PBT Trend Monitoring: Measuring Lead in Suspended Particulate Matter from Washington State Rivers and Lakes, 2010 Results

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Cover photo: Monitoring site at the Walla Walla River.

PBT Trend Monitoring: Measuring Lead in Suspended Particulate Matter from Washington State Rivers and Lakes, 2010 Results

by

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Waterbody Numbers: See Appendix A

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Abstract

This report summarizes results from the third year (2010) of a long-term monitoring study of lead in suspended particulate matter conducted by the Washington State Department of Ecology. Lead sampling began in 2008 as part of the persistent, bioaccumulative, and toxic chemical (PBT) monitoring program. The goal of this study is to detect trends in environmental levels of lead in rivers and lakes of Washington State.

During 2010, a total of 60 suspended particulate matter samples were collected in the spring and fall from 15 monitoring sites across the state.

Lead was detected in 93% of samples. Concentrations ranged from 1U (not detected above 1 mg/kg) to 1091 mg/kg in the spring (median = 20.5 mg/kg), and 1U to 1045 mg/kg in the fall (median = 22.4 mg/kg). Lead concentrations were low at the majority of monitoring sites and elevated (>100 mg/kg) only at the Spokane River sites and the Upper Columbia River.

A total of 10% of samples exceeded the Lowest Apparent Effects Threshold of 335 mg/kg for lead in freshwater sediments. All exceedances were from the Spokane River sites. Currently, no regulatory criteria exist for freshwater suspended particulate matter.

Over the last three years of sampling (2008 – 2010), lead concentrations during the spring were generally lowest in 2008 and slightly higher in 2009 and 2010. Fall levels were variable among the sampling years, but median levels were highest in 2008 followed by 2009 and 2010. High streamflows in 2008 likely influenced these patterns.

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- Olympic National Park for Queets River research permission.
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Introduction

Lead is a naturally occurring element, but re-distribution by humans has greatly increased its prevalence in the environment. It has been classified as a metal of concern under Ecology's PBT (Persistent, Bioaccumulative, and Toxic) Rule (WAC 173-333-110) because of its persistence in the environment, its bioaccumulation in organisms, and its highly toxic nature.

The use of lead as an additive in gasoline in the 20^{th} century resulted in widespread lead pollution until U.S. restrictions in the 1980s and 1990s phased out its use (Davies, 2009). In Washington State, historical sources of lead to the environment also included smelting activities and lead-arsenate insecticide applications. Currently, major anthropogenic sources of lead to the state's freshwater systems are: releases from sewage treatment plants and industrial facilities such as mining operations, the Hanford nuclear reservation, military bases, and large energy users (Davies, 2009).

Lead in the environment is a concern because it is highly toxic to humans and wildlife. Lead primarily affects developing nervous systems, but it can also harm cardiovascular, gastrointestinal, immune, and reproductive systems, as well as kidneys and blood (Davies, 2009). Lead uptake occurs through ingestion and inhalation of lead-containing materials, such as contaminated water or dust (ATSDR, 2009), after which the lead accumulates in bones.

Lead was the third PBT chemical to be addressed by the Washington State Department of Ecology (Ecology) through a Chemical Action Plan (Davies, 2009). Ecology and the Washington State Department of Health developed the plan to identify the toxic effects of lead, describe its occurrence in the environment, and recommend ways to reduce its harm.

In 2008, Ecology began a monitoring program to assess temporal changes in lead levels in rivers and lakes in Washington State. Suspended particulate matter (SPM) was the target medium because of lead's high affinity for the particulate phase. The primary objectives of the lead monitoring program were to (1) establish baseline levels of SPM-associated lead in the environment and (2) measure spatial and temporal trends in lead over time as Chemical Action Plan reduction strategies are implemented. This report summarizes the third year (2010) of the long-term monitoring effort.

Previous Studies

The first two years of sampling for lead in SPM were conducted in 2008 and 2009. Annual reports for each year are described in brief below.

2008

One SPM sample per season (spring and fall) was collected at 15 monitoring sites, along with a second sampling event at a subset of eight stations each season, for a total of 46 samples in 2008 (Meredith and Furl, 2009). Lead was detected in 93% of samples, and concentrations ranged from 1U – 3,121 mg/kg with a median of 26 mg/kg. Elevated concentrations were found in the Spokane River at the Idaho border and Nine Mile, as well as in the Upper Columbia River.

2009

Two samples were collected at each monitoring site per season (spring and fall) in 2009 (Meredith and Furl, 2010). A total of 95% of samples contained quantifiable amounts of lead. Concentrations ranged from 1U – 1,214 mg/kg, and the median value was 23 mg/kg. With the exception of the Spokane River (border and Nine Mile), Upper Columbia River and Duwamish River sites, lead concentrations were near or slightly above background sediment levels measured in Washington State by Sloan and Blakley (2009).

Study Design

A total of 60 SPM samples were collected during the spring and fall from 15 established monitoring sites in 2010. Two samples per season were collected at each site via in-line filtration of river or lake water. An attempt was made to capture high-flow and low-flow events in the spring and fall, respectively. No changes were made to the study design in 2010; sampling protocols followed the Quality Assurance Project Plan (Meredith and Furl, 2008).

Monitoring site locations are distributed across Washington State (Figure 1). Three of the sites were included in the sampling design to represent areas with potential contamination: Hylebos Creek, Spokane River at the Idaho border, and Upper Columbia River. These sites are primarily impacted by historical smelting, mining in the Coeur D'Alene basin, and an upstream lead-zinc smelter, respectively, and are undergoing clean-up actions (Ecology, 2007; Butkus and Merrill, 1999; Ecology, 2009; EPA, 2008). The Queets River watershed lies in the Olympic National Park and represents reference conditions for this study. The remaining sites cover a range of land uses and lead contamination potential.

For brief descriptions of monitoring sites see Appendix A.

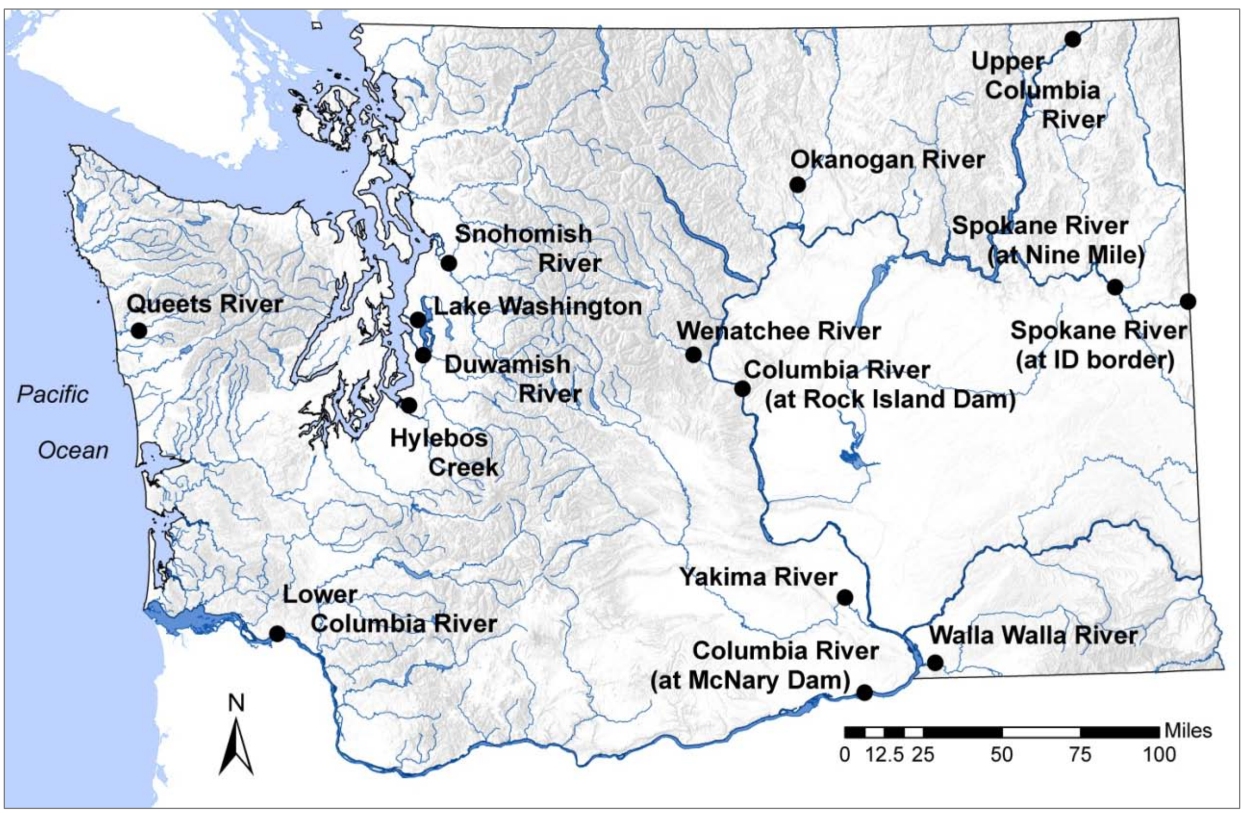

Figure 1. Monitoring Sites for Lead in SPM, 2010.

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Methods

Field Procedures

SPM samples were collected following Ecology's Environmental Assessment Program *Standard Operating Procedure for Collecting Freshwater Suspended Particulate Matter Samples Using In-line Filtration* (Meredith, 2008). River or lake water was pumped via a peristaltic pump and filtered through pre-weighed, 0.45 um pore-size (47 mm membrane) nitrocellulose filters using in-line Teflon filter holders. The intake of the tubing was placed 0.5 to 3feet below the water surface, suspended above the river or lake 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.

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 Manchester Environmental Laboratory (MEL) for analysis. Chain-of-custody procedures were maintained throughout.

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 U.S. Environmental Protection Agency (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 and as lead by volume in ug/L. Lead in ug/L was calculated by dividing the amount of lead measured on individual filters by volume of water passed through the filter.

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 um pore-size). MEL's standard TSS analyses are conducted using 1.5 um 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 performed all analyses of lead in SPM with no analytical problems. MEL received the samples in good condition and within proper method holding times. MEL provided case narratives documenting instrument calibration, calibration checks, internal standards, method blanks, matrix spikes, and laboratory control samples. All instrument calibrations and internal standard recoveries were within laboratory acceptance limits. Copies of case narratives are available upon request.

All laboratory quality control (QC) checks were within measurement quality objectives (MQOs) outlined in the Quality Assurance (QA) Project Plan (Meredith and Furl, 2008). QC tests included matrix spikes, laboratory control samples, and method blanks. Results of QC tests and MQOs are presented in Appendix B.

Field QC tests included two field replicates/season and three field blanks/season (Appendix B). Three out of four field replicates were within MQOs (< 50%). One replicate sample had a relative percent difference of 72% with the native sample. The native sample, collected from the Yakima River in the spring, measured 7.3 mg/kg and was qualified "J" as an estimate.

Two out of six field blanks collected in 2010 contained quantifiable amounts of lead, and the associated field samples were qualified "J" as estimates. These samples were collected at the Wenatchee and Yakima Rivers in the fall. The native Wenatchee sample measured 56.4 mg/kg, which is slightly higher than the range of previous measurements at that site. The sample was flagged "J" as an estimate. The native sample at the Yakima River was a non-detect; therefore no action was taken. See Appendix B for complete test results.

Sampling Results

Lead was detected in 93% of SPM samples in 2010. Concentrations ranged from 1U to 1091 mg/kg in the spring, with a median of 20.5 mg/kg. Fall samples ranged 1U to 1045 mg/kg and had a median value of 22.4 mg/kg. Maximum lead concentrations were found at the Spokane River Idaho Border site in both seasons. Table 1 displays lead in SPM and TSS data collected in 2010. A statistical summary of lead concentrations is presented in Table 2.

TSS values were measured above 1 mg/L in 93% of samples. The range of TSS values was 1 to 37 mg/L in the spring and 1U to 13 mg/L in the fall. Medians were 5 mg/L and 3 mg/L in the spring and fall, respectively. Complete sampling results, including lead, TSS, pH, conductivity, and temperature data, are available in Appendix C.

Table 1. Lead and Total Suspended Solids Results, 2010.

Waterbody	Spring			Fall		
	Date	Lead (mg/kg)	TSS (mg/L)	Date	Lead mg/kg	TSS (mg/L)
Columbia River, Lower	4/29/2010	12.8	17	9/8/2010	23.7	8
	5/27/2010	16.9	13	10/6/2010	25.7	4
Columbia River at McNary Dam	4/27/2010	29.0	3	9/8/2010	20.9	3
	5/26/2010	25.2	2	10/6/2010	44.0	1
Columbia River at Rock Island Dam	4/27/2010	33.0	3	8/31/2010	62.2	2
	5/25/2010	23.2	4	9/29/2010	50.3	1
Columbia River, Upper	4/28/2010	136	2	9/8/2010	114	2
	5/27/2010	122	5	10/8/2010	135	1 U
Duwamish River	4/28/2010	15.0	11	9/3/2010	17.1	9
	5/26/2010	35.7	4	10/5/2010	19.8	5
Hylebos Creek	4/28/2010	29.7	8	9/3/2010	32.9	13
	5/26/2010	34.5	4	10/5/2010	39.1	4
Lake Washington	4/28/2010	32.7	2	9/9/2010	55.5	1
	5/26/2010	54.4	2	10/5/2010	1 U	1 U
Okanogan River	4/26/2010	16.2	24	8/30/2010	1 U	1 U
	5/24/2010	12.4	31	9/29/2010	21.2	3
Queets River	4/30/2010	17.7	9	9/9/2010	19.8	3
	5/28/2010	16.9	14	10/7/2010	21.0	4
Snohomish River	4/28/2010	1 U	3	9/3/2010	18.7	10
	5/26/2010	17.5	6	10/5/2010	19.3	3
Spokane River at Idaho Border	4/29/2010	1091	1	9/9/2010	536	1
	5/27/2010	471	2	10/7/2010	1045	1 U
Spokane River at Nine Mile Dam	4/28/2010	338	3	9/9/2010	239	3
	5/27/2010	212	4	10/7/2010	362	1
Walla Walla River	4/27/2010	15.4	14	9/8/2010	13.1	3
	5/26/2010	11.2	29	10/6/2010	14.4	4
Wenatchee River	4/27/2010	12.3	7	8/31/2010	56.4 J	2
	5/25/2010	10.5	5	9/30/2010	14.3	3
Yakima River	4/27/2010	15.9	26	9/8/2010	1 U	2
	5/26/2010	7.3 J	37	10/6/2010	9.5	3

U: Not detected at level indicated; J: Value is an estimate.

Table 2. Statistical Summary of Lead Concentrations in SPM (mg/kg), 2010.

	Minimum	Maximum	Mean	Standard Deviation	Median
All Samples	1 U	1091	98.3	212	22.2
Spring	1 U	1091	95.5	215	20.5
Fall	1 U	1045	101	213	22.4

U: Not detected at level indicated.

Discussion

Ranking

Figure 2 ranks the 15 monitoring sites by annual mean lead concentration (mg/kg). The lowest average lead levels were found at the Yakima River site and the highest at the Spokane River (Idaho Border) site. The Spokane River at Nine Mile and Upper Columbia River also had elevated concentrations, with seasonal averages greater than 100 mg/kg. Overall, the majority of the monitoring sites had low lead levels, with 72% of samples (43 out of 60) below 50 mg/kg.

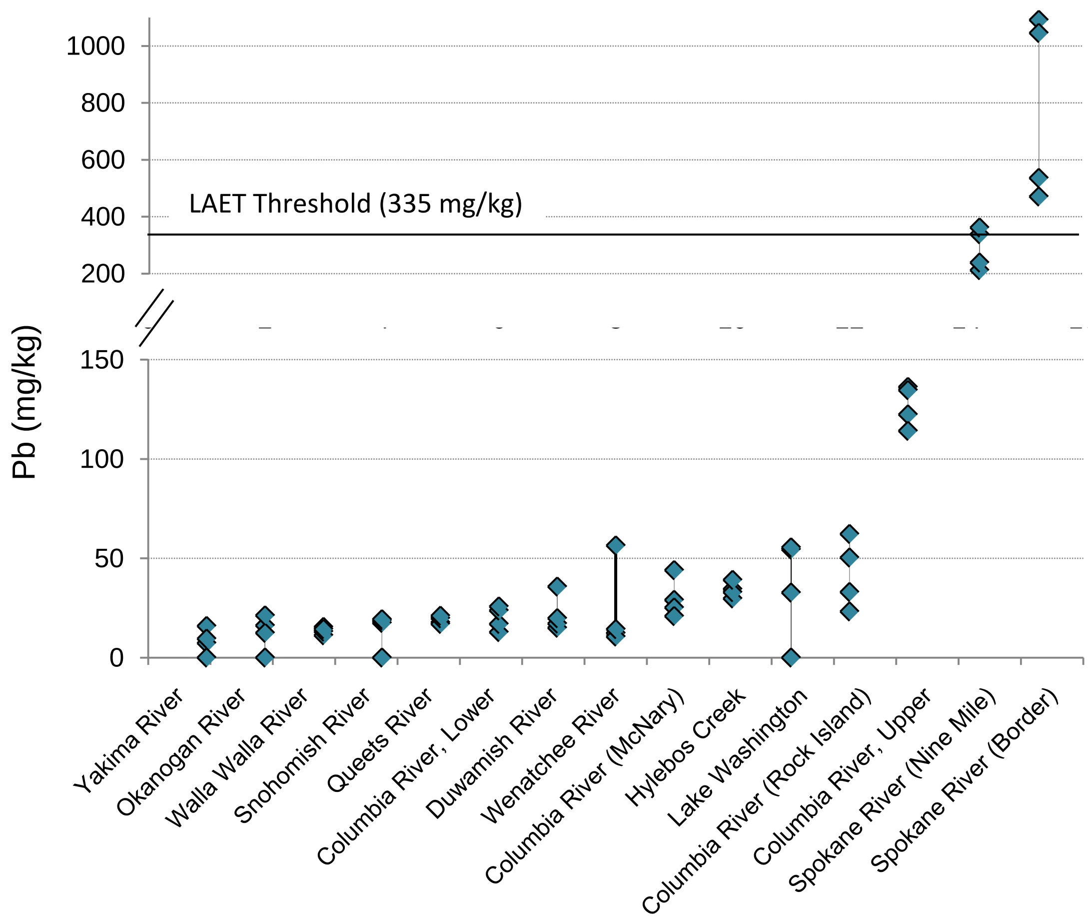

Figure 2. Concentrations of Lead in SPM (mg/kg) at Monitoring Sites, 2010.

Sites are ranked by annual average lead concentration.

LAET = Lowest Apparent Effects Threshold.

The two highest-ranking sites are located on the same river – the Spokane – but lead concentrations at the Idaho border site were over two times greater than at the Nine Mile site for samples taken on or near the same date. The monitoring site at Nine Mile is located 58 river miles downstream of the border site. The difference between lead levels at the two Spokane River monitoring sites suggests sources of lead upstream of the border are still present and concentrations are diluted downstream at Nine Mile. Resuspension of contaminated bed sediments, particularly at high flows, from historical mining in the Coeur d'Alene basin is likely the source of high lead concentrations at the border (Box et al., 2005). Also, SPM-associated lead is diluted at Nine Mile compared to the border by tributary inputs of metal-poor suspended sediment from Latah Creek (Box et al., 2005).

The Spokane River border site also had greater variation in lead concentrations within a season. The peak concentration in spring (1091 mg/kg) occurred as the streamflow was still rising. The second spring sample captured a similar flow rate as the first, but two spikes in the water level had occurred between sampling events, and lead concentrations were much lower (471 mg/kg) (see hydrograph in Appendix E). Similar variation was found in the two fall samples. However, the higher lead concentration was measured in the second sampling event of the season, when flows were only slightly higher than during the first sampling event. It is unclear what caused the high level found in fall.

Comparison to Guidelines

Washington State does not currently have regulatory criteria for freshwater sediments or SPM. However, guidelines exist to identify contaminant levels in sediments at which possible biological effects might occur. Ecology's proposed Lowest Apparent Effects Threshold (LAET) for lead in freshwater sediments (335 mg/kg) is one such guideline (Cubbage et al., 1997; Betts, 2003).

Figure 2 displays the SPM samples collected in 2010 in relation to this guideline. Six SPM samples (10%) were above the LAET of 335 mg/kg. All four samples taken from the Spokane River at the Idaho border exceeded this value, as did two samples from the Spokane River at Nine Mile. Most of the sites were well below this threshold.

Correlations

Non-parametric Spearman Rank correlations were calculated to evaluate relationships between lead concentrations by weight (mg/kg), lead by volume (ug/L), streamflow, and TSS. Lead on a volume basis (ug/L) was calculated by dividing the amount of lead on each filter by filtrate volume. Data from all years of the long-term monitoring program (2008-2010) for individual sites were used. Correlation coefficients of the relationships are presented in Appendix D.

Few of the correlations with lead by weight (mg/kg) were statistically significant. However, the following general relationships were seen: lead concentrations (mg/kg) decreased with TSS at all sites except for the Spokane River at Nine Mile. Lead (mg/kg) also decreased with flow at all sites with the exception of the two Spokane River stations and Columbia River at McNary. Relationship direction of lead by weight (mg/kg) with lead by volume (ug/L) varied by site.

Several of the monitoring sites, including the Queets River reference site, show significant inverse correlations between lead by weight (mg/kg) and lead by volume (ug/L), flow, and TSS. This has been explained as a dilution effect in rivers without contaminated banks and streambeds. Greater amounts of TSS and larger particle sizes present in heavier flows have lesser surface areas for metals binding (Benoit and Rozan, 1998; Dawson and Macklin, 1998).

In past years of sampling, the high contamination sites showed strong positive relationships between lead (mg/kg), lead (ug/L), and flow, indicating that contaminated sediments were being washed from the banks or streambed sediments were being redistributed in the river during high flows. With the addition of the 2010 sampling data, these relationships were only significant at the Spokane River at Nine Mile. The differences in relationships may be due to the low flows seen in 2010. Spring flows in 2010 were lower than normal in the Spokane River, while 2009 spring flows were typical and 2008 levels were higher. Spring flows at the Upper Columbia River were typical in 2008, and lower than normal in 2009 and 2010.

Particulate lead by volume (ug/L) was positively correlated with TSS and flow at all monitoring sites. The correlations between lead (ug/L) and TSS were particularly strong and were significant at all sites. Flow was significantly correlated with TSS at all sites with the exception of the Upper Columbia River.

Seasonal Variation

To assess seasonal effects on lead concentrations, Wilcoxon Signed Ranks tests were conducted using average lead values from spring and fall. A Wilcoxon Signed Ranks test is a nonparametric analog to the paired samples t-test and used here because of the non-normal distribution of the data. No significant differences were found in lead (mg/kg) between spring and fall for all sites, the low-contamination sites, or the high contamination sites grouped together ($p = 0.156$, $p = 0.308$, and $p = 0.285$, respectively).

Lead values on a volume basis (ug/L), however, showed significant seasonality (Wilcoxon Signed Ranks test; $p = 0.005$). Spring levels were higher than fall levels at all monitoring sites except for the Snohomish River. This difference likely reflects seasonality of flow, as lead values by volume (ug/L) were strongly correlated with flow and higher flows brought greater TSS levels. The majority of sampling dates captured high-flow periods in the spring, often on the rising limb, and low-flow baseline levels in the fall. For hydrographs of each monitoring site, along with sampling dates, see Appendix E.

Loading

Particulate lead loads were calculated for sampling dates using daily average streamflow (cfs) and lead concentrations by volume (ug/L). Loads were highest in the largest river system (Columbia River) and lowest in the Duwamish River. Figure 3 displays mean lead loadings at the 13 monitoring sites for which flow data were available.

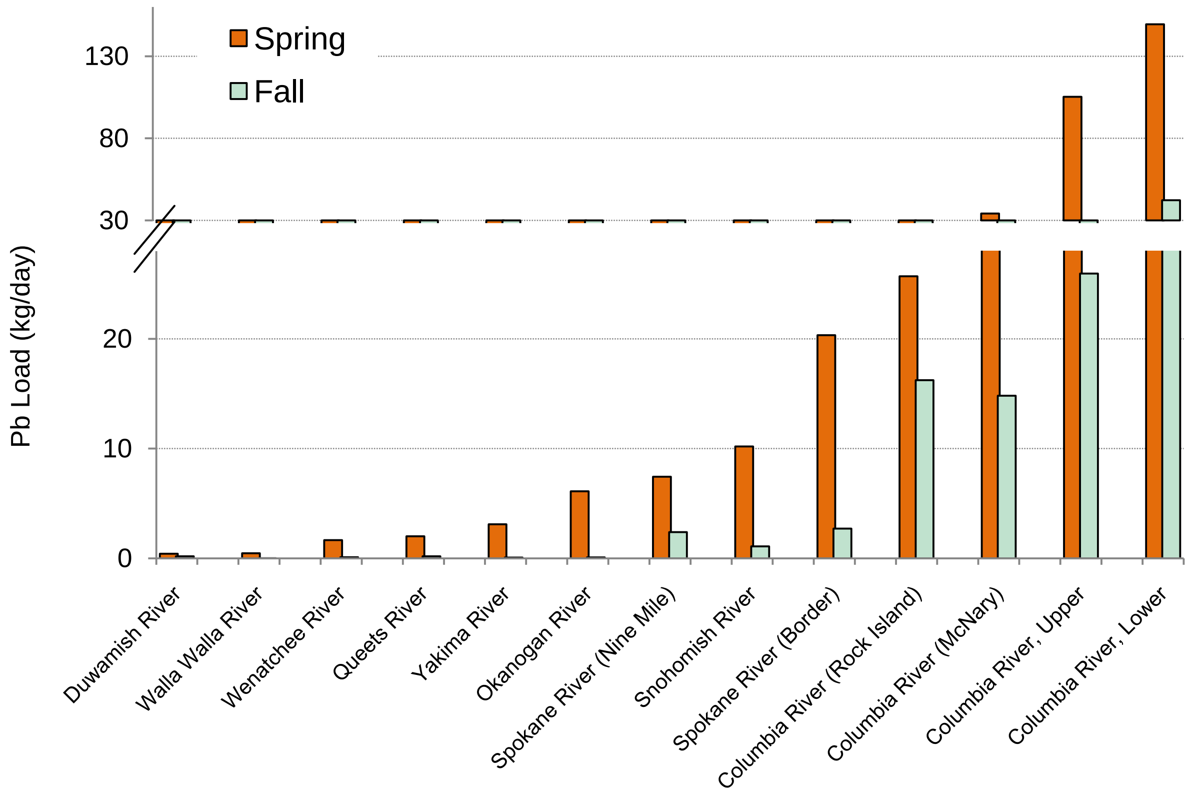

Figure 3. Mean Estimated Particulate-bound Lead Loadings (kg/day) for Spring and Fall Sampling Events at 13 River Monitoring Sites, 2010.

A significant seasonal difference was found between spring and fall mean lead loadings (Wilcoxon Signed Ranks test; $p = 0.001$). SPM-associated lead loads were greater in the spring than the fall at all monitoring sites. Again, this difference is reflective of higher flows in the spring.

Temporal Trends

Lead in SPM has been monitored by this program since 2008. With three years of sampling data (2008 – 2010), a qualitative assessment of temporal patterns and trends is possible. Quantitative statistical analyses of temporal trends in the data will be possible in the following years, as sample sizes increase to five or more years of data.

Over the last three years of sampling, the lowest lead concentrations (mg/kg) were seen in the spring of 2008 at the majority of monitoring sites. Spring lead levels in 2009 and 2010 were slightly higher than 2008, but no consistent pattern was seen among the sites between 2009 and 2010. This is likely reflective of the relatively high flows seen in 2008. Fall lead levels were highly variable over the last three years, with no apparent temporal pattern among the individual monitoring sites.

The three highest contamination sites – Spokane River at the Idaho border, Spokane River at Nine Mile, and Upper Columbia River – have shown consistently contrary trends to the rest of the monitoring sites. The greatest lead levels measured at the Spokane River and Upper Columbia River sites were in spring 2008 during the highest flows. This is not surprising based on the positive relationship at these sites between lead concentrations and flow over the past three years. However, a separate Ecology study monitoring ambient total and dissolved lead concentrations in water samples from the Spokane River found that metals in the river have significantly decreased since 1994 (Hallock, 2010). When adjusted for flow, dissolved lead concentrations still showed a decrease since 1994, while total lead did not.

Figures 4 and 5 are box plots that display the median and interquartile ranges of all sampling results from 2008 – 2010, along with median flow values for spring and fall data, respectively. Median spring lead concentrations (mg/kg) were lowest in 2008 and similar in 2009 and 2010, although 2010 was slightly higher. In the same time period, median spring flows were greatest in 2008 and have lowered each year (Figure 4). This pattern is consistent with the inverse correlation between lead (mg/kg) and flow discussed earlier.

Median fall lead concentrations (mg/kg) have been lower each consecutive year since 2008, with the first year of sampling (2008) having the highest median (Figure 5). Fall median flows were also highest in 2008, followed by 2010 and 2009.

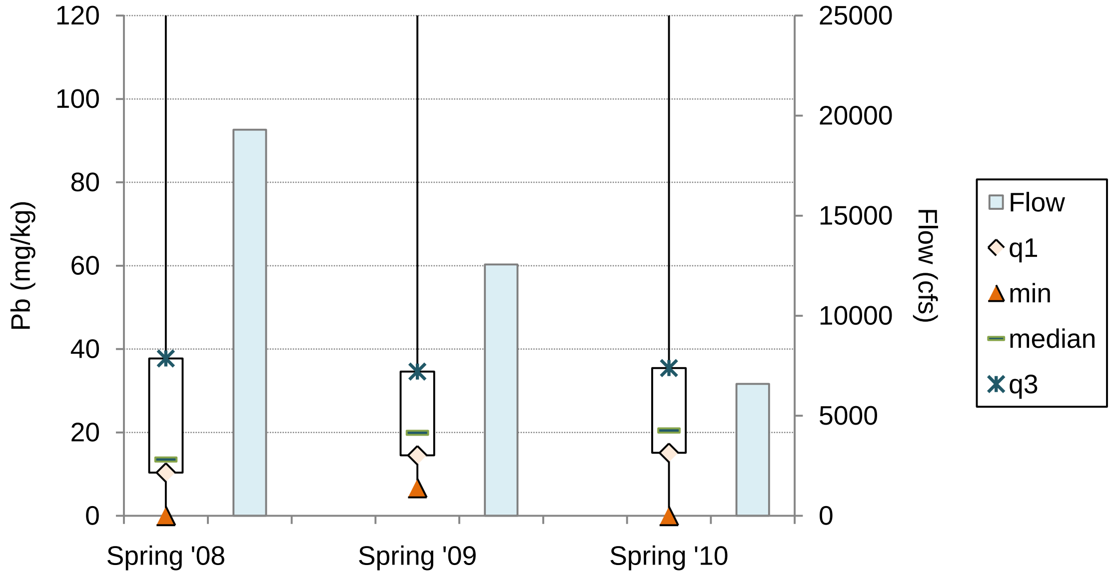

Figure 4. Box Plot Displaying Lead in SPM (mg/kg) and Median Flow (cfs) for Spring Sampling in 2008, 2009, and 2010.

q1 = first quartile; q3 = third quartile.

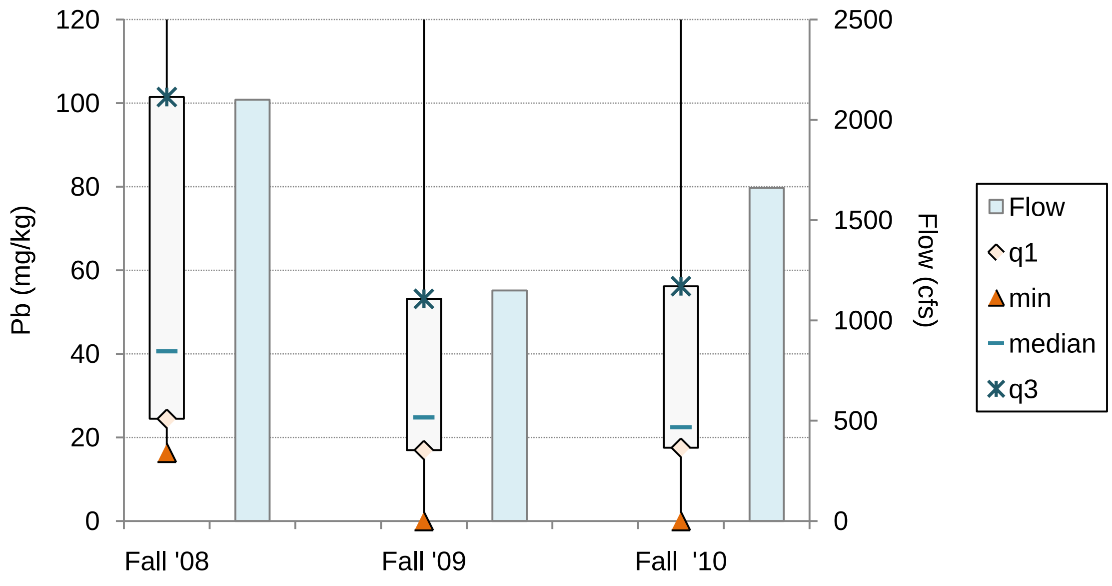

Figure 5. Box Plot Displaying Lead in SPM (mg/kg) and Median Flow (cfs) for Fall Sampling in 2008, 2009, 2010.

q1 = first quartile; q3 = third quartile.

Conclusions

This report summarizes results from the third year (2010) of monitoring lead in suspended particulate matter (SPM) at 15 sites across Washington State. Lead was detected in 93% of SPM samples, with concentrations ranging from non-detect (1U) to 1091 mg/kg in the spring and 1U to 1045 mg/kg in the fall. This study supports the following conclusions:

- Lead concentrations at the majority of monitoring sites were low, with 72% of samples below 50 mg/kg.

- The highest lead concentrations were found at the Spokane River Idaho Border site in both seasons. Elevated levels (> 100 mg/kg) were also found at the Spokane River at Nine Mile and the Upper Columbia River.

- A total of 10% of samples exceeded the Lowest Apparent Effects Threshold guideline for lead in freshwater sediments of 335 mg/kg. All exceedances were from Spokane River sites. Currently, no regulatory criteria exist for lead in freshwater SPM.

- Spring samples had higher lead by volume concentrations (ug/L) and lead loading (kg/day) than did fall samples.

- Over the last three years of sampling (2008 – 2010), spring lead concentrations (mg/kg) were generally lowest in 2008 and slightly higher in 2009 and 2010. Fall levels were varied among the sites, but median values were highest in 2008 followed by 2009 and 2010. Differences in streamflow are likely a key factor in these patterns.

- Sites known to have significant upstream lead contamination (Spokane and Upper Columbia Rivers) showed contrary temporal patterns to the rest of the monitoring sites. Peak concentrations were found in the spring of 2008, during the highest streamflows.

Recommendations

Recommendations for the lead monitoring program include:

- Continue the current sampling regime of two samples per season at 11 of the monitoring sites on a yearly basis. Quantitative trend analysis will be conducted after five years of data collections from these sites, in 2012. The authors recommend discontinuing sampling at the following sites: Lake Washington, Okanogan River, Snohomish River, and Walla Walla River.

- Add four monitoring sites to the sampling plan. These sites will include small streams in heavily urbanized watersheds, particularly in areas of high vehicle traffic. The addition of these streams will provide data on lead concentrations in areas potentially affected by *Lead Chemical Action Plan* recommendations (Davies, 2009), such as the 2011 ban on lead wheel weights in Washington State.

- Increase the frequency of field blank sampling to five per season, for a total of ten field blanks taken per year. This would provide field blank data from each field crew.

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Appendices

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Appendix A. Sampling Locations

Table A-1. Monitoring site descriptions, 2010.

Monitoring Site	County	WBID[1]	WRIA[2] Number	Latitude[3]	Longitude[3]	Description
Columbia River, Lower	Wahkiakum	WA-CR-1010	25	46.18490	-123.18760	Columbia River near Clatskanie, OR, RM 54.
Columbia River at McNary Dam	Benton	WA-CR-1026	31	45.93940	-119.29720	Columbia River at McNary Dam near Umatilla, OR, RM 292.0.
Columbia River at Rock Island Dam	Chelan-Douglas	WA-CR-1040	44	47.34390	-120.09390	Columbia River at Rock Island Dam, RM 453.5, 10 miles south of Wenatchee.
Columbia River, Upper	Stevens	WA-CR-1060	61	48.92161	-117.77445	Upper Columbia River at Northport, RM 735.
Duwamish River	King	WA-09-1010	9	47.48525	-122.26140	Duwamish River at Foster Golf Links in Tukwila, RM 10.
Hylebos Creek	Pierce	WA-10-1011	10	47.25335	-122.35013	Hylebos Creek in Fife, at 4th St. bridge.
Lake Washington	King	WA-08-9340	8	47.64750	-122.30190	Lake Washington, in Seattle, at Montlake Cut, east of University of Washington Marina.
Okanogan River	Okanogan	WA-49-1010	49	48.28060	-119.70500	Okanogan River at Malott, RM 17, private property.
Queets River	Jefferson	WA-21-1030	21	47.55220	-124.19780	Queets River in Olympic National Forest, 2 miles up Queets River Rd, RM 11.5.

Monitoring Site	County	WBID[1]	WRIA[2] Number	Latitude[3]	Longitude[3]	Description
Snohomish River	Snohomish	WA-07-1020	7	47.91080	-122.09920	Snohomish River at Snohomish, behind visitor's center, RM 12.5.
Spokane River at Idaho Border	Spokane	WA-57-1010	57	47.69483	-117.05133	Spokane River near the Idaho border, RM 96.
Spokane River at Nine Mile	Spokane	WA-54-1020	54	47.77470	-117.54440	Upstream side of Spokane River's Nine Mile Dam, RM 58.1.
Walla Walla River	Walla Walla	WA-32-1010	32	46.07090	-118.82680	Walla Walla River, about 5 miles east of Wallula Junction, RM 9, private property.
Wenatchee River	Chelan	WA-45-1010	45	47.50070	-120.42570	Wenatchee River, about 5 miles NW of Wenatchee, RM 7.1, near Old Monitor Rd. Bridge.
Yakima River	Benton	WA-37-1010	37	46.37830	-119.41810	Yakima River, 12 miles NW of Richland, RM 18.0. Diversion structure at Wanawish Dam.

[1]WBID: Waterbody Identification Number.
[2]WRIA: Water Resource Inventory Area.
[3]NAD83 HARN.
RM: River Mile.

Appendix B. Quality Assurance Data

The Quality Assurance (QA) Project Plan outlined the measurement quality objectives (MQOs) that the data must meet (Meredith and Furl, 2008).

Table B-1. Measurement Quality Objectives.

Analysis	Check Standards	Matrix Spikes (%recovery)	Field Replicates (RPD)	Lowest Concentration of Interest
Lead	± 15% LCS	70-130%	50%	1 mg/Kg dw

dw: dry weight.
RPD: Relative percent difference.

Laboratory QA tests consisted of matrix spikes, control samples, and method blanks. Tables B-2 through B-4 display results of laboratory QA samples.

Table B-2. Laboratory Matrix Spikes.

Sample Number	Analysis Date	Recovery (%)
1005036-13	5/12/2010	97
1006029-04	6/14/2010	94
1009064-11	9/28/2010	100
1010023-04	10/20/2010	101

Table B-3. Laboratory Control Samples.

Sample Number	Analysis Date	Recovery (%)
B10E064-BS1	5/12/2010	98
B10F139-BS1	6/14/2010	95
B10F139-BS2	6/14/2010	91
B10I217-BS1	9/28/2010	99
B10J113-BS1	10/20/2010	101

Table B-4. Laboratory Blanks.

Sample Number	Analysis Date	Result (ug)
B10E064-BLK1	5/12/2010	0.05 U
B10F139-BLK1	6/15/2010	0.05 U
B10F139-BLK2	6/14/2010	0.05 U
B10I217-BLK1	9/28/2010	0.05 U
B10J113-BLK1	10/20/2010	0.05 U

U: Not detected at or above the reported value.

Field QA tests included field replicates and field blanks. Results of field QA tests are presented in Tables B-5 and B-6.

Table B-5. Field Replicates.

Sample Number	Collection Date	Result (mg/Kg)	RPD (%)
1005036-11 Rep 1	4/28/2010	15.0	10.5
1005036-12 Rep 2	4/28/2010	16.7	
1006029-05 Rep 1	5/26/2010	7.3	72.1
1006029 -06 Rep 2	5/26/2010	15.6	
1009064-09 Rep 1	9/8/2010	20.9	2.7
1009064-10 Rep 2	9/8/2010	21.5	
1010023-02 Rep 1	9/29/2010	50.3	11.3
1010023-03 Rep 2	9/29/2010	56.4	

RPD: Relative percent difference.

Table B-6. Field Blanks.

Sample Number	Collection Date	Result (ug/filter)
1005036-09	4/28/2010	0.05 U
1006029-02	5/24/2010	0.05 U
1006029-13	5/26/2010	0.05 U
1009064-04	8/31/2010	**0.265**
1009064-13	9/8/2010	**0.1**
1010023-17	10/7/2010	0.05 U

U: Not detected at or above the reported value.
Bold: Detected values.

Appendix C. Sampling Results Data

Table C-1. Spring Sampling Results, 2010.

MEL ID	Waterbody	Date	Lead (mg/kg)	Lead (ug/L)	TSS (mg/L)	pH	Cond. (us/cm)	Temp. (ºC)
1005036-02	Columbia River at McNary Dam	4/27/2010	29.0	0.093	3	8.1	191	11.2
1006029-03	Columbia River at McNary Dam	5/26/2010	25.2	0.054	2	8.0	155	15.4
1005036-06	Columbia River at Rock Island Dam	4/27/2010	33.0	0.090	3	8.1	139	9.7
1006029-09	Columbia River at Rock Island Dam	5/25/2010	23.2	0.098	4	7.6	165	11.1
1005036-17	Columbia River, Lower	4/29/2010	12.8	0.216	17	8.5	161	11.2
1006029-18	Columbia River, Lower	5/27/2010	16.9	0.226	13	8.1	133	13.0
1005036-07	Columbia River, Upper	4/28/2010	136	0.329	2	8.1	129	8.9
1006029-10	Columbia River, Upper	5/27/2010	122	0.598	5	8.3	133	10.6
1005036-11	Duwamish River	4/28/2010	15.0	0.172	11	7.1	104	11.0
1006029-14	Duwamish River	5/26/2010	35.7	0.140	4	7.1	85	11.2
1005036-15	Hylebos Creek	4/28/2010	29.7	0.224	8	7.4	259	10.5
1006029-16	Hylebos Creek	5/26/2010	34.5	0.149	4	7.5	261	11.8
1005036-10	Lake Washington	4/28/2010	32.7	0.056	2	7.8	94	10.1
1006029-12	Lake Washington	5/26/2010	54.4	0.118	2	8.8	98	14.7
1005036-01	Okanogan River	4/26/2010	16.2	0.393	24	8.0	124	11.9
1006029-01	Okanogan River	5/24/2010	12.4	0.382	31	7.9	142	11.5
1005036-18	Queets River	4/30/2010	17.7	0.157	9	7.4	---	8.1
1006029-19	Queets River	5/28/2010	16.9	0.232	14	6.9	56	8.6
1005036-14	Snohomish River	4/28/2010	1 U	ND	3	7.0	33	8.8
1006029-15	Snohomish River	5/26/2010	17.5	0.109	6	7.1	31	10.0
1005036-16	Spokane River at Idaho Border	4/29/2010	1091	1.602	1	7.4	50	7.8
1006029-17	Spokane River at Idaho Border	5/27/2010	471	1.119	2	7.4	50	12.4
1005036-08	Spokane River at Nine Mile Dam	4/28/2010	338	0.902	3	7.5	92	8.8
1006029-11	Spokane River at Nine Mile Dam	5/27/2010	212	0.896	4	7.7	109	12.6
1005036-04	Walla Walla River	4/27/2010	15.4	0.220	14	7.8	134	15.0
1006029-07	Walla Walla River	5/26/2010	11.2	0.324	29	7.6	131	17.2
1005036-05	Wenatchee River	4/27/2010	12.3	0.081	7	7.9	48	8.0
1006029-08	Wenatchee River	5/25/2010	10.5	0.050	5	7.5	37	7.9
1005036-03	Yakima River	4/27/2010	15.9	0.410	26	7.6	173	12.6
1006029-05	Yakima River	5/26/2010	7.3 J	0.273 J	37	7.9	125	14.3

U: Not detected at or above the reported value. ND: Not detected in the original sample. J: Value is an estimate.

Table C-2. Fall Sampling Results, 2010.

MEL ID	Waterbody	Date	Lead (mg/kg)	Lead (ug/L)	TSS (mg/L)	pH	Cond. (us/cm)	Temp. (ºC)
1009064-09	Columbia River at McNary Dam	9/8/2010	20.9	0.057	3	8.1	143	22.0
1010023-10	Columbia River at McNary Dam	10/6/2010	44.0	0.059	1	7.8	207	20.4
1009064-02	Columbia River at Rock Island Dam	8/31/2010	62.2	0.110	2	7.6	130	17.8
1010023-02	Columbia River at Rock Island Dam	9/29/2010	50.3	0.054	1	7.7	129	20.1
1009064-08	Columbia River, Lower	9/8/2010	23.7	0.199	8	7.9	135	19.0
1010023-09	Columbia River, Lower	10/6/2010	25.7	0.100	4	7.7	140	17.9
1009064-19	Columbia River, Upper	9/8/2010	114	0.194	2	8.5	155	17.6
1010023-18	Columbia River, Upper	10/8/2010	135	0.101	1 U	8.3	147	15.0
1009064-07	Duwamish River	9/3/2010	17.1	0.163	9	7.3	123	15.4
1010023-08	Duwamish River	10/5/2010	19.8	0.109	5	7.0	95	13.7
1009064-05	Hylebos Creek	9/3/2010	32.9	0.421	13	7.6	283	13.1
1010023-06	Hylebos Creek	10/5/2010	39.1	0.150	4	7.3	315	11.6
1009064-15	Lake Washington	9/9/2010	55.5	0.058	1	7.7	101	18.4
1010023-13	Lake Washington	10/5/2010	1 U	ND	1 U	7.6	97	17.8
1009064-01	Okanogan River	8/30/2010	1 U	ND	1 U	8.2	285	18.9
1010023-01	Okanogan River	9/29/2010	21.2	0.057	3	8.5	237	18.8
1009064-16	Queets River	9/9/2010	19.8	0.056	3	7.8	74	14.0
1010023-14	Queets River	10/7/2010	21.0	0.087	4	7.2	59	11.1
1009064-06	Snohomish River	9/3/2010	18.7	0.187	10	7.3	34	14.2
1010023-07	Snohomish River	10/5/2010	19.3	0.060	3	6.8	45	13.5
1009064-18	Spokane River at Idaho Border	9/9/2010	536	0.728	1	8.3	63.7	18.9
1010023-16	Spokane River at Idaho Border	10/7/2010	1045	0.706	1 U	7.7	58	15.9
1009064-17	Spokane River at Nine Mile Dam	9/9/2010	239	0.712	3	7.9	286	13.3
1010023-15	Spokane River at Nine Mile Dam	10/7/2010	362	0.504	1	7.9	189	13.8
1009064-14	Walla Walla River	9/8/2010	13.1	0.041	3	9.0	276	18.2
1010023-12	Walla Walla River	10/6/2010	14.4	0.056	4	8.5	353	17.6
1009064-03	Wenatchee River	8/31/2010	56.4 J	0.087 J	2	7.7	63	13.7
1010023-05	Wenatchee River	9/30/2010	14.3	0.048	3	7.0	47	12.6
1009064-12	Yakima River	9/8/2010	1 U	ND	2	8.3	263	18.0
1010023-11	Yakima River	10/6/2010	9.5	0.031	3	8.3	310	14.2

U: Not detected at or above the reported value. ND: Not detected in the original sample. J: Value is an estimate.

Appendix D. Correlation Coefficients

Table D-1. Spearman Rank Correlation Coefficients for Relationships between Lead by Weight (mg/kg), Lead by Volume (ug/L), TSS, and Flow.

Bolded, shaded values are significant at the 95% confidence level. Negative values are in italics.

Waterbody	Lead (mg/kg) correlated with:			Lead (ug/L) correlated with:	
	Lead (ug/L)	Flow (cfs)	TSS (mg/L)	Flow (cfs)	TSS (mg/L)
Columbia River at McNary Dam	0.27	0.01	*-0.20*	0.58	**0.84**
Columbia River at Rock Island Dam	*-0.62*	***-0.73***	***-0.88***	**0.82**	**0.90**
Columbia River, Lower	*-0.21*	*-0.52*	*-0.52*	**0.78**	**0.89**
Columbia River, Upper	0.13	*-0.04*	*-0.33*	0.39	**0.84**
Duwamish River	*-0.46*	***-0.78***	***-0.89***	0.35	**0.77**
Hylebos Creek	0.28	---	*-0.09*	---	**0.89**
Lake Washington	0.29	---	*-0.15*	---	**0.86**
Okanogan River	***-0.83***	***-0.90***	***-0.90***	**0.95**	**0.95**
Queets River	***-0.66***	***-0.76***	***-0.70***	**0.79**	**0.99**
Snohomish River	***-0.68***	***-0.94***	***-0.88***	**0.66**	**0.88**
Spokane River at Idaho Border	0.24	0.34	*-0.17*	**0.94**	**0.78**
Spokane River at Nine Mile Dam	**0.76**	**0.73**	0.44	**0.89**	**0.90**
Walla Walla River	*-0.27*	*-0.45*	*-0.49*	**0.95**	**0.95**
Wenatchee River	*-0.19*	*-0.35*	*-0.40*	**0.89**	**0.92**
Yakima River	0.10	*-0.10*	*-0.19*	**0.88**	**0.93**

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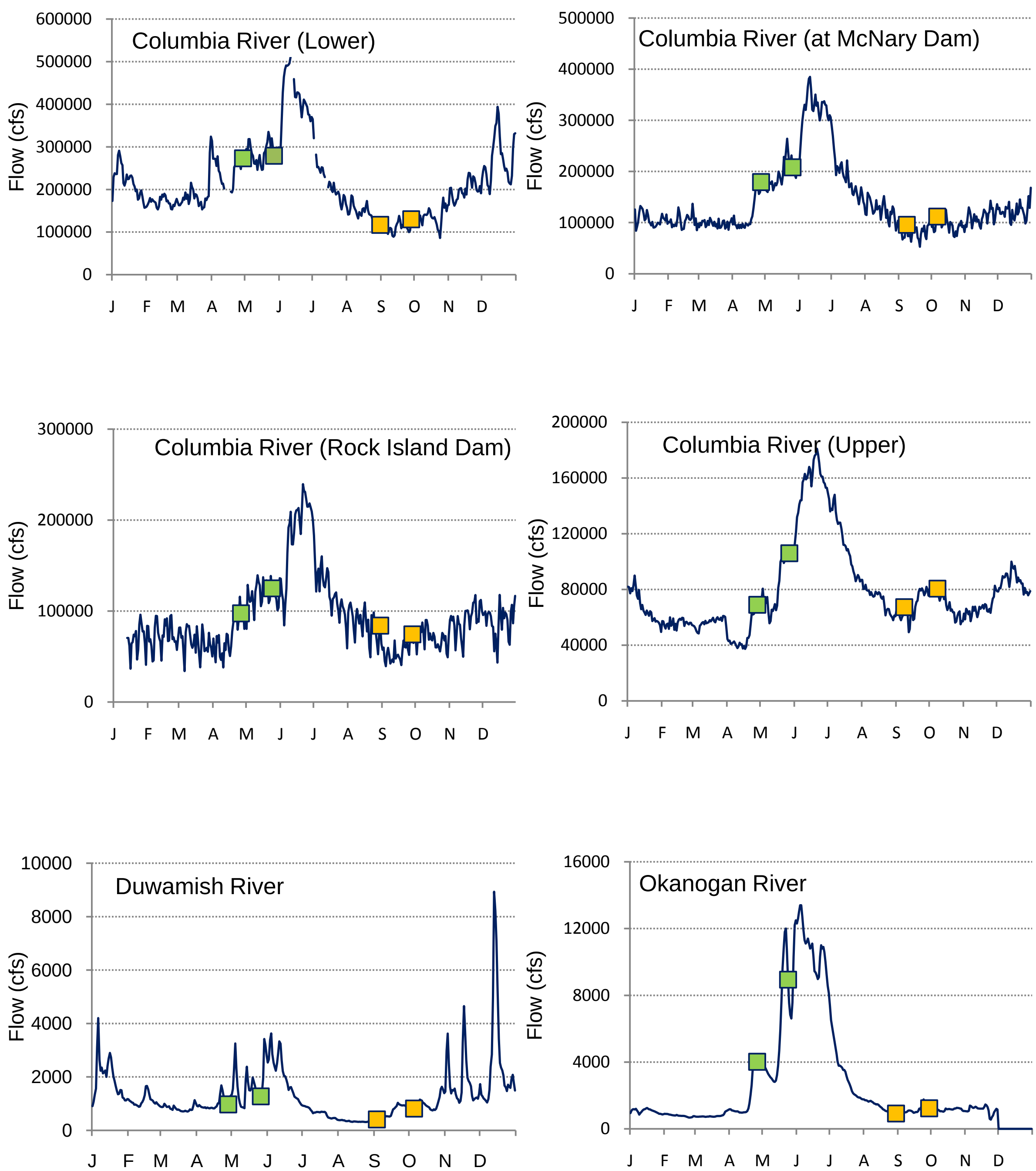
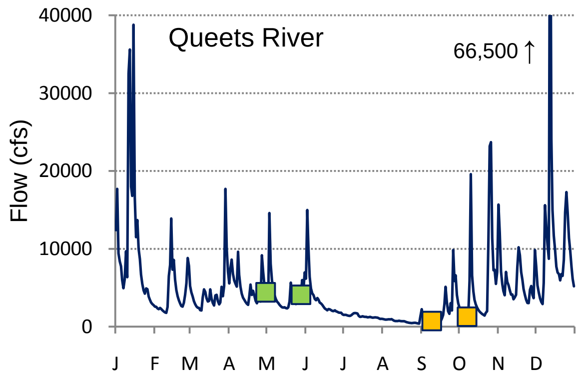
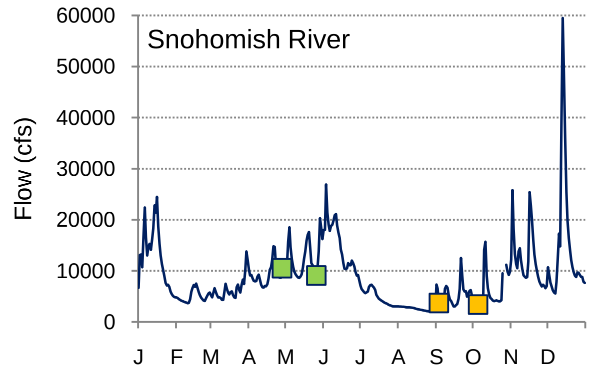
Appendix E. Flow Charts

Figure D-1. Flow Data and Sampling Dates for Lead in SPM Sampling, 2010.

Flow data were compiled from the USGS National Water Information System (retrieved from http://waterdata.usgs.gov/nwis on 1/26/2011) and the University of Washington's Columbia River Data Access in Real Time (retrieved from www.cbr.washington.edu/dart on 1/26/2011). Flow data were provisional at the time of data retrieval and are subject to change.




Queets River
66,500
Flow (cfs)
40000
30000
20000
10000
0
J F M A M J J A S O N D


Snohomish River
Flow (cfs)
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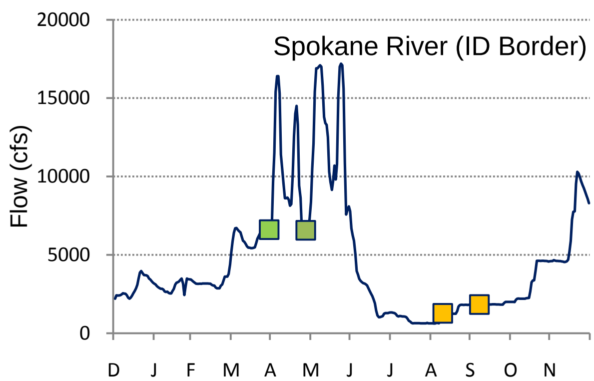
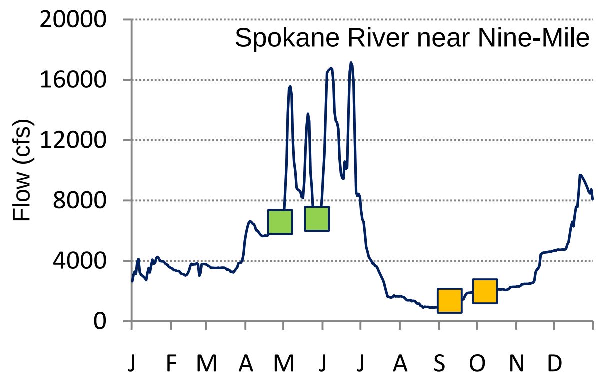
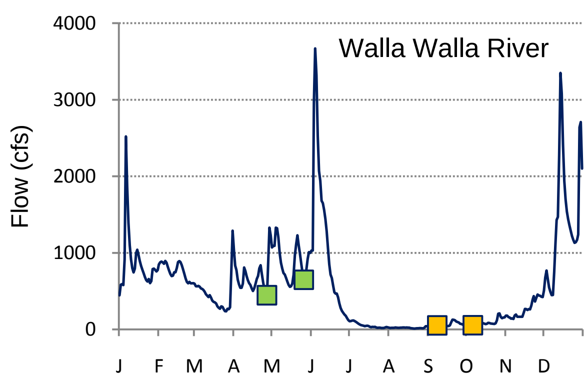
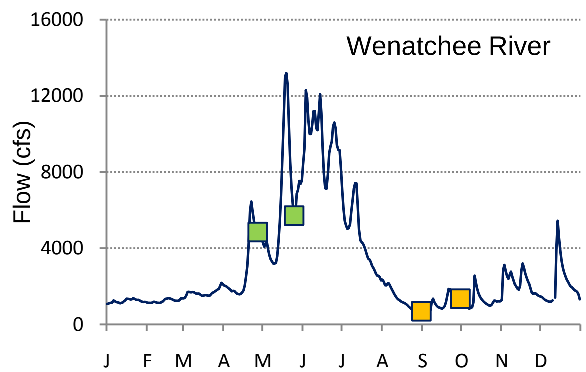
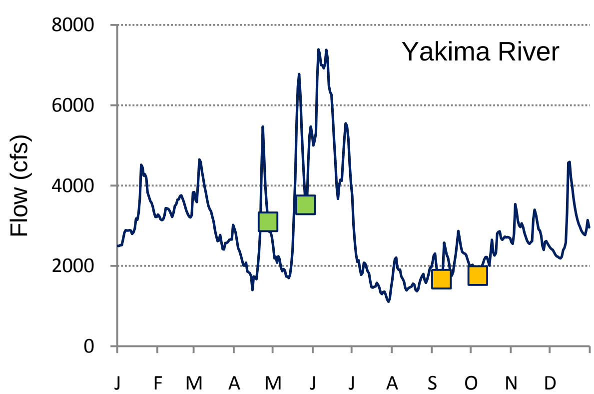
50000
40000
30000
20000
10000
0
J F M A M J J A S O N D


Spokane River (ID Border)
Flow (cfs)
20000
15000
10000
5000
0
D J F M A M J J A S O N


Spokane River near Nine-Mile
Flow (cfs)
20000
16000
12000
8000
4000
0
J F M A M J J A S O N D


Walla Walla River
Flow (cfs)
4000
3000
2000
1000
0
J F M A M J J A S O N D


Wenatchee River
Flow (cfs)
16000
12000
8000
4000
0
J F M A M J J A S O N D


Yakima River
Flow (cfs)
8000
6000
4000
2000
0
J F M A M J J A S O N D

Appendix F. Glossary, Acronyms, and Abbreviations

Glossary

Ambient: Background (environmental). Away from point sources of contamination.

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.

Hydrograph: A graph showing the discharge of a river over a period of time.

Persistent, bioaccumulative, toxic substance (PBT): A distinct group of chemicals that threaten the health of people and the environment. They (1) remain in the environment for a long time without breaking down (persist), (2) are accumulated by animals and humans and increase in concentration up the food chain (bioaccumulate), and (3) are linked to toxic effects in fish, wildlife, and humans (toxic).

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.

Spatial trends: How concentrations differ geographically.

Suspended particulate matter (SPM): Solids suspended in freshwater captured by filtration through a 0.45 µm filter membrane.

Temporal trends: Characterize trends over time.

Total suspended solids (TSS): The suspended particulate matter in a water sample as retained by a filter.

Acronyms and Abbreviations

Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
MEL	Manchester Environmental Laboratory
MQO	Measurement quality objective
Pb	Lead
PBT	Persistent, bioaccumulative, and toxic substance
RPD	Relative percent difference
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

°C	degrees centigrade
cfs	cubic feet per second
dw	dry weight
mg	milligrams
mg/Kg	milligrams per kilogram (parts per million)
mg/L	milligrams per liter (parts per million)
mL	milliliters
mm	millimeters
ug/L	micrograms per liter (parts per billion)
um	micrometer
uS/cm	microsiemens per centimeter, a unit of conductivity