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Bioassessment Monitoring and Analysis to Support Total Maximum Daily Load (TMDL) Development

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Squalicum Creek and Soos Creek

Bioassessment Monitoring and Analysis to Support Total Maximum Daily Load (TMDL) Development

by

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Water Resource Inventory Area (WRIA) and 8-digit Hydrologic Unit Code (HUC) numbers for the study area:

WRIAs
- Squalicum Creek (WRIA 1)
- Soos Creek (WRIA 9)

HUC numbers
- 17110004 (Squalicum Creek)
- 17110013 (Soos Creek)

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Abstract

Biological assessments in the Squalicum Creek and Soos Creek watersheds were conducted to evaluate the health of aquatic habitat in these watersheds and identify the principle stressors responsible for the observed conditions. Biological communities were found to be influenced by the multiple stressors of hydrology, water chemistry, and physical habitat. These same stressors are also commonly identified as the principal causes for degraded freshwater salmon habitat in the Puget Sound watershed (Ecology 2011). Hydrological modifications as a result of land-use changes such as stormwater delivery volumes or timing can affect the biological community as reflected in a Benthic Index of Biotic Integrity (B-IBI) or River InVertebrate Prediction and Classification System (RIVPACS) score.

Monitoring locations were selected to represent changes in the streams' gradients, surrounding land uses, and potential for stormwater impacts. The strategy for analyzing data was focused on identifying relationships among physical habitat, water quality, and biological metrics generated from assessment data for each reach. Stormwater stressor(s) and biological response were identified for the purpose of establishing targets for aquatic health.

Effects of stressors from stormwater flows, surrounding land use, or pollutant delivery are estimated. In both Squalicum Creek and Soos Creek watersheds, biological monitoring and stressor identification confirmed that multiple stressors related to pollutant loading, embeddedness, and stream hydrology are the principle causes of impact. Stormwater runoff was identified as a common causal agent for both pollutant delivery and hydrological changes for both of these watersheds.

Significant relationships between attributes describing condition of the benthic macroinvertebrate community and periphyton community were identified at several locations in both drainages. At the broadest scale, landscape development intensity (LDI) scores were highly correlated with the most sensitive indicators from the benthic macroinvertebrate (BMI) community: % Scrapers and Shredders, % Clingers, and % Ephemeroptera/Plecoptera/Trichoptera (EPT). Increasing LDI index scores for a stream reach at Squalicum Creek showed declines in the sensitive segment of the BMI community. Water quality conditions showed strong relationships with both BMI and periphyton community attributes; BMI Taxa Richness, % Clingers, and Total number of algal species were all strongly correlated with dissolved oxygen concentrations. Higher dissolved oxygen concentrations supported greater numbers of species represented by these pollution-sensitive metrics. Sediment toxics were measured at all sites in the Squalicum Creek drainage with several significantly related to BMI community condition; arsenic, lead, copper, PCBs, and DDT (pesticides) caused a decline in the % EPT metrics and was directly related to the % Pollution Tolerant Taxa.

The sensitive species, EPT, were not present at sites where toxics concentrations were elevated with evidence demonstrating substantial stormwater impacts like (1) highest number of storm conveyance pipes in the reach, (2) high percentage of bank instability, and (3) below major stormwater detention ponds. The pollution-tolerant taxa were highly represented where organic carbon-normalized toxics concentrations were highest.

This report supports a larger effort to explore the use of surrogates such as aquatic health biological metrics and the identified stressors to support total maximum daily load (TMDL) development for dissolved oxygen, temperature, toxics, and bioassessment listings. These indicators would provide meaningful restoration targets for improving attainment of water quality standards and instream habitat and biological integrity goals.

Biological community attributes and condition assessment agree with water quality and physical habitat impacts identified in the 303(d) listing process and those identified in this study. The biological communities reflect (1) response to multiple environmental stressors, (2) demonstrated response to select individual environmental stressors, and (3) impacts that have occurred in stream reaches over long periods.

Improvement in biological community condition as reflected by B-IBI and RIVPACS scores can be made by addressing stressors that do not meet water quality criteria (e.g., temperature and dissolved oxygen) and by improving physical habitat features through control of stormwater impacts (e.g., toxics contributions and scouring flows as reflected by bank instability). The instream habitat and water quality improvements will be reflected by response in the BMI and periphyton communities in as little as 2 years if stressor persistence related to toxics is eliminated and when substrate stabilization from catastrophic flows is reduced (Wallace 1990; Biggs et al. 2005). Community index scores (B-IBI and RIVPACS) should improve within a 5-year interval with reduction of stressors identified in this study.

In addition, the community attributes as components of the B-IBI score should be used to evaluate progress on improvements to reduction of individual stressors (e.g., % Clingers, Total Taxa Richness, Semi-voltine taxa) that will reflect sustained reduction of these stressors over time. Because biota at any point in the stream integrate conditions over time, restoration practices for water quality and physical habitat conditions must have a sustained effectiveness; otherwise, the biological community will respond negatively and require additional time to recover.

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Introduction

Project Purpose

With contractor support from Tetra Tech, the Washington State Department of Ecology (Ecology) is developing total maximum daily loads (TMDLs) for Soos and Squalicum Creeks in western Washington. Stormwater runoff is suspected to be the principle source of pollutants and hydraulic changes that affect water quality and stream habitat in these watersheds. The hydrologic change is a result of changes in surrounding land use and climate.

For this project, Tetra Tech evaluated existing bioassessment data, collected bioassessment monitoring data, calculated B-IBI and RIVPACS scores, and applied the U.S. Environmental Protection Agency (EPA) stressor identification process to identify principal reasons for the calculated scores. The primary goal is to establish if the relationship between the bioassessment data and stressors could be used as surrogates or targets in TMDLs. The TMDL process serves goals of the Clean Water Act and Endangered Species Act by prescription of improvements that would benefit salmon populations.

The technical basis for this document is described in detail in the *Final Quality Assurance Project Plan for Bioassessment Monitoring and Analysis to Support Stormwater TMDL Development* (referred to as the QAPP) and the appended technical approach document (Ecology 2012a).

This document presents summaries of historical data, sampling design, and methods for both Squalicum and Soos Creeks. The results and discussion sections are then presented separately for Squalicum and Soos Creeks to facilitate use of this information in future TMDL development.

Background and Historical Data

Squalicum Creek

Squalicum Creek drains approximately 22 square miles, originating in the Cascade Mountain foothills, east of Bellingham and north of Lake Whatcom (Figure 1). The stream flows southeast for approximately 10 miles before discharging into Bellingham Bay. Its major tributaries are Spring Creek, Baker Creek, Toad Creek, and McCormick Creek. As shown in Figure 2, the upper portion of the watershed transitions from a combination of forest, pasture, and small-scale agriculture (e.g., hobby farms) to urban development downstream. According to the 2008 Clean Water Act section 303(d) list, various reaches of Squalicum Creek are listed as impacted from temperature, fecal coliform, and dissolved oxygen (Ecology 2009a).

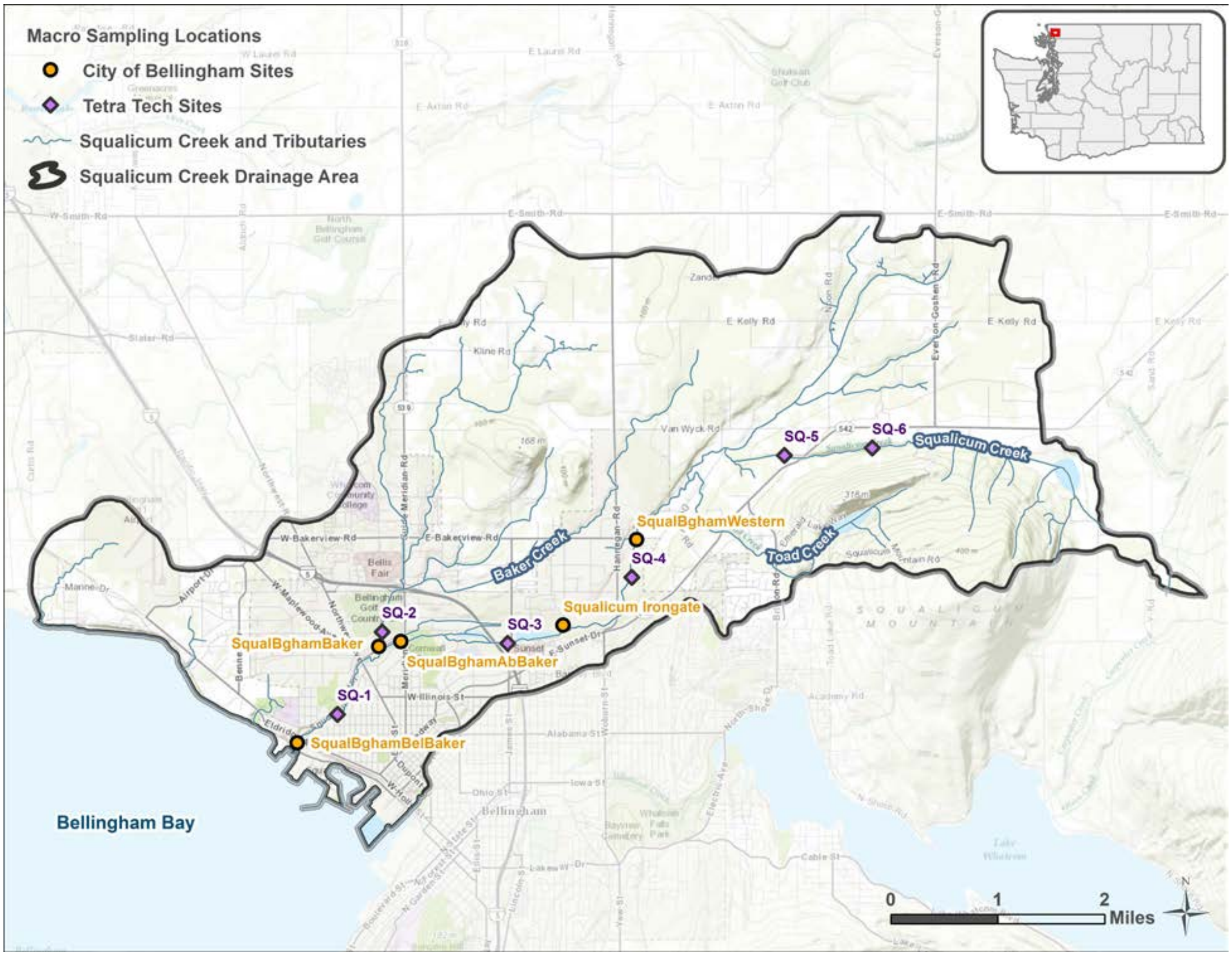
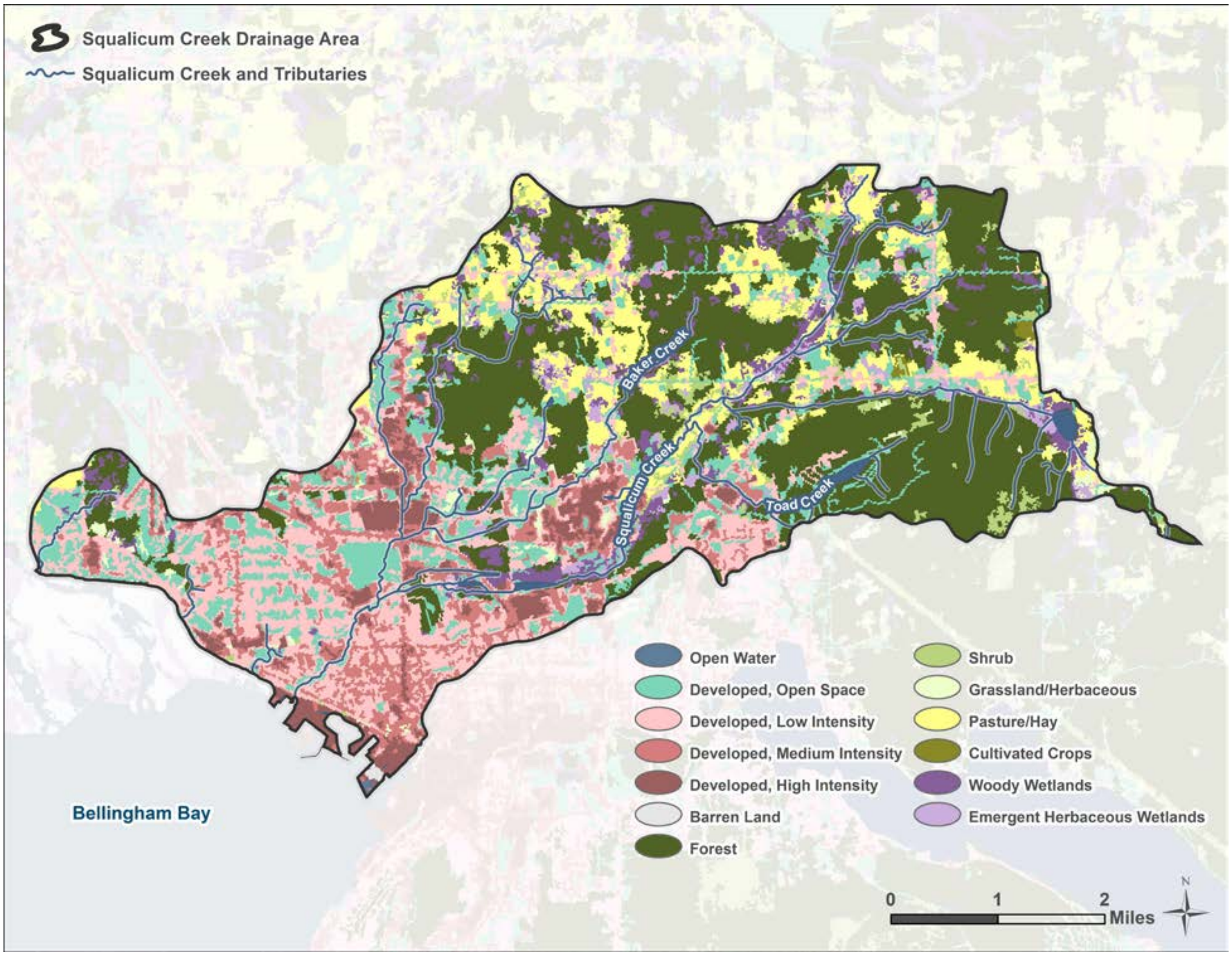


Figure 1. Squalicum Creek location map showing biomonitoring sites.



Source: NLCD 2006

Figure 2. Squalicum Creek watershed land use/land cover.

The city of Bellingham and Western Washington University have collected and described biological information for the Squalicum Creek drainage (City of Bellingham 2011; Vandersypen et al. 2006). The university found that, although the uppermost Squalicum Creek site had slightly better macroinvertebrate indices than downstream sites in the 2006 study, all sites had few sensitive organisms and were dominated by pollution-tolerant taxa, including amphipods, chironomids, and worms. Pollution-tolerant mayflies *(Baetis tricaudatus)* were also observed in higher numbers than expected.

Historical water and sediment quality data indicate that all reaches, except the segment between James Street and Hannegan Road, have some level of pollution for dissolved oxygen, temperature, fecal coliform, zinc, or pentachlorophenol (Ecology 2009a; Anderson and Roose 2004).

The city evaluated Squalicum Creek's ecological conditions as part of its shorelines assessment. Characteristic ecological functions of the creek and adjacent buffers decline in downstream areas beginning from Interstate 5. Increased development over the past 20 years has resulted in the loss of habitat for aquatic life and riparian vegetation. Moderate- to high-functioning conditions remain upstream of Interstate 5. These are areas where riparian vegetation still remains. A large wetland complex populated by a wide range of native vegetation remains in the upper reaches of Squalicum Creek (City of Bellingham 2011).

Anadromous fish populations that use Squalicum Creek include sea-run cutthroat, Chinook, coho, chum, and steelhead salmon. Chinook salmon and bull trout are listed as federal threatened species and listed by Washington as a species of concern (Washington State Department of Natural Resources - Washington Natural Heritage Program). Sea-run cutthroat and coho salmon are listed as a federal species of concern and do not appear under any state listing status.

Soos Creek

Soos Creek watershed drains about 70 square miles of land area and includes portions of King County and the cities of Auburn, Black Diamond, Covington, Kent, Maple Valley, and Renton (Figure 3). Major streams draining to Big Soos Creek are Soosette, Jenkins, Covington, and Little Soos Creeks. According to the most recent approved Clean Water Act section 303(d) list (Ecology 2009a), segments of the Soos Creek system are impacted relative to the water quality standards for temperature, dissolved oxygen, and fecal coliform bacteria.

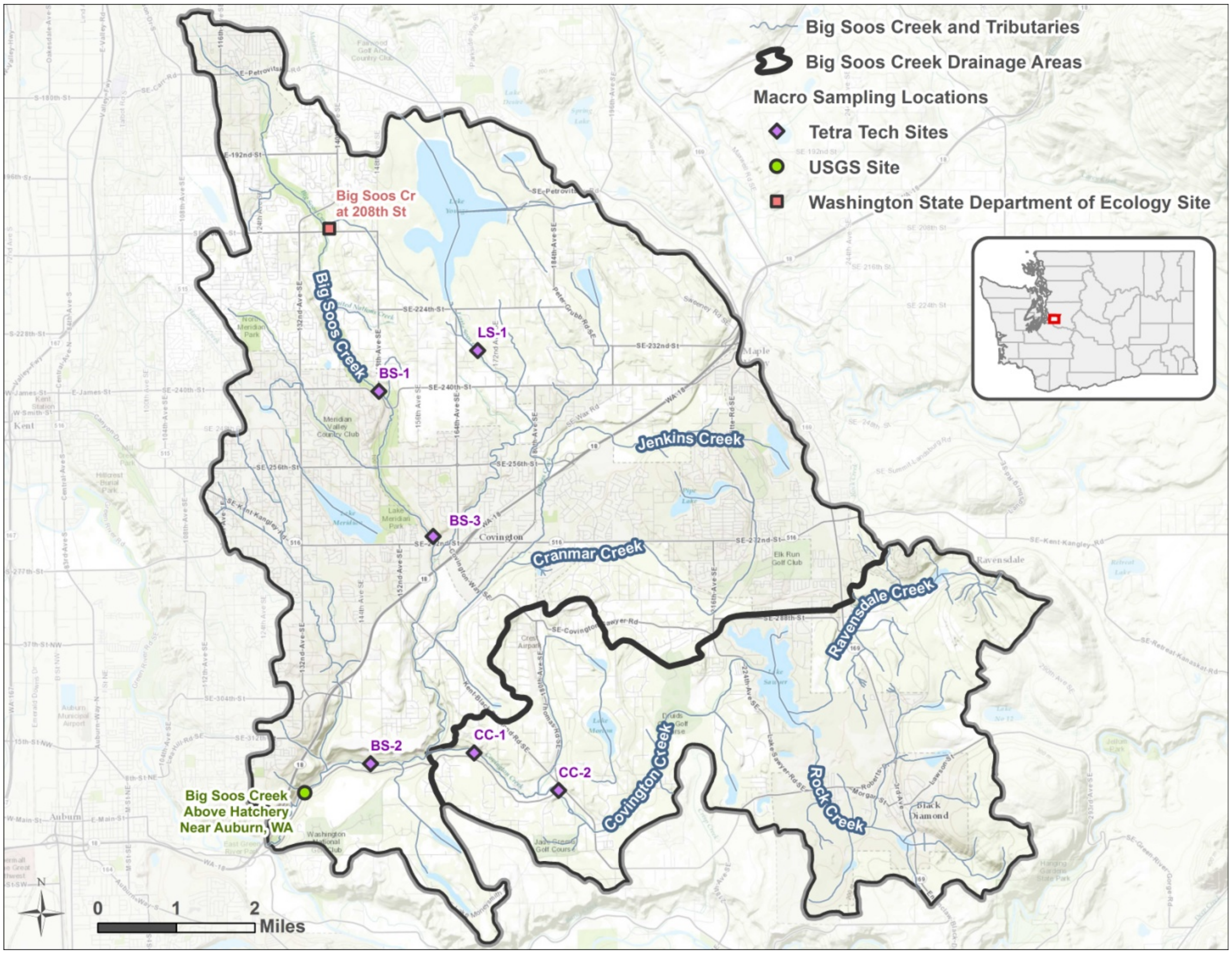
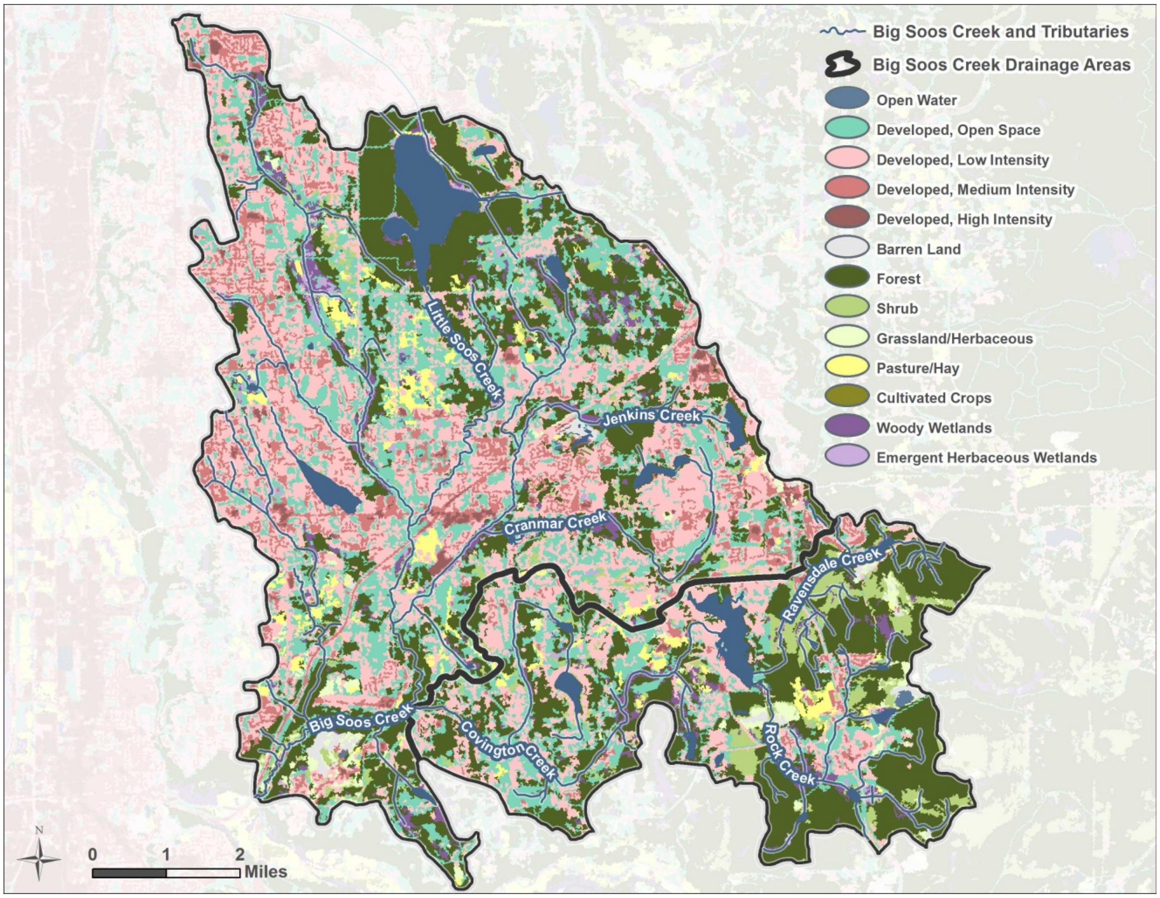


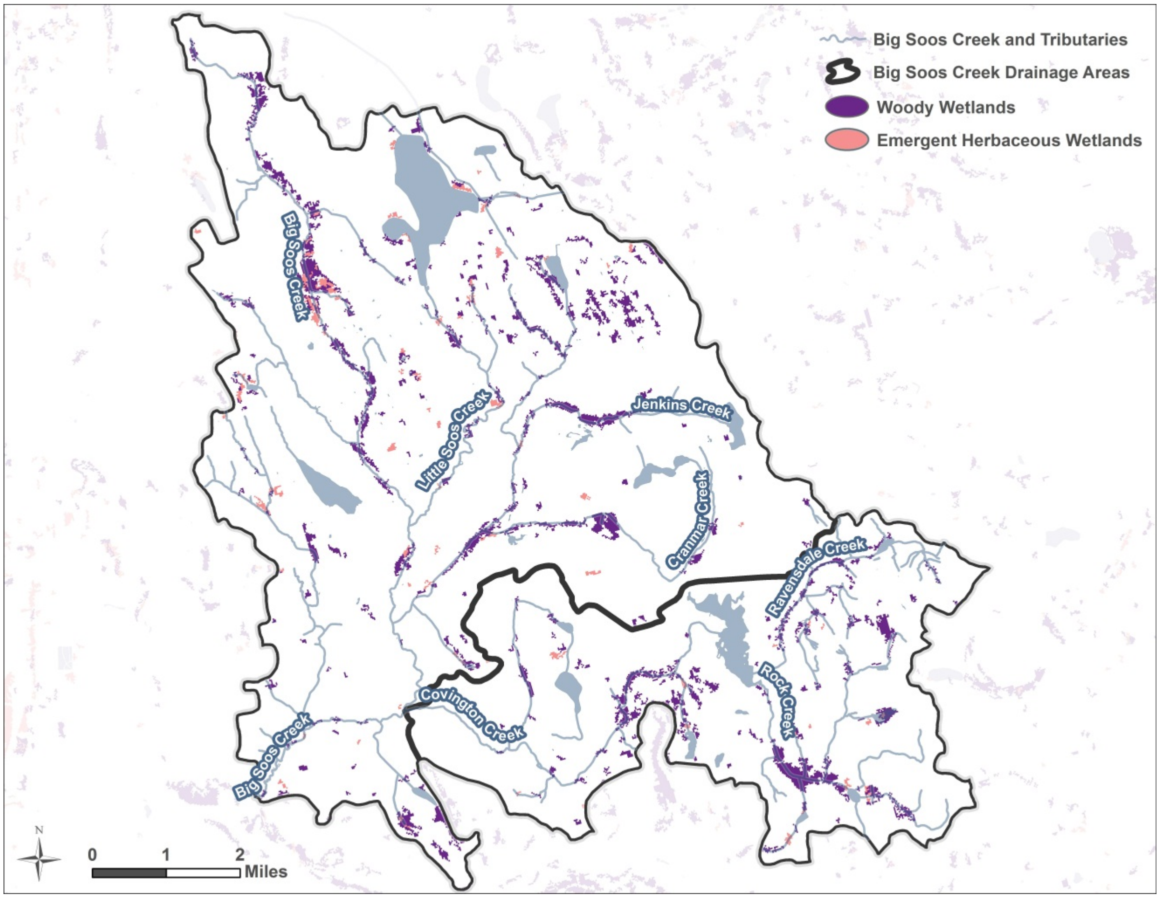
Figure 3. Soos Creek location map showing biomonitoring sites.

Land use in the study area includes urban and residential, commercial, some industrial, commercial forestry, and small-scale agricultural land uses (Figure 4). Extensive wetland areas are also in the watershed that, in addition to providing important habitat, might also function to adsorb pollutants and mitigate flows associated with changes in flow regime (Figure 5). Likewise, pollutants can be periodically released from wetlands and have an effect on stream water quality near the point of entry. Unlike the typical phenomenon of increasing development in a downstream direction, much of the urban development is in the upper and middle reaches of this watershed (Figure 5).



Source: NLCD 2006

Figure 4. Soos Creek watershed land use/land cover.



Source: NLCD 2006

Figure 5. Wetlands in the Soos Creek watershed.

Increased impervious surface area has contributed to decreases in summertime low flows and increases in winter stormwater flows (King County 1990). Some areas of the Soos Creek Basin are expected to have winter peak stream flows increase 3.5 times the 1985 levels because of the highly permeable soils being converted to urban areas with impervious surfaces (King County 1989). Increased groundwater withdrawal also contributes to the decline in instream flows. Kent, the Covington Water District, and King County Water District #111 are the largest consumers of water in the basin.

Available benthic data were identified in the Stormwater Pilot-Candidate Watersheds Assessment Technical Memorandum to Ecology (King 2011). One U.S. Geological Survey (USGS) gage on Soos Creek had co-located benthic data collection during one sampling event in 2007 and four sampling events in 1996–1998. In addition, King County has conducted benthic sampling as part of its Benthic Invertebrate Program. In Soos Creek, two sampling events occurred: one station was sampled in 2002, and two stations were sampled in 2010. Although protocols for characterizing BMI communities differ between King County and Ecology (bottom area collection of 3 versus 8 square feet [ft^2], respectively), the results are considered comparable (Karen Adams 2012, personal communication; Jo Wilhelm 2013, King County DNR). Ecology and contractors are leading an effort to identify how the collection area affects results when quantifying density and calculating biometric expressions.

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Sampling Design and Methods

The sampling design and methods are presented in the *Final Quality Assurance Project Plan for Bioassessment Monitoring and Analysis to Support Stormwater TMDL Development* and associated Technical Approach document (Tetra Tech 2012b). The following presents a brief summary of the sample locations and a brief introduction to the methods. Additional details are provided in Appendix F.

Sampling Locations

The site selection process included an effort to locate reference sites in Squalicum Creek and Soos Creek drainages using (1) land use maps, (2) existing reports and data that described stream reach conditions, and (3) field visits to verify the desktop review of information. The assessment tools (multi-metric index and RIVPACS) are based on more than 200 reference sites from western Washington. Scores generated for sites in Squalicum Creek and Soos Creek are compared to the reference conditions by the models. Sampling locations for Squalicum and Soos Creeks are described separately below.

Squalicum Creek

Tetra Tech biological sampling locations for the Squalicum Creek drainage are listed in Table 1 and shown in Figure 1 (above). Sampling was conducted from July 24 to 26, 2012.

Table 1. Tetra Tech biomonitoring sites in the Squalicum Creek watershed.

					Water Quality Assessment Status (2008)	
Site ID	**Waterbody**	**Site Name**	**Latitude**	**Longitude**	**Category**	**Pollutants**
SQ-6	Squalicum Creek	Upper Squalicum	48.801360	-122.390144	1	No listings
SQ-5	Squalicum Creek	Above SR542	48.800451	-122.408164	2	Pentachlorophenol, Zinc
SQ-4	Squalicum Creek	Below Hannegan Rd	48.784126	-122.439607	5 2	Fecal coliform, dissolved oxygen, Temperature
SQ-3	Squalicum Creek	Below Sunset Pond	48.775324	-122.465137	5 2	Fecal coliform, temperature, dissolved oxygen pH, Zinc
SQ-2	Baker Creek	Baker Creek	48.776980	-122.490842	5 2	Fecal coliform, dissolved oxygen temperature, pH
SQ-1	Squalicum Creek	At West Street	48.765875	-122.500094	5 2	Fecal coliform, dissolved oxygen temperature, pH

Soos Creek

Tetra Tech biological sampling locations for the Soos Creek drainage are listed in Table 2 and shown in Figure 3 (above). Sampling was conducted from July 31 to August 2, 2012.

Table 2. Biomonitoring sites in the Soos Creek drainage used for identifying response to stormwater impacts and current 303(d) listings for pollutants based on surface water quality.

Site ID	Waterbody	Site Name	Latitude	Longitude	Water Quality Assessment Status (2008)	
					Category	Pollutants
BS-1	Big Soos Creek	At 148th Ave SE	47.386341	-122.144080	5 2	Fecal coliform Dissolved oxygen
BS-2	Big Soos Creek	Near SR 58	47.317578	-122.147453	5 2	Fecal coliform Temperature
BS-3	Big Soos Creek	At 272nd St.	47.359432	-122.129762	1	No listings
CC-1	Covington Creek	At 168th Way SE	47.3193	-122.1193	5 2	Dissolved oxygen pH
CC-2	Covington Creek	SR 58 Crossing nr Kent-Black Diamond Road SE	47.3122	-122.0965	5 2	Dissolved oxygen pH
LS-1	Little Soos Creek	At 164th Ave SE	47.4001	-122.1226	1	No listings

Methods

Figure 6 illustrates the steps that were implemented and analytical tools used to determine relationships between physical and chemical water quality characteristics with biological response conditions. Ecology uses a stepwise process for identifying and systematically narrowing down the potential causes for impacts in biological condition (Adams 2010a) on the basis of the Causal Analysis Diagnosis/Decision Information System (CADDIS) approach was originally developed by EPA. Additional detail regarding each step in Figure 6 is provided in the QAPP (Tetra Tech 2012b; Adams 20120b). Details regarding methods not previously covered in detail in the QAPP or associated Technical Approach document are in Appendix F.

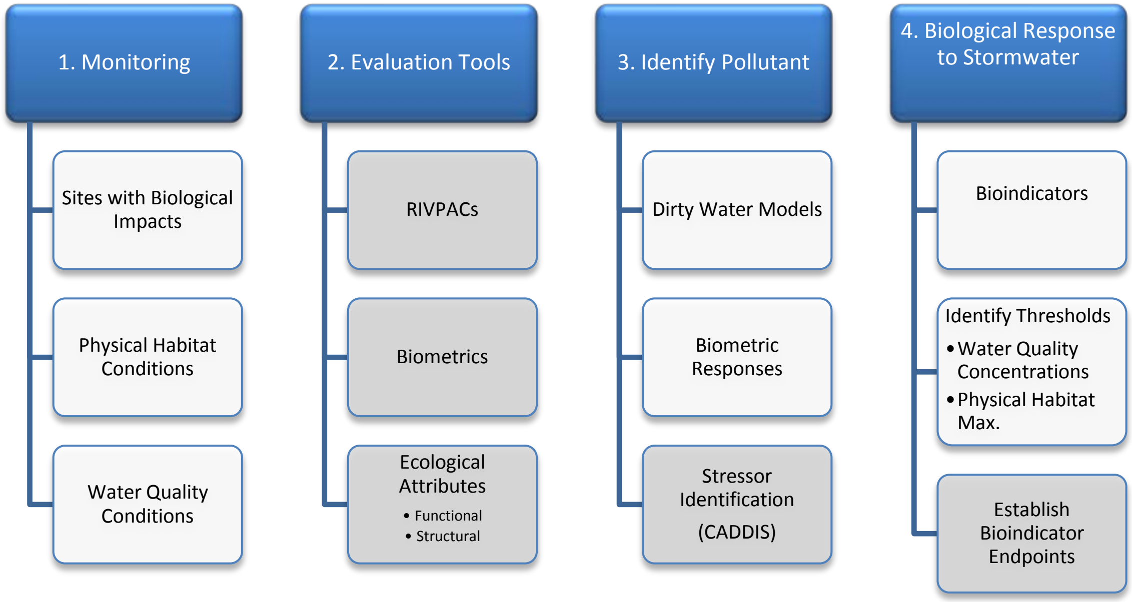

Figure 6. Biological information and analytical tools used to identify the biological response resulting from exposure to stormwater stressors.

Several biometrics (attributes of the biological community) were the focus for evaluation of stormwater effects on the benthic macroinvertebrate and periphyton communities. Past research has generated documentation for predicting biometric response to effects in freshwater aquatic ecosystems (Table 3). The directions of response and standard definitions have consistently been reported by several researchers.

Table 3. Biometric definitions and responses to stormwater impairments.

Biometric	Definition	Predicted Response to Impacts	Citations
Taxa Richness	A measure of the number of different kinds of organisms (taxa) in a collection.	Decrease—portions of the community taxa list will be absent in the presence of impacts.	Walsh 2004 Frondorf 2001
Percent (%) Pollution Tolerant taxa	Organisms that are tolerant of pollutants and are not affected as readily as other taxa.	Maintains or Increases—number of pollution-tolerant taxa usually increase in the presence of increasing pollution.	Cuffney 1999
Clinger Richness	Number of taxa constructing fixed retreats or adaptations for attachment to surfaces in flowing water.	Decrease—substrate instability resulting from *flashy* flow patterns will destabilize substrate preferred by *clingers*.	Cuffney 1999 Carter et al. 2009 Karr et al. 1986 Morley and Karr 2002
Semi-voltine Richness	Number of long-lived organisms found in a collection.	Decrease—hydrologically stable environment is preferred habitat for long-lived organisms.	Poff et al. 2006 Resh and Jackson 1993 Morley and Karr 2002
Percent (%) Top 3 Abundant	Proportion of the top three most abundant taxa collected in a sample.	Increase—taxa tolerant to physical and chemical changes will become dominant at a site.	Frondorf 2001 Morley and Karr 2002
Ephemeroptera	Number of mayfly taxa.	Decrease—a pollution-sensitive order of taxa with the exception of the Family Baetidae.	Walsh 2004 McGuire 2001 Morley and Karr 2002

Biometric	Definition	Predicted Response to Impacts	Citations
Plecoptera	Number of stonefly taxa.	Decrease—a pollution-sensitive order of taxa.	Walsh 2004 McGuire 2001 Morley and Karr 2002
Trichoptera	Number of caddisfly taxa.	Decrease—a generally pollution-sensitive order of taxa with exception of the Family Limnephilidae.	Walsh 2004 McGuire 2001 Morley and Karr 2002
Percent Predator	Proportion of the *predator* functional feeding group represented in a sample.	Decrease—*predator* taxa representation generally declines in the presence of change to physical habitat; also sensitive to chemical pollutants.	Wang and Kanehl 2003 Smith and Lamp 2008 Morley and Karr 2002
Percent (%) Pollutant Sensitive taxa	Organisms that are intolerant of pollutants and are affected more easily than other taxa.	Decrease—a community dominated by a greater portion of pollution-sensitive taxa indicates absence of stormwater impacts.	USEPA 2000 Stribling et al. 1998
Total # of Algal Species	Total # of algal species found in a collection.	Decrease or Maintains—physical substrate disturbance or increase in turbidity from impacts reduces the number of taxa in the periphyton community.	Barbour et al. 1999
Metals Tolerance Index	Taxa present are tolerant of exposure to high concentrations of metals in the substrate and in surface water at the boundary layer above the substrate.	Increases—the Metals Tolerance Index value increases (scale from 0 to 10) as effects from exposure to metals increases.	Richardson 2000 McGuire 1999
% Sediment Tolerant taxa	Proportion of *sediment-tolerant* taxa (taxa tolerant to sedimentation) in a sample.	Increase—pollution input to streams includes fine sediments that fill in spaces between coarse substrates and reduces the living space of more sensitive taxa.	Cuffney 1999 Relyea et al. 2012
% EPT	Proportion of mayflies, stoneflies, and caddisflies collected from a site; represent pollution-sensitive species.	Decrease—pollution-sensitive taxa belonging to this group declines and representation in the community declines.	Walsh 2004 Morley and Karr 2002
% Dominant Taxa	Measures the dominance of the single most abundant taxon. Can be calculated as dominant 2, 3, 4, or 5 taxa.	Increase—pollution-tolerant taxa increase in the presence of pollution input, individual taxa outcompete more sensitive taxa in the presence of physicochemical stressors.	Frondorf 2001
% Clinger	Proportion of taxa constructing fixed retreats or adaptations for attachment to surfaces in flowing water.	Decrease—substrate instability resulting from *flashy* flow patterns destabilizes substrate preferred by *clingers*.	Pederson and Perkins 1986
% Scraper and Shredder	Proportion of taxa in a community that belong to two functional feeding groups; harvest algae by scraping hard substrate surfaces and the other processing leaves conditioned by microbial activity.	Decrease—pollution effects substrate stability and cover surfaces with fine sediment, periphyton growth is diminished and *scrapers* density declines; detritus transported rapidly from a reach is not available to *shredders* for processing.	Frondorf 2001

Biomonitoring Results and Discussion

Two assemblages (i.e., BMI and periphyton) were used to characterize biological conditions at six sites each in Squalicum and Soos Creeks. The B-IBI and RIVPACS tools were applied to the sample results to calculate condition scores for the benthic macroinvertebrate community at each sample site. Individual biometrics for both periphyton and macroinvertebrates were calculated for each sample site and were compared to the following:

- Measured physical features (e.g., temperature, dissolved oxygen, stream velocity)
- Measured bottom substrate toxics (e.g., metals and pesticides in Squalicum Creek only)
- Streamflow
- Landscape development intensity (LDI) in Squalicum Creek only

The purpose of these comparisons was to evaluate statistical correlations between expressions for biological condition and various stressors in the watershed. The BMI model results were evaluated with the streams' physical features, hydrology, and surrounding land use. The results for these site assessments reflect the influence of a variety of physical habitat and water quality conditions. Changes that occur to instream characteristics and to biological communities from stormwater input are identified from data generated during summer 2012 and verified with data similarly generated in the drainage from past monitoring efforts. Isolating impacts from stormwater versus other sources is a primary focus for data analysis and interpretation in this study.

A total of 55 benthic macroinvertebrate metrics and 46 periphyton metrics were used for analyzing relationships with physical features, substrate toxics, streamflow, and LDI. Only those metrics correlated to these factors using minimum statistical performance thresholds were further analyzed for significant relationships.

Squalicum Creek

B-IBI and RIVPACS Evaluation

Evaluation of biological condition in Squalicum Creek was determined by using existing assessment models—a multi-metric index (B-IBI) and a predictive model (RIVPACS). RIVPACS is based on descriptions from dozens of reference stream surveys and reflects reference stream biological expectations (Hawkins 2006). The B-IBI used sites considered reference streams as the basis for determining thresholds of high-quality biological conditions (Wiseman 2003). Output from evaluating the biological condition using each assessment tool provides unique insight into potential causes of detectable impacts. Table 4 lists the quantitative ranges and corresponding categorical assessment of stream conditions.

Table 4. B-IBI and RIVPACS score ranges and corresponding condition category.

B-IBI range	Condition Category	RIVPACS Range	Condition Category
> 30	High Integrity good	≥ 0.86	Good
20–30	Moderate Integrity fair	0.73–0.85	Concern
< 20	Low Integrity poor	≤ 0.72	Poor

Sources: B-IBI: Wiseman 2003; RIVPACS: Ecology 2012b

The RIVPACS and B-IBI scores are listed in Table 4 with comparisons of scores used to determine relative condition levels of each site. This initial comparison was important for determining the intensity of biological impacts and components of the biological community used to interpret the stressor (i.e., pollutant group) cause for impacts.

The B-IBI and the RIVPACS scores represent community condition assessments for a reach in the drainage. Each score represents an overall assessment of a site by evaluating the presence and abundance of each species compared to a reference stream condition of similar size and location. The B-IBI assessment tool is based on reference conditions from fewer than 100 sites throughout the Puget Lowland ecoregion. The RIVPACS community assessment tool is calibrated for condition categories on the basis of hundreds of reference sites in the same region. The tools serve as controls to objectively evaluate each site for biological integrity.

Results from community condition assessments at each site in Squalicum Creek showed some agreement in condition category assessment and differed on three of the reach assessments (Table 5). The exception was for SQ-4, SQ-5, and SQ-6, where the B-IBI indicated biological condition was better than estimated by the RIVPACS tool.

In some situations, the RIVPACS tool is sensitive to certain types of impacts that other assessment tools miss. Using both tools detects impacts on the basis of changes in community structure, function, and species loss or replacement; each of these attributes is sensitive to specific stressors. In this study, using both tools ensured that all potential effects on the biological community were detected and that a more intense evaluation of stressors was conducted.

Table 5. Squalicum Creek B-IBI and RIVPACS scores.

Site ID	Site	B-IBI Score	B-IBI Score Condition Category	RIVPACS Score	RIVPACS Condition Category
SQ-1	At West St.	18	Low Integrity poor	0.55	Poor
SQ-2	At Baker Creek	16	Low Integrity poor	0.55	Poor
SQ-3	Below Sunset Pond	18	Low Integrity poor	0.47	Poor
SQ-4	Below Hannegan Rd	20	Moderate - Low Integrity Fair	0.54	Poor
SQ-5	Above SR 542	44	High Integrity Good	0.73	Concern
SQ-6	Upper Squalicum	42	High Integrity Good	0.55	Poor

For B-IBI and RIVPACS ranges and condition categories, see Table 4.

Biometric Relationships to Physical Parameters

Combinations of environmental factors and biological metrics were examined for relationships that had a minimum Pearson's product-moment correlation of greater than or equal to 0.50 (Table 6). The rationale for including correlations with $r \geq 0.50$ follows.

The biometrics used in generating a B-IBI score for each site was the same as those used in a Puget Sound regional index. Of the 10 biometrics selected for inclusion in the Puget Sound B-IBI (Morley and Karr 2002), the average Spearman rank correlation coefficient (non-parametric equivalent to Pearson's function) using the highest and lowest values correlated with percent of urban land use were as follows:

Range of "r" = 0.29 – 0.67
Average subbasin scale "r" = 0.51
Average local scale "r" = 0.40

Similarly, the Pearson's product-moment correlation coefficient, r, threshold used for examination of relationships between biometrics and independent variables was $r \geq 0.50$. Identifying relationships between individual biometrics with instream water quality, habitat, and landscape variable, coupled with a low number of sites, should not result in correlation strengths consistently greater than 0.50 in Puget Sound streams on the basis of Morley and Karr's (2002) experience.

Direct relationships were considered relationships that had a positive slope, using a correlation model. Inverse relationships were determined when slope of the correlation model had a negative value. Significant relationships were those with p-values less than or equal to 0.05.

Pearson's product-moment correlation coefficient, r, measures the degree of linear association between two variables. This Web address, www.epa.gov/caddis/da_exploratory_2.html, provides a more detailed explanation for how r is calculated and results interpreted, summarized here:

- A coefficient of 0 indicates that the variables are not related.
- A negative coefficient indicates that as one variable increases, the other decreases.
- A positive coefficient indicates that as one variable increases, the other also increases.

- Larger absolute values of coefficients indicate stronger associations. However, small Pearson coefficients might be due to a nonlinear relationship.

The numerous examined paired relationships that met or exceeded this threshold are summarized in Tables 5 and 6. These charts were used to determine central themes for response by biological communities and if each assemblage (e.g., BMI and periphyton) was differentially more sensitive to changes in the aquatic environment. Once relationships between biological condition and environmental measurement were established, a determination was made for the likelihood that any negative impact on biological response was related to past stormwater input.

The results for Squalicum Creek indicate that physical habitat characteristics have the strongest correlation to changes in BMI populations (Table 7). Direct relationships were found between %Silt/Clay/Muck (%SCM), coarse gravel, sand, and an increase in the *clinger* population. This indicates that substrate size and susceptibility to transport by stormwater directly affect benthic organisms that would typically cling to substrate.

Indirect relationships between habitat-sensitive organisms such as percent Ephemeroptera/ Plecoptera/Trichoptera (% EPT) and fine gravel were found throughout the creek, also indicating destabilization of habitable substrates. Rain intensity, high storm flows, subbasin development intensity, and land use practices can influence these characteristics of a stream.

The lower LDI index scores indicate a general lack of disturbance to the surrounding stream resources. Indicators related to LDI were % Scrapers and shredders, % Clingers, and % EPT (Table 8). The relationship between a land-use-scale parameter and a site-specific parameter in the stream indicates that intensity of human activity affects some components of the aquatic community, but it does not identify a specific mechanism for impact.

Table 6. Summary of Squalicum Creek's biometric and periphyton relationships (r-value and slope) and the significance of those relationships (p-value).

	Water Quality Parameters											
	Temperature			pH			Conductivity			Dissolved Oxygen		
Squalicum Creek Biometric Relationships	**Slope**	***r***	**p**	**Slope**	***r***	**p**	**Slope**	***r***	**p**	**Slope**	***r***	**p**
% Clinger	-1.23	-0.21	0.00	18.65	0.28	0.00	-0.01	-0.06	0.01	1.72	0.07	0.00
Pollution Tolerant %	-0.89	-0.41	0.01	12.19	0.50	0.18	-0.01	-0.08	0.00	-2.12	-0.22	0.12
% EPT	-7.84	-0.62	0.21	66.26	0.48	0.04	-0.27	-0.73	0.00	22.72	0.43	0.05
% Scraper and Shredder	-4.00	-0.72	0.65	37.35	0.61	0.27	-0.15	-0.85	-0.01	13.29	0.56	0.33
Squalicum Creek Periphyton Relationships												
% Acidophilus	-0.03	-0.15	1.16x10-5	0.08	0.04	1.49 x 10-7	0.00	-0.48	0.00	0.17	0.22	3.39x10-7
Total Chlorophyll A in Slurry	16.63	0.73	0.18	-205.95	-0.82	0.11	-0.02	-0.03	0.02	35.68	0.36	0.11
Dominant Taxa %	0.69	0.06	0.04	18.32	0.15	0.01	0.20	0.57	0.00	-21.64	-0.46	0.02
Metals Tolerant Taxa %	-0.58	-0.12	0.15	0.10	0.00	0.82	-0.09	-0.58	0.00	8.26	0.39	0.96
Pollution Tolerance %	2.20	0.21	0.15	-34.49	-0.29	0.05	-0.11	-0.33	0.01	18.64	0.41	0.05
Shannon H (log 2)	0.03	0.07	3.66x10-5	-1.62	-0.32	0.00	-0.01	-0.65	0.00	1.37	0.68	1.4x10-5
Total # of Algal Species	3.64	0.61	0.01	-47.99	-0.73	0.00	-0.01	-0.06	0.01	14.08	0.55	0.00

Notes:
Yellow highlighted parameters indicate significant relationships (Pearson's r-value ≥ 0.50 and p-value ≤ 0.05).
Green highlighted parameters indicate moderately significant relationships (Pearson's r-value ≥ 0.50 and p-value ≤ 0.20).

	Physical Parameters																																						
	Depth			Velocity			% Bank Instability			% Gradient			% Canopy Cover			% Embeddedness			% Cobble			% Coarse Gravel			% Sand			% Fine Gravel			% Silt Clay Mud			% Boulder			% Wood		
Squalicum Creek Biometric Relationships	**Slope**	***r***	**p**	**Slope**	***r***	**p**	**Slope**	***r***	**p**	**Slope**	***r***	**p**	**Slope**	***r***	**p**	**Slope**	***r***	**p**	**Slope**	***r***	**p**	**Slope**	***r***	**p**	**Slope**	***r***	**p**	**Slope**	***r***	**p**	**Slope**	***r***	**p**	**Slope**	***r***	**p**	**Slope**	***r***	**p**
% Clingers	74.75	0.71	6.88x10-5	15.45	0.38	6.99x10-5	-0.02	-0.04	0.07	5.88	0.31	7.76x10-5	4.34	0.47	0.00	-0.27	-0.19	0.00	-0.40	-0.47	0.01	-0.31	-0.17	0.00	1.24	0.55	6.9x10-5	0.36	0.33	0.00	2.82	0.78	3.29 x 10-5	-4.36	-0.59	0.00	3.10	0.14	7.03x10-5
Pollution Tolerant %	26.52	0.69	0.07	0.63	0.04	0.10	-0.01	-0.09	0.18	2.44	0.35	0.28	2.24	0.67	0.00	-0.19	-0.39	0.02	-0.08	-0.25	0.02	0.00	-0.01	0.00	0.24	0.29	0.09	-0.01	-0.02	0.02	0.81	0.62	0.75	-0.50	-0.19	0.18	2.45	0.32	0.08
% EPT	-125.13	-0.59	0.01	-30.63	-0.37	0.01	-0.39	-0.53	0.79	-7.60	-0.20	0.02	3.77	0.22	0.15	1.50	0.54	0.40	-0.30	-0.19	0.97	2.57	0.67	0.64	-0.28	-0.06	0.07	-1.34	-0.61	0.49	-0.19	-0.03	0.02	8.54	0.67	0.01	26.39	0.75	0.01
% Scraper and Shredder	-37.40	-0.39	0.04	-6.34	-0.17	0.05	-0.17	-0.51	0.45	1.59	0.09	0.07	3.61	0.43	0.80	0.60	0.49	0.15	-0.32	-0.42	0.19	1.10	0.66	0.01	0.29	0.14	0.52	-0.45	-0.45	0.35	0.92	0.28	0.10	1.80	0.28	0.05	17.86	0.92	0.04
Squalicum Creek Periphyton Relationships																																							
% Acidophilus	-0.89	-0.29	0.98	-0.08	-0.07	0.10	0.00	-0.27	0.12	-0.34	-0.59	0.00	0.03	0.10	2.02x10-6	0.02	0.36	0.00	-0.01	-0.39	0.01	0.00	0.06	0.00	0.02	0.24	-0.01	-0.01	-0.17	0.01	0.02	0.17	0.01	0.02	0.81	0.19	0.44	0.69	0.18
Total Chlorophyll A in Slurry	133.31	0.34	0.07	127.89	0.85	0.07	0.06	0.05	0.48	-62.29	-0.87	0.08	-19.63	-0.57	0.18	2.01	0.39	0.23	-2.14	-0.67	0.47	-5.72	-0.84	0.51	6.81	0.79	0.10	3.65	0.89	0.18	6.95	0.51	0.08	-1.31	-0.05	0.07	-18.94	-0.24	0.07
Dominant Taxa %	-46.42	-0.25	0.01	-27.51	-0.38	0.01	0.43	0.66	0.23	25.39	0.74	0.01	5.59	0.34	0.03	-1.52	-0.63	0.13	0.78	0.51	0.12	0.18	0.06	0.26	-1.84	-0.45	0.03	-0.05	-0.03	0.11	-2.47	-0.38	0.01	-9.81	-0.74	0.01	-14.90	-0.39	0.01
Metals Tolerant Taxa %	-27.09	-0.32	0.11	2.14	0.07	0.12	-0.08	-0.26	0.29	-9.36	-0.61	0.22	0.69	0.09	0.21	0.52	0.48	0.03	-0.38	-0.57	0.10	0.04	0.03	0.01	0.71	0.39	0.74	-0.03	-0.03	0.10	0.87	0.30	0.32	3.78	0.64	0.11	12.46	0.73	0.11
Pollution Tolerance %	132.16	0.73	0.02	57.63	0.83	0.02	-0.17	-0.27	0.87	-18.23	-0.55	0.03	-1.92	-0.12	0.13	0.77	0.33	0.29	-1.25	-0.85	0.81	-1.76	-0.55	0.96	3.70	0.94	0.03	1.27	0.67	0.24	5.74	0.91	0.02	-1.14	-0.09	0.02	5.12	0.14	0.02
Shannon H (log 2)	0.79	0.10	0.01	1.68	0.55	0.00	-0.07	-0.62	0.16	-1.23	-0.84	0.27	-0.34	-0.48	4.06x10-5	0.09	0.82	0.00	-0.04	-0.66	0.01	-0.02	-0.13	0.00	0.10	0.59	0.03	0.02	0.21	0.01	0.12	0.42	0.56	0.33	0.58	0.02	0.58	0.35	0.00
Total # of Algal Species	-30.72	-0.30	0.00	21.56	0.55	0.00	0.02	0.05	0.64	-9.79	-0.52	0.00	-6.99	-0.77	0.01	0.79	0.59	0.02	-0.22	-0.27	0.41	-0.64	-0.36	0.50	0.66	0.29	0.00	0.61	0.57	0.03	-0.21	-0.06	0.00	-1.71	-0.24	0.00	8.15	-0.39	0.00

Notes:
Yellow highlighted parameters indicate significant relationships (Pearson's r-value ≥ 0.50 and p-value ≤0.05).
Green highlighted parameters indicate moderately significant relationships (Pearson's r-value ≥ 0.50 and p-value ≤ 0.20).

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Table 7. Squalicum Creek relationships between benthic macroinvertebrate biometrics and physical characteristics and their significance.

Biometrics	**pH**	**DO**	**% Cobble**	**Conductivity**	**% SCM + % Coarse gravel**	**% Sand**	**Depth**	**% Fine gravel**	**% Coarse gravel**	**% SCM**	**% Bank Instability**	**Temperature**	**Canopy cover**	**% Cobble + SCM + fine gravel**	**% Embeddedness**	**% Boulder**	**% Wood**	**Development Intensity**
% Scraper and Shredder	D	D		**I***					**D***		I	I		I			**D***	I
% Clingers					D	**D***	**D***			**D***						**I***		I
% Pollution Tolerant Taxa	D						D			D			**D***					
% EPT				**I***			**I***	I	D		I	I			D	**D***	**D***	I

Notes:
I = Inverse relationship
D = Direct relationship
SCM = Silt/Clay/Muck substrate sizes
* Indicates statistically significant relationships (p value ≤ .05) along with bold highlighting

Table 8. Squalicum Creek relationships between periphyton biometrics and physiochemical characteristics.

Biometrics	Temperature	pH	D.O.	Velocity	% Gradient	Conductivity	% Bank Instability	% Cobble	% Coarse Gravel	% Sand	% Fine Gravel	% SCM	% Boulder	% Wood	% Embeddedness	Canopy Cover	Depth
Shannon H Index			**D***	**D***	D	**I***	I	**I***		**D***			**D***		**D***		
% Pollution Tolerant Taxa				**D***	**I***			I	I	**D***	D	**D***					**D***
Metals Tolerance Index					I	I		I					D	D			
% Acidophilus					**I***								D	D			
Dominant Taxa %					**D***	**D***	D	D					**I***		I		
Total Chl *a* in Slurry (mg/m^2)	D	I		D	I			I	I	**D***	D	D				I	
Total # of Algal Species	**D***	**I***	**D***	**D***	**I***	I					**D***				**D***	**I***	

Notes:
I = Inverse relationship
D = Direct relationship
SCM = Silt/clay/muck substrate sizes
* Indicates statistically significant relationships (p value ≤ 0.05) along with bold highlighting

Biometric Relationship to Sediment Toxics

For sites in Squalicum Creek, a complete set of toxics was analyzed: metals, pesticides, polychlorinated biphenyls (PCBs), and base-neutral-acids (BNAs). Most of the analytes showed low or no detectable concentrations in sediments from Squalicum Creek, but a subset has been the focus of concern in Puget Sound and implicated as the most persistent in Puget Sound Rivers and streams. A recent study of 16 lowland streams, *Toxics in Surface Runoff to Puget Sound,* found that instream storm-event concentrations of toxics were generally higher than baseflow conditions and that concentrations and detection frequencies were highest in commercial/ industrial basins, agriculture, and residential land uses (Ecology 2011). Flows from the land uses have higher concentrations of organic pollutants, metals, and nutrients. Organic pollutants included PCBs, PAHs, and pesticides, among others.

In the current study, sediment samples were collected from the same locations as biological samples in the Squalicum Creek watershed and analyzed for concentrations of these toxics: arsenic, copper, lead, zinc, DDT, Pesticides, PCBs, BNAs, and additional metals. Table 9 shows concentrations of selected analytes. The results were compared with select biometrics: percent top three dominant taxa, % EPT, % sediment tolerance taxa, metals tolerance index, and % pollution tolerance. These biometrics were selected from among dozens calculated for each of the reach samples, because each is expected to respond to toxics in sediment and surface water. These comparisons established relationships between the toxic and biological response (Table 10). Relationships for slope and Pearson's product-moment correlation ($r \geq 0.50$) between toxics and biometrics were retained for further analysis of stormwater impacts if they exceeded the threshold (Figures 7–14).

Detectable concentrations of some metals, organochlorines (PCBs), and pesticides were described from sites in the Squalicum Creek drainage. Three biometrics were related both directly and indirectly to these toxics (Table 11). Sediment-tolerant taxa all had direct relationships with concentration of detectable toxics in the sediment. The presence of some of the toxics was directly related to the amount of total organic carbon associated with the sample (i.e., copper, lead, and arsenic). Generally, greater amounts of fine organic materials will adsorb larger quantities of metals (especially organometals like arsenic). The association with organics increases the risk of consumption by benthic macroinvertebrates and of bioaccumulation. Biometric response to these metals in the presence of organics suggests the potential for effects from direct contact or ingestion of adsorbed toxics, as exemplified by the condition at SQ-1 (Squalicum Creek at West Street).

Table 9. Metals and organics concentrations in Squalicum Creek bottom substrate.

Site ID	Site	DDT (µg/kg dw)	Arsenic (mg/kg dw)	Lead (mg/kg dw)	Copper (mg/kg dw)	PCB Aroclor 1232 (µg/kg dw)	% TOC
SQ-6	Upper Squalicum	0.74	2.48	2.87	6.83	3.8	0.43
SQ-5	Above SR 542	0.76	2.28	2.84	9.6	3.5	0.44
SQ-4	Below Hannegan	0.75	1.87	2.86	6.97	3.8	0.18
SQ-3	Below Sunset Pond	0.73	3.41	2.42	8.66	3.7	0.31
SQ-2	At Baker Creek	0.74	2.83	5.78	12.5	5.9	0.33
SQ-1	At West Street	0.77	3.65	6.95	15.4	6.2	1.19

Note: TOC = total organic carbon

Table 10. Squalicum Creek biometrics and sediment toxics relationships using non-normalized metals concentrations.

Biometrics	Toxic (mg/kg dry weight)				Toxic (µg/kg dry weight)
	Arsenic	Lead	Copper	PCBs	DDT
%Pollution Tolerant Taxa	I		I		
Metals Tolerance Index				D	
Sediment Tolerance %	D	D	D	D	D

Notes:
I = Inverse relationship
D = Direct relationship

Table 11. Summary of Squalicum Creek's significant correlations (r - value and slope) and relationships (p - value) with non-normalized metals concentrations.

	Metals																	
	DDT			PCBs			Lead			Zinc			Arsenic			Copper		
Biometric Relationships	**Slope**	***r***	**p**	**Slope**	***r***	**p**	**Slope**	***r***	**p**	**Slope**	***r***	**p**	**Slope**	***r***	**p**	**Slope**	***r***	**p**
% Pollution Tolerant Taxa	-25.9	-0.08	0.1	-1.16	-0.29	0.97	-0.76	-0.31	0.79	-0.05	-0.17	0.0026	-5.73	-0.66	0.43	-0.74	-0.53	0.12
Metals Tolerance Index	23.4	0.3	0.0008	0.37	0.69	0.099	0.37	0.68	0.76	0.045	0.79	0.0014	-0.13	-0.086	0.11	0.13	0.43	0.0041
% Sediment Tolerance	124.2	0.61	0.22	1.42	0.86	0.06	1.42	0.9	0.063	0.12	0.76	0.00087	3.2	0.73	0.79	2.9x10-5	0.83	0.93
%EPT	564	0.41	0.055	-4.73	-0.28	0.102	-1.85	-0.17	0.095	-0.38	-0.34	0.085	-7.35	-0.25	0.076	-0.83	-0.14	0.24
Dominant Taxa	-387	-0.27	0.0009	7	0.39	0.0011	3.39	0.31	0.001	0.54	0.47	0.19	6.23	0.2	0.001	1.3	0.19	0.0017

Notes:
Yellow highlighted parameters indicate significant relationships (Pearson's r-value ≥ 0.50 and p-value ≤0.05).
Green highlighted parameters indicate moderately significant relationships (Pearson's r-value ≥ 0.50 and p-value ≤ 0.20).

Normalization of metals and other organic contaminant concentrations was accomplished using organic carbon (OC) content in the sediments. Concentrations of toxics (dry weight) in sediments have been described as being correlated with the organic fraction in sediments. This represents a more conservative approach in setting standards and preventing adverse biological effects (Michelson 1992). OC-normalized results for toxics concentrations are reported in Table 12.

Table 12. Metals and organics concentrations in Squalicum Creek bottom substrate normalized for organic carbon content.

Site ID	Site	DDT (µg/kg/OC)	Arsenic (mg/kg/OC)	Lead (mg/kg/OC)	Copper (mg/kg/OC)	PCB Aroclor 1232 (µg/kg/OC)	% TOC
SQ-6	Upper Squalicum	172	577	667	1,588	884	0.43
SQ-5	Above SR 542	173	518	645	2,182	795	0.44
SQ-4	Below Hannegan	417	1,039	1,589	3,872	2,111	0.18
SQ-3	Below Sunset Pond	235	1,100	781	2,794	1,194	0.31
SQ-2	At Baker Creek	224	858	1,752	3,788	1,788	0.33
SQ-1	At West Street	65	307	584	1,294	521	1.19

Note:
TOC = total organic carbon

A summary of significant relationships with select OC-normalized toxics is given in Table 12. The probabilities used to determine identity of these relationships are given in Table 13. The number of biometrics significantly correlated is greater using OC-normalized concentrations than for non-normalized concentrations.

Table 13. Squalicum Creek biometrics and sediment toxics relationships using organic carbon normalized concentrations.

Biometrics	Toxic (mg/kg/OC)				
	Arsenic	Lead	Copper	PCBs	DDT
% Pollution Tolerant Taxa	**D***	**D***	**D***	**D***	**D***
Metals Tolerance Index		**D***			
Sediment Tolerance %	**I***				**I***
% EPT	**I***	**I***	**I***	**I***	**I***
Dominant Taxa	**D***	**D***	**D***		

Notes:
I = Inverse relationship
D = Direct relationship
* Indicates statistically significant relationships (p value ≤ 0.05) with select biometrics

Although significant correlation relationships were identified for several biometrics and toxics combinations, slopes for each indicate very little change among locations where sediments were sampled. The effect of metals toxicity on the benthic community showed the same response with presence of all or most of the toxics. For example, % Pollution Tolerant Taxa responded positively to presence of metals, PCBs, and DDT. Percent EPT declined with increasing concentrations of metals, PCBs, and DDT (Table 14).

Table 14. Summary of Squalicum Creek's biometric relationships (r-value and slope) and the significance of those relationships (p-value) with organic carbon-normalized metals concentrations.

	Metals														
	DDT			PCBs			Lead			Arsenic			Copper		
Biometric Relationships	**Slope**	***r***	**p**	**Slope**	***r***	**p**	**Slope**	***r***	**p**	**Slope**	***r***	**p**	**Slope**	***r***	**p**
% Pollution Tolerant Taxa	0.035	0.86	0.006	0.0057	0.74	0.0047	0.005	0.57	0.005	0.0092	0.52	0.0023	0.002	0.56	0.002
Metals Tolerance Index	0.0019	0.212	0.0067	0.00082	0.48	0.0048	0.0013	0.68	0.0054	-0.00013	-0.04	0.0024	0.00037	0.38	0.002
% Sediment Tolerance	-0.015	-0.59	0.007	-0.0019	-0.39	0.0048	-0.00043	-0.23	0.026	-0.005	-0.53	0.0024	-0.001	-0.37	0.002
%EPT	-0.087	-0.5	0.0138	-0.022	-0.68	0.0056	-0.026	-0.66	0.0065	-0.043	-0.61	0.0018	-0.013	-0.72	0.002
Dominant Taxa	0.09	0.49	0.017	0.024	0.7	0.005	0.029	0.72	0.0062	0.042	0.63	0.0028	0.013	0.69	0.0023

Notes:
Yellow highlighted parameters indicate significant relationships (Pearson's r-value ≥ 0.50 and p-value ≤ 0.05).
Green highlighted parameters indicate moderately significant relationships (Pearson's r-value ≥ 0.50 and p-value ≤ 0.20).

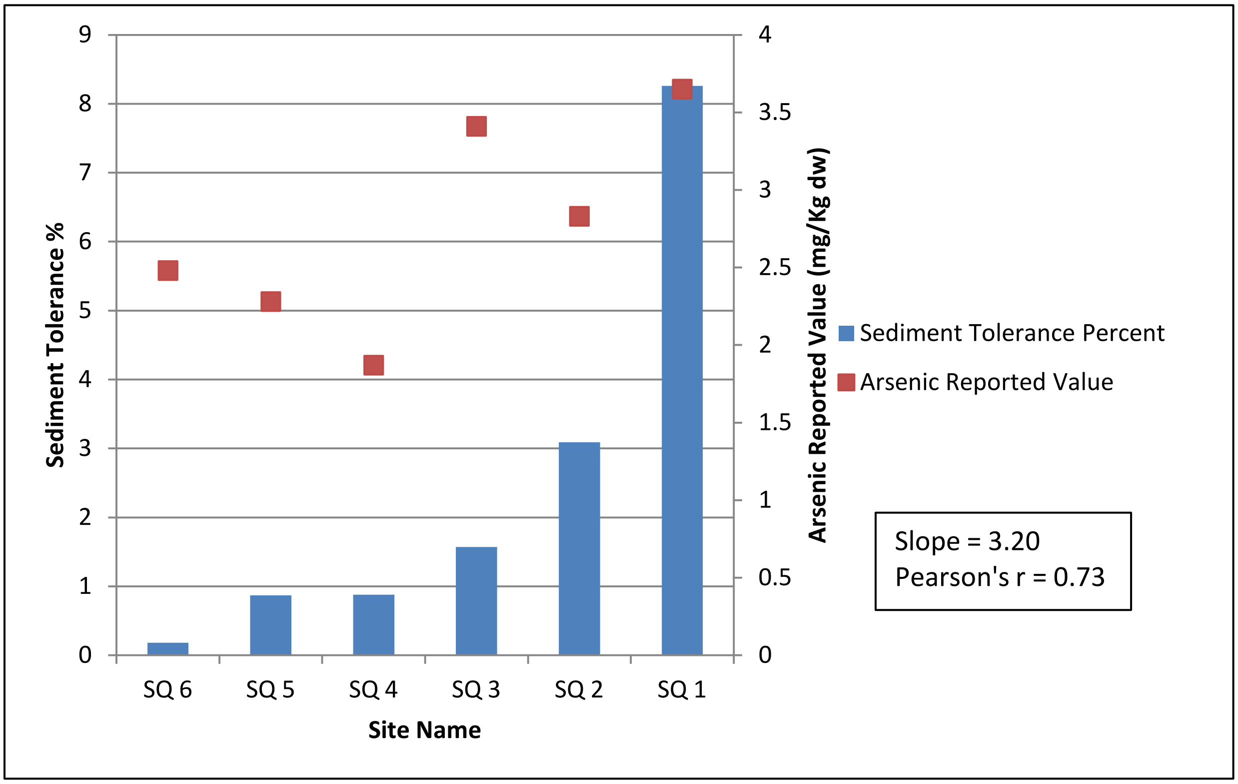


Figure 7. The relationship between arsenic and percent sediment tolerance.

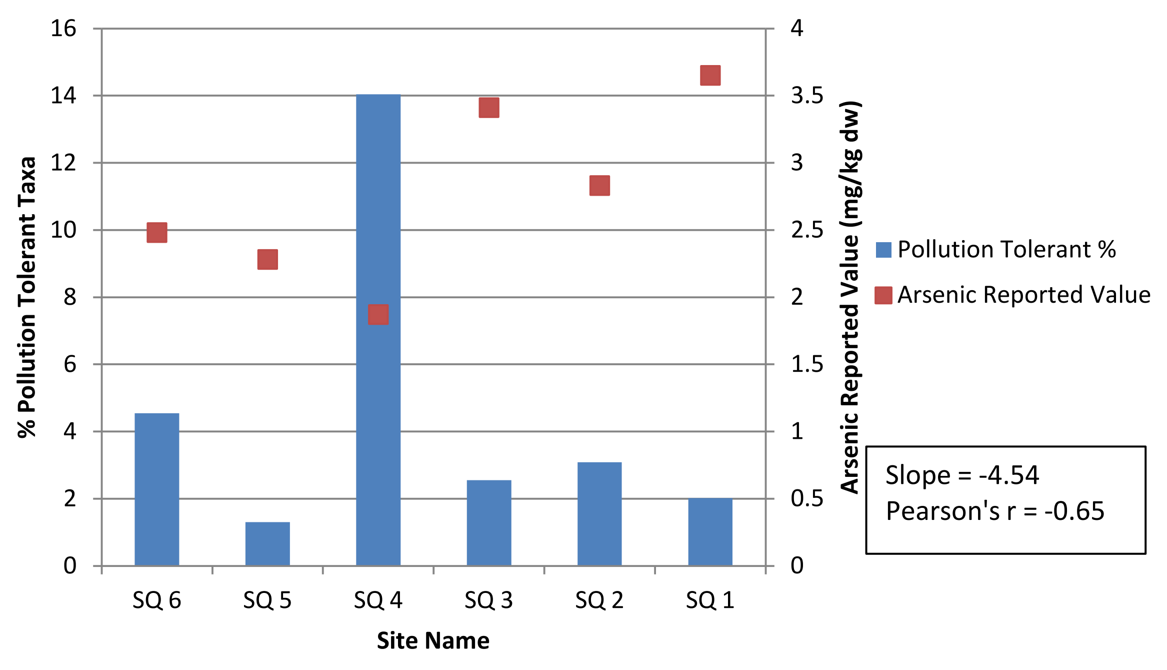


Figure 8. The relationship between arsenic and percent pollution-tolerant taxa.

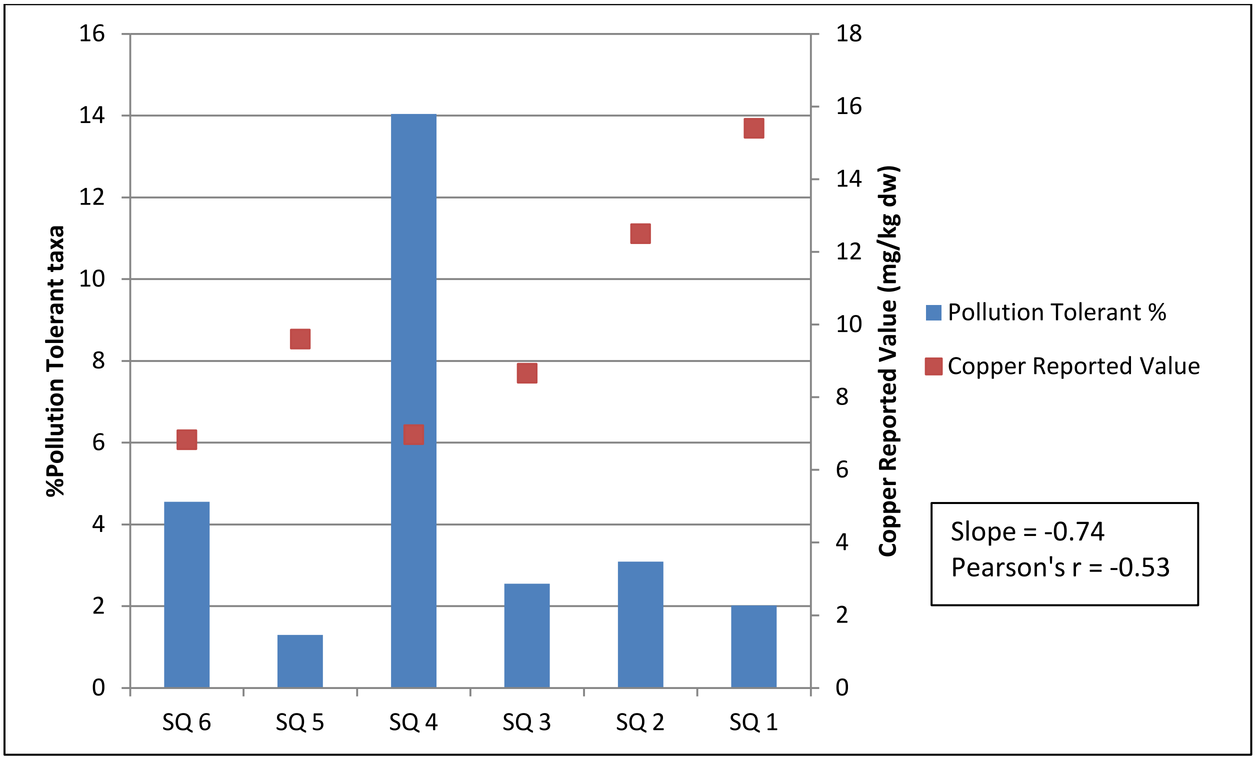


Figure 9. The relationship between copper and percent pollution-tolerant taxa.

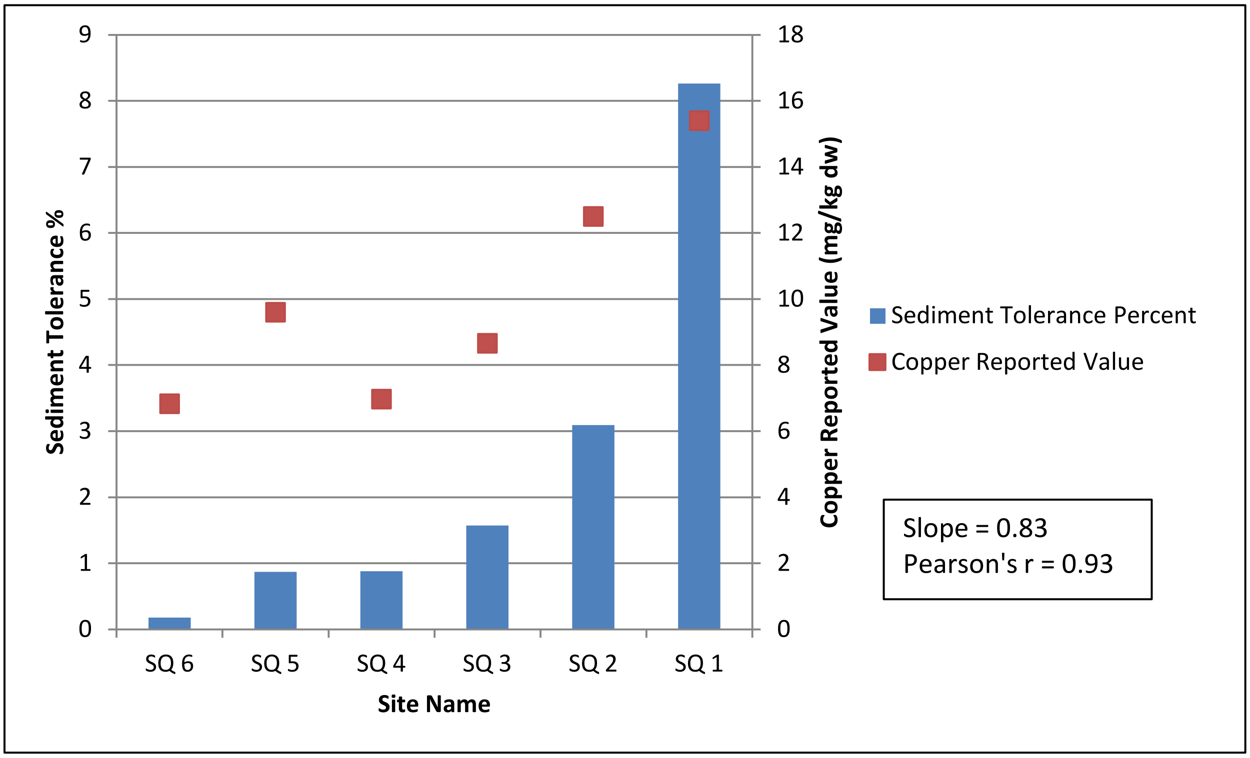


Figure 10. The relationship between copper and percent sediment tolerance.

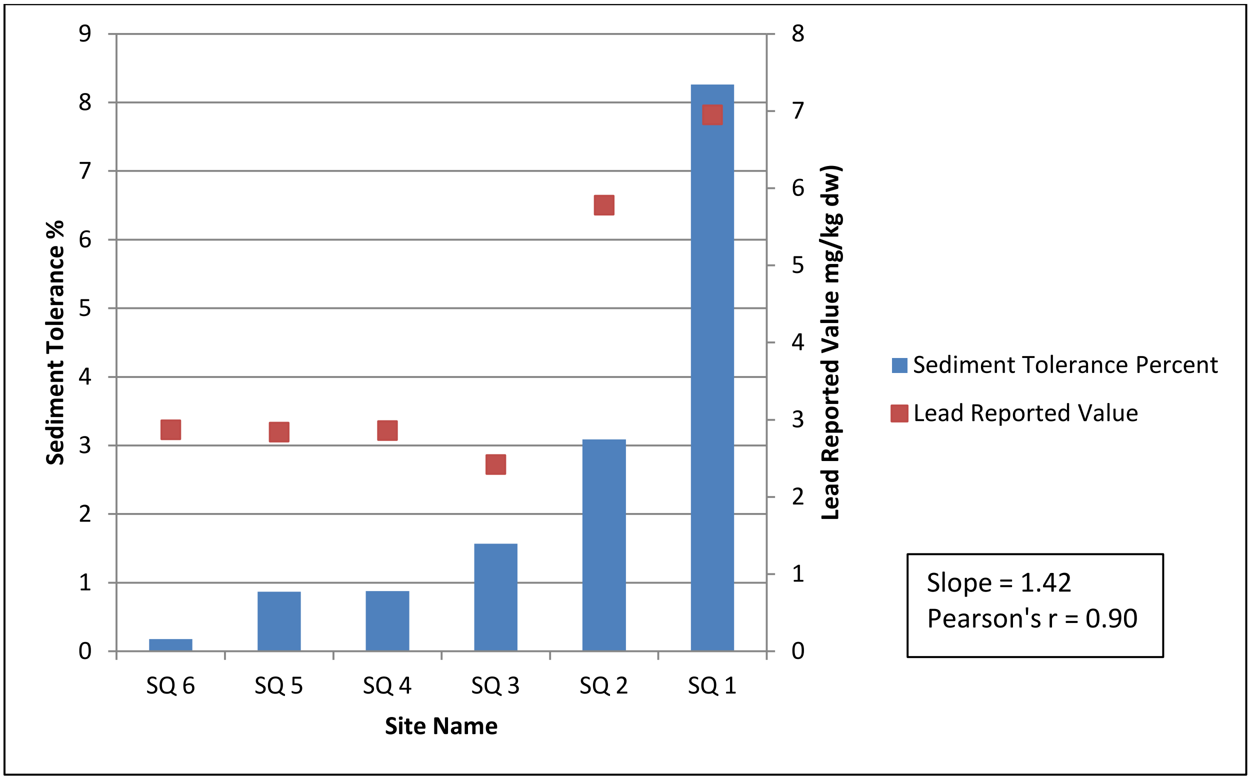


Figure 11. The relationship between lead and percent sediment tolerance.

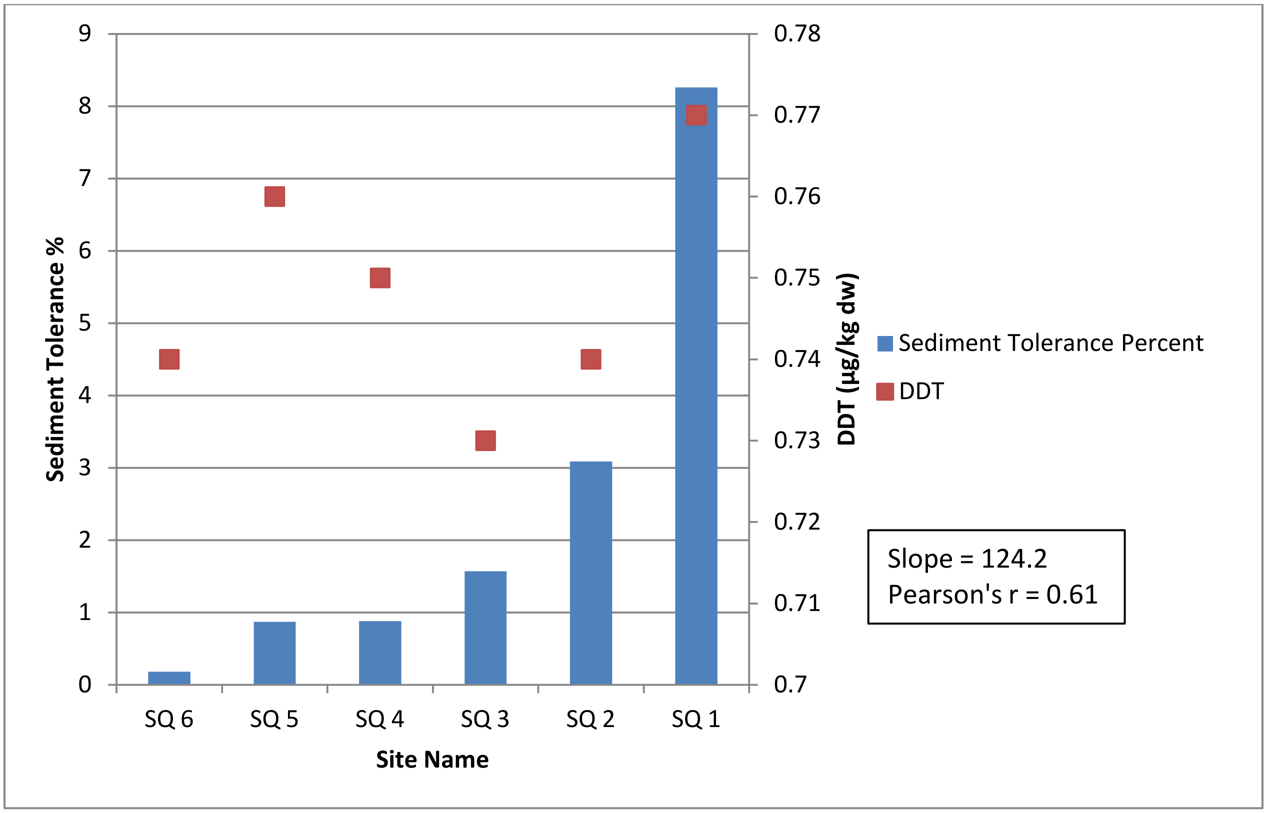


Figure 12. The relationship between DDT and percent sediment tolerance.

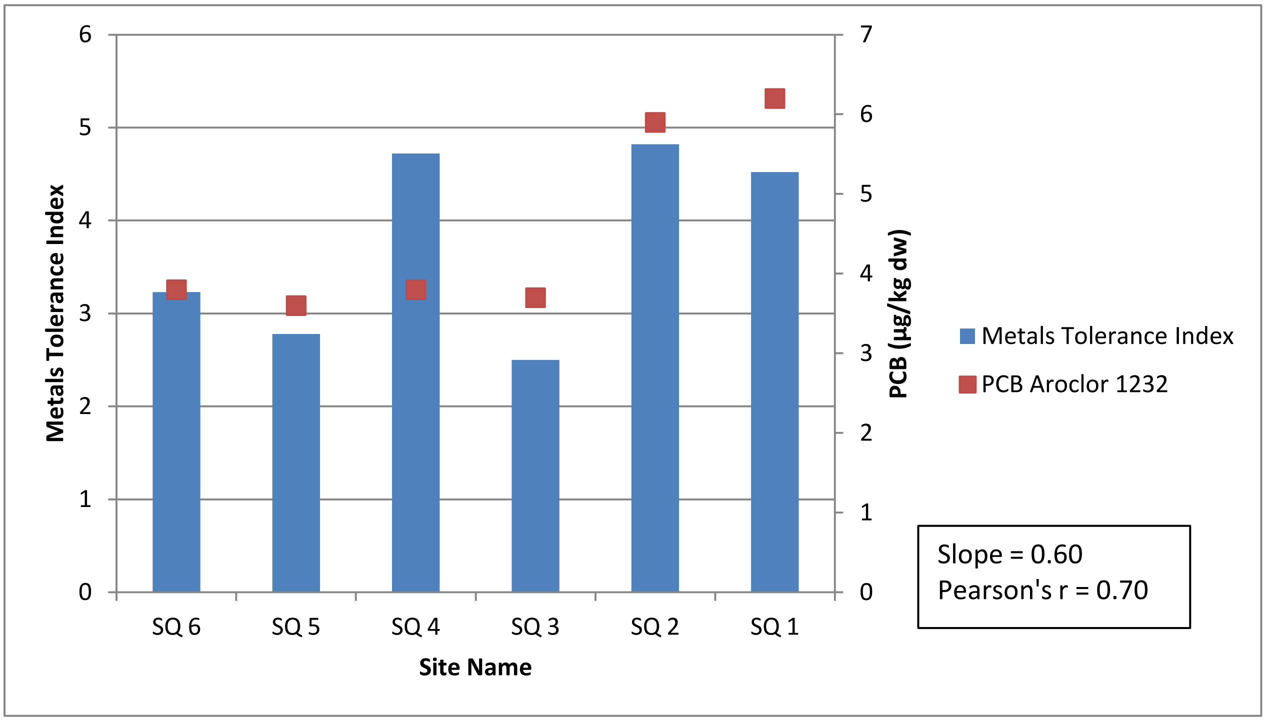


Figure 13. The relationship between PCB and metals tolerance index.

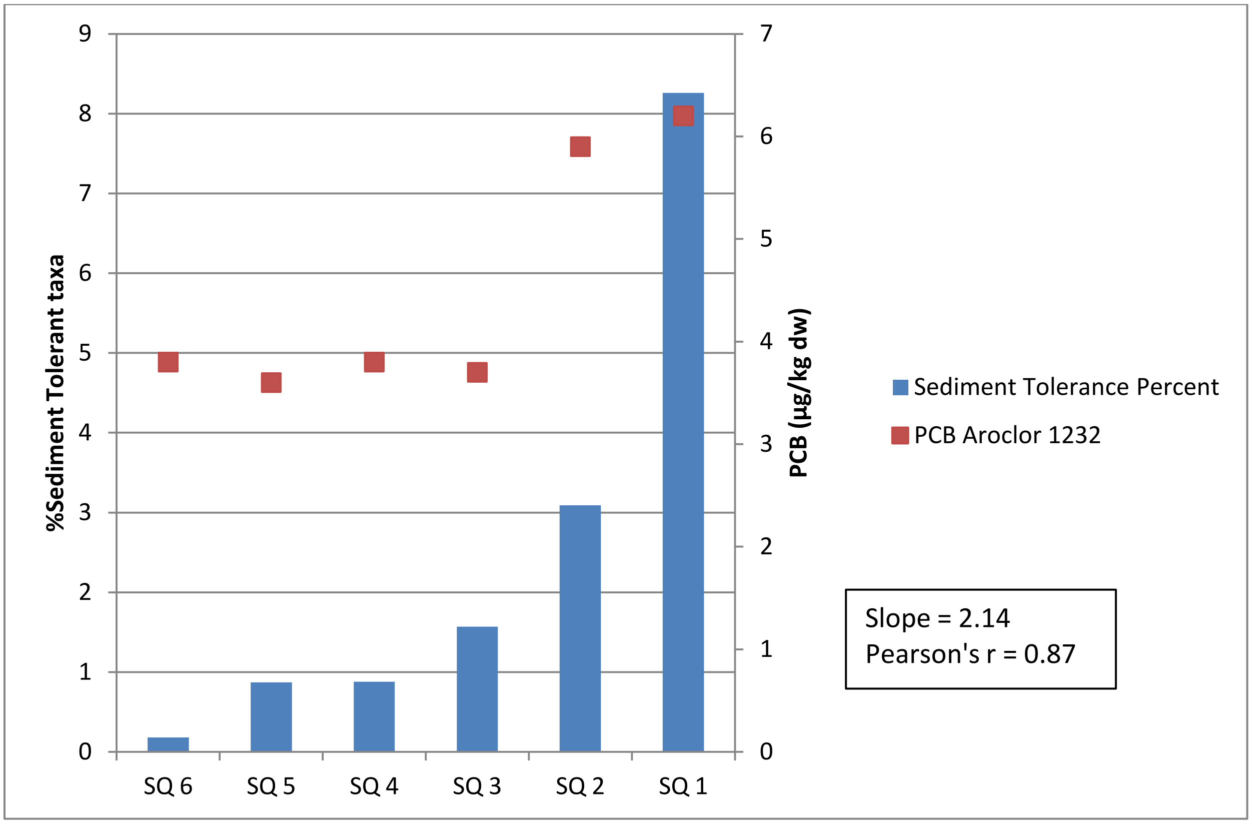


Figure 14. The relationship between PCBs (Aroclor 1232) and percent sediment tolerance.

Biologic Relationships to Flow

Flood flow events disturb and transport habitable substrate used by periphyton and benthic macroinvertebrates. Stream hydrology can be described by calculated descriptive metrics to gain an understanding of hydrological environment in the stream. Squalicum Creek hydrologic flow metrics (TQmean, and R-B Flashiness) were examined against other Puget Lowland streams and had a lower TQmean than similar streams in the region, indicating that rapid change in flow occurs (King et al. 2012). Results from examining this metric with the R-B Flashiness Index indicate that Squalicum Creek had among the highest *flashiness* (flood rise/recede interval) from 10 Puget Lowland streams (King et al. 2012). These metrics were examined as companion information to biologically affected sites to determine if altered hydrology was consistent with other related stressors. In other studies, Squalicum Creek, among other similar urban lowland streams throughout the Puget Sound (DeGasperi et al. 2009), has a particularly high flashiness and indicates the instability of substrate materials (Table 15).

Table 15. Flow metric comparisons for Squalicum Creek to area creeks.

Squalicum Creek Flow Comparison			
Site	**Average Flow (cfs/mi^2)**	**R-B Flashiness Index**	**TQmean**
Squalicum Creek	1.351	0.408	30.1
Average of other USGS gaged creeks in the area	2.3	0.34	31.09

Source: King et al. 2012

Surface water velocity is a component of flow and indicates potential of physical disturbance to the stream channel. Flows and average current velocity were calculated during each of the site assessments, and average current velocity was compared with biological response metrics (Figures 16 and 17). Average current velocity was positively correlated with presence of fine substrate material (e.g., % sand and % SCM) indicating that reach gradient was higher when stream channel depth is low.

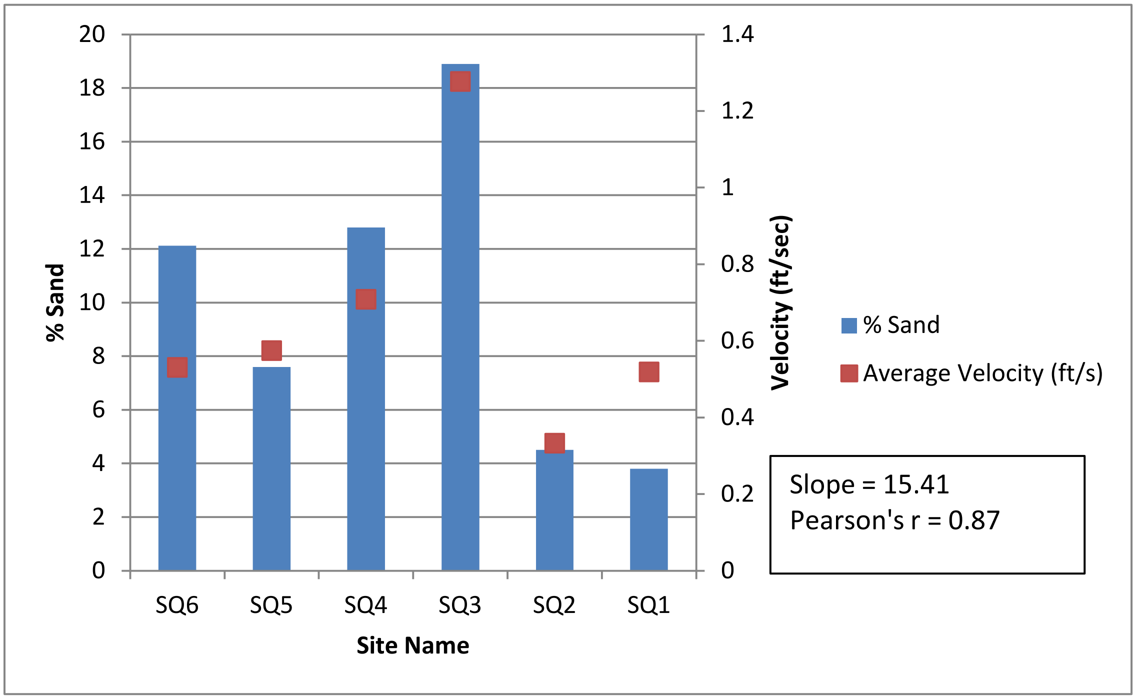


Figure 16. The relationship between % Sand and average current velocity (ft/s) at Squalicum Creek.

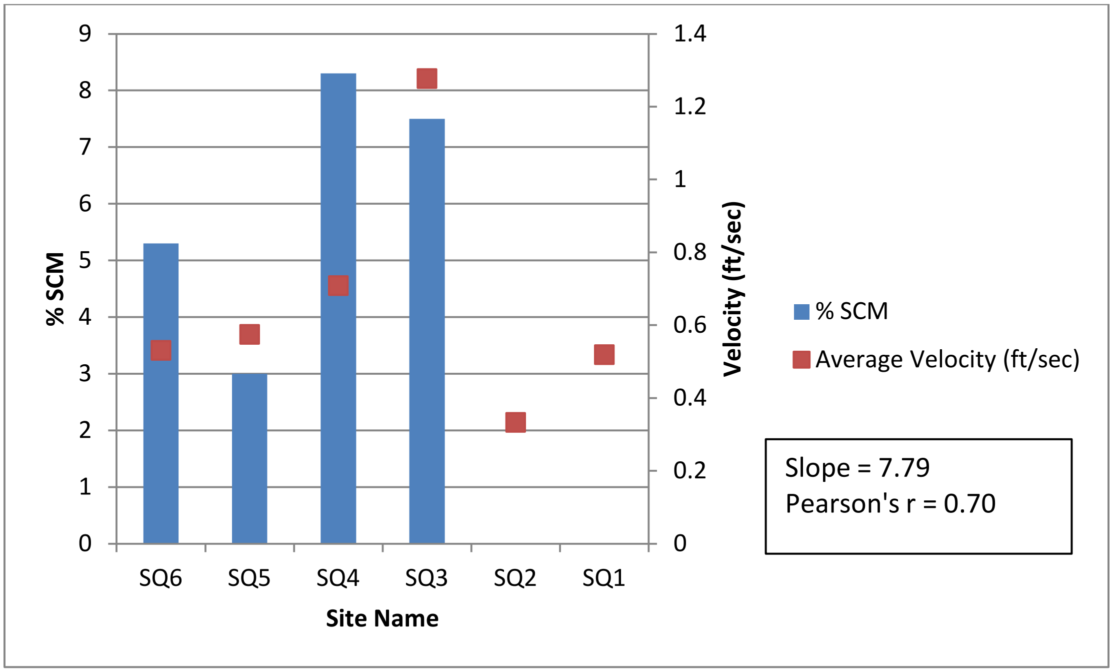


Figure 17. The relationship between % Silt, Clay, Muck, and average current velocity (ft/s) at Squalicum Creek.

Identifying physical habitat stressors with biometric responses was the focus for identifying potential impacts from past stormwater input to stream reaches. Several physical factors were identified as having substantial influence on biological condition resulting from stormwater input: substrate movement, substrate size and potential for transport and deposition, water velocity as a function of potential to move finer substrates, and flow characteristics. Each of these categories for describing physical conditions of the stream channel was evaluated using site assessment data at six sites in Squalicum Creek. The summary of results is discussed in Table 16 and addresses each of the questions presented as column headers.

Table 16. Squalicum Creek physical impacts from flow.

Site name	Physical Impacts in Squalicum Creek			
	Flow Variation			
	Substrate movement: Is substrate size subject to transport and at what intensity of stormwater input?	**Substrate size**: Are substrate size changes a result of stormwater input?	**Water velocity**: Do changes in water velocity patterns following stormwater input affect BMI communities?	**Flow volume**: Do seasonally significant volume changes affect BMI communities?
SQ-1	Substrate consists of 46% cobble, 33% coarse gravel, 12% fine gravel, and 3% sand. Substrate is 20% embedded. Fine particles are subject to stormwater flows.	Substrate size changes are a result of stormwater input, and numerous stormwater devices are within 500 meters upstream and in this reach.	Small wetted width (23.05 ft) compared to large bankfull width (43.275 ft) indicates changes in flow volume. The bank is fairly stable at 6.25% instability. BMI communities are distributed by flashy stormwater events.	Peak flows reach 107 cfs/mi^2/day during peak flow season (November through February). Low flows are measured at 0.50 cfs. Rapid changes in water velocity and quantity affect macroinvertebrates.
SQ-2	Substrate consists of 44% cobble, 26% coarse gravel, and 24% fine gravel. Substrate is 5% embedded indicating rapid transport of fine particles with stormwater flows.	Substrate size shift is a result of stormwater input, and numerous stormwater devices are within 500 meters upstream and in this reach.	Wetted width of 7.425 ft and bankfull width of 27.85 ft indicates increase in stormwater flows, 100% bank instability indicates high stormwater impacts and causes increased conductivity, flow, and decrease in stable BMI habitats.	Peak flows reach 23.6 cfs/mi^2/day during high-flow season (February). Low flows are measured at 0.07 cfs. Rapid changes in water velocity and quantity affect macroinvertebrates.
SQ-3	Substrate consists of 44% fine gravel, 19% sand, 19% coarse gravel, and embeddedness of 30%. This indicates inputs from stormwater flows.	Shift in substrate size could be a result of stormwater inputs because of high embeddedness measurements and amounts of small, easily transported substrate particles. Numerous stormwater devices are within 500 meters upstream and in this reach.	A wetted width of 8.88 ft and a bankfull width of 25.95 ft with 29.375% bank instability are characteristic of high stormwater inputs, which could affect BMI communities.	Squalicum Creek has an R-B Flashiness Index of 0.408, indicating rapid changes in water velocity and water quantity during peak, seasonal flows. Substrate sizes are less habitable and easily moved during storm events and benthic communities experience disruption in colonization. Runoff at this site is explained by high amounts of impervious surface.
SQ-4	Substrate consists of 31% coarse gravel, 21% fine gravel, 13% sand, and 21% cobble with 13.75% embeddedness. Smaller particles are subject to transport with stormwater flows.	Substrate sizes are a mixture of stable habitat (cobble) and easily moved particles (sand, gravel). Size changes are a result of stormwater flow, because multiple stormwater devices are 500 meters upstream and in the reach.	The 16.875% bank instability and 12.175 ft wetted width with a bankfull width of 38.45 ft gives evidence of higher stormwater flows and effects on BMI communities.	Squalicum Creek has an R-B Flashiness Index of 0.408, indicating rapid changes in water velocity and water quantity during peak, seasonal flows. Substrate sizes are less habitable and easily moved during storm events, and benthic communities experience disruption in colonization. Runoff at this site is explained by high amounts of impervious surface.
SQ-5	Substrate consists of 40% coarse gravel, 28% cobble, and 13% fine gravel. Substrate is 29% embedded. Smaller particles are subject to stormwater transport.	Substrate size changes are likely not a result of stormwater flow because there is no record of stormwater devices within 500 meters upstream and in this reach and few impervious surfaces.	The 3.125% bank instability indicates minimal changes in flow throughout the year and small effects on BMI communities.	Squalicum Creek has an R-B Flashiness Index of 0.408 indicating rapid changes in water velocity and amount during peak seasonal flows, disturbing macroinvertebrate communities. However, this site lacks impervious surfaces and stormwater devices, which increase the negative impacts of peak flows on streams.

Site name	Physical Impacts in Squalicum Creek			
	Flow Variation			
	Substrate movement: Is substrate size subject to transport and at what intensity of stormwater input?	**Substrate size**: Are substrate size changes a result of stormwater input?	**Water velocity**: Do changes in water velocity patterns following stormwater input affect BMI communities?	**Flow volume**: Do seasonally significant volume changes affect BMI communities?
SQ-6	Substrate consists of 37% clay, 5% silt, clay, muck mixture, 12% sand, and 33% coarse gravel. Embeddedness measures of 26% indicate that particles are subject to transport by stormwater.	Substrate size changes are likely not a result of stormwater flow because there is no record of stormwater devices within 500 meters upstream and in this reach and few impervious surfaces.	The bank instability of 12.5%, wetted width of 11.35 ft, and bankfull width of 13.275 ft indicate minimal changes in stormwater flow and small effects on BMI communities. Bank instability was localized in the reach with some evidence of installed stabilization structures. Severe bank instability is possible in this reach.	High flows of 55 cfs/mi^2/day during peak flow season (February) compared to 0.5 cfs low flows cause rapid changes in water velocity and volume . However, this site lacks impervious surfaces and stormwater devices, which increase the negative impacts of peak flows on streams.

Indicators of stormwater influence included in Table 16 are elements of the conceptual stormwater runoff diagrams (Figures 21 through Figure 23) and used as high-level indicators for identifying impacts. The observations are descriptive and use results from field assessments to explain physical habitat conditions and biological scores.

Biologic Relationship to Landscape Development Intensity

LDI reflects the cumulative impact any combination of adjoining land uses on a nearby stream. The LDI uses weighted factor scores for each type of land use on the basis of the intensity of the effect on stream conditions. The weighted factor score is multiplied by the percentage of each category of land use to determine total impact expected at one point in a stream. Higher LDI scores reflect a greater impact on a stream and potential for alteration of aquatic communities (Brown and Vivas 2005). Urban land-use types are expected to have a greater impact on an adjacent stream during storm events by contributing a higher load of pollutants, introducing scouring flows, and destabilizing substrates and other physical features in the stream channel. More stable stream channels and those protected from pollutant delivery and scouring floods are expected in areas where surrounding land use is dominated by intact forests in western Washington and LDI is low (Konrad and Booth 2002).

The LDI is a high-level indicator for potential to affect stream conditions. A high-level indicator means that a numerical value calculated for this metric might not be sensitive to minor changes in an instream response variable and might not always be correlated with some biological responses (e.g., RIVPACS scores). A comparison of the LDI index with RIVPACS scores demonstrates this inconsistency, meaning that other factors explained by relationships between biometrics and physicochemical conditions are responsible for lower RIVPACS scores where LDI is not as severe (Table 17). Booth et al. (2004) indicate that landscape metrics like impervious area cannot be used alone to explain changes in biological integrity. Surrogate expressions like hydrologic metrics reflect persistent impacts that have greater association with biological response and demonstrate direct mechanistic linkages with stormwater runoff.

Table 17. Squalicum Creek RIVPACS and LDI scores.

Site ID	LDI Index	RIVPACS Score	RIVPACS Condition
SQ-1	9.86	0.55	Poor
SQ-2	12.08	0.55	Poor
SQ-3	5.57	0.47	Poor
SQ-4	3.89	0.54	Poor
SQ-5	0.33	0.73	Concern
SQ-6	0.21	0.55	Poor

The following series of figures identifies characteristics of the benthic macroinvertebrate community responding to different intensities of development. The % Clingers shows an inverse relationship to LDI (Figure 18). Stronger relationships between LDI were demonstrated with % EPT (Figure 19) and with % Scrapers and Shredders (Figure 20). Taxa included in these biometrics (% EPT and % Scrapers and Shredders) are sensitive to changes in physical habitat, including past stream disturbances, and to toxics in sediment and surface water. Moderate correlation strength between individual biometrics and development intensity is reported in Table 13.

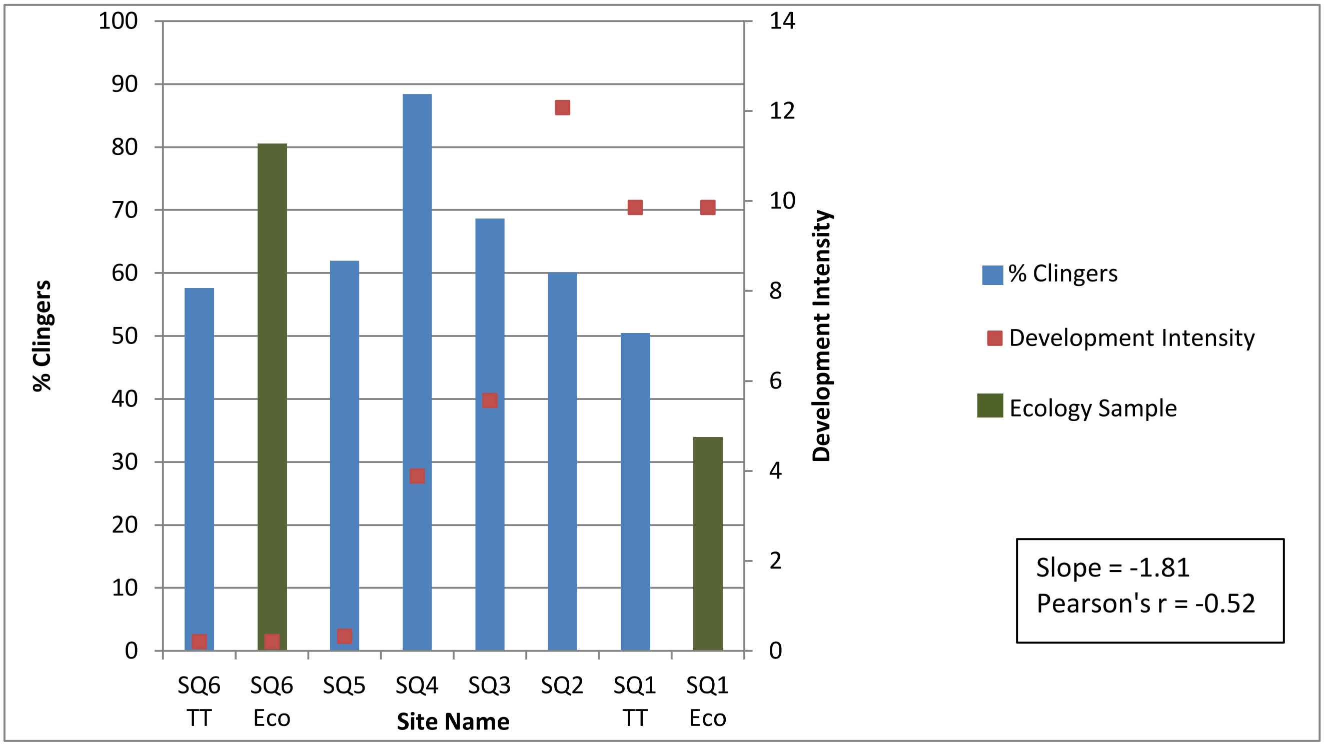


Figure 18. The relationship between LDI and % Clingers.

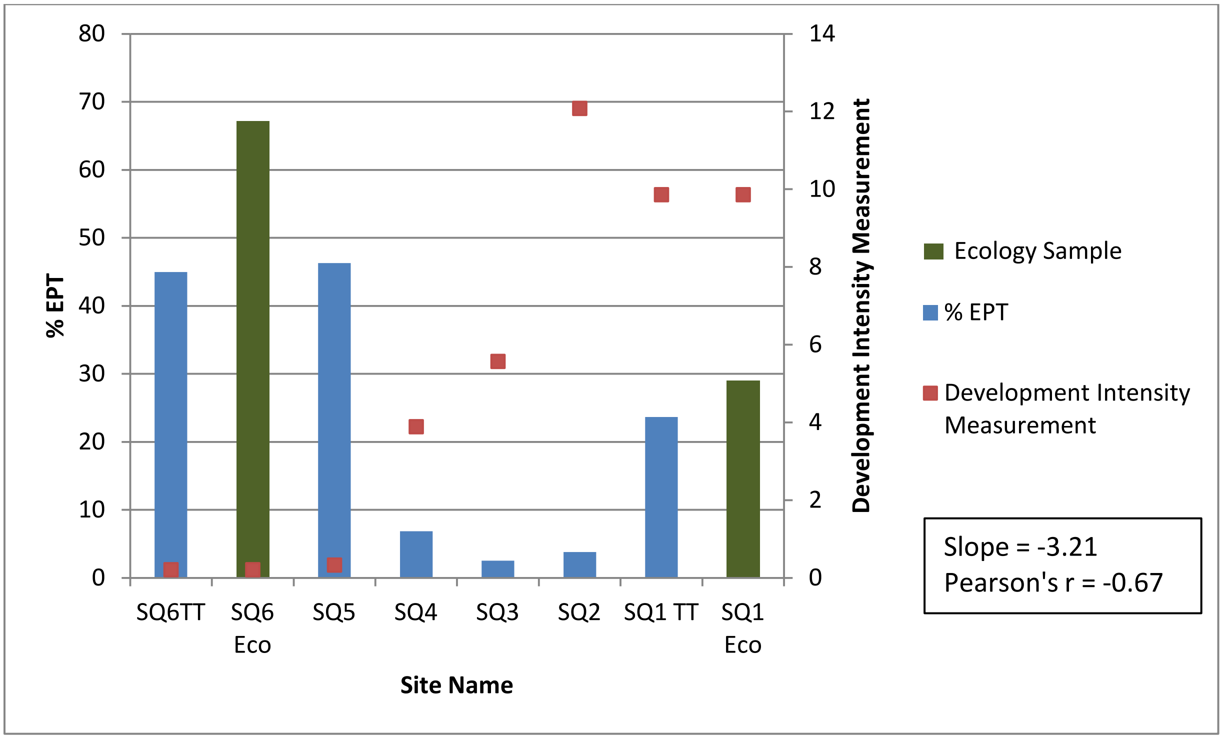


Figure 19. The relationship between development intensity and % EPT.

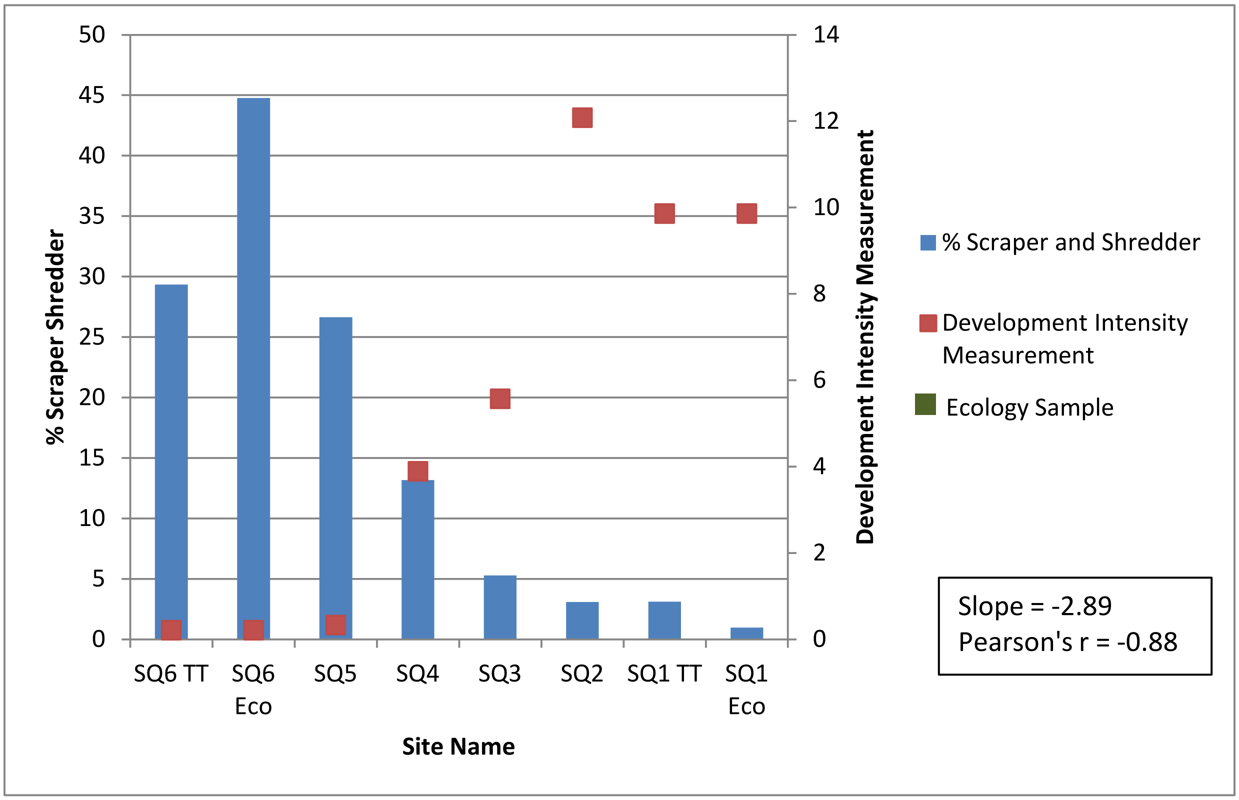


Figure 20. The relationship between development intensity and % scraper and shredder.

Results from correlations between biometrics and landscape descriptions identified some components of the benthic community that responded to LDI (Table 18). Each of the biological indicators showed a negative response to increasing landscape development.

Table 18. Significant relationships between LDI and BMI biometrics.

Biometric	Slope	Pearson's Product-Moment Correlation (r)
% Clingers	-1.81	-0.52
% EPT	-3.21	-0.67
% Scraper and Shredder	-2.89	-0.88

Linking Biological Response to Stormwater

Stormwater flows and associated pollutants are considered the principal source, though not the only potential stressors, to Squalicum Creek. Other potential sources of pollution could be logging, deposition by airborne particulates, permitted effluent to surface waters, water withdrawals / returns, groundwater, farming, or illicit discharges that are not stormwater related.

Analysis of the data in this project is focused on partitioning (to the extent possible) stormwater-related effects on stream biological communities from other sources of pollution, because biota are responding to the cumulative impact of all sources.

Various types of land use observed along Squalicum Creek introduce stormwater pollutants by different pathways and have different effects on physical habitat and biological communities. Figures 21–23 are stormwater runoff diagrams showing the different pathways for forested, commercial (impervious), and suburban (residential) settings and are described below. The diagrams describe movement of stormwater through each of the settings, the mechanism for stormwater introduction, and the resultant potential effect on BMI and periphyton communities (USEPA 2008; Adams 2010a).

The diagrams show two types of information: (1) the physical movement and transfer of stormwater from a terrestrial area to the stream, and (2) physicochemical factors affected by movement of stormwater in both terrestrial and aquatic environments.

Conceptual stormwater runoff diagrams describe the relationship with instream biological responses. Each of the land-use settings has a list of physicochemical factors and changes expected to occur in the presence of stormwater input to a stream channel. Relationships previously established through correlation analysis indicate which of the physicochemical factors are likely causes for biological impact.

Wherever a link occurred between biological impact and physicochemical factors altered from stormwater, a circled numeral was placed in the list. These numerals were followed by a more detailed explanation presenting evidence for determining stormwater effect on instream habitat and water quality.

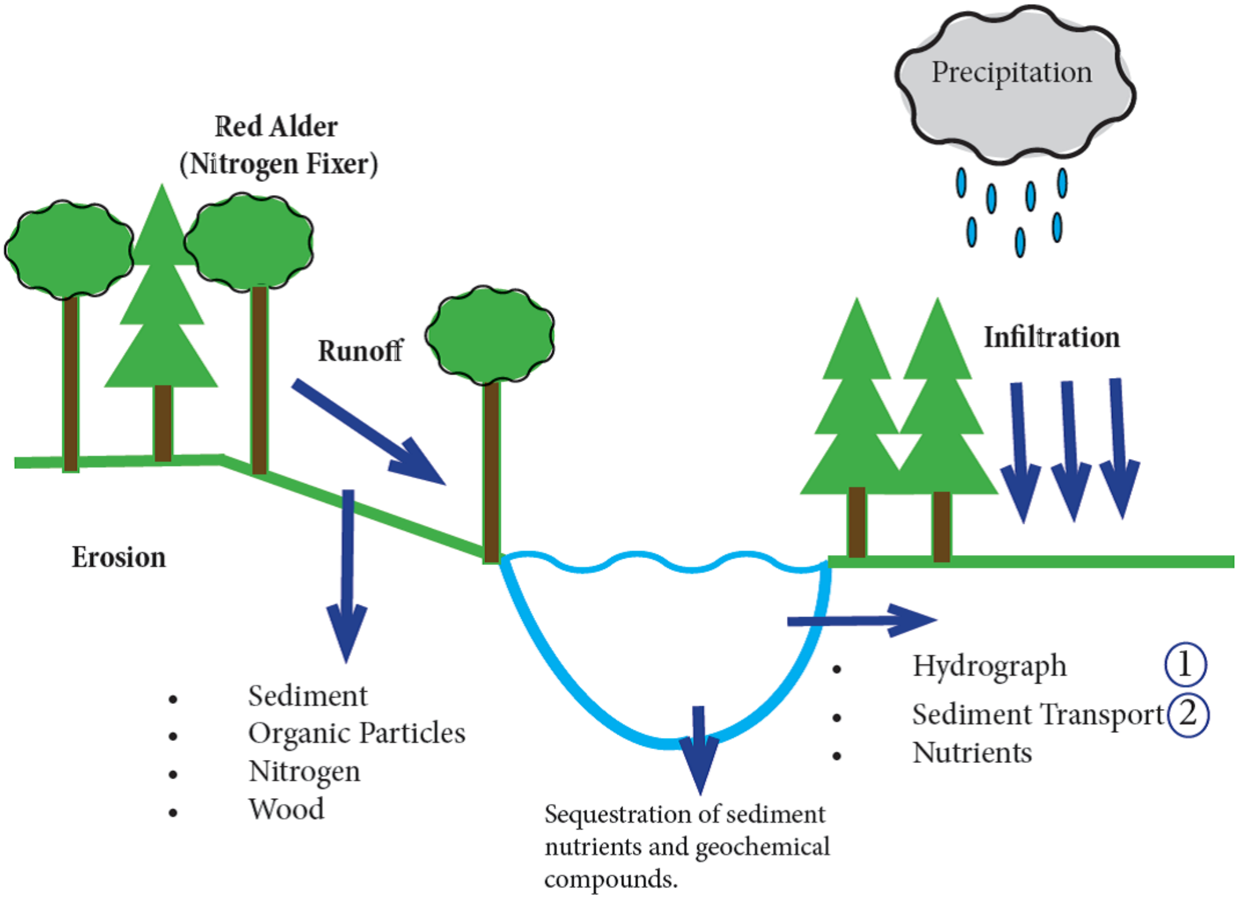
Mixed Forested Areas

The mixed forested setting represents sites SQ-5 and SQ-6 in Squalicum Creek. Forested settings (Figure 21) have lower peak flows than sites monitored with larger amounts of impervious surfaces and stormwater outfalls. However, these forested sites (mixed forest land use) experienced altered hydrographs because of reduced forested landscape, steep gradients, and erosion, causing decreases in total algal species and changes in macroinvertebrate species to less sensitive, more pollution-tolerant species.

Sediment transport was elevated at these mixed forested sites (SQ-5 and SQ-6) likely because of runoff from steep gradients. Within Squalicum Creek, changes in substrate size cause large effects on % EPT, total number of periphyton taxa, % Scrapers and shredders, and % Clingers.

The following summaries describe the affected physicochemical elements on the basis of site assessments in forested areas reported in Figure 21:

- *Altered Hydrology:* Forested land-use area sites have lower peak flow than sites with larger amounts of impervious surfaces and stormwater devices. However, increased hydrographs can still occur during stormwater events with steep-sided stream banks along the assessment reach and *rils* formed by stormwater runoff events, resulting in decreases in total algal species and changes in macroinvertebrate species to less sensitive, more pollution-tolerant species.
- *Sediment Transport:* Sediment transport is increased at forested sites because of stormwater runoff from steep-sided stream banks. A dominance of finer substrate sizes resulted in decreased representation of % EPT, total number of periphyton taxa, % Scrapers and shredders, and % Clingers than expected from a reference condition.



Physiochemical Factors	*Changes*
Increased Hydrograph	Moderate
Sediment Transport	Moderate
Increased Nutrients	High

Mixed Forested Areas

Squalicum Creek Sites
- SQ-5: Above SR 542
- SQ-6: Upper Squalicum

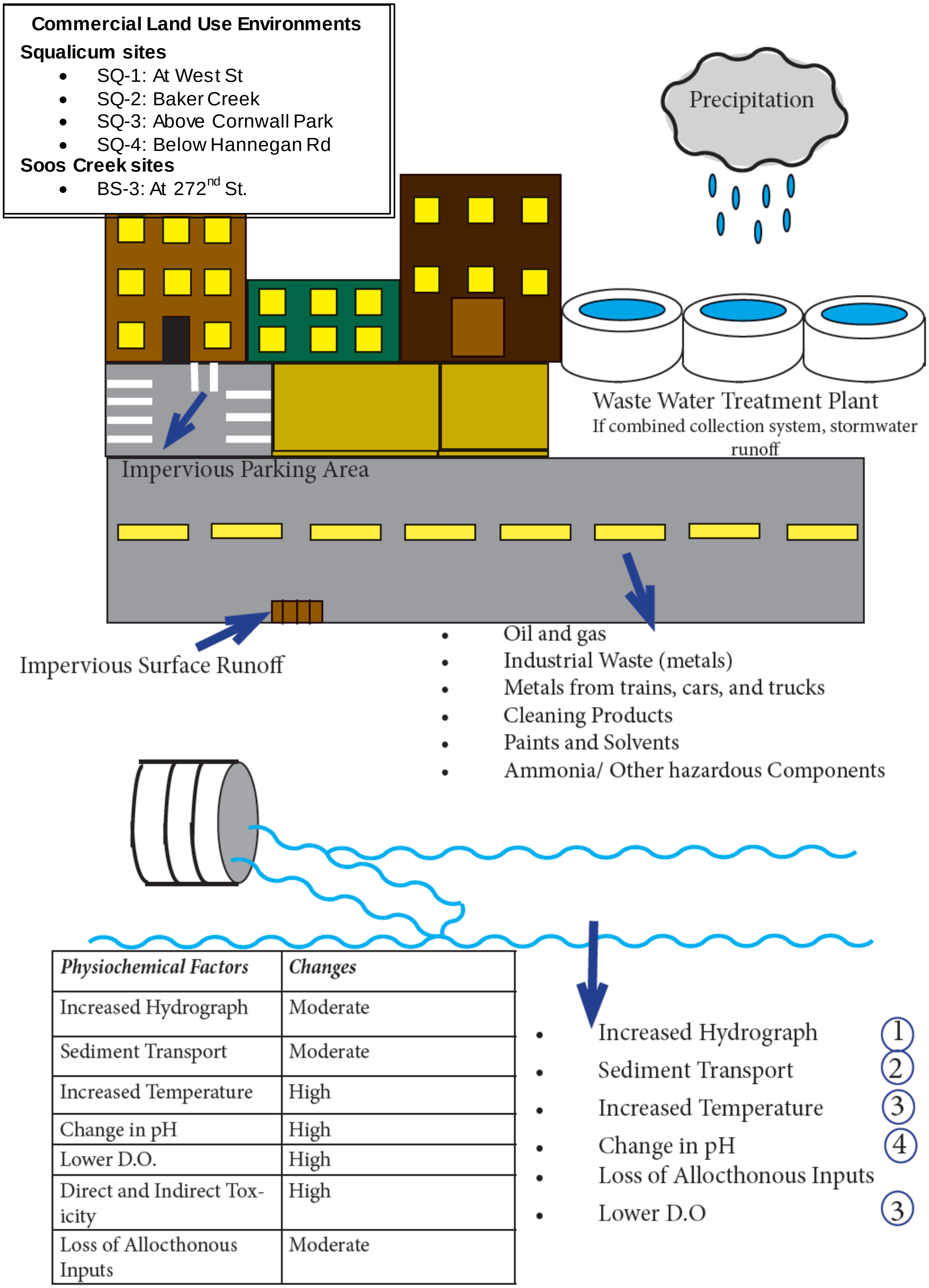
Soos Creek Sites
- CC-1: At 168th Ave
- BS-2: Near SR 58
- CC-2: SR 58 Crossing Kent Black Diamond Rd

Figure 21. Conceptual stormwater runoff diagram for mixed forested areas.

Commercial Setting

The commercial setting represents sites SQ-1, SQ-2, and SQ-3. SQ-4 in Squalicum Creek represents a mixture of rural residential and commercial (Figure 22). Biological response to stormwater from the commercial setting is influenced in the following ways:

- *Altered Hydrology*: Increased flow at Squalicum Creek has a direct impact on total number of algal species.
- *Sediment Transport*: At Squalicum Creek, changes in substrate size result in decreased % EPT, periphyton taxa richness, % Scrapers and shredders, and % Clingers.
- *Increased Temperature/Low Dissolved Oxygen*: Increased temperatures and decreased dissolved oxygen at Squalicum Creek are correlated with a decrease in % Scrapers and shredders. Temperature increases affect pollution-sensitive species and pollution-tolerant species.
- *Change in pH*: At Squalicum Creek, changes in pH are correlated with decreased amounts of % EPT, % Scrapers and shredders, and total number of algal species, increases in % pollution-tolerant taxa.
- *Direct/Inverse Toxic Effects (OC normalized results)*: Metals data collected from Squalicum Creek commercial sites show high amounts of arsenic, lead, copper, and PCBs in comparison with other sites. These metals have an inverse relationship with macroinvertebrate % sediment-tolerance taxa presence, and a direct relationship with % pollution-tolerant taxa.



Commercial Land Use Environments

Squalicum sites

- SQ-1: At West St
- SQ-2: Baker Creek
- SQ-3: Above Cornwall Park
- SQ-4: Below Hannegan Rd

Soos Creek sites

- BS-3: At 272nd St.

- Oil and gas
- Industrial Waste (metals)
- Metals from trains, cars, and trucks
- Cleaning Products
- Paints and Solvents
- Ammonia/ Other hazardous Components

Physiochemical Factors	*Changes*
Increased Hydrograph	Moderate
Sediment Transport	Moderate
Increased Temperature	High
Change in pH	High
Lower D.O.	High
Direct and Indirect Toxicity	High
Loss of Allocthonous Inputs	Moderate

- Increased Hydrograph ①
- Sediment Transport ②
- Increased Temperature ③
- Change in pH ④
- Loss of Allocthonous Inputs
- Lower D.O ③

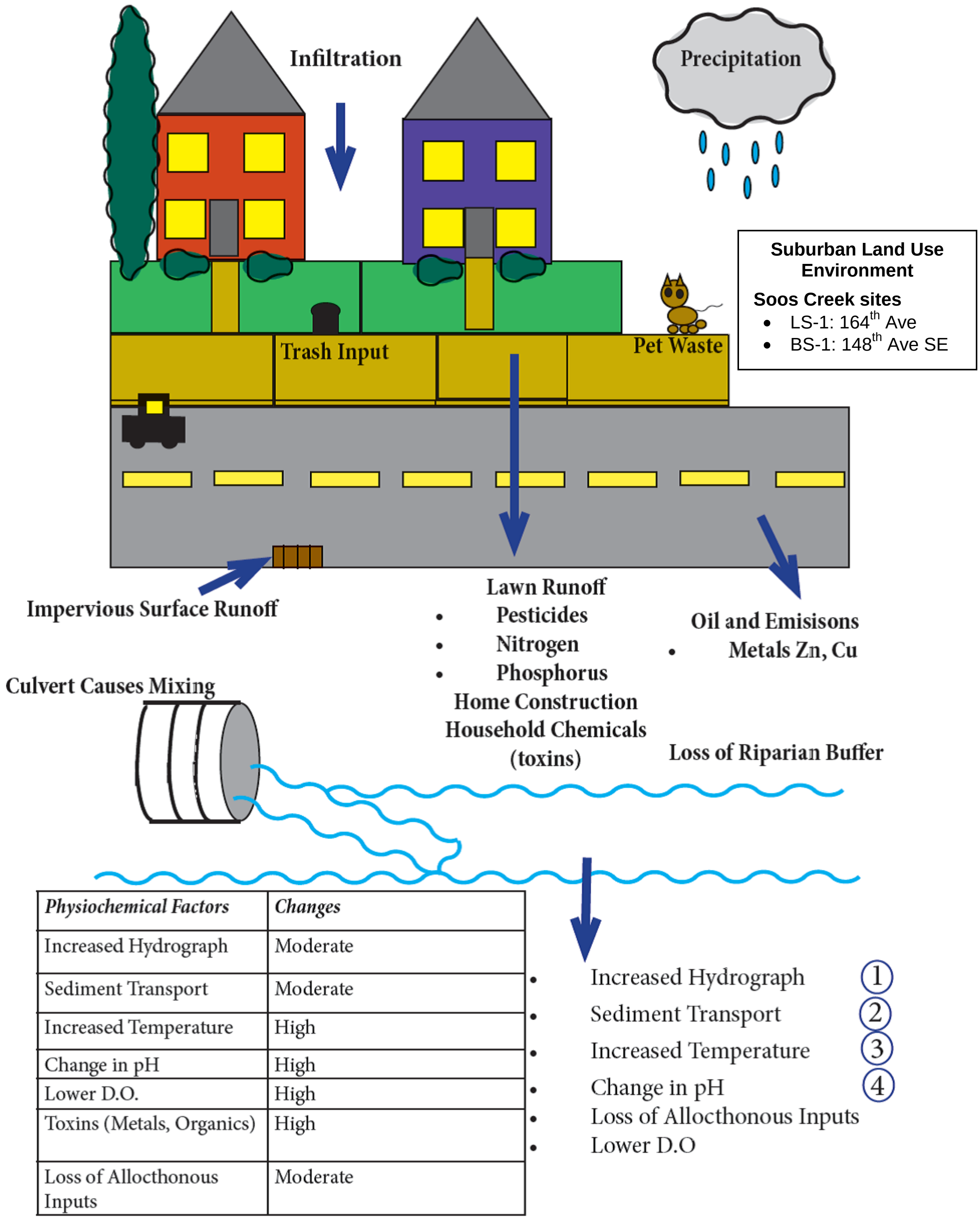
Figure 22. Conceptual stormwater runoff diagram for commercial areas.

Suburban Setting

The suburban setting represents sites LS-1 and BS-1 in the Soos Creek watershed (Figure 23). No suburban sites were assessed in the Squalicum Creek watershed. Biological response to stormwater from the suburban setting is influenced in many ways and is described for Soos Creek results:

- *Increased Hydrograph:* Increased flow at Soos Creek causes change in biological condition. Direct relationships were identified with current velocity on % Clinger richness, semi-voltine richness, Trichoptera, Ephemeroptera, pollution-sensitive species, and total number of algal species.
- *Sediment Transport:* Sediment at these sites is dominated by fines, sand, and silt/clay/muck, resulting in lower taxa richness and % top three abundant species.
- *Increased Temperature:* Increased temperatures at these suburban sites were correlated with an increase in % pollution-tolerant species, and an increase in % top three abundant species.
- *Change in pH:* Changes in pH because of stormwater runoff are correlated with a decrease in taxa richness, clinger richness, semi-voltine richness, Trichoptera, Ephemeroptera, total number of algal species, and % pollution-sensitive taxa.

Biometric relationships established with physical habitat and water quality conditions were sorted into one of several physicochemical factors (Figure 23). The evidence for impacts by past stormwater input was based on individual site assessments of each parameter (physical habitat and water quality stressors). The following tables summarize what is known about biological condition related to potential stormwater stressors in Squalicum Creek (Table 19).



Physiochemical Factors	*Changes*
Increased Hydrograph	Moderate
Sediment Transport	Moderate
Increased Temperature	High
Change in pH	High
Lower D.O.	High
Toxins (Metals, Organics)	High
Loss of Allocthonous Inputs	Moderate

Figure 23. Conceptual stormwater runoff diagram for suburban areas.

Table 19. Indicators of stormwater influences in Squalicum Creek

Site	Indicators of Stormwater Influences						
	Substrate and gradient[a]	Stormwater devices within 500-meter area (estimate)[b]	Land use[c]/ impervious surfaces[d]	Metals, PCBs, BNAs[e] (non-normalized for OC)	B-IBI score	RIVPACS scores	Development intensity scores
SQ-1	Substrate consists of 46% cobble, 33% coarse gravel, 12% fine gravel, and 3% sand. Substrate is 20% embedded. Although the majority of substrate is cobble, fine particles are subject to stormwater flows. Gradient is 2.25% or moderate with fine sediment deposition.	32 pipe ends, 17 manhole covers, 2 detention facilities, and 3 culverts.	Contributing area composed of 34% medium- to high-density developed land. 38% impervious	Concentrations of PCB (6.2 µg/kg/dw; avg of all sites. 4.5 µg/kg/dw), arsenic (3.65 mg/kg/dw; avg of all sites 2.75 mg/kg/dw), copper (15.4 mg/kg/dw; avg 10.0 mg/kg/dw), and lead (6.95 mg/kg/dw; avg for all sites 3.95 mg/kg/dw) are highest at this site. Zinc (69.7 mg/kg/dw; avg for all sites 49.06) is second highest at this site.	18 ± 2 indicates **poor** water quality conditions.	0.55 O/E indicates **poor** water quality conditions.	9.86
SQ-2	Substrate consists of 44% cobble, 26% coarse gravel, and 24% fine gravel. Substrate is 5% embedded, indicating rapid transport of fine particles with stormwater flows. Gradient is moderate at 2.75% and accompanied by fine sediment deposition.	35 pipe ends, 12 manhole covers, 2 culverts, 5 detention facilities.	Contributing area composed of 12% medium- to high-density developed land (Golf Course adjacent the stream reach). 14% impervious	Site with the second highest concentrations of most metals. PCB is 5.9 µg/kg/dw, copper is 12.5 mg/kg/dw, lead 5.78 mg/kg/dw, and zinc concentration is the highest at this site with 74.8 g/kg/dw.	16± 2 indicates **poor** water quality conditions.	0.55 O/E indicates **poor** water quality conditions.	12.08
SQ-3	Substrate consists of 44% fine gravel, 19% sand, 19% coarse gravel, and 30.204% embeddedness, indicating changes in substrate due to stormwater flows. Gradient is 1.375% and dominated by fine sediment.	64 pipe ends, 18 manhole covers, 6 detention ponds, and 2 culverts.	Contributing area composed of 28% medium- to high-density developed land. 29% impervious	Arsenic is second highest at this site with a concentration of 3.41 mg/kg/dw.	18± 2 indicates **poor** water quality conditions.	0.47 O/E indicates **poor** water quality conditions.	5.57
SQ-4	Substrate consists of 31% coarse gravel, 21% fine gravel, 13% sand, and 21% cobble with 13.75% embeddedness. Smaller particles are subject to transport with stormwater flows. Gradient is 3% or moderate and has fine sediment deposition.	33 pipe ends, 3 manhole covers, 3 detention ponds, and 0 culverts.	Contributing area composed of 4% medium- to high-density developed land. 7% impervious	Metal concentrations at this site are around or lower than average for all sites.	20 ± 2 indicates **poor** water quality conditions.	0.54 O/E indicates **poor** water quality conditions.	3.89

Site	Indicators of Stormwater Influences						
	Substrate and gradient[a]	**Stormwater devices within 500-meter area (estimate)**[b]	**Land use**[c]**/ impervious surfaces**[d]	**Metals, PCBs, BNAs**[e] **(non-normalized for OC)**	**B-IBI score**	**RIVPACS scores**	**Development intensity scores**
SQ-5	Substrate consists of 40% coarse gravel, 28% cobble, and 13% fine gravel. Substrate is 29% embedded. Smaller particles are subject to stormwater transport. 3% or moderate gradient and dominated by fine sediment.	0 pipes, manhole covers, detention ponds, or culverts.	Contributing area composed of > 1% medium- to high-density developed land. 1% impervious	Metals concentrations at this site are at or below average for all sites.	44 ± 2 indicates **good** water quality conditions.	0.73 O/E indicates **fair** water quality conditions (This site has some roads and stream crossings with degradation reflected in the RIVPACS score. Some stormwater impacts have occurred but are not as severe as those described in lower parts of the drainage).	0.33
SQ-6	Substrate consists of 37% clay, 5% silt, clay, mud mixture, 12% sand, and 33% coarse gravel. Embeddedness is 26%. 1.75% or low gradient slope and dominated by fine sediment.	0 pipes, manhole covers, detention ponds, or culverts.	Contributing area composed of > 1% medium- to high-density developed land. < 1% impervious	Metals concentrations at this site are at or below average for all sites.	42 ± 2 indicates **good** water quality conditions.	0.55 O/E indicates **poor** water quality conditions (Even though this site is at the upper end of the drainage and considered relatively unaffected by stormwater factors, several surrounding, rural land uses materialize as effects on the physical habitat including bank erosion. The RIVPACS score did not discriminate types of impacts and must be calibrated for factors associated with stormwater impacts; e.g., *Dirty Water Models*, see the Technical Approach, Tetra Tech 2012b).	0.21

*Notes***:**
[a] Substrate and gradient based on 2012 field assessments at each site.
[b] The estimate of the number of various stormwater devices within a 500-meter area is based on a utilities schematic provided by the City of Bellingham (2011).
[c] Land use from NLCD (2006). Estimated within the contributing drainage area between sample sites (i.e., these estimates are not cumulative).
[d] Percent impervious from NLCD (2006). Estimated within the contributing drainage area between sample sites (i.e., these estimates are not cumulative).
[e] Metals, PCBs, BNAs

Squalicum Creek Results Summary

The Squalicum Creek drainage shows a higher level of stream degradation and contamination at lower sites than at upper sites in the stream, explaining the poor biological condition as indicated by individual biometrics and with community index and RIVPACS scores. These biological expressions describing BMI and the periphyton community conditions were strongly related to changes in degraded physical habitat and water quality characteristics at a site. The most severe biological impact in Squalicum Creek was in sediments where arsenic, copper, lead, PCBs, and DDT concentrations were highest. Organic carbon content of the sediments was highest at SQ-1, along with copper, lead, and PCB concentrations. Potential for bioaccumulation is high where direct exposure or ingestion of organics with adsorbed toxics is enhanced by presence of high % total organic carbon (TOC).

The secondary effect on biological condition is related to physical habitat and embeddedness of available substrate. This single characteristic of habitat conditions affects biological condition regardless of the quantity of larger substrate particle sizes available for colonization by BMI or periphyton. Bank destabilization, as assessed at SQ-2 (Baker Creek site), loads the streambed with highly mobile size classes of material that are easily transported during peak storm event flows. The highest RIVPACS score (0.73) indicates slight impact from embedded hard sediments and source of fine materials from *rils* identified along the bank of the assessment reach.

None of the visited sites in this drainage are considered *good* by RIVPACS scoring standards, and upper sites showed signs of impact from surrounding land use (e.g., hobby farms and grazing). The development intensity for these sites (SQ-5 and SQ-6) scored lowest of all sites assessed in this study but did have some effects from current land uses surrounding each reach.

Squalicum Creek Stressors and Biological Condition

Identifying stressors from stormwater input and resulting biological condition in Squalicum Creek was possible by comparing upstream sites representing reduced impact of stormwater runoff. The upstream sites were similar to downstream sites in morphological characteristics, but they had distinct and different stressors that depressed biological integrity. The following stressors identified in the Squalicum Creek drainage were linked with stormwater impacts.

Stressors causing moderate biological impact (**mixed forested conditions**):

- Increased fines
- Slight embeddedness
- Minor (isolated) bank instability
- Biological condition [B-IBI range: 42–44, RIVPACS range: 0.55–0.73]

The RIVPACS assessment tool is more sensitive to isolated impacts of stormwater runoff in forested environments. The identity of species presence (and absence) in determining a RIVPACS score for each upstream site was used to categorize the sites that had lower quality than reference conditions. Visible impacts of stormwater runoff from surrounding drainage conduits was detected using the RIVPACS score. The B-IBI (multi-metric index) score ranked site condition in the same category as the RIVPACS tool, although the B-IBI score determined that the upstream sites were in better condition than predicted by the RIVPACS assessment tool. This is because of a greater volume of categorical data inherent in the B-IBI model, which is not as sensitive to minor increments of impact caused by stormwater stressors as the RIVPACS tool.

Stressors causing severe biological impact (commercial landscape):

- High embeddedness
- High input of fines
- High number of outfalls and pipes into the stream reach
- High concentrations of metals, pesticides, and PCBs
- High potential for mixing zone impacts
- Biological condition [B-IBI range: 16–20, RIVPACS range: 0.47–0.55]

Soos Creek

Multiple biological assemblages (BMI and periphyton) were collected from six sites in the Soos Creek drainage (sampled from July 31 to August 2, 2012). The results for these site assessments reflect the influence from a variety of physical habitat and water quality conditions. The link between stormwater input and biological response was established by comparing physicochemical factors with steps in the conceptual stormwater runoff diagrams (Figures 21 through 23). The combination of individual environmental factors and response in biological communities was summarized in tables that reported specific stormwater-related, long-term impacts resulting from stormwater input.

B-IBI and RIVPACS Evaluation

Biological condition in Soos Creek was evaluated by using the RIVPACS and B-IBI models. Output from evaluating the biological condition using each assessment tool provides unique insight into potential causes of detectable impacts.

The RIVPACS and B-IBI scores are listed in Table 20 with comparisons of scores used to determine relative condition of each site. This initial comparison was important for determining the intensity of biological impacts and component(s) of the biological community used to interpret the stressor impacts and causes. The quantitative ranges and corresponding qualitative assessments of stream condition are shown in Table 2.

Table 20. Soos Creek B-IBI and RIVPACS scores

	Soos Creek Matrix			
Site ID	**Site**	**B-IBI score**	**B-IBI score condition category**	**RIVPACS score**
CC-1	At 148th Ave	34	Moderate Integrity fair	0.61
BS-2	Near SR 58	40	High Integrity good	0.92
BS-2	Near SR 58 DUP	40	High Integrity good	0.95
BS-1	At 168th Way	36	Moderate Integrity fair	0.90
LS-1	At 164th Ave	20	Low Integrity poor	0.47
BS-3	At 272nd St.	32	Moderate Integrity fair	0.85
CC-2	SR 58 Near Kent Black Diamond Rd.	44	High Integrity good	0.97

Biometric Relationships to Physical Parameters

Combinations of environmental factors and biological metrics were examined for relationships that had a minimum Pearson's product-moment correlation, r, of greater than or equal to 0.50 (Table 21). Direct relationships were considered relationships that had a positive slope and Pearson product moment-correlation. Indirect relationships were determined by Pearson and slope calculations with negative values. These relationships were considered statistically significant if the p-value was less than or equal to 0.05, and moderately significant if p-value was less than or equal to 0.20.

Pearson's product moment-correlation coefficient, r, measures the degree of linear association between two variables. The EPA provides a more detailed explanation for how r is calculated and results interpreted at www.epa.gov/caddis/da_exploratory_2.html which is summarized here:

- A coefficient of 0 indicates that the variables are not related.
- A negative coefficient indicates that as one variable increases, the other decreases.
- A positive coefficient indicates that as one variable increases the other also increases.
- Larger absolute values of coefficients indicate stronger associations. However, small Pearson coefficients might be due to a nonlinear relationship.

The numerous paired relationships examined that met or exceeded this threshold are summarized in Tables 22 and 23 for Soos Creek. These tables were used to determine central themes for response by biological communities and if each assemblage (e.g., BMI and periphyton) was differentially more sensitive to changes in the aquatic environment.

The results from Soos Creek show correlations between pH, velocity, and the presence of boulders. Direct relationships were found between pH and taxa richness, the presence of clingers, % EPT, semi-voltine richness, pollutant-sensitive organisms, and total number of periphyton algal species. The pH can fluctuate at different sites depending on surrounding land use area and runoff potential during stormwater events. Oil and emissions from cars, pet wastes, lawn fertilizers and pesticides, solvents, and other chemicals used in industry are transported by runoff water from impervious surfaces in commercial and suburban environments, changing the pH of the creek and the presence of sensitive macroinvertebrate taxa.

Direct relationships were also found between velocity and most biometrics at the Soos Creek sites. Changes in velocity can be linked with stormwater events; however, it can also be an indication of channel size. The greater the velocity, depth, and channel width, the greater the potential of the creek to entrain and rapidly transport toxics, chemicals, and other sources of runoff from the surrounding land.

The percentage of boulders described from stream assessments directly correlates with taxa richness and algal species richness. The larger substrate is less susceptible to transport by stormwater and provides a larger habitable area for BMI and periphyton colonization.

Biological Relationships to Flow

Additional parameters describing the characteristic hydrological conditions of stormwater input were generated in a technical memorandum related to the TMDL study (King 2012). These parameters were examined as companion information to biologically affected sites to determine if hydrologic characterization of Soos Creek is consistent with other related stressors.

Descriptions of past flood/flow characteristics explain how direct disturbance and transport of substrate and the intensity of flow increases are damaging to habitable substrate used by periphyton and benthic macroinvertebrates. Flows and average current velocity were calculated during each of the Soos Creek site assessments and average current velocity compared with biological response metrics (Tables 22 and 23). Average current velocity was positively correlated with several biological response metrics: taxa richness, % Clinger richness, semi-voltine richness, Trichoptera richness, Ephemeroptera richness, and % pollutant-sensitive taxa. Average current velocity was negatively correlated with a single biological response metric: % pollution tolerant taxa. Simply stated, the slower velocities in the Soos Creek system were found to be correlated to higher pollution-tolerant taxa. A summary of physical characteristics influenced by flow at Soos Creek sites is presented in Table 24.

Table 21. Summary of Soos Creek's benthic macroinvertebrate biometrics and periphyton biometric relationships (r value and slope) and the significance of those relationships (p-value).

	Water Quality Parameters											
	Temperature			**pH**			**Conductivity**			**Dissolved oxygen**		
	Slope	***r***	**p**	**Slope**	***r***	**p**	**Slope**	***r***	**p**	**Slope**	***r***	**p**
Soos Creek biometric relationships												
Ephemeroptera Richness	-0.63	-0.36	5.32x10-5	4.84	0.89	0.00	0.03	0.47	0.00	1.19	0.66	0.00
Taxa Richness	-1.73	-0.24	0.00	18.46	0.81	0.00	0.11	0.49	0.00	5.11	0.67	0.00
Plectoptera Richness	-0.74	-0.53	4.49x10-5	2.18	0.51	0.01	0.01	0.30	0.00	0.23	0.16	0.00
Trichoptera Richness	0.39	0.19	0.00	3.45	0.55	0.12	0.02	0.34	0.00	1.54	0.73	0.66
% Pollution Sensitive Taxa	-0.14	-0.24	5.11x10-7	1.52	0.83	5.79x10-8	0.00	0.27	0.00	0.41	0.67	5.13x10-7
% Clingers	-1.40	-0.28	0.14	12.53	0.82	0.00	0.05	0.35	0.00	3.36	0.66	0.00
Semi-voltine Richness	-0.81	-0.38	0.00	4.40	0.67	0.93	0.03	0.52	0.00	1.16	0.53	0.06
% Pollution Tolerant Taxa	6.62	0.73	0.98	-22.51	-0.80	0.12	-0.17	-0.62	0.00	-2.27	-0.24	0.22
Predator %	-4.24	-0.64	0.38	5.25	0.26	-0.01	0.17	0.85	0.00	-2.24	-0.33	0.03
Top 3 Abundant	4.32	0.53	0.00	-2.45	-0.10	7.44x10-5	-0.12	-0.43	0.01	0.21	0.02	0.00
Soos Creek periphyton relationships												
Total # of Algal Species	-2.68	-0.23	0.00	25.49	0.73	0.00	0.20	0.63	0.02	4.87	0.46	9.86x10-5
% Acidophilus	-0.05	-0.12	1.91x10-7	-0.80	-0.65	1.14x10-6	0.00	0.12	0.00	-0.28	-0.67	1.08x10-5
Total Chlorophyll A in Slurry	4.95	0.11	0.21	32.72	0.24	0.13	0.23	0.17	0.04	14.28	0.32	0.14
Dominant Taxa %	-2.29	-0.21	0.12	3.48	0.10	0.02	0.05	0.14	0.00	3.64	0.32	0.02
Metals Tolerance Index	-2.88	-0.39	0.21	-6.57	-0.29	0.45	0.11	0.49	0.00	-7.09	-0.95	0.83
% Pollution Tolerant Taxa	-0.96	-0.13	0.50	5.61	0.24	0.03	0.14	0.58	0.00	-2.66	-0.34	0.06
Shannon H (log 2)	-0.05	-0.10	1.17x10-6	0.16	0.10	4.49x10-5	0.00	0.29	0.00	-0.17	0.29	0.00

Notes:
Yellow highlighted parameters indicate significant relationships [Pearson product-moment correlation (r) ≥ 0.50 and p ≤ 0.05].
Green highlighted parameters indicate moderately significant relationships [Pearson product-moment correlation (r) ≥ 0.50, and p value ≤ 0.20].

	Physical Parameters																																						
	Depth			Velocity			% Bank Instability			% Gradient			% Canopy Cover			% Embeddedness			% Cobble			% Coarse Gravel			% Sand			% Fine Gravel			% Silt Clay Mud			% Boulder			% Wood		
	Slope	*r*	p	Slope	*r*	p	Slope	*r*	p	Slope	*r*	p	Slope	*r*	p	Slope	*r*	p	Slope	*r*	p	Slope	*r*	p	Slope	*r*	p	Slope	*r*	p	Slope	*r*	p	Slope	*r*	p	Slope	*r*	p
Soos Creek Biometric Relationships																																							
Ephemeroptera Richness	0.09	0.55	0.01	4.65	0.86	0.01	0.05	0.28	0.00	-0.62	-0.06	0.08	-0.85	-0.74	0.00	-0.04	-0.37	0.00	0.01	0.06	0.02	0.10	0.47	0.00	0.17	0.48	0.17	0.00	0.02	0.02	-1.28	-0.77	1.73	0.44	0.48	0.16	-2.87	-0.68	0.15
Taxa Richness	0.02	0.61	6.93x10-5	4.65	0.86	0.01	0.09	0.12	0.26	-8.82	-0.19	9.6x10-5	-0.22	-0.80	0.00	0.00	0.00	0.00	-0.13	-0.16	0.05	0.48	0.56	0.14	0.77	0.52	0.00	0.19	0.18	0.01	-1.86	-0.74	0.00	2.22	0.57	4.77x10-5	-0.54	-0.55	0.01
Plectoptera Richness	-0.04	-0.19	0.02	0.93	0.22	0.00	0.06	0.47	0.00	4.51	0.53	0.01	-0.13	-0.09	0.00	-0.10	-0.39	0.00	0.01	0.05	0.02	0.05	0.33	0.00	0.19	0.68	0.26	-0.05	-0.24	0.02	0.01	0.01	0.99	-0.05	-0.07	0.10	-2.48	-0.46	0.17
Trichoptera Richness	0.10	0.74	0.00	5.63	0.89	0.00	-0.21	-0.04	0.01	-7.38	-0.59	0.00	-0.84	-0.85	0.08	-0.20	-0.52	0.00	-0.12	-0.57	0.10	0.14	0.58	0.00	0.17	0.40	0.47	0.16	0.56	0.06	-1.05	-0.73	0.12	0.77	0.65	0.00	-0.57	-0.16	0.62
% Pollution Sensitive Taxa	0.22	0.46	0.28	1.37	0.75	0.18	0.02	0.33	0.00	-0.21	-0.06	0.06	-2.01	-0.58	6.93x10-5	-0.06	-0.56	0.00	0.01	0.19	0.01	0.02	0.24	0.00	0.04	0.32	0.05	0.00	-0.01	0.01	-3.90	-0.78	0.09	0.10	0.32	0.27	-7.45	-0.59	0.05
% Clingers	0.02	0.31	0.00	11.16	0.73	0.00	0.15	0.30	0.15	1.85	0.06	0.00	-0.23	-0.56	0.06	-0.65	-0.69	0.37	-0.25	-0.13	0.90	0.27	0.46	0.05	0.68	0.68	0.00	0.06	0.09	0.38	-0.34	-0.57	0.00	0.79	0.30	0.00	-0.76	-0.52	0.14
Semivoltine Richness	0.09	0.69	0.00	5.75	0.88	0.00	0.07	0.32	0.00	0.00	0.00	0.00	-0.75	-0.78	0.02	-0.11	-0.26	0.00	-0.06	-0.03	0.05	0.17	0.70	0.00	0.24	0.55	0.98	0.03	0.11	0.05	-1.07	-0.76	0.34	0.75	0.68	0.00	-2.86	-0.81	0.44
% Pollution Tolerant Taxa	-0.01	-0.41	0.02	-16.41	-0.59	0.02	-0.37	-0.42	0.17	-12.98	-0.23	0.02	0.13	0.56	0.54	0.25	0.15	0.11	-0.48	-0.51	0.66	-0.36	-0.33	0.11	-0.48	-0.26	0.19	0.53	0.42	0.90	0.17	0.53	0.03	-1.66	-0.34	0.04	0.74	0.90	0.06
Preadator %	0.02	0.47	0.00	5.55	0.27	0.00	-0.12	-0.19	0.20	-2.46	-0.06	0.00	0.17	0.56	0.18	0.57	0.45	0.12	0.12	0.18	0.94	0.35	0.46	0.04	-0.07	0.06	0.03	-0.29	-0.32	0.64	-0.02	-0.04	0.01	1.90	0.55	0.00	-0.61	-0.54	0.24
Top 3 Abundant	-0.02	-0.43	3.38x10-5	-10.99	-0.44	3.43x10-5	0.58	0.73	0.02	24.51	0.49	3.34x10-5	0.09	0.38	0.00	0.00	0.00	0.00	0.24	0.28	0.00	-0.74	-0.77	0.07	-0.89	-0.54	0.00	0.04	0.04	0.00	0.11	0.30	3.9x10-5	-2.42	-0.56	8.08x10-5	0.79	0.86	2.59x10-6
Soos Creek Periphyton Relationships																																							
Total # of Algal Species	0.01	0.51	0.00	32.56	0.78	0.00	-0.10	-0.12	0.08	-34.64	-0.54	0.00	-0.12	-0.69	0.00	-0.57	-0.26	0.01	0.02	0.01	0.01	0.37	0.25	0.01	-0.27	-0.12	0.00	-0.02	-0.01	0.00	-0.12	-0.46	0.00	4.93	0.67	8.86x10-5	-0.17	-0.26	0.00
% Acidophilus	0.08	0.12	0.49	-0.97	-0.79	0.64	-0.03	-0.68	0.00	-0.99	-0.40	0.00	0.23	0.05	2.1x10-5	0.06	0.79	7.13x10-5	-0.01	-0.16	0.01	-0.02	-0.42	0.00	-0.06	-0.76	0.05	-0.02	-0.39	0.01	3.35	0.46	0.03	-0.09	-0.44	0.18	7.39	0.39	0.03
Total Chlorophyll A in Slurry	3.02x10-5	0.00	0.09	70.76	0.53	0.08	-0.19	-0.05	0.47	-4.80	-0.02	0.09	-0.01	-0.22	0.19	-3.88	-0.47	0.39	-2.25	-0.49	0.32	0.65	0.13	0.48	3.57	0.40	0.11	1.26	0.21	0.22	0.01	0.20	0.19	9.03	0.39	0.09	0.01	0.07	0.16
Dominant Taxa %	0.01	0.53	0.00	5.03	0.15	0.00	0.08	0.07	0.70	-9.92	-0.15	0.01	-0.09	-0.47	0.08	-0.05	-0.02	0.89	-0.45	-0.39	0.49	0.50	0.39	0.52	0.78	0.35	0.01	0.11	0.07	0.19	0.17	0.25	0.13	-0.21	-0.04	0.01	-0.14	-0.33	0.09
Metals Tolerance Index	-0.01	-0.24	0.05	-10.87	-0.49	0.05	-0.29	-0.41	0.05	3.49	0.08	0.06	0.06	0.20	0.45	1.06	0.78	0.01	0.32	0.43	0.09	-0.09	-0.11	0.02	-0.84	-0.57	0.60	-0.49	-0.48	0.36	0.31	0.75	0.09	0.27	0.07	0.08	0.09	0.09	0.87
% Pollution Tolerant Taxa	0.00	-0.12	0.00	5.43	0.23	0.00	-0.35	-0.47	0.24	-6.69	-0.14	0.01	-0.04	-0.14	0.23	0.04	0.03	0.21	0.08	0.10	0.86	0.02	0.03	0.09	-0.33	-0.22	0.06	-0.12	-0.12	0.71	0.16	0.41	0.01	2.07	0.52	0.00	0.15	0.16	0.18
Shannon H (log 2)	-0.06	-0.12	6.18x10-5	-0.01	-0.01	5.99x10-5	-0.02	-0.34	0.00	-0.43	-0.13	0.00	0.01	0.00	0.00	0.01	0.11	0.00	0.01	0.25	0.02	-0.02	-0.38	0.00	-0.05	-0.48	0.28	-0.02	-0.32	0.02	1.57	0.29	0.69	0.04	0.13	0.12	3.43	0.24	0.14

Notes:
Yellow highlighted parameters indicate significant relationships [Pearson product-moment correlation (r) ≥ 0.50 and p ≤ 0.05].
Green highlighted parameters indicate moderately significant relationships [Pearson product moment correlation (r) ≥ 0.50, and p value ≤0.20].

Table 22. Soos Creek relationships between benthic macroinvertebrate biometrics and physical characteristics.

Biometrics	**Velocity**	**pH**	**Temperature**	**Dissolved oxygen**	**Conductivity**	**Depth**	**% Embeddedness**	**% Sand**	**Canopy cover**	**% Bank instability**	**% Coarse gravel**	**% SCM**	**% Boulder**	**% Cobble**	**% Fine gravel**	**% Wood**	**% Gradient (slope)**
Taxa Richness	**D***	**D***		**D***		**D***		**D***	**I***		D	**I***	**D***			**I***	
% Pollution Tolerant Taxa	**I***	I	D		**I***				D			**D***		I		D	
% Clingers	**D***	**D***		**D***			I	**D***	I			**I***				I	
Semi-voltine Richness	**D***	D		D	**D***	**D***		D	**I***		**D***	I	**D***			I	
Trichoptera Richness	**D***	D		D		**D***	**I***		I		**D***	I	**D***	I	D		**I***
Ephemeroptera Richness	**D***	**D***		**D***		**D***			**D***			I				I	
% Pollutant Sensitive Taxa	D	**D***		**D***			**I***		**I***			I				**I***	
Top 3 Abundant			**D***					**I***		**D***	I		**I***			**D***	
Predator %			I		**D***				D				**D***			I	
Plecoptera Richness		**D***	**I***					D									**D***

Notes:
I = Inverse relationship
D = Direct relationship
* Indicates statistically significant relationships (p value ≤ 0.05) along with bold highlighting

Table 23. Soos Creek periphyton biometrics and physical/chemical relationships.

Biometrics	**Velocity**	**% Boulder**	**% Embeddedness**	**% Sand**	**D.O.**	**%SCM**	**Bank instability**	**Depth**	**pH**	**Conductivity**	**Canopy cover**	**% Gradient**
% Pollution Tolerant Taxa		**D***								**D***		
Metals Tolerance Index			**D***	I	I							
% Acidophilous	I		**D***	**I***	**I***	D	**I***		**I***			
Total chl *a* in slurry (mg/m^2)	D											
Total # of Algal Species	**D***	**D***						**D***	**D***	**D***	**I***	**I***
Dominant Taxa %								**D***				

Notes:
I = Inverse relationship
D = Direct relationship
* Indicates statistically significant relationships (P value ≤ 0.20) along with bold highlighting

Table 24. Soos Creek physical impacts from flow.

Site name	**Physical Impact in Soos Creek**			
	Flow variation			
	Substrate movement: Is substrate size subject to transport and at what intensity of stormwater input?	**Substrate size**: Are substrate size changes a result of stormwater input?	**Water velocity**: Do changes in water velocity patterns following stormwater input affect BMI communities?	**Flow volume**: Do seasonally significant volume changes affect BMI communities?
BS-1	Substrate consists of 16% boulder, 29% cobble, 11% silt/clay/muck, and 6.8% silt fence, which are 40% embedded. The lack of smaller particles and high amount of embeddedness indicates that high stormwater flows have washed away smaller particles.	The paucity of small particles (e.g., sand, gravel) and the presence of large amounts of silt/clay/muck indicate presence of stormwater flow impacts.	A slow current velocity of 0.08 ft/sec, in addition to a low dissolved oxygen content of 6.43 mg/L provides evidence of stagnant water conditions and a potentially flashy stormwater impact.	Evidence such as a visibly unstable bank and pollutants such as oil in the water indicate that water elevation rapidly increases with stormwater runoff from a nearby road, physically affecting BMI communities.
BS-2	Substrate consists of 43% coarse gravel, 10% cobble, and 23% fine gravel, which is 26.14% embeddedness. The smaller particles could be transported by stormwater flows.	Substrate size changes could be a result of stormwater input.	The average current velocity was 1.69 ft/sec, a deep and wide channel, and a stream bank covered by vegetation with riprap buffer in select locations (along SR 58 to protect from high flows).	No, the large size of the creek at this site ameliorates physical and chemical effects to some degree, and this threshold has not been exceeded. No significant impacts have been measured yet in the BMI or periphyton communities.
BS-3	Substrate consists of 23% cobble, 16% fine gravel, and 27% coarse gravel, which is 24.5% embedded. Smaller particles are subject to transport by stormwater flows.	Size changes could be a result of stormwater inputs, given the high levels of embeddedness measured in the reach and high quantities of small, easily transported particles present.	A low velocity of 0.5 ft/sec and a wetted width that is one-quarter the distance of bankfull width. More than 57% of the stream bank was rated as unstable in this reach and indicates that a large increase in flow occurs during stormwater events.	The increase of flows during stormwater events and the transport of fine particles decrease the amount of habitat available for BMI communities at this site.
CC-1	Substrate consists of 37% cobble, 13% coarse gravel, and 3% fine gravel, which are 18.5% embedded. Particles are not subject to much movement during stormwater flows.	Substrate sizes provide a stable habitat for BMI communities.	An average velocity, low water temperature, and low conductivity indicate minimal changes to water quality from stormwater flow.	A fairly stable bank, surrounding vegetation, and wetted width that is similar to bankfull width indicate that flows are nearly stable throughout the year and do not greatly affect BMI communities.
CC-2	Substrate consists of 35% coarse gravel, 16% fine gravel, and 15% sand, with an embeddedness measurement of 18.7%. Smaller particles are subject to transport during stormwater flows.	Substrate size changes could be a result of stormwater flow.	An average velocity, low water temperature, and low conductivity indicate minimal changes from past stormwater flow.	A fairly stable bank, surrounding vegetation, and wetted width that is similar to bankfull width indicate that flows are nearly stable throughout the year and do not greatly affect BMI communities.

Site name	**Physical Impact in Soos Creek**			
	Flow variation			
	Substrate movement: Is substrate size subject to transport and at what intensity of stormwater input?	**Substrate size**: Are substrate size changes a result of stormwater input?	**Water velocity**: Do changes in water velocity patterns following stormwater input affect BMI communities?	**Flow volume**: Do seasonally significant volume changes affect BMI communities?
LS-1	Substrate consists of 31% wood, 14% coarse gravel, 23% fine gravel, and 6.8% silt/clay/muck with an embeddedness of 24%, which indicates the presence of flashy stormwater events.	Substrate size changes could be a result of stormwater input.	At the time of sampling, a low current velocity of 0.21 ft/sec, high surface water temperature, and small wetted width (11.75 ft) compared with bankfull width (103.75 ft) indicate periods of high stormwater flow. A culvert inputs drainage to the creek at this site and could cause mixing, transport of particles, and higher temperatures which affect biological condition.	The transport of small particles, presence of a large amount of wood in the channel, and broad bankfull width indicate rapid changes are possible in the channel during stormwater input. These disturbance events are expected to affect biological condition.

Linking Biological Response to Stormwater

Analysis of the data in this project is focused on partitioning (to the extent possible) stormwater-related effects on stream biological communities from other sources of pollution because biota is responding to the cumulative effect of all sources.

The Soos Creek drainage is large and has some intense development including moderate-sized municipalities: Kent, Auburn, Covington, and Maple Valley, which generate stormwater flows and associated pollutants. Additional pollutant sources in the basin include logging, deposition by airborne particulates, permitted effluent to surface waters, water withdrawals/returns, groundwater, farming, or illicit discharges that are not stormwater related. Conceptual stormwater pathway diagrams showing the different runoff pathways for mixed forested areas, commercial (impervious) and suburban (residential) settings are presented above in Figures 21–23. These are mechanistic diagrams that describe how stormwater conveys pollutants and causes effects on components of the aquatic ecosystem including to BMI and periphyton communities (USEPA 2008; Adams 2010a).

Mixed Forested Areas

The mixed forested area represents sites CC-1, BS-2, and CC-2 in the Soos Creek drainage. Mixed forested areas (Figure 21) where timber harvest periodically occurs have lower peak flows than sites with larger amounts of impervious surfaces and stormwater devices. However, increased hydrographs can still occur during stormwater events because of steep streambank gradients and observed erosion, causing decreases in total algal species and changes in macroinvertebrate species to a less sensitive, more pollution-tolerant community. The upper portion of this watershed has historically been cleared of original timber stands with re-growth of mixed forest.

Sediment transport is increased at mixed forest sites because of stormwater runoff from steep gradients. At Soos Creek, the presence of silt/clay/muck, fines, and woody debris due to sediment transport affects macroinvertebrate taxa richness.

Commercial Setting

The commercial setting represents site BS-3 in Soos Creek (Figure 22). Biological response to stormwater from the commercial setting is influenced in the following ways:

- *Altered Hydrology:* Changes in flow and pH are two major factors affecting % Clinger taxa richness, semi-voltine richness, Trichoptera richness, Ephemeroptera richness, % pollution sensitive species, taxa richness, and total number of algal species.
- *Sediment Transport:* At Soos Creek, the presence of sand from sediment transport was correlated with macroinvertebrate taxa richness.

Suburban Setting

The suburban setting is represented by sites LS-1 and BS-1 in the Soos Creek watershed (Figure 23), both near the upper end of the watershed. Biological response to stormwater from the suburban setting is influenced in the following ways:

- *Increased Hydrograph:* Increased flow at Soos Creek causes changes in biological condition. Direct relationships were identified with current velocity and clinger richness, semi-voltine richness, Trichoptera richness, Ephemeroptera, pollution-sensitive species, and total number of algal species.
- *Sediment Transport:* Sediment at these sites is dominated by fines, sand, and silt/clay/muck, resulting in lower taxa richness and % top three abundant species.
- *Increased Temperature:* Increased temperatures at these suburban sites were correlated with an increase in % pollution-tolerant species and % top three abundant species.
- *Change in pH:* Changes in pH due to stormwater runoff are correlated with a decrease in taxa richness, clinger richness, semi-voltine richness, Trichoptera, Ephemeroptera, total number of algal species, and % pollution-sensitive taxa.

Evidence identified for potential stormwater impact on the basis of pathways were further interpreted, using individual biometric response to relevant stressors and determining whether this was a biological effect related to stormwater input. Results in Table 25 contain numerical values for stressors known to affect biological condition and then relate biological condition using two evaluation tools (B-IBI and RIVPACS). Table 25 summarizes what is known about biological condition related to potential stormwater stressors in Soos Creek. The observations are descriptive and use results from field assessments to explain current physical habitat conditions and associated biological scores.

Table 25. Indicators of stormwater influences in Soos Creek.

Site identifier	Soos Creek				
	Indicators of Stormwater Influences				
	Substrate and gradient	Stormwater devices within 500-meter area (estimate)	Land use/impervious surfaces	B-IBI score	RIVPACS scores
BS-1	Substrate consists of 16% boulder, 29% cobble, 11% silt/clay/muck, and 6.8% silt fence that is 40% embedded. The lack of smaller particles and high amount of embeddedness indicate the lack of interstitial spaces available for colonization. Stormwater flows might have initially deposited fine sediment here, but they now transport smaller particles from the reach.	28 storm drains	Suburban 20% impervious	34 ± 2 indicates **fair** water quality conditions.	0.61 O/E indicates **fair** water quality conditions.
BS-2	Substrate consists of 43% coarse gravel, 10% cobble, and 23% fine gravel, which is 26.14% embeddedness. The smaller particle sizes could be transported by stormwater flows.	0 stormwater devices	Forested 18% impervious	40 ± 2 indicates **good** water quality conditions.	0.92 O/E indicates **good** water quality conditions.
BS-3	Substrate consists of 23% cobble, 16% fine gravel, and 27% coarse gravel, which is 24.5% embedded. Smaller particles are subject to transport by stormwater flows.	4 storm drains	Commercial 25% impervious	32 ± 2 indicates **fair** water quality conditions.	0.85 O/E indicates **fair** water quality conditions.
CC-1	Substrate consists of 37% cobble, 13% coarse gravel and 3% fine gravel, which are 18.44% embedded. Storm events do not appear to affect particle size distribution at this reach.	0 stormwater devices	Forested 14% impervious	36 ± 2 indicates **fair** water quality conditions.	0.90 O/E indicates **good** water quality conditions.
CC-2	Substrate consists of 35% coarse gravel, 16% fine gravel, and 15% sand with embeddedness of 18.7%. Smaller particles are subject to transport during stormwater flows.	0 stormwater devices	Forested 7% impervious	44 ± 2 indicates **good** water quality conditions.	0.97 O/E indicates **good** water quality conditions.
LS-1	Substrate consists of 31% wood, 14% coarse gravel, 23% fine gravel, and 6.8% silt/clay/muck with an embeddedness of 24%, which could indicate occurrence of flashy stormwater effects.	0 stormwater devices	Suburban 4% impervious	20 ± 2 indicates **poor** water quality conditions.	0.47 O/E indicates **poor** water quality conditions.

Soos Creek Results Summary

As mentioned, development in the Soos Creek watershed is somewhat unique in that most of it is near the headwaters, rather than increasing in the downstream direction as do most streams in the Puget Sound area. Extensive wetlands in this watershed capture pollutants and peak flow events. The Soos Creek drainage exhibited effects on stream communities that are primarily associated with changes in physical habitat that affect the BMI and the periphyton communities. Soos Creek drainage has a much lower percentage of impervious surface area than other developed drainages in Puget Sound (e.g., 7–14% in forested areas), but it shows a higher percentage of embeddedness (greater than or equal to 40% at some sites) where stormwater conveyance systems to the stream were present (e.g., storm pipes, drains, and culverts). A RIVPACS score of less than 0.86 are considered sites of concern or poor. One of the sites visited in this study had a score of 0.97 (considered in the *good condition* category) and served as a reference for comparing how physical and chemical conditions at other sites influenced biological condition.

Soos Creek Stressors and Biological Condition

Identifying stressors from stormwater input and resulting biological condition in Soos Creek was possible by comparing stream reaches representing reduced impact by stormwater runoff. The sites assessed in the Soos Creek drainage represent a large variety of physical settings. The following stressors identified in the Soos Creek drainage were linked with stormwater impacts:

Stressors causing minor biological impact (**mixed forested areas**)

- Greater amount of coarse substrate availability (improves habitat suitability)
- Minor bank instability in localized areas of a reach
- Biological condition [B-IBI range: 36–44, RIVPACS range: 0.90–0.97]

Stressors causing severe biological impact (**commercial landscape**)

- High embeddedness
- High number of outfalls and pipes into the stream reach (indicator of stormwater input)
- Slow flowing, stagnant water (increased residence time)
- Biological condition [B-IBI: 32, RIVPACS: 0.50, similar impacts and biological scores as in the Suburban landscape]

Stressors causing severe biological impact (**suburban landscape**)

- High embeddedness
- High proportion of fines in substrate
- High number of outfalls and pipes into the stream reach (indicator of stormwater input)
- Increased residence time of water in the reach
- High potential for mixing zone impacts
- Biological condition [B-IBI range: 20–34, RIVPACS range: 0.47–0.61]

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Conclusions

Linkages between biological condition and recent past effects on physical habitat and water quality from storm events were made using the CADDIS framework. The sequential steps in the CADDIS framework provided insight into causal factors for effects on the biological community.

Squalicum Creek

B-IBI and RIVPACS scores were calculated for each of the six sampled sites in Squalicum Creek. In most cases, the multi-metric scores supported Ecology's water quality impact status determinations (i.e., *poor* or *low integrity* multi-metric scores at sites in Category 5 and *concern* at sites listed in Category 2). On the basis of data collected from this study, there appears to be a link between the biological response and water quality impact status (see the list below).

Individual biometrics were then evaluated against a number of physical and chemical stressors to determine if relationships could be established. Statistically significant relationships were observed between a number of the biometrics and the following:

Water Quality

- pH
- Dissolved oxygen
- Temperature

Stream Geomorphology

- Gradient
- Depth
- Velocity
- Flow
- Substrate composition (fine particle size ranges)

Riparian Condition

- Canopy cover

Landscape Scale

- Development intensity

Toxics in Sediments

- Arsenic
- Copper
- Lead
- DDT
- PCB

Soos Creek

B-IBI and RIVPACS scores were calculated for each of the six sampled sites in Soos Creek. Individual biometrics were evaluated against a number of physical and chemical stressors to determine if relationships could be established. Statistically significant relationships were observed between a number of the biometrics and the following:

Water Quality

- pH
- dissolved oxygen
- Temperature

Stream Geomorphology

- Gradient
- Velocity
- Flow
- Substrate composition (fine particle size ranges)
- Embeddedness
- Bank instability

Riparian Condition

- Canopy cover

The number and type of parameters related to biological response indicated that assessed locations in Covington Creek were the highest quality and were unique in having a very low percent impervious area surrounding the sites. In-stream characteristics that included coarser substrate (e.g., cobble and boulder dominance) and lower percent of embeddedness were related to the highest community condition according to RIVPACS and B-IBI scores.

The qualitative assessment examining relationships between the multi-metric scores and indicators of stormwater influence was conducted as reported in Table 25. Locations in Soos Creek like BS-1 and BS-3, where indications of stormwater drainage were noted (e.g.., storm drains in the assessed reach), had lower community condition scores. These lower scores are explained by the following stormwater inputs: increased hydrograph, sediment transport, increased temperature, and low dissolved oxygen (Figures 22 and 23) in commercial and suburban settings.

Recommendations

Salmon Habitat Limiting Factors

The improvement of physical habitat and water quality conditions through the TMDL process serves goals of the Clean Water Act and Endangered Species Act by prescription of improvements that would benefit salmon populations. Several physical habitat and water quality characteristics from this project that were affected by stormwater input are also primary limiting factors identified by National Oceanic and Atmospheric Administration-Fisheries (2012). Tables 26 and 27 show the relationships between stormwater-affected stream characteristics in this study and limiting factors for salmon and steelhead populations.

Table 26. Physicochemical impacts from stormwater and related salmon habitat limiting factors.

Stream resource type	Stormwater impacts (correlated with BMI/ Periphyton response)	Salmon habitat limiting factors (NOAA-Fisheries, August 2012)
Water Quality	pH	
	Dissolved oxygen	• (migration and rearing)
	Temperature	• (spawning and rearing)
Geomorphology	Gradient	
	Substrate (fine)	• (sedimentation of spawning grounds)
	Depth	• (altered streamflow and sedimentation; shallowing of streambed)
	Velocity	
Riparian Condition	Canopy cover	
Landscape Scale *(Squalicum only)*	Development intensity index	• (urbanization and development)
Toxics in Sediments *(Squalicum only)*	Arsenic	• (physiological problems)
	Copper	• (physiological problems)
	Lead	• (physiological problems)
	DDT	• (physiological problems)
	PCBs	• (physiological problems)

Several physical habitat and water quality characteristics related to stormwater impacts in streams explained impacts in the biological response of BMI and periphyton. A select group of these indicators of stormwater impacts (or stressors) were also related to limiting factors that affect salmon and steelhead fisheries in the study area drainages (Squalicum and Soos Creeks).

Although anadromous fish do not use the freshwater habitat of streams for their entire life cycle, their most sensitive life stages (spawning, egg development, and rearing) occur while they are in fresh water. The stressors associated with stormwater runoff from human activities have impacts on the aquatic habitat necessary to sustain both benthic organisms and the sensitive life stages of fish. Therefore, bioassessment techniques provide an important tool for assessing the aquatic health of streams and their ability to fully support native fisheries. The following list of biological response variables that are related to salmon and steelhead requirements in streams are recommended as future indicators for measuring improvements by the TMDLs (Table 27). The available criteria listed for stormwater impacts are concentrations or levels protective of aquatic life in freshwater environments. Benthic communities responded to much lower levels of the toxics concentrations than those described from sediments in Squalicum Creek. Their response at lower toxics sediment concentrations is due to simultaneous impacts and to conditions indicated by biological response metrics shown in Table 27.

Using individual biometrics as indicators for measuring presence of stressors listed in Table 27 will be useful for eventually determining effectiveness of stream improvement projects. Biological condition should be evaluated using condition categories for individual biometrics reported in Wiseman (2003) for Puget Lowland streams. Not all biometrics listed in Table 27 are included in the multi-metric index developed for streams in the Puget Lowland of western Washington, but they can be used to measure progress toward reducing (and eliminating) stressors identified for the Squalicum Creek and Soos Creek drainages.

Table 27. Biological response indicators for identifying stormwater impacts and related salmon habitat limiting factors condition for both Squalicum Creek and Soos Creek (available criteria listed with citations for results from other studies)

Biological response	Stormwater impacts (correlated with BMI/periphyton response)	Salmon habitat limiting factors (NOAA-Fisheries, August 2012)
BMI *% Scraper and Shredder* Periphyton Shannon H Index Total # of Algal Species	Dissolved oxygen (6.5 mg/L Ecology criterion)	• (migration and rearing)
BMI Top 3 Abundant *% Pollution Tolerant Taxa* % Predator Plecoptera Richness	Temperature (17.5 °C Ecology criterion)	• (spawning and rearing)
BMI Taxa Richness *% Pollution Tolerant Taxa* *% Clinger Richness* Semi-voltine Richness Trichoptera Richness Ephemeroptera Richness % Pollutant Sensitive Taxa	Depth	• (altered streamflow and sedimentation; shallowing of stream bed)
	Velocity (Resh 1993) (DeGasperi 2009) (Allan 1995) (Hawkins et al. 1982)	
BMI *% Clinger Richness* *% Pollution Tolerant Taxa* % EPT	Substrate (fine) (Relyea 2007) (Allan 1995) (Hawkins et al. 1982)	• (sedimentation of spawning grounds)
BMI Semi-voltine Richness Trichoptera Richness Ephemeroptera Richness *% Scraper and Shredder* *% Clinger Richness* *% Pollution Tolerant Taxa* Periphyton Total Chl *a* in Slurry (mg/m^2) Total # of Algal Species	Canopy cover (Wallace and Webster 1996) (Hawkins et al. 1982)	• (degraded or fragmented habitat) • (timber harvest) • (road development)
BMI *% Scraper and Shredder* *% Clinger Richness* % EPT	Development Intensity Index (May 2000) (DeGasperi 2009)	• (urbanization and development)
BMI *% Pollution Tolerant Taxa* Metals Tolerance Index % Sediment Tolerance	• Arsenic (SQS 14 mg/kg)	• (physiological problems)
	• Copper (SQS 400 mg/kg)	• (physiological problems)
	• Lead (SQS 360 mg/kg)	• (physiological problems)
	• DDT (SQS 100 mg/kg)	• (physiological problems)
	• PCBs (SQS 110 mg/kg)	• (physiological problems)

Notes:
Italics indicate the biometric is useful for measuring a broad range of stormwater impacts.
SQS = Sediment Quality Standards (Michelsen 2011).

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Glossary, Acronyms, and Abbreviations

Glossary

Benthic: Of or relating to bottom-dwelling organisms.

Biometrics: Attributes of the biological community.

Biota: Flora (plants) and fauna (animals).

Hydrology: The scientific study of the waters of the earth, especially with relation to the effects of precipitation and evaporation upon the occurrence and character of water in streams, lakes, and on or below the land surface.

Periphyton: Microscopic plants and animals that are firmly attached to solid surfaces under water such as rocks, logs, pilings, and other structures.

Stressors: A chemical or biological agent, environmental condition, external stimulus or an event that causes stress to an organism.

Total Maximum Daily Load (TMDL): Water cleanup plan. A distribution of a substance in a waterbody designed to protect it from not meeting (exceeding) water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a Margin of Safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Acronyms and Abbreviations

B-IBI: Benthic Index of Biotic Integrity
BMI: Benthic macroinvertebrate
BNA: Base-neutral-acid
CADDIS: Causal Analysis Diagnosis/Decision Information System
LDI: Landscape Development Intensity
NLCD: National Land Cover Database
OC: Organic carbon
PCB: Polychlorinated biphenyls
RIVPACS: River InVertebrate Prediction and Classification System.
SCM: Silt/clay/muck
TMDL: Total maximum daily load
% EPT: Ephemeroptera/Plecoptera/Trichoptera

Appendix A-F are available only on the Internet, linked to this report at

https://fortress.wa.gov/ecy/publications/SummaryPages/1303017.html