitat-building work (Andrews 1980; Leopold 1994; Rosgen 1996). Often BFW is used as a surrogate for stream discharge, which is important for determining the uppermost fish and extent of fish habitat (Harvey 1993). Fransen et al. (1998) estimated mean annual flow rates at the upstream extent of fish distribution for 79 streams in the western Cascade foothills and Willapa Hills and found that 90% of these streams had mean annual flows of 3.5 cfs (±0.1 m^3/s) or less at the upper bound; 80% had mean annual flows of 2 cfs (±0.06 m^3/s) or less at the upper bound; 65% had mean annual flows of 1 cfs (±0.03 m^3/s) or less at the upper bound; and approximately 25% of the sites had mean annual flows of 0.5 cfs (±0.01 m^3/s) or less at the upper bound (Figure 3).

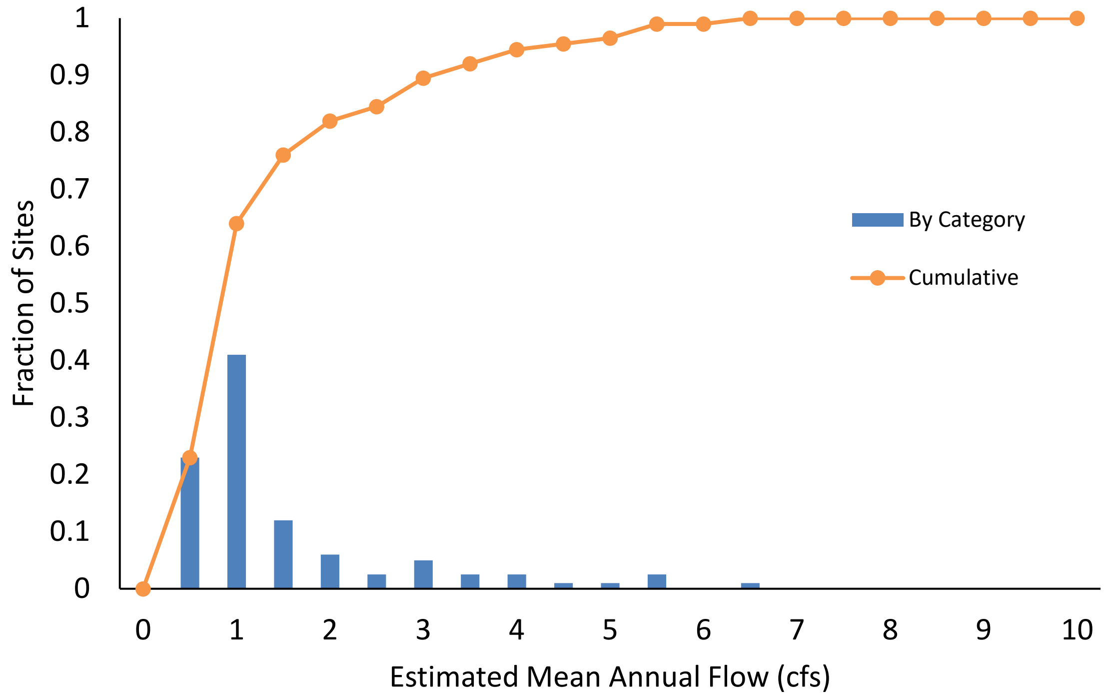

Figure 3. Estimated mean annual flows at uppermost fish locations in 79 streams in western Washington (Cascade foothills and Willapa Hills; Fransen et al. 1998).

The amount of drainage area required to generate a channel with a perennial source of water is not the same for all basins and varies with climate, geology, topography of the basin, and ecoregion (Montgomery 1999). For example, in coastal areas of Washington, perennial flow is often established in watersheds as small as 13 acres (5.3 ha), while the rest of western Washington needs a basin area of approximately 52 acres (21 ha) to establish perennial flow. Eastern Washington, on average, requires a basin area of approximately 300 acres (121.4 ha) to establish perennial flow (FFR 1999). Studies have shown that BFW is highly correlated with drainage area. For example, Beechie and Imaki (2014) developed an equation for BFW for Columbia Basin streams based on annual precipitation and catchment (drainage) area. Although their equation was developed for larger streams, we tested their equation using empirical BFW data from multiple smaller streams across Washington State and found that it accurately predicted BFW in headwater streams. This indicates that BFW serves as a good proxy for catchment/drainage area.

Food Resources

Many studies, particularly in Pacific Northwest streams, have demonstrated strong food limitations for fish inhabiting small streams (Warren et al. 1964; Mason 1976; Naiman and Sedell 1980; Bisson and Bilby 1998). Headwater segments are often characterized by closed forest canopies, requiring primary energy sources from allochthonous inputs of coarse particulate organic matter (CPOM). Shredder organisms occur in these reaches and feed on this CPOM. These aquatic organisms, along with any terrestrial invertebrates that fall into the stream, comprise the food base for trout and other predators (Vannote et al. 1980; Hawkins and Sedell 1981; Triska et al. 1982; Wipfli 1997). The total production of macroinvertebrate organisms is substantially lower in small headwater stream reaches than in the larger, lower-gradient reaches further downstream (Northcote and Hartmann 1988; Haggerty et al. 2004). As a result, resident fishes in headwater stream reaches tend to be small bodied, which limits their ability to negotiate obstacles to upstream movement and migration.

Fish Habitat Assessment Method (FHAM)

Water typing surveyors have used professional judgment to estimate “habitat likely to be used by fish” when proposing regulatory fish bearing/non-fish bearing water (F/N) breaks. Stream segments that are accessible to fish and exhibit the same characteristics to those of fish-bearing reaches are typically assumed to be fish habitat, whether or not fish are present at the time of a survey. Surveyors have assessed barriers and measurable changes in stream size and/or gradient to estimate the EOF habitat (Cupp 2002; Cole et al. 2006). Although research is somewhat limited, the upstream extent of fish distribution in forest lands appears to be strongly influenced by stream size, channel gradient, and access to suitable habitat (Fransen et al. 2006; PHB Science Panel 2018). In response to these findings, the Board adopted a methodology (FHAM) intended to be repeatable, implementable, and enforceable to establish the EOF habitat for a new water typing rule. The FHAM describes PHBs that reflect a change in the reach characteristics to approximate the EOF habitat and provide a suitable location to initiate a protocol electrofishing survey (Figure 4).

methodology (FHAM)

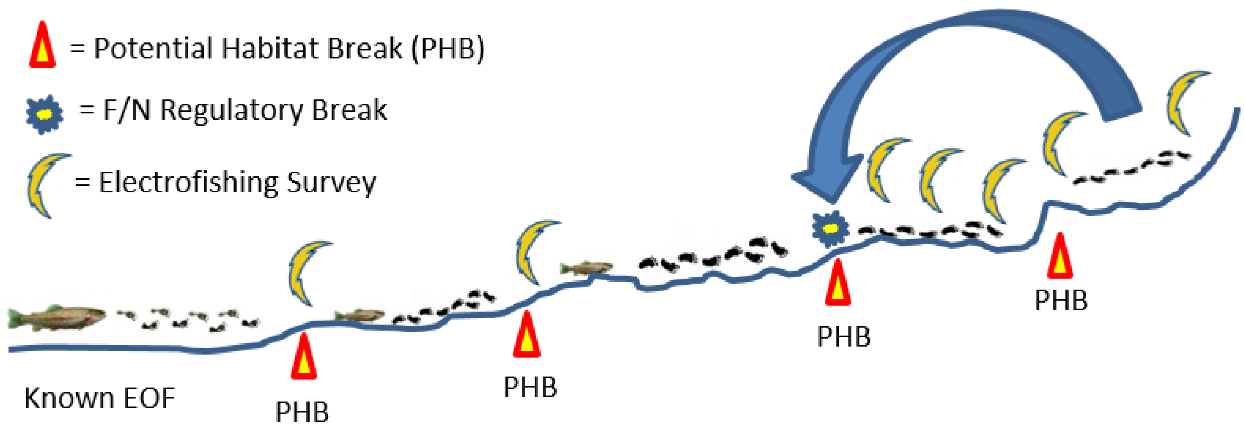

Figure 4. Example of how the PHB criteria and Fish Habitat Assessment Methodology (FHAM) are applied in the field. The first step is to identify the EOF (end of fish) location. Once the EOF is identified, the survey team would begin to measure bankfull width, gradient, and barrier (obstacle) criteria while moving upstream. Once a point in the stream meeting one of the PHB criterion (gradient, barrier, change in channel width) is identified, the survey team would apply a fish survey (e.g., electrofishing) upstream of the PHB to determine if fish are present upstream. If sampling yields no fish upstream to the next PHB, then the F/N break would occur at the location where the survey commenced (see arrow in the figure). If fish are encountered above any PHB, the process of measuring and moving upstream would repeat until fish are not encountered.

Currently, specific PHBs are based on stream size, gradient, and access to suitable habitat. Changes in these criteria are measured from the last known fish observation and again when the PHB criteria are met upstream of that location. The PHB Science Panel recently reviewed the available science and data on PHBs and provided recommendations to the Board for specific PHB criteria for eastern and western Washington (PHB Science Panel 2018). In developing our recommendations, we considered a variety of potential PHB attributes, including the physical features of a stream channel, water quality and quantity parameters, and other factors that might contribute to measurable habitat breaks. These attributes were evaluated in terms of their simplicity, objectivity, accuracy, and repeatability in the field, as well as the amount and relevance of existing scientific literature pertaining to each attribute. We concluded that it is possible to identify PHBs based on stream size, channel gradient, and non-permanent deformable (obstacles) and permanent natural barriers. These three attributes satisfied the objectives of simplicity, objectivity, accuracy, ease of measure, and repeatability, can be consistently identified in the field, and can be incorporated into a practical survey protocol. Based on available data, we provided recommendations for PHB criteria based on stream size, channel gradient, and permanent natural barriers. The Board then selected three potential combinations of criteria at their 14 February 2018 meeting and instructed the PHB Science Panel to develop a field study to evaluate the performance of PHBs used in FHAM to identify the appropriate locations for regulatory breaks between Type F and Type N waters (Table 1). It was important to the Board to determine which criteria most reliably identify PHBs in eastern and western Washington. The Board also instructed the Science Panel to stratify sampling by ecoregion and to examine crew variability in identifying PHBs.

Table 1. Three combinations of barrier, gradient, and width PHBs selected for evaluation by the Washington Forest Practices Board.

Type	Description of criteria
	Criteria 1
Barrier	Gradient >20%, and barrier elevation difference is greater than BFW
Gradient	10% gradient threshold (Upstream Grad>10% and downstream Grad<10%)
Width	2 ft upstream threshold (Upstream BFW <2ft)
	Criteria 2
Barrier	Gradient >30%, and barrier elevation difference is greater than twice BFW
Gradient	Gradient difference >= 5% (upstream grad - downstream grad >=5) and Downstream gradient >10%
Width	2 ft upstream threshold (Upstream BFW <2ft)
	Criteria 3
Barrier	Gradient >20%, and barrier elevation difference is greater than BFW
Gradient	Gradient difference >= 5% (upstream grad - downstream grad >=5)
Width	20% loss in width. Upstream to downstream width ratio <=.8

Study Purpose

The purpose of this study is to evaluate the PHB criteria selected by the Board to be used in FHAM as part of a water typing rule and explore potentially useful attributes that may help to more accurately describe PHB (Table 1). It is designed to identify PHB criteria that can be used to capture EOF habitat in forested streams across Washington and to better understand how PHBs may be influenced by seasonal and annual variability and by location within Washington State (e.g., reduce uncertainty). The overall goal is to test the reliability of PHB criteria as an aid in identifying EOF habitat in an objective and repeatable manner[1].

It is important to note that this study is not intended to evaluate the water typing system, the FHAM, or describe how the regulatory Type F/N break should be determined. Other factors such as temperature, flow, water quality, and biological interactions are important covariates that influence the distribution of fishes but do not affect PHBs. Therefore, they are not included in this study.

Study Questions

This study is designed to answer the following questions:

- Do the PHB criteria accepted by the Washington Forest Practices Board accurately capture the EOF?
- Based on data collected, what is the most accurate combination of metrics for determining PHB by region or ecoregion?
- Are there differences in PHB criteria by Environmental Protection Agency (EPA) Level III ecoregion, eastern vs western Washington, or some other geographic or landscape strata?
- Are there additional variables (e.g., geology, drainage area, valley width, land use, channel type, and stand age) that could improve the accuracy of existing criteria?
- Would adding additional thresholds to criteria improve PHB identification?
- What is the influence of season/timing of survey on PHB identification?

[1] While the study will gather considerable information on fish distribution, it is not a long-term (>25 years) study on the upper limits of fish distribution per se.

- What is the typical inter-annual variability in EOF and PHBs?
- Can protocols used to describe PHB be consistently applied among survey crews and be expected to provide similar results in practice?

Answering these questions requires identifying the EOF and surveying habitat above and below these points in a random representative sample of streams across the state.

Methods

Study Design

We propose to determine the end of fish use at 245 sites in forested watersheds of EPA Level III ecoregions across Washington State and measure the habitat characteristics (gradient, channel width, barriers) using a long-profile survey 200 m above and 100 m below the EOF. These surveys will provide the data necessary to evaluate differences among PHB criteria across ecoregions. Based on variability in the data examined from existing water type modification forms (WTMFs) that includes information on gradient, channel width, and barriers, we estimate that a sample size of 35 sites per ecoregion will be needed to determine if there are differences among ecoregions. Sample sizes were estimated from data on upstream and downstream changes in gradient surrounding end of fish points for the “Coast Range” ecoregion. We felt these data, which were collected using similar methods, accurately represent the variability we will encounter during the proposed PHB study. Because the data showed a non-parametric distribution, we estimated minimum sample sizes for each ecoregion using three approaches: power estimates for t-tests, samples required to estimate the mean, and a bootstrapping routine to estimate samples for non-parametric tests (Wilcoxon and Kolmogorov-Smirnov). All three methods suggested that a sample size of approximately 35 or more sites was needed to detect differences among ecoregions (See Appendix A for details). We would expect that data collected with consistent methods and crews would have lower variability than the WTMF data we used to estimate sample size. This was supported from data collected under the pilot study, which had lower variance around gradient and change in gradient seen than the WTMF data and suggested a sample size of 35 sites per ecoregion was appropriate.

Existing water type modification (WTM) data show geographic differences in the PHB criteria and F/N breaks for gradient, channel width, and barriers between eastern and western Washington and in some cases ecoregions. Ecoregions are defined by unique combinations of variables such as geology, climate, landforms, and vegetation that can be clustered geographically, reflecting ecosystem conditions (Omernik 1987)[2]. While there are nine EPA Level III ecoregions in Washington State, the Columbia Plateau ecoregion has little forest cover and only a small portion the Willamette ecoregion is in Washington State, leaving seven ecoregions in our proposed study.

Site Identification

The DNR database includes data layers of all modeled F/N breaks for all streams in the state of Washington as well as more than 28,000 points where a WTMF was submitted to modify the water type. The modeled F/N breaks include hundreds of thousands of potential breaks across the landscape. However, it is currently unclear whether these points are accessible or how accurate they are in terms of above and below end of fish. For our study, this uncertainty creates many logistical issues for field crews (e.g., land ownership, access points, roads) that could make field sampling of these points extremely costly. Moreover, more than a thousand water type modifications are submitted every year to correct modeled F/N breaks and DNR water type maps. The DNR's water typing database contains over 28,000 stream location points that have been visited over the past 15 years to establish the F/N regulatory break on state, private, and in some cases, federal lands. We propose to select a stratified random sample of these points to choose sites for this study. These sites have verified F/N breaks and information that in some cases includes monumented benchmarks in the field identifying specifically where the EOF fish was detected on a particular date. We propose to revisit these sites annually for three years to clarify how EOF may change over short (months to 3 years) and long-time periods (> 3 years) and under a variety of physical disturbances and weather conditions. While the WTMFs will be used to help

[2] We considered other finer scale stratification (e.g., geology, channel type, elevation, valley confinement), but these were not logistically feasible and would greatly increase the sample size, cost and time needed to complete the study. The Washington Forest Practices Board also instructed the PHB Science Panel to develop a study plan that specifically included stratification by ecoregion.

screen potential sites, the habitat data in the WTMFs have been shown to be inconsistently collected and not usable for this study.

Our goal is to sample 35 randomly selected suitable sites annually in each ecoregion over the course of this 3-year study (Figure 4). We suspect that many randomly drawn WTM points will not be suitable for this study for a variety of reasons, including problems associated with access (e.g., landownership, road failures, etc.), manmade barriers, non-fish bearing streams, potential upstream source populations, or active timber harvest activities near the riparian management zone. We will randomly select a group of 100 WTM points in each region to be used in a consecutive sampling frame (See Appendix B).

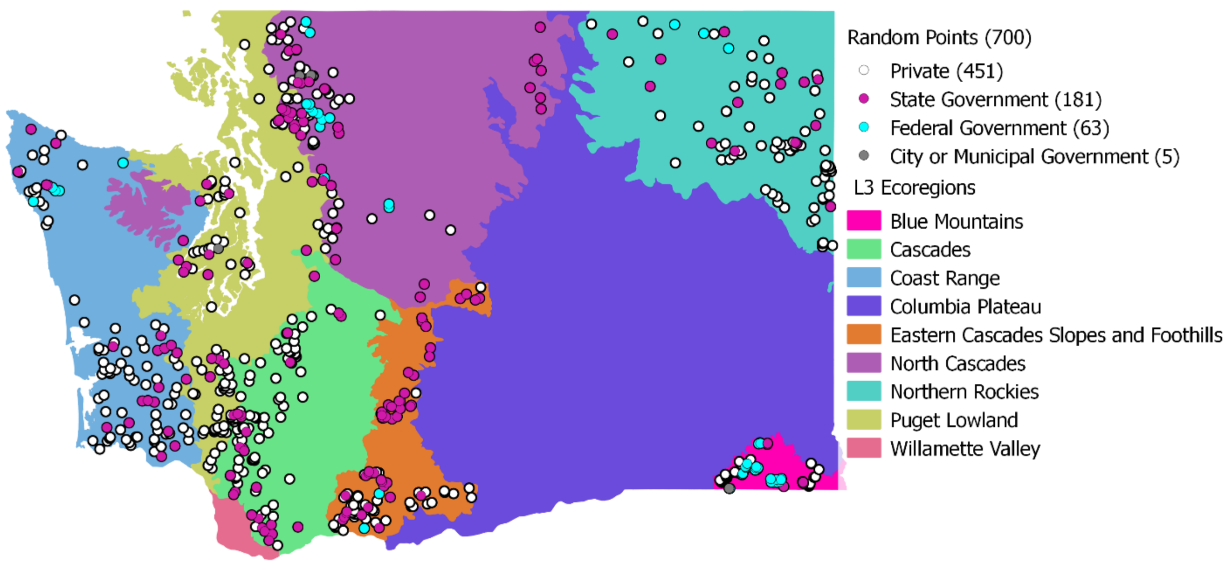

Figure 4. Randomly drawn potential F/N breaks from existing Water Type Modification Forms (WTMF) for inclusion in study. There are 100 random points for each of the Environmental Protection Agency Level III ecoregions. The Columbia Plateau and Willamette Valley were excluded due to lack of forest cover.

Prior to sampling, each of the 100 randomly selected sites will be numbered from 1 to 100. The first 35 suitable sites in each ecoregion will be selected as potential sample sites. Each site will be scouted prior to the sampling season to determine if the site is appropriate for a complete field study. If a site fails to meet the criteria we describe above, the scout will choose the next site identified in the sample pool and perform the same survey. Once we have identified the pool of 35 suitable sites, field crews will perform the full field survey. If sites do not meet our criteria, we will document why sites were excluded and the rationale for their exclusion. Our experience with studies of this nature suggests that more than one third of all sites will not be suitable. If less than 35 suitable sites are identified from our initial random sample of 100 sites, we will draw another random sample of 25 sites from the DNR database and evaluate these sites with a similar process until we locate 35 suitable sites.

Sampling Frequency and Season

All sites will be sampled every year during spring to early summer (current protocol electrofishing survey window of Mar 1 to July 15) for three years to examine inter-annual changes in EOF. In addition, one third of all sites will be resampled each year during summer low flow (July 16 to September 30) and fall to early winter (October 1 to December 31) (Table 2) to evaluate seasonal changes in EOF. Winter sampling would also be beneficial, but because of snow and access issues, it will not be feasible at most locations. Seasonal sampling sites will be randomly selected from the 245 sites for each year across ecoregions. All sites will receive summer and fall sampling in at least one year. In addition, 60 randomly selected sites will be sampled seasonally in all three years (30 east and 30 west) to allow examination of seasonal variation through time (Table 2).

Protocol Electrofishing and Habitat Surveys

Prior to sampling a site, crews will review existing information from the WTMF on access, previous location of EOF and habitat data, and obtain landowner permission for access and sampling. Field crews will use DNR protocol electrofishing surveys to determine EOF (DNR 2002)[3] (Figure 5a). The GPS coordinates of each EOF location will be recorded, and the location will be flagged and monumented with a marker including the survey date on an adjacent tree. The fish

[3] This includes electrofishing ¼ mile above the last known fish location to ensure that no fish are found above this point, as well as confirming there is no “perched habitat” or ponds or lakes containing fish above this point. In many cases, due to the size of these streams, ¼ mile extends to perennial flow initiation and the end of an actual stream channel.

species and approximate sizes will be recorded. The crew will measure 100 m downstream using a tape measure or hip-chain to determine the beginning point for the stream habitat survey.

Table 2. Overall sampling schedule by calendar year and season 2018 to 2022. All sites will be sampled in spring to early summer (March 1 to July 15) with 1/3 of sites each year being resampled in late summer (July 16 to September 30) and fall to early winter (October 1 to December 31). A pilot study sampling 27 sites in eastern (15 sites) and western Washington (12 sites) was completed in September 2018.

	Number of Sites Sampled				
Sampling Event	Pilot year (2018)	Year 1 (2019)	Year 2 (2020)	Year 3 (2021)	Year 4 (2022)
Spring to early summer		245 (35/ecoregion)	245 (35/ecoregion)	245 (35/ecoregion)	NA
Summer low-flow	27 to test methods	82 (1/3)	142 (60 same as year 1; plus 1/3, 82 sites)	142 (60 same as year 1; plus 1/3, 82 sites)	NA
Fall to early winter (same sites as summer sampling)		82 (1/3)	142 (60 same as year 1; plus 1/3, 82 sites)	142 (60 same as year 1; plus 1/3, 82 sites)	NA
Reporting	Pilot study report	Annual report	Annual Report	Annual Report	Final Report

Water temperature, conductivity, and electrofishing setting (e.g., voltage, frequency, pulse width) will be recorded at the beginning of each electrofishing survey. We will also record electrofishing survey time. A previous study of variability on the upper limits of fish distribution in headwater streams suggested that over 90% of the interannual variation in the EOF location occurred in less than 200 m upstream and downstream of an EOF location (Cole et al. 2006).

A longitudinal thalweg profile survey will be used to survey gradient, bankfull and wetted width, depth, stream bed elevation, habitat type, presence of large wood, substrate, and any steps or potential fish migration barriers 100 m below and 200 m above EOF (Figure 5b). While a thalweg distance of 20 times bankfull width is typically surveyed to adequately define habitat (Harrelson et al. 1994; Rosgen 1994), this may not provide an adequate sample reach in small streams (<2 m wide). Instead we will use a distance of 200 m above and 100 m below the EOF. This approach involves surveying the streambed elevation along the deepest portion of the stream (the thalweg), yielding a two-dimensional longitudinal profile of streambed elevations and has been shown to be a reliable and consistent method for measuring change in stream morphology and fish habitat independent of flow (Mossop and Bradford 2006). The survey is designed to capture changes in bed topography and habitat types by surveying more points in reaches that have more variable bed morphology. Rather than fixed distances, inflection points in topography are surveyed to capture changes in thalweg topography and gradient. Typically, 40 or more locations along the thalweg will be measured to adequately capture topographic changes within a 100-m reach. A laser range finder mounted on a monopod and a target on a second monopod will be used to collect distance and elevation data. All data will be entered into a computer tablet in the field. Measurements at each point will include depth, wetted widths, bankfull width, substrate size (i.e., boulder, cobble, gravel, sand, or less than sand), and habitat type (i.e., cascade, riffle, glide, or pool). Pools will be defined by minimum size and residual pool depth criteria (Pleus et al. 1999). All points or inflection points that meet the PHB criteria determined by the Board will be noted. For steps and potential migration barriers, the crew will record whether the step is formed by wood, bedrock, or another substrate. The presence of wood is particularly important because wood-formed barriers are considered deformable barriers and are not PHBs. Crews will also note whether flow is continuous or intermittent, the presence of beaver dams, groundwater inputs, and any other unusual features that could influence fish distribution. Because sites will generally be in small constrained streams that are unlikely to change significantly throughout the sampling year, it is likely that the habitat survey data for each stream will only need to be collected once each year. However, if the EOF point moves significantly (>20 m) from one season to the next, the survey will be repeated to assure we have a complete survey 200 m above and 100 m below the EOF found during each sampling event (Figure 5b; Figure 6). A similar protocol based on Mossop and Bradford (2006) has been used to survey barrier removal projects on small streams throughout the Columbia River Basin (See Appendix C for example of field protocol and data sheet) (https://www.monitoringresources.org/Document/Method/Details/4075). Water temperature to the nearest 0.1 °C, and conductivity (micro-Seimens) will also be recorded at the beginning and end of each electrofishing survey.

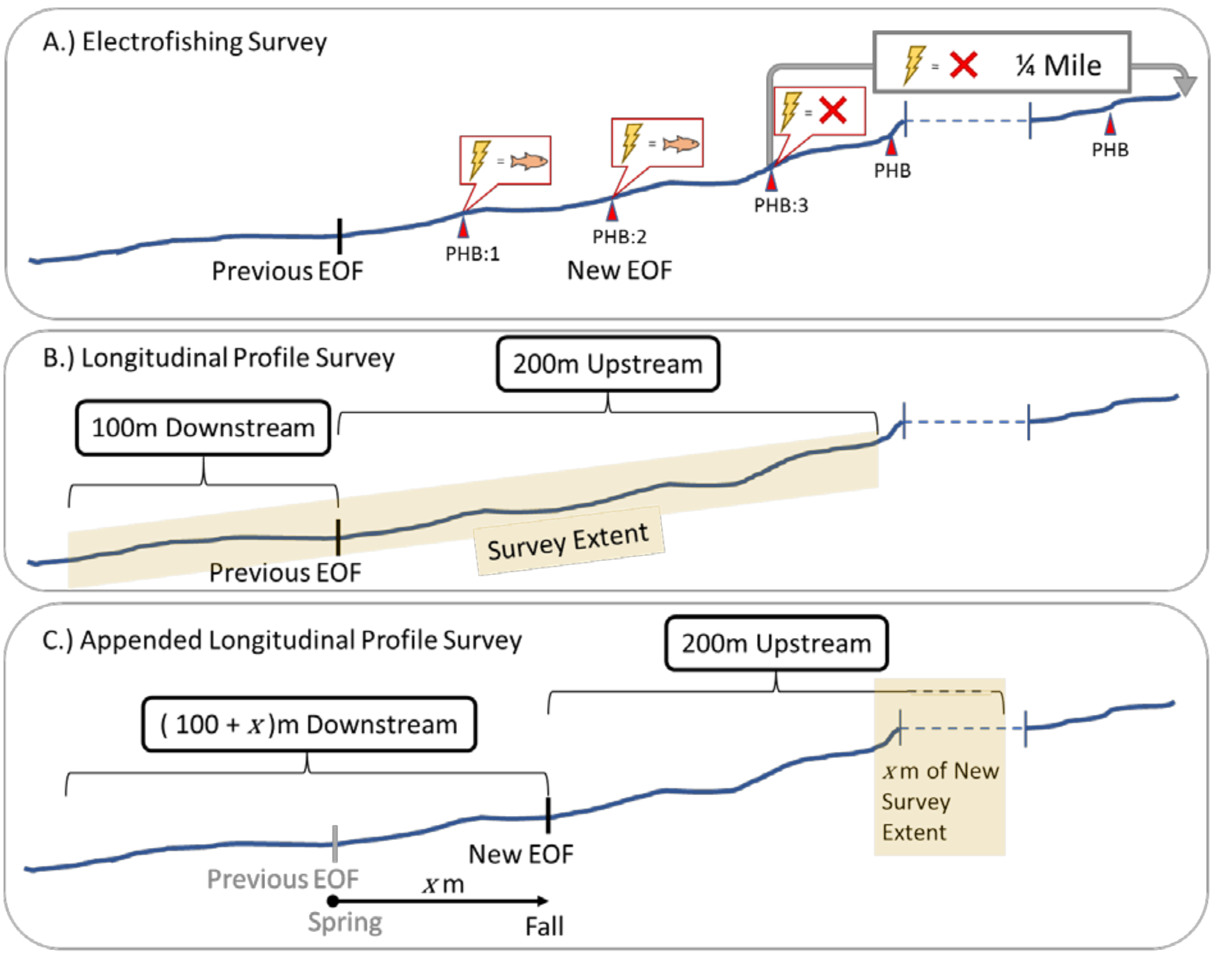

Figure 5. Components of field surveys demonstrating extents of protocol electrofishing survey to determine end of fish (EOF) (A), the initial longitudinal profile habitat survey (B), and example of how longitudinal profile survey would be appended if follow up protocol electrofishing surveys show that the EOF has moved (C).

Evaluations of various regional stream habitat survey protocols have demonstrated that with well-trained field crews, measurement error is small relative to naturally occurring variability and that due to differences among sites (Kershner et al. 2002; Roper et al. 2002; Whitacre et al. 2007). Therefore, all crews will participate in a three to five-day training course each year prior to initiation of spring sampling to assure consistency among crews in determining EOF, surveying habitat features (long-profiles), and data collection. Moreover, to quantify variability among crews in conducting longitudinal surveys, we propose that 10% of all sites sampled each spring should be resampled by other crews every year (i.e., 10% of the sites will have three replicate surveys). Because the longitudinal profile will not vary by flow, we assume that variability among crews will be minimal.

Additional Information Collected (Explanatory Variables)

We will also collect data on several other factors that are thought to play a role in EOF and identification of PHBs. These include: elevation, aspect, drainage area, valley width, geology, channel type, stand age, time since harvest, whether EOF and PHB is at a mid-channel point (mainstem or terminal) or confluence (tributary or lateral tributary), dominant drainage area geology, and whether a stream is accessible to anadromous fish or only resident fish. Many of these variables will be derived from existing GIS data layers. Drainage area and valley width are important because they are proxies for stream size, while other explanatory variables are other potential methods to stratify PHBs. While it is not initially possible to stratify site selection by these variables, they provide important information that may help explain differences in EOF and PHBs within and among ecoregions.

Data Analyses

The protocol electrofishing and habitat survey provides a rich data set to help inform and validate potential PHB definitions. The data, summarized in Figure 6, include measurements of elevation, channel width, substrate, habitat unit type, and the EOF and F/N points.

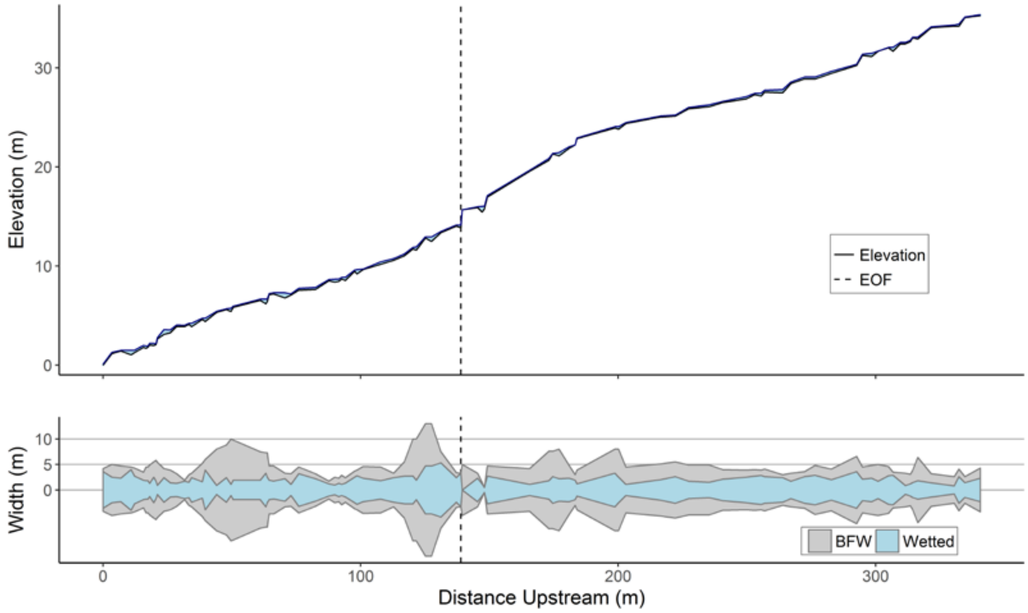

Figure 6. Example of long-profile from a western Washington PHB pilot study site showing stream bed elevation, water surface elevation, bankfull width (BFW), and wetted width (lower panel of each figure) along the surveyed stream thalweg. Additional data collected but not shown include substrate, habitat type (pool, riffle/cascade)>

For each surveyed point, we will test where the F/N break (first PHB encountered above EOF) would be located under various recommended PHB definitions. We will use the longitudinal profile from each surveyed reach to evaluate changes in gradient and channel width. Reach gradient will be calculated using a moving window approach that evaluates gradient over a specific length such as 20 bankfull channel widths (DNR 2004). In this way, any changes in physical conditions upstream and downstream of the EOF point are scaled to the size of the channel.

Beginning at the EOF point, the moving window will be used to examine the upstream and downstream gradient and width (as well as other possible factors as determined by PHB recommendations) to determine if these conditions meet the definition for a PHB according to various sets of recommendations (Figure 7). For each set of PHB recommendations, it is important that the first PHB encountered as the window moves upstream is identified under that set of recommendations.

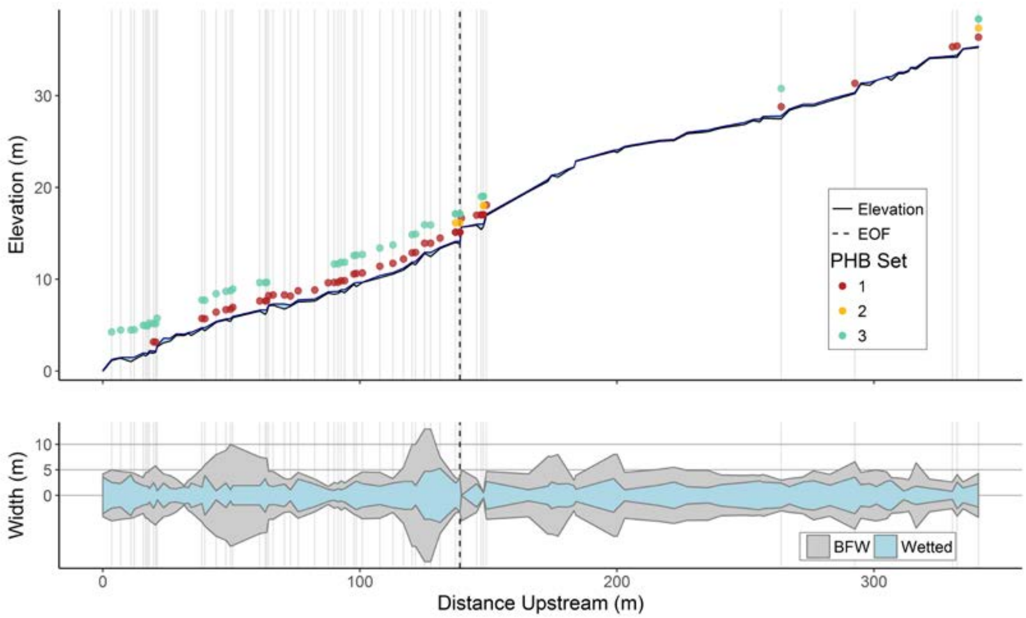

Figure 7: Example of frequency of PHB occurrence along stream profile upstream from end of fish (EOF) for different PHB recommendations (Y axis) for a PHB pilot study site in western Washington.

Finally, the first PHB identified from determined by the PHB recommendation set, will be compared to the EOF location determined by the survey crew, to estimate the distance to the first PHB identified upstream for each set of PHB recommendations. We will calculate this distance for each recommendation set and create density plots (histograms) for the distribution of distances from EOF (Figure 8). Tests of central tendency (T-tests, Wilcoxon rank-sum tests, ANOVA) will be used to analyze the mean response between the different PHB recommendations, while distribution tests (i.e. Kolmogorov-Smirnov) will be used to analyze the variance and overall shape of the response (Table 3). Comparing and analyzing these distributions by ecoregion will help determine how different PHB recommendations will play out across the state, and to see if there is consistent bias in how these recommendations would place F/N breaks across ecoregions.

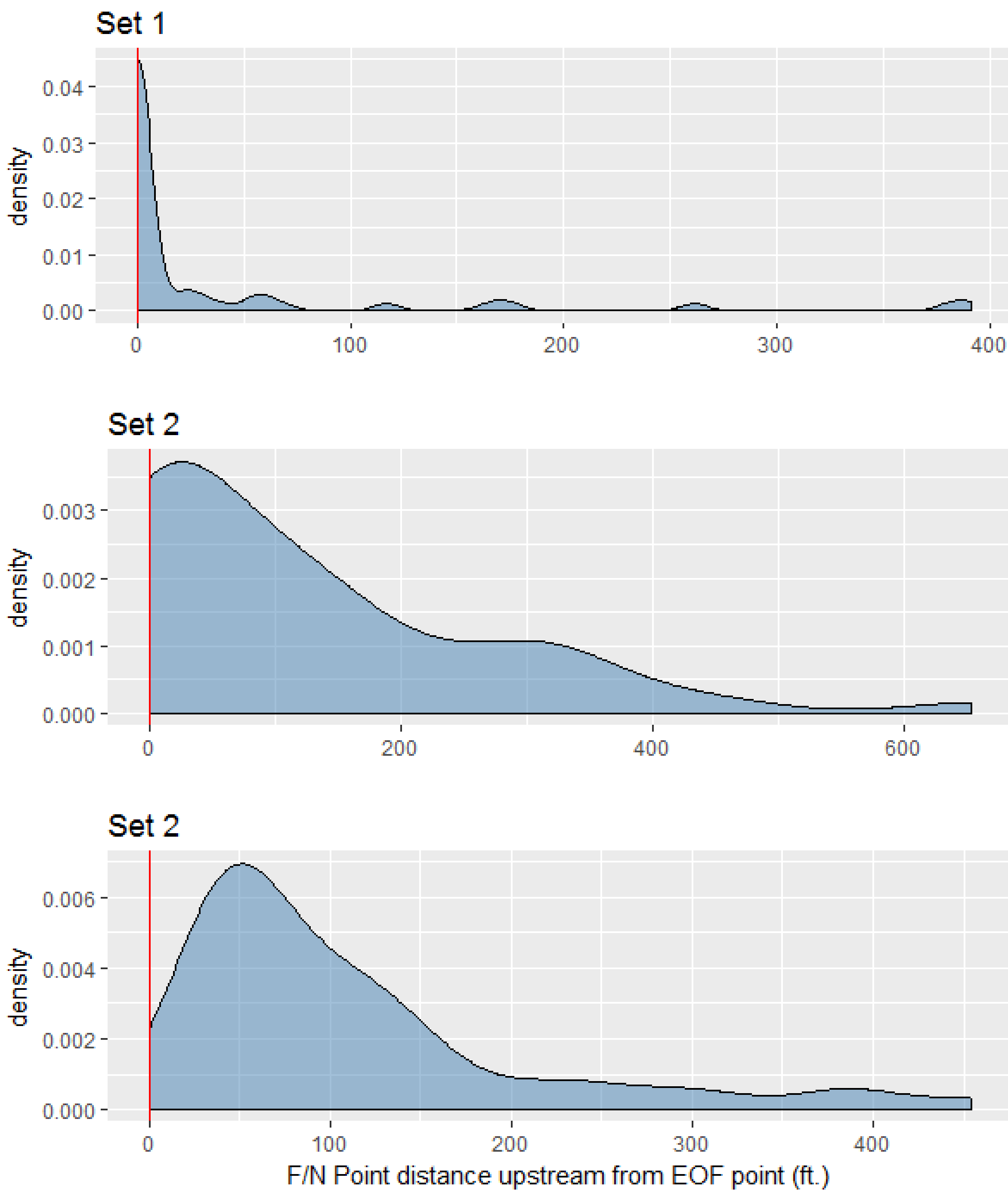

Figure 8. Example of density plots (histograms) for the distribution of distances from EOF that will be used to examine three different sets of PHB criteria. The above density plots or histograms demonstrate how far upstream of the EOF the F/N break would be placed for each set of criteria.

The additional information (e.g., elevation, aspect, drainage area, valley width, geology, channel type, stand age, time since harvest) collected with surveys will be analyzed with random forest models to see if there is additional explanatory power obtained by using a suite of these factors in the analysis. Random forests models offer several benefits: they work with non-parametric data without transformations, they work well with correlated variables, and they bin continuous data into discrete categories as part of the analysis, as opposed to arbitrary bins assigned *a priori*. Moreover, since most of the explanatory variables are additional strata to consider and random forests bin data, it is well suited for the suite of explanatory variables we are examining. Once factors are selected, we will test for significant differences in F/N break placement similar to the ecoregion analysis. Other exploratory tools like covariate analysis and biplots will be used to determine whether additional factors should be considered for inclusion in PHB determinations. This process is iterative, with a new round of analysis occurring for each set of proposed PHB definitions.

A final objective of the study is to assess crew variability when applying protocol and surveys. Given sample size and time required to collect data, at least three crews will be needed to collect data. As noted previously, 10% of sites will be surveyed by all crews. To test crew variability, we will compare longitudinal profiles collected by the crews to compare among crews the total number of PHBs identified and the distance of PHBS from EOF using an ANOVA or mixed effects model (Table 3).

Table 3. Description of data analyses procedures and statistical methods that will be used to analyze data and answer key study questions.

Analysis	Framework
Locate PHBs on measured streams	Moving window determined by BFW to evaluate gradient and width along the collected long profile data.
Determine how frequently PHBs are located at the EOF point	Summarize the first PHB encountered on each stream, and bin PHBs within 5 and 10 m of EOF.

Compare PHB placements between definitions	• Use first PHB upstream from EOF to calculate distance from EOF. • Statistical summaries and visual comparisons of bar-plots, box and whisker plots, and Kernel density functions. • Central tendency tests (T-tests, ANOVA). • Distributions tests (KS tests and their derivatives Anderson-Darling and the Cramer Von-Mises Test).
Compare PHB placement across ecoregions for each definition	As above but analyzing distributions of each definition set separately across ecoregions.
Tests for year and season effect	• Statistical summaries and visual comparisons of EOF location change, and the distance to the first upstream PHB. • T-tests, ANOVA, and GLMs depending on the number of repeat samples/current stage of study. •
Consider additional Strata	Random Forest modeling • Highlight variables of importance under each definition set and compare. • Determine if there are consistent parameters/strata associated with extreme values.
Refine definitions to improve consistency	• Identify factors that affect outliers, and important parameters from the Random Forest Modeling. Additional exploratory analysis using biplots, covariate analysis, etc. • Consider and test appropriate hierarchical factors in PHB definitions. For example, Definition 1a may apply to streams with elevations less than some threshold α, and Definition 1b would apply to streams with elevations greater than α. • Test to see if modifications to the PHB definitions produce more consistent results. Rerun the analyses using the revised definitions to test effects.
Assess crew variability when applying survey protocol	Compare long profile data and resulting PHB placement among streams surveyed by multiple crews. Analyze the number of PHBs found, as well as the distance to PHBs upstream from the EOF point • ANOVA / Mixed effect models to test differences between crews.

Exploratory tools like covariate analysis and biplots will be used to determine whether additional factors should be considered for inclusion in PHB determination. Similar to the ecoregion analysis, we will also test for significant differences in PHB break placement by categories based on geology (lithology), elevation band, aspect, and other factors.

Potential Challenges

Although the methods we propose have been widely used to quantify habitat conditions and identify EOF, there are some potential challenges. These include location of suitable sites, access to initially identified sites, and access to sites throughout the year. First, we assume that because we are using points with existing WTMF data, the sites will be accessible and that EOF will be within an area covered by the WTMF. It is possible that we may not have access to chosen sample sites due to changes in land ownership, landowner willingness, or changes in the road networks. Thus, if a site is not suitable due to access or other reasons (e.g., entire stream is Type F, stream is dry during wet season, or other reasons) a different site (the next consecutive site number from the initial random selection) would be used to replace the non-suitable site. We expect the random sample of 100 sites per ecoregion will allow us to select the 35 sites needed to satisfy the sample size requirement. A more challenging scenario would be if accessibility changes between or among seasons and years. For example, forest fires, heavy early or late snow, or road failures could affect repeat surveys at a site. In such cases, we would continue to sample sites during other seasons and years when possible. However, with 245 sites statewide, even if a handful of sites cannot be sampled as scheduled, we feel that there will still be a large enough sample size per ecoregion, in eastern and western Washington, and statewide to adequately evaluate different PHB criteria.

The first challenge will be largely financial and could result from underestimating or overestimated the amount of time and cost needed to adequately sample sites initially and repeatedly. Similarly, we need to ensure that the data collected will allow us to answer the PHB study questions. To successfully conduct such a large multi-year study as this, it is critical to implement a feasibility study to confirm the time and cost needed to sample each site and to assess the feasibility and performance of the protocols. To proactively assess these critical uncertainties, we conducted a pilot (feasibility) study in August of 2018 to test and refine protocols, confirm the time needed to collect data at a site, and examine the feasibility of collecting data on bankfull depth, width:depth ratio, large wood, evidence of hyporheic/groundwater sources, lithology, and other potential explanatory variables related to instream habitat and stream type. The pilot study included conducting longitudinal thalweg profile surveys upstream and downstream of known end-of-fish (EOF) points at 27 sites on private, state, and federal forest lands in western and eastern Washington. The analysis of longitudinal survey data from the pilot study demonstrated that PHBs based on gradient, BFW, and obstacles being examined by the Board could be easily determined from the survey data. The field surveys helped identify several modifications to the initial proposed protocol that are needed to assure the proposed and other potential PHBs can be easily identified (e.g., spacing of the survey points, habitat types, minimum habitat length, and substrate categories). It also provided important information on time needed to conduct surveys, which we have incorporated into the study plan and estimated cost to conduct the full validation study.

Another challenge is that this study does not address long-term changes in small streams that may render them unsuitable for fish occupancy, or conversely, may render previously unsuitable streams habitable for fish. At any point in time, some headwater streams are not used by fish during any season of the year due to a blockage to invasion or to unfavorable physical conditions (e.g., gradient) in the channel itself. Factors that determine whether small streams can be used by fish are typically related to disturbances such as exceptionally high discharge, landslides, debris flows, and windstorms. Such episodic disturbances are erratic and can be widely spaced in time (decades to centuries), but their overall effect in drainage systems is to create a mosaic of streams suitable for fish occupancy that changes over long intervals (often hundreds of years) in response to local disturbance regimes (Penaluna et al. 2018). An important implication of the notion that the potential use of small tributaries by fish can change over time is that while some tributaries are not now occupied by fish, there is no guarantee that they may not become suitable in the future, or that tributary streams which are currently habitable will always remain so. This study, however, does not address the expansion and contraction of fish habitat over long time intervals because the methods cannot predict with certainty where and in what form large disturbances capable of transforming a stream segment's ability to support fish will occur.

Expected Results and Additional Studies

Highly precise measurements of stream channel conditions both upstream and downstream of EOF locations will provide a nearly continuous dataset of physical features (PHB) that have the potential to inhibit fish movement. Thus, we will be able to objectively identify the PHB criteria most closely associated with EOF and the next upstream PHB. We expect that the study will validate the PHB criteria for gradient, channel width, and barriers that are most frequently associated with EOF. In addition, we are confident the methods will test the different PHB criteria under consideration by the Board in 2018. Seasonal and inter-annual sampling will allow us to examine the variation of EOF across years and seasons, which will help identify PHBs that consistently mark EOF across years, seasons, and flow conditions. Because we will be using sites for which a WTMF exists and EOF was potentially identified, examining longer-term inter-annual variation in EOF may be possible for a subset of sites where EOF has been previously identified and monumented. In addition, the 245 sites used in this study could be revisited several years from now to look at longer term changes in EOF if desired.

Ultimately, our analysis should provide information to the Board related to the mean distance from EOF for different PHB criteria being examined, how that differs among years and seasons and whether one set of criteria performs better in terms of consistently identifying EOF habitat and EOF across seasons and years, and whether different PHB criteria should be applied for different ecoregions or should be stratified by other factors. While the focus of the study is to test the three different sets of PHB criteria being examined by the board, we expect that our analyses will help identify other criteria that might more consistently capture EOF and EOF habitat. Finally, our results should also help inform the protocols for measuring gradient, bankfull width, and obstacles in the field to minimize variability among field crews and assure consistent identification of PHBs.

Included in the current budget is a collaborative complementary study with the U.S. Forest Service to compare environmental DNA (eDNA) and electrofishing to identify fish habitat.

Environmental DNA is a rapidly evolving and promising technique for identifying presence of species based on presence of their DNA in water sample (Rees et al. 2014; Jane et al. 2015). Because EOF is being identified, a companion study using eDNA techniques will be conducted to compare electrofishing and eDNA for detecting upper limits of fish distribution. Filtered water samples will be collected above and below the EOF point determined by electrofishing to examine the accuracy of eDNA at determining EOF. Recent studies have indicated that the number of samples required to accurately determine the presences of a fish species is dependent upon the volume of flow and drainage area (Goldberg et al. 2015; Jane et al. 2015). Despite this, eDNA shows promise in determining species presence or absence, and determining fish distribution. This study will be conducted during the second year of the overall study at seasonally sampled sites (82 sites) with the assistance of an additional crew member focused on collecting two eDNA water samples above and below the EOF detected with electrofishing (6 samples per sites x 82 sites x 3 seasons). This is a unique opportunity to partner with the U.S. Forest Service to complete the eDNA study. A similar eDNA study would require all the proposed fish and habitat surveying, and in the absence of the PHB study, would be very costly.

There are also some modifications or additions to the proposed study that could be beneficial and influence cost. First, the main cost of the study is in field data collection. Potentially identifying ways to reduce the number of sites sampled per ecoregion would affect the cost of the study. We had initially estimated sample size of 50 sites per ecoregion might be needed, but further analysis of WTMF data using a slightly less conservative statistical power (Type II error) coupled with evidence from the pilot study indicated that a sample size of 30 to 35 would be appropriate. Further, reducing the sample size would reduce the cost of the study, but reducing the number of samples to less than 35 per ecoregion would prevent us from examining differences among ecoregions. It should be noted that some costs are fixed (e.g., analysis, reporting, permitting) and will change little if the total number of sites sampled changes. Second, we initially propose to sample all sites in spring, late summer, and fall to early winter over the course of this study (see Table 2). While mid to late winter sampling (January 1 to March 1) would be helpful, most sites in eastern Washington and sites above 1500 ft in elevation in western Washington, will be inaccessible during much of the winter due to snow. However, winter sampling may be possible and could be conducted at some of the randomly selected lower elevation sites in western Washington ecoregions. This is of particular importance for anadromous fish like juvenile coho salmon, which may move several kilometers upstream or downstream in fall in search of overwintering areas or in summer to avoid ephemeral reaches or to find coldwater refugia (Skeesick 1970; Peterson 1982; Wiggington et al. 2006). The total cost of adding this to the study would depend upon the number of sites needed.

Once the main study is completed, a follow-up analysis will be necessary to examine variability in survey crews in identifying selected PHBs and whether this varies by ecoregion. Moreover, focus should be placed on specific protocols used to consistently and accurately identify and measure PHBs, including gradient, bankfull width, barriers, and any other PHB criteria identified in this study.

This study is specifically designed to test PHB criteria and explore the potential for other variables to provide useful information to refine PHB. While we are exploring a number of variables that have shown potential as co-variates in other similar types of studies, there is no guarantee that these variables may provide the same insight here. We will attempt to explore the usefulness of these variables in our early data analyses to evaluate whether to continue their use, but it may be difficult to judge until the larger dataset is available. We will use these analyses as one part of the overall program to make recommendations regarding PHB criteria.

We will also examine seasonal, short-term, and medium-term (3 to 10 years) changes in end of fish at more than 200 headwater streams across the state stratified by ecoregion. While it lays the groundwork for continued monitoring of long-term variability in the upper end of fish distribution, it is not specifically a long-term study (>25 years) on variability in the upper end of fish distribution. We strongly recommend that sites continue to be periodically revisited (every 5 or 10 years) to examine this variability, but doing so is beyond the current scope of this study.

Budget

The total estimate project cost including the pilot study in summer of 2018 (FY2019) is approximately $3.5 million. The pilot study demonstrated that initial site visits may take 2 full days to survey due to the time needed to clear necessary vegetation prior to survey. The proposed budget assumes that it would cost approximately $2400 for initial spring sampling at each selected site, with follow-up sampling costs of approximately $1200 per site visit (Table 3). All 245 sites would be sampled each year during the spring sampling window, whereas late summer and fall to early winter sampling would be repeated at one third of the sites (82) during each of the three years of the study (2020, 2021, and 2022). In addition, 60 of the seasonal sampling sites would be sampled across each year to examine inter-annual variability in seasonal sampling. Ten percent of all sites will also be resampled by all field crews in each year to examine crew variability.

Table 3. Estimated coast per major task by state fiscal year (July 1 to June 30) to implement study. Budget in FY2019 includes pilot study in summer of calendar year 2018, site reconnaissance and logistics, and spring sampling in calendar year 2019.

Task	FY2019	FY2020	FY2021	FY2022	FY2023	Total
Study design, coordination, site reconnaissance, permitting, crew training	147,400	105,000	87,000	82,500	N/A	421,900
Field sampling – Spring (245 sites)	563,500	465,500	490,000	N/A	N/A	1,519,000
Field sampling – Summer (82+60)	N/A	118,404	169,053	172,694	N/A	460,151
Field sampling – Fall (82+60); pilot in FY 19	121,000	118,404	169,053	172,694	N/A	581,151
Crew variability (10% of sites – all crews)	25,000	30,000	30,000	30,000	N/A	115,000
eDNA sampling (82 sites 3 times)		50,000				50,000
eDNA Lab Analysis and reporting		60,000	104,000			164,000
Data analysis and reporting	0	34,000	34,000	34,000	78,163	180,163
Project Management	12,000	14,769	15,132	15,506	15,262	72,669
Total	868,900	996,077	1,098,238	507,394	93,425	3,564,034

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Appendices

Appendix A. Details of sample size estimation.

Estimating required sample sizes depends on the population variance, which is generally unknown. Pilot projects, published values, and data proxies are often used to derive an estimate of the population variance to use in sample size calculations. Here, we rely on the provided Land Owner Sample Data set (PHB Science Panel 2018) to get an estimate of variance across an ecoregion.

The sample data exists across multiple ecoregions and contains habitat measurements surrounding each End of Fish (EOF) point. The data were reduced by only considering points within the "Coast Range" ecoregion. This level of granularity matches our proposed sampling strata and should give us insight into the variance of within an individual ecoregion. Moreover, similar to the proposed PHB study, these data were collected with consistent methods, while data in other ecoregions were collected with a variety of inconsistent methods. Of the metrics proposed and analyzed, difference in upstream and downstream gradient was the most normal and didn't include suspect channel width data. A square-root transformation further normalizes the distribution by pulling in the long right tail, but it still fails to pass the Shapiro-Wilks test for normality.

Because the sample data shows a non-parametric distribution, we estimated samples desired for each ecoregion in multiple ways including: 1) samples required to estimate the mean 2) power estimates for t-tests, and finally, 3) a bootstrapping routine to estimate samples for non-parametric tests (Wilcoxon and Kolmogorov-Smirnov). Power tests and mean estimates were applied to both the raw distribution, as well as the square-root transformed version.

First, calculating the number of samples required to estimate a population mean with a stated margin of error and certainty is accomplished using the following formula:

$$n = \frac{\left(z_{\frac{\alpha}{2}}\right)^2 \sigma^2}{E^2}$$

Where $▯_{▯}$ is the Z-score corresponding to the desired confidence level ▯, $▯^2$ is the estimated variance, and ▯ is the accepted margin of error. This can be stated as “Based on the assumption of population standard deviation being ▯, we require a sample size of ▯ to achieve ▯ margin of error at the $(100 - ▯)$% confidence level”. This formulation depends on both a stated confidence level, and acceptable margin of error.

Second, power estimates for t-tests have similar requirements to calculating samples required to estimate a population mean, but rely on ▯, the difference to be detected between the two samples, instead of a general error term ▯. Additionally, power estimates require desired power levels to be defined to calculate the number of samples required in each group.

Finally, a bootstrapping routine was used to determine the number of samples required to detect a given difference in means using non-parametric tests. The routine can be summarized as follows:

1.) Shift empirical distribution by ▯, by the desired difference to be detected.
2.) Draw ▯ samples from the original and shifted distributions
3.) Test with Wilcoxon and KS tests.
4.) Record if the test successfully detected the shift
5.) Repeat (2-4) many times (~10,000)
6.) Calculate the percent of replicates that failed to detect the shift.
7.) Repeat (2-6) for a range of sample sizes ▯.
8.) Repeat (1-7) for a range of differences ▯.

Results of the bootstrapping process can be visualized as a heatmap, depicting the percent of replicates that failed to detect the difference in samples for each combination of □ and □ (Figure A-1).

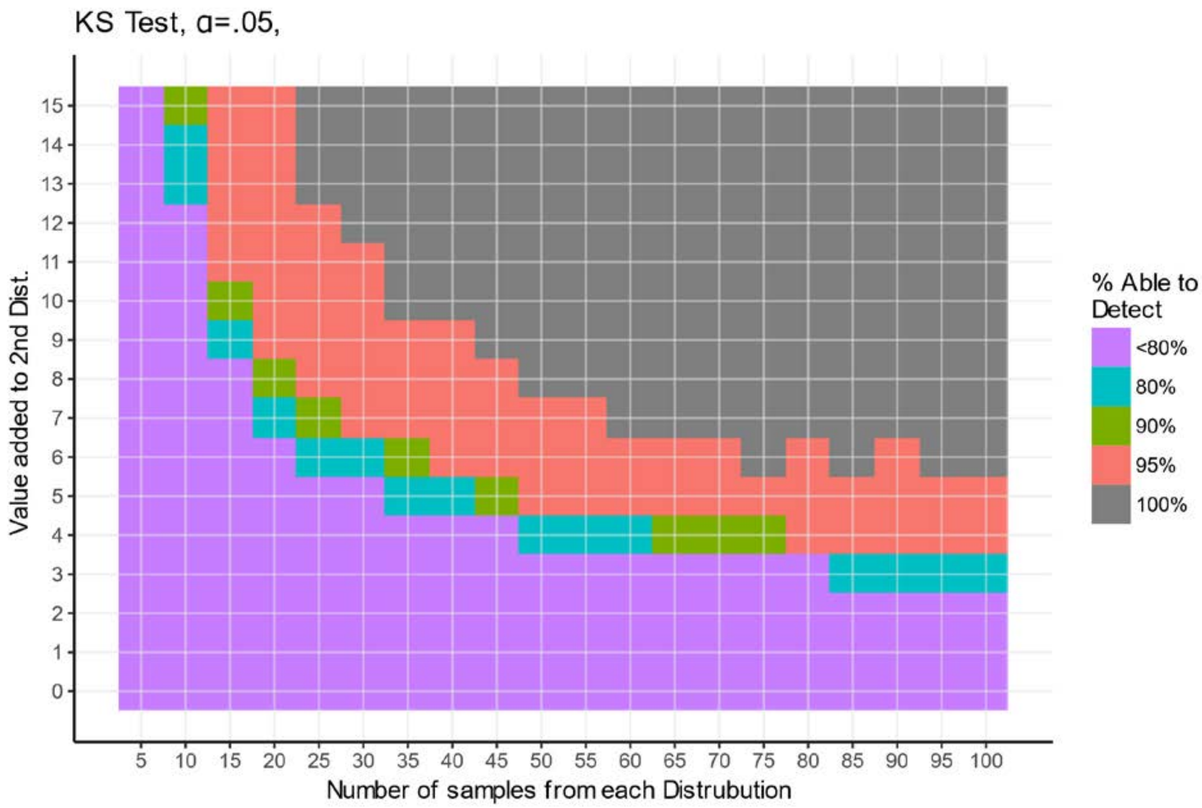

Figure A-1. Heatmap depicting results of bootstrapping procedure. Values have been binned to demarcate 100, 95, 90, and 80% detection rates (statistical power). In this example, 50 samples would be required to detect a difference of 5 units (gradient) with a 95% detection rate. Similarly, 35 samples would be needed to detect a difference of 5 units with an 80% detection rate.

Results from these estimation procedures are presented in Table A-1. The original and transformed distributions were used for estimating the mean, and t-test power estimates, while only the original distribution was used in the bootstrapping procedure, as it did not rely on assumptions of normality. For brevity, a limited selection of the bootstrapping results is reported.

Table A-1. Sample size estimation results from three estimation procedures. Both "Unmodified" and "Transformed" distributions were analyzed for the parametric tests.

Estimates for mean:	?	??	?	?
Unmodified	0.05	96.79	2.5	60
Unmodified	0.1	96.79	2.5	42
Transformed	0.05	1.11	0.3	48

Power t-test	Power	?	??	?	?
Unmodified	0.9	0.05	96.79	5	82
Unmodified	0.9	0.1	96.79	5	67
Unmodified	0.8	0.1	96.79	5	49
Transformed	0.9	0.05	1.11	0.6	65
Transformed	0.9	0.1	1.11	0.6	54
Transformed	0.8	0.1	1.11	0.6	39

Bootstrap	% Detection	?	Replicates	?	?
Wilcox	0.95	0.05	10000	5	50
Wilcox	0.9	0.05	10000	5	40
Wilcox	0.8	0.05	10000	5	30
KS	0.95	0.05	10000	5	50
KS	0.9	0.05	10000	5	45
KS	0.8	0.05	10000	5	35
Wilcox	0.95	0.1	10000	5	40
Wilcox	0.9	0.1	10000	5	35
Wilcox	0.8	0.1	10000	5	25
KS	0.95	0.1	10000	5	40
KS	0.9	0.1	10000	5	40
KS	0.8	0.1	10000	5	30

Appendix B. Example of 100 randomly selected sites for Cascades ecoregion including coordinates, basin name, elevation and land ownership. Ownership includes state, private and federal, though none of the points initially drawn from Cascades ecoregion were on federal lands.

POTENTIAL SITE	LATITUDE	LONGITUDE	BASIN NAME	ELEVATION	OWNERSHIP
1	47.03665	-121.97784	CARBON	1863	Private

2	47.10311	-121.89528	CARBON	2734	Private
3	46.99179	-122.05019	CARBON	1835	Private
4	46.13615	-122.57758	COWEEMAN	1152	Private
5	46.18591	-122.57078	COWEEMAN	1299	Private
6	45.82154	-122.25116	EAST FORK	1192	Private
7	45.83294	-122.36226	EAST FORK	1071	Private
8	45.86038	-122.32221	EAST FORK	2101	Private
9	45.73984	-122.33419	EAST FORK	1431	State
10	45.74782	-122.35548	EAST FORK	1330	State
11	45.76818	-122.26947	EAST FORK	2047	State
12	45.72529	-122.33179	EAST FORK	1512	State
13	45.80921	-122.38803	EAST FORK	1696	State
14	45.83117	-122.45127	EAST FORK	603	State
15	46.75158	-121.99434	GLACIER	1710	Private
16	46.71016	-122.22684	GLACIER	1559	Private
17	47.14867	-121.71266	GREEN WATERS	1619	Private
18	47.12430	-121.64195	GREEN WATERS	2350	State
19	46.10235	-122.35119	KALAMA	1467	Private
20	46.11008	-122.52981	KALAMA	1586	Private
21	46.03625	-122.58254	KALAMA	666	Private
22	46.12191	-122.32454	KALAMA	1668	Private
23	46.06947	-122.60266	KALAMA	860	Private
24	46.07809	-122.61313	KALAMA	601	Private
25	46.08089	-122.59259	KALAMA	827	Private
26	46.08495	-122.64968	KALAMA	801	State gov.
27	46.08752	-122.64951	KALAMA	829	State
28	47.11133	-121.25556	LITTLE NACHES	3765	Private
29	47.35756	-121.86811	LOWER GREEN	1328	State
30	46.84699	-122.03678	MASHEL-OHOP	2883	Private
31	46.85823	-122.04889	MASHEL-OHOP	2484	Private
32	46.80739	-122.08029	MASHEL-OHOP	2314	Private
33	46.92991	-122.22823	MASHEL-OHOP	763	Private
34	46.86879	-122.04818	MASHEL-OHOP	2719	Private
35	46.80953	-122.36960	MASHEL-OHOP	1233	Private
36	46.87684	-122.08648	MASHEL-OHOP	2481	Private
37	46.87757	-122.08933	MASHEL-OHOP	2355	Private

38	46.88170	-122.10328	MASHEL-OHOP	2835	Private
39	46.89287	-122.20396	MASHEL-OHOP	1387	Private
40	46.90079	-122.12769	MASHEL-OHOP	2342	Private
41	46.83691	-122.11397	MASHEL-OHOP	1743	Private
42	46.81273	-122.09325	MASHEL-OHOP	2046	State
43	45.98551	-122.41624	MERWIN	240	Private
44	45.89619	-122.25015	MERWIN	1914	Private
45	45.98041	-122.60519	MERWIN	1340	State
46	45.96363	-122.61993	MERWIN	461	State
47	46.01024	-122.40774	MERWIN	1679	State
48	46.86160	-122.76084	PRAIRIE	414	Private
49	47.10485	-121.61934	RAINIER	2132	State
50	45.75600	-122.41526	SALMON	558	Private
51	46.76764	-122.67439	SKOOKUMCHUCK	772	Private
52	46.72918	-122.46672	SKOOKUMCHUCK	2176	Private
53	46.72896	-122.66033	SKOOKUMCHUCK	1229	Private
54	46.69183	-122.47518	SKOOKUMCHUCK	2036	Private
55	46.83056	-122.75269	SKOOKUMCHUCK	899	State
56	46.83616	-122.82352	SKOOKUMCHUCK	489	State
57	46.80377	-122.70844	SKOOKUMCHUCK	638	State
58	47.52035	-121.94305	SQUAK	815	State
59	46.06407	-122.09884	ST HELENS	1013	Private
60	46.57485	-122.20169	TILTON-KIONA	1312	Private
61	46.46372	-122.42906	TILTON-KIONA	992	Private
62	46.58998	-121.97669	TILTON-KIONA	2523	Private
63	46.58887	-122.18366	TILTON-KIONA	1393	Private
64	46.47259	-122.46905	TILTON-KIONA	727	Private
65	46.53276	-122.15547	TILTON-KIONA	1020	Private
66	46.45616	-122.40366	TILTON-KIONA	1358	Private
67	46.45721	-122.41196	TILTON-KIONA	1225	Private
68	46.46133	-122.18169	TILTON-KIONA	993	Private
69	46.45976	-122.33460	TILTON-KIONA	2192	Private
70	46.45858	-122.41527	TILTON-KIONA	1194	Private
71	46.46195	-122.41682	TILTON-KIONA	1231	Private
72	46.38237	-122.58493	TOUTLE	826	Private
73	46.38971	-122.53364	TOUTLE	924	Private

74	46.39143	-122.47983	TOUTLE	1195	Private
75	46.39482	-122.52192	TOUTLE	972	Private
76	46.18449	-122.42676	TOUTLE	2509	Private
77	46.18624	-122.44654	TOUTLE	2041	Private
78	46.30538	-122.58529	TOUTLE	1429	Private
79	46.19308	-122.43555	TOUTLE	2075	Private
80	46.36050	-122.29501	TOUTLE	2009	Private
81	46.20363	-122.42296	TOUTLE	2470	Private
82	46.31487	-122.54222	TOUTLE	1433	Private
83	46.40769	-122.34573	TOUTLE	1967	Private
84	46.36063	-122.56427	TOUTLE	1086	Private
85	46.32399	-122.38076	TOUTLE	2425	Private
86	46.26112	-122.53349	TOUTLE	1178	State
87	46.26970	-122.56339	TOUTLE	1394	State
88	46.36804	-122.50197	TOUTLE	1440	State
89	46.24599	-122.52188	TOUTLE	992	State
90	46.85890	-122.70516	UPPER CHEHALIS	329	Private
91	46.67033	-122.63627	UPPER CHEHALIS	1105	Private
92	46.67820	-122.70085	UPPER CHEHALIS	658	Private
93	46.99542	-122.12728	UPPER PUYALLUP	1590	Private
94	46.94556	-122.05719	UPPER PUYALLUP	1518	Private
95	46.89987	-122.04643	UPPER PUYALLUP	1724	Private
96	46.99932	-122.11715	UPPER PUYALLUP	1729	State
97	45.63382	-122.21104	WASHOUGAL	721	Private
98	45.70737	-122.26008	WASHOUGAL	1466	State
99	45.66612	-122.29105	WASHOUGAL	1098	State
100	45.75315	-122.02144	WIND	1235	State

Appendix C. Step-by-step instructions for longitudinal thalweg profile used by BPA for evaluations of barrier removal projects (modified from https://www.monitoringresource).

Step 1: Prepare the proper equipment for a longitudinal profile. Equipment that can be used includes a surveyor's level, a measurement tape of sufficient length (typically at least 30 meters), and a stadia rod (see Harrelson et al. 1994 for details). Other options include a laser or other range finder with an accuracy of <4 cm that is fitted onto a monopod with a leveling bubble, together with a target placed on another monopod that can be adjusted to the height of the surveyor's laser range finder. In addition, it is important to carry a stadia rod or measuring stick to measure stream depths and widths. A simpler option is to mark off the monopod in 10ths of a meter and use it to measure stream depths and/or widths.

Step 2: Make sure the laser range finder "zeros out" in terms of vertical distance (VD on the screen for a LaserTech range finder) with the monopod. Adjust the monopod containing the laser range finder on a flat surface near the site so the vertical distance reading on the laser range finder reads at least 0.01 m when shooting the monopod target; ideally it should read 0.00 m. This means that the laser range finder is set to shoot at the same level as the monopod target and will allow the surveyors to read differences in elevation.

Step 3: A two or three-person crew consisting of a surveyor, monopod or rod person, and data recorder. If using a two people, the data recorder can also carry the stadia rod to measure depths and widths.

Step 4: Have the data recorder complete the header information on the form entitled "modified thalweg profile for full barrier removal" or, if using a tablet or iPad, have data recorder enter information in the tablet.

Step 5: Begin at the downstream end (station "0") of the longitudinal profile. Surveys should begin and end at riffle crests (the location in a riffle with the highest elevation) for streams with a pool–riffle structure. Station "0" will be put into the data sheet at distance of 0.0 and vertical elevation of 0.00. Water depth and wetted width will be measured to the nearest tenth of a meter. Substrate will be visually identified directly beneath the thalweg measurement and categorized as boulder, cobble, gravel, sand, or finer than sand. Habitat will be visually identified and categorized as pool, riffle, or glide.

Step 6: Once properly located, the monopod with target and stadia rod will then start to measure streambed elevation and associated habitat characteristics at the channel thalweg. The monopod holder with target will move a distance equal to the wetted width as well as every break in channel slope. The next station will become station “1.” The laser range finder will stay at station “0” and call out the horizontal distance to identify the distance from station “0” to station “1”, which will be entered by the data recorder.

Step 7: The laser range finder person will then call out the vertical distance to the data recorder. The data recorder will next use the stadia rod to measure the water depth at the point of the monopod, as well as the wetted width. If there is an island or gravel bar (dry area) within the wetted width make sure to measure the wetted width on each size of the dry area and sum the wetted widths. The monopod holder will identify the category of substrate as well as the habitat unit associated with the point at station “1”, which will be either cascade, riffle, pool, or glide. If the point is either at the top, maximum depth, or tailout of the pool then the monopod holder will also identify those characteristics. A minimum of 50 points should be surveyed in 100 m.

Notes for step 7 – Interval distance should be adjusted to bed morphology such that reaches containing more variable bed morphology will be sampled using a shorter interval. The rod should be supported, when necessary, to prevent it from sinking into areas with finer, softer substrates.

Step 8: Once the point at station “1” is shot and the data collected, then the laser range finder person will move to where the monopod with target is located and put the laser range finder and its associated holder down at the same exact location as the targeted monopod. The monopod with target will then be moved to the next break in slope or wetted channel width and identify that as station “2”. Stations will be surveyed until the survey crew get to the upper terminus of that reach. GPS coordinates will be then checked again against the original GPS point identified at the terminus to make sure the crew surveyed the entire reach. In general, the survey should include between 40 to 100 stations.

Table C-1 below provides an example of data typical collected with above protocol. A key difference would be that for the DNR PHB study bankfull width would be measured at every station rather than just every 25 meters.

Table C-1. Example of long-profiled data collected using the above protocol. Unpublished Bonneville Power Administration data from Corral Creek, Idaho. For the proposed PHB study, bankfull width would be recorded at every station.

Station	Distance (m)	Cummulative Distance	Elevation (m)	Cumulative Elevation	Depth (m)	Wet width (m)	Bankfull width	Max, tail, top	Substrate	Unit	Comments
0	0	0	0	0	0.19	1.9	2.5		C	R	
1	1.47	1.47	-0.04	-0.04	0.2	1.85			B	R	
2	2.28	3.75	0.27	0.23	0.2	1.92			C	R	
3	2.41	6.16	0.11	0.34	0.15	2.1			B	R	
4	4.13	10.29	0.27	0.61	0.1	2.5			C	R	
5	2.93	13.22	0.23	0.84	0.13	3.2			G	R	
6	1.74	14.96	0.01	0.85	0.08	4.3			G	R	
7	0.89	15.85	0.15	1	0.16	3.9			SA	R	
8	1.85	17.7	0.13	1.13	0.05	2.2		TAIL	SA	R/P	
9	1.4	19.1	-0.19	0.94	0.26	2.1		MAX	SA	P	
10	1.1	20.2	0.15	1.09	0.09	1.8		TOP	G	P	Tail of next pool
11	1.21	21.41	-0.2	0.89	0.28	2.3		MAX	SA	P	
12	1.3	22.71	0.09	0.98	0.13	1.8		TOP	G	P/R	Start of riffle
13	3.16	25.87	0.13	1.11	0.05	3.3		TAIL	SA	R/P	Start of pool
14	1.12	26.99	-0.19	0.92	0.28	3.9		MAX	G	P	
15	0.92	27.91	0.12	1.04	0.14	1.25		TOP	SA	R/P	Top of pool
16	1.23	29.14	-0.03	1.01	0.17	1.2	4.5	TAIL	G	P	Start of pool
17	1.86	31	-0.18	0.83	0.28	2.1		MAX	G	P	
18	1.17	32.17	0.19	1.02	0.06	3.5		TOP	C	R/P	
19	3.68	35.85	0.12	1.14	0.14	2.5			C	R	
20	3.42	39.27	0.24	1.38	0.09	2.8		TAIL	G	R/P	Top of pool
21	2.13	41.4	-0.24	1.14	0.31	3.2		MAX	G	P	
22	1.9	43.3	0.16	1.3	0.11	2.75		TOP	C	P/R	
23	4.5	47.8	0.08	1.38	0.22	2			C	R	
24	1.73	49.53	0.13	1.51	0.17	2.5			B	R	
25	1.46	50.99	-0.11	1.4	0.2	3.4			G	G	
26	1.98	52.97	0.06	1.46	0.15	3.3			C	R	
27	5.19	58.16	0.27	1.73	0.06	2.6		TAIL	G	R/P	
28	2.12	60.28	-0.3	1.43	0.35	1.8		MAX	G	P	
29	0.89	61.17	0.25	1.68	0.07	1.35		TOP	C	P/R	
30	2.9	64.07	0.09	1.77	0.13	2.3			G	R	
31	2.92	66.99	0.04	1.81	0.19	2.2	3.4		G	R	
32	5	71.99	0	1.81	0.17	1.9	2.65		B	R	Culvert/barrier
33	1.71	73.7	0.23	2.04	0.07	1.65			C	R	
34	2.82	76.52	0.11	2.15	0.2	3.32			B	R	
35	0.63	77.15	0.58	2.73	0.2	3.75		TAIL	SA	R/P	
36	0.37	77.52	-0.36	2.37	0.36	3.75		MAX	SA	P	
37	2.93	80.45	0.22	2.59	0.17	2.35		TOP	G	P/R	
38	4.8	85.25	0.12	2.71	0.14	2.9			G	R	
39	4.07	89.32	-0.08	2.63	0.25	1.7			C	R	
40	6.07	95.39	0.28	2.91	0.19	1.75			G	R	
41	7.75	103.14	0.33	3.24	0.13	1.62			SA	R	
42	3.22	106.36	-0.06	3.18	0.21	1.71			C	R	
43	2.28	108.64	0.1	3.28	0.15	2.02	3.14		C	R	
44	6.82	115.46	0.27	3.55	0.21	2.21			C	R	
45	4.92	120.38	0.24	3.79	0.12	2.3			G	R	
46	3.82	124.2	0.29	4.08	0.09	1.3		TAIL	G	R/P	
47	1.07	125.27	-0.12	3.96	0.24	1.14		MAX	G	P	
48	2.06	127.33	0.07	4.03	0.19	1.8		TOP	G	P/R	
49	0.66	127.99	0	4.03	0.19	1.2			G	R	
50	4.09	132.08	0.27	4.3	0.13	2.25		TAIL	SA	R/P	
51	2.78	134.86	-0.35	3.95	0.45	2.65		MAX	G	P	
52	0.86	135.72	0.45	4.4	0.02	2.3		TOP	G	P/R	
53	2.25	137.97	0.07	4.47	0.13	2.1	3.6		G	R	