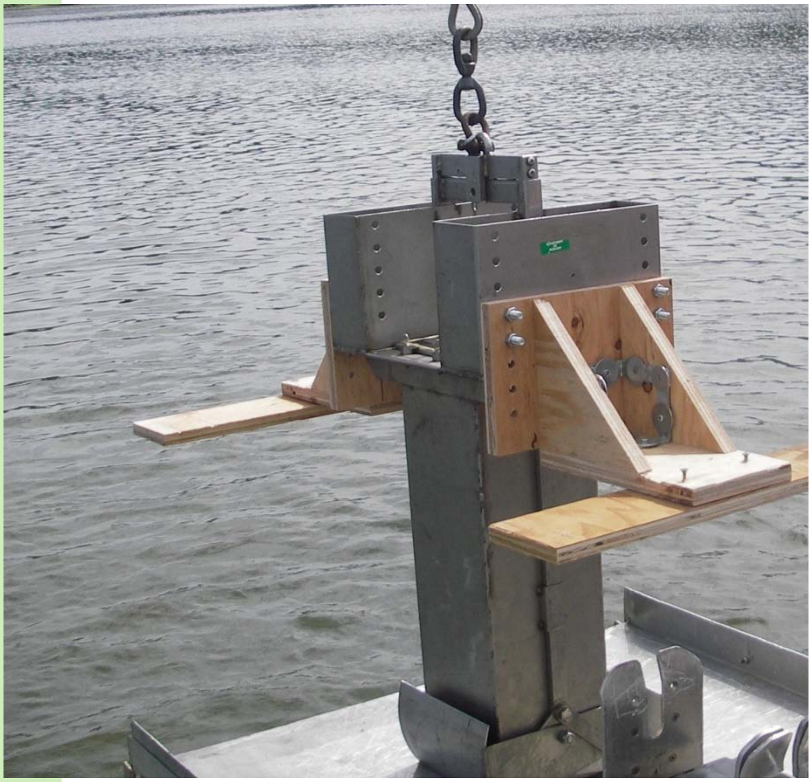

PBT Chemical Trends in Washington State Determined from Age-Dated Lake Sediment Cores

2010 Sampling Results

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Cover photo: Box corer (pictured at Lone Lake)

PBT Chemical Trends in Washington State Determined from Age-Dated Lake Sediment Cores

2010 Sampling Results

by

Chad Furl and Tanya Roberts

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

Waterbody Numbers:

Lone Lake - WA-06-9060
Sprague Lake - WA-34-9330
Lake Wenatchee - WA-45-9100

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Abstract

This report presents results from the fifth year of a monitoring program designed to evaluate contaminant trends in Washington State lakes using age-dated sediment cores. Since 2006, the Washington State Department of Ecology has collected deep sediment cores from 15 lakes throughout the state.

During the summer of 2010, cores were collected from Lake Wenatchee, Lone Lake, and Sprague Lake. Contaminants analyzed in the cores included mercury, lead, and polycyclic aromatic hydrocarbons (PAHs). Age-dating and sedimentation rates were estimated for the Lake Wenatchee core only.

- At Lake Wenatchee, contaminant concentrations have generally decreased since the mid 1900s. The exception is mercury where fluxes and concentrations were at their greatest around 2000. Modern concentrations of PAHs and lead fall within the range of values recorded in eastern Washington from previous years, while modern mercury fluxes are higher.

- Mercury concentrations have climbed consistently from the bottom of the Lone Lake core until leveling off over the top 10 cm. Lead concentrations followed a similar pattern except values appear to be declining over the top 10 cm. Erratic concentrations in the upper portion of the core obscured any existing PAH trends. PAH concentrations in Lone Lake were significantly elevated over the other two lakes.

- At Sprague Lake, concentrations of lead and mercury were both very low. The profiles for both contaminants have changed very little throughout the entire length of the core. PAH concentrations were found within the range of Lake Wenatchee and have shown a small decrease through approximately 20 cm where they level off.

Data from previous years of the project were collated, and recent contaminant trends were assessed by examining percent change from the 1990s - 2000s.

Acknowledgements

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Introduction

The Washington State Department of Ecology's (Ecology) Environmental Assessment Program (EAP) has conducted paleolimnological investigations of persistent, bioaccumulative, toxic chemicals (PBTs) in freshwater areas of Washington State since 2006. A single deep sediment core is collected from 3 lakes per year in order to reconstruct pollution histories. The goal of the project is to assess historical and current contaminant trends statewide through lake sediments. A complete project plan is described in detail by Coots (2006) and Meredith and Furl (2008).

Monitoring was initiated in response to Ecology's *Proposed Strategy to Continually Reduce Persistent, Bioaccumulative, Toxics in Washington State* (Gallagher, 2000). Since 2006, sediment cores have been analyzed from 12 lakes across Washington, with results presented in 4 reports (Furl, 2007; Furl, 2008; Furl et al., 2009; Furl and Roberts, 2010). In 2010, sediment cores were collected from Lake Wenatchee, Lone Lake, and Sprague Lake (Figure 1).

Contaminants measured in the 2010 cores are mercury, lead, and polycyclic aromatic hydrocarbons (PAHs). Each of these chemicals is included in the state's Persistent Bioaccumulative Toxins rule (WAC 173-333-110). Chemical action plans to protect human health and the environment have been prepared for mercury (Peele, 2003) and lead (Davies, 2009). A chemical action plan for PAHs is anticipated in 2011. Information on each of these contaminants including sources, environmental fate, and potential adverse effects can be found in the chemical action plans and in the 4 previous reports from this project.

Methods

Site Descriptions

Complete site selection criteria for study lakes are given in the Quality Assurance (QA) Project Plan (Coots, 2006). In the current study, Wenatchee, Lone, and Sprague lakes were selected primarily to provide broad coverage of the state in areas where sediment core data do not exist.

Figure 1 displays the coring position (●) in each lake. Table 1 provides general geographical and morphological information. A figure showing lake locations for all sediment cores through the first 5 years of the monitoring program can be found in Appendix B. Field sampling was conducted during the summer of 2010.

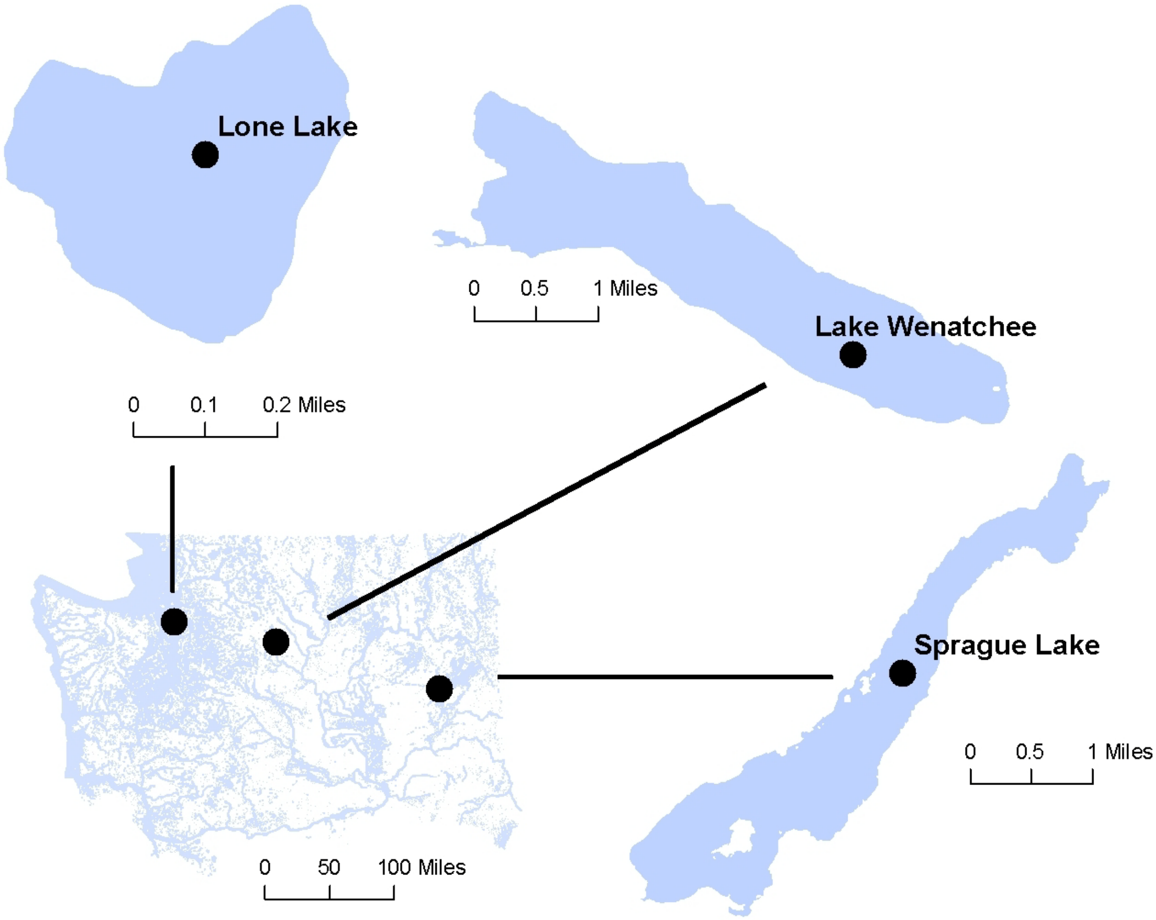

Figure 1. Sediment coring locations, 2010.

Table 1. Geographical and morphological information for study lakes, 2010.

Lake:	Lone	Sprague	Wenatchee
Surface Area (acre)	100	1,800	2,500
Drainage Area (acre)	1,792	184,320	174,720
Volume (acre-ft)	920	19,000	360,000
Coring Site Depth (ft)	17	17	68
Maximum Depth (ft)	17	20	240
Mean Depth (ft)	9	11	150
DA:SA Ratio[1]	18	102	70
Precipitation (in) [2]	28	14	34
Altitude (ft)	17	1,878	1,868
Coring Site Latitude/Longitude (dd)[3]	48.0214 / -122.4612	47.2656 / -118.0555	47.8127 / -120.7546
County	Whidbey	Adams/Lincoln	Chelan
Year Sampled	2010	2010	2010

[1] Drainage-area to surface-area ratio.
[2] 1984-2008 average. Precipitation data provided by PRISM www.prism.oregonstate.edu.
[3] NAD 83; decimal degrees.

Lone Lake

Lone lake is located on Whidbey Island, centered one mile from Highway 525 to the south, the Whidbey Airport to the east, and Lake Goss to the north. Two small inlet streams carry water into the lake, and it drains to Useless Bay on Puget Sound. At the last survey, residential development covered 28% of the lake shore area; land use in the drainage basin was mostly undeveloped (77%), with some agricultural (17%) and residential (<1%) use (Dion et al., 1976a).

Lone Lake falls within the Puget Lowlands, a level III eco-region spanning a continental glacial trough composed of many small islands, peninsulas, and bays covered in ground moraines, outwash plains, floodplains, and terraces in the Puget Sound region. It is characterized by a mild maritime climate and coniferous forests (USEPA, 2007).

Sprague Lake

Bordering Interstate 90, Sprague Lake lies between rural Adams and Lincoln Counties. Serving as the head of Cow Creek, a small dam at the lake outlet stabilizes lake water levels (Dion et al., 1976a). Land use in the lake basin was largely undeveloped (98%), with the majority (89%) used for agriculture as of the last known survey (Dion et al., 1976b).

Sprague Lake lies within the channeled scablands, a unique geological setting formed during the last ice age when massive floods scoured the region, leaving channelized formations of basalt and deposits of thick loess (USGS, 2006). The arid area is characterized by sagebrush steppe and grassland surrounded by moister, predominantly forested, mountainous regions (USEPA, 2007). Wheat fields dominate much of the landscape (USEPA, 2007).

Lake Wenatchee

Lake Wenatchee is located in an alpine region of the North Cascades, within both Chelan County and the Wenatchee National Forest. The area contains more glaciers than anywhere else in the contiguous U.S. (USEPA, 2007). The lake lies in a natural valley where it collects snowmelt and water from the White and the Little Wenatchee Rivers (Berg, 2004). The lake basin is largely undeveloped, with less than 1% of the drainage basin put to residential use (Dion et al., 1976). Highway 207 runs alongside the lake to the north. The Lake Wenatchee State airport, a small landing strip that serves approximately 600 planes per year, lies less than a mile from the lake (GCR, 2010).

Lake Wenatchee straddles the Leavenworth fault line, which runs east to north beneath the lake (Tabor et al., date unknown). The region contains sedimentary and metamorphic rock (USEPA, 2007), overlain with stony to bouldery sandy loams and rock outcrops (NRCS, 2010).

Field Methods

Sediment cores were collected from deep, flat areas of the lakes using a Wildco stainless steel box corer containing a 13 cm x 13 cm x 50 cm acrylic liner. Collection efforts were guided by EAP's standard operating procedure for *Collection of Freshwater Sediment Core Samples Using a Box or KB Corer* (Furl and Meredith, 2008). Cores were determined suitable for subsampling if the sediment-water interface was intact and the core was adequately deep (approximately 35 - 45 cm). Overlying water was siphoned off the top of the core, and 1 cm sections were removed using an extruding device.

Surface sediments for grain size analysis were collected at each coring location (within 3 meters) using a stainless steel Ponar grab. Sampling was conducted in accordance with EAP's standard operating procedure for *Freshwater Sediment Sampling* (Blakley, 2008). Sediment grabs were kept if the sediment-water interface was preserved. Overlying water was siphoned off and the top 2 cm of the sediments removed using a stainless steel spoon.

The corer, Ponar grab, and all equipment coming into contact with sediments were cleaned prior to sampling using the following procedure: Liquinox detergent and hot water wash, nitric acid rinse, de-ionized water rinse, and acetone rinse. The equipment was air dried and wrapped in foil until used in the field. The cleaning procedure was followed between lakes. If an initial core or grab proved unsuitable, the sampling equipment was washed with ambient lake water between samples.

Each core section and surface sediment grab sample was placed in a uniquely labeled 8-oz. I-Chem jar with a Teflon-lined lid. Samples were placed in plastic bags and put on ice in coolers until transport to Ecology headquarters. Core samples remained in coolers for no more than 48 hours before being frozen at Ecology headquarters at -20° C. Grab samples were stored at 4° C until undergoing grain-size analysis.

Sample Preparation and Analysis

Sediment core samples were processed at Ecology headquarters by homogenizing individual 1-cm horizons until the sediments were uniform in color and texture. Sub-samples were taken from the sediment homogenate and placed in the 4-oz. I-Chem jars with Teflon-lined lids for chemical analysis. All chemical analyses conducted on the sediment cores were performed on 1-cm intervals. Appendix C includes detailed information on the chemical analyses performed for each core and their results. Table 2 provides information on sample preparation and analysis.

Table 2. Sample preparation and analysis.

Analyte	Number of samples	Method	Method citation	Laboratory
Mercury	45	CVAA	EPA 245.5	MEL
Lead	45	ICP-MS	EPA 200.8	MEL
PAHs	30	GC/MS SIM	EPA 8270	MEL
Total Organic Carbon	30	Acidification followed by CO_2 measurement	PSEP - EPA, 1986	MEL
Grain size	3	Sieve and pipet	PSEP - EPA, 1986	CAS
^{210}Pb	45	Gas proportional counting	RL-GPC-011	Test America

CVAA: Cold vapor atomic absorption.
ICP-MS: Inductively coupled plasma/mass spectrometry.
GC/MS SIM: Gas chromatography/mass spectrometry single ion monitoring.
CO_2: Carbon dioxide.
EPA: U.S. Environmental Protection Agency.
PSEP: Puget Sound Estuary Program.
RL-GPC: Gas proportional counting.
MEL: Manchester Environmental Laboratory.
CAS: Columbia Analytical Services.

Data Quality

Ecology's Manchester Environmental Laboratory (MEL) prepared case narratives describing the quality of the analytical data. The narratives include a description of results, laboratory quality assurance data, and any special issues encountered during analysis. Case narratives are available upon request.

Brief descriptions of quality assurance results for each analyte are included below. Appendix D contains full results of the measurement quality objectives (MQOs) outlined in the QAPP.

Mercury and Lead

Mercury and lead samples were analyzed in 3 batches each. Quality control for each batch included a method blank, laboratory control sample (LCS), matrix spike, and matrix spike duplicate.

All blanks were below detection limits (<0.0050 mg/kg for mercury and 0.10 and 0.05 mg/kg for lead).

For mercury, LCS recoveries averaged 86% and matrix spike recoveries averaged 85%, with average duplicate precision of 1.7%.

For lead, LCS recoveries averaged 99% and matrix spike recoveries averaged 93%, with average duplicate precision of 2%. Standard reference materials were analyzed with 2 of the batches, with recoveries averaging 96%.

PAHs

PAH samples were analyzed in 2 batches. Quality control samples for each batch consisted of a method blank, LCS, matrix spike, matrix spike duplicate, standard reference material, and surrogate spikes (every sample). Instances where MQOs were violated include:

- Surrogate recoveries were outside of limits in 2 instances: naphthalene in a blank sample (B10H303) and benzo(a)pyrene-D12 in sample 1004078-63. The associated benzo(a)pyrene result was qualified as an estimate.
- Retene and chrysene failed to meet calibration criteria in several samples, and results were qualified as estimates.
- Several compounds were detected in method blanks, but native concentrations were 3 times or greater than those in associated method blanks, thus no qualifications were made.
- Matrix spike recoveries were within the MQOs, with the exception of dibenzofuran and carbazole (1007048-35), which were J qualified. Relative percent differences (RPDs) between matrix spike duplicates were within the MQOs for all analytes, with averages of 6 and 15%.
- LCS recoveries ranged between 42 and 160%, with several analytes exceeding the recovery limits (65-135%). No samples were qualified due to reference recoveries.

Total Organic Carbon

MEL analyzed 30 samples for total organic carbon. Quality control consisted of blanks, LCS, and duplicates. All method blanks were non-detects at 0.1%. The RPD between duplicates averaged < 3%. Control sample recoveries averaged > 91%.

Lead - 210

While the data generally met MQOs, several issues were encountered with Lead - 210 (^{210}Pb) analysis of sediments from Sprague and Lone Lakes due to low sediment density in the samples. Traditional gamma analysis resulted in elevated detection limits and numerous non-detects at the 2 lakes. Samples were reanalyzed by an extraction chromatography method and counted using gas flow proportional detectors resulting in lower detection limits.

Data quality tests consisted of one method blank and one LCS per batch. Lab duplicates were performed for 2 of the 3 batches. Insufficient sample volumes prevented a duplicate analysis for Lone Lake samples. Laboratory duplicates fell outside the acceptable range (<30%), at 37% (Sprague Lake) and 51% (Lake Wenatchee). Laboratory method blanks and control sample recoveries fell within the MQOs, with the exception of the LCS for Lone Lake (135%).

Data Processing

Sedimentation Calculations

The constant rate of supply (CRS) model was applied to the ^{210}Pb measurements to estimate dates and varying sedimentation rates throughout the core (Appleby and Oldfield, 1978). The model works by measuring the difference in supported and unsupported ^{210}Pb in sediment horizons. Supported ^{210}Pb is represented by the small amount of the precursor gas ^{222}Rn that is captured in soils. Unsupported ^{210}Pb represents atmospherically deposited ^{210}Pb resulting from the decay of ^{222}Rn that escapes into the atmosphere and is estimated by subtracting supported ^{210}Pb from total ^{210}Pb. Using the known half-life (22.3 years) of ^{210}Pb and the amount of the unsupported isotope, the rate of sedimentation and the date of formation can be calculated for approximately the last 150 years (Van Metre et al., 2004).

Supported ^{210}Pb present in the study cores was estimated as the amount present at deep intervals where it appeared to no longer decline. Sediment dry mass (g/cm^2) was calculated from percent solids data obtained from total lead and mercury measurements made at MEL. Estimates on percent solids were extrapolated where data did not exist. An assumed sediment density of 2.7 g/cm^3 was used based on other Washington State coring studies (Paulson, 2004).

Mercury Flux Calculations

Mercury flux rates (ug/m^2/yr) were calculated as the product of sediment mass accumulation rates and dry weight mercury concentrations. Mercury flux rate results are used to estimate net deposition to the lake. Flux rates normalize the variance involved with interpreting dry weight concentrations under varying sedimentation rates.

Enrichment Factors

Enrichment factors were calculated for the contaminants by dividing concentrations in the interval of interest by the baseline value. Baseline estimates were calculated by taking the average of the lowest contaminant values at the bottom of the core where concentrations were stable. The enrichment factor is a unitless value describing the amount concentrations have increased/decreased from the baseline.

PAH Data Processing

Summing procedures were conducted according to the Washington State Sediment Management Standards rule (Washington State Department of Ecology, 1995). Only detected concentrations were included in total PAH sums. When no PAHs were detected in a sample, the single highest detection limit, appropriately qualified, represented the total.

Statewide Trends Assessment

Lead-210 profiles from all previous years were reconstructed to confirm the original dating interpretation. This reanalysis resulted in a few minor changes from results previously reported. To examine modern trends, changes in contaminant concentrations from the 1990s (1990-2000) to the 2000s (2000-2010) were examined by calculating percent change of the decadal averages. Changes greater than 25% were recorded as an increasing/decreasing trend.

Results and Discussion

Core Dating

Lead-210 concentrations plotted against depth are shown in Figure 2.

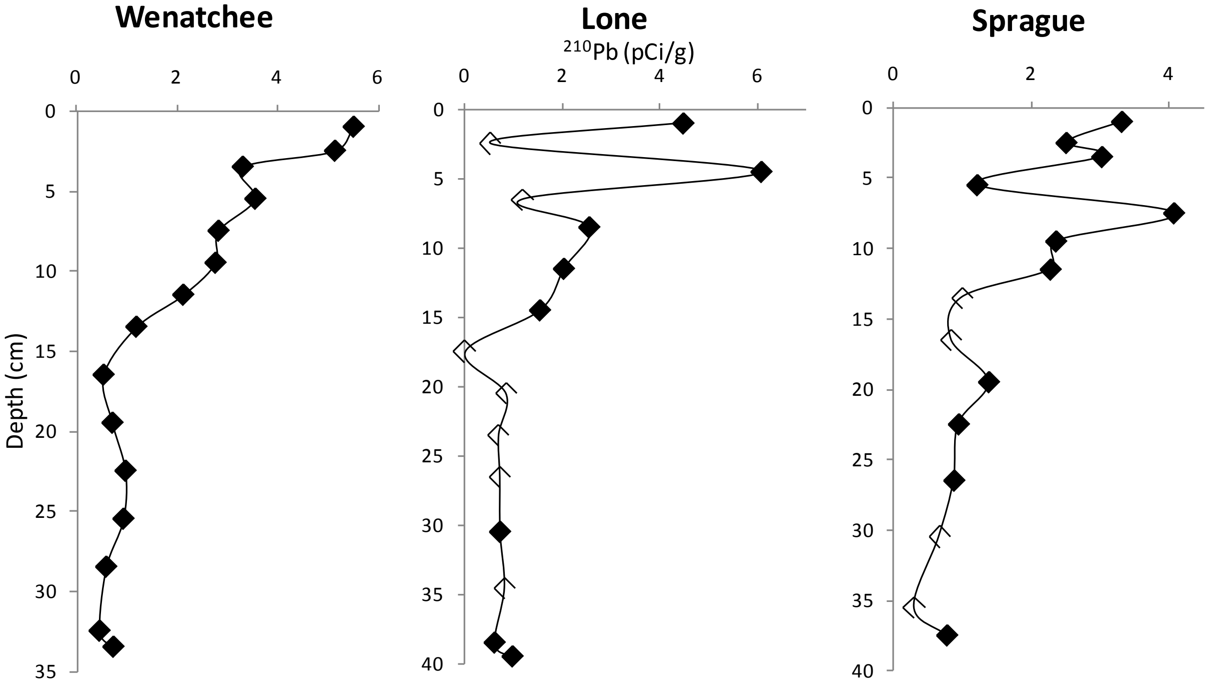

Figure 2. ^{210}Pb activity in sediment cores.

Unfilled markers indicated activity was not detected above concentration shown.

Lead-210 activity in the Lake Wenatchee core showed a monotonic decline from top to bottom with the exception of a slightly lower than expected value at 3.5 cm. Supported ^{210}Pb values were estimated at 0.71 (pCi/g). Inventories of unsupported ^{210}Pb were 9.15 pCi/cm^2, which is equivalent to a yearly unsupported flux of 0.28 pCi/cm^2/yr.

The Lone Lake core displayed an erratic pattern in the upper portion (top 7 cm) of the core with concentrations in adjacent horizons varying widely. Lead-210 activities from 8 - 15 cm (n = 3) declined monotonically before reaching supported ^{210}Pb. The core appears mixed in the upper portion and was deemed unacceptable for dating with the CRS model. Dates were applied to the core based on total lead concentrations (see below): however, very large amounts of error are likely associated with this method.

Similar to Lone Lake, the Sprague Lake core contained widely varying ^{210}Pb concentrations in the upper portion of the core. Applying the CRS model, sedimentation rates changed about an order of magnitude over a few years (between 5.5 cm and 7.5 cm). With those 2 data points removed, the model produced unrealistically high sedimentation rates for Sprague Lake (> 0.15 g/cm^2/yr). Therefore, no dates were applied to the core.

Sedimentation Rates

Sedimentation rates for Lake Wenatchee and Lone Lake are shown in Figure 3.

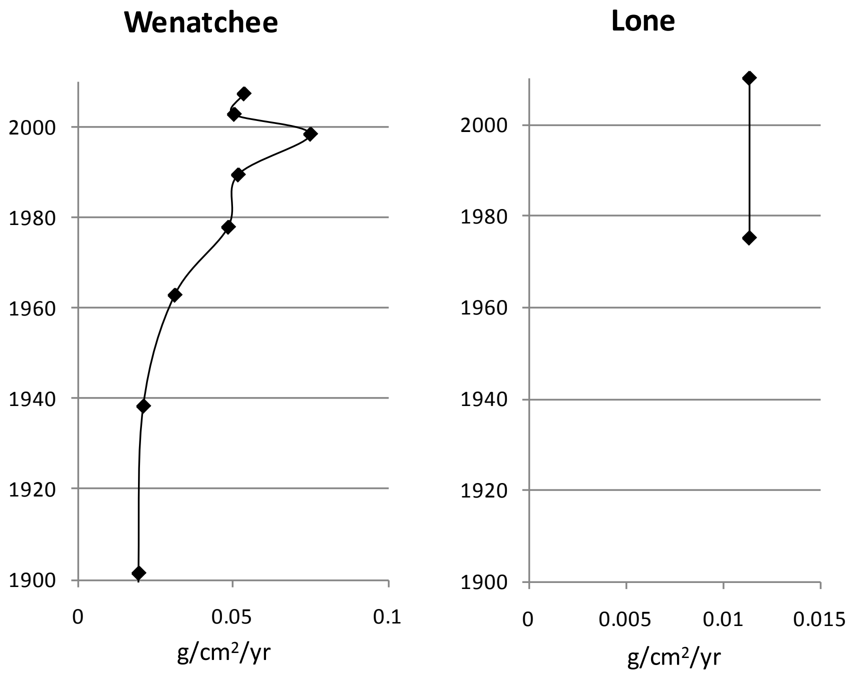

Figure 3. Sedimentation rates estimate at Lake Wenatchee and Lone Lake.

Sedimentation rates at Lake Wenatchee began to rise modestly above background levels during the 1940s. Since the late 1970s sedimentation rates have remained fairly constant at around 0.05 g/cm^2/yr with the exception of a brief period of increased levels during the late 1990s.

An estimated sedimentation rate of 0.0113 g/cm^2/yr was calculated at Lone Lake by dividing cumulative dry mass of sediment up to the peak lead concentration (≈ horizon 9-10) by 35 (years since approximate phase out of leaded gasoline - 1975). The core did not go deep enough to assign a date to the first appearance of elevated lead levels (≈ 1920). The same method could not be used at Sprague Lake due to the homogeneity of the lead profile.

Total Organic Carbon and Grain Size

Total organic carbon (TOC) concentrations in sediment intervals ranged from 1.99 - 27.8%. Average concentrations were 2.9%, 25.6%, and 4.9% at Wenatchee, Lone, and Sprague Lakes, respectively. Concentrations generally declined from top to bottom at Wenatchee and Sprague Lakes. At Lone Lake, TOC concentrations were highest at the bottom of the core. Within each of the cores, concentrations varied little. Results are included in Appendix C.

Percent fines (clay + silt) in grab samples taken near the coring site were 97%, 23%, 99% at Wenatchee, Lone, and Sprague Lakes, respectively

Contaminant Profiles

Mercury

Figure 4 displays mercury flux and dry weight concentration profiles for the lakes. Results are summarized in Table 3.

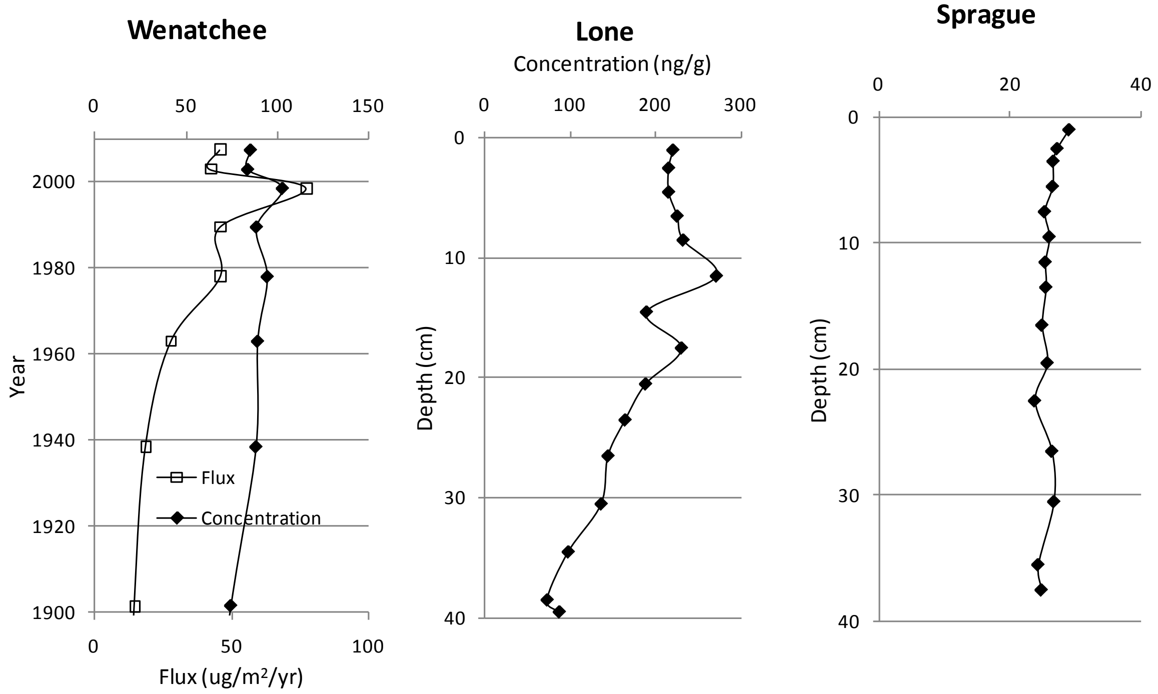

Figure 4. Mercury concentrations (ug/kg) and fluxes (ug/m^2/yr - Wenatchee only) in sediment cores.

Note differing y axes.

Table 3. Mercury concentrations and enrichment results.

Lake	Range (ng/g)	Baseline[1] (ng/g)	Peak Enrichment	Modern Enrichment
Wenatchee	36.4 - 103	36.8 (3)	2.8	2.3
Lone	72.7 - 232	79.8 (2)	3.4	2.7
Sprague	23.8 - 29	24.5 (2)	1.2	1.2

[1] Indicates number of samples used in average.

Mercury concentrations have remained fairly constant at Lake Wenatchee throughout the 1900s ranging from 75 - 103 ug/kg. The exception was a slight increase in concentrations in the late 1990s coinciding with the maximum sedimentation rate. Modern and peak enrichment factors at the lake were 2.3 and 2.8 respectively.

Flux patterns at Lake Wenatchee followed a similar pattern to the sedimentation profile due to the constancy of the concentration profile. Fluxes have remained fairly stable since the late 1970s at about 45 ug/m^2/yr with the exception of the peak flux in the late 1990s (77 ug/m^2/yr).

Mercury concentrations at Lone Lake were elevated over the other cores, ranging from 73 - 271 ug/kg. Concentrations climbed consistently until the top 10 cm (≈ 1975) where they have remained fairly stable. This may be indicative of mixing in the upper portion of the core which was suggested by the ^{210}Pb data. Peak and modern enrichment factors were 3.4 and 2.7. These are not true enrichment factors since real baseline values were likely not reached. Peak and modern enrichment factors are likely higher.

Flux profiles in the top 10 cm of the Lone Lake core (since 1975) followed the same pattern as the concentration profile since a single sedimentation rate was used. Values varied little and ranged from 24 - 26 ug/m^2/yr.

Concentrations in the Sprague Lake core were low compared to the other study lakes. Mercury concentrations in the core showed surprisingly little variance (24 - 29 ug/kg). Peak and modern enrichment factors were 1.2.

Lead

Figure 5 displays lead concentration profiles for the 3 study lakes. Results are summarized in Table 4.

Table 4. Lead concentrations and enrichment results.

Lake	Range	Baseline[1]	Peak Enrichment	Modern Enrichment
	(mg/Kg)	(mg/Kg)		
Wenatchee	4.8 - 14.4	4.9 (2)	3.0	1.8
Lone	13.7 - 56.8	13.7 (1)	4.2	3.8
Sprague	7.8 - 9.1	-	-	-

[1] Indicates number of samples used in average.

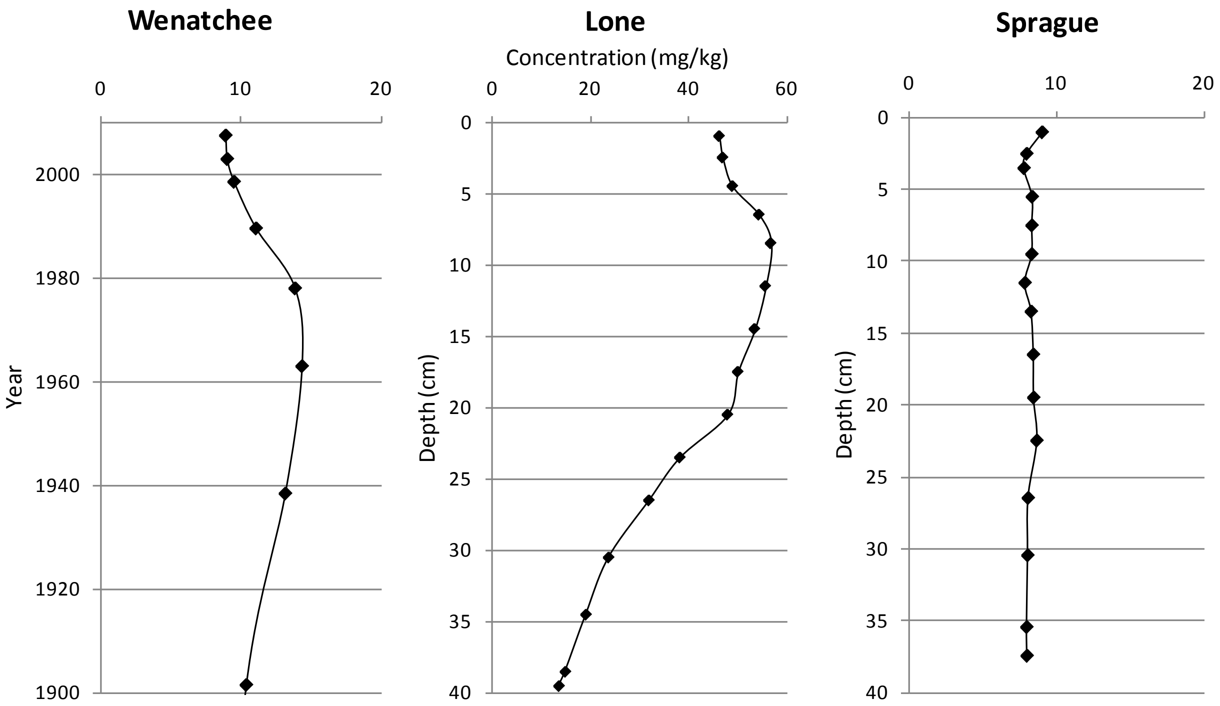

Figure 5. Lead concentrations (mg/kg) in sediment cores.

Note differing y axes.

At Lake Wenatchee, the ^{210}Pb dates applied to the core indicated peak concentrations in stable lead occurred during the 1970s, adding confidence to the dates created by the model. Lead concentrations remained low (< 15 mg/kg) throughout the 1900s, experiencing only modest increases during the middle part of the century. Values have continually decreased since peaking and are currently less than 10 mg/kg. Peak enrichment factors were about 3, and modern concentrations are approximately 1.8.

Dates for the Lone Lake sediment core were constructed using this profile, with the date 1975 placed at a depth of 9.5 cm. Throughout the core, concentrations ranged from 13.7 - 55.7 mg/kg. Concentrations steadily increased from baseline values until reaching the maximum. Since 1975, concentrations have realized modest declines and are currently less than 50 mg/kg. Peak and modern enrichment factors are 3.4 and 4.2 respectively. As with mercury, this is likely not a true baseline value since we believe the core did not extend into pre-industrial times.

Lead concentrations in the Sprague Lake core were very low and experienced little variance. All 15 lead measurements were within a very tight range of 7.81 - 9.07. This narrow range in lead concentrations is surprising given the lake's location adjacent to Interstate-90.

PAHs

Figure 6 displays total PAH profiles for the 3 study lakes. Results are summarized in Table 5.

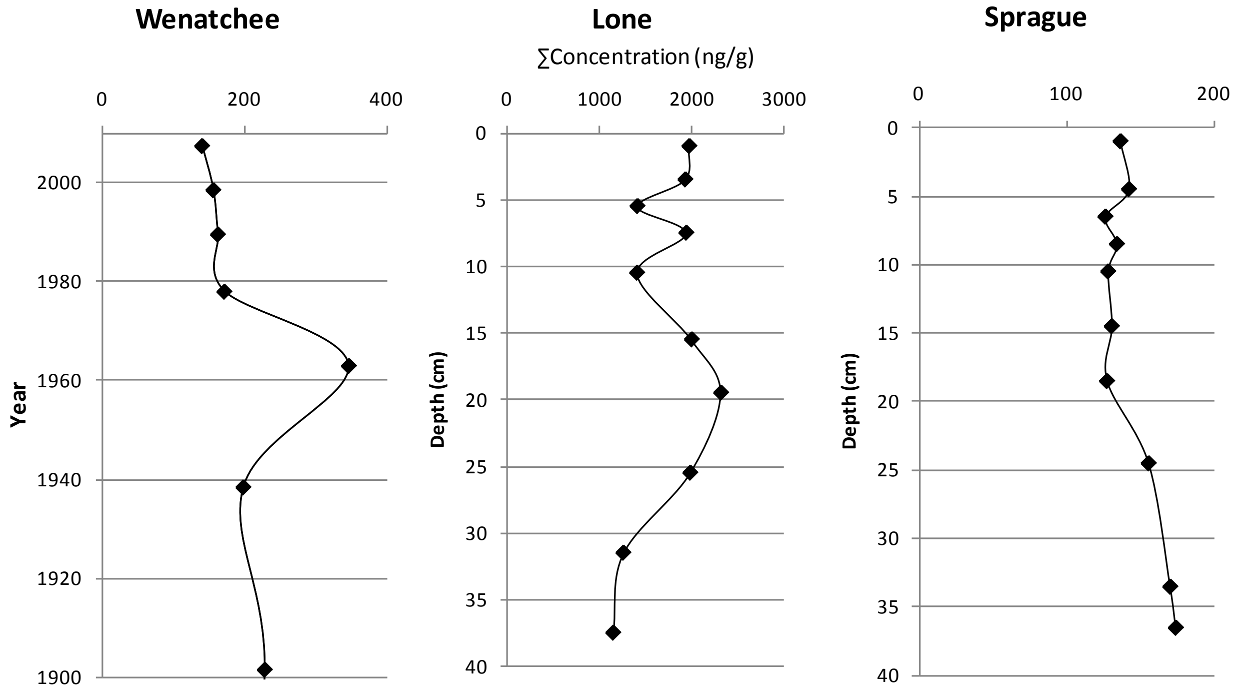

Figure 6. Total PAH concentrations (ng/g) in sediment cores.
Note differing y axes

Table 5. PAH concentrations and enrichment results.

Lake	Range	Baseline[1]	Peak Enrichment	Modern Enrichment
	(ng/g)	(∑ ng/g)		
Wenatchee	49.7 - 228.7	49.7 (1)	7.0	2.8
Lone	1151.1 - 2317.5	1151.1 (1)	2.0	1.7
Sprague	128.5 - 173.8	-	-	-

[1] Indicates number of samples used in average.

Total PAH concentrations at Lake Wenatchee ranged from 50 - 347 ng/g with the lowest concentrations occurring deep within the core (prior to 1900). Concentrations were moderately elevated by 1900 and have steadily decreased with the exception of an anomalous value around 1960. The 1960 interval represented the maximum concentration in the core and was approximately 7 times the baseline values. Current concentrations (140 ng/g) in the 0-2 cm horizon are approximately 2.8 times the baseline value.

PAH concentrations at Lone Lake were significantly elevated over the other study lakes. The minimum concentrations, in the 2 deepest intervals, measured over 1,000 ng/g. The maximum concentration of 2318 ng/g, approximately double the lowest value, appeared in the 19-20 cm horizon. Values in the upper reach of the core decreased slightly, and the modern enrichment factor is 1.7.

At Sprague Lake concentrations were within the range found at Lake Wenatchee. Values show a decreasing trend through approximately 20 cm. Since then they have remained fairly constant, ranging from 127 - 142 ng/g.

Normalized PAH Values

Figure 7 shows PAH concentration profiles at the 3 lakes normalized to TOC (ng/g/%OC).

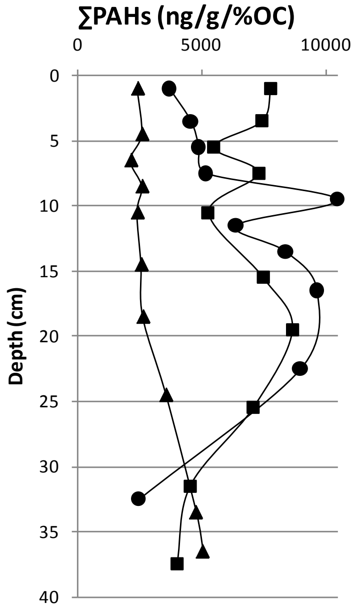

Figure 7. TOC normalized PAH profiles.

(■ - Lone, ▲ - Sprague, ● - Wenatchee)

Normalized concentrations in the top 5 cm of the core (n = 2 at all lakes) were greatest at Lone (≈ 7,600) > Wenatchee (≈ 4,100) > Sprague (≈ 2,500) (ng/g/%OC). Normalized concentration profiles at all 3 lakes appeared similar to non-normalized values (ng/g) due to the homogeneity of the TOC values throughout the cores.

PAH Sources

Several parent PAH ratios have been proposed to discriminate between sources in environmental samples (Yunker et al., 2002; Budzinski et al., 1997). A ratio using fluoranthene and pyrene has been used to distinguish between petroleum, petroleum combustion, and grass, wood, and coal combustion. Yunker et al. (2002) propose a fluoranthene / (fluoranthene + pyrene) (Fl/(Fl + Py)) ratio of 0.40 as the petroleum/combustion transition point. Additionally, Yunker et al. (2002) propose ratios between 0.40 - 0.50 to represent liquid fossil fuel combustion, whereas values greater than 0.50 are characteristic of grass, wood, or coal combustion.

A ratio using anthracene (An) and phenanthrene (Pn) has also been suggested to distinguish between petroleum and combustion derived PAHs. An/(An + Pn) ratios <0.10 usually indicates petroleum, and >0.10 indicate a dominance of combustion, although some high temperature processes are indistinguishable such as in the formation of creosote compared with coal tar or coal combustion (Yunker et al., 2002).

Both ratios throughout each of the cores are shown in Figures 8 and 9.

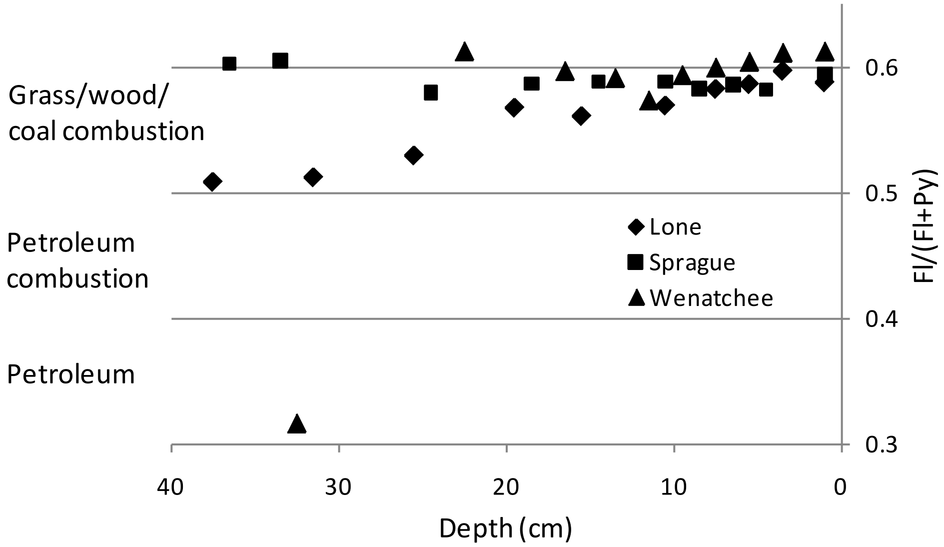

Figure 8. Fluoranthene/ (fluoranthene+pyrene) PAH ratio.

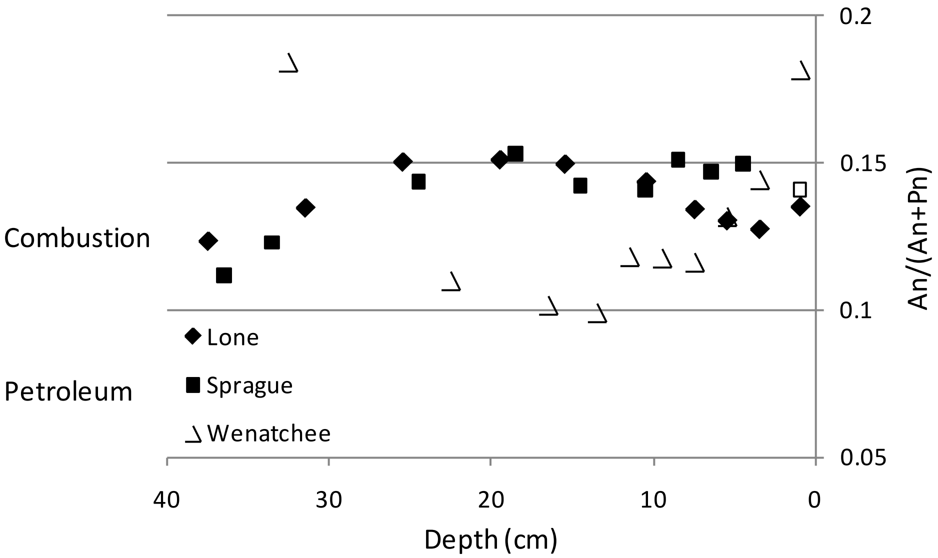

Figure 9. Anthracene / (anthracene + phenanthrene) PAH ratio.

Unfilled symbols represent non-detects used in calculations.

With the exception of the oldest interval in the Lake Wenatchee core, all Fl/(Fl + Py) ratios are greater than 0.5 suggesting grass/wood/coal combustion products are the dominate sources at the lakes. Fl/(Fl+Py) ratios at Sprague and Wenatchee Lakes have generally remained steady at 0.6 throughout the entirety of the cores. This may reflect forest fires or agricultural burning practices which were common in eastern Washington during the 1900s (Jimenez, 2002). Ratios at Lone Lake show an increasing trend from 0.5 to 0.6 near the surface of the core.

The An/(An+Pn) ratio agreed with the Fl/(Fl + Py) ratio in that all values fell within the combustion zone. Ratios at Lake Wenatchee could not be calculated since anthracene values were below detection limits in all instances.

Statewide Trends

Table 6 shows sedimentation rate estimates from the 12 cores where the constant rate of supply model was applied. Peak sedimentation rates tended to be higher in western Washington.

Table 6. Sedimentation rates estimated from sediment cores, 2006 - 2010.

Lake	Sedimentation Range ($g/cm^2/yr$)	Peak Year	Location
American	0.005 - 0.034	2004	W
Lacamas	0.011 - 0.067	1969	
Offutt	0.009 - 0.038	2001	
Washington	0.018 - 0.112	1977	
Ozette	0.040 - 0.118	2004	
Sammamish	0.019 - 0.066	1934	
St. Clair	0.017 - 0.122	1976	
Wenatchee	0.020 - 0.075	1999	E
Black	0.014 - 0.0411	1974	
Upper Twin	0.020 - 0.092	1969	
Loon	0.009 - 0.024	1993	
Wannacut	0.018 - 0.032	1954	

Mercury

Since 2006, Ecology has collected sediment cores from 15 lakes statewide. Table 7 contains information about mercury fluxes (not adjusted to unsupported ^{210}Pb fluxes) from 12 of these lakes where dates could be applied to the cores (n=12). Dates could not be applied to sediment cores from Walupt (2007), Sprague, or Lone (2010) lakes.

Table 7. Mercury fluxes and recent trends in sediment cores, 2006 - 2010.

Lake	Flux Range ($ug/cm^2/yr$)	Peak Year	Average Flux 2000 - 2010 ($ug/cm^2/yr$)	n	Location	1990s - 2000s Trend
American	4 - 110	1969	23.1	4	Western WA	decrease
Lacamas	13 - 124	1979	75.3	5		no change
Offutt	5 - 76	1998	69	3		no change
Washington	12 - 378	1957	144.4	4		no change
Ozette	37 - 268	1997	218	2		no change
Sammamish	18 - 269	1934	92.8	3		no change
St. Clair	17 - 270	1975	213.5	2		increase
Wenatchee	7 - 77	1999	44	2	Eastern WA	decrease
Black	12 - 96	1969	25.3	2		decrease
Upper Twin	8 - 46	1969	22.9	5		no change
Loon	2 - 22	1995	15.1	1		decrease
Wannacut	1 - 506	1950	12	1		decrease

Peak and modern mercury fluxes are higher in western Washington compared to eastern Washington. With the exception of Wannacut Lake (which was affected by mining operations in the drainage), peak fluxes have remained under 100 ug/cm^2/yr at lakes east of the cascades. Modern fluxes in eastern Washington ranged from 12 - 44 ug/cm^2/yr, averaging 23.9 ug/cm^2/yr.

Peak fluxes in western Washington lakes ranged from 76 - 378 ug/cm^2/yr. The timing of peak fluxes in western Washington waterbodies generally occurred in the middle part of the 1900s with the exception of Offutt and Ozette. The sediment core data from Offutt and Ozette are examined in greater detail in Furl and Meredith (2010) and Furl et al. (2010). In both instances it was suggested local factors (coal-fired power plant deposition and clearcut logging, respectively), not inherent to all of western Washington, have affected modern fluxes.

Average modern fluxes in western Washington ranged from 69-218 ug/cm^2/yr, averaging 119 ug/cm^2/yr. The elevated flux values in western Washington compared to eastern Washington may be the result of higher sedimentation rates, proximity to sources, greater urbanization, and larger amounts of rainfall. Meredith et al. (2010) found higher mercury concentrations in upper trophic level fish species in western Washington lakes compared to eastern Washington.

By our proxy (± 25% shift from 1990s to 2000s), 4 (Wenatchee, Black, Loon, and Wannacut) of the 5 eastern Washington Lakes showed a decreasing trend in mercury fluxes. In Western Washington, 5 of the lakes exhibited no change (Lacamas, Offutt, Washington, Ozette, and Sammamish), 1 decreasing (American), and 1 increasing (St. Clair).

The eastern Washington study lakes are much more rural. The declining trend at these lakes may be representative of continental or global trends. However, the lack of resemblance of the down core profile in each of the eastern Washington lakes suggests basin activity still plays a large role in moderating fluxes.

Lead

Table 8 shows lead levels from the 12 lakes with dated cores, along with conclusions about recent trends.

Modern concentrations of lead in the sediment cores were variable in both eastern and western Washington and did not appear dependent on degree of urbanization in the catchment. Black Lake (a rural lake east of Colville) and Lake Washington (an urban Lake in Seattle) contained the highest concentrations (≈ 70 mg/kg) over the last decade.

In general, modern concentrations are much lower than their maximum values primarily due to the removal of lead additives from gasoline in the mid 1970s. Excluding Black Lake and Upper Twin Lake (maximum year couldn't be calculated), lead concentrations peaked on average in 1968 (n=10). The exception is Offutt Lake where lead concentrations remain near the core maximum.

Trend data at the lakes show lead values have decreased by 25% or more from the 1990s - 2000s at 5 of the lakes. The remaining lakes showed no change. None of the lakes displayed an increasing trend.

Table 8. Lead concentrations and recent trends in sediment cores, 2006 - 2010.

Lake	Concentration Range (mg/kg)	Peak Year	Average Concentration 2000 - present (mg/kg)	n	Location	1990s - 2000s trend
American	46.5-281	1969	54.5	4	Western WA	decrease
Lacamas	16-51	1955	24.2	4		no change
Offutt	13-50	1988	49.1	3		no change
Washington	6-200	1977	70.9	4		decrease
Ozette	12-19	1971	14.5	1		no change
Sammamish	4-94	1974	29.8	1		no change
St. Clair	13-48	1983	24.6	1		no change
Wenatchee	5-14	1963	9.0	2	Eastern WA	no change
Black	11-114	1980 1992	68.3	2		decrease
Upper Twin	4-22	<1850	5.1	5		decrease
Loon	6-128	1941	54.0	1		decrease
Wannacut	1-108	1954	17.2	1		no change

PAHs

PAH analyses were added to the coring program in 2008. During the first 2 years, low-resolution GC/MS was used to quantify concentrations. In 2010, PAH analyses were analyzed using high-resolution GC/MS SIM to achieve better detection limits. Table 9 shows PAH concentrations from the 7 lakes with dated cores, along with conclusions about recent trends.

Table 9. PAH concentrations and recent trends in sediment cores, 2008 - 2010.

Lake	Concentration Range (mg/kg)	Peak Year	Average Concentration 2000 - present (mg/kg)	n	Location	1990s - 2000s trend
American	161 J - 1825	1931	236	2	Western WA	decrease
Lacamas	33 J - 577	< 1850	65	3		no change
Offutt	60 J - 219 J	2004	137.3	3		no change
Washington	167 J - 1117	1990	768	4		decrease
Wenatchee	50 - 347	1963	140	1	Eastern WA	no change
Black	41 U - 236	1974	-	-		-
Upper Twin	36 U - 150 U	-	-	-		-

J: Estimate.
U: Not detected at concentration shown.

PAH concentrations were highest at the dense urban locations of American Lake (Tacoma) and Lake Washington (Seattle). Decreasing trends were detected at both of these lakes. In eastern Washington, values remained under 350 ng/g. All 3 of the eastern Washington lakes sampled have very little development compared to the western Washington sites.

Figure 10 displays the Fl/(Fl + Py) ratio for all of the lakes with dated cores. Modern ratios are generally greater than 0.5 at all of the lakes. With the exception of American Lake, the ratios generally show an increasing trend away from petroleum combustion towards grass/wood/coal combustion since the 1950s.

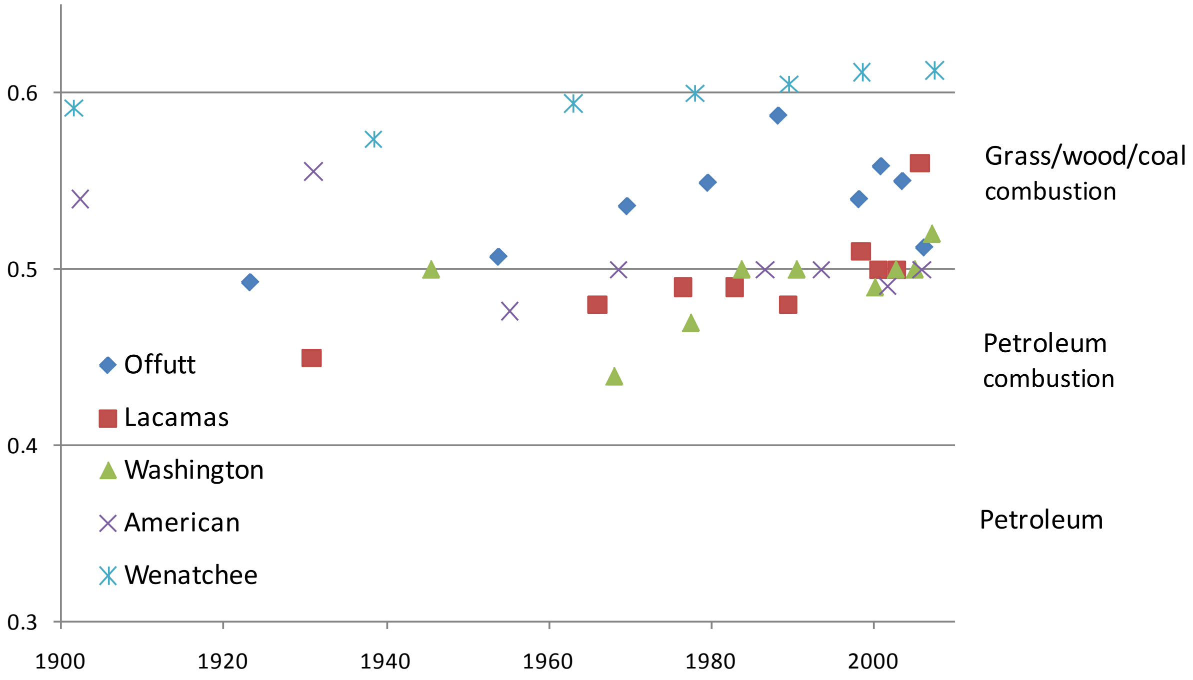

Figure 10. Fluoranthene/ (fluoranthene+pyrene) PAH ratios for all sediment cores, 2008 - 2010.

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Conclusions

This report represents the fifth year of an ongoing study seeking information on present and historical contaminant trends in Washington State as recorded in lake sediments. During 2010, deep sediment cores were collected from Lake Wenatchee, Lone Lake, and Sprague Lake and analyzed for mercury, lead, and PAHs. For Lake Wenatchee, dates and sedimentation rates were assigned to sediment intervals from ^{210}Pb measurements using the constant rate of supply model. The constant rate of supply model could not be used at Lone and Sprague Lakes.

- At Lake Wenatchee, contaminant concentrations have generally decreased since the middle part of the 1900s. The exception is mercury where fluxes and concentrations were at their greatest around 2000. Modern concentrations of PAHs and lead are within the range of values recorded at other eastern Washington Lakes. Modern mercury fluxes are higher than other eastern Washington Lakes.

- The ^{210}Pb concentrations from Lone Lake indicated the upper portion of the core was likely mixed, thus a single sedimentation rate was applied to the core from 1975 - 2010 based on the peak lead concentration. Mercury concentrations have climbed consistently from baseline values until leveling off over the top 10 cm. Lead concentrations followed a similar pattern except values appeared to be declining over the top 10 cm. PAH concentrations were significantly elevated over the other 2 study lakes. Concentrations moved somewhat erratically in the upper portion of the core making it difficult to discern a trend.

- At Sprague Lake, concentrations of both lead and mercury were very low, with profiles for each contaminant changing little throughout the length of the core. PAH concentrations were found within the range of Lake Wenatchee and show a small decrease through approximately 20 cm where they level off.

Data from previous years were collated, and contaminant trends were assessed by examining percent change from the 1990s - 2000s. For mercury, the majority of western Washington Lakes show no significant change in fluxes from the 1990s - 2000s. In eastern Washington, all but one show a declining trend. For lead, several lakes exhibited a declining trend; however, most showed no change. No lakes were found with an increasing trend. The PAH dataset was limited to only 5 lakes; 2 showed a decreasing trend while the remaining showed no change.

Recommendations

As a result of this 2010 study, the following recommendations are made:

- If coring a lake with low percent solids in sediments, 200 - 400 grams of wet material may be required for dating.
- Continue PAH analysis by GC/MS SIM method.
- Include source information in future analysis, such as population changes and development pattern in the lake basins.
- Consider taking a duplicate core.

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Appendices

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Appendix A. Glossary, Acronyms, and Abbreviations

Glossary

Basin: Watershed. A drainage area 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.

Baseline: Average of pre-industrial contaminant concentrations.

Bioaccumulative pollutants: Pollutants that build up in the food chain.

Flux rate: Sediment accumulation rate times analyte concentration. Estimates net deposition to the coring site.

Horizon: Sediment interval measured in centimeters along a vertical gradient.

Paleolimnological: Describes the historical study of inland waters.

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

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Sediment: Solid fragmented material (soil and organic matter) that is transported and deposited by water and covered with water (example, river or lake bottom).

Sediment core: Vertical sediment sample.

Acronyms and Abbreviations

CRS	Constant rate of supply
EAP	Environmental Assessment Program
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
GC/MS SIM	Gas chromatography/mass spectrometry single ion monitoring
LCS	Laboratory control sample
MEL	Manchester Environmental Laboratory
MQO	Measurement quality objective
n	Number
PAH	Polycyclic aromatic hydrocarbon

Pb	Lead
PBT	Persistent, bioaccumulative, and toxic chemical
QA	Quality assurance
Rn	Radon
RPD	Relative percent difference
SRM	Standard reference materials
TOC	Total organic carbon
USGS	U.S. Geological Survey
WAC	Washington Administrative Code

Units of Measurement

cm	centimeter
g	gram, a unit of mass
kg	kilograms, a unit of mass equal to 1,000 grams.
mg	milligrams
mg/Kg	milligrams per kilogram (parts per million)
ng/g	nanograms per gram (parts per billion)
pCi	pico curies
ug/Kg	micrograms per kilogram (parts per billion)

Appendix B. PBT Trends Sediment Coring Locations, 2006 - 2010.

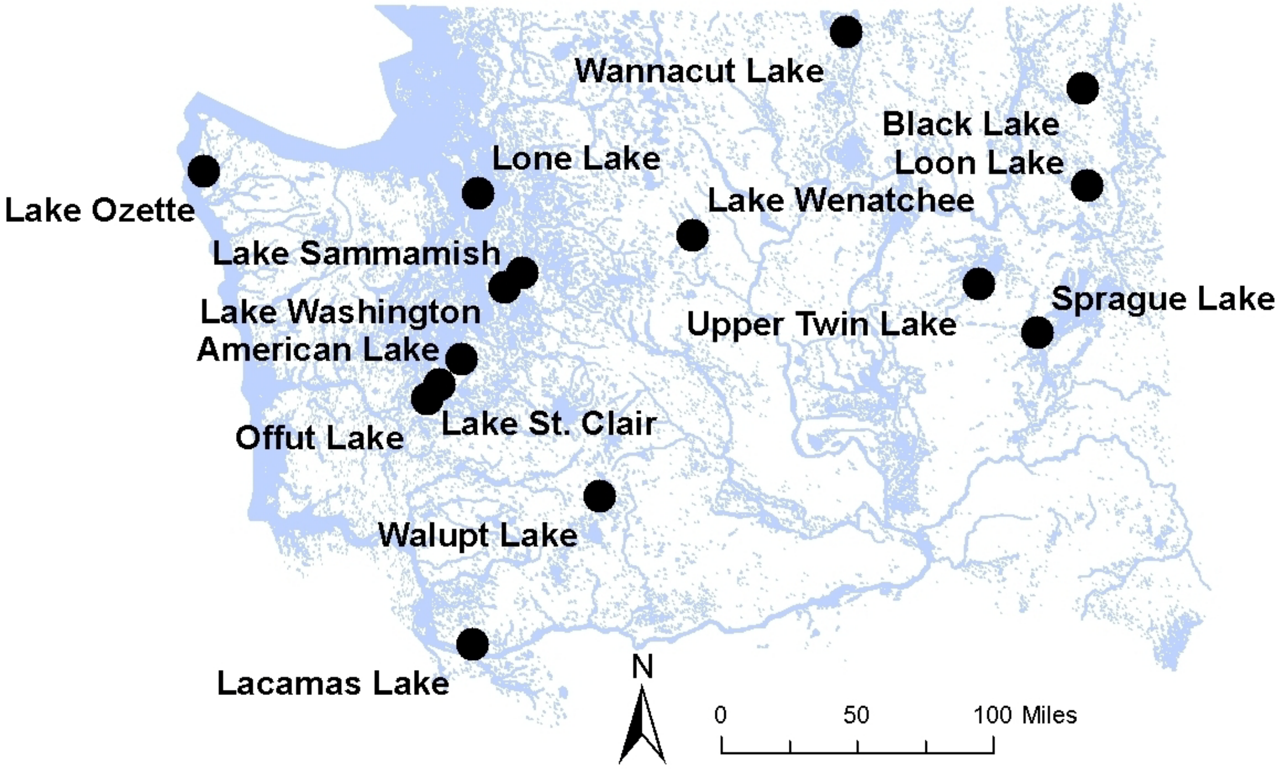

Figure B-1. Locations of sediment cores, 2006-2010.

Appendix C. Sediment Core and Surface Sediment Data.

Table C-1. Lake Wenatchee sediment core results.

Section (cm intervals)	Analyte			
	Mercury (ng/g)	Lead (mg/Kg)	Total PAHs (ug/Kg)	TOC (%)
0-2	85.5	8.92	140.42	3.83
2-3	84	9.03	-	-
3-4	103	9.52	156.24	3.45
4-5	-	-	-	-
5-6	88.8	11.1	162.73	3.35
6-7	-	-	-	-
7-8	94.7	13.9	171.81	3.34
8-9	-	-	-	-
9-10	89.4	14.4	347.11	3.33
10-11	-	-	-	-
11-12	88.5	13.2	198.58	3.13
12-13	-	-	-	-
13-14	74.7	10.4	228.72	2.74
14-15	-	-	-	-
15-16	-	-	-	-
16-17	53.5	8.54	191.17	1.99
17-18	-	-	-	-
18-19	-	-	-	-
19-20	41.1	7.56	-	-
20-21	-	-	-	-
21-22	-	-	-	-
22-23	46.6	7.45	180.75	2.02
23-24	-	-	-	-
24-25	-	-	-	-
25-26	44.8	6.54	-	-
26-27	-	-	-	-
27-28	-	-	-	-
28-29	37.3	5.17	-	-
29-30	-	-	-	-
30-31	-	-	-	-
31-32	-	-	-	-
32-33	36.4	4.75	49.67	2.04
33-34	36.7	4.96	-	-

Table C-2. Lone Lake sediment core results.

Section (cm intervals)	Analyte			
	Mercury (ng/g)	Lead (mg/Kg)	Total PAHs (ug/Kg)	TOC (%)
0-2	220	46.3	1973.7	23.8
2-3	215	47	-	-
3-4	-	-	1931	24.4
4-5	215	49	-	-
5-6	-	-	1412.6	24.3
6-7	225	54.4	-	-
7-8	-	-	1941.4	25.2
8-9	232	56.8	-	-
9-10	-	-	-	-
10-11	-	-	1408.9	25.4
11-12	271	55.7	-	-
12-13	-	-	-	-
13-14	-	-	-	-
14-15	189	53.5	-	-
15-16	-	-	2000.5	25.4
16-17	-	-	-	-
17-18	230	50.1	-	-
18-19	-	-	-	-
19-20	-	-	2317.5	25.3
20-21	188	48	-	-
21-22	-	-	-	-
22-23	-	-	-	-
23-24	164	38.3	-	-
24-25	-	-	-	-
25-26	-	-	1984.3	27.1
26-27	144	32	-	-
27-28	-	-	-	-
28-29	-	-	-	-
29-30	-	-	-	-
30-31	136	23.8	-	-
31-32	-	-	1260.61	26.8
32-33	-	-	-	-
33-34	-	-	-	-
34-35	97.4	19.2	-	-
35-36	-	-	-	-
36-37	-	-	-	-
37-38	-	-	1151.12	27.8
38-39	72.7	15	-	-
39-40	86.9	13.7	-	-

Table C-3. Sprague Lake sediment core results.

Section (cm intervals)	Analyte			
	Mercury (ng/g)	Lead (mg/Kg)	Total PAHs (ug/Kg)	TOC (%)
0-2	29	9.07	136.79	5.7
2-3	27.2	8	-	-
3-4	26.6	7.81	-	-
4-5	-	-	142.45	5.53
5-6	26.5	8.38	-	-
6-7	-	-	126.73	5.96
7-8	25.3	8.36	-	-
8-9	-	-	134.4	5.21
9-10	26	8.35	-	-
10-11	-	-	128.59	5.38
11-12	25.4	7.88	-	-
12-13	-	-	-	-
13-14	25.5	8.31	-	-
14-15	-	-	130.98	5.14
15-16	-	-	-	-
16-17	24.9	8.46	-	-
17-18	-	-	-	-
18-19	-	-	127.79	4.88
19-20	25.7	8.48	-	-
20-21	-	-	-	-
21-22	-	-	-	-
22-23	23.8	8.7	-	-
23-24	-	-	-	-
24-25	-	-	155.61	4.38
25-26	-	-	-	-
26-27	26.4	8.1	-	-
27-28	-	-	-	-
28-29	-	-	-	-
29-30	-	-	-	-
30-31	26.7	8.07	-	-
31-32	-	-	-	-
32-33	-	-	-	-
33-34	-	-	170.07	3.57
34-35	-	-	-	-
35-36	24.3	8	-	-
36-37	-	-	173.8	3.45
37-38	24.8	8.02	-	-

Appendix D. Quality Assurance Data

Table D-1. Measurement Quality Objectives.

Parameter	Surrogate % Recovery	SRM % Recovery	MS % Recovery	MSD RPD	Duplicate RPD	LCS % Recovery	Blank
Total Organic Carbon	---	75-125	---	---	< 20%	----	< LOQ
Grain Size	---	----	----	---	< 25%	----	---
Total Mercury	---	----	75 - 125	< 20%	---	85 - 115	< LOQ
Total Lead	---	----	75 - 125	< 20%	---	85 - 115	< LOQ
PAHs	2-Fluorobiphenyl - 30-115% Pyrene-D-10 - 50-150% Terphenyl-D-14 - 18-137%	65 - 135	50 - 150	<40%	< 40%	50 - 150	< LOQ
Lead^{210}	---	----	---	---	<30%	80 - 120	< LOQ

RPD: Relative Percent Difference.
LOQ: Limit of Quantitation.
MS/MSD: Matrix Spike/ Matrix Spike Duplicate.
LCS: Laboratory Control Sample.
SRM: Standard Reference Material.

Table D-2. Total Organic Carbon.

Lab Duplicate.

Sample	Result	Source Sample Result	RPD (%)
	(mg/kg dw)	(mg/kg dw)	
B10G243-DUP1	5.62	5.7	1
B10G243-DUP2	5.58	5.7	2
B10H048-DUP1	0.715	0.76	6
B10H048-DUP2	0.747	0.76	2

Lab Method Blanks.

Sample	Field ID	Result
		(mg/kg dw)
B10G243-BLK1	Lab BLNK	0.10 U
B10H048-BLK1	Lab BLNK	0.10 U

Reference Sample.

Reference	% Recovery
B10G243-SRM1	92
B10H048-SRM1	90

RPD: Relative Percent Difference.
U: Analyte not detected at detection limit shown.

Table D-3. Total Mercury.

Matrix Spikes (% Recovery).

Sample	LMX1	LMX2	RPD
B10G308-MS1/MSD1	81	80	0.3
B10G239-MS1/MSD2	91	92	2
B10G307-MS1/MSD1	83	83	3

Lab Method Blanks.

Sample	Field ID	Result (mg/kg dw)
B10G308-BLK1	Lab BLANK	0.005 U
B10G239-BLK1	Lab BLANK	0.005 U
B10G307-BLK1	Lab BLANK	0.005 U

Lab Control Samples.

Sample	Field ID	% Recovery
B10G308-BS1	Lab LCS	86
B10G239-BS1	Lab LCS	88
B10G307-BS1	Lab LCS	85

LMX: Laboratory matrix spike.
RPD: Relative percent difference.
U: Analyte not detected at detection limit shown.

Table D-4. Total Lead.

Matrix Spikes (% Recovery).

Sample	LMX1	LMX2	RPD
B10H030-MS1/MSD1	101	98	3
B10G248-MS1/MSD1	96	95	0.7
B10H027-MS1/MSD1	80	87	3

Lab Method Blanks.

Sample	Field ID	Result (mg/kg dw)
B10H030-BLK1	Lab BLNK	0.10 U
B10G248-BLK1	Lab BLNK	0.05 U
B10H027-BLK1	Lab BLNK	0.05 U

Lab Control Samples.

Sample	Field ID	% Recovery
B10H030-BS1	Lab LCS	96
B10G248-BS1	Lab LCS	106
B10H027-BS1	Lab LCS	94

Reference Sample.

Reference	% Recovery
B10H030-SRM1	99
B10H027-SRM1	92

LMX: Laboratory matrix spike.
RPD: Relative Percent Difference.
U: Analyte not detected at detection limit shown.

Table D-5 ^{210}Lead.

Lab Method Blanks.

Sample	Result (pCi/g)
MA9HQ1AA	0.195 U
MA9H21AA	0.00258 U
MA9JG1AA	0.00383 U

Lab Control Samples.

Sample	% Recovery
MA9HQ1AC	102.0
MA9H21AC	100
MA9JG1AC	135

Lab Duplicates.

Sample	Original (pCi/g)	Duplicate (pCi/g)	RPD (%)
1007048-01	3.94	2.7	37%
1007048-25	3.27	5.5	51%

RPD: Relative Percent Difference.
U: Analyte not detected at detection limit shown.

Table D-6. PAHs.

Matrix Spikes.

Analyte	Sample No. 1007048-35			Sample No. 1007048-63		
	MS1	MSD1	RPD	MS1	MSD1	RPD
	% Recovery		(%)	% Recovery		(%)
1,1'-Biphenyl				99	98	18
1,6,7-Trimethylnaphthalene				88	91	14
1-Methylnaphthalene	86	81	6	90	90	17
1-Methylphenanthrene				119	122	15
2,6-Dimethylnaphthalene				133	130	19
2-Methylnaphthalene	80	76	6	80	79	17
Acenaphthene	414	342	20	85	88	14
Acenaphthylene	90	88	3	82	82	16
Anthracene	88	84	5	80	82	14
Benzo(a)anthracene	82	76	7	74	73	16
Benzo(a)pyrene	69	74	5	80	80	14
Benzo(b)fluoranthene	83	75	8	75	75	11
Benzo(ghi)perylene	89	80	7	84	85	9
Benzo(k)fluoranthene	88	78	11	87	86	15
Benzo(e)pyrene				103	97	22
Chrysene	76	69	8	58	60	13
Dibenzo(a,h)anthracene	94	92	3	91	91	16
Dibenzothiophene				82	83	15
Fluoranthene	80	78	3	80	72	14
Fluorene	101	98	4	90	91	13
Indeno(1,2,3-cd)pyrene	86	80	5	110	109	12
Naphthalene	72	77	5	68	59	23
Perylene					74	9
Phenanthrene	88	83	5	77	73	13
Pyrene	84	79	6	82	76	13
Retene	83	79	4	72	76	7

MS: Matrix spike.
MSD: Matrix spike duplicate.
RPD: Relative percent difference.

Table D-6 (continued). PAHs

Lab Method Blanks.

Analyte	Sample No. B10H303-BLK1		Sample No. B10I192-BLK1	
	(ug/kg dw)			
1-Methylnaphthalene	2	U	2	U
2-Methylnaphthalene	2	U	2	U
Acenaphthene	5	U	5	U
Acenaphthylene	2	U	2	U
Anthracene	2	U	2	U
Benzo(a)anthracene	2	U	2	U
Benzo(a)pyrene	5	U	5	U
Benzo(b)fluoranthene	5	U	5	U
Benzo(ghi)perylene	2	U	2	U
Benzo(k)fluoranthene	5	U	5	U
Chrysene	2	U	2	UJ
Dibenzo(a,h)anthracene	2	U	2	U
Fluoranthene	2	U	2	U
Fluorene	2	U	2	U
Indeno(1,2,3-cd)pyrene	2	U	2	U
Naphthalene	5	UJ	5	U
Phenanthrene	2	U	2	U
Pyrene	5	U	5	U
Retene	10	U	10	U

U: Analyte not detected at detection limit shown.
BLK: Blank.

Table D-6 (continued). PAHs.

Lab Control Samples.

Analyte	Sample No. B10H303-BS1	Sample No. B10I192-BS1
	% Recovered	
1,1'-Biphenyl		98
1,6,7-Trimethylnaphthalene		85
1-Methylnaphthalene	2	90
1-Methylphenanthrene		114
2,6-Dimethylnaphthalene		88
2-Methylnaphthalene	2	82
Acenaphthene	5	83
Acenaphthylene	2	85
Anthracene	2	82
Benzo(a)anthracene	2	74
Benzo(a)pyrene	5	82
Benzo(b)fluoranthene	5	73
Benzo(ghi)perylene	2	85
Benzo(k)fluoranthene	5	92
Benzo(e)pyrene		75
Chrysene	2	62
Dibenzo(a,h)anthracene	2	99
Dibenzothiophene		80
Fluoranthene	2	77
Fluorene	2	93
Indeno(1,2,3-cd)pyrene	2	94
Naphthalene	5	74
Perylene		72
Phenanthrene	2	78
Pyrene	5	81
Retene	10	73

Table D-6 (continued). PAHs.

Lab Reference Samples.

Analyte	Sample No. B10H303-SRM1	Sample No. B10I292-SRM1
	% Recovered	
1,1'-Biphenyl		83
1-Methylnaphthalene	89	99
2-Methylnaphthalene	91	100
Acenaphthene	49	50
Anthracene	60	61
Benzo(a)anthracene	73	65
Benzo(a)pyrene	78	70
Benzo(b)fluoranthene	78	61
Benzo(ghi)perylene	85	78
Benzo(k)fluoranthene	89	82
Benzo(e)pyrene		74
Chrysene	95	69
Dibenzo(a,h)anthracene	160	153
Dibenzothiophene		86
Fluoranthene	59	69
Fluorene	49	42
Indeno(1,2,3-cd)pyrene	75	93
Naphthalene	87	92
Perylene		60
Phenanthrene	87	82
Pyrene	71	62