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**ECOLOGY**  
State of Washington

# **Pyrethroids in Freshwater Sediments of King County**

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For more information contact:

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

Washington State Department of Ecology - [www.ecy.wa.gov/](http://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

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# **Pyrethroids in Freshwater Sediments of King County**

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by

Paul D. Anderson

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

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## Abstract

Studies from other states have found that pyrethroid pesticides are most commonly found in urban streams that are influenced by stormwater. This study, conducted in December 2010, was designed to provide quantitative data on pyrethroids in urbanized areas in Washington and to determine if levels are high enough to adversely affect sediment-dwelling organisms.

Samples were collected from 20 creeks in western King County. Western King County was chosen because it has many urban streams that are highly impacted by stormwater. Samples were analyzed for 11 pyrethroids, the synergist piperonyl butoxide, total organic carbon, and grain size. Sediment temperature was also measured at each sampling site. Total organic carbon and sediment temperature were used to help understand the bioavailability and toxicity of any detected pyrethroids.

Nine of the 20 sites sampled had a detection of at least one pyrethroid. The most frequently detected pyrethroid was bifenthrin which was detected in eight of the 20 sampling sites.

In several instances concentrations of bifenthrin and lambda-cyhalothrin were above benthic toxicological endpoints. This indicates that there is potential for adverse impacts from these two compounds on sediment-dwelling organisms.

It is recommended that further research at the sites from this study should be conducted at different times to determine the true environmental state of pyrethroids in Washington. The research should include first-flush sampling, benthic community sampling, and biological toxicity testing at environmentally relevant temperatures.

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# Introduction

Currently, there is little data available on environmental concentrations of pyrethroid insecticides in Washington State. The primary goal of this study was to collect screening level information on concentrations of pyrethroid insecticides in freshwater sediments from creeks that are highly impacted by urban stormwater.

Sampling occurred for ten currently registered pyrethroid insecticides commonly used in urban areas, and for the synergist piperonyl butoxide (PBO) (San Francisco Estuary Project, 2008; Jennings, personal communication, 2010). These ten were chosen based on other research and market findings from California (San Francisco Estuary Project, 2008). The ten pyrethroids insecticides are: bifenthrin, cyfluthrin, cypermethrin, deltamethrin, esfenvalerate, lambda-cyhalothrin, permethrin, phenothrin, resmethrin, and tralomethrin. During analysis of the samples Manchester Environmental Laboratory (MEL) substituted cyphenothrin for phenothrin and added tetramethrin. This change brought the total up to 11 pyrethroids.

The data were used to determine if pyrethroid concentrations found in urban stream sediments have the potential to adversely affect sediment-dwelling organisms. Ultimately, this data may be used to assess the need for sediment monitoring for pyrethroids in future stormwater monitoring and permitting activities.

## Background

Pyrethroids are synthetic compounds similar to pyrethrum, a natural insecticide derived from flowers of the genus *Chrysanthemum*. In recent years, use of products containing pyrethroids by homeowners, commercial applicators, and the agricultural industry has substantially increased. This increase can be attributed to the substitution of pyrethroids for organophosphate pesticides. Organophosphate pesticides are being used less because of concerns over environmental impacts, toxicity to humans, and withdrawal by the U.S. Environmental Protection Agency (EPA) of registered uses of most products that contain chlorpyrifos and diazinon (Ding et al., 2010; Weston et al., 2005).

Many consumer insect treatments available for indoor and outdoor residential and commercial use include pyrethroids as the active ingredient. Pyrethroids are also in common products such as pet sprays and shampoos, household insecticides, mosquito repellents, and lice treatment for humans. Many products containing pyrethroids also contain PBO. PBO is used to enhance the toxicity of pyrethroids and other insecticides by blocking natural detoxification pathways (Amweg et al., 2006).

As a group, pyrethroids have low water solubility, high octanol-water partition coefficients ( $k_{ow}$ ), and strong affinity for sediment particulate matter (Todd and Wohlers, 2003). Pyrethroids are strongly adsorbed to sediments of natural water systems that contain large amounts of silt and clay particles (Laskowski, 2002).

## Supporting Data

Studies recently conducted on pyrethroid residues in California (Weston et al., 2005; Weston et al., 2009a; and Weston and Lydy, 2010), Texas (Hintzen et al., 2008), and Illinois (Ding et al., 2010) have shown the presence of pyrethroids in urban stream sediments at levels toxic to benthic organisms. Some pyrethroids have been found at concentrations that are many times higher than acutely toxic levels (Weston et al., 2009a). With the potential presence of PBO, toxicity levels could be even higher (Amweg et al., 2006).

Even with the potential for widespread homeowner and commercial use, there is little information on levels of pyrethroids in sediments of urban streams in Washington. A study by Weston et al. (2011) reported that four pyrethroids were found in two areas of Western Washington (Table 1). There is no information on concentrations of PBO in sediments in Washington.

Table 1. Frequency of detection for bifenthrin, cypermethrin, deltamethrin, and permethrin in two areas of Washington (Weston et al., 2011).

Area	Bifenthrin	Cypermethrin	Deltamethrin	Permethrin
Puget Sound	27%	0%	5%	9%
Vancouver	14%	14%	0%	0%

# Methods

## Sampling Design

This study was designed to be a screening level study to assess the occurrence and distribution of pyrethroid contamination in urban and suburban stream sediment from areas with a high potential for detection. The most likely pathway for pyrethroids to contaminate sediments in streams is transport during storm events. Surface run-off will carry pyrethroids to stormwater conveyance systems and into streams. During typical pesticide application periods (spring and summer), the best time to sample for pyrethroids in sediments is shortly after a storm event when rains have eased or stopped and streamflows have decreased.

This study collected samples during the winter wet season when little outdoor application of pesticides occurs. The timing of sampling means that several storm events most likely have washed the majority of the pyrethroid residues into streams.

Normally a study conducted during the wet season has sampling events tied to storm events. For the type of contaminant being evaluated in sediment and the timing of sample collection, tying sampling to a storm event would not have provided any significant advantage. Therefore, sampling occurred when the streamflows were low enough to access fine-grained sediments that were deposited during storm events.

Sediment samples were collected once at 20 sites for ten commonly available pyrethroid insecticides and the synergist PBO. In addition to pyrethroids, samples for total organic carbon (TOC) and grain size were collected. Pyrethroids are non-polar compounds that have high  $K_{ow}$  values that make them preferentially partition to the organic carbon fraction of sediments (Amweg et al., 2005).

Fine-grained sediments (silt and clay-sized material) provide a large surface area and are chemically active (Owens et al., 2005) which allows for adsorption of chemicals like pyrethroids. TOC and grain size data were used for normalization of sediment concentrations and aided in the interpretation of data. The temperature of the sediment at each collection site was measured to help determine the potential toxicity of pyrethroids to benthic organisms. Sediment temperature is important because pyrethroid toxicity increases as temperature decreases (Holmes et al., 2008; Weston and Lydy, 2010).

## Sampling Sites

The 20 sites selected for sampling were spread out across western King County covering mostly Water Resource Inventory Area (WRIA) 8 and the northern portion of WRIA 9. The majority of the sites drain to Lake Washington or Lake Sammamish. To help direct the selection of sampling sites, several characteristics were identified.

The sites were chosen for the following characteristics:

- They have potential for impacts from residential, commercial, or light industrial areas where use of pyrethroids is likely.
- The depositional area targeted for sediment collection receives stormwater discharge.
- They are highly impacted by stormwater during rain events.
- Sediment in depositional areas contains fine material such as silt and clay.

In addition, suggestions were provided by King County and City of Bellevue staff. After initial site selection work was completed, field reconnaissance was conducted to verify the feasibility of the sampling locations. Final site selection was based upon the field reconnaissance. Several alternate sites were chosen due to the likelihood that the sites would change from the time of reconnaissance to the time of sampling.

Due to a large rain event that occurred before sampling, one of the original sites, Cottage Lake Creek, was dropped and an alternate site, East Fork of Issaquah Creek, was used.

All sampling location positions were recorded using a handheld global positioning system (GPS) following Ecology SOP EAP013 *Standard Operating Procedure for Determining Coordinates Via Hand-held GPS Receivers* (Janisch, 2006). Where appropriate, positions relative to fixed streambank structures were recorded. In addition, pictures were taken of the sampling location with key reference points shown.

Figure 1 shows the location of King County and WRIAs 8 and 9 in Washington State and Figure 2 shows the locations of the 20 creeks that were sampled. Exact locations and descriptions of each site are located in Appendix A, Table A-1.

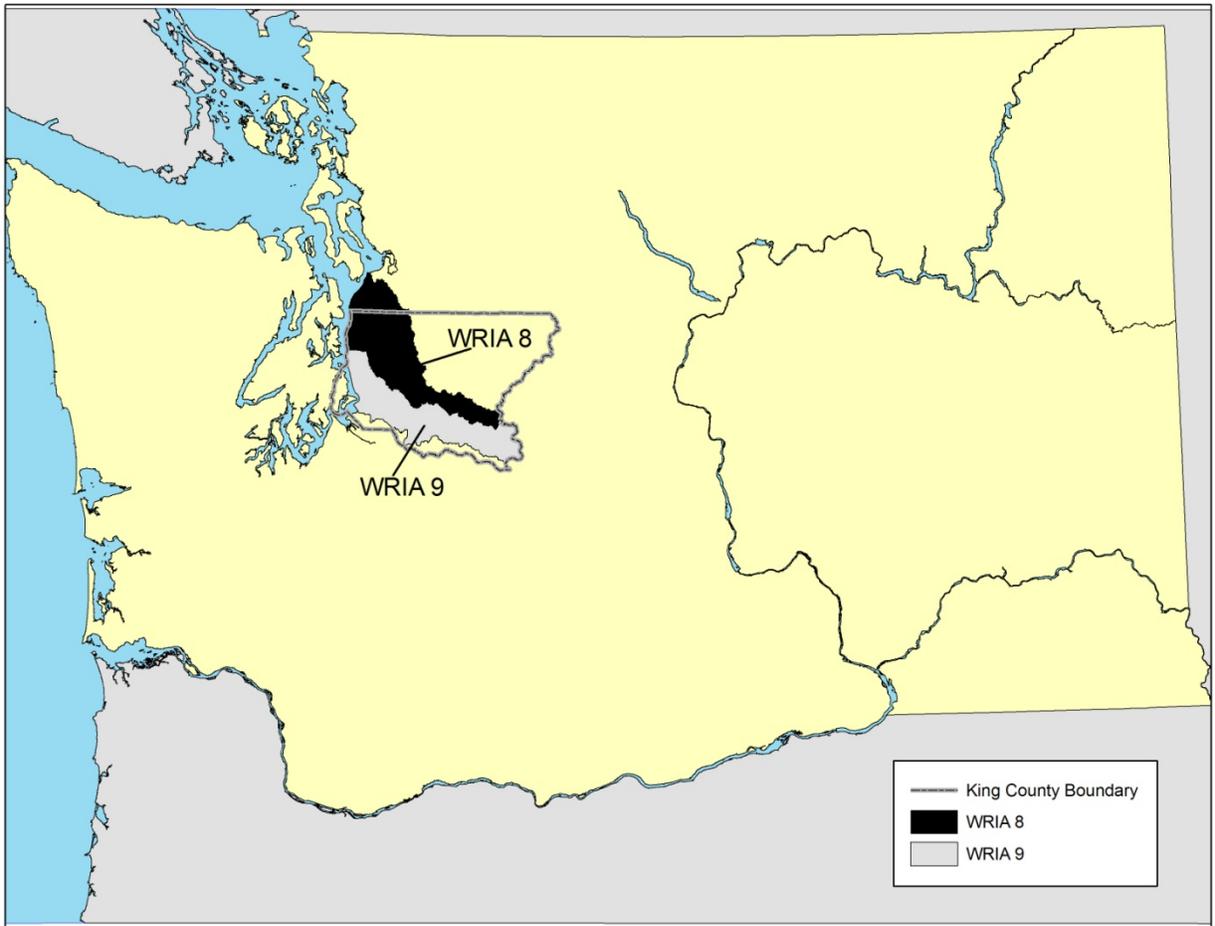


Figure 1. Location of King County and WRIAs 8 and 9 in Washington State.



Figure 2. Sampling locations within WRIA 8 and 9.

## Field Procedures

Sampling occurred in late December 2010. Collection of surface sediments for pyrethroids, TOC, and grain size analysis were performed according to Ecology SOP EAP040 *Standard Operating Procedure for Obtaining Freshwater Sediment Samples* (Blakley, 2008). A field log for each station was completed, recording information that was consistent with Ecology SOP EAP040. Sediment temperature was also recorded in the field log for each site.

Sediment temperature was measured using an alcohol-filled glass thermometer. The thermometer was inserted into the sediment near the site of collection and allowed to equilibrate before the reading was taken. Care was taken to place the thermometer in a location where it would only contact sediment. Before use in the field, the thermometer was checked against a National Institute of Standards and Technology (NIST) thermometer to ensure accuracy.

Hladik et al. (2009) recommends manual grab samples using stainless steel spoons or scoops as the best method for collection of sediment for pyrethroid analysis. At each site a stainless steel spoon or scoop was used to collect sediment. In accordance with Ecology SOP EAP040, the top two cm of depositional sediment were sampled at each location to reflect recently deposited material. Where possible, sediments were collected from depositional areas that were not covered with water. Collection of sediments from recently exposed sediment protects the sample from loss of fine-grained sediments. All sites had adequate amounts of sediment to fill the necessary sample containers.

After collection and homogenization in a stainless steel bowl, sediment was placed in labeled sample containers. The sample containers were then sealed in plastic bags to protect the samples from contamination during transport to the laboratory. All samples were placed in coolers on ice or in a refrigerator at 4° C until transported to the laboratory. Chain of custody was maintained throughout collection, storage, and transport to the laboratory.

## Decontamination Procedures

Stainless steel spoons and bowls used to collect and manipulate the sediments were pre-cleaned following the Ecology SOP described in EAP040 (Blakley, 2008). One change to the procedure was made for this study: methanol was used in place of the acetone and hexane rinse. A U.S. Geological Survey (USGS) report on the collection of pyrethroids in water and sediment (Hladik et al., 2009) deems methanol to be effective at removing surface-associated pyrethroids. Methanol is considered a safer solvent than acetone and hexane. Also, using just one solvent reduced the amount of waste generated during decontamination.

## Laboratory Procedures

Except for grain size samples, all samples were analyzed at MEL according to current SOPs. MEL had to modify an existing EPA method to quantify pyrethroids. Columbia Analytical Services performed the grain size analysis using the method selected for this study. Laboratory measurement procedures are presented in Table 2.

Table 2. Sediment measurement methods.

Analysis	Expected Range of Results	Reporting Limit	Sample Preparation Method	Analytical Method
Pyrethroids	0-50 mg/Kg	2.5-12.5 mg/Kg	EPA 3541A	EPA 8270D <sup>1</sup>
Total Organic Carbon	<1-20 mg/Kg	0.1 % carbon	N/A	PSEP 1986
Grain Size	N/A	N/A	N/A	PSEP 1986

<sup>1</sup> Method 8270 was modified by Manchester Environmental Laboratory (MEL) for quantification of pyrethroids.

N/A: not applicable.

PSEP: Puget Sound Estuary Program.

## Data Quality Assessment

Quality Assurance/Quality Control (QA/QC) results can be found in Appendix B.

### Field Measurements

All temperature measurements are usable as reported. The thermometers used to measure sediment temperature did not differ from the NIST thermometer.

### Laboratory

Results from MEL included case narratives describing QA/QC procedures used during analysis. These QA/QC results included: holding times, instrument calibrations, method blanks, matrix spikes/matrix spike duplicates (MS/MSD), laboratory duplicates, laboratory control samples, and surrogate spikes. Case narratives describing the quality of the data are available upon request.

Normally a standard reference material (SRM) is used in sediment analyses. For this study an SRM for pyrethroids was not available. The SRM is not available because there are so few laboratories analyzing sediment samples for pyrethroids.

Due to the recent development of the analysis method for pyrethroids, some difficulties were encountered in the analysis of the samples. After extraction it was discovered that there was a great deal of matrix interference that caused many results to be qualified. After a second extraction and additional cleanups of the sample extracts, there was much less matrix interference resulting in fewer qualified results (Westerlund, personal communication, 2011). For the replicate sample on Forbes Creek, there was less than the required sample left for the re-extraction which caused an increase in the reporting limit by a factor of 5. In addition, the percent solids were low compared to the other samples that increased the reporting limit by a factor of 2. Taken together the replicate sample had a reporting limit that was a factor of 10 greater than the rest of the samples.

Most QC analyses were within established acceptance limits described in the QA Project Plan (Anderson, 2011). All results that had QC results outside of established acceptance limits were qualified or rejected by the laboratory. All results are considered usable as qualified.

### **Qualification of Results**

Data collected for this study are considered usable, with qualification, as reported. Data qualifiers give an indication of the degree of confidence that can be placed in the reported results. The absence of a data qualifier means the reported concentration was above the practical quantitation limit, and no analytical factors are present which may influence data use. The highest degree of confidence can be placed in unqualified results.

Data with a *J* qualifier are defined as: the analyte is positively identified but the associated numerical result is an estimate (MEL, 2008). The use of *J* qualified data in regulatory decision-making is acceptable with proper consideration of analytical confidence (EPA, 1991). Embrey and Frans (2003), of the USGS, used estimated values for comparison to aquatic life standards.

*NJ* qualified data are defined as: the analysis indicates the presence of an analyte that has been “tentatively identified,” and the associated numerical value represents its approximate concentration (MEL, 2008). Designation of a result with an *NJ* qualifier normally occurs when there is not an exact match in chemical signature. Data that are *NJ* qualified are assigned a lower degree of confidence and are not treated as detections. EPA does not support the use of *NJ* qualified data in regulatory decision-making (EPA, 1991 and 1994).

### **Sediment Samples**

Split field replicates for laboratory analyses were used to provide an estimate of sampling and laboratory variability for the study.

The majority of the results from the pyrethroid split replicates had no detections to compare to the measurement quality objective of  $\pm 50\%$  relative percent difference (RPD). Of the two detections available for comparison, one detection was 0.8% above the measurement quality objective and the other was 11% above. There was also an inconsistent replicate pair on Forbes Creek for cis-permethrin. The sample had a non-detect and the replicate had a detection of 100 J (estimated). This sample was the same one that had a factor of 10 increase in the reporting limit. Upon further investigation it was determined that confidence in the replicate detection was not high enough to report and the sample was rejected by the project officer (Westerlund, personal communication, 2011).

All TOC split replicates agreed within  $\pm 25\%$  RPD, except one. The replicate RPD was 1% above the measurement quality objective of  $\pm 25\%$ . Most of the split replicate samples for grain size agreed within  $\pm 25\%$  RPD. The exceptions were one sample in the sand portion and all of the samples in the gravel portion of the analysis.

The sediment matrix is highly variable and if mixing of the sample does not achieve complete homogeneity then replicate results can easily be different. This likely can explain the difference seen in pyrethroids, TOC, and the sand portion of the grain size analysis. The failure to meet measurement quality objectives in the gravel particle size is due to the high variability found in the size range, especially with the sand and silt portion making up >90% of most samples. In addition to the highly variable nature of the gravel size range, failure of these samples can be attributed to the high amount of variability in detections near the minimum reporting limit (Mathieu, 2006; Martin, 2002). These small values can have a low mean which creates a high RPD.

The data quality assessment indicated most results for analysis of sediment met data quality objectives outlined by the QA Project Plan (Anderson, 2011). The data outside of the quality objectives were determined not to have an effect on the usability of the data set. This determination was based on the explanation given for the issues with replicates.

# Results

## Conventional Parameters

Table 3 summarizes results for sediment temperature, TOC, and grain size. Sediment temperature ranged from 2.8 to 8.8° C. TOC measurements were low at all sites, ranging from 0.34 to 14.8%. Grain size analysis showed that the majority of each sample was made up of sand and silt. For most samples the remaining portion of each sample was made up of clay.

Table 3. Conventional parameter results.

Site	Sediment Temperature (°C)	TOC (%)	Grain Size (%)				
			Gravel	Sand	Silt	Clay	Fines
Bear Creek	4.5	1.05	0.08	75.5	15.6	2.18	17.8
Coal Creek	3.7	8.32	0.39	35.8	51.7	6.66	58.4
EF Issaquah Creek	4.6	0.50	0.15	28.6	59.9	4.47	64.4
Eden Creek	8.3	0.59	0.06	58.8	27.4	5.93	33.3
Forbes Creek	7.0	14.8	1.51	59.6	29.9	2.48	32.4
Idylwood Creek	4.7	4.87	0.14	56.1	36.6	1.91	38.5
Issaquah Creek	4.8	2.46	0.00	39.0	49.3	4.28	53.6
Juanita Creek	6.5	1.37	0.02	61.2	28.4	1.83	30.2
Kelsey Creek	4.4	5.87	1.14	36.3	38.9	13.0	51.9
Lewis Creek	4.4	0.34	0.02	64.3	23.9	6.73	30.6
Little Bear Creek	7.2	1.13	0.67	77.9	12.1	1.44	13.5
Longfellow Creek	7.0	0.89	0.09	86.2	6.96	2.37	9.3
May Creek	2.8	1.01	0.04	50.1	38.1	4.31	42.4
McAleeer Creek	8.8	3.67	0.04	28.6	59.7	2.12	61.8
NF Issaquah Creek	4.5	3.36	0.07	23.7	62.0	4.88	66.9
North Creek	5.5	2.09	0.05	78.0	18.3	1.11	19.4
Pipers Creek	7.5	1.06	0.08	71.4	20.4	2.07	22.5
Springbrook Creek	5.3	2.27	2.18	70.1	21.2	1.39	22.6
Thornton Creek	6.8	2.14	2.55	67.1	22.1	1.11	23.2
Yarrow Creek	7.8	1.94	0.12	74.9	17.2	0.87	18.1

EF: East Fork

Fines: silt + clay

NF: North Fork

TOC: Total Organic Carbon

Detailed descriptions of surface sediment sample physical characteristics for each site can be found in Appendix A, Table A-2.

## Pyrethroids

Nine of the 20 sites sampled had at least one detection of a pyrethroid. Out of the nine sites with detections, only one site had two detections. The most frequently detected pyrethroid was bifenthrin which was detected in eight of the 20 sampling sites. The bifenthrin detections ranged from 5.2 to 44 ug/Kg dry weight. Bifenthrin organic carbon normalized data ranged from 970 to 490 ug/Kg. Resmethrin was detected at North Creek (18 J ug/Kg dw) and Idylwood Creek (11 ug/Kg dw) and lambda-cyhalothrin (12 J ug/Kg dw) was detected at Little Bear Creek. None of the sampling sites had a detection of the synergist PBO.

Table 4 presents detected pyrethroids on a dry weight basis as well as organic carbon normalized concentrations. A table containing all of the results for pyrethroids can be found in Appendix C, Table C-1.

Table 4. Summary of detected pyrethroids (ug/Kg dry weight).

Site	Bifenthrin		Lambda-Cyhalothrin		Resmethrin	
	(dw)	(OC)	(dw)	(OC)	(dw)	(OC)
Pipers Creek	5.2	490	nd	nd	nd	nd
Thornton Creek	6.1	290	nd	nd	nd	nd
North Creek	9.5	460	nd	nd	18 J	860
Little Bear Creek	nd	nd	12 J	1100	nd	nd
Forbes Creek	44	300	nd	nd	nd	nd
Yarrow Creek	8.5	440	nd	nd	nd	nd
Kelsey Creek	5.7	970	nd	nd	nd	nd
Springbrook Creek	4.4	190	nd	nd	nd	nd
Idylwood Creek	14	290	nd	nd	11	230

dw: dry weight

nd: non-detect

OC: organic carbon normalized

# Discussion

## Comparison to Other Published Data

### Study Details

Only one study conducted by Weston et al. (2011) has data from Washington that can be used as a point of comparison for this study. Even though there is little data for Washington, the available data are from a recent study, making the comparison relevant and useful. The study by Weston et al. (2011) was conducted in 2009 in two urbanized areas of Washington (eastern Puget Sound and Vancouver). Samples were collected in late August and again in late October. The August sampling was used to capture the dry season concentrations and the October sampling was used to capture the wet season. Other studies have shown that storm runoff is the major pathway for pyrethroids and other pollutants to enter stream systems in urbanized areas (Schiff and Tiefenthaler, 2011; Weston et al., 2009a).

This study was conducted in December 2010, well into the wet season, after a large rain storm that caused flooding in some of the target sampling creeks. While it was the intent of this study to sample for pyrethroids during the wet season to assess levels of pyrethroids in the streams after runoff had occurred, it was not the intent to sample after such a large rain event. This one rain event completely altered the streambeds of most of the target sampling sites. In quite a few instances the storm event deposited finer grained sediments than would have been available before the event.

The sampling location of most of the sampling sites was near the mouth of each creek, which means that any detection would represent what was happening in the watershed above. This storm event could have biased the results high because of the large scale movement of bedded sediment from the watershed. The storm could have also biased the results low due to dilution or complete movement of contaminants out of the sampling area.

Since sampling was not conducted during the dry summer months it is impossible to say whether the concentrations are biased high or low. Future sampling should include collections during the dry months and after the first large rain event in the fall months. Sampling after a first-flush would give a better indication of what was happening in each watershed during the summer application season.

### Data

Several of the sites sampled in the eastern Puget Sound for the Weston et al. (2011) study were the same creeks sampled for this study. Other than having several creeks in common there are few similarities in the data. Both studies found low organic carbon content in the creeks but differences in the time of year do not allow for direct comparison. Most sites showed a wide difference between the silt/clay percentages. This difference may be accounted for by the time of year each sample was collected and the fact that this study sampled after a large storm that altered the composition of the streambed.

One major similarity between the two studies was the detection of bifenthrin. This similarity is shared with a number of other pyrethroid studies from Oregon (Weston et al., 2011), California (Amweg et al., 2006; Budd et al., 2007; Holmes et al., 2008; Lao et al., 2010; Brown et al., 2010), Texas (Hintzen et al., 2008) and Illinois (Ding et al., 2010). Weston et al. (2011) state that the prevalence of bifenthrin is likely due to its much longer half-life in aquatic sediments compared to those of other pyrethroids. This long half-life in aquatic sediments and its prevalence in many regions make it the pyrethroid of greatest concern in urban systems (Weston et al., 2011).

Another similarity between the studies was that the detected concentrations of bifenthrin during the wet season were comparable. During the dry season sampling, the one detection of bifenthrin from the Weston et al. (2011) study was much higher than any from this Ecology study.

Other than bifenthrin the two studies did not detect similar compounds. In addition to bifenthrin, Weston et al. (2011) detected deltamethrin and permethrin. Of these three only bifenthrin and permethrin were detected during the wet season sampling. One other compound (deltamethrin) was found during the dry season sampling.

The differences between the types of pyrethroids detected in each study may be due to a change in use patterns or the large storm discussed earlier. The higher number of pesticides and concentrations detected during the dry sampling conducted by Weston et al. (2011) suggests that sampling earlier in the year may provide additional information on pyrethroid toxicity.

## Pyrethroid Toxicity Values

Currently there are no promulgated water quality standards for pyrethroids. Available toxicity values from EPA pesticide re-registration documents and other scientific studies were used for comparison. Three of the pyrethroids (cypermethrin, permethrin, and resmethrin) had available EPA re-registration documents. Of these, only the re-registration documents for cypermethrin contained the toxicity endpoints needed for this study.

Toxicity values range widely depending upon how the studies were conducted. Only toxicity endpoints from studies using standard EPA protocols were considered for use. All toxicological endpoints shown in Table 5 are from published scientific studies except for cypermethrin which is from the EPA re-registration document.

Several environmental factors influence the bioavailability and toxicity of pyrethroids (Holmes et al., 2008; Maund et al., 2002; Weston et al., 2011). Organic carbon normalization has been shown to make LC<sub>50</sub> values less variable and more applicable to other sediments (Amweg et al., 2005; Di Toro et al., 1991). Di Toro et al. (1991) also state that toxicity values that are not adjusted to organic carbon are not a good estimate for chemical activity. Since there are no state or federal water quality criteria for pyrethroids and this study is being conducted at a screening level, both dry weight and organic carbon normalized toxicity values are presented. This will allow for a broader comparison of available toxicity values to the results of this study.

Table 5 presents available acute and chronic toxicity values expressed on a dry weight and organic carbon normalized basis for the pyrethroids being studied. Acute toxicity values represent median lethal concentrations (LC<sub>50</sub>); chronic toxicity values represent lowest observable effect concentrations (LOEC). With the exception of cypermethrin, the toxicity values presented in Table 5 are averages from a single study that used standard EPA protocols to determine sediment toxicity values for *Hyaella azteca* (Amweg et al., 2005). Cypermethrin toxicity values are from the EPA re-registration eligibility decision (RED) (EPA, 2008). The chronic toxicity value for cypermethrin is not an LOEC. Instead EPA presents the chronic toxicity value as a no observable adverse effect concentration (NOAEC).

Organic carbon normalized data for cypermethrin are not available. No sediment toxicity values are available for cyphenothrin, resmethrin, tetramethrin, or tralomethrin.

Table 5. Acute (LC<sub>50</sub>) and chronic (LOEC) toxicity values for benthic organisms expressed on a dry weight and organic carbon normalized basis.

Chemical	Acute (ug/Kg)		Chronic (ug/Kg)	
	(dw)	(OC)	(dw)	(OC)
bifenthrin	12.9	520	8.23	350
cyfluthrin	13.7	1080	7.62	620
cypermethrin <sup>1</sup>	3.6	n/a	0.59 <sup>2</sup>	n/a
cyphenothrin	n/a	n/a	n/a	n/a
deltamethrin	9.9	790	10.4	890
esfenvalerate	41.8	1540	16.3	610
lambda-cyhalothrin	5.6	450	2.28	190
permethrin	201	10800	1.32	8370
resmethrin	n/a	n/a	n/a	n/a
tetramethrin	n/a	n/a	n/a	n/a
tralomethrin	n/a	n/a	n/a	n/a

<sup>1</sup>Acute and chronic toxicity values from the EPA re-registration eligibility decision.

<sup>2</sup>Chronic value is a NOAEC instead of a LOEC.

dw: dry weight

OC: organic carbon

n/a: not available

## Comparison to Toxicity Values

Concentrations of bifenthrin detected at Forbes Creek (44 ug/Kg dw) and Idylwood Creek (14 ug/Kg dw) were above the acute and chronic dry weight toxicity values. Little Bear Creek had a single detection of lambda-cyhalothrin (12 ug/Kg dw) that was above the acute and chronic dry weight toxicity values. It appears that even before normalization to organic carbon, several sites may have the potential to adversely impact benthic organisms. Beyond acute toxicity, benthic organisms may be adversely impacted by chronically being exposed to toxicologically relevant concentrations of bifenthrin. The potential for adverse impacts to benthic organisms is

increased when accounting for the low temperature of the sediments as well as the increased availability of these pyrethroids due to low organic carbon content.

After normalization of the detections of bifenthrin and lambda-cyhalothrin, several sites were above the acute or chronic organic carbon normalized toxicity values. For bifenthrin none of the sites with detections were above the organic carbon normalized acute toxicity value. However, organic carbon normalized concentrations of bifenthrin at Pipers Creek (491 ug/Kg OC), North Creek (455 ug/Kg OC), and Yarrow Creek (438 ug/Kg OC) were above the chronic LC<sub>50</sub> of 350 ug/Kg OC. This data suggests that bifenthrin in these three creeks has the potential to adversely impact benthic organisms. These chronic toxicological effects likely are being increased by the lower temperatures and the increased availability of pyrethroids due to the low organic carbon content.

The single detection of lambda-cyhalothrin at Little Bear Creek (1062 ug/Kg OC) was above both the acute (405 ug/Kg OC) and chronic (190 ug/Kg OC) organic carbon normalized toxicity values. These data show that lambda-cyhalothrin in Little Bear Creek has the potential to adversely impact benthic organism on an acute and chronic basis. As with bifenthrin lower temperatures and low organic carbon content likely is increasing the toxicity of lambda-cyhalothrin.

While bifenthrin and lambda-cyhalothrin have the potential to adversely impact benthic organisms it is impossible to know if there is an impact without direct evidence from studies of benthic communities. In addition to benthic community studies there would need to be in-situ and laboratory bioassays conducted at temperatures that are representative of Western Washington. These studies would provide the data necessary to assess toxicity from pyrethroids.

All other detections either were not above a toxicity value or a toxicity value was not available for comparison. Piperonyl butoxide was not detected during this study.

## **Relationship of Conventional Parameters and Synergists to Pyrethroid Availability and Toxicity**

### **Organic Carbon**

Pyrethroids are non-polar compounds that have high  $K_{ow}$  values that make them preferentially partition to the organic carbon fraction of sediments. As organic carbon content in sediment increases, bioavailability decreases (Maund et al., 2002 and Weston et al., 2011). This decrease makes pyrethroids less toxic to benthic organisms.

While the organic carbon content of sediment is a major factor in the adsorption of pyrethroids, its physical makeup may also play an important role (Maund et al., 2002). The surface area available for adsorption may differ depending on the size and the distribution of the organic carbon particles. Smaller particles likely have a higher potential for adsorption than larger particles (Maund et al., 2002).

Organic carbon can also vary widely within a single site depending upon the makeup of the sediment. Sediments that contain large amounts of woody debris or other organic debris can have large increases in organic carbon values (Michelsen, 1992). This variability most likely can explain the differences seen in the organic carbon values from the Weston et al. (2011) study and this study. Seasonal differences in organic carbon could also explain the differences seen in the organic carbon values.

## Temperature

Many pesticides, like carbamates and organophosphates, become less toxic as the temperature decreases. This decrease in toxicity is the result of a significant decrease in a biological process, called biotransformation, which occurs as temperature decreases (Harwood et al., 2009). Biotransformation is a series of chemical changes occurring in a compound as a result of enzymatic or other activity by a living organism. A decrease in biotransformation creates an elevated concentration of the original compounds which are less toxic than the compounds created through biotransformation.

Unlike many pesticides, the toxicity of pyrethroids increases with decreasing temperature (Harwood et al. 2009; Weston et al., 2009b). The decrease in biotransformation creates a buildup of the original compound, which in the case of pyrethroids, are more toxic than biologically transformed compounds (Harwood et al, 2009). In addition, the lower temperatures make the neurons more sensitive to the stimulative effect of pyrethroids (Harwood et al., 2009).

In Harwood et al. (2009) and Weston et al. (2009b) it was shown that many fold increases in pyrethroid toxicity occur at 10° C decreases in temperature. This was demonstrated through toxicity tests run at 23° C (standard temperature) and at 13° C. The lower temperature represented a more environmentally relevant temperature.

The temperatures measured for this study are at least 2° C lower than the toxicity tests run by Harwood et al. (2009) and Weston et al. (2009b). This suggests that the pyrethroids detected during this study are potentially more toxic to benthic organisms than would be demonstrated by a comparison to the available toxicity values derived using the standard toxicity test temperature of 23° C. It also suggests that the toxicity of any pyrethroids present in the creeks during the fall when water temperatures are decreasing will be underestimated by the available toxicity values.

## Synergism

Many chemicals are used to increase the toxicity of different pesticides. For pyrethroids the chemical used to increase toxicity is PBO (Amweg et al, 2006). Piperonyl butoxide is used as a synergist because it inhibits the biotransformation and detoxification of pyrethroids (Amweg and Weston, 2007). As discussed earlier, when biotransformation is decreased, more parent compound is available for exposure to the organism. This increased exposure coupled with the decrease in detoxification is what causes greater toxicity. Amweg et al. (2006) showed that PBO would most likely not have a synergistic effect under most environmental conditions. Even though PBO would most likely not be a factor in the toxicity of pyrethroids for this study it was still included in the analysis suite for this study. PBO was included because it can increase the toxicity of pyrethroids and because Washington lacks environmental data on it.

# Conclusions

Results of this 2011 study support the following conclusions.

- Only three of ten target pyrethroids were detected and were generally at low concentrations.
- The most frequently detected pyrethroid was bifenthrin.
- Sampling conditions could have affected the levels of detected pyrethroids.
- Toxicity may be underestimated due to mitigating factors like temperature and organic carbon.
- Without biological study it is impossible to determine the true effect of the levels of detected pyrethroids.

Bifenthrin was the most commonly detected pyrethroid, consistent with several studies from other states, and can likely be considered the pyrethroid of most concern for Washington. Lambda-cyhalothrin can also be considered a concern, if future studies find it, because of its lower toxicity values in relation to bifenthrin.

Concentrations of bifenthrin and lambda-cyhalothrin in the samples collected for this study may be causing acute and chronic toxicity to benthic organisms. The toxicity of these pyrethroids likely is being underestimated due to low temperatures and organic carbon content. Both temperature and organic carbon content have been shown to increase the toxicity of pyrethroids. However, the concentrations of the bifenthrin and lambda-cyhalothrin as well as resmethrin may be biased high or low due to the timing of the sample collection. Only further study can determine if the concentrations seen during this study are outside of the normal range.

The varying weather patterns in Washington make it likely that toxicity of any pyrethroids present in the sediment would change throughout the year. To truly understand the potential toxicity to benthic organisms, data from other times of the year (spring, summer, and fall) are needed. Samples collected during these times would show changes in temperature and organic carbon and would capture the application season.

Toxicity values from literature tell us that there is potential for toxicological harm but without further biological study it is impossible to make statements about true toxicity. To determine toxicologically relevant endpoints for Washington, in-situ and laboratory bioassays would need to be conducted using environmentally relevant temperatures.

# Recommendations

Results of this 2011 study support the following recommendations.

- Further research at the sites used for this study should be conducted during the spring, summer, and fall to determine the true environmental state of pyrethroids in Washington. First flush storm sampling in late spring or early summer should be included to evaluate toxicological impacts.
- Use a contract laboratory that specializes in pyrethroids to achieve lower detection limits and include additional commonly used pyrethroids.
- In future studies include biological studies that consist of in-situ and laboratory bioassays using environmentally relevant temperatures and benthic community sampling to determine if there are toxicological impacts from pyrethroids.
- Broaden the study area to include other urbanized areas.

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# Appendices

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## **Appendix A. Sampling Information**

Table A-1. Locations and Descriptions of sampling sites.

Table A-2. Field log descriptions of surface sediments.

Table A-1. Locations and descriptions of sampling sites.

Site	Latitude	Longitude	Location Description
Bear Creek	47.68577	-122.08889	Right bank upstream of bridge on NE 95th (east of Avondale Rd NE).
Coal Creek	47.56651	-122.18007	Left bank upstream of flow control structure at 119th Avenue SE.
EF Issaquah Creek	47.53399	-122.03366	Right bank under bridge on NE Dogwood Street.
Eden Creek	47.61548	-122.06818	In pool downstream of E Lake Sammamish Trail.
Forbes Creek	47.69656	-122.20980	Near the left bank under the bridge on 98th Avenue NE.
Idylwood Creek	47.64304	-122.10282	Left bank at the footbridge over the creek in Idylwood Park.
Issaquah Creek	47.55181	-122.04777	Left bank under bridge on SE 56th Street.
Juanita Creek	47.71166	-122.21023	Left bank ~20 meters upstream of the bridge on NE 124th Street.
Kelsey Creek	47.60247	-122.17449	Downstream of right bank culvert under westbound Lake Hills Connector Rd.
Lewis Creek	47.57059	-122.09225	Left bank ~6 meters upstream of bridge on 185th Place SE.
Little Bear Creek	47.75828	-122.16072	Left bank on upstream side of culvert on 134th Avenue NE.
Longfellow Creek	47.55393	-122.36664	Upstream of bridge crossing at Brandon Street.
May Creek	47.52808	-122.20469	Near right bank at the mouth of the creek.
McAler Creek	47.75207	-122.28184	Upstream of bridge on Hamlin Rd.
NF Issaquah Creek	47.5504	-122.04633	Left bank just upstream of the confluence with main stem Issaquah Creek.
North Creek	47.77531	-122.18549	Left bank ~180 meters upstream of the bridge on North Creek Parkway.
Pipers Creek	47.71154	-122.37682	Under bridge on closed road and at a pool downstream of the bridge.
Springbrook Creek	47.46633	-122.23294	Left bank ~15 meters downstream of bridge on SW 16th Street.
Thornton Creek	47.69611	-122.27625	Left bank ~30 meters upstream of footbridge over creek at Mathews Beach Park.
Yarrow Creek	47.64396	-122.20325	Left bank ~15 meters downstream of culvert under NE Points Drive.

EF: East Fork  
 NF: North Fork

Table A-2. Field log descriptions of surface sediments.

Site	Sediment type	Sediment Quality Description
Bear Creek	silt/clay/fine sand	Homogeneous brown/tan with no odor.
Coal Creek	silt/fine sand	Homogeneous dark brown with no odor.
EF Issaquah Creek	clay/silt	Homogeneous olive brown with no odor.
Eden Creek	silt/clay/fine sand	Homogeneous tan with no odor.
Forbes Creek	muddy	Homogeneous dark brown with no odor.
Idylwood Creek	silt/clay	Homogeneous brown with no odor.
Issaquah Creek	silt/clay/sand	Homogeneous brown with no odor.
Juanita Creek	silt/sand	Homogeneous brown with no odor.
Kelsey Creek	silt/clay	Homogeneous dark brown with organic matter and some roots. No odor.
Lewis Creek	clay/sand	Homogeneous light brown/rust with no odor.
Little Bear Creek	cobble/sand	Homogeneous brown.
Longfellow Creek	organics/sand	Homogeneous dark brown with no odor.
May Creek	silt/clay/sand	Homogeneous light brown with some wood fragments.
McAleer Creek	silt/clay/sand	Homogeneous dark brown.
NF Issaquah Creek	silt/clay/organics	Homogeneous brown.
North Creek	sand/organics	Homogeneous brown.
Pipers Creek	silt/sand	Homogeneous light brown.
Springbrook Creek	silt/clay	Homogeneous brown with leaves and roots. No odor.
Thornton Creek	sand	Homogeneous brown.
Yarrow Creek	organics/sand	Homogeneous brown fines with sand underneath. No odor.

EF: East Fork  
 NF: North Fork

## **Appendix B. Quality Assurance/Quality Control Data**

Table B-1. Total organic carbon and grain size field replicate results.

Table B-2. Matrix spike/matrix spike duplicate results.

Table B-3. Pyrethroid replicate results (ug/Kg dw).

Table B-1. Field replicate results.

Location	Sample Type	TOC (%)	Grain Size (%)			
			Gravel	Sand	Silt	Clay
EF Issaquah Creek	Sample	0.50	0.15	28.6	59.9	4.47
	Replicate	0.47	0.00	38.5	49.5	4.64
<b>RPD</b>		<b>6</b>	<b>200</b>	<b>30</b>	<b>19</b>	<b>4</b>
Forbes Creek	Sample	14.8	1.51	59.6	29.9	2.48
	Replicate	11.4	2.12	60.0	30.2	2.46
<b>RPD</b>		<b>26</b>	<b>34</b>	<b>1</b>	<b>1</b>	<b>1</b>
McAleeer Creek	Sample	3.67	0.04	28.6	59.7	2.12
	Replicate	3.86	0.00	30.1	59.9	2.37
<b>RPD</b>		<b>5</b>	<b>200</b>	<b>5</b>	<b>0</b>	<b>11</b>
Springbrook Creek	Sample	2.27	2.18	70.1	21.2	1.39
	Replicate	2.57	0.05	69.9	20.5	1.16
<b>RPD</b>		<b>12</b>	<b>191</b>	<b>0</b>	<b>3</b>	<b>18</b>

EF: East Fork

RPD: relative percent difference

TOC: total organic carbon

Table B-2. Matrix spike/matrix spike duplicate results.

Analyte	Matrix Spike	Matrix Spike Duplicate	RPD
alpha-cypermethrin	47.7	49.8	4
bifenthrin	62.1	66.4	7
cis-permethrin	67.4	72.9	8
cyfluthrin	46.8	49.0	5
cyphenothrin	52.8	47.6	10
deltamethrin	37.2	41.3	11
esfenvalerate	27.7	32.2	15
lambda-cyhalothrin	52.2	45.3	14
piperonyl butoxide	63.8	64.0	0.4
resmethrin	REJ	REJ	NC
tetramethrin	71.9	69.2	4
tralomethrin	28.3	27.1	4
trans-permethrin	80.7	83.3	3

NC: not calculated

RPD: relative percent difference

Table B-2. Pyrethroid replicate results (ug/Kg dw).

Analyte	McAleer	Rep	RPD	Forbes	Rep	RPD	Springbrook	Rep	RPD	EF Issaquah	Rep	RPD
alpha-cypermethrin	4.8 UJ	4.8 U	NC	4.9 U	29 U	NC	3.5 U	3.6 U	NC	2.9 U	3.0 U	NC
beta-cypermethrin	4.8 UJ	4.8 U	NC	4.9 U	29 U	NC	3.5 U	3.6 U	NC	2.9 U	3.0 U	NC
bifenthrin	4.8 UJ	4.8 U	NC	<b>44</b>	<b>83</b>	<b>61.4</b>	<b>4.4</b>	<b>7.4</b>	<b>50.8</b>	2.9 U	3.0 U	NC
cis-permethrin	4.8 UJ	4.8 U	NC	4.9 U	REJ	NC	3.5 U	3.6 U	NC	2.9 U	3.0 U	NC
cyfluthrin	4.8 UJ	4.8 U	NC	4.9 U	29 U	NC	3.5 U	3.6 U	NC	2.9 U	3.0 U	NC
cyphenothrin	4.8 UJ	4.8 U	NC	4.9 U	30 U	NC	3.5 U	3.6 U	NC	2.9 U	3.0 U	NC
deltamethrin	4.8 UJ	4.8 U	NC	4.9 U	31 U	NC	3.5 U	3.6 U	NC	2.9 U	3.0 U	NC
esfenvalerate	4.8 UJ	4.8 UJ	NC	4.9 UJ	32 UJ	NC	3.5 UJ	3.6 UJ	NC	2.9 UJ	3.0 UJ	NC
lambda-cyhalothrin	4.8 UJ	4.8 U	NC	4.9 U	33 U	NC	3.5 U	3.6 U	NC	2.9 U	3.0 U	NC
piperonyl butoxide	4.8 UJ	4.8 U	NC	4.9 U	34 U	NC	3.5 U	3.6 U	NC	2.9 U	3.0 U	NC
resmethrin	4.8 UJ	4.8 U	NC	4.9 U	35 U	NC	3.5 U	3.6 U	NC	2.9 U	3.0 U	NC
tetramethrin	4.8 UJ	4.8 U	NC	4.9 U	36 U	NC	3.5 U	3.6 U	NC	2.9 U	3.0 U	NC
tralomethrin	4.8 UJ	4.8 U	NC	4.9 U	37 U	NC	3.5 U	3.6 U	NC	2.9 U	3.0 U	NC
trans-permethrin	4.8 UJ	4.8 U	NC	4.9 U	38 U	NC	3.5 U	3.6 U	NC	2.9 U	3.0 U	NC

EF: East Fork

Rep: replicate

NC: not calculated

REJ: rejected

RPD: relative percent difference

U: the analyte was not detected at or above the reported sample quantitation limit.

UJ: the analyte was not detected at or above the reported sample quantitation limit. The reported quantitation limit is approximate.

## Appendix C. Pyrethroid Results

Table C-1. Pyrethroid results (ug/Kg dw).

Table C-1. Pyrethroid results (ug/Kg dw).

Site	alpha-cypermethrin	beta-cypermethrin	bifenthrin	cis-permethrin	cyfluthrin	cyphenothrin	deltamethrin
Longfellow Creek	2.8 U	2.8 U	2.8 U	2.8 U	2.8 U	2.8 U	2.8 U
Pipers Creek	2.9 U	2.9 U	5.2	2.9 U	2.9 U	2.9 U	2.9 U
Thornton Creek	3.3 U	3.3 U	6.1	3.3 U	3.3 U	3.3 U	3.3 U
McAlear Creek	4.8 UJ	4.8 UJ	4.8 UJ	4.8 UJ	4.8 UJ	4.8 UJ	4.8 UJ
North Creek	3.7 U	3.7 U	9.5	3.7 U	3.7 U	3.7 U	3.7 U
Little Bear Creek	3.3 U	3.3 U	3.3 U	3.3 U	3.3 U	3.3 U	3.3 U
Juanita Creek	3.1 U	3.1 U	3.1 U	3.1 U	3.1 U	3.1 U	3.1 U
Forbes Creek	4.9 U	4.9 U	44	4.9 U	4.9 U	4.9 U	4.9 U
Yarrow Creek	3.9 U	3.9 U	8.5	3.9 U	3.9 U	3.9 U	3.9 U
Kelsey Creek	4.7 U	4.7 U	5.7	4.7 U	4.7 U	4.7 U	4.7 U
Springbrook Creek	3.5 U	3.5 U	4.4	3.5 U	3.5 U	3.5 U	3.5 U
May Creek	3.0 U	3.0 U	3.0 U	3.0 U	3.0 U	3.0 U	3.0 U
Coal Creek	3.8 U	3.8 U	3.8 U	3.8 U	3.8 U	3.8 U	3.8 U
Lewis Creek	3.2 U	3.2 U	3.2 U	3.2 U	3.2 U	3.2 U	3.2 U
Issaquah Creek	3.6 U	3.6 U	3.6 U	3.6 U	3.6 U	3.6 U	3.6 U
EF Issaquah Creek	2.9 U	2.9 U	2.9 U	2.9 U	2.9 U	2.9 U	2.9 U
Eden Creek	3.0 U	3.0 U	3.0 U	3.0 U	3.0 U	3.0 U	3.0 U
Idylwood Creek	4.0 U	4.0 U	14	4.0 U	4.0 U	4.0 U	4.0 U
Bear Creek	2.9 U	2.9 U	2.9 U	2.9 U	2.9 U	2.9 U	2.9 U
NF Issaquah Creek	4.0 U	4.0 U	4.0 U	4.0 U	4.0 U	4.0 U	4.0 U

EF: East Fork

NF: North Fork

U: the analyte was not detected at or above the reported sample quantitation limit.

UJ: the analyte was not detected at or above the reported sample quantitation limit. The reported quantitation limit is approximate.

Table C-1 continued. Pyrethroid results (ug/Kg dw).

Site	esfenvalerate	lambda-cyhalothrin	piperonyl butoxide	resmethrin	tetramethrin	tralomethrin	trans-permethrin
Longfellow Creek	2.8 UJ	2.8 U	2.8 U	2.8 U	2.8 U	2.8 U	2.8 U
Pipers Creek	2.9 UJ	2.9 U	2.9 U	2.9 U	2.9 U	2.9 U	2.9 U
Thornton Creek	3.3 UJ	3.3 U	3.3 U	3.3 U	3.3 U	3.3 U	3.3 U
McAleer Creek	4.8 UJ	4.8 UJ	4.8 UJ	4.8 UJ	4.8 UJ	4.8 UJ	4.8 UJ
North Creek	3.7 UJ	3.7 U	3.7 U	18 J	3.7 U	3.7 U	3.7 U
Little Bear Creek	3.3 UJ	12 J	3.3 U	3.3 U	3.3 U	3.3 U	3.3 U
Juanita Creek	3.1 UJ	3.1 U	3.1 U	3.1 U	3.1 U	3.1 U	3.1 U
Forbes Creek	4.9 UJ	4.9 U	4.9 U	4.9 U	4.9 U	4.9 U	4.9 U
Yarrow Creek	3.9 UJ	3.9 U	3.9 U	3.9 U	3.9 U	3.9 U	3.9 U
Kelsey Creek	4.7 UJ	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U
Springbrook Creek	3.5 UJ	3.5 U	3.5 U	3.5 U	3.5 U	3.5 U	3.5 U
May Creek	3.0 UJ	3.0 U	3.0 U	3.0 U	3.0 U	3.0 U	3.0 U
Coal Creek	3.8 UJ	3.8 U	3.8 U	REJ	3.8 U	3.8 U	3.8 U
Lewis Creek	3.2 UJ	3.2 U	3.2 U	3.2 U	3.2 U	3.2 U	3.2 U
Issaquah Creek	3.6 UJ	3.6 U	3.6 U	3.6 U	3.6 U	3.6 U	3.6 U
EF Issaquah Creek	2.9 UJ	2.9 U	2.9 U	2.9 U	2.9 U	2.9 U	2.9 U
Eden Creek	3.0 UJ	3.0 U	3.0 U	3.0 U	3.0 U	3.0 U	3.0 U
Idylwood Creek	4.0 UJ	4.0 U	4.0 U	11	4.0 U	4.0 U	4.0 U
Bear Creek	2.9 UJ	2.9 U	2.9 U	2.9 U	2.9 U	2.9 U	2.9 U
NF Issaquah Creek	4.0 UJ	4.0 U	4.0 U	4.0 U	4.0 U	4.0 U	4.0 U

EF: East Fork

J: The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.

NF: North Fork

U: the analyte was not detected at or above the reported sample quantitation limit.

UJ: the analyte was not detected at or above the reported sample quantitation limit. The reported quantitation limit is approximate.

## Appendix D. Glossary, Acronyms, and Abbreviations

### Glossary

**Adsorbed:** To gather on a surface in a condensed layer.

**Octanol-water partition coefficient:** The octanol-water partition coefficient is a dimensionless concentration ratio whose magnitude expresses the distribution of a compound between equal volumes of two partially miscible solvents: n-octanol and water.

**Parameter:** Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

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

### Acronyms and Abbreviations

Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
LC <sub>50</sub>	Lethal concentration 50%
MEL	Manchester Environmental Laboratory
MS/MSD	Matrix spike/matrix spike duplicate
PBO	Piperonyl butoxide
QA	Quality assurance
QC	Quality control
RPD	Relative percent difference
SOP	Standard operating procedures
SRM	Standard reference materials
TOC	Total organic carbon
USGS	United States Geological Survey
WRIA	Water Resource Inventory Area

### *Units of Measurement*

°C	degrees centigrade
dw	dry weight
mg/Kg	milligrams per kilogram (parts per million)
OC	organic carbon
ug/g	micrograms per gram (parts per million)
ug/Kg	micrograms per kilogram (parts per billion)