Snohomish County Public Works Department

Surface Water Management Division

Watershed and Habitat Monitoring and Analysis Project

Snohomish Basin 2007 Status and Trend Monitoring of Physical Habitat for Fish

Working together for people, streams & fish.

Snohomish County

PUBLIC WORKS
SURFACE WATER MANAGEMENT
(425) 388-3464

www.surfacewater.info

ACKNOWLEDGEMENTS

Department of Public Works

Steve Thomsen, P.E., Director

Surface Water Management (SWM) Division

David Brookings, P.E., Director
Kathy Thornburgh, Water and Habitat Sciences Manager

Recommended Citation:
Leonetti, F.E., A.C. Thomas, B. Gaddis, M.D. Rustay, and A.D. Haas. 2008. Snohomish Basin 2007 Status and Trend Monitoring of Physical Habitat for Fish. Snohomish County, Public Works, Surface Water Management, Everett, WA.

Contributing Staff
The following people have made significant contributions to this project and the completion of this report: Michael Purser, Rob Simmonds, Tim Walls, Mike Cooksey, and Josh Kubo.

Report Inquiries:

Inquires regarding this report should be directed to:

Snohomish County Public Works
Surface Water Management Division
3000 Rockefeller Avenue, MS-607
Everett, WA 98201-4046
Phone: (425) 388-3464
Fax: (425) 388-6455
Contact: Frank Leonetti or Andy Haas

Table of Contents

List of Figures and Map

List of Tables

Executive Summary

To support salmon recovery in watersheds, Snohomish County Surface Water Management (SWM) conducts habitat monitoring in streams and rivers with the goal of documenting the current status and changing trends in salmon habitat quality and quantity. Wadeable stream habitat monitoring previously conducted by SWM directly supported salmon recovery planning by documenting stream condition status and comparing these results to regional performance standards for habitat quality. This analysis contributed to the evaluation of habitat limiting factors and informed the development of habitat protection and restoration strategies. Following the adoption of the Salmon Recovery Plan by NOAA in 2007, SWM's habitat monitoring program has focused on trend detection to evaluate if salmon recovery plan implementation is leading to habitat quantity and quality improvements identified in the Plan's goals.

In addition to trend detection, the monitoring strategy is designed to provide useful and relevant information to inform conservation and restoration decision-making and adaptive management pertaining to the following questions;

1. How does land use/land cover affect instream physical habitat conditions in Snohomish County?
2. What fraction of existing habitat conditions compare favorably or unfavorably to habitat performance standards and local targets?
3. Where are good and poor habitats located? Where will good and poor habitats remain over time?
4. How effective and suitable is the survey methodology developed for this analysis?
5. What restoration or protection needs (i.e., location or amount) can be identified based on the monitoring data and what restoration or protection needs change over time?

This document reports the results of wadeable stream monitoring conducted in 2007 in the Snohomish River basin (Watershed Resource Inventory Area 7). Status and trend monitoring allows for comparison of habitat conditions to selected performance standards to evaluate monitoring results. In this way we can answer whether habitat conditions for fish are functioning, impaired or degraded and assess the variability in condition by several independent factors (such as, location and land use). It also allows for the detection of trends in habitat conditions to be described based on performance (e.g.; % improvement) over time. Both allow comparisons of monitoring results over time to Salmon Recovery Plan-specific habitat targets where those have been described. Thus, monitoring results support adaptive management decision-making.

A random sampling approach enables us to extrapolate our results more broadly to streams that contain important spawning and rearing areas for ESA-listed salmon populations. We employed a relatively rapid assessment of key habitat parameters that relies on quantitative measurement to maximize precision and repeatability. Results from the 2007 wadeable stream monitoring program allow us to characterize the habitat status of sampled streams within the sampling frame in Snohomish County and to evaluate the likely sensitivity of habitat parameters to trend detection.

Key findings are summarized in the following Table based on the proportion (%) of reaches in each category of habitat function (good, fair, and poor). This Table is followed by descriptions of conditions or results from additional analysis for each habitat indicator. Results are strongly influenced by stream width and surrounding land use (designated forested or non-forested land use types) and depend on which habitat standards are applied.

		Function	
	Good	Fair	Poor
Bank stability	56%	27%	18%
Bank Modifications	50%	43%	7%
Mid-channel Canopy Cover	33%	67%	
Fox and Bolton’s (2007) LWD frequency criteria	0%	10%	90%
Number of pieces per 100m of Channel Length	0%	0%	100%
Pool Area, % (WFPB 1997)	27%	30%	43%
Pool Frequency, Pools/CW (WFPB 1997)	17%	50%	33%
Pool Frequency, Pools/mile (NMFS 1996)	70%	30%	
Pool depth (NMFS 1996) - Sufficient deep pools >1 m	17%	83%	
Exceed 25% composition in fines and sand <2mm	50%	50%	

- Streambank Conditions - Seven out of 30 sites (24%) were properly functioning for both bank modifications (<5%) and degree of instability (<10%). Nearly half of our sites contained 20-40% underlying bank instability (instability + modifications) and some indication that bank instability (averaging about 10%) is present no matter the amount of bank modifications. This suggests bank modifications placed to stabilize banks will not limit instability across a remaining 10% of the stream reach, except when modifications are very extensive (i.e., two instances where bank armoring exceeded 30% in our sample). Otherwise bank armoring may lead to bank instability by displacing stream energy to other areas.

- In-stream/ Streambank Cover – The data showed a relationship between instream riparian cover values (as a percentile range) and bankfull width. Width proved useful as a diagnostic criterion, especially with relevance to cover provided by forested reaches. Reduced cover appears to be similar among stream widths, but may influence temperature more significantly for streams <10 meters width, where cover is expected to be naturally higher (>70%) compared to larger streams, low flow water depth is shallow, and shallower pools (<<1m) have less thermal resistance to heating.

- Instream Wood - Wood abundance was strongly correlated with increasing survey length among forested reaches only. Among non-forested reaches, total wood count appeared to be largely independent of survey length. This suggests predictable woody debris frequency or spacing is absent where non-forested land uses are present. On average, woody debris frequency (for all wood size classes) was 242 pieces/km. We did, however, find that wood load (# per unit channel area) was significantly greater in forested reaches than non-forested reaches where bankfull width exceeded 10 meters. Larger instream wood was found in reaches associated with forested land use. Nonetheless, no reaches met habitat performance criteria for woody debris volume (m^3). We found only 3 out of 30 reaches met the median woody debris frequency value predicted by Fox and Bolton (2007). Although we compare our results to the National Marine Fisheries Service (NMFS - 80 pieces/mile) and Washington Forest Practices Board (WFPB – 2 pieces/channel width), these criteria don't consider criteria for large woody debris frequency, these criteria are not applicable to our sample frame, nor are these criteria still supported by best available science (i.e., Fox and Bolton 2007).

- Habitat Units – We identified and measured 289 individual pools. For most streams, percent pool area ranged from 27 to 57% (the average was 43%) of the total reach area, and percent riffle area ranged from 34 to 60%. Pool area decreased with increasing stream width, and riffle area was positively correlated. Glide area was higher than 40% in a few reaches, but commonly composed less than 15% percent of the reach. Because applying different diagnostic pool criteria proved to be not useful, we will focus on trends in changing pool frequency and area over time rather than rely on these criteria. The most common pools were free-formed and wood-formed, each category comprising at least a third of the pools. Pools formed by rip rap and bedrock tended to be among the deepest and largest pools. However, relative to their size, wood-formed pools are deeper (on a per area basis), suggesting woody debris is most efficient per area affected (and length of stream) at turning gravel streambed into pool habitat. Pool frequency (spacing) was significantly correlated with woody debris frequency for forested reaches based on a negative exponential relationship but non-significant for non-forested reaches where frequent pool spacing may exist associated with total reach bank modifications exceeding 10%.

- Side Channels - Sixteen of the 30 reaches contained side channels. Among those containing side-channels, mean total side channel area was 10% of the main-channel area. Mean side channel wet area was 130 m^2 per occurrence, while the mean total side channel area was 602 m^2 among reaches containing side channels. Trends in side channel abundance and characteristics may be challenging to interpret if any are observed and changes among years may be highly variable based on interceding flood events, sedimentation, channel switching, or other factors.

- Substrate size - The fine fraction (<2mm) of the bed has the greatest potential to limit salmonid egg incubation (e.g., from suffocation) and be detrimental to juvenile rearing (e.g., from loss of pool habitat). Cumulative distribution curves revealed that six (6) reaches were dominated by substrate <2mm. Otherwise, approximately 50% of the cumulative reach length (15 out of 30 reaches) exceed 25% composition of fines and sand <2mm, suggesting that these stream reaches fail habitat performance criteria given by NMFS and WFPB.

Key findings regarding the utility of habitat parameters to detect trends include:

- Percent bank modification, center channel riparian cover, bankfull width, and pool depth had the highest precision and repeatability. These parameters are expected to be most sensitive to change – we can be most confident in being able to detect smaller degrees of change with minimal lag time in our ability to detect change after it has occurred. Hence, we believe they will have the most value for early adaptive management responses.

- Parameters that are measured with moderate precision and repeatability include pool count and frequency (calculated metric based on pool count), woody debris frequency (based on wood count), and total pool area.

- Low measurement precision and repeatability of some parameters (percent fine sediment, side channel area) suggests there will be low power to detect trends over time. For these parameters, more time will likely be required to evaluate whether detectable and significant change (i.e., enhancement or degradation) is occurring and may require more detailed sampling and analysis.

As a next step, we will estimate interannual variance by performing limited sampling in 2008. Based on this future work, an estimate of analytical power to detect trends based on hypothetical trends in condition (1-2% change per year) will be generated in order to estimate time required to detect real trends. Of course, repeat visits in future years will begin to establish the direction and rate of actual change observed to compare to habitat benchmarks for adaptive management decision-making. Also, measurement precision may be improved by enhancements to our protocol or additional training which we will consider as part of our scope of work in 2008.

Introduction

In 2007, The Federal Government (NOAA) adopted the Puget Sound Salmon Recovery Plan which contains chapters for each of Snohomish County's watersheds. Development of habitat recovery activities for each of these watershed chapters was dependent, in part, upon documenting watershed and habitat limiting factors contributing to species listings under the Endangered Species Act (ESA). The conditions of wadeable streams and rivers in Snohomish County relative to regional performance standards for habitat quality and quantity were documented in numerous reports (Snohomish County 2002a; Snohomish County 2002b; SRBSRTC 2002; STAG 2002), many supported by this project since 2000. Findings contributed substantially to describing the status of habitat for recovery planning purposes to address habitat as a major listing factor. In 2008, the goals of this monitoring program are both to describe the status of habitat conditions for salmonid fishes in Snohomish County rivers and streams and track watershed and habitat trends over time.

Work implemented under this program seeks to contribute to successful long term adaptive management for aquatic resources in Snohomish County by providing foundational watershed and habitat monitoring information and analysis to inform conservation and restoration decision-making and adaptive management as the watershed plans are implemented (Figure 1). Fundamental components of this monitoring program include watershed land cover condition assessment, wadeable stream survey, and remote- and field-based large river habitat assessment. The components are capable of serving multiple management objectives:

1. Salmon conservation plan implementation;
2. Capital project development and monitoring;
3. GMA/SMA/CAO updates and code development; and
4. Integration of salmon, drainage, flood hazard planning and implementation.

This report includes wadeable stream monitoring results from project work implemented in 2007 that forms the baseline for future habitat trend detection. Wadeable stream monitoring is a component of Cumulative Effectiveness Monitoring, which evaluates both impacts and enhancement at multiple scales by synthesizing information concerning status and trend and project effectiveness. Project effectiveness documents the specific effectiveness and outcomes of individual projects implemented (as recommended by Salmon Recovery Plans). Status and trend monitoring complements project effectiveness monitoring by assessing general habitat conditions over a larger scale in order to document the cumulative response of habitat and biological indicators to both upland and instream activities that affect stream habitat (i.e.; capital improvement projects, buffer protections, and land-use on the watershed scale). Based on the scope and scale, cumulative effectiveness monitoring is intended to answer the overarching question,

Is the sum of all actions within a basin or across the watershed improving trends in physical habitat conditions for ESA-listed salmon populations?

Supporting questions include;

1. How does land use/land cover affect instream habitat conditions in Snohomish County?
2. What fraction of existing habitat conditions compare favorably or unfavorably to habitat performance standards and local targets?
3. How effective and suitable is the survey methodology developed for this analysis?
4. Where are good and poor habitats located? Where will good and poor habitats remain over time?
5. Do monitoring data help identify restoration or protection needs (i.e., location or amount) and changes over time?

Understanding cumulative effectiveness is dependent upon summarizing the status and trends of key watershed and habitat indicators (Figure 2) that affect biological responses. It is also dependent upon documenting the specific effectiveness of individual projects implemented as recommended by Salmon Recovery Plans, though this is beyond the scope of this monitoring program.

Recovery Plan/Adaptive Management Context

For salmon recovery implementation, the results or "effects" on habitat can be evaluated using key indicators weighed against Plan goals or future targets (Habitat Benchmarks in Figure 1) to help inform whether or not the strategy is leading to expected outcomes and whether Adaptive Management responses are needed.

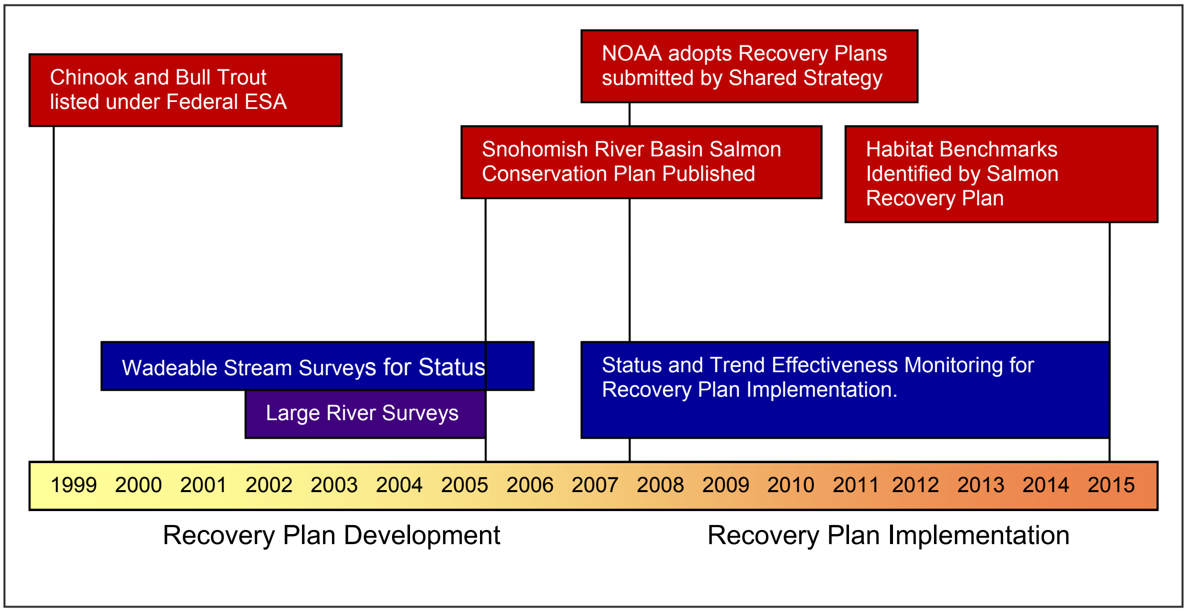


Figure 1: General timeline of major Recovery Plan development activities (ESA listing, planning, and status monitoring) and Recovery Plan implementation (Plan adoption, trend monitoring, and benchmark time point) representing crucial inputs for Adaptive Management.

The Puget Sound-wide monitoring and adaptive management process supporting the federally adopted Puget Sound Salmon Recovery Plan is unknown at this time. However, monitoring efforts in Snohomish County are consistent with the proposed regional monitoring framework. Fundamentally, local data are critical for addressing key uncertainties and informing adaptive management decision-making within Snohomish County watersheds, which will occur after 10 years of plan implementation (Figure 1), at which time monitoring results can inform the following questions;

1. Are the correct and most important habitat listing/limiting factors affecting salmon population recovery at various life stages being addressed?

2. Are the hypotheses related to habitat strategies and actions (in reaches, subareas, and watersheds) correct and validated based on actual relationships between watershed condition and processes, habitat status and trends?

3. Have we reached any of our established targets for habitat condition or trigger points based on status or trends that call for considering changing strategies or level of effort?
4. Are new factors emerging as limiting for populations in WRIAs? Are there lingering data gaps that create ongoing uncertainty over hypothesized important limiting factors?

These questions can be specifically addressed using results from status and trend habitat monitoring that focus on specific habitat limiting factors in wadeable streams. Wadeable streams comprise the largest proportion of any subbasin drainage network. Therefore aquatic habitats and riparian areas reflect upstream and upland watershed processes that govern the supply, transport and storage of water, sediment, and organic material.

Monitoring Approach

The distribution, composition, abundance, frequency and fate of habitats varies based on important controlling factors such as land cover, geology, basin geomorphology, channel network dynamics, and watershed disturbance history. The relationship among these independent and dependent factors is illustrated in the following diagram (Figure 2) that suggests linked hierarchical models can be used to interpret the effect or influence of independent variables on dependent variables. In our case, the middle panel represents those habitat factors identified as directly limiting salmon populations. The first panel represents various landscape or watershed controlling factors whose degree of influence on habitat for salmonids can be tested with alternative watershed models. Uncertainty regarding the relationships between the status and trends in habitats are tested (using hypotheses) and evaluated as part of validation monitoring of habitat and biological responses so that cumulative effectiveness is interpreted based on valid assumptions.

The status and trend monitoring approach described below allows for comparison of conditions to selected habitat standards to evaluate monitoring results. In this way we can answer whether habitat conditions for fish are functioning, impaired or degraded and assess the variability in condition by independent factors (e.g.; location and land use). It also allows for the detection of trends in habitats to be described based on performance (e.g.; % improvement) over time.

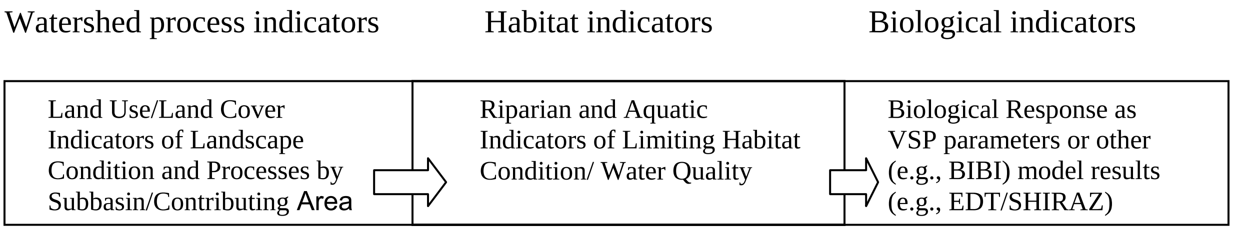


Figure 2: Hypothesized relationship between indicators of landscape condition that influence watershed processes to produce predictable responses in aquatic habitats or water quality with strong explanatory value for ecological or biological responses.

For monitoring wadeable streams, we chose to limit applicable survey sites based on gradient, channel width, and known distribution of ESA-listed Puget Sound Chinook salmon and the majority of steelhead distribution within Snohomish County (see more below regarding sample frame criteria). With the benefit of random sampling, we will be able to ascribe site specific results to a larger geographic area of inference, which is useful for reporting conditions at both watershed and regional scales. Based on the continuous distribution of all sites and conditions represented by them, the likely mechanism(s) operating to limit conditions or cause impairment (or improvement) in habitats will be investigated. Based on this approach, descriptive and predictive models can be developed and validated over time in new sampling areas and can be used to hypothesize likely future habitat changes. If successful, this approach to monitoring and assessment will strongly support adaptive management decision-making. For example, based on this approach we can describe how a regulated activity (e.g., buffer clearing) directly relates to conditions or functions targeted for improvement in salmon recovery plans, such as pool frequency, bank instability or vegetative cover.

Based on monitoring beginning in 2000, Snohomish County identified a limited set of habitat parameters relevant to habitat status and trend monitoring for these salmonids. To achieve strong inference, pertaining to the sample frame, we use a probabilistic sampling scheme. At the same time, targeted selection of wadeable stream sites established 6-14 years ago also represents an opportunity to detect early trends for some indicators based on same-site monitoring, albeit without inference to a larger population of sites. Management and monitoring questions important for assessing status and trends in this limited set of monitoring indicators are included in Table 1. The objectives of this report are to summarize data collected in 2007 in the Snohomish Basin and report results based on these questions and in consideration of parameter variability relating to method precision and repeatability.

Table 1: Monitoring indicators and associated management and monitoring questions for status and trend. Not all questions are addressed in this report.

Survey Parameter (functions)	Relevance	Question	Indicator (e.g.….)
Large Woody Debris (LWD) - (cover for fish, forms pools, retains sediment, makes complex habitat/hydraulics, dissipates energy, diverges flow for side channel formation)	Status	-What are the characteristics and functions of LWD? What condition based on performance criteria represents the baseline?	LWD frequency, loading, volume
		-What are the characteristics and functions of LWD jams? How much LWD is in jams?	Jam frequency, size, proportion of LWD
	Interactions	-Is large woody debris forming pools more frequently where LWD is abundant? Is LWD loading or frequency correlated with pool habitat quantity or quality?	% of pools formed by LWD, regression function
		-How does Jam number and frequency vary with total LWD, land use or channel size?	Jam number, frequency
		-How does LWD abundance vary with amount of streambank armoring?	LWD frequency
		-Is LWD abundance correlated with riparian cover condition or contributing area land cover?	LWD loading or volume
	Trends	-Is abundance and proportion of LWD in the low flow channel increasing?	LWD pool forming factor
		-Is large woody debris of different size fractions increasing in abundance?	LWD size fractions
		-Are LWD jams becoming more abundant and frequently spaced?	LWD jam frequency
Habitat types (pools, riffles, glides, side channels)	Status	-What are the characteristics and functions of pools based on performance criteria? What is the composition of riffles and glide habitats?	Pool, riffle, glide frequency/area
		-What forms most pools and what quality characteristics are present?	Pool forming factor, pool spacing, pool depth
		-What are the distinguishing differences between Primary and Backwater pools?	Pool area, depth, forming factor
		-What is the total and % length and area of side channels	Side channel frequency, length, area
	Interactions	-What relationships exist between LWD and pools? Between bank conditions and pools? Between land cover and pools?	Regression function; factorial analysis
		-Is the abundance of side channel habitat correlated with bank modifications or LWD abundance? Is side channel presence explained by stream slope only?	Regression function; factorial analysis
		-Are primary or backwater pools more typically correlated with LWD abundance or spacing?	Regression function; factorial analysis
	Trends	-Is pool frequency, area, and residual depth increasing?	Slope is not = 0 or >0
		-Are there more LWD formed pools? Does this decrease pool-pool spacing?	Slope is not = 0 or >0
		-Is mainstem riffle frequency/area increasing or decreasing?	Slope is not = 0 or >0
		-As habitat improves, is unit habitat composition shifting away from glide habitat?	Slope is not = 0 or >0

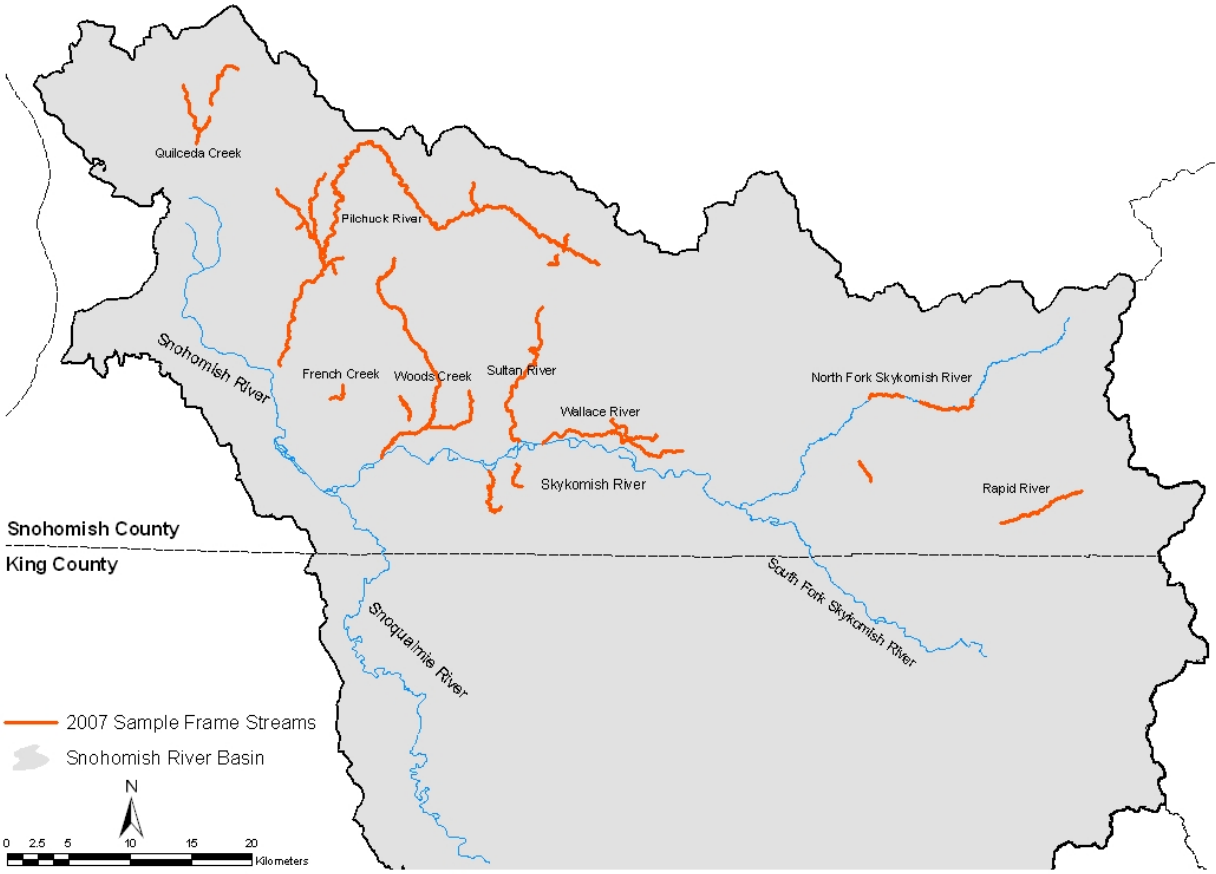
		-Is relative proportion and frequency of all habitat types (pools, riffles, glides, and side channels) more diverse?	Relative standard deviation is increasing

Survey Parameter	Relevance	Question	Indicator (e.g.…)
Riparian Condition (recruitment of woody debris to the stream channel, shading for temperature regulation, vegetative cover for streambank stability, bank resistance for natural pool formation)	Status	-What percentage of the riparian buffer is providing adequate cover for shading?	% canopy cover
	Interactions	-What spatial scales (i.e., reach, upstream riparian buffer, land use) are good predictors of LWD recruitment and jam formation?	% Cumulative Upstream Riparian Buffer > 150 ft
		-Are there subasins with high development but that still have an intact riparian buffer?	Vegetative cover classification, composition, and other vegetation metrics from low- and high-resolution satellite imagery (i.e., Landsat and Quickbird, respectively)
	Trends	-Is composition of natural land cover increasing in riparian and floodplain areas?	
		-Is composition of impervious area in buffers decreasing?	
		-is composition, extent, and connectivity of mature vegetation increasing?	
		-Is number of breaks (road crossings, utilities, clearing) decreasing?	
		-Is canopy cover (effective shading) increasing?	
Channel condition – (Including off-, side-channels)	Trends	-Is cross-channel area increasing or decreasing?	BFW, BFD, gradient,
		-Are channels aggrading or incising?	Width:depth ratio, percent riffle composition
		-Are side channels increasing in number, length or area?	Slope is not = 0 or >0
Substrate size	Status	- What is the proportion of fines and sand among sites and what is the level of impairment?	% < 2mm;
	Trends	- Are average sediment particle sizes increasing? Is the proportion of fines and sands increasing or decreasing?	Cumulative distribution; Slope is not = 0 or >0
Bank conditions – modification, stability and cover	Status	-What is the degree of modification and stability of streambanks?	Percent composition of modifications and stability by reach;
		-Are the amounts of armoring and instability related within survey sites?	
	Interaction	-Do bank modifications limit LWD storage, enhance LWD transport, limit LWD recruitment and reduce or eliminate vegetation resulting in lower stream LWD loading or frequency?	Regression functions;
		-Is LWD, canopy cover, pool habitats or substrate size correlated with modified or unstable streambanks?	
		-Do modified or unstable streambanks correlate with poor LWD pool quality or quantity?	
		Do areas with more bank modification have less bank cover for fish?	
	Trends	Are bank modifications (armoring) increasing or decreasing?	Cumulative distribution

Methods

Reach Definition and Selection

A reach selection process identified stream segments that would best meet the goals of monitoring federally-listed ESA salmon and steelhead habitat in wadeable streams. The first step in this process was to populate a sampling frame with reaches that met established criteria that reflected identified goals. Surveyed stream reaches were then randomly selected from the sampling frame. The random site selection process enables inference of monitoring under this program to all wadeable streams within the Snohomish Basin, within Snohomish County, that are represented in our sample frame. The area of inference is shown in Map 1.



Map 1. Sample frame for Snohomish County portion of Snohomish River Basin based on criteria for reach identification using GIS.

In order to be included in the sampling frame, stream reaches had to be within the steelhead and Chinook salmon distribution, ≤2% gradient and wadeable during the summer months. We focused on low gradient reaches because they contain important spawning and rearing areas for ESA-listed salmon populations and because they are highly responsive to changes in local and upstream watershed processes. Nonwadeable rivers are monitored using Snohomish County's large river survey protocol (SWM 2004).

Salmon and steelhead distribution and stream segment data was gathered from *StreamNet*, SSHIAP (Salmon and Steelhead Analysis Inventory and Analysis Program), and the Washington State Conservation Commission's *Salmon and Steelhead Habitat Limiting Factors Analysis* (WCC 2002) at WDFW's *SalmonScape* (Found at http://wdfw.wa.gov/mapping/salmonscape on the WDFW website). Stream reaches with ≤2% gradient were also identified using a 10m digital elevation model. Stream wadeability was inferred from contributing basin size and prior knowledge of stream size. The final result of the stream reach selection process was a sample frame of 70 reaches in the Snohomish. From this sampling frame, thirty primary reaches and five alternate reaches were randomly selected for survey.

Detailed information about the reach selection methodology is available in the wadeable stream survey protocol (Appendix A).

Field Procedures

The protocol for Snohomish County's wadeable stream and habitat survey is intended to direct data collection on stream parameters that provide habitat functions (with an emphasis on habitats associated with one or more life-stages of federally-ESA listed salmonids) or are physical indicators of watershed conditions. The suite of parameters selected for monitoring enable a relatively rapid assessment of a stream reach, while at the same time emphasizing more quantitative parameters with an explicit protocol so that data collection remains consistent between surveyors.

Surveyed reach length was determined by bankfull width (Table 2). Habitat parameters were either collected continuously along the reach or at evenly spaced transects. Stream bank condition, side channel habitat, woody debris counts, pool habitat measurements, riffle habitat measurements, and channel gradient were collected continuously along the reach. Bankfull width and depth, stream cover, and substrate size data were collected at the transects. For each habitat parameter we present the rationale for its inclusion into the survey and the general data collection method used.

Bankfull Width and Depth

Bankfull is used to describe channel dimensions (i.e., width and depth) that contain the stream flow up to the point when flows over-top the bank and enter the floodplain during a storm event. This flood stage generally corresponds to flows with a 1 – 2 year recurrence interval. Bankfull stage is important in stream systems because it is generally considered to be the channel-forming discharge when much sediment is transported and determines the channel morphology (Dunne and Leopold 1978). Indicators such as stain lines, bank under-cutting, sediment deposition, and bank vegetation were used to identify bankfull width and depth (USFS 1999).

Bankfull width is the primary measure of channel size and is used to determine the minimum size of functioning pools and woody debris along the reach, as well as the unit reach length (Table 2). Both changes in bankfull width and depth morphology over time can signal a change in the hydrologic, sediment, or large woody debris inputs from the upstream riparian area and contributing basin.

Table 2: Wadeable survey reach lengths and transect locations based on initial BFW.

Bank Full Width (m)	Reach Length (m)	Transect number (1-11) and interval distance										
		1	2	3	4	5	6	7	8	9	10	11
0 - 2.5	50	0	5	10	15	20	25	30	35	40	45	50
2.5 - 4.9	100	0	10	20	30	40	50	60	70	80	90	100
5.0 - 9.9	200	0	20	40	60	80	100	120	140	160	180	200
10.0 - 14.9	300	0	30	60	90	120	150	180	210	240	270	300
15.0 - 19.9	400	0	40	80	120	160	200	240	280	320	360	400
20 - 30	600	0	60	120	180	240	300	360	420	480	540	600
>30	800	0	80	160	240	320	400	480	560	640	720	800

Stream Bank Condition

Stream banks change over time and under natural conditions experience erosion and deposition as the stream channel responds to water, sediment, and wood delivery. Changes in water and sediment regimes and/or the loss of natural bank stabilization provided by riparian vegetation can result in elevated bank instability. Bank modifications include man-made structures intended to stabilize the bank. Bank stabilization activities can be in response to natural erosion and stream movement that threatens human infrastructure and property or in response to elevated erosion rates from changes in hydrology and sediment regimes or riparian vegetation loss.

Bank stability and modification data was collected continuously along the survey reach. Banks were categorized as *natural* or *modified* and modified banks were assigned a modification type. Modification types included *revetment*, *bulkhead*, and *berm*. Banks, whether natural or modified, were identified as *stable or unstable* based on whether or not they met bank instability definitions.

Finally, the modification toe class type was determined by visually examining primary bank material below the ordinary high water mark. Toe classes included *Riprap* (material > 256mm), *Rubble* (material < 256 mm), *Structural* (wood, concrete, gabion), and *Earth*.

Canopy Cover

Canopy cover is an indicator of the amount of shade provided for stream cooling and potential inputs of organic matter. This parameter was assessed by six measurements at each transect using a convex spherical densitometer (Lazorchak *et al.* 1998). Four readings were taken from the center of the channel, facing the right bank, upstream, the left bank, and downstream. Two readings were made at bankfull edges, one facing the right bank and one facing the left bank.

Instream Wood

Instream wood (also known as [Large] Woody Debris) provides habitat complexity, both in terms of instream cover and hydraulic roughness. In smaller streams, large woody debris has a large influence on channel form through the creation of pools and waterfalls and by affecting channel width and depth (Bilby and Bisson 1998).

During the stream survey, the minimum size for a qualifying piece of wood was 1.5 meters long and 10 cm in diameter over the length of the piece. Only downed wood that intercepted the bankfull channel was included in the survey. Wood above bankfull was recorded only if it was part of a jam that contained wood below the bankfull level. Jams were defined as 3 or more touching pieces of *large* wood (pieces larger than 30 cm in diameter at a distance of 7.6 m from the large end (USFS 1999) that together produced a single structure that intercepted the bankfull channel. Both wood and rootwads were counted as part of the survey. Rootwads were defined as having an average diameter of 1 meter or greater. Wood was tallied by size class (Table 3).

Table 3: Woody debris size classes for inventory.

Diameter Class	Length Class
< 30 cm	1.5 -7.6 m
30 - 60 cm	7.6 -15 m
60 - 90 cm	> 15 m
> 90 cm	

Habitat Units (Pools, Riffles, Glides)

Pools are a section of the stream channel where water is impounded within a closed topographical depression (Abbe and Montgomery 1996) and are important habitats for adult salmon holding and juvenile rearing (add reference). For pools to be counted in the survey, they had to meet the minimum area and depth requirements that were determined by bankfull width (Table 4). Pools were also identified by type and pool forming feature. Pool types referred to whether pools were located along the thalweg (primary pool) or were separated from the main flow (backwater pool) (Lazorchak *et al.*, 1998). Pool forming feature described the feature or process that led to the formation of a pool and included:

> Riprap: Pool is formed by scour along a hardened bank or other instream modification
>
> Bedrock: Pool is formed by scour along immoveable bedrock material

Wood: Pool is formed by scour around wood or by being impounded by wood

Beaver: Pool formed behind beaver dam or scoured from other beaver activity

Free Form: Pool formed by natural bed or bank resistance or flow convergence

Pools were measured at the maximum depth and tailout depth and the residual pool depth (maximum depth - pool tailout depth) was calculated. In order to be included in the survey, the residual pool depth met minimum requirements (Table 4). The functional area was defined by a depth greater than or equal to 0.2 m or the pool tailout depth, whichever was greater. This definition captured the deeper pool areas and excluded the shallow margins where the pool tapers toward the banks. The functional area could be equal to but never greater than the wetted pool area.

Table 4: Minimum pool size requirements (Pleus *et al*., 1999).

Bank Full Width (m)	Area (m^2)	Residual Pool Depth (m)
0 – 2.49	0.5	0.10
2.5 – 4.9	1.0	0.20
5.0 – 9.9	2.0	0.25
10.0 – 14.9	3.0	0.30
15.0 – 19.9	4.0	0.35
>20	5.0	0.40

Riffles describe stream sections with shallow, higher velocity flow. Water surface is rippled or has small waves but is generally unbroken (Lazorchak *et al.*, 1998). Since salmon tend to place their redds in areas with swiftly moving water over small- to medium-sized gravel (Quinn, 2005), the area of riffle habitat provides a good indication of the amount of suitable spawning habitat. The length and averaged wetted width were measured for identified riffles along the reach. Riffles were categorized based on dominant particle size: gravel, small cobble, large cobble, and boulder (Table 5).

Side-Channel Habitat

Side-channel habitat is important for freshwater rearing juvenile salmonids and, if the side-channel is sufficiently wide, spawning and incubation. Side-channel habitat increases in-stream habitat complexity, provides cover for predatory refuge, and facilitates floodplain-river connectivity.

Side-channel habitat was defined as channels that are separated from the main channel by a stable island and contain the smaller portion of the total flow. If a channel was not separated from the main flow by a stable island, then it was included with main channel measurements. Wetted length, mean wetted width, total length, and mean total width were measured.

Substrate

Streambed substrate size can be an indicator of particle size in spawning grounds, and the substrate size distribution reflects hydrologic and sediment conditions in the contributing basin. Streambed substrate size was characterized for the reach by assigning size classifications (Table 5) to five sediment samples collected across the wetted width of the stream channel at each of 11 transects and 10 half-transects, for a total of 105 particles recorded for the entire reach.

Table 5: Substrate size classes (adapted from Lazorchak *et al*., 1998)

Size Class	Size Range (mm)
Fines	< 0.06
Sand	> 0.06 to 2
Gravel (fine)	> 2 to 16
Gravel (course)	> 16 to 64
Cobble	> 64 to 250
Boulder	> 250 to 4000
Hardpan	> 4000
Bedrock (rough)	> 4000
Bedrock (smooth)	> 4000

Channel Gradient

A reach-average gradient was measured to ground-truth the GIS reach selection. Stream gradients were measured in a downstream direction between the wetted edges of transects 11 and 10, transects 6 and 5, and transects 2 and 1.

Data management procedures

Data Quality Assurance and Control

Quality assurance and control measures were taken to ensure that data collection and management minimized bias, uncertainty, and errors (entry or transcription) and maximized accuracy and precision. During data collection, a lead surveyor was designated who coordinated the survey so that metrics were not overlooked. Data were directly entered into field computer to avoid transcription errors with data entry. Data were reviewed after upload by the person who conducted the survey to screen for errors and any changes to the data were documented.

Quality Control Data Analysis

The Snohomish County protocol was designed to rapidly, and quantitatively assess habitat characteristics of a stream reach. This method allows data to be processed and analyzed on many levels, from individual measurements of discrete features to aggregate values at reach, subbasin and basin scales. Station numbers, collected as part of the survey, made it possible to match features in original (OR) and repeat (Quality Control – QC) surveys and compare individual measurements of these features. Analysis focuses generally on reach averaged values or total counts for each replicate pair of reaches, except in cases where investigation of differences based on individual survey stations might inform questions of bias/omission.

Expressions of precision and repeatability were calculated using three methods:

1. Root Mean Square Error (RMSE or σ_{rep}, Kaufmann *et al.* 1999). RMSE is defined as $\sigma_{rep,}$ where,

   $\sigma_{rep} = \sum$ standard deviation of repeat measurements of a habitat metric.

2. Signal to Noise ratio (S/N, Kaufmann *et al.* 1999). S/N is defined as a comparison of the variance of a "habitat metric observed across a regional sampling of streams ("signal") with the variance resulting from [replicate] field measurements within the sampling season" ("noise"), and is computed as,

   S/N=Variance of a population /$\sum$Variance between replicated pairs.

   The larger the calculated S/N value the more precise the measurement. Generally, values <2.5 are considered imprecise, between 2.5 and 6 are moderately precise and >6 are precise (for discussion see Kaufman *et al.* 1999).

3. Repeatability (R, Krebs 1989). Repeatability, R, is a value between 0 and 1, and the closer R is to 1 the more repeatable (precise) the measurement. Repeatability is calculated as,

   R =(Variance among unit reaches)/
   (Variance within replicates + Variance among unit reaches).

Data Analysis

Summary statistics of parameter metrics based on regionally applicable habitat standards or performance criteria for current status and function are reported. Habitat standards or performance criteria are included in Table 6, organized by threshold values for functioning or "good" habitat conditions. Additional threshold values are included in detailed result tables for several habitat parameters. Several sources for performance criteria were considered (NMFS 1996, WFPB 1997, May *et al*. 1997, Fox 2001, NOAA 2003, Fox and Bolton 2007).

Additionally, we apply factorial analysis based on groups of data organized, in particular, by bankfull width categories, land use categories (forested and non-forested reaches) or categorical assignments for streambank stability, pool forming factor, and others. We classified reaches as “forested” based on their adjacent land use (private forest, state forest, US Forest Service or wilderness), total contributing area and absolute land cover composition notwithstanding. Due to the limited number of sample sites and sample frame we did not similarly classify reaches into “urban,” “rural,” or “agricultural” uses as others have done (Pess *et al*. 2002) and simply refer to the other reaches as being “non-forested” in their land use. Lastly, the relationships between and among continuously distributed habitat metrics are explored using linear and non-linear regression analysis based on several of the questions identified in Table 1.

Table 6: Performance criteria for properly functioning stream habitat condition.

Indicator	Criteria	Metric	Source
Woody Debris	80 Pieces (≥15m length and ≥ 0.6m diameter)	Frequency (pieces/mile)	NMFS (1996)
	2 Pieces (≥ 2m length and ≥0.1m diameter)	Frequency (pieces/channel width)	
	Key pieces >0.3 (0 -10m BFW) >0.5 (10 - 20m BFW)	Frequency (pieces/channel width)	WFPB (1997)
	Woody debris volume >99 m^3 / 100m CL (<30mBFW) >317 m^3 / 100m CL (>30mBFW)	Volume (m^3/ 100m of channel length)	WFPB (1997)
	Predicted mean LWD pieces/CW	$Y=0.22x^{1.26}$	Fox and Bolton (2007)
Pool	Channel width - # pools/mile 1.5m - 164 3m - 96 4.5m - 70 6m - 56 7.6m - 47 15m - 26 23m - 23 30.5m - 18	Frequency (pools/Mile)	NMFS (1996)
	<2 channel widths per pool	Frequency (channel width/pool)	WFPB (1997)
	Percent pool > 55%	Percent (% pool)	WFPB (1997)
	Sufficient deep pools >1m deep with good cover and cool water	Count (pool)	NMFS (1996) WFPB (1997)
Substrate	Sand is never dominant or subdominant	Ranking (substrate size class)	WFPB (1997)
	Fines < 0.85 mm in spawning gravel are <12% good (12-17% fair, >17% poor)	Percent composition	NMFS (1996)
Stream-bank condition	> 90% Stable, <10% actively eroding banks	Percent (% stable or % eroding banks	NMFS (1996)
	>95% unarmored	Percent (natural banks)	NOAA (2003)
Off – Channel	Off channel areas are frequently hydrologically linked to main channel; over bank flows occur and maintain wetland functions , riparian vegetation and succession.	No metric	NMFS (1996)
Cover	Suitable cover ≥90% for bank cover; suitable center-channel cover for shading varies as a function of BFW dimension; 90-50% for increasing elevation (to 2000ft)	Percent cover or percent view-to- sky	WFPB (1997) Ecology (2007)

Results and Discussion

Reach Summary

The sample frame identified 204 kilometers of wadeable streams with Chinook and steelhead distribution. Thirty randomly selected reaches totaling 12.9 kilometers, 6.3% of the sample frame, were surveyed during the 2007 low flow season in the Snohomish County portion of the Snohomish Basin. Summary statistics of subbasin and channel characteristics are summarized in Table 7 and discussed by parameter following the Table. The surveyed reaches ranged from 200 – 800 meters in length, depending on bankfull width class. Reach-specific mean bankfull widths were 2.8–39.9m, bankfull depths were 0.33-1.36m, and channel gradients were 0.3-2.5% (Table 7). In some cases, field measurements revealed local width or slope that did not meet the sample frame criteria. We chose to include these reaches in our analysis based on their inclusion in our spatial frame – that is; geographically, we don't know which reaches within our entire sample frame actually meet our criteria based on field verification. By including the reaches, we assume our inference to the geographic extent of the sample frame remains intact.

Since the channel gradient averaged less than 2.5%, the application of channel classification (i.e., Montgomery and Buffington 1993) suggests streams reflected similar response channel types, being either pool-riffle or plane-bed in planform and were influenced by similar habitat-forming processes. We classified 8 of these reaches as "forested" based on their adjacent land use, total contributing area land cover composition notwithstanding. Due to the limited number of sample sites and sample frame we did not similarly classify reaches into "urban," "rural," or "agricultural" uses as others have done (e.g., Pess *et al*. 2002) and simply refer to the other reaches as being "non-forested" in their land use.

Table 7: Summary of Snohomish Basin reaches surveyed for 2007 Wadeable Stream Survey. See Appendix B for summary data tables for each of the 30 reaches.

Reach ID	Stream Name	Sub-Basin	Survey Length (m)/ No. Site Visits	Avg. Gradient (%)	Avg. BFW (m)	Avg. BFD (m)	Contributing Basin Area (ha)	Adjacent Land Use
1	Worthy Creek	Upper Pilchuck	200/1	2.50	6.9	0.4	17,582	Forested
2	Pilchuck River	Upper Pilchuck	600/1	2.17	20.7	1.0	94,755	Forested
10	Miller Creek	Upper Pilchuck	200/2	0.33	7.3	0.5	26,996	Forested
14	Panther Creek	Dubuque Creek	200/1	0.94	5.1	0.4	15,453	Non-forested
15	Pilchuck River	Lower Pilchuck	600/1	1.11	25.7	1.4	332,422	Non-forested
20	West Fork Woods Creek	West Fork Woods Creek	200/2	0.67	6.9	0.8	58,823	Forested
24	Olney Creek	Olney Creek	400/1	0.58	18.6	0.6	54,845	Forested
28	McCoy Creek	Lower Mainstem Skykomish	300/1	0.93	7.7	0.5	3,232	Non-forested
30	Rapid River	Rapid River	600/1	1.06	22.6	0.9	87,526	Forested
34	French Creek	French Creek	200/1	1.83	5.5	0.6	19,777	Non-forested
35	May Creek	May Creek	300/1	1.33	13.7	1.0	28,813	Non-forested
37	West Fork Quilceda Creek	Quilceda	200/1	0.83	2.8	1.0	28,945	Non-forested
41	Quilceda Creek	Quilceda	200/1	0.50	3.9	0.8	52,746	Non-forested
43	Dubuque Creek	Dubuque Creek	200/2	1.33	5.7	0.4	35,499	Non-forested
46	Wallace River	Upper Wallace River	600/1	0.56	28.8	0.5	164,870	Non-forested
47	Wallace River	Upper Wallace River	600/1	0.61	25.8	1.3	157,579	Non-forested
49	Wallace River	Upper Wallace River	600/1	0.89	18.1	1.1	50,473	Non-forested
54	Pilchuck River	Middle Pilchuck	600/1	0.33	23.2	1.1	175,753	Non-forested

Reach ID	Stream Name	Sub-Basin	Survey Length (m)/ No. Site Visits	Avg. Gradient (%)	Avg. BFW (m)	Avg. BFD (m)	Contributing Basin Area (ha)	Adjacent Land Use
55	Pilchuck River	Middle Pilchuck	600/1	0.83	21.7	0.3	161,738	Non-forested
56	Pilchuck River	Middle Pilchuck	600/2	0.44	31.8	0.8	143,675	Non-forested
57	West Fork Woods Creek	West Fork Woods Creek	200/1	0.50	7	1.0	74,596	Non-forested
58	West Fork Woods Creek	West Fork Woods Creek	200/1	0.50	7.7	0.7	66,080	Non-forested
60	Pilchuck River	Upper Pilchuck	600/1	0.67	23.1	1.2	30,732	Forested
62	Pilchuck River	Middle Pilchuck	600/2	0.56	22.9	1.0	165,304	Non-forested
66	North Fork Skykomish River	Upper North Fk Skykomish	800	0.96	39.9	0.9	150,172	Forested
67	Pilchuck River	Middle Pilchuck	600	0.78	23.2	0.9	285,133	Non-forested
69	Carpenter Creek	West Fork Woods Creek	200	0.33	4	1.1	25,490	Non-forested

Width-to-depth ratio

Channel width-to-depth ratio ranged from 2.9 to 121.4, with an average ratio of 24.1. Stream width-to-depth ratio provides a general indication of channel morphology. Streams with high width-to-depth ratios are shallow and wide and those with low width-to-depth ratios are narrow and deep. Streams with similar geology, hydrologic regime, and channel classification should have similar relationships between bankfull width, depth and drainage area (Booth 1990; Montgomery and Buffington, 1993). In addition to differences in surficial geology and soils influencing sediment production, hydrology, and contributing basin size, local controls over bankfull width and depth (i.e., reach gradient, riparian vegetation, and streambank condition) cause variability in these ratios.

The majority of reaches (83%) exceeded a width-to-depth ratio of 10, commonly cited as a threshold of channel impairment associated with sediment loading, eroding streambanks or altered hydrology (NMFS 1996) (Figure 3). Though performance standards have been created for width-to-depth ratios, these standards may not reflect natural channel configurations over a range of contributing influences. Due to this variability, channel morphology may not be informative in diagnosing status at any given point in time. However, channel changes, which would be reflective of changes within the contributing basin, and those that especially alter stream hydrology (e.g.; storm flow volume) or sediment supply and delivery to channels, may be measured over time at established stream cross-sections or survey reaches, and would be informative for trend monitoring assuming this channel response would occur within our sample frame

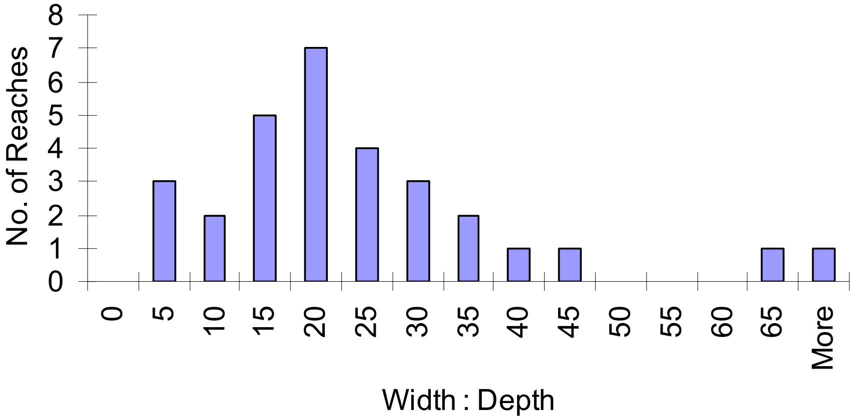


Figure 3: Frequency distribution of average width-to-depth ratios for each sampled reach.

Bank Condition

Bank condition was identified as natural or modified and stable or unstable for 25.8 kilometers of bank. Bank modifications consisted of dikes/revetments/levees, bulkheads, and berms. Within the study area, bank modifications totaled 9.7% of surveyed steam banks, and unstable bank modifications represented 0.7% of all streambanks (Table 8). The only unstable bank modifications observed were failing revetments, totaling 7.3% of all modifications. Natural stream bank instability totaled 12.7%. We assume bank modifications are placed to stabilize unstable bank conditions. Therefore, total underlying instability is the combination of observed instability plus those areas with modifications. For all reaches, the grand total exceeds 20% (Table 8).

Table 8: Natural and modified bank conditions for 30 sampled reaches.

	Natural - 90.3%		Modified - 9.7%	
	Stable	Unstable	Stable	Unstable
Total	77.6%	12.7%	9.0%	0.7%
Dikes/Revetments/Levees	--	--	84.7%	7.3%
Bulkheads	--	--	7.4%	0.0%
Berms	--	--	0.6%	0.0%

Bank stability ranged from 0-94% unstable banks among sampled reaches. Bank modification ranged from 0-33%. We assessed bank condition based on published performance criteria. For bank stability 56% of reaches surveyed met the criteria for properly functioning, 27% were at risk and 18% were rated as not properly functioning.

For bank modifications, 50% were rated as properly functioning, 43% were at risk, and 7% were in poor condition. Seven out of 30 reaches (24%) were properly functioning for both conditions. Bank modification and instability were related based on a hypothesized range of condition curve (diagonal line in Figure 4). Among reaches with high percentages of bank modifications, the amount of bank instability was low and the range was narrow. At lower levels of bank modification, the range and amount of bank instability was greater. Except for one outlier point (94% unstable banks), the range of condition where modifications and natural instability were combined rarely exceeded 40%, but often was more than 20% (see Figure 4). This suggests that among these 30 reaches, 20-40% underlying instability may be a range maxima for reach conditions. The plot relationship and coefficient of determination between percent modified and percent unstable banks suggests that among these reaches, a degree of bank instability (about 10%) is present no matter the amount of bank modifications (placed presumably to address instability), suggesting an average of 10% bank instability should be expected.

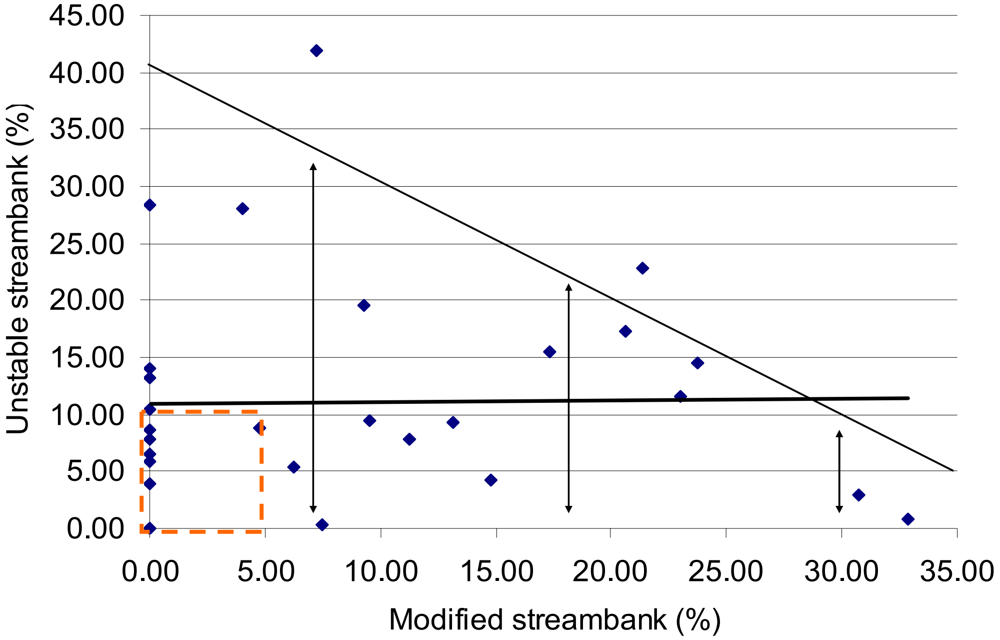


Figure 4: Relationship between modified streambanks and unstable streambanks with hypothesized range of condition curve (height of arrows), linear regression relationship (horizontal line), excluding outlier data point (94% instability). The dashed box at lower left represents the properly functioning condition based on Table 6.

We hypothesize that the amount of bank modifications will remain constant and natural bank stability will increase over time. Based on the distribution of instability and modifications among reaches, we hypothesize that the frequency of reaches not meeting criteria will stay the same or go down in number as a result of restoration, restrictions on placement of armor, other bank stabilization techniques, or riparian vegetation enhancement that improves streambank stability. We hypothesize that bank conditions may indirectly affect riparian woody debris recruitment, wood storage, gravel substrate size and pool characteristics based on questions posed in Table 1.

Canopy Cover

Canopy cover, an indicator of vegetative cover, stream closure, and potential shading, was characterized for each reach by averaging individual densiometer readings taken at transects. The average canopy cover for all reaches was 87% at the edge of the stream bank (both sides) and 43% at the center-channel location (center of stream). Reach canopy cover was more variable among reaches for center-channel canopy cover (7% - 92% cover, standard deviation 23.6) than for bank canopy cover (47% - 99% cover, standard deviation 13.3, Figure 5) Individual reach mean canopy cover for bank and center channel is listed in Appendix Table B-5.

Within reach variability in center-channel canopy cover was not governed by variability in bank canopy cover (Figure 6). Since canopy cover measured at the stream center is largely provided by taller vegetation, the variability in instream cover is governed by the variability in the tall shrub and tree canopies, which is expected to be patchier than bank cover, especially in non-forested reaches. Therefore, this parameter is not expected to change immediately in response to riparian improvements such as vegetation planting or the protection of buffers with immature trees, but will respond very quickly to degradation involving mature riparian forest loss.

Bankfull width must be considered when analyzing center channel cover, because wide streams will not have high center-channel canopy cover, even with adjacent mature riparian forests. The significant relationship between average bankfull width and center-channel cover explained 30% of observed variation (Figure 5, n=30, p=0.001, $r^2 = 0.3$). Center-channel cover measurements exceeded 85% where BFW was less than 10 m and where bank cover was high. Generally, center-channel cover was greatly reduced for bankfull width categories >15m (Figure 5). Sufficient sites were visited along a continuum of BFW dimensions and between forested and non-forested reaches to suggest a diagnostic criterion exists between BFW and instream riparian cover. The maximum center-channel cover values along this BFW continuum likely reflects the highest cover that intact (forested) riparian areas will provide for streams, as depicted by the range of lines shown in Figure 5. Understandably this would be roughly correspondent with other depictions of effective shading as governed strongly by BFW (Cristea and Janisch 2007). Although additional data collection may revise this relationship for higher BFW dimensions, optimal percent cover values from forested reaches, varying with BFW dimension, could be regarded as a diagnostic criterion. The departure from conformity with the diagnostic criterion will suggest how impaired instream cover is in the Snohomish basin. Stream reaches falling between or above the solid lines would meet the performance standard for cover - in this case, 10 out of 30 reaches.

Although bank cover may respond more quickly than instream cover to riparian forest improvements, it is less clear that bank enhancement in larger channels will provide instream cover. Smaller channels clearly have the greatest potential risk of loss in cover that would have the greatest impact on temperature (assuming smaller flow volumes and shallower depth in channels <10m), bank conditions, wood loading, and possibly pool metrics. While larger channel may also become impaired for canopy cover, shading potential is naturally limited and riparian cover may be more important to limit erosion and maintain channel dimensions.

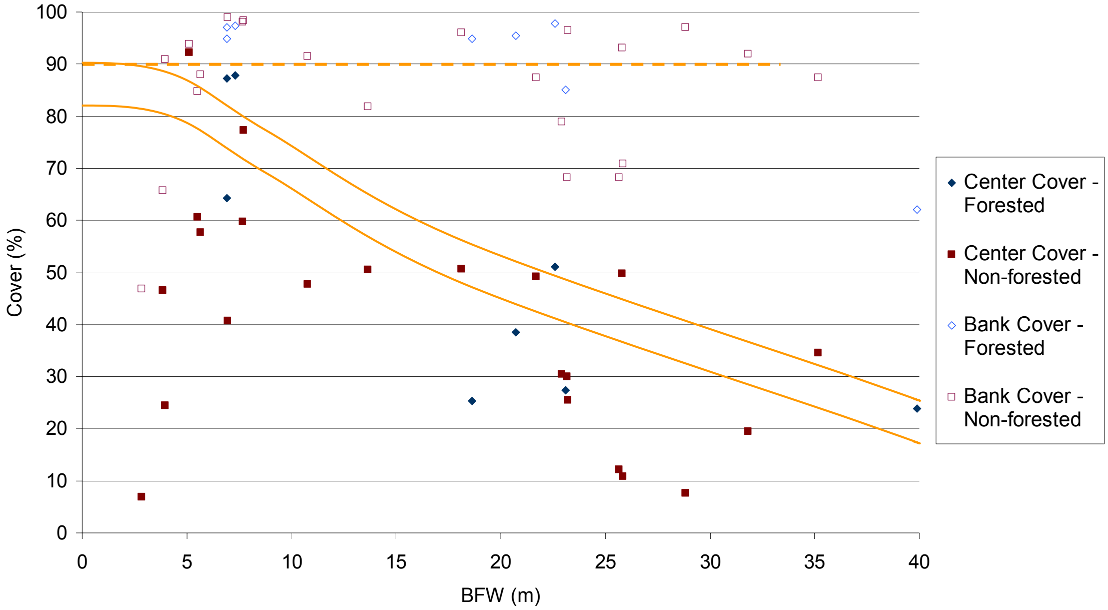


Figure 5: Relationship between average bankfull width and percent bank cover (open markers, n=30, F=12.5, p=0.001, r^2 = 0.31) and center-channel canopy cover (filled markers, n=30 F=0.08, p=0.78, r^2 = 0.01). The dashed line represents expected functional bank cover and the solid lines represent a range of functional center-channel cover based on modeled relationships between effective shading and BFW.

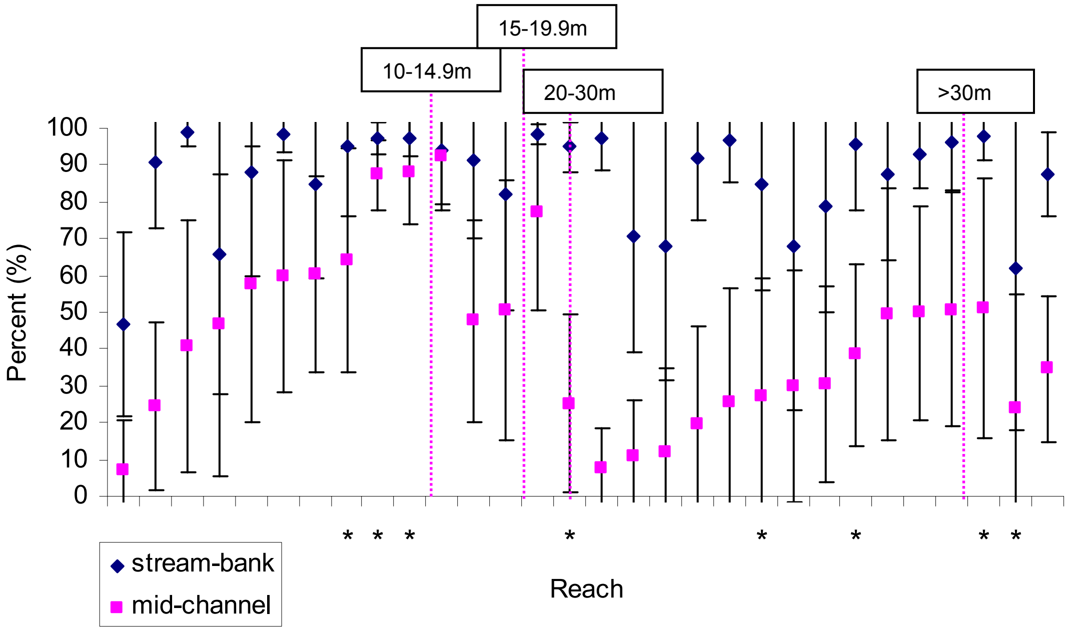


Figure 6: Reach average percent cover for mid-channel measurements and stream-bank. Error bars denote the standard deviation among all transect measurements made along each reach. Reaches are grouped by BFW categories, and within each BFW category, are organized by ascending center-channel measurements. Reaches denoted with an asterisk indicate reaches identified as forested.

While there are published performance criteria for buffer width, performance criteria for canopy cover are lacking, though models depicting effective shading from mature canopy cover as it varies by BFW are available (Cristea and Janisch 2007). The WDNR watershed analysis manual (WFPB 1997) provides guidance in the application of remotely sensed riparian canopy cover at the watershed level to stream temperature modeling. Field-based densitometer readings like the ones collected for this wadeable stream monitoring program are used to refine canopy closure estimates. County-wide riparian land-cover classification and analysis from remotely-sensed imagery should integrate field-collected riparian cover data in order to characterize, model and calibrate estimated cover and shading functions based on riparian condition. This approach will enable us to test monitoring questions about changes in riparian condition (composition, extent, and connectivity) and effective shading from canopy cover and determine if these changes are part of a trend (see Table 1).

Instream Wood (Woody Debris)

Woody debris summary data can be found in Appendix B, Tables B3 (by reach) and B6 (2007 survey mean). Pieces of woody debris ≥1.5m length and ≥10cm diameter were inventoried and placed in size classes. Woody debris frequency averaged 242 pieces per kilometer or 4.2 pieces per channel width for all wood size classes. For larger pieces (≥7.6m length/≥30cm diameter), woody debris frequency was 24.3 pieces per kilometer and 0.5 pieces per channel width. The frequency of large woody debris known as key pieces (either >15m length/>60cm diameter for NMFS 1996 or meeting minimum volume criteria as in Table 9) was 0.45 pieces per kilometer or 0.05 pieces per channel width.

Average total woody debris volume per reach was 78.4m^3 or 176m^3 per kilometer. Logjam frequency occurred at an average of 1.6 jams per kilometer, and logjams contained 13%, on average, of large wood (≥ 30cm diameter or <30cm with rootwad). Although rootwads were present on 16% of all wood, 33% of key pieces had rootwads. Twenty-six (26) percent of all wood was found in the low flow, wetted channel.

Table 9: Key piece minimum wood volume criteria (WFPB 1997 and Fox 2001).

WFPB 1997	
Bankfull width class	Min vol m^3
0 - 5m	1
5 - 10m	2.5
10 - 15m	6
15 - 20m	9
Fox 2001	
20 - 30m	9.75
30 - 50m	10.5*
* Must have rootwad	

The amount of wood present was apparently strongly related to the stream reach land use designation of forested or non-forested types. Total survey length for each reach was governed by bankfull width dimensions and ranged from 200-800m in length. In forested reaches, total woody debris abundance (count) was strongly correlated with survey length (Figure 7). For longer surveys, in wider channels, total wood count increased linearly (n=8, r^2=0.69, p=0.007), as might be expected. This increase typically produces increasing woody debris frequency (with increasing bankfull dimensions, e.g., Fox and Bolton 2007). However, among non-forested reaches, total wood count appeared to be largely independent of survey length (n=22, r^2=0.08, p=0.10), suggesting geomorphic, hydrologic and riparian processes have been altered or interrupted (e.g., wood removal) to the degree that predictable relationships have broken down.

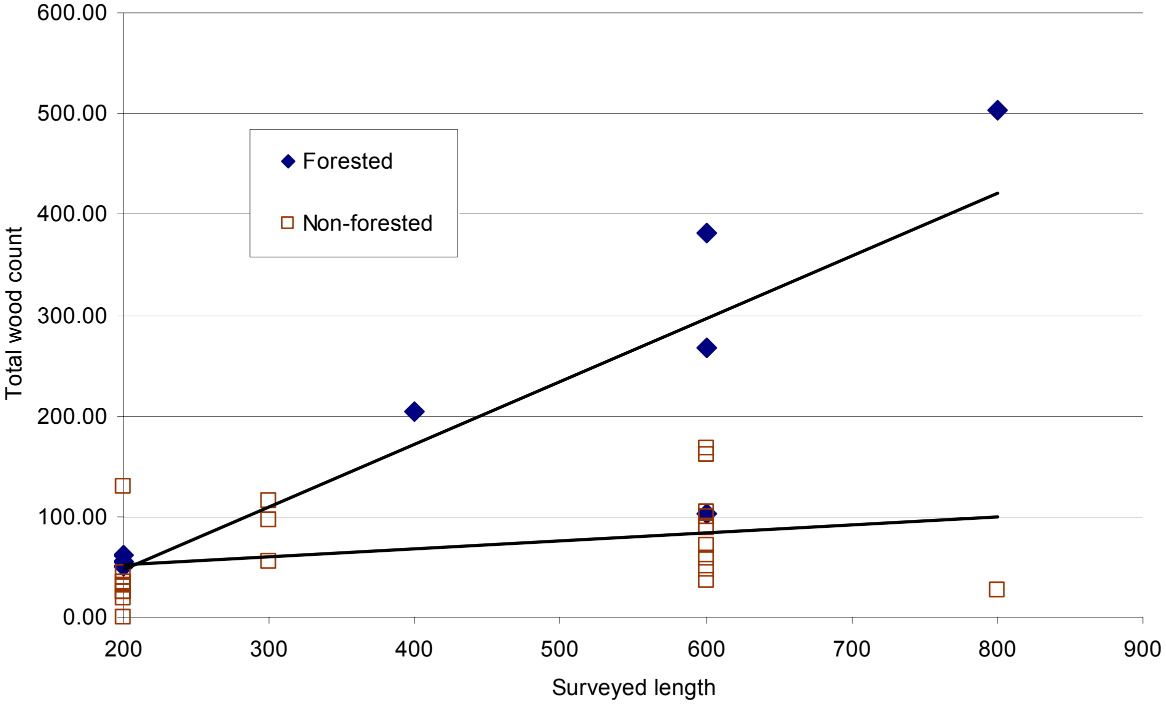


Figure 7: Wood (>1.5m length/>10cm diameter) abundance in relation to survey length (governed by bankfull width dimension). Longer surveys in non-forested reaches did not produce predictably increasing woody debris abundance suggesting woody debris recruitment and storage is highly variable spatially. Overall wood abundance is >3-fold higher in forested channels per unit survey length.

Woody debris loading (all wood size classes per m^2 channel area) was negatively correlated with increasing stream size bankfull width (n=30, f=17.3, r2=0.36, p=0.0003, Figure 8). Larger streams retained less woody debris per unit area than smaller streams and the best statistical relationship was based on exponentially declining wood load. Streams with bankfull widths <10m contained higher wood loading (albeit highly variable) per unit area, though the composition of wood sizes (small, large and key pieces) between large and small channels was indistinguishable (Chi-square=8.4, d.f.=5, p=0.13). However, among larger channels (>10m bankfull width), forested reaches contained higher woody debris loading than non-forested reaches as indicated in Figure 8 (based on non-parametric Mann-Whitney U-testing z=2.2, p=0.03). We found a significant difference in the composition of wood size between land uses, mostly attributable to higher abundance of large wood pieces (>7.6m length/>30cm diameter) in forested land use reaches (Chi-square=21.1, d.f.=5, p<0.001) as compared with non-forested reaches. The reduction in woody debris loading related to increasing bankfull width did not affect woody debris frequency (pieces/km of stream length) by bankfull width (see below).

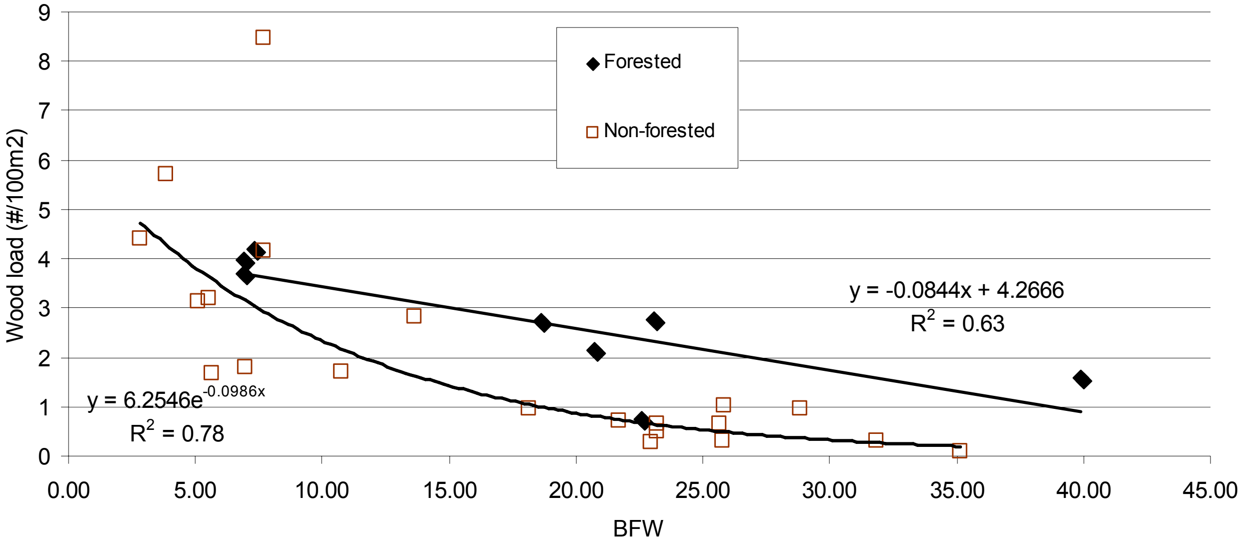


Figure 8: Woody debris loading related to bankfull width as shown for forested and non-forested reaches. For larger BFW dimensions, forested reaches contain higher wood load.

We compared common LWD metrics to regionally-based performance criteria. LWD was inventoried using EMAP (1998) protocols where the minimum length was 1.5m. This is less than the 2m minimum length used for several performance criteria. We believe this is a minor variation and these results are appropriately applied to the performance criteria.

Total reach LWD volume per 100m channel length ranged from 0-55.1m³ and averaged 17.6m³. Forested reaches ranged from 11.7 to 55.1m³ and averaged 34.1m³. Non-forested reaches had a range of 0-33m³ and averaged 11.6m³. Fox and Bolton (2007) compiled stream survey data collected in unmanaged forest lands in western Washington and established performance criteria for wood loading by volume based on cumulative percentile distributions corresponding to quality ranges (good, fair, and poor; Table 10)). None of the 30 reaches (i.e., 0%) are characterized as “good” for wood loading by volume (Table 11). Eight reaches are considered “fair”; 6 of which were forested land use and publicly owned - 2 of which were ~1 kilometer downstream of forested land use and publicly owned property.

No reaches (i.e. 0% in Table 11) met the NMFS (1996) performance criteria of 80 woody debris pieces/mile (>15m length/>60cm diameter). Fox and Bolton (2007) reported that this NMFS criterion was applicable to channels >40m width in western Washington, but not for smaller channels, such as those in our survey. For unmanaged forested channels smaller than 40m width, Fox and Bolton (2007) concluded streams supported 40 pieces/mile (the 75th percentile target condition) and the median value (representing a "fair" condition) was approximately 10-15 pieces/mile. In our survey, forested reaches averaged 12 pieces per mile; while the mean value among remaining reaches was 3 pieces/mile. Therefore forested reaches appeared to be in fair condition, while non-forested reaches were in poor condition for woody debris frequency.

Out of the thirty reaches surveyed, 11 reaches failed to meet WFPB (1997) criteria of 2 pieces LWD (>2m length/> 10cm diameter) per channel width. Nine of the 11 reaches that did not meet this criterion were <7m BFW, representing all reaches <7m BFW in our survey. However, Fox and Bolton (2007) demonstrated that a fixed criterion of 2 pieces per CW is unrepresentative of woody debris frequency in streams, normalized for bankfull width dimensions. Woody debris abundance per channel width varies with stream size and is lower in smaller streams in un-managed forests. According to this recent work, woody debris frequency usually is less than 2 pieces/CW for streams <6m BFW and is as low as approximately 0.5 pieces/CW for streams <3m BFW. Correspondingly, LWD frequency is higher then 2 pieces/CW for wider streams. When predicted LWD frequencies based on a modeled relationship (Table 6) between LWD pieces/CW and bankfull width (from Fox and Bolton 2007) are compared to observed LWD frequencies from this survey, a different pattern emerges in the reaches that meet or do not meet LWD frequency expectations.

Although applying the WFPB (1997) criterion primarily suggests small streams are not properly functioning, Fox and Bolton's (2007) work suggests that LWD frequency is impaired in larger streams, and more so than smaller streams – opposite of results implied by application of the WFPB criterion. Whereas surveyed reaches >20m BFW generally conformed with the tendency to exceed 2 pieces/CW, based on the relationship described by Fox and Bolton (2007), predicted values suggest the WFPB criterion is meaningless when applied to these channels. We found only 2 of 16 Snohomish reaches meet Fox and Bolton's (2007) (median) value, and thus are below any threshold for properly functioning condition or if compared to the 75th percentile target condition as recommended by Fox (2001) (Table 10). When Fox and Bolton's (2007) LWD frequency equation (for median wood abundance) is applied to data from the 2007 surveys, only 3 of 30 reaches exceeded expected median conditions for LWD (Figure 9). While 2 of the 3 reaches that exceeded these "fair" conditions were forested reaches, LWD loading was impaired in the majority (5 of 7) of forested reaches and in 16 out of 17 non-forested reaches. Although all reaches did not meet performance criteria for key piece frequency (based on the WFPB 1997 volume criterion for individual key pieces), forested reaches had greater frequency of key pieces than non-forested reaches.

Table 10. Woody Debris performance criteria

LWD[1] Volume: Cubic Meters per 100 meters of Channel Length, Table 9 in Fox 2001			
BFW Class	Good	Fair	Poor
0-30m	>99	28-99	<28
>30-100m	>317	44-317	<44
LWD Pieces[3] Per Mile NOAA (1996) Pathways and Indicators			
	Functioning	Not functioning	
0-40m	> 80/mile	< 80/mile	
> 40m	> 80/mile	< 80/mile	
Woody Debris[1] Pieces Per Channel Width, WFPB (1997)			
	Good		
0-20 m	2		
LWD[1] Piece Quantity: Number of pieces per 100m of Channel Length, Table 9 Fox (2001)			
	Good	Fair	Poor
0-6m	>38	26-38	<26
>6-30m	>63	29-63	<29
>30-100m	>208	57-208	<57
Key[2] Pieces Per Channel Width, WFPB (1997)			
	Good		
0-10m	>0.3		
10-20 m	>0.5		
Key[2] Piece Quantity: Number of pieces per 100m of Channel Length, Table 9 Fox (2001)			
	Good	Fair	Poor
0-10m	>11	4.0 - 11.0	<4
>10-100m	>4	1.0 - 4.0	<1

Table 11: Percent of reaches that meet performance criteria for woody debris: all reaches (forested reaches)

LWD[1] Volume: Cubic Meters per 100 meters of Channel Length, Table 9 in Fox 2001			
BFW Class	Good	Fair	Poor
0-30m, n = 27 (7)	0%	26% (71%)	74% (29%)
>30-100m, n = 3 (1)	0%	33% (100%)	67%
LWD Pieces[3] Per Mile NOAA (1996) Pathways and Indicators			
	Functioning	Not functioning	
0-40m n = 30 (8)	0%	100% (100%)	
Woody Debris[1] Pieces Per Channel Width, WFPB (1997)			
	Good		
0-10m, n = 12 (3)	25% (33%)		
10-20m, n = 4(1)	100% (100%)		
20+ m, n = 14 (4)	no criteria		
LWD[1] Piece Quantity: Number of pieces per 100m of Channel Length			
	Good	Fair	Poor
0-6m, n = 6	0%	0%	100%
>6-30m, n = 21(7)	4%	22% (57%)	52% (43%)
>30-100m, n = 3(1)	0%	33% (100%)	67%
Key[2] Pieces Per Channel Width, WFPB (1997)			
	Good		
0-10m, n = 12 (3)	0%		
10-20m, n = 4(1)	0%		
20+ m, n = 14 (4)	no criteria		
Key[2] Piece Quantity: Number of pieces per 100m of Channel Length, Table 9 Fox (2001)			
	Good	Fair	Poor
0-10m, n = 12 (3)	0%	0%	100% (100%)
>10-100m, n = 18 (5)	0%	0%	100% (100%)

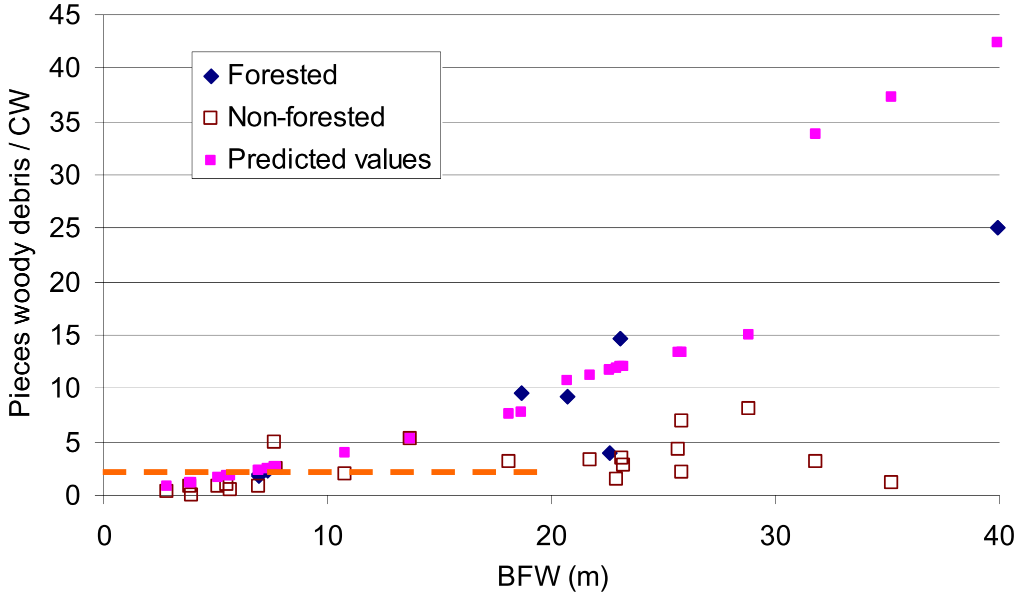


Figure 9: Woody debris frequency (for pieces >2m/>10cm) scaled as a function of channel width for surveyed reaches broken out by non-forested and forested reaches. Also shown are predicted reach median values based on Fox and Bolton (2007) corresponding to "fair" or "at risk" condition for each BFW dimension. The dashed line represents the 2 pieces/CW WFPB (1997) diagnostic rating for "good" condition in channels up to 20m BFW.

Based on the predicted woody debris values portrayed in Figure 9, the observed average LWD frequency in non-forested reaches is approximately 26% of the predicted functional value for streams >20m BFW (n=10). For streams <20m BFW and draining non-forested land use types, the average LWD frequency is approximately 64% of the predicted functional value (n=12). For streams draining forested land use types, the average LWD frequency is approximately 92% and 75% for BFW <20m and >20m, respectively.

Adherence to conclusions drawn from applying WFPB criteria suggest small streams require restoration of LWD to the exclusion of many larger streams. Just the opposite conclusion is made by applying predictions drawn from Fox and Bolton (2007), that larger non-forested streams have a much greater instream wood deficit than smaller streams. Whereas larger streams are disproportionately important for Chinook and coho salmon and whereas limits to LWD function in larger streams (compared to smaller streams) will be dependent upon scarce fractions of larger LWD with intact rootwads, the need for management intervention in larger streams seems apparent. This management implication is also borne out by the apparent lack of relationship between wood abundance and survey length, which, we hypothesize, is directly related to the frequency of LWD jams.

Jam frequency within reaches designated as forested and publicly owned was 5 jams/km (one every 200m – the minimum survey distance) containing an average of 38% of wood >30cm in diameter or having a rootwad. The remaining reaches, within the more developed areas, had an average jam frequency of 0.4 jams/km (1 every 2.5 km – exceeding the maximum survey distance) containing an average of 4% of wood >30cm in diameter or having a rootwad.

We hypothesize woody debris frequency or loading may be related to other reach specific conditions in addition to forested or non-forested condition. For example, increasing bank modifications may lead to reduced wood load or woody debris frequency as a result of lower local LWD recruitment from modified banks (regardless of riparian vegetation quality), lower LWD storage on banks, or enhanced LWD transport out of the survey reach due to channel cross-section modification (also see questions in Table 1). We found a negative correlation between the percent bank modifications and wood loading (#pieces/m^2 channel area; Figure 10), but bank modifications explained only a fraction of the variability in wood load. Although high rates of bank modification may preclude higher wood loading (as suggested by the boundary curve in Figure 10) and greater range in reach-specific wood load (arrows in Figure 10), other factors such as riparian condition are important.

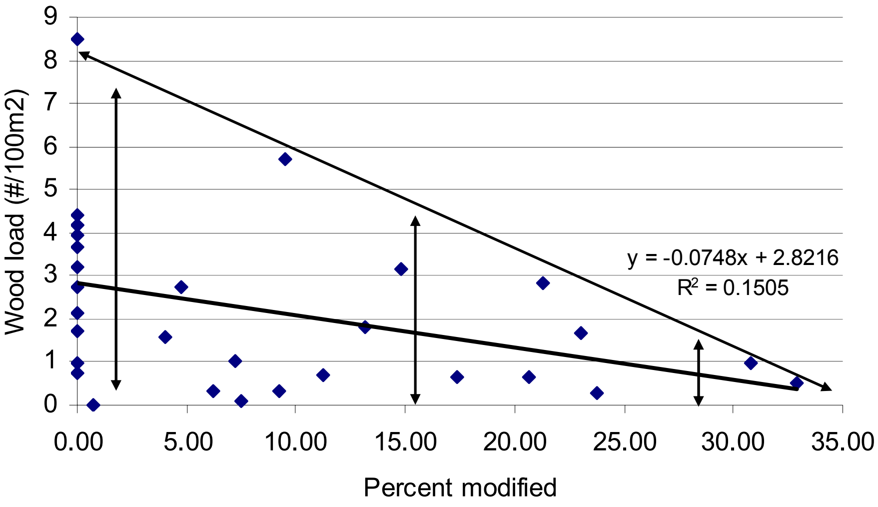


Figure 10: Relationship between percent modified (armored) banks and wood loading. The regression relationship is significant, p=0.03, at α=0.05. The range in conditions boundary (diagonal arrow) suggests that higher levels of bank modification may contribute to limit LWD loading amount and range (vertical arrows).

Our findings suggest management actions to restore woody debris functions should target larger streams >10m, in forested and non-forested land use types, by establishing frequent wood jams as points of new wood loading and storage to contribute to meeting 75th percentile targets (Fox and Bolton 2007) in locations of low bank hydromodification (<15%), where active riparian protection and restoration of long-term (>50 years) LWD potential is being implemented.

Habitat Units (Pools, Riffles, Glides)

Pool habitat is primarily characterized by abundance (total % pool area), spacing (pool frequency), hydraulic influence (pool forming factor) and quality (maximum/residual pool depth and pool type (primary or backwater). Over the 12.9 km of stream surveyed, 289 individual pools were identified and measured. There were individual stream reaches that were dominated by either pool or riffle habitat. The percent pool area per reach ranged from 2 – 90%, and the maximum percent riffle area was 84%. Pool area appeared to negatively correlate with increasing BFW, and riffle area was positively correlated (Figure 11). For most streams, percent pool area ranged from 27 to 57% (the average was 43%) and percent riffle area ranged from 34 to 60% (Figure 12). Glide area was higher than 40% in a few reaches, but commonly composed less than 15% percent of the reach.

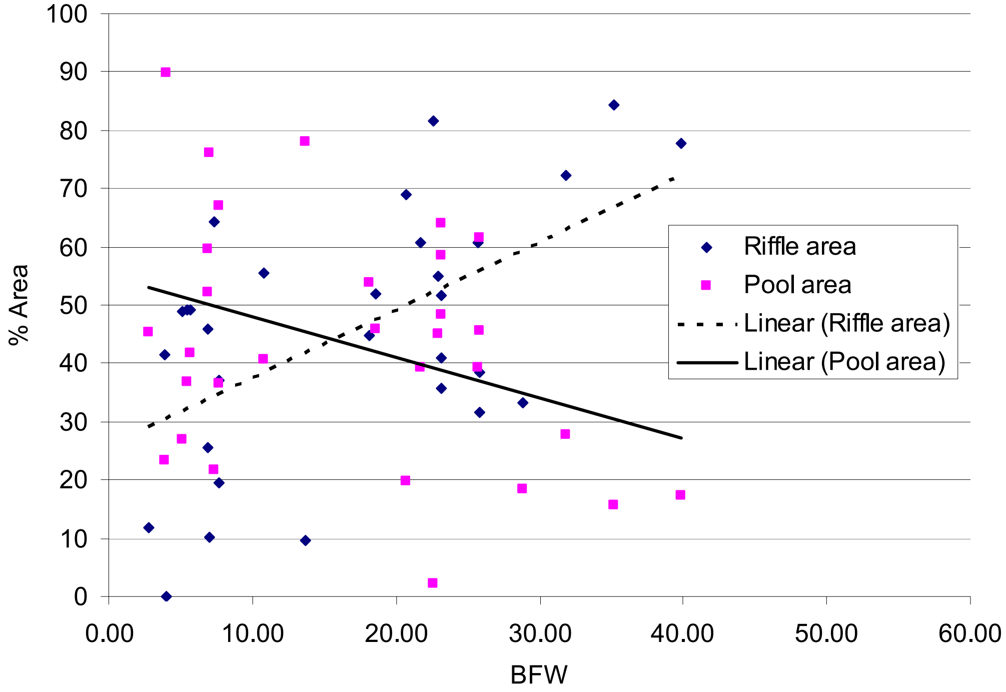


Figure 11: Relationship between bankfull width dimension and percent pool and percent riffle areas.

Pool type was designated as primary (located in alignment with the thalweg) or backwater (not in alignment with the thalweg). Primary pools composed 79% of the total pool count. Mean primary pool functional area was 198.6 (m^2) with an average maximum depth of 0.95 m and average residual depth of 0.66 m. Nineteen reaches contained pools classified as backwater pools. Backwater pools made up 21% of the total pool count. Mean backwater pool functional area was 64.4 (m^2) with an average maximum depth of 0.83 m and average residual depth of 0.65 m. Pool frequency averaged 44.3 pools/mile (0.4 pools/channel width or 4.3 CW/pool) among sites and ranged from 0.7 - 13.3 channel widths/pool.

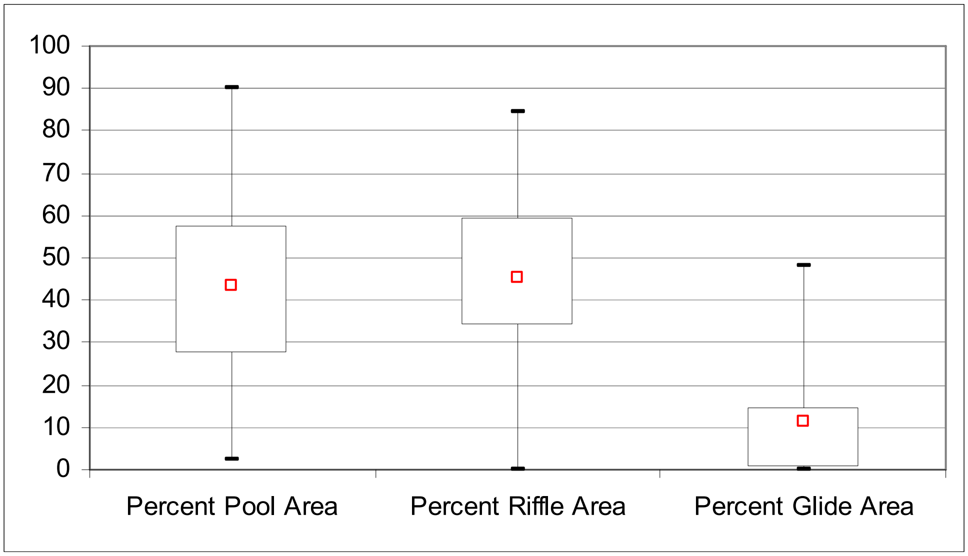


Figure 12: Percent habitat area across all surveyed reaches. The center point indicates the mean among reaches; larger boxed areas illustrate 25th to 75th percentile distributions, and whiskers show minimum and maximum values.

Based on the WFPB (1997) performance criteria for percent pool area, 43% of the stream reaches were characterized as poor. Only 27% of reaches were rated as good. For pool frequency more reaches fell into the fair rating category than for pool area, but the proportion of reaches rated good declined below that of pool area (Table 12). Although these results demonstrate few reaches are properly functioning based on WFPB criteria (17% of reaches), the interpretation is different based on the NMFS (1996) criterion for pool frequency. Based on this alternate habitat standard, 70% of reaches met NMFS (1996) pool frequency performance criterion for properly functioning condition. Although this glaring difference of interpretation is problematic for describing status, interpreting future trends from the current condition is more important.

Table 12: Percent of reaches (n=30) characterized by performance criteria for pool habitat.

Pool Parameter	Good	Fair	Poor
Pool Area, % (WFPB 1997)	27%	30%	43%
Pool Frequency, Pools/CW (WFPB 1997)	17%	50%	33%

Pool Frequency, Pools/mile (NMFS 1996)	70%	30%
Pool depth (NMFS 1996) - Sufficient deep pools >1 m	17%	83%

In alluvial, depositional channels with the exception of braided channels, cross-channel oscillating flow will cause alternating patterns of scour (pools) and deposition (riffles) (Montgomery and Buffington 1993). However, LWD loading can increase the complexity and frequency of habitat unit sequencing (Montgomery and Buffington 1993). Therefore, a 1:1 pool:riffle (area) ratio does not necessarily reflect good habitat forming processes, nor is it diagnostic of habitat quality, especially in the Pacific Northwest where wood loading forces habitat formation. A more important comparison may be between pools and glide habitat. Generally, increases in glide area accompanies habitat impairment (e.g., May *et al*. 1997) as pools fill with sediment, LWD is removed, or channel complexity and sinuosity decreases. Therefore, recovery of habitat quality should shift habitat unit composition away from glide habitats and toward pool habitats. Riffle area likely stays the same (May *et al*. 1997). In addition to the quantity of habitat units, habitat quality must be considered. There is no useful diagnostic criterion for riffle habitat performance pertaining to area or frequency other than with respect to quality of riffle substrate/sediment characteristics. We hypothesize that in response to changes in catchment-scale growth and development or riparian and stream restoration that the ratio of pool:glide habitat will decrease or increase, respectively.

Pools were characterized by forming factor based on classifying observed flow resistance into five categories: woody debris, free-form (by natural bed or bank resistance), riprap armor, bedrock, or beaver dam. The most common pools were free-formed and wood-formed, each category comprising at least a third of the pools (Table 13). Riprap and bedrock-formed pools each occurred 12% of the time. Beaver formed pools represented only 3% of the pools and were found in only 5 of the surveyed reaches. Pool morphology is influenced by the pool forming feature. Pools formed by rip rap and bedrock tended to be among the deepest and largest pools (Table 13 and Figures 13 and 14) due to strong resistance to lateral scour, while wood-formed pools tended to be shallower and smaller. Back-water pools, with different functions from primary pools, were predominantly formed by wood. Beaver-formed pools had the largest variation in area and depth, perhaps due to rarity and various states of construction/maintenance.

Because the frequency distribution of pool area and depth were non-normally distributed, we used non-parametric Kruskal-Wallis ANOVA to test for statistical differences in both pool area and depth when grouped by pool forming feature. Both residual pool depth and pool area varied significantly among pool forming factors (Figure 13 and 14). Post-hoc comparisons confirmed groupings of pool area by rip rap/bedrock and freeform/wood, while beaver pools were not significantly different than any of the other pool forming factors (Figure 15). Analysis of pool depth revealed significant differences in depths between pair-wise pool forming factors, but there were no distinct groupings (Figure 15). This appears to be due, in part, to the greater depth, relative to average pool area, of wood formed pools. For unit increases ($100 m^2$) in pool area, wood-formed pools are deeper, suggesting woody debris is most efficient by area (and length of stream) at turning gravel streambed into pool habitat.

Table 13: Pool forming factor and pool characteristics for Snohomish Basin wadeable stream reaches (n=30).

Pools	Wood	Riprap	Bedrock	Free formed	Beaver	Totals
Count, #	112	35	30	103	9	289
Reaches, #	21	13	10	24	5	30
Percent of total count	39%	12%	10%	36%	3%	100%
Primary pool, freq. (#/km)	87	28	26	95	6	242
Backwater pool, Freq. (#/km)	25	7	4	8	3	47
Mean wet area, m²	132	362	337	210	196	211
Mean max depth, m	0.84	1.15	1.24	0.87	1.02	0.93
Mean functional area, m²	95	274	255	153	187	148
Mean residual depth, m	0.63	0.79	0.88	0.53	0.92	0.65

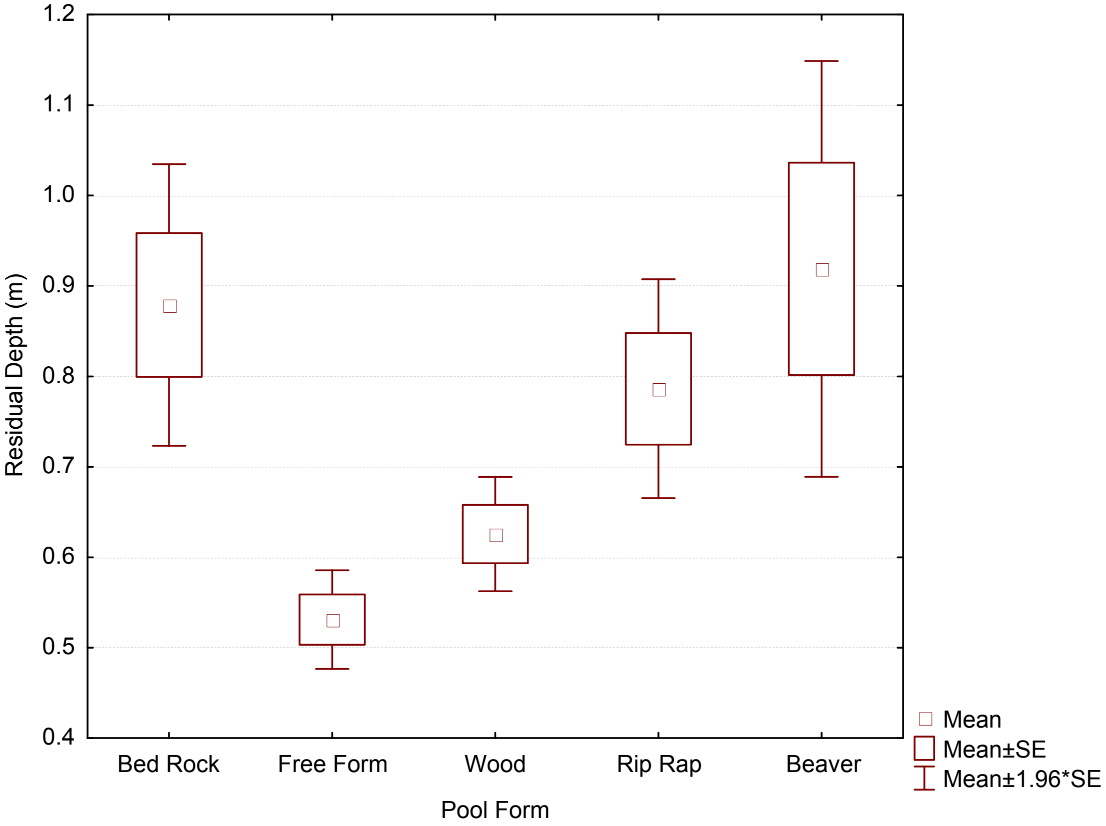


Figure 13: Mean residual pool depth with 95% confidence intervals by pool forming factors. Kruskal-Wallis ANOVA: H (4, N= 289) =36.3 p =0.00

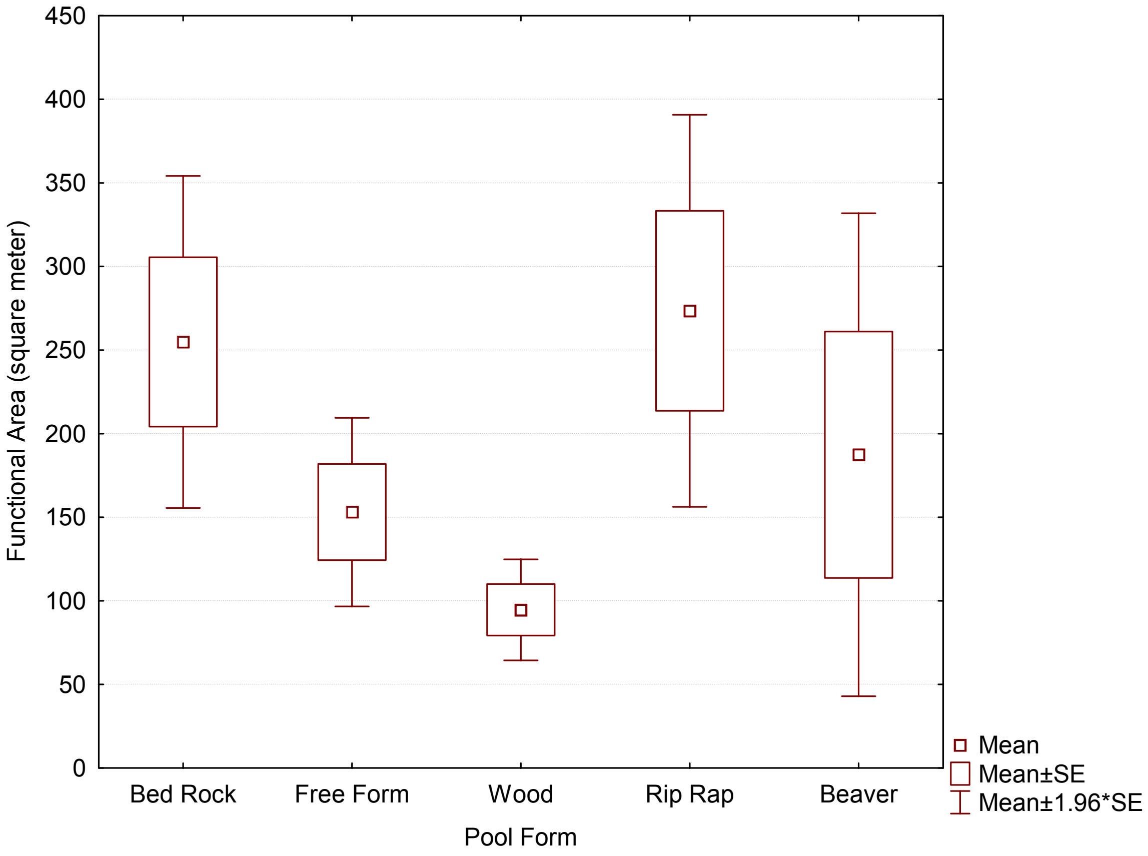


Figure 14: Mean functional pool area (m^2) with 95% confidence intervals by pool forming factors. Kruskal-Wallis ANOVA: H (4, N=289) = 25.0, p=0.0001

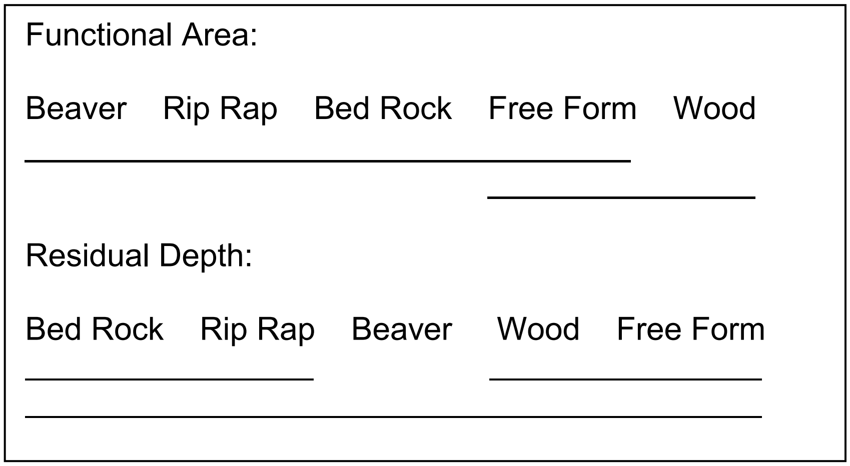


Figure 15: Multiple comparisons post-hoc test for pool functional area and mean residual pool depth by pool forming factor. "Lines" indicate groupings with no significant differences with $p < 0.05$.

Approximately 17% of the pools (50 pools), had a residual depth ≥ 1m deep – the remainder were shallower. Deep pools are important as holding areas near spawning habitat for large adult salmonids prior to or after spawning. Distribution of maximum pool depth is shown for each reach in Figure 16. There were 15 reaches with an average maximum depth of 1 m or greater. Nineteen had 75th percentile pool depths of at least 1 m; eight had 25th percentile pool depths of at least 1 m. Nine reaches had no pools ≥1 m deep; all had BFW <10 m. Of the 8 reaches with a 25th percentile of pools ≥1 m depth, 5 met the NOAA (1996) or WFPB (1997) pool frequency criteria. Pools ≥ 1 m max depth represented 58% of pools in reaches > 10 BFW; while 9% of pools in reaches <10 BFW.

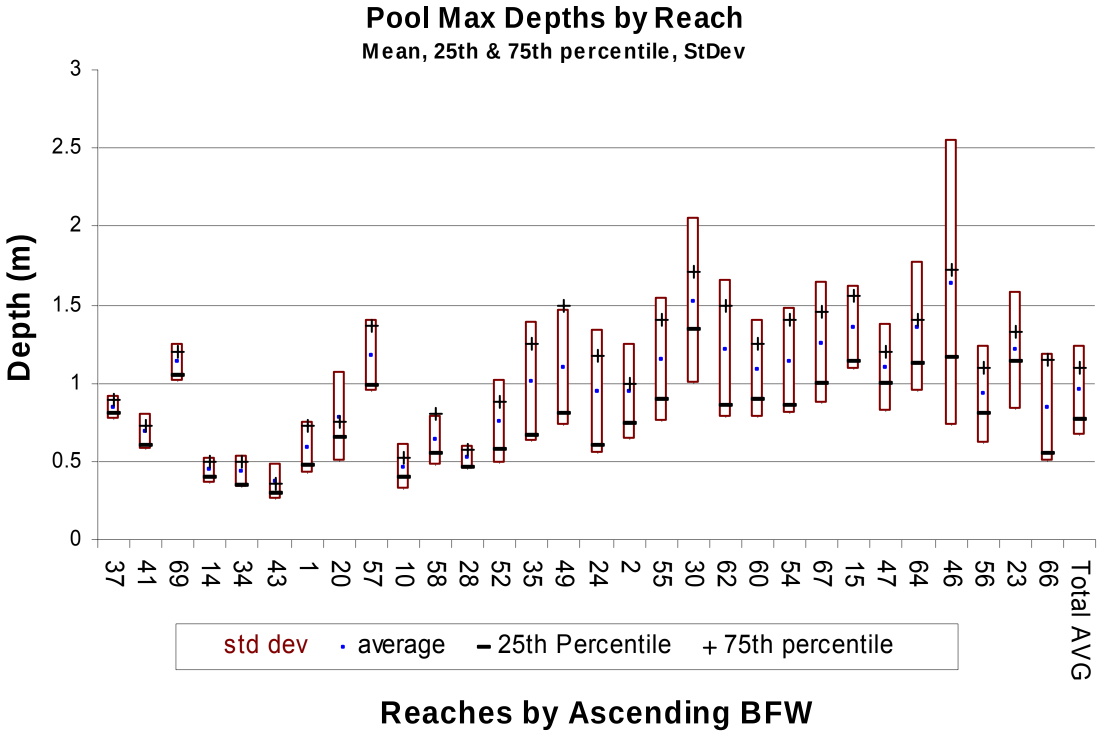


Figure 16: Mean max pool depth and variability for individual reaches by ascending BFW.

The frequency distribution of pool depths as just described will help with testing for future trends. For example, the cumulative distribution curve (Figure 17) will become steeper as residual depth decreases; alternatively, it will become shallower if hydrologic processes or restoration actions improve pool depth. At the same time, if we associate wood-formed pools with good pool habitat quality, then we would not necessarily expect to see average pool depth increase with an improvement in pool habitat quality, primarily due to an increase in more wood-formed pools over time. If new pool formation from increased LWD loading creates shallow pools, as observed initially after LWD restoration (Leonetti *et al*., unpublished data), then near-term average pool depth may decrease. As pools deepen over time to the average observed among wood formed pools (the 0.6-0.7 m depth range), the frequency distribution should shift higher than the current 0.4-.0.5 depth range (Figure 17). This response, combined with an increase in the proportion of wood-formed pools, would be expected.

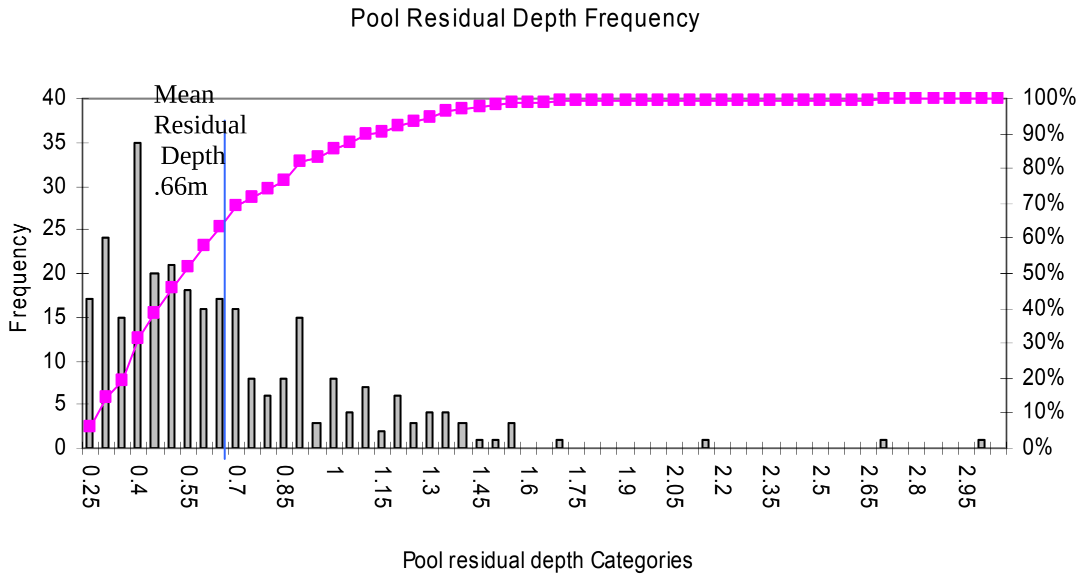


Figure 17. Frequency distribution of residual pool depth in 5 cm increments. A shallower cumulative frequency distribution will be indicative of deeper pools over time.

To examine the relationship between LWD and pools, we performed several analyses based on questions posed in Table 1. We determined LWD frequency (pieces/km) did not vary strongly by BFW dimensions. In smaller channels wood loading was higher overall, as reported, but in larger channels (especially in forested reaches), LWD was more abundant. In terms of LWD frequency (pieces/km), these LWD relationships with channel size were cancelled out. Because pool frequency (pools/km) was strongly negatively correlated with BFW (r=0.61), we chose to standardize pool frequency by channel width dimensions. For pools, we calculated the spacing between pools as the number of channel widths per pool (CW/pool). Pool frequency (spacing) was significantly correlated with woody debris frequency for forested reaches based on a negative exponential relationship ($y=15.3e^{-0.004x}$; $r^2=0.62$, $p=0.01$, Figure 18), but non-significant for non-forested reaches.

At the same time, higher woody debris frequency doesn't explain frequent pool spacing among non-forested reaches with low LWD frequency. It's possible that frequent pool spacing exists in several non-forested reaches based on pools formed by obstructions other than wood, such as riprap. Alternatively, frequent pool spacing may result naturally in many lower gradient channels that dominated our sample, regardless of wood load. Understandably, reaches with low LWD frequency tended to have fewer pools formed by LWD. But, the proportion of wood-formed pools tended to increase rapidly and plateau (but was highly variable) above a LWD frequency of 300-400 pieces/km (Figure 19). This interaction may be related to slope where pool-riffle planform would predominate in the absence of LWD loading or where frequent pool spacing was forced by bank modifications. Therefore no relationship between woody debris and pool spacing would be expected where few pools are formed by LWD. In future analyses with more sample points, we may investigate the relationship between LWD and pools based on pool forming factor and bank modifications, as well as adjacent land use type.

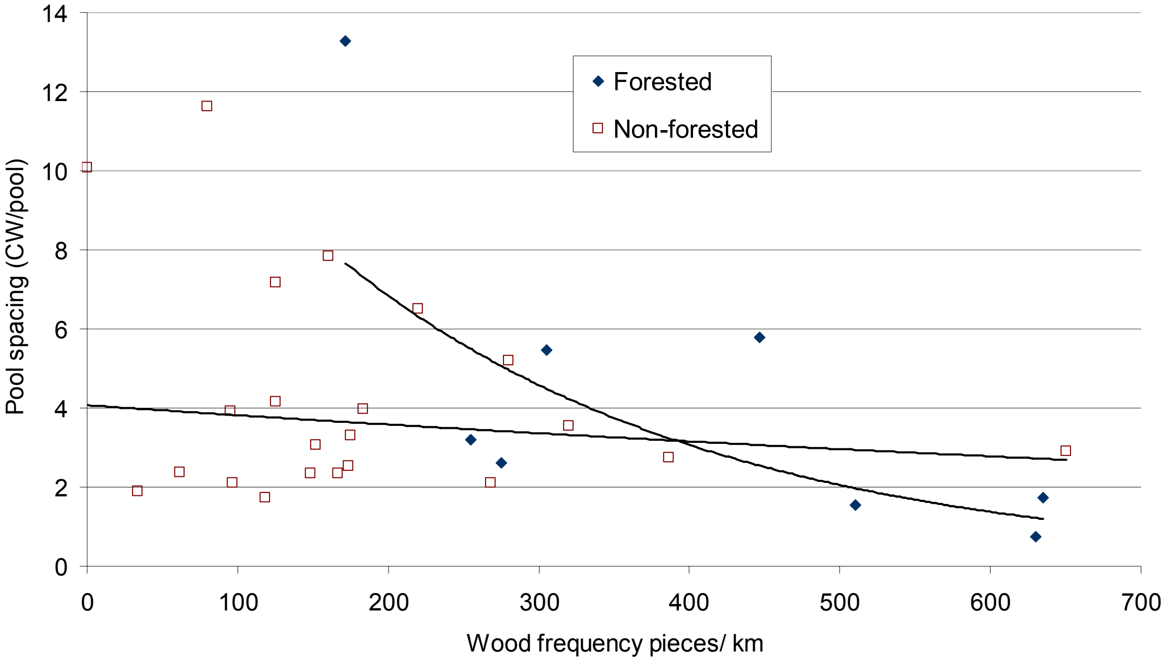


Figure 18: Relationship between woody debris frequency (pieces/km) and pool spacing based on channel width units for forested and non-forested reaches.

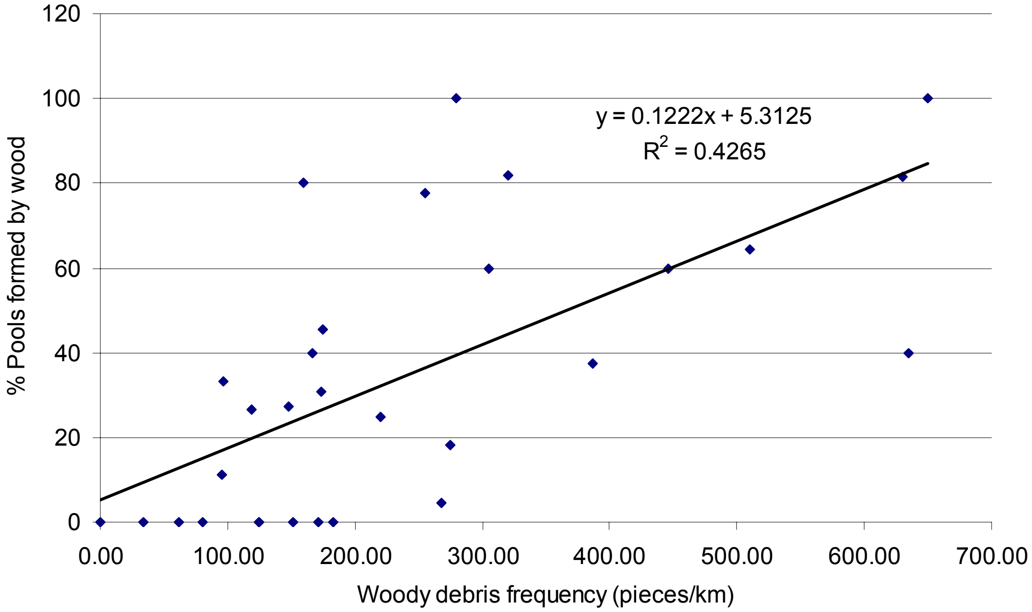


Figure 19: Relationship between LWD frequency and the proportion of pools formed by LWD among all reaches (F=20.8, r2=0.43, p<0.0001).

Side-Channel Habitat

Sixteen of the 30 reaches contained side channels. Among reaches containing side-channels, total side channel area was 10% of the main-channel area. Mean side channel wet area was 130 m² per occurrence, while the mean total side channel area was 602 m² among reaches containing side channels. Pools designated as off-channel or backwater account for 8.7% of the pool area. The amount of side channel area and the number of side channel connections within a reach is representative of channel complexity and habitat unit complexity. The presence or absence of side channels may correlate with other channel and habitat characteristics important for side channel maintenance, such as slope, LWD, or channel confinement by modifications. Characterization of side channel habitat may be subject to variation in flow stage. Thus, trends in side channel abundance and characteristics may be more challenging to interpret if any are observed and changes among years may be highly variable based on interceding flood events, sedimentation, channel switching, or other factors. Based on these considerations we will pursue analysis of Table 1 questions and hypotheses using the larger County-wide database of wadeable streams. However, overall we hypothesize side channel connections (#), and total length and area will increase over time with Salmon Recovery Plan implementation and habitat recovery in the low gradient, unconfined channels represented in our survey.

Substrate

Substrate size characteristics are reported based on category classes and for each reach are included in Appendix Table B-4. Coarse gravel was the dominant size category present among all reaches surveyed (Table 14). Correspondingly, this size class contained the mean particle size for half of the reaches surveyed. Cobbles and sand-sized particles were subdominant overall, and each composed a fifth of the substrate particles measured among all reaches.

Table 14: Substrate distribution by percentage for all reaches.

Size Classification	Percent
Fines/Silt (<.06mm)	11%
Sand (.06-2mm)	20%
Fine Gravel (2-16mm)	14%
Coarse Gravel (16-64mm)	24%
Cobble (64-250mm)	20%
Boulder (250-4000mm)	8%
Hardpan (>4000mm)	2%
Bedrock (>4000mm)	1%

The fraction of the bed composed of fines (containing silt) or fines and sand (all <2mm) represents the substrate size category in our survey with the greatest potential to limit salmonid egg incubation success or be detrimental to juvenile rearing (e.g., from loss of pool habitat). Sands were present in all stream reaches and when combined with fines, comprised 31% of the total among reaches. Cumulative distribution curves for the fines and fines plus sand component of the substrate revealed that six (6) reaches were dominated by substrate <2mm (Figure 20). Ninety-one percent of the stream length surveyed was characterized by 14% or less fine sediment and 50% of the stream length surveyed was characterized by 23% or less sediment in the sand class or smaller (Figure 20).

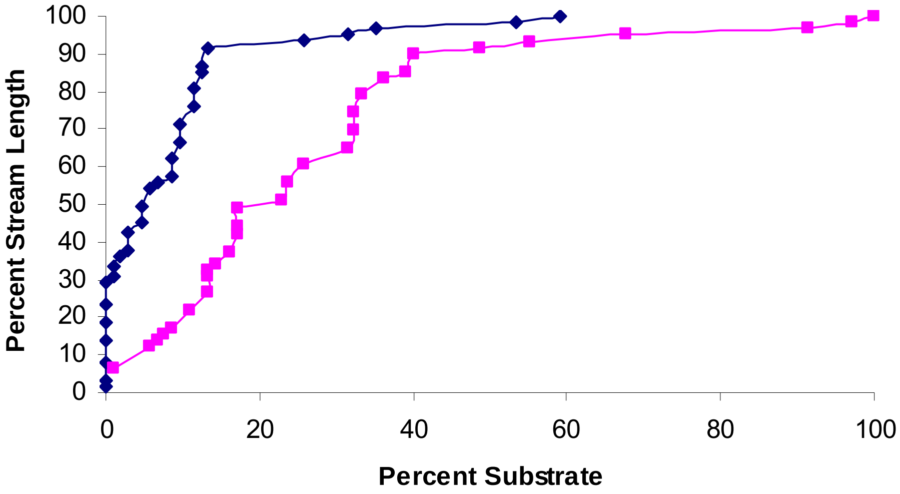


Figure 20: Cumulative Distribution Function comparing percent fines (blue diamonds) and percent fines and sand (pink squares).

NMFS (1996) and WFPB (1997) both provide performance criteria for surface fines, however, neither one of these sources provide quantitative criteria based on the composition of sediment size classes. Surface fines determinations for the WFPB (1997) criterion are made from visual estimates of fine sediment accumulations around in-stream obstructions. NMFS (1996) criteria are based on visual estimates of dominant and subdominant size classes and estimates of embededdness for substrate, as well as percent fine sediment as a water quality indicator (and referencing the WFPB criteria). Reach substrate size class composition (Appendix Table B.4) and cumulative distribution functions indicate that 6 sites are dominated by sands or finer material. Although the agency criterion for degradation due to gravel size <0.85mm is 17%, we hypothesize that the slightly higher composition (≈23%) of fines combined with sand (<2mm) is equally representative of impaired streambed substrate composition. Approximately 50% of the cumulative length (all reaches) exceed 23% composition in fines and sand <2mm, suggesting one-half the surveyed area was degraded by fine substrate. This composition (23%) also corresponds with a discontinuous break in the cumulative distribution where higher composition of fines and sands exist, suggesting that these stream reaches fail performance criteria given by NMFS and WFPB. Additionally, our estimate may underestimate the composition of surface fine sediments due to potential pebble count sampling bias against smaller size fractions.

Streambed particle size and the proportion of fines and sands in the particle distribution are important indicators of the sediment regime of the watershed, and of habitat quality for spawning, incubation and rearing of salmon and trout. For estimating trends in substrate size, we seek to determine if gravel composition is becoming more fine over time within and among reaches relative to our current observations. This can be described based on the frequency distribution of reaches meeting or exceeding lower thresholds for function, but will also be based on error variance and parameter uncertainty. If high uncertainty exists for estimating particle size distributions on the reach scale in heterogeneous stream beds (i.e., pool-riffle sequences; Snohomish County 2002c), then it will be difficult to detect trends in surface substrate (Bundt and Abt, 2001). Substrate analysis may detect major changes in surface sediments but more detailed studies or a longer timeline for monitoring may be necessary in order to meet status and trend goals.

Survey Precision and Repeatability and Implications for Trend Detection

Four components of variance that influence trend detection include: 1. Within-year variability among sites (i.e., contributing basin size, elevation, human impacts); 2. Year-to-year variation that impacts all study sites (i.e., wet vs. dry years); 3. Interactions between site and year (i.e., location-specific factors); and 4. Residual error (i.e., seasonal variation within sampling period and measurement error) (Larsen *et al*. 2001). Residual-error is estimated with within-year repeat site visits referred to hereafter as quality control (QC) sites. In addition to residual error, QC site visits enable us to evaluate within-year variability between sites, which is captured as the “signal” component of the signal:noise ratio. Future sampling at QC sites will provide an assessment of inter-annual variance and site-year interaction variance. An understanding of the relative contribution of variation components to observed differences will inform trend detection based on power analysis and help identify the size of trend we can expect to detect, and infer as being real, over a given time frame (Larsen *et al*. 2001, Larsen *et al*. 2004).

High measurement precision and repeatability were accomplished for the following parameters: % bank modification; center channel riparian cover; bankfull width; and pool depth. Parameters that are measured with moderate precision and repeatability include pool count (which affects frequency as a calculated metric), large woody debris frequency and total pool area. Lower measurement precision and repeatability of some parameters suggests there will be low power to detect trends over time. For these parameters, more time will likely be required to evaluate whether detectable and significant change (i.e., enhancement or degradation) is occurring. Given limited sampling effort, parameters with high measurement precision will be useful for assessing changes in conditions in shorter time frames. For each of the measurements of physical channel condition, we present precision and repeatability results and discuss implications for trend detection.

Within-year repeat site visits were conducted during several years of monitoring based on applying the same wadeable stream protocol. Among years, personnel varied as might be expected during a long-term monitoring program for trend evaluation. Only one parameter, percent fine sediment, was measured differently between 2000/2001 and 2006/2007, in part due to low precision and repeatability of the first method employed (Snohomish County 2002). Of the 8 parameters examined using pooled data from 2000, 2001, 2006, and 2007, 8 were determined to be either moderately precise or precise (as defined by Kaufmann *et al*. 1999) and had a repeatability score of at least 0.8 (Table 15 and Table 16). Data for bank instability were available for all survey years, but were not pooled because precision and repeatability was substantially different between 2000/2001 and 2006/2007 (Table 17). Pool data was also collected during all survey years, but percent pool area calculations differed between 2000/2001 and 2006/2007 and data were not pooled. For the 14 parameters analyzed for year 2006/2007 data, 6 were either precise or moderately precise and had repeatability scores greater than 0.8, and 8 were imprecise and had low repeatability (Table 16). The addition of more QC sites will contribute to better characterization of the precision and repeatability of these parameters.

Bank Condition

While bank instability precision and repeatability were analyzed for 2000/2001 and 2006/2007 QC sites, the data were not pooled due to large differences in precision and repeatability between survey years. Bank stability was determined to be precise and repeatable for data collected in 2000/2001, but for 2006/2007, this parameter had the lowest precision and repeatability among all parameters (Tables 14, 15). Apparently differences in the length of instability reported, often at different locations between survey teams, contributed to inconsistencies in percent bank instability reported (Table 18). Results from 2000/2001 indicate that bank stability has potential to be precisely measured and could therefore be a good habitat parameter for trend detection. However, 2006/2007's results highlight that this parameter can be overlooked in the field and identified differently between field teams. This parameter will only be useful for trend detection if field teams attentively watch for bank instability throughout the entire stream survey and consistently apply the same criteria to identify a bank as unstable. Another indicator of bank condition considered in 2006 and 2007, bank modification, was determined to be repeatable and precise. Quality assurance analysis for this parameter suggests that bank modification can reliably be detected and will be sensitive to trend detection.

Cover

Cover measurements in 2007 differed in precision and repeatability, depending on whether the measurement was taken at the bank or in the center of the channel. Instream measurements were precise and repeatable, while bank measurements were moderately precise and had lower repeatability (Table 16). The RMSE was similar for both of these parameters, indicating that differences in precision and repeatability reflects variation in the signal of the parameter measured, rather than sampling error. Because bank canopy cover was relatively constant and high among all QC reaches, these reaches did not provide the best “test” of measurement precision. However, since instream cover was more variable and error was low, the signal-to-noise ratio was very high. Mid-channel canopy cover is a useful parameter for trend monitoring because it is both measured accurately and is responsive to differences in riparian conditions. Cover measurements taken from the stream bank, however, are still useful in identifying areas with highly reduced riparian cover that signal severely degraded habitat conditions.

Large Woody Debris

Large Woody Debris (LWD) and Small Woody Debris (SWD) classifications were moderately precise and repeatable (Tables 14 and 15). Jam frequency counts were only analyzed in 2007 and precision and repeatability results were similar to other wood counts made from wood count data pooled from all years. Sources of measurement error include difficulty in counting obscure wood, differences in identifying the bankfull channel, and therefore identifying wood within the bankfull channel, and differences in the placement of diameter measurements. More careful consideration of these factors in the field will improve precision and repeatability for LWD measurements

Habitat Units (Pools, Riffles, Glides)

Analysis of pooled data from 2000, 2001, 2006 and 2007 indicates that pool counts and frequency were moderately precise to precise, and average residual pool depths were precise (Tables 14 and 15). Possible sources of measurement error for pool count and frequency include: Slightly different pool dimension measurements can result in the inclusion/exclusion of a pool by one of the survey groups; and differences between survey groups in the decision to lump or split pool-like closed depressions in close proximity. Conducting surveys during similar flows can help reduce variation in pool dimensions and lumping versus splitting decisions. Pool counts/frequency and percent pool area can be used for trend detection, but a longer monitoring period will be required to detect change in these pool parameters than for average pool depth. A caveat to this conclusion is that mean functional area was measured based on the pool marginal depth of 20cm (or the pool tailout depth, if greater than 20 cm) and excludes shallow lateral areas. Based on within-season repeat visits, this measurement tends to be more precise than total pool area and may be useful for estimating trends in mean pool area.

Analysis of 2007 QC reaches indicates that percent riffle area had low precision and repeatability. Riffle counts conducted in 2007 also had low precision and repeatability. Reaches should be surveyed under similar flow conditions, as within-year low flow variability will unduly influence measurement precision for habitat units (but not wood, bank conditions, sediment, or cover). More emphasis should be placed on both riffle identification and length determinations during training.

Side-Channel Habitat

Analysis of 2007 QC reaches indicates that side channel area and percent area measurements lacked precision and repeatability (Table 16). For this habitat parameter, an individual decision about whether an area meets side channel criteria determines whether entire sections of potential off-channel habitat will be included in the survey. As a result the magnitude of difference between repeat surveys of the same reach can be much higher for off-channel habitat than for other habitat parameters.

Substrate

For 2000/2001 QC sites, percent fine sediment (defined then as <6.3mm in 2000/2001) parameter precision and measurement repeatability was low – S/N was 0.3 and Repeatability (R) was 0.3 (Snohomish County 2002c). For example, for two stream reaches, different survey teams measured mean fine sediment composition among riffles to be in excess of 70% compared to approximately 20%. Differences may have resulted due to misapplication of the protocol, measurement bias, and real variability based on selecting different within-reach sampling locations. However, even when the same riffles were sampled by different teams, low precision and repeatability were observed (S/N=0.4, R=0.3). For 2006/2007, we chose to limit our definition of fines to <2mm, which targets a smaller size fraction for quantification. Also, by changing the measurement protocol to sample only at regularly spaced locations, we sample from conceivably all representative streambed surfaces (pools, riffles, glides), not just potentially spawnable riffles or pool-tailout areas. Although the reach estimates of sediment size <2mm do not just specifically apply to spawning habitats for large salmonids, the reach averaged fine sediment composition likely reflects a measure of risk that salmonid redds would be impacted after typical redd building activities by adult female salmonids dramatically reduces the fines content of streambed gravels (Chapman 1988).

Results for combined fine and sand measurements from the 2006 and 2007 dataset showed a modest increase in precision and repeatability (S/N=2.0, R=0.71) relative to earlier estimates, but the S/N ratio remained below the 2.5 criterion for higher precision, indicating moderately precise measurement (Table 16). Measurement error can be particularly high for quantifying small particles because it is difficult to feel and pick up a small individual grain when it is surrounded by larger particles (Bundt and Abt, 2001). Additionally, avoiding inaccessible areas where fine particles tend to accumulate can bias a survey against the detection of smaller particles. In addition to measurement error, statistical error is high in poorly sorted gravel beds (i.e., in habitat units that contain sands and boulders) and higher in the computation of percent fines or fines and sand than for mean particle size (Bundt and Abt, 2001). Finally, variability in substrate size is greater in heterogeneous stream beds than for streams that are more homogenous (i.e., pool-riffle vs. plane-bed morphology) (Bundt and Abt, 2001). While bed heterogeneity may not contribute largely to within year measurement error if transects are placed at the same stations along the reach, slight differences in transect placement may result in differences in substrate data.

While the fine sediment component of the stream substrate is important for describing spawning habitat suitability and egg incubation conditions, precision estimations indicate that trend detection of surface fine sediments will be difficult regardless of whichever rapid assessment protocol is applied. More detailed studies of fine sediment within spawning gravels may be necessary to quantify stream bed sediments with enough precision for trend detection.

Table 15: Estimates of select habitat parameter precision for quality control and analysis data collected in 2000, 2001, 2006, and 2007.

Habitat parameter	n	Grand Mean	RMSE	S/N	R
Bankfull width (m)	31	12.3	1.4	55	0.98
Riffle wetted width (m)	30	6.7	1.3	22	0.96
Pool count (#)	29	5.9	1.4	6.2	0.86
Pool Frequency (per km)	29	18.4	5.7	5.8	0.86
Average Pool Depth, Residual (m)	31	0.5	0.1	10.9	0.92
Small Woody Debris freq. (pieces/km)	24	174.8	56.5	3.9	0.80
Large Woody Debris freq. > 30 cm diameter & 7.6 m length (pieces/km)	31	24.7	8.5	4.4	0.82

Table 16: Estimates of habitat parameter precision for quality control and analysis data collected in 2006 and 2007 (n=8).

Habitat parameter	Grand mean	RMSE	S/N	R
Mean channel gradient	2.0	0.6	6.9	0.89
Bankfull depth	0.5	0.2	1.2	0.60
Percent Riffle Area (%)	53.7	15.0	0.9	0.52
Riffle Count	11.9	2.5	1.8	0.67
Large Woody Debris > 60cm diameter and 7.6m length frequency (pieces/km)	1.5	0.0	**	1.00
Jam frequency (jam/km)	0.9	1.3	3.4	0.80
Bank instability, %	18.1	13.0	-0.2	-0.15
Bank modification, %	11.1	0.9	172.8	0.99
Riparian bank cover (%)	90.8	3.5	2.6	0.75
Riparian center channel cover (%)	58.5	4.3	48.1	0.98
Substrate, Fines and Sand (<2.0mm) (%)	21.5	5.8	2.0	0.71
Side channel wet area (m^2)	6.7	5.9	1.8	0.68
Percent side channel area (%)	78.4	106.8	0.4	0.33

Table 17: Differences in estimates of bank instability and percent wetted pool area precision for quality control and analysis data collected 2000/2001 and 2006/2007. Data from 2000/2001 reported by Snohomish County (2002c).

Habitat Parameter	Year	n	Grand mean	RMSE	S/N	R
Bank instability, %	2000/2001	46	11	4.5	8.9	0.9
Bank instability, %	2006/2007	8	18.1	13	-0.2	-0.15
Unstable site count (#)	2006/2007	8	5	2.4	0.4	0.36
Pool area, wetted %	2000/2001	42	14.2	4.2	7.2	0.88
Pool area, wetted % (2000/2001 method for calculation)	2006/2007	8	34.1	11.6	2.8	0.77
Pool area, wetted % (2006/2007 method for calculation)	2006/2007	8	35.8	12.1	2.6	0.75

Table 18: Source of error in bank instability reported between field teams in 2007.

QC Reach Number	Reach Length (m)	Difference in length of instability due to stations identified by only 1 team as unstable (m)	Difference in length of instability reported at station identified by both field teams as unstable (m)
10	200	29.9	8.1
20	200	48.5	5.4
43	200	26	77.8
56	600	37.5	14
62	600	56	92.5
67	600	275	188.9
Total	2400	472.9	386.7

Conclusions

The goals of this monitoring program are both to describe the status of habitat conditions for salmonid fishes in Snohomish County rivers and streams and track watershed and habitat trends over time. Work implemented under this program seeks to contribute to successful long term adaptive management for aquatic resources in Snohomish County by providing foundational watershed and habitat monitoring information, analyses and reporting to inform conservation and restoration decision-making. This report includes wadeable stream monitoring results from project work implemented in 2007 that forms the baseline for future habitat trend detection in the Snohomish River basin.

The estimated degree of function (by category) for all reaches for selected parameters is included in Table 19. These indicators will be tracked over time for changes in conditions among reaches. If the proportional composition of streams with higher fair or good function increases over time, we will be able to interpret this as overall improvement, after considering the probability (given monitoring uncertainty) and power of detecting real change, should it occur.

Table 19: Summary of habitat parameter indicators and estimate of stream composition (%) for each level of function.

	Function		
	Good	Fair	Poor
Bank stability (% stable)	56%	27%	18%
Bank modifications (% armored)	50%	43%	7%
Mid-channel canopy cover (% cover)	33%	67%	
Fox and Bolton's (2007) LWD frequency criteria	0%	10%	90%
Number of wood pieces per 100m of channel length	0%	0%	100%
Pool area, % (WFPB 1997)	27%	30%	43%
Pool frequency, Pools/CW (WFPB 1997)	17%	50%	33%
Pool frequency, Pools/mile (NMFS 1996)	70%	30%	
Pool depth (NMFS 1996) - sufficient deep pools >1 m	17%	83%	
Exceed 25% composition in fines and sand <2mm	50%	50%	

Key findings regarding the utility of habitat parameters to detect trends include:

- Percent bank modification, center channel riparian cover, bankfull width, and pool depth had the highest precision and repeatability. These parameters are expected to be most sensitive to change – we can be most confident in being able to detect smaller degrees of change with minimal lag time in our ability to detect change after it has occurred. Hence, we believe they will have the most value for early adaptive management responses.

- Parameters that are measured with moderate precision and repeatability include pool count and frequency (calculated metric based on pool count), woody debris frequency (based on wood count), and total pool area.

- Low measurement precision and repeatability of some parameters (percent fine sediment, side channel area) suggests there will be low power to detect trends over time. For these parameters, more time will likely be required to evaluate whether detectable and significant change (i.e., enhancement or degradation) is occurring and may require more detailed sampling and analysis.

Bank full width and bankfull depth, although not inherently diagnostic of habitat conditions, are useful to consider where changes in hydrology, bank condition, sediment yield, or other subbasin scale changes related to land use/land cover conversion (generally as increases in impervious area and reduction in forest cover) would produce channel adjustment that may be a leading indicator of deleterious habitat change (Booth 1990). Measuring riffle wetted width at survey transects can also produce an estimate of variability (as the relative standard deviation of mean wetted width) in within-reach habitat unit complexity. Reaches with more frequent pool:riffle sequences, greater sinuosity, variable thalweg depths (especially influenced by stream obstructions (wood, boulders, bank resistance) will have more variable dimensions compared to an armored, straightened, and/or obstruction-free channel.

Estimating changes in leading indicators of stream habitat alteration (such as land cover, road coverage, stream crossings, extended drainage network, or wetland losses), especially in more sensitive subbasins (e.g.; with highly erodible soils) will be useful because channel responses, especially in higher order, lower gradient, anadromous fish-bearing channels, may be delayed in space and time from multiple influences in the upstream contributing area. Interpreting functions provided by existing conditions will be most informative if considered alongside of the context provided by the contributing upstream area. And, a departure from published performance criteria would be expected even in undeveloped settings due to variability in natural processes and conditions distributed spatially and temporally.

As a next step, we will estimate interannual site variability (as well as ongoing within-year variance) by performing limited repeat sampling of Snohomish Basin reaches in 2008. Based on this future work, an estimate of analytical power to detect trends based on hypothetical trends in condition (1-2% change per year) will be generated in order to estimate time required to detect real trends. Of course, repeat visits in future years will begin to establish the direction and rate of actual change observed to compare to habitat benchmarks for adaptive management decision-making. As indicated in the previous section, measurement precision may be improved by enhancements of our protocol or additional training.

Until then, the following indicators for trend detection are intended to inform audiences regarding several hypothesized changes in habitat parameters associated with habitat recovery, the anticipated relative probability of detecting the trend and the relative time required (short, moderate, long) to derive conclusions based on the limited sampling approach reported on in this study.

Indicator for trend detection	Hypothesized Change with habitat recovery	Probability of detection	Time required if real change is present
BFW	Decreasing, with increasing bank stability (or armoring) and enhanced riparian vegetation	High	Long (>>10 years), but short (<5 years) for increasing BFW
Bank Stability (%)	Increasing stability with no increase in modifications	Moderate, but may be low if measurement precision is low	Intermediate (5-10 years) or longer, but change may be overrun by larger infrequent flow events
Bank Modification (%)	Same or decreasing amount	High	Short (5 years) for decreasing or increasing amount
Bank cover (%)	Increasing cover	Low-moderate	Longer (>10 years) for recovery, but short (<5 years) if cover becomes degraded
Instream cover (%)	Increasing cover	High	Intermediate (5-10 years) especially for smaller streams, but short (<5 years) if cover becomes degraded
LWD piece count/ LWD frequency/ LWD loading	Increasing for given length of stream and increasing in larger channels (i.e., >10 m width)	Low –moderate for small steams – but may depend more on interannual variability (currently unknown)	Intermediate (5-10 years), but if large LWD (>60cm/>7.6m) forms in more jams, in channels >10m width, then shorter time to detect change
Pool count or frequency	Increasing	Low-moderate, but may be higher for frequency of wood-formed backwater pools	Longer (>10 years)
Pool depth (avg. and frequency distribution) and area	No change or decrease in average depth, if shallower wood formed pools become abundant	Low-moderate	Longer (>10 years) – Change in pool area may not be distinguishable if many smaller wood formed pools replace or supplement larger non-wood formed pools
Substrate size (<2mm)	Decreasing for most reaches (some may be more influenced by deposition from impounding due to low gradient or beaver)	Low	Longer >10 years

Literature Cited

Abbe, T.B. and D.R. Montgomery. 1996. Large woody debris jams, channel hydraulics, and habitat formation in large rivers. Regulated Rivers: Research and Management 12, 201-221.

Bilby R.E. and P.A. Bisson. 1998. “Function and Distribution of Large Woody Debris.” In *River Ecology and Management,* eds. Robert J. Naiman and Robert E. Bilby, 324-346. Springer, New York.

Cristea, N. and J. Janisch. 2007. Modeling the Effects of Riparian Buffer Width on Effective Shade and Stream Temperature. Washington State Department of Ecology, Olympia. Publication No. 07-03-028. June 2007, 68p.

Booth, D.B. 1990. Stream-channel incision following drainage-basin urbanization: Water Resources Bulletin, 26, p: 407-417.

Bundt, K. and S.R Abt. 2001. Sampling Surface and Subsurface Particle-Size Distributions in Wadable Gravel- and Cobble-Bed Streams for Analyses in Sediment Transport, Hydraulics, and Streambed Monitoring. United States Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-74

Fox, M.J. 2001. A new look at the quantities and volumes of instream wood in forested basins within Washington State. Masters Thesis. University of Washington, Seattle WA.

Fox, M.J. and S. Bolton. 2007. A Regional and Geomorphic Reference for Quantities and Volumes of Instream Wood in Unmanaged Forested Basins of Washington State. North American Journal of Fisheries Management 27:342–359.

Kaufmann P.R., P. Levine, E.G. Robinson, C. Seeliger and D.V. Peck. 1999. Quantifying Physical Habitat in Wadeable Streams. Environmental Protection Agency, OAO Corp., and Oregon Department of Forestry. EPA/620/R-99/003.

Larsen D.P., T.M. Kincaid, S.E. Jacobs and N.S. Urquhart. 2001. Designs for evaluating local and regional scale trends. BioScience 51(12):1069-78.

Larsen D.P., P.R. Kaufmann, T.M. Kincaid, and N.S. Urquhart. 2004. Detecting persistent change in the habitat of salmon-bearing streams in the Pacific Northwest. Canadian Journal of Fisheries and Aquatic Sciences 61(2):283-91.

Lazorchak, J.M., D.J. Klemm, and D.V. Peck (editors). 1998. Environmental Monitoring and Assessment Program – Surface Water: Field Operations and Methods for Measuring the Ecological Condition of Wadeable Streams. U.S. Environmental Protection Agency, Washington, D.C. EPA/620/R-94/004F.

Leonetti, F.E. Unpublished data. Twin Creeks Recovery Project: Testing Urban Creek Enhancement. Oral presentation at American Water Resources Association Summer Specialty Conference, Squaw Valley, CA. 2004.

May, C.W., R.R. Horner, J.R. Karr, B.W. Mar and E.B. Welch. 1997. Effects of Urbanization on small streams in the Puget Sound Lowland Ecoregion. Watershed Protection Techniques 2: 483-493.

Montgomery, D.R. and J.M. Buffington. 1993. Channel classification, prediction of channel response, and assessment of channel condition: Olympia, Washington State Department of Natural Resources Report TFW-SH10-93-002.

National Marine Fisheries Service (NMFS). 1996. Coastal salmon conservation: working guidance for comprehensive salmon restoration initiatives on the Pacific Coast. USDC-NOAA, NMFS, Portland, OR. Report dated September 15, 1996.

NOAA 2003. HCD Stormwater Online Guidance. ESA Guidance for Analyzing Stormwater Effects. Habitat Conservation Division. NOAA-Fisheries Northwest Region. March 2003.

Pess, G.R., D.R. Montgomery, E.A. Steel, R.E. Bilby, B.E. Feist, and H.M. Greenberg. 2002. Landscape characteristics, land use, and coho salmon (Oncorhynchus kisutch) abundance, Snohomish River, Wash., U.S.A. Can. J. Fish. Aquat. Sci. 59:613-623.

Quinn, T.P. 2005. *The Behavior and Ecology of Pacific Salmon and Trout*. American Fisheries Society and University of Washington Press, Seattle.

Snohomish County Public Works, Surface Water Management (SWM). 2002a. Wadable stream habitat survey preliminary results for the year 2001. Snohomish County, Public Works, Surface Water Management, Everett, WA. March 2002.

Snohomish County Public Works, Surface Water Management (SWM). 2002b. Aquatic Habitat Summary: A Regional Summary of the DNR Habitat Survey of Urban and Urbanizing Streams of Snohomish County. Snohomish County, Public Works, Surface Water Management, Everett, WA. December 2002.

Snohomish County Public Works, Surface Water Management (SWM). 2002c. Precision and repeatability of Wadable stream habitat survey methods. Snohomish County, Public Works, Surface Water Management, Everett, WA. November 2002.

Snohomish County Public Works, Surface Water Management (SWM). 2004. Physical Habitat Survey and Monitoring Protocol for Large Rivers Version 1.2. Snohomish County, Public Works, Surface Water Management, Everett, WA. July 2004.

Snohomish River Basin Salmonid Recovery Technical Committee (SRBSRTC). 2002. Snohomish River Basin Salmonid Habitat Conditions Review. Snohomish County Department of Public Works, Surface Water Management Division, Everett, WA.

Stillaguamish Technical Advisory Group (STAG). 2002. Stillaguamish Watershed Salmonid Habitat Evaluation Version 1.02. Stillaguamish Lead Entity, Snohomish County, Public Works, Surface Water Management, Everett, WA.

United States Forest Service. 1999. *Stream inventory handbook: Level I & II*. United States Department of Agriculture, Region 6, Version 9.9.

Washington Department of Fish and Wildlife. SalmonScape. http://wdfw.wa.gov/mapping/salmonscape

Washington State Forest Practices Board (WFPB). 1997. Watershed Analysis Manual, v. 4.0. Olympia, WA.

Washington State Conservation Commission. 2002. Salmonid Habitat Limiting Factors Analysis, Snohomish River Watershed, Water Resource Inventory Area 7. Final Report. 331p.

Appendices

Appendix A

Wadeable Survey Protocol

http://www1.co.snohomish.wa.us/Departments/Public_Works/Divisions/SWM/Library/Publications/Aquatic_Habitat/Inventory_Assessment_Restoration/

Appendix B
Reach Summary Data

Table B.1. Reach Channel Data

Reach ID	Stream Name	Sub-Basin	Reach Length, m	Average BFW, m	Average Slope, %	Average BFD, m	Side Channel area, %	Modified Bank, %	Unstable Bank, %
1	Worthy Creek	Upper Pilchuck	200	6.9	2.5	0.42	2.8	0	0
2	Pilchuck River	Upper Pilchuck	600	20.7	1.1	0.95	18.1	0	8
10	Miller Creek	Upper Pilchuck	200	7.3	2.2	0.52	7.3	0	10
14	Panther Creek	Dubuque Creek	200	5.1	0.3	0.43	0.0	15	4
15	Pilchuck River	Lower Pilchuck	600	25.7	0.9	1.36	0.0	17	16
20	West Fork Woods Creek	West Fork Woods Creek	200	6.9	0.7	0.77	0.0	0	14
23	North Fork Skykomish River	Upper North Fk Skykomish	800	35.2	1.7	1.31	0.0	8	0
24	Olney Creek	Olney Creek	400	18.6	0.6	0.61	6.6	5	9
28	McCoy Creek	Lower Mainstem Skykomish	300	7.7	0.9	0.49	10.7	0	9
30	Rapid River	Rapid River	600	22.6	1.1	0.89	0.0	0	0
34	French Creek	French Creek	200	5.5	1.8	0.55	5.5	0	13
35	May Creek	May Creek	300	13.7	1.3	1.04	3.6	21	23
37	West Fork Quilceda Creek	Quilceda	200	2.8	0.8	1.02	0.0	0	4
41	Quilceda Creek	Quilceda	200	3.9	0.5	0.78	0.0	10	10
43	Dubuque Creek	Dubuque Creek	200	5.7	1.3	0.40	0.0	23	12
46	Wallace River	Upper Wallace River	600	28.8	0.6	0.46	0.6	0	7
47	Wallace River	Upper Wallace River	600	25.8	0.6	1.32	0.0	6	5
49	Wallace River	Upper Wallace River	600	18.1	0.9	1.09	20.1	31	3
52	Woods Creek	Woods Creek	300	10.8	0.7	0.61	0.9	0	0
54	Pilchuck River	Middle Pilchuck	600	23.2	0.3	1.05	1.8	21	17
55	Pilchuck River	Middle Pilchuck	600	21.7	0.8	0.33	0.0	11	8
56	Pilchuck River	Middle Pilchuck	600	31.8	0.4	0.82	2.5	9	20

Reach ID	Stream Name	Sub-Basin	Reach Length, m	Average BFW, m	Average Slope, %	Average BFD, m	Side Channel area, %	Modified Bank, %	Unstable Bank, %
57	West Fork Woods Creek	West Fork Woods Creek	200	7.0	0.5	1.01	0.0	13	9
58	West Fork Woods Creek	West Fork Woods Creek	200	7.7	0.5	0.69	14.2	0	6
60	Pilchuck River	Upper Pilchuck	600	23.1	0.7	1.22	0.5	0	28
62	Pilchuck River	Middle Pilchuck	600	22.9	0.6	1.03	0.0	24	14
64	Pilchuck River	Middle Pilchuck	600	25.8	0.7	1.03	0.0	7	42
66	North Fork Skykomish River	Upper North Fk Skykomish	800	39.9	1.0	0.88	29.4	4	28
67	Pilchuck River	Middle Pilchuck	600	23.2	0.8	0.85	1.5	33	1
69	Carpenter Creek	West Fork Woods Creek	200	4.0	0.3	1.08	0.0	1	94

BFW – Bankfull width
BFD – Bankfull depth
CW – Channel widths
RW – Rootwad

Table B.2. Habitat Unit Data

Reach ID	% Pool Area	% Riffle Area	% other area	Pool-Pool spacing (no. of cw)	Pool Freq (pools/km)	Pool Freq (pools/cw)	Pool Avg. Max Depth	Pool Avg. Residual Depth	Pool Avg. Functional Area (m^2)	Pool Avg. Wet Area (m^2)
1	50	46	5	2.6	55	0.38	0.53	0.35	28	40
2	19	69	14	5.8	8	0.17	0.95	0.59	253	342
10	21	64	14	5.5	25	0.18	0.46	0.31	26	37
14	27	49	24	7.8	25	0.13	0.44	0.36	14	32
15	39	61	0	2.3	17	0.43	1.35	0.92	229	301
20	60	26	15	3.2	45	0.31	0.78	0.54	44	67
23	16	84	0	1.9	15	0.53	1.21	0.66	195	279
24	46	52	0	1.5	35	0.65	0.95	0.70	116	149
28	36	37	23	3.5	37	0.28	0.52	0.41	28	32
30	2	82	18	13.3	3	0.08	1.52	1.32	83	103
34	36	49	15	3.3	55	0.30	0.43	0.36	13	19
35	78	9	12	2.7	27	0.36	1.01	0.60	282	329
37	45	12	43	4.2	85	0.24	0.84	0.38	8	14
41	23	41	35	6.5	40	0.15	0.69	0.41	19	25
43	41	49	10	3.9	45	0.25	0.37	0.31	11	25
46	18	33	50	5.2	7	0.19	1.64	1.29	332	521
47	46	31	23	11.6	3	0.09	1.10	0.70	1973	2943
49	53	45	2	2.5	22	0.39	1.10	0.87	262	326
52	41	56	4	4.0	23	0.25	0.75	0.49	63	95
54	64	36	0	2.4	18	0.42	1.14	0.76	347	491
55	39	61	1	3.1	15	0.33	1.15	0.76	242	320
56	28	72	0	2.1	15	0.48	0.93	0.59	189	333
57	76	10	14	7.2	20	0.14	1.17	0.97	245	250
58	67	20	4	2.9	45	0.34	0.63	0.42	80	108
60	57	41	2	1.7	25	0.58	1.09	0.74	177	251
62	45	55	0	2.4	18	0.42	1.22	0.80	245	280
64	61	38	2	2.1	18	0.47	1.36	0.97	416	573
66	17	78	3	0.7	34	1.35	0.84	0.74	77	90
67	48	52	0	1.7	25	0.58	1.26	0.85	163	205
69	90	0	10	10.1	25	0.10	1.13	0.81	121	128

Table B.3. Reach LWD Data

Reach ID	All Wood Piece / CW	LWD / CW >30cm >7m	Total Wood Vol(m³)	LWD Volume per 100m	>60cm >15m Freq (pieces/km)	Jam Freq (jams/km)	% Wood (>30cm Diameter or with RW) in Jams
1	1.9	0.2	28.8	14.4	0	5.0	33
2	9.3	1.8	219.2	36.5	10	6.7	57
10	2.2	0.2	64.1	32.1	0	0.0	0
14	0.8	0.0	19.2	9.6	0	0.0	0
15	4.3	0.3	61.4	10.2	2	0.0	0
20	1.8	0.4	58.6	29.3	10	10.0	40
23	1.2	0.1	22.0	2.8	1	0.0	0
24	9.5	1.1	200.1	50.0	20	7.5	68
28	2.5	0.3	99.1	33.0	10	0.0	0
30	3.9	0.3	70.4	11.7	0	0.0	0
34	1.0	0.1	29.4	14.7	5	0.0	0
35	5.3	0.4	65.2	21.7	0	0.0	0
37	0.4	0.0	10.8	5.4	0	0.0	0
41	0.8	0.1	30.8	15.4	5	0.0	0
43	0.5	0.0	8.3	4.1	0	0.0	0
46	8.1	0.6	87.2	14.5	2	1.7	26
47	2.1	0.2	21.2	3.5	0	0.0	0
49	3.1	0.4	67.5	11.3	2	1.7	15
52	2.0	0.0	24.4	8.1	0	0.0	0
54	3.4	0.4	65.4	10.9	3	1.7	13
55	3.3	0.2	46.6	7.8	0	0.0	0
56	3.1	0.4	45.6	7.6	0	0.0	0
57	0.9	0.0	9.4	4.7	0	0.0	0
58	5.0	0.2	61.0	30.5	0	0.0	0
60	14.7	1.7	264.2	44.0	7	6.7	84
62	1.4	0.1	31.1	5.2	0	0.0	0
64	6.9	0.9	148.7	24.8	12	3.3	44
66	25.1	3.2	440.6	55.1	14	3.8	22
67	2.7	0.2	53.2	8.9	2	0.0	0
69	0.0	0.0	0.0	0.0	0	0.0	0

Table B.4. Reach Substrate Data

Reach ID	% Fines (<.06mm)	% Sand (.06–2mm)	% Fine Gravel (2-16mm)	% Coarse Gravel (16-64mm)	% Cobble (64-250mm)	% Boulder (250–4000mm)	% Hardpan (>4000mm)	%Bedrock (>4000mm)
1	0	9	25	8	27	22	1	5
2	0	13	11	22	40	12	1	0
10	0	8	16	39	20	16	1	0
14	1	6	9	34	31	8	11	0
15	6	11	15	43	20	5	0	0
20	9	30	22	28	10	1	0	0
23	0	1	5	18	20	56	0	0
24	2	14	24	23	29	7	2	0
28	1	16	30	37	8	2	6	0
30	0	11	19	28	24	15	0	1
34	7	8	18	39	25	1	3	0
35	26	42	10	14	8	1	0	0
37	59	41	0	0	0	0	0	0
41	35	62	2	1	0	0	0	0
43	3	10	14	39	20	13	0	0
46	12	21	30	32	4	0	0	0
47	13	19	12	32	18	5	0	0
49	0	13	9	24	50	5	0	0
52	5	18	10	14	37	13	2	0
54	11	25	9	33	15	7	0	0
55	3	14	15	30	25	5	0	8
56	10	30	6	11	31	11	0	0
57	31	24	30	5	10	0	0	0
58	12	36	29	21	2	0	0	0
60	5	21	13	26	25	2	7	2
62	10	14	7	29	26	10	4	2
64	9	23	5	31	19	2	10	1
66	0	6	5	21	52	16	0	0
67	11	21	13	30	20	5	0	0
69	53	38	8	1	0	0	0	0

Table B.5. Reach Canopy Cover Data

Reach ID	BANK COVER, Avg. (%)	CENTER-CHANNEL COVER, Avg. (%)
1	97	87
2	95	39
10	97	88
14	94	92
15	68	12
20	95	64
23	87	35
24	95	25
28	98	77
30	98	51
34	85	61
35	82	51
37	47	7
41	66	47
43	88	58
46	97	8
47	93	50
49	96	51
52	91	48
54	68	30
55	87	49
56	92	20
57	99	41
58	98	60
60	85	27
62	79	30
64	71	11
66	62	24
67	97	26
69	91	24

Table B6. 2007 Snohomish Basin Wadeable Habitat Survey, Summary Values.

Habitat Parameter	**Summary Metrics**	**2007 Reach Value**
Channel	Mean Channel gradient (%)	0.9
	Surveyed length (km)	12.9
	Mean bankfull width, CW (m)	16.7
	Mean bankfull depth (m)	0.83
Pools	Percent pool area (%)	43
	Percent riffle Area (%)	45
	Mean pool frequency (pools/km)	27.7
	Standard dev. of pool freq. (pools/km)	17.6
	Mean pool frequency (pools/CW)	0.4
	Standard dev. of pool freq. (pools/CW)	0.2
	Mean functional pool area (m²)	209.4
	Reach Mean Standard dev. of functional pool area (m²)	353
	Mean wetted pool surface area (m²)	290.3
	Reach Mean Standard dev. of pool surface area (m²)	526
	Mean pool residual depth (m)	0.66
Wood	Mean LWD frequency (pieces/km)	24.3
	Mean woody debris freq. (pieces/km), all wood	241.6
	Mean LWD frequency (pieces/CW)	0.5
	Standard dev. of LWD freq. (pieces/CW)	0.7
	Mean woody debris freq. (pieces/CW)	4.2
	Standard dev. of woody debris freq. (pieces/CW)	5.1
	Wood in wet channel freq (pieces/km)	63.5
	Wood >30cm diameter or with RW in jams (%)	13
	Jam freq (jam/km)	1.6
	>60cm>15m freq (pieces/km)	3.4
Instability	Mean streambank instability (%)	14
	Standard dev. of instability (%)	18
	Mean bank hydromodifications (%)	9
	Standard dev. of hydromodifications (%)	10

Habitat Parameter	Summary Metrics	2007 Reach Value
Substrate	Fines (silt), <.06mm (%)	11
	Sand, >.06 - 2mm (%)	20
	Fine Gravel, >2 - 16mm (%)	14
	Coarse Gravel >16 - 64mm (%)	24
	Cobble >64 - 250mm (%)	20
	Bolder >250 - 4000mm (%)	8
	Hardpan (%)	2
	Bedrock (%)	1
Canopy Cover	Bank cover (%)	87
	Standard dev. bank cover readings	19
	Center channel cover (%)	43
	Standard dev. center cover readings	26
Side Channel	Side channel wet area (m^2)	130
	Side channel total area (m^2)	602
	Percent Side Channel Area (%)	10

Appendix C

Woody Debris Summary Statistics

Table C.1. A comparison of the 2007 Snohomish Basin LWD summary values for all reaches, forested reaches, and non-forested reaches to criteria from WFPB (1997), NMFS (1996), and Fox (2001)

LWD[1] Volume: Cubic Meters per 100 meters of Channel Length

Source	BFW Class	All 2007 Reaches	Forested	Non-forested
2007 Wadeable Stream Survey Snohomish Random Reaches	0-30m	17	31	12
	>30-100m	22	55	5
Summary of ranges for instream wood quantity and volumes. Table 9 in Fox 2001.	Rating:	Good	Fair	Poor
	0-30m	>99	28-99	<28
	>30-100m	>317	44-317	<44

LWD Pieces[3] Per Mile

Source	BFW Class			
2007 Wadeable Stream Survey Snohomish Random Reaches	0-5 m	2.67	n/a	2.67
	5-10 m	4.44	5.33	4.00
	10-20 m	8.67	32.00	0.89
	20+ m	5.90	12.17	3.40
	All	5.51	12.08	3.12
NOAA (1996) Pathways and Indicators, "Properly Functioning"	0-40m	80/mile		
	40+m	80/mile		

Woody Debris[1] Pieces Per Cannel Width

Source	BFW Class	All 2007 Reaches	Forested	Non-forested
2007 Wadeable Stream Survey Snohomish Random Reaches	0-10 m	1.48	1.97	1.32
	10-20 m	4.98	9.50	3.47
	20+ m	6.39	13.24	3.65
	All	4.24	8.54	2.67
WFPB (1997) Diagnostic rating for "good" Condition	0-20 m	2	2	2

LWD[1] Piece Quantity: Number of pieces per 100m of Channel Length

Source	BFW Class			
2007 Wadeable Stream Survey Snohomish Random Reaches	0-6m	13	n/a	13
	>6-30m	27	28	22
	>30-100m	25	48	7
Summary of ranges for instream wood quantity and volumes. Table 9 in Fox 2001.	Rating:	Good	Fair	Poor
	0-6m	>38	26-38	<26
	>6-30m	>63	29-63	<29
	>30-100m	>208	57-208	<57

Key[2] Pieces Per Channel Width				
Source	BFW Class			
2007 Wadeable Stream Survey Snohomish Random Reaches	0-10 m	0.07	0.13	0.026
	>10m	0.02	0.05	0.003
WFPB (1997) Diagnostic rating for "good" Condition	0-10m	>0.3		
	10-20 m	>0.5		
Key[2] Piece Quantity: Number of pieces per 100m of Channel Length				
Source	BFW Class	All 2007 Reaches	Forested	Non-forested
2007 Wadeable Stream Survey Snohomish Random Reaches	0-10m	1.39	2.67	0.96
	>10-100m	0.11	1.20	0.03
Summary of ranges for instream wood quantity and volumes. Table 9 in Fox 2001.	Rating:	Good	Fair	Poor
	0-10m	>11	4.0 - 11.0	<4
	>10-100m	>4	1.0 - 4.0	<1

---

[1] Woody Debris are pieces that are ≥1.5m in length and ≥.1m diameter.

[2] Key Pieces are based on Table 9, WFPB (1997) and Fox (2001).

[3] LWD are pieces >15m in length and >60cm diameter