Amphibian Use of Seeps and Stream Reaches in Non-fish Bearing Stream Basins in Southwest Washington: A Preliminary Analysis

Year 2000 Annual Report

submitted by:

Marc P. Hayes, PhD; Timothy Quinn, PhD; Douglas E. Runde, PhD

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Table of Contents

Table of Contents i
List of Figures ii
List of Tables ii
Executive Summary v
1. Background 1
1.1 Why are seeps important to amphibians? 1
1.2 Research Questions and Hypotheses 2
1.3 Study Design 3
1.4 Criteria for Selection of Study Areas and Sites 4
2. Research Question 1 – How can seeps be defined and identified? 6
2.1 Methods and definitions 6
2.2 Results 9
2.3 Discussion 32
3. Research Question 2 – Are seeps more valuable for amphibians than other aquatic habitats in non-fish-bearing systems? 39
3.1 Method 39
3.2 Results 40
3.3 Discussion 48
4. Research Question 3 – Are some seeps more valuable to amphibians than others? 53
4.1 Method 53
4.2 Results 53
4.3 Discussion 66
5. Key Findings 70
6. Suggested Priorities for Future Research 73
7. Acknowledgments 74
8. Literature Cited 75
Appendix I – Technique Used to Distinguish Headwall from Side-slope Seeps (Stillman Watershed, Washington) in 2000 81
Appendix II – Plant Taxa Addressed in the Stillman Watershed, Washington, 2000 Seep Study 82
Appendix III – Methods Used To Measure Flow Velocity and Flow Volume In Headwater Seeps (Stillman Watershed, Washington) during 2000 83
Appendix IV – Index for Identifying Plants Associated with Seeps in Stillman Watershed, Washington, 2000 85
Appendix V – Geologic Formations in Stillman Watershed, Washington Subbasins Sampled, 2000 89
Appendix VI – Amphibian Species Known to Occur in the Stillman Watershed, Washington, 2000 90
Appendix VII – Amphibian Data from the Stillman Watershed, Washington, 2000 91
Appendix VIII – Aquatic Habitat-Associated Amphibian Species Data for Olympic National Park, 1995-1998 93

List of Figures

Figure 2.201 – Relationship between Basin Area (Type N) and Subbasin (Area Sampled) in the Stillman Watershed, Washington, 2000 11
Figure 2.202 – Frequency of Seeps by Subbasin in the Stillman Watershed, Washington, 2000 12
Figure 2.203 – Frequency Distribution of Areas of Sampled Seeps in the Stillman Watershed, Washington, 2000 15
Figure 2.204 – Distance of Seeps (n = 29) from the Stream in the Stillman Watershed, Washington, 2000 17
Figure 2.205 – Frequency Distribution of Seep Densities by Proximity to the Stream Channel in the Stillman Watershed, Washington, 2000 18
Figure 2.206 – Aspect of Reaches and Seeps in the Stillman Watershed, Washington, 2000 18
Figure 3.201 – Variation in Mean Density among Columbia Torrent Salamander Size Classes among Headwater Habitats in the Stillman Watershed, Washington, 2000 45
Figure 4.201 – Frequency Distribution of Species Richness among Sampled Seeps in the Stillman Watershed, Washington, 2000 54
Figure 4.202 – Relationship between Adjusted Species Richness and Seep Area based on Zero and Non-Zero Raw Species Richness Categories in the Stillman Watershed, Washington, 2000 57
Figure 4.203 – Relationship between Amphibian Density and Seep Area in the Stillman Watershed, Washington, 2000 60
Figure 4.204 – Relationship between Gradient and Density of Columbia Torrent Salamanders in Headwater Habitats in the Stillman Watershed, Washington, 2000 62
Figure 4.205 – Relationship between Adjusted Species Richness and Columbia Torrent Salamander Density in the Stillman Watershed, Washington, 2000 65

List of Tables

Table 2.201 – Sampled Subbasins in the Stillman Watershed, Washington, 2000 10
Table 2.202 – Subbasin Seep Data in the Stillman Watershed, Washington, 2000 13
Table 2.203 – Seep Characteristics in the Stillman Watershed, Washington, 2000 14
Table 2.204 – Five Flow Velocity Measurements at Five Seeps in the Stillman Watershed, Washington, 2000 15
Table 2.205 – Five Flow Measurements at Five Seeps in the Stillman Watershed, Washington, 2000 15
Table 2.206 – More Seep Characteristics in the Stillman Watershed, Washington, 2000 16
Table 2.207 – Seep Substrates in the Stillman Watershed, Washington, 2000 19

List of Tables (continued)

Table 2.208 – Plant Taxa Identified from Within and Outside of Seeps in the Stillman Watershed, Washington, 2000 21
Table 2.209 – Vegetation Cover Associated with Reaches and Seeps in the Stillman Watershed, Washington, 2000 26
Table 2.210 – Reaches Examined in the Stillman Watershed, Washington, 2000 28
Table 2.211 – Five Flow Velocity Measurements in Five Reaches in the Stillman Watershed, Washington, 2000 29
Table 2.212 – Five Flow Estimates in Five Reaches in the Stillman Watershed, Washington, 2000 29
Table 2.213 – Reach Substrates in the Stillman Watershed, Washington, 2000 30
Table 2.214 – Plant Taxa Identified along Reaches and in Adjacent Uplands in the Stillman Watershed, Washington, 2000 31
Table 3.201 – Amphibian Species Recorded in Headwater Habitats in the Stillman Watershed, Washington, 2000 41
Table 3.202 – Variation in Adjusted Amphibian Species Richness in the Stillman Watershed, Washington, 2000 42
Table 3.203 – Variation in Amphibian Densities (individuals/ac) in the Stillman Watershed, Washington, 2000 43
Table 3.204 – Variation in Columbia Torrent Salamander Densities (individuals/ac) in the Stillman Watershed, Washington, 2000 44
Table 3.205 – Density Variation in Columbia Torrent Salamander by 5-mm Size Class in the Stillman Watershed, Washington, 2000 46
Table 3.206 – Density Variation among Amphibians excluding the Columbia Torrent Salamander in Non-terminal Reaches in the Stillman Watershed, Washington, 2000 48
Table 3.207 – Density Variation among Amphibians excluding the Columbia Torrent Salamander in Seeps in the Stillman Watershed, Washington, 2000 49
Table 4.201 – Variation in Adjusted Species Richness among Seeps in the Stillman Watershed, Washington, 2000 55
Table 4.202 – Variation in Adjusted Species Richness with Substrate Type in the Stillman Watershed, Washington, 2000 56
Table 4.203 – Variation among Variables between Seeps with High and Low Adjusted Amphibian Species Richness in the Stillman Watershed, Washington, 2000 58
Table 4.204 – Variation in Amphibian Density among Seeps in the Stillman Watershed, Washington, 2000 58
Table 4.205 – Variation in Amphibian Density with Substrate Types in the Stillman Watershed, Washington, 2000 59
Table 4.206 – Variation among Variables between Seeps with High and Low Amphibian Densities in the Stillman Watershed, Washington, 2000 61

List of Tables (continued)

Table 4.207 – Variation in Columbia Torrent Salamander Density among Seeps in the Stillman Watershed, Washington, 2000 62

Table 4.208 – Variation in Columbia Torrent Salamander Density with Substrate Types in the Stillman Watershed, Washington, 2000 63

Table 4.209 – Variation among Variables between Seeps with High and Low Columbia Torrent Salamander Densities in the Stillman Watershed, Washington, 2000 64

Table 4.210 – Variation in Columbia Torrent Salamander Cover and Substrate in Seeps in the Stillman Watershed, Washington, 2000 65

Table 4.211 – Variation in Western Red-backed Salamander Cover and Substrate in Seeps in the Stillman Watershed, Washington, 200 66

Executive Summary

We examined amphibian distribution and use of habitat at seeps and stream reaches in the managed forest landscape of southwestern Washington. Within 16 1st- to 3rd-order stream subbasins on a mostly igneous geology randomly chosen from a large sample of perennial, non-fish bearing streams (Type Np basins) in Stillman Creek Watershed, we recorded amphibian species presence and abundance, and measured 31 physical and biotic variables. In the interval August-early November 2000, we sampled all off-channel aquatic habitats and selected channel-possessing units in these subbasins.

We treated seeps, as opposed to springs, based on the Forest and Fish (FFR) negotiation concept of near-surface wet areas that lack a down-slope scour channel and appreciable standing water. In examination of these headwater habitats, we made particular effort to evaluate criteria used to define sensitive sites near or adjacent to Type Np waters based on the Washington Administrative Code (222-16-010). We identified a total of 29 seeps and 20 springs in the 16 subbasins; we sampled all seeps and 14 stream reaches. Four reaches included springs and one reach comprised the only waterfall in the sampled area. As sampling was done during low-flow conditions in a year that was drier than average, reaches with flow during our surveys were probably perennial in year 2000.

Four subbasins lacked seeps; the remaining 12 had 1-8 seeps. Most (86%; n = 25) seeps were channel-adjacent (≤ 100 ft from the Type N channel). Density of channel-adjacent seeps (1 per 2.6 ac [1.1 ha]) was > 50 times that of off-channel seeps (1 per 37.0 ac [15 ha]). Twenty-six of the seeps had a side-slope position; 3 had a headwall position. Of side-slope seeps, 85% (n = 22) had side-slope gradients > 20%; 2 of 3 headwall seeps had gradients > 20%. Of 29 seeps examined, 18 had an overland flow connection to the Type N stream channel. All headwall seeps and 58% (n = 15) of side-slope seeps had an overland flow connection. Seeps connected to streams occurred most often in close proximity to the stream channel. Surface water connections to stream channel existed for 17 of the 25 channel-adjacent seeps, but only 1 out of 4 off-channel seeps was connected to the channel. Leaf litter, woody debris, and largely inorganic elements finer than small gravel dominated seep substrates. Rule language was ambiguous for substrate criteria of all seeps as well as the gradient (i.e., "steep") criterion of headwall seeps. Although the proposed FFR patch buffer would capture 100% of qualifying headwall and sideslope seeps under any interpretation of these criteria, considerable variation in the number of seeps protected will exist depending on interpretation. Moreover, substrate variation in seeps may be inconsistent with FFR negotiation expectations, but greater precision in the measurement of substrate will be needed to resolve this issue. Ambiguities may require that amphibian-based metrics for evaluating seep quality help guide the direction of rule language.

As expected, other characteristics of seeps were variable. Seep areas (water-saturated substrate) varied over two orders of magnitude (22-11,567 ft^2 [2-1,075 m^2]). We found measurable water flow at or near the surface (i.e., percolation) in 14 of the 29 seeps, the remaining 15 seeps lacked percolation. At air temperatures > 8°C, water temperatures in seeps were typically cooler than the air, but at air temperatures ≤ 8 C, seeps were warmer than the air.

Three vegetation features may help identify seeps. First, seeps had less tree canopy than surrounding upland forest, so tree canopy gaps might be used as first screen for locating potential seeps. Second, 3 deciduous tree species (red alder [*Alnus rubra*], Oregon ash [*Fraxinus latifolia*], and black cottonwood [*Populus balsamifera*]) were found either in seeps or on stream margins, so they may also prove a useful screen to identify potential seeps in a coniferous upland landscape. Lastly, 10 herbaceous plant taxa (maidenhair fern [*Adiantum pedatum*], lady fern [*Athyrium filix-femina*], a sedge [*Carex* sp.], snake liverwort [*Conocephalum conicum*], horsetails [*Equisetum* sp.], leafy liverworts [Hepaticae], coltsfoot [*Petasites frigidus*], piggyback plant [*Tolmiea menziesii*], skunk cabbage [*Lysichiton americanum*], and stinging nettle [*Urtica dioica*]) were either found exclusively or occurred mostly in seeps; these taxa may help locate seeps on the ground. However, of the 10 plant taxa recorded only in seeps, the species found most frequently was recorded only 8 times, and 5 taxa were each recorded only once. This suggests that a suite of indicator plant taxa, rather than one or a few, may be needed to identify seeps.

Limited physical comparisons between reaches and seeps revealed expected differences. Reach flows were greater than seeps, and reaches had more coarse and fewer fine and organic substrate types.

We recorded at least 7 species of amphibians (8 if unidentifiable small giant salamander larvae [*Dicamptodon* sp.] represented Cope's giant salamander [*Dicamptodon copei*]) in reaches and seeps sampled in this study. Salamanders were the dominant amphibian group; they were recorded in 32 (74%) habitat units, whereas frogs were in only 2 (5%). Reaches were richer in species than seeps, which resulted from two findings. First, all Pacific tailed frog (*Ascaphus truei*) larvae and almost all giant salamander larvae were found in reaches. Second, Columbia torrent salamander (*Rhyacotriton kezeri*), easily the most abundant amphibian across reaches and seeps in this headwater landscape (> 80% of amphibians found were torrent salamanders), was the only amphibian species recorded in most seeps. Asymmetry in the distribution of stream-associated amphibians (SAAs) may reflect flow-linked habitat requirements. Amphibian densities, largely a function of Columbia torrent salamanders, were also greater in reaches than seeps. Initiation reaches (reaches having a spring) not only had the highest Columbia torrent salamander densities among habitat units, but they had the highest densities of the smallest larval size classes. Thus, initiation reaches may represent nurseries for Columbia torrent salamanders. The

only waterfall sampled had the highest densities of the largest size classes of Columbia torrent salamanders; significance of this pattern is unclear.

Amphibian occupancy of seeps was highly variable. Twenty (69%) of 29 seeps sampled had at least one amphibian species present. We found up to 5 different amphibian species in a seep, but only 4 seeps had > 1 species. Amphibian species richness was significantly greater in seeps with higher gradients (> 20%), or higher amphibian or torrent salamander densities. If verified with additional data, torrent salamander density may provide a tool to identify local levels of amphibian species richness. Amphibian density was inversely correlated with seep area, which suggests that seeps shrink seasonally and that an effect on smaller seeps would be greater. A seasonal bias (cooler temperatures during the latter part of the sampling interval) having potentially affected species richness and amphibian density patterns, and species richness data having limited variation require that more data be collected to verify the patterns found in this study.

Four amphibians (coastal giant salamander [*Dicamptodon tenebrosus*], northern red-legged frog [*Rana aurora aurora*], Dunn's salamander [*Plethodon dunni*], and western red-backed salamander [*P. vehiculum*]) were recorded in seeps in low numbers. Seep data collected at times other than the low-flow interval of this study will be needed to determine whether appearance of these species in seeps at low frequency is consistent.

Noteworthy results from this preliminary study include:

1) The zone 100 ft from streams captures nearly all seeps within study basins.
2) Torrent salamander is the dominant amphibian in this headwater landscape.
3) During the low-flow seasonal interval, an inverse relationship may exist between seep size and amphibian density.
4) Initiation reaches seem more important to torrent salamander reproduction.
5) At the resolution measured, lack of relationship may exist between substrate characteristics and torrent salamander density.
6) Amphibians, especially Columbia torrent salamanders, occur in most head and side-slope seeps.
7) One waterfall has the highest relative density of adult Columbia torrent salamanders in this headwater landscape.

As this study had small sample sizes, results should be viewed as preliminary. The first priority should be to increase sample sizes to determine whether the preliminary patterns observed here hold. Eventually, understanding diel and seasonal patterns of seep use by amphibians will also be important, especially if we expect to understand the seasonal use by those amphibians irregularly detected in the low-flow interval of this study. Further,

as geology and precipitation strongly influence channel-forming processes in headwater streams and are known to vary over the landscape, examination of seeps and amphibian use of seeps on non-igneous geologies will ultimately be necessary to understand patterns across the larger landscape.

1. Background

This study addresses research needs for the Landscape and Wildlife Advisory Group (LWAG), the Scientific Advisory Group of the Cooperative Monitoring Evaluation and Research (CMER) Committee that is charged with providing new information in support of Forest and Fish Report (FFR: http://www.wa.gov/dnr/htdocs/fp/fpb/forests&fish.html) adaptive management. In particular, this study relates directly to two priority wildlife research and monitoring tasks outlined in Schedule L-2, the schedule that focuses more precisely the priority tasks identified in FFR Schedule L-1:

(1) G4 - Verification of models that address stream-associated amphibians (SAAs).
(2) G7 - Testing the effectiveness of buffer patches for amphibians in westside non-fish-bearing (Type N) streams.

Provisions in FFR for protection of SAAs are based on the assumption that seeps and related aquatic habitats are especially important to SAAs. Because of this presumed importance, these aquatic habitats are protected with special no-harvest patch buffers. This study helps determine the importance of seeps to SAAs and whether FFR buffer prescriptions are appropriate for protecting these habitats. This represents a key first step of the iterative process to reach G7.

1.1 Why are seeps important to amphibians?

Seeps have received little study despite the fact that they may be common in areas with high precipitation regimes like the forests of the Pacific Northwest (Highsmith and Kimerling 1996). Nonetheless, a plethora of anecdotal survey data exists on amphibian (especially torrent salamander) use of seeps (e.g., Bury and Corn 1991; Bury *et al.* 1991; Corn and Bury 1991; Diller and Wallace 1996; Ferguson 1956; Good and Wake 1992; Nussbaum 1969; Nussbaum and Tait 1977; Stebbins and Lowe 1951; Storm 1955; Welsh and Lind 1988, 1996; Wilkins and Peterson 2000; and others). However, such data are not easily interpreted and cannot be used to test the hypothesis that torrent salamanders (genus *Rhyacotriton)* are strongly associated with seep habitats (e.g., Welsh and Lind 1996, Wilkins and Peterson 2000) or select them preferentially over other stream types (e.g., small fish-bearing streams). This hypothesis is founded on anecdotal observations and two fundamental aspects of torrent salamander life history:

1) Torrent salamanders are desiccation intolerant, more so than other salamanders (Ray 1958). Desiccation intolerance is probably linked to a heavy dependence on skin surfaces for gas exchange as torrent salamander lungs are highly reduced (Whitford and Hutchinson 1966). Gas exchange is only possible through a water-saturated membrane surface (Shoemaker *et al.* 1992).
2) Torrent salamanders have the most primitive mode of oviposition known among amphibians. They lay unattached eggs among the interstitial spaces of rocky substrates in low-flow habitats (Nussbaum 1969, Karraker 1999, Russell *et al.* 2002; see discussion in Hayes, *in press*). Some seeps provide precisely this type of habitat, and observations suggest that young larval torrent salamanders are abundant in such habitats (e.g., Welsh and Lind 1996, Wilkins and Peterson 2000). Such observations have led to the idea that seeps may be nurseries and imply that torrent salamanders would be more appropriately termed seep salamanders (Jennings and Hayes 1994).

Torrent salamanders are not the only amphibians for which a link to seeps has been suggested. Seeps have been noted as important secondary habitat for Dunn's salamander (*Plethodon dunni*; Bury and Corn 1991, Bury *et al.* 1991, Corn and Bury 1991), and use of seeps has been casually mentioned for other species (e.g., VanDyke's salamander (*P. vandykei*): Leonard *et al.* 1993). This evidence for amphibian use of seeps was an important factor in the decision to designate certain seeps and related aquatic habitats as sensitive sites that require protection under FFR rules. Limited knowledge of seeps and their suspected importance to amphibians led to this study, which has four objectives:

1) To improve our ability to predict the location of seeps in managed forest landscapes;
2) To provide an initial assessment of the relative habitat value of seeps compared to Np stream channels for amphibians in general, but especially torrent salamanders and other FFR-covered species.
3) To begin testing the assumptions regarding the distribution and value of seeps at various distances from Type N stream channels and whether connection via overland flow with stream channels affects amphibian abundance and habitat use patterns; and
4) To improve characterization of seeps and ultimately, to develop a manual to facilitate seep identification. Manual assembly will come after data on seeps have been collected from managed landscapes across different regions in Washington State, and represents a latter phase in this study to which this year's data provide but a small piece.

1.2 Research Questions and Hypotheses

To meet these study objectives, we focused on three research questions:

1) How can seeps be defined and identified?

Identification of seeps appears superficially simple. Problems arise because seeps have not been defined using characteristics that distinguish them from other aquatic habitats. Indeed, it is not even clear whether they may be clearly distinguished from other aquatic habitats, which is essential for implementation of FFR rules. Although "seeps" and "springs" define sensitive sites in an FFR context (see paragraphs B, C, and D under section B.4 of Appendix B: http://www.wa.gov/dnr/htdocs/fp/fpb/forests&fish.html), they themselves are not defined. From a practical standpoint, during FFR negotiations, seeps were regarded as aquatic habitats with emerging perennial water at or near the surface, but lacking a down-gradient scour channel; springs were only different from seeps in that they resulted in a down-gradient channel. Because seeps lack a channel, they are difficult to identify especially when they occur away from the stream channel network. To answer our question regarding seep definition and identification, we used the working definitions of seeps and springs accepted during FFR negotiations as a starting point, testing the hypothesis that:

No differences exist in amphibian habitat characteristics between seeps and stream reaches in Type N systems.

To characterize the relative value of seeps and other aquatic habitats for SAAs, we asked the question:

2) Are seeps more valuable for amphibians than other aquatic habitats?

To begin to answer this question, we focused on two habitats in perennial headwater basins and tested the hypothesis that:

No differences exist in the refuge and/or reproductive value of habitat to amphibians between seeps and stream channels in Type N systems.

As some amphibians are thought to be linked to seeps (discussed above), and the physical characteristics of seeps may influence patterns of occupancy, we asked the question:

3) Are certain types of seeps more valuable for amphibians than others?

To examine the question of relative value we tested the hypothesis that:

No differences exist between habitat characteristics and amphibian occupancy among seeps in Type N systems.

1.3 Study Design

This study was designed as a multi-year approach to address sampling of Type N systems in different ecoregions of Washington State. Pilot year data was intended to guide the study in subsequent years. The full study will address all major landscape units that differ in terms of their amphibian faunal composition and/or physical characteristics.

We had proposed to study six Type N streams in each of two ecoregions: the Willapa Hills and South Cascades (*Westside*). However, we revised the study plan as drought conditions rendered many of our proposed sample streams dry. In addition, Type N streams in the South Cascades are very long relative to Type Ns in the Willapa Hills and thus require much more effort. We therefore conducted all field sampling in the Willapa Hills as we were certain to be able to sample at least 12 streams (per our study design). Moreover, the Willapa Hills have the highest amphibian species richness (Dvornich *et al.* 1997) and the highest local abundances of amphibians in Washington State (M. Hayes, D. Runde, *unpublished data*), so sampling in those managed landscapes first would increase the likelihood that sample sizes of individuals (or species) could distinguish potential differences among units even with moderate sampling variances. This was a concern as amphibian studies are known to have substantial among-unit sampling variances (e.g., Wilkins and Peterson 2000).

We originally planned to select study sites from Ellis Creek because these managed patches are the only forest stands > 90 years of age in the North Willapa Hills area. However, Ellis Creek sites lacked perennial water in 2000 and were unusable.

We also intend to sample basins in different lithologies. However, because igneous substrates are the dominant lithology in the Stillman Creek watershed (roughly 80% of the landscape; Wells 1981), our basin-wide random site selection resulted in mostly igneous substrates. Thus, in 2000 we chose to constrain sampling to the randomly selected sites on igneous substrates. This had the added benefit of reducing variability in amphibian presence and abundance as Wilkins and Peterson (2000) demonstrated that SAA relative abundance is significantly greater on igneous than on marine sedimentary formations. Marine sedimentary formations make up 20% of the Stillman watershed.

We also originally intended to visit each Type N system twice, but time constraints required us to complete all tasks in one visit. Thus, year 2000 data lack site-specific

temporal information.

Lastly, some Type Ns lacked seeps or seep-like habitats altogether, which required that we increase the number of Type Ns sampled. This change resulted in our sampling 15 Type N (two subbasins were sampled within one Type N basin for a total of 16 subbasins sampled) systems based on design modifications discussed above. This report presents the year 2000 data, analyses, and discussion.

1.4 Criteria for Selection of Study Areas and Sites

This pilot study focused on seep and related aquatic habitats in Type N systems in *Westside* Washington State. We located the initial study on the *Westside* because all six original SAAs [a] targeted in FFR occur in *Westside* systems. Moreover, the three torrent salamander species, the stream-associated species suspected to be most seep specialized (see Section 1.1), occur only in *Westside* systems (Dvornich *et al.* 1997, McAllister 1995). Only one of the six original target SAAs, tailed frog (*Ascaphus truei*), occurs in *Eastside* systems[a], and of the six, it has not been linked to seeps as primary habitat (see Bury and Adams 2000).

Our decision for initially focusing on the Willapa Hills region was based on similar reasoning. Four of the six target species (and representatives of all Washington SAA genera[b]) occur in the Willapa Hills (only the two torrent salamander species endemic to other regions are absent; Dvornich *et al.* 1997, McAllister 1995). Further, in Washington State, the Dunn's salamander, which is one of the six SAA species, has been recorded only in the Willapa Hills.

An equally important reason for focusing on the Willapa Hills was that on a regional basis, the Willapa Hills have, at least proportionally, more landscape that falls under the FFR than any other region in Washington State (Atterbury Consultants 1999).

We chose to focus on the Stillman Watershed because an abundance of physical and biotic information was available for this system, especially when compared to other similar-sized basins with Type N habitat in the Willapa Hills (D. Runde, *pers. comm.*). Notably, we viewed the quality of stream typing information as crucial to the success of the study because typing defines the downstream limits of Type N systems.

We selected Type N systems for sampling based on a stratified random approach used in the concurrent FFR study addressing amphibian sampling. Although the original strata included aspect, elevation, geology, and stand age, we eliminated geological stratification for reasons previously discussed (see Section 1.3). Site selection was based on 1,063

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[a] Six SAAs were originally covered in the FFR, but one of the six, tailed frog (*Ascaphus truei*) was recently split into two species: The Pacific tailed frog, which will retain the name *Ascaphus truei* and has a coastal and Cascades axis distribution, and the Rocky Mountain tailed frog, *Ascaphus montanus*, which is distributed in the Rocky Mountains of southeastern British Columbia, Idaho, and Montana, and the Wallowa-Blue Mountain complex of eastern Oregon and Washington (Nielson *et al.* 2001). As a consequence, seven FFR amphibian species now exist, and within Washington, one FFR target species is now exclusively on the eastside.

[b] Giant salamanders (genus *Dicamptodon*) are not FFR target species, but are SAAs. The Willapa Hills are one of the two ecoregions in Washington (the other being the westside south Cascades) in which the two species of giant salamanders known from Washington State, Cope's giant salamander (*D. copei*) and coastal giant salamander (*D. tenebrosus*), have been recorded.

road crossings of streams in Type Ns for the Stillman Creek Watershed that were located on Weyerhaeuser lands (85% of the watershed). Within this set, we randomly chose crossings from within each of the three 984 ft (300-m) elevation blocks: 0-986 ft (0-300 m), 987-1968 ft (301-600 m), and 1969-2953 ft (601-900 m). We chose streams that occurred in northwest to northeast (293°-66°) and southeast to southwest (113°-247°) aspects, but not east (67°-112°) or west (248°-292°). Subbasins with stands in the 0-15 year age group were not sampled, because in most cases, heavy logging slash prevented access to the stream channel. We also wanted to avoid spreading sites among too many age classes (see Analyses subsection under Section 2.1).

2. Research Question 1 – How can seeps be defined and identified?

Research Question 1 has practical and technical implications; practical in the sense that land managers must be able to identify seeps before they can protect them and technical in the sense that not all seeps protected under the FFR may be equally important to amphibians. Our approach was designed to address both types of questions.

2.1 Methods and Definitions

Sampling Units: Our sampling units (hereafter subbasins) were subunits of Type N basins (small portions of larger watersheds). We identified Type N basins as the area draining to a point where the Type N stream (perennial, non-fish bearing) joins a fish-bearing (Type F) stream (see WAC 222-16-030). For those cases where more than one channel arose from the end of the fish-bearing reach (i.e., end of Type F waters), each channel was considered to represent a separate basin.

We sampled all subbasins upstream from a road-crossing point selected based on the stratified random approach discussed previously (see Section 1.4). Within each subbasin, two surveyors walked the entire subbasin between stream and the delimiting ridgetops on either side of the stream with a spacing of roughly 16-33 ft (5-10 m) intervals. Spacing between surveyors was reduced where vegetation interfered with visibility of the substrate. Although most subbasins were sampled throughout their channel network in this manner, some subbasins were only sampled upstream to an intersecting road crossing as the random selection process was based on road crossing points.

Subbasin Characterization and Definitions: For each of the subbasins sampled, we characterized the full range of hydrological habitats according to the following variables:

(1) Hydrological habitat type: We divided all aquatic habitats into three types:
   (a) *seeps*: habitats with too little flow to create a scour channel and thus unconnected by *channel* to the rest of the stream network. Seeps may have an overland flow connection to the network (see 6).
   (b) *springs*: habitats with sufficient flow to create a scour channel and thus representing terminal points in the channel network.
   (c) *stream reaches*: reaches with enough water flow during some time period to develop a scour channel. These units are typically connected to the stream channel network whether or not they had perennial flow.
(2) Reaches: We further divided reaches into two categories:
   (a) *intermittent*: a reach lacking surface water at the time of survey (i.e., temporary or intermittent).
   (b) *perennial*: a reach with flowing water at the time of the survey. As our work was done during low-flow (dry season) conditions in a drier than average year, reaches with flow during our surveys were likely perennial in year 2000.
(3) Perennial Reaches: Perennial reaches were also divided into two categories:
   (a) *initiation*: a perennial reach that included a point of water initiation within a stream network.
   (b) *non-terminal*: a reach within the stream network that was at least 16 feet (~5 m) downstream of a water initiation point.

(4) Seeps: We further divided seeps into two different categories based on:
  (a) water condition, as:
    (i) *percolating*: where water percolated from the substrate. Percolating flow meant any visible surface flow, regardless of amount, at the time of the survey.
    (ii) *non-percolating*: a saturated area where no water flow was detected at the time of the survey.
  (b) position, as:
    (i) *headwall*: headwall seep is a seep near a head (or terminus) of any thread in a stream's perennial channel network. To separate headwall and side-slope seeps, we categorized seeps as headwall if they had at least some area above a perpendicular to the stream axis drawn at perennial termini (Appendix I).
    (ii) *side-slope*: side-slope seep is a seep on the side-slopes of any thread in a perennial channel network that lacked area above a perpendicular to the stream axis drawn at its perennial termini (Appendix I).

(5) Seep proximity to the stream channel: Seep location was characterized in 3 ways:
  (a) Channel proximity: We categorized seep locations relative to the channel as:
    (i) *channel-adjacent*: Seeps originating $\leq$ 100 feet (~30 m) from the channel.
    (ii) *off-channel*: Seeps originating > 100 feet (~30 m) from the channel.
  (b) Topographic position: We categorized relative topographic position based on Mitchell (1998) as: (i) *flat*, (ii) *lower side slope*, (iii) *mid side slope*, (iv) *upper side slope*, or (v) *ridge crest*.
  (c) Seep to stream distance: The shortest horizontal distance between the lower wetted boundary of a seep and the stream channel.

(6) Connection: We determined if there was water at-or-near-surface[c] between seeps and stream channels.

(7) Areas of the seep, as:
  (a) *area of percolating flow*: Surface area over which flow is visible.
  (b) *area of the seep*: Surface area of saturation inclusive of the area of percolating flow if present. We estimated areas of percolating flow and the seep from measurements of axes perpendicular to one another with one axis parallel to the slope.

(8) Aspect: Aspect was determined from maps or in the field to the nearest degree and put into one of the eight categories: N (338°-22°), NE (23°-66°), E (67°-112°), SE (113°-157°), S (158°-202°), SW (203°-247°), W (248°-292°), and NW (293°-337°).

(9) Gradient: We measured side-slope gradient for seeps and gradient of the stream channel for reaches. Side-slope gradient was measured across a seep along the shortest perpendicular to the stream axis. Stream channel gradients were measured over the length of the sampled reach, which was always < 50 ft [15 m] (see Table 2.210).

(10) Elevation: We estimated the elevation of all aquatic habitats from GIS data based on a 10-m Digital Elevation Model (DEM).

(11) Stream order: The stream order (Strahler 1952) was obtained for the nearest point within the Type N system to which the habitat was located (i.e., shortest distance

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[c] We used the FFR negotiation concept of finger depth as representing water that was at or near-surface.

to the stream axis).

(12) Stand Age: We obtained ages of forest stands associated with sampled Type N systems from Weyerhaeuser (*unpublished proprietary data*).

(13) Geology: We extracted geologic data from 1:62,500 scale Department of Natural Resources (DNR) geologic maps (Wells 1981). We verified the map-based information in the field wherever possible.

(14) Substrate: Substrates were classified as mud, sand, gravel, cobble, boulder, bedrock, leaf litter, small woody debris (SWD: ≤ 4 in [10 cm] maximum cross section), and large woody debris (LWD: > 4 in [>10 cm] minimum cross section). Mud included all particulates smaller than fine sand and was the only category that included an organic fraction. Definitions for sand, gravel, cobble, and boulder follow the standard descriptive classes (Busch 1997).

(15) Compressible depth: Compressible depth was the depth (in cm) to which the substrate could be compressed by stepping on it.

(16) Water temperature: We measured surface water temperatures no deeper than 2 in (5 cm), even where water was pooled using either digital hand (Taylor, Inc.) or infrared thermometers (Raytek Corporation Raynger ST™).

(17) Vegetation: We recorded all species in the canopy (> 10 ft [3 m] high) and shrub vegetation layers (woody non-canopy vegetation), and most species in the herbaceous layer. Unidentifiable herb layer species were grouped as mosses, sedges, and rushes. For seeps, we recorded all species in, and up to 16 ft (5 m) outside its saturated area (see 7 above). For reaches, we recorded vegetation within versus up to 10 ft (3 m) outside the area of hydric influence of the channel. The boundary of that hydric area was defined as the point on a bankslope surface at which moisture from capillary creep arising from the channel was no longer evident by visual inspection. Plant taxa recorded are listed in Appendix II.

(18) Flow: We addressed flow as:

(a) *velocity*: We made exploratory measurements of surface flow velocity in 5 seeps (Appendix III). For comparison, we measured surface flow velocity in 5 reaches.

(b) *flow (volume/unit time)*: We did exploratory measurements of flow using two different methods for the same five seeps in which flow velocity was measured (Appendix III). For reaches, flow was estimated from velocity and cross-sectional area data.

(19) Precipitation: We tried to estimate precipitation levels from mapped isohyets (i.e., lines mapping equivalent levels of rainfall) for sampled sites, but these data were insufficiently resolved at the scale at which we took data for useful analysis.

Reach selection was constrained in part to ensure that different perennial reach categories would be represented (see 3a, b above) and in part to assist comparisons with seeps. We selected 4 of the 18 initiation reaches available in the 16 subbasins sampled. We intentionally selected initiation reaches that were associated with the mainstem of local channel networks. We used a distinct change in channel morphology (e.g., gradient) to identify the length of initiation reaches to be surveyed to minimize variation. All but one non-terminal reach (n = 10) was selected ≤ 164 ft [50 m] from sampled channel-adjacent seeps or initiation reaches. This was done to ensure some similarity, based on stream size, to initiation reaches or reaches next to which channel-adjacent seeps were located.

We adjusted sampled lengths of these non-terminal reaches to match channel distances of 4 initiation reaches and 5 reaches bordering 5 channel-adjacent seeps. The waterfall was one non-terminal reach not selected in this manner because it was the only one found in the sampled area.

Variables (identification numbers from the above list indicated in parens) involving distances or areas (5, 6, 7) were measured with tapes or by using sonic (Hagloff Vertex III™) or laser hypsometers (Laser Technology, Inc. Laser Hypsometer™) to the nearest 0.3 ft [0.1 m]. Gradient (9), also using the hypsometers, was measured to the nearest 0.2% [0.1°]. DEM-based elevation data (10) had a maximum ± 16.4 vertical-foot [5 m] error. Weyerhaeuser also provided the stream-typing maps from which we estimated stream order (11). We measured water temperature (16) to the nearest 0.5° Centigrade (C). Approach to measuring flow velocity (18) and flow (19) is given in Appendix III.

Analyses: We used standard statistical procedures (Zar 1996), relying predominantly on non-parametric statistics. Non-parametric analyses are often based on differences in medians, but we also frequently provided the mean ($\bar{x}$), standard deviation (s), standard error of the mean (se), and range to describe the data. We used Fisher's Exact test on two-way contingency tables, and results of all other pertinent non-parametric tests were corrected for tied ranks. Analysis employed Statview 5.0 (SAS Institute, Inc.) software.

For unpaired comparisons, we used Spearman Rank correlations for continuous variables, and Mann-Whitney tests where one variable was categorical. For unpaired comparisons related to stand age, we divided the data into two groups using the median forest stand age (36.5 yr) of our study basins: 18-to-36 years old versus 37-to-55 years old.

Flow and flow velocity data required Friedman tests because all represented repeated measurements. Two-way contingency tables were used for comparisons of substrate, frequency of occurrence between habitat types, and comparisons of plant species between reaches and seeps.

To determine what plant taxa might be useful in identifying seeps, we used an index (described in Appendix IV) to rank taxa based on their reliability as seep indicators.

We also performed analyses to examine potential sources of sampling bias. In particular, Spearman Rank correlations were performed between basin size and the size of subbasins sampled, seep density and sampled areas, and water temperature and sampling date.

We defined significance as $\alpha = 0.05$. However, as samples sizes were small, we believe it more useful to look at probabilities as a guide of what to expect as more data become available.

2.2 Results

Landscape Data: We surveyed the entire area of 16 subbasins within 15 different Type N basins for seeps and related aquatic habitats. These subbasins varied over about an order of magnitude in size (4.7-44.6 ac [1.9-18.1 ha]; Table 2.201). Time constraints forced us to sample roughly similar areas in each Type N basin. Thus, less area was sampled in larger basins (Spearman correlation: $\rho = -0.859$, $z = -3.329$, $p = 0.0009$; Figure 2.201).

Table 2.201 – Sampled Subbasins in the Stillman Watershed, Washington, 2000

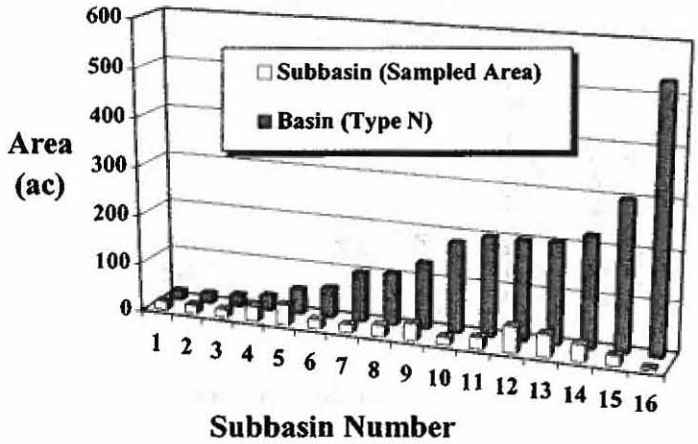
Subbasin Code[1]	Area		Elevation[2]				Geology[3]			Hydrology	
			Lower Limit		Upper Limit						
	ac	ha	ft	m	ft	m	Tcb	Tig	Tml	Seeps	Springs[4]
STL11040221	29.5	12.0	741	226	1160	354	0	100	0	2	*1*
STL11040313	32.6	13.2	705	215	1200	366	0	30	70	1	1
STL11040814	14.4	5.8	2106	642	2560	780	20	80	0	1	1
STL11040825	44.6	18.0	2018	615	2720	829	20	80	0	2	4
STL11041008	20.5	8.3	1745	532	2160	658	0	100	0	3	1
STL12041708	15.7	6.3	817	249	1200	366	0	100	0	1	0
STL12041720	33.5	13.6	935	285	1400	427	0	100	0	5	1
STL12041731	17.7	7.2	958	292	1120	341	0	100	0	3	1
STL12042005	18.2	7.4	1214	370	1840	561	0	100	0	1	1
STL12042120	22.2	9.0	1381	421	1800	549	0	100	0	0	1
STL12042330	17.4	7.0	495	151	880	268	0	100	0	0	1
STL12043108	4.7	1.9	2208	673	2840	866	0	100	0	1	0
STL12043223	22.2	9.0	2067	630	2107	642	0	100	0	1	*3*
STL12043316	52.0	21.0	1608	490	1780	543	0	100	0	0	0
STL12043407	40.8	16.5	1168	356	1520	463	0	100	0	8	3
STL12043410	15.8	6.4	915	279	1280	390	0	100	0	0	1
Summary Data[5]											
Mean ($\bar{x}$)	25.1	10.2	1318	402	1723	525	2.5	93.1	4.4	1.8	1.3
Median	21.4	8.7	1191	363	1650	503	0.0	100.0	0.0	1.0	1.0
SD (s)	12.7	5.1	568	173	610	186	6.8	18.2	17.5	2.1	1.1
SE	3.2	1.3	142	43	153	46	1.7	4.5	4.4	0.5	0.3

[1] Subbasin code is an 11-character alphanumeric: The first 3 letters identify the drainage basin; the next 6 numbers identify the township, range, and section in successive pairs, respectively; and the last 2 numbers refer to a north-to-south sequential series identifying the road crossings within a particular section based on maps that Weyerhaeuser provided. Italicized subbasins were from the same Type N system; remaining subbasins were from different Type N systems.
[2] Lower elevation limit was estimated from a 10-m DEM; upper elevation limit was estimated from an 80-ft (24 m) contour resolution map.
[3] Geologic formations (3-letter codes) are described in Appendix V.
[4] Sampled springs are in emboldened italics.
[5] SD = Standard deviation; SE = Standard error of mean.

Subbasins ranged from 459 ft [140 m] to ~2,800 ft [701 m] (Table 2.201), which includes 82% of the 2,860 ft [1,000 m] elevation range in the Stillman Watershed. It was 87% of the elevation range with igneous geology[d]; lands < 427 ft [130 m] with only sedimentary geologies were not available (see Section 1.4). The lower elevation limit of 4 subbasins was ≥ 1968 ft [600 m], the lower elevation limit of 5 subbasins were ≥ 984 ft [300 m] and < 1968 ft [600 m], and the lower limit of the remaining 7 subbasins was < 984 ft [300 m].

[d] Elevation range in the Stillman Watershed ranges from 250 ft [76 m] where Stillman Creek meets the Chehalis River near Boisfort to 3110 ft [948 m] on Boisfort (also Baw Faw) Peak on the boundary of the Chehalis River and Stillman Creek headwaters.

Figure 2.201 - Relationship between Basin Area (Type N) and Subbasin (Area Sampled) in the Stillman Watershed, Washington, 2000



Almost all (97%)[e] of the area of these 16 subbasins occurred on two igneous formations, which were composites of basalts, breccias, and gabbros (Appendix V). The dominant igneous formation, which was found over 91% of the sampled area, consisted of GABBRO AND BASALT INTRUSIVE ROCKS (Tig: Table 2.201); this formation was the only one found in all 16 subbasins, the exclusive substrate in 13 subbasins, and 30-80% of the area in the remaining 3 subbasins. The second igneous formation, found over 3% of sampled area, was the CRESCENT FORMATION (Tcb: Table 2.201). This formation, a mix of breccias and alkalic basalts, occurred over 20% of sampled area in 2 subbasins. Remaining sampled area (6%) had a sedimentary formation, the MACINTOSH FORMATION (Tml: Table 2.201), which was sandstones and siltstones. This formation was found in 70% of 1 subbasin.

Only 1 subbasin intersected mapped faults (Wells 1981); 300 ft [91 m] of one fault and 120 ft [36 m] of its tributary fault intersected subbasin STL11041008.

In these 16 subbasins, we encountered and sampled 29 seeps, and we found 20 springs, of which we sampled 4 (Table 2.201).

Seeps: We found no seeps in 4 (25%) of 16 subbasins and 1 to 8 seeps in the remaining 12 subbasins (Figure 2.202) for a mean of 1.8 seeps per subbasin (Table 2.201).

We recorded a mean density of 0.08 seep/acre [0.03 seep/ha] (Table 2.202) or 1 seep every 14.1 ac [5.7 ha]. For basins where we found at least one seep, seep density varied from 0.03 seep/ac [0.01 seep/ha] to 0.21 seep/ac [0.09 seep/ha], representing a range of 1 seep per 32.3 ac [13.1 ha] to 1 seep per 4.7 ac [1.9 ha] (Table 2.202).

Within the Stillman Watershed igneous landscape, seeps represented a small fraction of the total area of Type N basins. Combined area of seeps was 0.8 ac [0.3 ha] or 0.2% of the total surveyed area (401.8 ac [162.6 ha]).

Variation existed in stream order near seeps. By definition, headwall seeps (n = 3) were close to 1st-order channels (see Appendix I). Of 26 side-slope seeps, 16 were associated with 1st-order channels, 9 with 2nd-order channels, and 1 with a 3rd-order channel.

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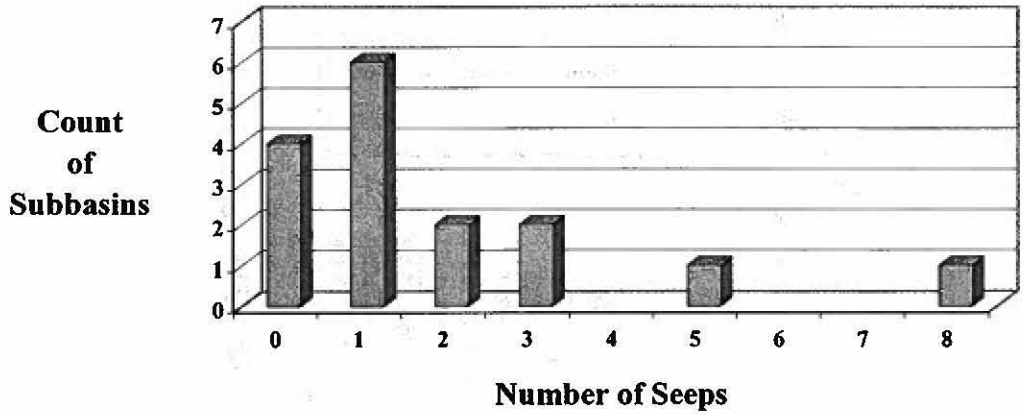
[e] Differences with summary totals in Table 2.201 result from variation in individual subbasins.

Figure 2.202 - Frequency of Seeps by Subbasin in the Stillman Watershed, Washington, 2000



Area of individual seeps ranged over two orders of magnitude (41 ft^2 [4 m^2] to 6,265 ft^2 [582 m^2]; Table 2.203). Seeps averaged 0.22% of the sampled area in the 12 subbasins with seeps (range: 0.004-1.366%).

Seep characteristics were highly variable. Of 29 seeps, 14 had and 15 lacked percolating flow (Table 2.203). One of 3 headwall seeps had percolating flow, and 13 of 26 seeps on side slopes had percolating flow. Mean flow velocity in 5 seeps (see Appendix III) was 0.9 cm/sec [0.4 in/sec] to 1.3 cm/sec [0.5 in/sec] (Table 2.204). Flow, measured over a small area (i.e., 0.11 ft^2 [0.01 m^2], Appendix III), was also variable (Table 2.205). Mean flow levels were very low, ranging from 0.001 ft^3/sec[f][0.00003 m^3/sec] to 0.003 ft^3/sec [0.00008 m^3/sec]. No difference was found in flow velocity (Friedman's test: $\chi^2 = 0.408$, df = 4, $p = 0.9818$) or flow measured over a constant area ($\chi^2 = 3.423$, df = 4, $p = 0.4897$) among the 5 seeps, but significant differences were found among seeps when flow was measured across the area of the seep (Friedman's test: $\chi^2 = 9.600$, df = 4, $p = 0.0477$).

Most seeps (83%) had areas ≤ 1500 ft^2 [143 m^2] (Figure 2.203); only 6 seeps, all side-slope in position, had areas > 1500 ft^2. For the 15 seeps with percolating flow, ratio of percolation area to seep area varied from 0.0005% to 100%. Area lacking percolating flow was > 80% of the area in 11 of the 15 seeps, and 0%-50% in the remaining four. Areas of seeps with percolation flow were similar to areas of seeps lacking percolating flow (Mann-Whitney test: $U = 101$, $U' = 110$, z = -0.196, $p = 0.8442$; see Table 2.203). For seeps with percolating flow, we found no significant relationship between seep area and area of percolating flow (Spearman correlation: $\rho = -0.233$, z = -0.901, $p = 0.3676$). We also found no significant relationship between seep area and seep distance from the stream (Spearman correlation: $\rho = 0.115$, z = 0.321, $p = 0.7481$), or between percolation area and seep to stream distance (Spearman correlation: $\rho = 0.365$, z = 1.277, $p = 0.2018$).

[f] For scale, 0.0005 ft^3 is the volume of a tablespoon, so 0.001 ft^3 is two tablespoons.

Table 2.202 – Subbasin Seep Data in the Stillman Watershed, Washington, 2000

Subbasin Code	Density				Overall Area of Seeps[2]	
	Seeps / Unit Area		Unit Area / Seep[1]			
	acres	hectares	acres	hectares	acres	hectares
STL11040221	0.07	0.03	14.7	6.0	0.099	0.040
STL11040313	0.03	0.01	32.3	13.1	0.009	0.004
STL11040814	0.07	0.03	14.5	5.9	0.005	0.002
STL11040825	0.05	0.02	22.2	9.0	0.002	0.001
STL11041008	0.15	0.06	6.8	2.8	0.068	0.027
STL12041708	0.06	0.03	15.6	6.3	0.110	0.044
STL12041720	0.15	0.06	6.7	2.7	0.111	0.045
STL12041731	0.17	0.07	5.9	2.4	0.015	0.006
STL12042005	0.06	0.02	18.2	7.4	0.008	0.003
STL12042120	0.00	0.00	∞	∞	0.000	0.000
STL12042330	0.00	0.00	∞	∞	0.000	0.000
STL12043108	0.21	0.09	4.7	1.9	0.012	0.005
STL12043223	0.05	0.02	22.2	9.0	0.001	0.001
STL12043316	0.00	0.00	∞	∞	0.000	0.000
STL12043407	0.20	0.08	5.1	2.1	0.558	0.226
STL12043410	0.00	0.00	∞	∞	0.000	0.000
Summary Data[4]						
Mean ($\bar{x}$)	0.08	0.03	14.1	5.7	0.062	0.025
Median	0.06	0.03	14.6	6.0	0.009	0.004
SD (s)	0.07	0.03	8.7	3.5	0.139	0.056
SE	0.02	0.01	2.5	1.0	0.035	0.014

[1] This value approaches infinity (∞) for those subbasins where no seeps were recorded.
[2] This is the combined hydrological area of all seeps found in a subbasin. See (7) under Subbasin Characterization and Definition in section 2.1.
[4] SD = Standard deviation; SE = Standard error of the mean.

Percolating flow was not related to seep positions on side-slopes or headwalls (Fisher's Exact test: $p = 0.5977$). Three headwall seeps had an average area of less than half of the 26 side-slope seeps, but this difference was not significant (Mann-Whitney test: $U = 33$, $U' = 46$, $z = -0.466$, $p = 0.6414$). Headwall seeps were all next to the water initiation point of the channel, and side-slope seeps varied from being 0 to 157 ft [48 m] away from the channel (Table 2.203). This difference was also not significant (Mann-Whitney test: $U = 15$, $U' = 63$, $z = -1.802$, $p = 0.0716$), but marginally so.

Seeps also varied in overland flow connection to stream channels (Table 2.203). Of the 29 seeps examined, 18 had an overland flow connection to the stream channel. The three headwall seeps were all connected by overland flow, whereas 58% (n = 15) of the side-slope seeps had such a connection. This difference was not significant (Fisher's Exact test: $p = 0.2685$).

Table 2.203 – Seep Characteristics in the Stillman Watershed, Washington, 2000

Subbasin Code	Seep[1]	Area[2]		Area of Percolating Flow[3]		Seep to Stream Distance[3]		Compressible Depth[3]		Water Connection to Channel[3]
		ft^2	m^2	ft^2	m^2	ft	m	in	cm	Yes or No
STL11040221	A	3563	331	0.00	0.00	131	40	0.4	1.0	No
	B	764	71	0.00	0.00	0	0	0.0	0.0	Yes
STL11040313	A	388	36	0.00	0.00	7	2	0.8	2.0	Yes
STL11040814	*A*	*226*	*21*	*10.76*	*1.00*	*0*	*0*	*1.2*	*3.0*	*Yes*
STL11040825	A	22	2	0.00	0.00	7	2	0.2	0.5	Yes
	B	65	6	0.00	0.00	157	48	0.2	0.5	Yes
STL11041008	A	41	4	41.33	3.84	3	1	0.8	2.0	Yes
	B	431	40	430.56	40.00	0	0	---	---	Yes
	C	2476	230	0.00	0.00	0	0	1.6	4.0	Yes
STL12041708	A	4783	444	0.00	0.00	0	0	2.4	6.0	No
STL12041720	A	510	47	64.58	6.00	46	14	2.0	5.0	Yes
	B	625	58	75.35	7.00	125	38	0.8	2.0	No
	C	1436	133	0.00	0.00	0	0	0.8	2.0	Yes
	D	1199	111	0.97	0.09	46	14	0.8	2.0	Yes
	E	1059	98	86.11	8.00	20	6	0.4	1.0	No
STL12041731	***A***	***431***	***40***	***0.00***	***0.00***	***0***	***0***	***0.8***	***2.0***	***Yes***
	B	108	10	0.00	0.00	10	3	---	---	No
	C	108	10	53.82	5.00	16	5	1.6	4.0	Yes
STL12042005	A	334	31	0.00	0.00	0	0	0.8	2.0	No
STL12043108	A	538	50	0.00	0.00	69	21	0.4	1.0	No
STL12043223	A	266	25	53.82	5.00	22	7	2.0	5.0	No
STL12043407	A	538	50	1.08	0.10	121	37	0.6	1.5	No
	B	1406	131	10.76	1.00	0	0	1.2	3.0	Yes
	C	3255	302	43.06	4.00	72	22	3.1	8.0	No
	D	6265	582	0.05	0.01	0	0	---	---	Yes
	E	11567	1075	0.00	0.00	0	0	1.2	3.0	No
	F	***894***	***83***	***0.00***	***0.00***	***0***	***0***	***3.9***	***10.0***	***Yes***
	G	43	4	0.11	0.01	0	0	0.8	2.0	Yes
	H	339	32	0.00	0.00	3	1	2.4	6.0	Yes
Summary Data										
Mean ($\bar{x}$)		1506	140	30.08	2.80	29.5	9.0	1.2	3.0	Yes = 18 No = 11
Median		538	50	0.00	0.00	3.0	1.0	0.8	2.0	
Standard Deviation (s)		2462	229	81.50	7.57	47.2	14.4	0.2	2.4	
Standard Error of Mean		457	42	15.14	1.41	8.8	2.7	0.9	0.5	

[1] Headwall seeps are in ***emboldened italics***; side-slope seeps are not italicized.
[2] Area = hydrological area of a seep; see (7) under Subbasin Characterization and Definition in Section 2.1.

Figure 2.203 - Frequency Distribution of Areas of Sampled Seeps in Stillman Watershed, Washington, 2000

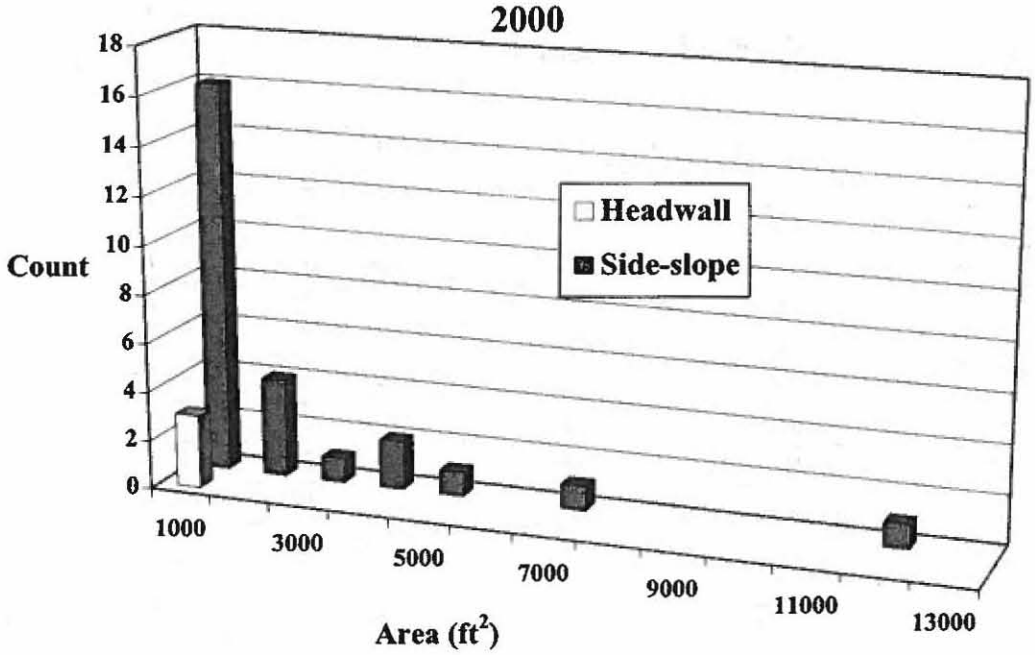


Table 2.204 – Five Flow Velocity Measurements at Five Seeps in the Stillman Basin, Washington, 2000.

Subbasin/Seep		Surface Flow Velocity Measurements (cm/sec)					Descriptive Statistics[1]		
		1	2	3	4	5	Mean ($\bar{x}$)	SD (s)	SE
12041720	A	4.0	0.5	0.1	1.6	0.3	1.3	1.6	0.7
	B	1.2	0.3	2.5	0.1	1.8	1.2	1.0	0.5
	E	1.5	0.1	2.8	0.8	0.7	1.2	1.0	0.5
12043407	B	0.1	2.4	0.8	0.1	1.0	0.9	0.9	0.4
	C	0.2	0.7	0.1	2.7	1.4	1.0	1.0	0.5

[1] SD = standard deviation, SE = standard error of the mean.

Table 2.205 – Five Flow Measurements at Five Seeps in the Stillman Basin, Washington, 2000.

Subbasin/Seep		Flow Volume Measurements (ft^3/sec)					Descriptive Statistics[1]		
		1	2	3	4	5	Mean ($\bar{x}$)	SD (s)	SE
12041720	A	0.00080	0.00209	0.00048	0.00080	0.00289	0.001	0.001	0.0005
	B	0.00257	0.00112	0.00064	0.00048	0.00096	0.001	0.001	0.0004
	E	0.00128	0.00353	0.00289	0.00417	0.00225	0.003	0.001	0.0010
12043407	B	0.00177	0.00048	0.00289	0.00193	0.00096	0.002	0.001	0.0004
	C	0.00193	0.00128	0.00096	0.00048	0.00112	0.001	0.001	0.0002

[1] SD = standard deviation, SE = standard error of the mean.

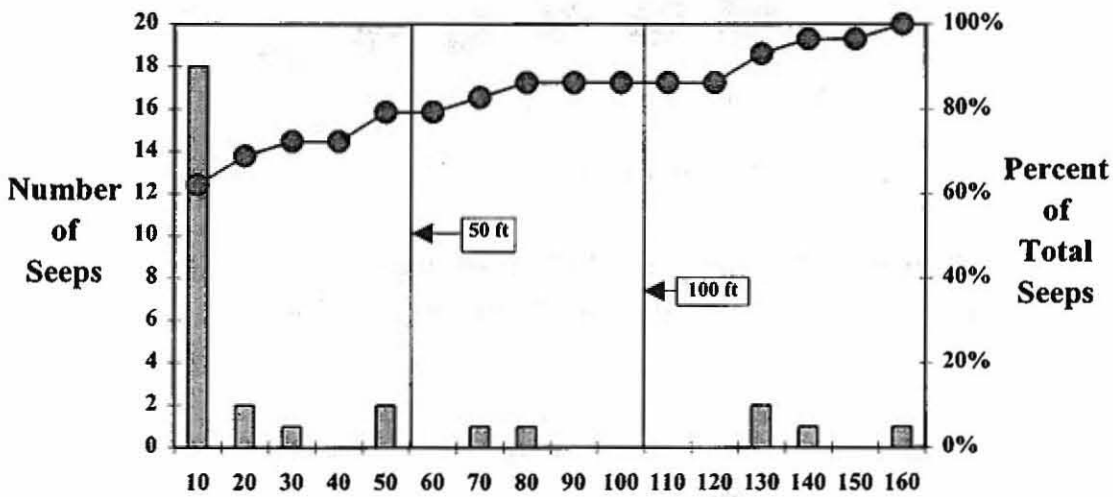
Table 2.206 – More Seep Characteristics in the Stillman Watershed, Washington, 2000

Subbasin	Seep	Gradient		Aspect	Water Temperature						
					Mean		n =	Range			
								Low		High	
		%	deg (°)		°C	°F		°C	°F	°C	°F
STL11040221	A	67.2	30.3	N	5.8	42.5	2	4.4	40.0	7.2	45.0
	B	76.2	34.3	E	---	---	0	---	---	---	---
STL11040313	A	120.0	54.0	E	9.1	48.4	13	7.2	45.0	10.3	50.5
STL11040814	***A***	***48.4***	***21.8***	***N***	***6.3***	***43.3***	***3***	***6.1***	***43.0***	***6.7***	***44.0***
STL11040825	A	71.1	32.0	NE	---	---	0	---	---	---	---
	B	44.2	19.9	E	---	---	0	---	---	---	---
STL11041008	A	53.1	23.9	W	8.3	47.0	2	8.3	47.0	8.3	47.0
	B	50.9	22.9	W	---	---	0	---	---	---	---
	C	54.2	24.4	W	---	---	0	---	---	---	---
STL12041708	A	30.7	13.8	N	10.0	50.0	1	10.0	50.0	10.0	50.0
STL12041720	A	39.8	17.9	E	---	---	0	---	---	---	---
	B	38.2	17.2	E	11.4	52.5	1	11.4	52.5	11.4	52.5
	C	60.5	27.2	E	8.6	47.5	1	8.6	47.5	8.6	47.5
	D	55.4	24.9	E	---	---	0	---	---	---	---
	E	70.8	31.9	W	---	---	0	---	---	---	---
STL12041731	***A***	***48.2***	***21.7***	***E***	---	---	***0***	---	---	---	---
	B	43.8	19.7	NE	10.0	50.0	1	10.0	50.0	10.0	50.0
	C	46.7	21.0	N	9.4	49.0	3	9.4	49.0	9.4	49.0
STL12042005	A	9.3	4.2	E	10.2	50.4	1	10.2	50.4	10.2	50.4
STL12043108	A	60.2	27.1	E	7.6	45.8	2	7.2	45.0	8.1	46.5
STL12043223	A	2.7	1.2	NE	6.9	44.4	1	6.9	44.4	6.9	44.4
STL12043407	A	22.3	10.0	S	12.8	55.1	16	10.3	50.5	13.9	57.0
	B	71.4	32.1	N	14.2	57.5	10	10.0	50.0	16.7	62.0
	C	41.3	18.6	N	12.6	54.7	9	10.0	50.0	15.0	59.0
	D	8.0	3.6	W	---	---	0	---	---	---	---
	E	11.6	5.2	NE	10.5	50.9	4	10.3	50.5	10.6	51.0
	F	***19.8***	***8.9***	***NE***	***11.0***	***51.8***	***3***	***9.4***	***49.0***	***13.6***	***56.5***
	G	41.3	18.6	SE	11.9	53.3	3	11.1	52.0	12.2	54.0
	H	50.0	22.5	SE	11.8	53.3	5	11.7	53.0	11.9	53.5
Summary Data											
Mean ($\bar{x}$)		46.8	21.1		9.9	49.9	2.8	9.1	48.4	10.6	51.0
Median		48.2	21.7		10.0	50.0	1.0	10.0	50.0	10.2	50.4
SD (s)		24.5	11.0		2.3	4.1	4.1	1.9	3.5	2.8	5.0
SE		4.5	2.1		0.5	0.9	0.8	0.4	0.8	0.6	1.2

Note: Headwall seeps are in ***emboldened italics***; side-slope seeps are not italicized.

Of 29 seeps, 25 (86%) were channel-adjacent (≤ 100 ft [30 m] from the stream; Figure 2.204; Table 2.203). Based on topographic position (5(b) in Section 2.1), 19 seeps were on the "flat"[g], 7 on lower side slopes, and 3 on mid side slopes. With this categorization, we found no seeps on upper side slopes or the ridge crest. Channel-adjacent seep density was over 50 times that of the density of off-channel (> 100 ft [30 m] from the stream) seeps, a significant difference (Wilcoxon Signed Rank test: n = 16, z = -3.059, p = 0.0022; Figure 2.205). The average density of channel-adjacent seeps in sampled subbasins was 1 per 2.6 ac [1.1 ha], but off-channel seep density was 1 seep per 143 ac [58 ha]. No significant relationships were identified between seep density and sampled area or stand age (Spearman correlation: sampled area: ρ = -0.180, z = -0.695, p = 0.4869; stand age: ρ = 0.248, z = 0.961, p = 0.3365).

Figure 2.204 - Distance of Seeps (n = 29) from the Stream in the Stillman Watershed, Washington, 2000



Seep gradient varied from 2.7% [1.2°] to 120.0% [54.0°]; 5 seeps had gradients ≤ 20% [9.0°] (Table 2.206). Seep aspects were mostly north to east (Figure 2.206).

Seep water temperatures ranged from 7.2°C [45.0°F] to 10.2°C [50.4°F] (n = 38). At the higher air temperatures (≥ 8.4°C [47.1°F]) measured, seep temperatures averaged 2.1°C (3.8°F; s = 1.1°C [2.0°F], range: 0.8-5.0°C [1.4-9.0°F]) colder than air temperatures. In contrast, at the lower air temperatures (< 8.8°C [48.0°F]), seep water temperatures averaged 0.9°C (1.6°F; s = 1.0°C [1.8°F], range: 0.4-2.6°C [0.7-4.7°F]) warmer than air temperatures. Significant relationships were found between seep temperature and elevation (Spearman correlation: ρ = 0.604, z = 3.676, p = 0.0002), seep temperature and stand age (ρ = 0.419, z = 2.548, p = 0.0108), and seep temperature and sample date (ρ = 0.558, z = 3.349, p = 0.0007). However, significant correlations were also found between sample date and each of elevation and stand age (Spearman correlation: elevation: ρ = 0.539, z = 3.279, p = 0.0010; stand age: ρ = 0.582, z = 3.538, p = 0.0004).

[g] Mitchell's (1998) categorization can sometimes be difficult to reconcile with local conditions. In most of the streams we surveyed, his flat, the category closest to the channel, was a downcut channel margin.

Figure 2.205 - Frequency Distribution of Seep Densities by Proximity to the Stream Channel in the Stillman Watershed, Washington, 2000

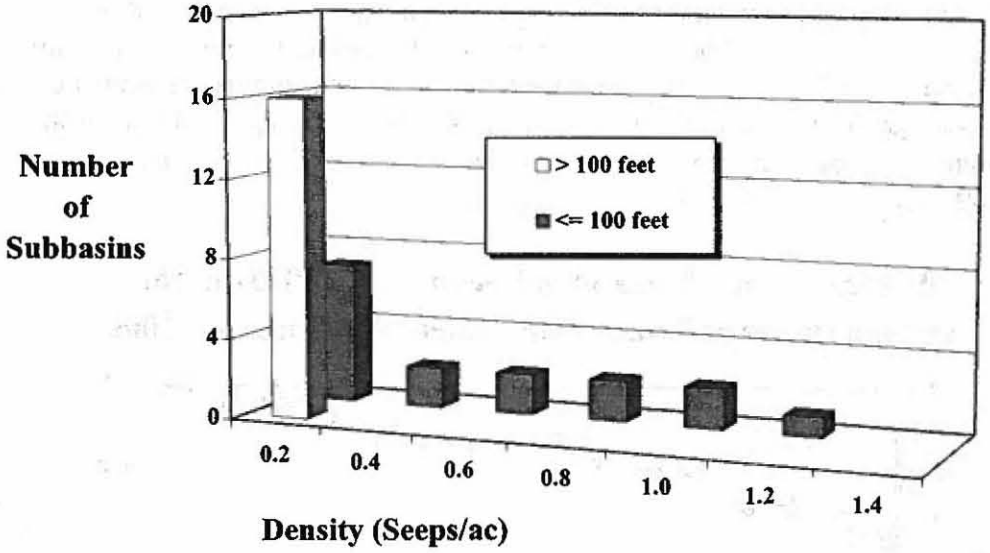
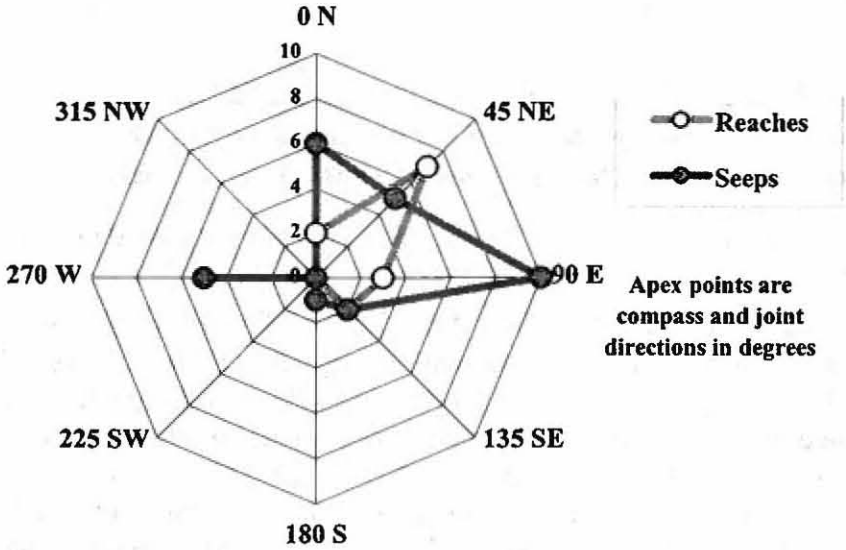


Figure 2.206 - Aspect of Reaches and Seeps in the Stillman Watershed, Washington, 2000



Seep geology reflected subbasin geology. Of 29 seeps, 23 were on GABBRO AND BASALT INTRUSIVE ROCKS, the only seep in subbasin STL11040313 (see Tables 2.203 and 2.206) was on MACINTOSH FORMATION, and all 3 seeps in the STL11040814 and STL11040825 subbasins were on CRESCENT FORMATION (see Appendix V for explanation of geologies).

Seep substrates were variable, but some substrate types were more frequent. Mud, SWD, leaf litter, and LWD were each recorded in > 70% of seeps (Table 2.207); other substrate

Table 2.207 – Seep Substrates in the Stillman Watershed, Washington, 2000

Subbasin	Seep	Substrate Categories[1]												Total Types
		Bedrock	Boulder	Cobble	Gravel	Sand	Mud	LWD	SWD	Leaf Litter	Live Veg	Coarse	Fine	
		A	B	C	D	E	F	G	H	I	J	A-D	E-F	A-J
STL11040221	A		+	+				+	+	+		+		5
	B		+	+				+	+	+		+		5
STL11040313	A	+			+		+		+		+	+	+	5
STL11040814	***A***				+	+	+	+	+	+		+	+	***6***
STL11040825	A			+	+			+				+		3
	B			+	+			+		+		+		3
STL11041008	A					+	+		+	+			+	4
	B	---	---	---	---	---	---	---	---	---	---	---	---	---
	C			+			+		+	+		+	+	4
STL12041708	A						+	+	+	+			+	4
STL12041720	A						+	+	+	+			+	4
	B				+		+	+	+	+		+	+	5
	C						+	+	+	+			+	4
	D				+		+	+	+	+		+	+	5
	E				+		+		+	+		+	+	4
STL12041731	***A***						+	+	+	+			+	***4***
	B						+			+			+	2
	C						+	+	+	+			+	4
STL12042005	A						+	+	+				+	3
STL12043108	A		+	+				+	+			+		4
STL12043223	A						+	+		+	+		+	4
STL12043407	A						+	+	+	+			+	4
	B				+		+	+	+	+		+	+	5
	C							+	+	+				3
	D						+	+	+	+			+	4
	E				+		+	+	+	+		+	+	5
	F						+	+	+				+	***3***
	G			+	+		+	+				+	+	4
	H				+		+		+			+	+	3
Seeps with Category		**1**	**3**	**7**	**11**	**2**	**22**	**22**	**23**	**21**	**2**	**15**	**22**	
% of Seeps		**4**	**11**	**25**	**39**	**7**	**79**	**79**	**82**	**75**	**7**	**54**	**79**	

Note: Headwall seeps in ***emboldened italics***; side-slope seeps not italicized.
[1] Substrate types are described under (14) in the Subbasin Characterization and Definitions Subsection in Section 2.1. Dashes (---) indicates no data.

types were found in no more than 39% of seeps. Coarse substrates (gravel and coarser) occurred in 54% of seeps (n = 15) and were not significantly associated with seeps that

had percolating flow (Fisher's Exact test: $p = 0.4661$). We recorded fine substrates (sand or finer) in 79% (n = 22) of seeps. About one-third of seeps evaluated (n = 9) were scored in both coarse and fine substrate categories. No obvious substrate differences were noted between headwall and side-slope seeps.

Median age of stands at seeps with coarse substrates (49 yrs) was 7.5 years older than the median age of stands at seeps where coarse substrates were not recorded (41.5 yrs). This is a non-significant difference (Mann-Whitney test: $U = 92$, $U' = 119$, $z = -0.598$, $p = 0.5497$). Median stand age around seeps with fine substrates (39 yrs) was 10 years younger than the median age of stands around seeps where fine substrates were not found (49 yrs). This difference was also not significant (Mann-Whitney test: $U = 52$, $U' = 116$, $z = -1.585$, $p = 0.1129$).

Median percent gradient was significantly lower (by 20% [9°]) in seeps in which fine substrate types were scored than in seeps in which fines were not scored (Mann-Whitney test: $U = 36$, $U' = 133$, $z = -2.367$, $p = 0.0179$).

Compressible depth of seep substrates ranged from 0.0 in [0.0 cm] to 3.9 in [10.0 cm] (Table 2.203). Median compressible depth of substrates in seeps having fine substrate types (0.8 in [2 cm]) was twice as great as the median compressible depth of substrates in seeps where fines were not scored (0.4 in [1 cm]). This difference was marginally non-significant (Mann-Whitney test: $U = 43$, $U' = 109$, $z = -1.779$, $p = 0.0752$).

We identified 35 plant taxa in and around seeps. This included 29 species, and 4 genera (sedges [*Carex* sp.], rushes [*Cyperus* sp.], horsetails [*Equisetum* sp.], and willows [*Salix* sp.]) and 2 non-vascular groups (leafy liverworts [Hepaticae] and mosses [Bryophyta]; Table 2.208). Except for snake liverwort (*Conocephalum conicum*), members of these genera and non-vascular groups were not identified to species.

We recorded 10 plant taxa exclusively in seeps: 8 herbaceous taxa, 2 trees, and no shrubs. In descending order of how often they were found, piggyback plant (*Tolmiea menziesii*), horsetails (*Equisetum* sp.), leafy liver-worts (Hepaticae), coltsfoot (*Petasites frigidus*), and snake liverwort were the most often encountered taxa. However, even the species found most frequently, piggyback plant, was recorded only 8 times. The remaining 5 species (black cottonwood [*Populus balsamifera*], maidenhair fern (*Adiantum pedatum*), Oregon ash [*Fraxinus latifolia*], a sedge [*Carex* sp.] and stinging nettle [*Urtica dioica*]) were each recorded but once.

We found 8 more taxa more often in seeps than around them. Species in this group that we recorded at the highest frequencies (> 80% of the time) in seeps were skunk cabbage (*Lysichiton americanum*) and lady fern (*Athyrium filix-femina*; Table 2.208). The other 6 taxa were found in seeps ≤ 67% of the time that we recorded them. Further, we noted an apparently water-loving moss that appeared superficially similar to *Fontinalis* relatively frequently in seeps (see the F designation in the BRYO column of Table 2.208).

Vegetation cover (as herbs, shrubs, or trees) around seeps was variable (Table 2.208). Of the three cover classes, only percent tree canopy cover was significantly less above seeps than around them (Table 2.209). Comparison of percent cover over versus around seeps for each of the shrub and herb layers revealed no significant differences (Table 2.209), but the test showing that the herb layer might be greater within seeps failed marginally.

Table 2.208 – Plant Taxa Identified from Within and Outside of Seeps in the Stillman Watershed, Washington, 2000

Subbasin	Seep	ACCI[1]		ACMA		ADPE		ALRU		ATFI		BLSP		BRYO		CAsp	
		I[2]	O	I	O	I	O	I	O	I	O	I	O	I	O	I	O
STL11040221	A	+	+		+			+	+	+	+			+	+		
	B		+			+		+	+								
STL11040313	A	+	+						+	+	+			+	+		
STL11040814	*A*	+	+							+		+					
STL11040825	A																
	B																
STL11041008	A							+						F			
	B	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	C							+		+				F			
STL12041708	A							+						F			
STL12041720	A							+	+	+		+		+	+		
	B							+		+		+		+	+		
	C							+	+	+			+	+	+		
	D							+	+	+	+	+	+	+	+		
	E									+		+		+	+		
STL12041731	*A*													*F*			
	B									+				F	+		
	C									+				F	+		
STL12042005	A									+				F			
STL12043108	A	+	+					+						F			
STL12043223	A							+	+					+	+		
STL12043407	A											+	+	+	+		
	B							+	+								
	C								+					F			
	D							+	+								
	E							+	+							+	
	F													*F*			
	G							+	+					F			
	H							+						F	F		
Number Detected In		**4**	**5**	**0**	**1**	**1**	**0**	**16**	**12**	**12**	**3**	**6**	**3**	**21**	**12**	**1**	**0**
% Units Detected In		**14**	**18**	**0**	**4**	**4**	**0**	**57**	**43**	**43**	**11**	**21**	**11**	**75**	**43**	**4**	**0**

Note: Headwall seeps in ***emboldened italics***; side-slope seeps not italicized.

[1] Four-letter codes correspond to the first two letters of the genus and species of the scientific name. Scientific and common names corresponding to four-letter codes are provided in Appendix II. Color coding is dark gray for trees, light gray for shrubs, and white for herbaceous plant species.

[2] I = inside seep (as defined by the seep area; see 7(b) under Subbasin Characterization and Definitions Subsection in Section 2.1), O = outside seep; + indicate a species detection, dashes (---) indicate no data.

Table 2.208 – Plant Taxa Identified from Within and Outside of Seeps in the Stillman Watershed, Washington, 2000 (continued)

Subbasin	Seep	CYsp		COCO		DIFO		EQsp		FRLA		GASH		HEPA		HODI	
		I[1]	O	I	O	I	O	I	O	I	O	I	O	I	O	I	O
STL11040221	A																
	B																
STL11040313	A																+
STL11040814	*A*																
STL11040825	A																
	B																
STL11041008	A													+			
	B	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	C												+				
STL12041708	A																
STL12041720	A																
	B												+				
	C																
	D																
	E																
STL12041731	*A*																
	B																
	C																
STL12042005	A																
STL12043108	A																
STL12043223	A	+	+														
STL12043407	A							+				+	+				
	B							+									
	C							+									
	D							+		+							
	E							+									
	F																
	G			+		+	+							+			
	H			+										+			
Number Detected In		**1**	**1**	**2**	**0**	**1**	**1**	**5**	**0**	**1**	**0**	**1**	**3**	**3**	**0**	**0**	**1**
% Units Detected In		**4**	**4**	**7**	**0**	**4**	**4**	**18**	**0**	**4**	**0**	**4**	**11**	**11**	**0**	**0**	**4**

Note: Headwall seeps in ***emboldened italics***; side-slope seeps not italicized.

[1] Four-letter codes correspond to the first two letters of the genus and species of the scientific name. Scientific and common names corresponding to four-letter codes are provided in Appendix II. Color coding is dark gray for trees, light gray for shrubs, and white for herbaceous plant species.

[2] I = inside seep (as defined by the seep area; see 7(b) under Subbasin Characterization and Definitions Subsection in Section 2.1), O = outside seep; + indicate a species detection, dashes (---) indicate no data.

Table 2.208 – Plant Taxa Identified from Within and Outside of Seeps in the Stillman Watershed, Washington, 2000 (continued)

Subbasin	Seep	LYAM		MANE		OPHO		OXOR		PEFR		POBA		POMU		PREM	
		I[1]	O	I	O	I	O	I	O	I	O	I	O	I	O	I	O
STL11040221	A					+			+					+	+		
	B					+	+										
STL11040313	A							+	+					+	+		
STL11040814	*A*							+	+					+	+		
STL11040825	A						+	+	+					+			
	B							+	+					+			
STL11041008	A													+	+		
	B	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	C					+				+				+	+		
STL12041708	A	+						+	+					+	+		
STL12041720	A	+	+			+	+	+	+					+	+		
	B	+			+	+			+	+					+		
	C	+				+	+	+	+					+	+		
	D	+						+	+					+	+		
	E					+		+	+					+	+		
STL12041731	*A*													+	+		
	B							+	+					+	+		
	C	+												+	+		
STL12042005	A	+				+	+								+		
STL12043108	A				+	+		+	+					+	+		
STL12043223	A																
STL12043407	A	+												+	+		
	B	+						+						+	+		
	C	+				+	+	+	+					+	+		
	D					+	+			+					+		
	E					+	+							+	+		
	F	+				+		+						+	+		
	G						+	+						+	+		
	H				+			+						+	+		
Number Detected In		**11**	**1**	**0**	**3**	**13**	**9**	**16**	**14**	**3**	**0**	**1**	**0**	**23**	**24**	**0**	**1**
% Units Detected In		**39**	**4**	**0**	**11**	**46**	**32**	**57**	**50**	**11**	**0**	**4**	**0**	**82**	**86**	**0**	**4**

Note: Headwall seeps in ***emboldened italics***; side-slope seeps not italicized.

[1] Four-letter codes correspond to the first two letters of the genus and species of the scientific name. Scientific and common names corresponding to four-letter codes are provided in Appendix II. Color coding is dark gray for trees, light gray for shrubs, and white for herbaceous plant species.

[2] I = inside seep (as defined by the seep area; see 7(b) under Subbasin Characterization and Definitions Subsection in Section 2.1), O = outside seep; + indicate a species detection, dashes (---) indicate no data.

Table 2.208 – Plant Taxa Identified from Within and Outside of Seeps in the Stillman Watershed, Washington, 2000 (continued)

Subbasin	Seep	PSME		PTAQ		RIBR		RUSP		RUUR		SAsp		THPL		TOME	
		I[1]	O	I	O	I	O	I	O	I	O	I	O	I	O	I	O
STL11040221	A		+			+		+							+		
	B																
STL11040313	A	+	+				+	+	+								
STL11040814	*A*	+	+													+	
STL11040825	A	+	+														
	B	+	+														
STL11041008	A	+	+													+	
	B	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	C	+	+					+								+	
STL12041708	A	+	+					+	+								
STL12041720	A		+					+	+							+	
	B		+					+			+						
	C							+	+					+	+		
	D	+	+												+		
	E	+	+													+	
STL12041731	*A*	+	+					+	+								
	B	+	+					+	+			+					
	C							+	+				+		+		
STL12042005	A	+	+			+	+	+	+								
STL12043108	A	+	+														
STL12043223	A	+	+					+	+								
STL12043407	A		+														
	B		+													+	
	C	+	+														
	D		+	+				+	+							+	
	E		+					+		+						+	
	F	+	+	+	+												
	G	+	+		+												
	H	+	+														
Number Detected In		**18**	**25**	**2**	**2**	**2**	**2**	**14**	**10**	**1**	**1**	**1**	**1**	**1**	**4**	**8**	**0**
% Units Detected In		**64**	**89**	**7**	**7**	**7**	**7**	**50**	**36**	**4**	**4**	**4**	**4**	**4**	**14**	**29**	**0**

Note: Headwall seeps in ***emboldened italics***; side-slope seeps not italicized.

[1] Four-letter codes correspond to the first two letters of the genus and species of the scientific name. Scientific and common names corresponding to four-letter codes are provided in Appendix II. Color coding is dark gray for trees, light gray for shrubs, and white for herbaceous plant species.

[2] I = inside seep (as defined by the seep area; see 7(b) under Subbasin Characterization and Definitions Subsection in Section 2.1), O = outside seep; + indicate a species detection, dashes (---) indicate no data.

Table 2.208 – Plant Taxa Identified from Within and Outside of Seeps in the Stillman Watershed, Washington, 2000 (continued)

Subbasin	Seep	TSHE		URDI		VAPA		Totals		Canopy (%)		Shrubs (%)		Herbs (%)	
		I[1]	O	I	O	I	O	I	O	I	O	I	O	I	O
STL11040221	A							8	9	10	60	30	30	90	90
	B						+	2	4	20	50	35	35	95	80
STL11040313	A							7	10	50	50	40	40	70	70
STL11040814	***A***	+	+			+		***9***	***5***	***50***	***80***	***10***	***15***	***80***	***50***
STL11040825	A	+	+					4	4	15	50	0	5	80	30
	B	+	+					4	3	80	80	0	0	30	15
STL11041008	A							5	2	90	95	0	0	40	90
	B	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	C						+	8	4	65	85	20	25	95	95
STL12041708	A							6	4	90	90	60	10	70	20
STL12041720	A						+	10	10	70	70	20	35	85	85
	B	+						9	8	70	60	35	90	20	80
	C	+	+				+	10	10	85	85	40	40	45	45
	D		+				+	8	10	70	80	0	5	70	50
	E	+	+				+	9	6	50	70	40	10	90	30
STL12041731	***A***							***3***	***3***	***10***	***50***	***2***	***5***	***100***	***90***
	B		+					6	6	90	75	20	10	80	90
	C	+	+					5	6	50	70	75	30	40	20
STL12042005	A							6	5	80	80	70	70	30	30
STL12043108	A							6	5	70	80	5	0	25	10
STL12043223	A							5	5	10	80	20	90	90	10
STL12043407	A					+	+	8	6	85	90	10	5	70	70
	B						+	6	4	70	60	0	10	95	95
	C							6	5	40	65	30	10	85	95
	D							8	5	50	80	35	90	95	90
	E			+				9	4	40	90	65	10	95	70
	F					+	+	***7***	***4***	***80***	***80***	***20***	***10***	***95***	***100***
	G							7	6	10	80	0	20	90	95
	H							6	3	60	60	0	5	80	75
Number Detected In		**7**	**9**	**1**	**0**	**3**	**9**	**Mean**		**56**	**73**	**24**	**25**	**73**	**63**
% Units Detected In		**25**	**32**	**4**	**0**	**11**	**32**	**SD (s)**		**27**	**14**	**23**	**28**	**25**	**31**

Note: Headwall seeps in ***emboldened italics***; side-slope seeps not italicized.

[1] Four-letter codes correspond to the first two letters of the genus and species of the scientific name. Scientific and common names corresponding to four-letter codes are provided in Appendix II. Color coding is dark gray for trees, light gray for shrubs, and white for herbaceous plant species.

[2] I = inside seep (as defined by the seep area; see 7(b) under Subbasin Characterization and Definitions Subsection in Section 2.1), O = outside seep; + indicate a species detection, dashes (---) indicate no data.

Table 2.209 – Vegetation Cover Associated with Reaches and Seeps in the Stillman Watershed, Washington, 2000

Habitat Type	Vegetation Layer	Location						Wilcoxon Signed Rank Test Result	
		Marginal or Within[1]			Upland				
		$\bar{x}$[2]	SD (s)	SE	$\bar{x}$	SD	SE	Z value	p[3]
Reaches[4] (n = 8)	Tree Canopy	50.0	42.2	14.9	83.8	11.6	4.1	-2.370	0.0176
	Shrubs	21.3	33.1	11.7	19.3	13.2	4.7	-0.085	0.9325
	Herbs	47.8	29.1	10.3	57.5	34.0	12.0	-0.677	0.4982
Seeps (n = 29)	Tree Canopy	55.7	27.3	5.2	73.0	13.6	2.6	-3.333	0.0009
	Shrubs	24.4	23.0	4.3	25.2	27.9	5.3	-0.175	0.8614
	Herbs	72.5	25.1	4.7	63.2	31.0	5.9	-2.000	0.0453

[1] Marginal means along a stream reach, and within means in a seep.
[2] Mean ($\bar{x}$), standard deviation (SD), and standard error of the mean (SE).
[3] Probability (p); significant results are emboldened; α was conservatively adjusted using Sidak's multiplicative inequality ($\alpha' = 1-(1-\alpha)^{1/n}$) for the 3 tests in each habitat category (n = 3); the new rejection criterion (α') with this adjustment is 0.017.
[4] Includes springs; 14 reaches were sampled, but only 8 had vegetation data.

Of the 13 plant taxa in the seep dataset that occurred either exclusively or with high frequency (≥ 80% of the time) in seeps, no taxon appeared to favor headwall versus side-slope seeps. The 9 taxa in this group recorded ≤ 5 times were found exclusively in side-slope seeps; the remaining 4 taxa, which were recorded > 7 times in the seep dataset, were found at low frequency (1-2 times) in headwall seeps. These patterns parallel the observed occurrence frequency of the two seeps categories.

Ten plant taxa (bleeding heart, deer fern, maidenhair fern, leafy liverworts, salal, snake liverwort, vine maple, western hemlock, western red cedar, and willow), when recorded from seeps, were recorded exclusively in seeps with gradients > 20% [9°]. However, all but two of these (leafy liverworts and snake liverwort) were found only in seeps (i.e., not from adjacent uplands) and both were recorded few (≤ 3) times (Table 2.208). Of plant species recorded in seeps ≥ 8 times, 8 taxa (deer fern, Douglas-fir, lady fern, mosses, red alder, redwood sorrel, salmonberry, and skunk cabbage) were recorded from seeps having gradients > 20% [9°] more than 70% of the time. However, among these taxa, only lady fern and skunk cabbage were not recorded in adjacent uplands with moderate frequency (Table 2.208). Similarly, 6 plant taxa (dewberry, bracken fern, Oregon ash, a rush, a sedge, and stinging nettle) were recorded in seeps with gradients ≤ 20% [9°]. However, only Oregon ash, the rush, the sedge, and stinging nettle were recorded exclusively from seeps and each was recorded but once.

Of plant species recorded in seeps ≥ 8 times, none occurred in percolating seeps more frequently than expected, although piggyback plant approached significance (Fisher's Exact Test: $p = 0.0957$).

Of plant species recorded in seeps ≥ 8 times, we found no significant associations with particular substrate types[h]. However, 11 associations approached significance (Fisher's Exact test probabilities in parens after each): Devil's club with boulders ($p = 0.0873$) and SWD ($p = 0.0178$); Douglas-fir was with leaf litter ($p = 0.0302$), LWD ($p = 0.0619$), and SWD ($p = 0.0619$); piggyback plant with sand ($p = 0.0741$) and leaf litter ($p = 0.0749$); skunk cabbage with cobble ($p = 0.0233$), LWD ($p = 0.0549$), and SWD ($p = 0.0549$); and each of a *Fontinalis*-like moss, redwood sorrel, mosses (in general) and western hemlock with gravel ($p = 0.0540$ for the first two; $p = 0.0764$ for the latter two).

Reaches and Springs: We evaluated 14 stream reaches in 7 of the subbasins containing seeps. Of the 14 reaches evaluated, 4 were initiation (having a spring; see Table 2.201); the remaining 10 reaches were non-terminal. Three of the 4 initiation reaches had spatially discontinuous surface flows associated with decommissioned roads; the fourth was an initiation reach associated with continuous perennial flow downstream.

We recorded no initiation reaches in 3 of 16 subbasins (19%)[i] and 1 to 4 springs in each of the remaining 13 subbasins for a total of 20 springs and a mean of 1.3 springs/subbasin (s = 1.1 springs/subbasin, se = 0.2 springs/subbasin). Based on the total area sampled, we had a mean of 0.05 springs/ac [0.12 springs/ha] or 1 spring/19.5 ac [7.9 ha]. In subbasins in which we recorded springs, density of springs varied from 0.03/ac [0.07/ha] to 0.14/ac [0.33/ha], or a range of 1 spring/33.5 ac [13.6 ha] to 1 spring per 7.4 ac [3.0 ha].

Aspects of reaches were predominantly north and east, mostly northeast (Figure 2.206).

Geology of reaches reflected subbasin geology. Except for one non-terminal reach on the MACINTOSH FORMATION, all reaches sampled were on GABBRO AND BASALT INTRUSIVE ROCKS (Appendix V).

Variation existed in stream order (Table 2.210). By definition, initiation reaches were 1st order. Six of 10 non-terminal reaches were 1st order; 2 were 2nd order; 1 was 3rd order.

Reach gradients had an over 15-fold range, 6.0% [2.7°] to 112.0% [50.4°] (Table 2.210). Gradients for initiation reaches ranged from 7.6% [3.4°] to 60.0% [27.0°], whereas non-terminal reaches ranged from 6.0% [2.7°] to 112.0% [50.4°]. Initiation reach gradients did not differ significantly from non-terminal reach gradients (Mann-Whitney test: $U = 18$, $U' = 22$, $z = -0.283$, $p = 0.7773$). The non-terminal reach with the highest gradient 112.0% [50.4°] was the only waterfall sampled; no other sampled reaches were over 62.0% [27.9°].

Flow velocity in 5 reaches ranged from 0.4 cm/sec [0.2 in/sec] to 4.8 cm/sec [1.9 in/sec] (Table 2.211). In the 4 initiation reaches, flow velocity ranged from 0.6 cm/sec [0.2 in/sec] to 2.1 cm/sec [0.8 in/sec], but no overlap in flow velocity existed with the one non-terminal reach measured, which had a higher range (3.6 cm/sec [1.4 in/sec] to 4.8 cm/sec [1.9 in/sec]). Flow in these 5 reaches ranged from 0.048 ft^3/sec [0.001 m^3/sec] to 1.104 ft^3/sec [0.027 m^3/sec] (Table 2.212). Flow in initiation reaches ranged from 0.046 ft^3/sec [0.001 m^3/sec] to 0.961 ft^3/sec [0.027 m^3/sec], whereas flow in the only non-terminal reach was greater (0.828 ft^3/sec [0.023 m^3/sec] to 1.104 ft^3/sec [0.031 m^3/sec]).

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[h] One test for each of the 9 substrate types required readjustment of α to 0.005.

[i] No initiation reaches were recorded in a few subbasins because their survey began and ended at a road crossing and no tributaries existed between these main channel survey points.

The reaches differed significantly in flow velocity (Friedman's test: $\chi^2 = 10.085$, df = 4, $p = 0.0390$), but not flow (Friedman's test: $\chi^2 = 4.130$, df = 4, $p = 0.3890$).

Table 2.210 – Reaches Examined in the Stillman Watershed, Washington, 2000

Subbasin	Unit Type			Area of Flow		Stream Order	Length		Gradient (slope)		Associated Unit[2]
	Cat[1]	Unit Label									
		Spring	Reach	ft²	m²		ft	m	%	°	
STL11040221	I	A	---	65	6	1	9.8	3.0	60.0	27.0	---
STL11040313	N	---	A	129	12	3	23.0	7.0	21.4	9.7	Seep A
STL11041008	N	---	A	82	8	1	25.0	7.6	57.1	25.7	Seep A
	N	---	B	---	---	1	32.8	10.0	61.1	27.5	Seep B
	N	---	C	215	20	1	32.8	10.0	46.4	20.9	Seep C
STL12041720	N	---	A	323	30	2	49.2	15.0	20.2	9.1	Seep C
STL12041731	N	---	A	54	5	1	32.8	10.0	21.3	9.6	Seep B
STL12043223	I	A	---	215	20	1	16.4	5.0	7.6	3.4	---
	I	B	---	11	1	1	16.4	5.0	36.0	16.2	---
	I	C	---	43	4	1	6.6	2.0	20.4	9.2	---
	N	---	A	119	11	1	20.7	6.3	23.1	10.4	Spring B
STL12043407	N	---	A	269	25	2	33.5	10.2	112.0	50.4	---
	N	---	B	11	1	1	3.3	1.0	18.9	8.5	Seep G
	N	---	C	---	---	1	---	---	6.0	2.7	Seep E
Summary Data	I = 4 N = 10	**Total**		1536	143	1 = 11 2 = 2 3 = 1	---	---	---	---	**Total**
		Mean ($\bar{x}$)		128	12		23.3	7.1	36.5	16.5	**Mean ($\bar{x}$)**
		Median		101	10		23.0	7.0	22.3	10.1	**Median**
		SD (s)		104	10		12.9	3.9	28.6	12.9	**SD (s)**
		SE		30	3		3.6	1.1	7.6	3.4	**SE**

[1] Category (Cat): initiation (I) and non-terminal (N).
[2] Comparative or nearby unit (see discussion in Section 2.1).

Sampled lengths of initiation reaches ($\bar{x}$ = 12.3 ft [3.7 m], s = 4.9 ft [1.5 m], se = 2.4 ft [0.7 m]) were significantly shorter than the sampled lengths of non-terminal reaches[j] ($\bar{x}$ = 28.1 ft [8.6 m], s = 12.5 ft [3.8 m], se = 4.2 ft [1.3 m]); Table 2.210; Mann-Whitney test: $U = 4$, $U' = 32$, $z = -2.180$, $p = 0.0296$). Area sampled in non-terminal reaches ($\bar{x}$ = 150 ft² [14 m²], s = 109 ft² [10 m²], se = 38 ft² [10 m²]) averaged roughly twice as large as the area sampled in initiation reaches ($\bar{x}$ = 84 ft² [14 m²], s = 90 ft² [10 m²], se = 45 ft² [10 m²]), but the difference was not significant (Mann-Whitney test: $U = 9$, $U' = 23$, $z = -1.190$, $p = 0.2328$).

[j] Sample size for reach length in non-terminal reaches was 9 because length data were missing for one reach; for similar reasons, sample size for reach area in non-terminal reaches was 8.

All reaches had from 2-7 substrate types but most reaches had 4-7 types (Table 2.213). Gravel and SWD were the most frequently recorded substrates types in the reaches for which we have data. We found coarse substrates, small gravel or larger, in 88% (n = 7) of the reaches; fine substrates (sand or finer) were recorded in 75% of the reaches as well.

Table 2.211 – Five Flow Velocity Measurements at Five Reaches in the Stillman Watershed, Washington, 2000.

Subbasin	Cat[1]	Label[2]	Surface Flow Velocity (cm/sec)					Descriptive Statistics[3]		
			1	2	3	4	5	$\bar{x}$	SD (s)	SE
11040814	I	---	0.8	1.3	1.3	0.9	1.1	1.1	0.2	0.1
12041720	N	A	3.6	3.9	4.8	4.2	4.4	4.2	0.5	0.2
12043223	I	A	1.7	1.9	1.6	2.1	1.9	1.8	0.2	0.1
12043223	I	B	0.8	1.3	1.7	1.2	1.4	1.3	0.3	0.1
12043407	I	---	0.4	0.6	0.7	0.6	0.6	0.6	0.1	0.1

[1] Category (Cat): initation (I), non-terminal (N).
[2] Corresponds to labels for described reaches in Table 2.210.
[3] Mean ($\bar{x}$), standard deviation (**SD**), and standard error of the mean (**SE**).

Table 2.212 – Five Flow Estimates for Five Reaches in the Stillman Watershed, Washington, 2000.

Subbasin	Cat[1]	Label[2]	Flow Measurements (ft^3/sec)[3]					Descriptive Statistics[4]		
			1	2	3	4	5	$\bar{x}$	SD (s)	SE
11040814	I	---	0.128	0.208	0.208	0.144	0.176	0.173	0.036	0.016
12041720	N	A	0.828	0.897	1.104	0.966	1.012	0.961	0.106	0.047
12043223	I	A	0.527	0.589	0.496	0.651	0.589	0.570	0.060	0.027
12043223	I	B	0.104	0.169	0.221	0.156	0.182	0.166	0.043	0.019
12043407	I	---	0.132	0.048	0.056	0.048	0.048	0.066	0.037	0.016

[1] Category (Cat): initiation (I), non-terminal (N).
[2] Corresponds to labels for described reaches in Table 2.210.
[3] Flow was measured over a cross-sectional area of 100 cm^2 [0.11 ft^2]; see Appendix III for details.
[4] Mean ($\bar{x}$), standard deviation (**SD**), and standard error of the mean (**SE**).

Reach water temperatures averaged 8.2°C [46.8°F] (s = 1.6°C [2.9°F], range: 5.6-9.8°C [42.1-49.6°C]; n = 33). At air temperatures ≥ 8.4°C [47.1°F] (n = 15), reach water temperatures were 1.2-3.3°C (2.2-5.9°F; $\bar{x}$ = 1.3°C [2.4°F], s = 0.5°C [1.0°F]) colder than air temperatures. At air temperatures < 8.4°C [47.1°F] (n = 18), reach water temperatures were 0.6-3.1°C (1.1-5.6°C; $\bar{x}$ = 1.5°C [2.7°F], s = 1.7°C [3.1°F]) warmer than air temperatures. Initiation reaches had significantly colder water temperatures ($\bar{x}$ = 6.5°C [43.7°F], s = 0.8°C [1.5°F], range: 5.6-7.2°C [42.1-45.0°C]; n = 11) than non-terminal reaches ($\bar{x}$ = 9.1°C [48.3°F], s = 1.1°C [2.0°F], range: 7.5-9.8°C [45.5-49.6°C], n = 22; Mann-Whitney test: $U = 0$, $U' = 242$, z = -4.856, $p < 0.0001$), but most non-terminal reach sampling dates were earlier than initiation reach sampling dates. We found a significant inverse correlation between reach water temperature and sample date (Spearman Rank correlation: $\rho = -0.966$, z = 5.467, $p < 0.0001$), and a significant positive correlation between reach water temperature and stand age (Spearman Rank correlation: $\rho = 0.688$, z = 3.892, $p < 0.0001$). No relationship was found between reach water

temperature and elevation (Spearman Rank correlation: $\rho = 0.142$, $z = 0.806$, $p = 0.4202$).

Table 2.213 – Reach Substrates in the Stillman Watershed, Washington, 2000

Subbasin	Unit Label[1]	Substrate Categories[2]												Total Types
		Bedrock	Boulder	Cobble	Gravel	Sand	Mud	LWD	SWD	Leaf Litter	Live Veg	Coarse	Fine	
		A	B	C	D	E	F	G	H	I	J	A-D	E-F	A-J
STL11040221	SA		+	+	+	+		+	+			+	+	6
STL11040313	RA	---	---	---	---	---	---	---	---	---	---	---	---	---
STL11041008	RA	---	---	---	---	---	---	---	---	---	---	---	---	---
	RB	---	---	---	---	---	---	---	---	---	---	---	---	---
	RC	---	---	---	---	---	---	---	---	---	---	---	---	---
STL12041720	RA	---	---	---	---	---	---	---	---	---	---	---	---	---
STL12041731	RA						+	+	+	+			+	4
STL12043223	SA			+	+				+	+		+		4
	SB			+	+	+			+	+		+	+	5
	SC			+	+	+	+	+	+	+		+	+	7
	RA				+	+	+		+	+		+	+	5
STL12043407	RA	+						+				+		2
	RB				+		+	+	+			+	+	4
	RC	---	---	---	---	---	---	---	---	---	---	---	---	---
Reaches with Category		**1**	**1**	**4**	**6**	**4**	**4**	**5**	**7**	**5**	**0**	**7**	**6**	
% of Reaches		**12**	**12**	**50**	**75**	**50**	**50**	**63**	**88**	**63**	**0**	**88**	**75**	

[1] Unit label elements correspond to the letters labeling springs (S) and reaches (R) in Table 2.210.
[2] Substrate types are described under (14) in the Subbasin Characterization and Definitions Subsection in Section 2.1. Dashes (---) indicate no data.

We identified 18 plant taxa along reaches and their adjacent uplands. This included 16 species, 1 genus (horsetails) and 1 non-vascular group (mosses; Table 2.214). Horsetails and mosses were not identified to species.

Four taxa (bracken fern, dewberry, stink currant, and vine maple) were found along stream margins that were not observed in nearby uplands (Table 2.214), but each species was recorded only once. Only one other plant taxon (mosses) was recorded more frequently along reach margins than in the surrounding uplands.

Percent canopy cover was significantly less along reach margins than in adjacent uplands, but we found no significant differences in either shrub or herbaceous cover between reach margins and uplands (Table 2.209; see also Table 2.214).

Comparisons: Based on our selection process, seeps and reaches were similar in elevation, geology, and the stream order associated with sampled units (see Section 2.1). Seeps and reaches were also generally similar in aspect (see Figure 2.206). Gradients of the seeps sampled averaged ca. 10% [4.5] steeper than gradients of sampled reaches (compare Table 2.206 to Table 2.210), but the difference was not significant (Mann-

Whitney test: $U = 145$, $U' = 261$, $z = -1.503$, $p = 0.1328$). The areas of seeps were significantly larger than the sampled areas of reaches (compare Table 2.206 to Table 2.210; Mann-Whitney test: $U = 53$, $U' = 295$, $z = -3.468$, $p = 0.0005$).

Table 2.214 – Plant Taxa Identified along Reaches and in Adjacent Uplands in the Stillman Watershed, Washington, 2000

Subbasin	Unit Label	ACCI		ALRU		ATFI		BLSP		BRYO		EQsp		HODI	
		R[1]	U	R	U	R	U	R	U	R	U	R	U	R	U
STL11040221	SA			+			+			+					
STL11040313	RA	---	---	---	---	---	---	---	---	---	---	---	---	---	---
STL11041008	RA	---	---	---	---	---	---	---	---	---	---	---	---	---	---
STL11041008	RB	---	---	---	---	---	---	---	---	---	---	---	---	---	---
STL11041008	RC	---	---	---	---	---	---	---	---	---	---	---	---	---	---
STL12041720	RA	---	---	---	---	---	---	---	---	---	---	---	---	---	---
STL12041731	RA														
STL12043223	RA									+	+				
STL12043223	SA									+	+				
STL12043223	SB									+	+				+
STL12043223	SC									+	+				
STL12043407	RA	+		+	+				+	+	+		+		
STL12043407	RB			+	+					+					
STL12043407	RE	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Number Detected In		**1**	**0**	**2**	**3**	**0**	**1**	**0**	**1**	**7**	**5**	**0**	**1**	**0**	**1**
% Units Detected In		**13**	**0**	**25**	**38**	**0**	**13**	**0**	**13**	**88**	**63**	**0**	**13**	**0**	**13**

[1] Four-letter codes correspond to the first two letters of the genus and species of the scientific name. Scientific and common names corresponding to four-letter codes are provided in Appendix II. Color coding is dark gray for trees, light gray for shrubs, and white for herbaceous plant species.

[2] R = along reaches (as defined the channel margin; see 7(b) under Subbasin Characterization and Definitions Subsection in Section 2.1), U = upland; + indicate a species detection, dashes (---) indicate no data.

Mean flow velocity was somewhat greater in reaches than in seeps (compare Table 2.211 to Table 2.204), but the difference was not significant (Mann-Whitney test: $U = 9$, $U' = 17$, $z = -0.841$, $p = 0.4005$). However, reaches had mean flows about 100 times greater than seeps (compare Table 2.212 to Table 2.205), which was significant (Mann-Whitney test: $U = 0$, $U' = 25$, $z = -2.643$, $p = 0.0082$).

Seeps differed from reaches in substrate composition. For substrate categories scored at least 4 times, mud, LWD, and leaf litter occurred more often in seeps than in reaches, and cobbles, gravel, and sand occurred more often in reaches than seeps (compare summaries of percentages in Tables 2.207 and 2.213).

We recorded a few differences between the vegetation on stream margins and within seeps (compare Tables 2.208 and 2.214). We did not record any plant taxa in reaches that was not also found either in seeps (n = 1; piggyback plant) or in seeps and uplands (n = 10). Eight plant taxa found in seeps were not found in either reaches or uplands, but only two of these (leafy liverworts and snake liverwort) were recorded more than once.

No plant taxa were found in reaches and uplands but not seeps.

Table 2.214 – Plant Taxa Identified along Reaches and in Adjacent Uplands in the Stillman Watershed, Washington, 2000 (continued)

Subbasin	Reach or Spring	OPHO		OXOR		POMU		PSME		PTAQ		RIBR		RUSP	
		R	U	R	U	R	U	R	U	R	U	R	U	R	U
STL11040221	SA				+		+								+
STL11040313	RA	---	---	---	---	---	---	---	---	---	---	---	---	---	---
STL11041008	RA	---	---	---	---	---	---	---	---	---	---	---	---	---	---
STL11041008	RB	---	---	---	---	---	---	---	---	---	---	---	---	---	---
STL11041008	RC	---	---	---	---	---	---	---	---	---	---	---	---	---	---
STL12041720	RA	---	---	---	---	---	---	---	---	---	---	---	---	---	---
STL12041731	RA					+	+	+						+	+
STL12043223	RA				+			+	+						
STL12043223	SA			+			+		+					+	+
STL12043223	SB							+	+						
STL12043223	SC							+	+						+
STL12043407	RA		+				+		+			+			
STL12043407	RB		+	+		+		+	+	+					
STL12043407	RE	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Number Detected In		**0**	**2**	**2**	**2**	**2**	**4**	**5**	**6**	**1**	**0**	**1**	**0**	**2**	**4**
% Units Detected In		**0**	**25**	**25**	**25**	**25**	**50**	**63**	**75**	**13**	**0**	**13**	**0**	**25**	**50**

[1] Four-letter codes correspond to the first two letters of the genus and species of the scientific name. Scientific and common names corresponding to four-letter codes are provided in Appendix II. Color coding is dark gray for trees, light gray for shrubs, and white for herbaceous plant species.

[2] R = along reaches (as defined the channel margin; see 7(b) under Subbasin Characterization and Definitions Subsection in Section 2.1), U = upland; + indicate a species detection, dashes (---) indicate no data.

Seep temperatures (n = 38) were not significantly different from reach temperatures (n = 33; Mann-Whitney test: U = 629, U' = 633, z = -0.071, p = 0.9431).

2.3 Discussion

In the Stillman watershed, seeps represent only a small fraction of the forested landscape. This pattern may be general, but these data represent a first glimpse for a largely basaltic geology in an area with moderately high precipitation (annual mean = ~50 in [127 cm])[k]. We expect that the abundance of seeps will vary with differences in geology and annual precipitation levels. In particular, we expect seep and spring abundance to increase in coastal areas of Washington where 2- to over 4-fold the mean annual precipitation levels found in the Stillman watershed exist. In such areas, seeps are likely to represent a larger proportion of the total landscape.

[k] Data from the Western Region Climate Center (see http://www.wrcc.dri.edu/summary/climsmwa.html) for the two stations closest to the Stillman watershed indicate a mean annual precipitation of 53.18 in [135.08 cm] (Doty 3 E: Station No. 452220: period of record 1978-2001) and 54.83 in [139.27 cm] (Rainbow Falls 2 E: Station No. 456887: period of record 1948-1963).

Table 2.214 – Plant Taxa Identified along Reaches and in Adjacent Uplands in the Stillman Watershed, Washington, 2000 (continued)

Subbasin	Reach or Spring	RUUR		THPL		TOME		VAPA		Totals		Canopy (%)		Shrub (%)		Herb (%)	
		R	U	R	U	R	U	R	U	R	U	R	U	R	U	R	U
STL11040221	SA						+		+	1	7	0	70	0	40	30	90
STL11040313	RA	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
STL11041008	RA	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
STL11041008	RB	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
STL11041008	RC	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
STL12041720	RA	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
STL12041731	RA				+					3	3	60	75	40	30	40	70
STL12043223	RA									2	3	85	90	0	0	75	50
STL12043223	SA									3	4	0	75	90	30	60	40
STL12043223	SB									2	3	95	10	0	10	2	15
STL12043223	SC									2	3	90	10	0	15	50	10
STL12043407	RA	+				+				6	7	50	80	40	10	30	90
STL12043407	RB									6	3	10	80	0	20	95	95
STL12043407	RE	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Number Detected		**1**	**0**	**0**	**1**	**1**	**1**	**0**	**1**	**Mean**		**50**	**84**	**21**	**19**	**54**	**58**
% Units Detected		**13**	**0**	**0**	**13**	**13**	**13**	**0**	**13**	**SD (s)**		**42**	**12**	**33**	**13**	**29**	**34**

[1] Four-letter codes correspond to the first two letters of the genus and species of the scientific name. Scientific and common names corresponding to four-letter codes are provided in Appendix II. Color coding is dark gray for trees, light gray for shrubs, and white for herbaceous plant species.

[2] R = along reaches (as defined the channel margin; see 7(b) under Subbasin Characterization and Definitions Subsection in Section 2.1), U = upland; + indicate a species detection, dashes (---) indicate no data.

Most seeps (90%) were relatively close (≤ 100 ft) to the stream (see Figure 2.204). Even within 50 ft, 83% of the seeps would be included. This validates one basic assumption of the FFR, that the patch buffer design can capture most seeps, at least in a landscape with a basaltic geology with annual rainfall levels of the range found in the Stillman watershed. Data from other studies also support this finding in a general fashion. Active erosion on channel bankslopes increases the probability of intercepting aquifers (Brooks *et al.* 1991). Likelihood of seep formation also increases as the side-slope elevation decreases (all else being equal) because water availability typically increases lower in the basin (Street *et al.* 1998). Nonetheless, we again caution that local geology may significantly influence seep location. Watershed Analysis or other maps showing areas at higher risk of mass wasting may be useful to locate low-elevation deep-seated landslides near streams, which through erosion, may expose, create or modify seeps.

Most seeps were located on side-slopes rather than headwalls. This may simply reflect stream networks possessing a much greater area in side-slopes, so this pattern may also be general. Nonetheless, we expect that abundance of headwall seeps may change with the degree of local ramification in stream networks. Where local ramification of stream networks are high, the proportion of headwall seeps may increase significantly.

Based on regulatory definition, a headwall seep is:

> "...a seep located at the toe of a cliff or other steep topographical feature and at the head a Type Np Water which connects to the stream channel network via overland flow, and is characterized by loose substrate and/or fractured bedrock with perennial water at or near the surface throughout the year." (WFPB 2000: *WAC 222-16-010: p. 16-15, 16-16*)

All 3 headwall seeps we found would qualify as sensitive sites based on the channel connection and perennial water criteria in this definition[1]. Whether these seeps qualify based on the gradient and substrate criteria is ambiguous. The language that relates to gradient is "at the toe of a cliff or other steep topographical feature", the notion of steep being central. If interpretation of steep was meant to parallel the gradient threshold that qualifies side-slope seeps (i.e., > 20%), 2 of 3 headwall seeps we found would qualify as sensitive. Something like the threshold that defines a qualifying side-slope seep was the intent arising out of FFR negotiations. Nonetheless, significant latitude for interpretation exists, and the language would benefit significantly from refinements that would make this criterion less ambiguous. Language relating to substrate is that qualifying headwall seeps possess "loose substrate and/or fractured bed-rock". Again, we realize that some of the intent with this language was to attempt to capture the idea of a coarse substrate grain, but strict interpretation of the language would be pressed to view it as guidance on grain size. Nonetheless, if one interpreted the substrate language as meaning having grain sizes coarser than gravel, then only 1 of 3 headwater seeps we found would qualify.

Based on regulatory definition, a side-slope seep is:

> "...within 100 ft of a Type Np Water located on side-slopes which are > 20%, connected to the stream channel network via overland flow, and characterized by loose substrate and fractured bedrock, excluding muck with perennial water at or near the surface throughout the year. Water delivery to the Type Np channel is visible by someone standing in or near the stream." (WFPB 2000: *WAC 222-16-010: p. 16-16*)

Based on channel connection, gradient, and perennial water criteria of this language, 14 of 26 (54%) side-slope seeps found would qualify as sensitive sites. As with headwall seeps, whether these 14 seeps qualify based on substrate criteria is ambiguous for similar reasons. If one interprets the substrate language as meaning with only grain sizes gravel or coarser, then only 2 of the side-slope seeps found would qualify. If one interprets the substrate language as meaning simply having gravel or coarser grain sizes present, then 5 of the side-slope seeps found would qualify. Our absolute scoring of substrate type being present or not, an intentional approach with first-year data to determine whether a simple scoring approach could be effectively applied, may complicate identifying potentially important differences between seeps. Under such scoring, seeps having few fines would score the same as seeps with abundant fines if all the same substrate types were present. Variation in number of qualifying seeps with different interpretations of absolute scoring of substrate types is potentially large, so it seems important that scoring incorporate an element that identifies relative abundance of each type. Clearly, the bottom line is that

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[1] Channel connection and perennial water are interpreted simply from connectedness and water presence during the low flow interval.

the description of seeps be refined enough to identify those that are important for amphibians. Regardless of interpretation, the existing sensitive site definitions capture 100% of qualifying seeps within the proposed FFR buffer. The issue is whether these seeps, which vary somewhat in number according to interpretation, really include those important to amphibians. Based on this discussion, we fully expect that the language defining seeps as sensitive sites will likely require some modification, but we expect such efforts will come following more research on determining which seeps are important to amphibians. The latter is the focus of subsequent research questions.

The criterion used in FFR negotiations to distinguish seeps from springs was the absence of a down-gradient scour channel in the former, a pattern that presumably results from insufficient flow needed to create and maintain such a channel (Brooks *et al.* 1991, Street *et al.* 1998). While we found it is possible to define seeps in this manner (partitioning them as the off-channel portion of the headwater network), the definition is arbitrary because it partitions over a continuum of flow conditions. That continuum is one reason that some have chosen to view seeps synonymous with springs (e.g., Allaby 1994). The problem can be simply illustrated by considering the two sensitive site categories currently recognized in FFR that address the terminal elements of upstream channel network: headwall seeps and headwater springs. Headwater springs represent the headwatermost points of the perennial channel network. As with all aquatic sites, headwater springs influence the moisture level of the substrate immediately around them. Depending on substrate characteristics, but especially the soil porosity and gradient, the spatial prism of this influence is variable, ranging from highly restricted (essentially not exceeding the outflow area of the spring) to broad (influencing a large area around the spring). On the other hand, headwall seeps are defined as features above the headwatermost point of the perennial channel network, and based on definition, are considered to qualify as sensitive sites only if they have a water connection (at or near surface flow) to the headwater spring. Thus, as the area that is influenced by a headwater spring increases, save perhaps with sophisticated knowledge of hyporheic flow, it cannot be practically distinguished from the substrate moistened by a headwall seep[m]. We point this out because it may not be practical to have landowners distinguish between sensitive sites whose characteristics, depending on scale, merge together. On the other hand, since both site categories currently require protection, the need to be able to distinguish them may be moot. Nonetheless, as current rules appear relatively encumbered, the potential that two sensitive site categories might be merged represents a simplification that may be useful to consider.

Much unneeded frustration in attempting to define seeps might be avoided by recognizing that they probably represent the low flow end of a hydrological continuum. An important impediment to this understanding is that knowledge of variation in flow around the range of conditions where channel development does and does not occur is lacking. Moreover, knowledge of how different landscapes (e.g., geology) influence such variation is equally

[m] We have simplified this point. A continuum of flow conditions exists between those developing a well-defined scour channel and those in which no scour-channel can be identified. This results in a range of spatially complex intermediate channel development conditions that are likely influenced by variation between years and local conditions (e.g., geology). This situation is an important factor contributing to ambiguity in distinguishing some headwater springs from headwall seeps.

lacking. This knowledge could not only improve understanding of whether and how this range of conditions should be logically partitioned, but would improve prediction of the occurrence and types of entities currently termed seeps.

Our exploratory measurements of flow in seeps clearly show that seeps are very low flow entities; flows may be measured in tablespoon volumes over small areas. We measured four initiation reaches for comparison to seeps in order to measure entities having flows likely to be most similar to what we might expect in seeps. Our few flow velocity data show significant overlap between initiation reaches and seeps, but flow measurements imply that initiation reaches may typically involve much larger volumes. At least three aspects of context for these measurements is important. First, reaches, whether initiation or non-terminal, address measurement of flow somewhere in or across a channel thalweg, a feature, by definition in our treatment, that is absent in seeps. Reaches may or may not be influenced by hyporheic flow, but our measurement remains a thalweg measurement. In contrast, our measurement of flow in seeps is a measurement of flow emerging from a hyporheic source, whose matrix structure and extent is unknown, but potentially vast (e.g., Naiman *et al.* 2000). We expect these differences to constrain flow in ways that will be reflected in their measurement. Second, in context of recent record in southwestern Washington (http://tao.atmos.washington.edu/data_sets/gpcp/), the year 2000 had lower than average annual precipitation. How low precipitation conditions may influence flow among reaches and seeps is unknown (that is why we use a channel as the cutoff point). Third, coefficient of variation for 5 measurements of each of flow and flow velocity in seeps were relatively high (~1). It is unclear whether this variation is instrinsic to flow variation in seeps, to the mode of measurement, or both. Novel methods or continuous monitoring technologies may be needed to describe flow velocity variation over time. Clearly, understanding how flow varies among seeps and other headwater habitats will require data over a broader spatial and temporal scope.

Substrate data generally support the notion that greater flows influence reaches versus seeps; we found fewer coarse substrates in seeps than reaches and vice versa. Regardless of our current inability to precisely define seeps hydrologically, our finding a greater frequency of fine substrate types in seeps supports the idea that low flows in seeps permit greater accumulation of these substrates. While this might seem an obvious consequence of how seeps were defined, and as per earlier discussion quantification of substrate type proportions is needed, current FFR guidelines about seeps appear to imply a category of seeps where fines are limited or absent. This view may not be consistent with either our findings or patterns one might expect in seeps given their low flow nature.

Certain features associated with vegetation appeared promising in helping to identify the location of seeps. Such features have practical importance because as relatively small entities on the landscape (at least in the Stillman watershed), we expect that seeps may be difficult to locate, especially if vegetation conceals their surface hydrology. Two aspects of the vegetation data we collected might be applied at a coarse scale to help locate seeps: tree canopy cover and deciduous trees. Tree canopy cover was lower at seeps than in the surrounding area (see Table 2.209), reflecting gaps in the canopy. Many reasons exist for tree canopy gaps, but seeking canopy gaps across a landscape, a task that might be done from aerial photographs, may be a logical, coarse-level first step in identifying possible seep locations. Second, three species of deciduous trees (red alder, black cottonwood,

Oregon ash) were found associated with seeps. Each species has a unique morphological signature that can be easily distinguished in aerial photography or on the ground within a coniferous landscape, especially during fall colors before their leaves are lost. Although all these taxa are frequent along the margins of some streams (e.g., black cottonwood and Oregon ash in riverine floodplains; Pojar and MacKinnon 1994), they will remain useful if their association with seeps is frequent in the forested landscape. Further, even in sites where these trees line stream channels, irregular lateral expansion of the riparian margin by clusters of these tree species may indicate seeps. Black cottonwood and Oregon ash were each found in one side-slope seep, the former in one that would be disqualified as a sensitive site based on gradient criteria, and both of which might be disqualified based on substrate criteria. Thus, some species may be used to suggest seeps that disqualify under rule language. Clearly, more data will be required to determine the usefulness of these trees as seep indicators. Further, field tests will be needed to verify which species can best predict seep presence and which may be most useful in identifying qualifying seeps.

At a local scale (i.e., on the ground in a particular Type N system), several non-tree plant taxa also appeared promising in identifying seeps, either because these species occurred only in seeps, or more frequently in seeps than elsewhere on the landscape. We found that 8 herb-layer taxa (coltsfoot, maidenhair fern, leafy liverworts, piggy-back plant, an unidentified sedge, skunk cabbage, snake liverwort, and stinging nettle) may be useful in indicating seeps. As all these plant taxa except piggyback plant and skunk cabbage were recorded but three or fewer times in seeps, just how exclusive these species are in seeps has yet to be determined. Mosses and moss-like liverworts might also be included in this group. However, these are a diverse assemblage within which species identification is difficult, as large groups of species are superficially similar. While it may be useful to determine which taxa in these groups may be associated with seeps, this effort probably has limited practical value for locating seeps in the field. Thus, mosses and moss-like liverworts should be simply used as another clue to wet conditions. Piggyback plant and skunk cabbage currently represent the herbaceous species that have the greatest promise for indicating seeps. Although both were associated with seeps in high frequency, each was found in only about one third of the seeps encountered. No shrub species we recorded in 2000 could be regarded as an especially useful indicators of seeps. Devil's club was the closest to a potential indicator, but it occurred with moderate frequency outside of seeps as measured in this study. We caution that in a year with annual precipitation closer to the mean over recent history, devil's club may appear to be a better indicator. Clearly, evaluation of seeps under different annual precipitation regimes will be important to a complete understanding of variation.

Low frequencies of seep-associated plant species may reflect metapopulation dynamics of seep-specific plants. Because seeps are widely dispersed and represent small patches in a forest matrix, seep vegetation may reflect differences in colonization ability and extirpation probability. Thus, any single species may be unlikely to occupy many seeps at any given time. A suite of seep-associated species rather than one or a few indicators may be necessary to aid in identification or location of seeps. We further caution that this situation may apply only to conditions where seeps are only a small fraction of the landscape. Larger sample sizes will be necessary to clarify this and other plant-associated patterns that may exist for seeps.

In this pilot study, we measured temperature primarily to obtain a preliminary indication of what to expect in seeps and headwater reaches; temperature data were not collected for the purposes of enabling a strict comparison. What the data did reveal is that there seems to be a turnover point in the relationship between air and water temperatures somewhere around air temperatures of 8-9°C [46.4-48.2°F]. At air temperatures above 8-9°C, water temperatures in seeps and headwater reaches tend to be colder than the air, whereas at air temperatures below this range, water temperatures in seeps and headwater reaches tend to be warmer than the air. This may have consequences for amphibians using such habitats at different seasons. Continuous temperature measurement (with dataloggers) will be needed to identify subtleties of temperature variation among seeps and reaches across the headwater landscape.

We have too few data to coherently comment on springs and their relationship to the headwater spring definition in the rules except to say that based on our treatment, all initiation reaches would have a spring. As springs in the literature frequently imply a significant hyporheic input (e.g., Allaby 1994), treatment of springs may require that variation in hyporheic input be understood.

3. Research Question 2 – Are seeps more valuable for amphibians than stream reaches in non-fish-bearing systems?

The FFR is based on the assumption that some seeps and springs are more important to SAAs than other headwater habitats. This research question focuses on potential differences in the value of seeps and non-seep habitats. We asked:

a) Do seeps have greater value for amphibians (based on species composition, species richness, and density) than other aquatic habitats in non-fish bearing systems?

b) What features make seeps more important to single amphibian species or the amphibian community than non-seep aquatic habitats in non-fish bearing systems?

3.1 Method

Amphibian Sampling: Two surveyors conducted area-constrained searches (Corn and Bury 1990) with a search time no less than 0.5 hr in each unit. Surveyors examined the substrate, looked beneath moveable surface objects as well as around and in vegetation or woody debris matrices that might conceal amphibians. We dismantled woody debris in our searches of seeps, but not along reaches.

We recorded the following information for each amphibian found:

1) Species: We identified the species. Based on knowledge of the amphibian fauna (Dvornich *et al.* 1997, McAllister 1995), 12 species[n] were possible (Appendix VI).
2) Life stage: We scored five life stage categories: (1) *egg*, (2) *larvae*, (3) *metamorph*, (4) *juvenile*, or (5) *adult*. Life stage information was used to suggest whether *in situ* reproduction had occurred; larval stages, which are thought to have limited vagility in some species (e.g., torrent salamanders), may be used to infer reproduction.
3) Life stage size: Life stage size was measured using standard body-length metrics for amphibians (snout-urostyle length [SUL] on anurans, and snout-vent length [SVL] on salamanders). As life stage size is correlated with age, especially for younger life stages (e.g., Nussbaum and Tait 1977), we used life stage size coupled with life stage (see 2 above) to help gauge the potential for *in situ* reproduction. We also used life stage size as a potential measure of habitat quality.

Analyses: We used 2 x 2 contingency tables (Fisher's Exact test) to compare frequency of species or species group occurrence between reaches and seeps. We also used Mann-Whitney U tests to compare amphibian species richness and amphibian density between reaches and seeps. As sampled units varied considerably in size and species richness is well known to increase as area increases (Blake and Karr 1987, Brown 1971, Kodrick-Brown and Brown 1993, Peake and Quinn 1993), we adjusted richness for area for all species richness comparisons among sampled units both here and in Research Question 3 using the standard equation that adjusts for the effect of a covariate, in this case area, before making comparisons (e.g., Quinn and Schneider 1991):

$$\ln(\mathbf{SR_a}) = \ln(\mathbf{SR_m}+1) + 0.2\,[\ln(\mathbf{AS}) - \ln(\mathbf{A_x})]$$

where $\mathbf{SR_a}$ = adjusted species richness, $\mathbf{SR_m}$ = measured species richness, and $\mathbf{A}$ = area of

[n] Cope's and coastal giant salamander were treated as one "species" in most analyses because we could not confidently provide a species assignment for some small larvae even though postmetamorphic individuals and most larvae could be identified.

each unit surveyed, and **AS** = area standard to which $\mathbf{SR_m}$ was corrected (typically near the mean of areas compared). The coefficient 0.2 represents a conservative value of the power to which area is raised to obtain the corresponding number of species in species-area curves. Using the inflection point of the negative logarithmic distribution of reach and seep areas, we used an **AS** value of 807 ft^2 [75 m^2]. As some species richness values were 0, we added 1 to $\mathbf{SR_m}$ prior to obtaining its natural logarithm, and then subtracted 1 from $\mathbf{SR_a}$ to ensure that realistic area-adjusted values were generated; $\mathbf{SR_a}$ values that were negative after subtracting 1 were adjusted to 0. The overall effect of this equation is to inflate species richness in small seeps but proportionately deflate it in large ones.

We used density, measured as individuals per acre, to compare abundance among units and species. For analyses involving size variation in the Columbia torrent salamander, we used 5-mm intervals in SVL.

3.2 Results

Amphibian Species Composition: We sampled 43 habitats in headwater stream basins, including 29 seeps and 14 reaches. We found 6 amphibian taxa (Table 3.201, Appendix VII) when we considered the two giant salamander species collectively. Salamanders were overwhelmingly the dominant amphibian group; they were recorded in 32 (74%) habitat units, whereas frogs were found in only 2 (5%), a significant difference (Fisher's Exact test: $p < 0.0001$).

Columbia torrent salamanders were by far the most frequently recorded species across all headwater habitats. This species was recorded in 28 (65%) of 43 headwater habitats and did not occur at frequencies that were significantly different between reaches (11 of 14) and seeps (17 of 29; Fisher's Exact test: $p = 0.3084$; Table 3.201).

We found the second most often recorded species, the western red-backed salamander, in only 6 (14%) of 43 habitats. Dunn's salamander was recorded only once. Both Dunn's and western red-backed salamanders were recorded only in seeps (Table 3.201).

Giant salamanders (both species combined) were also found in 6 (14%) of 43 habitats and were equally frequent in seeps and reaches. Giant salamander larvae, which were generally not identifiable to species, were found mostly in reaches, but metamorphosed life stages, which were identifiable to species, were encountered in seeps (Table 3.201).

The tailed frog larvae were recorded from one reach, and an adult northern red-legged frog was recorded from one seep (Table 3.201).

Amphibian Species Richness: Amphibian species richness varied from 0-3 in reaches and 0-5 in seeps. Adjusted species richness was significantly higher in reaches than in seeps (Table 3.202; Mann-Whitney test: $U = 90$, $U' = 317$, $z = -2.942$, $p = 0.0033$). Adjusted species richness was higher in initiation than in non-terminal reaches, but the difference was not significant (Mann-Whitney test: $U = 11$, $U' = 30$, $z = -1.345$, $p = 0.1786$).

No difference was found in adjusted species richness (seep and reach data combined) between 1st and larger order basins (Mann-Whitney test: $U = 184$, $U' = 206$, $z = -0.291$, $p = 0.7711$). We also found no difference between basin order categories with reaches and seeps considered separately (Mann-Whitney test: reaches: $U = 15$, $U' = 18$, $z = -0.234$, $p = 0.8151$; seeps: $U = 80$, $U' = 110$, $z = -0.689$, $p = 0.4910$).

We found no significant differences in adjusted species richness (seep and reach data combined) in units within older versus younger stands (Mann-Whitney test: $U = 157$, $U' = 249$, $z = -1.193$, $p = 0.2330$). Likewise, when reaches were considered separately, adjusted species richness did not differ between units within younger versus older stands (Mann-Whitney test: $U = 21$, $U' = 28$, $z = -0.452$, $p = 0.6510$). For seeps, adjusted species richness was significantly greater in older stands than in younger stands (Mann-Whitney test: $U = 41$, $U' = 127$, $z = -2.099$, $p = 0.0358$). Sample sizes for reach categories broken out by stand age were too small for analysis.

Table 3.201 - Amphibian Species Recorded in Headwater Habitats in the Stillman Watershed, Washington, 2000

Taxon		Frequency of Occurrence in Headwater Habitats		Fisher's Exact Test Result
Common Name	**Scientific Name**	**Reaches** (n = 14)	**Seeps** (n = 29)	**p =**
Frogs	**Anura**			
Tailed frog	*Ascaphus truei*	1	0	0.3256
Northern red-legged frog	*Rana aurora aurora*	0	1	> 0.9999
Frog Totals		1	1	> 0.9999
Salamanders	**Caudata**			
Pacific giant salamander[1]	*Dicamptodon tenebrosus*	0	2	0.5504
Unidentified giant salamanders[2]	*Dicamptodon* sp.	3	1	0.0936
Giant salamander Subtotals		3	3	0.3728
Dunn's salamander	*Plethodon dunni*	0	1	> 0.9999
Western red-backed salamander	*Plethodon vehiculum*	0	6	0.1546
Columbia torrent salamander	*Rhyacotriton kezeri*	11	17	0.3084
Rough-skinned newt[3]	*Taricha granulosa*	0	0	---
Salamander Totals		12	20	0.2914
Overall Amphibian Totals		12	20	0.2914

[1] All records of this species that were identifiable were adults.
[2] All unidentified giant salamanders were larvae; Pacific giant salamanders or Cope's giant salamander (*Dicamptodon copei*) may be represented.
[3] Not observed in reaches or seeps, but we made one incidental observation in uplands of one subbasin.

Amphibian Densities: Amphibian densities ranged from 0 to 24,281 individuals/ac [0-50,000 individuals/ha] across the 43 headwater habitats (Table 3.203). Densities in reaches were significantly greater than densities in seeps (Mann-Whitney test: $U = 90$, $U' = 316$, $z = -2.953$, $p = 0.0031$). Densities in initiation reaches averaged 3 times as high as densities in non-terminal reaches (Table 3.203), but this was not significant (Mann-Whitney test: $U = 12$, $U' = 28$, $z = -1.133$, $p = 0.2574$). Variation was high (Coefficient of variation (CV) for both initiation and non-terminal reaches > 1).

We found no significant differences in density between units associated with 1st- and larger-order streams (Table 3.203), whether we treated reaches and seeps collectively or

each separately (Mann-Whitney test: reaches and seeps: $U = 191$, $U' = 199$, $z = -0.107$, $p = 0.9151$; reaches: $U = 13$, $U' = 20$, $z = -0.546$, $p = 0.5854$; seeps: $U = 83$, $U' = 107$, $z = -0.559$, $p = 0.5762$).

Table 3.202 Variation in Adjusted Amphibian Species Richness in the Stillman Watershed, Washingon, 2000

Variable		Unit Type	Unit Category	Descriptive Statistics					
				Median	$\bar{x}$[1]	SD(s)	SE	range	
								min	max
Species Richness		All		1.4	1.5	1.3	0.2	0.0	5.5
		Reaches	Overall	1.9	2.2	1.1	0.3	0.5	4.8
			Initiation	2.5	2.6	0.9	0.4	1.6	3.7
			Non-terminal	1.6	2.1	1.2	0.4	0.5	4.8
		Seeps		1.1	1.2	1.3	0.2	0.0	5.5
Stream Order	1st-Order	All		1.4	1.4	1.1	0.2	0.0	3.7
		Reaches	Overall	2.2	2.1	1.0	0.3	0.5	3.7
			Initiation	2.5	2.6	0.9	0.4	1.6	3.7
			Non-terminal	1.6	1.9	1.0	0.4	0.5	3.5
		Seeps		1.0	1.0	0.9	0.2	0.0	2.6
	> 1st Order	All		1.3	1.9	1.8	0.5	0.0	5.5
		Reaches	Overall	1.5	2.6	1.9	1.1	1.4	4.8
			Initiation[2]	---	---	---	---	---	---
			Non-terminal	1.5	2.6	1.9	1.1	1.4	4.8
		Seeps		1.1	1.7	1.8	0.6	0.0	5.5
Stand Age	18-36 years	All		0.9	1.3	1.5	0.4	0.0	4.8
		Reaches	Overall	2.1	2.4	1.6	0.7	0.5	4.8
			Initiation	2.6	2.6	1.1	0.6	1.6	3.7
			Non-terminal	1.4	2.2	2.3	1.3	0.5	4.8
		Seeps		0.3	0.5	0.5	0.2	0.0	1.3
	37-55 years	All		1.5	1.7	1.3	0.2	0.0	5.5
		Reaches	Overall	1.9	2.0	0.7	0.3	1.4	3.5
			Initiation[3]	2.3	2.3	---	---	2.3	2.3
			Non-terminal	1.6	2.0	0.8	0.3	1.4	3.5
		Seeps		1.3	1.5	1.4	0.3	0.0	5.5

[1] Mean ($\bar{x}$), standard deviation (SD), and standard error of the mean (SE).
[2] Initiation reaches, by definition, are 1st-order.
[3] Sample size of 1.

For reaches and seeps combined as well as for reaches or seeps considered separately, we found no significant differences in amphibian density between units within older versus younger stands (Mann-Whitney test: reaches and seeps: $U = 160$, $U' = 246$, $z = -1.124$,

$p = 0.2611$; reaches: $U = 20$, $U' = 29$, $z = -0.582$, $p = 0.5608$; seeps: $U = 49$, $U' = 119$, $z = -1.734$, $p = 0.0830$).

Table 3.203 Variation in Amphibian Densities (individuals/ac) in the Stillman Watershed, Washingon, 2000

Variable		Unit Type	Unit Category	Descriptive Statistics					
				Median	$\bar{x}$[1]	SD(s)	SE	range	
								min	max
Density (individuals/ ac)		All		174	1,574	3,968	605	0	24,281
		Reaches	Overall	1,821	3,934	6,389	1,708	0	24,281
			Initiation	3,035	7,689	11,161	5,581	405	24,281
			Non-terminal	1,518	2,431	2,944	931	0	8,903
		Seeps		70	435	732	136	0	3,035
Stream Order	1st-Order	All		188	1,972	4,686	856	0	24,281
		Reaches	Overall	2,023	4,602	7,103	2,142	0	24,281
			Initiation	3,035	7,689	11,161	5,581	405	24,281
			Non-terminal	1,416	2,837	3,436	1,299	0	8,903
		Seeps		18	450	826	190	0	3,035
	> 1st Order	All		135	656	851	236	0	2,698
		Reaches	Overall	1,619	1,484	1,287	743	135	2,698
			Initiation[2]	---	---	---	---	---	---
			Non-terminal	1,619	1,484	1,287	743	135	2,698
		Seeps		75	407	547	173	0	1,349
Stand Age	18-36 years	All		50	2,214	6,411	1,713	0	24,281
		Reaches	Overall	1,214	4,924	9,547	3,897	0	24,281
			Initiation	2,023	8,903	13,342	7,703	405	24,281
			Non-terminal	135	944	1,520	878	0	2,698
		Seeps		5	182	472	167	0	1,349
	37-55 years	All		405	1,265	2,057	382	0	8,903
		Reaches	Overall	2,666	3,191	3,041	1,075	0	8,903
			Initiation[3]	4,047	4,047	---	---	4,047	4,047
			Non-terminal	1,619	3,069	3,263	1,233	0	8,903
		Seeps		174	532	798	174	0	3,035

[1] Mean ($\bar{x}$), standard deviation (SD), and standard error of the mean (SE).
[2] Initiation reaches, by definition, are 1st-order.
[3] Sample size of 1.

Individual Species Data: Columbia torrent salamanders were by far the most frequently recorded amphibian across all headwater reach or seep habitats (131 (82%) of 160 individuals), and was the only species we recorded in initiation reaches (Appendix VII).

Columbia torrent salamander densities were significantly higher in reaches than in seeps (Table 3.204: Mann-Whitney test: $U = 101$, $U' = 306$, $z = -2.715$, $p = 0.0066$). Torrent

salamander densities in initiation reaches averaged 4 times higher than in non-terminal reaches, but the difference was not significant (Table 3.204: Mann-Whitney test: $U = 10$, $U' = 30$, $z = -1.420$, $p = 0.1555$).

Table 3.204 Variation in Columbia Torrent Salamander Densities (individuals/ac) in the Stillman Watershed, Washingon, 2000

Variable		Unit Type	Unit Category	Descriptive Statistics					
				Median	$\bar{x}$[1]	SD(s)	SE	range	
								min	max
Density (individuals/ ac)		All		146	1,425	3,927	599	0	24,281
		Reaches	Overall	1,518	3,575	6,430	1,718	0	24,281
			Initiation	3,035	7,689	11,161	5,581	405	24,281
			Non-terminal	1,045	1,929	2,768	875	0	8,903
		Seeps		30	387	715	133	0	3,035
Stream Order	1st-Order	All		181	1,871	4,640	847	0	24,281
		Reaches	Overall	2,023	4,329	7,121	2,147	0	24,281
			Initiation	3,035	7,689	11,161	5,581	405	24,281
			Non-terminal	1,416	2,409	3,226	1,219	0	8,903
		Seeps		18	448	827	190	0	3,035
	> 1st Order	All		81	394	548	152	0	1,619
		Reaches	Overall	674	809	751	434	135	1,619
			Initiation[2]	---	---	---	---	---	---
			Non-terminal	674	809	751	434	135	1,619
		Seeps		50	270	448	142	0	1,349
Stand Age	18-36 years	All		50	2,069	6,422	1,716	0	24,281
		Reaches	Overall	540	4,586	9,676	3,950	0	24,281
			Initiation	2,023	8,903	13,342	7,703	405	24,281
			Non-terminal	135	270	357	206	0	674
		Seeps		0	181	473	167	0	1,349
	37-55 years	All		202	1,114	1,917	356	0	8,903
		Reaches	Overall	2,226	2,816	2,894	1,023	0	8,903
			Initiation[3]	4,047	4,047	---	---	4,047	4,047
			Non-terminal	1,619	2,641	3,079	1,164	0	8,903
		Seeps		146	465	784	171	0	3,035

[1] Mean ($\bar{x}$), standard deviation (SD), and standard error of the mean (SE).
[2] Initiation reaches, by definition, are 1st-order.
[3] Sample size of 1.

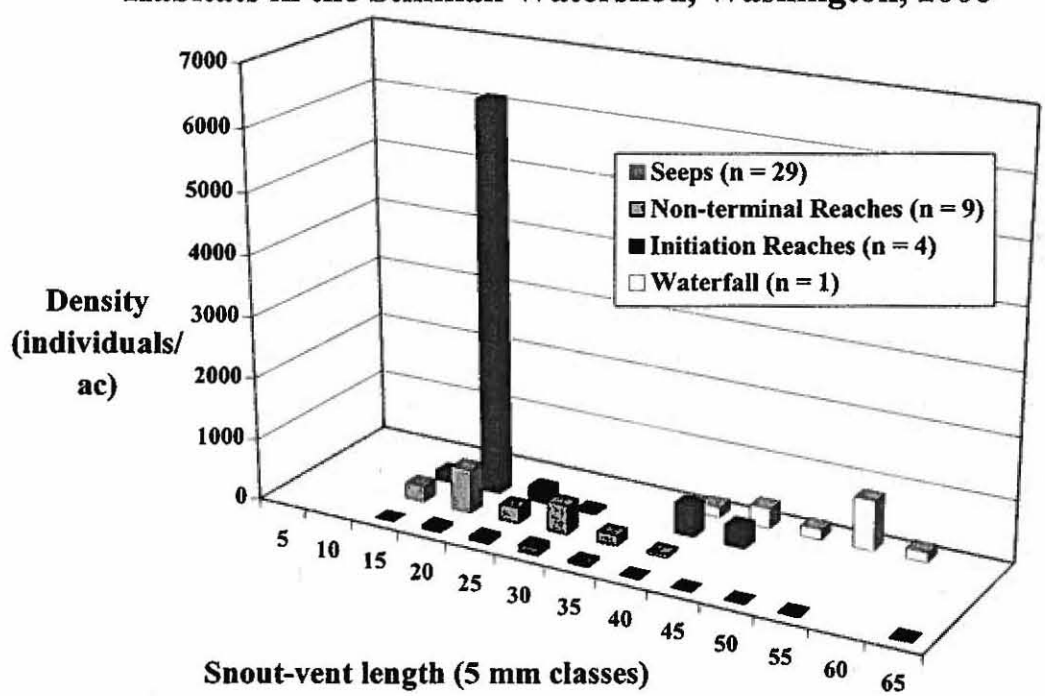
We found no significant differences in Columbia torrent salamander densities between 1st- and larger-order streams either with reaches and seeps combined (Mann-Whitney test: $U = 175$, $U' = 215$, $z = -0.540$, $p = 0.5889$), or with each of reaches and seeps separately (Mann-Whitney test: reaches: $U = 12$, $U' = 21$, $z = -0.704$, $p = 0.4816$; seeps: $U = 93$, $U' = 97$, $z = -0.095$, $p = 0.9242$).

We found no difference in Columbia torrent salamander densities between older versus younger stands when reach and seep data were combined (Mann-Whitney test: $U = 170$,

$U' = 237$, $z = -0.887$, $p = 0.3749$), when reach data was treated separately (Mann-Whitney test: $U = 19$, $U' = 29$, $z = -0.648$, $p = 0.5168$), or when seep data was treated separately (Mann-Whitney test: $U = 55$, $U' = 114$, $z = -1.493$, $p = 0.1354$).

Densities among Columbia torrent salamander size classes differed across headwater aquatic habitats (Figure 3.201); variation was high (Table 3.205). The highest densities, which involved small (≤ 25 mm SVL) larval Columbia torrent salamanders, were found in initiation reaches. The highest densities of adult Columbia torrent salamanders were recorded from the only waterfall sampled. Columbia torrent salamanders > 45 mm SVL were recorded exclusively in seeps and the waterfall. Non-terminal reaches had moderate to low densities of Columbia torrent salamanders; seeps had relatively low densities of Columbia torrent salamander, but densities were more evenly represented across the size distribution among seeps (Figure 3.201; Table 3.205). We were unable to find Columbia torrent salamander < 36 mm SVL, representing larvae and metamorphs, at the waterfall.

Figure 3.201 - Variation in Mean Density among Columbia Torrent Salamander Size Classes among Headwater Habitats in the Stillman Watershed, Washington, 2000



We recorded 13 or fewer individuals for each of all other amphibian species (Appendix VII). Our relatively sparse recording of these taxa is reflected in densities that were generally lower than for Columbia torrent salamanders in individual habitat units (Tables 3.306 and 3.207). Significantly, we recorded no species of amphibian other than Columbia torrent salamander in initiation reaches.

Collectively, giant salamanders were numerically the second most frequently recorded taxon, but they were found in only 6 habitat units: 3 non-terminal reaches and 3 seeps (Appendix VII). Moreover, the giant salamander life stages found were asymmetrically

distributed among headwater habitat types. We found 10 (91%) of 11 giant salamander larvae in pools located in 3 non-terminal, perennial reaches, two of which were 2nd-order. The remaining giant salamander larva was found in a small (1 ft x 2 ft [0.3 m x 0.6 m]) pool associated with a stream-adjacent, percolating seep connected to the stream channel by overland flow. The only two metamorphosed giant salamander life stages found, both identifiable as coastal giant salamander adults, were detected in seeps beyond 100 ft from the stream channel. One of these seeps was connected to the channel by overland flow; the other was not.

All individuals of the two lungless salamanders, western red-backed (n = 8) and Dunn's salamanders (n = 3), were found in association with seeps. All the Dunn's salamanders and 2 (25%) of the western red-backed salamanders were removed from decaying logs.

Table 3.205 Density Variation in the Columbia Torrent Salamander by 5-mm Size Class in the Stillman Watershed, Washington, 2000

Subbasin	Unit[1]	Label[2]	Size Class (SVL in mm): Data are Densities (individuals/ac)											Overall Density
			11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65	
11040221	I	A	674	0	0	0	0	2,023	1,349	0	0	0	0	4,046
12043223	I	A	0	202	0	202	0	0	0	0	0	0	0	404
12043223	I	B	0	24,281	0	0	0	0	0	0	0	0	0	24,281
12043223	I	C	0	1,012	1,012	0	0	0	0	0	0	0	0	2,024
Summary Data	Median		**0**	**607**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**3,035**
	Mean ($\bar{x}$)		**169**	**6,374**	**253**	**51**	**0**	**506**	**337**	**0**	**0**	**0**	**0**	**7,689**
	SD[3]		**337**	**11,946**	**506**	**101**	**0**	**1,012**	**675**	**0**	**0**	**0**	**0**	**11,161**
	SE[4]		**169**	**5,973**	**253**	**51**	**0**	**506**	**337**	**0**	**0**	**0**	**0**	**5,581**
	Range	min	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**405**
		max	**674**	**24,281**	**1,012**	**202**	**0**	**2,023**	**1,349**	**0**	**0**	**0**	**0**	**24,281**
11040313	N	A	0	0	337	0	337	0	0	0	0	0	0	674
11041008	N	A	0	1,591	0	1,061	530	530	0	0	0	0	0	3,712
11041008	N	B	0	405	405	1,619	405	0	0	0	0	0	0	2,834
11041008	N	C	0	405	0	809	202	0	0	0	0	0	0	1,416
12041720	N	A	0	0	0	0	135	0	0	0	0	0	0	135
12041731	N	A	2,428	4,047	1,619	809	0	0	0	0	0	0	0	8,903
12043223	N	A	0	0	0	0	0	0	0	0	0	0	0	0
12043407	N	A	0	0	0	0	0	162	324	162	809	162	0	1,619
12043407	N	B	0	0	0	0	0	0	0	0	0	0	0	0
12043407	N	C	0	0	0	0	0	0	0	0	0	0	0	0
Summary Data	Median		**0**	**0**	**0**	**0**	**68**	**0**	**0**	**0**	**0**	**0**	**0**	**1,045**
	Mean ($\bar{x}$)		**243**	**645**	**236**	**430**	**161**	**69**	**32**	**16**	**81**	**16**	**0**	**1,929**
	SD[3] (s)		**768**	**1,294**	**510**	**597**	**200**	**170**	**102**	**51**	**256**	**51**	**0**	**2,767**
	SE[4]		**243**	**409**	**161**	**189**	**63**	**54**	**32**	**16**	**81**	**16**	**0**	**875**
	Range	min	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
		max	**2,428**	**4,047**	**1,619**	**1,619**	**530**	**530**	**324**	**162**	**809**	**162**	**0**	**8,903**

[1] Units: Initiation reaches (I), Non-terminal reaches (R), and Seeps (S).
[2] Labels correspond to the Unit Label designations provided in Table 2.210.
[3] **SD** = standard deviation.
[4] **SE** = standard error of the mean.

The two frog species found were each recorded in one habitat unit (Table 3.201). The only tailed frog life stages were 4 larvae found in one non-terminal, 2nd-order reach. We recorded one northern red-legged frog, an adult female, from a seep beyond 100 ft from the stream channel that had an overland flow connection with the channel.

Table 3.205 Density Variation in the Columbia Torrent Salamander by 5-mm Size Class in the Stillman Watershed, Washington, 2000 (continued)

Subbasin	Unit[1]	Label[2]	Size Class (SVL in mm): Data are Density (individuals/ac)											Overall Density
			11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65	
11040221	S	A	0	0	0	0	0	0	0	0	0	0	0	0
11040221	S	B	0	0	0	0	0	0	0	0	0	0	0	0
11040313	S	A	0	112	225	225	450	0	112	112	112	0	0	1,348
11040814	S	A	0	0	193	385	0	0	0	0	0	0	0	578
11040825	S	A	0	0	0	0	0	0	0	0	0	0	0	0
11040825	S	B	0	0	0	0	0	0	0	0	0	0	674	674
11041008	S	A	0	0	1,054	1,054	0	0	0	0	0	0	0	2,108
11041008	S	B	0	0	0	0	0	202	0	0	0	0	0	202
11041008	S	C	0	0	0	0	0	18	0	0	0	0	0	18
12041708	S	A	0	0	0	0	0	0	0	0	0	0	0	0
12041720	S	A	0	0	0	0	0	0	0	0	0	0	0	0
12041720	S	B	0	0	0	0	0	0	0	70	0	0	0	70
12041720	S	C	0	0	0	0	0	0	0	30	0	0	0	30
12041720	S	D	0	0	0	0	0	0	0	0	0	0	0	0
12041720	S	E	0	0	0	0	0	0	0	0	0	0	0	0
12041731	S	A	0	0	0	0	0	0	0	0	0	0	0	0
12041731	S	B	0	0	0	0	0	0	0	0	405	0	0	405
12041731	S	C	0	405	405	405	0	0	0	0	0	0	0	1,215
12042005	S	A	0	0	0	0	0	0	0	0	0	0	0	0
12043108	S	A	0	0	0	0	0	0	0	0	0	0	0	0
12043223	S	A	0	0	0	0	0	0	0	0	0	0	0	0
12043407	S	A	0	0	0	0	0	0	81	0	0	0	0	81
12043407	S	B	0	62	124	155	93	31	31	0	0	0	0	496
12043407	S	C	13	80	13	27	13	0	0	13	0	0	0	159
12043407	S	D	0	0	0	0	0	0	0	0	0	0	0	0
12043407	S	E	0	4	0	0	4	4	0	0	0	0	0	12
12043407	S	F	0	0	0	49	97	0	0	0	0	0	0	146
12043407	S	G	0	1,012	0	1,012	1,012	0	0	0	0	0	0	3,036
12043407	S	H	0	257	128	128	0	0	0	128	0	0	0	641
Summary Data	Median		0	0	0	0	0	0	0	0	0	0	0	30
	Mean ($\bar{x}$)		1	67	74	119	58	9	8	12	18	0	23	387
	SD[3] (s)		2	203	210	276	200	38	26	33	77	0	130	715
	SE[4]		1	38	39	51	38	7	5	6	14	0	23	133
	Range	min	0	0	0	0	0	0	0	0	0	0	0	0
		max	13	1,012	1,054	1,054	1,012	202	112	128	405	0	674	3,036

[1] Units: Initiation reaches (I), Non-terminal reaches (R), and Seeps (S).
[2] Labels correspond to the Unit Label designations provided in Table 2.203.
[3] **SD** = standard deviation.
[4] **SE** = standard error of the mean.

Table 3.206 Density Variation among Amphibians excluding the Columbia Torrent Salamander in Non-terminal Reaches in the Stillman Watershed, Washington, 2000

Subbasin	Label[1]		Species[2]: Data in Density (individuals/ac)					Overall Density
			ASTR	RAAU	DISP	PLDU	PLVE	
11040313	A		1,349	0	674	0	0	2,023
11041008	A		0	0	0	0	0	0
11041008	B		0	0	2,833	0	0	2,833
11041008	C		0	0	0	0	0	0
12041720	A		0	0	0	0	0	0
12041731	A		0	0	0	0	0	0
12043223	A		0	0	0	0	0	0
12043407	A		0	0	0	0	0	0
12043407	B		0	0	0	0	0	0
12043407	C		0	0	164	0	0	164
Summary Data	Median		0	0	0	0	0	0
	Mean ($\bar{x}$)		135	0	367	0	0	502
	SD[3] (s)		427	0	892	0	0	1,034
	SE[4]		135	0	282	0	0	327
	Range	min	0	0	0	0	0	0
		max	1,349	0	2,833	0	0	2,833

[1] Unit Label designations in Table 2.210.
[2] See Appendix VI for species codes.
[3] SD = standard deviation.
[4] SE = standard error of the mean.

3.3 Discussion

Salamanders, which represented over 90% of amphibians recorded, were the numerically dominant group of amphibians in Stillman headwater habitats. This finding parallels that from other stream studies conducted in the westside Pacific Northwest (e.g., Bury and Corn 1988, Bury *et al.* 1991, Wilkins and Peterson 2000).

What differs markedly in this study is that torrent salamanders, in this case the Columbia torrent salamander, were overwhelmingly the most abundant taxon. This finding differs from previous studies, which have focused in reach habitats, where giant salamanders and tailed frogs have been recorded as the most abundant taxa (Bury *et al.* 1991, Wilkins and Peterson 2000). We expect that this difference is in part due to the fact that this study represents the most extreme possible headwater focus and addresses aquatic habitats with the lowest flows. Our results support the idea that low flows favor torrent salamanders. We must also note that Columbia torrent salamander densities in the managed landscape we studied can, at least locally, appear extraordinary. We simply note here that this finding diverges from the widely circulated and published statements regarding torrent salamander sensitivity (e.g., Bury et al. 1991, Welsh and Lind 1992). Whether this pattern reflects a response specific to the Columbia torrent salamander that is related to its biology or the geography of its habitat is unclear. However, this finding agrees with other studies from Oregon (K. Russell, *pers. comm.*) and southwestern Washington (D.

Runde, *unpubl. data*). This peculiarity clearly justifies further study because the implications for managed landscapes are significant.

Table 3.207 Density Variation among Amphibians Excluding the Columbia Torrent Salamander in Seeps in the Stillman Watershed, Washington, 2000

Subbasin	Label[1]		Species[2]: Data in Density (individuals/ac)					Overall Density
			ASTR	RAAU	DISP	PLDU	PLVE	
11040221	A		0	0	0	0	0	0
11040221	B		0	0	0	0	0	0
11040313	A		0	0	0	0	0	0
11040814	A		0	0	0	0	0	0
11040825	A		0	0	674	0	0	674
11040825	B		0	0	0	0	0	0
11041008	A		0	0	0	0	0	0
11041008	B		0	0	0	0	0	0
11041008	C		0	0	0	0	0	0
12041708	A		0	0	0	0	0	0
12041720	A		0	0	0	0	0	0
12041720	B		0	0	0	0	0	0
12041720	C		0	0	0	0	0	0
12041720	D		0	0	0	0	0	0
12041720	E		0	0	0	0	0	0
12041731	A		0	0	0	0	0	0
12041731	B		0	0	0	0	0	0
12041731	C		0	0	0	0	0	0
12042005	A		0	0	0	0	0	0
12043108	A		0	0	0	0	81	81
12043223	A		0	0	0	0	0	0
12043407	A		0	81	81	243	81	486
12043407	B		0	0	31	0	93	124
12043407	C		0	0	0	0	13	13
12043407	D		0	0	0	0	0	0
12043407	E		0	0	0	0	0	0
12043407	F		0	0	0	0	0	0
12043407	G		0	0	0	0	0	0
12043407	H		0	0	0	0	0	0
Summary Data	**Median**		**0**	**0**	**0**	**0**	**0**	**0**
	Mean ($\bar{x}$)		**0**	**3**	**27**	**8**	**10**	**48**
	SD[3] (s)		**0**	**15**	**126**	**45**	**26**	**152**
	SE[4]		**0**	**3**	**23**	**8**	**5**	**28**
	Range	**min**	**0**	**0**	**0**	**0**	**0**	**0**
		max	**0**	**81**	**674**	**243**	**93**	**674**

[1] Unit Label designations in Table 3.203.
[2] See Appendix VI for species codes.
[3] **SD** = standard deviation.
[4] **SE** = standard error of the mean.

The ease with which we found Columbia torrent salamanders may not just be a function of their abundance, it may also reflect year-round residency in headwater habitats. The few data on torrent salamander movements, all addressing other species, have implied limited vagility (Nijhuis and Kaplan 1998, Welsh and Lind 1992) or have stated that residency in headwater habitats may be typical (Nussbaum and Tait 1977, Welsh and Lind 1996, Hunter 1998). Such an interpretation strongly justifies study as movement distances have been consistently underestimated in animal studies (Barrowclough 1978, Sumner *et al.* 2001), and remain unstudied in the Columbia torrent salamander (Wilkins and Peterson 2000).

The high densities of small Columbia torrent salamander larvae occurring in initiation reaches suggests these sites may have greater importance in reproduction, and supports one of the assumptions of FFR, that initiation reaches and their headwater springs, have greater value for amphibians than other types of headwater habitats. As initiation reaches, along with seeps, are among the lowest flow habitats in the headwater stream landscape, use of such sites for reproduction would be consistent with the notion that the eggs of Columbia torrent salamanders, which are laid unattached, may have to be placed in low flow habitats where they will not be scoured. Moderately high densities of small Columbia torrent salamander larvae were also encountered in non-terminal reaches and unexpectedly low densities of small Columbia torrent salamander larvae were found in seeps. The basis of the latter pattern is unclear, and we currently lack the data to distinguish whether this is a consistent pattern or whether our observations for seeps reflect drought year phenomena. We expect that understanding flow requirements of Columbia torrent salamander oviposition sites will provide significant insights into the spatial and temporal aspects of this species' pattern of landscape use.

We have little doubt that the Columbia torrent salamander is not only the numerically dominant amphibian species in these headwater systems during late summer-early fall, but that our data underestimate its actual abundance. However, our sampling (3-4 hr on single days during late summer-early fall) may bias against detecting some amphibian species that we encountered infrequently to a greater degree than any bias that may exist in detecting the Columbia torrent salamander. These species may use seeps and streams at times of the day or during seasons that we did not sample, or occupy cryptic refuges to which we have little or no access. Our basis for this view is that some rarely encountered species are highly mobile or cryptic (northern red-legged frog: Hayes *et al.* 2001, Ritson and Hayes 2000), some seek concealed refuge sites during the dry season (all of the few Dunn's salamanders we found were in woody debris), and some have life stages that are active at times of day that we did not sample (post-metamorphic life stages of tailed frogs may be typically nocturnal). Except for inaccessible refuge sites, estimating the level of most of these biases can be addressed through sampling approaches that address different times of day, seasons, levels of effort, and focus in microhabitat.

Despite these biases, some species-level patterns are consistent with available data and a larger data set would be unlikely to be refute them. One basic pattern is that tailed frog and giant salamander larvae are associated with reaches, and are either infrequent or non-existent in seeps. Giant salamander larvae are frequent in streams with scour-developed channels (Bury *et al.* 1991) or step pools (Wilkins and Peterson 2000). Mountain stream step-pools with gradients of 15-40% (7-18°) are thought to be ideal breeding habitat for

tailed frog (Dupuis 1999). Reach habitats probably have much higher flow volumes than seeps based on our limited data at low-flow conditions. Our finding that all tailed frog and most giant salamander larvae were in 2nd-order rather than 1st-order reaches supports the idea that the larvae of these two species require higher flows than may be needed for the Columbia torrent salamander. For example, greater stream power is required for pool development (Jackson *et al.* 2001), the habitat in which larval giant salamanders are often found. As important, these data also support the idea that Columbia torrent salamanders increase in abundance in the upper-most reaches of stream systems (see discussion in Wilkins and Peterson 2000), a notion that has been proposed for other torrent salamander species (e.g., *R. cascadae*: Hunter 1998). Clearly, detailing of the flow requirements for stream-associated amphibians would have value in more precise habitat characterization for these species.

Two lungless salamanders (Dunn's and western red-backed salamanders) were found in seeps, but any assessment of lungless salamander distribution will be biased because only woody debris in seeps was dismantled during searches for amphibians. We found all 11 individuals of lungless salamanders in concealed locations of seeps, almost half of which were in LWD. As Dunn's salamander is known to occur with greater frequency along stream margins (Bury *et al.* 1991, McComb *et al.* 1993), we anticipate that both species of lungless salamander would have been found more frequently had woody debris along reaches been dismantled.

Too few northern red-legged frogs or post-metamorphic giant salamanders were found to suggest patterns. However, that the three individuals of these two taxa found were found in seeps > 100 ft from stream channels may be significant.

We found few patterns in species richness; two merit mention. Lower species richness associated with 1st-order system is consistent with the previously discussed notion that as Columbia torrent salamander dominate the uppermost reaches, species richness may not be expected to increase in a downstream direction until flow characteristics (i.e., greater flow) allow either giant salamanders or tailed frogs to occupy reaches. More data will be needed to determine whether uppermost reaches of 1st-order systems are consistently species poor.

The second pattern was the significantly higher species richness in seeps associated with older- versus younger-aged stands. We should also note that data on amphibian densities tended to fit this pattern. Seeps may require more time to recover from disturbance (sedimentation) than reaches because relatively low flow rates may take longer to displace fine sediments than for the presumably higher flow rates associated with reaches. If true, this pattern supports the notion of needing buffers as proposed in the FFR.

One amphibian density pattern that deserves mention was high density of adult torrent salamanders found in the waterfall. Waterfalls, and especially, their splash zones, have long been a focus of amphibian searches (e.g., Slater 1933, 1939) and some (Nussbaum *et al.* 1983) have suggested that they are hotspots of amphibian abundance. The finding of only larger torrent salamanders in the waterfall suggests that waterfalls may play a life stage-specific role in torrent salamander life history. Systematic study of this distinctive landscape feature would increase our understanding of the value and role of waterfalls to amphibians.

The patterns we observed for densities of all amphibian species combined (i.e., Columbia torrent salamander, Dunn's salamander, giant salamanders, northern red-legged frog, tailed frog, and western red-backed salamander) were less clear when Columbia torrent salamander densities were considered individually. We believe that the Columbia torrent salamander data is more reliable since we have little data for other species. Only more data on non-torrent salamander amphibians can satisfactorily resolve this question.

In conclusion, amphibians appear to use different types of reaches and seeps differently, but definitive answers to the questions of value must be deferred until more data can confirm apparent patterns. Nonetheless, some differences between reaches and seeps may be related to reach hydroperiod (i.e., greater intermittency may limit numbers of amphibians or number of amphibian species). Certain life stages of some species, i.e., larval tailed frogs and giant salamanders, may be excluded from most seeps. Higher densities of small torrent salamanders in initiation reaches suggest that these habitats may be used for reproduction. Increasing the diel, seasonal, and refuge microhabitat breadth of sampling will be required to understand occupancy patterns for species or life stages having diel, seasonal, or refuge constraints.

4. Research Question 3 – Are some seeps more valuable for some species of amphibians than others?

Research Question 3 is similar to the previous research question except that it focuses on variation among seeps. Here, we asked:

a) Are certain seeps either richer in amphibian species or have higher densities of amphibians than other seeps in non-fish bearing systems?

b) What features make certain seeps more important to single amphibian species or the amphibian community?

4.1 Method

We used methods to examine these questions similar to those for the previous research question. As before, we present adjusted species richness data for the same reasons.

To gain a perspective on patterns of seep use that might reflect aspects of seep condition, we analyzed the following microhabitat data for Columbia torrent salamander (the only species for which we had at least 10 observations):

1) Position: We scored position of amphibians encountered as concealed or not. We judged amphibians concealed if more than half their body was under cover. We used position to help characterize the microhabitat utilization patterns.
2) Microhabitat features: We scored or measured variables to characterize the microhabitat of each amphibian found. These included:
   a) *Microenvironment*: We scored an animal's microenvironment as in water or not. An amphibian was judged to be in water if at least half its body contacted pooled water.
   b) *Substrate*: Scoring addressed the substrate on which an amphibian was positioned. Substrate categories we used were the same as those used to characterize reach and seep descriptions (see Section 2.1).
   c) *Substrate moisture*: If an amphibian was not in water (see 2a above), we scored the hydric conditions of its substrate as dry, moist, or saturated.
   d) *Cover*: If an amphibian was concealed (see Position above), we scored the cover object(s) into same substrate categories as 2b above except for bedrock.

We also attempted to address interstitial spacing, but complications with measurement of this variable made it unsuitable for analysis.

We first treated species composition, species richness, and densities of individuals of all amphibian species combined as response variables. We subsequently addressed densities of individual species.

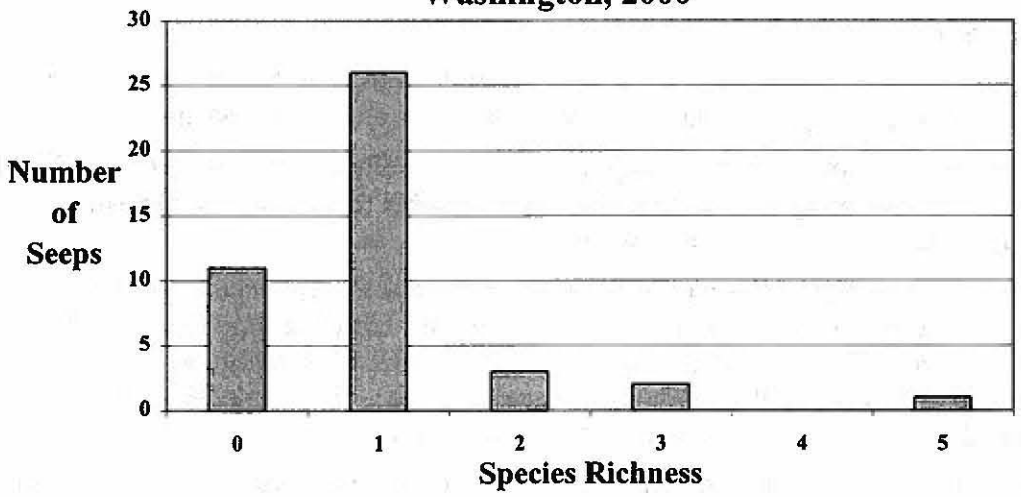
Analyses: Analyses performed were similar to those in Research Question 2. However, we also build a multivariate regression model addressing Columbia torrent salamander density using the most promising variables from univariate analyses.

4.2 Results

Amphibian Species Composition: We detected no amphibians in 9 (31%) of 29 seeps; the other 20 seeps had at least one amphibian species present, but we found > 1 amphibian species in only 4 (14%) of 29 seeps (range: 2-5 species; Figure 4.201, Appendix VI).

We also found no significant association between amphibian presence in seeps units and each of gradients > 20%, location ≤ 50 ft (15 m) from a Type N channel, location ≤ 100 ft (30 m) from a Type N channel, or an overland connection to a Type N channel. Of these, location ≤ 50 ft (15 m) most closely approached significance (Fisher's Exact test: $p = 0.1375$).

Figure 4.201 - Frequency Distribution of Species Richness among Sampled Seeps in the Stillman Watershed, Washington, 2000



We found no significant differences in distribution among amphibian species among geocodes (see Appendix V; Chi-square test: $\chi^2 < 1.97$, df = 2, $p > 0.3729$ for all species comparisons).

We found the only northern red-legged frog, giant salamanders, and Dunn's salamanders in 3 seeps associated with 2nd-order segments. Northern red-legged frog and Dunn's salamanders were recorded from seeps > 100 ft (30 m) from the channel, with gradients > 20%, lacking an overland flow connection to the channel, and having percolating flow. However, these two species were found in only one seep, which was the same for both.

We found no significant differences in the median sampling date among the 9 seeps at which no amphibians were found, and the median sampling date for the 20 seeps at which at least 1 amphibian species was found (Mann-Whitney U test: $U = 77$, $U' = 104$, $z = -0.639$, $p = 0.5230$).

Amphibian Species Richness: We found no relationship between adjusted species richness and distance to the stream channel (Spearman Rank correlation: $\rho = 0.187$, $z = 0.991$, $p = 0.3215$). Adjusted species richness was higher for seeps > 50 ft (~15 m) from the channel (n = 6) than for seeps ≤ 50 ft (~15 m) from the channel (n = 23; Table 4.201), but the difference was not significant (Mann-Whitney test: $U = 39$, $U' = 99$, $z = -1.616$, $p = 0.1061$). Similarly, adjusted species richness was higher for seeps > 100 ft (30 m) from the channel (n = 4) than for seeps ≤ 100 ft (30 m) from the channel (n = 25; Table 4.201), but the difference was not significant (Mann-Whitney test: $U = 26$, $U' = 74$, $z = -1.519$, $p = 0.1288$).

We found no relationship between adjusted species richness and gradient expressed as a continuous variable (Spearman Rank correlation: $\rho = 0.067$, z = 0.356, $p = 0.7218$). Yet, seeps with gradients > 20% (n = 24) had an adjusted species richness averaging over 4 times as high as seeps with gradients ≤ 20% (n = 5; Table 4.201), a significant difference (Mann-Whitney test: $U = 25$, $U' = 95$, z = -2.022, $p = 0.0432$).

Table 4.201 – Variation in Adjusted Species Richness among Seeps in the Stillman Watershed, Washington, 2000

Variable	Status	Descriptive Statistics[1]					
		Median	Mean	SD (s)	SE	range	
						min	max
Distance to Channel	≤50 feet	0.8	1.0	0.9	0.2	0.0	2.6
	> 50 feet	1.2	2.3	2.0	0.8	0.5	5.5
	≤100 feet	1.0	1.0	0.9	0.2	0.0	2.6
	> 100 feet	2.5	2.8	2.4	1.2	0.5	5.5
Gradient	≤ 20 %	0.2	0.3	0.4	0.2	0.0	1.0
	> 20 %	1.2	1.4	1.3	0.3	0.0	5.5
Overland Flow Connection	Yes	1.0	1.2	1.1	0.3	0.0	4.0
	No	1.1	1.4	1.7	0.6	0.2	5.5
Percolating Area	Yes	1.3	1.5	1.5	0.4	0.0	5.5
	No	0.8	1.0	1.0	0.3	0.0	4.0
Seep Type	Headwall	1.0	0.9	0.7	0.4	0.1	1.6
	Side-slope	1.1	1.3	1.3	0.3	0.0	5.5

[1] Standard deviation (**SD**), and standard error of the mean (**SE**).

Adjusted species richness for seeps that were connected by overland flow (n = 9) was similar to adjusted species richness for seeps not connected by flow (n = 20; Table 4.201; Mann-Whitney test: $U = 83$, $U' = 98$, z = -0.354, $p = 0.7235$).

Percolating seeps (n = 14) had a slightly higher adjusted species richness than non-percolating seeps (n = 15; Table 4.201), but the difference was not significant; Mann-Whitney test: $U = 90$, $U' = 121$, z = -0.677, $p = 0.4985$).

We found no significant difference in adjusted species richness between headwall (n = 3) and side-slope (n = 23) seeps (Table 4.201; Mann-Whitney test: $U = 36$, $U' = 42$, z = -0.215, $p = 0.8298$).

We found no significant differences in amphibian species richness among 12 substrate categories analyzed (Table 4.202), but differences were greatest for two that approached significance. Species richness tended to be higher with sand present and SWD absent (Mann- Whitney test: sand: $U = 8$, $U' = 44$, z = -1.607, $p = 0.1081$; SWD: $U = 29$, $U' = 104$, z = -2.101, $p = 0.0356$)[°].

We found an inverse relationship between adjusted species richness and sample date (Spearman Rank correlation: $\rho = -0.315$, z = -1.667, $p = 0.0955$), which marginally failed significance.

[°] The SWD analysis failed significance because α was conservatively adjusted for 12 tests.

Table 4.202 – Variation in Adjusted Species Richness with Substrate Type in the Stillman Watershed, Washington, 2000

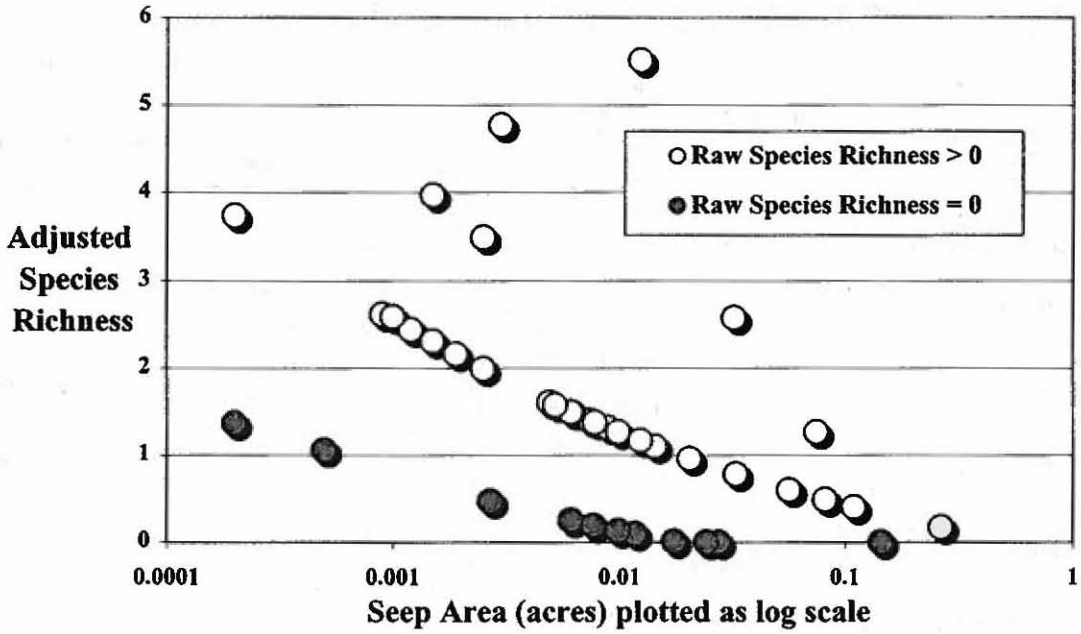
Substrate Category	Status	Descriptive Statistics[1]					
		Median	Mean	SD (s)	SE	range	
						min	max
Bedrock (A)	Present	1.3	1.3	---	---	1.3	1.3
	Not Present	1.0	1.2	1.3	0.3	0.0	5.5
Boulder (B)	Present	0.5	0.6	0.6	0.3	0.0	1.2
	Not Present	1.1	1.3	1.4	0.3	0.0	5.5
Cobble (C)	Present	1.1	1.4	1.4	0.5	0.0	4.0
	Not Present	1.0	1.2	1.3	0.3	0.0	5.5
Gravel (D)	Present	1.3	1.4	1.2	0.4	0.0	4.0
	Not Present	0.6	1.1	1.4	0.3	0.0	5.5
Sand (E)	Present	2.1	2.1	0.7	0.5	1.6	2.6
	Not Present	0.9	1.2	1.3	0.3	0.0	5.5
Mud (F)	Present	0.9	1.2	1.3	0.3	0.0	5.5
	Not Present	1.1	1.3	1.4	0.6	0.0	4.0
LWD	Present	0.9	1.2	1.4	0.3	0.0	5.5
	Not Present	1.3	1.3	0.9	0.4	0.0	2.6
SWD	Present	0.7	1.0	1.2	0.3	0.0	5.5
	Not Present	2.3	2.1	1.3	0.5	0.2	4.0
Leaf Litter	Present	0.6	1.2	1.5	0.3	0.0	5.5
	Not Present	1.2	1.2	0.7	0.3	0.2	2.6
Live Vegetation	Present	0.8	0.8	0.8	0.5	0.2	1.3
	Not Present	1.0	1.3	1.3	0.3	0.0	5.5
Coarse (A-D)	Present	1.1	1.2	1.1	0.3	0.0	4.0
	Not Present	0.8	1.2	1.5	0.4	0.0	5.5
Fine (E-F)	Present	0.9	1.2	1.3	0.3	0.0	5.5
	Not Present	1.1	1.3	1.4	0.6	0.0	4.0

[1] Standard deviation (SD), and standard error of the mean (SE); dashes (---) mean no value.

Adjusted species richness was significantly inversely correlated with seep area (Spearman Rank correlation: $\rho = -0.531$, $z = -2.811$, $p = 0.0049$) and the relationship between amphibian species richness and seep area improved when we excluded seeps in which no animals were found (Spearman Rank correlation: $\rho = -0.803$, $z = -3.501$, $p = 0.0005$; Figure 4.202). Adjusted species richness was also inversely correlated with seep area in the percolating seep subset (n = 14), but the relationship marginally failed significance (Spearman Rank correlation: $\rho = -0.519$, $z = -1.870$, $p = 0.0614$).

Analysis that *a priori* defined seeps with high adjusted amphibian species richness as being ≥ 2 (n = 5) to those with low adjusted amphibian species richness as being < 2 (n = 24) showed 3 variables (amphibian density, Columbia torrent salamander density,

Figure 4.202 - Relationship between Adjusted Species Richness and Seep Area based on Zero and Non-Zero Raw Species Richness Categories in the Stillman Watershed, Washington, 2000



and stand age) to be significantly associated with adjusted amphibian species richness (Table 4.203). Significant patterns were identified between high adjusted amphibian species richness values and high amphibian or Columbia torrent salamander densities, or older stand ages (Table 4.203).

Amphibian Densities: We found no relationship between amphibian density and distance to the stream channel (Spearman Rank correlation: $\rho = 0.082$, z = 0.431, $p = 0.6662$). Amphibian density in seeps ≤ 50 feet from the channel (n = 23) averaged higher than that in seeps > 50 feet from the channel (n = 6; Table 4.204), a non-significant difference (Mann-Whitney test: $U = 50$, $U' = 88$, z = -1.04, $p = 0.2991$). Similarly, amphibian density in seeps ≤ 100 feet from the channel (n = 25) averaged higher than that in seeps > 100 feet from the channel (n = 4; Table 4.204), but the difference was not significant (Mann-Whitney test: $U = 35$, $U' = 65$, z = -0.963, $p = 0.3355$).

We found no relationship between amphibian density and gradient expressed as a continuous variable (Spearman Rank correlation: $\rho = 0.118$, z = 0.623, $p = 0.5331$). However, seeps with gradients > 20% (n = 24) had amphibian densities averaging over 10 times as high as seeps with gradients ≤ 20% (n = 5; Table 4.204), but variability was high and the difference marginally failed significance (Mann-Whitney test: $U = 28$, $U' = 92$, z = -1.880, $p = 0.0607$).

Amphibian density in seeps that were connected by overland flow (n = 20) was over 3 times as high as amphibian density for seeps not connected by flow (n = 9; Table 4.204), but variability was high and the difference was not significant (Mann-Whitney test: $U = 77$, $U' = 103$, z = -0.622, $p = 0.5339$).

Table 4.203 – Variation among Variables between Seeps with High and Low Adjusted Amphibian Species Richness in the Stillman Watershed, Washington, 2000

Variable	Adjusted Amphibian Species Richness Category	Descriptive Statistics[1]						Mann-Whitney test	
		Median	Mean	SD(s)	SE	range min	range max	z	p[2]
Amphibian Density (#/ac)	High	1349	1536	1047	468	567	3035	-3.106	**0.0019**
	Low	15	206	378	77	0	1349		
Columbia Torrent Salamander Density	High	674	1279	1243	556	81	3035	-2.755	**0.0059**
	Low	6	201	380	78	0	1349		
Distance to Channel (ft)	High	3.0	56.2	76.7	34.2	0.0	157.0	-0.515	0.6069
	Low	5.0	23.9	38.8	7.9	0.0	131.0		
Gradient (%)	High	44.2	46.5	17.9	8.0	22.3	71.4	-0.029	0.9770
	Low	48.3	46.9	26.0	5.3	2.7	120.0		
Seep Size (ac)[3]	High	0.001	0.010	0.014	0.006	0.001	0.032	-1.640	0.0998
	Low	0.010	0.040	0.060	0.010	0.000	0.265		
Stand Age (yr)	High	55.0	52.4	3.6	1.6	48.0	55.0	-2.130	0.0324
	Low	44.0	39.7	13.9	2.8	18.0	55.0		
Stream Order	High	2.0	1.6	0.5	0.2	1	2	-1.180	0.2373
	Low	1.0	1.3	0.6	0.1	1	3		

[1] Standard deviation (SD), and standard error of the mean (SE).
[2] The rejection criterion α was conservatively adjusted for the number of tests ($n = 7$) to $\alpha = 0.0073$.
[3] The minimum seep size in the low richness category was 0.00049 acres.

Table 4.204 – Variation in Amphibian Density among Seeps in the Stillman Watershed, Washington, 2000

Variable	Status	Descriptive Statistics[1]					
		Median	Mean	SD(s)	SE	range min	range max
Distance to Channel	≤50 feet	18	451	787	164	0	3035
	> 50 feet	127	375	517	211	12	1349
	≤100 feet	30	425	759	152	0	3035
	> 100 feet	318	499	619	309	12	1349
Gradient	≤ 20 %	0	31	64	29	0	146
	> 20 %	127	519	780	159	0	3035
Overland Flow Connection	Yes	88	565	845	189	0	3035
	No	70	146	204	68	0	567
Percolating Area	Yes	188	612	920	246	0	3035
	No	18	270	474	122	0	1349
Seep Type	Headwall	146	241	301	174	0	578
	Side-slope	50	458	767	150	0	3035

[1] Standard deviation (SD), and standard error of the mean (SE).

Amphibian density in seeps with percolating flow (n = 14) averaged over twice the amphibian density in seeps lacking percolating flow (n = 15; Table 4.204); but variation was high and the difference was not significant (Mann-Whitney test: $U = 90$, $U' = 120$, $z = -0.665$, $p = 0.5063$).

We found no significant difference in amphibian density between headwall (n = 3) and side-slope (n = 23) seeps (Mann-Whitney test: $U = 38$, $U' = 40$, $z = -0.073$, $p = 0.9420$).

We found no significant differences in amphibian density among 12 substrate categories analyzed (Table 4.205), but similar to species richness, LWD, sand, and SWD were the analyses that most closely approached significance. Amphibian densities were higher where sand was present, and LWD and SWD were absent (Mann-Whitney test: LWD: $U = 41$, $U' = 91$, $z = -1.423$, $p = 0.1546$; sand: $U = 7$, $U' = 45$, $z = -1.723$, $p = 0.0848$; SWD: $U = 43$, $U' = 89$, $z = -1.309$, $p = 0.1904$).

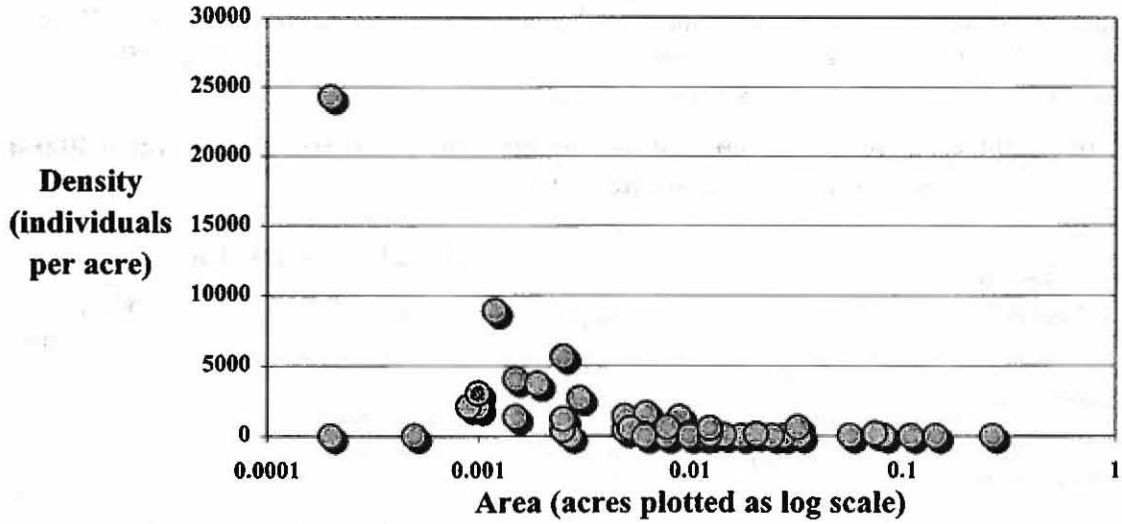
Table 4.205 – Variation in Amphibian Density with Substrate Type in the Stillman Watershed, Washington, 2000

Substrate Category	Status	Descriptive Statistics					
		Median	Mean	SD(s)	SE	range	
						min	max
Bedrock (A)	Present	1349	1349	0	0	1349	1349
	Not Present	30	410	736	142	0	3035
Boulder (B)	Present	12	31	44	25	0	81
	Not Present	70	493	774	155	0	3035
Cobble (C)	Present	18	642	1166	441	0	3035
	Not Present	70	377	567	124	0	2108
Gravel (D)	Present	578	696	931	281	0	3035
	Not Present	18	280	566	137	0	2108
Sand (E)	Present	1343	1343	1082	765	578	2108
	Not Present	24	374	694	136	0	3035
Mud (F)	Present	50	491	795	170	0	3035
	Not Present	47	269	533	218	0	1349
LWD	Present	21	359	716	153	0	3035
	Not Present	524	754	828	338	0	2108
SWD	Present	24	251	404	86	0	1349
	Not Present	877	1149	1242	507	0	3035
Leaf Litter	Present	18	341	571	125	0	2108
	Not Present	146	751	1120	423	0	3035
Live Vegetation	Present	674	674	954	674	0	1349
	Not Present	50	426	746	146	0	3035
Coarse (A-D)	Present	70	518	844	218	0	3035
	Not Present	30	358	632	175	0	2108
Fine (E-F)	Present	50	491	795	170	0	3035
	Not Present	47	269	533	218	0	1349

[1] Standard deviation (SD), and standard error of the mean (SE).

Amphibian density was significantly inversely correlated with seep area (Spearman Rank correlation: $\rho = -0.405$, $z = -2.141$, $p = 0.0322$, Figure 4.203); the relationship improved when we excluded seeps in which no animals were found (Spearman Rank correlation: $\rho = -0.880$, $z = -3.837$, $p = 0.0001$). Amphibian density was not significantly correlated with the area of percolation in that subset of seeps (n = 14; Spearman Rank correlation: $\rho = -0.228$, $z = -0.820$, $p = 0.4120$).

Figure 4.203 - Relationship between Amphibian Density and Seep Area in the Stillman Watershed, Washington, 2000



Amphibian density was significantly correlated with adjusted species richness (Spearman Rank correlation: $\rho = 0.917$, $z = 4.852$, $p < 0.0001$); the relationship remained basically unchanged when seeps in which no animals were found were excluded (Spearman Rank correlation: $\rho = 0.883$, $z = 3.847$, $p = 0.0001$). Amphibian density was also significantly correlated with adjusted species richness in the percolating seep subset (n = 14; Spearman Rank correlation: $\rho = 0.901$, $z = 3.248$, $p = 0.0012$).

Analysis *a priori* defining high density seeps as having ≥ 1,000 amphibians/acre (n = 5) compared to those with low density as having < 1,000 amphibians/acre (n = 24) showed 2 variables (seep size and adjusted species richness) to be significantly associated with amphibian density in seeps (Table 4.206). High amphibian densities were associated high adjusted amphibian species richness and small seep size.

We found no significant inverse correlation between amphibian density and sample date (Spearman Rank correlation: $\rho = -0.220$, $z = -1.165$, $p = 0.2441$).

Individual Species Data: *Columbia torrent salamander*: Columbia torrent salamander was the most frequently detected and widespread amphibian among surveyed seeps. We found 1-16 individuals in the 17 seeps (59% of 29 seeps) in which it was observed, and most (82%; n = 70) of the 85 amphibians found associated with seeps were Columbia torrent salamanders.

We found no relationship between Columbia torrent salamander density and distance to the stream channel (Spearman Rank correlation: $\rho = -0.037$, $z = 0.198$, $p = 0.8433$). Columbia torrent salamander density in seeps ≤ 50 feet from the channel (n = 23)

averaged higher than that in seeps > 50 feet from the channel (n = 6; Table 4.207), but variation was high and the difference not significant (Mann-Whitney test: $U = 69$, $U' = 69$, $z = 0$, $p > 0.9999$). Similarly, Columbia torrent salamander density in seeps ≤ 100 feet from the channel (n = 25) averaged higher than that in seeps > 100 feet from the channel (n = 4; Table 4.207), but the difference was not significant (Mann-Whitney test: $U = 46$, $U' = 55$, $z = -0.295$, $p = 0.7678$).

Table 4.206 – Variation among Variables between Seeps with High and Low Amphibian Densities in the Stillman Watershed, Washington, 2000

Variable	Amphibian Density Category	Descriptive Statistics[1]						Mann-Whitney test	
		Median	Mean	SD(s)	SE	range min	range max	z	p
Distance to Channel (ft)	High	7.0	36.6	67.5	30.2	0.0	157.0	-0.666	0.5055
	Low	1.5	28.0	43.6	8.9	0.0	131.0		
Gradient (%)	High	46.7	61.1	33.2	14.9	41.3	120.0	-0.606	0.5443
	Low	48.3	43.8	22.1	4.5	2.7	76.2		
Seep Size (ac)	High	0.001	0.003	0.003	0.002	0.001	0.009	-2.859	**0.0043**
	Low	0.016	0.041	0.060	0.012	0.001	0.265		
Stand Age (yr)	High	48.0	45.2	8.1	3.6	35.0	55.0	-0.176	0.8604
	Low	46.0	41.2	14.5	3.0	18.0	55.0		
Adjusted Species Richness	High	2.6	2.5	1.0	0.4	1.3	4.0	-2.860	**0.0042**
	Low	0.7	1.0	1.2	0.2	0.0	5.5		
Stream Order	High	1.0	1.6	0.9	0.4	1	3	-0.556	0.5781
	Low	1.0	1.3	0.5	0.1	1	2		

[1] Standard deviation (SD), and standard error of the mean (SE).
[2] Significant probabilities are emboldened; the rejection criterion α was conservatively adjusted for the number of tests (n = 6) to α = 0.0085.

Torrent salamander density averaged over 10 times as high in seeps with gradients > 20% than in those with gradients ≤ 20% (Table 4.207; Figure 4.204), but variability was high and the difference not significant (Mann-Whitney U test: $U = 36$, $U' = 85$, $z = -1.467$, $p = 0.1423$; Figure 4.204).

Torrent salamander density averaged over 5 times as high in seeps with an overland flow connection to the channel (n = 20) than those without a connection (n = 9; Table 4.207), but variability was high and the difference not significant (Mann-Whitney test: $U = 61$, $U' = 120$, $z = -1.442$, $p = 0.1492$).

We found higher torrent salamander densities in percolating seeps (n = 14) versus non-percolating seeps (n = 15; Table 4.207), but the difference was not significant (Mann-Whitney test: $U = 83$, $U' = 128$, $z = -1.019$, $p = 0.3084$).

We found no significant difference in Columbia torrent salamander density between headwall seeps (n = 3) and side-slope seeps (n = 26; Table 4.207; Mann-Whitney test: $U = 37$, $U' = 42$, $z = -0.186$, $p = 0.8527$).

We found no significant differences in Columbia torrent salamander density as a function of the 12 substrate categories examined (Table 4.208). However, analyses using boulder,

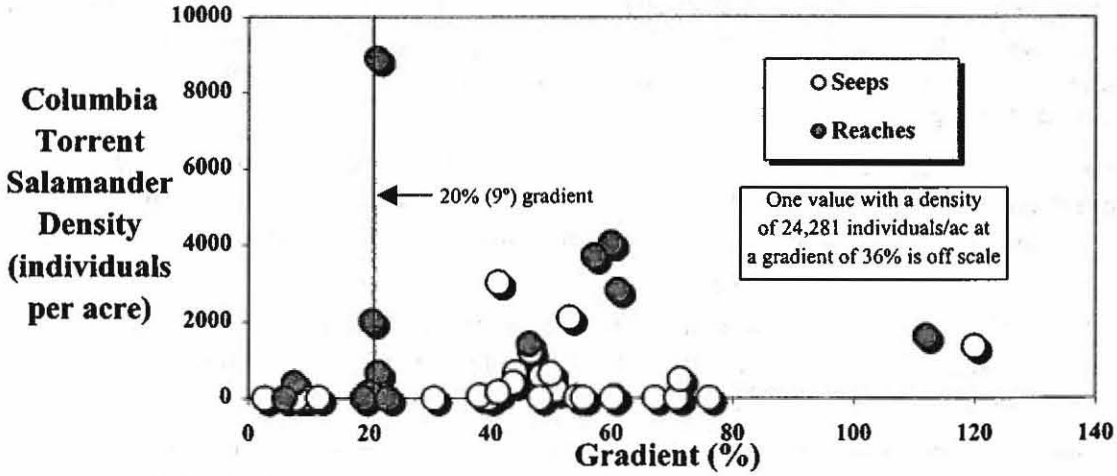
gravel, sand, SWD, and LWD approached significance (Mann-Whitney test: boulder: $U = 14$, $U' = 62$, $z = -1.857$, $p = 0.0633$; gravel: $U = 61$, $U' = 127$, $z = -1.617$, $p = 0.1059$; sand: $U = 6$, $U' = 46$, $z = -1.858$, $p = 0.0631$; SWD: $U = 41$, $U' = 91$, $z = -1.458$, $p = 0.1449$; LWD: $U = 37$, $U' = 96$, $z = -1.720$, $p = 0.0854$).

Table 4.207 – Variation in Columbia Torrent Salamander Density among Seeps in the Stillman Watershed, Washington, 2000

Variable	Status	Descriptive Statistics[1]					
		Median	Mean	SD (s)	SE	range	
						min	max
Distance to Channel	≤50 feet	18	445	787	164	0	3035
	> 50 feet	75	164	257	105	0	674
	≤100 feet	18	416	760	152	0	3035
	> 100 feet	75	206	314	157	0	674
Gradient	≤ 20 %	0	31	64	29	0	146
	> 20 %	75	461	767	157	0	3035
Overland Flow Connection	Yes	88	525	825	185	0	3035
	No	0	80	134	45	0	405
Percolating Area	Yes	121	567	931	249	0	3035
	No	11	218	393	101	0	1349
Seep Type	Headwall	146	241	301	174	0	578
	Side-slope	24	404	750	147	0	3035

[1] Standard deviation (SD), and standard error of the mean (SE).

Figure 4.204 - Relationship Between Gradient and Density of Columbia Torrent Salamanders in Headwater Habitats in the Stillman Watershed, Washington, 2000



Columbia torrent salamander density was also significantly positively correlated with adjusted amphibian species richness (Spearman Rank correlation: $\rho = 0.847$, $z = 4.483$, $p < 0.0001$; Figure 4.205), but significantly negatively correlated with seep area

(Spearman Rank correlation: $\rho = -0.450$, $z = -2.383$, $p = 0.0172$). Excluding seeps for which no torrent salamanders were found, Columbia torrent salamander density remained significantly positively correlated with adjusted amphibian species richness (Spearman Rank correlation: $\rho = 0.690$, $z = 2.761$, $p = 0.0058$).

Table 4.208 – Variation in Columbia Torrent Salamander Density with Substrate Type in the Stillman Watershed, Washington, 2000

Substrate Category	Status	Descriptive Statistics[1]					
		Median	Mean	SD (s)	SE	range	
						min	max
Bedrock (A)	Present	1349	1349	---	---	1349	1349
	Not Present	18	358	716	138	0	3035
Boulder (B)	Present	0	0	0	0	0	0
	Not Present	70	441	757	151	0	3035
Cobble (C)	Present	0	532	1132	428	0	3035
	Not Present	70	347	567	124	0	2108
Gravel (D)	Present	496	623	906	273	0	3035
	Not Present	0	245	566	137	0	2108
Sand (E)	Present	1343	1343	1082	765	578	2108
	Not Present	14	320	669	131	0	3035
Mud (F)	Present	50	463	800	170	0	3035
	Not Present	0	139	270	110	0	674
LWD	Present	6	295	685	146	0	3035
	Not Present	524	754	828	338	0	2108
SWD	Present	14	218	396	85	0	1349
	Not Present	540	1037	1251	511	0	3035
Leaf Litter	Present	18	278	526	115	0	2108
	Not Present	146	739	1129	427	0	3035
Live Vegetation	Present	674	674	954	674	0	1349
	Not Present	24	372	727	143	0	3035
Coarse (A-D)	Present	18	458	817	211	0	3035
	Not Present	30	319	633	176	0	2108
Fine (E-F)	Present	50	463	800	170	0	3035
	Not Present	0	139	270	110	0	674

[1] Standard deviation (SD), and standard error of the mean (SE).

Similar to the analysis addressing overall amphibian densities, analyses comparing seeps *a priori* defined as having high torrent salamanders densities (> 1,000 individuals/ac; n = 4) to those with low Columbia torrent salamanders densities (≤ 1,000 individuals/ac; n = 25) showed 2 variables (seep size and adjusted amphibian species richness) to be associated with torrent salamander density (Table 4.209). Similar to the overall analysis, high Columbia torrent salamander densities were associated with high amphibian adjusted species richness and small seep sizes (Table 4.209).

We found no significant inverse correlation between Columbia torrent density and

sample date (Spearman Rank correlation: $\rho = -0.219$, $z = 1.157$, $p = 0.2473$).

Most (84%; 59 of 70) Columbia torrent salamanders in seeps were encountered beneath cover. In descending order (percentage; occurrences [n =] in parens), cover consisted of woody debris 53% (31), leaf litter 22% (13), cobble 14% (8), gravel 10% (6), and fines 1% (1). Nearly all (99%: n = 69) of the Columbia torrent salamanders found in seeps were either in contact with a visible surface water source (n = 22) or a terrestrial but water-rich surface (n = 47); one individual was found on a dry terrestrial substrate. In descending order, the substrates on which we found Columbia torrent salamanders were mud 70% (49), gravel 14% (10), woody debris 7% (5), sand 4% (3), leaf litter 3% (2), and cobble 2% (1). Significant differences existed in the frequency of materials used by Columbia torrent salamanders as substrate versus cover (Table 3.210; Chi-square test: $\chi^2 = 75.892$, df = 2, $p < 0.0001$).

Table 4.209 – Variation among Variables between Seeps with High and Low Columbia Torrent Salamander Densities in the Stillman Watershed, Washington, 2000

Variable	RHKE Density Category	Descriptive Statistics[1]						Mann-Whitney test	
		Median	Mean	SD(s)	SE	range min	range max	z	p
Distance to Channel (ft)	High	5.0	6.5	7.0	3.5	0.0	16.0	-0.199	0.8423
	Low	3.0	33.2	50.0	10.0	0.0	157.0		
Gradient (%)	High	50.0	65.3	36.8	18.4	41.3	120.0	-0.791	0.4291
	Low	48.2	43.8	21.6	4.3	2.7	76.2		
Seep Size (ac)	High	0.002	0.003	0.004	0.002	0.001	0.009	-2.440	0.0149
	Low	0.017	0.046	0.067	0.017	0.001	0.265		
Stand Age (yr)	High	43.5	44.3	9.0	4.5	35.0	55.0	-0.064	0.9488
	Low	48.0	41.5	14.3	2.9	18.0	55.0		
Adjusted Species Richness	High	2.3	2.1	0.6	0.3	1.3	2.6	-2.310	0.0209
	Low	0.8	1.1	1.3	0.3	0.0	5.5		
Stream Order	High	1.0	1.5	1.0	0.5	1	3	-0.076	0.9393
	Low	1.0	1.4	0.5	0.1	1	2		

[1] Standard deviation (SD), and standard error of the mean (SE).
[2] Significant probabilities are emboldened; the rejection criterion α was conservatively adjusted for the number of tests (n = 6) to $\alpha = 0.0085$.

Other amphibian species: Western red-backed salamander (n = 8) was the only species besides the Columbia torrent salamander found in > 2 seeps. We found 1 western red-backed salamander in each of 5 seeps and 3 others in 1 seep (see Appendix VII). We recorded western red-backed salamanders only in concealed, terrestrial locations in side-slope seeps having a gradient > 20%. Two were removed from woody debris, and 5 of the remaining six were beneath woody debris (n = 2) or leaf litter (n = 3); one individual was beneath a boulder. In descending frequency (percentage; occurrences [n =] in parens), western red-backed salamanders were found on mud 38% (3), 25% (2) for each of gravel and woody debris 25%, and once (12%) for sand. As with the Columbia torrent salamander, significant differences existed in the frequency of materials used by

western red-backed salamanders as substrate versus cover (Table 3.211: Chi-square test: $\chi^2 = 7.111$, df = 2, $p = 0.0286$).

Figure 4.205 - Relationship between Adjusted Species Richness and Columbia Torrent Salamander Density in the Stillman Watershed, Washington, 2000

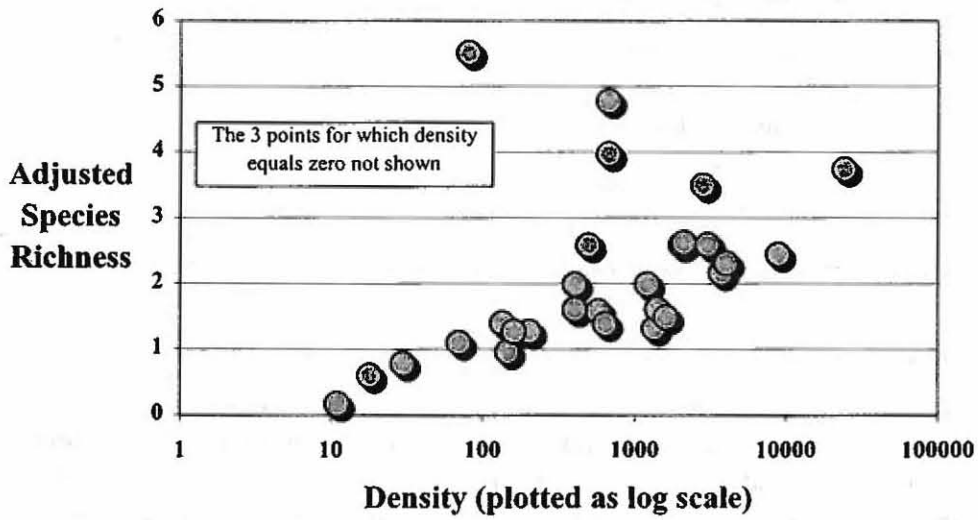


Table 4.210 – Variation in Columbia Torrent Salamander Cover and Substrate in Seeps in the Stillman Watershed, Washington, 2000

Material Classes		Included Substrate/Cover Types	Cover	Substrate
			n = 59	n = 70
Inorganic	Coarse	gravel or coarser	1	11
	Fine[1]	sand or finer	14	53
Organic		leaf litter and woody debris	44	7

[1] We recognize that fine substrates can include a variable organic fraction; in this analysis, we scored fines as inorganic.

The only northern red-legged frog encountered, an adult female, was observed exposed on the wet mud of the only seep with black cottonwood. The only 3 Dunn's salamanders and one of the 2 adult coastal giant salamanders came from the same seep as the northern red-legged frog; the Dunn's salamanders were within woody debris and the adult coastal giant salamander was concealed beneath woody debris. Notably, the seep in which the Dunn's salamander, the northern red-legged frog, and one coastal giant salamander was found was a side-slope seep that lacked an overland flow connection to the Type N channel and was also located > 100 ft from it. Another adult coastal giant salamander was found under woody debris in a different seep. A third and last giant salamander found was a small (32 mm SVL) larva in a small (2 ft^2) pooled area within the percolating area of a third

seep; this animal was too young to identify to species.

Table 4.211 – Variation in Western Red-backed Salamander Cover and Substrate in Seeps in the Stillman Watershed, Washington, 2000

Material Classes		Included Substrate/Cover Types	Cover	Substrate
			n = 8	
Inorganic	Coarse	gravel or coarser	1	2
	Fine[1]	sand or finer	0	4
Organic		leaf litter and woody debris	7	2

[1] We recognize that fine substrates can include a variable organic fraction; in this analysis, we scored fines as inorganic.

4.3 Discussion

The most important patterns from these data were the significant inverse relationships between seep area (or area of percolating flow) and each of amphibian density, Columbia torrent salamander density, and area-adjusted species richness. Increases in each metric could be interpreted as an increase in seep habitat quality, so that hypothesis must be at least considered a possibility. This notion is counterintuitive, as its corollary is that smaller, less complex habitat patches will have greater habitat quality than larger, more complex ones. One alternative hypothesis is that seeps shrink in size during the dry season, and this effect is more pronounced in smaller seeps, i.e., they shrink to a smaller proportion of their original size than larger seeps. A concentration of amphibians with a seasonal shrinkage in seep size would be more marked in smaller seeps. As amphibians like Columbia torrent salamander seem tied to certain minimum moisture conditions (see microhabitat data in Section 4.2 and discussion in Section 1.2), increased density as a consequence of reduced seep area is easy to understand. However, why more species occur in smaller seeps is puzzling, as the species-area theory is clearly established to be a positively increasing function (e.g., Brown 1971, Kodric-Brown 1993). We cannot explain the latter pattern; indeed, it may be spurious as we obtained raw amphibian species richness values of > 1 for only 4 seeps and a seasonal sampling bias likely existed (see discussion below). We currently lack the data to examine our density-influencing seasonal shrinking hypothesis, but this idea could be easily tested with at least one repeat survey of the same seeps. We also note that the seep shrinkage phenomenon could either be a result of the dry 2000 season or a typical seasonal pattern. Repeating surveys of seeps in different water years (dry versus wet) will be needed to distinguish alternatives.

Another important result was the significant positive relationships we observed between adjusted species richness and density data (amphibian or Columbia torrent salamander). If more data support this relationship, it could mean that assessment of Columbia torrent salamander density could be a tool for identifying biodiverse hotspots, at minimum for amphibians. This interpretation takes into account the fact that torrent salamanders are the overwhelming contributors to amphibian density. Since Columbia torrent salamander is widespread on the landscape, such a tool may have practical application. Clearly, this

hypothesis needs further testing since this pattern may also be spurious for reasons discussed above, i.e., our findings are based on few sites having adjusted species richness values > 1 and a probable seasonal bias that likely reduced species richness during later surveys (see discussion below).

We found no significant relationships between species richness and stand age, but the positive relationship between adjusted species richness and stand age failed marginally, and more data may support this relationship. If real, this pattern is consistent with a slow recovery following a decline in species richness after timber harvest (or other disturbance). Alternatively, this pattern may be the result of seasonal bias; we tend to find fewer species as the season progresses.

We found no significant relationships between any substrate categories and any richness or density metric. However, presence of sand and absence of either of the woody debris were consistently the substrate categories that approached significance with most metrics, so exploration of their potential importance with further data is justified. Some kind of frequency measure of substrate types may improve resolution ability (see Section 1.3).

We found no significant differences between headwall and side-slope seeps using any of amphibian metrics, and none of these metrics provide an indication that the addition of more data will be promising. While we do not exclude the possibility of a relationship appearing with additional data, existing data supports the notion that, at least from an amphibian viewpoint, partitioning of headwall seeps from side-slope seeps is arbitrary. Thus, the data imply that if these seep categories are recognized, their recognition may have to be justified by something other than amphibians, or a different type of categorization that pays more attention to the physical characteristics of seeps (see Section 3.3).

Other than substrate type, several criteria used to define seep categories showed potential patterns. Seeps with gradients > 20% were richer in species and more data may to reveal the same for density. Thus, support exists at least for the gradient criterion for side-slope seeps (see Section 1.3 for a discussion of the ambiguous gradient criterion for headwall seeps). Columbia torrent salamander density data imply that the 20% threshold could not have been closer to value the data indicate (see Figure 4.204), but we reserve judgment on the precise threshold value until more data become available.

Evaluation of density suggested no patterns with distance from the channel (partitioned as categories around each of 50 ft and 100 ft), but species richness data imply that richness might increase with distance from the channel. More data are clearly required to evaluate this possibility because only 4 seeps had > 1 species, and the pattern is counterintuitive, and again, may reflect a seasonal sampling bias (see discussion below). Columbia torrent salamander density was the only metric that showed some promise with the overland flow criterion, implying increased densities where connecting overland flow was present.

Most variation we found in species composition involved 3 or 4[p] species (i.e., northern red-legged frog, giant salamanders, and Dunn's salamander), which were infrequently encountered. Infrequent detection in seeps has one of several possible explanations:

Irregular or infrequent use: Some species may use seeps infrequently either because

[p] Four species if the unidentified *Dicamptodon* larva represented Cope's giant salamander.

these species exist in low abundance in the landscape or because seeps represent only one of several habitats used. This pattern may describe at least some of the pattern of seep use by the northern red-legged frog and post-metamorphic giant salamanders (2 of 3 giant salamanders linked to seeps were post-metamorphic adults).

Seasonal sampling bias: The finding of an inverse relationship between sampling date and adjusted species richness implies a seasonal sampling bias. After 1 October 2000, some sampling occurred when ground temperatures were at or just below 8°C. Northern red-legged frogs make late-fall moves to aquatic sites as the temperature of the substrate drops to 8°C (Ritson and Hayes 2000), so northern red-legged frogs may vacate seeps sampled in early fall. Moreover, the likelihood of detecting Dunn's salamanders beneath surface objects decreases sharply when substrate temperatures are < 10°C (M. Hayes, *unpubl. data*). Lower substrate temperatures in the latter part of the sampling interval may have contributed to the lack of detection of this species. Surveying when substrate temperatures ≥ 8°C or ≥ 10°C, respectively, may be needed to avoid biasing sampling against northern red-legged frogs and Dunn's salamanders. A seasonal bias may have influenced detection of giant salamanders as well, because like Dunn's salamander and northern red-legged frog, all these species were detected only from seeps sampled before 1 October, and sampling extended to 14 November in 2000. Columbia torrent salamander was the only species found in November, but it also showed a downward trend in the later season even though the relationship between decreased torrent salamander density and sampling date was not significant. Collectively, our exploratory late-season sampling implies that seep evaluation likely should not extend much past 1 October and only under favorable temperatures.

Association to unique habitats: Northern red-legged frog and Dunn's salamanders occurred in the only seep in which black cottonwood was present. This seep was the richest in species, but it was > 100 feet from its Type N channel and not connected to the channel by overland flow. Cottonwood, a species with a high evapotranspiration rate, is relatively infrequent over most of the off-channel landscape across the Stillman Watershed. As a result, it may be a particularly useful indicator of near-surface water. Whether black cottonwood is consistently linked to high amphibian species richness will require examination of additional seeps with and without this tree species.

Our observation of little variation in species richness may reflect regular occupancy by one species: Columbia torrent salamander. However, we sampled in short intervals (i.e., a few hours in each seep), which could bias against detecting those amphibians that use any one seep for brief periods.

We have discussed potential temperature-related seasonal biases for northern red-legged frog and Dunn's salamander, but temporal biases may also exist (e.g., our diurnal regime may have missed tailed frog post-metamorphic stages that may be more nocturnal).

The only species for which we had sufficient data for species-level analyses was the Columbia torrent salamander. We comment briefly on the remaining species first.

Tailed frog: Tailed frog was conspicuously absent from the seep data. This pattern is not surprising as larvae may need flow sufficient to produce stream channels. Thus, tailed frog larvae may be habitat limited in seeps (as we defined them). Further, flow in seeps may be insufficient to flush sediment inputs from disturbances such as bank failures

(Dupuis and Bunnell 1997). Moreover, post-metamorphic tailed frogs are generally thought to be nocturnal (Metter 1967, Leonard *et al.* 1993), which may vary with elevation (L. Jones, *pers. comm.*). As our sampling was exclusively during the day, we may have missed post-metamorphic tailed frogs from refuges that could not be searched. Post-metamorphs may represent the life stage most likely to use seeps, as tailed frogs have been observed in upland habitats in late summer and fall (Bury and Corn 1987, 1988; unpubl. data: K. Aubry, B. Bury, L. Jones, J. MacCracken, *pers. comm.*), and tailed frog life stages have been recorded from seep habitats on the Olympic Peninsula (Bury and Adams 2000). Nighttime sampling may be needed to assess whether post-metamorphic tailed frogs were missed.

Van Dyke's salamander: We found no Van Dyke's salamanders, and it has not yet been recorded from the Stillman Watershed, although it occurs just to the east in the Chehalis headwaters (D. Runde, L. Jones, *pers. comm.*). We discuss this species here because essentially all sampling to date by us and others in the basin has occurred at times (seasonally and in our case, during a drought year) when the detection rates of Van Dyke's salamander are expected to be very low (Jones 1999).

Northern red-legged frog, giant salamanders, and Dunn's salamander: As previously noted, bias against detection of these three species may exist as a function of season, and/or behavior. Surveys having greater diel and seasonal breadth will be needed to fully understand the distribution of these species in headwater habitats and correct potential biases.

Western red-backed salamander: Western red-backed salamander is frequently the most abundant terrestrial salamander in westside forested landscapes in Washington State (Leonard *et al.* 1993). Behind Columbia torrent salamander, western red-backed salamander was the most frequently recorded species. This pattern parallels the data of Adams and Bury (2000), who found Olympic torrent salamanders and western red-backed salamanders the two most frequently recorded species in seep habitats in the Olympics. Despite this pattern, we found it in relatively low numbers. Low numbers may reflect late-season conditions or habitat limitation that is not currently understood. Most of the terrestrial salamanders in the Pacific Northwest are known to be much more difficult to detect during the drier low-flow seasonal interval, during which time many are thought to occupy inaccessible refuges (L. Jones, *pers. comm.*). As 2000 was a drought year, this pattern may have been especially pronounced. Seep habitats would have to be sampled during less dry seasonal intervals to exclude the possibility that western red-backed salamanders are somehow habitat-limited in this landscape.

Columbia torrent salamander: An overwhelming majority of the amphibians found in association with seeps were Columbia torrent salamanders. Moreover, even if numbers of all other species detected increased 5-fold, Columbia torrent salamanders would still be the dominant species. In addition to the relationships already discussed regarding this species, two patterns in its microhabitat use are notable: use of mostly organic materials (leaf litter, woody debris) as cover and use of mostly fine, largely inorganic materials (mud and sand) as substrates. Organic cover may be used because it provides a more favorable temperature or hydric environment; fine inorganic substrates may be used because they present a more favorable hydric environment with greater consistency. Data on available microhabitats at the right spatial scale would be required to evaluate

these interpretations. Two other aspects of microhabitat are noteworthy. First, the data on microhabitat use in the western red-backed salamander, albeit sparse, seem to parallel that for the Columbia torrent salamander. This indicates that the habitat use pattern may be more general than simply for the Columbia torrent salamander. Second, these data seem inconsistent with the coarse substrate requirement that currently forms the basis of the seep sensitive sites categories and reinforces the notion, already discussed, that more detailed evaluation of seeps substrates is in order.

We conclude (with some qualification) that some seeps are richer in amphibians, and that some seeps support higher densities of amphibian numbers than others. We have an ambiguous assessment because the headwater landscape we examined seems to be Columbia torrent salamander dominated, detectability issues seem to exist with species other than the Columbia torrent salamander, and a seasonal bias likely influenced our results. While we have indication that selected environment variables (e.g., gradient) are significant in density (and perhaps richness) patterns, many showed no patterns and a few (e.g., substrate) seemed to contradict our notions. Greater precision in the collection of some habitat variables (e.g., substrate) with a sampling regime free of seasonal confounds will be required to clearly evaluate the elements we suspect contribute to amphibian habitat quality in seeps.

5. Key Findings

These pilot-year study key findings are preliminary:

- Headwater seep occurrence is **highly variable** among subbasins within the igneous geology of the Stillman Watershed.
- Likelihood of seep occurrence **decreases rapidly** with increasing distance from the Type N stream channel in this geology and local precipitation levels.
- Columbia torrent salamander is the numerically **dominant** amphibian species in headwater reaches of the Stillman watershed, despite the fact that our sampling may have been biased towards detecting this species over other amphibian species (see Section 6).
- Columbia torrent salamander is the numerically **dominant** amphibian species in seeps in Stillman headwaters basins.
- Initiation reaches are **nursery areas** for Columbia torrent salamanders in Stillman Watershed.
- Columbia torrent salamanders begin to appear (in high densities) in streams and seeps with > **20% gradient,** which appears consistent, with FFR guidelines for protection of side-slope seeps.

Besides our key findings, we have several intriguing, and in a few cases, unexpected findings that will require additional information to understand:

- Our sampling methods for species that occur in low frequency or only in selected habitats may be biased.

  TAILED FROG: Tailed frog larvae are well known to utilize stream reach habitats, so finding tailed frog larvae only in stream reaches was not surprising. However, we

sampled exclusively during the day, and post-metamorphic stages of tailed frog can be nocturnal (L. Jones, *pers. comm.*). Further, post-metamorphic tailed frogs being recorded moving across upland habitats (McComb *et al.* 1993, Bury and Corn 1987, 1988; *unpubl. data*: K. Aubry, L. Jones, J. MacCracken, *pers. comm.*) and tailed frog life stages being found in seep habitats[q] on the Olympic peninsula (Bury and Adams 2000) may indicate that post-metamorphic tailed frog life stages might be expected in Willapa ecoregion seep habitats. Thus, even though post-metamorphs would seem to be the most likely tailed frog life stage to be found in seeps, we saw none. Nighttime sampling and seasonally broadened sampling interval would help us determine whether the diel or seasonal restriction of our surveys underestimated the importance of seeps to post-metamorphic tailed frogs.

NORTHERN RED-LEGGED FROG: A significant proportion of sampling occurred when ground temperatures were at or just below 8°C. Ritson and Hayes (2000) have recorded at least one amphibian species (northern red-legged frog) making a late-fall move to stillwater aquatic sites when substrate temperature reached the 8°C range. If other amphibian species move away from seeps to more permanent sites for overwintering, we may underestimate the importance of seeps that were sampled during late fall when substrate temperatures were at or below 8°C. Even if the biases against recording northern red-legged and tailed frogs in seeps are severe, our conclusions regarding predominance of Columbia torrent salamander in Stillman Watershed headwater habitats would remain unchanged.

DUNN'S SALAMANDER: A potential temperature-associated bias against sampling Dunn's salamander may also have existed. Dunn's detections beneath moveable surface objects decreases when substrate temperature is ≤ 10°C (M. Hayes, *unpubl. data*). Similar to the northern red-legged frog, all Dunn's salamanders were detected under conditions with warmer substrate temperatures.

- Our substrate results seem to conflict with the sensitive site specificiations indicated in rule. This may be a function of our resolution of measurement of substrate types, although the habitat use data for individual animals seems to support the conflicting substrate finding. Nonetheless, more resolved measurement of substrate would help having confidence in this finding.
- The inverse relationship between amphibian or Columbia torrent salamander densities and seep area suggests that density increases as seeps shrink in size. Our year 2000 data collection season was significantly drier than average; whether seep shrinkage is a typical dry-season phenomenon or only a drought-year phenomenon needs to be understood. The finding also needs to be understood in context of torrent salamander movement patterns, which may be limited for torrent salamanders in general (Nijhuis and Kaplan 1998, Nussbaum and Tait 1977, Welsh and Lind 1992), but unstudied for Columbia torrent salamanders in particular. Both may be essential to understanding how forest management affects seeps and torrent salamanders.
- Understanding temperature variation in headwater habitats may be an important

[q] Characterization of seeps by Adams and Bury (2000) likely including springs based on our partitioning of these habitat types (M. Adams, *pers. comm.*), so without detailing of the habitat characteristics of the sites Adams and Bury sampled, whether tailed frogs were found in what we termed seeps is ambiguous.

corollary to understanding habitat use patterns among SAAs as local temperature differences may favor or disfavor certain taxa. Moreover, the seep temperature flip-flop between colder and warmer air temperatures may be important in how seeps and reach habitats in headwater systems are used.

- Our finding of high densities of adult Columbia torrent salamanders in association with a waterfall was not completely unexpected. Scattered investigators have implied that waterfalls, and notably, their splash zones, are amphibian or torrent salamander hotspots (e.g., Nussbaum *et al.* 1983; Slater 1933, 1939). However, we found only large adults, larger even than adults found in the other aquatic headwater habitats we sampled. If this observation is not aberrant (unpublished data suggests it is not), we need to better understand this pattern in the context of inter-year variation (e.g., typical or only a drier-year phenomenon?) and movement patterns (i.e., if seeps are nesting habitat, what is the relationship between reproductive adults in waterfalls and where reproduction occurs?). Answers to these questions will be fundamental to assessing the significance of waterfalls to torrent salamanders and other amphibians in the landscape.
- Our finding that initiation reaches (including a spring) may be nurseries for Columbia torrent salamanders does not demonstrate that initiation reaches are where torrent salamanders reproduce consistently, nor that seeps are preferred over other aquatic habitats, nor that they are the highest quality reproductive sites. Reproductive data for torrent salamanders in general are based on only seven nest locations (Nussbaum 1969, Karraker 1999, Russell *et al.* 2002; N. Karraker, *unpubl. data*), including five for Columbia torrent salamanders (Nussbaum 1969, Russell *et al.* 2002). We emphasize Stebbins' (1949) caution that little nest data may mislead rather than illuminate, and may represent only the "tail" of the distribution of possible nesting habitats that humans may most easily discover. We believe two approaches can resolve this issue. Neither is low-cost, but both may be necessary to arrive at a solution. The first would be to search appropriate habitats for nests during the several-month time window prior to when the smallest larval torrent salamanders appear in these habitats. However, what habitats are appropriate to search will remain ambiguous until more nests are found, requiring that diverse headwater aquatic habitats be searched. Where possible, efforts should be focused on aquatic microhabitats with the greatest numbers of the smallest larval torrent salamanders. The second approach would require acquiring growth and movement data on the smallest size class of larval torrent salamanders in their habitat. If the smallest larvae are sedentary and growth is slow, as implied from the few data on other species (Nijhuis and Kaplan 1998, Nussbaum and Tait 1977, Welsh and Lind 1992), the scale of microhabitat searches could be reduced with greater confidence.
- Indications of higher species richness and higher amphibian densities in older forests stands should be investigated further. While the findings are based on small sample sizes and biases that potentially confound this pattern. However, if true, this pattern would be consistent with the idea that amphibian assemblages are recovering from previous declines following timber harvest or other disturbance.
- We were unable to adequately characterize rates of water flow at seeps. Some effort to precisely characterize flow in seeps will be necessary to understand just

how seeps systems differ from other low flow aquatic habitats and whether flow rate is an important habitat characteristic for amphibians. Further, characterization of both surface and hyporheic flows will be necessary to fully understand variation among seeps. Until we have such measurements, our characterization of seepage flows will remain vague. An adaptation of the recently developed method, a salt table conductivity and diffusion method, used for measuring flow at specific points where hyporheic insects dwell may prove successful for measuring seep flow (R. Vadas, *pers. comm.*). Regardless, innovative methods (e.g., Madsen and Warncke 1983, Pettigrew and Kalff 1991) will be required to measure flow in seeps.

6. Suggested Priorities for Future Research

The array of issues discussed here led us to suggest priorities for the direction of future research in order of descending importance:

- An increase in overall sample size to no fewer than 50 seeps in the igneous substrate of Stillman Creek Basin is needed to ensure sufficient statistical power to allow confidence in our findings. Based on our year 2000 sampling, this would require sampling subbasins in another 24 type N streams, which will likely require more than one year. Year 2000 sampling occurred during a relatively dry year. We anticipate that 2001, like 2000, will be a dry year requiring a large amount of scoping time.
- Biases should be eliminated to ensure that the entire assemblage of amphibians, life-stage inclusive, is adequately sampled. Specifically, this means that seasonally, surveys should typically not occur after 1 October if we hope to include the entire amphibian assemblage that might be found. Night surveys may also be needed to determine whether post-metamorphic tailed frogs use seeps. These survey requirements impose substantial seasonal constraints. If these biases are to be addressed, seep surveys must be initiated substantially before early August, the year 2000 start date. Moreover, because addition of night surveys fundamentally doubles the amount of time, and the same field crews cannot complete both day and night surveys for anything more than relatively brief time intervals (i.e., a few days), more time and/or surveyors would be necessary to effect this sampling regime.
- In contrast to the substrates implied in FFR sensitive site definitions, we found fine substrates frequent in seeps and coarse substrates less frequent there. A more precise substrate measurement (i.e., beyond a presence/absence scoring) will be necessary to determine which substrates are most strongly associated with different types of seeps. A frequency measurement of substrate types would fulfill this need.
- Torrent salamanders are sensitive to temperature (e.g., Welsh and Lind 1996), so eliminating temporal sampling elements that confound temperature effects should be a priority. This will not require much additional effort other than precise planning and deployment of data loggers across a series of seeps chosen for their variation in structure and amphibian occupancy patterns. We anticipate that such a study could be easily coupled to increasing sample size to complete the igneous model with minimal extra effort. Furthermore, opportunity may exist here for the Upland Processes Scientific Advisory Group (UPSAG) or the Riparian Processes Scientific

Advisory Groups (RSAG) to obtain temperature data that may help fulfill at least one of their objectives. Effort should be made to coordinate research with UPSAG or RSAG, especially on issues of where to place temperature data loggers in seeps.

- The notion that seep shrinkage results in concentration of amphibians should be tested through measurement of seep area and amphibian density at least twice seasonally.
- Effort to date has focused exclusively on igneous substrates in the Willapa Hills ecoregion, but model development for seep distribution on sedimentary substrates within this ecoregion is needed. At least one amphibian species is postulated to be absent from certain types (e.g., tailed frog in marine sedimentary formations), whereas others may occur in lower abundance on selected sedimentary formations (Wilkins and Peterson 2000). However, model development for sedimentary formations in the Willapa Hills is important as these formations occur over nearly half the landscape in this ecoregion. We expect that effort required to develop such a model will be equal to or greater than that needed to develop the igneous model.
- Waterfalls were not a focal element of the original seep study design. Yet, waterfalls may be hot spots for SAAs. More waterfalls should be sampled to clarify why we only found adult Columbia torrent salamanders in the one waterfall surveyed. Special attention should be paid to physical parameters that make high-gradient reaches unique and the size, life stage, and reproductive state of amphibians located in these reaches.
- The original study was designed to examine seeps in the headwaters of other regions of Washington State, with surveys next occurring in westside south and central, and perhaps eastside Cascade Mountains in the year 2001. This is unrealistic if the level of effort in year 2001 is similar to that for year 2000. Further, our preliminary scoping indicates that non-fish bearing systems in the westside south Cascade Mountains ecoregion are 2-5 times as large as those in the Willapa ecoregion. Thus, greater effort will be required to access those basins and sampling them will take more time.

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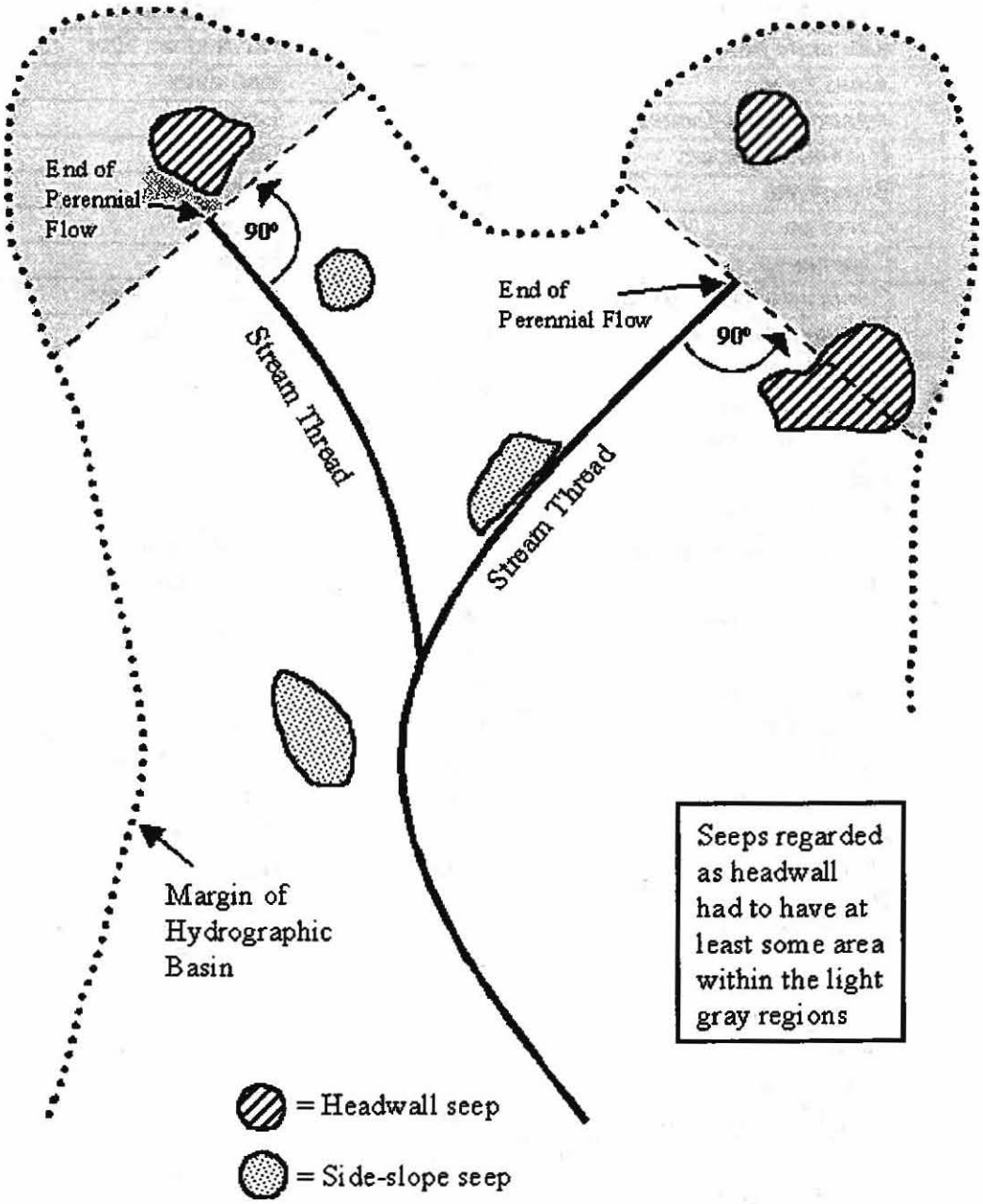
Appendix I

Method Used to Distinguish Headwall and Side-slope Seeps (Stillman Watershed, Washington) in 2000



Appendix II

Plant Taxa Addressed in the Stillman Watershed, Washington, 2000 Seep Study

Scientific Name	Code	Common Name
Acer circinatum	ACCI	Vine maple
Acer macrophyllum	ACMA	Big-leaf maple
Adiantum pedatum	ADPE	Maidenhair fern
Alnus rubra	ALRU	Red alder
Athyrium filix-femina	ATFI	Lady fern
Blechnum spicant	BLSP	Deer fern
Bryophyta	BRYO	Mosses
Carex sp.	CAsp	Sedge
Cyperus sp.	CYsp	Rush
Conocephalum conicum	COCO	Snake liverwort
Dicentra formosa	DIFO	Bleeding heart
Equisetum sp.	EQsp	Horsetails
Fraxinus latifolia	FRLA	Oregon ash
Gaultheria shallon	GASH	Salal
Hepaticae	HEPA	Liverworts
Holodiscus bicolor	HOBI	Ocean spray
Lysichiton americanum	LYAM	Skunk cabbage
Mahonia nervosa	MANE	Dull Oregon grape
Oplopanax horridus	OPHO	Devil's club
Oxalis oregana	OXOR	Redwood sorrel
Petasites frigidus	PEFR	Coltsfoot
Polystichum munitum	POMU	Sword fern
Populus balsamifera	POBA	Black cottonwood
Prunus emarginata	PREM	Bitter cherry
Pseudotsuga menziesii	PSME	Douglas-fir
Pteridium aquilinum	PTAQ	Bracken fern
Ribes bracteosum	RIBR	Stink currant
Rubus spectabilis	RUSP	Salmonberry
Rubus ursinus	RUUR	Dewberry
Salix sp.	SAsp	Willow
Thuja plicata	THPL	Western red cedar
Tolmiea menziesii	TOME	Piggy-back plant
Tsuga heterophylla	TSHE	Western hemlock
Urtica dioica	URDI	Stinging nettle
Vaccinium parvifolium	VAPA	Red huckleberry

Appendix III

Methods Used to Measure Flow Velocity and Flow Volume
in Headwater Seeps (Stillman Watershed, Washington) during 2000.

Flow Velocity: We estimated flow velocity for surface water in seeps by measuring travel rate of wheat flour over a known distance. For effective measurement, use of flour required at least a thin, laminar flow surface. We found that a surface as thin as 0.5-1.0 mm [0.02-0.04 in] over a distance of 5-10 cm [~2-4 in] was sufficient. If a seep lacked visible surface flow, but water was flowing through the substrate, we altered existing surfaces to establish an area with such a surface. We secured a 15 cm [~6 in] ruler parallel to the axis of flow, dusted a tiny amount of flour (about $^{1}/_{10}$ a culinary pinch) onto the water surface, and timed the movement of the head of flour particles over a fixed distance. We found that 2 mm [0.08 in] over 5–10 cm was roughly the error in repeated measurements at the same seep. Flour in the smallest amounts will ride on the surface of water for centimeters; larger amounts often adsorb water rapidly.

Flow (Volume): We measured flow using two methods: (1) a bag-filling method, a technique considerably modified from the Isiorho and Meyer (1999) method of measuring seepage in lakes; and (2) a novel method that using a partially enclosed screen.

Bag method: Our bag method used a flexible, 12 cm x 30 cm piece of aluminum flashing. A Teflon™ T-junction pipe with an inside diameter of 10 mm was firmly attached upside-down (i.e., with the stem of the T pointing upwards) to the flashing 3 cm below the center of one side of its long axis. The long axis of the flashing was bent in a manner that three sides of a 100 cm^2 [0.11 ft^2] square were enclosed. To begin, we sank the flashing into the substrate at the desired point so that the two bent (free) sides pointed against the axis of flow and the side with the T-junction intercepted it. We sank the flashing deep enough that flow ran fully through the crosspiece of the T-junction, but did not flow out of the skyward-pointing stem. At a time zero, we attached a bag over the end of the horizontal Teflon™ stem. Although we tried different bags, condoms were of the size and strength that worked best. We found that putting one's finger over the bag fitting during attachment resulted in the most reliable measurement as one could then release the already attached bag at the appropriate time zero. We interrupted flow by pinching off the bag behind its fitting, removing the bag and emptying its contents into a graduated cylinder.

Screen method: For this method we used a semi-circular, fine screen strainer. We used marine epoxy to seal one half of the strainer and to alter the inside volume of the strainer so that it would contain 100 cm^2 [0.11 ft^2]. To begin, we sank the strainer into the substrate to the level of its rim at time zero and recorded the time it took to fill the strainer to 100 cm^2 [0.11 ft^2]. Placement was such that the sealed half of the strainer intercepted the axis of flow.

Both methods had disadvantages. Neither method could be deployed in areas where it was not possible to dig into the substrate. We observed that measurements with the screen method were easily changed through compression of fine substrates, although we could reduce the effects of compression by wiggling rather than pressing the screen

directly into the substrate. Test of these systems under known flow conditions revealed that we could expect variation of about 25% in measurements. With this variation, measurements obtained with the screen method averaged somewhat higher, but not significantly different. Data in Table 2.205 was collected using both methods.

Appendix IV

Index for Identifying Plants Associated in Stillman Watershed, Washington, 2000

As one stage in the development of a field manual for seep identification, we developed an index to allow us to score plant taxa as to their usefulness in identifying seeps. Usefulness here means the degree to which plant taxa are associated with seep habitats. Since we examined the relative association of plant taxa with reaches and seeps (Appendix Table IVa), much of this index draws from those analyses. We developed an index over a small (versus unwieldy) numerical range in which smaller values show greater quality a seep indicator. We used probabilities, with minor modifications, generated as a result of the statistical tests that we performed to identify patterns of occurrence among different plant taxa between reaches and seeps and adjacent uplands (see Appendix Table IVa). We felt it important that this index be sensitive to sample size (i.e., confidence as a result of the amount of data that was used to generate an index value), that it be consistent with available knowledge of plant taxa associated with more hydric conditions, and that it be simple, but vary in a consistent way in identifying a greater or lesser association with seeps. In keeping to these conditions, the index or Seep Indicator Score (**SIS**) we produced varies between -1 and 10.5, and included the following elements:

1) Seep factor (**SF**): The seep factor consisted of the slightly modified probabilities of the Fisher Exact tests run on the occurrence of difference species within and outside of (i.e., uplands) seeps. Because these tests could generate significant results in the direction of seeps or in the direction of uplands, we subtracted the probability value of tests in the direction of uplands (italicized in the probability (**p**) column under the seeps heading in Table 2.10) from 1 and added the difference to 1 to generate **SF** values. This modification created values between 0 and 2 that increase as the level of association with seeps decreases. The **SF** could not be 0, only approach zero as an asymptote.
2) Reach factor (**RF**): The reach factor is identical in its calculation to the seep factor except that we multiplied the reach factor by two. Our reasoning was that our focal interest was the degree of association with seeps, not reaches, but that we expected, because of the hydric conditions there, that some species along reach margins would be found in seeps. Thus, we thought it important to have a reach factor to distinguish those species found in both reach margins and seeps from those found in seeps alone. Reach factor values could vary between 0 and 4.
3) Sample size factor (**NF**): The sample size factor was included to account for substantial differences in sample sizes used to run Fisher's Exact tests that addressed the differential occurrence of plant taxa between uplands versus reaches or seeps. The **NF** is the number of units sampled (n = 45) divided into the negative value of the sum of the occurrences of each taxon in reaches ($\mathbf{n_r}$) and seeps ($\mathbf{n_s}$: Table 2.10). Taxa with larger sample sizes (n_r, n_s, or both) would have their overall index score reduced by a larger amount, whereas those with smaller sample sizes would have their scores reduced by a lesser amount. Sample size factor values are always negative. They could reach a maximum of 1 and could approach, but not reach zero.

4) Factors emphasizing seep importance: As this index was intended to reflect association with seeps, greater devaluation of the index should occur for links to other available habitats (i.e., reach margins and uplands). We therefore add a factor to emphasize the association or disassociation with each of these habitats:

   a) *Reach occurrence factor* (**RO**): If a plant taxon occurred along reach margins, 1 was added to its index score. A plant taxon not occurring along reach margins scored a 0.

   b) *Upland occurrence factor* (**UO**): If a plant taxon was only recorded from uplands, we added 3 to its score, because such species were viewed as the least likely to occur in seeps.

5) Adjustment for score evenness (**AE**): After generating **SIS** values from the five factors described, we found that plant taxa with only one observation in a reach, seep, or upland category could sometimes take on the same **SIS** value as taxa with one observation in each of a seep and an upland, or in a reach and an upland. Our notion was that the non-symmetric observations should have greater value than symmetric ones, so we added a value of 0.5 to all symmetric occurrence patterns. Symmetric occurrence patterns were those where occurrences of a plant taxon were identical in number between reaches and uplands, seeps and uplands, or both. To gain the 0.5 adjustment, a taxon had to have non-zero symmetric occurrence in compared categories (see Table 2.10).

The five factors and the adjustment described were summed into the **SIS** score:

$$\mathbf{SIS = SF + RF + NF + RO + UO + AE}$$

Based on our distribution of SIS values we observed, we heuristically grouped plant taxa with SIS values to indicate their level of quality as seep indicators. These groupings were:

SIS Value	Quality as Seep Indicator
≤ 2.000	High
> 2.000 and ≤ 3.000	Fair
> 3.000 and ≤ 4.000	Poor
> 4.000	Unusable

Appendix Table IVa – Plants near Reaches and Seeps in the Stillman Watershed, Washington, 2000

Taxon Name	Sampled Units (n = 37)											Fisher's Exact Test Result				Seep Indicator Score[c]	Quality as a Seep Indicator
	Reaches (n = 8)					Seeps (n = 29)					Sample Size Factor[c] $\frac{-(n_r+n_s)}{37}$	Reaches		Seeps			
	Marginal[a]		Upland		n_r[b]	Within		Upland		n_s[b]							
	Obs	Not Obs	Obs	Not Obs		Obs	Not Obs	Obs	Not Obs			p[d]	Reach Factor[c]	p[d]	Seep Factor[c]		
Skunk cabbage	3	20	0	23	3	8	14	1	21	8	-0.244	0.233	0.466	0.021	0.021	1.243	**High**
Horsetails[e]	2	21	0	23	2	4	18	0	22	4	-0.133	0.489	0.978	0.108	0.108	1.953	**High**
Piggy-back plant	3	20	1	22	4	7	15	0	22	7	-0.244	0.608	1.216	0.009	0.009	1.981	**High**
Lady fern	4	19	2	21	5	9	13	2	20	9	-0.311	0.665	1.330	0.034	0.034	2.053	**Fair**
Mosses[f]	20	3	19	4	22	20	2	13	9	20	-0.933	0.999	1.998	0.034	0.034	2.099	**Fair**
Liverworts[g]	0	23	0	23	0	3	19	0	22	3	-0.067	0.999	1.998	0.233	0.233	2.164	**Fair**
Red alder	8	15	7	16	9	14	8	10	12	16	-0.556	0.999	1.998	0.364	0.364	2.806	**Fair**
Salmonberry	7	16	6	17	9	12	10	8	14	15	-0.533	0.999	1.998	0.364	0.364	2.829	**Fair**
Devil's club	5	18	5	18	7	11	11	7	15	16	-0.511	0.999	1.998	0.358	0.358	2.845	**Fair**
Sedge[e]	0	23	0	23	0	1	21	0	22	1	-0.022	0.999	1.998	0.999	0.999	2.975	**Fair**
Oregon ash	0	23	0	23	0	1	21	0	22	1	-0.022	0.999	1.998	0.999	0.999	2.975	**Fair**
Stinging nettle	0	23	0	23	0	1	21	0	22	1	-0.022	0.999	1.998	0.999	0.999	2.975	**Fair**
Black cottonwood	0	23	0	23	0	1	21	0	22	1	-0.022	0.999	1.998	0.999	0.999	2.975	**Fair**
Rush[e]	0	23	0	23	0	1	21	0	22	1	-0.022	0.999	1.998	0.999	0.999	2.975	**Fair**
Deer fern	4	19	4	19	6	4	18	2	20	5	-0.244	0.999	1.998	0.664	0.664	3.418	**Poor**
Redwood sorrel	7	16	6	17	9	13	9	12	10	15	-0.533	0.999	1.998	0.999	0.999	3.464	**Poor**
Bleeding heart	0	23	0	23	0	1	21	1	21	1	-0.022	0.999	1.998	0.999	0.999	3.475	**Poor**

[a] Occurrence categories: observed (Obs), not observed (N Obs). [b] Number of times a species occurred in a sampled unit (reaches or seeps), either within the unit, in nearby upland, or both. [c] Sample size, reach, and seep factors represent three of five factors comprise the Seep Indicator Score (see Appendix III for details). [d] Italicized test statistic probabilities indicate greater frequencies of occurrence outside the sample units (i.e., in uplands versus reaches or seeps) [e] Genus level taxon. [f] Class level taxon. [g] Leafy liverworts only; two of the three liverworts recorded were snake liverwort (see Appendix V).

Appendix Table IVa – Plants near Reaches and Seeps in the Stillman Watershed, Washington, 2000 (continued)

Taxon Name	Sampled Units (n = 37)											Fisher's Exact Test Result				Seep Indicator Score[c]	Quality as a Seep Indicator
	Reaches (n = 8)					Seeps (n = 29)					Sample Size Factor[c]	Reaches		Seeps			
	Marginal[a]		Upland		n_r[b]	Within		Upland		n_s[b]	$\frac{-(n_r+n_s)}{45}$						
	Obs	Not Obs	Obs	Not Obs		Obs	Not Obs	Obs	Not Obs			p[d]	Reach Factor[c]	p[d]	Seep Factor[c]		
Sword fern	12	11	14	9	21	19	3	19	3	22	-0.956	*0.767*	2.466	0.999	0.999	3.509	**Poor**
Salal	0	23	0	23	0	1	21	4	18	5	-0.111	0.999	1.998	*0.345*	1.655	3.542	**Poor**
Western hemlock	2	21	3	20	3	6	16	7	15	9	-0.267	0.999	1.998	0.999	0.999	3.730	**Poor**
Vine maple	3	20	2	21	4	3	19	3	19	5	-0.200	0.999	1.998	0.999	0.999	3.797	**Poor**
Bracken Fern	2	21	1	22	2	1	21	1	21	2	-0.089	0.999	1.998	0.999	0.999	3.908	**Poor**
Willow[e]	1	22	0	23	1	0	22	1	21	1	-0.044	0.999	1.998	0.999	0.999	3.953	**Poor**
Stink currant	1	22	0	23	1	1	21	1	21	1	-0.044	0.999	1.998	0.999	0.999	3.953	**Poor**
Maidenhair fern	1	22	0	23	1	0	22	0	22	0	-0.022	0.999	1.998	0.999	0.999	3.975	**Poor**
Dewberry	2	21	2	21	4	1	21	1	21	2	-0.133	0.999	1.998	0.999	0.999	4.364	**Unusable**
Douglas-fir	13	10	15	8	17	13	9	19	3	20	-0.822	*0.763*	2.474	*0.088*	1.912	4.564	**Unusable**
Western red cedar	1	22	3	20	3	1	21	3	19	3	-0.133	*0.608*	2.784	*0.607*	1.393	5.044	**Unusable**
Red huckleberry	3	20	6	17	8	1	21	6	16	7	-0.333	*0.459*	3.082	*0.095*	1.905	5.654	**Unusable**
Big-leaf maple	0	23	0	23	0	0	22	1	21	1	-0.022	0.999	1.998	0.999	0.999	5.975	**Unusable**
Bitter cherry	0	23	0	23	0	0	22	1	21	1	-0.022	0.999	1.998	0.999	0.999	5.975	**Unusable**
Oregon grape[f]	0	23	0	23	0	0	22	3	19	3	-0.067	0.999	1.998	*0.233*	1.767	6.698	**Unusable**
Ocean spray	0	23	3	20	3	0	22	0	22	0	-0.067	*0.233*	3.534	0.999	0.999	7.466	**Unusable**

[a] Occurrence categories: observed (Obs), not observed (N Obs). [b] Number of times a species occurred in a sampled unit (reaches or seeps), either within the unit, in nearby upland, or both. [c] Sample size, reach, and seep factors represent three of five factors comprise the Seep Indicator Score (see Appendix III for details). [d] Italicized test statistic probabilities indicate greater frequencies of occurrence outside the sample units (i.e., in uplands versus reaches or seeps). [e] Genus level taxon. [f] Class level taxon. [g] Dull Oregon grape (see Appendix V).

Appendix V

Geologic Formations in Stillman Watershed, Washington Subbasins Sampled, 2000

Descriptions of geocode map units occurring in the Stillman Watershed subbasins in which our sampling occurred. The descriptions are abbreviated from (Wells 1981).

	Map Code	Description
1)	**Tcb**	CRESCENT FORMATION (lower and lower middle Eocene): Pillow flows, massive and columnar jointed flow interiors, pillow breccia, lapilli tuff breccia, and filled lava tubes of tholeiitic and alkalic basalt, basalt groundmass altered to green and brown clays; zeolite and calcite fracture fillings are ubiquitous; contains minor amounts of mudflow breccia, basaltic sandstone, and interbedded laminated siltstone.
2)	**Tig**	GABBRO AND INTRUSIVE ROCKS (early or middle Eocene): Massive to blocky jointed and columnar jointed, fine to very coarse-grained gabbro sill complex; marginal facies are basalt and have well-developed columnar jointing, while interiors are very coarse-grained to pegmatitic; gabbro and basalt are vesicular and typically flow banded, a result of planar concentrations of vesicles and/or crystal sorting; interstitial glass is generally altered to green clays and vesicles are filled with clay, calcite, or zeolite.
3)	**Tml**	McINTOSH FORMATION, LOWER MEMBER (lower and middle Eocene): Massive to thin bedded and laminated very fine grained to coarse grained basaltic sandstone, arkosic sandstone and laminated tuffaceous siltstone; sandstone commonly shows graded bedding.

Appendix VI

Amphibian Species Known to Occur in the Stillman Watershed, Washington, 2000.

Scientific Name	Code	Common Name
Anura		**Frogs and Toads**
Ascaphus truei	ASTR	Tailed frog
Bufo boreas	BUBO	Western toad
Hyla regilla	PSRE	Pacific treefrog
Rana aurora aurora	RAAU	Northern red-legged frog
Caudata		**Salamanders**
Ambystoma gracile	AMGR	Northwestern salamander
Ambystoma macrodactylum	AMMA	Long-toed salamander
Dicamptodon copei	DICO	Cope's giant salamander
Dicamptodon tenebrosus	DITE	Pacific giant salamander
Ensatina eschscholtzi	ENES	Ensatina
Plethodon dunni	PLDU	Dunn's salamander
Plethodon vehiculum	PLVE	Western red-backed salamander
Rhyacotriton kezeri	RHKE	Columbia torrent salamander
Taricha granulosa	TAGR	Rough-skinned newt

Note: Data from Weyerhaeuser (D. Runde, *pers. comm.*), and the Washington Department of Fish and Wildlife database. Scientific and common names follow Crother *et al.* (2000, 2001).

Appendix VII

Amphibian Data from the Stillman Watershed, Washington, 2000

Subbasin	Unit Type[1]	Unit Code[2]	Category[3]	Gradient > 20%	Overland Flow[4]	Distance[5]		Frogs			Salamanders							Total Individuals	Species Richness	
						≤ 50 ft	≤100 ft	ASTR[6]	RAAU	Total Frogs	DIsp	DITE	Total Giant Salamanders	PLDU	PLVE	RHKE	Total Salamanders		Raw	Adjusted
STL11040221	S	A	SS	Y	N	N	N	-	-	0	-	-	0	-	1	-	1	1	1	0.5
STL11040221	S	B	SS	Y	Y	Y	Y	-	-	0	-	-	0	-	-	-	0	0	0	0.0
STL11040313	S	A	SS	Y	Y	Y	Y	-	-	0	-	-	0	-	-	12	12	12	1	1.3
STL11040825	S	A	SS	Y	Y	Y	Y	-	-	0	-	-	0	-	-	-	0	0	0	1.1
STL11040825	S	B	SS	Y	Y	N	N	-	-	0	-	1	1	-	-	1	2	2	2	4.0
STL11041008	S	A	SS	Y	Y	Y	Y	-	-	0	-	-	0	-	-	2	2	2	1	2.6
STL11041008	S	B	SS	Y	Y	Y	Y	-	-	0	-	-	0	-	-	2	2	2	1	1.3
STL11041008	S	C	SS	Y	Y	Y	Y	-	-	0	-	-	0	-	-	1	1	1	1	0.6
STL12041708	S	A	SS	Y	N	Y	Y	-	-	0	-	-	0	-	1	-	1	1	1	0.4
STL12041720	S	A	SS	Y	Y	Y	Y	-	-	0	-	-	0	-	-	-	0	0	0	0.1
STL12041720	S	B	SS	Y	N	N	N	-	-	0	-	-	0	-	-	1	1	1	1	1.1
STL12041720	S	C	SS	Y	Y	Y	Y	-	-	0	-	-	0	-	-	1	1	1	1	0.8
STL12041720	S	D	SS	Y	Y	Y	Y	-	-	0	-	-	0	-	-	-	0	0	0	0.0
STL12041720	S	E	SS	Y	Y	Y	Y	-	-	0	-	-	0	-	-	-	0	0	0	0.0
STL12041731	S	B	SS	Y	N	Y	Y	-	-	0	-	-	0	-	-	1	1	1	1	2.0
STL12041731	S	C	SS	Y	Y	Y	Y	-	-	0	-	-	0	-	-	3	3	3	1	2.0
STL12042005	S	A	SS	N	N	Y	Y	-	-	0	-	-	0	-	-	-	0	0	0	0.2
STL12043108	S	A	SS	Y	N	N	Y	-	-	0	-	-	0	-	1	-	1	1	1	1.2
STL12043223	S	A	SS	N	N	Y	Y	-	-	0	-	-	0	-	-	-	0	0	0	0.2
STL12043407	S	A	SS	Y	N	N	N	-	1	1	-	1	1	3	1	1	6	7	5	5.5
STL12043407	S	B	SS	Y	Y	Y	Y	-	-	0	1	-	1	-	3	16	20	20	3	2.6
STL12043407	S	C	SS	Y	N	N	Y	-	-	0	-	-	0	-	1	12	13	13	2	1.3
STL12043407	S	D	SS	N	Y	Y	Y	-	-	0	-	-	0	-	-	-	0	0	0	0.0
STL12043407	S	E	SS	N	Y	Y	Y	-	-	0	-	-	0	-	-	3	3	3	1	0.2
STL12043407	S	G	SS	Y	Y	Y	Y	-	-	0	-	-	0	-	-	3	3	3	1	2.6
STL12043407	S	H	SS	Y	Y	Y	Y	-	-	0	-	-	0	-	-	5	5	5	1	1.4
Side-slope Seep Subtotals								0	1	1	1	2	3	3	8	64	78	79	8	3.1
STL11040814	S	A	HW	Y	Y	Y	Y	-	-	0	-	-	0	-	-	3	3	3	1	1.6
STL12041731	S	A	HW	Y	Y	Y	Y	-	-	0	-	-	0	-	-	-	0	0	0	0.1
STL12043407	S	F	HW	N	Y	Y	Y	-	-	0	-	-	0	-	-	3	3	3	1	1.0
Headwall Seep Subtotals								0	0	0	0	0	0	0	0	6	6	6	1	0.8
Seep Summary Data			**Total Individuals**					0	1	1	1	2	3	3	8	70	84	85		
			Total Units Present					0	1	1	1	2	3	1	6	17	20	20		

[1] Unit Type: Reach (R) or Seep (S)
[2] Corresponds to the Seep letter codes in Table 2.203.
[3] Category: Headwall (HW), Side-slope (SS); see Appendix I for differentiation.
[4] Yes (Y) means that an overland flow connection existed between the seep and Type N channel.
[5] Shortest distance to the Type N channel; a yes (Y) means falls within the indicated category.
[6] Species codes are described in Appendix VI. A dash (-) means species not recorded.

Appendix VII (continued)

Amphibian Data from the Stillman Watershed, Washington, 2000

Subbasin	Unit Type[1]	Unit Code[2]	Category[3]	Gradient > 20%	Overland Flow[4]	Distance[5]		Frogs			Salamanders							Total Individuals	Species Richness	
						≤ 50 ft	≤100 ft	ASTR[6]	RAAU	Total Frogs	DIsp	DITE	Total Giant Salamanders	PLDU	PLVE	RHKE	Total Salamanders		Raw	Adjusted
STL11040313	R	A	N	Y	-	-	-	4	-	4	2	-	2	-	-	2	4	8	3[7]	4.8
STL11041008	R	A	N	Y	-	-	-	-	-	0	-	-	0	-	-	7	7	7	1	2.2
STL11041008	R	B	N	Y	-	-	-	-	-	0	7	-	7	-	-	7	14	14	2[7]	3.5
STL11041008	R	C	N	Y	-	-	-	-	-	0	-	-	0	-	-	7	7	7	1	1.6
STL12041720	R	A	N	Y	-	-	-	-	-	0	-	-	0	-	-	1	1	1	1	1.4
STL12041731	R	A	N	Y	-	-	-	-	-	0	-	-	0	-	-	11	11	11	1	2.4
STL12043223	R	A	N	Y	-	-	-	-	-	0	-	-	0	-	-	-	0	0	0	0.5
STL12043407	R	A	N	Y	-	-	-	-	-	0	-	-	0	-	-	10	10	10	1	1.5
STL12043407	R	B	N	N	-	-	-	-	-	0	-	-	0	-	-	-	0	0	0	1.4
STL12043407	R	C	N	N	-	-	-	-	-	0	1	-	1	-	-	-	1	1	1	1.5
Non-terminal Reach Subtotals								**4**	**0**	**4**	**10**	**0**	**10**	**0**	**0**	**45**	**55**	**59**	**3**	
STL11040221	I	A	I	Y	-	-	-	-	-	0	-	-	0	-	-	6	6	6	1	2.3
STL12043223	I	A	I	N	-	-	-	-	-	0	-	-	0	-	-	2	2	2	1	1.6
STL12043223	I	B	I	Y	-	-	-	-	-	0	-	-	0	-	-	6[3]	6	6	1	3.7
STL12043223	I	C	I	Y	-	-	-	-	-	0	-	-	0	-	-	2	2	2	1	2.6
Initiation Reach Subtotals								**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**16**	**16**	**16**	**1**	
Reach Summary	**Total Individuals**							**4**	**0**	**4**	**10**	**0**	**10**	**0**	**0**	**61**	**71**	**75**		
	Total Units Present							**1**	**0**	**1**	**3**	**0**	**3**	**0**	**0**	**11**	**12**	**12**		
Overall Reaches + Seeps Summary	**Total Individuals**							**4**	**1**	**5**	**11**	**2**	**13**	**3**	**8**	**131**	**155**	**160**		
	Total Units Present							**1**	**1**	**2**	**4**	**2**	**6**	**1**	**6**	**28**	**32**	**32**		

[1] Unit Type: Reach (R) or Seep (S)
[2] Corresponds to the Unit label letter codes in Table 2.210.
[3] Category: Initiation (I) or Non-terminal (N) reach; see Section 2.1 for a description.
[4] Yes (Y) means that an overland flow connection existed between the seep and Type N channel.
[5] Shortest distance to the Type N channel; a yes (Y) means falls within the indicated category.
[6] Species codes are described in Appendix VI. A dash (-) means species not recorded.
[7] Based on our treatment (see footnote "n" in Section 3.1); actual species richness would increase by one if both Cope's and coastal giant salamanders were among the individuals recorded in these reaches.

Appendix VIII

Aquatic Habitat-Associated Amphibian Species Data[1] from Olympic National Park (adapted from Bury and Adams 2000)

Drainage	Habitat Type	N =	Salamanders[2]									Anurans[3]						Totals	
			AMGR	AMMA	AMsp	DICO	PLVA	PLVE	RHOL	TAGR	Totals	ASTR	BUBO	HYRE	RAAU	RACA	Totals	n =	%
Bogachiel	Seep	58				3	2	4	34		43	1					1	44	6.29
Bogachiel	Stream	31				17		16			33	13					13	46	6.57
Cameron	Seep	14									0	4					4	4	0.57
Dosewallips	Stream	9							1		1	7					7	8	1.14
East Fork Quinault	Seep	22				7		3	9		19	4					4	23	3.29
East Fork Quinault	Stream	7				4			5		9	3					3	12	1.71
Elwha	Seep	47						3	24		27	5					5	32	4.57
Elwha	Stream	28						1	18		19	20					20	39	5.57
Gray Wolf	Pond	16		4	6						10					14	14	24	3.43
Gray Wolf	Stream	9									0	7					7	7	1.00
Hamma Hamma	Pond	18	4	4	10						18			1		14	15	33	4.71
Hoh	Pond	6									0		3	1	2		6	6	0.86
Hoh	Seep	9				1			5		6	1				1	2	8	1.14
Hoh	Stream	9				2			2		4	4					4	8	1.14
Lake Quinault	Seep	9				3			4		7						0	7	1.00
Lake Quinault	Stream	11				7			3		10	4					4	14	2.00
Lyre	Seep	4						1	2		3	1					1	4	0.57
Lyre	Stream	5							4		4	4					4	8	1.14
Morse	Stream	6							3		3	4					4	7	1.00
North Fork Quinault	Pond	2	1								1		1	1		1	3	4	0.57

[1] Data are number of sites (= units) at which a species was found.

[2] Salamander codes: Northwestern salamander, *Ambystoma gracile* (AMGR); long-toed salamander, *Ambystoma macrodactylum* (AMMA); unknown ambystomatid salamander, *Ambystoma* species (AMsp); Cope's giant salamander, *Dicamptodon copei* (DICO); Van Dyke's salamander, *Plethodon vandykei* (PLVA); western red-backed salamander, *Plethodon vehiculum* (PLVE); Olympic salamander, *Rhyacotriton olympicus* (RHOL); and rough-skinned newt, *Taricha granulosa* (TAGR).

[3] Anuran codes: Tailed frog, *Ascaphus truei* (ASTR); western toad, *Bufo boreas* (BUFO); Pacific treefrog, *Hyla* (now *Pseudacris*) *regilla* (HYRE), northern red-legged frog, *Rana aurora aurora* (RAAU), and Cascade frog, *Rana cascadae* (RACA).

Appendix VIII (continued)

Aquatic Habitat-Associated Amphibian Species Data from Olympic National Park (adapted from Bury and Adams 2000)

Drainage	Habitat Type	N =	Salamanders									Anurans						Totals	
			AMGR	AMMA	AMsp	DICO	PLVA	PLVE	RHOL	TAGR	Totals	ASTR	BUBO	HYRE	RAAU	RACA	Totals	n =	%
North Fork Quinault	**Seep**	**34**				**2**			**17**		**19**	**2**					**2**	**21**	**3.00**
North Fork Quinault	Stream	15				7	1		9		17	9					9	**26**	**3.71**
North Fork Soleduck	**Seep**	**9**							**3**		**3**	**2**			**1**		**3**	**6**	**0.86**
North Fork Soleduck	Stream	8				7			8		15	7					7	**22**	**3.14**
Queets	Pond	18	6		5	3				2	16		2	2	2	8	14	**30**	**4.29**
Queets	**Seep**	**8**				**1**			**8**		**9**	**2**	**1**				**3**	**12**	**1.71**
Queets	Stream	5							3		3	2	1				3	**6**	**0.86**
Quillayute	Pond	1	1								1				1		1	**2**	**0.29**
Skokomish	Pond	7			1					1	2					3	3	**5**	**0.71**
Skokomish	**Seep**	**13**						**1**	**3**		**4**						**0**	**4**	**0.57**
Skokomish	Stream	7				2		1	3		6	2					2	**8**	**1.14**
Soleduck	Pond	131	27	34	46	1				4	112	1	5	2		73	81	**193**	**27.57**
Soleduck	**Seep**	**8**							**1**		**1**	**1**					**1**	**2**	**0.29**
Soleduck	Stream	18				5			9		14	11					11	**25**	**3.57**
Species Totals		**602**	**39**	**42**	**68**	**72**	**3**	**30**	**178**	**7**	**439**	**121**	**13**	**7**	**6**	**114**	**261**	**700**	
Habitat Type Species Totals	Ponds	199	39	42	68	4	0	0	0	7	160	1	11	7	5	113	137	199	
	Streams	168	0	0	0	51	1	18	68	0	138	97	1	0	0	0	98	168	
	Seeps	**235**	**0**	**0**	**0**	**17**	**2**	**12**	**110**	**0**	**141**	**23**	**1**	**0**	**1**	**1**	**26**	**235**	
Percent of Habitat Type Total (%)	Ponds	33.1	19.6	21.1	34.2	2.01	0.0	0.0	0.0	3.5	80.4	0.5	5.5	3.5	2.5	56.8	68.8	100.0	
	Streams	27.9	0.0	0.0	0.0	30.4	0.6	10.7	40.5	0.0	82.1	57.7	0.6	0.0	0.0	0.0	58.3	100.0	
	Seeps	**39.0**	**0.0**	**0.0**	**0.0**	**7.2**	**0.9**	**5.1**	**46.8**	**0.0**	**60.0**	**9.8**	**0.4**	**0.0**	**0.4**	**0.4**	**11.1**	**100.0**	
Percent of Species Total (%)	Ponds		100.0	100.0	100.0	5.6	0.0	0.0	0.0	100.0	36.5	0.8	84.6	100.0	83.3	99.1	52.5		
	Streams		0.0	0.0	0.0	70.8	33.3	60.0	38.2	0.0	31.4	80.2	7.7	0.0	0.0	0.0	37.6		
	Seeps		**0.0**	**0.0**	**0.0**	**23.6**	**66.7**	**40.0**	**61.8**	**0.0**	**32.1**	**19.0**	**7.7**	**0.0**	**16.7**	**0.9**	**10.0**		

[1] Data are number of sites (=units) at which a species was found.

[2] Salamander codes: Northwestern salamander, *Ambystoma gracile* (AMGR); long-toed salamander, *Ambystoma macrodactylum* (AMMA); unknown ambystomatid salamander, *Ambystoma* species (AMsp); Cope's giant salamander, *Dicamptodon copei* (DICO); Van Dyke's salamander, *Plethodon vandykei* (PLVA); western red-backed salamander, *Plethodon vehiculum* (PLVE); Olympic salamander, *Rhyacotriton olympicus* (RHOL); and rough-skinned newt, *Taricha granulosa* (TAGR).

[3] Anuran codes: Tailed frog, *Ascaphus truei* (ASTR); western toad, *Bufo boreas* (BUFO); Pacific treefrog, *Hyla* (now *Pseudacris*) *regilla* (HYRE), northern red-legged frog, *Rana aurora aurora* (RAAU), and Cascade frog, *Rana cascadae* (RACA).