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Report

Water Temperature and Amphibian Use in Type Np Waters with Discontinuous Surface Flow in Western Washington Project

Draft Scoping Document

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1. CONTEXT

The *Water Temperature and Amphibian Use in Type Np Waters with Discontinuous Surface Flow in Western Washington Project* (hereafter, Discontinuous Np Project) is being developed by the Landscape and Wildlife Scientific Advisory Group (LWAG) as a part of Washington's Department of Natural Resources (DNR) Forest Practices Adaptive Management Program (FPAMP). The Discontinuous Np Project is a part of the Type N Riparian Prescriptions and Type N Amphibian Response (Effectiveness) Rule Groups.

For the purposes of this study discontinuous surface flow refers to the areas of the Type Np (perennial non-fish habitat) stream network with intermittent dry reaches. Under WAC 222-16-30 (3) Type N "Perennial streams are flowing waters that do not go dry any time of a year of normal rainfall and include the intermittent dry portions of the perennial channel below the uppermost point of perennial flow." This study primarily focuses on stream temperature and FP-covered amphibians in reaches with surface flow and how intermittent dry reaches affect these resources. Seasonal Type N waters (Type Ns Waters), which are typically upstream of the Type Np streams, are outside the scope of this proposal, as are Type F waters with discontinuous flows.

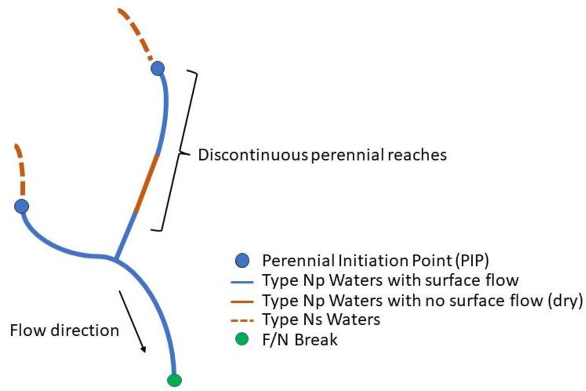

Figure 1. Schematic of a headwater stream network illustrating non-fish-bearing perennial stream reaches (Type Np Waters) with discontinuous or intermittent surface flow (i.e., discontinuous perennial reaches) and seasonal non-fish-bearing channels (Type Ns Waters). The black arrow shows the direction of surface water flow.

Discontinuous surface flow is a common occurrence in Type Np stream networks (approximately 20% of the total Type Np stream length) , as demonstrated in previous CMER studies and in peer-reviewed literature (see Appendix A, section 1.0). However, uncertainty exists about the potential influence of these reaches on stream resources (water quality and habitat), and their potential influence on the resource objectives outlined by the Forests and Fish agreement (USFWS, 1999).

This effort was formerly proposed as the *Amphibians in Intermittent Streams Project* by the Type N Amphibian Response Program, LWAG and CMER in 2007. LWAG proposed waiting until the Type N Experimental Buffer Treatment in Hard Rock Lithologies (Hard Rock Study) project was complete to determine how that study could inform critical questions and project development for the current proposed effort. To date, several CMER studies have included data collection components that inform surface water discontinuities, including the Hard Rock Study, Type N Experimental Buffer Treatment in Incompetent Lithologies project (Soft Rock Study), Eastside Forest Hydrology Study, and the PIP Demarcation Studies. We include a comprehensive description of those efforts in the Best Available Science (BAS) document that we developed to support scoping for this project (Appendix A). These efforts focused on parameters and features associated with discontinuous flow (temperature, hydrology, PIP locations, etc.) but were not focused exclusively on the characterization and effects of discontinuity. The exceptions are the Forest Hydrology Studies which did characterize hydrologic aspects of discontinuity across the landscape on the eastside of the state (Appendix A, section 1.3.1). This proposed study would characterize discontinuity on the westside while also investigating influences on stream temperature and the FP-covered amphibians of discontinuous reaches.

Surface water expression is linked to adaptive management considerations because of its effect on water quality and aquatic habitat availability and condition. It is also a defining characteristic of instream classification and has a direct impact on the delineation of RMZs. Water typing in Washington State involves the classification of streams based on two broad criteria: fish use and perennial surface flow. Water type dictates timber harvest prescriptions under FP rules, including the locations and extent of RMZs. The FP rules apply to all Type Np Waters, regardless of whether they exhibit continuous surface water expression. These regulations, which apply to state and private landowners lacking an individual HCP, are outlined in Title 222 WAC − *Forest Practices Rules* and in the Forest Practices Rules, Board Manual and Act (WFPB, 2001).

Presently, there is a rule making effort that may result in updated buffering requirements on Np streams under the Washington State Forest Practices Habitat Conservation Plan (FPHCP). That effort is in response to several previous CMER studies and is currently being evaluated through a formal process by the Washington Department of Natural Resources. Note that the proposed effort is not an effectiveness study, and as such it does not propose to address or evaluate a specific rule. As such, the potential for rule change does not impact the Problem Statement or the potential for discontinuous reaches to affect the natural resources of concern (namely, stream temperature and stream-associated amphibians). The current rule making effort does not affect study design considerations for this research as proposed herein.

The current Master Project Schedule (MPS) has Study Design development budgeted for FY2025 and implementation beginning in FY2026, and budget placeholders for implementation and reporting across five fiscal years to FY2030. The proposed alternatives outlined below include a shorter option that includes one year of site selection, two years of field data collection, and one year for data analysis and reporting, or four years total. Two longer options both include one additional year of field data collection, for five years total. The current approved MPS suggests the research would be conducted FY26-30. Ultimately, the timing and length of project implementation will depend on study design approval, FPAMP priorities, and funding availability/allocation.

2. PROBLEM STATEMENT

Previous CMER and other efforts have demonstrated that discontinuous Np reaches are a frequent occurrence in Washington streams, however, little is understood about their spatial and temporal patterns and the potential of these reaches to effect aquatic resources of interest to the FPAMP. This project will help inform the likelihood of discontinuous Np reaches to affect resources outlined by the Overall Performance Goals, which are to meet or exceed water quality standards and to support the long-term viability of other covered species, i.e., FP-covered stream-associated amphibians. The proposed study will evaluate stream temperature in, and amphibian use of, discontinuous perennial reaches of Type Np streams. Type Np Waters are perennial streams that do not go dry at any time of a year of normal rainfall and include the intermittent dry portions of the perennial channel below the uppermost point of perennial flow (WAC 222-16-010). In an investigation of perennial initiation point (PIP) expression, Hunter et al. (2005) found that discontinuous perennial reaches frequently occurred near the origin of headwater streams during periods of low flow, and that they exhibited one of two spatial patterns of surface flow, i.e., a single dry reach located adjacent to the PIP or flowing sections interspersed with dry sections. The frequency and distribution of discontinuous perennial reaches of Type Np streams may affect stream temperature and biota. Under future climate change scenarios the frequency and distribution of these reaches may change (see Appendix A, section 2.5), with potential implications for aquatic resources. Previous CMER research studies have informed the occurrence and spatial patterns of discontinuous perennial reaches across the FP managed landscape. However, these previous efforts do not fully inform the influence of these reaches on stream temperature or amphibians. These uncertainties motivated a synthesis of BAS from CMER-supported studies and other published literature (Appendix A).

3. PURPOSE STATEMENT

The purpose of this study is to inform the potential for discontinuous Np reaches to affect resources outlined by the Overall Performance Goals, including their influence on stream temperature and FP-designated amphibians, as well as how variability in spatial and temporal expression may affect the resources of interest. This subject is of particular interest due to the potential for upslope harvest activities and/or global climate change to influence the frequency and distribution of discontinuous perennial reaches, which may impact stream temperature and amphibian habitat in turn (see Appendix A, section 2.4).

An effectiveness study could be designed, but our review of previous efforts and peer-reviewed literature (see Appendix A) highlighted a need to characterize discontinuous perennial reaches and investigate their potential to influence stream temperature and amphibians prior to proposing or developing a more extensive effort. However, the investigation proposed herein would certainly inform the value of a more expensive and time-consuming investigation of buffer effectiveness, if desired. A possible outcome could be that a future effectiveness study is recommended, based on the results of this effort, which could be timed for after the current rule making process is complete, if desired. The proposed effort could also provide information on discontinuous surface flow that may also prove of use to the to the current Board-directed CMER Extensive Monitoring efforts.

4. PROJECT OBJECTIVES AND CRITICAL QUESTIONS

The objective of the proposed study is to inform critical questions relative to the influence of discontinuous perennial reaches on stream temperature and stream-associated amphibian populations. The study will evaluate patterns in spatial and temporal intermittency of discontinuous perennial reaches and, importantly, will explore factors (i.e., stream and stand characteristics) that may influence intermittency.

The critical questions related to the issue of discontinuous perennial reaches are described in the 2023-2025 Biennium CMER Work Plan under the Type N Amphibian Response and Type N Riparian Effectiveness Programs (Table 1~~Table 1~~). As a part of the scoping process, the Project Team proposes some modifications to the critical questions outlined in the current Work Plan so that they more clearly articulate the questions relative to the proposed research. Our investigation into the peer reviewed literature and previous CMER studies revealed that there are still basic aspects of discontinuous Np reaches that have yet to be investigated and as such it is necessary to address a subset of critical questions prior to evaluating the need for a future effectiveness project. Additional critical questions informing effectiveness of buffers adjacent to discontinuous Np reaches and predicting the spatial occurrence could be addressed through future phases. In addition to the proposed modifications to the current Work Plan critical questions, the Project Team identified two additional critical questions based on the scoping process that will be addressed under the proposed alternatives (Table 1~~Table 1~~).

Table 1. Type N Riparian Prescriptions Rule Group: Project-Related Programs and Rule Group Critical Questions from the 2023-2025 Biennium CMER Work Plan, modifications proposed in response to the review of BAS and Scoping development, and whether the question is addressed in the current proposed study alternatives.

Program	**Rule Group Critical Questions from CMER 2023-2025 Work Plan**	**Proposed Modifications to Critical Questions[1]**	**Addressed in Current Study Alternatives?**
Type N Amphibian Response	What is the frequency of occurrence of discontinuous surface flow in streams across the landscape?	What is the frequency of occurrence of discontinuous perennial reaches in Type Np Waters throughout FPHCP lands in Washington?	Yes, clarified in the BAS Section 12.2
	How do stream-associated amphibians utilize intermittent stream reaches at or near the origins of Type N (headwater) streams?	Do stream-associated amphibians utilize discontinuous perennial reaches of Type Np Waters and, if so, do occupancy and abundance differ from reaches with continuous surface flow?	Yes
	How do site-specific factors (e.g., streams dominated by groundwater) affect abundance and condition of amphibian populations?	Do FP-covered amphibians utilize discontinuous Np reaches differentially based on site specific factors (e.g., lithology, gradient)?	Yes
Type N Riparian Effectiveness	What is the effect of buffering or not buffering spatially intermittent stream reaches in Type Np streams?	The proposed study does not inform this critical question. However, implementation of the scoped study may support refinement of this critical question and inform a future investigation.	
	[new Project Team proposed critical question based on Scoping]	How do discontinuous perennial reaches influence stream temperature	Yes

[1] If approved, these would replace the Rule Group Critical Questions from CMER 2023-2025 Work Plan

		across a range of stream and stand characteristics?	
	[new Project Team proposed critical question based on Scoping]	What is the influence of discontinuous perennial reaches (spatial and temporal pattern of surface water expression) on stream temperature and FP-covered amphibian populations in Type Np reaches?	Yes

Results from the alternatives proposed in this scoping can be used to inform the need for and value of a future, more costly effectiveness study to address the Type N Riparian Effectiveness Program (Table 1). A more robust characterization of discontinuous perennial reaches, such as those proposed herein, and their nexus with Schedule L-1 resources objectives (stream temperature and FP-covered amphibians) is warranted prior to investment in a more costly manipulative study.

Though not scoped or addressed as a part of the proposed effort, predicting the prevalence of flow permanence across the FP managed landscape is a current issue of interest to CMER and others (e.g., stream mapping for other current CMER efforts, such as Extensive Monitoring and Potential Habitat Breaks). The proposed study would include collection of data that could help inform or validate current and future stream modeling efforts, such as *PROSPER*, a new hydrography layer that is based on high-resolution LiDAR digital elevation models and returns probabilistic estimates describing flow permanence (See Appendix A, section 2.3).

5. DATA REQUIREMENTS

Field surveys, continuous data loggers, and GIS data sources will be used to address the critical questions. Field surveys will be conducted to record amphibian observations and stream habitat characteristics including surface water expression (wet versus dry channels). Continuous data loggers will be deployed to monitor stream temperature and assist in the determination of the spatial and temporal extent of dry stream conditions. Additional data such as topographic characteristics will be gathered from GIS data sources.

6. BEST AVAILABLE SCIENCE

We reviewed the BAS to inform the prevalence and characteristics of discontinuous perennial reaches in Washington State, and their potential to influence instream water quality (i.e., stream temperature) and stream-associated amphibians. We reviewed previous CMER efforts, peer-reviewed literature, and other data sources to provide a summary of relevant information. As a part of that effort, we identified a number of TFW, CMER and related studies that included monitoring data with the ability to inform surface water expression in discontinuous perennial reaches of Type Np Waters. The earliest CMER studies associated with Type Np Waters focused on PIP identification, since accurate application of the riparian buffer strategy for Type Np Waters relies on accurately identifying the PIP. More recent Effectiveness Monitoring research has tested how upland timber harvest may influence surface water expression. A summary of select lessons learned from these CMER studies is presented in Table 2. A detailed review of relevant CMER studies and peer reviewed literature is provided in **Appendix A**.

Table 2. Select-lesson learned from CMER studies with implications for discontinuous perennial reaches. BACI refers to a study with a Before-After Control-Impact study design.

Theme	Lesson Learned	Citation
Technical		

Theme	Lesson Learned	Citation
PIP Movement	Some PIP locations appear to be stable, others have been shown to move seasonally and annually (see Appendix A, Table 7).	Pleus and Goodman 2003 Veldhuisen 2004 Palmquist 2005 Ehinger 2021
Frequency of Occurrence	East of the Cascades, 21% of the Np channel network was dry.	Miller and Peterson 2009
	West of the Cascades, approximately 15-20% of the Np channel network was dry.	McIntyre et al. 2018 Ehinger et al. 2021
	Discontinuous perennial reaches are very common both West and East of the Cascade Mountains.	TFW Policy Type N Technical Subgroup 2012 Palmquist 2005
Patterns of Discontinuity	Lower order reaches tend to have the greatest proportion of dry streambed in the Np channel network.	Ehinger et al. 2021
	Underlying lithology can affect the extent to which surface flows are expressed in headwater streams over the summer season (increased length in unconsolidated lithologies).	TFW Policy Type N Technical Subgroup 2012
Stream Temperature	BACI studies showed that reaches with discontinuous perennial flow may have reduced the warming effect of harvest.	McIntyre et al. 2018 Ehinger et al. 2021
Stream-associated Amphibian Use	Torrent salamanders have been observed occupying small reaches of surface water in otherwise dry channels.	McIntyre et al. 2018
Implementation and Study Design		
Site Selection – Population	Be cautious about relying on DNR Hydrography or national hydrography dataset (NHD) with random site selection as it may lead to many sites lacking channels and surface water. CMER studies suggest much of the Ns network is represented as Np.	CMER Work Plan 2023, pg. 46
Site Selection - Access	Gaining landowner permission to conduct studies can lead to delays and denials, especially with larger pools and random selection of sites. This has been especially true of small forest landowners and select industrial landowners.	Ecology 2019
Implementation	Quality stream temperature data requires maintaining temperature sensors fully in shallow streams.	McIntyre et al. 2018 Ehinger et al. 2021

7. ALTERNATIVES ANALYSIS

This section provides potential research approaches for the Discontinuous Np Study including the benefits and limitations of each approach for meeting objectives and addressing critical questions. Once CMER and TFW Policy select and approve a preferred alternative for further development, a detailed study design will be developed that describes specific data collection and analysis methods following the CMER Protocols and Standards Manual (Chapter 7).

The Project Team proposes consideration of three potential alternatives to address research objectives and address critical questions. All three study alternatives propose using GIS and field verification for site selection of first-order streams with discontinuous perennial reaches. First order streams provide a natural reach break at the confluence, simplifying the amphibian protocols and analysis. This approach also provides an opportunity to have multiple first-order reaches within a larger Type Np watershed. Under each alternative, the design includes field data collection to support characterization of surface water expression, stream temperature, and FP-covered amphibians. Each alternative proposes the collection of stream and stand characteristics, and other environmental variables to enable identification of their associations with the presence of discontinuous perennial reaches and to investigate the relative influence of discontinuous perennial reaches on stream temperature and amphibians. The alternatives vary in the number of study sites proposed for sample, study duration, and the scope of the field data collection effort (Table 3). The details of sampling will be further developed in the study design.

All three alternatives proposed by the Project Team include study design development in year one. All alternatives include one year for site selection, including landowner outreach, GIS screening and field reconnaissance. Site selection could proceed in year 2, immediately following study design development and approval. All alternatives propose field data collection beginning the year following site selection. A second year of data collection is proposed for all alternatives. It is at this point that the alternatives begin to vary in terms of their timeline (

Table ~~Table 3~~). Alternatives, their differences, and benefits and considerations for each are discussed in greater detail below. All alternatives have the same potential environmental and landowner limitations, requiring identification of study sites with a range of wet vs. dry stream lengths across a range of stand ages and other covariates. It may be difficult to identify enough sites that meet the selection criteria and are located where there is landowner willingness to participate in the study.

Table 3. Summary of alternatives proposed for consideration to address critical questions as a part of the Water Temperature and Amphibian Use in Type Np Waters with Discontinuous Surface Flow Project.

	Alternative 1	**Alternative 2**	**Alternative 3**
Sample size	30-45	45-60	60-75
Time	1 year site selection + 2 years data	1 year site selection + 3 years data	1 year site selection + 3 years data collection = **4 year study**

	collection = **3 year study**	collection = **4 year study**	
FP-covered Amphibian	Presence	Abundance adjusted for imperfect detection	Abundance adjusted for imperfect detection
Stream Temperature[2]	3 sensors arrayed across 1st-order reach	4 sensors arrayed across 1st-order reach	4 sensors arrayed across 1st-order reach and Thermal heterogeneity surveys at a subset of sites.
Surface water expression	Annual survey during low flow	Annual survey during low flow	Repeat surveys at a subset of sites to document intra-annual variation
Hard and Soft Rock Wetted Extent	N/A	Revisit a subset of sites with greatest discontinuous Np	Revisit all sites with discontinuous Np

Table 4. Timeline of proposed alternatives across fiscal years for the Water Temperature and Amphibian Use in Type Np Waters with Discontinuous Surface Flow Project. Proposed fiscal years, consistent with the current approved MPS for the 23-25 biennium, are presented in italics.

Study Phase	**FY1** *(FY25)*	**FY2** *(FY26)*	**FY3** *(FY27)*	**FY4** *(FY28)*	**FY5** *(FY29)*	**FY6** *(FY30)*
	Study design development	Site selection	Field data collection		Reporting	

Alt 1	Study design development	Site selection	Field data collection	Field data collection	Reporting	
Alt 2	Study design development	Site selection	Field data collection	Field data collection	Field data collection	Reporting
Alt 3	Study design development	Site selection	Field data collection	Field data collection	Field data collection	Reporting

7.1. Alternative 1

Alternative 1 proposes the shortest timeline and the smallest budget in exchange for being less representative of the temporal and spatial variability of discontinuous perennial reaches across the broader landscape (i.e., smallest sample size and shorter study timeline.). This alternative also will not evaluate continued patterns in surface flow expression in what were previously identified as discontinuous perennial reaches at study sites included in the Hard and Soft Rock Studies.

Timeline

[2] **air sensors will be deployed near sites to inform drying of instream water sensors.**

This alternative proposes the shortest timeline, with implementation in four years. The first year would include site selection and field reconnaissance to verify site conditions (currently proposed for FY26 in the MPS). The next two years would include field data collection July-September (currently proposed in FY27 and FY28). A final year would be required for data analysis and reporting. Under the current proposed timeline reflected in the approved MPS, data analysis and reporting could begin in October 2027 (FY28) upon completion of field sampling and would continue through development, review, and revisions through June 2029 (FY29).

Cost

This alternative presents the lowest cost option, estimated at $650,000 over four years of implementation (Table 4).

Benefits

This alternative would provide a coarse assessment that informs the critical questions with the lowest cost and in the shortest amount of time.

Limitations

While this alternative presents the shortest timeframe and lowest cost, with only two years of data collection, extreme summer conditions (i.e., extreme wet or dry years) could have a stronger influence on the study results than the longer-term efforts proposed in Alternatives 2 and 3. Additionally, a shorter two year study period also risks missing or minimizing important annual variation in the timing and spatial expression of discontinuous Np reaches. This is an especially important consideration relative to our changing environment in response to climate change (e.g., changes to timing and duration of precipitation, increased summer high temperatures), and in consideration of the environmental sensitivity of focal FP-covered amphibians. Amphibian survey effort will be limited and focus on an assessment of presence based on observations during a single visit rather than abundance adjusted for imperfect detection, which risks missing important variation in population size. This alternative may be more limited in its ability to allow inference across differing stand ages and stream and stand characteristics, as well as in its ability to understand the relative influence of discontinuous perennial reaches on stream temperature and amphibians.

7.2. Alternative 2

Timeline

Alternatives 2 and 3 expand upon the timeline proposed in Alternative 1 with one additional year of field data collection. Implementation under these alternatives would be five years. As with Alternative 1, the first year would include site selection and field reconnaissance (proposed in current MPS in FY26). However, in these alternatives, this would be followed by three years of field data collection July-September (currently proposed for FY27, FY28 and FY29). A final year would be required for data analysis and reporting. Under the current proposed timeline reflected in the approved MPS, data analysis and reporting could begin in October 2028 (FY29) upon completion of field sampling and would continue through development, review, and revisions through June 2030 (FY30).

Costs

Alternative 2 presents a moderate cost option with a total estimated budget of $1,150,000 (Table 4). Implementation of this alternative relies on a larger field crew, additional equipment, and additional travel costs to cover the additional sites along with the additional year of data collection.

Benefits

More sites across an additional year of data collection with more robust methods will increase the reliability and generalizability of the study results over Alternative 1. Field data collection across an additional year will increase the chance of capturing the annual variation in weather and site conditions across the area of interest. The increased sample size will allow for increased replication across covariates such as stand age and allow for more reliable inference about the influence of environmental covariates on stream temperature, amphibians, and surface water expression. The addition of one more stream temperature sensor (increased from three in Alternative 1 to four in Alternatives 2 and 3) better captures the temporal and spatial variation in stream temperature within study sites. The addition of multi-pass sampling to our amphibian methodology will allow us to estimate abundance adjusted for detection, giving a more reliable and accurate evaluation of amphibian populations in and near discontinuous Np reaches. Finally, Alternative 2 proposes including a reassessment of the spatial pattern of wetted extent in discontinuous perennial reaches at a subset of Hard and Soft Rock Study sites. This effort will allow evaluation of changes in surface flow over an extended period, as well as before and after timber harvest. Due to the lack of experimental manipulation, any effort to draw linkages between timber harvest and variation in surface water expression in discontinuous perennial reaches based on this effort would be limited in scope. However, repeat surveys at these sites will provide valuable information relative to the temporal variation of surface water expression over a period that would not be achievable without the prior years of data that these sites provide (Hard Rock 2006-2017, Soft Rock 2012-2020). In addition, by including these sites and using the same methods and time of data collection, comparisons could be made between the two studies that were not available during the writing of the original reports (e.g., Lithology). Under this alternative we would focus selection of a subset of Hard and Soft Rock study sites on those with the most potential to inform the project critical questions.

Limitations

This alternative does not have as large of a sample size as Alternative 3, so while being more robust than Alternative 1, it will have less opportunity to detect spatial and temporal variation relative to stand and stream covariates and be less generalizable across the landscape. Unlike Alternative 3, it will also not inform intra~~er~~-annual variation in surface water expression or within stream thermal heterogeneity.

7.3. Alternative 3

Timeline

Alternative 3 proposes the same timeline as Alternative 2, with one year for site selection (FY26), followed by three years of field data collection (FY27, FY28 and FY29, with report development, review, and revisions through June 2030 (FY30).

Costs

This alternative presents the most expensive cost option with a total estimated budget of $1,400,000 (Table 4). The increased cost is due primarily to the increased field staff needed to implement sampling at more sites in combination with more intensive monitoring efforts related to censusing more Hard and Soft Rock sites in addition to repeat surveys at a subset of study sites to inform intraer-annual variation in surface water expression and thermal heterogeneity.

Benefits

In addition to the benefits mentioned in Alternative 2, this alternative has the added component of multiple surface water expression surveys across the low flow period allowing for a better understanding of intra-annual variation in low flow expression. This will help inform how variable patterns of drying impact stream temperature and amphibians. In addition to using continuous stream temperature sensors, this alternative also includes a survey of thermal heterogeneity across reaches to identify and characterize thermally differentiated patches. This higher-resolution assessment of stream temperature will contribute to a richer understanding of how hyporheic exchange and groundwater inputs may affect stream temperature within the Np network. Adding all the Hard and Soft Rock sites will have the same benefits as Alternative 2, with the addition of an increased spatial scale.

Limitations

Alternative 3 requires the largest sample size and depends on successfully identifying an adequate pool of sites across covariates. Consistent with all alternatives, this approach would not directly evaluate the effect of timber harvest of discontinuous perennial reaches on stream temperature or amphibians.

8. RECOMMENDED APPROACH

The Project Team recommends Alternative 3 (Figure 2Figure 2). This alternative provides the greatest opportunity to address the project critical questions and to evaluate how stream and stand characteristics inform the pattern of surface water extent and the influence of discontinuous perennial reaches on stream temperature and amphibians (Table 5). The larger sample size and more robust sampling methods ensure greater statistical power to reduce the risk of Type II errors (false negatives, i.e., the likelihood of not detecting a difference when one exists). It also allows for enhanced generalizability ensuring the findings are applicable to a broader range of contexts across western Washington. Alternative 3 also allows for greater power to analyze covariates. Additionally, Alternative 3 would leverage existing wetted extent datasets from the Hard Rock and Soft Rock study sites to inform the temporal variation in surface water expression through a good portion of the harvest rotation (~ 20 years after harvest at most sites).

Table 5. Overview of how alternatives address critical questions.

Critical Questions	**Alternative 1**	**Alternative 2**	**Alternative 3**
How do discontinuous perennial reaches influence stream temperature across stream and stand characteristics?	Limited ability to address co-variates	Moderate ability to address co-variates	Greater ability to address co-variates
What is the relative influence of discontinuous perennial reaches (spatial and temporal pattern of surface water expression) on stream temperature and FP-covered amphibian populations in Type Np reaches?	Limited ability to address inter-annual variability and no ability to address intra-annual variability	Moderate ability to address inter-annual variability and no ability to address intra-annual variability	Greater ability to address both inter-annual and intra-annual variability in spatial and temporal patterns
How do FP-covered amphibians respond differentially to discontinuous Np reaches based on site specific factors (e.g., lithology, gradient)?	Limited ability to address co-variates	Moderate ability to address co-variates	Greater ability to address co-variates
Do stream-associated amphibians utilize discontinuous perennial reaches of Type Np Waters and, if so, do occupancy and abundance differ from reaches with continuous surface flow?	Yes, occupancy only	Yes, occupancy and abundance	Yes, occupancy and abundance

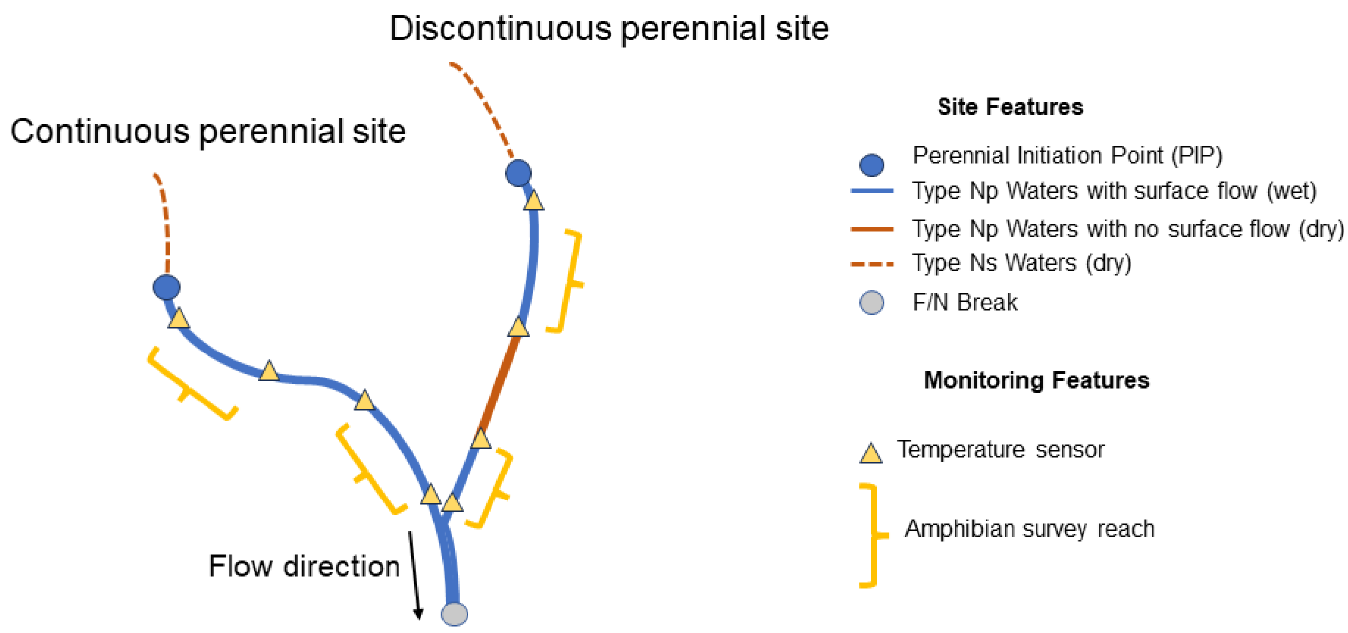

Figure 2. Study site schematic of showing layout of two study sites with varying flow patterns. . The different alternatives propose similar study site layouts, however Alternative 1 would employ fewer stream temperature sensors.

9. BUDGET

We developed budget estimates for each of the three proposed alternatives (Table 6).

Table 6. Estimated budgets for each of three proposed alternatives evaluated during scoping of the proposed study. Colors indicate site selection (green), field data collection (blue), and reporting (orange).

Alternative	FY2 *(FY26)*	FY3 *(FY27)*	FY4 *(FY28)*	FY5 *(FY29)*	FY6 *(FY30)*	Project Total
Alternative 1	$151,564	$197,231	$169,434	$114,500		$650,000
Alternative 2	$219,734	$295,185	$245,546	$245,546	$114,500	$1,150,000
Alternative 3	$272,682	$367,989	$305,113	$305,113	$114,500	$1,400,000

If interest exists, a Study Design could be developed, for which funding has been allocated in the CMER Master Project Schedule (MPS) for FY25.

Appendix A. Best Available Sciences Review

In this synthesis, we review the BAS to inform the prevalence and characteristics of discontinuous perennial reaches in Washington State, and their potential influence on instream water quality (i.e., stream temperature) and stream-associated amphibians. We review previous CMER efforts, peer-reviewed literature and other data sources, provide a summary of relevant information, and sources of variability and uncertainty.

1. CMER AND TFW RESEARCH INFORMING THE TOPIC OF DISCONTINUOUS PERENNIAL REACHES

FP rules first required the protection of Type Np Waters in 2001. At the time of FPHCP negotiations, limited research was available to inform rule negotiations for Type Np Waters and the anticipated effectiveness of the various protections under consideration. Also, uncertainty existed about accurate and consistent delineation of Type Np Waters, including for the demarcation of F/N breaks and the PIP. As a result of scientific uncertainties and operational challenges specific to Type Np Waters, CMER has dedicated time and resources to evaluating surface water expression in Type Np Waters in a variety of studies**.**

1.1. Perennial Initiation Point (PIP) Demarcation

One of the earliest CMER-supported adaptive management studies evaluated surface water expression in Type Np Waters as a part of PIP demarcation. Since Type Np streams require riparian buffers in the RMZ along at least 50% of their length, and Type Ns streams do not (WAC 222-30-021 WAC 222-30-023), the location of the Np/Ns break (i.e., PIP) is important for rule implementation and resource protection. We identified five TFW, CMER, and related studies that investigated PIP characteristics and movement to inform the FPAMP (Table ~~Table 7~~). In an early effort, the Type N Stream Demarcation Study (Palmquist, 2005) sought to refine the delineation of PIP locations in Type Np basins throughout Washington State through topographic modeling and field validation. One intent was to test the adequacy and replicability of a pilot field protocol for identifying PIPs based on contributing basin area for accurate implementation of the new FP rules. A series of companion studies, not all of which were formally part of CMER, were conducted by multiple TFW stakeholders and other researchers during the same period. For example, Pleus and Goodman (2003) expanded on the work started by Palmquist (2005) by revisiting a subset of the sites evaluated in the previous effort, and new sites, using the same field protocols. Though this research is not formally a CMER study, the report went through the TFW peer-review process. In an additional effort, recategorized data from the Type N Stream Demarcation Study was used to address supplemental information requests from TFW Policy (TFW Policy Type N Technical Subgroup 2012).

Field validation revealed limited variation in PIP location across the landscape and found that PIPs are located very near the channel head (Hunter et al., 2005; Palmquist, 2005; Pleus & Goodman, 2003; Veldhuisen, 2004). These efforts also found that the basin areas above PIPs were smaller than the default basin size criteria defined in the pilot protocol. Notably, these evaluations ultimately led to the first adaptive management rule change, resulting in a policy shift away from using default basin size criteria as a predictor of PIP location and instead relying on field indicators to locate PIPs. Our synthesis of PIP studies found that discontinuous reaches are very common both West and East of the Cascades and the PIP is commonly co-located near the channel head. It also highlighted that dry channels may increase in frequency and length in unconsolidated materials (TFW Policy Type N Technical Subgroup 2012).

A subsample of PIP demarcation study sites were evaluated for PIP stability seasonally or annually. In an evaluation of intra-annual variation, Palmquist (2005) found that 56% of PIPs remained stable throughout the summer months. In evaluations of inter-annual variation, Veldhuisen (2004) and Pleus and Goodman (2003) reported that 83% and 100% of PIPs remained stable, respectively, across multiple years. However, these are contrasted with data from the Soft Rock Study (Ehinger et al. 2021) which found that only 26% of PIPs were stable throughout the study period (Table 7).

Table 7. Data from the PIP demarcation (Palmquist, 2005; Pleus & Goodman, 2003; Veldhuisen, 2004) and Soft Rock (Ehinger et al., 2021) studies related to PIP movement.

Study	Inter/Intra annual	n	Spatial Resolution	Percent PIP stability
Pleus and Goodman 2003	inter	8	Unk	100%
Palmquist 2005	intra	9	5m	56%
Veldhuisen 2004	inter	17	60m	82%
Ehinger et al. 2021	inter	47	2m	26%

In addition to evaluating the locations and stability in PIP locations across the landscape, these studies examined additional characteristics of discontinuous perennial reaches. Palmquist (2005) evaluated the distance between the start of discontinuous water (Pd) and the start of continuous perennial water (Pc; Figure 3). Across five sites evaluated with repeat dry season surveys, Palmquist (2005) did not find a pattern of drying in discontinuous Np reaches; however, they did observe a decrease in the stream distance between Pd and Pc in response to rain inputs from an August storm (Figure 4).

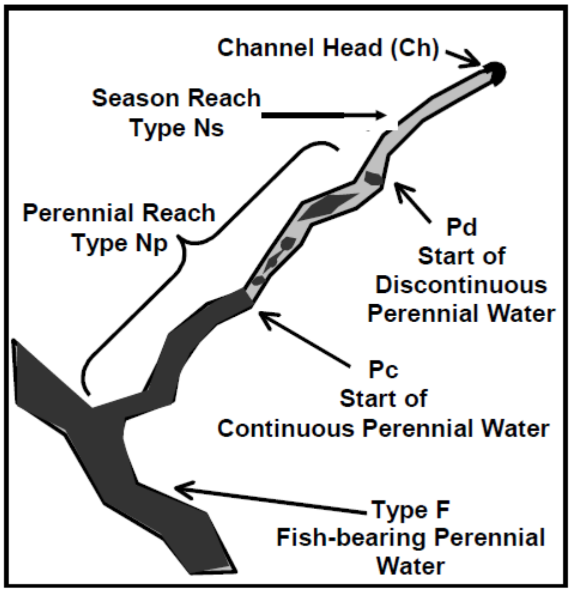

Figure 3. The location and definition of the hydrologic points that define the limits of the seasonal and perennial water types (Palmquist, 2005).

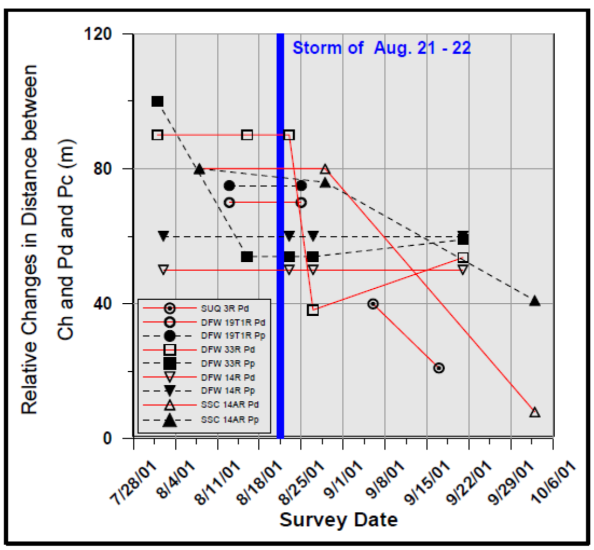

Figure 4. Seasonal changes in PIP location (Palmquist, 2005).

Though not part of a formal analysis, Veldhuisen (2004) noted that of the sites that were resurveyed in 2003, 37% the segment-scale flow categories were drier than in 2001. Sites resurveyed in 2002 were also drier than in 2001 even though annual precipitation was higher. This was likely due to lower-than-normal precipitation in the summer months, which is consistent with results from Hunter (2005).

Collectively, the efforts of the PIP demarcation studies contributed to CMER's appreciation of the variability in surface water expression and the need for field verification, rather than GIS models or a standard basin area rule, to predict surface water expression.

Table 8. Adaptive Management Program and related studies evaluating PIP demarcation in Washington State. Study type is Before-After Control-Impact (BACI) or observational (OBS).

Citation	Study Name	Geographic Area/Region	Study Duration (Timing)	Sample Size and Unit
Pleus and Goodman 2003	Type N Demarcation Study	Statewide	2 years (2001-2002)	86 study sites in the 300 dba and 152 study sites in the 52 dba
Veldhuisen et al. 2004	Summary of Headwater Perennial Stream Surveys in the Skagit and Neighboring Basins	Skagit and adjacent watersheds	3 years (2001-2003)	25 headwater basins
Jaeger et al. 2007	Channel and perennial flow initiation in headwater streams: management implications of variability in source-area size.	Southwest WA (Black and Willapa Hills)		81 channel heads across 4 headwater basins
Hunter et al. 2005	Low flow spatial characteristics in forested headwater channels of southwest Washington	Southwest WA (Stillman Creek in Willapa Hills)	2 years (2001, 2002)	23 stream reaches
Palmquist 2005	Type N Demarcation Study	Statewide (Cascades, Northern Rockies, Coast Range, Puget Lowland)	1 year (2001)	224 streams

1.2. Studies West of Cascade Crest

We identified five additional studies specific to western Washington that inform the prevalence and characteristics of discontinuous perennial reaches across the landscape in western Washington (Table 9).

Table 9. Adaptive Management Program studies conducted west of the Cascade crest that inform prevalence and characteristics of discontinuous perennial reaches in western Washington State. Study type is Before-After Control-Impact (BACI) or observational (OBS).

Citation	Study Name	Geographic Area/Region	Study Duration (Timing)	Sample Size and Unit	Study Type

Hayes et al. 2002	Amphibian Use of Seeps and Stream Reaches in Non-fish Bearing Stream Basins in Southwest Washington	Willapa Hills	1 year (2000)	16 sub-basins	OBS
Jackson et al. 2003	Integrated Headwater Stream Riparian Management Study (i.e., Amphibian Recovery Project)	Willapa Hills	4 years (1998-2001)	15 Type N streams within 5 logging sites	BACI*
McIntyre et al. 2018 & McIntyre et al. 2021	Hard Rock Study – Phase I Hard Rock Study – Phase II	Olympics, Willapa Hills, South Cascades	12 years (2006-2017)	17 Type N basins	BACI
Ecology 2019	Westside Extensive Riparian Status & Trends– Stream Temperature	Western Washington	2 years (2008-2009)	55 Type F/S and Type Np streams	OBS
Ehinger et al. 2021	Soft Rock Study	Willapa Hills	9 years (2012-2020)	10 Type N basins	BACI

* Funded by the National Council for Air and Stream Improvement (NCASI)

1.2.1. Type N Westside Riparian Effectiveness Studies

The Type N Westside Riparian Effectiveness Studies, including both the Hard and Soft Rock Studies, evaluated the effectiveness of riparian forest management prescriptions for Type N stream basins on hard rock (i.e., competent) and soft rock (i.e., incompetent) lithologies, respectively, in western Washington. These studies evaluated the magnitude, direction (positive or negative), and duration of change for riparian-related inputs and response of instream and downstream components, including an evaluation of basin-wide perennial surface water expression. Both studies were a Before-After Control-Impact (BACI) design that included a pre- and post-harvest period of data collection, and both control (i.e., reference) and treatment sites. Treatments for both studies included Type N basins receiving the current Forest Practices rules prescription in the RMZ. The Hard Rock Study further evaluated the effectiveness of riparian forest management prescriptions by comparing the current FP prescription to alternatives with full-length two-sided 50-foot no-cut riparian leave-tree buffers (100% treatment) and no buffers (0% treatment). Both studies had temperature sensors deployed throughout the stream network and surveys of surface water expression. However, only the Hard Rock Study included surveys of stream associated amphibians. Summaries of the relevant parts of the individual studies are listed below as well as a brief comparison of the studies reported by Ehinger et al. (2021).

1.2.1.a. Effectiveness of Experimental Riparian Buffers on Perennial Non-fish-bearing Streams on Competent Lithologies in Western Washington (Hard Rock Study)

In the Hard Rock Study, McIntyre et al. (2018) evaluated the length of dry channel throughout the entire study basin at 17 study sites during summer low flow. These surveys were conducted concurrent with amphibian sampling in 2006 (pre-harvest year), and 2010, 2015 and 2016 (post-harvest years). Most sites had some portion of dry length in the perennial reach, but the absolute number of dry perennial reaches, lengths of those reaches, and proportion of the basin stream length lacking surface flow differed among sample years (Table 10).

Table 10. Numbers of Hard Rock Study sites with at least one dry reach ≥ 1 m in length, and the ranges (min, max, mean) in the number of dry perennial reaches, cumulative dry basin length (m), and proportion (%) of dry basin across sites by year. Sample period is Pre (pre-harvest) or post (post-harvest).

Sample Year	**Sample Period**	**Number of sites with dry** (N=17)	**Number of Dry Perennial Reaches**			**Cumulative Dry Basin Length (m)**			**Proportion of Basin**		
			Min	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
2006	Pre	15	1	17	6	14	1132	233	1%	51%	21%
2010	Post	14	1	30	8	9	807	174	1%	46%	13%
2015	Post	16	1	40	16	5	1074	227	<1%	63%	22%
2016	Post	15	1	41	16	4	1088	210	<1%	42%	17%

McIntyre et al. (2018) statistically evaluated the response of mean annual proportion of dry channel length to variable length riparian buffers. They did not find clear evidence that dry channel length varied among treatments (P = 0.25). However, when examined by harvest treatment, the post-harvest change in stream temperature increased with greater length of contiguous surface flow above the monitoring location in all three treatments and decreased with increasing proportion of dry channels in the summer months (Ehinger et al., 2021). The length of surface flow above the monitoring station provides an index of the stream area that could be exposed to increased solar radiation after harvest. The finding may have been influence by relatively large effects of groundwater inputs and hyporheic exchange on stream temperature relative to surface flow (Johnson & Jones, 2000; Story et al., 2003; Wondzell, 2006).

The influence of discontinuous Np reaches on amphibians has received very little consideration. Although not a focus of the Hard Rock Study, we do have limited data on the use of discontinuous Np reaches by amphibians. To put amphibian use of these reaches in context, we summarize amphibian observations in dry stream reaches for a single sample year. In 2006 (pre-treatment), only 3.5% of Coastal Tailed Frog (*Ascaphus truei*), torrent salamander (*Rhyacotriton* spp.) and giant salamander (*Dicamptodon* spp.) observations (71 of 2029) were in dry reaches of a perennial stream. Alternatively, 34 of 45 observations (76%) of Western Red-backed (*Plethodon vehiculum*) and Van Dyke's (*P. vandykei*) Salamanders were observed in dry reaches. Coastal Tailed Frog and the three Washington species of torrent salamanders (Cascade *R. cascadae*, Columbia *R. kezeri*, and Olympic *R. olympicus*) are designated as species of focus under Washington FP rules.

1.2.1.b. Effectiveness of Forest Practices Buffer Prescriptions on Perennial Non-fish-bearing Streams on Marine Sedimentary Lithologies in Western Washington (Soft Rock)

Data were collected on surface water expression during the summer low-flow period (mid-August) from 2013-2020 in 10 study sites as a part of the Soft Rock Study. Start and end points for dry sections (> 2m) of perennial reaches were identified and mapped relative to flagging placed at 10m intervals. Discontinuous Np reaches were present in all 10 study sites, including all the 46 individual tributaries present across those sites.

Substantial portions of Type Np streams were without surface water during the summer low-flow, however the absolute proportion varied annually and by harvest treatment. Due to an unusually dry spring and summer, the lowest overall percentage of stream channel with surface flow was observed in post-harvest year 1 (2015), when only 59% of the total stream length in reference sites had visible surface flowing water, down from an average of 91% and 85% in the previous two years. A pair-wise comparison of post-harvest change showed an increase in percent wetted channel at the harvest treatment sites, relative to the references, in post-harvest years 1 and 2 (2015 and 2016; Table 11). This was considered an increase in surface water expression since the decrease in percent wetted channel at the references in 2015 (Post 1) and 2016 (Post 2) were not reflected at the harvest treatment sites (Table 12). Starting in post-harvest year 3 (2017) there were no differences in percent wetted channel observed between the reference and treatments for the remainder of the study period (2018-2020). There was also a slight positive correlation between the Mean Monthly Temperature Response (MMTR) and the amount of visible flowing water at the treatment sites in the first two years post-harvest (Table 13).

Table 11. Post-harvest change in percentage of stream channel with surface flow in the treatment sites relative to the reference sites by year. Estimates and confidence intervals are in Beta-space. P-values were not adjusted for multiple comparisons. SE = standard error; DF = degrees of freedom; C.I. = confidence intervals (Ehinger et al., 2021).

Year	Estimate	SE	DF	t-value	P-value	95%	C.I.
Post 1	1.20	0.32	34	3.81	0.0006	0.56	1.84
Post 2	1.40	0.34	34	4.16	0.0002	0.72	2.08
Post 3	0.18	0.37	34	0.50	0.6183	-0.56	0.93

Table 12**.** Least squares means by treatment and period expressed in percentage of stream channel with surface flow. Treatment is reference (REF) or harvest treatment (TRT); Period = Pre- or Post-harvest year; SE = standard error; LCL = lower 95% confidence limit; UCL = upper 95% confidence limit (Ehinger et al., 2021).

Treatment	Period	Mean	SE	LCL	UCL
REF	Pre	88	4.44	76	94
	Post 1	59	9.90	39	76
	Post 2	71	8.56	52	85
	Post 3	86	5.58	71	94
TRT	Pre	82	3.79	73	88
	Post 1	75	4.81	65	84
	Post 2	86	3.37	78	91
	Post 3	82	3.99	73	89

Table 13. Pearson correlation coefficients and P-values for Pearson correlations with July Mean Monthly Temperature Response (MMTR; Ehinger et al., 2021).

Year	% Wetted Channel	Wetted Channel Length
Post 1	0.726/0.056	0.742/0.065
Post 2	0.510/0.243	0.763/0.046

1.2.1.c. Hard Rock and Soft Rock Comparison

Ehinger et al. (2021) and McIntyre et al. (2018) both reported that the main factor influencing the stream temperature response (post-harvest increases in temperature) was the loss of riparian cover. It is possible that the degree of hyporheic exchange had an influence on stream temperature response. An analysis of the MMTR in the Soft Rock study indicates that less surface water expression may have reduced the warming effect of harvest. Temperature change in both studies may have also been influenced by the proportion of wetted channel or the length of wetted stream (Figure 6). However, a formal analysis comparing studies has not been completed. It is also possible that the loss of riparian cover and increase in surface water expression interacted to affect stream temperature. Although not examined, this possibility could be an area of future research.

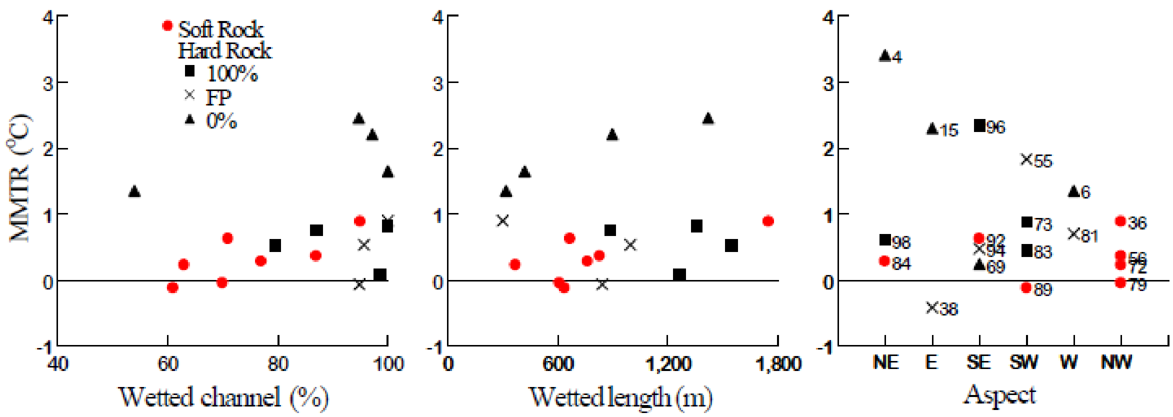

Figure 6. July mean monthly temperature response (MMTR) vs. percent of stream channel with surface water (wetted channel), total wetted channel length, and aspect for the Soft (red) and Hard Rock (black) Studies. Values are from the first-year post-harvest except for the Hard Rock Study values for wetted channel and wetted length, which were measured in 2010, the second-year post-harvest at most sites. Numbers in the Aspect plot are mean canopy closure.

In both studies there was some indirect evidence of groundwater influence on the temperature response near the downstream outlet of the basin at some sites. One FP treatment from the Hard Rock Study and one harvest treatment from the Soft Rock Study had persistent dry reaches within a dense canopy located downstream of unbuffered reaches. Both saw an increase in the summer temperature response upstream of the dense canopy and dry reach and little to no temperature increase downstream, near the F/N break. Ehinger et al. (2021) and McIntyre et al. (2018) reported that this could be, in part, a result of hyporheic influence on stream temperature.

The underlying lithology of marine sediment may have played a role in the amount of channel that dried up during the summer low flow period for sites included in the Soft Rock Study. However, it is difficult to make a direct comparison with the basalt lithology of the Hard Rock Study. Data for these two studies were collected in different years so it is possible that prevalent weather played a larger role than lithology.

A more in-depth look into the surface water expression data for the Soft Rock Project was conducted as part of an unpublished thesis(Bretherton, 2020*). The same survey methods, data, and harvest treatment effect analysis were used in both studies (see Soft Rock section for details). However, the extended post-harvest period (post 4-6) was described in more detail in (Bretherton, 2020*) and is included below. This study also included analysis of the topographic and precipitation effects on surface water expression.

As noted in the Soft Rock section, the percentage of surface water present in the treatment basins increased in the first two years post-harvest (Figure 7). No treatment effect was detected in post-harvest years 3-6.

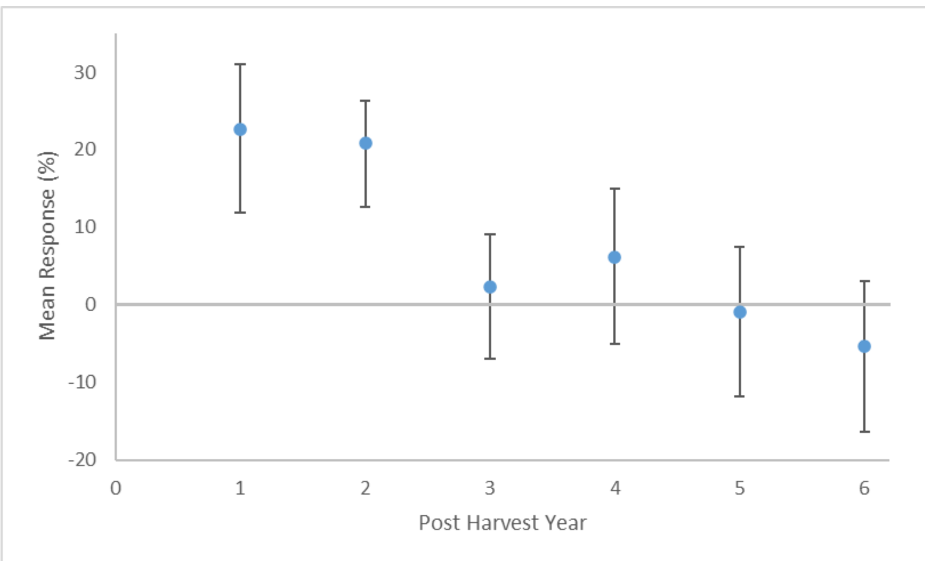

Figure 7. The mean response in the extent of the wetted channels, at the treatment sites, for each year after harvest, relative to a static reference represented as the 0 line.

This increase in surface water expression is consistent with other research that has shown that discharge increases after a timber harvest within a watershed (Harr, 1983, 1986; Harr et al., 1975; Jones & Post, 2004). Specifically, McIntyre et al. (2018) found that in the Hard Rock study, with similar basins and similar harvest treatments, mean daily discharge increased by an average of 59%. It seems reasonable to conclude that an increase in discharge at the outlet of a Type Np basin would correspond to greater presence of surface flow throughout the watershed.

Like McIntyre et al. (2018), Bretherton (2020*) also found this increase to be temporary and only last through the first 2 years after harvest.

Annual precipitation was not correlated with surface water expression (likely due to the flashiness of these rain-dominated headwater systems), however precipitation rates closer to the time of the surveys do seem to be correlated (Table 14). This was a loose correlation possibly because a single precipitation gage was used instead of a local rain gage at each of the sites. More precise measurements of precipitation could provide a better understanding of the relationship between summer precipitation and surface flow expression.

Table 14. Correlation values (R) of each of the reference sites for the amount of rain in the proceeding x number of days by the percent wetted extent of the network in that water year (Bretherton,2020*).

	Precipitation x Percent Wet (R value)				
TRT ID	7 Days Prior	14 Days Prior	30 Days Prior	Water Year	30+14+7 Days
REF 1	0.76	0.85	0.54	0.20	0.74
REF 2	0.59	0.39	0.47	0.30	0.53
REF 3	0.63	0.56	0.73	0.24	0.73

A random forest model was also used to analyze the surface water expression at the reach scale. There were three main topographic features that seemed to be important to whether a reach would be dry or wet. The drainage area (flow accumulation), valley slope and stream slope were found to be the most important variables in the model (Figure 8). However, the random forest model had an "error rate of 0.0875 for the wet segments and a 0.4953 rate for the dry segments, making this model more accurate at predicting whether a segment will be wet (92% of the time) than predicting dry segments (50% accuracy)" (Bretherton, 2020*).

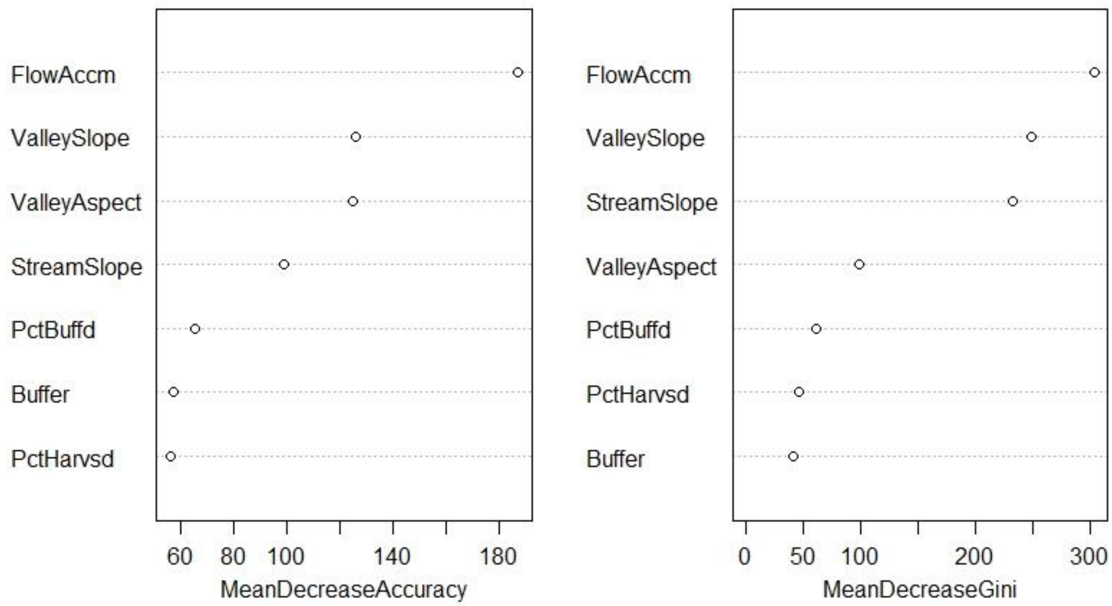

Figure 8. Variable importance plot for random forest model for wet vs dry segments for each year of the study in the treatment sites. The scale is relative to indicate the importance of each variable (Bretherton, 2020*).

The random forest models confirmed that higher stream slopes, lower valley slopes and smaller drainage areas were associated with reaches that had a higher percent of years dry. All these features are more likely to be higher up in the watershed, so it is difficult to conclude what role stream and valley slope play apart from the location in the watershed. Miller et al. (2015) also found that drainage area was predictive in determining the likelihood of discontinuous channels (Bretherton, 2020*).

1.2.1.d. Westside Extensive Riparian Status and Trends – Stream Temperature

Two hundred twenty-eight Type Np sites were evaluated and 55 were sampled.
Objectives included:

- Describe the frequency distribution of stream temperature (maximum summer stream temperature and seven-day average maximum stream temperature) and canopy closure in Type F/S and Type Np streams on forest lands managed under the FPR in western Washington.
- Estimate frequency distributions of several descriptive non-temperature variables.

Air and stream temperature were collected. The focus was on maximum stream temperature and periods of drying were removed and not reported: “data loggers at several monitoring stations were exposed to air as stream water levels dropped. These data were identified and excluded from analysis.” The data from the 55 Np sites could be re-analyzed to show the temporal frequency of drying at those randomly selected points.

This was Phase 1 of Extensive Monitoring. The intent was to repeat the monitoring but there was no appetite for doing so given the cost and products associated with Phase 1. Also, of the 228 "Type Np" sites that were evaluated, 22.4% were rejected as not being Type Np or having no-channel and 40% were not sampled for other reasons including not having enough water to submerge a temperature logger. Also, landowner permission was a big issue in this study. The intent was to monitor at least 50 sites in each stream type and to install all temperature loggers by 30 June 2008 to record each stream's annual thermal peak; but by mid-July 2008 only one half that number of sites were installed due to delays in locating and obtaining permission to access private property.

This project provides an estimate of status of stream condition across the landscape and was intended to be the baseline for future trend monitoring of stream temperature, riparian cover, and channel metrics. Thalweg depth was measured at 5 transects along 300 m reaches. Very few instances of dry channels were measured, likely due to the rejection of sites without sufficient flowing water. The practice of excluding sites without sufficient water limits the use of this study to inform discontinuous surface flow.

1.2.2. TFW Reports

1.2.2.a. Recovery of Amphibian and Invertebrate Communities in Recently Logged Coastal Headwater Streams

Jackson et al. (2003) evaluated abiotic and biotic responses to timber harvest in non-fish-bearing headwater channels. The study was funded by National Council for Air and Stream Improvement (NACSI) and the WA DNR AMP. The study included an investigation of geomorphology, and macroinvertebrate and amphibian communities in 15 study streams within and near four timber harvest sites in the Coast Ranges of Washington State. This BACI study included one year of pre-harvest (1998) and up to three years of post-harvest data collection (1999, 2000, 2001). In each of the four timber harvest sites, one stream served as a reference (4), and the remaining streams were buffered or partially buffered (4), or clearcut to the channel (7). Surveys of stream flow found that subsurface habitat, where dense alluvial material accumulated on the valley floor and stream flow was below and/or through this alluvial material, comprised 6% of the channel length in these small perennial streams. Note that this finding likely underestimated this occurrence more broadly, as streams with large amounts of subsurface flow were intentionally excluded from the study. The authors speculate about the potential influence of subsurface and/or dry perennial reaches on larval stream-associated amphibians, concluding that since larval movement requires a continuous aquatic environment, movement in their harvested study streams was likely inhibited by post-harvest slash accumulations and changes to channel morphology. The raw data from this effort were unavailable.

1.2.2.b. Amphibian Use of Seeps and Stream Reaches in Non-Fish-Bearing Stream Basins in Southwest Washington: A Preliminary Analysis

This observational study evaluated 16 randomly selected headwater basins in hard rock lithologies in the Stillman Basin of SW Washington to evaluate stream-associated amphibian distribution and use of seeps and stream reaches. Sampling was conducted from August- early

November 2000 and included collection of data on surface water intermittency. Due to the small sample sizes representing only a single year of data, results should be viewed as preliminary. The overall emphasis of the study was on seeps and there is relatively little evaluation or discussion of surface water expression in the sampled stream reaches. The study highlighted that reaches near PIPs seemed to be important for Columbia Torrent Salamander and had spatially discontinuous surface flow.

1.3. Studies East of Cascade Crest

In eastern Washington, more recent evaluations included observational and modeling efforts to quantify the spatial variability of hydrologic condition relative to basin characteristics in four studies (Table 15). Eastside Type N Riparian Effectiveness Project (ENREP), an on-going CMER effectiveness study, also informs buffering effects on intermittency in eastern Washington. Due to climatic, geophysical, and regulatory differences this geographic region is summarized separately.

Table 15. Adaptive Management Program studies conducted east of the Cascade crest that inform prevalence and characteristics of discontinuous perennial reaches in western Washington State. Study type is Before-After Control-Impact (BACI) or observational (OBS).

Citation	**Study Name**	**Study Duration (Timing)**	**Sample Size and Unit**	**Study Type**
Miller and Peterson 2009	Eastside Forest Hydrology Study	1 year (2012)	146 headwater basins	OBS
Stewart 2014*	Eastside Forest Hydrology Study Extension	1 year (2014)	40 Type Np basins	OBS
Ehinger 2013**	Eastside Extensive Riparian Status & Trends– Stream Temperature	2 years (2007 and 2008)	73 Type Np streams	OBS
Link (in progress)	ENREP	Ongoing (2018 to present)	10 paired streams	BACI

* Not in CMER Work Plan, name taken from WA DNR Project Plan – no final report was submitted to CMER.
** Only 10% of the Type Np sites included had surface flow during the summer. The TFW Policy committee deprioritized the Eastside Type N strata.

1.3.1. Eastside Forest Hydrology Study (FHS)

The purpose of this study was to characterize hydrologic attributes and their patterns of occurrence across the landscape. Study objectives included:

1. Determine the spatial and temporal characteristics of surface water discharge in Type N streams across eastern Washington FFR (Forests and Fish Report) lands.

2. Investigate process relationships between stream hydrology, landforms, and management activity.
3. Develop criteria for characterizing and mapping streams with similar characteristics across the FFR landscape.

The effort included data collection from one field survey in each basin, sampled during the driest time of year. Study authors used logistic regression to relate a wet channel to geologic, climatic, landcover, and topographic variables.

Of the 146 basins identified for inclusion, 14 were found not to have channels and 12 were determined not to have perennial flow (i.e., Type Ns). Of the remaining 101 basins, 78 were found to have dry reaches during the period of examination while the remaining 23 had continuous flow from the uppermost point of perennial flow (PIP). Seventy-nine percent (79%) of the Np channel network had flowing water while the remaining 21% was dry.

Factors distinguishing whether a channel was wet or dry include planform curvature, slope, topographic position, and geology. Divergent or planar planforms, steeper slopes, and higher relative topographic position (e.g., sites closer to the ridge line) were all associated with a greater proportion of dry channel. The relationship to geology is more complicated and varies with contributing area, but in general more porous lithologies (e.g., volcanic, sedimentary) are more likely to have dry channels than competent lithologies.

1.3.2. Eastside Forest Hydrology Study Extension

The Eastside Forest Hydrology Study Extension built on knowledge gained from the Forest Hydrology Study (FHS) to inform the ENREP study design. Thirty-nine FHS Type Np basins were selected to determine how the length, proportion, and configuration of dry Np reaches vary seasonally. The FHS Extension included data collected during four surveys from late May through early October 2014. Sites were selected based on the known occurrence of dry perennial reaches as determined during the 2012 field survey for the FHS. To investigate change in hydrologic condition occurring between field surveys, presence or absence of stream water was monitored using temperature sensors and time-lapse photography.

Survey of 39 Np basins was conducted to determine the:

- Spatial and temporal variability of flow.
- Spatial and temporal variability of channel continuity.
- Temporal variability of connectivity to fish-bearing waters.

Field surveys indicated that the length of wetted Np channel decreased, and length of dry channel increased, from late spring through early fall. Length of dry Np channel increased from approximately 7% in the first early-season survey to 21% in late summer. The pattern of drying was progressive and there was spatial consistency in dry reaches observed between years, though this observation was not quantified. Detailed maps were produced. Data showed that only 11% of the total Np RMZ was associated with reaches that were dry all summer. However, the “dry” Np basins known to have at least 500’ of dry channel in late summer 2012 increased to 29% of the Np buffer associated with dry reach by late summer. Despite substantial channel drying over the field season, most of the monitored drying at instrumented sites occurred as a discrete event, rather than a prolonged process of alternating drying and re-wetting. In addition, the locations of many wet channel to dry channel transition points were largely stationary throughout the FHS Extension.

1.3.3. Eastside Extensive Riparian Status and Trends – Stream Temperature

This project was intended to develop estimates of stream temperature in Type Np streams across eastern Washington but was never completed. Sites were selected for the study via a random draw of sampling locations using the DNR Hydrography GIS data. Sixty-six out of 73 of the selected sites were dry, preventing further implementation of the study (W. Ehinger, personal communication). Importantly, this highlights the challenges of using DNR Hydrography GIS data to randomize site selection and predict surface flow for studies in eastern Washington.

1.3.4. Eastside Type N Riparian Effectiveness Project (ENREP)

The ENREP Project is currently in implementation, and its study objectives and pre-harvest site conditions suggest that the study will yield useful information on the occurrence of dry reaches and the effect of dry reaches on stream temperature change after harvest in eastern Washington. Policy expressed interest in "*What is the effect of buffering or not buffering spatially intermittent stream reaches in Type Np streams"* (CMER Work Plan, 2023). The objective is to inform Policy of the quantitative changes in FPHCP covered resources, water quality, and aquatic life coincident with forest harvest activities in eastern Washington, and to determine if and how observed changes are related to activities associated with forest management.

ENREP follows a paired-BACI design with five watershed pairs. The study is designed with at least two-years of pre-treatment monitoring and at least two-years of post-treatment monitoring. The basin-scale treatment that will be applied represents the most common application of riparian protection under Forest Practices rules for Type Np streams in eastern Washington (WAC 222-30-022(2)). Two of the paired sites were selected in part because they have dry Np reaches in most years. The spatial extent of dry and flowing reaches is being determined near the start of the late spring drying period and end of the summer dry periods (McNamara et al., 2005) by direct observations.

Harvest treatment recommendations in 2020 were driven in part by dry stream reaches. The project team secured a variance from the FP Board to deviate from FP rules to clearcut harvest dry reaches of the stream network, including within 500ft of the Type Np/Type F break. The harvest at one study site included an approximately 300ft reach with the first 500ft of the Type Np stream, with many wet-dry sections. Continuous stage/flow measurements are being collected in this section, so detailed hydrologic conditions will be recorded. ENREP is ongoing and will provide some limited insights into discontinuous perennial reaches in eastern Washington.

2. BEST AVAILABLE SCIENCE SYNTHESIS

2.1. Perennial Initiation Point (PIP) Location and Variation

PIP locations associated with stable groundwater sources such as seeps and springs can be relatively stationary even with differing amounts of precipitation from year to year (See Table 7;Veldhuisen, 2004; Whiting & Godsey, 2016; Winter, 2007). However, other PIPs have been observed to migrate up and down stream channels across years, highlighting interannual variation in surface water expression (Bretherton, 2020; Winter, 2007). The seasonal migration of PIPs may be in response to precipitation patterns with upstream movement in response to the wetter season and downstream movement in response to the dryer season (Winter, 2007). Other factors that influence PIP migration include changes to and depth of the bedload that may influence surface expression (Edwards et al., 2015; Winter, 2007). These patterns have been associated with lithology as an important control on PIP locations (Jaeger et al., 2007; Montgomery & Dietrich, 1988). Basalt lithologies have bedrock springs that may provide for a more stable PIP, while marine sedimentary lithologies may follow drainage area-slope relationships. In addition, the location of PIPs was influenced by the fractured nature of the local bedrock and were independent of slope and area (Montgomery & Dietrich, 1988).

2.2. Frequency of Occurrence

Approximately 50% of all streams by length in the continental US are headwater streams (defined as 1st order streams in a watershed) and approximately half of these are perennial (Nadeau & Rains, 2007), while the other half are seasonal. These classifications are for a "normal year" (i.e., based on 30-year average for precipitation) and can vary depending on the source of stream flow such as groundwater, subsurface flow through the soil, precipitation over the surface, or overland flow (Brooks et al., 2012).

In several studies of flow permanence in Washington, stream reaches with discontinuous perennial flow were found to be relatively common in eastern and western Washington during summer low flow conditions (Ehinger et al., 2021; Jaeger et al., 2007; McIntyre et al., 2018; Veldhuisen, 2004). Fifty to 75 percent of Type Np Waters in western Washington are estimated to have discontinuous perennial reaches (Palmquist, 2005). We note that inter- and intra-annual variation complicate efforts to identify discontinuous perennial reaches across the landscape.

The extent and distribution of stream flow permanence across the landscape is complicated for several reasons: In mountainous terrain where the groundwater expression can be influenced by fracture pattern from stress in the Earth's crust (Domenico & Schwartz, 1997; Sophocleous, 2002). Dry reaches may also occur in areas with porous substrates, potentially due to unconsolidated glacial lithology, when the stream is captured by the hyporheic zone (Hunter et al., 2005). Subsurface flow can cross watershed boundaries by following flow paths along folded or tilted relatively impermeable bedrock layers (Edwards et al., 2015). Classical understanding of surface flow patterns in headwater systems is that seasonal streams transition into perennial streams in the downstream direction (Edwards et al., 2015). However, this pattern can vary depending on the climate and the hydrogeology of the watershed (Winter, 2007; Winter et al., 1999). In addition, the transition between seasonal and perennial streams may include spatially discontinuous segments of surface flow and dry channels, especially in the drier months (Dohman et al., 2021). The source for both perennial and seasonal streams is groundwater but the inputs to seasonal streams may be more reliant on seasonal aquifers that expand during seasons where precipitation is high and /or evapotranspiration is low (Edwards et al., 2015).

An effort initiated in 2023 to map stream flow permanence in Oregon, Washington, and Idaho has been initiated by a joint effort between USDA Forest Service, U.S. Geological Survey, and USDI Bureau of Land Management (Western Oregon Streamflow Permanence | US Forest Service Research and Development (usda.gov)). A mobile field application, FLOwPER, was developed to record field observations of surface flow permeance, which is then uploaded to a centralized database. These data will be incorporated in the USGS 3D Hydrography Program and used in the predictive model, Western Oregon Wet Dry model, which is currently being tested in western Oregon and may provide more clarity around the frequency and distribution of discontinuous portions of headwater streams.

2.3. Patterns of Surface Flow Discontinuity in Perennial Streams

The spatial pattern of surface flow discontinuity reflects locations along a perennial stream where subsurface flow capacity at a given time and location is less than the flow necessary for surface expression (Dohman et al., 2021; Winter et al., 1999). A stream reach is considered a gaining reach when the groundwater flows into the streambed or a losing reach when the reach loses water to groundwater (Winter et al., 1999). In general, gaining reaches are more likely to have perennial flow and losing reaches are more likely to have seasonal flow only. Whether a reach is gaining or loosing depends on the relative contribution among lateral, vertical, and longitudinal subsurface flow paths into a given reach at a given time (Dohman et al., 2021). For example, a reach has a high likelihood for surface flow if it is a gaining reach, such as when the longitudinal hydrologic gains and persistent lateral subsurface flow from the hillslopes outweigh the vertical losses as well as transpiration from riparian vegetation (Dohman et al., 2021).

The complex interaction of the various flow paths that contribute to the expression of surface flow can result in a discontinuously perennial flow pattern where surface flow and subsurface flow (e.g., dry portions of the channel) can vary over short longitudinal distances (Dohman et al., 2021). Investigations have revealed high variation in the lengths of discontinuous perennial reaches across Type Np Waters in western and eastern Washington. Some efforts have concluded that the length of discontinuous perennial flow at a site is generally less than 100 m (Palmquist, 2005); others documented examples of much longer discontinuous reaches across multiple study sites (Ehinger et al., 2021; McIntyre et al., 2018; Pleus & Goodman, 2003). Also, expression of discontinuous perennial reaches was related to dry years (Pleus & Goodman, 2003; Veldhuisen, 2004), and the first expression of dry presented itself lower in the stream during drier summers (Veldhuisen, 2004).

Although PIP locations typically associated with seeps and springs can be relatively stable in some sites across years, research has consistently supported the conclusion that the location of highest continuous surface flow in Type Np Waters varied more from year to year than the location of the PIP (Hunter et al., 2005; Palmquist, 2005; Veldhuisen, 2004). These findings suggest a higher incidence of variation (both between and within sample years) in the surface water expression within discontinuous perennial reaches (Hunter et al., 2005).

Numerous simulation models have explored the surface water-groundwater interactions (see reviews in Barthel & Banzhaf, 2016; Ntona et al., 2022). Recent research has focused on predicting streamflow permanence in headwater streams (see review, Mahoney et al., 2023). For example, a model has recently been developed to predict spatial and temporal patterns of stream connectivity in the Pacific Northwest. Probability of Streamflow Permanence Model (PROSPER) was designed to predict the probability of annual stream flow for free-flowing streams without dams or diversions stream channel in the Pacific Northwest (Jaeger et al., 2019). PROSPER is a GIS raster-based empirical model with a 30-m spatial resolution. A Random Forest classification was applied to an extensive dataset of streamflow permanence observations using 257 climatic and 35 physical predictor variables. The final models (a global model and three subregion models) consisted of 29 predictor variables where the top 3 variables (excluding basin elevation and drainage area) were total annual precipitation, percent forest cover, and mean monthly minimum temperature. An application of the PROSPER model to the Mount Rainier National Park found drainage area, covariates describing geology, topography, and land cover as the top predictors of stream flow permanence(Jaeger et al., 2023). For the global and sub-model applications applied to the Pacific Northwest region, PROSPER had a classification accuracy of ~80%, and a classification accuracy of ~75% for the application to Mount Rainier National Park. This error rate reflects the challenge in predicting stream permanence.

2.3.1. Factors that Influence Surface Expression

Headwater streams exhibit surface flow discontinuity resulting from a complex interaction between groundwater and surface water, which are influenced by climate, landform, geology, and biotic factors in a hydrogeology framework (Sophocleous, 2002;). Because the movement and storage of water varies both spatially and temporally, predicting the longitudinal expression of surface flow can be difficult (Hafen et al., 2022).

Several efforts, including the model PROSPER discussed above, have been conducted to classify streams by flow permanence at the landscape scale for Pacific Northwest streams (Hafen et al., 2022; Liermann et al., 2012; Nadeau et al., 2015). Although these efforts are not specifically designed to predict discontinuous flow section in perennial streams, we assume that these factors also control the discontinuous surface flow. Other studies have explored various aspects of the complex interactions within the hydrogeology framework (Hancock et al., 2009; Sophocleous, 2002) and together, are summarized in Table 16.

Table 16: Factors in the hydrogeology framework with example metrics that influence surface flow expression.

Factor	**Example Metrics**	**Reference**

Climate	Annual and seasonal precipitation (including snow vs. rain) Temperature (snow melt)	Kormos et al. 2016; Jaeger et al. 2019; Hafen et al. 2022 Kormos et al. 2016; Hafen et al. 2022
Landform	Headwater basin area Slope, gradient, aspect, and elevation Channel metrics such as entrenchment ratio	Fritz et al. 2008; Olson and Burton 2019; Jaeger et al. 2023 McGuire et al. 2005; Jaeger et al. 2019, 2023 Fritz et al. 2008
Geology	Soil water holding capacity and catchment storage capacity Bedrock composition and permeability	Whiting and Godsey 2016; Hafen et al. 2022; Jaeger et al. 2019, 2022 Hale 2011; Hale and McDonnell 2016; Hale et al. 2016; Pfister et al. 2016; Jaeger et al. 2019, 2023
Biotic	Percent forest cover Evapotranspiration	Jaeger et al. 2019, 2023 Jaeger et al. 2019, 2023

2.3.2. Stream Temperature

Although associations between temperature responses in larger non-fish-bearing streams and forest management practices have been evaluated frequently, relatively little work has been conducted on small headwater streams including discontinuous perennial reaches. Existing efforts suggest substantial spatial variation exists in temperature in headwater streams, similar to observations from larger non-fish-bearing waters, that cannot be attributed reliably to shading (Dent et al., 2008; Martin et al., 2021).

Potential explanations of spatial variation in these studies beyond the effects of shading include groundwater and hyporheic exchange and stream surface area. For example, Janisch et al. (2012) reported an average daily maximum temperature increase in clearcut catchments (~2-5 ha headwater basins) of ~ 1.5 °C in the first year post-harvest and observed a maximum change in one basin of 3.6 °C. In contrast, Gomi et al. (2006) reported post-harvest increases in clearcut catchments ranging from 2 to 8 °C. Janisch et al. (2012) cited the amount of exposed surface water above the stream temperature monitoring station as a potential explanation of temperature variation in their results as wetland extent was not similar across their study basins.

Substrate influences temperature variation in small streams by moderating stream-groundwater interactions and hyporheic exchange (Brown, 1969; Johnson, 2004; Moore & Wondzell, 2005). Coarse stream substrates are more likely to have high saturated hydraulic conductivity (K) that facilitates groundwater exchange (which contributes to cooling) while fine-textured sediments will have lower K and be less able to buffer warmer stream temperatures (Moore et al., 2005). As a result, discontinuous perennial reaches can support patches of cold water or deliver cooler water downstream because subsurface flow reduces the effects of solar radiation (Ebersole et al., 2014). Guenther et al. (2014) reported that reaches with greater upwelling tended to be cooler than those with downwelling, a result consistent with other reports (Curry et al., 2002; Malcolm et al., 2002; Moore et al., 2005).

Finally, a reasonable prediction for basins <100 ha is that stream temperature is associated with the percent of the basin that has been harvested, regardless of whether stream shading is present although the mechanisms responsible for this variation may vary (Martin et al., 2021; McIntyre et al., 2018). For example, increases in ambient air temperature may be sufficient to raise the temperature of small streams even when understory and overstory shading is present. Small streams with high surface area/volume ratios may be especially prone to this influence, given equivalent substrates and other physical controls. As a result, the expectation that riparian buffers are sufficient to maintain stream temperatures within desired ranges may not be reasonable in all settings.

2.3.3. Amphibian Use

Generally, most stream-associated amphibians are low order stream obligates (e.g., first, second, and third order streams) that use the wetted channel width and associated riparian area for important aspects of their life history. Seven stream-associated amphibians (Table 17**)** are designated as “other covered species” in the Forests and Fish Report (USFWS, 1999), and an Overall Performance Goal is to support their long-term viability and persistence.

Associations of these species with wetted channels vary based on desiccation tolerance across life stages. For example, tailed frogs and torrent salamanders use wetted surface or flowing water habitats for egg laying and larval development. Post-metamorphic tailed frogs migrate overland and along stream channels, but torrent salamander post-metamorphs are more reliant on surface moisture throughout all stages of their life history, using upland habitats primarily during periods of high precipitation (e.g., the winter). As a result, all of these species may be less likely to use discontinuous perennial reaches where surface flow is irregular and more prone to drying than perennial reaches downstream. However, we note the common observation of adult tailed frogs in first order perennial and discontinuous reaches during the late summer months, a pattern of seasonal use thought to be associated with increased food availability (Hayes et al., 2006). In contrast, Plethodon *spp.* use of the riparian area may not be dependent on continuous stream flow per se. Also, Plethodon *spp.* will use the riparian area regardless of streamflow depending on whether other factors maintain the hydrology/conditions necessary, such as wetted surface, saturated gravel and soils, and/or the presence of suitable cover within the bankfull width of a stream.

Generally, potential benefits of discontinuous perennial hydrology for these species are anecdotal. For example, although some studies report high abundance of torrent salamanders near the upper extent of perennial surface flow (Hayes et al., 2002; Hunter, 1998; Wilkins & Peterson, 2000), available data are insufficient to support an explanation for these observations. Discontinuous reaches may support fewer predators of amphibian larval stages (Welsh Jr et al., 2005). Stable, low volume flows of cool groundwater into unconsolidated gravels may provide oviposition sites for torrent salamanders (Thompson et al., 2018) similar to those that may persist at PIPs in stream networks with discontinuous perennial reaches. (Hayes et al., 2002; Hunter, 1998; Wilkins & Peterson, 2000)

Finally, vertical movement of amphibians into the hyporheic zone is poorly understood, but some observations suggest that as surface flow recedes, amphibians can occupy the wet interstitial spaces maintained by subsurface flow. For example, Feral et al. (2005) incidentally captured Pacific Giant Salamander (*Dicamptodon tenebrosus*) larvae in the hyporheic zone of two seasonally discontinuous perennial reaches while sampling for macroinvertebrates in Humboldt County, California. Out of 22 observations, 15 were captured in PVC traps placed 0 to 30 cm below the streambed and seven were captured in traps buried 30 to 60 cm below the stream bed. Captures occurred throughout the year and did not appear to vary with season, although most captures occurred when surface flow was absent. How torrent salamanders use hyporheic habitats seasonally is not well-documented.

Table 17. Stream-associated amphibians designated under the Washington State Forest Practices Habitat Conservation Plan (FPHCP), reliance of the species on permanent surface streamflow for some portion of their life history (Surface Flow Reliant), and known or anticipated use of discontinuous perennial reaches (Discontinuous Np Use).

Taxa	**Species**	**Surface Flow Reliant**	**Discontinuous Np Use**
Torrent Salamanders (*Rhyacotriton* spp.)	Cascade (*R. cascadae*) Columbia (*R. kezeri*) Olympic (*R. olympicus*)	Yes	Yes
Tailed Frogs (*Ascaphus* spp.)	Coastal (*A. truei*) Rocky Mountain (*A. montanus*)	Yes	Less frequent
Lungless Salamanders (*Plethodon* spp.)	Dunn's (*P. dunni*) Van Dyke's (*P. vandykei*)	No	Yes

2.4. Potential Forest Management Impacts

Forest management, including harvesting, silviculture, and infrastructure (roads, bridges, and culverts) can modify the hydrology and ecology of discontinuous stream reaches. Potential modifications include altered base flows; increased rates and severity of debris flows and upslope failures; accumulation of slash during and after harvesting in discontinuous perennial reaches; and increased rates of sedimentation during harvest, from poorly routed or orphaned roads, or from bank erosion if green tree buffers fail (Jackson et al., 2007; Moore & Wondzell, 2005; Turner et al., 2010). We note that existing engineering controls, including culvert and bridge upgrades, increased regulation of road construction standards and management (e.g., he Road Maintenance and Abandonment Plans (RMAP) process; https://www.dnr.wa.gov/publications/fp_form_rmap_infoinstructions.pdf), and slope stability buffers, have been implemented in the current forest practices rules in response to these issues.

In contrast, modification to basin hydrology due to variation in forest cover is a more difficult challenge to resolve (Jaeger et al., 2019; Perry & Jones, 2017). For example, a reduction in overall tree cover can increase water yield due to reduced evapotranspiration rates (Bosch & Hewlett, 1982; Hibbert, 1965; Keppeler & Ziemer, 1990). However, reduction in forest cover may increase insolation rates (Moore et al., 2005). How these factors may interact to influence temperature changes is difficult to determine because of site-specific conditions (e.g., upstream cool inflow) and the duration of the summer drought period (Moore et al., 2023; Naman et al., 2024). Slash (Kibler et al., 2013) and/or understory vegetation (Gravelle & Link, 2007) provided sufficient shading to maintain stream temperatures post-harvest (Jackson et al., 2001; Janisch et al., 2012) Importantly, increased baseflows during summer may reduce insolation effects due to increased water volume subsurface versus increased exposure to insolation (Harr & McCorison, 1979). Additional research suggests that increases in flow may be of short duration in some basins; however, high evapotranspiration rates of densely stocked and fast-growing plantations may decrease summer low flows (Perry & Jones, 2017). Finally, relatively little information is available to describe how longitudinal expression of flow in discontinuous Np reaches may be modified by forest management activities (Coble et al., 2020).

2.5. IMPLICATIONS OF CLIMATE CHANGE

Realized and potential future climatic variation has consequences for the physical structure, hydrology, and ecology of small, discontinuous perennial forest streams (Creed et al., 2014). Higher peak flows in winter could result in physical modification of stream channels including wood inputs and sorting of fine and coarse substrates. In turn, pool formation and retention could differ from historic patterns and lead to alterations to water storage and hyporheic exchange. In contrast, decreased summer precipitation rates are likely to exacerbate summer low flows that characterize many headwater basins and may result in historically perennial streams becoming seasonally dry or spatially intermittent (Coble et al., 2020; Hunter et al., 2005) However, broad spatial changes are likely to vary in snow vs. Rain-dominated systems, with the former likely to be more susceptible to summer droughts (Abatzoglou et al., 2014; Stewart et al., 2004).

Importantly, general predictions of more variable precipitation rates annually, with events of higher intensity and lower frequency becoming more common, suggest that stream networks may “migrate” downstream in response (Olson & Burton, 2019). That is, PIP locations may occur further down in basins, discontinuous perennial reaches become dry, Np reaches become discontinuous, and so forth. General models to predict streamflow may be formulated based on lithology, aspect, and geography. However, the consequences of these changes for stream biota are more challenging to evaluate. Discontinuous perennial and perennial streams play complimentary and unique functions in lotic ecosystems (Richardson & Danehy, 2007) but the relative capacity of these functions to migrate downstream with flowing water has not been evaluated.

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