Status of Puget Sound Tributaries 2009

Biology, Chemistry, and Physical Habitat

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Cover photo: The Skykomish River

Status of Puget Sound Tributaries 2009

Biology, Chemistry, and Physical Habitat

by

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Abstract

To satisfy directives of the Comprehensive Monitoring Strategy, in 2009 the Washington State Department of Ecology began implementing the program: *Status and Trends Monitoring for Watershed Health & Salmon Recovery (WHSR)*. This program is developing the state's first publicly accessible database for managing physical habitat data and other data generated from standardized, probability-based monitoring.

This report presents baseline results from monitoring biological, chemical, and physical stream conditions during July 1 through October 15, 2009 in randomly selected streams of the Puget Sound Status and Trends Region (STR), the first of eight STRs to be assessed across the state. For available metrics with sufficient signal-to-noise, we describe estimated cumulative scores across the network (10,536 km) of target streams in the STR. We also provide an evaluation of the metrics based on precision.

These results are considered to be just a first step while database development continues. The final version of the database will include a much more extensive set of metrics. Upon completion of the database, we recommend further analysis of a full set of metrics to determine which would be best for inclusion into multi-metric, high-level indices for describing biology, chemistry, and physical habitat.

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Introduction

Project Overview

Background

The Status and Trends Monitoring for Watershed Health and Salmon Recovery program (WHSR) is a statewide monitoring effort designed to provide consistent and integrated information on biological, chemical, and physical habitat in Washington State's rivers and streams. WHSR is a response to state and federal law.

State Law

In 2001, Governor Locke signed Substitute Senate Bill (SSB) 5637. This established a law requiring production of a statewide comprehensive monitoring strategy (CMS) for assessing watershed health and salmon recovery (Monitoring Oversight Committee, 2002). The CMS was developed to promote data consistency and data sharing. To help satisfy requirements of the CMS, the Washington Monitoring Forum requested the Washington State Department of Ecology (Ecology), the Washington Department of Fish and Wildlife, and the Washington Conservation Commission to prepare a quality assurance monitoring plan (Cusimano et al. 2006) using input from a series of public workshops. Funding was from the Salmon Recovery Funding Board. The WHSR was developed using the quality assurance monitoring plan.

Federal Laws

Development of the WHSR was a response to recommendations in the CMS to provide monitoring that will meet requirements of federal laws, such as the Clean Water Act (CWA) and the Endangered Species Act (ESA).

Clean Water Act

The objective of the CWA is to restore and maintain the biological, physical, and chemical integrity of the nation's waters (Section 101(a)). Washington is obligated under CWA Section 305(b) to periodically report to EPA the status of waters of the state.

Endangered Species Act

The ESA is intended to protect species and "the ecosystems upon which they depend." In Washington, salmonid populations have dwindled so much that salmon and bull trout are listed under the ESA as threatened or endangered in nearly three-fourths of the state. Pollution and habitat degradation are two major causes cited (RCO 2012a; NOAA 2011). De-listing under ESA requires an explicit analysis of the physical or biological conditions that affect the species' continued existence (ESA Section 4(f)(1)(B)) (NOAA 2007; Crawford and Rumsey 2011).

The quality assurance monitoring plan outlines three key features of the WHSR that will assist with fulfilling these state and federal needs:

- Standardized protocols for biological and environmental data collection.
- Randomized site selection to provide unbiased status and trends reports.
- Centralized, publicly accessible, and comprehensive database.

Standardized Protocols

WHSR protocols are based in large part on two federal projects:

1. EMAP: Environmental Monitoring and Assessment Program (EPA 2010; Peck et al. 2005; Peck et al. 2006).
2. ISEMP: Integrated Status and Effectiveness Monitoring Program (NOAA 2010; Hillman 2004; Merritt 2005)

The United States Environmental Protection Agency's (EPA) EMAP program is the foundation of Ecology's WHSR program. Ecology participated in EMAP during 1994-2006. During 2004-2009, Ecology also participated in an ISEMP survey of the Wenatchee Basin for the National Oceanic and Atmospheric Administration (NOAA). WHSR also draws from these ISEMP methods (i.e., Hillman 2004; Moberg 2006). The first working draft of WHSR field data collection protocols was completed in 2009. Protocols are available from the project's home page (Ecology 2012a).

Randomized Site List

A site-selection method that is based on a randomized sampling approach eliminates bias by randomly selecting sites from the target population. Determining the status and trends of a resource over large geographic regions can be accomplished with a census or by random sampling. A census, by definition, requires every unit of a population to be sampled. Since this approach is impractical on a statewide scale or watershed scale, random samples of the population are taken (i.e., a sample survey) to make statistical inferences about a population with known confidence. In this case, our population is a linear stream network, with results being expressed in units of kilometers or percentage of network length.

In 2006, EPA assisted Ecology with developing a statewide list of random sample sites for use with WHSR protocols. This site list is the Washington Master Sample (Ecology 2012b). We produced this GIS layer using a Generalized Random Tessellation Stratified (GRTS) survey design. The GRTS design is a way to combine randomization with geographic spacing in order to mimic the spatial density pattern of the resource (Olsen 2005). The Master Sample is composed of 387,237 points located on a 1:24,000-scale stream framework. The frame, as described in Ecology (2012b) was published in 2005 by the Washington Department of Natural Resources (WDNR). The frame was created prior to Washington's coverage of the state's current standard hydrography layer, the National Hydrography Dataset (NHD; USGS 2012).

Public Database Construction

One major aspect of the WHSR project (and significant cost) is the development of a database structure that can accommodate complex physical habitat data and metrics. Ecology uses the Environmental Information Management System (EIM) as its central database for traditional environmental monitoring data. However, until WHSR started, EIM has been unable to manage much of the data generated by probability-based ecological surveys.

Since 2009, work has been in progress on a new, integrated database. Federal projects provided much of its foundation, including:

- Database schema from NOAA ISEMP (Rentmeester 2006).
- Metric calculation algorithms from EMAP (Kaufmann et al. 1999).

The new database (Status & Trends: Riverine Ecology & Assessment Monitoring, or STREAM) will communicate seamlessly with EIM to provide all the project data to the public through an online user interface (Appendix B).

At the time of this publication, about one-fifth of the WHSR habitat metrics are coded in STREAM. When the present phase of development is completed during summer 2012, public users will be able to:

- Search for sites by using either a map or a tabular list.
- Retrieve WHSR field or laboratory data (chemical, physical, or biological) for all sites sampled:
    - Report at least 60 calculated metrics.
    - Report field data from which metrics are calculated.

We will continue coding to develop a complete set of metrics.

2009 Puget Sound Assessment

Status and Trends Region

With the help of funding from the Puget Sound Partnership (PSP), in 2009 Ecology selected and sampled 48 sites in the Puget Sound Status and Trends Region (STR) (Figure 1). Each site was drawn from the Washington Master Sample and met protocol target criteria. During the July 1-October 15 index period, two crews (four persons per crew) collected data at these locations using WHSR field data collection protocols.

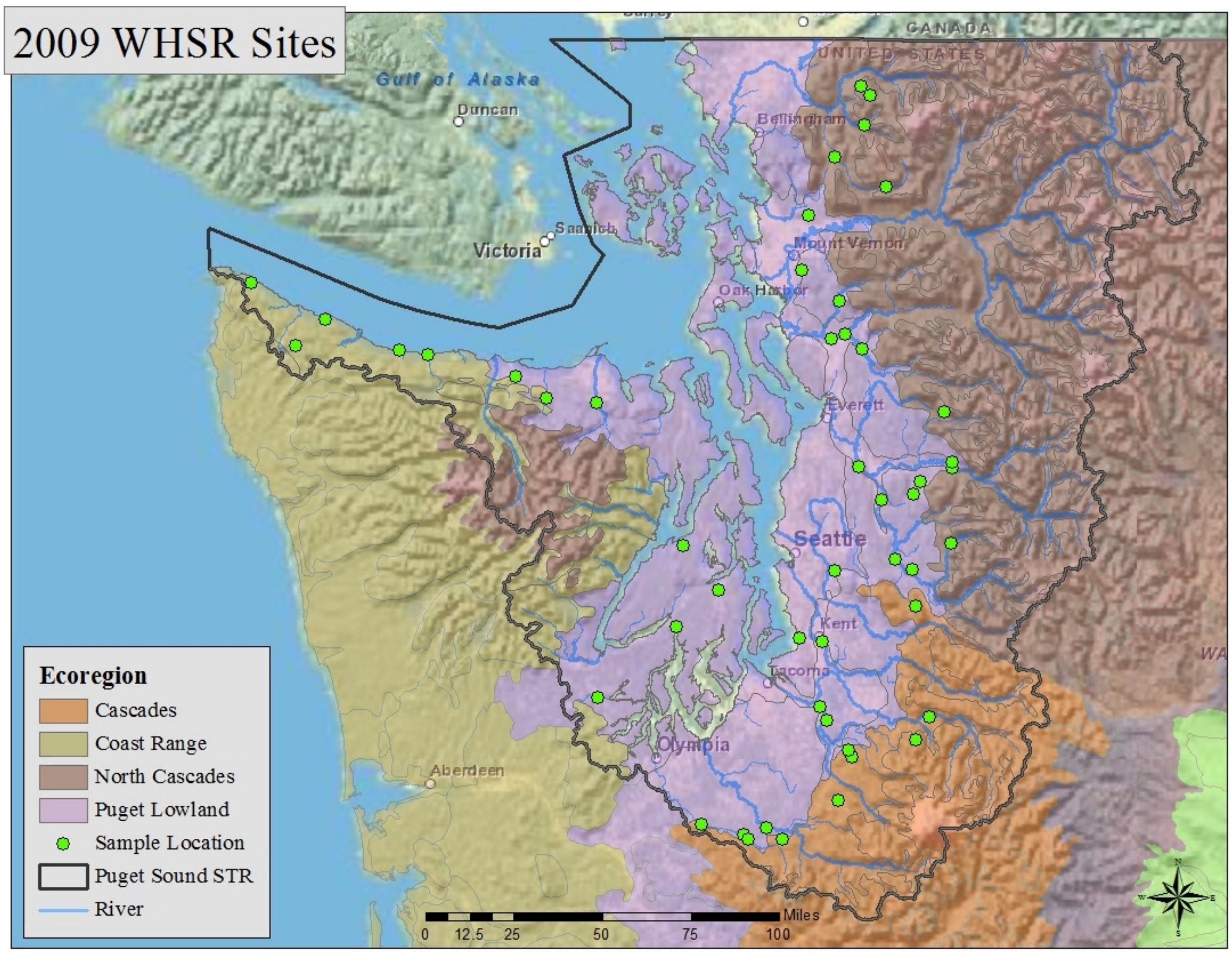

Figure 1. The Puget Sound Status and Trends Region (STR) with ecoregions and probability sites sampled during 2009.

We performed similar work in other regions during 2010 and 2011. Ecology plans to complete the first of the statewide field surveys, including all 8 STRs, by October 15, 2012.

The Puget Sound STR faces many severe challenges. Increasing types and intensity of human influence have taken their toll on watershed health. This includes industrial and municipal pollution, land conversions, and contamination from polluted stormwater. There have been major physical habitat changes to rivers of the region (UW 2012). The regional human population is expected to grow from 3.5 million to 5 million by 2025. This will likely bring increases in habitat destruction and pollution (PSP 2012).

Ecoregions

The Puget Sound STR crosses 4 ecoregions and encompasses 3,564,897 hectares (ha). This report focuses on the assessment of the non-federal portion of the STR, which covers 59.7% of the area (2,127,625 ha). Within the non-federal portion of the region, ecoregion representation is as follows:

- Puget Lowlands 62.6%
- North Cascades 18.4%
- Cascades 12.9%
- Coast Range 6.1%

These ecoregions are each described in Pater et al. (1998).

Elevation range for the non-federal portion of the Master Sample is as follows:

- Puget Lowlands 0 to 1600 meters (m)
- North Cascades 12 to 2633 m
- Cascades 0 to 2664 m
- Coast Range 0 to 1542 m

Reporting

This report provides a snapshot picture of the status of the Puget Sound stream network for:

- Extent of the network meeting our target criteria.
- Cumulative distributions of select metric values for
  - Biological integrity
  - Water quality
  - Physical habitat

The assessment is limited to tributaries that are not otherwise monitored by federal programs (see Lanigan et al. 2012). The snapshot provides baseline for comparison to future results. It also provides a starting point for building multi-metric, high-level indices. Toward that goal, this report also provides an initial precision assessment of some metrics.

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Methods

Sites and Representation

This monitoring effort is limited to non-federal streams of the Puget Sound STR. To do this, we used three attributes of the Washington Master Sample:

- SALMON_RR (Salmon Recovery Region from Governor's Salmon Recovery Office).
- WGT_KM (original site weight from GRTS design).
- OWNER_NM (land owner name from the Major Public Lands layer).

See the Master Sample's metadata for more details.

Puget Sound STR

We filtered all points of the Washington Master Sample to exclude those that do not have the SALMON_RR value of either *Puget Sound* or *Hood Canal/Puget Sound*.

Non-federal

We filtered all Puget Sound STR points of the Master Sample to exclude those sites that have the OWNER_NM value of *US Federal Government*. Searches in county parcel records also indicated that none of the sample sites were located on federal land.

Stream Length

Each Master Sample point represents about 1 km of stream on the frame, as indicated by the weight attribute (WGT_KM). Therefore, to estimate the length of non-federal streams on the source map, we summed the values of the attribute WGT_KM for all 45,657 non-federal Master Sample points in the Puget Sound STR. The sum was 45,657.48695 km.

During reconnaissance, we evaluated the first 741 non-federal points on the list of 45,657. The evaluation of this sub-sample enabled us to make estimates of sub-population lengths. We calculated proportions of sites in each size class then multiplied by 45,657.48695 km to estimate stream length in each class.

Sample Weights

Seven hundred forty-one (741) Master Sample sites were each evaluated for target status. Sites met target status when they were estimated to be perennial, lotic, freshwaters, in pre-historic channels. We also required target sites to be on an NHD stream (USGS 2012). Reconnaissance relied heavily on the use of air photos, usually those from the National Agriculture Imagery Program (NAIP; USDA 2006). The process also used attributes of the frame hydrography (Ecology 2012b) and attributes of NHD+ (Horizon Systems 2006). Landowners also provided much useful feedback for reconnaissance.

Each site was assigned to one of these categories:

- Target
    - sampled
    - inaccessible
    - no permission
    - unused (neither access nor sampling attempted)
- Non-target
    - dry (non-perennial or subsurface)
    - lentic (wetland, pond, lake, or reservoir)
    - artificial channel
    - not freshwater
    - not on NHD (1:24,000)

We assigned Strahler order (Strahler 1957) size classes by comparison with streams on NHD+ (Horizon Systems 2006). We assigned 0-order to sites located at higher elevations than the 1-100,000-scale NHD+ streams. For each size class we estimated the length of target streams represented on the map. This was done by multiplying the total stream length in each size class by the proportion of reconnoitered sites in each class that were determined to be target.

Weights (km/site) for sample sites were then determined by dividing the total length of each target stream size class by the number of sample sites in the class.

High-Level Indicators

Washington's Monitoring Forum (RCO 2010) sought to coordinate monitoring efforts through promotion of consistent High Level Indicators (HLIs). For on-the-ground monitoring, they recommended assessing these four HLIs:

- Biological Health
- Water Quality
- Physical Habitat as Instream Habitat
- Physical Habitat as Riparian Condition

These indicators each provide information necessary to support decisions to de-list fishes (NOAA 2007). Ultimately we hope to evaluate how closely these HLI scores compare with natural settings (measurements among reference sites for the ecoregion). Spence et al. (1996) provide a good discussion on practical expectations for habitat data relative to salmonids.

Eventually, we hope to develop multi-metric indices for each of these HLIs. That is beyond the scope of this report, however, because (1) we are still identifying reference conditions for the ecoregions in the STR, and (2) most of the metrics that we seek to evaluate have not yet been constructed by the new STREAM database. We seek to provide some metric precision analysis (Appendix C), however, that can be used toward deciding on the usefulness of individual metrics. This includes:

- Range
- Signal-to-noise
- Root Mean Square Error (RMSE)

Biological Health

Biological health information provides an integrated summary of the habitat conditions as described by the other three HLIs. Like Karr (1998) and Scholz and Booth (2001), we believe that the ultimate goal of most stream monitoring and management is to improve biological health. Physical conditions are only part of what determines biological health, and so measuring only habitat cannot be sufficient. In consort with careful biological monitoring, however, these measurements can help evaluate overall stream health.

The Monitoring Forum's Biological Health HLI is addressed through monitoring of the macroinvertebrate community (RCO 2010). Our Biological Health HLI is also addressed through monitoring of aquatic vertebrate distributions as requested by the Forum during review of the quality assurance monitoring plan (Cusimano et al. 2006) and as recommended by NOAA (Crawford and Rumsey 2011).

Macroinvertebrates

Invertebrate Kick-Sampling

The macroinvertebrate sample for each data collection event is a composite of 8, one-ft^2 kick samples collected across the stream reach with a 500-um mesh D frame kick net. Each kick sample was collected along a major transect. Crews randomly chose 8 out of 11 (equidistant) transects for sampling the composite. Find details in Appendix G of Merritt (2009) and Appendix F of Merritt et al. (2010).

For sites sampled with the "narrow" protocol (Merritt 2009), 4 kicks were collected in the center of the wetted channel and 4 were collected at the margins (25% into the wetted channel from the right and left banks). This method is consistent with Adams (2010) and Hayslip (2007).

For sites sampled with the "wide" protocol (Merritt et al. 2010), macroinvertebrate samples were collected anywhere within a 10 x 20 meter littoral plot centered on major transects. The sample location within each plot was selected to typify the substrate for that plot.

Different collection methods were employed depending on the conditions at a given transect. A slack-water technique was used when the stream current was not sufficient to push organisms into the net (i.e., pools), and a flowing-water technique was used when it was sufficient (i.e., riffles). Organisms on larger substrate particles within the one-ft^2 plot were transferred to the net by scrubbing with either a brush or by hand. To remove the rest of the organisms from the plot, the finer substrate was vigorously kicked for 30 seconds. The composite sample was preserved with 95% ethanol as soon as possible following collection.

Invertebrate Laboratory Analysis

Invertebrate samples were analyzed by Rhithron Associates, Inc. They sub-sampled using a screened tray (Caton 1991) to obtain a targeted count of 500 or more aquatic animals per sample. Sub-sampling was performed according to methods of Plotnikoff and Wiseman (2001).

The laboratory identified invertebrates according to taxonomic standards listed in Appendices G and H of Adams (2010). Results were then loaded to the Puget Sound Stream Benthos database (King County 2009) for later download to Ecology's EIM database.

Aquatic Vertebrates

Vertebrates were sampled according to Merritt (2009) and Merritt et al. (2010). Sampling was conducted by single-pass electrofishing across the entire length of the site. Vertebrates were identified to species in the field and tallied for relative abundances. Identities of select preserved (jarred) specimens and photographed specimens were later checked at Ecology. Molly Hallock (Washington Department of Fish and Wildlife) provided further review of the voucher samples.

Biological Metric Calculations

Benthic macroinvertebrates are reported based on a single metric, EPT percent. This is the percentage of individuals in the sample that are mayflies (order = Ephemeroptera), stoneflies (order = Plecoptera), or caddis flies (order = Trichoptera). We expect this metric to decrease with increasing human disturbance. (Barbour et al. 1999)

Aquatic vertebrates are reported based on whether each species was detected at each sample site. Whenever a species was detected, the site's weight (km) was added to the Puget Sound stream network distribution for that species.

Water Quality

Laboratory Samples

Five jars of water were collected for each sampling event, according to Merritt (2009) and Merritt et al. (2010). We sampled water for these analyses:

- Total persulfate nitrogen
- Total phosphorus
- Chloride
- Total suspended solids
- Turbidity

Samples were managed and analyzed at Ecology's Manchester Environmental Laboratory, according to their user's manual (MEL 2008).

Field Measurements

We measured the following four parameters according to Merritt (2009) and Merritt et al. (2010):

- Water temperature
- Oxygen percent saturation
- pH
- Conductivity

Water Quality Metric Calculations

The water quality metrics are listed in Table 1. For each water sample, the metric value is equivalent to the result reported by Manchester Laboratory. These results are available in Ecology's EIM database.

Table 1. Forum attributes for the Water Quality High-Level Indicator, and relevant metrics reported here.

Forum Attribute	Subcategory	Metric	Units
Instantaneous Temperature	Mean Water Temperature	X TempC	°C
Water Quality	Sample - Nitrogen	TPN	mg/L
	Sample - Phosphorus	Tot-P	mg/L
	Sample - Total Suspended Solids	TSS	mg/L
	Sample - Turbidity	Turb	NTU
	Sample - Chloride	Cl	mg/L
	In situ - Mean Oxygen saturation	X O2Sat	%
	In situ - Mean pH	X pH	pH units
	In situ - Mean Conductivity	X Cond	uS/cm at 25°C

For each *in situ* attribute (temperature, oxygen, pH, and conductivity), we calculated an average value for the metric at each sampling event. This is a mean of 2 values for the event, 1 measured upon arrival and another measured prior to departure.

Physical Habitat

Field Measurements

Physical habitat was sampled according to Merritt (2009) and Merritt et al. (2010). Measurements fall into 2 broad categories, those collected at 11 equidistant transects and those collected while traversing the length of the site. Site length is 20 bankfull widths (≥ 150 m and ≤ 2 km).

Transects-based Measurements

These features were measured at each of 11 equidistant transects:

- Bankfull width
- Bankfull depth cross-section
- Bankfull height
- Wetted width
- Substrate size composition
- Embeddedness
- Fish cover percentage by category
- Bank quality (instability)
- Canopy cover (shade by densiometer)

In wadeable streams, we collected additional measurements of substrate, embeddedness, and width among 10 secondary transects, located mid-way between the 11 primary transects.

Measurements Across the Site Length

While travelling up or down the length of the site, the field crew measured thalweg depth at each of 100 equidistant points. The following features were also measured during this part of the sampling event:

- Habitat unit identity
- Pool maximum depth
- Pool crest depth
- Large wood tally by size class

Physical Habitat Metrics and Calculations

Although the STREAM database is being built to construct several hundred habitat metrics, that work is still in development. About 20% of the habitat metrics have been coded and are reported by the database at this time. From this short list of STREAM metrics, we focus on those that relate to the Monitoring Forum HLIs. We have also added a few others that were hand-calculated for this report. Table 2 indicates how each reported physical habitat metric relates to the Forum's "on-the-ground" HLIs for physical habitat or to the 5 indicator sub-categories that we understand to have been the Forum's intended focus.

For physical habitat, we considered 5 indicator sub-categories:

1. Instream spatial complexity
2. Instream large woody debris (LWD)
3. Instream substrate composition
4. Instream bank conditions
5. Riparian condition

Table 2. The Physical Habitat High-Level Indicators and their relevant reported metrics.

Indicator	Forum Attribute	Metric	Units
Instream spatial complexity	Wetted width	X WetWidth	m
	Bankfull Width	X BFWidth	m
	% Pools	PCT Pool	%
	Res. Pool Depth	X PoolUnitDepth	cm
	Res. Pool Depth (alternative)	SD TWDepth	cm
	Res. Pool Depth (alternative)	X TWDepth	cm
Instream LWD	LWD Frequency	LWD Pieces100m	pcs/100 m
	LWD (alternative)	PFC LWD	%
	LWD (alternative)	XFC LWD	%
Instream substrate composition	% Fine Sediment	PCT Fines	%
	% Fine Sediment (alt.)	PCT SandFines	%
	% Fine Sediment (alt.)	X Embed (%)	%
Instream bank conditions	Bank angle (alternative)	X Instability	%
	Bank angle (alternative)	PFC Undercut	%
Riparian condition	Canopy Cover	X ShadeBnk	%

Physical habitat metrics were calculated according to methods outlined in Ecology (2012a):

- See the subheading: *Field Methods Development for Data Collection.*
- Within the above subheading, see item 5b: *Folders describing the methods for deriving the metrics.*

Most of these physical habitat attributes relate directly to methods described by Kaufmann et al. (1999).

Results

Site Representation and Stream Length

Sample Frame

We estimate that there are 45,657.5 km of non-federal streams and rivers mapped within the Puget STR. Based on mostly desktop reconnaissance of 741 Master Sample Points during 2009, we estimate the size composition of this network to be as listed in Table 5.

Table 3. The size composition of the Puget Sound STR stream network.

Size Class	% Network	Mapped Streams (km)
0-Order[1]	73.5%	33580.7
1-Order	16.1%	7332.3
2-Order	5.7%	2587.9
3-Order	2.4%	1109.1
4-Order+	2.3%	1047.5

[1]Where the frame is above the NHD+ streams.

Target Streams

Table 4 and Figure 2 indicate the proportion of streams in each size class that meet the technical criteria for "target" streams. Target streams are estimated to be perennial, flowing surface waters, and in natural channels. They are also required to be freshwater and on the 1:24,000-scale NHD map (USGS 2012).

Table 4. Estimated target portion of the stream network (by size class) based on site evaluations.

Size Class	Non-Target Sites	Target Sites	Estimated Part of Class Network as Target
0-Order	505	40	7.3%
1-Order	50	69	58.0%
2-Order	11	31	73.8%
3-Order	2	16	88.9%
4-Order+	2	15	88.2%

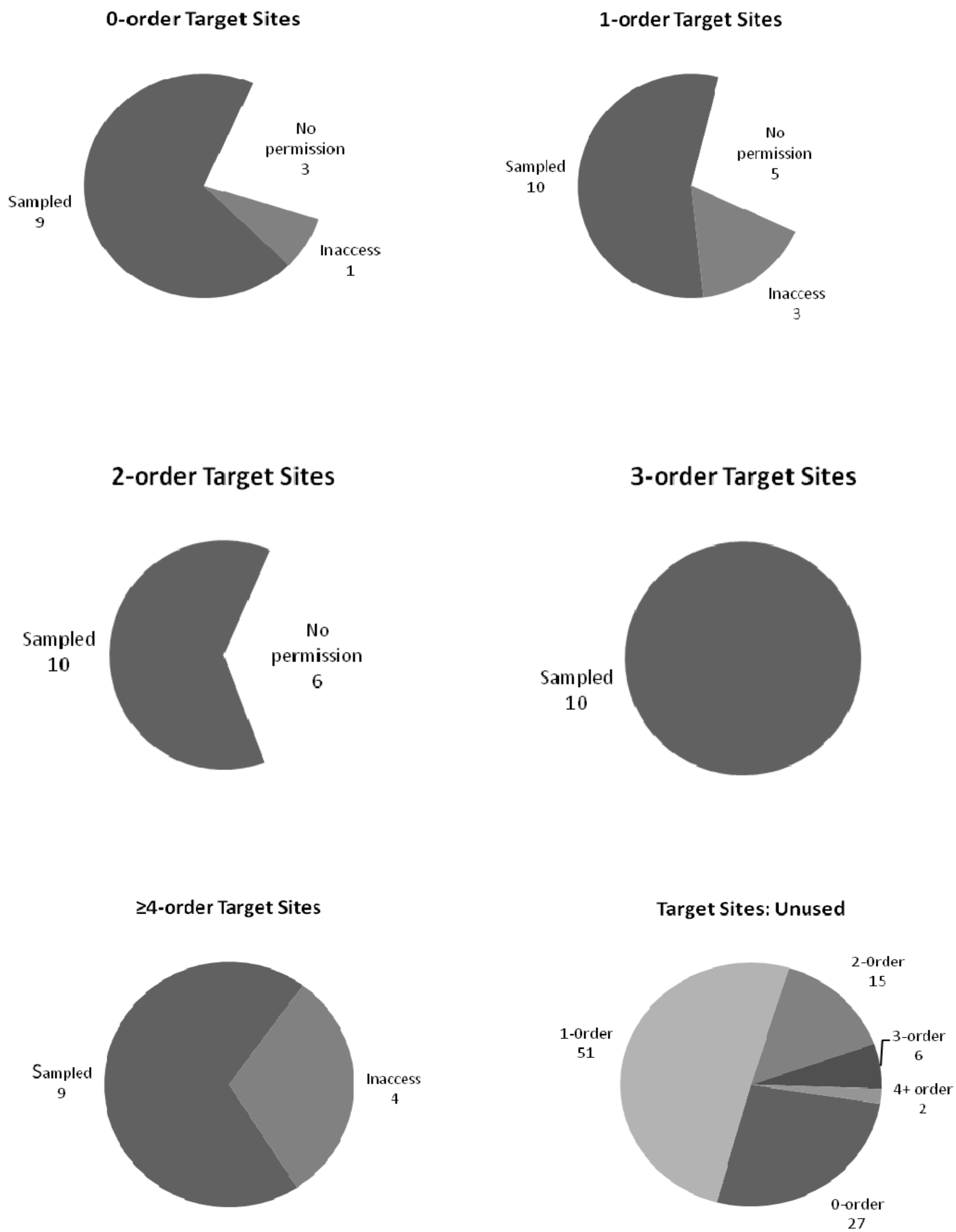

Figure 2. Allocation of target sites in the Puget Sound STR 2009.

Target Streams Sampled

Forty-eight Master Sample sites were sampled in the Puget Sound STR during the 2009 index period (Tables 5 and 6; Figure 2). Weights by size class are listed in Table 7. These 48 sites represent 10,536 km of streams across the region.

Table 5. The 29 small (Strahler 0-2) streams sampled during 2009.

Site_ID	Description	Elevation (m)	Strahler Order
WAM06600-000451	McSorley Creek tributary	26	0
WAM06600-000550	Edna Creek tributary	318	0
WAM06600-000815	Dick Creek	363	0
WAM06600-000988	Nooksack River, South Fork tributary	440	0
WAM06600-001251	Raging River tributary	629	0
WAM06600-001422	White River tributary	654	0
WAM06600-001480	Pilchuck Creek tributary	211	0
WAM06600-001556	Tumwater Creek	137	0
WAM06600-001908	Herman Creek, East Branch tributary	235	0
WAM06600-000211	Coulter Creek tributary	2	1
WAM06600-000391	Coal Creek	42	1
WAM06600-000987	Crandall Creek tributary	175	1
WAM06600-001228	Willard Creek	14	1
WAM06600-001415	Mud Creek	111	1
WAM06600-001418	Twentyfive Mile Creek	528	1
WAM06600-001768	Snow Creek	86	1
WAM06600-001983	Surveyor Creek	228	1
WAM06600-001995	Cherry Creek	185	1
WAM06600-006123	May Creek	56	1
WAM06600-000398	Fennel Creek	56	2
WAM06600-000426	Voight Creek above Frame Creek	363	2
WAM06600-000672	Racehorse Creek	832	2
WAM06600-000831	Canyon Creek	182	2
WAM06600-001192	Carpenter Creek	6	2
WAM06600-001402	Canyon Creek	1014	2
WAM06600-001590	Powell Creek	120	2
WAM06600-001639	Big Beef Creek	32	2
WAM06600-001715	Blackjack Creek	48	2
WAM06600-005232	Racehorse Creek	606	2

Table 6. The 19 large (Strahler 3-6) streams or rivers sampled during 2009.

Site_ID	Description	Elevation (m)	Strahler Order
WAM06600-000222	Goldsborough Creek	34	3
WAM06600-000456	Clallam River	8	3
WAM06600-000566	Deschutes River above Hwy 507	101	3
WAM06600-001002	Voight Creek	256	3
WAM06600-001660	Nooksack R., South Fork at Saxon Bridge	108	3
WAM06600-001702	Deschutes River at Cougar Mtn. Trail	141	3
WAM06600-002596	Jim Creek	39	3
WAM06600-003124	East Twin River	6	3
WAM06600-003366	Deschutes River by Shell Rock Ridge	153	3
WAM06600-003492	Lyre River	17	3
WAM06600-000308	Stillaguamish River – North Fork at mouth	19	4
WAM06600-000676	Stillaguamish R. at Blue Stilly Ballpark	10	5
WAM06600-001003	Snohomish River below Lord Hill Park	4	6
WAM06600-001047	Snoqualmie River near Janicke Slough	21	5
WAM06600-001899	Skykomish River	57	5
WAM06600-002007	Snoqualmie River – North Fork	378	4
WAM06600-003728	Nooksack River - Middle Fork	343	4
WAM06600-005067	Snoqualmie River in Duvall	7	5
WAM06600-006467	Green River at Kent	8	5

Table 7. Weight (km/site) of sample sites by size class.

Class	Mapped Streams (km)	Target Streams (km)	Sample Sites	Weight (km/ sample site)
0-Order	33,580.7	2,464.6	9	273.9
1-Order	7,332.3	4,251.5	10	425.2
2-Order	2,587.9	1,910.1	10	191.0
3-Order	1,109.1	985.9	10	98.6
4-Order+	1,047.5	924.2	9	102.7
All	45,657.5	10,536.3	48	

Non-Target Sites

Of the 741 Master Sample sites evaluated during reconnaissance, 540 were estimated to be non-target (Table 8 and Figure 3). Non-perennial sites (mostly 0-order) accounted for 85% of these.

Table 8. The non-target site count by size class and category

Size Class	Not freshwater	Artificial channel	Lentic	Not on NHD map	Non-perennial
0-Order	4	9	26	12	454
1-Order	3	5	11	0	31
2-Order	1	0	8	0	2
3-Order	0	0	2	0	0
4-Order+	1	0	1	0	0
Total	9	14	48	12	487

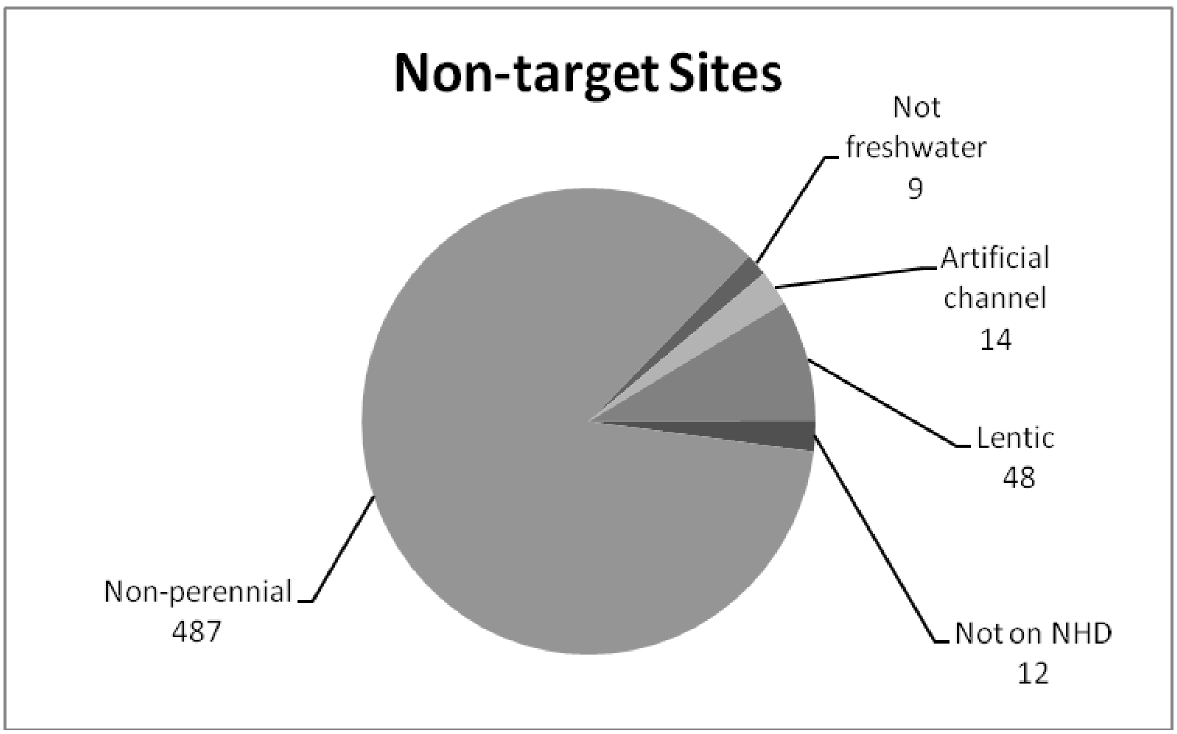

Figure 3. The non-target site composition by category.

Descriptions of the Puget Sound STR

Graphical results are presented below. Data will be available from the STREAM and EIM databases.

Biological Health

Macroinvertebrates

At this time, we report one metric for macroinvertebrate community health. The metric (EPT Percent) is the percent of individuals in the sample as members of Ephemeroptera, Plecoptera, or Trichoptera. Existing macroinvertebrate multi-metric indices and predictive models are not yet calibrated for use across the entire Puget Sound STR (Appendix C, Discussion and Conclusions).

Figure 4 displays the regional results for EPT Percent.

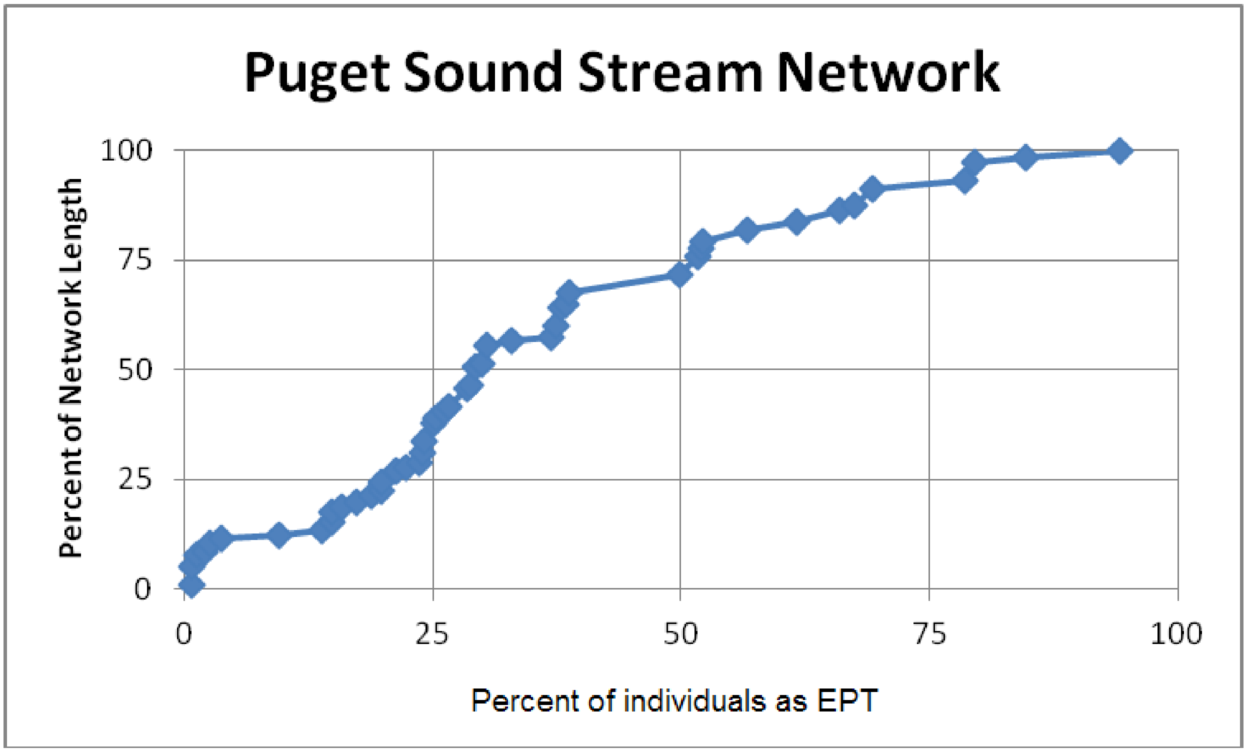

Figure 4. Distribution of EPT Percent scores in the Puget Sound target stream network in 2009.

Selected percentile scores for EPT Percent are as follows:

- Minimum (0.7%)
- 24.2 percentile (19.8%)
- 50.6 percentile (29.2%)
- 75.7 percentile (51.7%)
- Maximum (94.1%)

Aquatic Vertebrates

Estimated detectable aquatic vertebrate species' distributions are displayed in Figure 5.

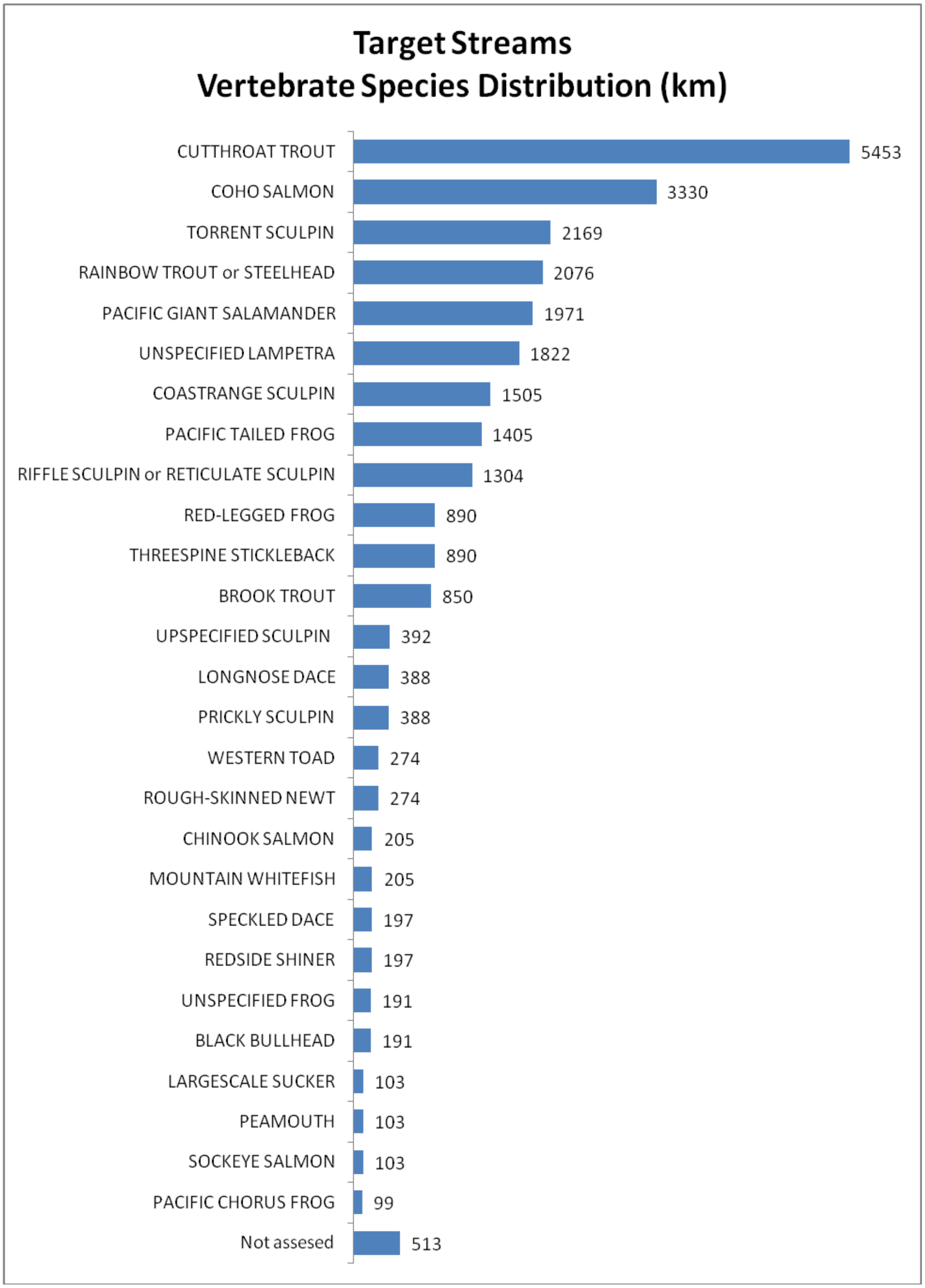

Figure 5. The estimated distribution of detectable fishes and amphibians in 10,536 km of Puget Sound target streams during summer 2009.

Water Quality

Laboratory Samples

We report two water sample parameters:

- Total nitrogen (TPN)
- Chloride concentration (Cl)

The distribution of total nitrogen values in the Puget Sound stream network for 2009 is displayed in Figure 6.

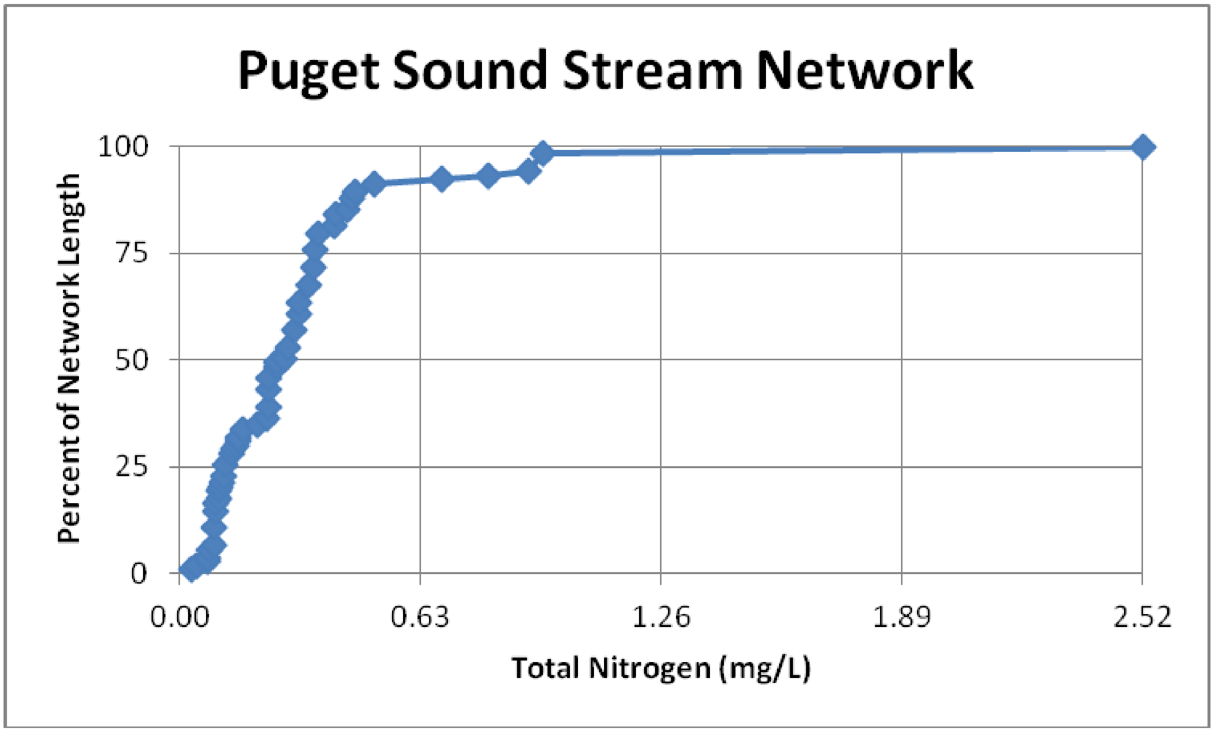

Figure 6. Extent of total nitrogen scores in the Puget Sound target stream network in 2009.

Selected percentile scores for total nitrogen are as follows:

- Minimum (0.03 mg/L)
- 25.6 percentile (0.12 mg/L)
- 50.3 percentile (0.276 mg/L)
- 75.7 percentile (0.353 mg/L)
- Maximum (2.52 mg/L)

The distribution of chloride concentration values in the Puget Sound stream network for 2009 is displayed in Figure 7.

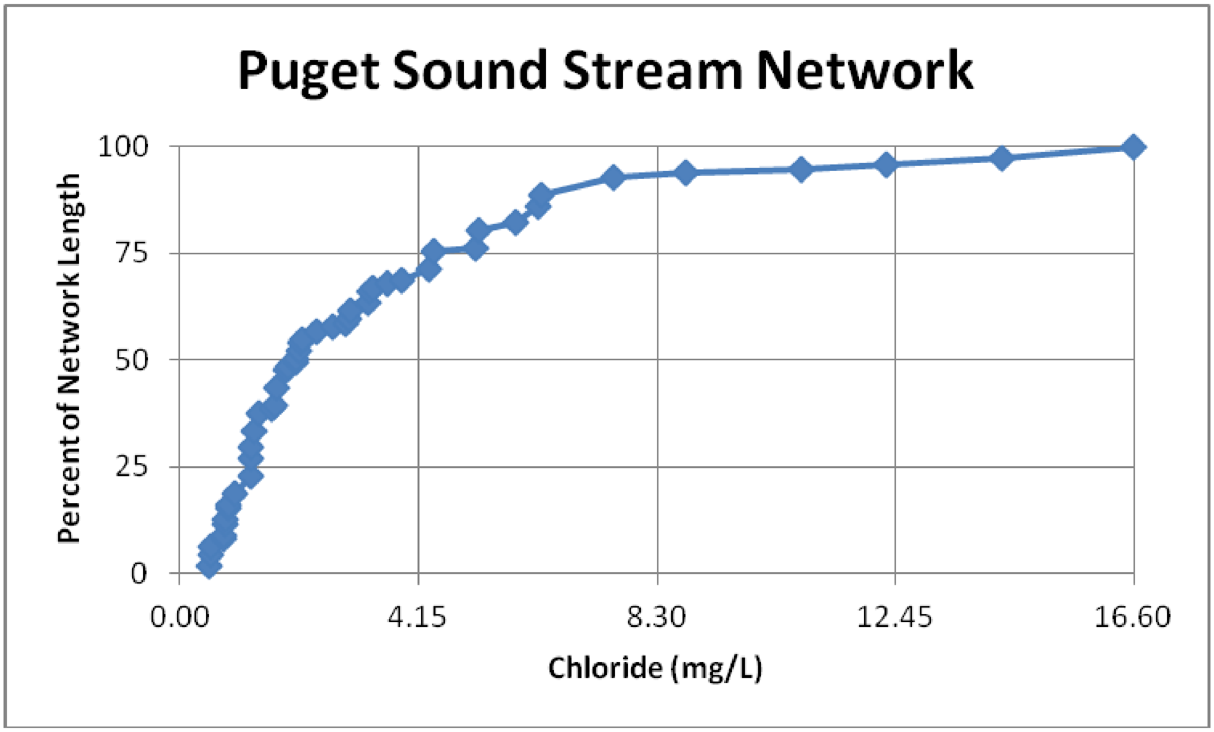

Figure 7. Extent of chloride concentration scores in the Puget Sound target stream network in 2009.

Selected percentile scores for chloride concentration are as follows:

- Minimum (0.52 mg/L)
- 26.8 percentile (1.24 mg/L)
- 50.4 percentile (2.02 mg/L)
- 75.3 percentile (4.42 mg/L)
- Maximum (16.6 mg/L)

Field Measurements

We report three *in situ* water quality parameters:

- Mean (instantaneous) water temperature (X TempC)
- Mean oxygen percent saturation (X O2Sat)
- Mean specific conductivity (X Cond)

The distribution of mean instantaneous water temperature values in the Puget Sound stream network for 2009 is displayed in Figure 8.

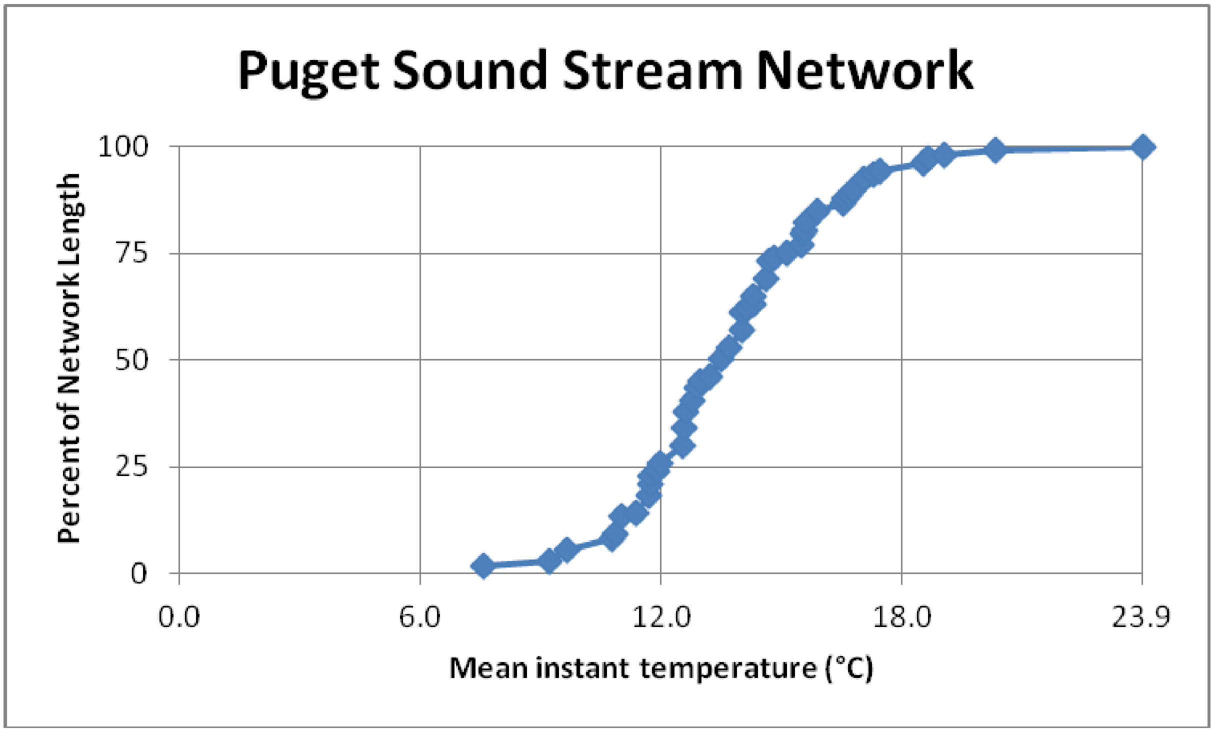

Figure 8. Extent of mean instantaneous water temperature values in the Puget Sound target stream network in 2009.

Selected percentile scores for mean instantaneous water temperature values are as follows:

- Minimum (7.55 °C)
- 23.8 percentile (11.85 °C)
- 50.2 percentile (13.45 °C)
- 75.0 percentile (15.1 °C)
- Maximum (23.95 °C)

The distribution of mean oxygen percent saturation values in the Puget Sound stream network for 2009 is displayed in Figure 9.

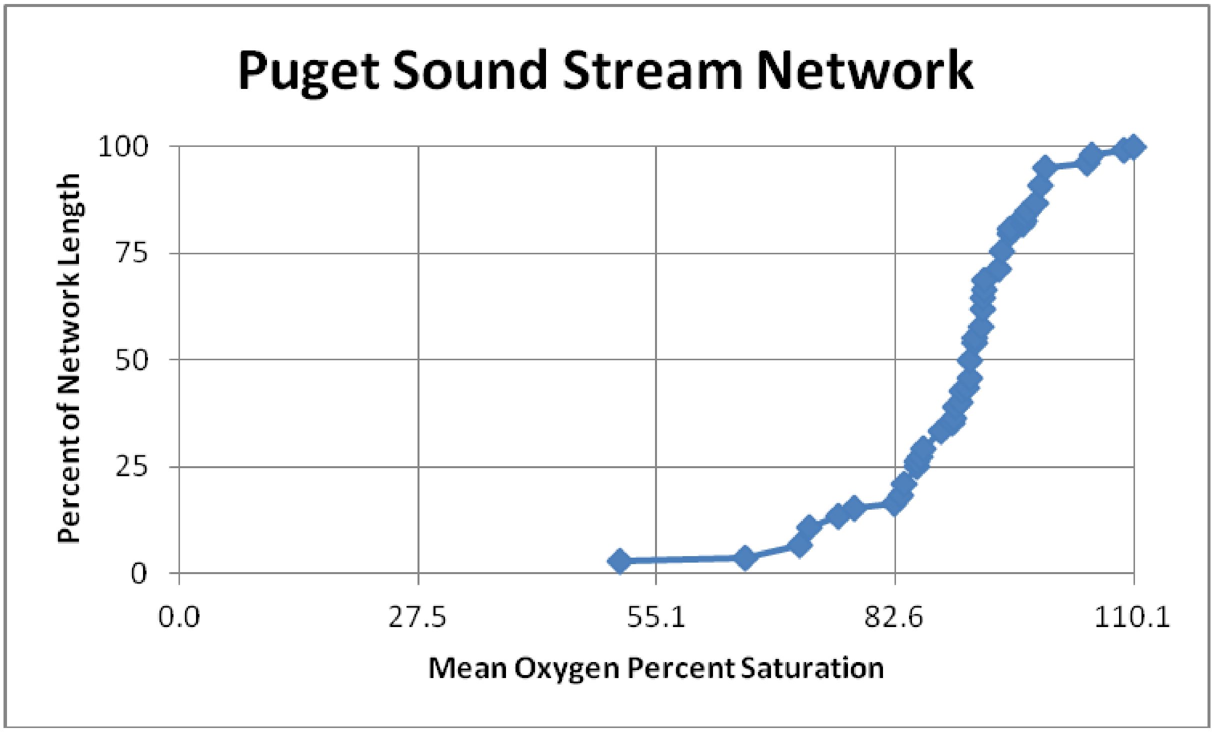

Figure 9. Extent of mean oxygen percent saturation values in the Puget Sound target stream network in 2009.

Selected percentile scores for mean oxygen percent saturation values are as follows:

- Minimum (50.85%)
- 25.2 percentile (85.1%)
- 49.8 percentile (91.25%)
- 75.4 percentile (94.95%)
- Maximum (110.15%)

This excludes 490.9 km of estimated stream length with missing oxygen data (equipment failure).

The distribution of mean specific conductivity values in the Puget Sound stream network for 2009 is displayed in Figure 10.

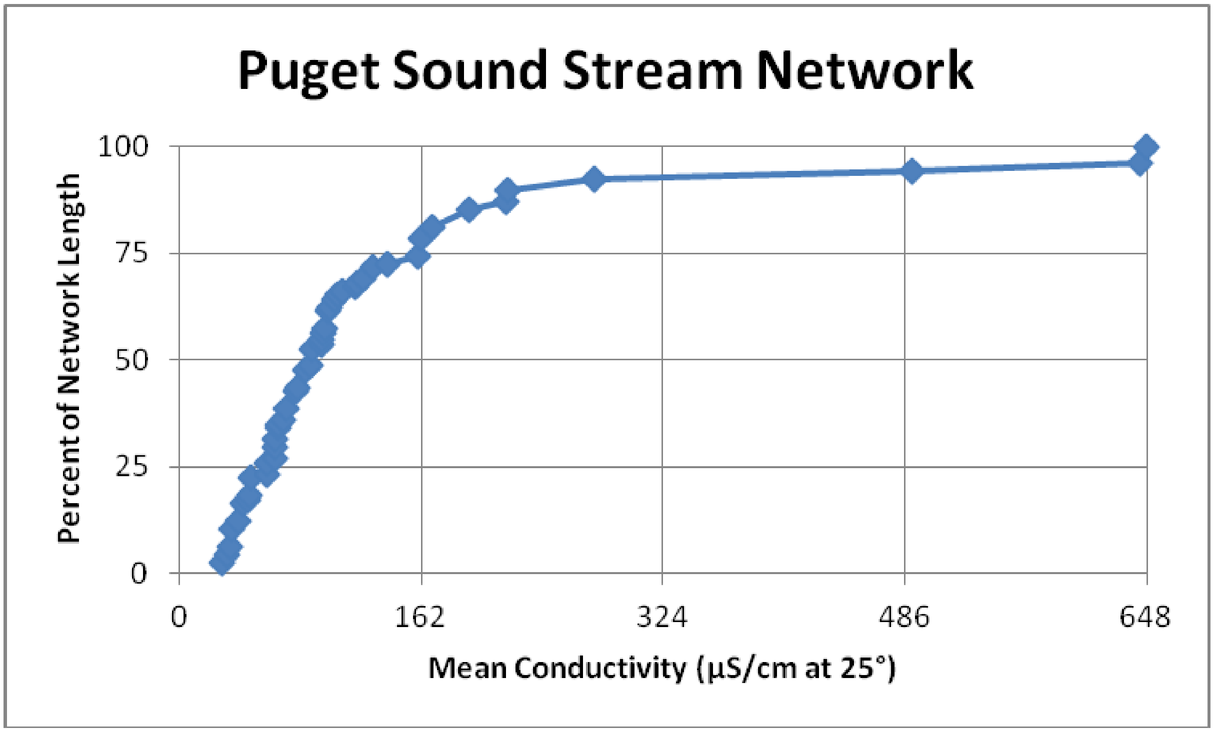

Figure 10. Extent of mean conductivity values in the Puget Sound target stream network in 2009.

Selected percentile scores for mean conductivity values are as follows:

- Minimum (28.1 uS/cm at 25 °C)
- 25.9 percentile (58.9 uS/cm at 25 °C)
- 48.6 percentile (87.8 uS/cm at 25 °C)
- 74.4 percentile (159.6 uS/cm at 25 °C)
- Maximum (647.9 uS/cm at 25 °C)

This excludes 98.6 km of estimated stream length with missing conductivity data (equipment failure).

Physical Habitat

Instream Complexity or Space

We report 6 instream habitat complexity metrics:

- Mean wetted width (X WetWidth)
- Mean bankfull width (X BF Width)
- Mean thalweg depth (X TW Depth)
- Thalweg depth standard deviation (SD TW Depth)
- Mean residual pool depth (X PoolUnitDepth)
- Percent of site as pool (PCT Pool)

The distribution of mean wetted width values in the target Puget Sound stream network for 2009 is displayed in Figure 11.

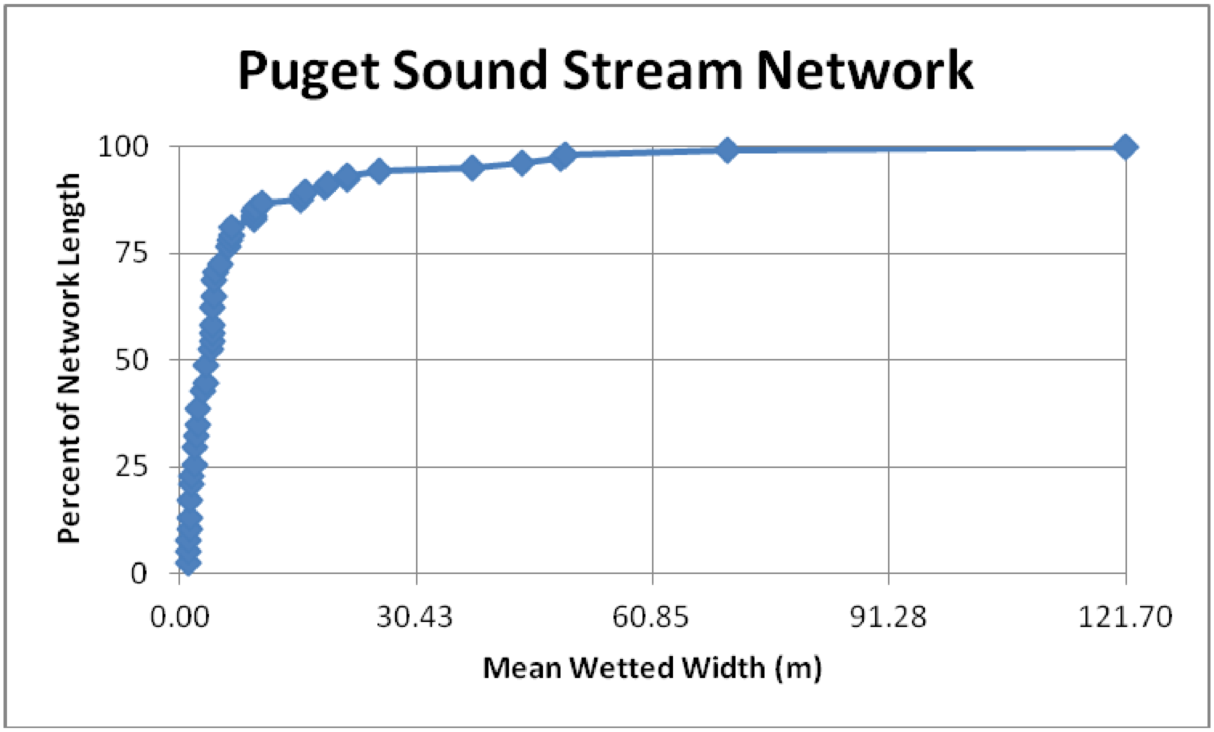

Figure 11. Mean wetted width values in the Puget Sound target stream network in 2009.

Selected percentile scores for mean wetted width values are as follows:

- Minimum (1.0 m)
- 25.5 percentile (1.9 m)
- 48.6 percentile (3.4 m)
- 76.4 percentile (6.2 m)
- Maximum (121.7 m)

The distribution of mean bankfull width values in the target Puget Sound stream network for 2009 is displayed in Figure 12.

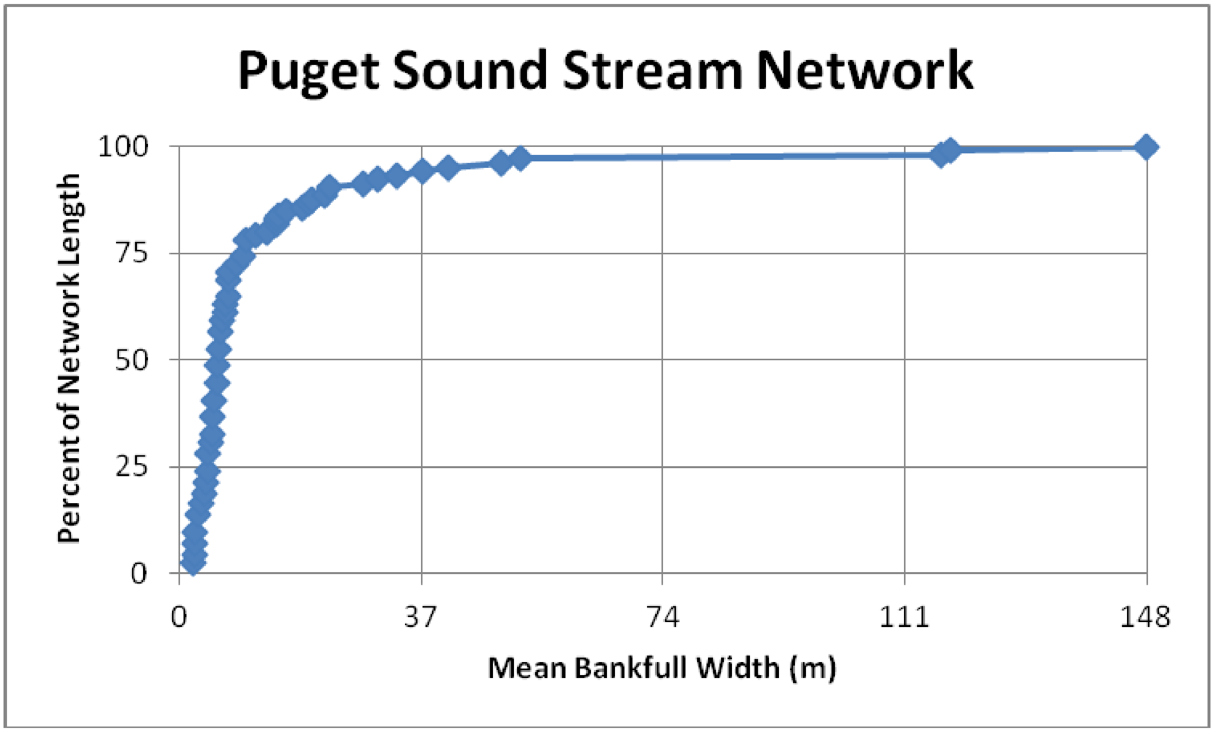

Figure 12. Mean bankfull width values in the Puget Sound target stream network in 2009.

Selected percentile scores for mean bankfull width values are as follows:

- Minimum (1.91 m)
- 24.0 percentile (4.2 m)
- 48.6 percentile (5.8 m)
- 74.2 percentile (9.7 m)
- Maximum (147.8 m)

The distribution of mean thalweg depth values in the target Puget Sound stream network for 2009 is displayed in Figure 13.

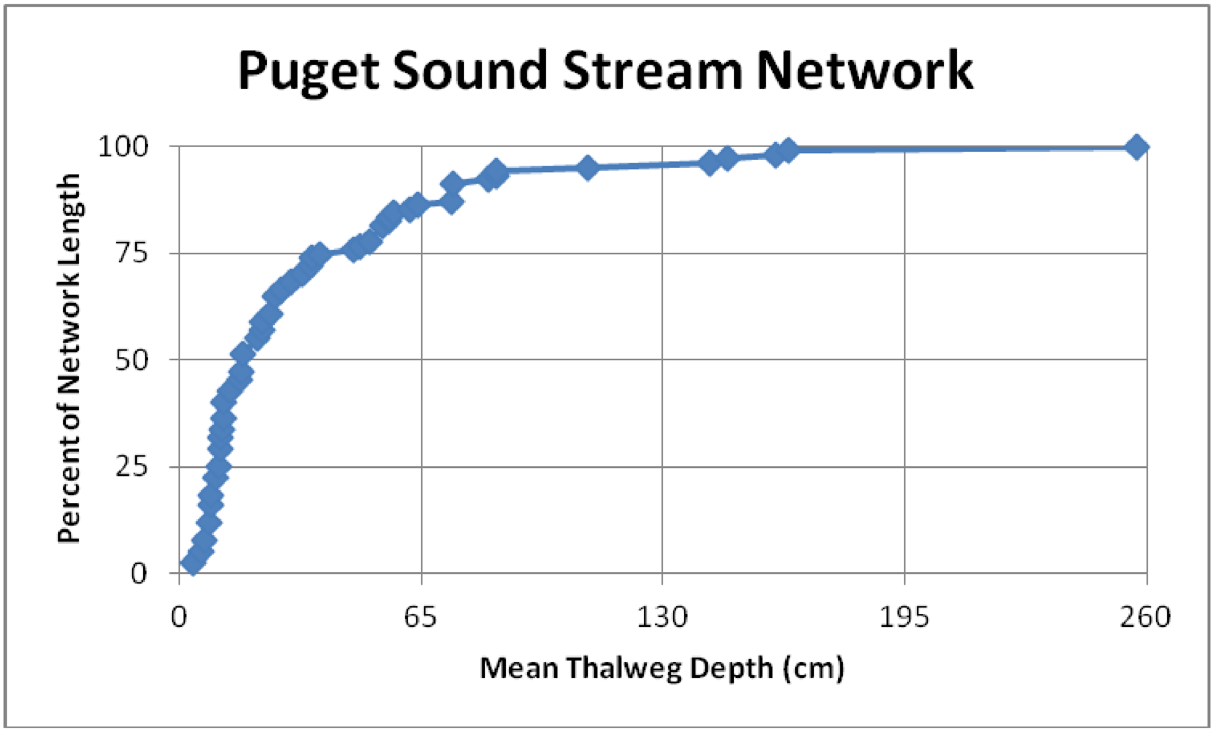

Figure 13. Mean thalweg depth values in the Puget Sound target stream network in 2009.

Selected percentile scores for mean thalweg depth values are as follows:

- Minimum (3.5 cm)
- 25.1 percentile (10.5 cm)
- 51.2 percentile (17.1 cm)
- 75.7 percentile (46.6 cm)
- Maximum (257.5 cm)

The distribution thalweg depth standard deviation values in the target Puget Sound stream network for 2009 is displayed in Figure 14.

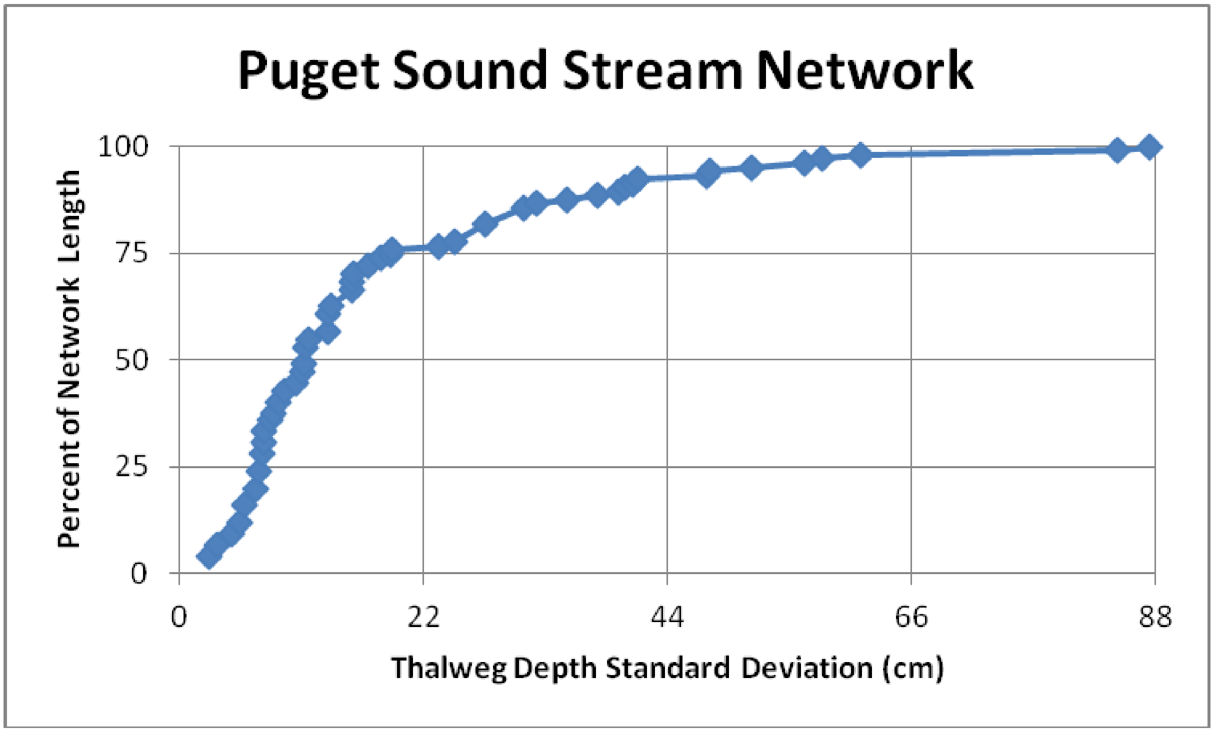

Figure 14. Thalweg depth standard deviation values in the Puget Sound target stream network in 2009.

Selected percentile scores for thalweg depth standard deviation values are as follows:

- Minimum (2.7 cm)
- 23.9 percentile (7.2 cm)
- 49.0 percentile (11.2 cm)
- 74.8 percentile (19.0 cm)
- Maximum (87.5 cm)

The distribution of the mean residual depth of pools (X PoolUnitDepth) in the target Puget Sound stream network for 2009 is displayed in Figure 15.

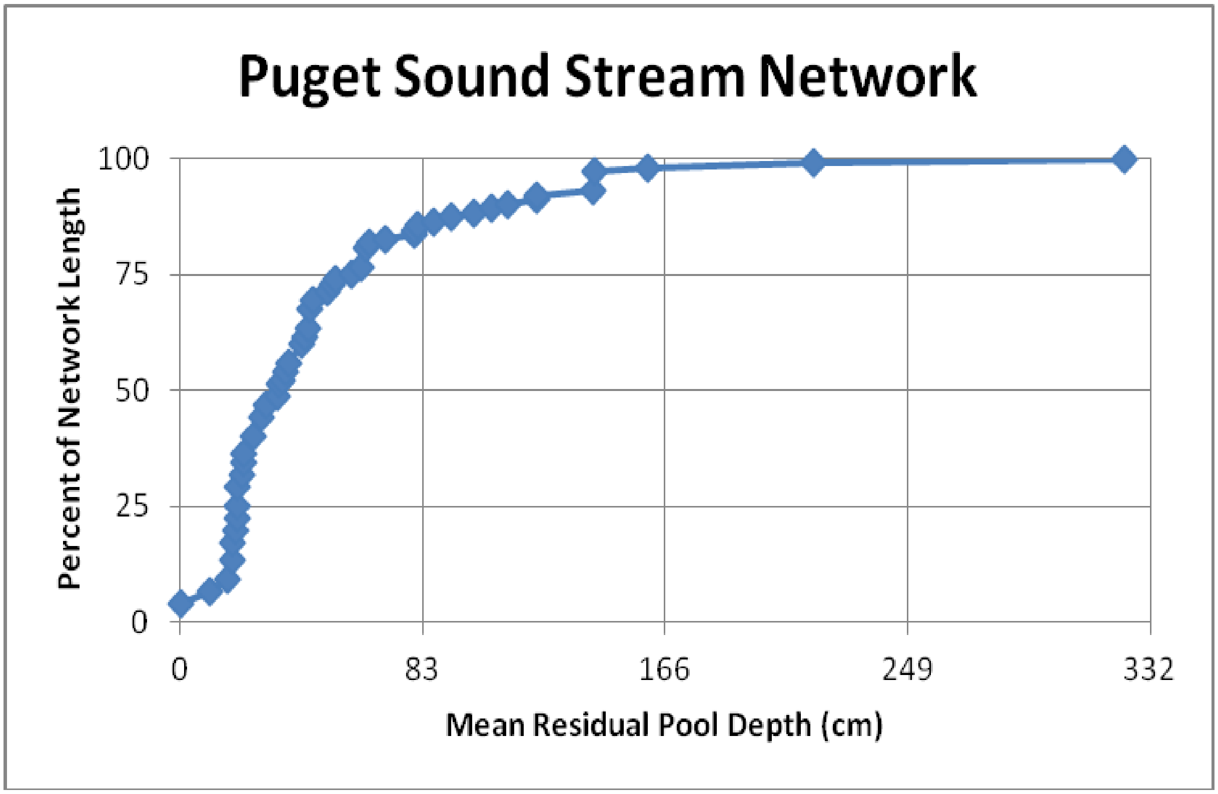

Figure 15. Mean residual depth of pools (X PoolUnitDepth) in the Puget Sound target stream network in 2009.

Selected percentile scores for X PoolUnitDepth values are as follows:

- Minimum (0 cm)
- 25.1 percentile (19 cm)
- 51.2 percentile (34 cm)
- 74.9 percentile (59 cm)
- Maximum (323 cm)

The distribution of values for the percent of site as pool (PCT Pool) in the target Puget Sound stream network for 2009 is displayed in Figure 16.

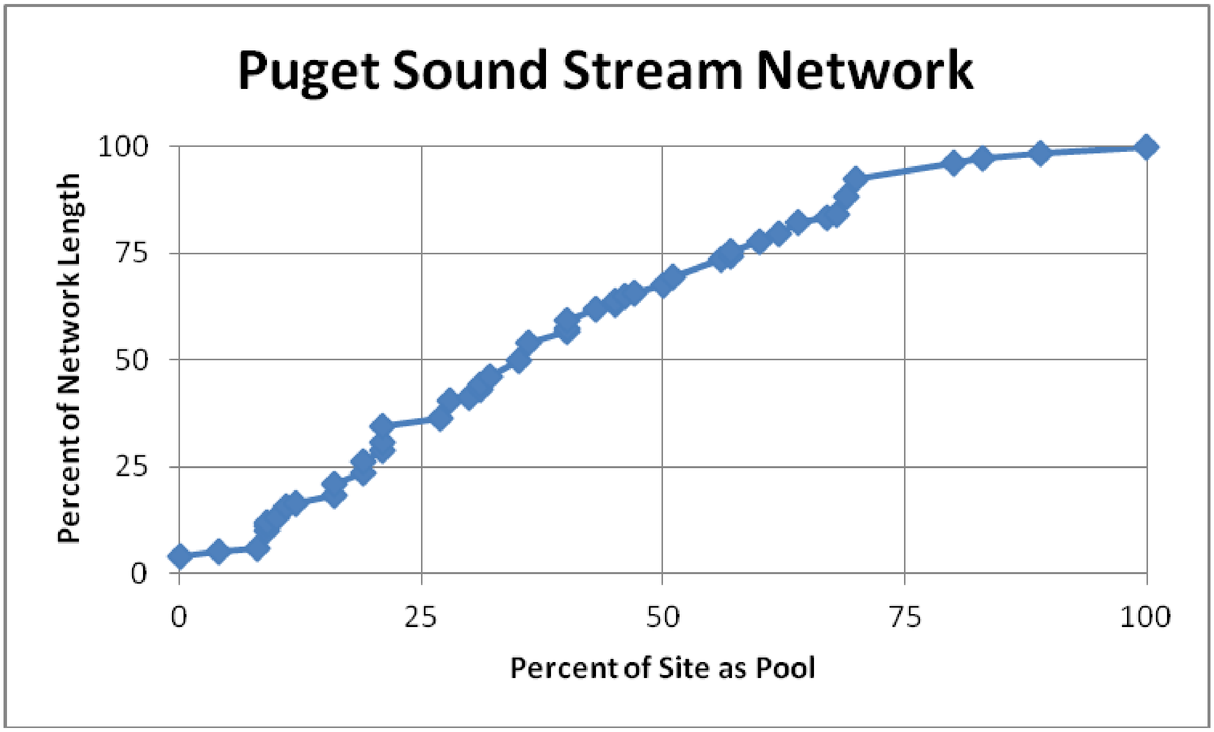

Figure 16. Percent of site as pool (PCT Pool) in the Puget Sound target stream network in 2009.

Selected percentile scores for PCT Pool values are as follows:

- Minimum (0%)
- 26.1 percentile (19%)
- 50.0 percentile (35%)
- 75.3 percentile (57%)
- Maximum (100%)

Instream Large Woody Debris (LWD)

We report 3 metrics for instream large woody debris:

- Mean fish cover from large woody debris (XFC LWD)
- Extent-of-reach with large woody debris (PFC LWD)
- Large woody debris frequency (LWD Pieces100m)

The distribution of values for mean fish cover from large woody debris (XFC LWD) in the target Puget Sound stream network for 2009 is displayed in Figure 17.

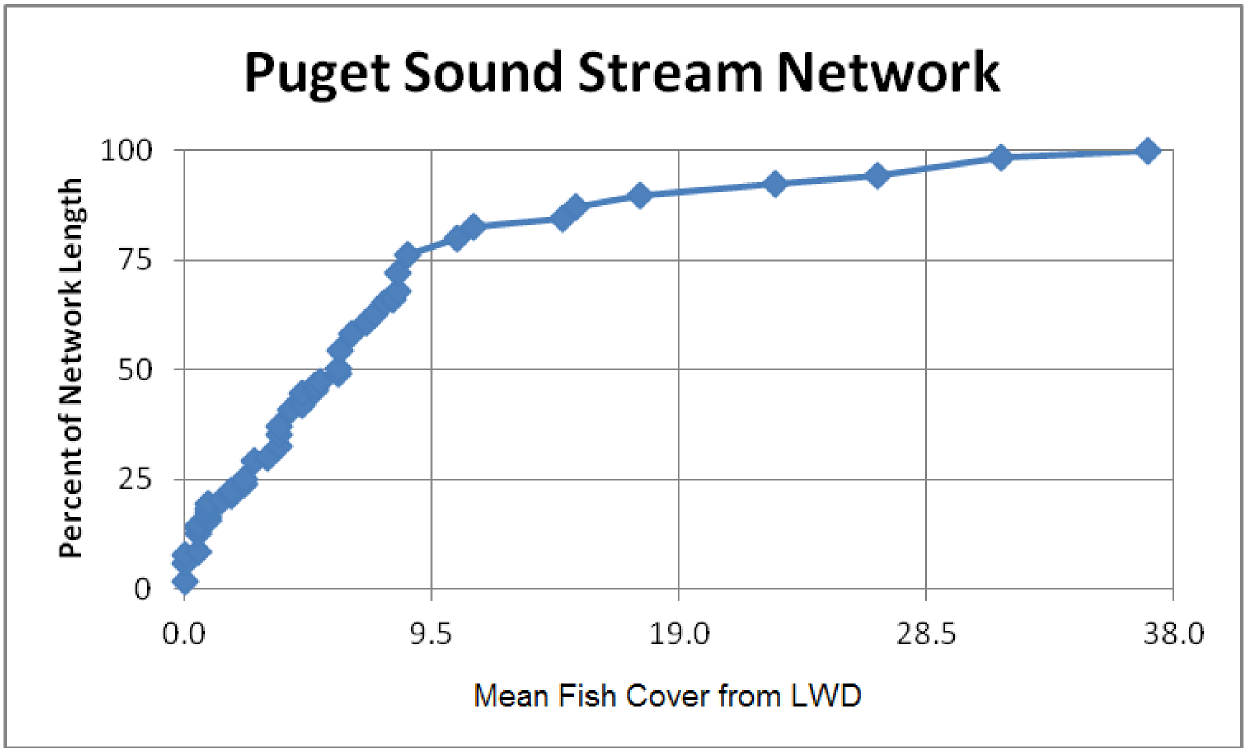

Figure 17. Distribution of values for mean fish cover from large woody debris (XFC LWD) in the Puget Sound target stream network in 2009.

Selected percentile scores for XFC LWD values are as follows:

- Minimum (0%)
- 25.0 percentile (2.3%)
- 50.2 percentile (5.9%)
- 76.1 percentile (8.6%)
- Maximum (37.0%)

The distribution of values for extent of fish cover from large woody debris (PFC LWD) in the target Puget Sound stream network for 2009 is displayed in Figure 18.

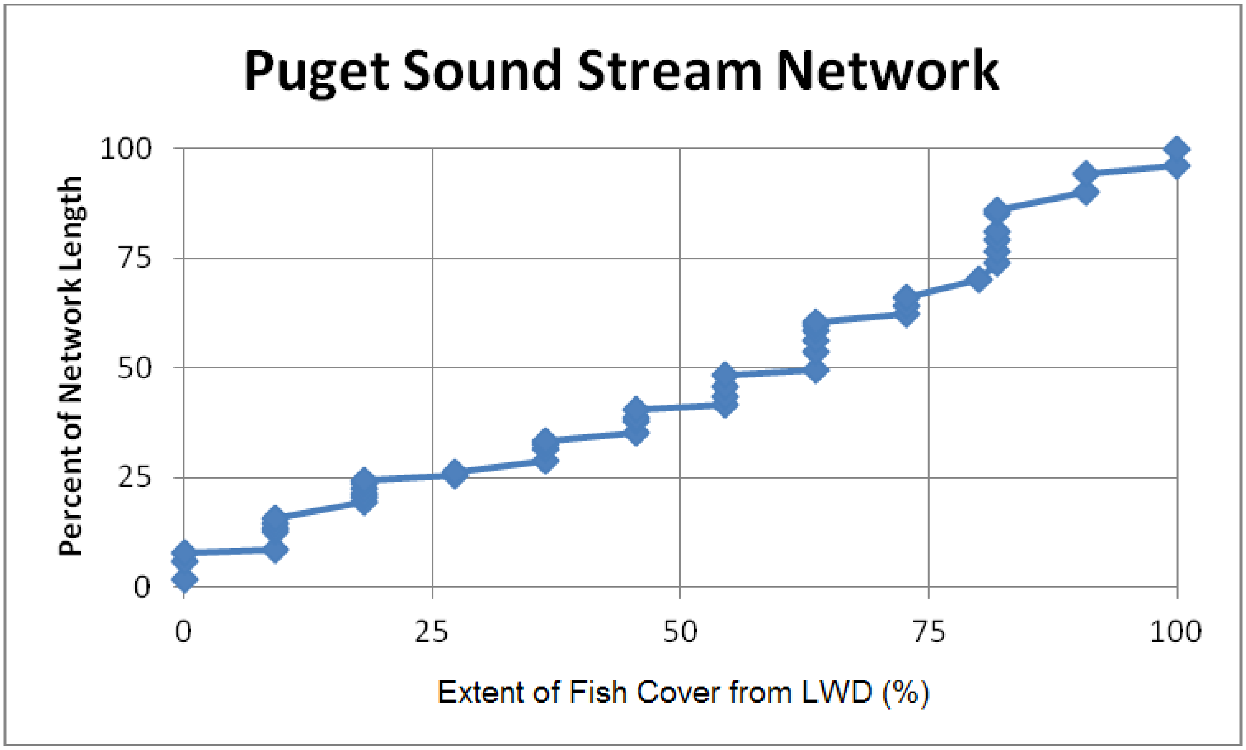

Figure 18. Distribution of values for extent-of-reach with fish cover from large woody debris (PFC LWD) in the Puget Sound target stream network in 2009.

Selected percentile scores for PFC LWD values are as follows:

- Minimum (0%)
- 25.3 percentile (27.3%)
- 49.4 percentile (63.6%)
- 74.1 percentile (81.8%)
- Maximum (100%)

The distribution of values for large woody debris frequency (LWD Pieces100m) in the target Puget Sound stream network for 2009 is displayed in Figure 19.

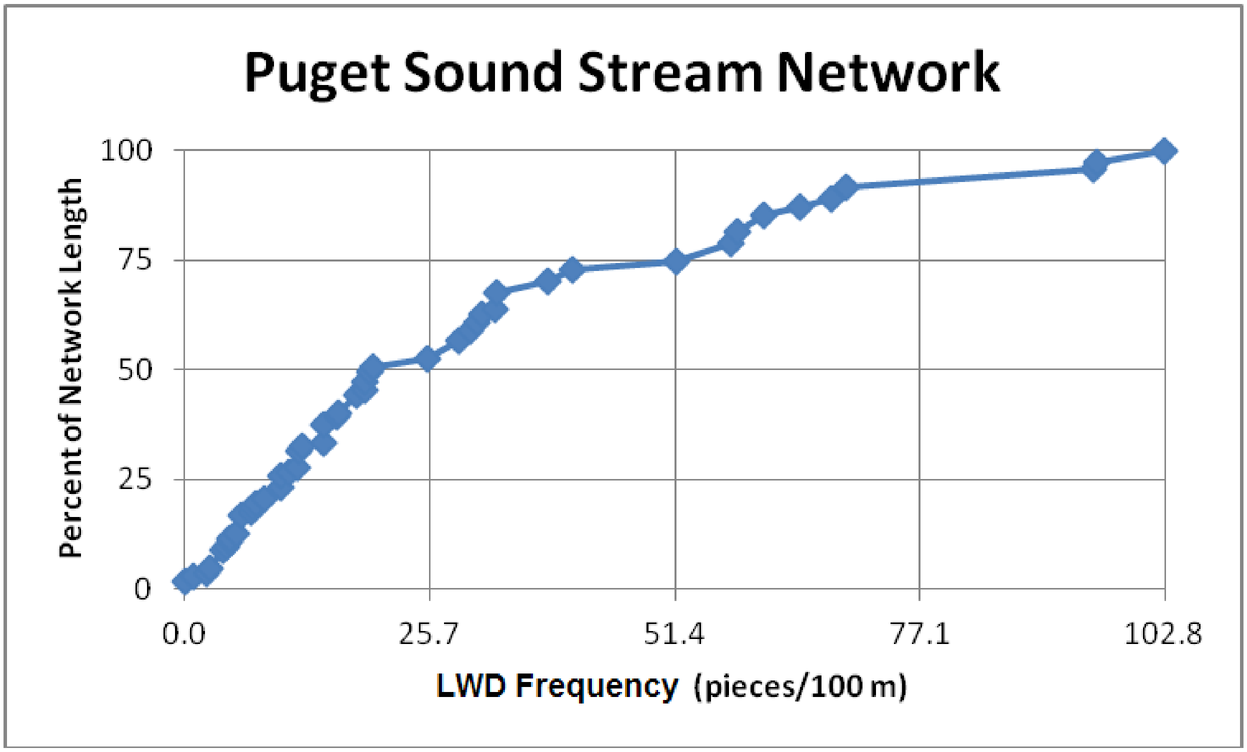

Figure 19. Large woody debris frequency (LWD Pieces100m) in the Puget Sound target stream network in 2009.

Selected percentile scores for LWD Pieces100m values are as follows:

- Minimum (0 pieces/100m)
- 25 percentile (10.0 pieces/100m)
- 49.7 percentile (19.3 pieces/100m)
- 74.7 percentile (51.5 pieces/100m)
- Maximum (102.7 pieces/100m)

Instream Substrate

We report 3 instream substrate metrics:

- Percent of substrate as fines (PCT Fines)
- Percent of substrate as sand or fines PCT SandFines)
- Percent embeddedness (X Embed)

The distribution of values for percent of substrate as fines (PCT Fines) in the target Puget Sound stream network for 2009 is displayed in Figure 20.

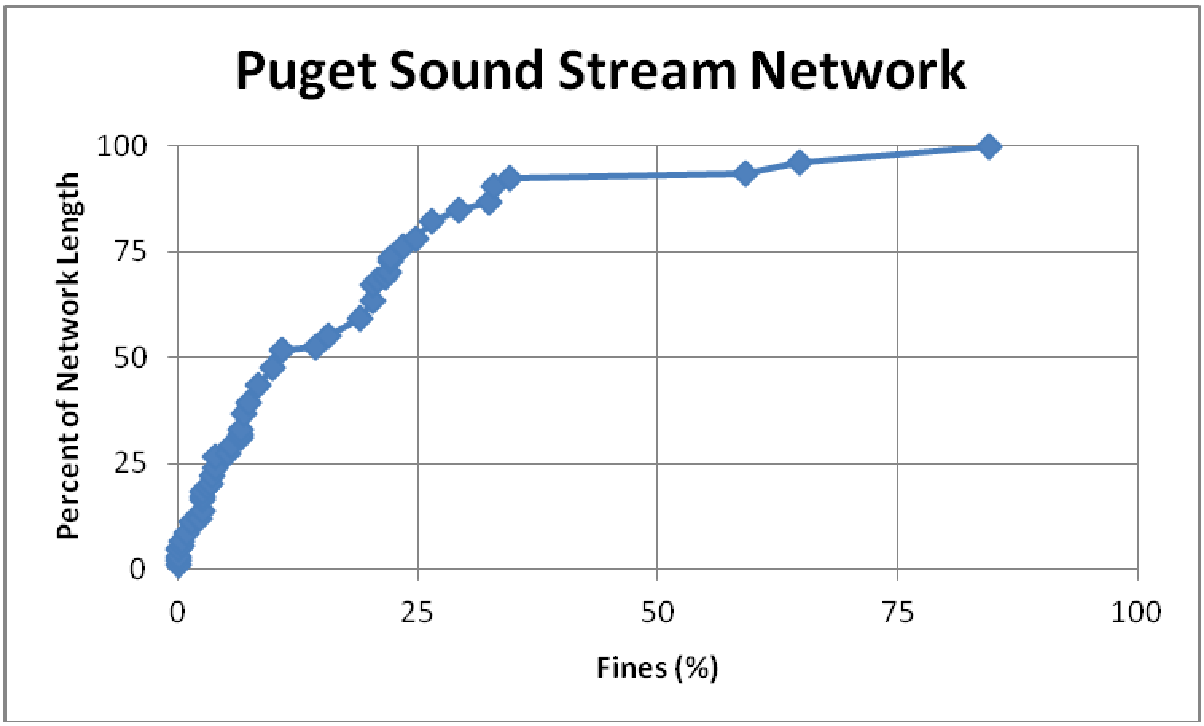

Figure 20. Distribution of values for percent of substrate as fines (PCT Fines) in the Puget Sound target stream network in 2009.

Selected percentile scores for PCT Fines values are as follows:

- Minimum (0%)
- 25 percentile (3.9%)
- 51.6 percentile (10.9%)
- 76.3 percentile (23.4%)
- Maximum (84.5%)

The distribution of values for percent of substrate as sand or fines (PCT SandFines) in the target Puget Sound stream network for 2009 is displayed in Figure 21.

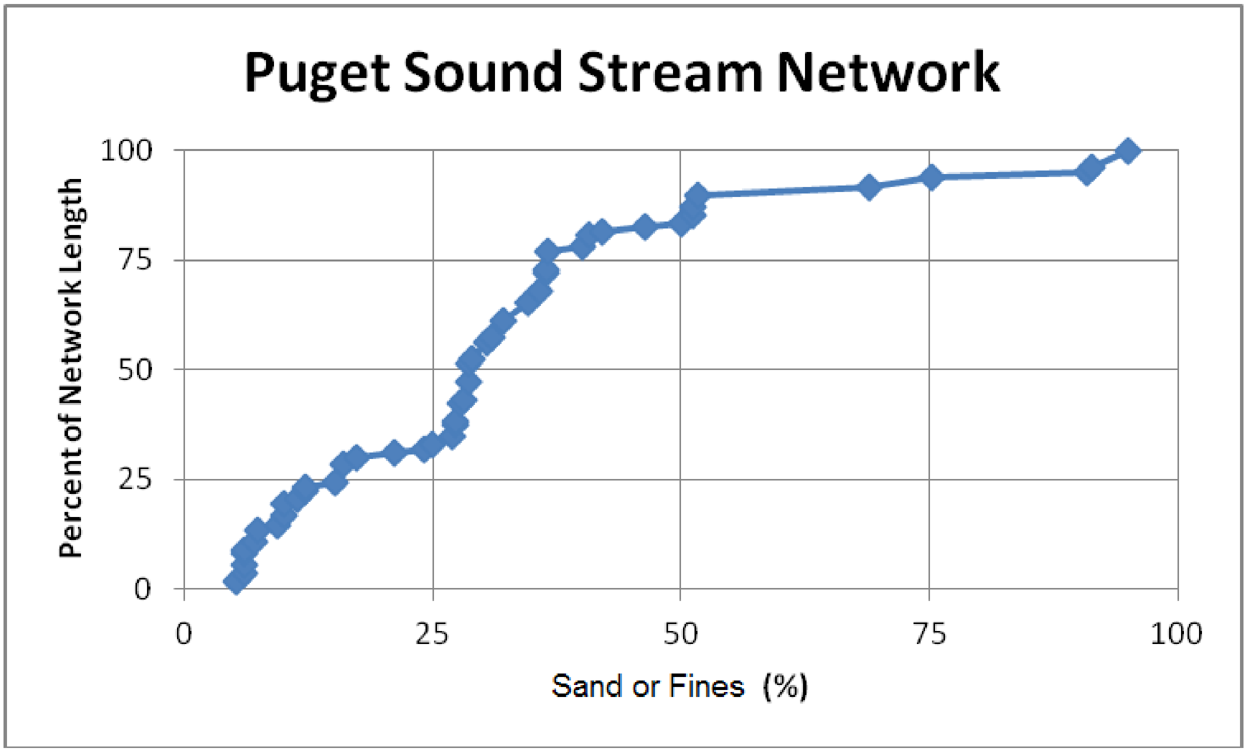

Figure 21. Distribution of values for percent of substrate as sand or fines (PCT SandFines) in the Puget Sound target stream network in 2009.

Selected percentile scores for PCT SandFines values are as follows:

- Minimum (5.2%)
- 24.3 percentile (15.2%)
- 51.3 percentile (28.6%)
- 77.0 percentile (36.6%)
- Maximum (95%)

The distribution of values for mean embeddedness (X Embed) in the target Puget Sound stream network for 2009 is displayed in Figure 22.

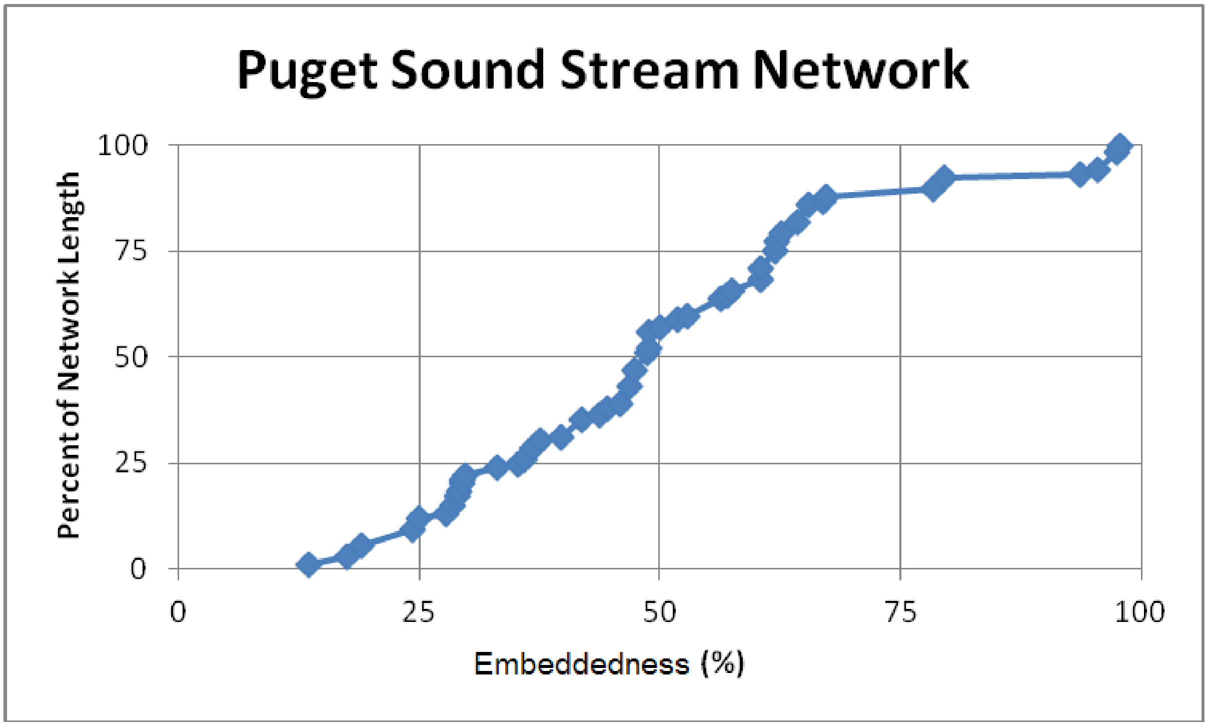

Figure 22. Distribution of values for mean embeddedness (X Embed) in the Puget Sound target stream network in 2009.

Selected percentile scores for X Embed values are as follows:

- Minimum (13.5%)
- 24.9 percentile (35.2%)
- 51.0 percentile (48.6%)
- 74.9 percentile (61.9%)
- Maximum (97.8%)

Bank Quality

We report 1 metric for bank quality (PFC Undercut). This is the only bank quality metric available with a signal-to-noise score above 1 (Appendix C). The distribution of values for PFC Undercut in the target Puget Sound stream network for 2009 is displayed in Figure 23.

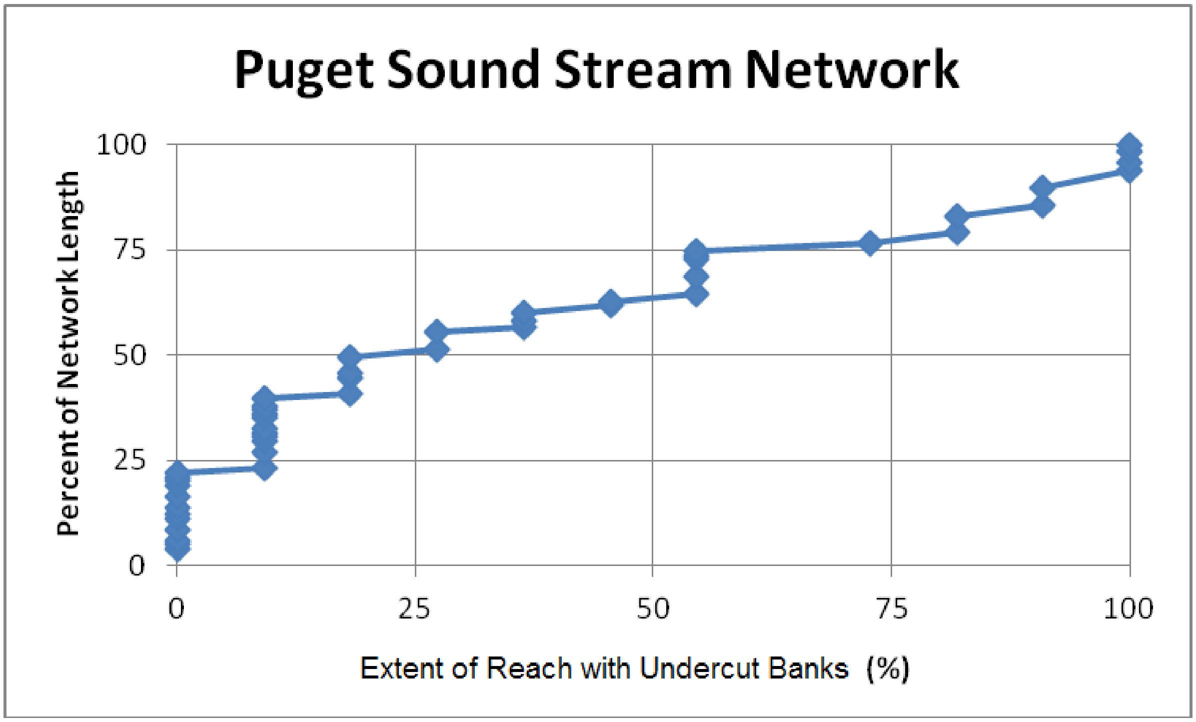

Figure 23. Distribution of values for extent-of-reach with undercut banks (PFC Undercut) in the Puget Sound target stream network in 2009.

Selected percentile scores for PFC Undercut values are as follows:

- Minimum (0%)
- 25 percentile (9.1%)
- 49.7 percentile (18.2%)
- 74.7 percentile (65.5%)
- Maximum (100%)

Riparian Condition

At this time, X ShadeBnk serves as our sole metric for riparian condition. The distribution of values for X ShadeBnk in the target Puget Sound stream network for 2009 is displayed in Figure 24.

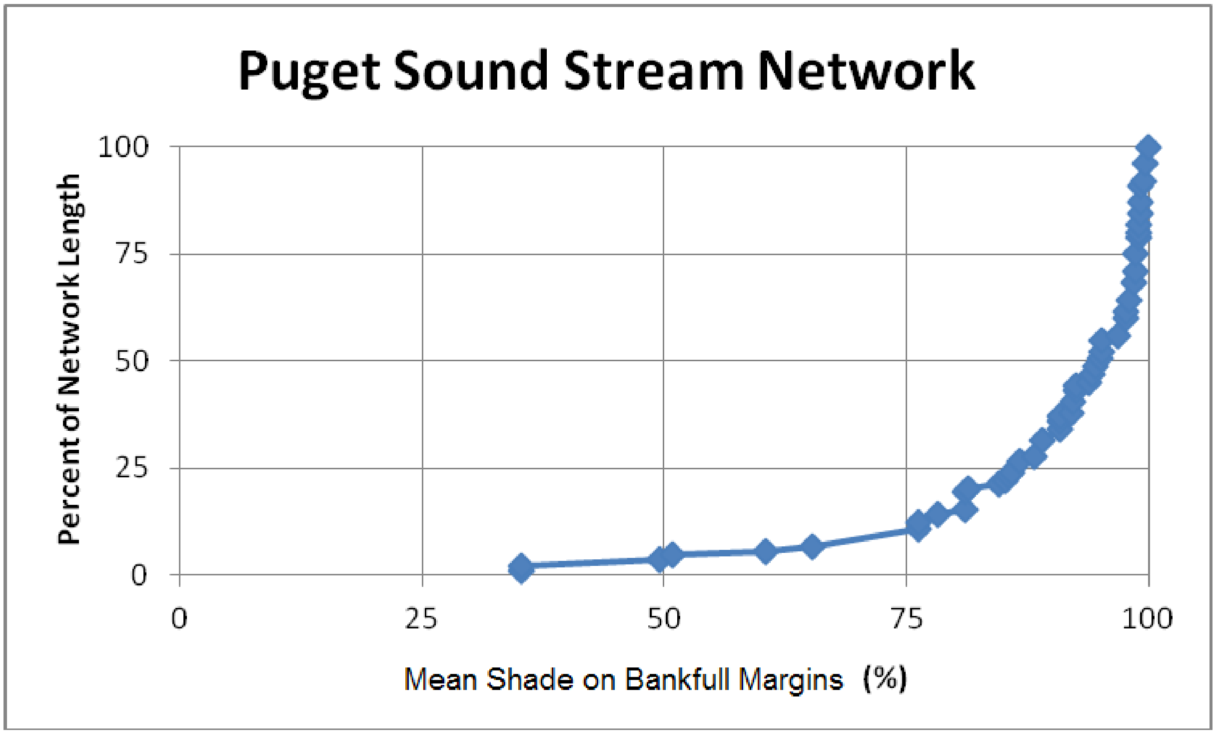

Figure 24. Distribution of values for mean shade on the banks (X ShadeBnk) in the Puget Sound target stream network in 2009.

Selected percentile scores for X ShadeBnk values are as follows:

- Minimum (35.3%)
- 24.0 percentile (85.8%)
- 50.5 percentile (94.9%)
- 74.9 percentile (98.7%)
- Maximum (100%)

Discussion

The results of our sampling reflect regional conditions for an index period (July 1-October 15, 2009). They are not intended to describe specific sites or to describe conditions in other seasons.

Evaluating the Frame

Reconnaissance results help us to interpret the map of streams from which sites were randomly chosen (the frame).

We designated sites as non-target primarily due to estimated flow status. Non-perennial streams compose 85% of non-target sites evaluated. These are mainly 0-order streams. Excluding 0-order streams, the frame seems to accurately depict regional ground conditions (i.e., we classified most sites as target). However, we designated about 8% of the non-target streams (8%) as lentic (Figure 3).

The 0-order streams are by far the largest part of frame length (73.5%; Table 5) and provide about 23% of the target stream length for the region (Table 9). The 1-order streams provide the largest percentage (40%) of target stream length for the region (Table 9). Clearly, watershed health is highly dependent upon what happens in and above small streams. Larger rivers (3-order and larger streams) provide about 18% of the network.

The public was cooperative in allowing access for sampling, with a landowner rejection rate of only 20% for target sites that we tried to schedule for sampling. We believe that this could have been lower with an earlier lead-time to begin mailing request letters. We received some responses too late in the season for us to schedule the sites, even though permission had been granted.

Regional Baseline Conditions

We present cumulative frequency distribution curves as baseline reference (Figure 4 and Figures 6-24). Variables that increase with human disturbance should show curves that shift right as a result of restoration. Conversely, curves should shift left for the other variables, as conditions improve. We can draw 95% confidence intervals around the curves to assist with trend detection. Rating of these metric scores (i.e., as good fair or poor) will require evaluation of reference conditions in each ecoregion. This work is in progress.

Biological Health

Macroinvertebrates

The baseline description of the macroinvertebrate community condition may be found in Figure 4. If the cumulative distribution shifts left in later surveys, this will indicate improving watershed health, with a higher proportion of streams having high EPT Percent scores.

Aquatic Vertebrates

Figure 5 provides a baseline description of detectable aquatic vertebrates.

Common Species

Cutthroat trout are apparently the most widely distributed vertebrate species in Puget Sound streams during the index period, followed by coho salmon, torrent sculpin, and rainbow trout/steelhead. Another widely distributed vertebrate is the Pacific giant salamander.

ESA-listed Species

There are four fishes listed (threatened) by the Endangered Species Act for streams and rivers in the Puget Sound Salmon Recovery Region (RCO 2009):

- Steelhead or rainbow trout (*Oncorhynchus mykiss*)
- Chinook salmon (*Oncorhynchus kisutch*)
- Bull trout (*Salvelinus confluentus*)
- Hood Canal summer chum (*Oncorhynchus keta*)

Steelhead or rainbow trout were detected in streams representing an estimated 2,076 km of the network. These fish have also been historically documented (WDFW 2008) among four of the five river sites where we sampled but were not permitted to fish. This represents another 411 km of the target stream network.

Chinook salmon were detected among streams representing just 205 km of the network. Historical documentation (WDFW 2008) represents an additional 411 km.

We did not detect bull trout. However, this species has been documented in rivers where we did not fish due to permit restrictions. This represents another 513 km of the stream network.

Although we entered the range of chum salmon, we did not enter the range of Hood Canal summer chum. We did not detect chum of any type.

Non-native or Invasive Species

Non-native species detected include the eastern brook trout (estimated in 850 km) and the black bullhead (estimated in 191 km). Historical documentation (WDFW 2008) is found for largemouth bass presence at a river site that we did not fish. This represents 103 km of the Puget Sound network.

For later surveys, we hope to see an increased extent of streams where native, sensitive, or coldwater species will be detected. Conversely, we hope to see a decrease in the extent of streams with non-native, pollution-tolerant, or warm-water species.

Water Quality

The baseline description of the water quality is represented with cumulative distribution function (CDF) graphs for:

- nitrogen (TPN; Figure 6)
- chloride (Cl; Figure 7)
- temperature (X TempC; Figure 8)
- oxygen (X O2Sat; Figure 9)
- conductivity (X Cond; Figure 10)

Values for Cl, X TempC, and X Cond are expected to increase with increasing human disturbance in the watershed. Where watershed restoration is effective at mitigating human disturbance, we might expect cumulative distributions from later surveys to shift right. This would indicate a higher percentage of streams have lower disturbance levels.

We are not sure which direction to expect for changes to total persulfate nitrogen (TPN) values. Anthropogenic sources of nitrogen to tributaries include chemical fertilizers and failing septic systems (e.g., Steinberg et al. 2011). However, we also know that marine-derived nitrogen has been greatly diminished within the last 150 years as salmon runs have declined (Stockner 2003). With salmon recovery, we might expect increases in marine-derived nitrogen to the watershed. Nitrogen fixation by bacteria in riparian red alder roots can also be a factor (Edwards 1998).

If the cumulative distribution of X O2Sat (Figure 9) shifts left in later surveys, this will indicate improving watershed health with regard to available oxygen.

Physical Habitat

The baseline description of the physical habitat is represented by CDF graphs for:

- complexity metrics (Figures 11-16)
- large woody debris metrics (Figures 17-19)
- substrate composition metrics (Figures 20-22)
- a bank quality metric (Figure 23)
- a riparian condition metric (Figure 24)

We expect metric values for complexity, large woody debris, bank quality, and riparian canopy cover to increase with watershed restoration. We expect values for the 3 substrate metrics to decrease with watershed restoration, although in some local areas we might want higher values if excess scour has been a problem.

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Conclusions

Results of this 2009 study support the following conclusions:

- The STREAM database is under construction and will soon provide the public with easy access to habitat metrics and the data from which these metrics are calculated.
- In the Puget Sound Status and Trends Region (STR), the stream map from which the Washington Master Sample was selected (the sample frame) represents about 45,658 km of streams on non-federal lands.
- In the Puget Sound STR, about 10,536 km of streams on the frame meet our criteria as target (freshwater, perennial, above ground, flowing, on the National Hydrography Dataset (NHD), and non-federal ownership).
- In the Puget Sound STR, by far, the greatest portion of non-target streams is non-perennial, 0-order streams.
- In the Puget Sound STR, small streams (0-order and 1-order) comprise about 63.7% of the target streams on the frame.
- Precision analysis suggests that several of our metrics will not provide a large enough signal relative to noise in Puget Sound stream surveys. These include:
    - Mean pH per sample session (X pH)
    - Turbidity (Turb)
    - Total phosphorus (Tot-P)
    - Total suspended solids (TSS)
    - Mean bank instability (X Instability)
    - Extent of site with fish cover from undercut banks (PFC Undercut)
- Most metrics considered for this report provide enough signal-to-noise for inclusion in further metric analyses.
- These are the most frequent vertebrate species inhabiting the Puget Sound stream network during the index period: cutthroat trout, coho salmon, torrent sculpin, rainbow trout/ steelhead, and the Pacific giant salamander.
- The Puget Sound stream network is occupied by at least the following non-native vertebrate species: brook trout, black bullhead, and largemouth bass.
- We have established a baseline report on Puget Sound tributaries that includes a small set of metrics for biology, chemistry, and physical habitat. We can evaluate later surveys relative to these data.

Recommendations

Results of this 2009 study support the following recommendations:

- Finish building the database, including the full suite of metrics. Address hydrologic function (e.g., Kaufmann et al. 2008), which we have found to be highly related to biology in past surveys.
- Establish reference conditions for each of the 4 ecoregions. Measurements from Puget Lowland sentinel sites (e.g., Herger et al. 2012) can be used toward this goal. Also use the sampled, least-impacted Master Sample sites plus sites assessed by Ecology's Ambient Biological Monitoring Program (Adams 2010).
- If the following metrics show similar precision results in all other Status and Trends Regions (STRs), then consider discontinuing their measurement in Watershed Health and Salmon Recovery (WHSR) surveys: X pH, Turb, Tot-P, TSS, and X Instability.
- Find a better bank quality metric or indicator. The bank condition analysis of Henshaw and Booth (2000) might be one to consider.
- Evaluate the full suite of metrics for development of multi-metric indices. Consider range, signal-to-noise, responses to anthropogenic stress, and redundancy (i.e., Whittier et al. 2007b). Also consider new species attribute information (PSSB 2012 and Whittier et al. 2007a).
- Provide this project's data in support of Ecology's reports to EPA under the Clean Water Act Section 305(b).
- Provide this project's data for salmon recovery accountability reports such as the State of the Salmon in Watersheds (RCO 2012b) or the Pacific Coastal Salmon Recovery Fund Reports to Congress (PCSRF 2012).

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Appendices

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Appendix A. Glossary, Metric Names, Acronyms, and Abbreviations

Glossary

Anthropogenic: Human-caused.

Bankfull width: The width of the stream channel measured at bankfull stage. Bankfull stage is the elevation at which the stream reaches its high-water mark on average about every 1-2 years.

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

Diel: Of, or pertaining to, a 24-hour period.

Embeddedness: The fraction of a substrate particle's surface that is surrounded by (embedded in) sand or finer sediments (≤ 2 mm).

Frame: The map from which the Washington Master Sample sites were selected (1:24:000-scale Washington Department of Natural Resources Watercourses, February 2005).

Metric: A value resulting from the reduction or processing of measurements taken within a data collection event.

Percentile: A statistical number obtained from a distribution of data, below which the numerical percentage of the data exists. For this study it is discussed in terms of estimated regional stream length within which a value is at or below a given value.

pH: A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is considered to be neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

Riparian: Relating to the banks along a natural course of water.

Salmonid: Fish that belong to the family *Salmonidae*.

Specific conductivity: A measure of water's ability to conduct an electrical current. Conductivity is related to the concentration and charge of dissolved ions in water. Specific conductivity adjusts the reported value to what would occur at 25 °C.

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Thalweg: Path of a stream that follows the deepest part of the channel.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Metric names

Cl: A metric reported by the Manchester Environmental Laboratory. It describes the chloride concentration measured in units of mg/L from a water sample.

LWD Pieces100m: A metric that describes the tally of large wood pieces in the site. It is standardized to a site length of 100 meters.

PCT Fines: A metric that describes estimated percent of the substrate that is composed of fines particles (< 0.06 millimeter in diameter).

PCT SandFines: A metric that describes estimated percent of the substrate that is composed of sand or smaller particles (< 2 millimeter in diameter).

PFC LWD: A metric that describes the percentage of transects at each sample site where there is fish cover provided by large woody debris.

PFC Undercut: A metric that describes the percentage of transects at each sample site where there is fish cover provided by undercut banks.

SD TWDepth: A metric that describes the standard deviation of the wetted depth (cm) of the site based on a series of measurements along the thalweg profile.

Tot-P: A metric reported by the Manchester Environmental Laboratory. It describes the total phosphorus measured in units of mg/L from a water sample.

TPN: A metric reported by the Manchester Environmental Laboratory. It describes the total nitrogen (by persulfate method) measured in units of mg/L from a water sample.

TSS: A metric reported by the Manchester Environmental Laboratory. It describes the total suspended solids concentration measured in units of mg/L from a water sample.

Turb: A metric reported by the Manchester Environmental Laboratory. It describes the turbidity measured in units of NTU measured from a water sample.

X BFWidth: A metric that describes the average bankfull width (m) of the site based on a series of transect measurements.

X Cond: A metric that describes the specific conductivity of water (uS/cm at 25 °C). This metric is an average of two conductivity measurements: one recorded upon arrival, and another recorded before departure.

X Embed: A metric that describes the average embeddedness of particles in the substrate.

X Instability: A metric that describes the average estimated bank instability (at bankfull stage) at each side of 11 transects.

XFC LWD: A metric that describes the average estimated fish cover provided by large woody debris. This is an average of a series of transect-based observations.

X O2Sat: A metric that describes the amount of oxygen dissolved in water expressed as percentage of how much the water will have when saturated. This metric is an average of two percent oxygen saturation measurements: one recorded upon arrival, and another recorded before departure.

X pH: A metric that describes pH (pH units). This metric is an average of two pH measurements: one measured upon arrival, and another measured before departure.

X ShadeBnk: A metric that describes the average percent shade measured with a convex densiometer at the bankfull stage among transects.

X TempC: A metric that describes water temperature (°C). This metric is an average of two water temperature measurements: one recorded upon arrival, and another recorded before departure.

X TWDepth: A metric that describes the average wetted depth (cm) of the site based on a series of measurements along the thalweg profile.

X WetWidth: A metric that describes the average wetted width (m) of the site based on a series of transect measurements.

Acronyms and Abbreviations

CWA	Clean Water Act
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EMAP	Environmental Monitoring and Assessment Program
EPA	United States Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera, or Trichoptera
ESA	Endangered Species Act
Forum	Washington Monitoring Forum
GIS	Geographic Information System software
HLI	High Level Indicator
ISEMP	Integrated Status and Effectiveness Monitoring Project
LWD	Large Woody Debris
MEL	Manchester Environmental Laboratory
NHD	National Hydrography Dataset
NOAA	National Oceanic and Atmospheric Administration
PSP	Puget Sound Partnership
QA	Quality Assurance
STR	Status and Trends Region
STREAM	Status and Trends: Riverine Ecology and Assessment Monitoring database
USGS	United States Geological Survey
WDFW	Washington Department of Fish and Wildlife

WDNR	Washington Department of Natural Resources
WHSR	Status and Trends Monitoring for Watershed Health and Salmon Recovery
WRIA	Water Resources Inventory Area

Units of Measurement

°C	degrees centigrade
cm	centimeter
ha	hectare
km	kilometer, a unit of length equal to 1,000 meters.
m	meter
mg/L	milligrams per liter (parts per million)
NTU	nephelometric turbidity units
uS/cm	microsiemens per centimeter, a unit of conductivity
%	percent

Appendix B. Data Management System Description

Data Loading

The data management relies on input from scanned field forms to the STREAM database and from uploading of laboratory results to EIM (Figure B-1). Water and sediment chemistry results from Manchester Environmental Laboratory are transferred from their LIMS (Laboratory Information Management System) reports to EIM. Invertebrate taxa counts provided by contract laboratories are routed through the Puget Sound Stream Benthos system and transferred to EIM.

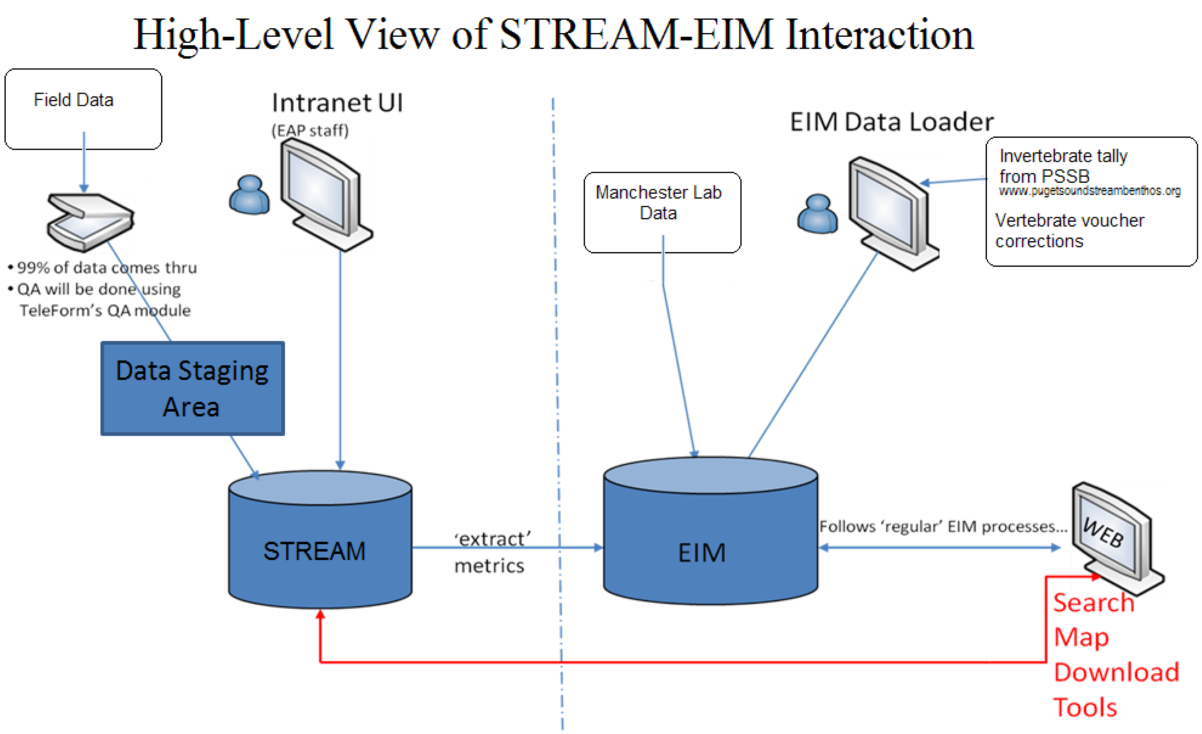

Figure B-1. Data management system overview.

Public Access to Data

Public access to metric data is through EIM. Public access to quality-assured raw data is through a web interface with STREAM (available later this year). The STREAM portal will be available through the EIM web page.

Schema

The June 2009 version of the database design may be found on the project web page:
www.ecy.wa.gov/programs/eap/stsmf/docs/STMDataModelScema_06_09.pdf
Newer versions are available upon request.

Appendix C. Evaluation of Metrics Using Precision

Introduction

We intend to develop multi-metric indices to describe high-level indicators for biology, chemistry, and physical habitat. This is a multi-step process in which metrics are assessed for:

- precision
- response to anthropogenic stress
- redundancy with other metrics

Steps 2 and 3 depend upon further work. We must describe the reference condition in each ecoregion, and we should calculate a full suite of metrics. We are, therefore, not ready for performing those steps 2 and 3, but we can begin step 1.

Methods

Precision of the regional scores is expressed in terms of three types of calculations.

1. Regional **range** describes the differences between maxima and minima (from initial site visits) among random sample sites from across the Puget Sound Status and Trends Region (STR).
2. The **Signal-to-noise** ratio compares replicate (within-site) precision with among-site precision.
3. Root Mean Square Error (**RMSE**) is precision data from re-visited sites.

Range and signal (among site variance) provide an indication of metric performance across the region. Small values indicate little descriptive information in what is measured.

Noise (pooled within-site variance) and RMSE (pooled within-site standard deviation) indicate error of the measurement process. Large values indicate a need for better training or a better method.

Regional Range

We measured the difference between highest and lowest values recorded when examining the set of sampled probability sites (among site range). We examined this within each stream size class.

Signal-to-Noise Ratio

We calculated the signal-to-noise ratio of each metric according to Kaufmann et al. (1999). For methods (e.g., water samples) that are equivalent between the field protocols (wadeable streams vs. wide streams/rivers), the signal is the variance of the sample of 48 regional sites. Noise is the pooled within-site variance from repeat visits to 6 sites.

For select data that have different field protocols, we segregated variance components as in Table C-1. Replicates in 2009 did not include data collected with the wide streams and rivers protocol (Merritt et al. 2010). Therefore, we made noise estimates for this protocol based on replicates at 2 sites sampled during 2010: the Willapa River (WAM06600-000194) and the Toutle River (WAM06600-000041). These are both located outside the Puget Sound STR but are both situated in Western Washington. For 3 metrics that had values of zero at each visit to the Toutle river (PCT Fines, LWDPieces100m, and PFC Undercut), we substituted 2 trips to the Hamma Hamma River (SEN06600-HAMM03), sampled once each in 2009 and 2010.

Table C-1. Components of precision for metrics with different field protocols.

Component of precision	**Source of Data**
Noise for wadeable streams	Pooled variance (6 repeat sites)
Noise for wide streams & rivers	Pooled variance (2 repeat sites*)
Signal for wadeable streams	Among site variance (38 sites)
Signal for wide streams & rivers	Among site variance (10 sites)

* From outside the 2009 Puget Sound probability sample.

For signal-to-noise calculations, data were transformed according to Table C-2 by methods described in Zarr (1999) to make the distributions approximately normal.

Table C-2. Metric data transformations.

Parameters with Arcsine Transformations[1]	**Parameters with Log10(X+1) Transformations[1]**
XFC LWD	TSS
PFC LWD	Turbidity
X ShadeBnk	TPN
X Instability	Total P
PCT Fines	Chloride
PCT SandFines	TSS
X Embed	Turbidity
PFC Undercut	TSS
X ShadeBnk	

[1]Based on Zarr (1999).
Other parameters were not transformed.

Root Mean Square Error (RMSE)

RMSE was calculated with the same replicate data as were used for signal-to-noise calculations. Data were not transformed, however, so that we could interpret results in the units of measurement. RMSE is simply the square root of the pooled within-site variance. The error includes *overall* uncertainty in effects of differences between visits based on changes in field crews, laboratory crews, season, and site layout.

Results

Precision results are presented as:

- Raw replicate data in Tables C-3 through C-27
- Regional range data in Tables C-28 through C-37
- Signal-to-noise data in Tables C-38 and C-39
- Root Mean Square Error (RMSE) in Tables C-40 and C-41

All dates in the tables are for 2009 unless indicated otherwise.

Replicate Data

Biology

Table C-3 presents replicate results for EPT Percent.

Table C-3. Replicate results for the metric EPT Percent.

Site	Initial Date	Initial Results (%)	Duplicate Date	Duplicate Results (%)
WAM06600-000211	July 9	25.1	Aug. 11	10.7
WAM06600-000391	July 14	51.7	Aug. 12	9.1
WAM06600-000672	Aug. 4	78.5	Sept. 23	90.1
WAM06600-000831	July 8	52.0	Sept. 16	70.3
WAM06600-001251	July 29	14.8	Sept. 23	30.5
WAM06600-001702	Aug. 18	23.6	Sept. 10	30.7

Water Quality

Tables C-4 through C-12 present replicate results for water quality metrics.

Table C-4. Replicate results for the metric **X TempC**.

Site	Initial Date	Initial Results (°C)	Duplicate Date	Duplicate Results (°C)
WAM06600-000211	July 9	11.00	Aug. 11	11.05
WAM06600-000391	July 14	14.65	Aug. 12	15.55
WAM06600-000672	Aug. 4	14.25	Sept. 23	missing
WAM06600-000831	July 8	11.95	Sept. 16	12.05
WAM06600-001251	July 29	15.85	Sept. 23	12.40
WAM06600-001702	Aug. 18	17.40	Sept. 10	16.40

Table C-5. Replicate results for the metric **TPN**.

Site	Initial Date	Initial Results (mg/L)	Duplicate Date	Duplicate Results (mg/L)
WAM06600-000211	July 9	0.09	Aug. 11	0.09
WAM06600-000391	July 14	0.353	Aug. 12	0.48
WAM06600-000672	Aug. 4	0.116	Sept. 23	0.069
WAM06600-000831	July 8	0.077	Sept. 16	0.154
WAM06600-001251	July 29	0.12	Sept. 23	0.099
WAM06600-001702	Aug. 18	0.148	Sept. 10	0.127

Table C-6. Replicate results for the metric **Tot-P**.

Site	Initial Date	Initial Results (mg/L)	Duplicate Date	Duplicate Results (mg/L)
WAM06600-000211	July 9	0.137	Aug. 11	0.0572
WAM06600-000391	July 14	0.0169	Aug. 12	0.0311
WAM06600-000672	Aug. 4	0.005	Sept. 23	0.0056
WAM06600-000831	July 8	0.0158	Sept. 16	0.0215
WAM06600-001251	July 29	0.0099	Sept. 23	0.0086
WAM06600-001702	Aug. 18	0.0124	Sept. 10	0.0187

Table C-7. Replicate results for the metric **TSS**.

Site	Initial Date	Initial Results (mg/L)	Duplicate Date	Duplicate Results (mg/L)
WAM06600-000211	July 9	36	Aug. 11	6
WAM06600-000391	July 14	1	Aug. 12	5
WAM06600-000672	Aug. 4	1	Sept. 23	1
WAM06600-000831	July 8	3	Sept. 16	1
WAM06600-001251	July 29	1	Sept. 23	1
WAM06600-001702	Aug. 18	1	Sept. 10	1

Table C-8. Replicate results for the metric **Turb**.

Site	Initial Date	Initial Results (NTU)	Duplicate Date	Duplicate Results (NTU)	Qualifiers (MEL 2008)
WAM06600-000211	July 9	14	Aug. 11	2.8	Visit 1 (J)
WAM06600-000391	July 14	4.7	Aug. 12	13	
WAM06600-000672	Aug. 4	1.5	Sept. 23	0.173	Visit 1 (J); Visit 2 (UJ)
WAM06600-000831	July 8	0.7	Sept. 16	0.7	
WAM06600-001251	July 29	0.325	Sept. 23	1.3	Visit 1(UJ)
WAM06600-001702	Aug. 18	0.6	Sept. 10	0.6	Visit 1(J)

Table C-9. Replicate results for the metric **Cl**.

Site	Initial Date	Initial Results (mg/L)	Duplicate Date	Duplicate Results (mg/L)
WAM06600-000211	July 9	1.84	Aug. 11	1.91
WAM06600-000391	July 14	6.22	Aug. 12	5.48
WAM06600-000672	Aug. 4	0.54	Sept. 23	0.51
WAM06600-000831	July 8	2.37	Sept. 16	3.16
WAM06600-001251	July 29	1.24	Sept. 23	1.31
WAM06600-001702	Aug. 18	10.8	Sept. 10	9.67

Table C-10. Replicate results for the metric **X O2Sat**.

Site	Initial Date	Initial Results (%)	Duplicate Date	Duplicate Results (%)
WAM06600-000211	July 9	94.95	Aug. 11	86.6
WAM06600-000391	July 14	99.4	Aug. 12	97.3
WAM06600-000672	Aug. 4	89.15	Sept. 23	85.7
WAM06600-000831	July 8	98.75	Sept. 16	97.55
WAM06600-001251	July 29	71.55	Sept. 23	77.8
WAM06600-001702	Aug. 18	90.8	Sept. 10	105.8

Table C-11. Replicate results for the metric **X pH**.

Site	Initial Date	Initial Results (pH units)	Duplicate Date	Duplicate Results (pH units)
WAM06600-000211	July 9	4.87	Aug. 11	7.245
WAM06600-000391	July 14	7.355	Aug. 12	8.26
WAM06600-000672	Aug. 4	6.58	Sept. 23	6.99
WAM06600-000831	July 8	6.48	Sept. 16	8.06
WAM06600-001251	July 29	7.325	Sept. 23	7.13
WAM06600-001702	Aug. 18	7.615	Sept. 10	7.735

Table C-12. Replicate results for the metric **X Cond**.

Site	Initial Date	Initial Results (uS/cm at 25°C)	Duplicate Date	Duplicate Results (uS/cm at 25°C)
WAM06600-000211	July 9	88.55	Aug. 11	88.7
WAM06600-000391	July 14	647.85	Aug. 12	536.5
WAM06600-000672	Aug. 4	34.1	Sept. 23	missing
WAM06600-000831	July 8	159.55	Sept. 16	162.25
WAM06600-001251	July 29	28.1	Sept. 23	28.75
WAM06600-001702	Aug. 18	117.7	Sept. 10	112.05

Physical Habitat

Tables C-13 through C-27 present replicate results for physical habitat metrics.

Table C-13. Replicate results for the metric **X WetWidth**.

Site	Initial Date	Initial Results (m)	Duplicate Date	Duplicate Results (m)
WAM06600-000211	July 9	4.39	Aug. 11	3.96
WAM06600-000391	July 14	4.24	Aug. 12	4.30
WAM06600-000672	Aug. 4	4.14	Sept. 23	4.62
WAM06600-000831	July 8	4.54	Sept. 16	4.59
WAM06600-001251	July 29	2.28	Sept. 23	1.61
WAM06600-001702	Aug. 18	16.08	Sept. 10	15.15

Table C-14. Replicate results for the metric **X BFWidth**.

Site	Initial Date	Initial Results (m)	Duplicate Date	Duplicate Results (m)
WAM06600-000211	July 9	4.95	Aug. 11	6.64
WAM06600-000391	July 14	7.41	Aug. 12	7.95
WAM06600-000672	Aug. 4	8.59	Sept. 23	9.98
WAM06600-000831	July 8	7.41	Sept. 16	8.10
WAM06600-001251	July 29	4.82	Sept. 23	3.64
WAM06600-001702	Aug. 18	20.21	Sept. 10	20.21

Table C-15. Replicate results for the metric **PCT Pool**.

Site	Initial Date	Initial Results (%)	Duplicate Date	Duplicate Results (%)
WAM06600-000211	July 9	9	Aug. 11	13
WAM06600-000391	July 14	70	Aug. 12	51
WAM06600-000672	Aug. 4	27	Sept. 23	24
WAM06600-000831	July 8	16	Sept. 16	52
WAM06600-001251	July 29	43	Sept. 23	15
WAM06600-001702	Aug. 18	31	Sept. 10	36

Table C-16. Replicate results for the metric **X PoolUnitDepth**.

Site	Initial Date	Initial Results (cm)	Duplicate Date	Duplicate Results (cm)
WAM06600-000211	July 9	45	Aug. 11	42
WAM06600-000391	July 14	41	Aug. 12	31
WAM06600-000672	Aug. 4	46	Sept. 23	41
WAM06600-000831	July 8	50	Sept. 16	32
WAM06600-001251	July 29	19	Sept. 23	29
WAM06600-001702	Aug. 18	81	Sept. 10	59

Table C-17. Replicate results for the metric **SD TWDepth**.

Site	Initial Date	Initial Results (cm)	Duplicate Date	Duplicate Results (cm)
WAM06600-000211	July 9	11.4	Aug. 11	10.7
WAM06600-000391	July 14	15.5	Aug. 12	15.2
WAM06600-000672	Aug. 4	15.7	Sept. 23	17.3
WAM06600-000831	July 8	13.7	Sept. 16	12.5
WAM06600-001251	July 29	5.4	Sept. 23	7.7
WAM06600-001702	Aug. 18	23.4	Sept. 10	25
WAM06600-000041	July 24, 2010	48.1	Sept. 16, 2010	51.7
WAM06600-000194	July 25, 2010	36	Sept. 9, 2010	39.6

Table C-18. Replicate results for the metric **X TWDepth**.

Site	Initial Date	Initial Results (cm)	Duplicate Date	Duplicate Results (cm)
WAM06600-000211	July 9	13.6	Aug. 11	12.0
WAM06600-000391	July 14	20.7	Aug. 12	20.9
WAM06600-000672	Aug. 4	27.3	Sept. 23	22.8
WAM06600-000831	July 8	22.3	Sept. 16	24.2
WAM06600-001251	July 29	25.5	Sept. 23	28.0
WAM06600-001702	Aug. 18	37.7	Sept. 10	39.5
WAM06600-000041	July 24, 2010	104.2	Sept. 16, 2010	95.5
WAM06600-000194	July 25, 2010	72.6	Sept. 9, 2010	74.6

Table C-19. Replicate results for the metric **LWD Pieces100m**.

Site	Initial Date	Initial Results (pieces/100m)	Duplicate Date	Duplicate Results (pieces/100m)
WAM06600-000211	July 9	6.0	Aug. 11	2.7
WAM06600-000391	July 14	18.0	Aug. 12	61.3
WAM06600-000672	Aug. 4	51.5	Sept. 23	33.8
WAM06600-000831	July 8	30.7	Sept. 16	36.9
WAM06600-001251	July 29	58.0	Sept. 23	45.3
WAM06600-001702	Aug. 18	7.1	Sept. 10	4.5
WAM06600-000194	July 25, 2010	6.6	Sept. 9, 2010	3.8
SEN06600-HAMM03	Aug. 17, 2009	19.2	Aug. 3, 2010	13.4

Table C-20. Replicate results for the metric **PFC LWD**.

Site	Initial Date	Initial Results (%)	Duplicate Date	Duplicate Results (%)
WAM06600-000211	July 9	18.2	Aug. 11	18.2
WAM06600-000391	July 14	63.6	Aug. 12	81.8
WAM06600-000672	Aug. 4	45.5	Sept. 23	27.3
WAM06600-000831	July 8	54.5	Sept. 16	45.5
WAM06600-001251	July 29	81.8	Sept. 23	54.5
WAM06600-001702	Aug. 18	18.2	Sept. 10	36.4
WAM06600-000041	July 24, 2010	9.1	Sept. 16, 2010	0
WAM06600-000194	July 25, 2010	36.4	Sept. 9, 2010	9.1

Table C-21. Replicate results for the metric **XFC LWD**.

Site	Initial Date	Initial Results (%)	Duplicate Date	Duplicate Results (%)
WAM06600-000211	July 9	2.7	Aug. 11	0.9
WAM06600-000391	July 14	8.6	Aug. 12	5
WAM06600-000672	Aug. 4	5.9	Sept. 23	3.2
WAM06600-000831	July 8	8.2	Sept. 16	2.3
WAM06600-001251	July 29	7.7	Sept. 23	4.5
WAM06600-001702	Aug. 18	0.9	Sept. 10	1.8
WAM06600-000041	July 24, 2010	0.5	Sept. 16, 2010	0
WAM06600-000194	July 25, 2010	3.6	Sept. 9, 2010	0.5

Table C-22. Replicate results for the metric **PCT Fines**.

Site	Initial Date	Initial Results (%)	Duplicate Date	Duplicate Results (%)
WAM06600-000211	July 9	32.9	Aug. 11	34.6
WAM06600-000391	July 14	26.5	Aug. 12	21.7
WAM06600-000672	Aug. 4	2.6	Sept. 23	2.6
WAM06600-000831	July 8	0.9	Sept. 16	0
WAM06600-001251	July 29	1.3	Sept. 23	0.9
WAM06600-001702	Aug. 18	5.2	Sept. 10	7.8
WAM06600-000194	July 25, 2010	18.6	Sept. 9, 2010	6.5
SEN06600-HAMM03	Aug. 17, 2009	7.3	Aug. 3, 2010	5.2

Table C-23. Replicate results for the metric **PCT SandFines**.

Site	Initial Date	Initial Results (%)	Duplicate Date	Duplicate Results (%)
WAM06600-000211	July 9	36.4	Aug. 11	49.8
WAM06600-000391	July 14	27.8	Aug. 12	44.3
WAM06600-000672	Aug. 4	6.1	Sept. 23	7.4
WAM06600-000831	July 8	6.1	Sept. 16	15.6
WAM06600-001251	July 29	10	Sept. 23	4.3
WAM06600-001702	Aug. 18	27.3	Sept. 10	21.9
WAM06600-000041	July 24, 2010	32.4	Sept. 16, 2010	29.6
WAM06600-000194	July 25, 2010	22.1	Sept. 9, 2010	14.7

Table C-24. Replicate results for the metric **X Embed**.

Site	Initial Date	Initial Results (%)	Duplicate Date	Duplicate Results (%)
WAM06600-000211	July 9	65.5	Aug. 11	74.1
WAM06600-000391	July 14	47.3	Aug. 12	64.3
WAM06600-000672	Aug. 4	37.5	Sept. 23	16.1
WAM06600-000831	July 8	29.4	Sept. 16	28.9
WAM06600-001251	July 29	29	Sept. 23	42.9
WAM06600-001702	Aug. 18	52.9	Sept. 10	29.9
WAM06600-000041	July 24, 2010	52.6	Sept. 16, 2010	38
WAM06600-000194	July 25, 2010	28.7	Sept. 9, 2010	20.7

Table C-25. Replicate results for the metric **X Instability**.

Site	Initial Date	Initial Results (%)	Duplicate Date	Duplicate Results (%)
WAM06600-000211	July 9	0.0	Aug. 11	30.0
WAM06600-000391	July 14	39.1	Aug. 12	1.8
WAM06600-000672	Aug. 4	22.7	Sept. 23	31.8
WAM06600-000831	July 8	14.1	Sept. 16	5.5
WAM06600-001251	July 29	13.0	Sept. 23	20.5
WAM06600-001702	Aug. 18	16.8	Sept. 10	32.4
WAM06600-000041	July 24, 2010	70.8	Sept. 16, 2010	1.4
WAM06600-000194	July 25, 2010	0.0	Sept. 9, 2010	7.6

Table C-26. Replicate results for the metric **PFC Undercut**.

Site	Initial Date	Initial Results (%)	Duplicate Date	Duplicate Results (%)
WAM06600-000211	July 9	0	Aug. 11	27.3
WAM06600-000391	July 14	100	Aug. 12	54.5
WAM06600-000672	Aug. 4	27.3	Sept. 23	81.8
WAM06600-000831	July 8	54.5	Sept. 16	27.3
WAM06600-001251	July 29	100	Sept. 23	18.2
WAM06600-001702	Aug. 18	18.2	Sept. 10	54.5
WAM06600-000194	July 25, 2010	0	Sept. 9, 2010	27.3
SEN06600-HAMM03	Aug. 17, 2009	36.4	Aug. 3, 2010	75.0

Table C-27. Replicate results for the metric **X ShadeBnk**.

Site	Initial Date	Initial Results (%)	Duplicate Date	Duplicate Results (%)
WAM06600-000211	July 9	76.2	Aug. 11	84.5
WAM06600-000391	July 14	98.4	Aug. 12	90.6
WAM06600-000672	Aug. 4	95.2	Sept. 23	87.7
WAM06600-000831	July 8	78.3	Sept. 16	96
WAM06600-001251	July 29	92.2	Sept. 23	96.8
WAM06600-001702	Aug. 18	85.6	Sept. 10	93.3
WAM06600-000041	July 24, 2010	35.8	Sept. 16, 2010	21.4
WAM06600-000194	July 25, 2010	58.8	Sept. 9, 2010	59.4

Regional Range

Range is the difference between minimum and maximum values for the first visit to random sampled sites in the Puget Sound STR.

Biology

Table C-28 lists the ranges of scores for **EPT Percent** by stream class.

Table C-28. Minimum, maximum, and range of **EPT Percent** scores by stream class.

Stream Order	EPT Percent Minimum (%)	EPT Percent Maximum (%)	EPT Percent Range (%)
0	1.2	66.0	64.8
1	0.8	79.5	78.7
2	2.6	94.1	91.5
3	13.9	38.5	24.6
4+	0.7	84.8	84.0
Overall	0.7	94.1	93.4

Water Quality

Table C-29 lists the ranges of scores for select water sample metrics. In addition to the tabular data, the range for TSS scores was 33 mg/L across the region, with 46% of the scores measuring 1 mg/L. The range for Turbidity was 14 NTU, with 33 values below 2 NTU and 13 values between 2 and 4.7 NTU.

Table C-29. Minima, maxima, and ranges of water sample metric values.

Stream Order	TPN Minimum (mg/L)	TPN Maximum (mg/L)	TPN Range (mg/L)
0	0.12	0.451	0.331
1	0.09	0.951	0.861
2	0.077	2.52	2.443
3	0.03	0.912	0.882
4+	0.071	0.807	0.736
Overall	0.03	2.52	2.49
Stream Order	**Tot-P Minimum (mg/L)**	**Tot-P Maximum (mg/L)**	**Tot-P Range (mg/L)**
0	0.0074	0.0829	0.0755
1	0.006	0.137	0.131
2	0.005	0.0527	0.0477
3	0.006	0.0216	0.0156
4+	0.005	0.0386	0.0336
Overall	0.005	0.137	0.132
Stream Order	**Cl Minimum (mg/L)**	**Cl Maximum (mg/L)**	**Cl Range (mg/L)**
0	0.53	16.6	16.07
1	1.23	7.55	6.32
2	0.52	14.3	13.78
3	0.84	12.3	11.46
4+	0.77	3.37	2.6
Overall	0.52	16.6	16.08

Table C-30 lists the ranges of scores for *in situ* metric data.

Table C-30. Minima, maxima, and ranges of values from *in situ* data, by stream class.

Stream Order	X TempC Minimum (°C)	X TempC Maximum (°C)	X TempC Range (°C)
0	9.66	17	7.34
1	11	14.65	3.65
2	7.55	18.5	10.95
3	13.2	23.95	10.75
4+	9.2	20.3	11.1
Overall	7.55	23.95	16.4
Stream Order	**X O2Sat Minimum (%)**	**X O2Sat Maximum (%)**	**X O2Sat Range (%)**
0	50.85	94.55	43.7
1	72.65	99.85	27.2
2	77.8	105.3	27.5
3	85.15	97.45	12.3
4+	65.3	110.15	44.85
Overall	50.85	110.15	59.3
Stream Order	**X Cond Minimum (uS/cm @ 25 °C)**	**X Cond Maximum (uS/cm @ 25 °C)**	**X Cond Range (uS/cm @ 25 °C)**
0	28	278	250
1	35	648	613
2	31	644	613
3	63	139	76
4+	46	106	60
Overall	28	648	620
Stream Order	**X pH Minimum**	**X pH Maximum**	**X pH Range**
0	6.13	7.975	1.845
1	4.87	7.925	3.055
2	6.48	7.86	1.38
3	6.765	7.71	0.945
4+	6.605	8.295	1.690
Overall	4.87	8.295	3.425

Physical Habitat

Table C-31 lists the ranges of values for width metrics.

Table C-31. Minima, maxima, and ranges of width metric values, by stream class.

Stream Order	**X WetWidth Minimum (m)**	**X WetWidth Maximum (m)**	**X WetWidth Range (m)**
0	1	4.3	3.3
1	1.4	6.2	4.9
2	1.5	9.6	8
3	6.6	49.1	42.5
4+	18.6	121.7	103.1
Overall	1	121.7	120.6
Stream Order	**X BFWidth Minimum (m)**	**X BFWidth Maximum (m)**	**X BFWidth Range (m)**
0	1.9	6.4	4.5
1	2.7	10.2	7.5
2	2.2	23	20.7
3	11.7	116.4	104.7
4+	19.7	147.8	128.1
Overall	1.9	147.8	145.9

Table C-32 lists the ranges of values for thalweg depth metric data values.

Table C-32. Minima, maxima, and ranges of thalweg depth metrics, by stream class.

Stream Order	X TWDepth Minimum (cm)	X TWDepth Maximum (cm)	X TWDepth Range (cm)
0	3.5	16.1	12.6
1	7.7	73.3	65.6
2	11.2	35.4	24.2
3	37.7	85.1	47.4
4+	46.6	257.5	210.9
Overall	3.5	257.5	254
Stream Order	**SD TWDepth Minimum (cm)**	**SD TWDepth Maximum (cm)**	**SD TWDepth Range (cm)**
0	3.3	11	7.7
1	2.7	31	28.3
2	8.4	18.2	9.8
3	23.4	47.6	24.2
4+	19	87.5	68.5
Overall	2.7	87.5	84.8

Table C-33 lists the ranges of values for pool metrics.

Table C-33. Minima maxima, and ranges of pool metrics, by stream class.

Stream Order	**X PoolUnitDepth Minimum (cm)**	**X PoolUnitDepth Maximum (cm)**	**X PoolUnitDepth Range (cm)**
0	10	34	24
1	0	142	142
2	22	62	40
3	59	122	63
4+	35	323	288
Overall	0	323	323
Stream Order	**PCT Pool Minimum (%)**	**PCT Pool Maximum (%)**	**PCT Pool Range (%)**
0	11	64	53
1	0	80	80
2	16	100	84
3	30	89	59
4+	4	83	79
Overall	0	100	100

Table C-34 lists the ranges of values for large woody debris metrics.

Table C-34. Minima, maxima, and ranges of large woody debris metrics, by stream class

Stream Order	XFC LWD Minimum (%)	XFC LWD Maximum (%)	XFC LWD Range (%)
0	3.6	22.7	19.1
1	0	31.4	31.4
2	0	37	37
3	0.9	5.2	4.3
4+	0.5	8	7.5
Overall	0	37	37
Stream Order	**PFC LWD Minimum (%)**	**PFC LWD Maximum (%)**	**PFC LWD Range (%)**
0	36.4	81.8	45.4
1	0	100	100
2	0	100	100
3	9.1	63.6	54.5
4+	9.1	81.8	72.7
Overall	0	100	100
Stream Order	**LWD Pieces100m Minimum (pieces/100m)**	**LWD Pieces100m Maximum (pieces/100m)**	**LWD Pieces100m Range (pieces/100m)**
0	10	102.7	92.7
1	4	95.3	91.3
2	16	95.6	79.6
3	4.7	32.5	27.8
4+	0.9	18.9	18
Overall	10	102.7	92.7

Table C-35 lists the ranges of values for substrate composition metrics.

Table C-35. Minima, maxima, and ranges of substrate composition metrics, by stream class.

Stream Order	PCT Fines Minimum (%)	PCT Fines Maximum (%)	PCT Fines Range (%)
0	1.3	64.8	63.5
1	6.9	84.5	77.6
2	0	34.5	34.5
3	0.4	22	21.6
4+	0	59.1	59.1
Overall	0	84.5	84.5
Stream Order	**PCT SandFines Minimum (%)**	**PCT SandFines Maximum (%)**	**PCT SandFines Range (%)**
0	6.1	75.2	69.1
1	16	95	79
2	5.2	68.9	63.7
3	9.3	46.3	37
4+	6.1	91.3	85.2
Overall	5.2	95	89.8
Stream Order	**X Embed Minimum (%)**	**X Embed Maximum (%)**	**X Embed Range (%)**
0	19	79.5	60.5
1	24.2	97.5	73.3
2	17.5	97.8	80.3
3	13.5	67.2	53.7
4+	29.1	95.5	66.4
Overall	13.5	97.8	84.3

Table C-36 lists the ranges of values for the bank quality metrics: **X Instability** and **PFC Undercut**.

Table C-36. Minima, maxima, and ranges of values for bank quality metrics, by stream class.

Stream Order	X Instability Minimum (%)	X Instability Maximum (%)	X Instability Range (%)
0	0.7	54.8	54.1
1	0	50.0	50.0
2	3.6	46.1	42.5
3	2.3	43.2	40.9
4+	0.9	59.0	58.1
Overall	0	59.0	59.0
Stream Order	**PFC Undercut Minimum (%)**	**PFC Undercut Maximum (%)**	**PFC Undercut Range (%)**
0	0	100	100
1	0	100	100
2	0	100	100
3	0	45.5	45.5
4+	0	54.5	54.5
Overall	0	100	100

Table C-37 lists the ranges of values for the metric **X ShadeBnk**.

Table C-37. Minima, maxima, and ranges of **X ShadeBnk** values, by stream class.

Stream Order	X ShadeBnk Minimum (%)	X ShadeBnk Maximum (%)	X ShadeBnk Range (%)
0	86.6	99.2	12.6
1	76.2	100	23.8
2	49.5	98.9	49.4
3	50.8	98.9	48.1
4+	35.3	99.5	64.2
Overall	35.3	100	64.7

Signal-to-Noise

Signal-to-noise is the ratio of variance between sites and the pooled variances of repeatedly visited sites. Stoddard et al. (2006) rejected biological metrics with signal-to-noise < 1 for sites in ecoregions that overlap the Puget Sound STR. Kaufman et al. (1999) and Crawford and Rumsey (2011) consider signal-to-noise values of 2-10 as moderate to high precision. We have rated signal-to-noise scores as follows:

- A (>10)
- B (5-10)
- C (2-5)
- D (1-2)
- F (< 1)

Biology

Signal-to-noise for the metric *EPT Percent* was 2.5 (rated C), based on results for 48 sites (signal) and 6 replicates (noise).

Water Quality

Water quality signal-to-noise scores are listed in Table C-38.

Table C-38. Temperature and water quality metrics signal-to-noise.

Metric	Signal-to-Noise	Score
X TempC	6.8	B
X pH	0.40	F
X O2Sat	6.4	B
X Cond	14.9	A
TSS	1.7	D
Turbidity	0.004	F
TPN	35.7	A
Total P	1.1	D
Chloride	71.5	A

Physical Habitat

Physical habitat signal-to-noise scores are listed in Table C-39.

Table C-39. Physical habitat metrics signal-to-noise.

Metric	Signal-to-Noise[1]	Signal-to-Noise (rivers)	Score
X WetWidth	3313.0		A
X BFWidth	1628.7		A
X TWDepth	158.5	186.8	A,A
SD TWDepth	158.2	86.4	A,A
XFC LWD	6.5	1.1	B,D
PFC LWD	8.3	1.1	B.D
LWD Pieces100m	3.8	1.0	C,D
PFC Undercut	1.2	0.9	D,F
X ShadeBnk	2.1	13.4	D,A
X Instability	0.8	0.3	F,F
PCT Fines	44.3	8.6	A,B
PCT SandFines	9.0	49.7	B,A
X Embed	3.7	11.5	C,A
X PoolUnitDepth	39.5		A
PCT Pool	3.5		C

[1] When accompanied by results for rivers, this represents results for wadeable streams. Otherwise results reflect all sampled streams.

Root Mean Square Error (RMSE)

RMSE is the pooled standard deviation of repeated sampling, expressed in the units of measurement. Sometimes, to compare metrics with different units, the RMSE is converted to a coefficient of variation (CV). This can be misleading, however, because equal errors can report much different CV's for the same metric, depending upon the mean (Kaufmann, 1999, see page 58). Therefore, we do not report the CV here. Interpretation of RMSE must be examined on an individual metric basis. Smaller RMSE indicates less noise, for a given metric.

Biology

RMSE for *EPT Percent* was 15%.

Water Quality

Table C-40 presents RMSE results for water quality metrics.

Table C-40. RMSE for water quality metrics.

Metric	RMSE
X TempC	1.2 ℃
X pH	0.94 units
X O2Sat	5.8%
X Cond	35.3 uS/cm
TSS	8.8. mg/L
Turbidity	4.1 NTU
TPN	0.046 mg/L
Total P	0.024 mg/L
Chloride	0.45 mg/L

Physical Habitat

Table C-41 presents RMSE results for physical habitat metrics.

Table C-41. RMSE for physical habitat metrics.

Metric	RMSE[1]	RMSE (rivers)
X WetWidth	0.38 m	
X BFWidth	0.76 m	
X TWDepth	1.7 cm	4.5 cm
SD TWDepth	1.0 cm	2.6 cm
XFC LWD	2.4%	1.6%
PFC LWD	12.3%	14.4%
LWD Pieces100m	14.2 pcs/100m	6.8 pcs/100m
PFC Undercut	34.8%	23.6%
X ShadeBnk	7.0%	7.2%
X Instability	15.1%	34.9%
PCT Fines	1.7%	6.1%
PCT SandFines	7.1%	4.0%
X Embed	11.3%	8.3%
X PoolUnitDepth	9.4 cm	
PCT Pool	14.4%	

[1] When accompanied by results for rivers, this represents results for wadeable streams. Otherwise results reflect all sampled streams.

Discussion and Conclusions

We seek to evaluate metrics for development of multi-metric indices, in ways that others have done (Stoddard et al. 2006; Whittier et al. 2007b; Al-Chokhachy et al. 2010). This includes using the measures of dispersion, such as range, signal-to-noise, and Root Mean Square Error (RMSE), as described by Kaufmann et al. (1999).

For 2009 data, signal-to-noise calculations for streams sampled with the wide streams and rivers protocol (Merritt et al. 2010) are limited to just a few points, and these replicates extend outside the region and sample year. Therefore, this might not be a representative measure of precision.

At this time, our precision evaluations are limited to less than 20% of the ultimate metric list for the STREAM database. This evaluation step is critical for developing multi-metric indices that allow us to assess HLIs. Our evaluation of existing metrics can help us to get started on the process. The simplest metrics (as opposed to the most valuable) were the first to be coded in the database. Therefore, some high-value metrics are not part of this report. They will be available for public download and evaluation soon.

Biological Health

Macroinvertebrates

Below we discuss precision for EPT Percent, preceded by an explanation of why we did *not* report two other macroinvertebrate community methods.

Our macroinvertebrate sampling, as guided by the Monitoring Forum (RCO 2010), is intended to provide collection procedures for analysis of benthic data with either of these methods (Hayslip 2007):

- multi-metric models (e.g., see Wiseman 2003; Stoddard et al. 2006)
- predictive models (e.g., see Plotnikoff and Wiseman 2001; USU 2012)

Multi-metric Indices

Ecology has developed multi-metric indices (MMI) for streams in 2 of the Ecoregions that overlap the Puget Sound STR: Cascades and Puget Lowland (Wiseman 2003). However, these were developed prior to the use of taxonomic standards that are now in place for Washington State (Adams 2010). These new taxonomic standards call for identification of midges beyond the family level. There are also recently updated taxa attributes for the Northwest (PSSB 2012). We have not yet developed indices for the other 2 ecoregions of the STR: North Cascades and Coast Range. We are not ready to report multi-metric indices for the Puget Sound STR.

O/E Scores

We cannot use existing predictive models (i.e., observed-to-expected or O/E), for example that of Plotnikoff and Wiseman (2001), because some of our samples were collected in field conditions that are beyond the range upon which this model was built. Slope is the most common factor for the model not fitting. Some sites occur at higher slope and some occur at lower slope than what the model describes. We are not ready to report O/E scores for the Puget Sound STR until we build another model.

EPT Percent

In the interim, we have examined one simple metric (EPT Percent) to help describe overall biological health. This metric has a broad range of scores across the region (Figure 4 and Table C-28) suggesting that it is an acceptable metric. The signal-to-noise (2.5) far exceeds the inclusion threshold of 1.0 that EPA used for EMAP benthic metrics in this region (Stoddard et al. 2006). The RMSE for this metric (15%) is not large relative to the overall range of metric values (93.4%).

EPT Percent is a “composition measure” (Barbour et al. 1999) that is based on the abundance of individuals in key taxa relative to the rest of the sample. Key taxa are those that are of special interest or ecologically important. In this case they are stoneflies, mayflies, and caddis flies. Loss in representation by these taxa have been related to effects of urbanization (Coles et al. 2004) and to human disturbances in the Northwest (Herlihy and Whittier 2010; Lanigan et al. 2012).

Water Quality

Samples

Two water sample parameters passed our tests of precision (TPN and Cl), and 3 others were deemed as impractical for our monitoring design (single, summer sample) within the Puget Sound STR. Nitrogen and chloride are each known to be related to urbanization and to biological integrity (Morgan et al. 2007).

Nitrogen

Total persulfate nitrogen (TPN) could be a useful metric for monitoring in the Puget Sound STR. For the nutrients, its range of values is relatively broad (2.49 mg/L; Table C-29) relative to an extremely small RMSE (0.046 mg/L; Table C-40). We rate its signal-to-noise (35.7) as an A (Table C-38).

Chloride

Chloride concentration (Cl) could be a useful metric for monitoring in the Puget Sound STR. It has a somewhat broad range of values (16.08 mg/L; Table C-29) relative to a small RMSE (0.45 mg/L; Table C-40). We rate its signal-to-noise (71.5) as an A (Table C-38).

Phosphorus

Total phosphorus (Tot-P) range of values (0.132 mg/L) is too narrow for this metric to be useful in the Puget Sound STR (Table C-29). The RMSE (0.024) is even smaller than that calculated for nitrogen measurements (Table C-40), but there is relatively little signal provided by the values recorded among sites of the region. Signal-to-noise for Tot-P is 1.1 (Table C-38).

Suspended Solids

Total suspended solids (TSS) range of values (33 mg/L) is too narrow for this metric to be useful in the Puget Sound STR, especially since almost half the values are below 1 mg/L. Its RMSE (8.8 mg/L; Table C-40) is low, but there was not much signal provided by the values recorded among sites of the region. Almost half of the measurements had matching values (1 mg/L). Signal-to-noise for TSS is 1.7 (Table C-38).

Turbidity

The turbidity (Turb) range of values (14 NTU) is too narrow for this metric to be useful. There is also a predominance of low values. Thirty-three of the values are below 2 NTU. The RMSE is 4.1 NTU (Table C-40). Signal-to-noise for Turb (0.004) is extremely low (Table C-38).

Field Measurements

Mean temperature (X TempC), mean oxygen saturation (X O2Sat), and mean conductivity (X Cond) are all likely useful metrics for the region, based on precision analyses. The noise of diel variations has been reduced by using mean within-date values for these metrics. Mean pH (X pH) is a seemingly impractical metric for our monitoring design in the Puget Sound STR, due to the reasons discussed below.

Temperature

The mean site-visit temperature (X TempC) metric seems to be a good choice for monitoring in the Puget Sound STR. It has a fairly broad range of values (16.4 °C; Table C-30) relative to the RMSE (1.2 °C; Table C-40). The signal-to-noise (6.8) is rated as a B (Table C-38). In recent years, temperature has been one of the most widely considered factors for assessment of watershed health (e.g., RMRS 2012). It is highly related to biology (e.g., Brandt 2001; Huff et al. 2005; McCullough et al. 2009; Stamp et al. 2010).

Oxygen

The mean oxygen percent-saturation (X O2Sat) metric seems to be a good choice for monitoring in the Puget Sound STR. It has a fairly broad range of values (59.3%; Table C-30) relative to the RMSE (5.8%; Table C-40). The signal-to-noise (6.4) is rated as a B (Table C-38).

Conductivity

The mean specific conductivity (X Cond) metric seems to be a good choice for monitoring in the Puget Sound STR. It has a fairly broad range of values (620 uS/cm at 25 °C; Table C-30) relative to the RMSE (35.3 uS/cm at 25 °C; Table C-40). The signal-to-noise (14.9) is rated A (Table C-38). Conductivity, like nitrogen and chloride, is known to be related to urbanization and to biological integrity (Morgan et al. 2007).

pH

The other *in situ* metric (X pH) failed in our precision analysis. Its signal-to-noise (Table C-38) was poor (0.4). It had a small range of values in the signal (3.4 pH units; Table C-30) and a somewhat broad RMSE (0.94 pH units; Table C-40).

Physical Habitat

Complexity

These physical habitat metrics address available living space and diversity of habitat for stream inhabitants. They also help with describing hydrologic settings. All of the width and depth metrics have excellent precision and will likely work well in combination with each other to create new metrics (e.g., width:depth ratios or cross-sectional area). Two pool metrics (PCT Pools and X PoolUnitDepth) also passed our precision tests.

Wetted Width

Mean wetted width (X WetWidth) signal-to-noise (3,313; Table C-39) was excellent. The RMSE of 0.38 m (Table C-41) shows high repeatability, relative to the large range of stream widths (120.6 meters: see Table C-31).

Bankfull Width

Mean bankfull width (X BFWidth) signal-to-noise (1,628.7; Table C-39) was extremely good. The RMSE of 0.76 m (Table C-41) shows high repeatability, relative to the large range of stream widths (145.9 meters: see Table C-31).

Thalweg Depth Mean

The range of stream X TWDepth (254 cm; Table C-32) was large relative to the RMSE (Table C-41) of 1.7 cm (streams) or 4.5 cm (rivers). Signal-to-noise was rated as an A (Table C-39), whether measured in wadeable streams (158.5) or in wide streams and rivers (186.8).

Thalweg Depth Standard Deviation

The range of stream SD TWDepth (84.8 cm; Table C-32) was large relative to the RMSE (Table C-41) of 1.0 cm (streams) or 2.6 cm rivers. Signal-to-noise was rated as an A (Table C-39), whether measured in wadeable streams (158.2) or in wide streams and rivers (86.4). The SD TWDepth metric can be useful at helping to describe hydraulic storage (Kaufmann and Faustini 2011).

Percent Pools

PCT Pool is likely to be a useful metric. It was broad in range (100%: see Table C-33). However, identifying habitat units is dependent upon flow conditions. A moderate amount of measurement error was represented in RMSE of 14.4% (Table C-41). Therefore, signal-to-noise for PCT Pool is fair (3.5) which is rated as C (Table C-39).

Residual Pool Depth

Residual pool depth (X PoolUnitDepth) is possibly an excellent metric. It displayed a large range (323 cm: see Table C-33) and small RMSE of 9.4 cm (Table C-41). Its signal-to-noise was 39.5 (Table C-39), rated A.

Large Woody Debris

Large woody debris is extremely influential to stream habitat formation (Gregory et al. 2003; Bilby and Bisson 1998; Buffington and Montgomery 1999). Wood abundance has severely diminished in Puget Sound rivers since the middle of the 19th century (Collins et al. 2002).

One metric that we evaluated is based on a tally of pieces. The other 2 are based on visual estimation of fish habitat cover provided by large woody debris. Large woody debris was tallied differently depending upon protocol (Merritt 2009 or Merritt et al. 2010). The method for wadeable streams is a census of all pieces within the site, whereas the method for wide streams and rivers is based on evaluation of sub-sampled plots within the site. Fish cover metrics, including those analyzed for large wood, were also measured differently between protocols. Therefore we have evaluated large woody debris metrics separately for precision, depending upon the protocol used.

We have limited replicate data from the rivers for now. However, the occurrence of large wood is generally less frequent and patchier in larger streams and rivers (Bilby and Bisson 1998). We would therefore expect a greater amount of sampling error and smaller range of values in the larger sites.

Large Woody Debris Frequency

LWD Pieces100m is likely to be a useful metric, at least for wadeable streams sampled using Merritt (2009). It was broad in range (92.7 pieces/100 m: see Table C-34), with a moderate amount of measurement error represented in RMSE of 14.2 pieces/100m in streams and 6.8 pieces/100m in rivers (Table C-41). Signal-to-noise (Table C-39) is 3.8 (rated C) for streams and 1.0 (rated D) for rivers.

Extent of Fish Cover by Large Woody Debris

PFC LWD is likely to be a useful metric, at least for wadeable streams. It was broad in range (100%: see Table C-34), but with a moderate amount of measurement error represented in RMSE of 12.3% in streams and 14.4% in rivers (Table C-41). Signal-to-noise (Table C-39) is 8.3 (rated B) for streams and 1.1 (rated D) for rivers.

Average Fish Cover by Large Woody Debris

XFC LWD is likely to be a useful metric, at least for wadeable streams. It was moderate in range (37%: see Table C-34), with a moderate amount of measurement error represented in RMSE of 2.4% in streams and 1.6% in rivers (Table C-41). Signal-to-noise (Table C-39) is 6.5 (rated B) for streams and 1.1 (rated D) for rivers.

Substrate

Disruption of sediment dynamics in the forms of excess sedimentation or scour are frequently cited causes for declining biological assemblages (Waters 1995). The embedding of interstitial habitat harms crevice-occupying invertebrates and gravel-spawning fishes, and it reduces stream depth heterogeneity, leading to decrease in pool species (Allan 2004). We evaluated 3 metrics for substrate composition (PCT Fines, PCT SandFines, and X Embed). All of them demonstrated good signal-to-noise.

Substrate composition was measured differently depending upon protocol (Merritt 2009 or Merritt et al. 2010). The method for wadeable streams is from 231 points among 21 transects. The method for rivers is based on variable numbers of points from 11 transects; one point per transect is a visually estimated average from a littoral plot. Therefore, we have evaluated substrate metrics separately for precision, depending upon the protocol used. River precision estimates have a limited number of sites and, therefore, less confidence.

Percent Substrate as Fines

PCT Fines is likely to be a useful metric. It was broad in range (84.5%: Table C-35), with a relatively small amount of measurement error represented in RMSE of 1.7% in wadeable streams and 6.1% in rivers (Table C-41). Signal-to-noise (Table C-39) is 44.3 (rated A) for streams and 8.6 (rated B) for rivers.

Percent Substrate as Sand or Fines

PCT SandFines is likely to be a useful metric. It was broad in range (89.8%: Table C-35), with a relatively small amount of measurement error represented in RMSE of 7.1% in wadeable streams and 4.0% in rivers (Table C-41). Signal-to-noise (Table C-39) is 9.0 (rated B) for streams and 49.7 (rated A) for rivers.

Average Embeddedness of Substrate

X Embed is likely to be a useful metric. It was broad in range (84.3%: Table C-35), with a relatively small amount of within-site error represented in RMSE of 11.3% in wadeable streams and 8.3% in rivers (Table C-41). Signal-to-noise (Table C-39) is 3.7 (rated C) for streams and 11.5 (rated A) for rivers.

Bank Quality

We attempted to assess streambank quality using each of two metrics: X Instability and PFC Undercut. These are measured slightly differently depending upon protocol. Therefore, we assessed precision for these separately, by protocol. Signal-to-noise was poor for both metrics using either protocol. Bank quality is an important feature and is included in some Northwestern habitat quality indexes (e.g., Al-Chokhachy et al. 2010; McClean et al. 2009). We need to find other metrics to assess this feature for future monitoring in the Puget Sound STR.

Bank Instability

The X Instability range was moderate (59%: see Table C-36), but there was a large amount of within-site error represented in RMSE (Table C-41) of 15.1% for wadeable streams and 34.9% for wide streams and rivers. Signal-to-noise (Table C-39) was 0.8 (rated F) for streams and 0.3 (rated F) for rivers. We believe that the large measurement error for this metric is related to subjectivity in judgment required within the field method. We should explore new methods for assessing the erosion or instability of bankfull margins.

Extent of Fish Cover by Undercut Banks

PFC Undercut range is broad (100%: see Table C-36), but within-site error is large as reflected in RMSE (Table C-41). This is 34.8% for wadeable streams and 23.6% for wide streams and rivers. Signal-to-noise (Table C-39) is 1.2 (rated D) for streams and 0.9 (rated F) for rivers. The poor signal-to-noise for this metric is likely due to the fact that this metric is flow dependent. Cover from undercut banks will change based on stage.

Riparian Condition

Canopy Cover

Canopy cover at bankfull margins (X ShadeBnk) is likely to be a useful metric. It is moderate in range (64.7%: Table C-37) with a small amount of within-site error represented in RMSE of 7.0% in wadeable streams and 7.2% in rivers (Table C-41). Signal-to-noise (Table C-39) is 2.1 (rated C) for streams and 13.4 (rated A) for rivers.