Defining default physical criteria (DPC) for fish-bearing streams in forested landscapes in Washington State

Study Design prepared for the Washington Forest Practices Board

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Submitted by:

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Preface

After completion of the previous Potential Habitat Breaks (PHB) study design in 2019 (PHB Science Panel 2019), the PHB Science Panel convened by the Forest Practices Board (FPB) developed a draft study design to define default physical criteria (DPC) for fish-bearing streams on private and state forested landscapes in Washington State (FPHCP 2005). There were varying levels of comments and criticisms from all caucuses participating in the Forest Practices Adaptive Management Program (AMP) to particular aspects of the DPC study design and the review process. Later in 2019, the Forest Practices Board remanded the project to the Department of Natural Resources' adaptive management science program, tasking the Cooperative Monitoring, Evaluation and Research (CMER) committee with developing the DPC study design following CMER's protocols and standards, referenced in Forest Practices Board Manual Section 22 (WA Forest Practices Board 2019). CMER assigned the DPC study design development to the Instream Science Advisory Group (ISAG). The DPC study design presented here was developed by a project team formed within ISAG.

Summary

The upstream extent of both fish distribution and suitable and accessible fish habitat in forested watersheds is influenced by many factors including channel gradient, channel size, channel condition, nutrients, flow, barriers to migration, history of anthropogenic and natural disturbance, fish abundance, and the life histories of whichever fish species are in play at a given location. Default physical criteria (DPC) describe potentially suitable fish habitat based on local channel characteristics (bankfull width, gradient, and basin area) of locations with known fish use and are applied where fish use has not been determined by protocol surveys. Current DPC are shown in Figure 3. Related to DPC, potential habitat breaks (PHBs) are defined as permanent, distinct, and measurable in-channel physical characteristics that limit the upstream extent of fish distributions. The PHBs threshold criteria will be identified and assessed in a companion study with the intent for use in the Fish Habitat Assessment Methodology (FHAM), also currently under development as part of Forest Practices Board Manual Section 23.

DPC are used in three ways:

1) Where field surveys for determining fish use have not been done, water type is determined by applying the physical characteristics contained in WAC 222-16-031(3)(b)(i).
2) To determine where protocol surveys are needed to refute the presumption of fish use.
3) To provide stopping points beyond which protocol surveys are not needed.

Detailed information is needed on the uppermost fish location and associated habitat in small streams across Washington State to evaluate which physical criteria would best delineate the regulatory break between fish-bearing and non-fish-bearing waters (F/N breaks) in the absence of a protocol survey while also encompassing the vast majority of habitat actually or potentially used by fish.

The purpose of this study is to develop criteria for accurately defining DPC as part of a water typing rule. The study is designed to assess the accuracy[1] and utility of current DPC and to evaluate whether alternative combinations of gradient, channel width, and basin area (and/or other physical characteristics) would better identify the upstream extent of potentially suitable fish habitat. Additionally, this study is intended to provide insight into how last detected fish points, upstream extent of fish habitat based on FHAM, and PHBs relate to DPC and whether or how the DPC in this study vary across geography and time. We anticipate that the Board will use the study findings to inform which DPC criteria to use as part of a permanent water typing rule (CMER 2020).

The DPC study is a companion to and integrated with the PHB validation study (ISAG Project Team 2023). Data for the DPC and PHB studies will be collected concurrently from the same sites. Both the DPC and PHB studies will use the same end of fish (EOF) and end of fish habitat (EOFH) points generated for the PHB study as input to some of the analyses in this study. Ecogeohydrologic covariates (e.g., elevation, ecoregion, and basin area) assessed for the various PHB EOFH points will also be determined for the identified DPC locations and incorporated into the analyses.

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[1] "Accuracy" herein refers to alignment with and encompassment (capture) of EOF/EOFH points. See questions 1 and 2 in Appendix D, Table 2, and Figure 6.

The studies will be conducted across two sampling seasons (spring and fall/winter) in each of three years at 350 sites statewide; 160 in Eastern and 190 in Western Washington. Uppermost detected fish locations will be determined during each season at each site following modified DNR protocols for electrofishing surveys. The electrofishing surveys will be accompanied by simultaneous collection of coarse habitat data. Once the uppermost fish is located during each sampling event, the uppermost detected fish location will be flagged, GPS coordinates will be recorded, and an intensive longitudinal profile habitat survey will be conducted to characterize habitat and geomorphic conditions 660 ft (200 meters) downstream and 660 ft upstream of the uppermost detected fish location.

To evaluate seasonal changes in the location of the uppermost detected fish, the sites that can be accessed in the fall/winter season will be visited with an augmented serially alternating panel design. One quarter of the sites will be assigned to the fixed panel and will be surveyed every fall/winter, and the remainder will be allocated to three alternating panels. One of the three alternating panels will be surveyed each year, and the sample is augmented by the fixed panel of sites such that every accessible site will be surveyed at least once during the fall/winter. Surveys at all study sites over three years will increase the likelihood of capturing the uppermost extent of fish use by incorporating both temporal and spatial variability in fish movement due to physical (e.g., stream flow) and biological (population dynamics) factors. If an uppermost detected fish location changes during any subsequent survey, additional longitudinal profile survey data will be collected to ensure that there are channel data 660 ft above and 660 ft below uppermost detected fish locations for all seasons and years.

Data will be analyzed using a suite of statistical methods (e.g., random forest, classification, and regression) to determine the combinations of gradient, channel width, and other geomorphic features associated with the uppermost detected fish locations and the upstream extent of fish habitat as defined by PHBs across all seasons and years at each site that will allow DPC to best fulfill the multiples roles they play in the overall water typing system and whether these vary across Eastern and Western Washington.

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List of Acronyms

AFF	Anadromous Fish Floor
AMP	Forest Practices Adaptive Management Program
BFW	Bankfull Width
CMER	Cooperative Monitoring, Evaluation & Research Committee
DNR	Washington State Department of Natural Resources
DPC	Default Physical Criteria
eDNA	Environmental DNA
EOF	End of Fish (Last detected fish following a Protocol Survey)
EOFH	End of Fish Habitat
F/N Break	Regulatory break between fish and non-fish-bearing waters
FFR	Forests & Fish Report
FHAM	Fish Habitat Assessment Methodology
FHTG	Fish Habitat Technical Group
FP	Forest Practices
FPA/N	Forest Practices Application/Notification
FPB, or “Board”	Washington State Forest Practices Board
FPHCP	Forest Practices Habitat Conservation Plan
GIS	Geographic Information System
GLMM	Generalized Linear Mixed Models
ISPR	Independent Scientific Peer Review
PHB	Potential Habitat Break(s)
TFW	Timber, Fish & Wildlife
Type F	Fish-Bearing Streams
Type N	Non-Fish-Bearing Streams
WTM	Water Type Modification
WTMF	Water Type Modification Form

Introduction

In Washington State, forest practices are regulated by the Forest Practices Act (RCW 76.09) established by the legislature, with rules (WAC 222) 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 (FFR 1999). Rules pertaining to aquatic and riparian habitats are specifically included in the Forest Practices Habitat Conservation Plan (FPHCP), 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 timber harvest and road prescriptions (rules) are applied to waters used by fish to protect fish and their habitats.

The Board is responsible for rulemaking and overseeing the implementation of forest practice rules. The evaluation of the effectiveness of these rules is conducted by the Forest Practices Adaptive Management Program (AMP) and administered by the Washington Department of Natural Resources (DNR). 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 or potentially could be used by fish. Streams identified as having fish habitat are classified as Type F waters, defined in the water typing rule (WAC 222-16-030), 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, an interim rule (WAC 222-16-031) allows for the delineation of Type F waters through the use of either physical characteristics (see Figure 3) or a protocol electrofishing survey[2]. Landowners may use the default physical criteria (DPC) or the results from protocol survey electrofishing to identify the regulatory Type F/N break. DPC describe *potentially suitable* fish habitat based on local channel characteristics (bankfull width, gradient, and basin area) of locations with known fish use and are applied where fish use has not been determined by protocol surveys. The DNR provides a map showing stream segments

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[2] WAC specifies presumption of fish use in streams meeting the physicals described where fish use has not been determined via a protocol survey/FHAM. See WAC 222-16-031 and Board Manual Section 13.

of modeled fish habitat. The Forest Practices Rules require forest landowners to verify, in the field, the type of any regulated waters identified within proposed harvest areas prior to submitting a forest practices application/notification (FPA/N).

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 (WA Forest Practices Board 2018). An important part of the permanent rule will be guidance on a specific protocol to determine the regulatory break between Type F (fish-bearing) and Type N (non-fish-bearing) waters. The Board is considering the use of a fish habitat assessment method that incorporates known fish use with PHBs to identify the upstream extent of fish habitat. The Board accepted the TFW Policy recommendation from the Fish Habitat Technical Group (FHTG) that PHBs be based on permanent physical channel characteristics such as gradient, stream size, and/or the presence of non-deformable vertical and non-vertical natural obstacles as potential barriers to upstream fish movement (FHTG memo 2017; TFW Policy meeting minutes 2017; WA Forest Practices Board 2017a). The relationship between DPC and other aspects of the overall water typing system will likely remain intact under new water typing rules, even though minor modifications to survey protocols are being made in development of a new Fish Habitat Assessment Methodology (FHAM) that incorporates PHBs (Forest Practices Board Manual Section 23).

Study Purpose

The purpose of this study is to develop criteria for accurately defining DPC as part of a water typing rule. The study is designed to assess the accuracy[3] and utility of current DPC and to evaluate whether alternative combinations of gradient, channel width, and basin area (and/or other physical characteristics) would better identify the upstream extent of potentially suitable fish habitat. Additionally, this study is intended to provide insight into how last detected fish points, upstream extent of fish habitat based on FHAM, and PHBs relate to DPC; and whether or how the DPC in this study vary across geography and time. We anticipate that the Board will

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[3] "Accuracy" herein refers to alignment with and encompassment (capture) of EOF/EOFH points. See questions 1 and 2 in Appendix D, Table 2, and Figure 6.

use the study findings to inform which DPC criteria to use as part of a permanent water typing rule (CMER 2020).

It is important to note that this study is not intended to evaluate the entire current water typing system or the FHAM; nor is it intended to describe how the regulatory Type F/N break should be determined. Current DPC are based on channel gradient, channel width, and basin area. Other factors such as temperature, flow, water quality, population dynamics, anthropogenic and natural disturbance, and biological interactions are important covariates that might influence the distribution of fishes but do not affect DPC. Therefore, they are not being evaluated in this study.

Project Research Questions

The following project-specific research questions were developed to address key uncertainties and provide information needed to assess the accuracy of current DPC and to evaluate if alternative combinations of gradient, channel width, and basin area (and/or other physical characteristics) are better associated with the upstream extent of potentially suitable fish habitat. The research questions also incorporate certain aspects of the CMER Workplan Rule Group critical questions listed in Appendix A.

1. **How frequently does the upstream extent of fish use and/or fish habitat[4] end at a point downstream, upstream, or coincident with current DPC thresholds for bankfull width, gradient, or both?**
2. **What is the distribution of distances between the upstream extent of fish use and/or fish habitat[4] points downstream, upstream, or coincident with current DPC thresholds for bankfull width, gradient, or both?**
3. **How do physical and ecogeohydrologic covariates influence the frequency and distribution of distances addressed in RQs 1 and 2?**
4. **How frequently and by how much do the physical channel conditions (e.g., bankfull width and gradient) at the locations initially identified as the end of current DPC change over the course of the study?**
5. **Can protocols used to identify DPC be consistently applied among survey crews and be expected to provide similar results in practice?**
6. **Are there singular or combinations of physical channel metrics (e.g., stream gradient**

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[4] For the purposes of this study, “fish habitat” is as defined by each PHB option derived from the PHB study field data as it would be applied within FHAM (see Appendix B for PHB options).

and bankfull width) and basin characteristics (e.g., basin area) alternative to current DPC that would serve as more accurate[3] DPC criteria relative to the location of the last detected fish? If so, what are they?

Approach

We will use data from electrofishing and physical habitat channel surveys in a spatially balanced sample of 350 streams across Eastern and Western Washington (same sites already identified for inclusion in the PHB study) to address the DPC Project Research Questions above. The companion PHB study will use the same sites and data to evaluate proposed criteria to be used as potential habitat breaks when implementing FHAM. We will conduct multiple surveys over a three-year period to document seasonal and interannual changes in fish distribution and to maximize the likelihood of identifying the upper extent of fish use in each stream. This will allow us to address questions about seasonal and interannual changes in uppermost fish location and evaluate potential changes to the physical characteristics at the locations identified as the end of current DPC over the course of the study.

Background

In 1996, after reviewing data primarily collected by the Point-No-Point Tribal Council, the Quinault Indian Nation, Washington Trout, and the Department Fish & Wildlife, the Forest Practices Board (Board) adopted a consensus package of actions, including emergency water typing rule, with defaults for presumed fish use and a fish survey protocol to determine fish use (Light 1997). The Board also approved guidance (Board Manual, section 13) for the Department of Natural Resources (DNR) and others to use when implementing the rule, and a long-term plan for riparian management that would address Clean Water Act and Endangered Species Act concerns. This long-term riparian management plan ultimately resulted in the Forests & Fish Report (FFR 1999) and the Forest Practices Habitat Conservation Plan (FPHCP 2005). Water typing—the designation of streams as fish-bearing or non-fish-bearing, and perennially or seasonally flowing—was a critical component of these efforts. As negotiations for FFR continued, the Board adopted a series of emergency rules based on the 1996 emergency rule. Several key principles were identified as critical in the development of a water typing model and resulting maps envisioned for FFR, including high accuracy, minimized risk, and remaining uncertainty balanced between overestimation and underestimation of the locations of the lines of demarcation (F/N breaks[5]; Conrad et al. 2003; Cupp 2002; Duke 2005).

Reliance on both the DPC and protocol electrofishing surveys to determine the break between fish-bearing (Type F) and non-fish-bearing (Type N) waters was intended to be a temporary (interim – WAC 222-16-031) solution within the 1996 emergency rule with the intention of adopting a permanent water typing rule in the future. While attention to date has focused on the potential uncertainties related to protocol surveys, a systematic review of the rule also necessitates a review of the uncertainties related to the default physical criteria. The default physical criteria that are used to delineate the end of Type F waters where fish use has not been determined by a protocol electrofishing survey and/or an ID team are described in WAC 222-16-031(3)(b)(i), as follows:

> (i) Waters having any of the following characteristics are presumed to have fish use:
>
> (A) Stream segments having a defined channel of 2 feet or greater within the bankfull width in Western Washington; or 3 feet or greater in width in Eastern Washington; and having a gradient of 16 percent or less;
>
> (B) Stream segments having a defined channel of 2 feet or greater within the bankfull width in Western Washington; or 3 feet or greater within the bankfull width in Eastern Washington, and having a gradient greater than 16 percent and less than or equal to 20 percent, and having greater than 50 acres in contributing basin size in Western Washington or greater than 175 acres contributing basin size in Eastern Washington, based on hydrographic boundaries.

Sub-sections (C) and (D) from WAC 222-16-031(3)(b)(i) address DPC for ponds and impoundments rather than streams and rivers and will be examined and included where they occur in the sample.

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[5] "The modeling process shall be designed to achieve a level of statistical accuracy of 95% in separating fish habitat streams and nonfish habitat streams. Furthermore, the demarcation of fish and nonfish habitat waters shall be equally likely to over and underestimate the presence of fish habitat" (from WAC 222-16-030).

Since 1996, there have been policy-level disagreements over how well the current DPC correspond to and/or capture points identified in field-verified data across participants in the Adaptive Management Program. As defined in current rule, the DPC thresholds are set to encompass the vast majority of End of Fish / End of Fish Habitat (EOF/EOFH) points (WA Forest Practices Board 1996), but they frequently do not align with field-determined EOF/EOFH points and often fall upstream of them (Cole and Lemke 2006). Many factors can limit the distribution of fishes including barriers to migration, stream gradient, flow, and channel size. Understanding the current science on how these factors influence fish distribution is important when discussing how they can be used to most accurately define the upstream limits of fish habitat in forested streams of Washington State. This study does not address barrier or obstacles that limit upstream fish distribution (which are covered in the PHB Study) but is instead focused on the physical channel metrics (e.g., stream gradient and bankfull width) and basin characteristics (e.g., basin area) directly associated with DPC.

DPC describe habitat characteristics of streams known to be used by fish at the limits of their distribution in at least some places, with the understanding that not all streams having such characteristics are necessarily used by fish (WA Forest Practices Board 1996; Light 1997). The DPC are not intended to predict upper extents of fish use or fish habitat as determined by PHBs in surveys implementing the Fish Habitat Assessment Method (FHAM; see Appendix B). The DPC do not necessarily account for all features that might limit fish access to otherwise suitable upstream habitats or stream characteristics that could impact habitat suitability. PHBs represent some of those limiting features and characteristics, provide starting points for protocol surveys, indicate potential F/N type breaks where no fish are found above them, and offer plausible explanations for why fish use does not extend to the end of DPC at some locations. By describing potentially suitable habitat, DPC indicate where protocol surveys are to be applied using FHAM in cases when proponents choose not to rely on the presumption of fish use indicated by default characteristics.

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., Leathe 1985; 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). Several studies conducted in the state of Washington found that 10% to 15% of uppermost detected fish locations in forested streams occurred upstream of reaches with channel gradients steeper than 15-16% (Fransen et al. 1997; Light 1997; Cole et al. 2006; PHB Science Panel unpublished 2017 data compilation). Using map-based estimates, Fransen et al. (1997) found that when the gradient downstream from last fish points was calculated over reaches with 40-foot elevation change (1 contour interval) instead of 120-foot elevation change (3 contour intervals), the percentage of last fish points above 16% gradient increased to 18% of streams. In a field-based study, Kondolf et al. (1991) reported that 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% (Figure 1). These observations indicate that in some cases fish habitat in headwater streams can extend into the types of steep step-pool and cascade reaches described by Montgomery and Buffington (1993). Both Fransen et al. (1997) and Kondolf et al. (1991) illustrate how measurement scale can influence the determination of channel gradient.

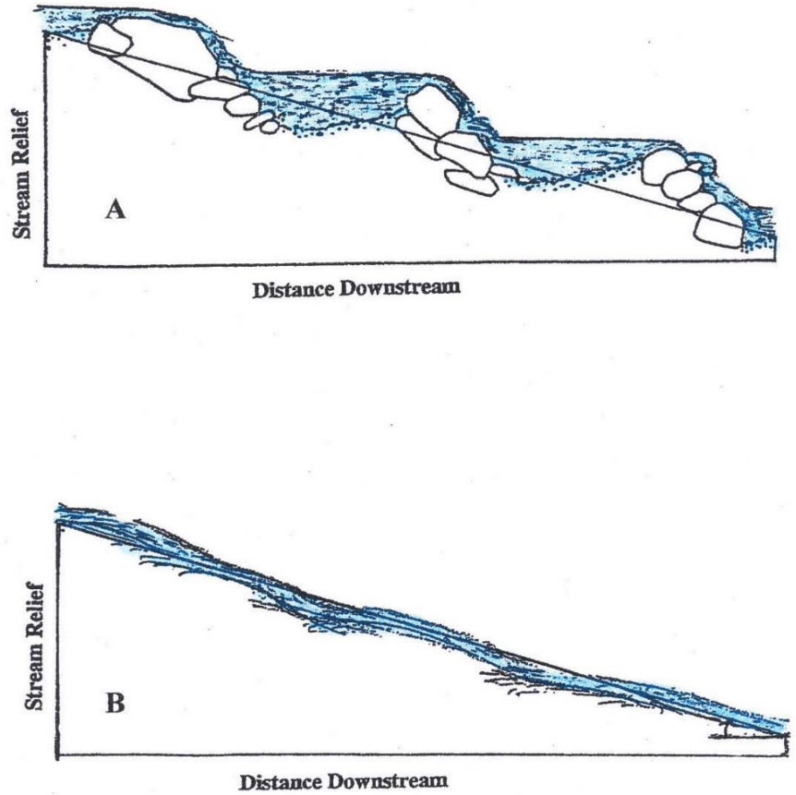

Figure 1. Two very different profiles of a headwater reach with the same overall reach gradient. Illustration (A) demonstrates how roughening elements create local gradients that are lower than the overall reach gradient, while reaches without such features (B) do not. (PHB Science Panel 2019)

Streamflow, Bankfull Width, and Contributing Basin Area

Bankfull width (BFW) is related to stream flow and reflects the stage of discharge at peak flows occurring every 1-2 years (Andrews 1980; Leopold 1994; Rosgen 1996). Other studies have shown that BFW is correlated with drainage area and varies with climate, geology, and topography of the basin (Castro and Jackson 2001). However, the strength of correlations varies among studies, geographic area, and stream types investigated. For example, Beechie and Imaki (2014) developed equations modeling the 2-year peak discharge and BFW for Columbia Basin rivers based on annual precipitation and catchment (drainage) area but did not attempt to model these relationships for streams less than 8 meters wide. They qualified the errors in their regressions stating: "Slope and bankfull width were slightly less accurate, and both were slightly biased at low values (i.e., we tended to overestimate the slope of low gradient channels and the bankfull width of small channels)." Castro and Jackson (2001) found that while BFW and drainage area relationships worked well in areas of similar lithology/geology and precipitation regimes to those for which they were developed, they were less useful in the Pacific coastal areas of western Washington where the geology and precipitation patterns are highly variable. Because of the importance of channel space and stream flow to fish use of streams, and the variability in the relationships between stream flow, channel width, and basin area, contributing basin area and channel width are both included as factors in the current DPC.

Stream flow is often important for determining the upstream extent of fish use and fish habitat (Trotter 2000). 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 in Washington and found that 90% of these streams had mean annual flows of ~3.5 cfs or less and ~10% of sites had mean annual flows of 0.25 cfs or less at the upper boundary of fish presence (Figure 2).

However, streams with low annual discharge can be important at certain times of year during peak discharges. Similarly, streams with intermittent flow can also provide important habitat at key life stages (Hartman and Brown 1987, Hubble 1992, Ebersole et al 2006, Wigington et al 2006, Glasgow and Hallock 2009, Matthews 2021). Fish can use seasonal streams for several reasons including thermal and high-flow refuge, feeding, spawning, and predator avoidance. Where such streams are used by fish, flow levels when water is present in the channel can correspond to the expansion of available stream habitat and may be more important than mean annual flows. In these cases, bankfull width can be a good indicator of what those periodic flows are.

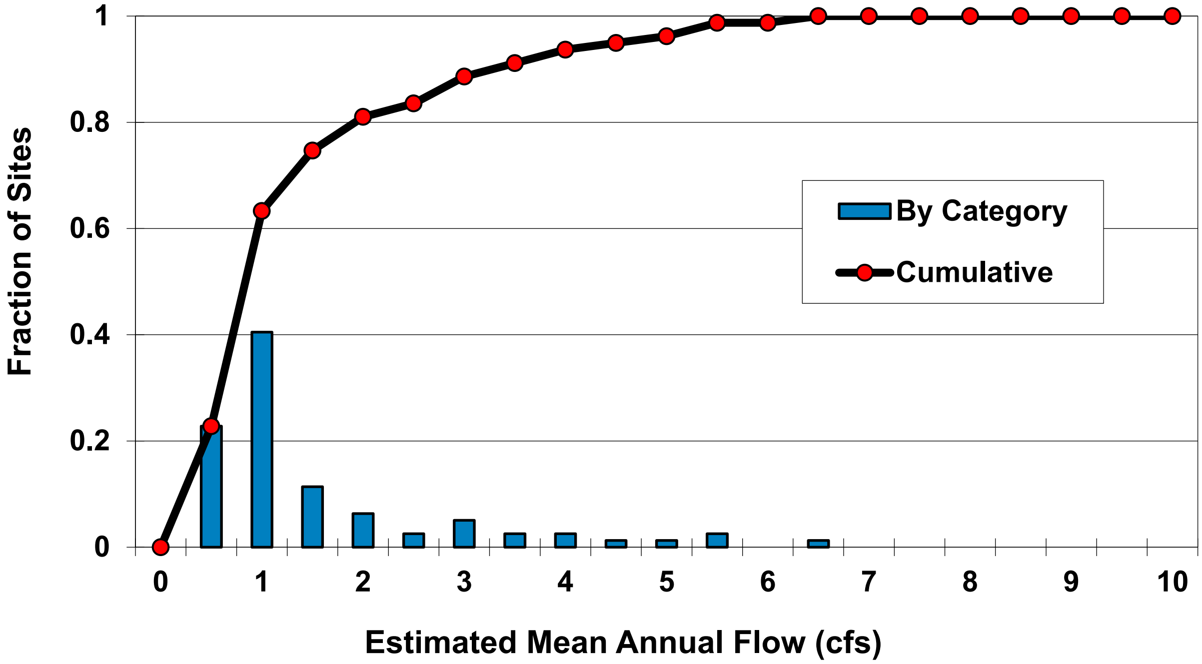

Figure 2. Estimated mean annual flows at uppermost fish locations in 79 streams in the Cascade foothills and Willapa Hills of western Washington (from Fransen et al. 1998)

Default Physical Criteria Field Application

DPC are used in three different ways:

1) Where field surveys for determining fish use have not been done, water type is determined by applying the physical characteristics contained in WAC 222-16-031(3)(b)(i).
2) To determine where protocol surveys are needed to refute the presumption of fish use.
3) To provide stopping points beyond which protocol surveys are not needed.

Under current rule, the DPC extend upstream to the point where the stream channel ceases to meet any one or more of the defined criteria shown in Figure 3, and no stream segments meeting all of the DPC for Type F exist further upstream. The flow charts (Figure 3) illustrate the logic followed when applying the DPC.

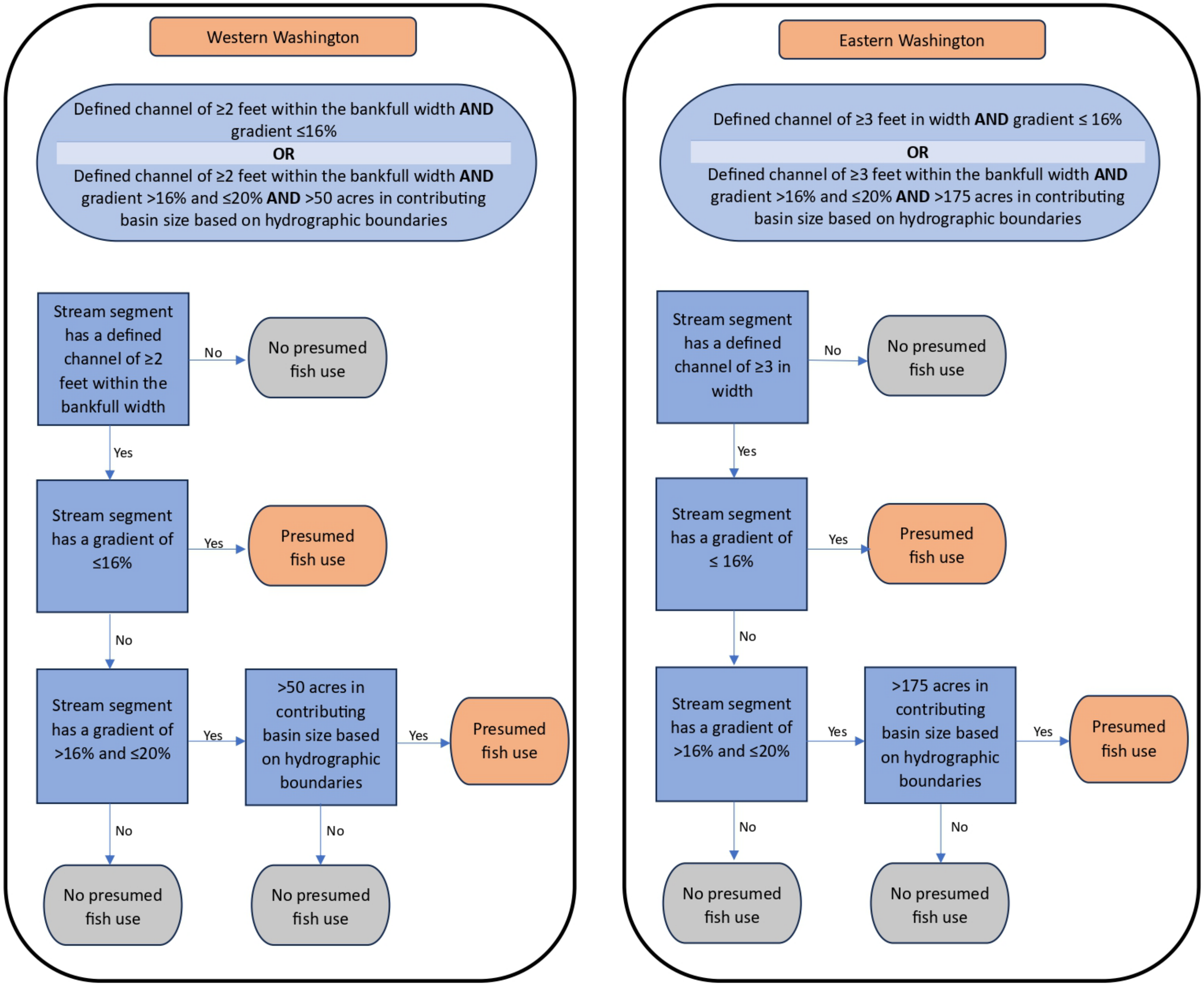

Figure 3. Tables and flow charts illustrating the components and use of Default Physical Criteria as defined in WAC 222-16-031.

Current Options for Water Typing

Either protocol electrofishing surveys or DPC can be used to verify water type. The use of protocol electrofishing surveys is an alternative to using the DPC in situations where fish use and fish habitat do not extend to the upstream limit of DPC. The Water Type Modification (WTM) process is used to make formal changes to and justification for the location of F/N breaks on DNR water type maps where protocol electrofishing surveys have been conducted. In contrast, water type verifications made using only DPC do not result in permanent changes to locations of F/N breaks on DNR Forest Practices water type maps. The DPC do, however, indicate which streams would need protocol surveys and WTMs to demonstrate that they are not fish habitat. 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 WTMFs have been submitted to the DNR to modify water types and modify the location of the break between Type F and Type N waters.

Under the current water typing rules, proponents have used professional judgment to estimate “habitat likely to be used by fish” when proposing regulatory fish-bearing/non-fish-bearing (F/N) water type breaks. Stream segments that are accessible to fish and exhibit the same characteristics as 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 embraced the concept of a Fish Habitat Assessment Methodology (FHAM), developed by a diverse group of AMP technical stakeholders, which was intended to be repeatable, implementable, and enforceable (WA Forest Practices Board 2018; WA DNR 2019).

Fish Habitat Assessment Methodology (FHAM)

The FHAM is a series of steps used to delineate the upper extent of fish habitat coincident with the regulatory water type break between Type F and Type N Waters. The FHAM is applied in waters situated upstream from areas of known fish use. The FHAM requires the identification of geomorphic features meeting the definition of a potential habitat break (PHB). The FHAM utilizes PHBs that reflect a measurable change in the physical stream characteristics at or upstream from a detected fish point, above which a protocol electrofishing survey would be undertaken (Figure 4). The first PHB located at or upstream from the uppermost detected fish would serve as the end of fish habitat (F/N Break) when no fish are detected above this PHB. Per FHAM, PHBs are based on stream size, gradient, and access to fish habitat.

Relationship between DPC and PHBs

The DPC describe potentially suitable fish habitat based on locations of known fish use that exhibit similar physical characteristics (bankfull width, gradient, and basin area). They are applied where fish use has not been determined by protocol surveys. By describing potentially suitable habitat, DPC also indicate where protocol surveys are to be applied using FHAM in cases where proponents choose not to rely on the presumption of fish use indicated by DPC. The DPC are not intended to predict upper extents of fish use or fish habitat. These determinations are made using PHBs in implementing FHAM. The upper extents of DPC can provide stopping points for protocol surveys in circumstances when fish are not being observed via electrofishing. The DPC do not necessarily account for all features that might limit fish access to upstream habitats that might otherwise be suitable or stream characteristics that could impact habitat suitability. PHBs represent some of those limiting features and characteristics, provide starting points for protocol surveys, indicate potential F/N type breaks where no fish are found above them, and offer plausible explanations for why fish use does not extend to the end of DPC at some locations.

Integration With PHB Study

The DPC study is designed to assess the physical characteristics of potentially suitable fish habitat based on local channel characteristics (bankfull width, gradient, and basin area) of locations with known fish use. DPC can be applied where fish use has not been determined by protocol surveys. The PHB study is a separate but related study designed to assess which combinations of gradient, channel width, barriers to migration, and other physical habitat and geomorphic conditions are indicative of the upstream extent of fish habitat as defined in WAC 222-16-010.

The implementation of the DPC study will be coordinated with the PHB study to take advantage of their shared elements (e.g., sample sites, upstream extent of fish distribution information), but maintain separate study-specific elements, particularly analyses, that are designed to accomplish study objectives and answer project-related critical questions in the 2023-2025 CMER Work Plan (CMER 2023). The two studies will share sites and some data will be collected simultaneously, but different subsets of the data will be used for the two studies and their results will inform different parts of FHAM and the overall water typing system.

The electrofishing and habitat surveys for each PHB study stream will extend up to or beyond the end of current DPC. Therefore, the PHB study will yield a data set that can be analyzed regarding the frequency with which fish are found up to the limits of current DPC, including how this varies across seasons, years, and geography. The coarse-scale data collected during the electrofishing survey will also provide channel profiles and other data for the segments between EOF/H and end of current DPC that can be analyzed for possible explanations as to what habitat attributes and/or features are limiting fish distributions for those sites where fish use does not extend to end of current DPC. These field-derived data will include channel gradient, bankfull width, wetted width and confinement within unequal length segments of relatively uniform habitat character. These field-derived results in conjunction with geographic information systems (GIS)-derived data might suggest opportunities for more refined criteria that are only applied under certain conditions, similar to the way basin size is currently used for stream reaches with 16-20% gradients (WAC 222-16-031). This could potentially reduce the degree to which the current DPC, when used on their own in the absence of a protocol survey, predict potential fish use where there are no fish, and are not likely to ever be.

The PHB study design was reviewed and approved by Independent Scientific Peer Review (ISPR) and CMER in August 2023, allowing study implementation to commence. Site selection is underway as of summer 2024.

Methods

We will use data from electrofishing and physical habitat channel surveys in a spatially balanced sample of 350 streams across Eastern and Western Washington to address the DPC Project Research Questions above. The companion PHB study will use the same sites and data to evaluate proposed criteria to be used as potential habitat breaks when implementing FHAM. While there is an allowance built into the sample size calculations to account for potential site attrition, we will also consider after the first full year of sampling whether additional sites are needed to balance allocation of sites among ecoregions and between laterals and terminals.

Survey Design

Sampling Frame and Study Sites

Current F/N break points on the DNR Forest Practices water type map will serve as the sampling frame for this study. The target population is defined as the set of all F/N break points on streams on Forests & Fish (FFR) lands in Washington. A sampling frame that matches the target population as closely as possible is needed for unbiased inference. Fish/non-fish stream type break points extracted from the current DNR water type GIS map layer (DNR Forest Practices hydro, watercourses (“wchydro"); https://data-wadnr.opendata.arcgis.com/datasets/wadnr::dnr-hydrography-watercourses-forest-practices-regulation/about) represent an accessible source of possible study sites. Some of these points are based on field surveys that were concurred (survey-based) through the WTM review process while others are modeled points obtained from a logistic regression model that predicts F/N points based on basin area, upstream and downstream gradients, elevation, and precipitation (Conrad et al. 2003; Duke, 2005). The hybrid approach using both modeled and concurred F/N break points as the sampling frame incorporates existing information while allowing a broad scope of inference.

This study uses the study sites that were selected using a spatially-balanced Generalized Random Tessellation Stratification (GRTS; Stevens and Olsen 2003, 2004) sample created according to the ISPR-approved PHB study design.

The spatially balanced sample of F/N points will be stratified by region (eastern or western Washington)[6]. The western region of Washington consists of about one-third of the state's area but has twice the stream density. Given the differences in stream distribution across the state and the different sources of frame error in each region, east-west stratification will be applied to ensure that spatial balance is maintained within each region.

Previous iterations of this study design incorporated ecoregion as a stratification variable. Ecoregions reflect broad ecological patterns occurring on the landscape. In general, each ecoregion has a distinctive composition and pattern of plant and animal species distribution. Abiotic factors, such as climate, landform, soil, and hydrology, are important in the development of ecosystems and thus are factors used in the delineation of ecoregions. The physical characteristics of the channel, while symptoms of the abiotic factors, are what fish experience and make sense for us to measure and evaluate. While it is possible that there is something about ecoregions, particularly precipitation patterns, that might cause differences in the barriers to fish movement, there is no strong reason to restrain the analysis of results to that factor at the expense of our ability to investigate other, potentially more important factors. There are likely to be differences among ecoregions in where the fish and barriers to movement occur on the landscape but identifying those spatial patterns of occurrence is not the purpose of this study.

The Washington State Natural Heritage Program modified ecoregions defined by the US EPA into Level III ecoregions specific to Washington, each of which is described at http://www.landscope.org/washington/natural_geography/ecoregions (Figure 4).

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[6] 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 (WA Forest Practices Board 2018).

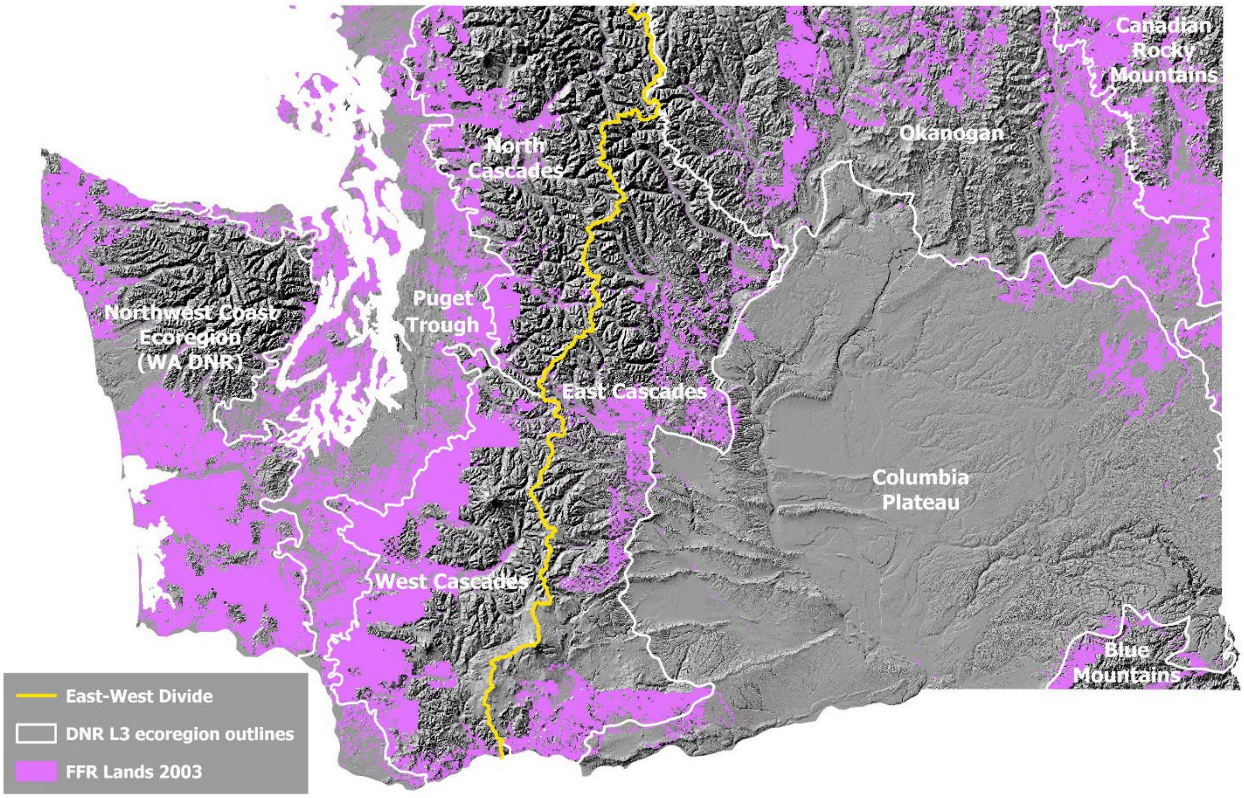

Figure 4. Washington Natural Heritage Program Level III ecoregions with Lands subject to the Forests & Fish (FFR) forest practices rules designated in purple. Note the general absence of FFR lands in the Columbia Plateau ecoregion. FFR lands mapped as of 2003. Ecoregion data downloaded from https://data-wadnr.opendata.arcgis.com/datasets/wadnr::ecoregions-of-the-pacific-northwest/explore?location=46.585091%2C-118.050200%2C6.03 in 2022.

In this design, we do not propose the use of *a priori* stratification by ecoregion but will instead include the assigned Natural Heritage Program ecoregions as a site attribute and covariate to allow for analysis of any significant role ecoregions might play in PHBs and/or DPC. *A priori* stratification would be advisable for this study to model PHBs by ecoregion, to attain a desired level of precision for each ecoregion, for administrative convenience, or to apply different survey methodologies by ecoregion (Cochran 1977). However, none of these considerations apply in this sampling design. We expect the sampling effort to be allocated proportionally to the relative area of ecoregions due to the implicit probability-proportional-to-size sampling obtained from spatially balanced sampling. However, smaller ecoregions, such as the Blue

Mountains ecoregion, may receive fewer sampling points due to its smaller area and remote location. “Islands” of sampling frame that are not contiguous can affect overall spatial balance (Don Stevens, personal communication), in which case *a priori* stratification might be necessary. When the sampling frame is available, the allocation of sites will be examined for test sample draws to determine if adequate sample sizes within each ecoregion are obtainable.

Sampling effort will be apportioned among mapped terminal or lateral F/N break point types (Figure 5) with post-hoc stratification. This approach is useful when the point types are not known for each site before the survey, so no sampling frame is available to identify each subpopulation for *a priori* stratification. Survey crews will record the point type at the time of the survey and, when the desired sample size for a point type is satisfied, survey data from this point type will not be collected at subsequent points of this type. Because the point type is not known *a priori* so cannot be included as a survey design variable for stratification, employing this technique will require adherence to the spatially balanced ordered list of sites to ensure that the obtained sample of sites within each point type is also spatially balanced. The point type will be recorded for each site so that inclusion probabilities for each site may be calculated prior to analysis for any design-based summaries such as means and totals (Larsen et al. 2008, section 2.4). This apportionment will only occur during the initial site surveys. If a site changes from lateral to a terminal over the course of the study, we will not add any study sites to accommodate that change.

Based on an analysis of observed variability in channel gradient and width upstream of uppermost detected fish points from previous CMER studies and existing water type modification forms (Appendix C), we propose to determine the location of uppermost detectable fish at 160 sites in forested watersheds in eastern Washington and 190 sites in forested watersheds in western Washington[7]. Habitat characteristics (gradient, channel width, obstacles) will be measured using a longitudinal stream channel profile survey 660 ft (200 m) above and 660 ft below the uppermost detected fish. The uppermost detected fish locations will be determined during each sampling event via electrofishing surveys. The corresponding

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[7] The recommended sample size includes sites in addition to the minimum number calculated to meet the specified statistical requirements. This allows for site attrition over life of the project.

habitat surveys surrounding the located uppermost fish point are expected to provide the data necessary to evaluate differences among PHB criteria across the state and within the eastern and western Washington regions. Data collected with consistent methods and crews might have lower variability than the data we used to estimate sample size.

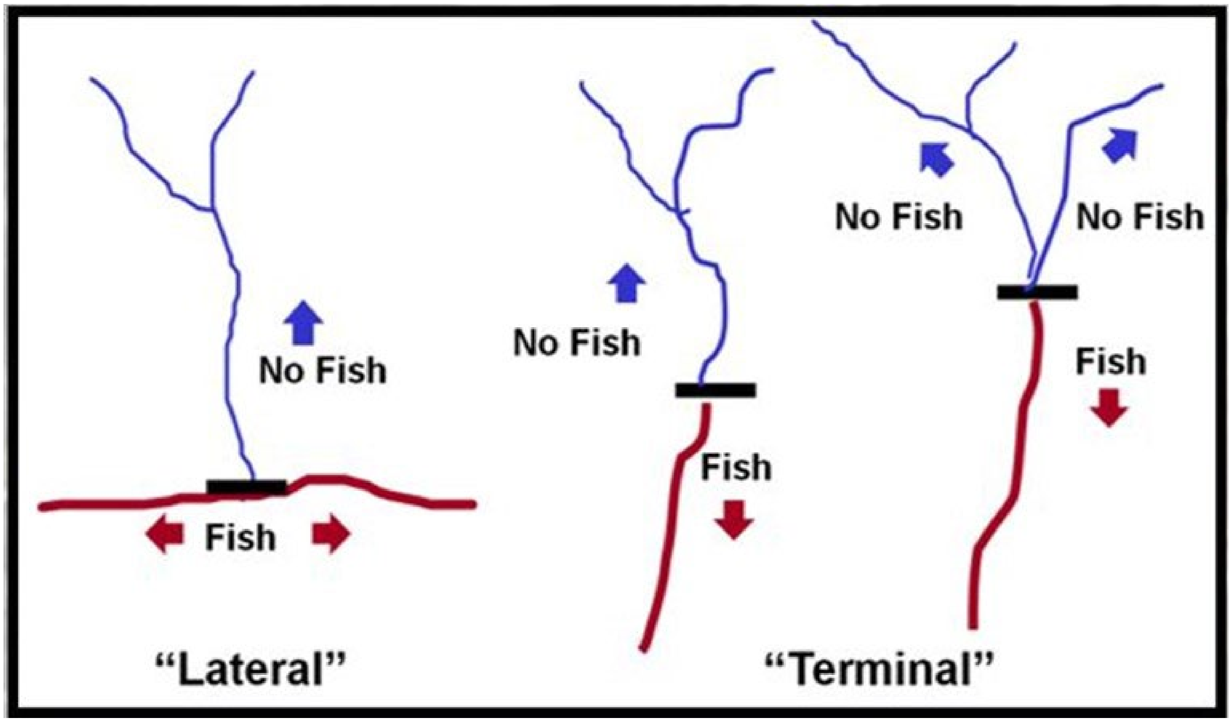

Figure 5. Schematic diagram of lateral versus terminal upstream limits of fish occurrence within streams. The black bar(s) indicate the location of the uppermost fish (Fransen et al. 2006).

Site Identification

The DNR Hydro Watercourses hydrography GIS data layer contains stream channel locations across the state. Stream lines are kept as segments with properties of each segment stored as attributes. Segments are divided at intersections with other stream segments and any place where their recorded properties change (e.g., fish use/non-fish use). The points at which this classification changes from fish (Type F) to non-fish (Type N) will be extracted from this hydro layer. The properties of the segments below and above the break will be retained with those data points and stored in the new point layer. The attributes (properties) of interest for this study include the criteria for fish use determination, such as whether it was a segment modeled as likely fish habitat, a concurred point from a water type modification form, or a legacy determination. Another attribute is whether that determination was based on biological information (fish observation or electroshocking findings) or on physical habitat assessment. Such information will be important for locating the optimum survey starting location but will not be used for the purposes of selecting sample streams.

The F/N break points will be intersected with the East/West Washington polygons to assign them an East/West attribute. Points will also be intersected with the DNR Ecoregions polygon layer to assign them an Ecoregion attribute. However, that attribute will be used as a covariate in post-hoc analyses rather than as a stratification variable unless test sampling indicates otherwise. The point layer will be subjected to the GRTS spatial randomization procedure, which will assign a sequence number to each point. The points to be inspected for this study will be selected from each side of the state in the sequence assigned. As points are discarded according to our rejection criteria (below), the next sequential point will be added to the sample population. In this way, spatial balance and random validity should be maintained. For each site in the GRTS design file that is considered for surveys, notes on any frame error (e.g., not actually forest land) or reasons for site rejection will be recorded so that inclusion probabilities for each site can be accurately calculated.

In practice, batches of points will be selected and assessed for suitability, access permission, and field crew accessibility to facilitate the sample set delineation prior to field surveys. These batches will ensure that more points (streams) are ready to be sampled than are actually needed in case selected points are rejected during the first study season. GRTS sample locations will be obtained from the sample draw in a GRTS design file. Surveys that maintain the order of sites in the GRTS design file are spatially balanced relative to the sampling frame from which the sample was drawn. Any sequential subset of sites in the GRTS ordering is a spatially balanced subset of sites. Note that spatial balance does not require that sites are *visited* in the order of the design file, but the sequential list of sites should be fully field-sampled by the end of the survey season with no skipped sites. This allows field crews to visit the sites in an efficient manner while maintaining overall spatial balance of the sample within any given year.

The F/N break point will identify the stream to be sampled, not necessarily the sample starting point. The starting points will be the uppermost known fish location for that stream based on any available information that can be obtained about that stream. The GIS layer contains some information, such as the typing basis. Other information may be obtained from landowners, tribal entities that monitor that stream area, and other local experts. In the case of tributary streams that have no reliable fish observations, the electrofishing survey will start at the confluence of the subject stream with the known fish-bearing mainstem stream. The initial survey will determine lateral versus terminal status of the selected tributary for site allocation purposes during site selection.

Site Rejection Criteria

Some potential study sites will be excluded from the sample population due to unforeseen circumstances. During the site selection and field validation task, study sites may be dropped as follows:

- Sites where the uppermost detected fish is associated with a man-made barrier;
- Streams showing evidence of recent (e.g., within five years) debris flows through the subject stream;
- Sites where we cannot obtain landowner permission for the full survey length;
- Sites that are not safely accessible by field crews;
- Other reasons determined by project team.

In every case that a site is excluded from the sample, the reasons will be thoroughly documented. Site rejection decisions will be approved by project managers in concert with the project team and are not the responsibility of field crews.

Temporal Revisit Design

Field surveys (electrofishing and habitat data collection) will be conducted during the spring/early summer and the late fall/early winter sampling periods (seasons). These two sample periods were chosen because they represent the most likely time periods for fish to be found at their uppermost point in the stream network, and therefore should be adequate to evaluate seasonal differences in the upper extent of fish use. Summer sampling may be beneficial to compare seasons; however, due to the low flows typical of summer, it is unlikely that fish would move higher into the system in that season (Cole and Lemke, 2006).

All sites will be surveyed every year during spring/early summer (current protocol electrofishing survey window of March 1 to July 15) for three years to examine inter-annual changes in uppermost detected fish locations. Surveys at all study sites over three years will increase the likelihood of capturing the uppermost extent of fish use by incorporating both temporal and spatial variability in fish movement due to physical (e.g., stream flow) and biological (population dynamics) factors.

To evaluate seasonal changes in the location of the uppermost detected fish, the sites that can be safely accessed in the fall/winter season will also be visited with an augmented serially-alternating panel design. One quarter of the sites will be assigned to the fixed panel and will be surveyed every fall/winter, and the remainder of sites will be allocated to three alternating panels. One of three alternating panels will be surveyed each year, with the sample augmented by the fixed panel to connect the sample across years and seasons. The fixed panel will consist of the full count of sites from Table 1, while the alternating panel counts will vary depending on site accessibility. The survey timing within both sampling periods will be determined through consultation with regional experts to optimize the timing based on local hydrology, fish life history, and potential for site access, and resurvey timing will be consistent (within two weeks of the original survey date) across years.

Table 1. Overall sampling schedule and number of sample sites by calendar year and season 2025 to 2027. All sites will be sampled in spring to early summer (March 1 to July 15) with the seasonal fixed and alternating panel being resampled in fall to early winter high flow period (dates determined through consultation with regional experts). A pilot study sampling 15 sites in eastern and 12 sites in western Washington was completed in September of 2018 (Roni et al. 2018).

Sampling Event	Pilot year (2018)	Year 1 (2025)	Year 2 (2026)	Year 3 (2027)
Spring to early summer		160 eastern Washington 190 western Washington	160 eastern Washington 190 western Washington	160 eastern Washington 190 western Washington
Late Fall/Winter Fixed Panel Sampled All Years (same sites)	27 to test methods	40 E WA 48 W WA	40 E WA 48 W WA	40 E WA 48 W WA
Late Fall/Winter Alternating panel, Sampled Only in Single Season		40 E WA 48 W WA	40 E WA 47 W WA	40 E WA 47 W WA

Reporting	Pilot study report	Annual report	Annual Report	Final Report

Data Collection

Protocol Electrofishing and Habitat Surveys

Electrofishing and longitudinal habitat surveys will provide a robust data set to inform the PHB and DPC analyses. Electrofishing surveys will be conducted to determine the location of the uppermost fish at each survey event. An intensive longitudinal thalweg and water surface profile survey (based on Roni et al. 2018) will be conducted up- and downstream of the uppermost fish points following the electrofishing surveys. The channel survey data will be used to partition the study reach into variable-length stream segments that are scaled to lengths of homogeneous habitat attributes within the long-channel profile. The length of segments will be based on changes in gradient and channel width that are associated with inflection points and/or changes in habitat features (e.g., vertical and non-vertical obstacle). Vertical and near-vertical obstacles will be captured as individual segments, as such features will have some segment length associated with them. Confluences with inconsequentially small tributaries can be noted as attributes of the receiving stream, whereas confluences with relevant larger tributaries will constitute segment breaks (see field methods for decision criteria).

Prior to sampling a site, the project team will review existing information from any available sources on access, previous location of uppermost detected fish and habitat data, and obtain landowner permission for access and sampling. In determining the upstream extent of fish distribution, multiple upstream segments may be available for survey. When this situation occurs, the selected surveyed segment will be the mainstem channel, defined as the stream segment with the largest contributing basin area upstream from a tributary junction (should have largest bankfull width, most flow, etc.). Where basin area upstream from a junction appears approximately equal, additional on-site metrics such as bankfull width and/or flow will be relied on to determine upstream direction of survey. Stream segments not included in the GIS hydro layer may be encountered when moving upstream. These stream segments will be documented and included in the survey process in accordance with the above criteria.

Field crews will use modified DNR protocol electrofishing surveys, which will only be conducted when sampling conditions are suitable (avoiding periods of extreme high/low flow or temperature, elevated turbidity, etc.). Water temperature (to the nearest 0.1 °C), conductivity (microsiemens), and electrofishing setting (e.g., voltage, frequency, pulse width) will be recorded at the beginning of each electrofishing survey. The GPS coordinates of each uppermost detected fish 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 species and approximate sizes will be recorded. Electrofishing surveys will continue from the uppermost detected fish point upstream to at least the end of current DPC. In the event the uppermost detected fish is found at the end of DPC, electrofishing will continue 660 feet (upstream) to align with the extent of the detailed habitat surveys. We will also record electrofishing survey time (shock seconds). In addition, coarse scale habitat data will be collected on the full extent of the stream sampled during the e-fishing survey. These data will include channel gradient, bankfull width, wetted width and confinement within unequal length segments of relatively uniform habitat character.

An intensive longitudinal thalweg and water surface profile survey (based on Roni et al. 2018) will be used to assess key habitat attributes (i.e., gradient, bankfull and wetted width, water depth, substrate size composition, and height of channel steps) below and above the uppermost detected fish (Figure 6). 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 uppermost detected fish location occurred within 200 m (Cole et al. 2006). Therefore, we will use a distance of 660 feet (200 m) below and 660 feet above the uppermost detected fish as our intensive habitat survey reach. The crew will measure 660 feet (horizontal distance) downstream from the uppermost detected fish point to determine the beginning point for the intensive stream habitat survey.

The intensive habitat survey involves surveying the streambed elevation along the deepest portion of the stream (the thalweg), yielding a two-dimensional longitudinal profile of streambed elevations. This 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). We will also be recording water surface heights because surface levels are what are important to fish with regard to obstacle heights. Survey measurements will be taken every ten feet, and at any significant inflection points in topography or planform to be sure we capture all changes in thalweg topography and gradient. 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 and observations at each point will include horizontal distance, vertical distance, and slope between survey points, water depths, wetted widths, bankfull width, dominant substrate (e.g., sand, gravel, cobble), large wood, habitat feature type (e.g., pool, riffle, cascade), and general characterization of flow and water conditions. Water surface elevation will be calculated after the survey from the bed elevation plus the measured water depth. 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 and obstacles are considered deformable and therefore 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 (e.g., tunneled or sub-surface flow) 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 with or immediately following the spring sampling effort. The survey will be repeated annually to ensure we have a complete survey 660 feet above and 660 feet below the uppermost detected fish found during each sampling event (Figure 6). During each survey, fixed elevation benchmarks will be placed at the bottom, middle (uppermost fish point) and top of the intensive habitat survey reach to facilitate the coherence of repeat surveys. 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 (Clark et al. 2019, 2020).

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 amongst sites (Kershner et al. 2002; Roper et al. 2002; Whitacre et al. 2007, Archer et al. 2004).

Therefore, all crews will participate in a three to five-day training course each year prior to initiation of spring sampling to ensure consistency among crews in determining uppermost detected fish locations, surveying habitat characteristics (long-profiles), and data collection. Training should incorporate identifying potential sources of variation in measurement that can result from dense vegetation, identification of features, and clarity of protocols (Roper et al. 2010). In addition, mid-season check-in/corrections will be conducted with each crew to prevent sampling drift (this process will be outlined in the Quality Assurance Plan). Moreover, to quantify variability among crews in conducting longitudinal surveys, we propose to resample a subset of sites each spring during the same year and season by other crews every year. Since variation in stream flow during subsequent surveys should not affect the longitudinal bed profile, we don't expect flow changes to contribute to variability observed among crews in these resurveys.

We will evaluate crew variability on select streams where the DPC was located within the length of the intensive survey to be able to compare the two (intensive and coarse habitat) survey methods. A fixed reference point for each stream will be established at the uppermost fish point identified during the first survey. This point will be benchmarked and used as a measurement anchor point throughout the study, even if the uppermost fish point in subsequent surveys moves (those movements will also be measured from the benchmark).

The streams to be used for the crew variability test can be selected to meet this requirement based on the assumption the among-crew variability in locating the DPC on each stream is independent of the distance from the uppermost fish point (EOF). This is due to the GPS-based method we expect to use to conduct the coarse survey, which will not depend on turnpoints or other distance-associated measurement error compounding. If there is an indication this assumption is not true after the first survey event and that there is a distance-related bias in the variability, a different test stream selection method can be implemented that would not be based on that assumption.

Reach- and Basin-Scale Explanatory Variables Derived from Office and Remote Sources

We will also collect data on several other factors that are thought to play a role in uppermost detected fish point and identification of PHBs and DPC from sources other than field data. These include: elevation, aspect, drainage area, distance-from-divide[8], valley width, annual precipitation, channel type[9], riparian stand condition[10], whether uppermost detected fish and PHB is at a mid-channel point (mainstem or terminal) or confluence (tributary or lateral tributary), dominant drainage area geologic competence category[11], stream order, 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, distance-from-divide, and valley width are important because they, combined with annual precipitation, are related to flow and stream size. The local geology around the stream determines whether stream substrate tends to consist of hard, resistant, larger particles or friable, fine-grained substrates, which have been shown to influence fish distribution (Gresswell et al. 2006; Torgersen et al. 2008).

Data Preparation

Physical attribute and fish presence data will be organized by site and variable-length segment as laid out in Appendix G. To prepare data for analysis, the stream profile will be divided into variable-length homogeneous segments, and each segment will be populated with a suite of segment-scale physical attributes and fish presence or absence. Variable-length segments will also be populated with associated basin-scale attributes that will be derived from GIS. Other basin-scale characteristics will be included for each site. Measures such as gradient and channel width can be used to form threshold variables and cumulative metrics (e.g., gradient and width expressed over multiple segments) that can be assessed as predictors of PHBs. Data sets will be developed for each sampling event to assess changes in distribution over time.

For the purposes of this study, we define the “DPC point” as the point where the stream channel ceases to meet any one of the DPC, when surveying in the upstream direction, and where no reaches that do meet DPC exist further upstream. Although the DPC conditions must

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[8] Palmquist (2005) found distance-from-divide to be less variable and more reliably calculated than basin area.

[9] Montgomery & Buffington, 1993

[10] Watershed Analysis categories, WA DNR 1997

[11] Competent/Incompetent, per McIntyre et al. 2009

persist for minimal reach lengths, the DPC point is the downstream-most location where the default physical criterion was exceeded, and these conditions persist upstream. This location will be determined by field crews during surveys.

Data Analyses

Data Exploration, Summary Statistics, and Initial Tests

Data for the DPC and PHB studies will be collected concurrently and from the same sites. Both the DPC and PHB studies will use the same EOF and EOFH points. Ecogeohydrologic covariates (e.g., elevation, ecoregion, and basin area) assessed for the various PHB EOFH points will also be determined for the identified DPC locations and incorporated into the analyses. The coarse-scale habitat data (channel gradient, bankfull width, wetted width and confinement, within unequal length segments of relatively uniform habitat character) collected during the electrofishing survey (see PHB/DPC field manual, to be developed) will be used to identify the upstream extent of current DPC. Initial exploration of these coarse-scale habitat data will include graphical examination of habitat metrics for segments within a site and segment means of physical characteristics for each site between EOF and EOFH points and the upstream extent of current DPC. The length of segments will be based on changes in channel gradient (e.g., inflection points), changes in channel width (e.g., tributary junctions), and/or specific habitat features (e.g., vertical [falls] and non-vertical obstacles [steep cascades]). See Appendix D for a more detailed description of analyses.

Assessment of Current DPC (Research Questions 1-4)

Distances between DPC points and EOF/EOFH as determined from the PHB study analyses will be used to generate two performance metrics for the DPC analysis (Table 2 and Figure 6):

1. Encompassment is a binary variable for each stream that is true when the DPC point is upstream of EOF/EOFH points. It is summarized across the sample population as the proportion of streams for which the DPC point falls upstream of EOF/EOFH point and reflects the degree to which DPC thresholds encompass EOF/EOFH points across the sample population (Research Question #1).

2. Alignment describes the direction and distances between the end of DPC thresholds for each stream and two metrics of interest: EOF and EOFH, as defined by potential habitat breaks (PHBs). Positive distance values represent EOF/EOFH upstream of DPC thresholds and negative distance values would represent EOF/EOFH downstream of DPC thresholds (Research Question #2).

These two metrics can vary inversely. Adjusting the current DPC would change the relationship between these response variables. For example, DPC thresholds that correspond to the channel head of every stream channel would encompass 100% of EOF/EOFH points but would result in reduced alignment with them. DPC thresholds that fall further downstream from the channel head in an effort to improve alignment could result in reduced encompassment. Further, if the DPC threshold falls too far downstream in a watershed (i.e., downstream of EOF/EOFH points), it would encompass fewer EOF/EOFH locations while also not resulting in increased alignment (Figure 6). In addition, the influence of physical and ecogeohydrologic covariates on the encompassment and alignment addressed in RQ 1 and RQ 2 will be assessed using generalized mixed models (Research Question #3).

The variation (deformability) in stream characteristics at the current DPC thresholds will be assessed to determine the temporal stability of physical features for the duration of the study. Change in stream metrics across sample years will be assessed using various statistical models (Research Question #4).

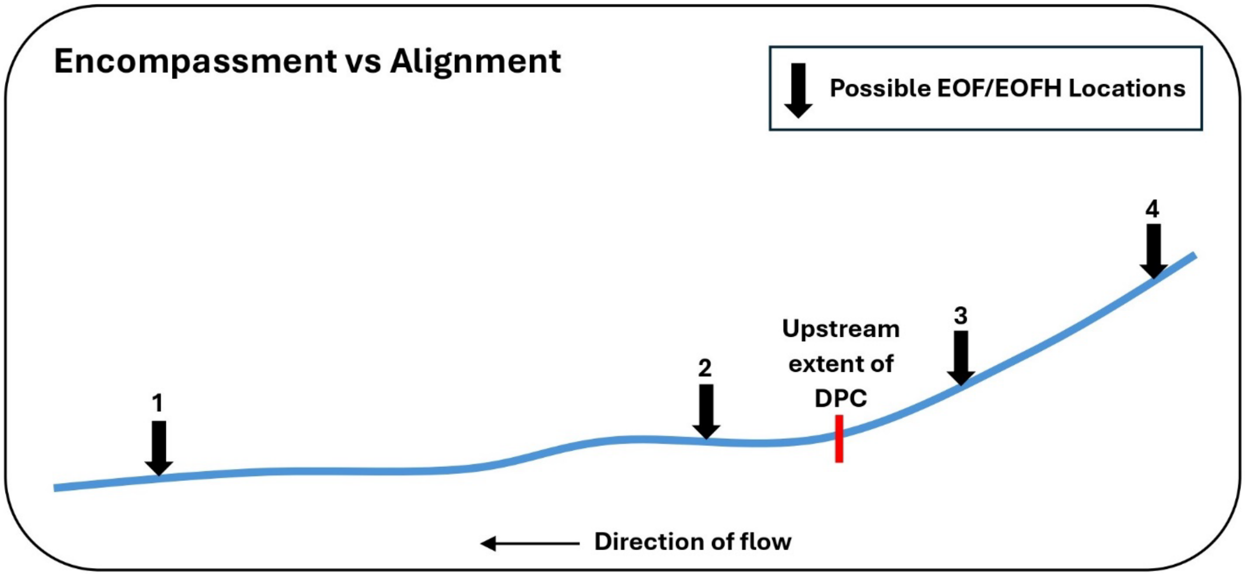

Figure 6. Illustration of four possible EOF/EOFH locations in relation to the upstream extent of DPC point on a hypothetical stream segment. The assessment of 'encompassment' and 'alignment' conditions vary depending on the location of the EOF/EOFH relative to the DPC point. Encompassment is a binary response variable, where a DPC point that occurs upstream from an EOF/EOFH location is considered to 'encompass' that location (Encompassment = YES), while a DPC point that occurs downstream from an EOF/EOFH location does not (Encompassment = NO). Alignment is a continuous quantitative response variable that represents the distance between the EOF/EOFH location and the DPC point, where a DPC point that occurs in relatively close proximity to an EOF/EOFH location is considered to be more 'aligned' with that location, while a DPC point that does not occur in relatively close proximity to an EOF/EOFH location is considered to be less 'aligned' with that location. For alignment, negative distance values represent EOF/EOFH locations downstream from the DPC point (examples 1 and 2), while positive distance values represent EOF/EOFH locations upstream from the DPC point (examples 3 and 4). Results for the four possible EOF/EOFH locations presented in this figure would be: (1) Encompass = YES / less aligned; (2) Encompass = YES / more aligned; (3) Encompass = NO / more aligned; and (4) Encompass = NO / less aligned.

Consistency in Identifying DPC Thresholds (Research Question #5)

Crew-variability testing conducted within this study will provide insight into the ability to identify the end of DPC using data collected by different survey crews when implementing FHAM in the field in the future (Research Question #5). It will also assess the contribution of crew variability to the overall variability found within the study.

Data from the subset of streams surveyed multiple times by different survey crews will be used to assess crew variability in measuring the physical stream characteristics that would be used to identify DPC. Physical characteristics measured at the same streams by different survey crews will be analyzed to identify attributes that are more susceptible to survey crew variability. Distances between DPC identified at the same stream based on data collected by different crews will be modeled as a function of spatial characteristics such as region and ecoregion to determine if spatial factors influence crew variability.

For the crew variability test, the distances between the first year uppermost detected fish habitat unit ("reference point") and each of the DPC thresholds as determined by each crew in a given year will be calculated. The intensive longitudinal survey crew variability will also be evaluated on these same streams. Doing so will allow comparison between the crew variabilities found for each survey method (or survey method-analysis method).

Identify and Compare Alternative DPC (Research Question #6)

A classification and regression tree analysis will be used to explore alternate combinations of stream gradient, bankfull width, and basin characteristics to assess tradeoffs between encompassment of and alignment with EOF and EOFH (Research Question #6). See Table 2 and Appendix D for details.

Assessment of Habitat Associated with EOF/EOFH Locations Conducted in the Companion PHB Study

Spatial patterns in physical channel and basin characteristics (e.g., bankfull width; average gradient, basin size) associated with the identified upstream extent of fish habitat will be examined to determine how these metrics vary geographically across the state of Washington. Maps and histograms of physical channel and basin characteristics will be used to assess distributional patterns in attributes associated with the uppermost detected fish and the upstream extent of fish habitat. Summaries statistics (mean, median, standard deviation, range) of physical channel and basin characteristics will be calculated by spatial categories such as region (e.g., eastern versus western Washington) and ecoregion. Generalized linear mixed models (GLMM; McCullagh and Nelder 2019, Bolker et al. 2009) of physical channel and basin characteristic metrics, as response variables, will incorporate fixed effects for region, ecoregion, point type (terminal and lateral), and other spatial factors. Random effects reflecting spatial structure (e.g., segments within streams) will be incorporated to account for correlation.

Surveys will identify the uppermost detected fish point during each sample period at each study site, and the first PHB by each definition encountered upstream from that point will be derived from these data. Characteristics of these PHBs and changes in the locations of uppermost detected fish between surveys will be used to determine how survey timing might influence which PHB would be associated with the proposed F/N break and how frequently the PHB might be identified differently. Distributions of continuous habitat metrics (e.g., gradient, channel width) will be compared with boxplots or violin plots for sites where fish have moved above PHBs compared to sites where fish did not. These graphical summaries will be used to identify factors associated with fish movement by year and season. The probability that the uppermost PHB at a site is consistently selected during different survey occasions will be modeled as a function of season, spatial factors, point type, and physical channel and basin characteristics to determine what factors influence repeatability of identifying a PHB.

Physical changes in features originally identified as PHBs over time will also be assessed. For each measured physical characteristic, a GLMM will be applied to examine effects of time to estimate trends or changes over the course of the study. An examination of how similar features appear to limit upstream fish distributions in some contexts but not others will be conducted to examine any potential interactions among physical characteristics (e.g., headwaters vs. downstream; different flow levels). These relationships will be assessed in GLMMs with significance tests of the interaction effects.

Table 2. Proposed data analysis methods by Research Question

Question	Proposed Analysis
Assessment of Current DPC	
1. How frequently does the upstream extent of fish use and/or fish habitat[a] end at a point downstream, upstream, or coincident with current DPC thresholds for bankfull width, gradient, or both?	Calculate, for all combinations, the proportion of occurrences when the EOF/EOFH is downstream/upstream/coincident with bankfull width/gradient/both thresholds. These results will be presented in a table for all nine combinations. To address the direction and frequency of how well the thresholds encompass fish use, we will also combine the downstream and coincident categories.
2. What is the distribution of distances between the upstream extent of fish use and/or fish habitat[a] points downstream, upstream, or coincident with	Generate histograms of distances from EOF/EOFH location to DPC thresholds to investigate alignment of EOF/EOFH and

Question	Proposed Analysis
current DPC thresholds for bankfull width, gradient, or both?	DPC. Additional histograms will be made for the distance from the locations at which each of the PHB criteria[b] is met and DPC thresholds to investigate relationships between DPC and PHB. Positive distance values on the histograms would represent EOF/EOFH or PHBs upstream of DPC thresholds, negative distance values would represent EOF/EOFH or PHBs downstream of DPC thresholds, and values of 0 would be coincident. Calculate quantiles and other summary statistics to capture the distribution of distances for each metric.
3. How do physical and ecogeohydrologic covariates influence the frequency and distribution of distances addressed in RQs 1 and 2?	Use stream-level physical and ecogeohydrologic covariates with a binomial generalized linear mixed model of the frequency that the DPC encompasses fish use to investigate relationships with frequency (i.e., encompassment). Similarly, use stream-level physical and ecogeohydrologic covariates in generalized linear mixed models of distances between the DPC and the EOF location and the locations at which each of the PHB criteria is met to investigate relationships with distribution (i.e., alignment). Produce marginal effects plots to demonstrate impact of each physical and ecogeohydrologic covariate on encompassment and alignment.
4. How frequently and by how much do the physical channel conditions (e.g., bankfull width and gradient) at the locations initially identified as the end of current DPC change over the course of the study?	Summarize the degree of change in each metric (deformability) at the first location identified as end of current DPC. Perform a univariate trend analysis conducted with generalized linear mixed models (GLMM) for each of the channel condition metrics over time. Produce marginal effects plots to understand the degree of change. Identify location of current end of DPC on each survey occasion and model the distance between these initial DPC points and subsequent DPC points based on resurveys as a function of related covariates.
Consistency in Identifying DPC Thresholds	
5. Can protocols used to identify DPC be consistently applied among survey crews and be expected to provide similar results in practice?	In the DPC crew variability study, we will assess crew variability as well as consistency and repeatability of measurements. For assessment of variability, distances will be calculated between the first year uppermost detected fish habitat unit ("reference point")

Question	Proposed Analysis
	and each of the DPC thresholds as determined by each crew's measurements as well as the DPC location identified using the intensive longitudinal habitat survey data. The resulting distances (as absolute values) will be modeled to (1) estimate variability among survey crews and protocols and (2) to identify factors that influence the DPC location and variation. The variability among the number of identified segments in a stream, measured lengths, and measured elevations by field crews, will be modeled to assess the consistency and repeatability of metrics collected by field crews on the same streams and to assess which metrics are more prone to crew variability. Stream level measurement error will be characterized at each test stream and across all test streams.
Identify and Compare Alternative DPC	
6. Are there singular or combinations of physical channel metrics (e.g., stream gradient and bankfull width) and basin characteristics (e.g., basin area) alternative to current DPC that would serve as more accurate[12] DPC criteria relative to the location of the last detected fish? If so, what are they?	Conduct a classification and regression tree analysis to identify alternative default physical criteria. Set model parameters for false negatives at different allowance thresholds to investigate trade-offs for various alternative thresholds. Visually display the distribution of distances from last detected fish to alternative DPC for each of the false negative thresholds. Generate HTML tool for decision making purposes and investigation. Apply current DPC to new stream data and compare stream segment classifications between the current and alternative DPC.
[a] For the purposes of this study, "fish habitat" is as defined by each PHB option derived from the PHB study field data as it would be applied within FHAM (see Appendix B for PHB options). [b] PHB criteria includes the existing Board-proposed PHBs and newly derived criteria. See Appendix A for PHB Board-proposed criteria and variable definitions.	

Potential Challenges and Limitations

Although the methods we propose have been widely used to quantify habitat conditions and identify the location of uppermost detected fish, there are some potential challenges. These include location of sites that meet selection criteria, access to initially identified sites, and

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[12] "Accuracy" herein refers to alignment with and encompassment (capture) of EOF/EOFH points. See questions 1 and 2 in Appendix D, Table 2, and Figure 6.

access to these sites throughout the two seasons and three years. It is possible that we may not have access to selected sample sites due to issues with land ownership, landowner willingness to permit access, or problems with the road networks. Thus, if a site is not suitable due to access or for other reasons, a different site (the next consecutive site number from the initial random selection) would be used to replace the non-suitable site, and the reasons the site is excluded will be documented. This study is targeted at identifying the features and channel characteristics that limit the upstream extent of fish distribution, which should not be strongly dependent on particular land uses or ownership types. Therefore, results should have broad applicability despite any site selection biases that may occur. 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. The recommended sample size includes sites in addition to the minimum number calculated to meet the specified statistical requirements. This allows for some site attrition over the life of the project.

Consistent identification of the upstream extent of DPC by different field crews, across sites and time, could prove to be a challenge. Quality assurance measures are planned that will reduce this source of variability. In addition, the crew variability investigation will enable us to estimate the effect of this variation on the study findings.

An additional challenge with study implementation will be largely financial and could result from underestimating or overestimating the amount of time and cost needed to adequately sample sites initially and repeatedly. Loss of funding over the time frame of the study could conceivably occur.

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 blockages 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 or low 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 relatively longer time intervals in response to local disturbance regimes (Kershner et al. 2018; Penaluna et al. 2018). Major disturbances can radically alter the basic physical characteristics of streams, such as width and gradient, and can also create new obstacles and/or remove previously existing ones. An important implication of the notion that the potential use of small tributaries by fish can change over time is that while some stream segments are not now occupied by fish, there is no guarantee that they may not become suitable in the future, or that those 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 sample time is limited to three years and 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. We rely on the large number of sampling sites to capture fish use of channel conditions that might be temporarily rendered unusable at some sites due to such episodic events.

A 3-year study period also may not capture a sufficiently broad range of hydrological conditions associated with shifts in climatic cycles (e.g., El-Nino/La-Nina) to allow for the estimation of the relationship between EOF and the upstream extent of DPC. The plan to visit many sites multiple times is an attempt to eliminate the background noise of climate on the EOF-DPC relationship as a whole. Study sites could be revisited in the future to look at longer-term changes in uppermost detected fish locations and in the physical characteristics of the streams in the vicinity of EOF and upstream extent of DPC, if desired.

Expected Results

Highly precise measurements of stream channel conditions both upstream and downstream of uppermost detected fish locations will provide a nearly continuous dataset of physical stream characteristics within the surveyed area. Thus, we will be able to objectively identify the physical stream characteristics most closely associated with uppermost detected fish. However, we will only have these more precise measurement data for the DPC where the EOF points fall within 200 m of the upstream extent of DPC. Seasonal and inter-annual sampling will allow us to examine any variation of stream physical characteristics in the vicinity of the upper extent of DPC across years and seasons.

The results should also help inform the protocols for measuring gradient and bankfull width in the field to minimize variability among field crews and ensure consistent identification of the upstream extent of DPC. Focus should be placed on specific protocols used to consistently and accurately identify and measure physical stream characteristics, including gradient, bankfull width, and any other criteria that may be used to identify the upstream extent of DPC in this study.

Related Studies

The DPC study is a companion to and integrated with the PHB validation study (ISAG Project Team 2023). Data for the DPC and PHB studies will be collected concurrently from the same sites. Both the DPC and PHB studies will use the same end of fish (EOF) and end of fish habitat (EOFH) points generated for the PHB study as input to some of the analyses in this study.

The Anadromous Fish Floor (AFF) study will delineate areas where anadromous fish use can reasonably be presumed regardless of whether those fish are present when surveys are conducted. While the AFF is intended to be used in conjunction with the Fish Habitat Assessment Methodology (FHAM), AFF points would play a different role in the water typing process than PHB and DPC points. Conceptually, the AFF and DPC function as bookends, between which implementation of FHAM begins.

See also the Board-approved Water Typing Strategy for the relationship to the water type mapping and modeling projects.

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https://www.dnr.wa.gov/publications/bc_fb_mtgminutes_20180213_14.pdf, https://www.dnr.wa.gov/publications/bc_fpb_mtg_packet_20180213.pdf?p3kh5ut FPB meeting minutes Feb 2018: "Berge reiterated that a PHB is not necessarily the Type F/N break, but rather the first point of potential unfavorable habitat and the starting point for a protocol survey."

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Appendix A. CMER Work Plan and Prior Science Panel Study Questions

CMER Workplan Water Typing Rule Group Critical Questions

The following are CMER Work Plan critical questions from the Water Typing Rule Group Program this study will address:

CQ 1. To what extent do current default physical criteria for Type-F waters, considering potential geographic differences, accurately identify the upstream extent of (detected) fish presence (all species) and/or fish habitat?

CQ 2. Can alternative (to current) default physical criteria for Type-F waters, considering potential geographic differences, be identified that would more accurately and consistently identify the upstream extent of (detected) fish presence (all species) and/or fish habitat?

CQ 3. Are there sustained gradient or stream size thresholds alone that serve as default physical criteria?

Appendix B. Fish Habitat Assessment Method (FHAM)[13]

Water typing surveyors have used professional judgment to estimate "habitat likely to be used by fish" when proposing regulatory fish-bearing/non-fish-bearing (F/N) water type breaks. Stream segments that are accessible to fish and exhibit the same characteristics as 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 embraced the concept of a Fish Habitat Assessment Methodology developed by a diverse group of AMP technical stakeholders intended to be repeatable, implementable, and enforceable (WA Forest Practices Board 2018; WA DNR 2019). The FHAM will utilize PHBs that reflect a measurable change in the physical stream characteristics at or upstream from a detected fish point, above which a protocol electrofishing survey would be undertaken (Figure B-1B-1). The first PHB located at or upstream from the uppermost detected fish would serve as the end of fish habitat (F/N Break) when no fish are detected above this PHB.

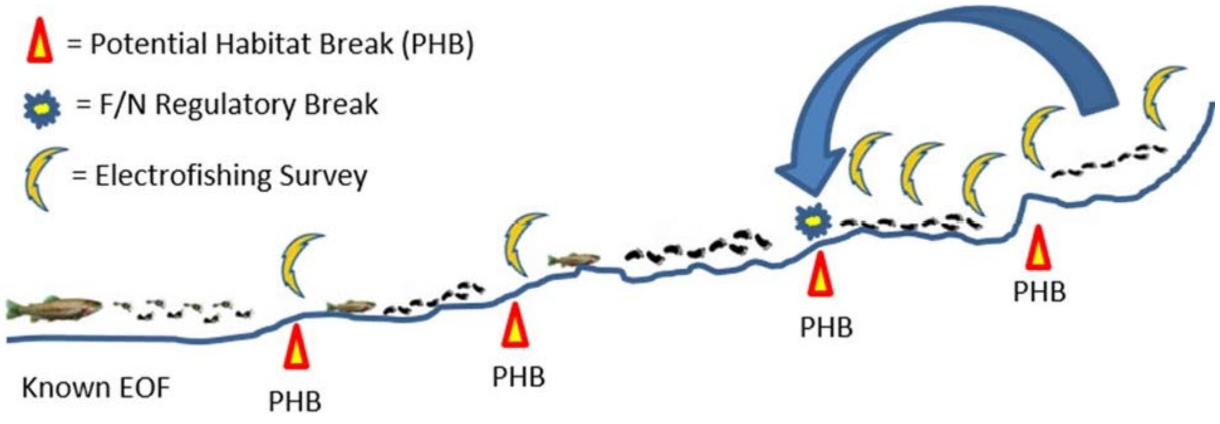

Figure B-1. Example of how the PHB criteria and Fish Habitat Assessment Methodology (FHAM) will be applied in the field. The first step is to identify the uppermost detected fish location. Once the point is identified, the survey team would begin to measure bankfull width, gradient, and barrier (obstacle) criteria while moving upstream. Once a point in the stream meeting one of the PHB

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[13] From "Evaluation of potential habitat breaks (PHBs) for use in delineating the upstream extent of fish habitat in forested landscapes in Washington State" (PHB Study Design), May 2023.

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 ¼ mile upstream, 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. (PHB Science Panel 2019)

Per FHAM, PHBs are based on stream size, gradient, and access to fish habitat. The PHB Science Panel 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). The Panel considered a variety of potential PHB criteria, including the physical attributes of a stream channel, water quality and quantity parameters, and other factors that might contribute to measurable habitat breaks. These attributes were evaluated for the ability to simply, objectively, accurately and repeatably measure them in the field, as well as the amount and relevance of existing scientific literature pertaining to each. The Panel concluded that it was possible to identify PHBs based on stream size, channel gradient, and natural non-deformable obstacles. These three attributes satisfied the objectives of simplicity, objectivity, accuracy, ease of measurement, and repeatability that can be consistently identified in the field and can be incorporated into a practical survey protocol. The Board then selected three combinations of stakeholder-proposed PHB criteria for these attributes at their 14 February 2018 meeting (WA FPB 2018) and instructed the PHB Science Panel to develop a field study to evaluate the performance of these proposals (Table 1). It was important to the Board to determine which of the proposed 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, especially evaluating aspects of field measurement practicality and repeatability (WA Forest Practices Board 2017b). This study is designed to evaluate which Board-identified PHB criteria most accurately identify the upstream extent of fish habitat and to determine whether an alternative set or combination of empirically derived criteria more accurately achieves this goal (CMER 2020).

Table 3. Three combinations of barrier (obstacle), gradient, and width PHBs selected for evaluation by the Washington Forest Practices Board during their February 2018 meeting. Descriptions are

abbreviated for readability from WA Forest Practices Board 2018. Criteria may be revised by the Forest Practices Board before project is implemented.

Type/	Description of Criteria
Criteria Set 1	
Width	2 ft BFW threshold (upstream BFW ≤2ft)
Gradient	Gradient increase of ≥10%
Vertical Obstacle	Obstacle height ≥3ft
Non-Vert Obstacle	Obstacle gradient ≥20%, AND elevation difference is ≥ 1x upstream BFW
Criteria Set 2	
Width	2 ft BFW threshold (upstream BFW ≤2ft)
Gradient	Gradient increase of ≥5%
Vertical Obstacle	Obstacle height ≥3ft AND ≥ 1x upstream BFW
Non-Vert Obstacle	Obstacle gradient ≥30%, AND elevation difference is > 2x upstream BFW
Criteria Set 3	
Width	20% BFW decrease (up- to downstream BFW ratio at tributary junctions ≤.8)
Gradient	Gradient increase of ≥5%
Vertical Obstacle	Obstacle height ≥3ft
Non-Vert Obstacle	Obstacle gradient ≥20%, AND elevation difference is ≥ upstream BFW

Appendix C. Sample Size Estimation Memo of Jan 4, 2022

ENVIRONMENTAL & STATISTICAL CONSULTANTS
2725 NW Walnut Blvd., Corvallis, OR 97330
Phone: 541 738 6198 ◆ www.west-inc.com

MEMO

To: Instream Science Advisory Group
From: Leigh Ann Starcevich (WEST, Inc.)
Date: January 4, 2022
Re: Sample size approximation from Eastern WA and Western WA data

The Instream Science Advisory Group (ISAG) is developing a sampling design for surveys of potential habitat breaks (PHB) for fish use. A sample size approximation is needed to ensure that the data collected to assess criteria defined by the Washington Forest Practices Board (Board) for the Fish Habitat Assessment methodology (FHAM) yield useful covariates for PHB modeling. Cooperative Monitoring, Evaluation, and Research (CMER) data from eastern Washington surveys conducted in 2001, 2002, and 2005 were provided by Chris Mendoza. Stream habitat data associated with uppermost detected fish points from concurred water type modification forms for surveys conducted in western Washington between 2016 and 2020 were provided by Weyerhaeuser. These data were used to approximate sample sizes needed to estimate means of PHB model covariates with desired levels of precision and accuracy.

Eastern Washington Data

The eastern Washington data were collected in 2001 by Terrapin Environmental (Cupp 2002) and in 2002 and 2005 by ABR, Inc. Environmental Research & Services (Cole and Lemke 2003, 2006). Channel characteristic metrics included mean channel widths and means gradients for reaches extending up to 100m above and 100m below the last fish point obtained in the 2001 survey. Data for barriers were collected but inconsistencies in how barriers were classified and recorded prevented sample size evaluation specific to barriers. For surveys conducted after 2001, the last fish distance relative to the 2001 last fish was provided. A metric for the maximum change in distance from the 2001 last fish point was calculated for each site. Using the 2001 point as baseline, the range of distances where the last fish was observed during subsequent surveys was calculated and used to inform the sample size approximation.

Data screening was used to limit the data set to a subset of locations with natural habitat breaks. Unscreened data sets included sites where large woody debris jams were found, no surface flow occurred for at least 100m, and surveys were conducted past July 15. The screened data sets eliminated many of these sites. Sites where fish passage was limited by culverts were removed from all data sets. About 46% of the unscreened points were classified as lateral points.

Western Washington Data

Water type modification form data from western Washington were collected between 2016 and 2021 and included gradient and bankfull width metrics for stream segments upstream and downstream of the last fish point. For many lateral points, only the upstream measurements were provided because the point was located on a river mainstem. At these points, data on gradient and bankfull width metrics downstream of the confluence were not always collected, so these points are omitted for sample size calculations based on the downstream metrics. About 70% of the points were classified as lateral points.

Sample Size Approximation

Estimated means of channel characteristic metrics and change in last fish locations among years were used as the basis for the sample size approximation. Let z reflect the quantile of a standard normal random variable for a given Type I error rate (α). For $\alpha = 0.10$ we have that $z = 1.645$. Let d be the maximum absolute error (i.e., confidence interval half-width), let r be the relative precision of the estimate, and let γ be the coefficient of variation (CV). The coefficient of variation is a standardized measure of precision calculated as the standard deviation (SD) of the outcome divided by the mean of the outcome (Thompson 2002). The sample size approximation formula below is applied with the mean and standard deviation for each outcome of interest. The sample size needed to obtain an estimate that is within 100*r% of the true mean with probability 1 - α was calculated. In other words, the confidence interval half-width of the mean should be 100*r% of the true mean. The sample size to accomplish this goal is based on a normal approximation and calculated as:

$$n = \frac{z^2\gamma^2}{r^2}.$$

For each outcome of interest from the eastern Washington data sets, the coefficient of variation was computed from the mean and standard deviation of the screened (Tables 1 through 3) and unscreened (Tables 4 through 6) data, and sample sizes were approximated for relative precision values of 0.10, 0.15, 0.20, and 0.30. Variation was slightly higher in the unscreened data set, resulting in slightly larger sample sizes. For the eastern data, the coefficients of variation were higher for terminal points than for lateral points for the upstream reach gradient, reach gradient difference, and maximum change in distance (Tables 2 and 3, Tables 5 and 6). The coefficients of variation were higher for lateral points than for terminal points for downstream reach gradient and downstream bankfull width.

Similar results were observed for the western Washington data. For estimation of mean channel metrics across point types, coefficients of variation ranged from 0.69 to 0.79 for reach gradient metrics and for the bankfull width above the point. However, bankfull width measured below the last fish point was less precise than in the eastern Washington data set with a CV of 1.28 (Table 7). The precision for the gradient difference was similar to that observed for the eastern Washington data with coefficients of variation near or above one. For the western data, the coefficients of variation were higher for terminal points than for lateral points for the reach gradient difference (Tables 8 and 9). The coefficients of variation were higher for lateral points than for terminal points for reach gradient metrics and the downstream bankfull width. The higher variability in these metrics suggest larger sample sizes are needed for precise estimation of means. While mean estimation of channel characteristics is not the ultimate inferential goal, we assume that samples large enough to provide information on the range of values for each of the potential PHB modeling covariates will yield a useful data set for modeling.

The maximum change in distance from the eastern data was highly variable and generated large sample sizes for levels of desired precision. The difference in reach gradient exhibited high variability across both the eastern and western data sets, and sample sizes needed for precise mean estimation are large. To obtain relative precision of 0.15, the required sample size is nearly double that calculated for relative precision of 0.20. Note that the sum of the sample sizes calculated for lateral and terminal points generally exceeds the sample size calculated from data pooled across point types. This indicates that overall sample sizes may need to be larger than indicated by the pooled analysis to achieve the same level of precision for means of channel characteristics for lateral and terminal points.

Table 1: Estimates of means, standard deviations, and coefficients of variation from *screened eastern WA data pooled across point types* with sample size approximations for four levels of relative precision.

Outcome	n	Est. Mean	SD	CV	*r* = 0.10	*r* = 0.15	*r* = 0.20	*r* = 0.30
Reach gradient (%) above LF point	193	21.56	13.98	0.65	114	50	28	13
Reach gradient (%) below LF point	161	10.31	6.73	0.65	115	51	29	13
Reach gradient difference (%)	161	9.96	11.19	1.12	341	152	85	38
Bankfull width (m) above LF point	197	2.14	1.41	0.66	117	52	29	13
Bankfull width (m) below LF point	174	1.84	1.35	0.74	146	65	37	16
Maximum change in distance (m)	121	73.26	186.34	2.54	1751	778	438	195

Table 2: Estimates of means, standard deviations, and coefficients of variation from *screened eastern WA data at lateral point types* with sample size approximations for four levels of relative precision.

Outcome	n	Est. Mean	SD	CV	*r* = 0.10	*r* = 0.15	*r* = 0.20	*r* = 0.30
Reach gradient (%) above LF point	67	24.03	12.36	0.52	72	32	18	8
Reach gradient (%) below LF point	53	8.30	9.25	1.11	336	149	84	37
Reach gradient difference (%)	53	18.30	10.77	0.59	94	42	23	10
Bankfull width (m) above LF point	74	1.42	0.79	0.55	83	37	21	9
Bankfull width (m) below LF point	64	0.83	0.74	0.89	214	95	53	24
Maximum change in distance (m)	13	72.12	72.49	1.01	273	121	68	30

Table 3: Estimates of means, standard deviations, and coefficients of variation from *screened eastern WA data at terminal point types* with sample size approximations for four levels of relative precision.

Outcome	n	Est. Mean	SD	CV	*r* = 0.10	*r* = 0.15	*r* = 0.20	*r* = 0.30
Reach gradient (%) above LF point	126	20.25	14.64	0.72	141	63	35	16
Reach gradient (%) below LF point	108	11.30	4.81	0.43	49	22	12	5
Reach gradient difference (%)	108	5.87	8.92	1.52	624	277	156	69
Bankfull width (m) above LF point	123	2.57	1.52	0.59	95	42	24	11
Bankfull width (m) below LF point	110	2.43	1.28	0.53	75	34	19	8
Maximum change in distance (m)	108	73.40	195.84	2.67	1926	856	481	214

Table 4: Estimates of means, standard deviations, and coefficients of variation from *unscreened eastern WA data pooled across point types* with sample size approximations for four levels of relative precision (recommended eastern WA sample size in bold).

Outcome	**n**	**Est. Mean**	**SD**	**CV**	***r* = 0.10**	***r* = 0.15**	***r* = 0.20**	***r* = 0.30**
Reach gradient (%) above LF point	268	18.73	13.30	0.71	136	61	34	15
Reach gradient (%) below LF point	227	9.72	6.42	0.66	118	52	29	13
Reach gradient difference	227	8.13	10.23	1.26	428	190	107	48
Bankfull width (m) above LF point	282	2.02	1.47	0.73	**143**	63	36	16
Bankfull width (m)below LF point	264	1.59	1.30	0.81	179	79	45	20
Maximum change in distance (m)	153	74.21	172.56	2.33	1463	650	366	163

Table 5: Estimates of means, standard deviations, and coefficients of variation from *unscreened eastern WA data at lateral point types* with sample size approximations for four levels of relative precision.

Outcome	**n**	**Est. Mean**	**SD**	**CV**	***r* = 0.10**	***r* = 0.15**	***r* = 0.20**	***r* = 0.30**
Reach gradient (%) above LF point	104	19.65	12.76	0.65	114	51	29	13
Reach gradient (%) below LF point	83	7.90	8.22	1.04	293	130	73	33
Reach gradient difference (%)	83	13.65	10.92	0.80	173	77	43	19
Bankfull width (m) above LF point	129	1.38	0.81	0.59	93	41	23	10
Bankfull width (m) below LF point	116	0.72	0.71	0.98	261	116	65	29
Maximum change in distance (m)	14	67.89	71.42	1.05	299	133	75	33

Table 6: Estimates of means, standard deviations, and coefficients of variation from *unscreened eastern WA data at terminal point types* with sample size approximations for four levels of relative precision.

Outcome	**n**	**Est. Mean**	**SD**	**CV**	***r* = 0.10**	***r* = 0.15**	***r* = 0.20**	***r* = 0.30**
Reach gradient (%) above LF point	164	18.15	13.64	0.75	153	68	38	17
Reach gradient (%) below LF point	144	10.77	4.83	0.45	55	24	14	6
Reach gradient difference (%)	144	4.94	8.31	1.68	765	340	191	85
Bankfull width (m) above LF point	153	2.55	1.67	0.65	115	51	29	13
Bankfull width (m) below LF point	148	2.28	1.24	0.55	80	36	20	9
Maximum change in distance (m)	139	74.85	179.75	2.40	1561	694	390	173

Table 7: Estimates of means, standard deviations, and coefficients of variation from *western Washington WTMF data pooled across point types* with sample size approximations for four levels of relative precision (recommended western WA sample size in bold).

Outcome	n	Est. Mean	SD	CV	*r* = 0.10	*r* = 0.15	*r* = 0.20	*r* = 0.30
Reach gradient (%) above LF point	1982	17.59	13.97	0.79	**171**	76	43	19
Reach gradient (%) below LF point	1512	5.96	4.13	0.69	130	58	32	14
Reach gradient difference (%)	1505	10.79	13.39	1.24	416	185	104	46
Bankfull width above LF point	1900	1.00	0.76	0.76	157	70	39	17
Bankfull width below LF point	1502	4.18	5.79	1.38	518	230	130	58

Table 8: Estimates of means, standard deviations, and coefficients of variation from *western Washington WTMF data at lateral point types* with sample size approximations for four levels of relative precision.

Outcome	n	Est. Mean	SD	CV	*r* = 0.10	*r* = 0.15	*r* = 0.20	*r* = 0.30
Reach gradient (%) above LF point	1393	19.65	15.45	0.79	167	74	42	19
Reach gradient (%) below LF point	921	4.23	2.81	0.66	119	53	30	13
Reach gradient difference (%)	916	15.13	14.86	0.98	261	116	65	29
Bankfull width (m) above LF point	1318	0.81	0.54	0.67	121	54	30	13
Bankfull width (m) below LF point	913	5.90	6.86	1.16	367	163	92	41

Table 9: Estimates of means, standard deviations, and coefficients of variation from *western Washington WTMF data at terminal point types* with sample size approximations for four levels of relative precision.

Outcome	n	Est. Mean	SD	CV	*r* = 0.10	*r* = 0.15	*r* = 0.20	*r* = 0.30
Reach gradient (%) above LF point	589	12.71	7.60	0.60	97	43	24	11
Reach gradient (%) below LF point	591	8.65	4.41	0.51	70	31	18	8
Reach gradient difference (%)	589	4.06	6.34	1.56	661	294	165	73
Bankfull width (m) above LF point	582	1.44	0.98	0.68	125	55	31	14
Bankfull width (m) below LF point	589	1.53	0.92	0.61	99	44	25	11

Initial results from the sample size approximation (Tables 1 through 9) suggested to the ISAG subgroup that upstream metrics provided a robust basis for sample size approximation. Upstream gradient and bankfull width metrics were consistently measured and are ecologically meaningful for both point types, were available for both eastern and western WA data, and were the most precise among the channel characteristics examined. Furthermore, the subgroup also decided to use the unscreened data for sample size approximations based on eastern WA data because the metrics were slightly more variable in this data set and provide more conservative sample sizes.

To obtain an overall statewide sample size that accounted for variation across the state, the unscreened eastern data and the western data were pooled. Coefficients of variation for estimates of means of both upstream metrics were computed to generate statewide sample sizes across both point types (Table 10), for lateral points (Table 11), and for terminal points (Table 12). From this analysis, a conservative statewide minimal sample size of surveyed sites to provide relative precision of 0.10 is obtained from the upstream bankfull width approximation of 190 sites (Table 10). Assuming that the proportion of sites classified as lateral points is similar to the proportion observed in the eastern WA data set (46%) and western WA data set (70%), we can expect roughly 87 to 133 lateral sites and 57 to 103 terminal sites from this sample of 190 sites. These sample sizes within each point type should be sufficient to obtain means of the two upstream metrics with at least 0.15 relative precision (Tables 11 and 12).

Table 10: Estimates of means, standard deviations, and coefficients of variation from *pooled eastern and western Washington data at all point types* with sample size approximations for four levels of relative precision.

Outcome	**n**	**Est. Mean**	**SD**	**CV**	***r* = 0.10**	***r* = 0.15**	***r* = 0.20**	***r* = 0.30**
Reach gradient (%) above LF point	2250	17.73	13.89	0.78	166	74	42	18
Bankfull width (m) above LF point	2182	1.13	0.95	0.84	190	84	47	21

Table 11: Estimates of means, standard deviations, and coefficients of variation from *pooled eastern and western Washington data at lateral point types* with sample size approximations for four levels of relative precision.

Outcome	**n**	**Est. Mean**	**SD**	**CV**	***r* = 0.10**	***r* = 0.15**	***r* = 0.20**	***r* = 0.30**
Reach gradient (%) above LF point	1497	19.65	15.28	0.78	164	73	41	18
Bankfull width (m) above LF point	1447	0.86	0.59	0.69	129	57	32	14

Table 12: Estimates of means, standard deviations, and coefficients of variation from *pooled eastern and western Washington data at terminal point types* with sample size approximations for four levels of relative precision.

Outcome	**n**	**Est. Mean**	**SD**	**CV**	***r* = 0.10**	***r* = 0.15**	***r* = 0.20**	***r* = 0.30**
Reach gradient (%) above LF point	753	13.90	9.52	0.69	127	56	32	14
Bankfull width (m) above LF point	735	1.67	1.24	0.74	149	66	37	17

This analysis provides guidance for establishing the sample size of sites for PHB surveys in eastern and western Washington. If the data sets that were provided are not representative of the larger population of PHBs in Washington, then variation may be underestimated causing approximated sample sizes to be lower than needed for the desired precision. The unscreened CMER data were used for the sample size approximation because they provided more conservative sample sizes than when the screened data were used. However, this application does not imply a preference for the unscreened data set relative to other analyses. Differences in site selection for eastern and western Washington data sets were not considered when pooling the data, but the combined data set provided an index of statewide variability that was not available otherwise. While the ultimate goal of this project is to identify criteria with which to identify PHBs, ensuring that the data collected on potential PHB criteria represent the range of conditions in the population will provide a robust basis for PHB modeling when three years of data are available.

Sampling Design Recommendations

Probabilistic selection of the sampling locations from the sampling frame is recommended to avoid selection bias and to provide a basis for inference to the larger population of interest (Lohr 2009). For ecological surveys, spatially-balanced sampling approaches provide methods to obtain probabilistic samples across large areas without risking selection of clustered points that are correlated and provide duplicate information. Several methods for selecting spatially-balanced samples are available and include generalized random tessellation stratified (GRTS) sampling (Stevens and Olsen 2003, 2004), balanced acceptance sampling (BAS; Robertson et al. 2013), and Halton iterative partitioning (HIP, Robertson et al. 2018). Data from samples selected with spatially-balanced sampling can be analyzed with design-based tools available in the *spsurvey* package (Dumelle et al. 2022). All three of the sampling techniques can be implemented in the *SDraw* package (McDonald and McDonald 2020). However, since the *SDraw* package is currently not maintained on the CRAN website (as of 12/6/21 and since 11/16/21), drawing GRTS samples with the *spsurvey* package is recommended to ensure that best practices for security protocols and package functionality are maintained.

The sampling design for the PHB surveys will incorporate *a priori* geographic stratification by region (east or west WA) so that spatial balance is obtained for each region. Additionally, sampling effort will be apportioned among point types (terminal or lateral points) with “soft stratification” (Larsen et al. 2008, section 2). This approach is useful when the point types are not known for each site before the survey so no sampling frame is available to identify each subpopulation for a priori stratification. Survey crews will record the point type at the time of the survey and, when the desired sample size for a point type is satisfied, survey data from this point type will not be collected at subsequent points of this type. Because the point type is not known a priori so cannot be included as a survey design variable for stratification, employing this technique will require adherence to the spatially-balanced ordered list of sites to ensure that the obtained sample of sites within each point type is also spatially balanced. The point type should be recorded for each site so that inclusion probabilities for each site may be calculated prior to analysis for any design-based summaries such as means and totals (Larsen et al. 2008, section 2.4).

Based on the sample size approximation for data pooled across region, the total sample size should be no less than 190 sites (Table 10) to obtain relation precision of 0.10 for the statewide estimates of mean channel characteristics. ISAG members expressed a desire to obtain estimates of means for channel characteristics with geographic stratum-level relative precision of 0.10. For the two metrics of interest (reach gradient above LF point and bankfull width above LF point), obtaining the more conservative sample size for each region is recommended. Therefore, the eastern WA sample should consist of 143 sites (Table 4) and the western WA sample should consist of 171 sites (Table 7) for a total of 314 sites across the state.

Given the ISAG statement that there are roughly five times more lateral points than terminal points, I examined methods to allocate sampling effort among the two point types. Proportional allocation of effort will favor lateral points since they exist more frequently throughout the landscape. Optimal allocation accounts for the relative precision of lateral and terminal points but is still influenced by the larger relative frequency of lateral points as compared to terminal points. The final sample sizes were based on reach gradient above LF point in eastern WA and bankfull width above LF point in eastern WA. The precision in the means for these two sets of estimates were similar between lateral and terminal point types. Therefore, I recommend an equal allocation of sampling effort among the two point types. Based on the sample size approximation of lateral and terminal points for eastern and western WA (Tables 5, 6, 8, and 9), equal allocation of effort between the two point types should still provide channel characteristic means with relative precision between 0.10 and 0.15.

Note that the suggested sample sizes are the numbers of sites where data are successfully collected. To account for inaccessible sites and sites that do not meet the definition of the target population (such as in reaches with no water), a larger sample of sites (perhaps three to five times larger than the desired sample size) should be drawn to successfully collect data at the desired number of sites. There is no penalty for selecting a much larger sample than needed, but the final set of surveyed sites should consist of a contiguous set of sites from the spatially-balanced randomized list of locations to avoid any sort of systematic or geographic bias in the sample locations caused by surveying a disproportionate number of sites in one area. For each site visited, notes on any frame error or nonresponse error should be recorded so that inclusion probabilities for each site can be accurately calculated. For model-based analysis approaches, incorporating design variables such as *a priori* and soft stratification variables such as region and point type (lateral or terminal) may account for the sampling design without directly incorporating inclusion probabilities.

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Appendix D. DPC Proposed Analysis Memo

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MEMO

To: Instream Scientific Advisory Group (ISAG)
From: Jared Swenson (WEST) and Leigh Ann Starcevich (WEST)
Date: February 2, 2024
Re: Default Physical Criteria Proposed Analysis

The purpose of this memo is to provide analysis recommendations for the forthcoming study to define default physical criteria (DPC) for fish-bearing streams on forestlands in Washington State. Specifically, this memo will address the analysis and summary statistics recommended for the six research questions (RQs, Table 1) put forth by ISAG that outline the assessment of the current DPC (RQs 1 through 4), the consistency in which current DPC can be identified on a given stream (RQ 5), and the identification and comparison of alternative DPC criteria (RQ 6). The six questions relate to two ways of assessing suitability of DPC thresholds, measured as (1) encompassment, the degree to which DPC thresholds encompass end of fish use (EOF) and end of fish habitat (EOFH) and (2) alignment, the degree to which DPC are aligned with EOF and EOFH as a function of distance. Encompassment relates to the proportion of points with fish use/fish habitat captured by the DPC thresholds. Alignment describes the distributions of distances between the end of DPC thresholds for each stream and two metrics of interest: EOF and EOFH, as defined by potential habitat breaks (PHBs). The EOF and EOFH locations may or may not be coincident. In this memo, we describe summaries and analyses to address the research questions and examine sample size considerations.

Table 1: Proposed data analysis methods by Research Question

Question	Proposed Analysis
Assessment of Current DPC	
1. How frequently does the upstream extent of fish use and/or fish habitat[a] end at a point downstream, upstream or coincident with current DPC thresholds for bankfull width, gradient, or both?	Calculate, for all combinations, the proportion of occurrences when the EOF/EOFH is downstream/upstream/coincident with bankfull width/gradient/both thresholds. These results will be presented in a table for all nine combinations. To address the direction and frequency of how well the thresholds encompass fish use, we will also combine the downstream and coincident categories.
2. What is the distribution of distances between the upstream extent of fish use and/or fish habitat[a] points downstream, upstream or	Generate histograms of distances from EOF/EOFH location to DPC thresholds to investigate alignment of EOF/EOFH and DPC. Additional histograms will be made for

Question	Proposed Analysis
coincident with current DPC thresholds for bankfull width, gradient, or both?	the distance from the locations at which each of the PHB criteria[b] is met and DPC thresholds to investigate relationships between DPC and PHB. Positive distance values on the histograms would represent EOF/EOFH or PHBs upstream of DPC thresholds, negative distance values would represent EOF/EOFH or PHBs downstream of DPC thresholds, and values of 0 would be coincident. Calculate quantiles and other summary statistics to capture the distribution of distances for each metric.
3. How do physical and ecogeohydrologic covariates influence the frequency and distribution of distances addressed in RQs 1 and 2?	Use stream-level physical and ecogeohydrologic covariates with a binomial generalized linear mixed model of the frequency that the DPC encompasses fish use to investigate relationships with frequency (i.e., encompassment). Similarly, use stream-level physical and ecogeohydrologic covariates in generalized linear mixed models of distances between the DPC and the EOF location and the locations at which each of the PHB criteria is met to investigate relationships with distribution (i.e., alignment). Produce marginal effects plots to demonstrate impact of each physical and ecogeohydrologic covariate on encompassment and alignment.
4. How frequently and by how much do the physical channel conditions (e.g., bankfull width and gradient) at the locations initially identified as the end of current DPC change over the course of the study?	Summarize the degree of change in each metric (deformability) at the first location identified as end of current DPC. Perform a univariate trend analysis conducted with generalized linear mixed models for each of the channel condition metrics over time. Produce marginal effects plots to understand the degree of change. Identify location of current end of DPC on each survey occasion and model the distance between these initial DPC points and subsequent DPC points based on resurveys as a function of related covariates.
Consistency in identifying DPC Thresholds	
5. Can protocols used to identify DPC be consistently applied among survey crews and be expected to provide similar results in practice?	In the DPC crew variability study, we will assess crew variability as well as consistency and repeatability of measurements. For assessment of variability, distances will be calculated between the first year uppermost detected fish habitat unit ("reference point") and each of the DPC thresholds as determined

Question	Proposed Analysis
	by each crew's measurements as well as the DPC location identified using the intensive longitudinal habitat survey data. The resulting distances (as absolute values) will be modeled to (1) estimate variability among survey crews and protocols and (2) to identify factors that influence the DPC location and variation. The variability among the number of identified segments in a stream, measured lengths, and measured elevations by field crews will be modeled to assess the consistency and repeatability of metrics collected by field crews on the same streams and to assess which metrics are more prone to crew variability. Stream level measurement error will be characterized at each test stream and across all test streams.
Identify and Compare Alternative DPC	
6. Are there singular or combinations of physical channel metrics (e.g., stream gradient and bankfull width) and basin characteristics (e.g., basin area) alternative to current DPC that would serve as more accurate DPC criteria relative to the location of the last detected fish? If so, what are they?	Conduct a classification and regression tree analysis to identify alternative default physical criteria. Set model parameters for false negatives at different allowance thresholds to investigate trade-offs for various alternative thresholds. Visually display the distribution of distances from last detected fish to alternative DPC for each of the false negative thresholds. Generate HTML tool for decision making purposes and investigation. Apply current DPC to new stream data and compare stream segment classifications between the current and alternative DPC.

[a] For the purposes of this study, "fish habitat" is as defined by each PHB option derived from the PHB study field data as it would be applied within FHAM (PHB Study Design, Table 1).

[b] PHB criteria includes the existing Board-proposed PHBs and newly derived criteria. See Appendix A for PHB Board-proposed criteria and variable definitions.

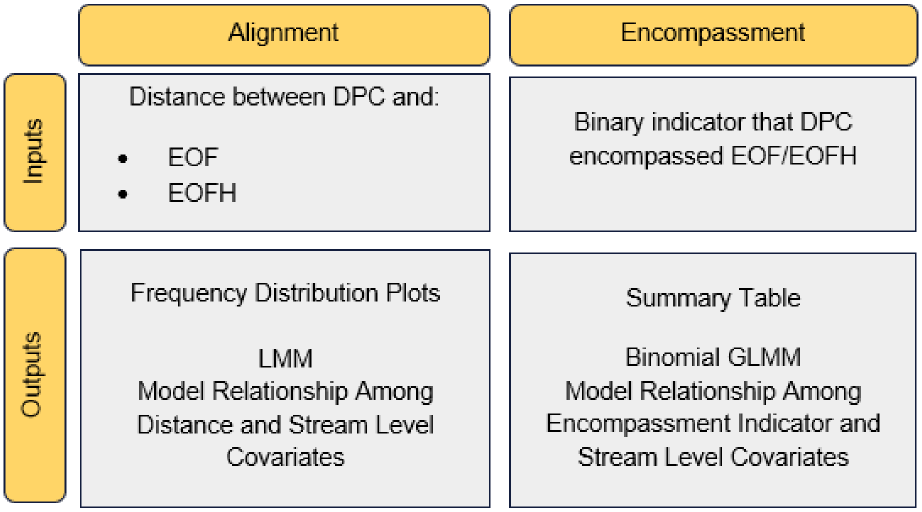
Assessment of Current DPC

One of the goals of this study is to understand the extent to which the current DPC for Type-F waters encompass/align with the upstream extent of (detected) fish presence of any species and/or fish habitat as determined by potential habitat breaks considering potential geographic differences. To adequately assess the current DPC, we will assess the proportion of EOF/EOFH locations encompassed by the default physical thresholds and evaluate the degree to which thresholds align with the EOF/EOFH based on the distance between the two. Research questions 1-4 provide a starting point for evaluating encompassment and alignment. Encompassment is examined with the frequency of the EOF/EOFH use upstream of, downstream of, or coincident with the current DPC thresholds. Alignment is evaluated with (1) the distribution of distances between the upstream extent of fish use and current DPC and (2) the distribution of distances between the EOFH as defined by the various PHB criteria and current DPC. Both metrics will be modeled as a function of factors that contribute to these distances and the stability of physical channel characteristics across time to identify whether certain factors warrant further consideration.

The frequency at which the upstream extent of fish use and habitat end at a point downstream, upstream or coincident with current DPC thresholds for bankfull width, gradient, or both (RQ1) will be assessed with summary methods, graphical exploration, and modeling exercises. We will calculate the proportion of occurrence for each combination of fish use end point relative to DPC threshold (i.e., downstream, upstream, or coincident) and physical criteria (i.e., bankfull width, gradient, bankfull width and gradient). These nine combinations will be displayed in a table and can be further broken down by region or other combination if necessary. The proportion of stream segments for which the upstream extent of fish use is encompassed by the DPC threshold (i.e., at a point downstream of or coincident with current DPC thresholds) will also be summarized for levels of physical criteria (i.e., bankfull width, gradient, bankfull width and gradient). Cases where the points are coincident are expected to be rare.

Prior to modeling, graphical approaches will be used to visually examine the effect of physical and ecogeohydrologic covariates on encompassment. The binary indicator of encompassment will be modeled as a function of physical and ecogeohydrologic covariates summarized at the stream level to investigate factors that influence the frequency of encompassment. Generalized linear mixed models assuming a binomial probability distribution will be applied so that covariate relationships can be assessed with fixed effects while accounting for correlations in space and time with random effects. The modeled relationships between covariates and the encompassment can be displayed using marginal effects plots (Lüdecke 2018).

To assess alignment of current DPC, we will generate histograms from stream level measurements of the distance from EOF/EOFH to DPC thresholds across all streams. The EOF/EOFH points may be downstream of (negative distance values), upstream of (positive distance values), or coincident with DPC thresholds (zero distance values). Additional histograms will be made for the distance between the locations at which each PHB criteria is met and DPC thresholds. Each histogram will represent a different physical, channel metric grouping: gradient, size, and both gradient and size. The distribution of distances provides a quantitative comparison of each stream characteristic threshold to represent fish use and/or habitat across all streams. A high proportion of negative values would indicate that current DPC thresholds tend to occur upstream of the observed extent of fish use/habitat, a high proportion of positive values would indicate that current DPC thresholds tend to occur downstream of the observed extent of fish use/habitat, and a large number of zero distance values would indicate that the current DPC thresholds align with the upstream extent of potential fish habitat. A graphical longitudinal profile of each stream will be generated displaying the end of current DPC, the EOF/EOFH, and any identified PHBs. Additionally, summary statistics including the quantiles, mean, median, variance, and skew for the distances from the EOF/EOFH to the current DPC will be calculated for all metrics of interest to aid interpretation of the histograms and enable comparisons among DPC criteria thresholds. Appropriate generalized linear mixed models will be applied to assess the conditions that influence the distribution of distances (alignment) based on physical and ecogeohydrologic covariates calculated at the stream level, and marginal effects plots (Lüdecke 2018) will be applied to visualize effects of model predictors. The inputs and outputs for assessing DPC alignment and encompassment are illustrated in Figure 1.



	Alignment	Encompassment
Inputs	Distance between DPC and: • EOF • EOFH	Binary indicator that DPC encompassed EOF/EOFH
Outputs	Frequency Distribution Plots LMM Model Relationship Among Distance and Stream Level Covariates	Summary Table Binomial GLMM Model Relationship Among Encompassment Indicator and Stream Level Covariates

Figure 1: Analysis inputs and outputs for assessing DPC alignment and encompassment.

To better understand the temporal variation (deformability) in stream characteristics at the current DPC thresholds, the variation in physical channel conditions at the end of the current DPC will be assessed. On a given stream, the location identified as the end of current default physical criteria for gradient and bankfull width during the first year of data collection will serve as the baseline. Subsequent measurements at this location will serve as comparisons. Depending on the number of revisits, we can summarize the percent change, range, mean, standard deviation, and confidence intervals for metrics at a particular site to characterize the temporal variation. Additionally, we can use a mixed model with a random effect to account for repeated measurements at the same location to investigate relationships and significant deviations from baseline.

Consistency in Identifying DPC Thresholds

An important consideration in applying current DPC and developing potential alternatives is that both researchers and field practitioners must be able to identify the default physical stream characteristic thresholds consistently across survey crews and locations. To investigate the variability and precision in identifying the DPC in each stream and assess the repeatability and consistency of measurements, multiple analyses will be conducted.

For the assessment of variability, the first-year uppermost habitat unit containing fish will serve as a reference point. The absolute value of the distances between the reference point and the locations identified as the DPC by each crew and by the intensive longitudinal habitat survey (ILHS) will be calculated for each stream and modeled to characterize and identify covariates (e.g., east/west region, distance to divide, elevation, survey method) that impact variability among DPC locations as identified by survey crews in the DPC surveys and from DPC obtained from repeated ILHS conducted by different crews in the PHB study. The distances to the reference point will be modeled as a function of fixed effects of the survey method (DPC survey or ILHS) and physical characteristics and random effects of the crews, streams, and years to assess magnitude and sources of variation.

To assess consistency and repeatability, independent models of survey metrics that contribute to DPC thresholds such as the number of identified segments in a stream, measured lengths, and measured elevations can be developed to assess the among-crew variability in each metric and determine which metrics demonstrate more crew variability. Among-crew variability may be standardized for comparison across metric types by computing the ratios of crew variation to the metric mean and determining which metrics are estimated more precisely among survey crews.

Identify and Compare Alternative DPC

The data collected at the field sites from the PHB study will also be used to develop potential alternative DPC, and these new criteria will be assessed and compared to existing criteria. We will apply machine learning classification approaches to develop DPC thresholds for physical characteristics that best represent potential fish use and/or habitat across regions, ecoregions, elevations, habitats, and other spatial domains. In this section we review how we can 1) use random forest (RF) (Cutler et al. 2007) and interaction forest (Hornung 2022) to identify variables that are influential in classification of potentially suitable fish habitat, 2) incorporate important variables into a classification and regression tree (CART; Morgan 2014) to establish baseline thresholds for stream characteristics, 3) produce additional CART models for specific subsets of stream features (i.e., bankfull width and gradient), 4) optimize CART models by constraining the sensitivity parameter to include more fish-bearing stream segments to evaluate tradeoffs, and 5) compare alternative DPC to one another and current DPC.

Random forest methodology is a nonparametric approach used for classification and prediction and can be used to identify important predictor variables among a large suite of possible covariates, even when those covariates are highly correlated (Cutler et al. 2007, Kubosova et al. 2010). Interaction forest from the *diversityForest* R package (Hornung 2022) evaluates pairwise interactions that influence categorical outcomes. While random forest and interaction forest are adept at classification and prediction, they are not ideal for establishing thresholds. Alternatively, CART models are a type of decision tree machine learning model for classification or regression that will return thresholds used for branching events in a decision tree. Therefore, we will utilize all three approaches, maximizing their strengths to determine thresholds for alternative physical stream characteristics. While the CART model facilitates this study’s primary objective to evaluate the current and alternative DPC, we want to acknowledge alternatives and trade-offs regarding model classification. Beyond the benefits listed previously, CART models can identify variables of importance, can accommodate unequal spatial sampling, and can classify thresholds based on continuous and categorical predictors (Morgan 2014, Loh 2011). CART models, however, cannot accommodate a large number of predictors and may correctly partition true positives and true negatives less frequently than a random forest that incorporates many decision trees. Therefore, we recommend assessing correlation among covariates prior to the CART and RF modeling exercise to remove highly correlated variables to account for the influence of multicollinearity between variables. This should reduce the number of predictors of interest and improve model performance. CART models sacrifice some classification accuracy, compared to random forest and interaction forest, in exchange for interpretability of results that reflect real-world decision making (Gareth et al. 2021) and ease of implementation for land managers. Random forest and interaction forest classification models are not ideal for establishing physical criteria thresholds because they employ many individual decision trees (a forest) to deal with the uncertainty inherent in a single decision tree (Maroco et al. 2011). For each node in a decision tree, a threshold is established to partition points. When you combine information across multiple decision trees (into a forest), those individual thresholds are lost because the machine learning algorithm generates many alternative decision trees to improve model performance. Therefore, a single decision tree, like CART, produces thresholds because it is a single tree rather than a collection of decision trees.

Recent studies suggest that spatial autocorrelation between observations may impact predictive power and introduce some bias to classification and regression trees (e.g., Deppner and Cajias 2022, Stojanova et al. 2013, Ancell and Bean 2021). In the context of modeling the upper limit of fishes, accounting for spatial autocorrelation resulted in marginally higher performing predictive logistic regression models as compared to random forest (Penaluna et al. 2022). It is important to recognize that consecutive stream segments are non-independent; however, the degree to which spatial autocorrelation between segments influences prediction is unknown. Other researchers investigating the upper limits of fish utilized predictive models (logistic regression or random forest) without incorporating spatial autocorrelation adjustments (Fransen et al. 2006, Romey and Martin 2021). In both cases the authors acknowledge that the samples are non-independent and likely influenced by spatial distance and suggest that their predictions be considered an index of fish likelihood rather than a probability. Given this uncertainty, prior to CART analysis we will investigate spatial autocorrelation amongst stream segments and across streams to determine if some accounting for spatial autocorrelation should be built into the CART model as has been done in other classification and regression tree studies (Ancell and Bean 2021, Saha et al. 2022).

We propose developing several CART models based on different subsets of model predictors. The first alternative DPC will use the full suite of physical covariates to investigate which physical covariates represent the most important variables related to fish use/habitat. We will first narrow the inclusion of variables based on a correlation matrix or covariance-matrix to address issues of multicollinearity that may bias results and increase sample size requirements due to increased model complexity (Genç and Mendeş 2021). We will then determine influential variables through a random forest model and an interaction forest model. We will incorporate those influential variables in CART classification models to develop thresholds for physical stream characteristics. Three additional CART models, and associated thresholds, will be developed based on subsets of predictors including gradient only, bank full width only, and gradient and bank full width together.

The CART models described above rely on decision trees that are programmed to maximize classification accuracy. However, higher model accuracy may result in DPC thresholds that reduce the encompassment of fish use/fish habitat. Therefore, to investigate the relationship and trade-offs between the CART model's classification accuracy and encompassment we can tune the sensitivity parameter in the CART model and corresponding DPC threshold values. Sensitivity is the number of true positives (stream segments with fish use that are categorized as fish-bearing) divided by the total number of stream segments. A sensitivity value of 1 would maximize the number of fish-bearing segments encompassed by the threshold produced by the CART model. By constraining the sensitivity metric, we can ensure thresholds include a particular proportion of fish-bearing streams and enable us to examine tradeoffs in model classification accuracy, alignment and proportion encompassed. Each of the CART models will be developed without a constraint on the sensitivity parameter, and with a constraint to sensitivity set to 0.8 (80% of true positives), 0.9 (90% of true positives), and 1 (100% of true positives).

Model results will be compared using metrics and summaries such as model sensitivity, specificity, Matthews Correlation Coefficient (MCC), and confusion matrices. Sensitivity summarizes the true positives identified by the model, and specificity is the proportion of stream segment true negatives. MCC is a statistical representation of all four confusion matrix categories (true positives, true negatives, false positives, and false negatives) that is a reliable and holistic indicator of model performance (Chicco and Jurman 2020). A visual decision tree will be presented for each model to display the threshold values for each model. Alignment and encompassment will also be assessed for comparison with the Board criteria DPC. For alignment, a suite of graphs will be generated to compare the distances between the DPC and the EOF (the distance between the EOF and DPC is denoted "ΔEOF2DPC") and between the DPC and the EOFH (the distance between a PHB and DPC is denoted “ΔEOFH2DPC”) for alternative DPC thresholds. The ΔEOF2DPC parameter will indicate the direction and magnitude of alignment between the DPC and EOF, and the ΔEOFH2DPC parameter will indicate the direction and magnitude of alignment between the DPC and the EOFH as defined by each of the PHB criteria identified in the three sets of Board criteria as well as the PHB criteria identified with the CART analysis. The ΔEOF2DPC metric has also been referred to as mean absolute error (MAE) in other studies (e.g., Fransen et al. 2006 see Tables 6 & 7, Penaluna et al. 2022 see Figure 3). These graphs may be presented in an interactive HTML document that will facilitate visual model comparison. A tabular summary of encompassment will be generated for all alternative CART models to enable comparison with Board criteria DPC. Additionally, separate generalized linear mixed models will be used to describe the set of distances (alignment) between each DPC location and EOF/EOFH locations and encompassment as a function of covariates such as east/west regions, distance from the divide, and elevation.

To compare the alternative DPC to the current DPC we will apply the current Board DPC thresholds to the stream data set utilized above. We can then calculate the sensitivity, specificity, MCC, and confusion matrix values, and model ΔEOF2DPC and ΔEOFH2DPC as a function of covariates for the Board DPC thresholds. These metrics can be used to directly compare the performance of Board DPC to CART derived alternatives. The analyses proposed in this memo are illustrated with a flowchart in Figure 2.

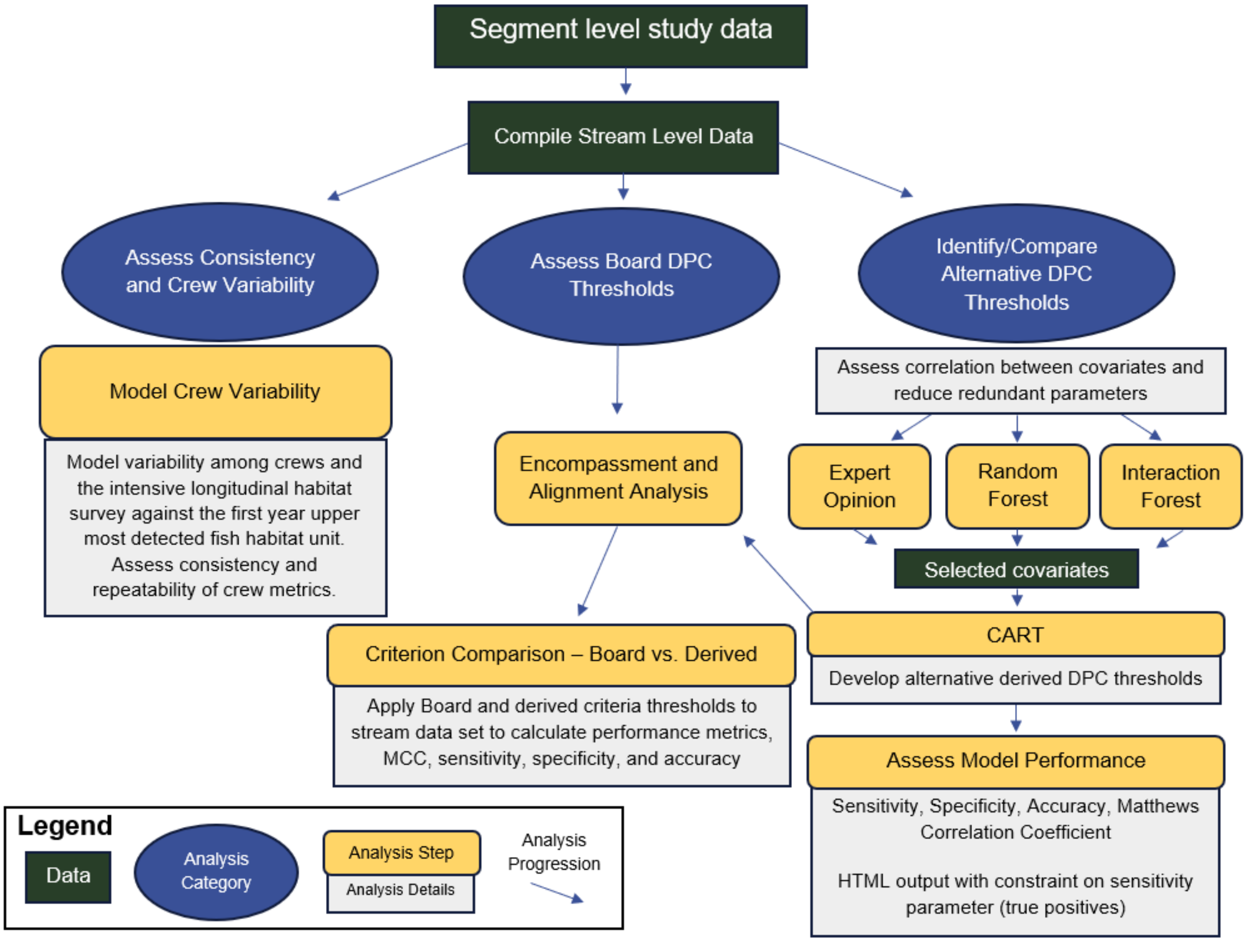


Figure 2: Flowchart of DPC analysis approach.

SAMPLE SIZE APPROXIMATION

The PHB study design incorporates a sample size of 350 streams, consisting of 160 streams in eastern WA and 190 streams in western WA. ISAG would like to determine if this sample size is adequate for assessing current DPC and any new DPC identified with the RF and CART approach described above. ISAG expects that 15-30% of study streams will contain a barrier (insurmountable obstacles based on PHB Study findings), and the impact of these streams may need to be considered in the DPC analysis. For example, the CART analysis may be conducted with and without the streams with barriers to ensure that DPC thresholds are obtained from streams where fish distribution is limited only by physical characteristics.

Guidance on sample size approximations for machine learning analytical techniques such as CART and RF is lacking. Several journal articles state that machine learning techniques require more data but do not provide a recommendation for sample sizes (Genç and Mendeş 2021, Luan et al. 2020, van der Ploeg et al. 2014). However, there are several paths forward for determining a reasonable sample size estimate: 1) examine sample sizes used in comparable studies, 2) run simulations from preliminary sampling efforts to examine error rates and relationships between covariates that may impact classification, and/or 3) establish a sample size approximation based on evaluation metrics such as false negative rates and ΔEOF2DPC.

A few recent studies with similar goals and analyses may provide insight into baseline sample sizes needed. Luan et al. (2020) applied RF modeling to trawl survey data in the coastal waters of China. In examining a range of sample sizes of 10 to 80 sites, the authors found that the predictive performance of the RF model improved when the sample size was increased to 30 sites but did not improve substantially for larger samples. A separate simulation study determined that estimates from a machine learning model was influenced by sample size, the number of variables, and the variance-covariance matrix (Genç and Mendeş 2021). As the number of predictors of interest increases, the sample size must also increase. For five predictors they recommend 10,000 data points.

Two additional studies, Romey and Martin (2022) and Penaluna et al. (2022) demonstrated the impact of sample size on classification accuracy. Romey Fisheries and Aquatic Science used 373 last fish observations (LFO) for their study that predicted the upper limit occupancy for resident salmonids with random forest (Romey and Martin 2022). The LFO's were then used to assign a resident salmonid presence-absence response to all portions of the mainstream downstream and upstream of the LFO's. The LFO's points from all available sources resulted in a total of 7,430 and 62,500 digitized fish presence and absence reaches, respectively. For Romey and Martin (2022) the overall percentage of correctly classified reaches was greater than 98% for their random forest models. Penaluna et al. (2022) investigated the extent of trout at 100 different sites across 21 sub-watersheds spanning various land ownership categories. This research also made an effort to undersample the majority class (fish) to balance the sampling effort so that the probability of classification centered at 50%. Model accuracy for all models used in Penaluna et al. (2022) were greater than 94%. Given the similarity in model accuracy for all models, mean absolute error (the distance between the observed end of fish and the model predicted upper limit of fish) was used as an additional metric of comparison — akin to alignment in our study. Logistic regression models as opposed to random forest models generally resulted in lower mean absolute error. Additionally, model performance did not improve substantially with the inclusion of more than four predictor variables suggesting that models with a full suite of covariates may be overparameterized and overly complex without sufficient justification.

In our study, if each of the 350 streams have on average about 32 segments, then 10,000 individual sampling units should be available for the classification model. Based on the results above our sample size should provide the basis for strong model performance to identify DPC thresholds.

A promising avenue for estimating appropriate sample sizes with CART models specifically is a progressive simulation approach reported by Sug et al. (2009). Using very large sample sizes, as demonstrated by Luan et al. (2020), may not necessarily increase performance. However, through simulations of both the training and validation data sets with progressively larger sample sizes following an arithmetic or geometric sampling strategy, we can determine when error rates plateau or an acceptable error rate is reached (Sug 2009). In the context of our study, we will sample from the first year of data collection to determine a range of sample sizes required for various iterations of model complexity and consider adjusting sample size(s) as needed.

A simple approach to estimating appropriate sample sizes is to use a normal approximation for the binomial distribution to obtain an approximate sample size for estimating the encompassment with specified precision. Note that this minimum sample size would be required within each desired level of estimation, such as within regions, ecoregions, and/or classes of related physical characteristics. The sample size approximation below provides a measure of the number of streams needed to estimate encompassment but does not directly address the sample size needed to conduct a CART model analysis. Therefore, these approximations are most helpful for answering RQ #3 but should be treated as a minimum for RQ #6 and the CART model.

Applying the Thompson (1987) sample size approximation for binomial proportions, the sample size needed to obtain estimates of the proportions of streams within each of the two possible groups that are within 100*r% of the true mean with an overall probability of $1 - \alpha$ was calculated. We assumed a Type I error rate of 0.1; relative precision values of 0.10, 0.15, and 0.20; and encompassment proportions ranging from 0.5 to 0.9. The absolute difference between the estimated proportion and the true value is calculated as the proportion multiplied by the relative precision. Based on these assumptions, the recommended sample sizes range from 31 to 403 sites. The current sample size of 350 streams will be sufficient to estimate encompassment for all scenarios examined except for a low encompassment proportion of 0.5 with relative precision of 0.1 (Table 2).

Table 2: Sample size approximation to estimate the encompassment proportion assuming a binomial distribution and Type I error rate of 0.10.

Encompassment Proportion (p)	Relative precision (r)	Absolute difference (d = p*r)	Minimum sample size
0.5	0.10	0.05	403
0.6	0.10	0.06	280
0.7	0.10	0.07	205
0.8	0.10	0.08	157
0.9	0.10	0.09	124
0.5	0.15	0.08	179
0.6	0.15	0.09	124
0.7	0.15	0.11	91
0.8	0.15	0.12	70
0.9	0.15	0.14	55
0.5	0.20	0.10	101
0.6	0.20	0.12	70

Encompassment Proportion (p)	**Relative precision (r)**	**Absolute difference (d = p*r)**	**Minimum sample size**
0.7	0.20	0.14	51
0.8	0.20	0.16	39
0.9	0.20	0.18	31

Overall, the current sample size of 350 streams is in line with Romey and Martin (2021) and Luan et al. (2020) and potentially larger than Luan et al. (2020) and Penaluna et al. (2022). However, the study's objective to determine exact thresholds for DPC may limit the comparability with these other studies. Therefore, we recommend an evaluation of sample size following the first year of data collection through simulation and sample size approximation as described above.

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WEST DPC Memo Appendix A: Board Proposed PHB Criteria and Variable Definitions

FHAM PHB Option	Criterion Type	FHAM Criterion Description	Test Criterion #
A	Gradient	Sustained gradient increase >= 5%; sustained = over 20*BFW	1
A	Width	Bankfull width <= 2 feet (ft), sustained over 20*BFW	2
A	Obstacle	Vertical obstacle height >= BFW AND >= 3 ft	3
A	Obstacle	Non-vertical step >= 30% AND elevation increase > 2*BFW	4
B	Gradient	Gradient >10%, sustained over 20 * BFW	5
B	Width	Bankfull width <= 2 ft, sustained over 20*BFW	2
B	Obstacle	Vertical obstacle height >= BFW AND >= 3 ft	3
B	Obstacle	Non-vertical step >= 20% gradient AND elevation increase >= upstream BFW	6
C	Gradient	Sustained gradient increase >= 5%; sustained for >= 20 * BFW	1
C	Width	[Downstream to Upstream] BFW decrease >20%, sustained over 20 * BFW (at tributary junctions)	7
C	Obstacle	Vertical obstacle height >= BFW AND > 3 feet	3
C	Obstacle	Non-vertical step >= 20% gradient, and elevation increase >= upstream BFW	6
A, B, C	Tributary Jctn	Tributary junctions must meet one of the other PHB criteria	

Appendix E. Potential for a Concurrent Environmental DNA (eDNA) Study

The project team explored ways to include further eDNA components into the PHB and this (DPC) study designs. The team determined that the best option would be to recommend that an additional complementary study is developed by the Adaptive Management Program that utilizes the sample sites and the fish location data that are collected in these studies. This companion study can further compare electrofishing and eDNA as methods for determining the location of the upper extent of fish use, as well as different methods for eDNA collection and analysis, and can take advantage of the lessons learned from the eDNA pilot study. Conducting a complementary study in association with the PHB and/or DPC studies might save time, money, and resources.

Appendix F. Budget for Combined PHB and DPC Studies

Budget estimate for PHB and DPC studies from DNR PM Anna Toledo as of February 18, 2022. Estimates are based on figures updated from the FY19 PHB study design, expenditures from the FY19 PHB pilot study, and existing contract budgets for similar work. These estimates may change based on revisions made during CMER, ISAG, and ISPR reviews. As of fall 2024, there is an active Request for Qualifications and Quotations to solicit budgetary information for the implementation of the PHB and DPC studies. This budget table will be updated following selection of the Principal Investigator.

Task	Expenditures FY17-FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	Total
Study design, coordination, site reconnaissance, permitting, crew training		31,247	69,250	163,679	114,167	30,512	30,918	N/A	N/A	439,773
Field sampling – Spring/summer (350 sites)					723,697	723,433	737,901	N/A	N/A	2,185,031
Field sampling – Fall/winter (175 sites: fixed + alternating panels)					N/A	176,389	179,917	183,515	N/A	539,821
Crew variability (10% of sites – all crews)					57,944	55,028	56,129	25,505	N/A	194,606
Data collection equipment					183,600	27,540	27,540	27,540	N/A	266,220
Data analysis and reporting				12,485	39,202	67,832	69,189	94,796	61,229	344,733
Project Management				9,364	15,918	16,236	16,561	10,930	4,460	73,469
Total	**398,702**	**31,247**	**69,250**	**185,528**	**1,134,529**	**1,096,970**	**1,118,155**	**342,286**	**65,689**	**4,442,355**

Appendix G. Data Tables and Attribute Descriptions

Table G-1. Site selection initial fish survey start point attributes – GIS-derived

Attribute	**Source**	**Units**	**Description**
SiteID	GIS		Identifier from DNR hydro layer
Stream Name	GIS		Local name
Stream Order	GIS		Strahler Stream Order #
Ecoregion	GIS		DNR Natural Heritage Level III [Northwest Coast, Puget Trough, North Cascades, West Cascades, East Cascades, Okanogan, Canadian Rocky Mountains, Blue Mountains]
Side of State	GIS		Location relative to cascade crest [East, West]
Latitude of currently mapped F/N break	GIS	dd	WGS1984
Longitude of currently mapped F/N break	GIS	dd	WGS1984
Elevation of currently mapped F/N break	GIS	m	
Currently mapped F/N break point type	GIS		Terminal or Lateral
Broad-scale land use class	GIS		Industrial timberland, USFS, small private timberland, conservation forest, residential, other forestry, other non-forest
30-year annual and seasonal normal precipitation	GIS	mm	PRISM model and data from neighborhood reference rain gauges
30-year annual and seasonal normal flows for one or more neighboring gauged streams	Calculated	cms	30-year or as close to that as possible; the point is to be able to place the survey year flow levels in the broader long-term flow context
Seasonal Sampling Scheme	Assigned		Fixed or alternating panel, and if alternating, which of (3) years
Optimal Spring Survey Timing	Assigned		Based on information provided by local/regional experts
Optimal Seasonal Survey Timing	Assigned		Based on information provided by local/regional experts

Table G-2. Site field attribute table

Attribute	**Source**	**Units**	**Description** (detail in Methods Manual)
SiteID	GIS		Identifier from DNR Hydro layer
Landscape Reference Point (LRP)	Field		Narrative description of a permanent topographic/physical feature used to help locate the FRPs and LFPs
LRP Latitude	Field	dd	Decimal degrees; WGS 1984
LRP Longitude	Field	dd	Decimal degrees; WGS 1984
Fixed Reference Point (FRP)	Field		Narrative description of FRP closest to initial LF point relative to permanent topographic/physical feature such as a confluence point with mainstem, tributary junction, etc.
FRP Latitude	Field	dd	Decimal degrees; WGS 1984
FRP Longitude	Field	dd	Decimal degrees; WGS 1984
FRP Elevation	Field	m	Will be baseline from which habitat surveys are conducted
Notes	Field		Any features significant at a site level

Table G-3. Uppermost fish survey data for each survey event; Uppermost fish point (EOF) will be baseline from which habitat surveys are conducted.

Attribute	**Source**	**Units**	**Description** (detail in Methods Manual)
SiteID	GIS		Identifier from DNR Hydro layer
SurveyID	Assigned		Which survey (year/season)
Date			
Weather Conditions	Field		sunny, rainy, snowy, cloudy
Air Temp	Field	C	
Field Crew			
Fish Survey Start Point	Field	dd, m	Lat, Long, Elev at fish survey start point
Fish Survey Start Water Temp	Field	C	
Stream Conductivity	Field	uS/cm	
Electrofisher Setting	Field		
Fish Survey End Point	Field	dd, m	Lat, Long, Elev at fish survey end point
Fish Survey End Water Temp	Field	C	
EOF Latitude	Field	dd	Decimal degrees; WGS 1984
EOF Longitude	Field	dd	Decimal degrees; WGS 1984
EOF Elevation_GPS	Field	m	NAD83

Attribute	**Source**	**Units**	**Description** (detail in Methods Manual)
EOF Stream Distance From Topographic Reference Point (RP)	Field	m	EOF point field-identifiable location relative to a permanent topographic or physical feature such as a confluence point with mainstem, tributary junction, etc., if feasible Also identify reference objects to help locate
EOF Date-Time	Field		YYYY-MM-DD-24-hour; Standard Time;
EOF WaterTemp	Field	C	To nearest 0.5 C
Upstream-Most Fish Species/Family	Field		When it can be determined (salmonid; sculpin (cottid); stickleback; mudminnow; etc)
Fish Size Category	Field	mm	<25mm, 25-75mm, 75-150mm, >150mm
EOF Point Type	Field		Terminal or Lateral
EOF Flow Status	Field		Flowing, Dry
EOF Habitat Unit Type	Field		Pool, Riffle, Step-Pool, Step (>=2’ vertical)
EOF Measurement Point Type	Field		e.g., crest of tailout; bottom of pool; head of pool
Potential Reason (Feature) for Uppermost Fish	Field		If present and identifiable; e.g., deformable obstacle/debris jam; dry channel; falls; other; etc
Vertical/Near-vertical Obstacle(s) present?	Field	Yes/No	
Lateral/Terminal Stream	Field		May vary based on uppermost fish location
EOF Riparian Stand Type (RB)	Field		Watershed Analysis methods
EOF Riparian Stand Type (LB)	Field		Watershed Analysis methods
Streamside Land Use Class at EOF	Field		Industrial timberland, USFS, small private timberland, conservation forest, agriculture, residential, other forestry, other non-forest
Notes	Field		Include potential explanatory features (CMZ, alluvial fan, debris flow, end of channel)
EOF Elevation_GIS	GIS	m	Lidar-based
EOF Drainage Area	GIS	km^2	
EOF Distance-From-Divide	GIS	m	
EOF D/S to Confl with Stream Order Change	GIS	m	Might be a combination of GIS and found distances
EOF Valley Aspect	GIS		Compass points [N, NE, E, SE, S, SW, W, NW]
EOF Valley Width	GIS	m	
EOF Valley Confinement	Calculated		Valley Width/Channel Width ratio

Attribute	**Source**	**Units**	**Description** (detail in Methods Manual)
EOF Geologic Competence	GIS		Resistant or Erodible, based on classifications provided for Hard/Soft Rock Type N studies [Competent/Medium/Incompetent]
Total Annual Precipitation for Current Hydrologic Year	nearby reference rain gauges	mm	from nearby reference rain gauges (see Table G-1)
Total Seasonal Precipitation for Survey Season	nearby reference rain gauges	mm	from nearby reference rain gauges
% of AnnualNormal Precipitation	Calculated	%	Total annual P for survey year/annual Normal
% of Seasonal Normal Precip	Calculated	%	Total seasonal P for survey season/seasonal Normal
Total Annual Streamflow for Current Hydrologic Year	nearby reference stream gauges	cms	from nearby reference stream gauges (see Table G-1)
Total Seasonal Streamflow for Survey Season	nearby reference stream gauges	cms	from nearby reference stream gauges (see Table G-1)
% of AnnualNormal Streamflow	Calculated	%	Total annual Q for survey year/annual Normal
% of Seasonal Normal Streamflow	Calculated	%	Total seasonal Q for survey season/seasonal Normal

Table G-4. Habitat survey site field attributes

Attribute	**Source**	**Units**	**Description**
SiteID	GIS		Identifier from DNR Hydro layer
SurveyID	Assigned		e.g., 2024-spring; 2025-fall, etc.; precise form of survey ID to be determined
Survey Date	Field		
Weather	Field		sunny, rainy, snowy, cloudy
Field Crew	Field		
Bottom of Survey (BOS) Latitude	Field, GPS	dd	WGS84
BOS Longitude	Field, GPS	dd	WGS84 (Negative dd for west)

Attribute	Source	Units	Description
BOS Elevation	Field, GPS	m	NAD83
Top of Survey (TOS) Latitude	Field, GPS	dd	WGS84
TOS Longitude	Field, GPS	dd	WGS84 (Negative dd for west)
TOS Elevation	Field, GPS	m	NAD83
Turnpoint Numbers and Locations	Assigned during survey		Turnpoints may be set on a Station, in which case the station can be identified as the location, or may be set outside of the channel thalweg, in which case the location relative to the previous turnpoint must be recorded.

Table G-5. Habitat Survey Channel Survey Station Measured Attributes

Attribute	Source	Units	Description
SiteID	GIS		Identifier from DNR Hydro layer
SurveyID			
Station Number	Assigned during survey		sequential numbering of survey stations from Bottom of Survey
Turnpoint Number	Assigned		Turnpoint ID (see Table G-4) from which station location is measured
Station Distance from Turnpoint	Measured	m	
Station Azimuth from Turnpoint	Measured	deg	
Station Elevation from Turnpoint	Measured	m	
Uppermost Fish Segment	Observation of Monument	LF	Observation of Uppermost Fish monument from Fish Survey occurs within measurement segment; not necessarily at the surveyed station if LF is monumented within a homogeneous segment
Water Depth	Measured	m	Instantaneous depth at station along thalweg (not BFD)
Channel Width	Measured	m	At bankfull elevation
Wetted Width	Measured	m	Water’s edge
Flow Status	Observation		Dry, Flowing
Dominant Substrate	Ocular estimate	Categ.	Categorical (e.g., sand, gravel, cobble, boulder, bedrock, silt/clay/fines, wood)
Habitat Unit Type	Ocular estimate	Categ.	Pool, Riffle, Step, Step-Pool, Obscured

Attribute	Source	Units	Description
Station Point Type	Ocular estimate	Categ.	e.g., crest of tailout; bottom of pool; head of pool (may be blank)
Obstacle Type	Ocular estimate	Categ.	Vertical/Non-Vertical
Step Forming Medium	Ocular estimate	Categ.	Categorical (e.g., wood (log, debris, roots), hardpan, boulder, bedrock)
Tributary Junction	Observation	1	Flag if present; place station at point
Vertical Step Height	Measured	m	Continuous variable with 0 as an allowable value

Table G-6. Stream habitat survey segment calculated attributes

Attribute	Source	Units	Description
SiteID			
SurveyID			
Station #			
Segment Length [m]	Calculated	m	Calculated distance from Station n-1 to Station n; segment data relate to the segment below the station (i.e., “stations” are the upstream point of the segment)
Distance from Bottom of Survey			Running total of segment lengths from BOS (BOS = Station 0)
Above, at, or Below Uppermost Fish Segment	Calculated	US/DS/LF	Calculated based on location of LF segment from Table G-5; required for calculation of other attributes
Fish Presence	Calculated	FISH/NO-FISH	Assigned to segments based on location relative to LF point; needed for random forest models
Bankfull Width 10 (=bfw10)	Calculated	m	Average of bankfull widths from 4 stations downstream, current station, and 5 stations upstream, in approximate conformance with Forest Practices rule
Average BFW for 10 * bfw10 upstream	Calculated	m	Average of bankfull widths for a distance of 10*bfw10 upstream Required to test for FPB criteria
Average BFW for 20 * bfw10 upstream	Calculated	m	Average of bankfull widths for a distance of 20*bfw10 upstream Required to test for FPB criteria
Average BFW for 10 * bfw10 downstream	Calculated	m	Average of bankfull widths for a distance of 10*bfw10 downstream Required to test for FPB criteria
Segment Thalweg Bed Rise (Vertical Distance)	Calculated	m	Vertical Distance from Beg to End of Segment; calculated as change in elevation from station n-1 to station n
Thalweg Bed Gradient	Calculated	%	Segment Thalweg Bed Elevation Change/Segment Length

Attribute	Source	Units	Description
Effective Elev	Calculated	m	Calculated for pools based on pool tailout elevation; that (residual pool) elevation is translated to the segment upstream of the pool to determine the "effective" bottom elevation of the next (n+1) stream segment, for the purpose of calculating "effective, fish-eye" gradient of the n+1 segment
Effective Segment Rise		m	elevation of segment end minus the Effective Elevation, if there is one; otherwise, equals segment thalweg bed rise
Effective Segment Gradient		%	Effective Segment Rise/Segment Length
Effective Gradient Change From Downstrm Segment			Effective Gradient change from n-1 to n
Effective Gradient Change To Upstrm Segment			Effective Gradient difference from n to n+1
Maximum Effective Gradient Downstream from EOF	Calculated	%	Calculated from segment data using effective gradients
Length of Max Dnstrm Gradient Feature	Calculated	m	Calculated from segment data using effective gradients
Max sustained5 gradient downstrm	Calculated		Max of the running Minimum gradient feature over 5 cw; using effective gradients
Sustained Gradient Downstream	Calculated	%	Minimum gradient feature over 20 cw downstream of station n (including segment n); using effective gradients
Maximum Gradient Upstream of EOF	Calculated	%	Calculated from segment data; using effective gradients
Length of Max upstrm Gradient	Calculated	m	Calculated from segment data
Max sustained5 gradient upstrm	Calculated		Max of the running Minimum gradient feature over 5 cw; using effective gradients
Sustained upstream gradient	Calculated	%	Minimum gradient feature over 20 cw upstream of station n; using effective gradients
Delta Sustained Gradient upstrm	Calculated	%	Sustained upstream gradient – Sustained downstream gradient
Maximum Step Height Upstream	Calculated	bfw10s	

Attribute	Source	Units	Description
Maximum Step Height Downstream	Calculated	bfw10s	
Pool Frequency Upstream of Segment	Calculated	pool count/ bfw10	Calculated over 20*bfw10 upstream of current station
Pool Spacing Upstream of Segment	Calculated	m	Calculated over 20*bfw10 upstream of current station
Pool Frequency Downstream of Segment	Calculated	pool count/ bfw10	Calculated over 20*bfw10 downstream of current station
Pool Spacing Downstream of Segment	Calculated	m	Calculated over 20*bfw10 downstream of current station

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Attribute	Source	Units	Description
SiteID	GIS		Identifier from DNR Hydro layer
SurveyID			
LF[14] Distance from BOS	Calculated	m	
LF Elevation_GIS	GIS	m	Lidar-based
LF Drainage Area	GIS	km^2	
LF Distance-From-Divide	GIS	m	
Elevation at Divide			
Distance to Stream Mouth			Distance downstream to nearest confluence that involves a stream order change
Elevation at Stream Mouth			Elevation at above confluence
Segment Elevation Range			Divide elevation minus stream mouth elevation
LF Valley Aspect	GIS		Compass points [N, NE, E, SE, S, SW, W, NW]
LF Valley Width	GIS	m	
LF Valley Confinement	Calculated		Valley Width/Channel Width ratio
LF Geologic Competence	GIS		Resistant or Erodible, based on classifications provided for Hard/Soft Rock Type N studies [Competent/Medium/Incompetent]

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[14] LF and EOF are synonymous.

Attribute	**Source**	**Units**	**Description**
Total Annual Precipitation for Current Hydrologic Year	nearby reference rain gauges	mm	from nearby reference rain gauges (see Table G-1)
Total Seasonal Precipitation for Survey Season	nearby reference rain gauges	mm	from nearby reference rain gauges
% of AnnualNormal Precipitation	Calculated	%	Total annual P for survey year/annual Normal
% of Seasonal Normal Precip	Calculated	%	Total seasonal P for survey season/seasonal Normal
Total Annual Streamflow for Current Hydrologic Year	nearby reference stream gauges	cms	from nearby reference stream gauges (see Table G-1)
Total Seasonal Streamflow for Survey Season	nearby reference stream gauges	cms	from nearby reference stream gauges (see Table G-1)
% of AnnualNormal Streamflow	Calculated	%	Total annual Q for survey year/annual Normal
% of Seasonal Normal Streamflow	Calculated	%	Total seasonal Q for survey season/seasonal Normal
Habitat Unit Upstream of LF	Calculated		
Effective Gradient of Segment Upstream of LF	Calculated	%	
BFW of segment Upstream of LF	Calculated	m	
Delta Sustained Gradient upstrm of LF	Calculated	%	Sustained upstream gradient – Sustained downstream gradient
Maximum Gradient Downstream from LF	Calculated	%	Calculated from segment data
Length of Max Dnstrm Gradient Feature	Calculated	M	Calculated from segment data
Maximum Sustained Gradient Downstream from LF	Calculated	%	Defined based on 20 bfw (multiple versions)

Attribute	Source	Units	Description
Length of Max Sustained Dnstrm Gradient Feature	Calculated	Multiples of bfw (m)	Calculated from segment data
Max Gradient Change Downstream of LF	Calculated	%	Calculated from segment data
Maximum Gradient Upstream of LF	Calculated	%	Calculated from segment data
Length of Max upstrm Gradient	Calculated	m	Calculated from segment data
Max sustained upstream gradient	Calculated	%	Sustained for minimum of 20*bfw10 to be in line with PHB proposals
Length of Max sustained upstream gradient	Calculated	m, bfw10	Length of the above in meters and also in multiples of bfw10
Max Sustained Gradient Change upstrm of LF	Calculated	%	Calculated from segment data; each gradient sustained for 20* bfw10
Maximum Step Height Upstream of LF	Calculated	bfw10s	
Maximum Step Height Downstream of LF	Calculated	bfw10s	
Pool Frequency Upstream of Segment	Calculated	count/ bfw10	Calculated over 20*bfw10 upstream of current station
Pool Spacing Upstream of Segment	Calculated	m	Calculated over 20*bfw10 upstream of current station
Pool Frequency Downstream of Segment	Calculated	pool count/ bfw10	Calculated over 20*bfw10 downstream of current station
Pool Spacing Downstream of Segment	Calculated	m	Calculated over 20*bfw10 downstream of current station

Table G-8. DPC-specific attributes

Attribute	Source	Units	Description
Dist Initial EOF to EO DPC	Field or GIS	m	Distance
EO DPC Type	Field		Bankful width, gradient, or both

Appendix H. Glossary

Alignment: Describes the direction and distances between the end of DPC thresholds for each stream and two metrics of interest: EOF and EOFH, as defined by potential habitat breaks (PHBs). Positive distance values represent EOF/EOFH upstream of DPC thresholds and negative distance values would represent EOF/EOFH downstream of DPC thresholds.

Anadromous Fish Floor (AFF): Defined by the Board as measurable physical stream characteristics downstream from which anadromous fish habitat is presumed.

Concurred F/N Breaks: Supported by approved Water Type Modification Form

Cumulative Metrics (defined in the data tables): Those metrics averaged or calculated over greater than one measurement

Default Physical Criteria (DPC): Ranges of values for physical stream attributes presumed to represent fish use in the absence of protocol surveys

Distance-From-Divide: The distance from the watershed divide downstream along the flow path to the point of interest on the stream. Where there are tributaries upstream of the point of interest, the distance-from-divide is through the longest channel path.

Encompassment: A binary variable for each stream that is true when the DPC point is upstream of EOF/EOFH points. It is summarized across the sample population as the proportion of streams for which the DPC point falls upstream of EOF/EOFH point and reflects the degree to which DPC thresholds encompass EOF/EOFH points across the sample population.

FHAM (Fish Habitat Assessment Methodology): A new protocol survey methodology to be described in the revised Water Tying rules (WAC 222-16-0301) and the accompanying Forest Practices Board Manual Section 23, both currently under development.

Lateral (end of fish/end of habitat points): Sites where a stream without fish intersects a fish-bearing stream reach with fish both upstream and downstream of the junction with the fishless stream (Fransen et al 2006)

Legacy Water Type (from DNR Hydrolayer but not based on the model): See data dictionary (https://www.dnr.wa.gov/publications/fp_fpamt_wt_defn_viewingguide.pdf)

Region: East vs. west of the Cascade crest

Terminal (end of fish/end of habitat points): Sites where fish occurrence terminates within a continuous reach of stream or at the junction of two or more fishless streams (Fransen et al 2006)

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