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Measuring Lead in Suspended Particulate Matter from Washington State Rivers and Streams

2016 Results

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WRIAs:

- 8 – Cedar-Sammamish
- 9 – Duwamish-Green
- 12 – Chambers-Clover
- 15 – Kitsap
- 54 – Lower Spokane
- 57 – Middle Spokane
- 61 – Upper Lake Roosevelt

HUC numbers:

- 17010305 – Upper Spokane
- 17010307 – Lower Spokane
- 17110012 – Lake Washington
- 17110019 – Puget Sound
- 17020001 – Franklin D. Roosevelt Lake

Contact Information

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 – https://ecology.wa.gov

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

COVER: Longfellow Creek, City of Seattle. Photo by Dave Serdar.

Measuring Lead in Suspended Particulate Matter from Washington State Rivers and Streams

2016 Results

by

Melissa McCall, Christopher Clinton, Callie Mathieu, and Siana Wong

Environmental Assessment Program
Washington State Department of Ecology
Olympia, Washington

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Acknowledgments

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Abstract

From 2008 through 2016, the Washington State Department of Ecology (Ecology) monitored lead in suspended particulate matter (SPM) in Washington State rivers and streams to establish baseline lead concentrations and to evaluate trends. Ecology collected SPM samples twice in the spring and twice in the fall for analysis of total lead at monitoring sites across the state. This report summarizes results from 2016, the final year of sampling, as well as the entire monitoring period.

During the 2008-2016 study period, the two Spokane River monitoring sites consistently had the highest lead concentrations of all monitoring sites, ranging from 135 to 3,121 mg/kg. Spokane River lead concentrations were highest at the Idaho border site (median = 725 mg/kg) and lowest at the Nine Mile site (median = 332 mg/kg). The next-highest lead SPM concentrations were observed at three urban streams (Leach, Longfellow, and Thornton Creeks; 60–300 mg/kg, median = 156 mg/kg), followed by the Upper Columbia River (50–200 mg/kg; median = 117 mg/kg).

Mid- to large-sized rivers, other than the Spokane and Upper Columbia, were sampled during the first 3 to 7 years of the study. However, these were removed from the monitoring site list due to consistently low lead concentrations that reflected background conditions (10–40 mg/kg).

Few statistically significant temporal trends were observed during the study. Thornton Creek was the only monitoring site to show a statistically significant temporal trend in lead concentrations. Lead levels declined over the sampling years 2011 to 2016, with estimated reductions of 5.4 and 14 mg/kg per year for fall and spring, respectively. Restoration efforts in the watershed may have helped reduce lead-containing SPM in the upper reaches.

This report concludes the long-term monitoring of lead in SPM across the state. The report recommends future monitoring by (1) other Ecology long-term monitoring programs (for the Spokane and Upper Columbia Rivers), and (2) local jurisdictions (for urban streams).

Introduction

Lead Sources

Historically, the largest source of environmental contamination of lead was through the use of lead as an additive in gasoline during the 20th century. Leaded gasoline resulted in widespread pollution until the 1980s and 1990s when U.S. restrictions phased out this use (Davies, 2009). In Washington State, historical sources of lead to the environment also included smelting emissions and lead-arsenate insecticide applications. Currently, major anthropogenic sources of lead to the state's environment include releases from ammunition and hunting shot, fishing weights, and vehicle wheel weights (Ecology, 2011). Other significant sources include emissions from industrial, commercial, and institutional facilities, with the highest releases from military bases, paper mills, and steel manufacturers (Ecology, 2011). Roberts et al. (2011) provides a summary of potential lead sources in the Puget Sound region.

Effects of Lead

Lead is a concern because it is highly toxic to humans and wildlife. It primarily affects developing nervous systems, but can also harm cardiovascular, gastrointestinal, immune, and reproductive systems, as well as the kidneys and blood (Davies, 2009). Lead uptake occurs through ingestion and inhalation of lead-containing materials, such as dust, after which lead accumulates in bones (ATSDR, 2007). There are many sources of lead exposure to humans from the indoor and outdoor environment; even small exposures may cause some harm (Davies, 2009).

Actions in Washington State

Lead is included on Washington State's persistent, bioaccumulative, and toxic (PBT) List as a metal of concern (WAC 173-333-110). In 2009, the state Department of Ecology (Ecology) and the state Department of Health developed a Chemical Action Plan (CAP) for lead (Davies, 2009). The plan identified the toxic effects of lead, described its occurrence in the environment, and recommended ways to reduce human and wildlife exposure to lead. Also in 2009, legislation was passed in Washington to require alternatives to lead wheel weights on vehicles 14,000 pounds or less (RCW 70.270). Effective January 1, 2011, lead weights were required to be replaced with environmentally preferred weights whenever tires are replaced or balanced. In 2011, the state also restricted the use of lead fishing tackle at lakes that loons use as habitat.

Ecology's Lead Trends Monitoring Program

Ecology began a long-term monitoring program in 2008 to assess temporal changes of lead in Washington rivers and streams. Suspended particulate matter (SPM) was the target medium because of lead's high affinity for the particulate phase. The primary goals of the lead monitoring program were to (1) establish baseline levels of SPM-associated lead in the aquatic environment, and (2) measure spatial and temporal trends in lead over time as Chemical Action Plan reduction strategies are implemented.

Ecology collected SPM from monitoring sites during four sampling events each year. Two samples were collected in the spring during river run-off conditions and two samples were collected during low-flow conditions in the fall. Seasonal sampling was conducted three weeks apart. In the beginning of the monitoring program, SPM samples were collected from 15 sites across the state for analysis of total lead. Twelve sites were originally chosen to correspond with ongoing organic trend monitoring sites (Johnson, 2007), and three additional sites were selected because of their expected high lead concentrations: Spokane River, Upper Columbia River, and Hylebos Creek. Queets River served as a reference site for the original study design.

Monitoring sites were discontinued or added with changes to the monitoring program in 2011 and 2015, described in Quality Assurance Project Plan (QAPP) addendums (Meredith, 2011; Mathieu, 2015). Mid- to large-sized rivers originally included in the study design tended to reflect unchanging background lead concentrations over the first few years of sampling and were dropped. The number of sites was eventually reduced to seven in order to focus on small urban streams and large rivers with substantial lead contamination – areas where temporal trends were more likely. Huge Creek was added as a reference site for the urban streams during 2011. Table 1 presents the monitoring sites and sampling years associated with each site.

Table 1. Lead monitoring sites and years sampled.

Monitoring Site	2008	2009	2010	2011	2012	2013	2014	2015	2016
Huge Creek				X	X	X	X	X	X
Leach Creek				X	X	X	X	X	X
Longfellow Creek				X	X	X	X	X	X
Thornton Creek				X	X	X	X	X	X
Spokane River (Nine Mile)	X	X	X	X	X	X	X	X	X
Spokane River (Idaho border)	X	X	X	X	X	X	X	X	X
Upper Columbia River	X	X	X	X	X	X	X	X	X
Columbia River (McNary)	X	X	X	X	X	X	X		
Columbia River (Rock Island)	X	X	X	X	X	X	X		
Duwamish River	X	X	X	X	X	X	X		
Hylebos Creek	X	X	X	X	X	X	X		
Lower Columbia River	X	X	X	X	X	X	X		
Queets River	X	X	X	X	X	X	X		
Wenatchee River	X	X	X	X	X	X	X		
Yakima River	X	X	X	X	X	X	X		
Lake Washington	X	X	X						
Okanogan River	X	X	X						
Snohomish River	X	X	X						
Walla Walla River	X	X	X						

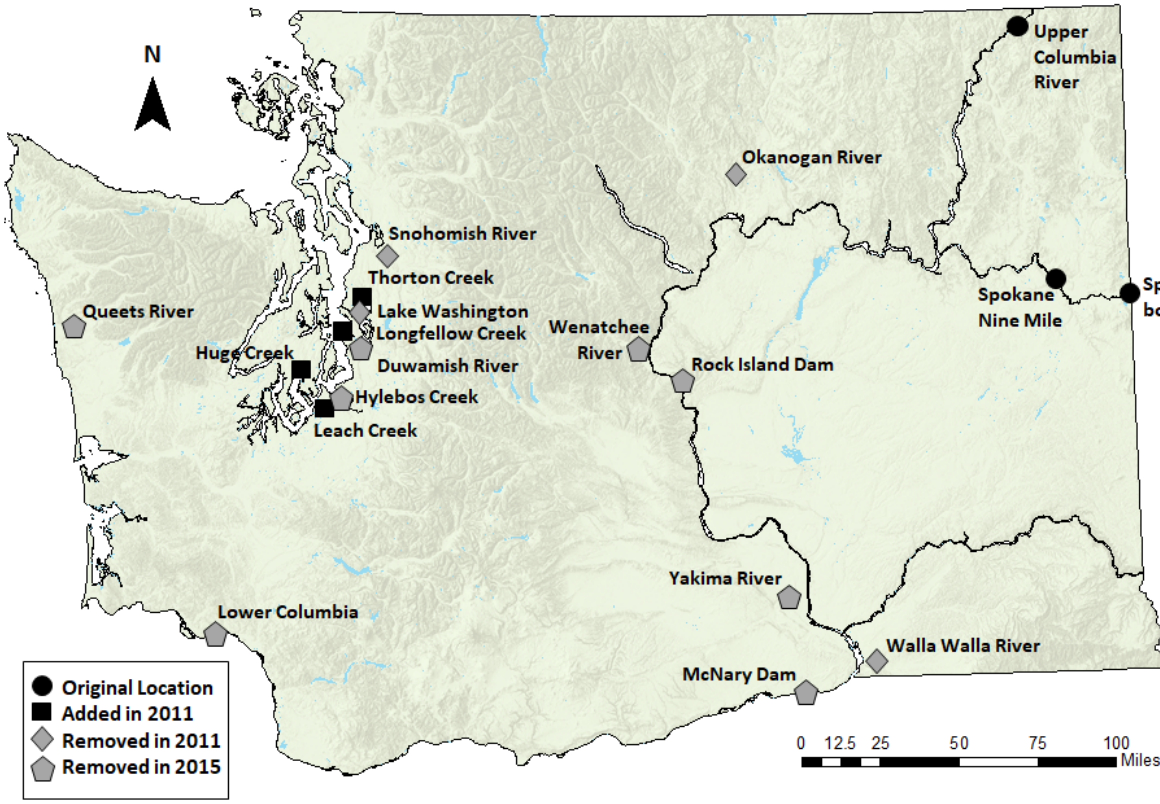

Figure 1. SPM lead monitoring sites in Washington.

Methods

Field Procedures

Ecology's Environmental Assessment (EA) Program staff collected SPM samples following the Ecology Standard Operating Procedure for Collecting Freshwater Suspended Particulate Matter Samples using In-line Filtration (Meredith, 2008). River or stream water was pumped via a peristaltic pump and filtered through pre-weighed, 0.45 µm pore-size nitrocellulose filters (47 mm membrane) using in-line Teflon filter holders. The intake of the tubing was placed 0.5-3 feet below the water surface, suspended above the river or stream bottom, for the duration of sampling. Water was pumped through the filtration apparatus until enough SPM had accumulated to restrict water flow. Filters were then carefully removed from the filter holder and placed in pre-acid-washed aluminum sample containers. Samples were bagged, labeled, and stored upright with blue ice for transport to Ecology headquarters.

Field blanks were sampled at rotating monitoring sites by pumping lab-prepared blank water through decontaminated tubing, filtration apparatus, and filter. Field replicates were collected following the same procedure used to collect the other SPM samples (Meredith, 2008). The volume of water that passed through each filter was recorded after sampling. One filter was collected per sample. Samples were stored at Ecology headquarters at 4 ºC until shipment to the Ecology's Manchester Environmental Laboratory (MEL) for analysis. Chain-of-custody procedures were maintained throughout the project.

Ambient water temperature, pH, and conductivity were measured in situ at each site. pH was measured following Standard Operating Procedures for the Collection and Analysis of pH Samples (Ward, 2007).

Laboratory Procedures

MEL analyzed lead in SPM following EPA Method 200.8 (ICP-MS). Prior to analysis, filters were dried at 103-105 ºC, weighed to determine dry SPM weight, and digested following EPA Method 3050B. Dry SPM weight was used to determine lead results in mg/kg. Results are presented in this report as lead by weight in mg/kg (parts per million) dry weight (dw) and as lead by volume in µg/L (parts per billion). Lead in µg/L was calculated by dividing the amount of lead measured on individual filters by the volume of water passed through the filter. One 2016 sample from Spokane River at Nine Mile dam was rejected for this study due to a negative filter weight.

Several lead samples from Huge Creek were below the reporting limit but above the method detection limit. These estimated values were used in loading calculations and correlations presented in this report. Due to the level of uncertainty, these values are entered into Ecology's EIM database as non-detects ("U"-qualified). Total suspended solids (TSS) values were estimated as the dried SPM weight on sample filters divided by filtrate volume. These are not standard TSS values due to the filter size used in the study (0.45 µm pore-size). MEL's standard TSS analyses are conducted using 1.5 µm pore-size filters. TSS calculations < 1 mg/L are reported as 1 U; however, for loading calculations and correlations, the raw data were used.

Data Quality

MEL received all samples in good condition and performed analyses within method holding times. All instrument calibrations and internal standard recoveries were within laboratory acceptance limits. Copies of case narratives documenting instrument calibration, calibration checks, internal standards, method blanks, matrix spikes, and laboratory control samples are available upon request.

Measurement Quality Objectives (MQOs) outlined in the QAPP and QAPP addendums (Meredith and Furl, 2008; Meredith, 2011; Mathieu, 2015) were met for the 2016 sampling year. Six field blanks were collected in 2016, and all were non-detects. Six field replicates were also collected. Relative percent differences between the native sample and replicate were 25% or less.

2016 Results

Twenty-seven SPM samples were analyzed for lead in 2016. Detected lead concentrations ranged from 1.90 to 821 mg/kg. Samples collected from the Spokane River at the Idaho border contained the highest lead levels, followed by the Spokane River at Nine Mile. Lead concentrations were higher than 100 mg/kg at the three urban streams and the Upper Columbia River.

Lead in samples collected from Huge Creek, the urban reference stream, was mostly below the reporting limit of 0.05 µg lead per filter. Only one sample from Huge Creek was detected above the reporting limit, at a concentration of 1.9 mg/kg. This was the lowest concentration measured across the monitoring sites in 2016.

A summary of the 2016 lead results is shown in Table 2, and individual concentrations are displayed in Figure 2.

Table 2. Statistical summary of lead in suspended particulate matter sampled in 2016.

Season	Sample Size	Frequency of Detection	Minimum (mg/kg)	Maximum (mg/kg)	Median (mg/kg)	Mean (mg/kg)	Standard Deviation
Spring	13	85%	ND	821	153	292	249
Fall	14	93%	ND	643	151	192	169
2016 Total	27	89%	ND	821	152	238	211

ND = non-detect

Comparison to Guidelines

Currently, no Washington State regulatory criteria exist for lead in freshwater SPM. The Sediment Management Standard rule, which includes a freshwater Sediment Cleanup Objective (SCO) for lead, took effect September 1, 2013 (WAC 173-204). Although the SCO is applicable to bottom sediments only, it is a useful threshold to assess levels of lead in SPM since some of the particulate matter will presumably settle to the bottom of the sampled stream or a receiving waterbody.

Eighteen percent of samples (5 of 26) contained lead concentrations above (not meeting) Washington's freshwater SCO of 360 mg/kg (Figure 2). Three samples collected from the Spokane River at the Idaho border, and both of the spring samples from the Spokane River at Nine Mile were also above this threshold.

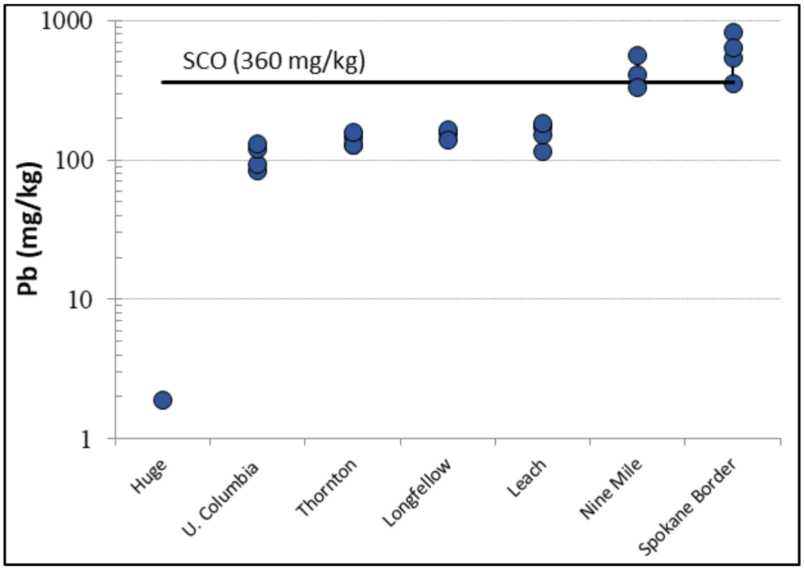

Figure 2. SPM monitoring locations ranked by mean 2016 lead concentrations.
SCO = Sediment Cleanup Objective. Values below reporting limits were excluded.

Loading

Daily particulate lead loads were estimated for 2016 using lead concentrations calculated from SPM sampling and daily mean streamflow. Streamflow data were provided by the U.S. Geological Survey and the City of Seattle. Figure 3 displays the instantaneous lead loads for the Spokane River, Upper Columbia River, and small stream monitoring sites.

The Upper Columbia River site contained the highest lead loads (18-86 kg/day), followed by the Spokane River Border (1.7-28 kg/day) and Nine Mile (0.80-30 kg/day) sites. For the large rivers, higher loads during spring sampling corresponded with much higher flows in the spring compared with fall.

Small streams SPM lead loads ranged from 0.0003 to 0.06 kg/day, with the highest loads at Leach Creek (0.002-0.06 kg/day) and the lowest at the rural reference stream, Huge Creek (0.0002-0.006 kg/day). Like the larger rivers, seasonal lead loads within each stream generally corresponded to changes in discharge volume (i.e. streamflow); however, the relationship was not as strong, and higher loads were typically present in the fall coincident with higher rainfall.

Since the SPM lead loads reported here are instantaneous loads, they are strongly influenced by streamflow on the day of sampling. Therefore, caution should be used in comparing year-on-year loads.

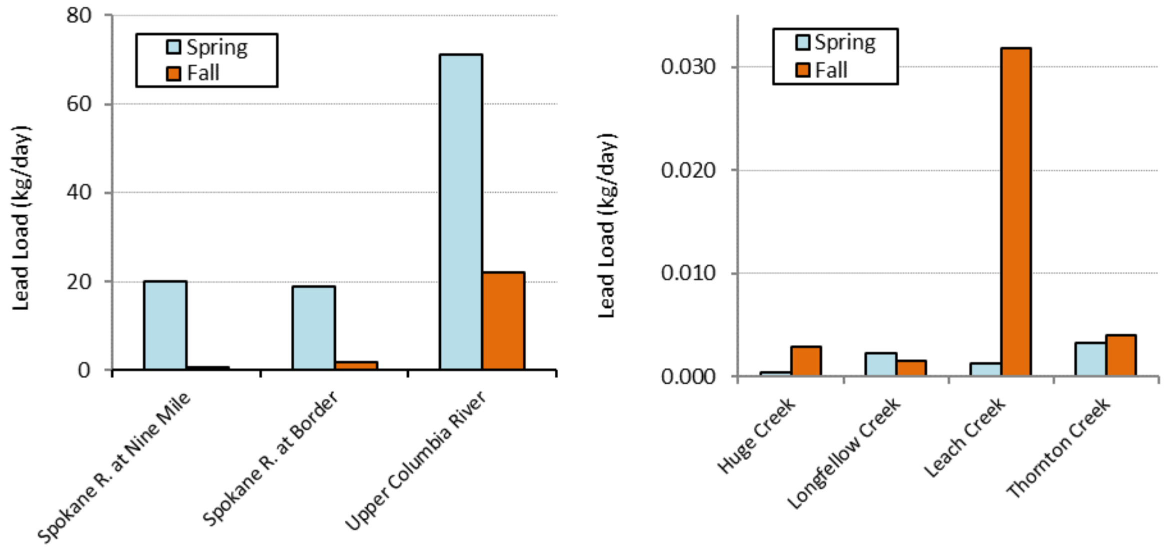

Figure 3. Estimated mean particle-bound lead loading (kg/day) at SPM monitoring sites, spring and fall 2016. *Values show the average of two samples per season where two samples were available. Note the different y-axis scales.*

Temporal Trends

This program monitored lead in SPM from the Upper Columbia River and Spokane River sites during 2008-2016. The small creeks (Thornton, Longfellow, Leach, and Huge) were monitored during 2011-2016. Temporal trends for these monitoring sites over the full sampling period are presented in Table 3 and discussed over the following sections. Scatterplots of lead concentrations over time are presented in the following sections with fitted simple (least squares) regression lines as a visual tool to display patterns in the data.

Mid-sized river sites were discontinued earlier in the program; temporal trends for those sites were described by Meredith and Roberts (2011) and Clinton et al. (2016). The mid-sized river sites reflected background lead concentrations and no consistent temporal trends were observed.

The Seasonal Kendall Test—a non-parametric rank test for identifying trends in seasonal time series data—was used to evaluate the SPM lead data for temporal trends over the sampling period. Sen's slope estimates were also calculated separately for spring and fall seasons. Huge Creek was excluded from this analysis since 90% of the results were below reporting limits; all other data were included.

Estimates of slopes were downward during the spring and fall except for fall results at Longfellow Creek. Thornton Creek, showing relatively large downward slope estimates for both spring and fall, was the only location demonstrating a significant temporal trend at a p value of <0.05. Table 2 shows results of the Seasonal Kendall Test and seasonal Sen's slope estimate for each site.

Table 3. Temporal trend statistics for all SPM lead data, 2008-2016.

Waterbody	Sample Size	Seasonal Kendall		
		Spring: Sen's Slope Estimate (mg/kg/yr)	Fall: Sen's Slope Estimate (mg/kg/yr)	Pooled Season p-value
Spokane River at Idaho Border	36	-37	-24	0.12
Spokane River at Nine Mile	35	-3.3	-1.6	1.00
Columbia River, Upper	36	-4.5	-1.3	0.27
Thornton Creek	24	-5.4	-14	**0.005**
Longfellow Creek	23	-1.9	3.1	0.69
Leach Creek	24	-6.3	-10	0.69

P-value of statistical significance ($p < 0.05$) is bolded for emphasis.

Spokane River

Figure 4 displays lead concentrations and streamflow at the Spokane River Idaho border and Nine Mile Dam respectively. No temporal trend has emerged for either of the Spokane River sites. Spring concentrations have shown high variability year to year, while fall concentrations remained lower and within a tighter range.

Maximum lead concentrations for both sites occurred in the spring of 2008 and 2012 during the highest flows, and minimum spring concentrations occurred during low-flow years (2009, 2010, and 2015). This supports the work by Hallock (2010), which found that total lead in the Spokane River was significantly ($p < 0.05$) correlated with flow. His analysis also revealed a significant ($p < 0.10$) decreasing trend in total lead concentrations in Spokane River water samples collected 1994 through 2009, although these decreases were not significant when data were flow-adjusted or when only data from 2001-2009 were evaluated.

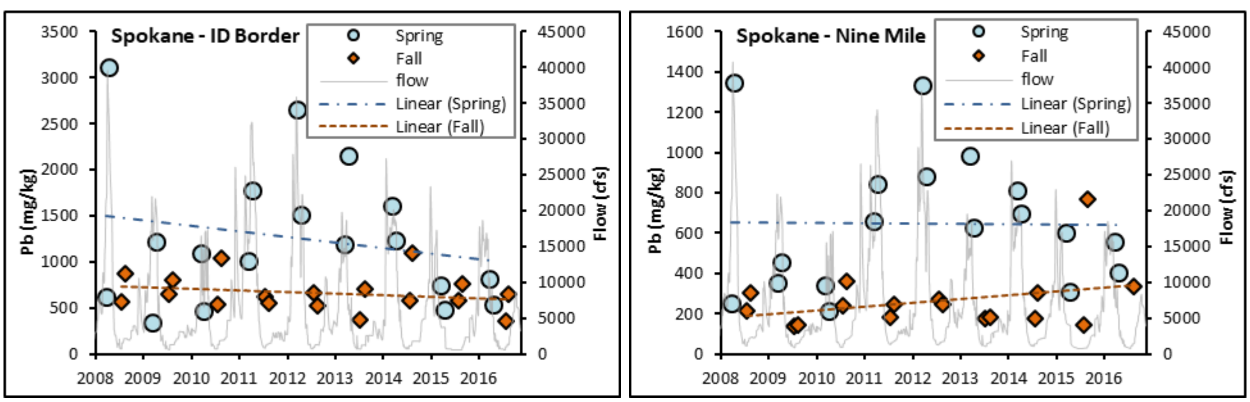

Figure 4. Lead concentrations in SPM with trend lines and streamflow at the Spokane River Idaho Border (left) and Nine Mile (right), 2008 to 2016. *Spokane River flow data provided by the U.S. Geological Survey. Note the different y-axis scales.*

Small Streams

Figure 5 shows SPM lead concentrations of the four small streams plotted against time and flow. While trends were not statistically significant, a slight downward slope in lead concentrations was also observed at Leach Creek. Lead concentrations measured from Huge and Longfellow Creeks were variable across the sampling period, with no apparent temporal trend.

The Seasonal Kendall test showed a significant downward trend in lead concentrations in SPM collected from Thornton Creek ($p < 0.05$). Both spring and fall concentrations declined over the sampling period (2011-2016) in Thornton Creek, with fall concentrations decreasing the most sharply. Restoration efforts in the Thornton Creek watershed have included (1) a 2009 reconstructed water quality channel designed to settle out sediments and associated pollutants in stormwater entering the system (SPU, 2009) and (2) floodplain reconnection projects in 2014 with engineered hyporheic zones to increase the hydraulic retention times and improve water quality (Peter et al., 2019). The engineered hyporheic zones have been shown to improve contaminant removal (Peter et al., 2019), though lead has not been assessed.

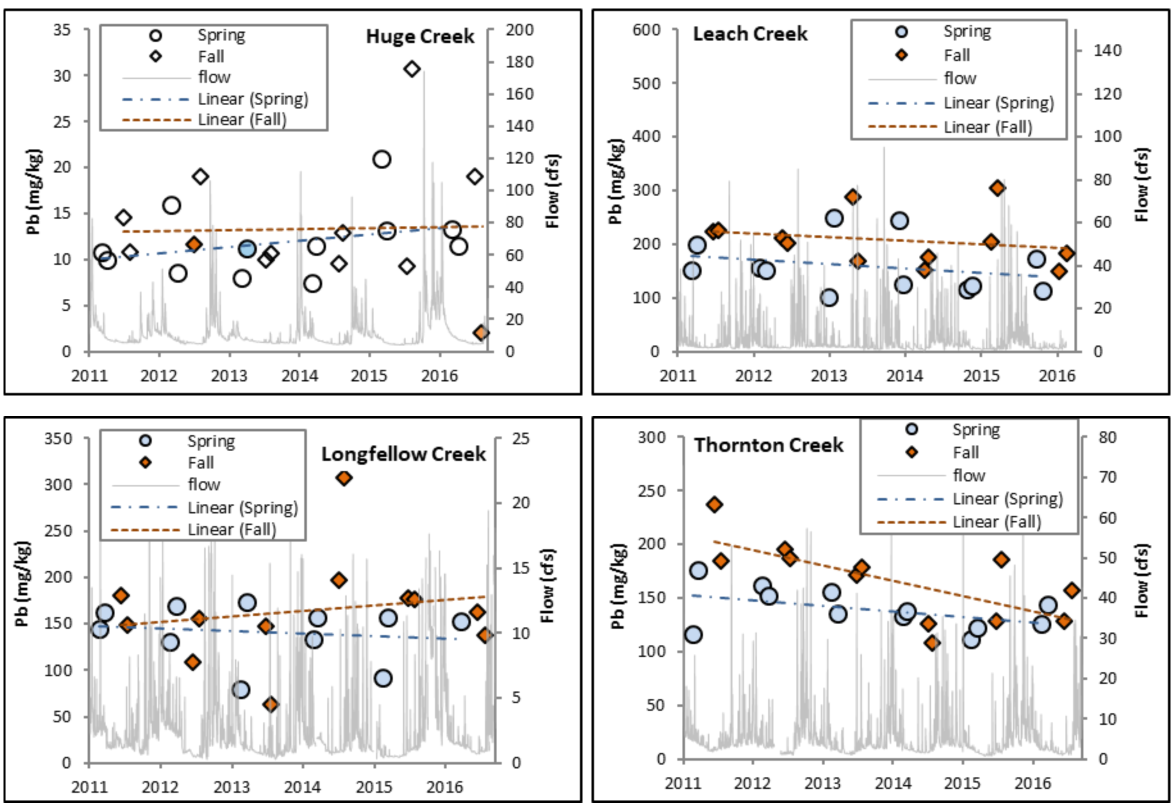

Figure 5. Lead concentrations in SPM with trend lines and streamflow at Huge Creek, Leach Creek, Longfellow Creek, and Thornton Creek, 2011 to 2016. *Unfilled symbols=values above detection limit and below reporting limit. Flow data provided by the U.S. Geological Survey and Seattle Public Utilities. Note the different y-axis scales.*

Upper Columbia River

Lead concentrations in the Upper Columbia River (Figure 6) show nearly identical spring and fall trend lines, both having a slight downward trend. No significant trend was observed for this site, and lead concentrations generally remained within the range of 50-200 mg/kg. Two exceptions to this occurred with a lower than normal sample in spring 2009 (21 mg/kg) and a higher concentration in spring 2012 (386 mg/kg).

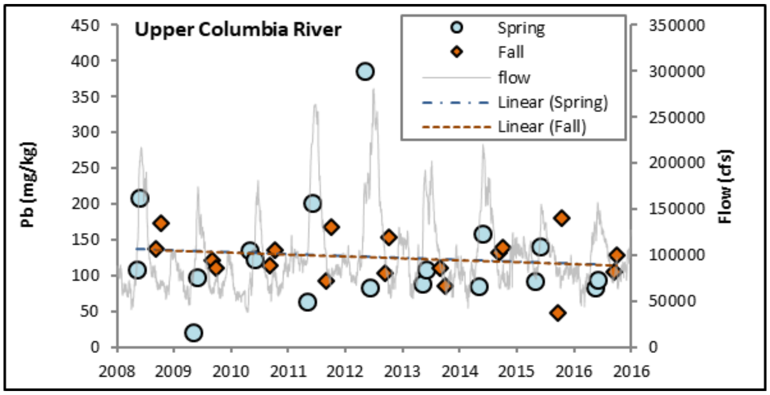

Figure 6. Lead concentrations in SPM with trend lines and streamflow at Upper Columbia River, 2008 to 2016. *Columbia River flow data provided by the U.S. Geological Survey.*

Overview of the Lead Trends Program

The 2016 sampling year was the final year of the Lead Trends Monitoring Program. An overview of concentrations and patterns observed over the course of the entire monitoring period is given below. Figure 7 displays mean lead concentrations for active monitoring stations for each year of sampling.

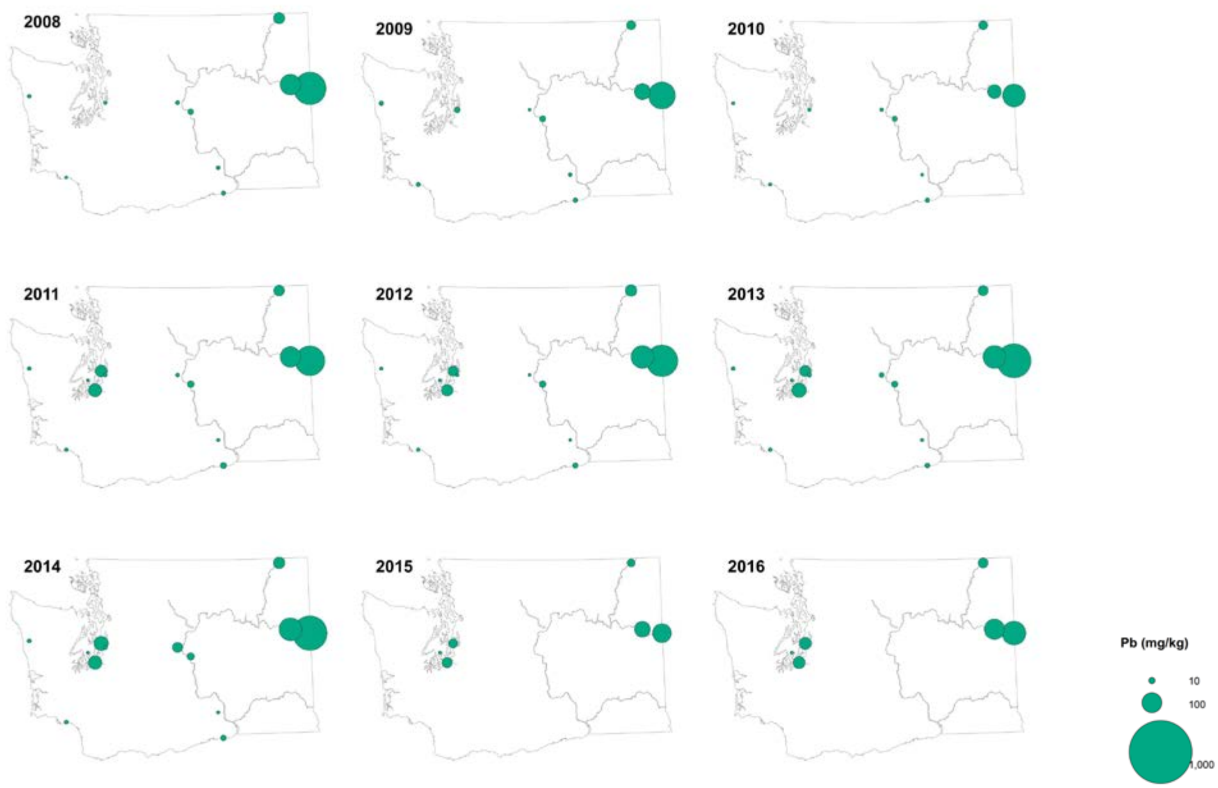

Figure 7. Mean lead concentrations at the sampling sites for each sampling year.

Ranking

During the 2008–2016 monitoring period, the highest lead concentrations were consistently measured in samples collected from the Spokane River, a system impacted by upstream mining activities. The two Spokane River sites had the highest median lead concentrations among all sites and dates sampled (Figure 8). Concentrations at the Spokane River sites (ranging 135-3,121 mg/kg) were 1 to 2 orders of magnitude higher than the lowest concentrations observed at the reference creek site, Huge Creek (ranging 1.9–30.8 mg/kg). Almost all samples collected from the Spokane River at the Idaho border over the course of monitoring (34 of 36 samples) exceeded the SCO of 360 mg/kg.

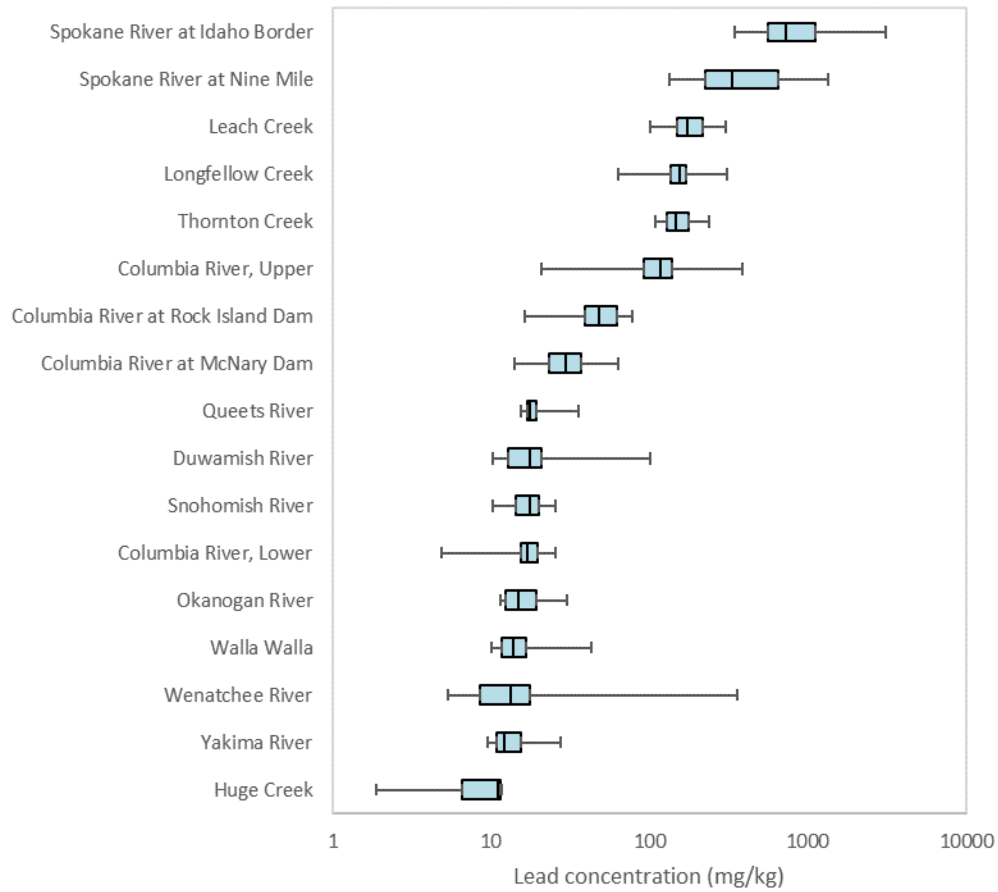

Figure 8. Boxplots of detected lead SPM concentrations (mg/kg) from samples collected 2008-2016. *Boxes represent median and quartile values, and whiskers represent minimum and maximum values. Lead concentrations are plotted on a log_{10} scale. Monitoring sites are organized by median lead concentration in decreasing order.*

The downstream Spokane River site at Nine Mile was consistently lower in lead concentration than the border site during sampling events. The Idaho border site had a median lead concentration of 725 mg/kg over the monitoring period, while the median at the Nine Mile site was 332 mg/kg. The decrease in lead concentration between the Idaho border and Nine Mile – 30 river miles downstream – is likely due to the settling out of contaminated particulate matter behind dams and the input of relatively clean sediment inputs from Latah Creek between the two sites.

Slightly less than half of the Nine Mile samples (15 of 36) were above the SCO. These exceedances occurred on spring sampling dates during the highest peak flow years. Lead concentrations were positively correlated with flow for both Spokane River sites (Table 4). As flows increase at these sampling stations, additional contaminated sediments in the watershed are washed into the river or re-suspended from bed sediments, elevating the lead concentrations in the river. Sampling years 2008 and 2012 captured particularly high flows, and these Spokane River samples were the highest sampled over the monitoring program.

Table 4. Spearman's rank correlation values between lead concentrations (mg/kg and µg/L), TSS, and flow for each site sampled, 2008-2016.

Waterbody	N	Pb (mg/kg) Correlation Values with:			Pb (µg/L) Correlation Values with:	
		Pb (µg/L)	TSS (mg/L)	Flow (cfs)	TSS (mg/L)	Flow (cfs)
Columbia River at McNary Dam	26	**0.34***	−0.066	0.37	**0.87***	**0.62***
Columbia River at Rock Island Dam	26	−0.28	**−0.61***	−0.21	**0.92***	**0.83***
Columbia River, Lower	26	−0.024	**−0.40***	**−0.41***	**0.91***	**0.75***
Columbia River, Upper	36	**0.23***	−0.062	0.0044	**0.86***	**0.46***
Duwamish River	28	0.045	**−0.53***	**−0.64***	**0.78***	**0.45***
Huge Creek	24	−0.061	**−0.52***	−0.28	**0.80***	**0.37***
Leach Creek	24	0.47	0.39	0.22	**0.88***	0.37
Longfellow Creek	23	0.083	**−0.44***	−0.23	**0.79***	0.18
Queets River	28	−0.29	**−0.41***	**−0.47***	**0.97***	**0.79***
Spokane River at Idaho Border	36	**0.51***	−0.052	**0.56***	**0.72***	**0.81***
Spokane River at Nine Mile Dam	36	**0.74***	**0.38***	**0.76***	**0.85***	**0.94***
Thornton Creek	24	**0.50***	0.11	−0.011	**0.85***	**0.33***
Wenatchee River	25	−0.39	**−0.87***	−0.61	**0.65***	**0.71***
Yakima River	24	−0.17	**−0.39***	−0.30	**0.96***	**0.81***

Bolded values with asterisks indicate a statistically significant correlation ($p < 0.05$).
cfs = cubic feet per second.

The next highest lead concentrations (ranging 63.5–307 mg/kg) were observed at the three urban creeks located in the Seattle/Tacoma area (Leach, Longfellow, and Thornton) which were monitored between 2011 and 2016. Median concentrations at the urban creek sites were similar to each other, ranging from 148 mg/kg in Thornton Creek to 174 mg/kg in Leach Creek. Particulate lead concentrations in these creeks reflect urban and vehicular traffic sources, which are transported to waterways by washing off of street dust and urban soils enriched with lead from historical use of leaded gasoline (Callender and Rice, 2000). Lead-based wheel weights are also sources of lead in urban settings (Root, 2000) but were banned in Washington in 2011; this source is likely to decrease.

High lead concentrations (ranging 20.8–386 mg/kg) were also observed at the Upper Columbia River site near the Canadian border, downstream of a large lead-zinc smelter. Moving downstream in the Columbia River toward the mouth, median lead concentrations decreased, appearing to reflect dilution owing to higher flows downstream, or attenuation from upstream sources.

Lead concentration ranges measured in the mid-sized river sites (Duwamish, Queets, Wenatchee, and Yakima) were generally in the range of 10-40 mg/kg. Overall, levels at these sites were more comparable to the reference creek site than to the more contaminated Spokane River sites. Lead concentrations in these sites that are not historically impacted by lead contamination had generally negative correlations with flow and TSS, explained by a dilution effect: lead concentrations are diluted by relatively clean sediments that become washed into the river during higher flows.

The highest instantaneous SPM lead loads among all sampled sites and dates were observed in the Columbia River, followed by the Spokane River, mid-sized rivers, urban creeks, and the reference creek (Figure 9). In general, higher lead loads were observed at the sites with greater flows.

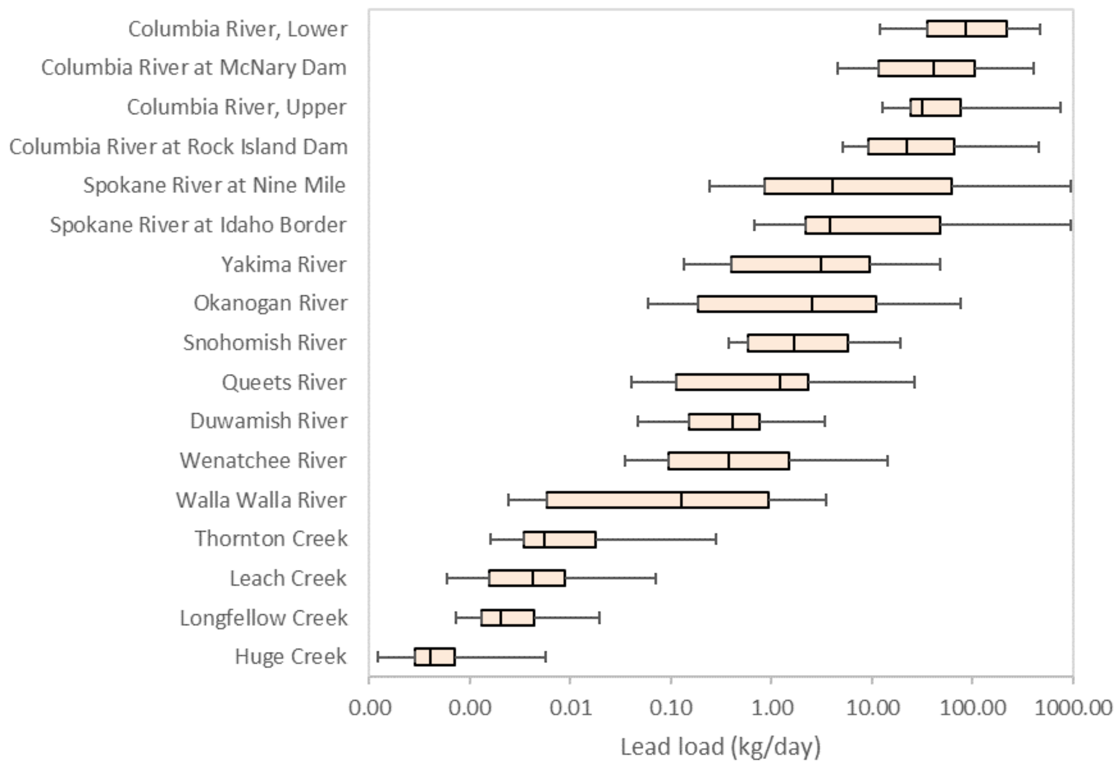

Figure 9. Boxplots of instantaneous lead loads based on lead concentration and streamflow data from samples and measurements collected 2008-2016.

Boxes represent median and quartile values, and whiskers represent minimum and maximum values. Loads are plotted on a log_{10} scale. Monitoring sites are organized by median load in decreasing order.

Summary and Conclusions

This report summarizes results from the final year (2016) of a long-term (2008-2016) lead monitoring study. The goal of this study was to support the state's lead Chemical Action Plan by (1) establishing a baseline of lead concentrations in Washington State rivers and streams, and (2) evaluating spatial and temporal trends over time. From 2008-2016, Ecology collected suspended particulate matter (SPM) twice each in the spring and fall for analysis of total lead at sites across the state each year. The following conclusions can be made from this study:

- SPM collected from the two Spokane River monitoring sites consistently had the highest lead concentrations of all monitoring sites, ranging from 135-3,121 mg/kg over the course of the study. Spokane River lead concentrations were highest at the Idaho border site (median = 725 mg/kg) and followed by the Spokane River Nine Mile site (median = 332 mg/kg). Of the 36 samples collected from each Spokane River site during 2008-2016, all but two samples from the Idaho border were above the freshwater SCO of 360 mg/kg, while 15 of the Nine Mile samples were above this threshold. No temporal trend emerged for either of the Spokane River sites over the sampling period.
- Lead concentrations in three urban creeks (Leach, Longfellow, and Thornton) sampled during 2011-2016 were in the 60-300 mg/kg range (median = 156 mg/kg). The reference stream (Huge Creek) had much lower concentrations, with the majority of samples below the reporting limit (range = ND-11.6 mg/kg). Statistical tests showed a significant decline of lead SPM concentrations in Thornton Creek during 2011-2016. Slope estimates show reductions in SPM lead of 5.4 and 14 mg/kg per year for spring and fall seasons, respectively. Restoration efforts in Thornton Creek may have helped to trap lead-bound particulates in stormwater entering the upper watershed. No significant trends were observed for the other small streams.
- Upper Columbia River SPM samples were generally in the 50-200 mg/kg range during 2008-2016, with a median of 117 mg/kg. Only one sample — collected in spring 2012 — exceeded the SCO. No significant temporal trend was evident for Upper Columbia River lead concentrations.
- The program monitored lead at mid- to large-sized rivers during 2008-2010 (Okanogan, Snohomish, and Walla Walla) and during 2008-2014 (Lower Columbia, Mid-Columbia, Duwamish, Queets, Wenatchee, and Yakima). Lead concentrations in SPM collected from these sites were generally within background levels, with most samples in the 10-40 mg/kg range. No significant or consistent temporal trends were observed for these sites.
- The lack of trends observed during the sampling periods for this study may be due to a lack of statistical power from small annual sample sizes, or because lead concentrations were already at background levels (mid-large sized rivers with no point sources) and are unlikely to change significantly.

Recommendations

Results of this study support the following recommendations:

- Continued monitoring of the Spokane River and Upper Columbia River should be conducted through already existing programs, such as Ecology's Ambient River and Stream Water Quality Monitoring program. This program already collects a sufficient number of samples each year for better temporal resolution, although only as dissolved and total lead in water. Lead reductions in the Spokane River and Upper Columbia River are likely to occur from targeted clean-up strategies upstream, not Chemical Action Plan recommendations.
- Monitoring lead in small urban streams, where declines due the state's lead wheel weight ban is most likely to be observed, could be conducted by local jurisdictions (e.g., King County's stream monitoring program) or on a less frequent basis by Ecology.
- Future monitoring should take a more targeted approach to evaluate lead reductions as a result of specific restoration efforts. Additional studies could (1) evaluate the effectiveness of stormwater particle reductions in streams, or combine with efforts to look at tire wear particles and other vehicle sources, and (2) make recommendations on effective strategies to reduce lead from traffic sources in waterbodies.

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Glossary, Acronyms, and Abbreviations

Glossary

Anthropogenic: Human-caused.

Conductivity: A measure of water's ability to conduct an electrical current. Conductivity is related to the concentration and charge of dissolved ions in water.

Hyporheic: The area beneath and adjacent to a stream where surface water and groundwater intermix.

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 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.

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.

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

Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
MEL	Manchester Environmental Laboratory
QAPP	Quality assurance project plan
SCO	Sediment cleanup objective
SOP	Standard operating procedure
SPM	Suspended particulate matter
TSS	Total suspended solids
USGS	U.S. Geological Survey
WAC	Washington Administrative Code
WRIA	Water Resource Inventory Area

Units of Measurement

cfs	cubic feet per second
dw	dry weight
ft	feet
g	gram, a unit of mass
kg/d	kilograms per day
m	meter
mg	milligram
mg/kg	milligrams per kilogram (parts per million)
mg/L	milligrams per liter (parts per million)
µg/L	micrograms per liter (parts per billion)