DEPARTMENT OF
ECOLOGY
State of Washington

Stressor Identification for Peabody Creek (Port Angeles)

November 2013

Publication No. 13-03-040

Publication and Contact Information

This report is available on the Department of Ecology's website at
https://fortress.wa.gov/ecy/publications/SummaryPages/1303040.html

Data for this project are available at Ecology's Environmental Information Management (EIM) website www.ecy.wa.gov/eim/index.htm. Old Study ID PeabodySID2012. The updated Study ID as of April 27, 2017 is WHM_BIO.

The Activity Tracker Code for this study is 13-007.

For more information contact:

Publications Coordinator
Environmental Assessment Program
P.O. Box 47600, Olympia, WA 98504-7600
Phone: (360) 407-6764

Washington State Department of Ecology - www.ecy.wa.gov

- Headquarters, Olympia (360) 407-6000
- Northwest Regional Office, Bellevue (425) 649-7000
- Southwest Regional Office, Olympia (360) 407-6300
- Central Regional Office, Yakima (509) 575-2490
- Eastern Regional Office, Spokane (509) 329-3400

Stressor Identification for Peabody Creek (Port Angeles)

by

Karen Adams

Environmental Assessment Program
Washington State Department of Ecology
Olympia, Washington 98504-7710

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

WRIA
- 18

HUC number
- 17110020

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Abstract

Peabody Creek is approximately 4.8 miles long and runs through a small watershed of 2.6 square miles from the foothills of the Olympic Mountains to the Strait of Juan de Fuca. The upper reaches of the creek run through relatively undisturbed forest land, while the lower half of the creek runs through suburban and urban settings and is ultimately channeled through a culvert to the Strait in the lower 0.2 miles.

The lower mile of Peabody Creek is one of 13 stream reaches listed for Category 5 impairment for the parameter of Bioassessment on Washington State's Water Quality Assessment's 303(d) list. Peabody Creek has been listed since 2006. Before biologically impaired streams can be delisted, the cause of impairment must be determined and the proper measures taken to solve the problem. This study used the Guidance for Stressor Identification in Washington State to identify the most likely causes of biological impairment in Peabody Creek.

A conceptual diagram was constructed to identify potential sources of stressors, and 19 candidate causes related to urbanization were considered. During September 2012, sampling was conducted at two sites: an impaired reach in the City of Port Angeles and a relatively unimpacted upstream site.

The data presented here point to stressors associated with urbanization as the likely cause of biological impairment at the lower reach of Peabody Creek. These stressors include (1) riparian and channel alteration and (2) stormwater runoff. Water and sediment chemistry data did not show biologically meaningful concentrations of toxics and are therefore not considered to be stressors in the sampled portions of Peabody Creek. The remaining candidate causes were evaluated based on the snapshot of information collected in September 2012.

While the data suggest impairment associated with urbanization, a more comprehensive and thorough assessment of conditions in Peabody Creek is recommended to definitively link shifts in biological communities to the effects of stressors associated with increased urbanization.

Acknowledgements

The author of this report thanks the following people for their contributions to this study:

- Kathryn Neal, City of Port Angeles
- Randy Brackett, City of Port Angeles
- Mike Puntenney, City of Port Angeles
- Ed Chadd, Clallam County Streamkeepers
- Cathy Lear, Clallam County
- Liz Maier, Clallam County
- Adar Feller, Clallam County
- Cathy Lucero, Clallam County
- Kay Kassinger, Peninsula Housing Authority
- Jack Entringer, North Olympic Salmon Coalition
- Bob Campbell, Feiro Marine Life Center
- Rhithron Associates, Inc.
    - Wease Bollman
    - Jen Bowman
    - Diane Winter
- Washington State Department of Ecology staff:
    - Jill Lemmon
    - Chris Hartman
    - Nancy Rosenbower
    - George Onwumere
    - Glenn Merritt
    - Chad Larson
    - Scott Collyard
    - Cindy Cook
    - Jean Maust
    - Joan LeTourneau

Introduction

Regulatory Context

Total Maximum Daily Loads (TMDLs) are used to create pollution control plans for impaired Washington State rivers and streams. A TMDL includes a written, quantitative assessment of water quality problems and the pollutant sources that cause the problems. The TMDL determines the amount of a given pollutant that can discharge to the waterbody and still meet standards (the loading capacity), and it allocates that load among the various sources. The U.S. Environmental Protection Agency (EPA) requires states to (1) set priorities for restoring waters that have exceeded Washington State water quality standards (designated a Category 5 impairment on the State 303(d) list) and (2) create a TMDL for each listing in each waterbody. The water quality standards are intended to protect beneficial uses for surface waterbodies.

Peabody Creek has Category 5 listings for bacteria and bioassessment on the lower one mile of the stream. The impacted beneficial uses for Peabody Creek include *Fish, Shellfish, and Wildlife Protection and Propagation*. This study addresses the listing for Bioassessment. The Washington State Department of Ecology (Ecology) began to list streams for Bioassessment in the 2006 Water Quality Assessment.

In 2006, the Clallam County Streamkeepers submitted data from various streams to Ecology (Table 1). Portions of these data led to listing Peabody Creek on the 303(d) list. At the time, Ecology's Policy 1-11 stated that two years of data reflecting impaired conditions would be adequate to list a stream segment as Category 5 impaired. Delisting criteria have not yet been set; however, part of the process is to identify the cause of the impairment and then set a TMDL or recommend other mitigation measures.

Table 1. Benthic invertebrate data that led to the listing of lower Peabody Creek on the Washington State 303(d) list.

Site ID	Year	BIBI score
Peabody Cr RM 0.2	1998	14
	1999	14
Peabody Cr RM 0.5	1998	14
	1999	16
Peabody Cr RM 1.0	1998	10
	1999	18

BIBI: Benthic Index of Biotic Integrity
RM: River mile

The objective of this study was to conduct a basic stressor identification assessment (Adams, 2010a) at Peabody Creek to identify probable causes (candidate causes) of biological impairment. Results from this study can be acted upon or used to support a more detailed investigation.

Pilot Project Summary

This project serves as a pilot to demonstrate the most basic level of application of the stressor ID process (Adams 2010a). A basic biological and habitat assessment of the site provides a solid baseline of data that help to pinpoint sources of stressors. Coarse signals of disturbance from various types of pollutants in the water and sediment chemistry samples can be identified. Habitat measurements show if and where impacts to the riparian zone may be affecting the stream habitat. Macroinvertebrate and periphyton samples can help to (1) identify problems occurring at times other than at the time of collection and (2) reflect the types of conditions found within a stream reach.

A site visit and meeting with stakeholders are important steps before beginning a study. Data collection requires a minimum of one day and a team of two people at each site. Cost in terms of sample analysis comes to approximately $1200 per site, plus an additional $500 to $1000 for field supplies, assuming that crews already have the basic equipment needed to conduct the habitat assessment (Adams, 2010). Sample processing costs are shown in Table 2.

Table 2. Biological and chemical analysis costs per site associated with Basic Stressor Identification studies.

Sample Type	Parameter	Method	Matrix	Cost
Chemistry	Total Phosphorus	Colorimetric	Water	19.92
	Total Persulfate Nitrogen	Persulfate	Water	18.81
	Chloride		Water	14.39
	Turbidity		Water	12.17
	Total Suspended Solids		Water	12.17
	Chlorophyll A	Field Filtered	Water	47.59
	Metals (Cu, Pb, Zn, Ar)		Sediment	107.00
	Polyaromatic Hydrocarbon	Standard List	Sediment	401.00
	Total Organic Carbon		Sediment	45.52
Biology	Macroinvertebrate Analysis	500 Enumeration		295.00
	Periphyton Analysis			300.00
Total Cost Per Site				1273.57

*Costs based on 2013 prices.

Stressor ID is an iterative process that proceeds through data collection, analysis, and assessment of the need for more data. A basic assessment like this one establishes current conditions, verifies impairment, and can point to or eliminate candidate causes. Results from this basic stressor ID will direct further studies to pinpoint details and clarify exact causes of impairment, which will focus restoration efforts. Data resulting from this effort can either guide remediation directly or inform subsequent TMDL work, expediting that process.

Field Sites

For the purpose of this study, Ecology conducted a biological assessment at two sites along Peabody Creek in September 2012. With input of a stakeholder group in July 2012, Ecology chose sites that provided a comparison between biologically impaired and unimpaired conditions in the same creek. Efforts were made to locate the sites within the region of known impaired and unimpaired conditions, while trying to stay within the same geomorphic context at both sites. Natural changes in slope, geology, and stream type occur in a stream, moving from upstream to downstream. Therefore, selecting sites within the same geomorphic context helps to (1) minimize confounding effects of these factors and (2) increase the ability to differentiate between natural or anthropogenic processes. The impaired reach at Peabody Creek river mile 1.0 is located roughly in the middle of the urbanized portion of this stream, just upstream of the 8th Street bridge. This site coincides with a routine monitoring site used by Clallam County Streamkeepers and has a forested riparian zone with mature cottonwood (*Populus*) and alder (*Alnus*).

The unimpaired site is located just upstream of the Olympic National Park Headquarters Maintenance Yard at river mile 1.9. It is toward the lower end of the unimpaired reach of Peabody Creek, with riparian habitat consisting of mature conifers, mainly Douglas fir (*Pseudotsuga menziesii*) and western red cedar (*Thuja plicata*). The riparian buffer is intact and much wider throughout the upper watershed.

Description of the Watershed

Peabody Creek is a small (2.6 square miles), rain-dominated watershed that originates in the foothills of the Olympic Mountains in the Olympic National Park (Figure 1). It travels 4.8 miles to the Strait of Juan de Fuca. Average rainfall in the drainage is between 26 and 29 inches per year, and baseflow of 1.02 cfs (Elwha-Dungeness Planning Unit, 2005) in the creek is maintained by springs, seeps, and wetlands (Clallam County, 2013). This stream originally supported moderately low numbers of coho salmon and, possibly, chum. However, fish access is hampered by a large culvert at the mouth. This problem is compounded by other culverts located throughout the lower reaches, which are perched above the stream channel, effectively blocking upstream fish passage (Elwha-Dungeness Planning Unit, 2005). The stream currently supports cutthroat trout, and the WRIA 18 management plan states that Peabody Creek should be managed to maintain the existing cutthroat population (Elwha-Dungeness Planning Unit, 2005).

The underlying geology of the area is largely sedimentary rock in the valley and basalts in the upper portion of the watershed in the foothills. The entire streambed and the lower two thirds of the watershed consist of glacial gravel deposits left by the continental ice sheet movement (Elwha-Dungeness Planning Unit, 2005). The soils of the watershed are mostly Neilton soils along the riparian corridor. These soils typically have a two-inch mat of organic material overlaying deep, well-drained outwash materials. Generally, Neilton soils have very rapid permeability and low runoff. On moderate slopes the erosion hazard is slight, but on the steeper slopes (30-65% slope) the hazard of water erosion is high (Halloin, 1987).

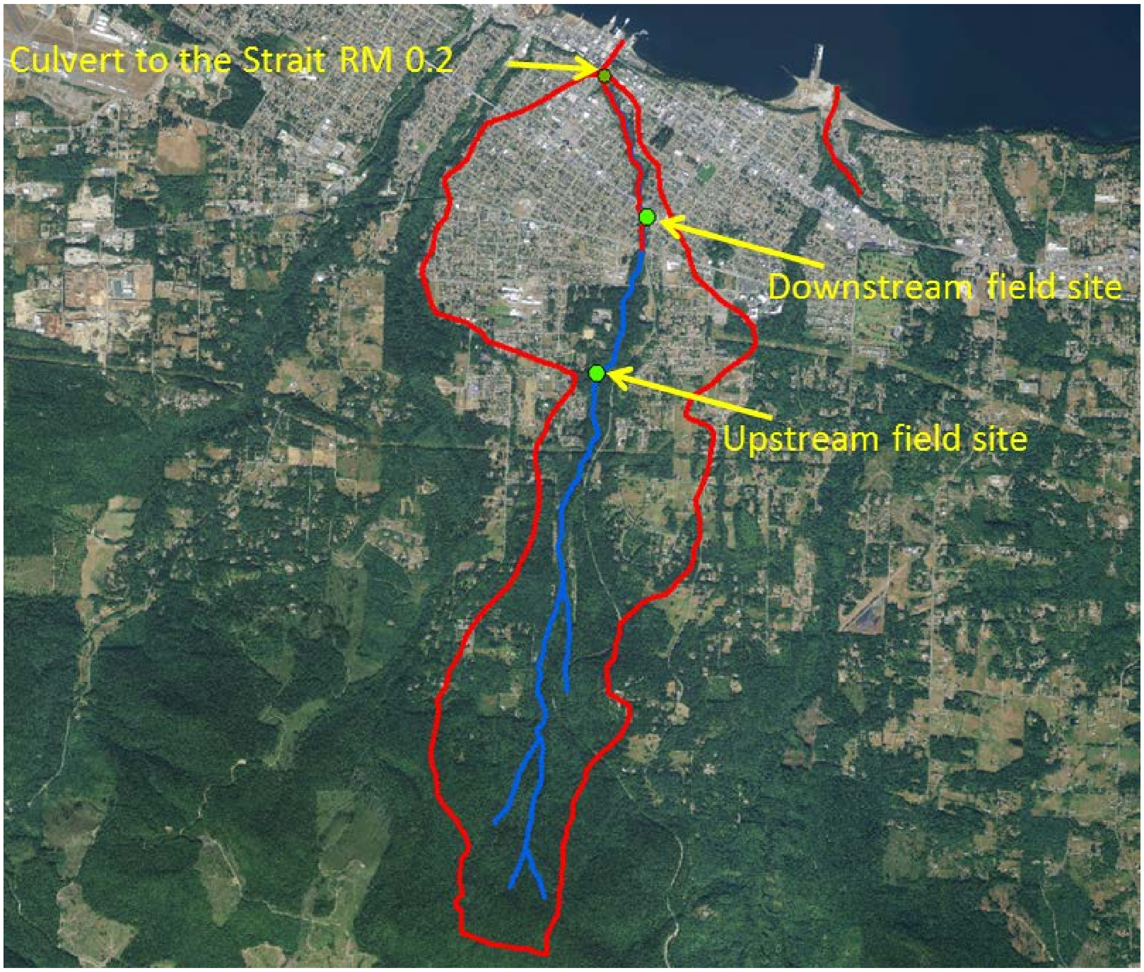

Figure 1. Peabody Creek watershed.

The downstream reach in red represents the impaired (Category 5) reach.

The unimpaired reaches of the creek flow through second growth mixed forest. The lower half of the creek flows through suburban and urban settings with a well-forested riparian zone (Figure 2). The major land cover in the basin includes 46% forested land and 48% developed land. Though historic logging has occurred in the watershed, all above-ground reaches of the creek have at least 75% canopy cover and moderate to abundant bank cover, with some signs of bank erosion (Elwha-Dungeness Planning Unit, 2005).

Historically, sewage was discharged directly into Peabody Creek. In 1996, the City of Port Angeles implemented improvements to the stormwater/sanitary sewer system, removing the major source of raw sewage. Additional ongoing efforts to eliminate the remaining combined sewer overflow will likely lead to further improvements. However, large quantities of stormwater are currently routed into the creek.

Figure 2. General condition of the unimpaired (left) and impaired (right) riparian zone.

There is local interest in this creek. Aside from the Peabody Creek trail, school groups conduct environmental education programs in the creek. There are public access trails in the upper and lower reaches of this watershed. Any demonstrated improvement to this creek could provide a public awareness tool for the state, county, and city.

Potential Sources of Stressors

Urban impacts in the lower watershed and historic logging impacts are the major potential sources of stress. Urban impacts include three proximate stressors: riparian/channel alteration, wastewater inputs, and stormwater runoff. These stressors decrease water and sediment quality, increase temperature, alter flows, modify habitat, and shift the energetics/food chain in the system. Logging impacts also include stressors of riparian/channel alteration which affect temperature, energetics, runoff patterns, flow alteration, and water and sediment quality. There is no active logging in the watershed currently, however, and any legacy effects from historical logging are hard to detect in the stream. The riparian zone of the urban portion of the watershed is impacted by historical logging, but the signal from that activity is confounded by the continuing disturbance related to urbanization. The area upstream of the National Park Visitor Center has mature forest and dense undergrowth.

Peabody Creek receives significant runoff from the city's impervious surfaces, although there are no listed National Pollutant Discharge Elimination System (NPDES) dischargers in the watershed. This runoff has resulted in flashy flows and significant downcutting and channel scouring. The steeper slopes along the whole length of the stream are unstable with many showing signs of failure, reflecting what Halloin (1987) described earlier as having elevated erosion potential. These unstable points contribute sediments to the stream either directly or through surface water runoff. About half of the road crossings use large culverts which are perched so high above the water surface that they prevent fish passage. Other stressors come from trash, both in the stream and along its banks, and also from vegetation removal from the banks and slopes by residents whose property is adjacent to the creek.

Candidate Causes

Selection of Candidate Causes

A stakeholder group met on July 1, 2012 to discuss conditions in Peabody Creek and to start suggesting possible stressors and stressor sources. The group identified candidate causes during this meeting. These were analyzed using the CADDIS method outlined by EPA (http://www.epa.gov/caddis/ssr_urb_intro.html) and a conceptual diagram illustrating pathways of disturbance associated with urbanization was developed (Figure 3). Urbanization can lead to alterations of the riparian area and stream channel. Urbanization also increases wastewater inputs and stormwater runoff. Table 2 shows the responses, or "symptoms" of a stream to urbanization (Walsh et al., 2005).

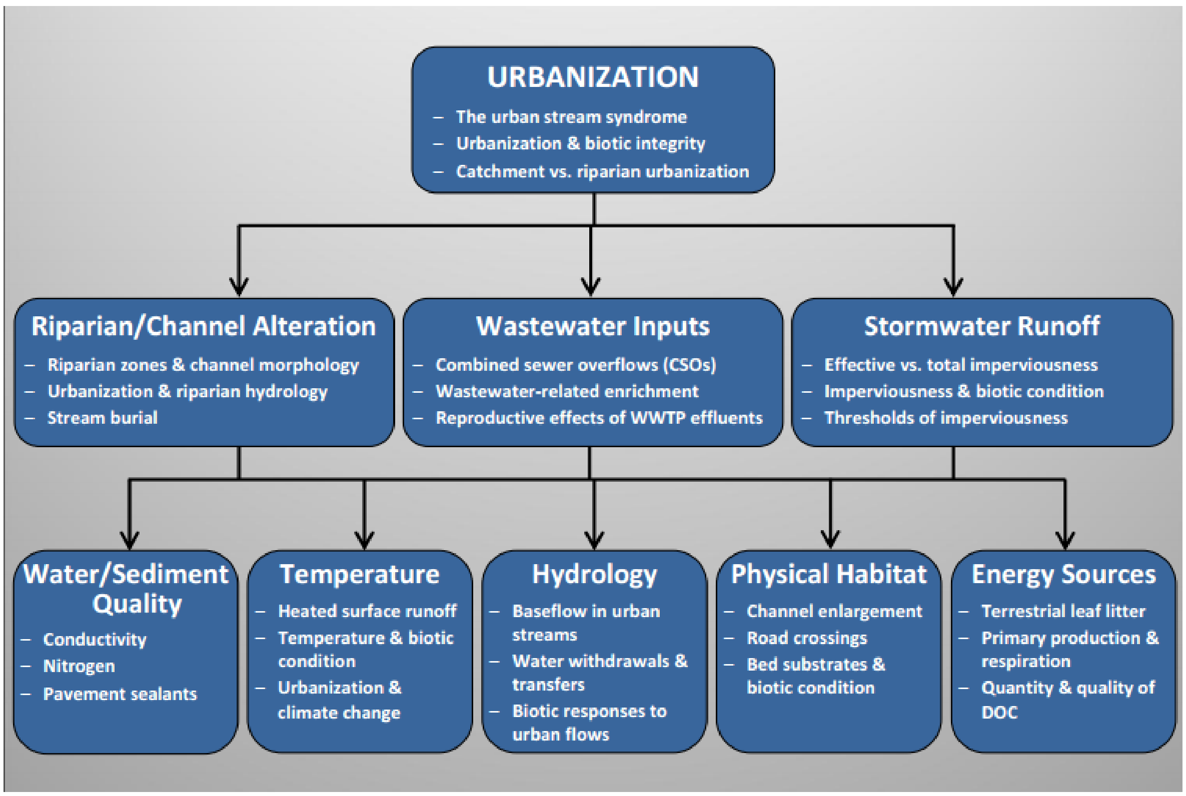

Figure 3. Conceptual diagram designed by EPA CADDIS describing the stressors and responses resulting from urbanization.

Most of the stressors and symptoms in Table 2 apply to Peabody Creek. Though there are no major NPDES dischargers and no single source of toxics, the increase in urban impervious surface and automotive traffic results in higher rates of stormwater and toxins entering the system. All five of the stressor categories in Table 2 are considered candidate causes on Peabody Creek.

Table 3. Candidate causes related to urbanization.

Stressor Category	Symptom
Water/Sediment Quality	Increase in Nutrients
	Increase in Toxics
	Change in Suspended Sediment
Temperature	Increase in Temperature
Hydrology	Increase in Overland Flow Frequency
	Increase in Erosive Flow Frequency
	Increase in Storm Flow Magnitude
	Increase in Flashiness
	Decrease in Lag Time to Peak Flow
	Change in Baseflow Magnitude
Physical Habitat	Increase in Direct Channel Modification (e.g., channel hardening)
	Increase in Channel Width (in non-hardened channels)
	Change in Pool Depth
	Increase in Scour
	Decrease in Channel Complexity
	Change in Bedded Sediment
Energy Sources	Decrease in Organic Matter Retention
	Change in Organic Matter Inputs and Standing Stocks
	Change in Algal Biomass

The symptoms listed in Table 3 are among those that could result in the following responses to the biological communities in Peabody Creek:

- **Increase in Nutrients –** Increased levels of nutrients (e.g., fertilizers, pet waste, atmospheric deposition, and wastewater inputs) enter the stream via stormwater runoff. Increased nutrients often lead to shifts in both the macroinvertebrate and periphyton community assemblage. In addition, increased nutrient availability causes algal bloom and decomposing, leading to dangerously low dissolved oxygen levels which, in turn, may kill fish.
- **Increase in Toxics –** Increased levels of toxics enter the stream via stormwater runoff. Surface runoff inputs during storm events carry oils, grease, herbicides, pesticides, and other toxics into stream systems. Toxics can impact biological communities, altering species richness and abundance, and/or deformities. An increase in toxins also typically favors communities dominated by pollution-tolerant taxa.
- **Change in Suspended Sediment –** Suspended sediment or deposited fine sediments can increase when increased storm flows begin to erode banks and scour the channel bottom. In some watersheds, eroding hillsides or improperly armored construction sites can contribute to increased sediment inputs. Increased suspended sediment can alter invertebrate, periphyton, and macrophyte communities in a waterbody by clogging the gills of both fish and macroinvertebrates and by eliminating habitats in the substrate. This is likely to decrease numbers of organisms that cling to rock surfaces and increase numbers of burrowers and filter feeders.

- **Increase in Temperature –** Increased temperature can result from runoff coming from relatively warm, impervious surfaces of the urban environment. In addition, reduced cold groundwater inputs may result from decreased infiltration caused by impervious surfaces. Wastewater inputs also contribute relatively warm water directly to the system. Warm water has a lower capacity to hold dissolved gases, including oxygen. Therefore it is expected that the macroinvertebrate community would shift towards species tolerant to low oxygen conditions. Also, fish may school at the top, gulping for air, or congregate near groundwater inputs.

- **Increase in Overland Flow Frequency –** Due to impervious surfaces that define urban areas, higher frequency and amount of overland stormwater flow is expected. These flows are the sources of many of the incoming stressors discussed thus far. More frequent surface runoff leads to more frequent exposure for stream organisms, and higher doses of each stressor.

- **Increase in Erosive Flow Frequency –** Higher storm flow frequency can lead to increased erosion, altering substrate through scouring and deposition, which may impact taxa richness and taxonomic composition of macroinvertebrate and periphyton communities, and over longer periods, similarly impact fish communities.

- **Increase in Storm flow Magnitude –** Increased magnitude of storm flows can lead to increased erosion and redistribution of instream wood and coarse substrates. This can lead to channel widening, which undermines stream banks, which, in turn, reduces riparian cover. Removing canopy in this way can lead to a host of changes associated with temperature, light, and energetics in the stream system.

- **Increase in Flashiness –** Impervious surface can dramatically affect the hydrograph of a stream, leading to high peak flows immediately after rain events. Increased impervious surface and decreased infiltration can also lead to lower groundwater and a lower baseflow in the stream. Also, due to either anthropogenic or erosional changes in channel morphology, water is often conveyed out of the stream more rapidly, resulting in longer periods of baseflow. Shallow water depth and adjacent impervious surface, rather than riparian vegetation and canopy cover, can lead to elevated water temperatures. All of these factors create highly unstable conditions for stream organisms.

- **Decrease in Lag Time to Peak Flow –** Decreased lag time to peak flow can create unpredictable conditions for stream organisms. Instead of a gradual change in flows and depths that allows mobile species to seek refuge, the rapid onset of peak flow can sweep organisms out of their habitats. This can lead to decreased taxonomic richness, increased generalist taxa, and reduced productivity of the stream.

- **Change in Baseflow Magnitude –** A change in baseflow magnitude can lead to shallower and warmer conditions in the stream. Warmer conditions can favor more tolerant organisms and reduce diversity of stream organisms. When warmer conditions are accompanied by abundant sunlight, the macroinvertebrate community can shift toward scrapers and filter feeders. Less water can also prohibit larger fish taxa from using some habitats, and lower baseflows that cut off pool habitats can strand fish and lead to fish kills.

- **Increase in Direct Channel Modification –** Direct channel modification such as the use of culverts, cement drains, and channelization eliminates habitat and restricts the movement of highly mobile organisms. Direct channel modification can result in a specific form of erosion called downcutting which deepens and widens the stream downstream of the outfall of such a modification. This can create a drop that is too steep for many organisms to overcome. In addition, in cases where the channel is run through a culvert, the culvert may be too steep for organisms to navigate. No natural habitat exists within most channels modified in these ways, resulting in very long stretches of the river where organisms are exposed to highly artificial conditions.
- **Increase in Channel Width** (in non-hardened channels) **–** Increased channel width is often associated with decreased channel and habitat complexity. Wider channels are also subjected to increased exposure to sunlight which may lead to elevated water temperatures and decreased dissolved oxygen levels. These changes can interact with other parameters to decrease habitat quality and lead to shifts in the macroinvertebrate, periphyton, and fish communities. For example, in the presence of excessive nutrients, an increase in light and temperature associated with a wider channel can lead to an algal bloom. This, in turn, may alter macroinvertebrate communities, favoring dominance by scrapers and grazers. In addition, decreased channel complexity is associated with decreased habitat complexity which may alter the diversity of stream organisms.
- **Change in Pool Depth –** Pools in a stream can either increase in depth due to scour or decrease in depth due to sediment deposition. Pools may serve as a refuge from high-flow settings for steam organisms. Pools that have been scoured may become larger, but there is little cover. Moreover, organic matter that serves as a food source for many organisms can be swept away during a storm event. Pools that become shallower due to sediment deposition may experience elevated temperatures. Both conditions can negatively impact aquatic communities.
- **Increase in Scour –** Decreased infiltration, increased storm flow magnitude and increased flashiness all contribute to an increase in scour. Scouring of streams removes organic materials that serve as food or habitat for many organisms and also removes substrates used for habitat or spawning fish. An increase in scour can alter the diversity and abundance of all biological communities.
- **Decrease in Channel Complexity –** City governments often "clean" streams, removing large wood, boulders, and vegetation in an attempt to increase water transport and decrease the chances of flooding. In addition, some streams are purposely channelized for the same reason. This leads to decreased instream habitat complexity necessary to support diverse assemblages and different life stages of various organisms.
- **Change in Bedded Sediment –** Urban streams can exhibit extremes in substrate composition. Areas prone to scouring often have substrate composed only of coarse substrates or bedrock. Engineered channels may have cement bottoms. In areas where water slows, fine sediments can drop out of the water column, leading to silt-dominated substrates. All of these factors can decrease habitat complexity, such that in areas where fine sediments settle, the interstitial spaces can become clogged and oxygen levels can decrease. Additionally, many pollutants adhere to the surfaces of fine substrate particles, creating concentrated areas of pollutants in depositional areas, which impacts the resident biota.

- **Decrease in Organic Matter Retention –** High erosive flows can scour the stream bottom and redistribute organic matter. A lack of organic matter in areas prone to scouring can lead to reduced food and cover for macroinvertebrates, periphyton, and fish, with possible negative impacts to these communities.
- **Change in Organic Matter Inputs and Standing Stocks –** Urban streams often lack adequate riparian canopy and plant communities to provide sufficient inputs of allochthonous organic matter into the stream. This also allows more sunlight to enter the stream and increases water temperatures. Additionally, a lack of riparian habitat leads to elevated nutrient inputs from runoff and wastewater. This combination of factors can dramatically alter the stream system, leading to shifts in macroinvertebrate and periphyton diversity and abundance. Increased abundance of warm water taxa and changes in macroinvertebrate functional feeding groups from shredders to scrapers and filter feeders are also likely.
- **Change in Algal Biomass –** Depending on the situation, urban settings can alter algal biomass in different ways. High scour events can remove algal mats and floating colonies. In reaches with decreased canopy cover, additional sunlight and nutrients from runoff can lead to an exponential increase in algal biomass. Algal decomposition can lead to a drop in dissolved oxygen levels, which can contribute to fish kills and shifts in the macroinvertebrate and periphyton communities.

Data Used for Causal Analysis

Data collection followed protocols outlined by Adams (2010b) and Plotnikoff and Wiseman (2006). The basic monitoring data were collected at Ecology's ambient biological monitoring sites, providing a baseline of conditions at the time of the study that can be compared to post restoration conditions. Also the data were comprehensive enough to provide a signal that may indicate whether or not a potential stressor is acting on the stream reach.

Data for this project were collected in September 2012; this was at the end of the dry season, when baseflow conditions typically predominate.

Due to a lack of true replication, comparison of characteristics between upstream and downstream reaches was limited to descriptive statistics (i.e., means and standard deviations) calculated with Systat (Systat 13.1, Systat Software, Inc., 2009).

In-Situ Chemistry

In-situ measurements included water chemistry, turbidity, and discharge. Water chemistry was measured using a Hach® HQ40d multi-probe meter, which provides instantaneous measurements of dissolved oxygen, conductivity, temperature, and pH. These measurements were taken upon arrival at the site and at the end of the data collection event. Reported measurements are from those made at the end of the data collection event. Discharge was measured using a Marsh McBirney Flowmate 2000. In addition, we used a Hach® 2100P IS Portable Turbidimeter to measure turbidity on site. Table 4 outlines the type of analysis, methods, and quality standards for all in-situ measurements.

Table 4. Methods used to analyze in-situ samples for field analysis.

Analysis	Equipment Type and Method	Accuracy (deviation or % deviation from true value)	Method Reporting Limits and/or Resolution	Number of Samples/ Measurements Per Site
Dissolved Oxygen	EAP033 (Swanson, 2007)	+/- 0.5 mg/L	0.1 mg/L	2
Specific Conductivity	EAP033 (Swanson, 2007)	+/- 10 us/cm	0.1 uS/cm 0.2 @ 25° C	2
pH	EAP033 (Swanson, 2007)	0.075 SU (pH<5.75) +/- 0.15 (pH>5.75)	1 to 14 SU	2
Temperature	EAP033 (Swanson, 2007)	+/- 1° C of thermometer reading	1 - 26° C	2
Turbidity	SM 180.1	20% RPD	0.5 NTU	1

SM: Standard Method
RPD: Relative Percent Difference

Water Chemistry

Water chemistry samples were collected in containers obtained from Ecology's Manchester Environmental Laboratory (MEL). Staff collected these samples upon arrival and then stored them in the creek in the shade in a black plastic trash bag while on site. At MEL the samples were stored at <4° C until analyzed. Table 5 outlines the type of analysis, methods, and quality standards for all water chemistry sampling methods.

Table 5. Laboratory methods used to analyze water chemistry samples for field analysis.

Analysis	Equipment Type and Method	Accuracy (deviation or % deviation from true value)	Method Reporting Limits and/or Resolution	Number of Samples/ Measurements per site
Chlorophyll *a*	SM 10200H(3)	20% RPD	0.1 ppb	1
Total Persulphate Nitrogen	SM 600/4-79-020 4500-NO3-B	20% RPD	0.025 mg/L	1
Total Phosphorus	SM 4500PF	20% RPD	0.005 mg/L	1
Total Suspended Solids	SM 2540D	20% RPD	1.0 mg/L	1
Chloride	SM 300.0	20% RPD	0.1 mg/L	1

SM: Standard Method
RPD: Relative Percent Difference

Sediment Chemistry

Sediment chemistry samples were collected at each site according to protocols (Adams, 2010b). During sample collection, non-powdered nitrile gloves were worn to prevent contamination. The sample was collected by mixing sediment from three different instream locations upon arrival. From each location, the top 2 cm of sediment were placed into the collection bowl, mixed until a uniform color and texture was achieved, and allowed to settle. The overlying water was then removed before the sediment was placed into a sample jar. Jars were stored in the creek and in the shade in a black plastic garbage bag until sampling was complete; the jars were then transported on ice to MEL. Table 6 outlines the type of analysis, methods, and quality standards for all sediment chemistry sampling methods.

Table 6. Laboratory methods used to analyze sediment chemistry samples.

Analysis	Equipment Type and Method	Accuracy (deviation or % deviation from true value)	Method Reporting Limits and/or Resolution	Number of Samples/ Measurements per site
Total Organic Carbon in Sediment	PSEP (1986, with 1997 Update) MEL (2008)	20% RPD	0.1%	1
Arsenic	ICP Method 200.8 (EPA 1983) MEL (2008) Pg 134	20% RPD	0.1 mg/Kg	1
Copper	ICP Method 200.8 (EPA 1983) MEL (2008) Pg 134	20% RPD	0.1 mg/Kg	1
Lead	ICP Method 200.8 (EPA 1983) MEL (2008) Pg 134	20% RPD	0.1 mg/Kg	1
Zinc	ICP Method 200.8 (EPA 1983) MEL (2008) Pg 134	20% RPD	5 mg/Kg	1
Polynuclear Aromatic Hydrocarbons (Appendix B-16)	GC/MS Method 8270 (EPA 1996) MEL (2008) Pg 164	+/- 50% RPD	40 µg/Kg	1

RPD: Relative Percent Difference

Habitat

Habitat measurements were made at 11 equidistant transects and along the entire thalweg at each site, according to Adams' protocol (2010b, appendices 6 through 17). Table 7 outlines the type of measurement, methods, and quality standards for all habitat measurement methods.

Table 7. Methods used to collect habitat data for field analysis.

Analysis	Equipment Type and Method	Accuracy (deviation or % deviation from true value	Method Reporting Limits and/or Resolution	Number of Samples/ Measurements per site
Slope	EAP062 (Werner, 2009a)	10% RPD	0.5 cm	101
Bearing	Merritt (2009)	10% RPD	0-360°	101
Thalweg Depth	EAP062 (Werner, 2009a)	10% RPD	0 – 1.2 meters	11
Habitat Unit Presence	Merritt (2009)	10% RPD	NA	11
Side Channel Presence	Merritt (2009)	10% RPD	NA	11
Edge Pool Presence	Merritt (2009)	10% RPD	NA	11
Bar Presence	Merritt (2009)	10% RPD	NA	11
Wetted Width	EAP062 (Werner, 2009a)	10% RPD	0.1 meters	11
Bankfull Width	EAP062 (Werner, 2009a)	10% RPD	0.1 meters	11
Bar Width	EAP062 (Werner, 2009a)	10% RPD	0.1 meters	11
Substrate Sizes	Merritt (2009)	10% RPD	NA	11
Substrate Depths	Merritt (2009)	10% RPD	0 – 1 meter	11
Shade	EAP064 (Werner, 2009b)	10% RPD	0-100%	11
Human Influence	Merritt (2009)	10% RPD	NA	11
Riparian Vegetation	Merritt (2009)	10% RPD	NA	11
Large Woody Debris	Merritt (2009)	10% RPD	NA	11

RPD: Relative Percent Difference

Macroinvertebrate Community

For each site, one kick sample was collected using a D-frame kick net (500 um mesh net) at each of 8 randomly selected transects. Each kick sample represented 1 square foot of streambed surface area for a total of 8 square feet sampled at each site (Table 8). Each kick sample was added to a composite sample for the site and preserved with 95% non-denatured ethanol. Samples were sent to Rhithron Associates, Inc., Missoula, MT for analysis according to Adams (2010b, Appendix C-2).

Table 8. Methods used to collect and analyze biological samples for field analysis.

Analysis	Equipment Type and Method	Accuracy (deviation or % deviation from true value	Method Reporting Limits and/or Resolution	Number of Samples/ Measurements per site
Periphyton	Barbour et al. (1999)	90% RPD	NA	1 composite from 8
Macroinvertebrate	Targeted = Plotnikoff and Wiseman (2001) Monitoring = Merritt (2009)	90% RPD	NA	1 composite from 8 transects

RPD: Relative Percent Difference

Sample material was spread over a Caton tray from which at least two randomly chosen grid squares were selected and the insects removed. Additional squares were selected as needed until a minimum of 500 organisms were counted. For each composite sample, Rhithron counted and identified all taxa in a 500-organism count subsample. All organisms were identified to "Lowest Practical Level", generally to genus or species. Rhithron reported the number of individuals identified for all taxa and provided a detailed metrics report.

Periphyton

A rock (roughly cobble-sized) was selected from the bottom of the stream, close to but not within the randomly selected macroinvertebrate sample locations. The exposed upward-facing surface of the rock was scrubbed with a new, firm, bristled toothbrush and rinsed with DI water into a clean bucket. At each transect, enough rocks were scrubbed to sample a 7.5 cm diameter surface area circle for a total of 353 cm^2 sampled across transects. The rinsate from each transect was composited into the sample jar (Table 8). These samples were sent to Rhithron Associates, Inc., Missoula, MT, for analysis according to Adams (2010b, Appendix C-4).

For each composite sample, Rhithron transferred a subsample to a Palmer-Maloney counting chamber for enumeration of soft bodied algae and 300 algae cells containing chloroplasts were counted at 400X magnification. Another subsample was acid digested and mounted with Naphrax® for diatom identification, with 300 diatom frustules counted at 1000X. Soft algae were identified to genus and, if possible, to species. Diatoms were identified to species and, if possible, variety. Rhithron reported the number of individuals identified for all taxa in the subsamples and provided a detailed metrics report.

Evaluation of Data

Deferring of Candidate Causes

In general, issues associated with overall water quality in a chemical sense can be deferred. The data do not indicate any point or non-point sources of chemical pollution that is entering the water.

In-Situ Chemistry

In-situ water chemistry data are presented in Table 9. There were no substantial differences in the in-situ conditions between the sites with the exceptions of turbidity and flow. Temperature, pH, and dissolved oxygen were all within the water quality standards. Because we do not have enough monitoring data to determine what a background condition for this stream is, we cannot say whether this measurement is within the water quality standards for turbidity. Turbidity went from near 0 to 57 NTUs[1]. While this is not a level that would be of concern, the increase in turbidity during a baseflow indicates there is likely some disturbance in the listed reach. Further monitoring may be required to determine if this could be a contributing factor to the biological impairment. Similarly, conductivity is four times higher than that found in reference streams in the area, though those reference stream sites are located in a slightly different setting. This level of conductivity does not represent a stressor by itself, but it indicates that some form of disturbance may be present in the watershed.

Table 9. In-situ water chemistry results for Peabody Creek.

Site	Temperature (°C)	pH	Conductivity (us/cm @25 °C)	Dissolved Oxygen (mg/L)	Percent Oxygen Saturation	Turbidity (NTU)
Impaired Site AM	11.2	7.89	487	10.7	97.2	57
Impaired Site PM	12.0	7.82	424	10.6	98.2	
Unimpaired Site AM	11.6	7.68	430	10.3	95.3	0.5
Unimpaired Site PM	11.7	7.85	42.8	10.4	96.6	

[1] nephelometric turbidity units

Water Chemistry

Water chemistry data are presented in Table 10. Total persulfate nitrogen levels are elevated at both sites and are not substantially different from each other. Both locations are mesotrophic in their nitrogen content.

Table 10. Water chemistry results for Peabody Creek.

Site	Chlorides (mg/L)	Total Phosphorus (mg/L)	Total Persulfate Nitrogen (mg/L)	Total Suspended Solids (mg/L)	Chlorophyll- *a* (ug/L)
Impaired Site	8.14	0.072	0.75	1	1120
Unimpaired Site	5.21	0.031	0.89	1	441

In contrast, phosphorus concentration at the impacted site was more than double the concentration at the non-impacted site, with levels of 31 and 72 micrograms per liter, respectively. Phosphorus is often a limiting nutrient in aquatic systems. Likely sources of nutrients in Peabody Creek include runoff from residential landscaping, pet waste, and potentially leaking septic systems.

Chlorophyll-*a* levels appear to have responded to the differences in nutrients. Chlorophyll-*a* at the impaired site was nearly three times higher than at the non-impaired site. The chlorophyll-*a* sample represents the periphyton community and there was noticeably more biofilm accumulation on the stream bottom at the impaired site despite no evidence of attached filamentous algae.

Chlorides were slightly higher in the impaired reach than in the unimpaired reach. Chlorides are often used to reflect the degree of urbanization of a watershed, typically increasing as impervious surfaces increase (Herlihy et al., 1998). Chlorides can enter the stream from several sources in the watershed, including particles from vehicle exhaust, discharge from wastewater treatment plants, and the natural weathering of rock. Chronic exposure to chlorides higher than 250 mg/L are considered harmful to freshwater aquatic life (Sprague et al., 2007), much higher than the levels found in our water samples. Though chlorides do increase slightly in the impaired reach, this level of chloride is not likely to be above the background levels expected from the natural weathering of the rocks and substrate in the watershed. More data could be collected to verify this. However, because the levels are far below those known to cause biological impairment, it is not necessary to conduct this investigation.

Total suspended solids were not above the detection limits in samples from either upstream or downstream.

Sediment Chemistry

All metals tested (Table 11) were below the Lowest Apparent Effects Threshold for Freshwater Sediment Quality (Ecology, 2003) in Washington. Though most levels of the various metals tested were higher in the impaired reach, none were high enough to warrant concern for stream organisms. Likely sources of these metals in Peabody Creek include stormwater runoff from the urban and suburban road network where particulates from vehicular traffic and exhaust may land on the road and later wash into the streams. Additionally, pesticides and/or fertilizers applied to landscaping are likely incorporated in runoff and enter the stream during storms or through water treatment outfalls.

Table 11. Sediment chemistry results for Peabody Creek.

Site	Percent Solids (%)	Total Organic Carbon (%)	Arsenic (mg/Kg dw)	Copper (mg/Kg dw)	Lead (mg/Kg dw)	Zinc (mg/Kg dw)
Impaired Site	52.0	2.64	5.22	21.4	9.06	73.8
Unimpaired Site	70.0	0.53	4.33	27.1	5.93	63.0

Total organic carbon in the sediment samples increased from 0.5% at the unimpaired site to 2.6% at the impaired site. This likely indicates an increase in fine substrate particles including sands, silts and clay at the impaired site compared to the unimpaired site. This is common in areas with sedimentation issues, but is also a natural pattern in the downstream portion of rivers and streams. The slope at this site (Table 11) is high enough that the substrates should not be significantly embedded, indicating that these results reflect a sediment impact in the impaired reach. The surface of organic carbon provides binding sites for metal ions, which can contribute to higher metal concentrations in areas with increased fine sediment.

Polyaromatic hydrocarbons (PAHs) were undetected at the non-impaired site with the exception of Retene (which was also detected at similar concentrations in the impaired site), which is derived from conifer sap, and is commonly found in forested streams running though conifer stands. Of the 23 PAHs that were tested, 14 were present in detectable amounts at the impaired (downstream) site (Table 12), although these levels were not above the Lowest Apparent Effects Threshold, where they are established. The PAHs that were detected at the impaired site are likely derived from largely anthropogenic sources. While several PAHs could be derived from burning wood products (e.g., Benzo(a)anthracene and Benzo(a)pyrene), they could also be a component of vehicular exhaust. Based on the likely sources for the PAHs present (Table 13), stormwater runoff is a strong candidate cause.

Table 12. Polyaromatic hydrocarbons (PAHs) measured in this study and their minimum detection limits.

Analyte	Impaired Reach Result (ug/Kg dry weight)	Minimum Detection Limit (ug/Kg dry weight)	Non-Impaired Reach Result (ug/Kg dry weight)	Minimum Detection Limit (ug/Kg dry weight)
1-Methylnaphthalene	Not detected	13	Not detected	9.9
2-Chloronaphthalene	Not detected	15	Not detected	11
2 Methylnaphthalene	Not detected	13	Not detected	9.9
Acenaphthene	Not detected	8.6	Not detected	6.4
Acenaphthylene	Not detected	13	Not detected	9.9
Anthracene	18	8.9	Not detected	6.7
Benz(a)anthracene	96	5.6	Not detected	4.2
Benzo(a)pyrene	140	5.3	Not detected	4.0
Benzo(b)fluoranthene	190	6.0	Not detected	4.5
Benzo(ghi)perylene	120	6.1	Not detected	4.6
Benzo(k)fluoranthene	83	7.9	Not detected	5.9
Carbazole	17	4.9	Not detected	3.7
Chrysene	130	7.3	Not detected	5.5
Dibenzo(a,h)anthracene	27	5.4	Not detected	4.1
Dibenzofuran	Not detected	11	Not detected	8.6
Fluoranthene	220	4.4	Not detected	3.3
Fluorene	Not detected	9.1	Not detected	6.8
Indenol(1,2,3-cd)pyrene	130	8.6	Not detected	6.4
Naphthalene	Not detected	9.4	Not detected	7.1
Phenanthrene	110	7	Not detected	5.2
Pyrene	260	6	Not detected	4.5
Retene	34	9.4	26	7.0

Table 13. Sources of PAH chemicals that were detected in the soils of Peabody Creek in the biologically impaired reach.

Polyaromatic Hydrocarbon	Source
Anthracene	Product of coal tar distillation. Used in dye production, manufacture of synthetic fibers, synthesizing chemotherapy drug (Amsacrine), and in wood preservatives.
Benzo(a)anthracene	Found naturally from burning - volcanoes, forest fires, or barbeques. Also a byproduct of burning fossil fuels.
Benzo(a)pyrene	Found naturally from burning - volcanoes, forest fires, or barbeques. Also a byproduct of burning fossil fuels.
Benzo(b)fluoranthene	Found in coal and petroleum products, released by burning.
Benzo(ghi)perylene	Used to make dyes, plastics, pesticides, explosives, drugs, steroids, and cholesterols.
Benzo(k)fluoranthene	Found in petroleum products, released by burning.
Carbazole	Used in fluorescent dyes, pharmaceuticals, and agrochemicals.
Chrysene	Found in coal tar pitch, creosote, and wood preservatives.
Dibenzo(a,h)anthracene	Found in paint, lacquers, and varnishes.
Fluoranthene	Used in fluorescent dyes, pharmaceuticals, and agrochemicals.
Indeno(1,2,3-cd)pyrene	Found in paint, lacquers, and varnishes.
Phenanthrene	Used to make dyes, plastics, pesticides, explosives and drugs.
Pyrene	Used to make dyes, plastics, and pesticides.

Habitat

Habitat analyses are presented in Table 14. Though the sites were less than one mile apart, they were located in slightly different geomorphic settings, which results in natural differences in habitat characteristics. The slope at the unimpaired site was 6.9%, while the slope at the impaired site downstream was 3.7%. The mid-channel substrates (Table 14) were generally larger and dominated by coarse gravels and cobble in the impaired (downstream) reach (Figure 4). The substrate in the unimpaired reach (upstream) was dominated by wood and coarse gravel. More data from other streams should be collected to provide a frame of reference for comparison to help determine if differences in the substrate types are reflective of natural characteristics or human influence.

There were habitat differences between these two sites that could also be caused by anthropogenic disturbance. While there was no difference in bank instability between the two sites, stream channel characteristics showed signs of entrenchment in the impaired reach, reflected by higher bankfull heights, deeper thalweg depths, and more embedded mid-channel substrates.

Fewer pieces of large woody debris were in the stream channel of the impaired reach than were in the unimpaired reach (Table 14).

Despite the disturbance to the understory in the impaired reach, the riparian overstory was largely intact, resulting in a well-shaded creek (Table 14).

Table 14. Habitat data for Peabody Creek

Habitat Metric	Unimpaired Reach	Impaired Reach
Slope	6.9%	3.7%
Mean bankfull height (cm)	23±5.7	19±4.7
Mean embeddedness (%)	28.8±26.4	18.3±17.6
Thalweg depth (cm)	9.5±7.4	12.9±6.9
D50 at the center of the stream – cobble or greater	0.12	0.36
D50 at the center of the stream – gravel or finer	0.66	0.54
Large woody debris (number of pieces per 15 m transect)	16.6	4.7
Shade (proportion of canopy closure at the center of the stream)	0.95±0.06	0.99±0.03
Average number of occurrences of human influence in the riparian zone per transect	0.42±0.32	6.17±0.67
Average proportion of the transect with fish cover	0.19±0.19	0.11±0.08
Proportion of persistent fish cover	0.19±0.24	0.06±0.05

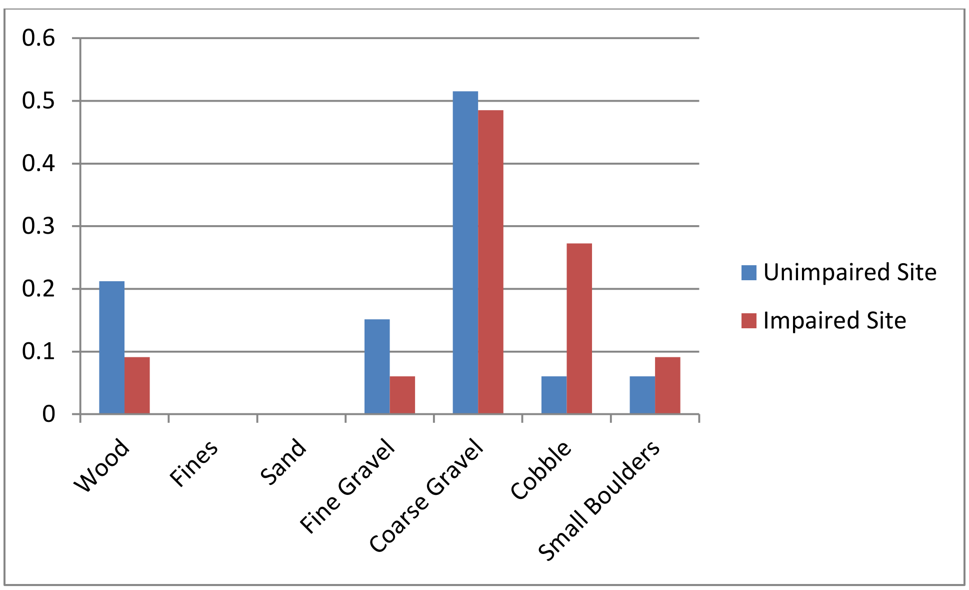

Figure 4. Distribution (proportion) of substrate types in the impaired and unimpaired reaches of Peabody Creek.

In the unimpaired reach, the only human influence documented in the riparian area was the Peabody Creek foot trail on the hillside. The documented human influence was higher in the riparian area of the impaired reach. In the impaired reach, the primary forms of disturbance, in addition to foot paths, were trash, homes, out buildings, and a large area with a motocross bike course on the left bank from transect D to transect I (Figure 5). Most of the disturbance in the impaired reach occurred within 10 meters of the bank, while the footpath in the unimpaired reach was from 10 to 30 meters from the bank.

Figure 5. The motocross course located between transects D and I of the impacted field site.

Culverts are also destroying habitat, as culverts entering the stream are often inadequate for the volume of water they carry. The runoff is creating gullies around the culvert and carrying sediment and trash to the creek (Figure 6). The large culverts that carry stream water under some of the road crossings are perched on the downstream side (Figure 7). These culverts carry large volumes of water that shoot out, at a high speed, at the streambed and banks on the downstream end. This causes significant erosion, scouring and suspending substrate and organic material such as pieces of wood that might have fallen during the dry season. Replacing these culverts with bridges would be ideal, but this may not be feasible due to costs.

Figure 6. Culverts are not effectively conveying runoff to the stream.

Looking Upstream | Looking Downstream

Upstream of the 1st (the same) Culvert

Downstream of the 1st (the same) Culvert

Figure 7. A comparison of immediately upstream and immediately downstream of the first culvert that conveys Peabody Creek under a road on the upstream end of the impaired reach.

Finding a way to reduce flows and protect the receiving portion of the stream are therefore crucial stop-gaps to improve conditions in Peabody Creek. An example of such a structure is already being implemented with some success in Peabody Creek (Figure 8). The water is conveyed downhill in a pipe which discharges into a rock basket and then down an armored path to the creek. There are no significant signs of erosion around these structures. However, based on the lack of vegetation surrounding them, they appear to have only been in use for a relatively short period of time.

Figure 8. Structures built to convey stormwater from streets adjacent to Peabody Creek.

Fish cover varied between sites in both the amount (Table 15) and predominant type (Figures 9 and 10). In the unimpaired reach, there was more cover overall, composed mostly of non-aquatic vegetation. In addition, there was more persistent cover found in the unimpaired site than in the downstream site. Fish cover available in the creek responded differently to disturbance. The predominant cover type shifted from predominantly vegetative cover in the upstream to non-vegetative cover at the downstream site. This was due to a decrease in the amount of vegetative cover in the impaired reach as compared to the unimpaired reach but no change in the amount of non-vegetative cover types. Likewise, there was a decrease in the amount of persistent cover types in the impaired reach as compared to the unimpaired reach.

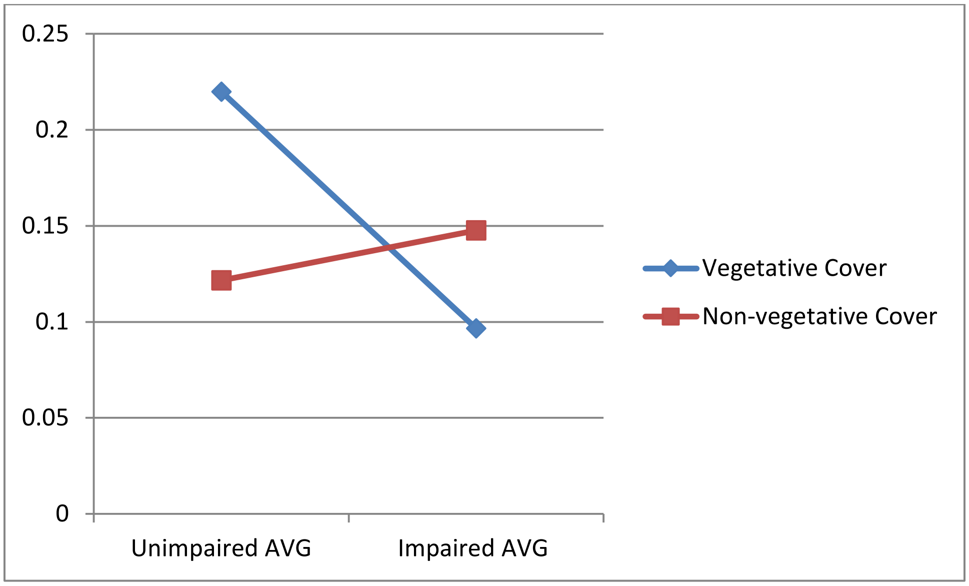

Figure 9. Comparison of non-vegetative and vegetative cover in impaired and unimpaired sites.

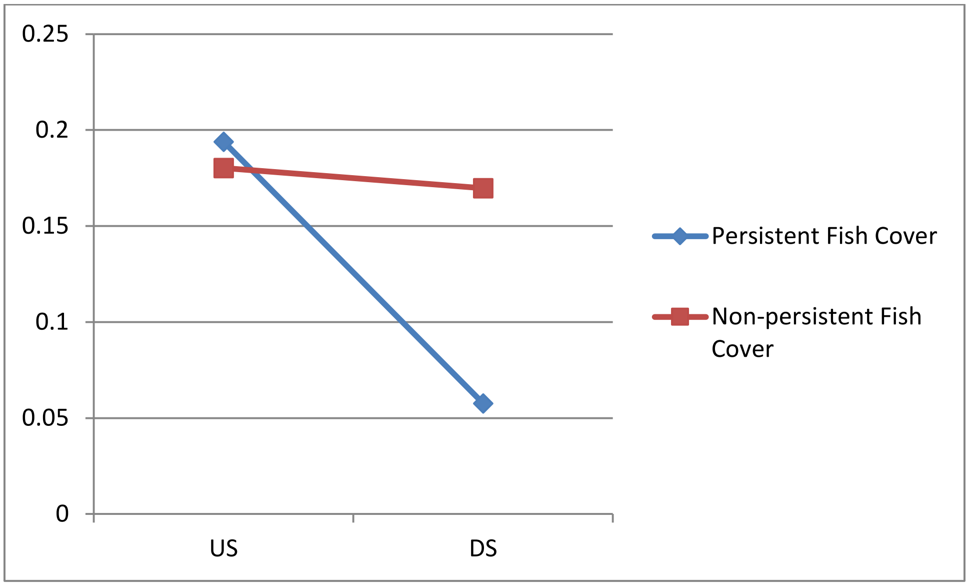

Figure 10. Comparison of persistent and non-persistent cover types in the impaired reach.

Macroinvertebrate Community

Macroinvertebrate community data verified that a biologically impaired condition still exists in Peabody Creek (Table 15). The unimpaired reach had a Benthic Index of Biotic Integrity (BIBI) score of 50 out of a possible 50. The score in the impaired reach was 28. Water quality criteria for biological impairment (Category 5) states that a BIBI Score of 27 or lower must be recorded for at least 2 years in 5. A score of 28 is within the natural variation expected for an impaired condition and the site's past history consistently reflects biological impairment (Table 1).

Table 15. Metric values for the Benthic Index of Biological Integrity (BIBI) at impaired and unimpaired sites in Peabody Creek.

Good Condition = 38-50, Fair Condition = 28-37, Poor Condition = 0-27.

Metric	Unimpaired Metric Value	Unimpaired Metric Score	Impaired Metric Value	Impaired Metric Score
Taxa Richness	70	5	47	5
Ephemeroptera Richness	9	5	3	1
Plecoptera Richness	11	5	5	3
Trichoptera Richness	11	5	4	1
Pollution Sensitive Richness	7	5	2	1
Clinger Richness	30	5	12	3
Long-lived Richness	7	5	3	3
Percent of Community that are Pollution Tolerant	0.32%	5	0.37%	5
Percent of Community that are Predators	23.16%	5	14.78%	3
Dominant Taxa (top 3) Percent	24.12%	5	51.28%	3
Total BIBI Score		50		28

Components of the BIBI score that showed the greatest impacts were Ephemeroptera (mayfly) richness, Trichoptera (Caddis fly) richness, and pollution-sensitive metrics. Mayflies and Caddis flies are generally thought to be the number 1 and number 2 most reliable orders of insects for indicating the health of a stream (Voshell, 2002). An overwhelming majority of taxa within these orders are pollution-sensitive and are only found in clean water (Voshell, 2002). Their relative scarcity in the lower reach of Peabody Creek is an indication of environmental stress. They are sensitive to chemical pollutants and low dissolved oxygen conditions, and are more susceptible to competition in disturbed environments. The majority of the taxa in these groups have an aquatic larval stage that lasts from 3 to 6 months, usually during the warmer periods of the year. The low diversity of these taxa at the impaired field site likely indicates that the stressful environmental conditions are present during this time of year.

The low percentage of pollution-tolerant individuals in both samples indicates that the likely source of stress does not include pollutants directly toxic to the macroinvertebrate community. The decrease in pollution-sensitive taxa might reflect stress related to the impacts of warmer temperatures, low dissolved oxygen, excessive fine sediment, rather than direct impacts of pollutants. Increased phosphorus concentrations exist in the impaired reach, which can negatively impact pollution-sensitive taxa by causing an increase in the biomass of algae which, when it is decomposed by aerobic bacteria, can lead to low dissolved oxygen conditions in the water column. Increased monitoring of the periphyton communities should be conducted to determine the influence of nutrients on the producer communities.

Reduced semivoltine richness (those organisms that require more than one year for their aquatic life stage, or long-lived richness) at the impacted site may indicate a shift to less stable environment conditions. Long-lived organisms are generally found in more stable/predictable environments, while environments more regularly impacted by drastic changes in water quality or flow may not support long lived organisms. Along with fewer long-lived organisms in the impaired reach of Peabody Creek, there was also an increase in the number of multivoltine organisms, or those generating multiple generations in one year. These organisms would be well suited to take advantage of conditions in more unstable environments. For fuller discussion of these hypotheses, further data collection of instream and stormwater chemistry during the rainy season would be necessary.

Other community components measured in the BIBI which showed a decrease with condition included clinger richness and taxa richness. Clingers are adapted to survive in fast moving water and are often associated with cold, oxygenated water. A decrease in clinger taxa is common in downstream reaches of streams. Yet the slope and extensive shade of Peabody Creek in the impaired reach means that with normal flows, these types of conditions could exist even in the lower end of the stream. However, changes in channel morphology and flow patterns, as well as periodic inputs of pollutants from stormwater runoff, could be negatively impacting the clinger population at this site. More extensive data should be collected to clarify whether the decrease in clingers at the impaired site is a result of the location of the impaired site at the bottom of the watershed or whether it is due to periodic inputs of warmer or polluted water associated with stormwater runoff.

A decrease in the evenness of community diversity is a common response to stress. A shift in community composition is also commonly observed along a stream gradient, moving from highly diverse upstream habitats to downstream habitats dominated by finer substrate and low slope. Our data seem to support such a shift in composition, as the top three dominant taxa in the impaired reach included (21%) *Baetis tricaudatus* (common pollution-tolerant mayfly), (17%) *Polypedilum* (midge), and (12%) *Stylodrilus* (segmented worm living in fine substrates), while in the unimpaired reach the dominant taxa were (11%) *Sweltsa* (stonefly), (8%) *Glossosoma* (caddisfly), and (7%) *Zapada oregonensis* (stonefly).

Other components of the macroinvertebrate community of Peabody Creek were noticeably different between stream reaches and are highlighted in Table 16. Overall, these differences suggest shifts in oxygen levels, temperature, and flow-related habitat between the two reaches. An increase in the percent of hemoglobin-bearing organisms, which can persist in low oxygen conditions, was observed at the impaired site relative to the unimpaired site, suggesting reduced oxygen levels at the impaired site.

Table 16. Macroinvertebrate community metrics for impaired and unimpaired sites in Peabody Creek.

Metric	Unimpaired Site	Impaired Site
Air Breather Percent	2.40%	2.37%
Air Breather Richness	3	2
All Non-Insect Percent	9.90%	18.61%
All Non-Insect Richness	13	14
Baetidae/Ephemeroptera	0.08	0.98
Burrower Percent	3.19%	3.10%
Burrower Richness	4	4
Clinger Percent	64.86%	19.53%
Clinger Richness	30	12
Cold Stenotherm Percent	5.11%	0.55%
Cold Stenotherm Richness	6	2
Collector Percent	29.55%	60.95%
CTQa	71.69	82.95
Dominant Taxa (10) Percent	55.59%	78.47%
Dominant Taxa (2) Percent	17.41%	39.23%
Dominant Taxa (3) Percent	24.12%	51.28%
Dominant Taxon Percent	10.06%	21.72%
E Richness	9	3
E Percent	18.05%	22.08%
EPT Percent	67.89%	33.03%
EPT Richness	31	12
Evenness	0.03	0.05
Filterer Percent	3.04%	7.48%
Filterer Richness	3	2
Hemoglobin Bearer Percent	1.44%	17.70%
Hemoglobin Bearer Richness	2	2
Hilsenhoff Biotic Index	2.07	4.30
Hydropsychidae/Trichoptera	0.24	0.09
Intolerant Percent	59.42%	15.15%
Margalef D	10.72	7.32
Metals Tolerance Index	2.06	4.27
Multivoltine Percent	15.97%	55.11%
Oligochaeta+Hirudinea Percent	4.95%	12.96%
Other Non-Insect Percent	4.95%	5.66%
P Richness	11	5
Pollution Sensitive Richness	7	2
Pollution Tolerant Percent	0.32%	0.37%
Predator Percent	23.16%	14.78%
Predator Richness	20	12
Scraper/Filterer	7.26	0.07

Metric	Unimpaired Site	Impaired Site
Scraper/Scraper+Filterer	0.88	0.07
Scraper+Shredder Percent	44.41%	24.09%
Sediment Sensitive Percent	10.22%	0.00%
Sediment Sensitive Richness	2	0
Sediment Tolerant Percent	2.24%	2.55%

Low oxygen levels are associated with elevated water temperatures, and there was a large decrease in both the number and percent of Cold Stenotherm organisms at the impaired site compared to the unimpaired site. These organisms can only survive in a narrow range of cold temperatures. Additionally, we observed that the proportion of Ephemeroptera in the sample represented by Baetidae mayflies increased from 0.08 to 0.98 at the impaired site, mostly a result of changes in the abundance of *Baetis tricaudatus*. *B. tricaudatus* is a fairly tolerant taxon that can survive in warmer, oxygen-poor water. Less than one mile separates the two sites and the riparian corridor is well forested throughout the watershed; yet a decrease in these cold adapted organisms indicates that Peabody Creek may be receiving water inputs with elevated temperatures. The most apparent source for the inputs of warmer water at this time is from urban/stormwater runoff which absorbs heat from the impervious surfaces as it makes its way to the stream.

Overall, data suggest a shift in the insect community at the impaired reach. The unimpaired reach of Peabody Creek supports a diverse macroinvertebrate community composed of sensitive taxa and the presence of long-lived organisms, suggesting relatively stable conditions at this site. The macroinvertebrate community at the impaired reach of Peabody Creek, composed of fewer sensitive taxa, suggests relatively unstable conditions, including periods of warm temperatures with the possibility of low oxygen levels. These conditions are common in systems impacted by frequent stormwater events.

Periphyton

Periphyton samples between impaired and unimpaired reaches were very similar in terms of diatom metrics (Table 17). There were a few small but measurable differences (i.e., metals tolerant taxa percent, polysaprobous taxa percent, and motile taxa percent); yet these differences were inconsistent in pattern from the other data. Water and sediment chemistry, habitat, and macroinvertebrate data all suggested a consistent pattern reflecting an undisturbed condition in the upper watershed and an impaired condition in the urban portion of the watershed. Data from diatoms suggested the opposite situation: signals of disturbance were seen in the upper undisturbed site. It is unclear if these data reflect the true condition or if error was introduced in the field through mislabeled samples. For this reason, other periphyton samples should be collected before drawing conclusions.

Table 17. Periphyton community metrics for impaired and unimpaired sites in Peabody Creek.

Environmental Attribute	Attribute Group	Metric	Unimpaired Site	Impaired Site
Community Structure	Distribution	Cosmopolitan Taxa Percent	90.50%	89.33%
	Distribution	Native Taxa Percent	1.33%	1.83%
	Diversity	Shannon H (log2)	2.960	2.701
	Diversity	Species Richness	24	22
	Dominance	Dominant Taxon Percent	38.83%	38.00%
	Rare Taxa	Mountains Rare Taxa Percent	0.00%	0.00%
	Rare Taxa	Plains Rare Taxa Percent	1.00%	0.17%
Inorganic Nutrients	Rhopalodiales	Rhopalodiales Percent	0.00%	0.00%
	Autotrophism	Nitrogen Autotroph Taxa Percent	95.50%	88.83%
	Trophic State	Eutraphentic Taxa Percent	88.17%	85.67%
Metals	Abnormality	Abnormal Cells Percent	0.50%	0.00%
	Acid Tolerance	Acidophilous Taxa Percent	0.00%	0.00%
	Disturbance	Disturbance Taxa Percent	0.00%	2.00%
	Metals Tolerance	Metals Tolerant Taxa Percent	15.67%	4.00%
Organic Nutrients	Heterotrophism	Nitrogen Heterotroph Taxa Percent	2.00%	2.00%
	Oxidation	Low DO Taxa Percent	0.50%	0.17%
	Pollution	Pollution Index	2.808	2.928
	Saprobity	Polysaprobous Taxa Percent	17.83%	6.33%
Sediment	Brackishness	Mountains Brackish Taxa Percent	97.00%	97.17%
	Brackishness	Plains Brackish Taxa Percent	3.33%	1.00%
	Motility	Motile Taxa Percent	8.33%	50.00%
	Siltation	Siltation Taxa Percent	2.67%	2.67%

Data from Other Sources

This level of study did not incorporate data collected from other sites in the region; therefore, there is no statistical replication involved in this analysis. Our results cannot strongly differentiate between natural changes that occur from upstream to downstream and those impacts from flow alterations due to stormwater discharge in the impaired reach.

Additional data from other sites within and outside of this drainage should be collected to provide a stronger case for the conclusions that follow.

Conclusions

Based on the results of this preliminary study, we suggest that two of the three main stressors predicted to be associated with urbanization in this watershed (i.e., riparian/channel alteration and stormwater runoff) may be acting to impair the benthic invertebrate community (Figure 3). Wastewater inputs can likely be eliminated as a stressor since (1) sewer outfalls are no longer operational in the watershed and (2) the one that historically discharged into Peabody Creek had its outfall at the very bottom of the stream before it entered a culvert and exited in the Strait of Juan de Fuca.

Although a more comprehensive study is needed to determine how much altered riparian conditions contributed to changes in Peabody Creek that might be impacting benthic invertebrates, it is possible that nutrient dynamics have shifted due to changes in the composition of the understory and herbaceous communities. These canopy layers are reduced in the impaired reach and include several non-native plants, most notably Japanese Knotweed (*Polygonum cuspidatum*), blackberry (*Rubus spp.*), and English Ivy (*Hedera helix*). These changes to the understory may impact the instream system by altering the amount and type of organic matter entering the stream.

However, the most likely scenario, based on the data collected, is impacts consistent with stormwater flow events in flashy urban streams. Substrates differed between the two sites, with the impacted site having slightly larger-sized particles and slightly higher embeddedness than the unimpacted site. These results suggest that most of the smaller particles are being removed with high-flow events, with the larger particles becoming embedded as flows recede and the suspended fines settle out. Consistent with these findings, shifts in the macroinvertebrate communities also reflect differences between the two sites, suggesting a change in substrate conditions.

An impacted riparian zone and the potential for an altered flow regime with increased impervious cover could be contributing to elevated inputs of pollutants entering Peabody Creek. While no notable toxins were found in the water or sediment, elevated levels of phosphorus were observed at the impacted site, which may contribute to the accumulation of periphyton as reflected by a chlorophyll-*a* concentration more than double that of the unimpacted site. Accumulation of periphyton can lead to a cascade of effects for macroinvertebrate communities, starting with a reduction of available habitat through smothering by algal growth, and ending in reduced oxygen levels due to decomposition of algal material by aerobic bacteria.

Additionally, there were small but measurable amounts of metals at both sites, with higher levels observed in the impaired reach. As there are no direct dischargers of nutrients or metals into Peabody Creek, the most likely source for these pollutants entering the system is stormwater runoff. Additional data are needed to verify this, as well as being able to link changes in oxygen and/or temperature to stormwater runoff.

Additional data will allow identification of the main window of impact, thereby guiding decision-making and contributing to the restoration of Peabody Creek.

Recommendations

While this preliminary study was limited to a single collection event at each site, and therefore limited in scope, results still suggest the primary stressors at the impaired site in Peabody Creek are likely associated with stormwater runoff. Therefore, more data should be collected to help distinguish whether the chemical nature, the flow-related attributes of stormwater, or both, are contributing to the degradation of water quality and invertebrate communities in Peabody Creek. Greater replication of sample sites, as well as sampling during different times of the year, will increase the ability to link water quality to various stressors related to stormwater runoff.

As biological impairment in streams has been linked to hydrologic indicators in urban settings (e.g. DeGasperi et al., 2009), understanding flow in Peabody Creek will be critical if improvements in aquatic health are to be made. The City of Port Angeles is in the process of acquiring a stormwater permit and addressing issues associated with the impacts of stormwater on water quality. Over the long-term, it may be necessary to model flow and set targets for the amount of water that can be diverted directly into Peabody Creek. It is crucial to implement mechanisms that reduce the speed at which runoff enters Peabody Creek and travels through culverts during storm events. Also, points of concentrated water inputs (e.g., bridge crossings) should be modified to reduce the "fire-hose" effects created by large volumes of water entering the creek. Similar issues related to stormwater runoff and bioassessment are currently being addressed in other parts of Washington (e.g. Horner, 2013; Plotnikoff and Blizard, 2013) and should be used to help guide policy decisions in Peabody Creek.

In the short-term, improvements to the riparian understory of impaired portions of Peabody Creek will increase organic matter in the soil, thus helping to impede overland runoff and allowing water greater time to soak into the ground. To reduce the riparian impacts, removing invasive plants and replanting with native understory trees is encouraged. In addition, converting the canopy to conifers in the urban reach is recommended. For example, at the location of the unofficial motocross course, the left bank of the stream is devoid of vegetation and there are signs that sediment is entering the stream at this site. Efforts should be made to return the site back to natural vegetative conditions, perhaps incorporating the existing foot path that extends along the entire reach. This would help reduce the amount of fine substrate entering the creek and improve the buffer between human influences beyond the riparian zone.

Finally, community outreach and program development could inform citizens on ways to help reduce pollutants entering streams. See:
www.kingcounty.gov/environment/waterandland/stormwater/introduction/stormwater-runoff.aspx

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Appendix. Glossary, Acronyms, and Abbreviations

Glossary

Benthic macroinvertebrates: Invertebrate organisms which are in or on the substrate of waterbodies and visible with the naked eye.

Dissolved oxygen (DO): A measure of the amount of oxygen dissolved in water.

Hemoglobin-bearing organism: An organism that uses hemoglobin as a means of oxygen transport through the body. Hemoglobin is a protein that gives blood its red color due to the use of iron molecules to bind and carry oxygen through the body of vertebrates. Some invertebrate species known to be tolerant of low oxygen conditions also use hemoglobin to store and carry oxygen.

Nonpoint source: Pollution entering waters of the state from dispersed land-based or water-based activities, including atmospheric deposition, surface water runoff, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the NPDES program. Generally, any unconfined and diffuse source of contamination.

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

Point source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites where more than 5 acres of land have been cleared.

Standard Operating Procedure (SOP): A document which describes in detail a reproducible and repeatable organized activity (Kammin, 2010).

Taxa: Species or group of organisms having similar characteristics. The lowest level of identification for organisms.

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.

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

Acronyms and Abbreviations

BIBI	Benthic Index of Biotic Integrity
DO	(See Glossary above)
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
HBI	Hilsenhoff Biotic Index
MEL	Manchester Environmental Laboratory
NPDES	National Pollutant Discharge Elimination System
PAHs	Polyaromatic hydrocarbons
SOP	(See Glossary above)
TMDL	(See Glossary above)

Units of Measurement

cm	centimeter
ft	feet
mg/L	milligrams per liter (parts per million)
NTU	nephelometric turbidity units
SU	standard unit
uS	microsiemens