Summary of Headwater Perennial Stream Surveys

in the Skagit and Neighboring Basins: 2001 - 2003

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Introduction and Objectives

The location of perennial and seasonal reaches of non-fish-bearing streams in Washington timberlands has been of particular interest during and since the development of the Forest and Fish Report (FFR) in 1998. Under the current Washington Forest Practices Rules (WFPB 2001), modified to conform to the FFR in 2001, perennial reaches ("type Np waters") receive greater protection from forest practices than do seasonal reaches ("type Ns waters"). In the context of water typing, the Np type applies to any waters as downstream of the highest surface flow, regardless of whether or not all intervening reaches have year-around surface flow. The FFR provides cursory field criteria and basin area methods for field application of water types, though the scientific basis for default basin areas has been questioned.

An improved understanding of flow regimes and associated basin areas of headwater streams was the goal of previous studies by the Skagit System Cooperative (SSC) in northwest Washington (Veldhuisen 2000) and similar recent studies (e.g. Liquori 2001, MacCracken and Boyd 2002, Pleus et al. 2003, Jaeger 2004) elsewhere in Washington. SSC participated in the 2001 CMER perennial stream study (Palmquist 2003) and the findings from the 25 SSC sites were analyzed among 200+ sites visited by the many cooperators involved. This document summarizes the 2001 SSC results to provide more detailed analysis of the SSC data set and to provide context for subsequent observations at the same headwater sites in 2002 and 2003. Our objectives in 2002 and 2003 were to evaluate year-to-year differences in the spatial distribution of dry season surface flow. In particular, we were interested in relocating the highest surface water in each channel (AKA "Pd" in CMER study), which indicates the regulatory break between type Np and Ns waters.

Hydrologic Conditions during Study

Although streams are typed as perennial if they "do not go dry any time of a year of normal rainfall" (WFPB 2001, see WAC 222-061-031 (4)), making this determination is seldom straightforward because every water year includes a unique sequence of spatially varying precipitation events. Flow rates within headwater streams are observed to be seasonally variable in response to varying rates of water delivery from precipitation, soils, wetlands and/or deeper sources. Because different pathways involve widely varying lag times before water appears in the channel, determining the time period in which relevant moisture inputs arrived is problematic. Although it would be highly informative to evaluate whether flows were "normal" during survey periods on the basis of flow gauging, rather than precipitation, we are not aware of any active gauges on comparable headwater streams (forested basins of 0-10 ha). In contrast, flows in actively-gauged rivers (e.g. Skagit River) bear limited resemblance to headwater conditions due to the influence of hydro-power flow regulation, glacial melt and deep groundwater inputs that don't affect most headwaters.

For this reason, year-to-year differences were evaluated on the basis of precipitation at Sedro Woolley, a long-term (1931-to-present) weather station in the lower Skagit watershed (Figure 1). Although average annual precipitation at Sedro Woolley is about half of that at many study sites (1170 mm vs. 2140 mm), experience suggests it reasonably reflects seasonal and year-to-year precipitation patterns for the study area and allows them to be viewed within a multi-decadal historical context. Significant contrasts in precipitation inputs at Sedro Woolley are evident between water years 2001, 2002 and 2003, as shown in Figure 2. Precipitation amounts during individual summer month are segregated in Figure 2 because we have observed that low flows in small streams are more

Figure 1. Location of headwater stream sites in the Skagit basin surveyed in 2001 and 2003. Stream network is truncated in extensive portions of the basin that are in Federal ownership and thus are not subject to Forest Practices Rules.

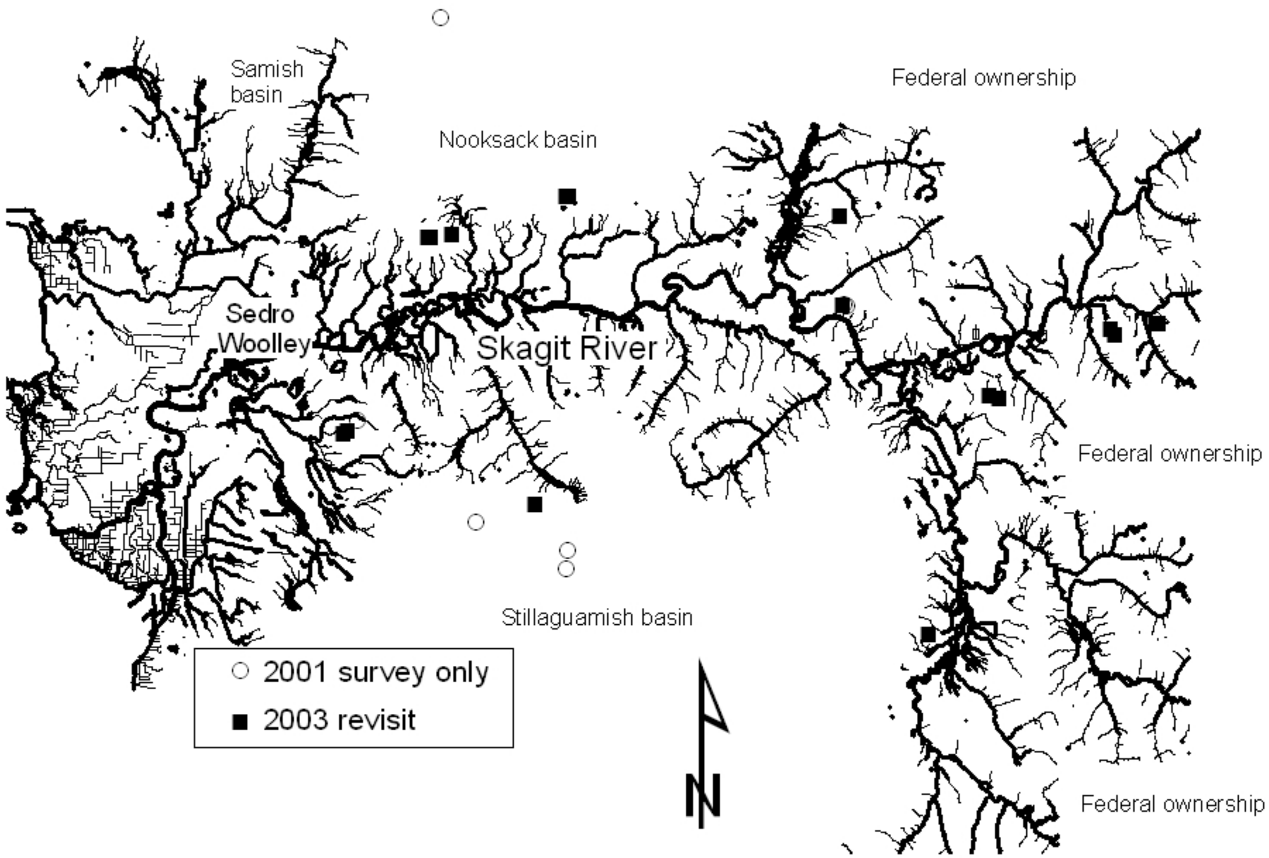

Table 1. Characteristics of headwater perennial stream study sites in the Skagit basin in 2001, 2002 and 2003.

	Basin attributes:			2001					2002		2003		
				CH	HSW		HCSW		HSW		HSW		
Site number	Average annual precip.	Litho-logy	Forest age	Basin area*	Distance below CH	Basin area*	Distance below CH	Basin area*	Distance below CH	Basin area*	Distance below CH	Basin area*	Comments
	mm			ha	m	ha	m	ha	m	acres	m	ha	
3A	2769	MS	I	0.7	0	0.7	20	0.9			0	0.7	
18A	1956	MS	I	0.8	56	1.2	116	1.5			56	1.2	
18B	1956	MS	C	0.8	0	0.8	0	0.8			7	0.8	
23B	2108	QD	M	1.4	0	1.4	112	1.9			0	1.4	
23C	2108	QD	M	0.5	27	0.5	no data				27	0.5	No HCSW located in 2001
23D	2108	QD	M	1.2	0	1.2	0	1.2					No access in 2003
28A	1880	P	C	1.3	0	1.3	0	1.8	0	1.3	0	1.3	
28B	1981	P	M	0.7	50	0.9	321	1.9	50	0.9	50	0.9	
28C	2134	P	M	0.6	64	0.8	1586	11.6					Road piracy
40A	1956	P	C	0.6	0	0.6	380	3.3			0	0.6	
40W	1956	MV	C	3.8	0	3.8	0	3.8			0	3.8	
41A	1905	P	M	3.9	0	3.9	248	13.6	28	3.9	28	3.9	
41B	1905	P	M	3.5	35	3.5	160	8.8			35	3.5	
47W	1854	P	C	0.9	0	0.9	727	11.5			0	0.9	
63A	2159	P	M	1.7	6	1.7	88	2.7					No access in 2003
67A	2515	MS	M	2.7	0	2.7	343	15.1					No access in 2003
67B	2667	MS	M	1.0	0	1.0	234	6.2					No access in 2003
71A	2388	MV	M	0.6	52	1.0	223	5.3					No access in 2003
77C	2565	P	M	0.7	30	0.9	986	10.5			211	4.5	
83A	2616	P	M	0.7	0	0.7	no data		52	0.7	22	0.7	No HCSW located in 2001
83W	2616	P	M	0.9	0	0.9	370	3.1	0	0.9	501	3.8	
88A	1905	P	C	0.8	225	7.8	650	63.5			223	7.8	
105A	1828	MS	I	6.9	0	6.9	0	7.3			0	6.9	
105B	1828	MS	I	2.6	0	2.6	0	2.6					No access in 2003
105C	1828	MS	I	2.6	0	2.6	143	3.3					No access in 2003
			n:	25	25	25	23	23	5	5	17	17	
			average:	1.7	22	2.0	292	7.9	26	1.6	68	2.5	
			median:	0.9	0	1.2	160	3.3	28	0.9	22	1.3	

CH=Channel Head, HSW=highest surface water, HCSW=highest continuous surface water

Lithology categories: MS=meta-sedimentary, QD=quartz diorite, P=phyllite, MV=meta-volcanic

Forest categories: C=clearcut (0-5 years), I=immature (5-40), M=mature (40+).

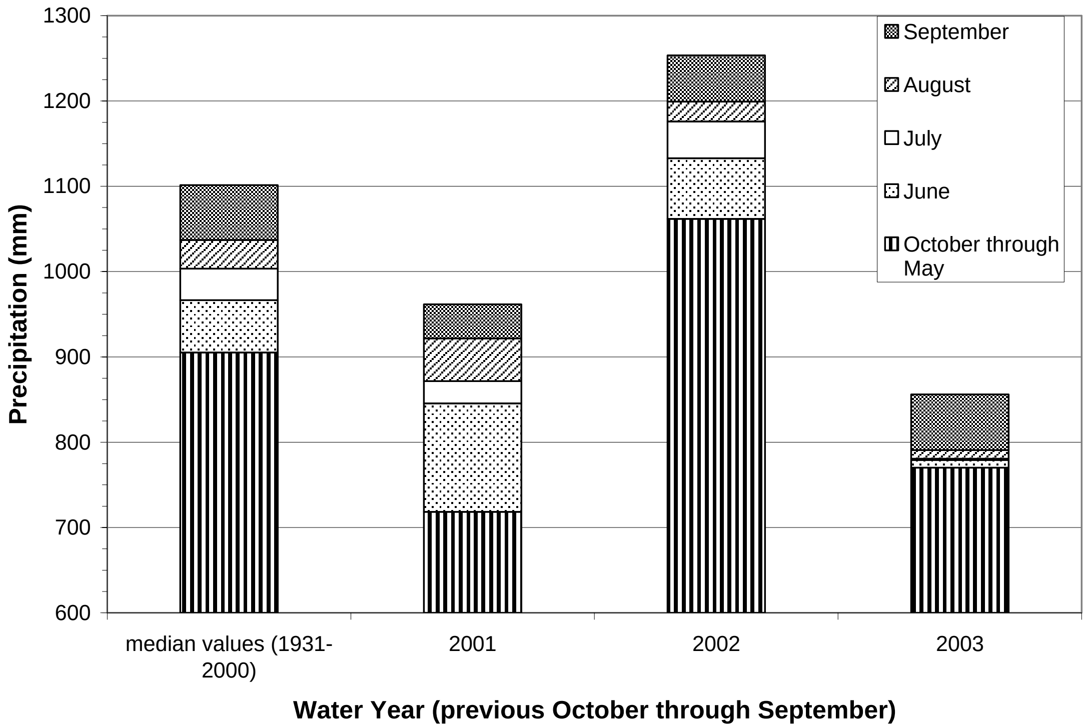

Figure 2. Precipitation recorded in Sedro Woolley in water years 2001, 2002, and 2003 used to evaluate hydrologic conditions during the perennial stream studies. WaterYear 2001 included a dry winter followed by a somewhat wet summer; 2002 had a somewhat wet winter and typical summer; while 2003 had a dry winter followed by an unusually dry summer. Convert amounts into inches by dividing mm values by 25.4.

strongly influenced by precipitation within the previous months than by earlier inputs. Water Year (WY) 2001 was mixed in that an unusually dry (i.e. $<25^{th}$ percentile) fall-winter-spring was followed by a somewhat wet summer (between 50 and 75^{th} percentile). In 2002, Sedro Woolley had a wetter than average fall-winter-spring followed by typical precipitation during the summer months (Figure 2). WY 2003 was unusually dry throughout, with a dry fall-winter-spring period followed by the second driest summer (June/July/ August combined total of 21 mm = 0.81 inch) since record-keeping began in 1931.

Methods

All study sites are distributed across FFR-regulated timberlands (state and private ownership) in the Skagit basin and closely adjoining areas (Figure 1). The 25 sites visited in 2001 were initially located by proximity to streams randomly selected for a prior wind-throw study. Many sites are located in clusters of two or three because of ease of access. The sites were located on a Geographic Information System using maps and aerial photos and relocated in 2002 and 2003 on the basis of remaining flagging and string.

The 2002 effort involved revisiting five sites with easy access. The more extensive 2003 effort included all 17 of the 2001 sites for which landowner access was provided. The 2002 and 2003 revisits documented flow conditions using categories slightly modified but compatible with the 2001 CMER protocols (revised protocols documented in Appendix A in Pleus and Goodman, 2003). Surveys extended 200 m downstream from the channel head or to the highest perennial water, whichever was farther. At some sites, 200+ m of continuous surface flow was encountered, which infers that the uppermost point of continuous flow (AKA "Pp" using CMER protocols) had been documented. None of the channel attributes collected in 2001 were re-measured on the assumption that channel conditions had not changed appreciably, an assumption we found to be reasonable. All surveys were conducted between early August and early October during the late summer low flow season.

Most study streams are not shown on the DNR "hydro" layer or other stream maps. We located sites visually on ortho-photos and estimated basin areas for highest surface water using 10-m digital elevation models (DEMs). Because the topographic relief separating adjacent headwater basins is often less than the minimum resolution of these DEMs, the accuracy of basin area estimates is moderate. This document uses medians to represent the central tendency of attributes which are skewed; average values are provided in Table 1.

Results and Discussion

Location of Highest Surface Water

Despite some differences, we observed remarkable consistency in the highest surface water (HSW) at low flow conditions during the three different water years (Table 1). As in 2001, the HSW in 2002 and 2003 was observed in close proximity to the channel heads at most sites. At 14 of 17 (82%) of revisited sites, the HSW was observed within 60 m of the channel head during all visits (Figure 3), most notably during drought conditions in 2003. At two sites, the HSW was found within 30 m of the channel head in 2001 and 2002, but was 200-500 m downstream in 2003. Still, this downstream jump was observed at a minority of sites and it appears likely that field water type determinations at the majority would be consistent between years of markedly differing rainfall amounts, so long as the investigation extends to the channel heads. From experience, we have found that surveys that do not proceed to the channel head have a high likelihood of misidentifying the highest surface water at a dry segment downstream (discussed further later in this report) of the highest surface water. Although the basin areas above the highest surface water at the two shifting sites increased from 0.9 in 2001 to around four hectares in 2003, central tendencies among basin areas for all sites changed relatively little (Table 1). The median (1.2-1.3 ha = approximately 3 acres) and average (2.0-2.5 ha = approximately 5-6 acres) of all basin areas are around one-tenth of the regulatory default value (52 acres) for the study area.

Location of Highest Continuous Surface Flow

Although the 2002 and 2003 revisits did not locate the highest continuous surface water (or "HCSW", defined as >200 m of continuous water) at all sites, some observations are worth reporting. The CMER report (Palmquist 2003) which included the 2001 SSC data, concluded that the location of the HCSW (referred to as "Pp") is more variable between streams than is the highest surface water, in terms of both basin areas and the distance downstream from channel head. Our limited 2002-03 data (Table 1) suggest that this pattern holds true for our study area and also indicates that the HCSW point is more variable between years, as over half of the 2003

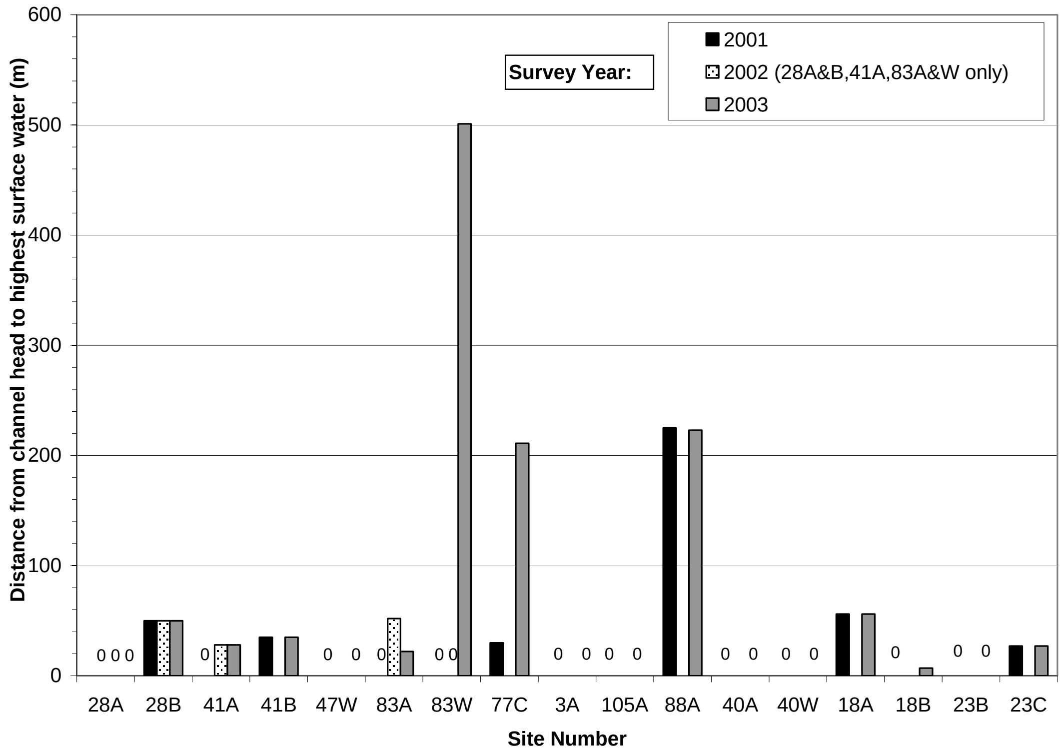

Figure 3. Downstream distances from channel head to the highest surface flow during summer low-flow seasons of 2001, 2002 and 2003 (adjacent bars). At most sites, surface water was observed within 100 m of the channel head even during the very dry year of 2003. The lengths represented by the bars are the total length of type Ns water in the study streams. Sites are ordered by site location left to right along the X-axis from west to east.

HCSW locations were 200 m or more downstream from those observed in 2001 (Table 1). The sites in which the HCSW was not located in 2003 would only increase this variability as the undocumented HCSW points were downstream of the lower end of the 2001 survey. When in-channel flows reach very low levels, as many did in 2003, localized gravel accumulations provide sufficient inter-gravel flow capacity to interrupt surface flow and thus shift the HCSW downstream to the lowest interruption, as documented by Hunter et al (2004).

Changes in the Spatial Arrangement of Surface Water

A larger portion of the resurveyed channel segments were dry in 2002 than 2001, though the extent of 2002 surveys was insufficient for detailed comparison. Typical examples of “drier” channel conditions would include patchy flow in a segment which previously had continuous surface flow, or a dry bed where patchy flow had been observed. Among the larger pool of sites resurveyed in 2003, 37% of segment-scale flow categories were drier than in 2001; most of the rest were the same flow category. By comparing year-to-year differences among segments revisited in 2002, it appears that flow rates during 2002 surveys were lower than in 2001 and lowest of all in 2003. The low precipitation rates throughout the 2003 water year (Figure 2) provides a basis for the dry flow conditions during the 2003 surveys. The lower flow observed in 2002 than 2001 was more unexpected and suggests that rainfall occurring during early summer, rather than the previous winter, is most critical in sustaining late summer low flows. Given the dry winter prior to the 2001 surveys, it appears that the substantial rains in June and in August (several weeks prior to many surveys) may have elevated the low flows observed during August and September surveys. Low flows in 2002 were less because of the absence of above-normal summer months (Figure 2), which allowed a prolonged period of soil moisture drainage without the soil moisture recharge that occurred in summer 2001. The increasing occurrence of "fragmented" surface flow observed in drier years 2002 and 2003 is consistent with the pattern of seasonal flow recession observed in southwest Washington by Hunter et al. (2004). As mentioned in the previous paragraph, our notes show certain locations where surface flow was interrupted each year due to greater subsurface flow through a segment-scale (~10-50 m) length of thicker gravel in the bed due to a landslide deposit or concentration of woody debris.

Headwater Flow Categories and Seasonal and Lithologic Influences

Although we have not attempted to explore the implications of basin geometry or slope gradient in this paper, there is some value in categorizing study sites based on their observed flow pattern (Palmquist 2004). Our sites can be divided into three flow categories, defined as follows. Sites in which sufficient flow originates at or near the channel head to support continuous surface flow for 100+m were categorized as "springs". Sites in which surface flow originating near the channel head is spatially discontinuous were categorized as "headwater seeps". The few remaining streams which were dry from the channel head for 100+m until a point where spatially discontinuous flow began were termed "mid-channel seeps".

Of the 17 sites visited in 2001 and 2003, most sites fell into the same flow source category both years. Of the seven "springs" in 2001 (41%), one shifted to the seep category in 2003 due to fragmented surface flow. Of the nine headwater seeps observed in 2001, two shifted to the mid-channel seep category in 2003 because the headwater seep was dry and surface flow began in-channel several hundred meters downstream, as discussed previously. These two sites are especially relevant to water typing implementation because they represent the atypical situation where the apparent Np/Ns type break location differs substantially between years. The basins above both of the headwater seeps were relatively small (0.9 ha or 2 acres) and steep (40-70%) though not unique in either regard. The one "mid-channel seep" in 2001 had a similar a long dry headwater segment in 2003.

Our observations support the finding that prevalent headwater flow categories differ between bedrock types, as has been observed in southwestern Washington (Jaeger 2004). The 12 phyllite sites were mostly categorized as headwater seeps (67% in 2001) but also included all three of the in-channel seep sites (including the two 2001 headwater seeps that were dry in 2003). This suggests that streams on phyllite hillslopes occasionally include a sizable dry headwater reach that would be considered type Ns water. In contrast, most of the sites within the other common (n=8) rock type – meta-sedimentary rocks – were categorized as springs in both years. Where exposed, local meta-sedimentary rocks are well fractured though generally competent and as such, may have similar hydraulic properties to the marine basalts in SW Washington in which Jaeger (2004) observed perennial springs at channel heads. We included too few sites in other rock types to make similar generalizations, though we have noticed perennial flow from channel head springs along the toe of ancient landslides deposits, presumably due to deep moisture storage. Similarly, we have observed headwater springs with relatively small basin areas (median=1.3 ha) along terrace faces of deep glacial sediment deposits in the central Skagit basin (Veldhuisen 2000).

Summary of Key Conclusions

Conclusions relating to surface water in headwater streams during summer low-flow conditions:

- **Perennial flow typically occurs near channel heads:** The location of the highest surface water was generally at or within 100 m downstream of the channel heads in all years. Channel heads probably represent locations where subsurface drainage is preferentially forced to the surface at a range of flow levels.
- **Location of highest surface water does not differ much between years of widely differing precipitation amounts**: The location of the highest surface water was relatively stable between 2001, 2002 and 2003 summer dry seasons at most sites. This suggests that headwater seeps and springs typically maintain some surface flow during extended droughts. It further suggests that basin areas for the highest surface water would be similar to 2001 values in any water year.
- **Spatially intermittent reaches are common, especially during dry years:** Stream segments with dry or patchy surface water are common during summer low flow conditions (>100 m of channel length at 61% of sites surveyed in 2001) and extend further downstream during an unusually dry summer. At low flow levels, surface water is easily interrupted at channel segments where the entire flow infiltrates into the bed material.
- **Summer surface flow largely reflects precipitation that occurred within spring and early summer months, rather than the previous winter:** Rainfall occurring during the previous June, July, and August, appears to be a better indicator of low flows in late August and September than is precipitation from the preceding winter.

Water typing implications for streams represented by our study sites in the northwest Cascades:

- **Most headwater stream length is type Np:** Most headwater streams are continuous perennial or spatially intermittent to within 100 m of the channel head and thus nearly their full length would be considered type Np. Correspondingly, headwater dry reaches considered Ns waters are limited in extent (4 to 14% of the uppermost 500 m of channel length, depending on year).
- **Basin areas above field-located Ns/Np breaks are around one-tenth of the regulatory default value:** The median and average basin areas from our sites were three and six acres respectively, relative to the west Cascade regulatory default value of 52 acres.
- **No year-around field indicators of the Ns/Np break were identified**: Aside from proximity to the channel head, we did not identify any year-around field indicators (plants, channel dimensions, etc.) that would be definitive.
- **Field efforts to determine the upper limit of Np water must observe in-channel flow conditions to the channel head to be reliable**: Although many segments of the study streams were observed to be dry, most dry segments were downstream of perennial segments and thus are within spatially intermittent Np waters. Year-to-year differences in rainfall amounts appear to have little effect on the location of the upper end of Np waters, however.

Acknowledgement

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