Metals Concentrations in Sediments of Lakes and Wetlands in the Upper Columbia River Watershed: Lead, Zinc, Arsenic, Cadmium, Antimony, and Mercury

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For more information contact:

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

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

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

Cover photo: Sediment Box Corer, Cedar Lake, September 11, 2012
(Brendan Dowling, Ecology Eastern Regional Office)

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by

Art Johnson, Michael Friese, and Randy Coots
Environmental Assessment Program
Washington State Department of Ecology
Olympia, Washington 98504-7710

and

John Roland, Brendan Dowling, and Charles Gruenenfelder
Toxics Cleanup Program
Washington State Department of Ecology
Spokane, Washington 99205-1295

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Abstract

Sediments were collected from ten lakes and wetlands in the Upper Columbia River watershed of northeast Washington in 2012. Samples were analyzed for lead, zinc, arsenic, cadmium, copper, antimony, mercury, total organic carbon, and grain size. Lead-210 also was analyzed in a selected sediment core for age-dating and assessment of sedimentation rates.

The current 2012 study builds upon findings from a broader areal investigation of northeast Washington lakes conducted in 2010. The 2010 study reported comparatively elevated metals concentrations in lake sediments from portions of the study area generally in the vicinity of the Upper Columbia River valley. Historical transboundary air pollution from the Trail smelter in British Columbia was identified in the 2010 study as the probable, predominant area-wide source of upland lakes sediment contamination (metals) in the vicinity of the Upper Columbia River valley.

Spatial and temporal patterns in metals concentrations are described and the potential for adverse biological effects assessed. The chronology of metals deposition is illustrated with an age-dated sediment core collected from Cedar Lake near the international border with British Columbia, Canada. The history of smelter operations within this region is briefly reviewed as it pertains to the probable source(s) of contamination and observed sediment results.

The 2012 findings are consistent with and refine the spatial metals concentration patterns identified in the 2010 study. For all the lakes and wetlands sampled by both studies, the findings document:

1. Higher concentrations of lead, zinc, arsenic, cadmium, antimony, and mercury occur in lake sediment from the western part of the northeast Washington study area (nearer the Upper Columbia River).
2. Sediment from lakes located closest to the Upper Columbia River valley shows an overall northward-increasing metals concentration trend, with highest concentrations typically observed in lakes located nearer to the international border.
3. Mercury appears to be dispersed more broadly, across the west and north-central portions of the study area, than is observed for lead, zinc, arsenic, cadmium, and antimony.

Concentrations of lead and cadmium in sediments from selected northeast Washington lakes/wetlands pose a potential concern for adverse biological effects. This assessment is based on a comparison of measured metals concentrations to literature-based probable effects concentration thresholds for freshwater ecosystems.

Data from this 2012 lake/wetland sediment study further demonstrate the need for additional investigation to more fully characterize the geographic extent of historical smelter emission metals enrichment associated with potential ecological concerns, including terrestrial soils associated with upland environments in the Upper Columbia River watershed.

Acknowledgements

The authors thank the following people for their contributions to this study:

- Many individuals granted or assisted in gaining access to the lakes and wetlands sampled in this study. Bill Baker of the Washington Department of Fish and Wildlife and Arne Johnson of the Washington State Department of Natural Resources were particularly helpful.

- Washington State Department of Ecology staff:
    - Manchester Environmental Laboratory staff analyzed project samples and reviewed contract laboratory data.
    - Callie Mathieu advised on dating sediment cores and did the dating calculations for Cedar Lake.
    - Paul Anderson assisted with field work.
    - Joan LeTourneau formatted and proofed the final report.

Background

A 2010 study by the Washington State Department of Ecology (Ecology) provided an initial assessment of selected metal and organic contaminant concentrations in sediments from 15 lakes in northeast Washington and one lake in north Idaho (Johnson et al., 2011). Waterbodies thought to exhibit relatively low impact from local human activities were selected for sampling. The data were collected to better understand area and regional background concentrations within these aquatic environments and to support cleanup decisions by Ecology's Toxics Cleanup Program.

An important finding from the 2010 study was the occurrence of elevated levels of lead, zinc, arsenic, cadmium, antimony, and mercury in lake sediments from the western part of the study area within the Upper Columbia River watershed. Historical transboundary air pollution (i.e., smelter-emitted particulates and aerosols) from the Trail smelter (Teck Cominco[1]) in British Columbia was identified as the probable primary source of metals contamination to these lakes. The Trail smelter is one of the largest fully integrated zinc and lead smelters in the world. A smaller, shorter-lived smelter operation (LeRoi) in Northport, Washington also was identified as a possible localized, secondary source of metal contamination.

The 2010 report included an evaluation of metals concentrations in an age-dated sediment core from Black Lake, centrally located within the study area. The core, collected by Ecology in 2009, documented changes in lead and mercury inputs over time and showed a steady increase in concentrations throughout most of the 1900s. The deeper layers of the core provided an historical benchmark approaching background concentrations of lead, mercury, and other metals.

The 2012 study provides for additional assessment of lead, zinc, arsenic, cadmium, antimony, and mercury contamination in lake and wetland sediments from a portion of the previous 2010 study area in northeast Washington. The 2012 study area concentrates on seven upland lakes and three wetlands (Bodie, Dry, and Peterson Swamp) located within the Upper Columbia River valley. Consistent with the 2010 study, waterbodies thought to exhibit relatively low impact from local human activities were selected for sampling. Apparent smelter-related impacts were most evident within this portion of the 2010 study area and warranted a follow-up assessment to further inform the apparent distribution and magnitude of metals impacts within the upland aquatic environment nearer the Upper Columbia River valley.

In the earlier part of the last century, Upper Columbia River valley timber and other vegetation within approximately 30 miles of the international border had been severely injured by sulfur dioxide (SO_2) emissions from the Trail smelter (ICF International, 2011). The design of the current 2012 study was influenced by, and utilized the documented historical footprint of, the SO_2 injuries to assist in the further sampling of lake and wetland sediments for potentially associated metals enrichment.

One of the lakes included in the 2012 study (Cedar Lake) had been sampled as part of the 2010 effort. Cedar Lake is located four miles south of the international boundary, east of the Columbia River. Findings from the 2010 study, and consideration of its size and location,

[1] Now Teck Resources Ltd.

favored a more refined evaluation of sediment from Cedar Lake – specifically, the collection of an age-dated sediment core. Information from an age-dated sediment core could help to improve the understanding of vertical variations in sediment metals concentrations over time and associated impacts.

The 2010 and 2012 studies followed quality assurance project plans (Johnson, 2010, 2012). The field work for 2012 was conducted by Ecology's Environmental Assessment Program and Toxics Cleanup Program during September and October.

Objectives of Study

The objectives of this 2012 study were to:

- Further characterize lead, zinc, arsenic, cadmium, antimony, and mercury concentrations in sediments from selected upland lakes and wetlands in the proximity of the historically mapped SO_2 damage zone associated with the Trail smelter.
- Evaluate historical changes in these metals within the sediment profile.
- Estimate lake sedimentation rates.

Samples Collected

Figure 1 shows the study area for the lakes and wetlands sampled in 2012. Figure 2 shows their location relative to lakes where sediments were collected in 2010. Detailed maps for each of the 2012 waterbodies are provided in Appendix A.

A brief description of the 2012 study area lakes and wetlands, as well as methods of sediment collection, is provided in Table 1. Waterbodies thought to exhibit relatively low impact from local human activities were selected for sampling. A mix of surface sediment and sediment cores was collected. Surface sediment samples were obtained from six waterbodies and consisted of the top 10-cm layer from three grab samples. These samples were taken with a clam-shell type sampler (Ponar) and either composited or analyzed separately.

Sediment cores ranging from 10 to 50 cm in length were obtained from six waterbodies, one core each. Except for Cedar Lake, the coring was done with a two-inch diameter Plexiglas tube, either housed in a gravity coring device (K-B corer) or pushed into the sediments by hand. A 13 cm x 13 cm rectangular box core was used in Cedar Lake. Cedar Lake and Elbow Lake were sampled both by surface grab and corer.

The 2-inch diameter cores were analyzed in 10 to 20 cm increments, providing up to four sediment samples representing the surface and subsurface layers. The Cedar Lake box core was analyzed in finer detail for age-dating by the lead-210 technique. This core was generally sectioned in 1 - 2 cm increments, depending on the layering encountered and consistency of the material.

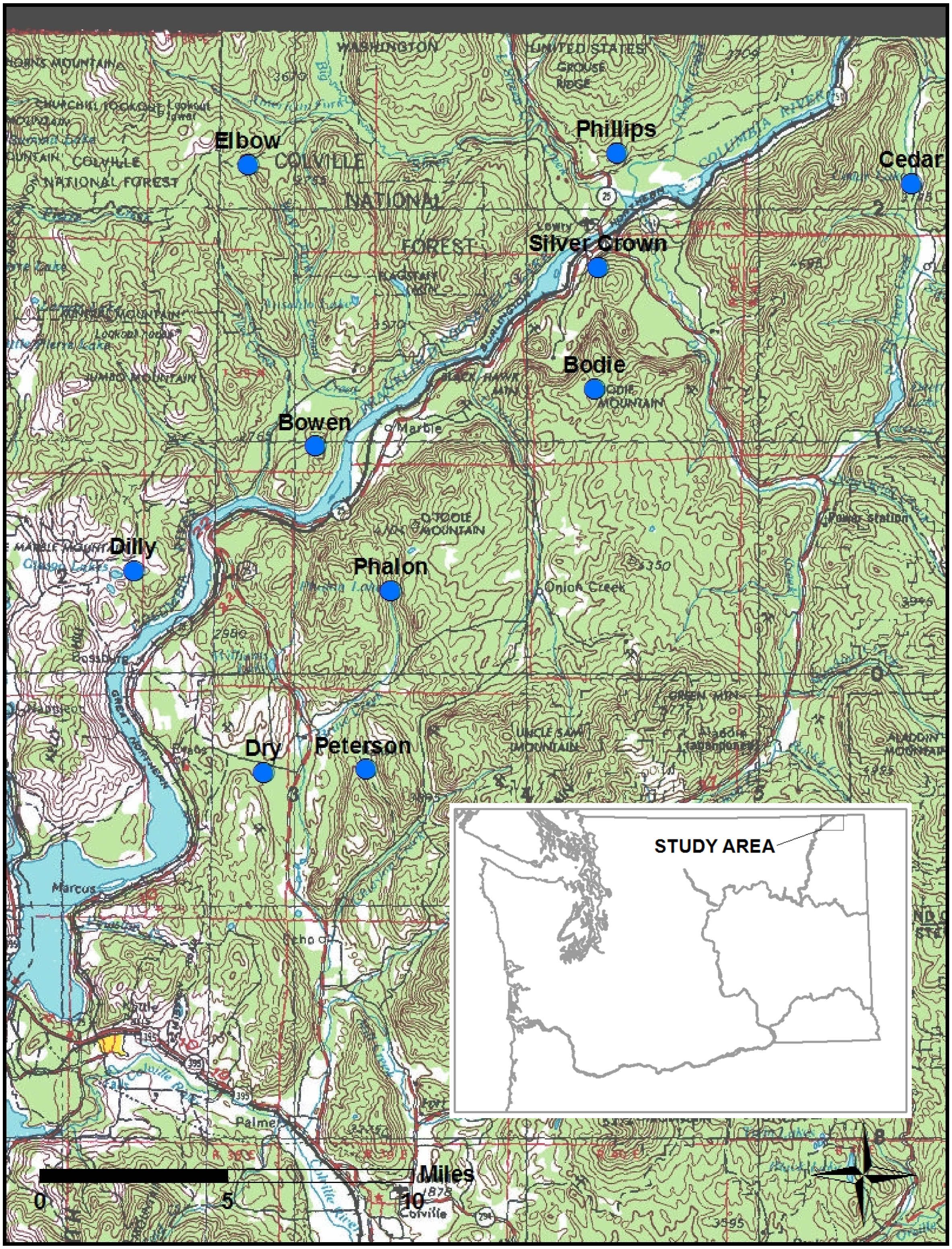


Figure 1. Study Area for Lakes and Wetlands Sampled in 2012.

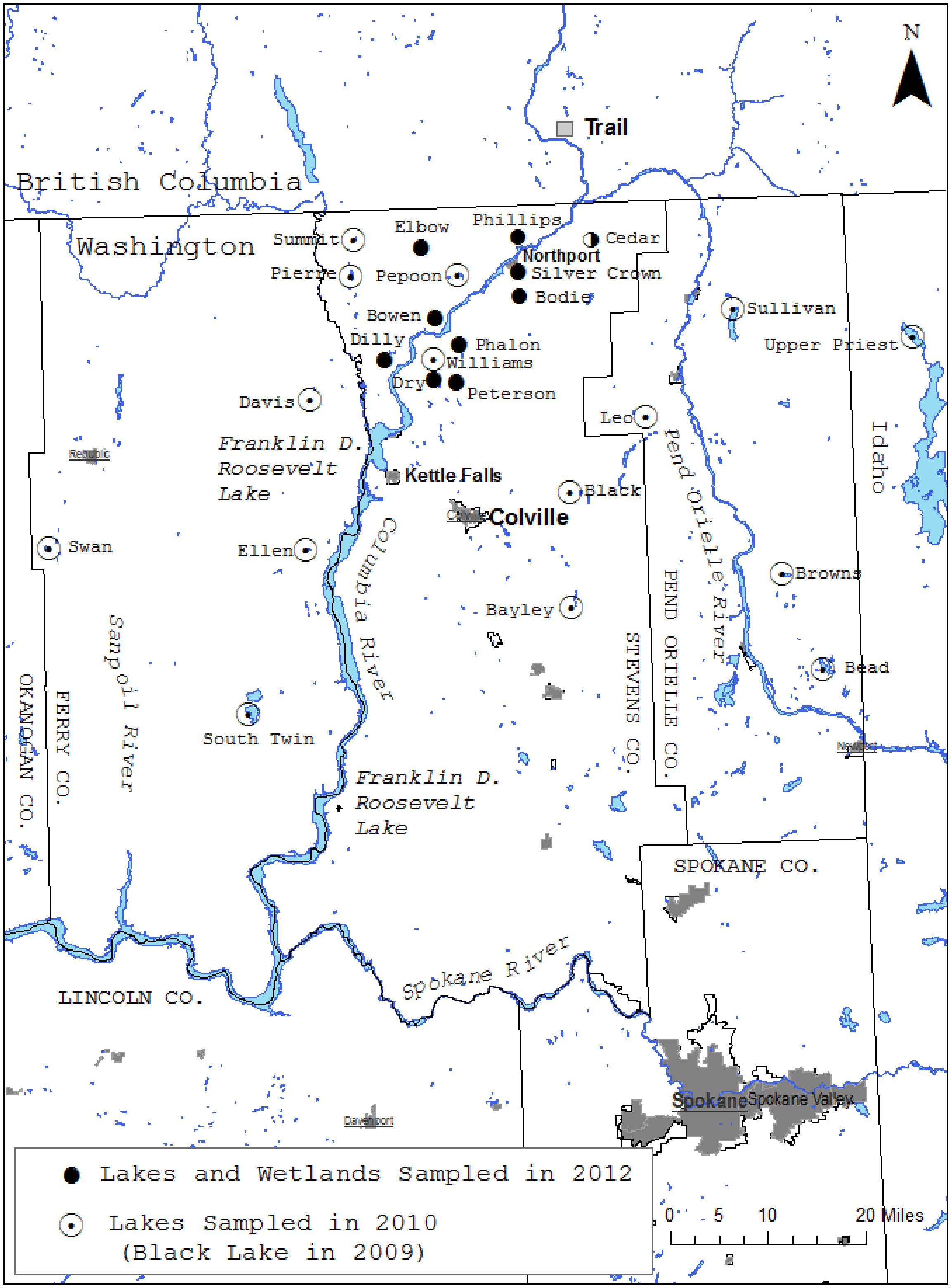


Figure 2. Lakes and Wetlands where Sediments Samples were Collected in 2012 in Relation to Lakes Sampled in 2009-2010.

Table 1. Sediment Samples Collected in 2012 (NAD 83 datum).

Waterbody Name	Location	Elevation (ft.)	Surface Area (acres)	Samples Collected	Water Depths (ft.)	Collection Date (2012)	Latitude	Longitude
Cedar Lake	5.8 miles south of international border on Deep Lake-Boundary Rd.	2,135	51	Box core and 3 separate 0.05m^2 Ponar grabs	22 - 23	11-Sep	48.943	-117.594
Phillips Lake	4 miles north of Northport off Mitchell Rd.	1,810	1	K-B core	3.5	11-Sep	48.954	-117.767
Silver Crown Lake	0.5 miles east of Northport	2,280	~5	K-B core	30	11-Sep	48.909	-117.778
Elbow Lake	14 miles west of Northport off Sheep Creek Rd.	2,775	14	K-B core and composite of 3 0.02m^2 Ponar grabs	13 - 16	9-Oct	48.948	-117.984
Bodie Wetland*	5.5 miles south of Northport, jeep trail off Bodie Mountain Rd.	3,200	~3	Composite of 3 0.05m^2 Ponar grabs	0.3 - 0.8	10-Oct	48.862	-117.779
Bowen Lake*	14 miles southwest of Northport off Moore Rd.	2,000	1.4	Composite of 3 0.02m^2 Ponar grabs	6 - 15	9-Oct	48.839	-117.943
Phalon Lake	16 miles southwest of Northport, end of Dead Medicine Rd.	2,375	18	K-B core	25	12-Sep	48.783	-117.898
Dilly Lake (Glasgow Lakes)	19 miles north of Kettle Falls off Hill Loop Rd.	2,175	35	Composite of 3 0.02m^2 Ponar grabs	15 - 45	9-Oct	48.790	-118.049
Dry Lake*	13 miles northeast of Kettle Falls off Evans Cutoff Rd.	1,900	6	Hand core, K-B tube	1.5	12-Sep	48.712	-117.971
Peterson Swamp*	15 miles northeast of Kettle Falls off Echo Valley Rd.	2,710	38	Composite of 3 0.02m^2 Ponar grabs	0.8	10-Oct	48.714	-117.911

*Wetland or wetland dominated

Sampling Methods

Sediment collection and sample handling followed the Environmental Assessment Program's standard operating procedures (SOPs) for freshwater sediments (Blakley, 2008; Furl and Meredith, 2008). The samples were either collected with a 0.05 m^2 or 0.02 m^2 stainless steel Ponar grab, K-B corer fitted with a 2-inch diameter acrylic tube, or Wildco stainless steel box corer containing a 13 cm x 13 cm x 50 cm acrylic liner.

Three grab samples were taken from each waterbody where a Ponar was used. The grabs were located along a transect, generally from deep to shallower water, and composited into a single sample. Cedar Lake was an exception, in that the grabs were confined during the 2012 sampling to the deeper part of the lake, and each sample was analyzed individually. For waterbodies where the K-B or box corer was used, a single sample was obtained from the deepest area. The core sample from Dry Lake, a wetland, was collected by wading in and pushing a K-B core tube into the substrate by hand.

A grab sample was considered acceptable if the Ponar was not over-filled, overlying water was not excessively turbid, the sediment surface was relatively flat, and the desired depth penetration was achieved. Overlying water was siphoned off, and the top 10 cm of sediment was removed with a stainless steel scoop, placed in a stainless steel bowl, homogenized by stirring, and split into appropriate sample containers. Material touching the side walls of the grab was not used for composite sample preparation. The samples were placed on ice for transport back to Ecology headquarters where they were placed in a freezer and maintained at a temperature of <0 degrees C.

Penetration depths for the K-B corer ranged from approximately 30 to 50 cm, except only 15 cm at Dry Lake. After overlying water was siphoned off, the core tubes were placed on ice in a vertical position, returned to Ecology headquarters, and frozen. The cores were later thawed, extruded, and cut into 10 to 20 cm sections. The smearing action that occurs during penetration and extrusion can contaminate adjacent parts of the sediment core. Therefore, the outermost layer of each section was cut away and either used for grain size and total organic carbon analysis or discarded. Subsamples were then homogenized in stainless steel bowls by stirring and split into appropriate sample containers and refrozen.

One box core was collected from the center of Cedar Lake. The core was considered suitable for subsampling in that the sediment-water interface was intact and sufficient penetration depth had been achieved (approximately 45 cm). Overlying water was siphoned off the top of the core and sections incrementally removed by pushing the sediment column up through the liner. The outer layers were cut away for grain size and total organic carbon analysis or discarded. The subsamples were then homogenized in stainless steel bowls by stirring and split into appropriate sample containers.

Sample containers were glass or polyethylene jars that had been cleaned to U.S. Environmental Protection Agency (EPA, 1990) quality assurance/quality control specifications. The samples were held frozen until transported with chain-of-custody record to the Ecology Manchester Environmental Laboratory (MEL). MEL shipped the lead-210 and grain size samples to contract laboratories. Excess sample was archived at Ecology headquarters. Sample containers and holding times for the project are listed in Table 2.

Table 2. Sample Containers, Preservation, and Holding Times.

Parameter	Container	Field Preservation	Holding Time
Metals	4 oz. glass w/ Teflon lid liner	Cool to 4°C	2 years (frozen); mercury 28 days
Lead-210	4 oz. glass w/ Teflon lid liner	Cool to 4°C	2 years (frozen)
Total Organic Carbon	2 oz. glass w/ Teflon lid liner	Cool to 4°C	6 months (frozen)
Grain size	8 oz. polyethylene	Cool to 4°C	6 months

Stainless steel implements used to collect and manipulate the sediments were cleaned by washing with Liquinox detergent, followed by sequential rinses with tap water, dilute nitric acid, deionized water, and pesticide-grade acetone. The equipment was then air dried and wrapped in aluminum foil for transport into the field. Cleaning of the Ponar between lakes consisted of thorough brushing and rinsing using on-site lake water.

Chemical Analysis

Table 3. Analytical Methods and Laboratories

Analysis	Method	Reference	Laboratory
Antimony	ICP/MS	EPA 3050B / 200.8	Manchester (MEL)
Arsenic	ICP/MS	EPA 3050B / 200.8	Manchester (MEL)
Cadmium	ICP/MS	EPA 3050B / 200.8	Manchester (MEL)
Copper	ICP/MS	EPA 3050B / 200.8	Manchester (MEL)
Lead	ICP/MS	EPA 3050B / 200.8	Manchester (MEL)
Zinc	ICP/MS	EPA 3050B / 200.8	Manchester (MEL)
Mercury	CVAA	EPA 245.5	Manchester (MEL)
Total Organic Carbon	NDIR	PSEP (1986)	Manchester (MEL)
Grain Size	Sieve and pipette	PSEP (1986)	Analytical Resources
Lead-210	Alpha spectroscopy	EML Po-2	Eberline Analytical

ICP/MS: Inductively coupled plasma - mass spectrometry
CVAA: Cold vapor atomic absorbance
NDIR: Non-dispersive infrared detector
PSEP: Puget Sound Estuary Program

Data Quality

Data Review and Verification

MEL reviewed and verified all the chemical data for this project. MEL prepared written case narratives assessing the quality of the data. The reviews include a description of analytical methods and an assessment of holding times, calibration, method blanks, matrix spike recoveries, laboratory control samples, and laboratory duplicates, as appropriate. With few exceptions, the results met acceptance criteria for these analyses, and the data are usable as qualified. The reviews and data reports are in Appendix B. Quality assurance and quality control at MEL are described in MEL (2008, 2012).

Analytical Precision

Estimates of analytical precision were obtained by analyzing laboratory duplicates (one homogenized sample split into two duplicate subsamples). The results are summarized in terms of relative percent difference (RPD) in Table 4. RPD is the difference between duplicates expressed as a percent of the mean value.

Table 4. Summary of Results on Laboratory Duplicate (Split) Samples (relative percent difference).

Sample No. (1210038-)	Lake/Site	Sediment Layer (cm)	Lead	Zinc	Arsenic	Antimony	Cadmium	Mercury
34	Cedar #1	12	3.0%	0.5%	0.5%	20%	0.9%	3.8%
43	Cedar #1	34-36	0.4%	0.9%	0.4%	12%	2.0%	10%
03/04	Cedar #3	0-10	15%	12%	20%	5.1%	14%	2.8%
51	Dilly #1-#3	0-10	1.7%	1.6%	1.4%	27%	2.6%	2.1%
		Mean RPD =	5%	4%	6%	16%	5%	5%

RPD: relative percent difference; difference between duplicates as percent of mean value

The duplicates were in good agreement. Lead, zinc, arsenic, cadmium, and mercury results differed by 6% or less, on average. The antimony duplicates averaged 16% RPD. MEL's quality control acceptance limit for laboratory duplicates is 20% RPD.

The average of duplicate results is used in the remainder of this report.

Sediment Dating Calculations

Age-dating of the sediments in the Cedar Lake core sample used lead-210[2] measurements and the constant rate of supply (CRS) model. A detailed description of this technique as applied to lead, mercury, and other contaminants in sediment cores from Washington lakes can be found in Mathieu and Friese (2012) and references therein.

The CRS model uses lead-210 to estimate dates and sedimentation rates throughout a core (Appleby and Oldfield, 1978). The model evaluates the difference in supported and unsupported lead-210 in sediment horizons. Supported lead-210 is represented by the small amount of the precursor gas radon-222 that is captured in soils.

Unsupported lead-210 represents atmospherically deposited lead-210 resulting from the decay of radon-222 that escapes into the atmosphere and is estimated by subtracting supported lead-210 from total lead-210. Using the known half-life of lead-210 (22.3 years) 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; Charles and Hites, 1987).

For the present study, supported lead-210 was estimated as the average activity present at deep intervals where it appeared to no longer decline. Sediment dry mass (g/cm^2) was calculated from percent solids data. An assumed sediment density of 2.7 g/cm^3 was used, based on other Washington lake coring studies (Paulson, 2004).

[2] Lead-210 and radon-222 are radioisotopes of stable lead and radon.

Results[3] and Discussion

Sediment Physical Characteristics

Table 5 and Figure 3 summarize the information obtained on grain size and total organic carbon content. Due to sample size requirements, not all samples could be analyzed for these parameters. Subsamples from some core segments were composited to provide enough material.

The sediments tended to be soft, light tan to dark greenish brown in color, and comprised mostly of fine material. Percent fines (silt + clay) averaged 53% and sand averaged 40%. The highest metals concentrations often are associated with the finer-grained fraction of a sediment (i.e., silt and clay). The finest sediments were encountered in Cedar and Silver Crown Lakes, 77% and 81%, respectively. Only Phalon and Elbow Lakes had significant amounts of gravel, 34% and 37 %, respectively. Total organic carbon ranged from approximately 7% to 31% and averaged about 20%.

Table 5. Grain Size and Total Organic Carbon Content of Sediment Samples (%).

Sample No. (1210038-)	Lake or Wetland	Depth Increment (cm)	Gravel	Sand	Silt	Clay	Total Organic Carbon
05	Cedar	0 - 10	0.0	22	31	46	11
23	Phillips	0 - 30	0.0	70	19	11	31
14	Silver Crown	0 - 50	0.0	19	55	26	17
52	Bowen*	0 - 10	0.0	39	53	8.2	7.0
19	Phalon	0 - 50	34	23	21	22	27
50	Elbow	0 - 10	37	34	11	19	27
51	Dilly	0 - 10	0.0	58	32	10	10
24	Dry*	0 - 10	0.0	30	40	30	15
53	Peterson*	0 - 10	0.1	62	33	5.3	19
55	Bodie*	0 - 10	0.0	40	52	8.0	9.1

*Wetland or wetland dominated

[3] The complete chemical data for this project can be accessed through Ecology's Environmental Information Management (EIM) System: www.ecy.wa.gov/eim; search User Study ID AJOH0066.

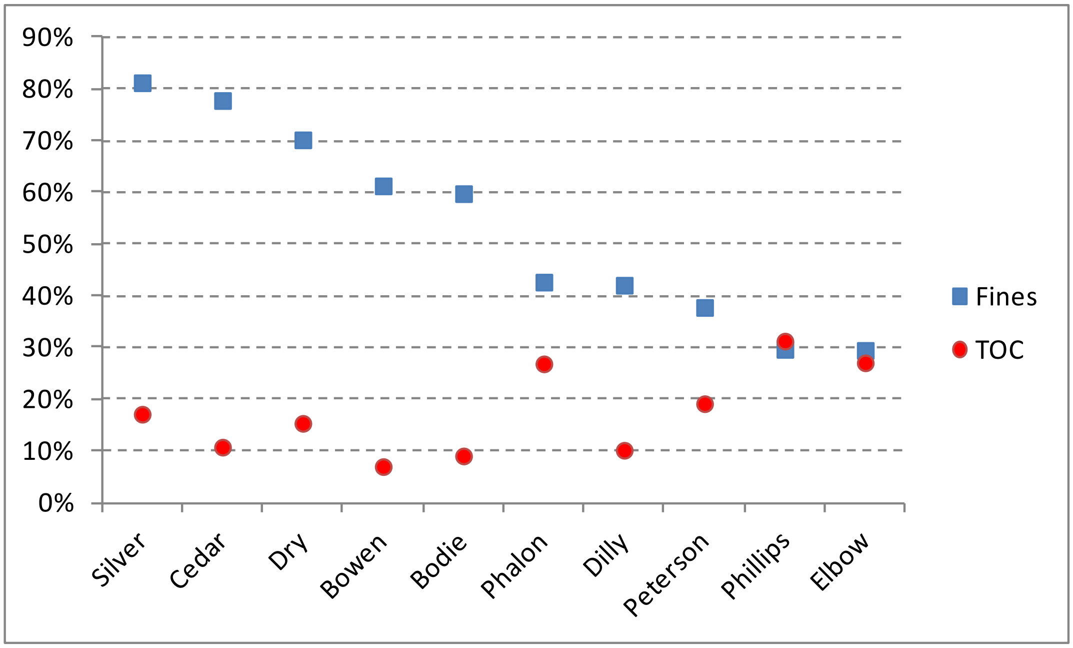


Figure 3. Percent Fines and Total Organic Carbon in Sediment Samples.

Metals Concentrations

Surface Sediments

Of the six metals analyzed, the highest concentrations in the surface sediments (top 10 cm layer) were for lead and zinc, followed by arsenic, cadmium, antimony, and mercury, in decreasing order (Table 6; parts per million). Total metals (last column of data) gives a sense of the overall variation in metals concentrations among these waterbodies. Higher levels were found in Silver Crown, Phillips, Cedar, Bowen, and Phalon Lakes in the north and central part of the study area, compared to Dilly, Dry, Peterson, and Bodie to the south or east and Elbow Lake to the west (Figure 4). Elbow Lake had one of the higher mercury concentrations.

Table 6. Metals Concentrations in Surface Sediments.
(mg/Kg, dry weight; top 10 cm layer)

Sample No. (1210038-)	Lake or Wetland	Lead	Zinc	Arsenic	Cadmium	Antimony	Mercury	Total Metals
01, 02, 03*	Cedar	408	341	24	10	14	0.13	796
20	Phillips	371	670	25	11	6.9	0.15	1,083
10	Silver Crown	545	947	45	17	15	0.28	1,569
52	Bowen†	262	256	26	7.2	4.8	0.09	556
15	Phalon	203	223	26	8.7	3.5	0.14	464
50, 59*	Elbow	76	101	16	3.0	1.8	0.16	198
51	Dilly	74	64	14	2.0	2.1	0.04	156
24	Dry†	34	27	11	4.5	2.3	0.06	78
53	Peterson†	13	72	6.0	0.77	0.81	0.06	92
55	Bodie†	16	62	1.1	0.52	0.24	0.01	80

*mean of replicate samples
†wetland or wetland dominated

A statistical summary of the data is provided in Table 7. The northern and centrally located lakes had significantly higher concentrations for all metals analyzed (Mann-Whitney test, $p<0.05$)[4]. Lead, zinc, and cadmium were higher by an order of magnitude. Antimony was elevated by a factor of about 6, and arsenic and mercury by factors of about 3 to 4.

[4] p represents the probability of an error in accepting a result as valid and representative of the population being sampled. At $p = 0.05$ there is a 5% probability that the difference in a variable measured in two groups of samples is due to chance.

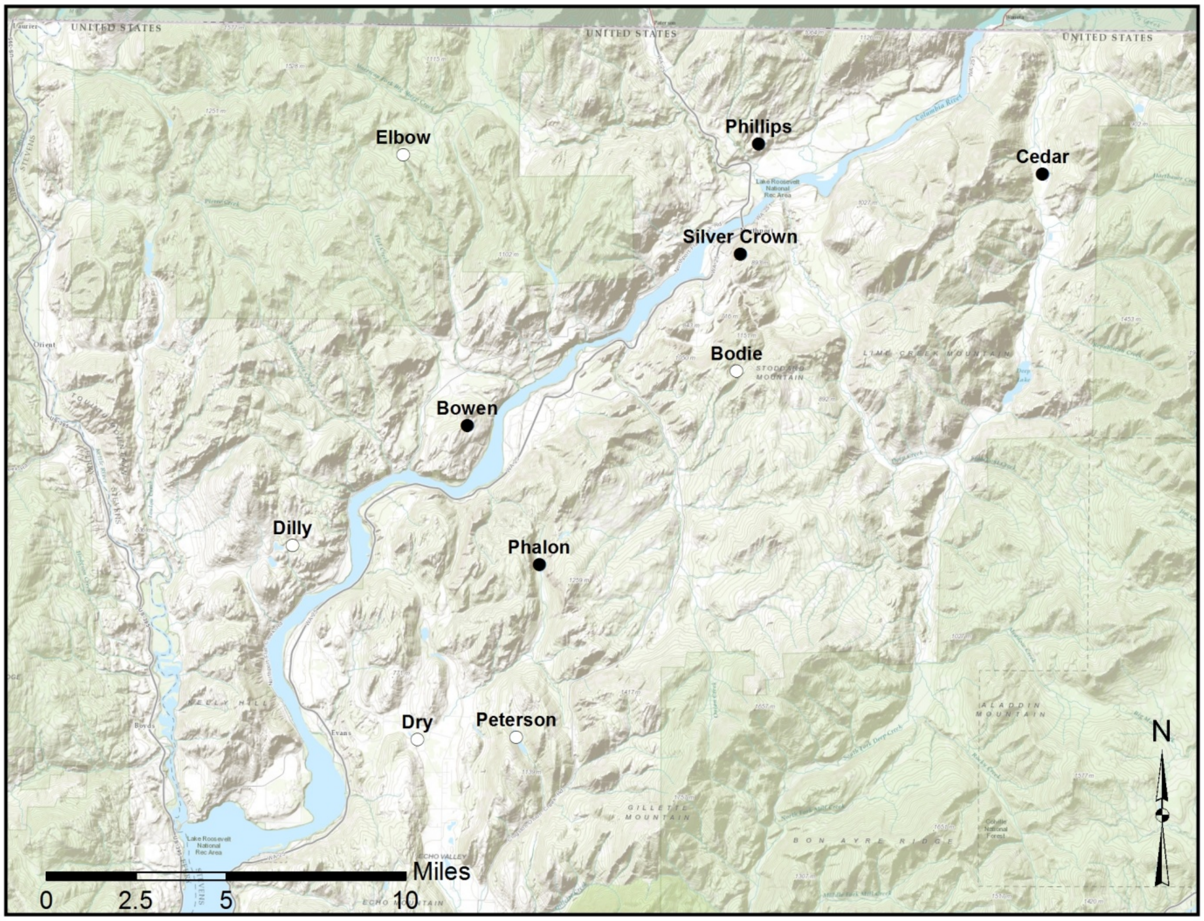


Figure 4. 2012 Study Area Waterbodies with the Highest Metals Concentrations.

Shown as filled markers.

Darker green shading generally identifies National Forest lands; lighter shading identifies primarily privately owned land areas.

Table 7. Statistical Summary for Metals in Surface Sediments: 2012 Waterbodies.
(mg/Kg dry weight, top 10 cm)

Location:	North / Central*	Other†	North / Central	Other	North / Central	Other
	Lead		**Zinc**		**Arsenic**	
N =	5	5	5	5	5	5
Median	371	34	341	64	26	11
Mean	358	43	487	65	29	10
Minimum	203	13	223	27	24	1.1
Maximum	545	76	947	101	45	16
90th Percentile	490	76	836	89	38	15
	Cadmium		**Antimony**		**Mercury**	
N =	5	5	5	5	6	4
Median	10	2.0	6.9	1.8	0.15	0.05
Mean	11	2.2	8.8	1.4	0.16	0.04
Minimum	7.2	0.5	3.5	0.2	0.09	0.01
Maximum	17	4.5	15	2.3	0.28	0.06
90th Percentile	14	3.9	15	2.2	0.22	0.06

*Cedar, Phillips, Silver Crown, Bowen, and Phalon (includes Elbow for mercury)
†Elbow, Dilly, Dry, Peterson, and Bodie (except Elbow excluded for mercury)
N = number of samples

Figure 5 ranks each waterbody by metals concentrations. The sediments in Silver Crown Lake consistently showed the highest comparative concentrations of lead, zinc, arsenic, cadmium, antimony, and mercury. Cedar and Phillips Lakes ranked second or third behind Silver Crown, except for arsenic where Bowen and Phalon Lakes had similarly elevated levels. Elbow Lake had the second highest mercury concentration, comparable to Phillips Lake. The lowest metals levels were found in the Bodie, Dry, and Peterson Swamp wetlands, and in Dilly Lake.

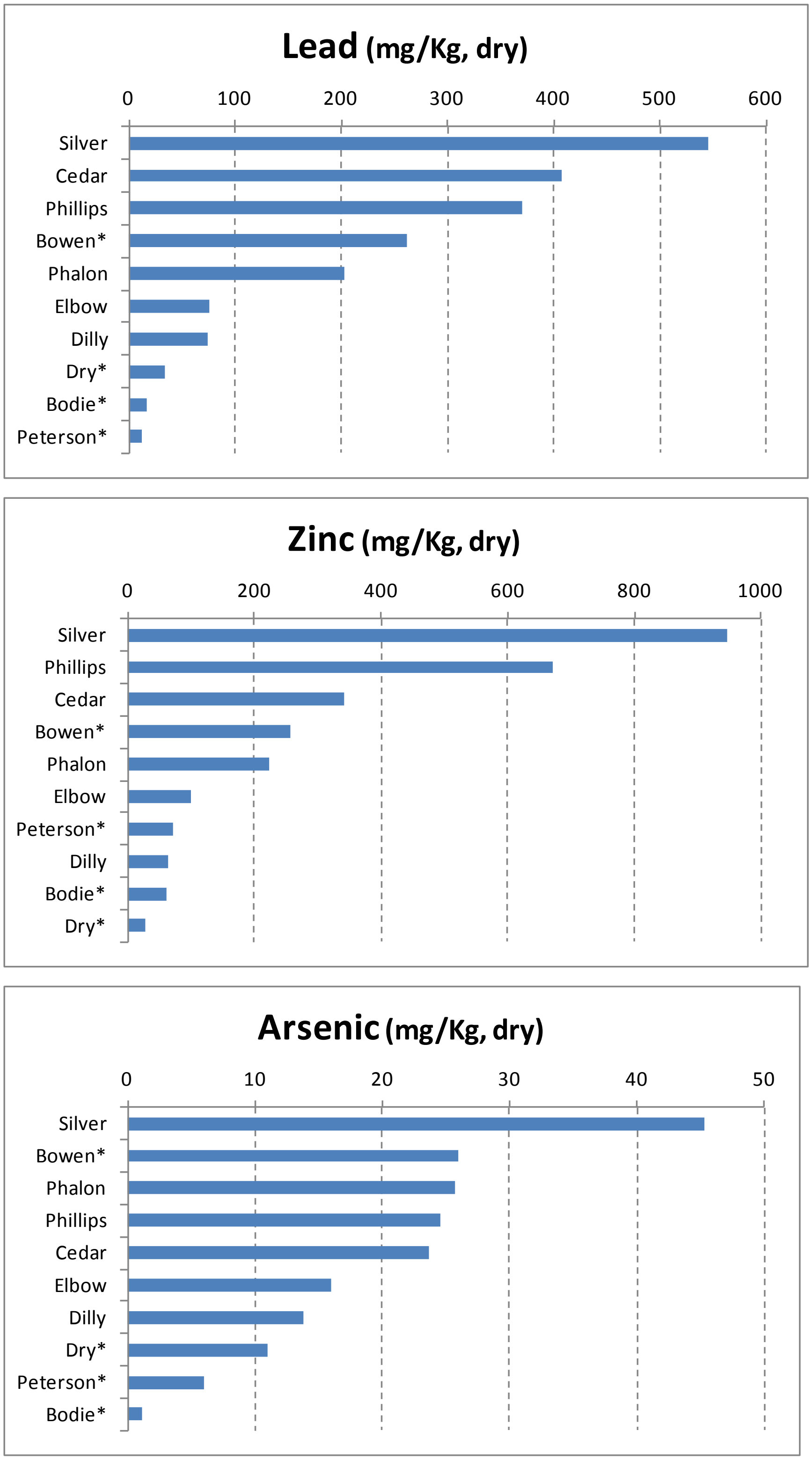


Figure 5. Waterbodies Ranked by Metals Concentrations in the Surface Sediments.

Top 10-cm layer; asterisk indicates wetland or wetland dominated.

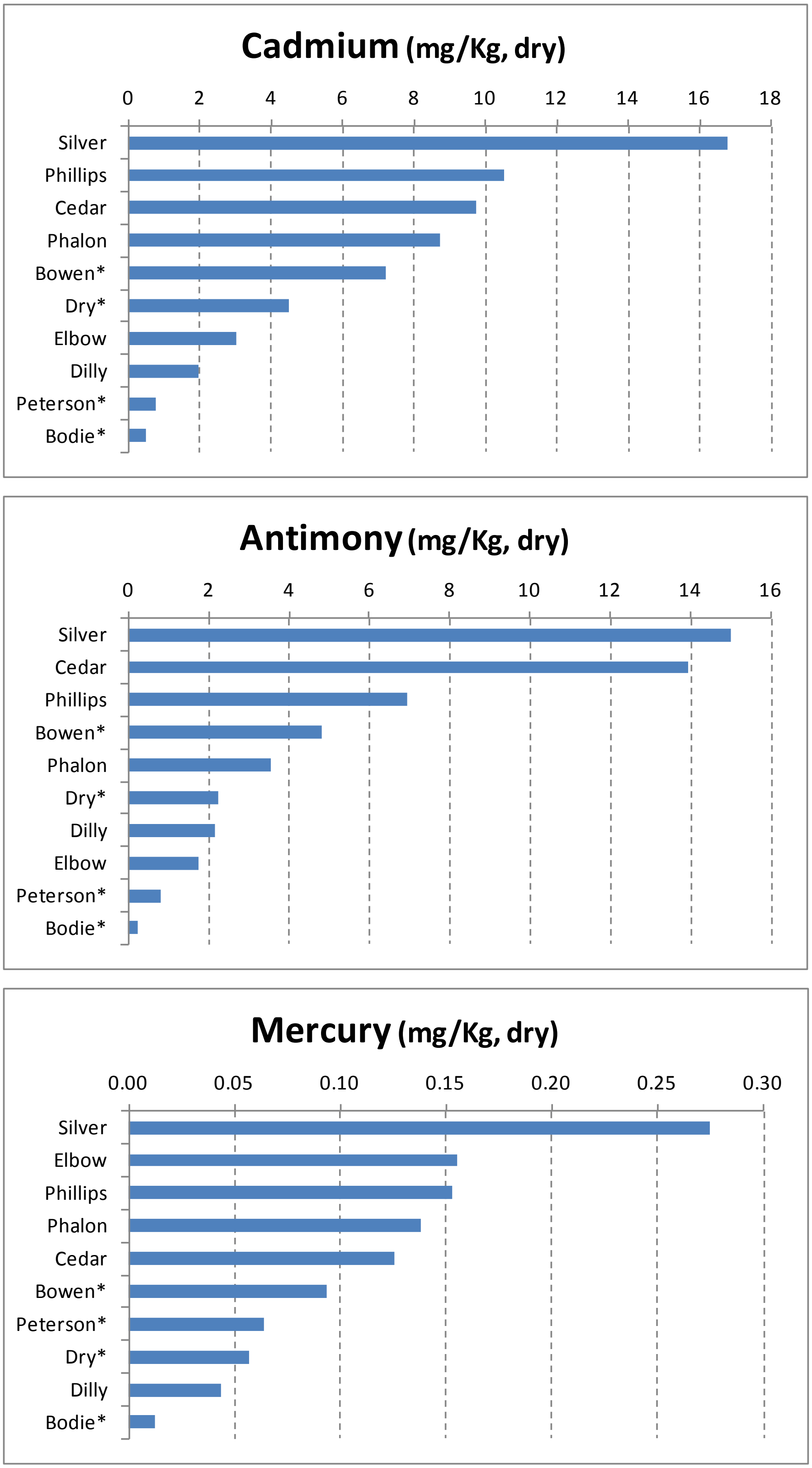


Figure 5. (continued)

Variability within Lakes

Cedar and Elbow Lakes, 2012

Replicate (separate) sediment samples were analyzed for Cedar and Elbow Lakes in 2012 (Table 8). The results provide (1) a perspective on spatial variability in these moderately-sized waterbodies and (2) comparability of the sampling techniques used.

Table 8. Comparison of Replicate Shallow (top 10 cm) Sediment Samples (mg/Kg, dry weight).

Sample No. (1210038-)	Lake/Site	Collection Method	Water Depth (ft)	Lead	Zinc	Arsenic	Cadmium	Antimony	Mercury
01	Cedar #1	Ponar	23	308	259	19	7.5	9.9	0.10
02	Cedar #2	Ponar	22	478	403	27	11	16	0.13
03	Cedar #3	Ponar	22	437	362	25	10	16	0.15
30, 31, 32*	Cedar #1	Box Corer	23	385	449	27	10	12	0.19
			RSD =	18%	22%	16%	17%	22%	25%
50	Elbow #1-#3	Ponar	13-16	70	99	15	2.9	1.5	0.13
59†	Elbow #1	K-B Corer	16	83	102	17	3.1	2.0	0.18
			RPD =	16%	3%	18%	4%	30%	29%

*thickness weighted average concentration for 0-6, 6-9, and 9-10 cm layers
† 0-10 cm layer
RSD: relative standard deviation; standard deviation as percent of mean value
RPD: relative percent difference; difference between duplicates as percent of mean value

Ponar grabs were taken at each lake along a three-point transect. The three Cedar Lake samples were spread over a line approximately 1,200 feet long, whereas the three Elbow Lake samples were spread over a line approximately 500 feet long (see sampling site maps, Appendix A). These transect samples were collected from the deeper, central portions of the lakes and did not include shallower side bank/littoral areas. The Cedar Lake grabs were analyzed separately while the Elbow Lake grabs were composited into a single sample. One core was also taken from the center of each lake. Results for the top 10 cm of the cores are shown in Table 8 for comparison with the grabs.

The replicate sample results provide another metric to assess the overall representativeness of the sediment metals data set. Metals concentrations measured in the replicates are comparably similar within each lake. Variability attributable to sampling methods (grabs or cores) and sample type (single sample or composite) appears to be low. Some of the observed differences in replicate metals concentrations are due to standard analytical variability, which averaged about 5% for lead, zinc, arsenic, cadmium, and mercury, but 16% for antimony (Table 4). Overall, the replicate sediment sample results suggest that metals concentrations within the deeper, interior portions of these moderate-sized upland lakes likely do not vary to a large degree at comparable depths.

Sampling Procedures 2012 vs. 2010

The sampling approach used for the 2012 investigation concentrated more on sediment from interior portions of each waterbody and did not necessarily follow the shallow-intermediate-deep sampling protocol applied in 2010. Metals concentrations in the finer grained sediments from the deeper portions of the lakes likely were higher than levels found in sediments from along the littoral or intermediate depth horizons which tend to be coarser grained. Composite samples from the 2010 study, which included more material from the lakeshore margins, may have shown a greater degree of dilution. Similarly, the wetland area sampling protocols were influenced by access, vegetation thickness, and presence/absence of open water.

Cedar Lake was the only waterbody sampled in both 2010 and 2012. The 2010 sample was a composite of two grabs taken in 23 and 17 feet of water. Portions of the lake shallower than 17 feet were too weedy to sample. In 2012, three separate grabs were collected, confined to the deeper portions of the lake (22-23 feet), as previously described. In both cases, a 0.05 m^2 Ponar grab was used and the top 10 cm layer analyzed. The metals concentrations in these samples are compared in Table 9.

Table 9. Metals Concentrations in Cedar Lake Sediment Grabs (top 10 cm) Collected in 2012 and 2010 (mg/Kg, dry weight).

Year Collected	Sample Description	Water Depths (ft)	Lead	Zinc	Arsenic	Cadmium	Antimony	Mercury
2012	3 grabs (mean)	22-23	408	341	24	9.8	14	0.13
2010	2 grab composite	24 and 17	141	151	12	3.0	3.4	0.08

Metals concentrations were much higher in the 2012 samples. This may reflect finer grain size in the deeper parts of the lake and metals dilution in shallower water, as alluded to above. Sub-sampling procedures used to remove the top 10 cm layer could also be a contributing factor. The box core from Cedar Lake showed steep gradients in metals concentrations in the surface sediments, particularly in the vicinity of 10 centimeters (see *Chronology of Metals Deposition*). Thus, a small variation between surveys in the depths and relative amounts of material taken from the grabs could have a marked effect on the results.

Subsurface Sediments

Sediment cores were obtained from four of the northernmost lakes (Cedar, Phillips, Silver Crown, and Elbow) and one of the southern lakes (Phalon) in the 2012 study area. The cores were sectioned and analyzed in 10 or 20 cm increments, except for Cedar which was sectioned in greater detail for age-dating.

Metals concentrations from discrete depth intervals within the cores are shown in Table 10. For comparison, the Cedar Lake box core data were averaged for the sections of interest. For all of these lakes, metals concentrations in the top 10 or 20 cm of the sediment core were much higher than in the deeper layers. Note that penetration depths of the cores varied somewhat.

Table 10. Depth-Specific Metals Concentrations in Sediment Core Samples (mg/Kg, dry weight).

Sample No. (1210038-)	Depth Increment (cm)	Lead	Zinc	Arsenic	Cadmium	Antimony	Mercury
Cedar Lake*							
31, 32	0-10*	385	449	27	10	12	0.19
33 - 39	10-20	25	70	14	1.0	1.4	0.05
40, 41	20-30†	2.5	67	19	0.7	1.7	0.05
42, 44	30-40**	2.3	99	24	1.2	2.3	0.04
Silver Crown Lake							
10	0-10	545	947	45	17	15	0.28
11	10-20	864	619	55	26	18	0.28
12	20-30	13	64	8.0	0.42	0.50	0.03
13	30-50	2.9	32	2.8	0.16	<0.41	0.01
Phillips Lake							
20	0-10	371	670	25	11	6.9	0.15
21	10-20	263	351	23	7.5	5.5	0.09
22	20-30	9.3	70	4.5	0.59	0.72	0.05
Elbow Lake							
59	0-10	83	102	17	3.1	2.0	0.18
56	10-20	106	122	19	3.5	2.7	0.12
57	20-30	10	94	17	1.7	0.76	0.06
58	30-40	14	100	15	1.8	1.2	0.05
Phalon Lake							
15	0-10	203	223	26	8.7	3.5	0.14
16	10-20	20	119	16	4.5	0.76	0.05
17	20-30	4.7	127	17	4.5	0.87	0.04
18	30-50	6.1	137	19	5.3	0.95	0.03

*thickness weighted average of 0-6, 6-9 and 9-10 cm layers
†average of 22-24 and 26-28 cm layers
**average of 30-32, 34-36, and 36-38 cm layers

The core sample results also were used to compute enrichment factors for each metal at each lake (Table 11, Figure 6). The computed enrichment factor represents the ratio of a given metals concentration in the top 10 cm interval divided by the corresponding concentration in the lowermost bottom 10 or 20 cm interval, as sectioned. The highest measured enrichment factors for all six metals were observed at Silver Crown Lake; enrichment factors in the Silver Crown core exceed 100 for both lead and cadmium, and 15 for the remaining four metals. At Cedar, Phillips, and Phalon Lakes, lead enrichment factors of 171, 40, and 33 are present. Mercury and arsenic concentrations showed the smallest difference between surface and subsurface layers, with enrichment factors of 6 or less for all lakes except Silver Crown. Based on the time horizons observed in the Cedar Lake core, metals concentrations in the deepest layers likely are approaching natural, pre-industrial background levels (see discussion that follows).

Table 11. Metals Enrichment Factors for Surface vs. Subsurface Sediments in Core Samples. *Top 10 cm concentration divided by bottom 10 or 20 cm concentration, as sectioned.*

	Silver Crown	Phillips	Cedar	Phalon	Elbow
Lead	189	40	171	33	6.1
Cadmium	105	18	9.0	1.6	1.7
Antimony	36	10	4.5	3.7	1.8
Zinc	30	10	5.0	1.6	1.0
Mercury	21	3.2	5.1	4.1	3.7
Arsenic	16	5.5	1.0	1.4	1.1

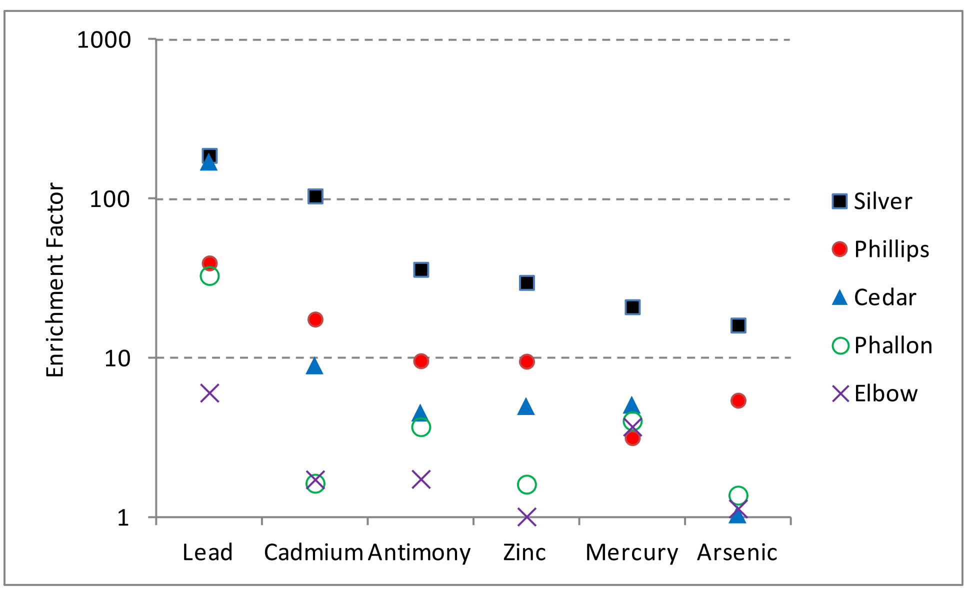


Figure 6. Metals Enrichment Factors for Surface vs. Subsurface Sediments in Core Samples.

Chronology of Metals Deposition

Cedar Lake

Cedar Lake, located about four miles south of the international border, is situated in a valley meadow surrounded by forested uplands. The 51-acre lake has a maximum depth of 24 feet. Cedar Lake has no defined surface water inlet. The lake serves as the headwaters for Cedar Creek which flows north, eventually discharging to the Pend Oreille River in British Columbia. The lake has two private residences and a public boat launch.

The Cedar Lake box core was dated using the lead-210 technique (see *Sediment Dating Calculations*). The metals, lead-210, and percent solids data for the core are presented in Appendix C.

The core was analyzed in 1 – 2 cm increments, except for a 6-cm layer at the surface because the material was too soft to section accurately. For the deeper parts of the core, alternating layers were analyzed (e.g., 18-20 cm, 22- 24 cm). As previously noted, there is increased uncertainty in lead-210 dates older than 150 years.

Sedimentation Rates

Estimates of sedimentation rates in Cedar Lake are shown in Figure 7. The supporting data are in Appendix D.

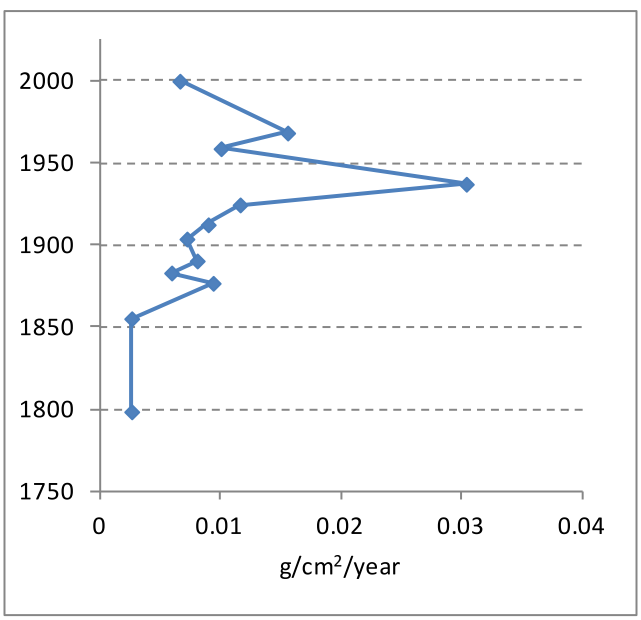


Figure 7. Sedimentation Rate Estimates for Cedar Lake.

Until the latter part of the 1800s, the sedimentation rate in Cedar Lake was low, approximately 0.003 g/cm^2/year. Beginning around 1900, sediment deposition began to accelerate rapidly, reaching a maximum of about 0.03 g/cm^2/year in the 1940s, an increase of a factor of 10. Logging and associated factors may be the primary reason for the increase. Recent rates (top 6 cm, past 30 years) have averaged about 0.01 g/cm^2/year, or three times the rate in the early- to mid-1800s.

Metals Deposition

Figure 8 illustrates how metals concentrations have changed over time in Cedar Lake sediments. Lead, zinc, cadmium, antimony, and mercury have generally similar profiles. Concentrations remained relatively unchanged until the late 1800s, followed by a period of fluctuating concentrations. For lead, zinc, cadmium, and antimony, the initial positive spike in the profile is primarily due to a single data point estimated at 1890. For unknown reasons, arsenic shows a contrasting pattern of overall decreasing concentrations from the earliest core layers into the 1900s.

Sedimentation rates began rising during the early 1900s (Figure 7) which may explain decreasing concentrations of all metals during this specific time, prior to increasing smelter influences. The diluting effect that local erosion and sedimentation can have on metals concentrations has been observed in other coring studies (Engstrom et al., 2007).

All metals increased rapidly during the first half of the 20^{th} century, peaking in the 1950s or 1960s for lead, zinc, cadmium, and antimony. Arsenic and mercury appear to continue increasing. However, because of the way the core was sectioned, the recent history of metals deposition cannot be seen in detail.

The time sequence of metals concentration changes in Cedar Lake sediments is consistent with the history of the Trail B.C. smelter (Appendix E). Smelter operations have been underway almost continuously since 1896. Around 1900, the smelting of lead sulfide ores began. Electrolytic zinc and copper refineries came on line in 1916. Cadmium recovery began in 1927. In 1931, operations expanded to include the manufacturing of ammonium sulfate and ammonium phosphate fertilizer.

Baghouses to better recover dust and condensed fume from lead blast-furnace offgas were installed at Trail in 1951 (Queneau, 2010). In 1997, the Kivcet lead smelter was commissioned, which decreased stack emissions of particulates, lead, arsenic, mercury, fluoride, and SO_2 by 68 to 98%.

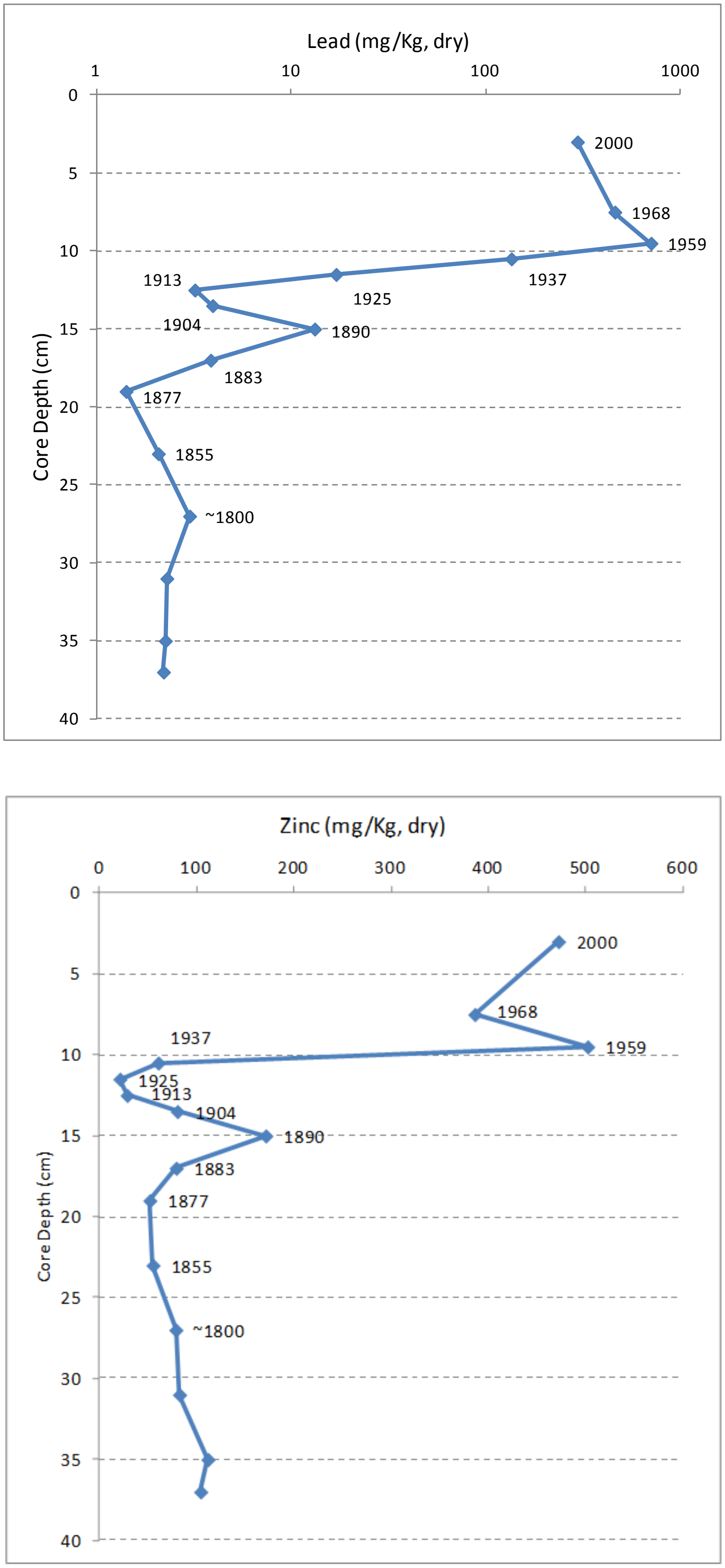
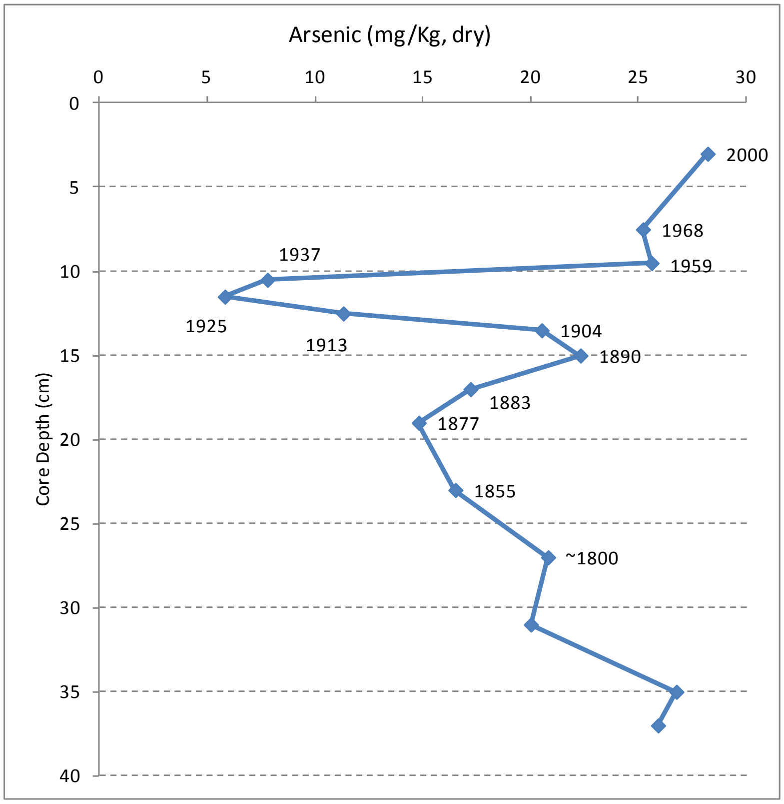


Figure 8. Chronology of Metals Deposition in Cedar Lake.



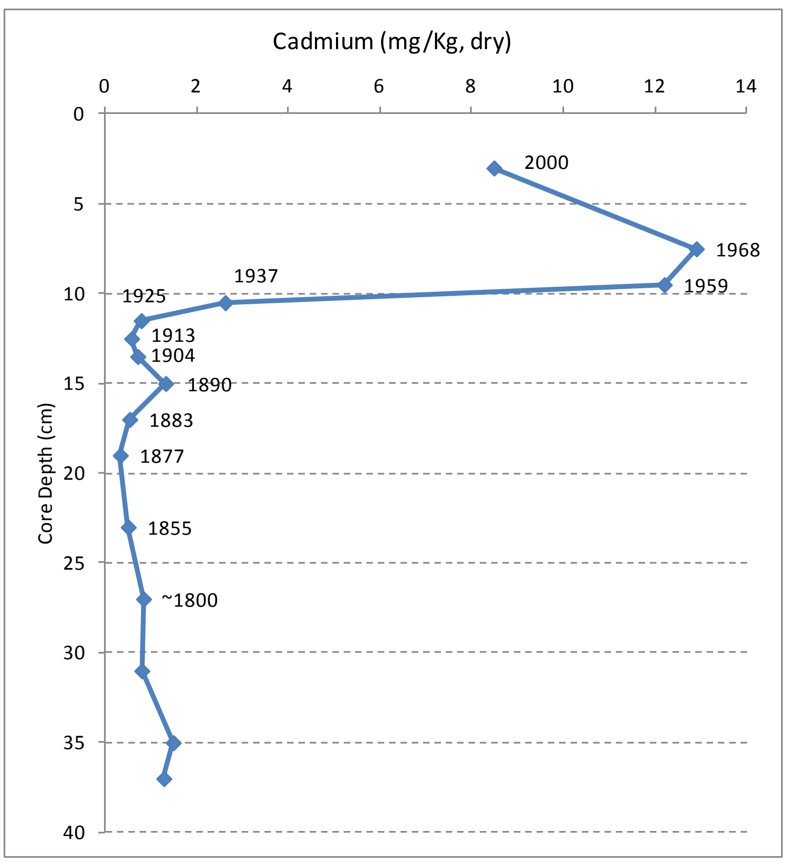
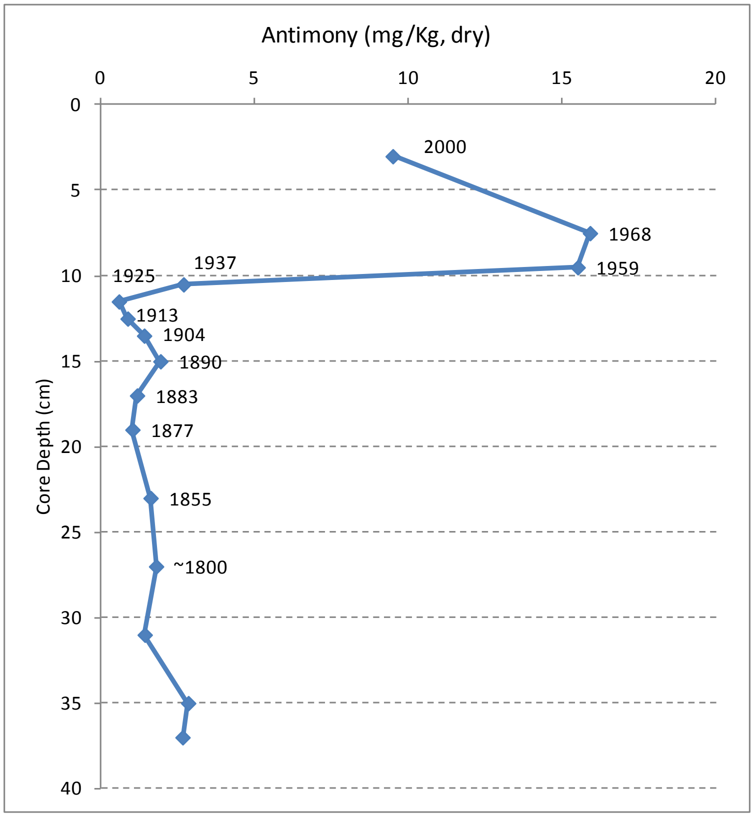


Figure 8. (continued)



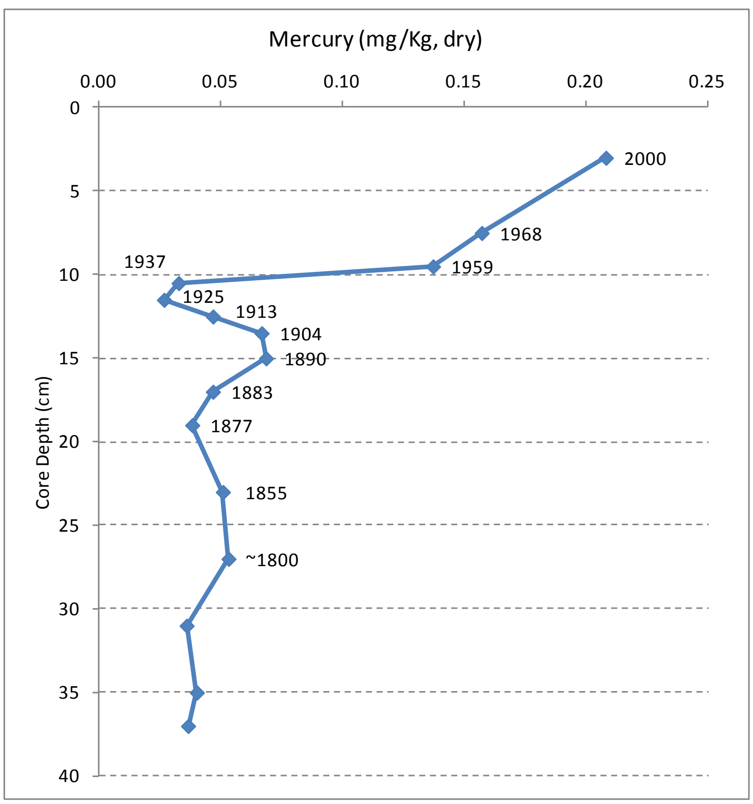


Figure 8. (continued)

Thus, the first half of the 1900s was a period of ramped-up production, and it was not until the 1950s that more notable steps were taken to begin reducing metal emissions from the lead smelter (Queneau, 2010). Based on the CRS model used to date the Cedar Lake core, lead flux to the sediments over this timeframe (sedimentation rate x lead concentration) increased from 0.01 ug/cm^2/year in the 1800s to 4 – 7 ug/cm^2/year in the early to mid-1900s, decreasing to an average of 2 ug/cm^2/year in the recent 30-year past.

Pre-industrial concentrations of lead and mercury in Cedar Lake sediments are approximately 2.5 mg/Kg and 0.044 mg/Kg, respectively. These are the average values for the deepest layers of the core (older than 1890) where measured concentrations appear to be stable. Enrichment factors in more recent sediment layers are as high as 280 for lead and 5 for mercury (Table 12).

Table 12. Pre-Industrial-Core-Measured Average Concentrations and Enrichment Factors for Lead and Mercury in the Cedar Lake Sediment Core.

Metal	Mean Pre-Industrial Concentration (mg/Kg, dry)	Peak Concentration		Recent Concentration	
		Enrichment Factor	Estimated Date	Enrichment Factor	Estimated Date
Lead	2.5 (<1890)	280	1958*	120	2000†
Mercury	0.04 (<1890)	5	2000†	5	2000†

*9 - 10 cm layer
†0 - 6 cm layer

Sediment Profiles from Other Areas

The sediment profiles for lead and mercury in Cedar Lake were compared to box cores Ecology has collected from two lakes in other parts of eastern Washington (Figure 9). Black Lake is 26 miles due south of Cedar Lake. Current land use in the watershed is largely undeveloped forest, with some vacation homes and a small resort. The lake has intermittent surface inflow and outflow. Wenatchee Lake lies to the west in the alpine region of the North Cascades in central Washington. The lake basin is undeveloped, with less than 1% of the drainage put to residential use. Inflows are intermittent.

The lead and mercury data for Black and Wenatchee Lakes are from Furl and Roberts (2010, 2011). The Black Lake metals profile – including previously unpublished results for zinc, arsenic, cadmium, antimony, and other metals – was reviewed in Ecology's report on the 2010 northeast Washington sediment survey (Johnson et al., 2011).

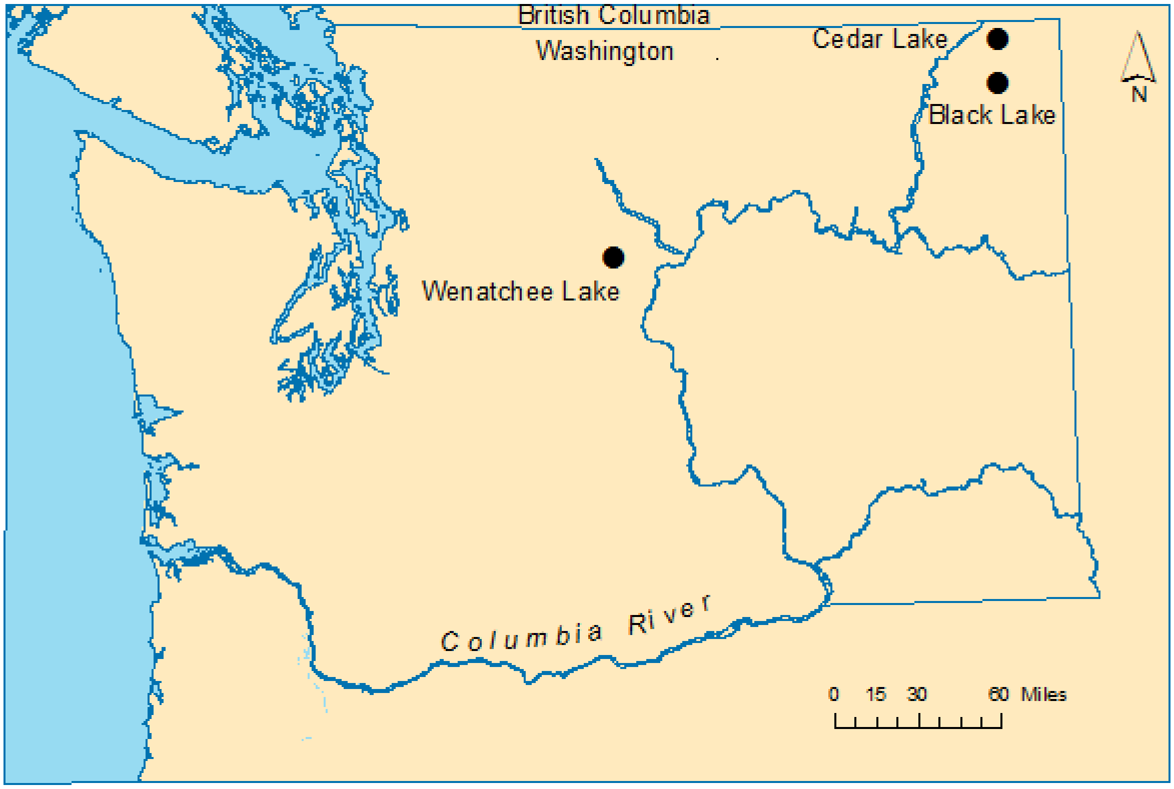


Figure 9. Location of Sediment Cores Compared for Lead and Mercury.

The lead and mercury profiles in these three cores are shown in Figures 10 and 11, respectively. For comparative purposes, the time span begins around 1900, the deepest penetration of the Wenatchee Lake core. Note that the X-axis scale of metals concentrations is different for each lake.

Wenatchee Lake has typical lead and mercury profiles for a nonpoint-source, forested watershed in Washington with low levels of contaminants (Mathieu, 2013). Lead concentrations remained low (< 15 mg/Kg) throughout the 1900s, experiencing only modest increases during the middle part of the century. Levels have continually decreased since peaking in the 1960s and 1970s, and are currently less than 10 mg/Kg. These changes can be attributed to the use of alkyl-lead additives in gasoline beginning in the 1920s and their removal from gasoline in the mid-1970s (Furl and Roberts, 2011).

Mercury levels remained fairly constant in Wenatchee Lake throughout the 1900s, confined to the narrow range of 0.08 – 0.10 mg/Kg. The exception was a slight increase in the late 1990s coinciding with the maximum sedimentation rate (Appendix D). In the absence of local sources, most of the mercury deposited in Washington lakes comes from the regional and global atmospheric reservoir (Furl, 2008).

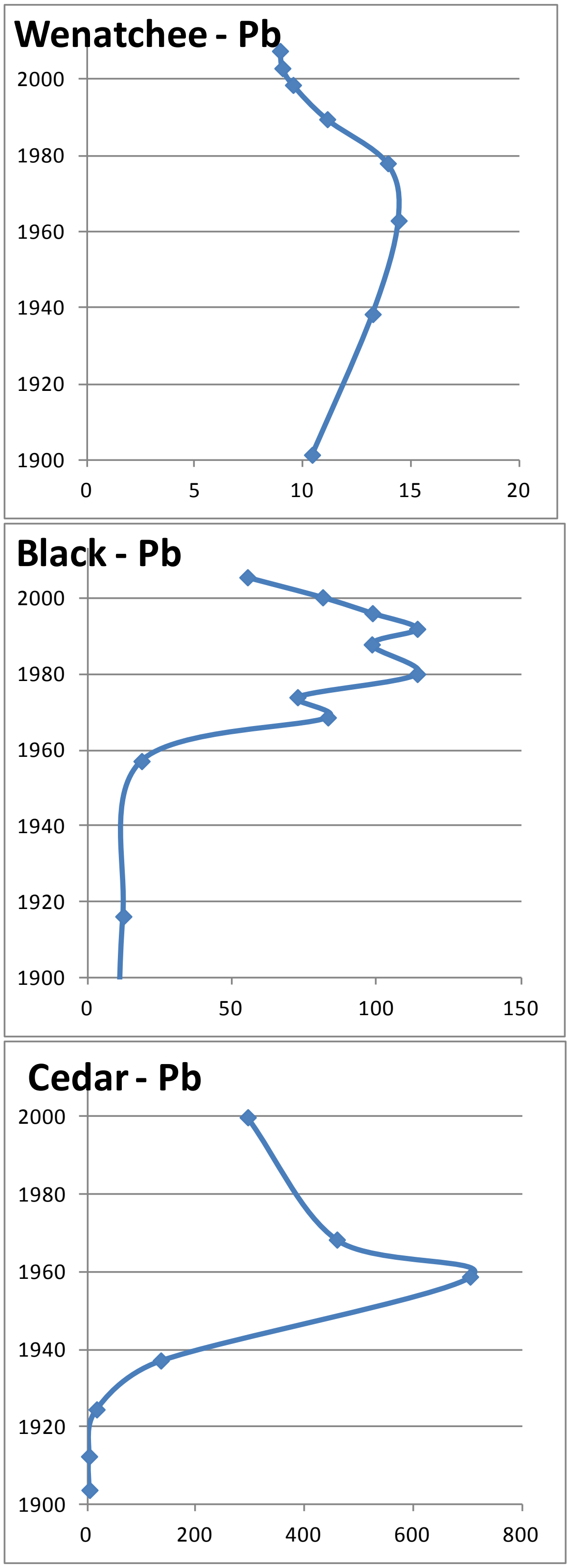


Figure 10. Lead Profiles in Sediment Cores from Cedar, Black, and Wenatchee Lakes (mg/Kg, dry weight).

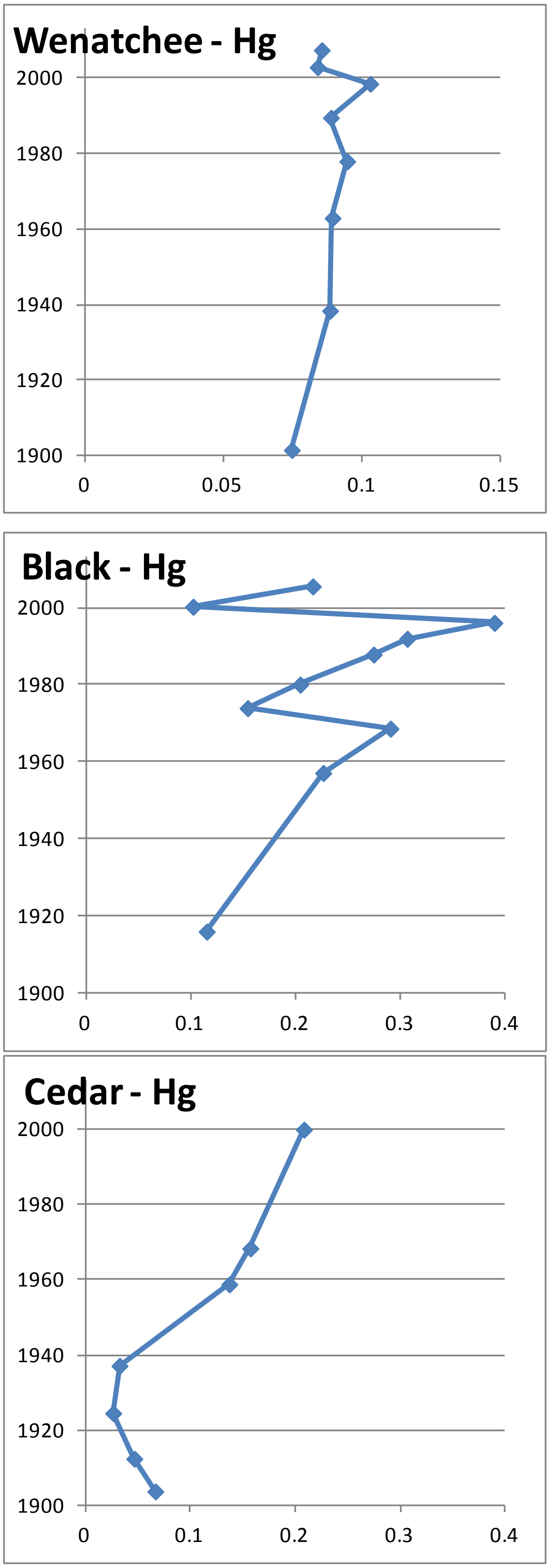


Figure 11. Mercury Profiles in Sediment Cores from Cedar, Black, and Wenatchee Lakes (mg/Kg, dry weight).

Lead and mercury levels in the Black Lake core are higher than expected for a nonpoint-source lake (Mathieu, 2013). Lead began to gradually increase after 1920 (from 12 to 19 mg/Kg) and accelerated rapidly in the 1960s and 1970s, reaching 115 mg/Kg vs. a peak concentration of 14 mg/Kg in Wenatchee Lake in the late 1990s. Since the early 1990s, concentrations in Black Lake have consistently decreased. The most recent sediments contain lead concentrations near 50 mg/Kg, compared to less than 10 mg/Kg in Wenatchee Lake.

The Black Lake mercury profile displays an erratic pattern with several large concentration changes over a short time period. Mercury showed significant elevation by the mid-1950s. Concentrations declined briefly before a steady rise to the overall maximum value of 0.40 mg/Kg in the late 1990s. The changes in mercury concentrations appeared to be strongly affected by sedimentation rates: periods of increasing concentrations were marked by falling sedimentation rates and vice versa (Appendix D). Furl and Roberts (2011) have observed a lack of resemblance among mercury sediment core profiles in eastern Washington lakes in general. They conclude that basin activity and local sediment geochemistry play a large role in moderating fluxes to the sediments.

Pre-industrial (oldest) vs. peak concentrations of lead and mercury in Cedar, Black, and Wenatchee Lakes, from approximately 1900 to the present, are compared in Table 13. Values at the turn of the century were not greatly different, 4 - 12 mg/Kg for lead and 0.07 - 0.12 mg/Kg for mercury. The peak concentrations reached for lead represent enrichment factors of approximately 200 and 10 in Cedar and Black Lakes, respectively. The rate of increase was slower, and the maximum lead concentration occurred later in Black Lake (1992) than in Cedar Lake (1953). Considering the Trail smelter as a predominant source of contamination and assuming the core dates are representative, this may reflect a quicker response to evolving smelter emission patterns and mechanisms by the closer lake as well as variations in emissions transport and deposition behavior across the area. Enrichment factors for lead in the surface sediment layer of Cedar and Black Lakes are now about half of peak enrichment.

Mercury concentrations in Cedar and Black Lake sediments have also increased over time but to a lesser extent. Compared to earliest concentrations, enrichment factors are 2 – 3 compared to slightly more than 1 in Wenatchee Lake. The notably different sediment enrichment factors for lead and mercury may be related, in part, to the predominant form (particulate versus aerosol) these metals were in when atmospherically transported and deposited. Differences in the biological and geochemical processes affecting sorption and fate of these metals in the lacustrine environment also could be a factor.

Table 13. Concentrations and Enrichment Factors for Lead and Mercury in Sediment Cores from Cedar, Black, and Wenatchee Lakes (since approximately 1900).

Lake	Early 1900s (mg/Kg, dry)	Peak Concentration		Recent Concentration	
		Enrichment Factor	Estimated Date	Enrichment Factor	Sediment Layer Analyzed (cm)
Lead					
Cedar	4 (1904)	197	1958	83	0 - 6
Black	12 (1916)	9	1992	4	0 - 2
Wenatchee	10 (1902)	1.4	2005	0.9	0 - 2
Mercury					
Cedar	0.07 (1904)	3	2000	3	0 - 6
Black	0.12 (1916)	3	1996	2	0 - 2
Wenatchee	0.08 (1902)	1.4	1999	1.1	0 - 2

Comparison with Sediment Quality Guidelines

The report on Ecology's 2010 northeast Washington lakes survey concluded with an assessment of the potential for adverse biological effects due to elevated metals concentrations in the sediments (Johnson et al., 2011). Some degree of sediment toxicity appeared likely in lakes from the western part of the study area. This observation was based primarily on a comparison with the sediment quality guidelines in MacDonald et al. (2000). A similar assessment follows for the lakes and wetlands Ecology sampled in 2012.

MacDonald et al. developed a set of consensus-based sediment quality guidelines for protecting freshwater ecosystems, derived from values proposed by six federal, state, or provincial agencies in North America. MacDonald et al. presents (1) threshold effect concentrations (TECs) intended to identify the concentrations of sediment-associated contaminants below which adverse effects on sediment-dwelling organisms are not expected to occur and (2) probable effect concentrations (PECs) intended to define the concentrations of sediment-associated contaminants above which adverse effects on sediment-dwelling organisms are likely to be observed. The MacDonald et al. PECs are commonly used to screen sediment chemistry data for potential to adversely affect aquatic life.

Table 14 compares the MacDonald et al. PECs to the range of metals concentrations measured in surface sediment samples from the present study. MacDonald et al. does not include guidelines for antimony.

Table 14. Comparison of 2012 Lake/Wetland Surface Sediment Sample Data to Freshwater Sediment Quality Guidelines (mg/Kg, dry weight).

Chemical	Probable Effect Concentrations*	North / Central Waterbodies**	Other Waterbodies††
Lead	128	203 - 545	13 - 76
Zinc	459	223 - 947	27 - 101
Arsenic	33	24 - 45	1.1 - 16
Cadmium	5.0	7.2 - 17	0.5 - 4.5
Mercury	1.1	0.09 - 0.28	0.01 - 0.06

*MacDonald et al. (2000)
**Cedar, Phillips, Silver Crown, Bowen, and Phalon (includes Elbow for mercury)
††Elbow, Dilly, Dry, Peterson, and Bodie (except Elbow excluded for mercury)

All of the northern and centrally located lakes – Cedar, Phillips, Silver Crown, Bowen, and Phalon – exceed one or more probable effects thresholds for lead, zinc, arsenic, and cadmium.

Exceedance factors (metals concentration divided by guideline) are plotted in Figure 12. Note that the concentrations are on a log scale (factors of 10). In these waterbodies, cadmium and lead appear to be the metals of greatest concern for adverse effects to sediment-dwelling organisms based on the available PECs. Silver Crown, Cedar, and Phillips Lakes have the highest potential for sediment toxicity.

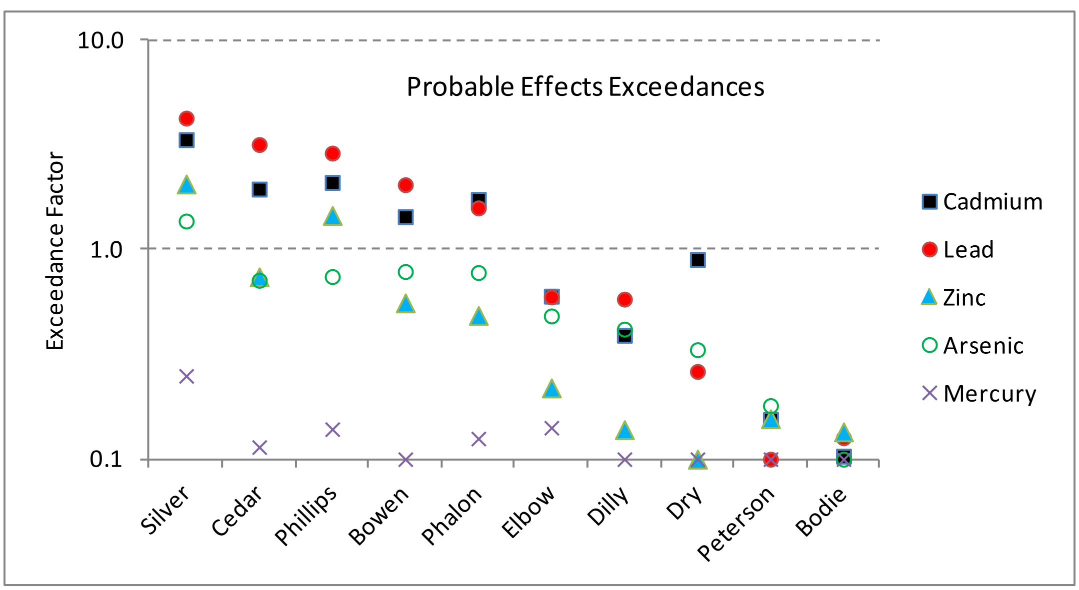


Figure 12. Exceedances of Sediment Quality Guidelines in Surface Sediments.

Values >1 exceed guideline; log scale.

Northeast Washington Spatial Patterns

Metals Concentrations

Lead, zinc, arsenic, cadmium, antimony, and mercury data on surface sediments from Ecology's 2010 and 2012 sediment surveys are overlaid on a map of the study area in Figures 13 - 18. Cedar Lake was sampled in both 2010 and 2012; the 2012 data are shown here. The figures include average surface layer concentrations from the Black Lake core (Furl and Roberts, 2010; Johnson et al., 2011). In all, metals data have been obtained on the sediments of 26 lakes and wetlands in the northeast Washington area.

The 2012 findings are consistent with, and help refine, the spatial patterns identified during the 2010 survey:

1. Higher concentrations of lead, zinc, arsenic, cadmium, antimony, and mercury occur in lake sediment from the western part of the northeast Washington study area.
2. Sediment from lakes located closest to the Upper Columbia River valley shows an overall northward-increasing metals concentration trend, with highest concentrations typically observed in lakes located nearer to the international border.
3. Mercury appears to be dispersed more broadly, across the west and north-central portions of the study area, than is observed for lead, zinc, arsenic, cadmium, and antimony.

Mercury differs from the other metals analyzed in being subject to complex biogeochemical cycling that can strongly affect its behavior in a lake (Rudd, 1995; Engstrom et al., 2007; Furl et al., 2009). Land use and rainfall also can greatly modify the net flux of mercury to a lake by altering sedimentation rates. Such complicating factors may be at play in the apparent westward shift seen for mercury, along with variations in gaseous or particulate smelter emissions transport and fate relative to other metals.

Pepoon Lake and Bodie Wetland have lower metals concentrations than might be expected, given their relative locations. Aside from the potential for unknown local watershed factors, two related factors may inform these results: (1) Each are at a higher elevation relative to the other sampled waterbodies in this immediate area near the river (2,450 and 3,200 feet, respectively), and (2) due to their locations, Pepoon and Bodie may have been less affected by the historical air pollution plume from the Trail smelter. Both are located along or beyond the outer fringe of the 1930s SO_2 injury boundary and not within the highest impact zone bounding the river corridor. (See *Sources of Contamination*.)

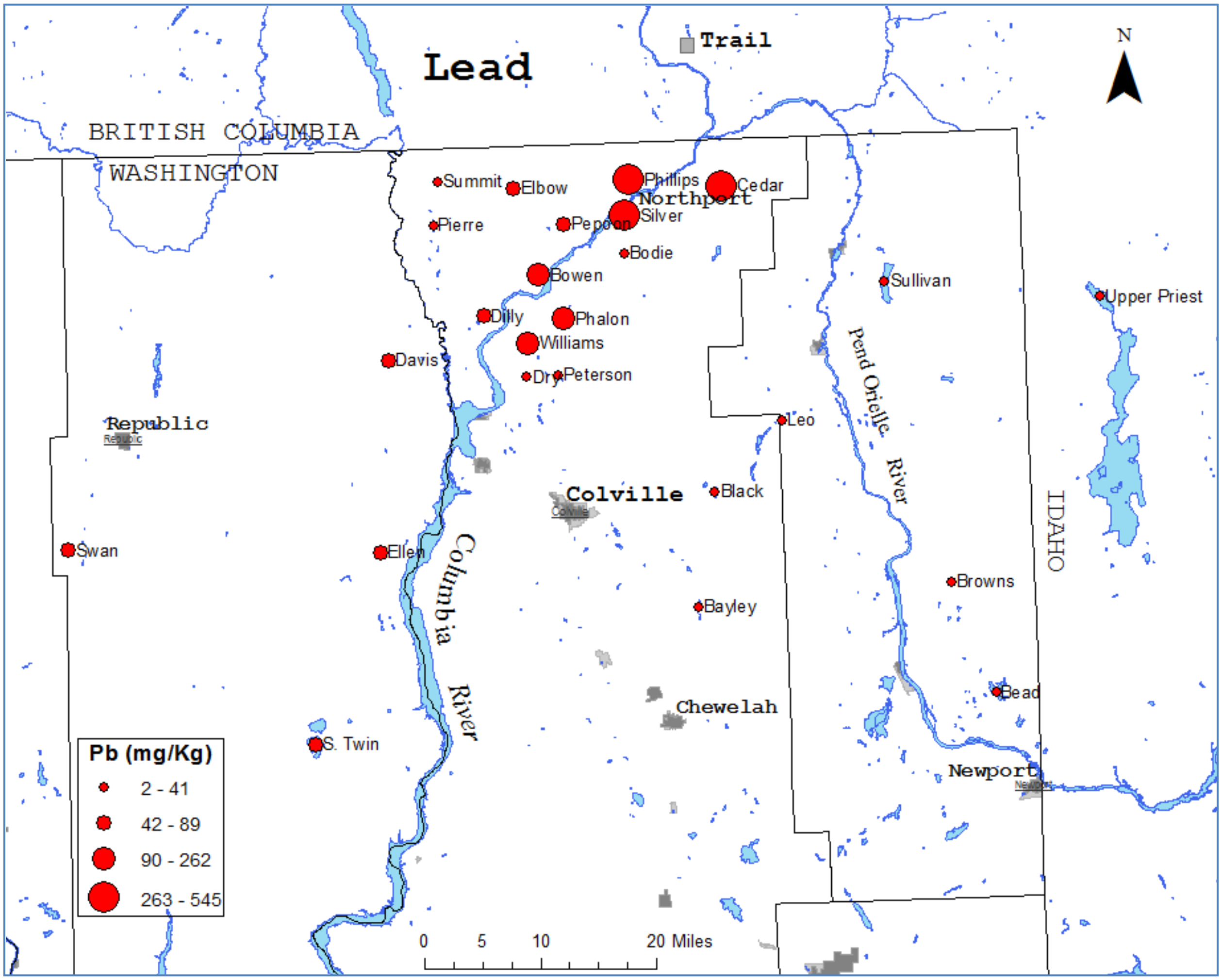


Figure 13. Lead Concentrations in Lake and Wetland Sediments of Northeast Washington, 2009-2012. (Top 10 cm layer)

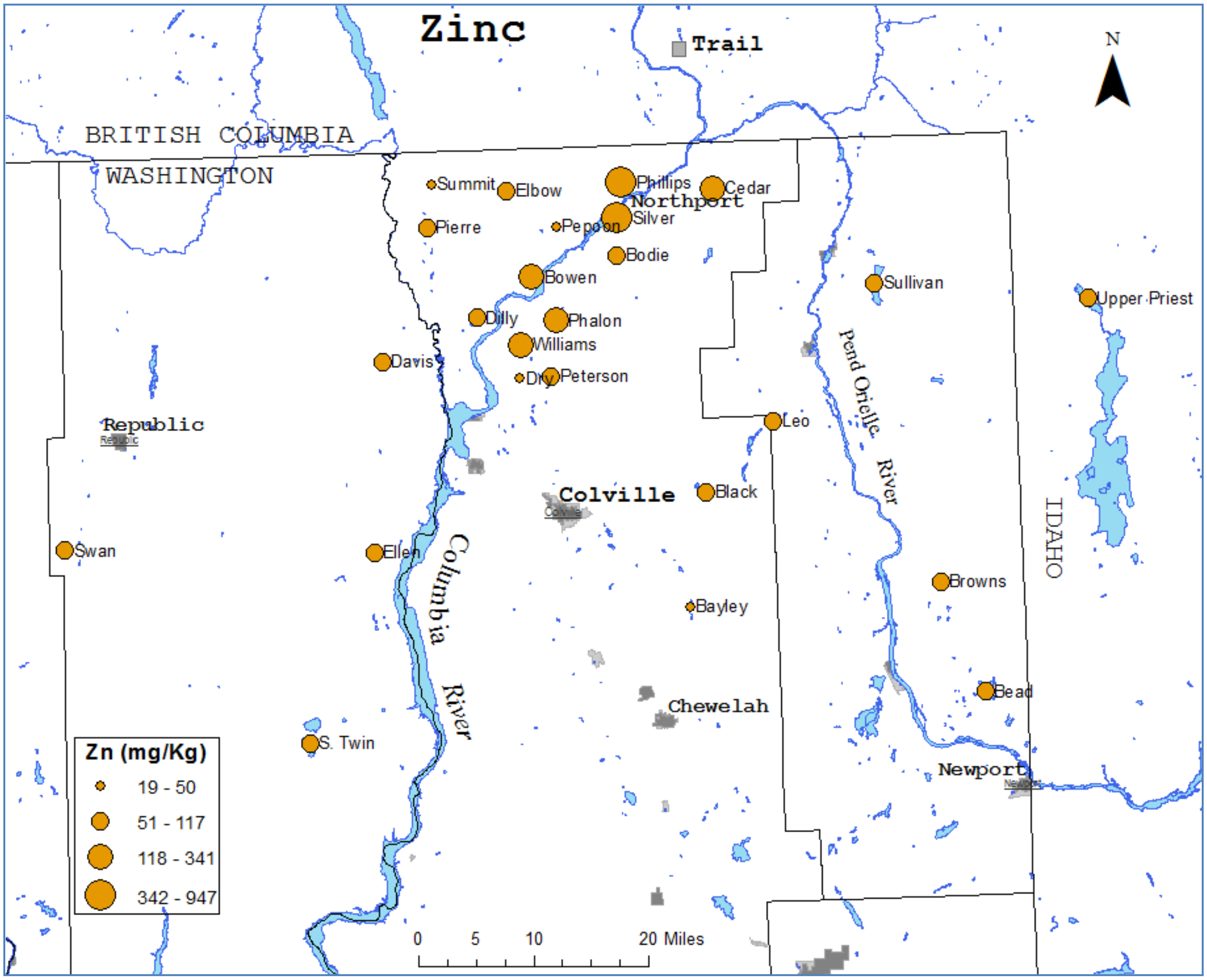


Figure 14. Zinc Concentrations in Lake and Wetland Sediments of Northeast Washington, 2009-2012. (Top 10 cm layer)

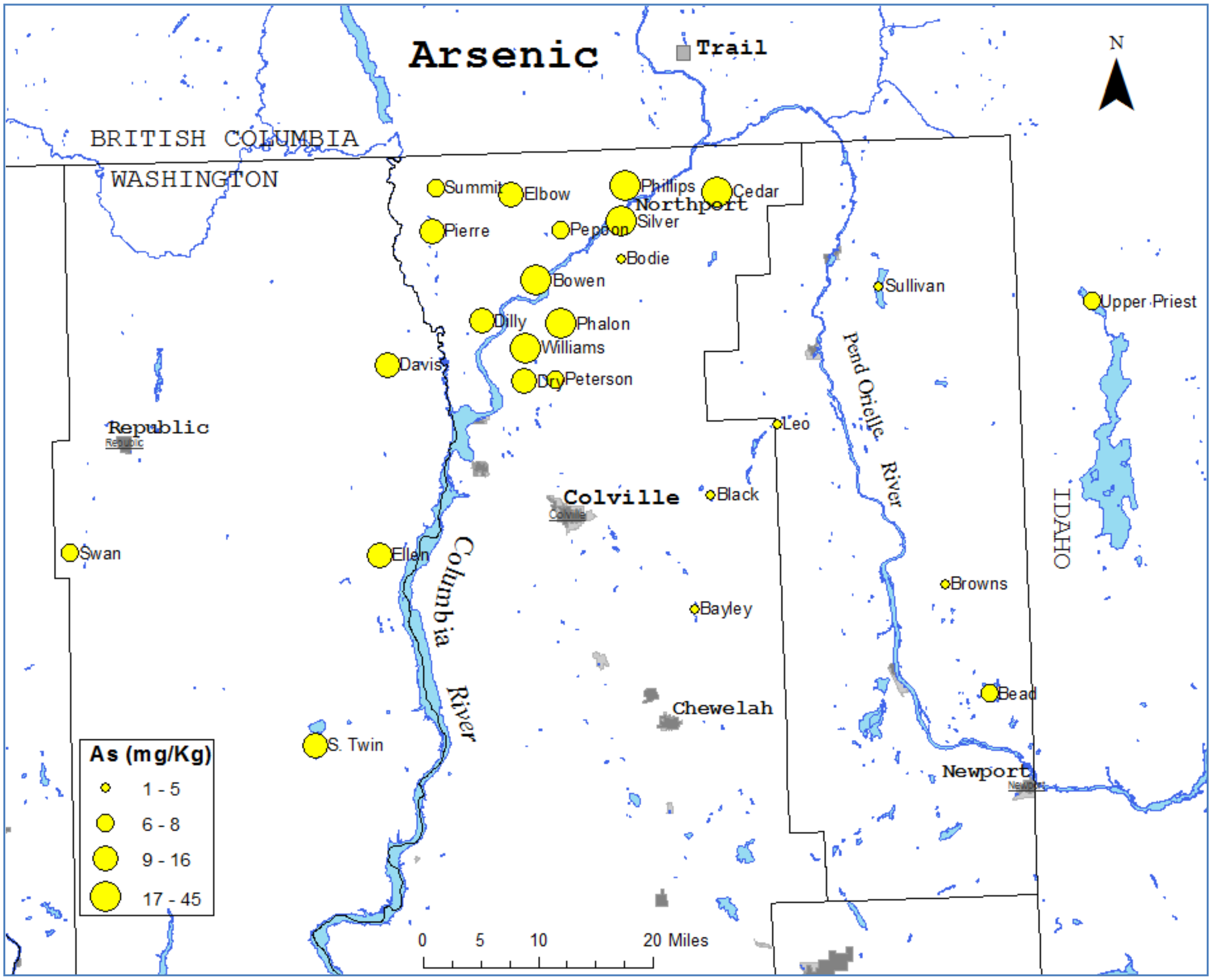


Figure 15. Arsenic Concentrations in Lake and Wetland Sediments of Northeast Washington, 2009-2012. (Top 10 cm layer)

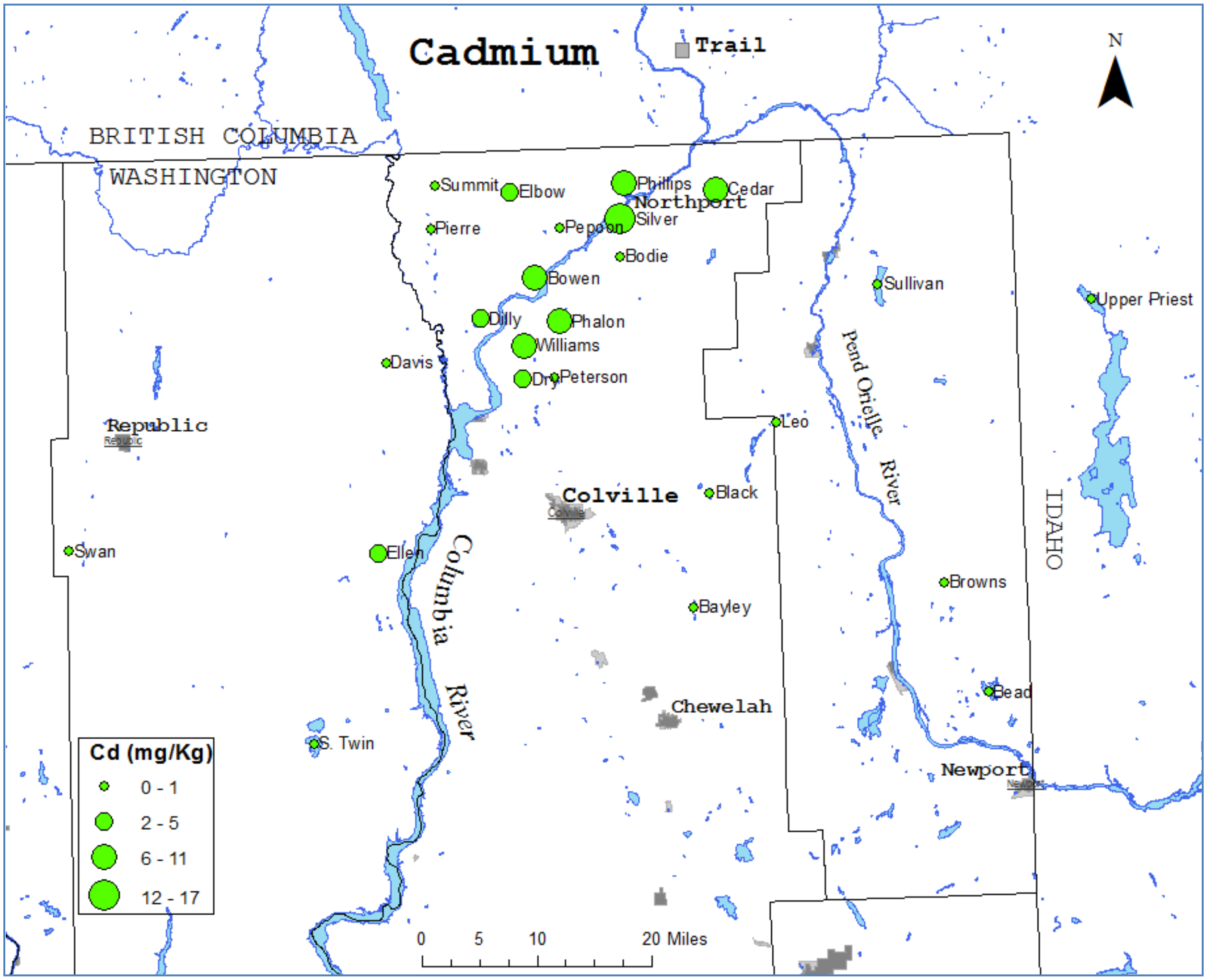


Figure 16. Cadmium Concentrations in Lake and Wetland Sediments of Northeast Washington, 2009-2012. (Top 10 cm layer)

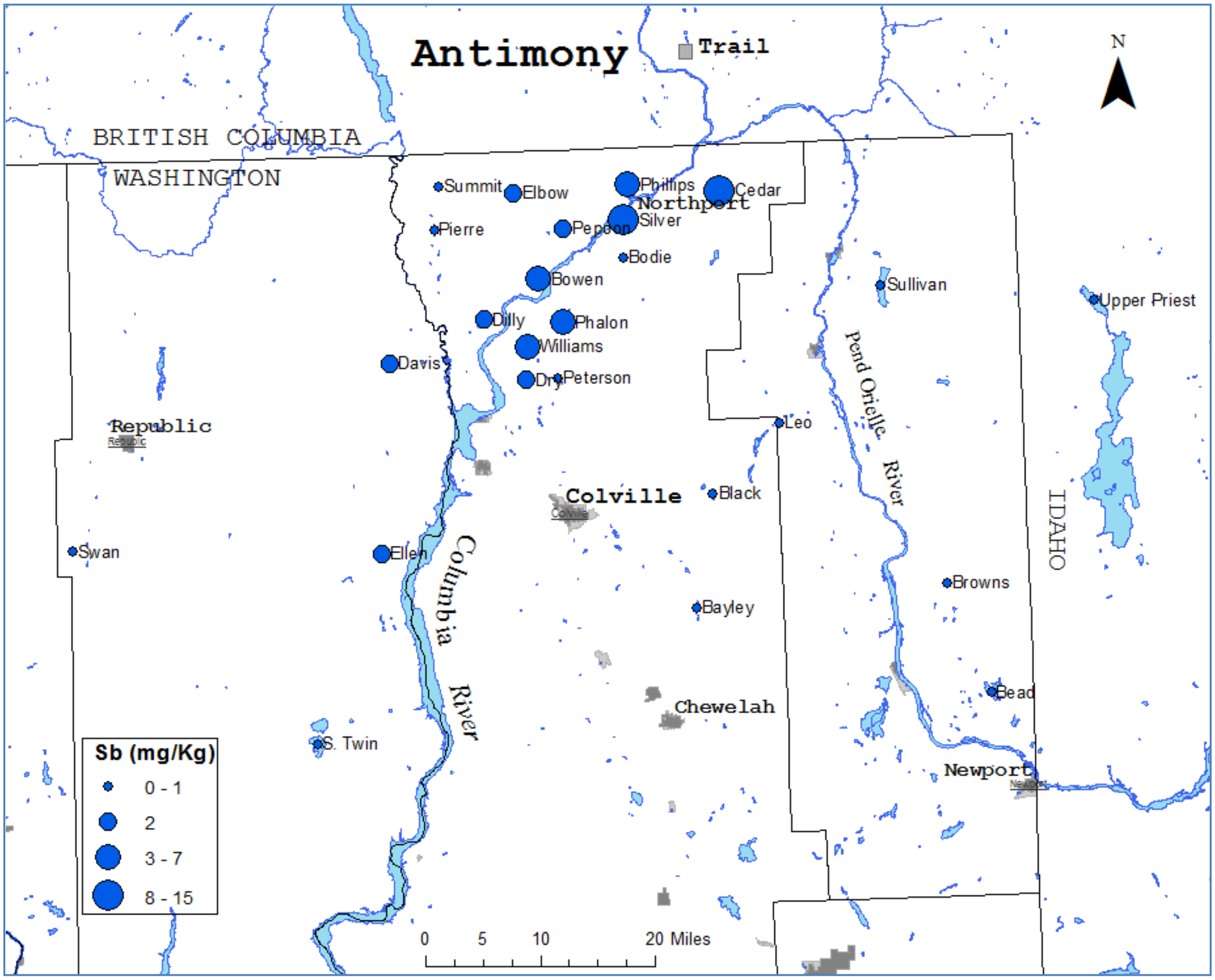


Figure 17. Antimony Concentrations in Lake and Wetland Sediments of Northeast Washington, 2009-2012. (Top 10 cm layer)

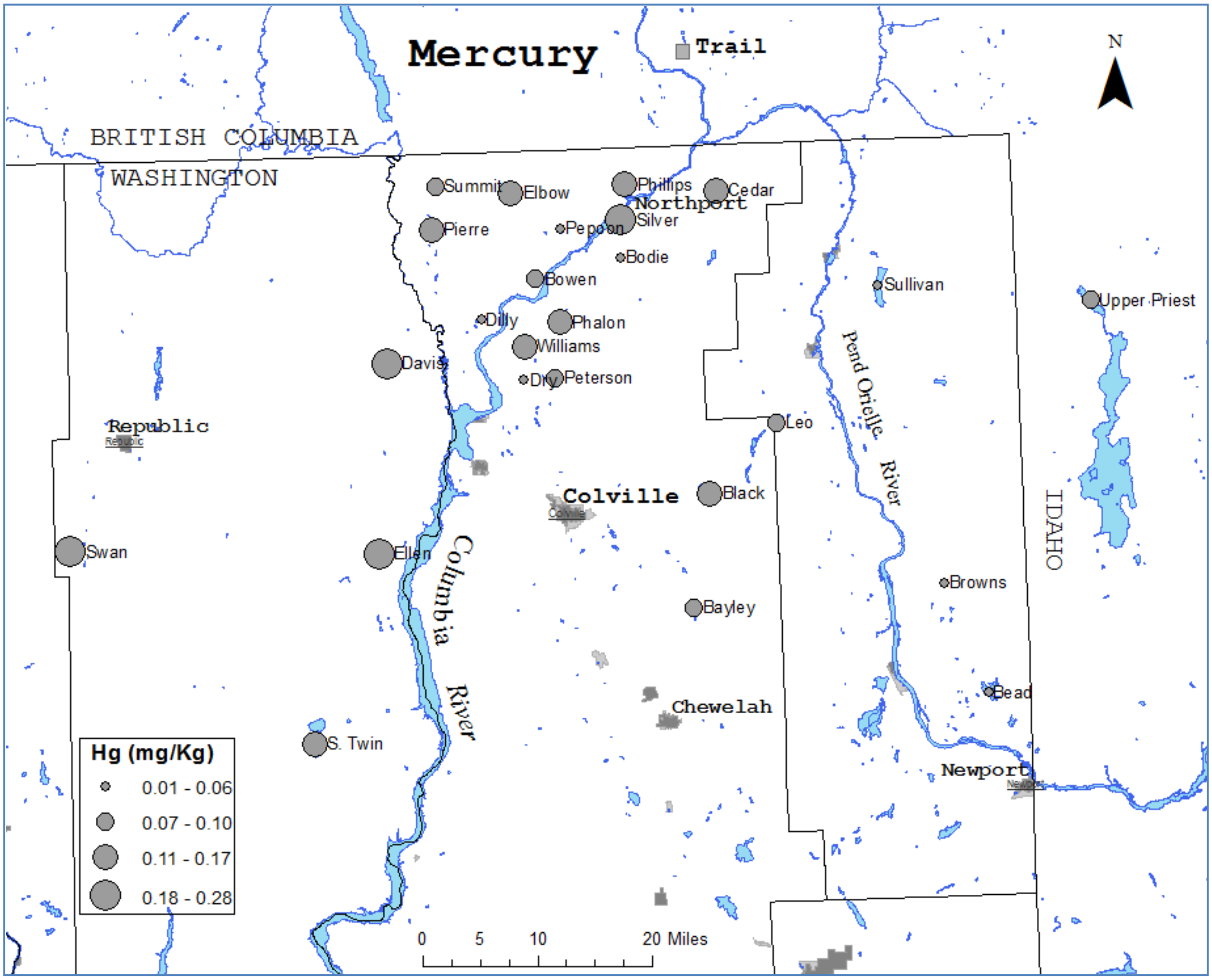


Figure 18. Mercury Concentrations in Lake and Wetland Sediments of Northeast Washington, 2009-2012. (Top 10 cm layer)

Sediment Toxicity

Figures 19 and 20 show lakes and wetlands from the 2010 and 2012 surveys that exceed the 2000 McDonald et al. PEC guidelines for lead and cadmium in sediments. In general, these indicators of potential sediment toxicity closely parallel the concentration data shown in Figures 13 and 16.

Three other instances of potential sediment toxicity were observed in the 2012 survey water-bodies (Figure 12). Silver Crown Lake exceeded the zinc and arsenic PECs by factors of 2.1 and 1.4, respectively. Phillips Lake exceeded the zinc PEC by a factor of 1.5.

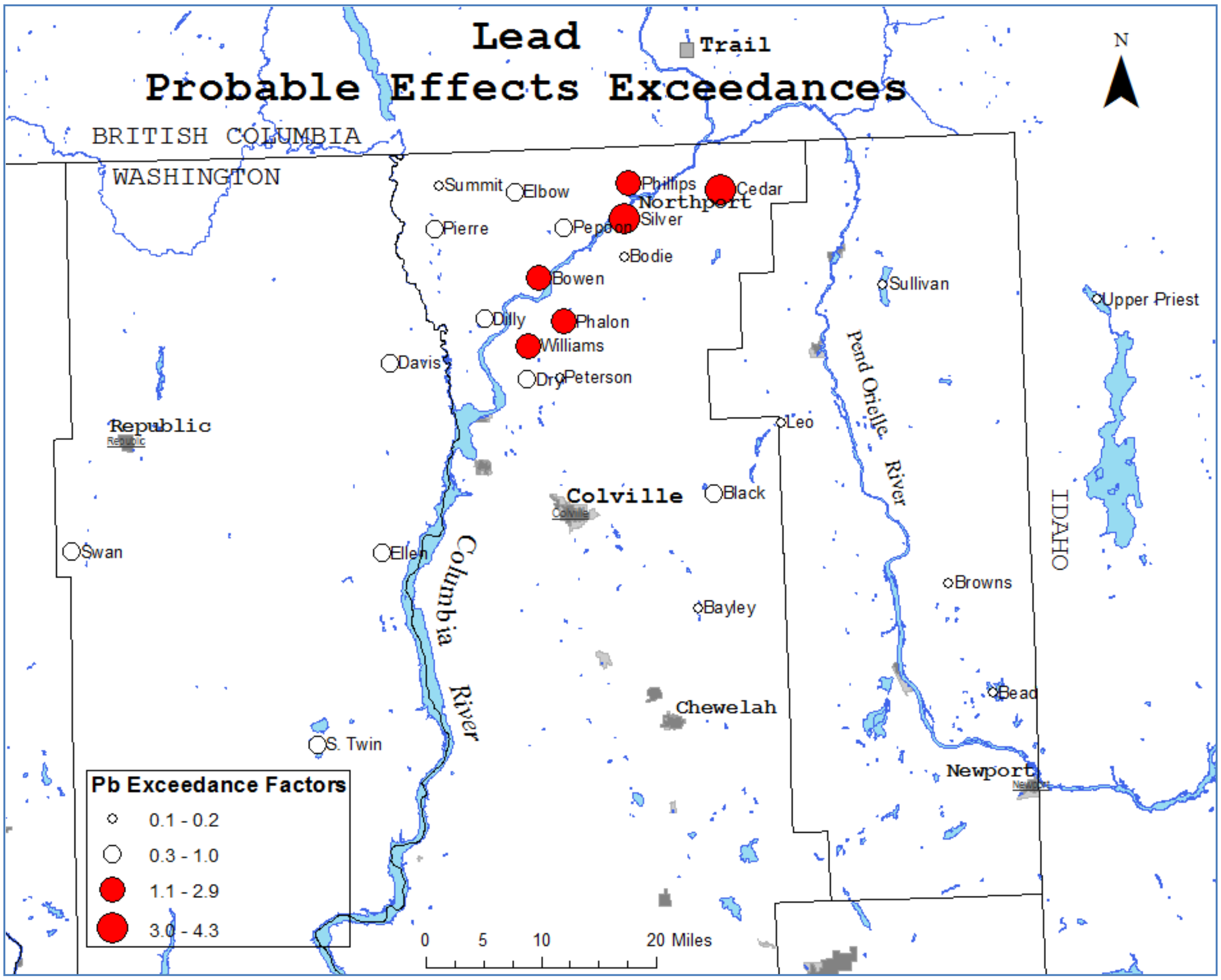


Figure 19. Exceedance Factors for Lead Compared to Probable Effect Concentrations (PEC), Lake and Wetland Sediments of Northeast Washington, 2009-2012.

Top 10 cm layer; values greater than 1.0 exceed PEC.

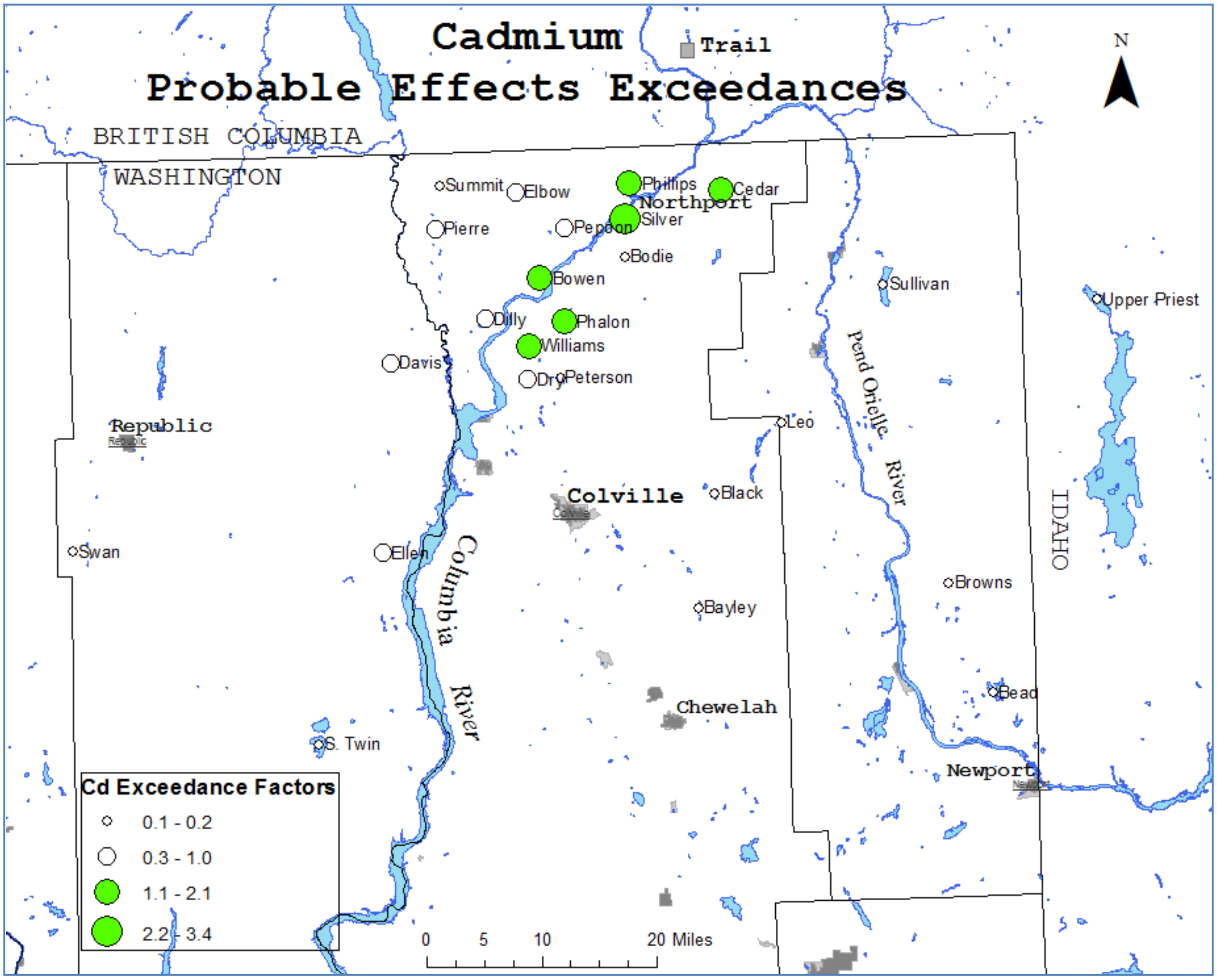


Figure 20. Exceedance Factors for Cadmium Compared to Probable Effect Concentration (PEC), Lake and Wetland Sediments of Northeast Washington, 2009-2012.

Top 10 cm layer; values greater than 1.0 exceed PEC.

Sources of Contamination

Ecology's report on the 2010 sediment survey concluded that the predominant source of metals contamination in northeast Washington lakes was historical transboundary air pollution from the Trail smelter (Johnson et al., 2011). This conclusion was based on the following lines of evidence:

- Spatial patterns and extent of sediment contamination in northeast Washington lakes.
- Path of the smelter SO_2 plume as reconstructed from historical mapping of forest damage (ICF International, 2011).
- Air deposition patterns of metals in the Pacific Northwest, revealed through a U.S. Forest Service monitoring program that analyzes lichens (Geiser, 2011; see Appendix F in present report).

Results from the current 2012 study provide additional support for this conclusion. In particular, high metals concentrations are observed in a cluster of lakes within the Upper Columbia River watershed. These lakes appear to correspond predominantly within the historical Trail smelter SO_2 plume timber injury footprint (e.g., Figures 21 and 22). Sediment age-dating approaches used during this study have provided further information on how the chronology and rate of metals deposition in Cedar Lake sediments generally coincide with historical smelter emissions.

The 2010 report also noted the existence of a smaller local source of metals contamination from the historical LeRoi smelter located on the Upper Columbia River at Northport, Washington. LeRoi operated for about 12 years, on and off from 1897 until 1921. The unusually high levels of lead, zinc, arsenic, cadmium, and antimony in the sediments of Silver Crown Lake, positioned less than a mile to the south of the LeRoi site, may include additional locally transported historic influence from the LeRoi stacks (see second map, Appendix A). A Cleanup of the old LeRoi site was conducted as an EPA response action in 2004.

In contrast to the near-continuous, 116-year history of the Trail smelter operations, the LeRoi/ Northport smelter was significantly smaller and experienced a short, intermittent operational life. An additional brief discussion of the operational histories of the Trail and LeRoi smelters is summarized in Appendix E.

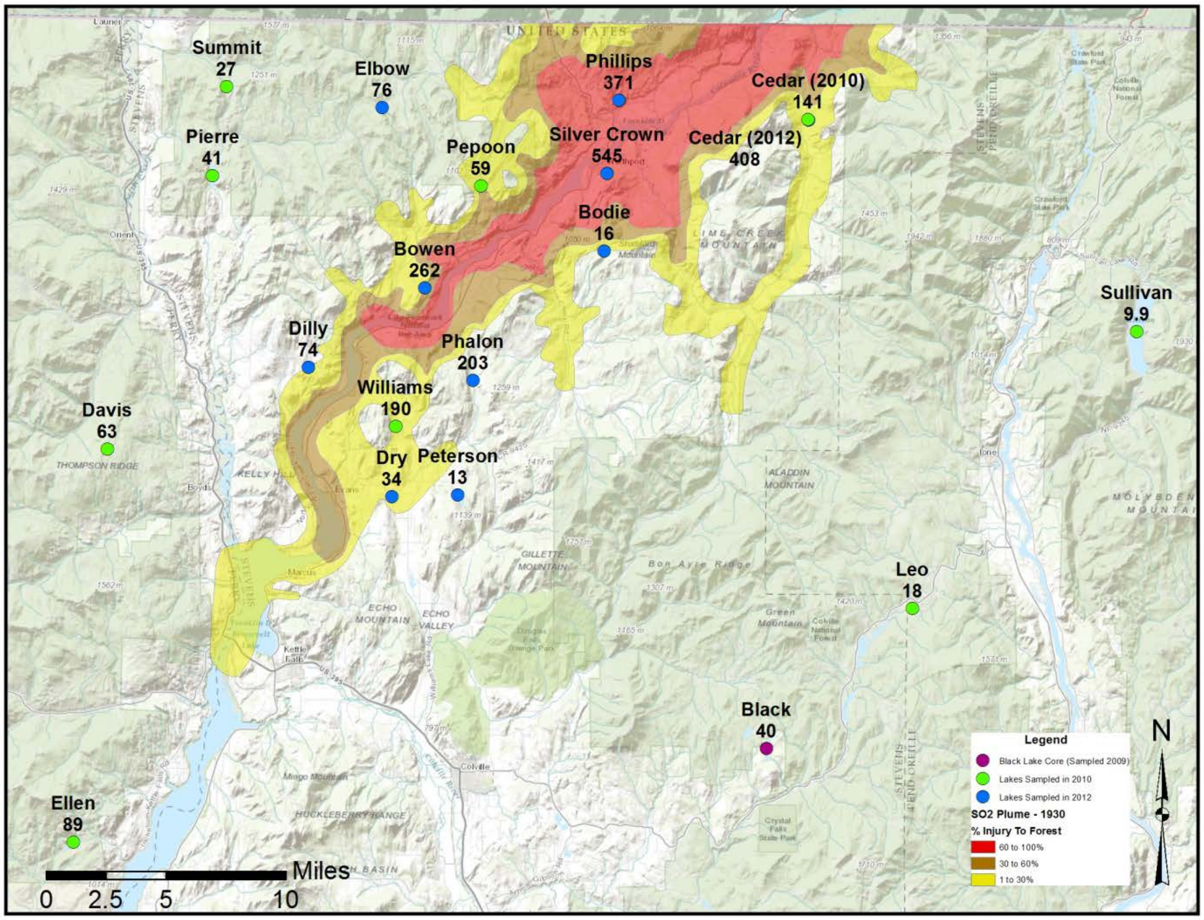


Figure 21. Lead Concentrations (mg/Kg, dry weight) in Sediments of Upper Columbia River Lakes and Wetlands, Sampled 2009-2012, Compared to Historical Record of Forest Damage from Trail SO_2 Air Emissions in 1930.

Historical SO_2 injury footprints digital reproduction provided courtesy of Environment International, Ltd.

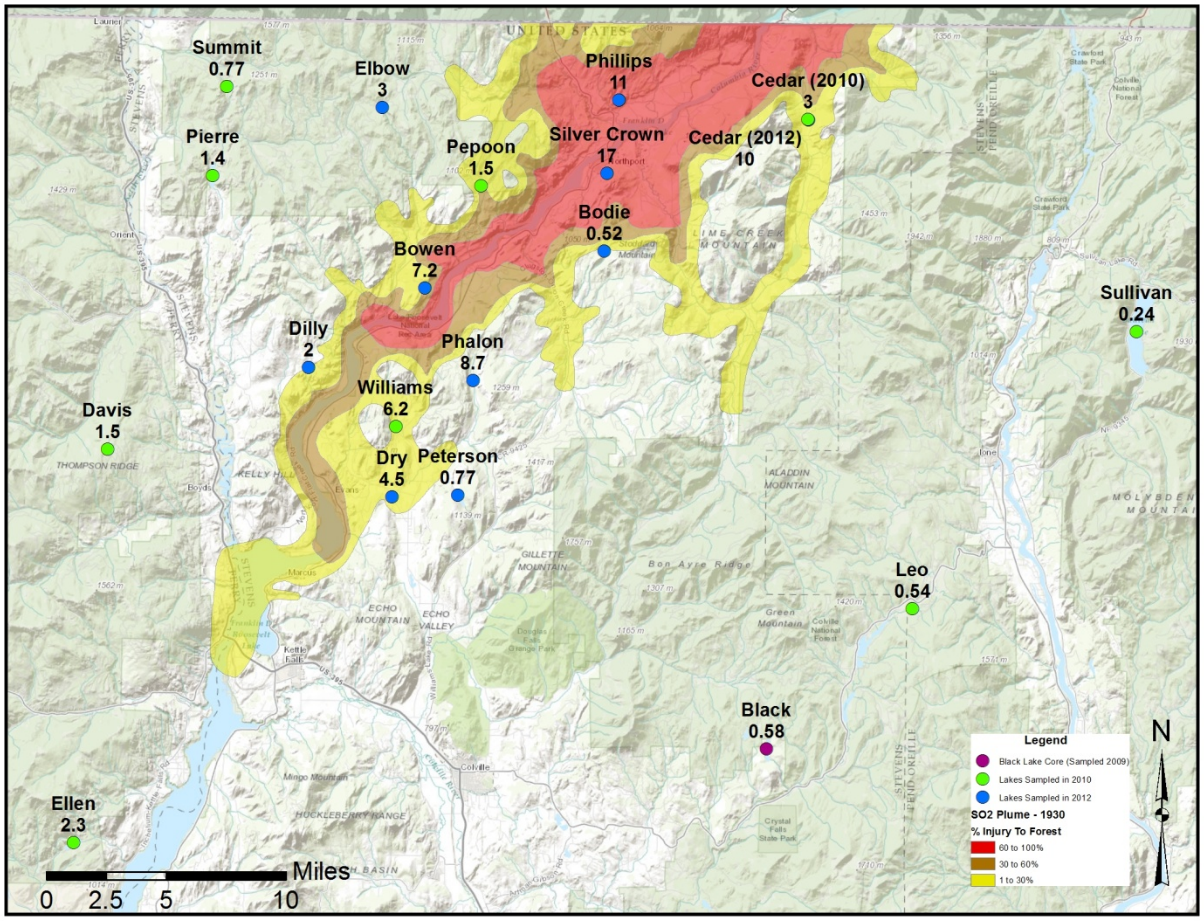


Figure 22. Cadmium Concentrations (mg/Kg, dry weight) in Sediments of Upper Columbia River Lakes and Wetlands, Sampled 2009-2012, Compared to Historical Record of Forest Damage from Trail SO_2 Air Emissions in 1930.

SO_2 plume overlay information courtesy of Environment International Ltd.

Summary and Conclusions

Sediments collected in 2012 from ten lakes and wetlands within the Upper Columbia River watershed were analyzed for lead, zinc, arsenic, cadmium, antimony, and mercury. The samples were a mix of surface grabs representing the top 10 cm and cores up to 50 cm in length. This study followed a previous lakes study performed in 2010.

The 2010 study evaluated 15 lakes over a broad portion of northeast Washington and one lake in Idaho. The 2010 study results indicated elevated levels of metals in the sediments from lakes located closer to the upper Columbia River valley. Consistent with the 2010 approach, waterbodies having relatively low impact from local human activities were selected for the 2012 sampling.

The ten lakes and wetlands sampled in 2012 affirm the marked enrichment of sediments in upland lake and wetland waterbodies along the upper Columbia River corridor, particularly nearer to the international border. This study, and other associated lines of evidence, further supports the conclusion that historical trans-boundary air pollution from the long-operated Trail smelter in British Columbia is the primary origin of the contamination. Also, historic emissions from the smaller LeRoi smelter that operated intermittently in Northport, Washington near the beginning of the 20^{th} century should be expected to have contributed toward metals enrichment in soils more closely surrounding that community.

The highest metals concentrations in the 2012 surface sediment samples were for lead and zinc, followed by arsenic, cadmium, antimony, and mercury, in decreasing order. Much higher levels were found in Cedar, Phillips, Silver Crown, Bowen, and Phalon Lakes in the north and central part of the study area, compared to Dilly Lake and the three wetlands (Bodie, Dry, and Peterson Swamp) to the south and east, and Elbow Lake to the west. Silver Crown Lake shows the highest levels of metal contamination, followed by Cedar and Phillips Lakes. Elbow Lake had one of the higher mercury concentrations. The lowest metals levels were found in the Bodie, Dry, and Peterson Swamp wetlands.

Sediment cores were obtained from five of the lakes. Enrichment factors for the top 10 cm layer compared to the lowermost core bottom 10 or 20 cm intervals were as much as two orders of magnitude for lead and cadmium, and one order of magnitude for the other metals. Mercury and arsenic showed the smallest difference between surface and subsurface layers. In most of the lakes, the enrichment by mercury and arsenic was a factor of 6 or less. Silver Crown Lake, however, showed enrichment factors for mercury and arsenic of about 20 and 15, respectively. The deepest layers of sediment in these cores likely are approaching the natural, pre-industrial background within this portion of northeast Washington.

The sediment core from Cedar Lake was age-dated to estimate sedimentation rates and establish the chronology of metals deposition. Sedimentation was low in the 1800s, approximately 0.003 g/cm^2/year, and began to accelerate rapidly around 1900, reaching a maximum of about 0.03 g/cm^2/year in the 1940s. Recent rates (past 30 years) have averaged about 0.01 g/cm^2/year, three times the rate in the early 1800s.

Metals deposition in Cedar Lake increased rapidly during the first half of the 20th century, peaking in the 1950s or 1960s for lead, zinc, cadmium, and antimony. Although arsenic and mercury appear to continue increasing, the recent history could not be seen in detail due to the way the core was sectioned. The time sequence of changes in metals concentrations in this core is consistent with the known operational history of the Trail smelter. Cedar Lake is located approximately four miles south of the international boundary and lies within the historical SO_2 damage zone.

Six of the northern and centrally located lakes – Cedar, Phillips, Silver Crown, Bowen, Phalon, and Willams (sampled in 2010) – exceed one or more of the probable effect concentrations (PECs) thresholds for lead and cadmium. Additional metals exceed PECs in Silver Crown Lake (zinc and arsenic) and Phillips Lake (zinc). Metals concentrations in these lakes may pose a potential concern for adverse biological effects. This determination is based on a comparison of measured metals concentrations to literature-based, effects-concentration thresholds for freshwater ecosystems

The 2012 findings are consistent with, and help refine, the spatial patterns identified in 2010:

1. Higher concentrations of lead, zinc, arsenic, cadmium, antimony, and mercury occur in the bottom sediment of lakes from the western part of the northeast Washington study area.
2. Sediment in lakes located closest to the Upper Columbia River valley show an overall northward-increasing metals concentration trend, with highest concentrations typically observed in lakes located within about 10 miles of the international border.
3. Elevated mercury concentrations appear to be more prevalent in the west and north-central portions of the study area, relative to lead, zinc, arsenic, cadmium, and antimony concentration patterns.

Recommendations

The 2012 findings described in this report have important implications for the health and integrity of aquatic environments in northeast Washington State. The direct applicability of these latest data and results, coupled with the previous findings from the 2010 study, demonstrate the need to further evaluate and define the geographic extent of heavy metals impacts attributable to historical smelter emissions. These impacts include potential adverse risks to aquatic and terrestrial ecological receptors which may come into contact with contaminated sediments and/or terrestrial soils within this portion of the Upper Columbia River watershed in northeast Washington.

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Appendices

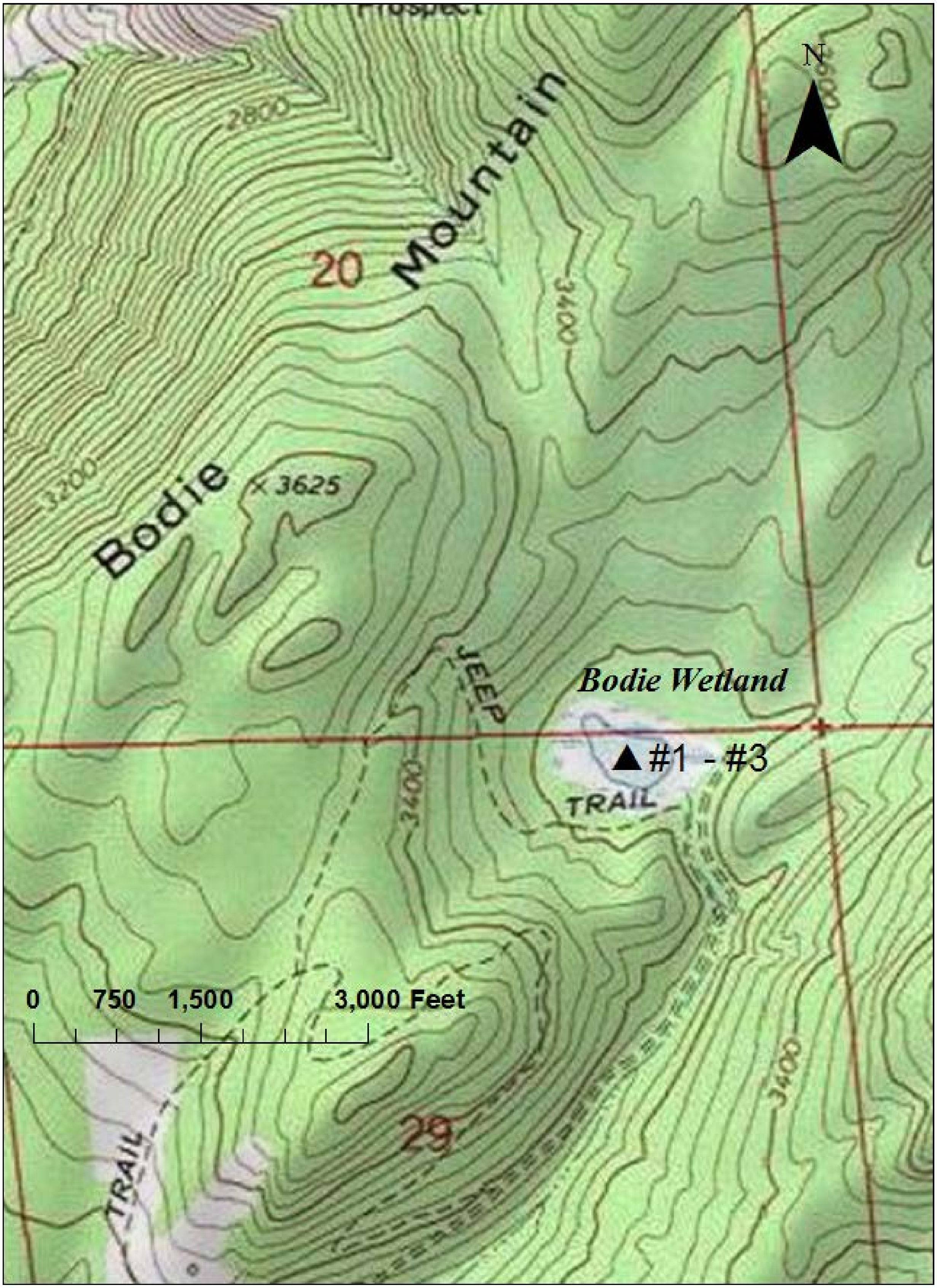
Appendix A. Maps of Sediment Sampling Sites for 2012


N
BM 2210
2400
2200
26
#2
Cedar Lake
#1 (core)
2135
#3
2187
2400
Deep Lake Boundary Rd.
0 500 1,000 2,000 Feet
2200
2179

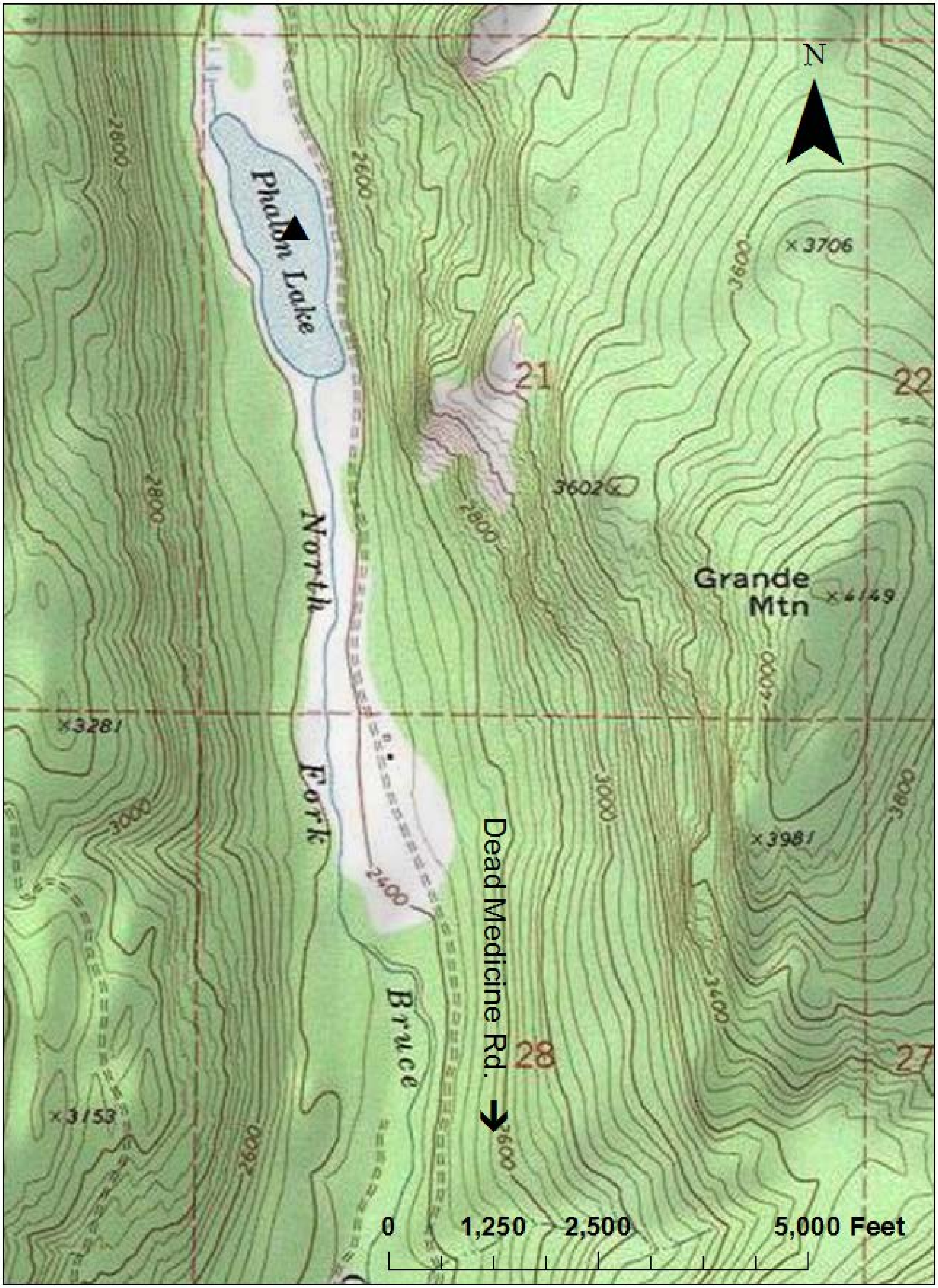

N
Northport
(BM 1328)
WT
Northport Sch
2000
Northport
2292
Silver Crown
Lake
1600
2400
0
500
1,000
2,000 Feet

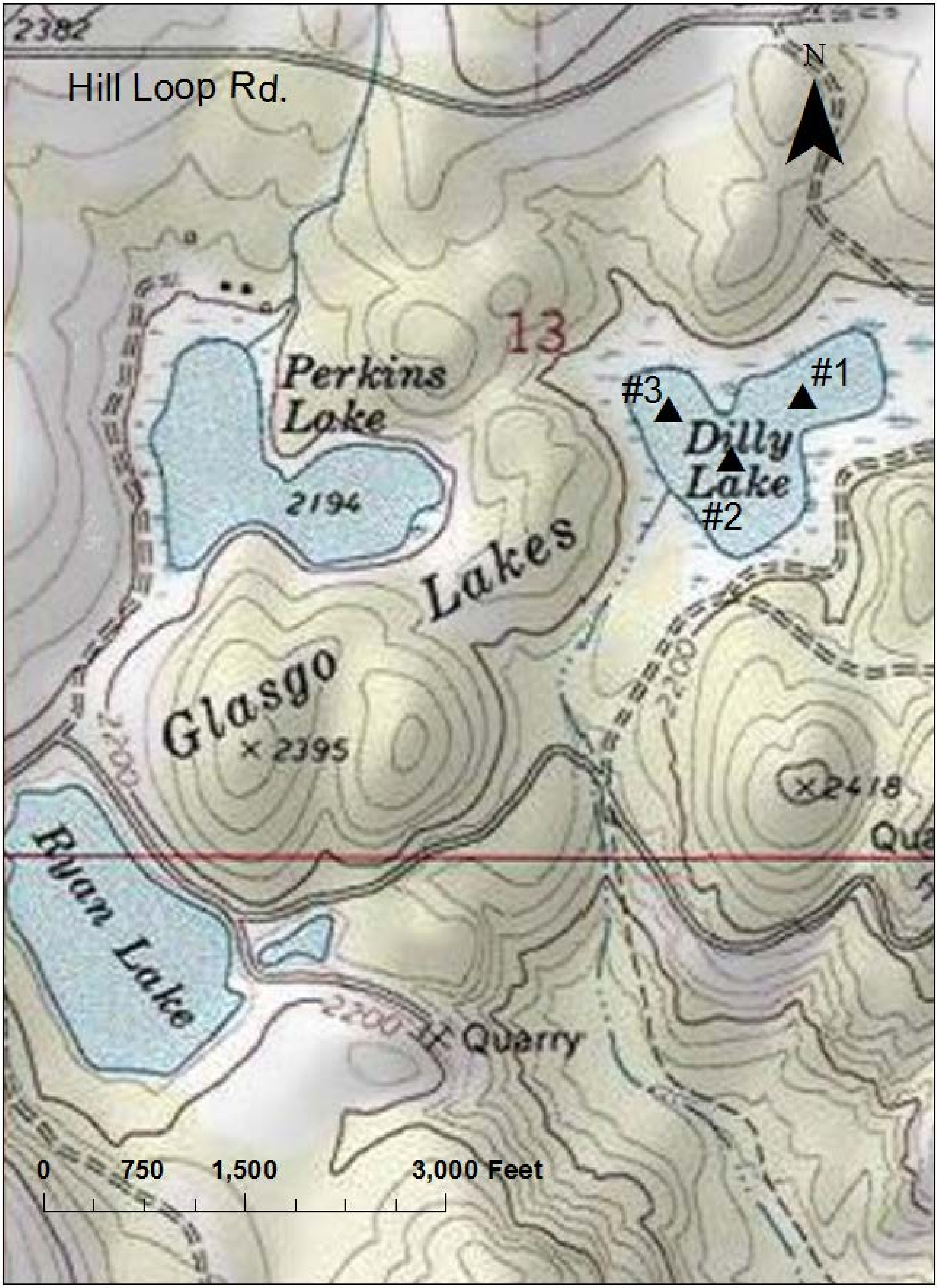
N
Phillips
Lake
1600
1400
19
Mitchell Rd.
1340
BM 1317
29
MC
30
0
750
1,500
3,000 Feet
25
Steamboat
Rock
1393 ×
31
Mile

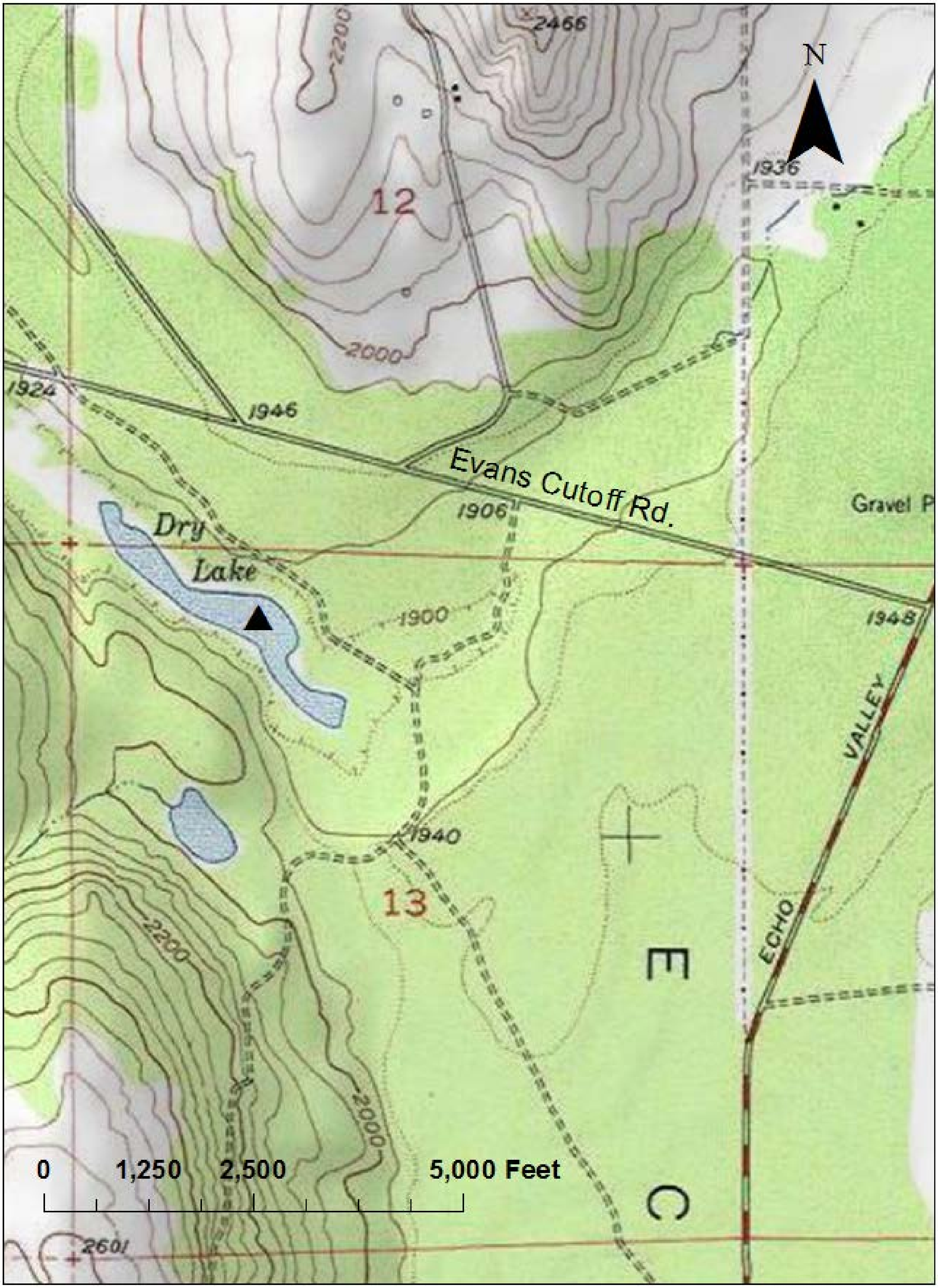

N
Sheep Creek Rd.
#3
2875
#2 (core)
#1
21
Elbow Lake
0 250 500 1,000 Feet

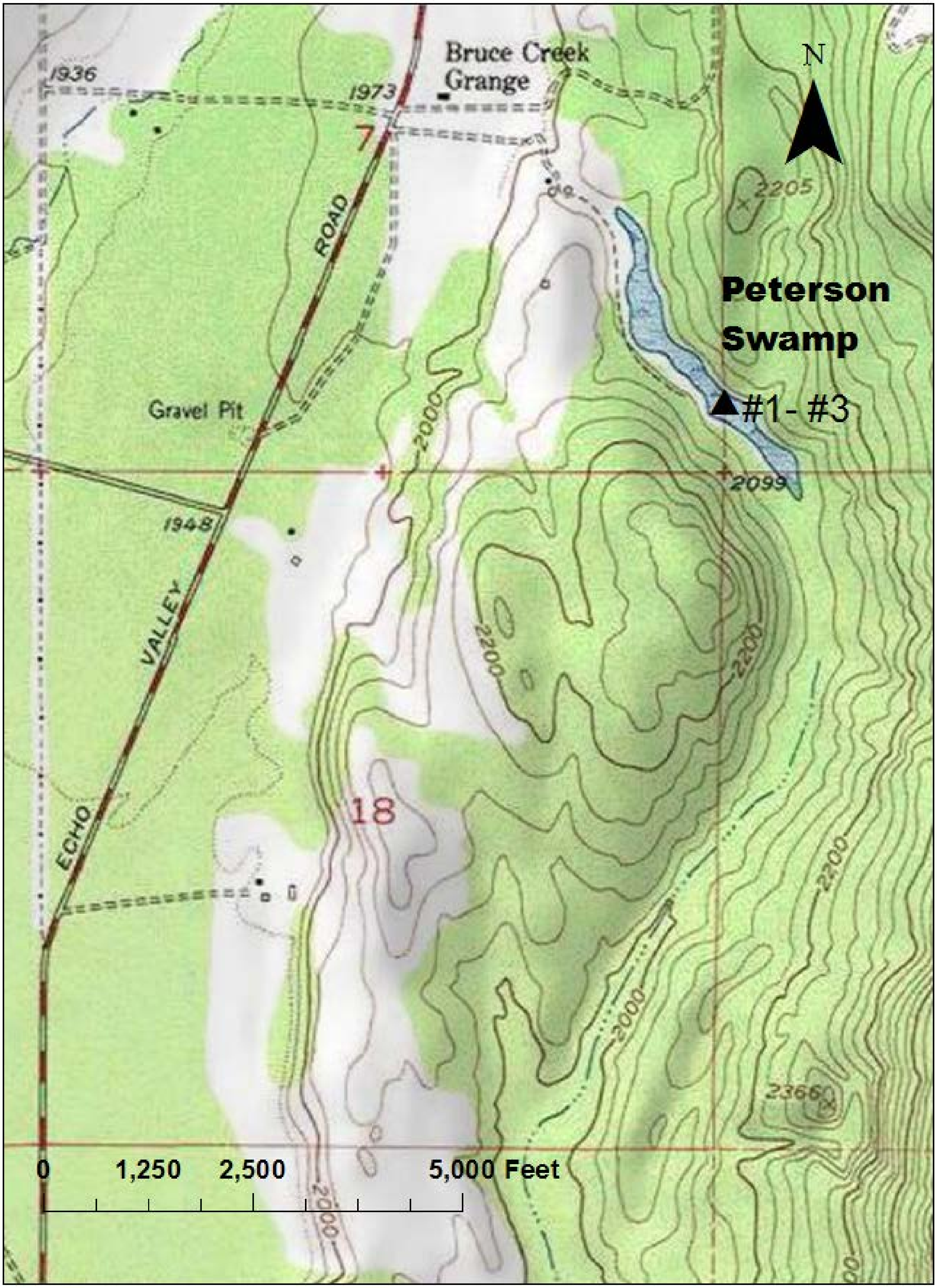

Prospect
N
2800
20
Bodie Mountain
3400
3200
Bodie
× 3625
JEEP
Bodie Wetland
▲ #1 - #3
TRAIL
3400
0 750 1,500 3,000 Feet
3400
29
TRAIL


N
Moore Rd.
Bowen Lake
#1
#2
#3
0 250 500 1,000 Feet
35


N
Phalon Lake
North Fork
Bruce
Grande Mtn
Dead Medicine Rd.
21
22
28
27
0 1,250 2,500 5,000 Feet


2382
Hill Loop Rd.
N
13
Perkins Lake
2194
#3
#1
Dilly Lake
#2
Lakes
Glasgo
× 2395
2200
×2418
Bryan Lake
2200
Quarry
0
750
1,500
3,000 Feet


N
2466
2200
12
1936
2000
1924
1946
Evans Cutoff Rd.
Gravel P
1906
Dry
Lake
1900
1948
VALLEY
1940
13
ECHO
2200
E
2000
C
0
1,250
2,500
5,000 Feet
2601


Bruce Creek
Grange
N
1936
1973
7
ROAD
Peterson
Swamp
Gravel Pit
#1- #3
2205
2000
2099
1948
VALLEY
2200
2200
ECHO
18
2200
2000
2366
0
1,250
2,500
5,000 Feet
2000

Appendix B. Data Reviews and Data Reports for 2012 Sediment Samples

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Manchester Environmental Laboratory

7411 Beach Drive E, Port Orchard, Washington 98366

Case Narrative

November 20, 2012

Project: Metals NE Washington Sediments

Work Order: 1210038

Project Manager: Johnson, Art

By: Dean Momohara

Summary

The laboratory followed EPA 245.5 for the preparation and analysis of mercury and EPA 3050B for the preparation and EPA 200.8 for the analysis of trace metals. Samples for antimony were digested following section 7.5 within EPA 3050B to increase analyte recoveries.

All analyses requested were evaluated by established regulatory quality assurance guidelines.

Sample Information

The samples were received at the Manchester Laboratory on 9/27/2012, 10/17/2012 and 10/24/2012. One of the coolers was received at 8°C, above the proper temperature range of 0°C - 6°C. All results for samples 56, 57, 58 and 59 were qualified as estimates. The samples were received in good condition. Forty samples were received and assigned laboratory identification numbers 01 to 04, 10 to 13, 15 to 18, 20 to 22, 24, 30 to 44, 50 to 53 and 55 to 59.

Holding Times

The laboratory performed all analyses within their hold times.

Calibration

The instruments were calibrated following the appropriate methods. All initial and continuing calibration verification checks were within the acceptance limits.

All initial and continuing calibration verification and blank checks were within the acceptance limits. All standard residuals were within acceptance limits. All r-values were within acceptance limits. The instruments were calibrated with NIST traceable standards and verified to be in calibration with a second source NIST traceable standard. Oven drying temperatures were monitored before and after drying.

Method Blanks

No analytically significant levels of analyte were detected in the method blanks associated with these samples.

Laboratory Control Samples

All laboratory control sample recoveries were within the acceptance limits.

Replicates

All duplicate relative percent differences (RPD) of samples with concentrations greater than 5 times the reporting limit were within the acceptance limit except for mercury. The duplicate RPD for sample 55 for mercury was greater than the acceptance limit. The sample was qualified as an estimate.

Matrix Spikes

All matrix spike (MS) recoveries were within the acceptance limits except for zinc, lead and mercury.

Both MS/MSD recoveries for sample 32 for lead were outside of the acceptance limits. One of the MS/MSD recoveries for sample 32 for zinc was outside of the acceptance limits. The standard spiking level was insufficient for the elevated concentration in the source sample therefore the recoveries were not evaluated.

One of the MS/MSD recoveries for sample 55 for mercury was outside of the acceptance limits due to sample inhomogeneity. The source sample was qualified as an estimate.

One of the matrix spike recoveries for mercury were outside of the acceptance limits. The source sample was from a different work order and was not evaluated.

The MS and MSD for batch B12J219 and the source sample (13) were re prepared due to one of the MS recoveries was unusually low.

Internal Standards

All internal standard recoveries were within the acceptance limits.

Other Quality Assurance Measures and Issues

U - The analyte was not detected at or above the reported result.

J - The analyte was positively identified. The associated numerical result is an estimate.

bold - The analyte was present in the sample. (Visual Aid to locate detected compounds on report sheet.)

Please call Dean Momohara at (360) 871-8808 to further discuss this project.

cc: Project File

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Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Antimony

Project Name: NE Washington Sediments

Work Order: 1210038
Project Officer: Johnson, Art
Date Collected: 09/11/2012

Analyte: Antimony
Method: EPA200.8
Date Analyzed: 10/25/2012

Matrix: Sediment/Soil
Units: mg/Kg dw

Sample #	Sample ID	Result	Qualifier	RL	MDL	Collected	Analyzed	Batch ID
1210038-01	**CEDAR 1**	**9.91**		0.200	0.008	09/11/12	10/25/12	B12J219
1210038-02	**CEDAR 2**	**16.2**		0.833	0.031	09/11/12	10/25/12	B12J219
1210038-03	**CEDAR 3**	**15.3**		0.207	0.008	09/11/12	10/25/12	B12J219
1210038-04	**CEDAR DUP**	**16.1**		0.199	0.007	09/11/12	10/25/12	B12J219
1210038-10	**SILVER 0-10**	**15.0**		0.200	0.008	09/11/12	10/25/12	B12J219
1210038-11	**SILVER 10-20**	**17.9**		0.200	0.008	09/11/12	10/25/12	B12J219
1210038-12	**SILVER 20-30**	**0.495**		0.200	0.008	09/11/12	10/25/12	B12J219
1210038-13RE1	SILVER 30-50	0.413	U	0.413	0.016	09/11/12	11/20/12	B12J219
1210038-15	**PHALON 0-10**	**3.53**		0.199	0.007	09/12/12	10/25/12	B12J219
1210038-16	**PHALON 10-20**	**0.759**		0.199	0.007	09/12/12	10/25/12	B12J219
1210038-17	**PHALON 20-30**	**0.865**		0.200	0.008	09/12/12	10/25/12	B12J219
1210038-18	**PHALON 30-50**	**0.945**		0.201	0.008	09/12/12	10/25/12	B12J219
1210038-20	**PHILLIPS 0-10**	**6.94**		0.199	0.007	09/11/12	10/25/12	B12J219
1210038-21	**PHILLIPS 10-20**	**5.53**		0.199	0.007	09/11/12	10/25/12	B12J219
1210038-22	**PHILLIPS 20-30**	**0.716**		0.182	0.007	09/11/12	10/25/12	B12J219
1210038-24	**DRY 0-10**	**2.26**		0.200	0.008	09/12/12	10/25/12	B12J219
1210038-30	**CEDAR 1-6**	**9.48**		0.198	0.007	09/11/12	10/25/12	B12J219
1210038-31	**CEDAR 7-9**	**15.9**		0.199	0.007	09/11/12	10/25/12	B12J219
1210038-32	**CEDAR 10**	**15.5**		0.198	0.007	09/11/12	10/25/12	B12J219
1210038-34	**CEDAR 12**	**0.626**		0.200	0.008	09/11/12	10/25/12	B12J219

QC Results for Batch ID: B12J219

Method Blank	Sample ID	Result	Qualifer	RL	MDL	Analyzed
B12J219-BLK1	Blank	0.200	U	0.200	0.008	10/25/12

Sample #	QC Sample	Result	Spike Level	Source Sample	Source Result	%Rec	%Rec Limits	RPD	RPD Limit
B12J219-BS1	LCS	88.0	80			110	85-115		
B12J219-DUP1	Duplicate	0.512		1210038-34	0.626			20	20
B12J219-MS1	Matrix Spike	137	153	1210038-13RE1	0.296	89	75-125		
B12J219-MSD1	Matrix Spike Dup	139	155	1210038-13RE1	0.296	89	75-125	2	20
B12J219-SRM1	Reference	220	120			183	0-219.2		

Authorized by: Dm

Release Date: 11/20/12

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Antimony

Project Name: NE Washington Sediments

Work Order: 1210038 | **Analyte:** Antimony | **Matrix:** Sediment/Soil
Project Officer: Johnson, Art | **Method:** EPA200.8 | **Units:** mg/Kg dw
Date Collected: 09/11/2012 | **Date Analyzed:** 11/05/2012

Sample #	Sample ID	Result	Qualifier	RL	MDL	Collected	Analyzed	Batch ID
1210038-33	**CEDAR 11**	**2.67**		0.199	0.007	09/11/12	11/05/12	B12K005
1210038-35	**CEDAR 13**	**0.853**		0.199	0.007	09/11/12	11/15/12	B12K005
1210038-36	**CEDAR 14**	**1.39**		0.199	0.007	09/11/12	11/15/12	B12K005
1210038-37	**CEDAR 15-16**	**1.92**		0.200	0.008	09/11/12	11/15/12	B12K005
1210038-38	**CEDAR 17-18**	**1.16**		0.199	0.007	09/11/12	11/15/12	B12K005
1210038-39	**CEDAR 19-20**	**1.01**		0.200	0.008	09/11/12	11/20/12	B12K005
1210038-40	**CEDAR 23-24**	**1.60**		0.199	0.007	09/11/12	11/15/12	B12K005
1210038-41	**CEDAR 27-28**	**1.78**		0.200	0.008	09/11/12	11/15/12	B12K005
1210038-42	**CEDAR 31-32**	**1.41**		0.198	0.007	09/11/12	11/15/12	B12K005
1210038-43	**CEDAR 35-36**	**2.66**		0.198	0.007	09/11/12	11/05/12	B12K005
1210038-44	**CEDAR 37-38**	**2.64**		0.199	0.007	09/11/12	11/05/12	B12K005
1210038-50	**Elbow**	**1.49**		0.198	0.007	10/09/12	11/15/12	B12K005
1210038-51	**Dilly**	**1.85**		0.198	0.007	10/09/12	11/15/12	B12K005
1210038-52	**Bowen**	**4.81**		0.200	0.008	10/09/12	11/05/12	B12K005
1210038-53	**Peterson**	**0.812**		0.201	0.008	10/10/12	11/15/12	B12K005
1210038-55	**Bodie**	**0.236**		0.198	0.007	10/10/12	11/15/12	B12K005
1210038-56	**Elbow10-20**	**2.72**	J	0.198	0.007	10/09/12	11/05/12	B12K005
1210038-57	**Elbow20-30**	**0.762**	J	0.200	0.008	10/09/12	11/15/12	B12K005
1210038-58	**Elbow30-40**	**1.15**	J	0.198	0.007	10/09/12	11/15/12	B12K005
1210038-59	**Elbow 0-10**	**2.02**	J	0.200	0.008	10/09/12	11/15/12	B12K005

QC Results for Batch ID: B12K005

Method Blank	Sample ID	Result	Qualifer	RL	MDL	Analyzed
B12K005-BLK1	Blank	0.200	U	0.200	0.008	11/15/12

Sample #	QC Sample	Result	Spike Level	Source Sample	Source Result	%Rec	%Rec Limits	RPD	RPD Limit
B12K005-BS1	LCS	82.3	80			103	85-115		
B12K005-DUP1	Duplicate	2.99		1210038-43	2.66			12	20
B12K005-DUP2	Duplicate	2.43		1210038-51	1.85			27	20
B12K005-MS1	Matrix Spike	70.8	79.1	1210038-53	0.812	88	75-125		
B12K005-MSD1	Matrix Spike Dup	71.1	79.4	1210038-53	0.812	89	75-125	0.5	20
B12K005-SRM1	Reference	216	120			180	0-219.2		

Authorized by: DM **Release Date:** 11/20/12

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Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Arsenic

Project Name: NE Washington Sediments

Work Order: 1210038 | **Analyte: Arsenic** | **Matrix: Sediment/Soil**
Project Officer: Johnson, Art | **Method: EPA200.8** | **Units: mg/Kg dw**
Date Collected: 09/11/2012 | **Date Analyzed: 10/15/2012**

Sample #	Sample ID	Result	Qualifier	RL	MDL	Collected	Analyzed	Batch ID
1210038-01	**CEDAR 1**	**18.9**		1.00	0.163	09/11/12	10/15/12	B12J079
1210038-02	**CEDAR 2**	**27.1**		0.996	0.162	09/11/12	10/15/12	B12J079
1210038-03	**CEDAR 3**	**22.4**		0.994	0.162	09/11/12	10/15/12	B12J079
1210038-04	**CEDAR DUP**	**27.3**		0.998	0.162	09/11/12	10/15/12	B12J079
1210038-10	**SILVER 0-10**	**45.3**		1.00	0.163	09/11/12	10/15/12	B12J079
1210038-11	**SILVER 10-20**	**54.8**		0.994	0.162	09/11/12	10/15/12	B12J079
1210038-12	**SILVER 20-30**	**8.03**		0.996	0.162	09/11/12	10/15/12	B12J079
1210038-13	**SILVER 30-50**	**2.79**		0.099	0.016	09/11/12	10/15/12	B12J079
1210038-15	**PHALON 0-10**	**25.7**		0.996	0.162	09/12/12	10/15/12	B12J079
1210038-16	**PHALON 10-20**	**16.2**		0.994	0.162	09/12/12	10/15/12	B12J079
1210038-17	**PHALON 20-30**	**16.9**		0.994	0.162	09/12/12	10/15/12	B12J079
1210038-18	**PHALON 30-50**	**18.5**		1.01	0.164	09/12/12	10/15/12	B12J079
1210038-20	**PHILLIPS 0-10**	**24.6**		1.00	0.163	09/11/12	10/15/12	B12J079
1210038-21	**PHILLIPS 10-20**	**22.9**		1.00	0.163	09/11/12	10/15/12	B12J079
1210038-22	**PHILLIPS 20-30**	**4.49**		1.00	0.163	09/11/12	10/15/12	B12J079
1210038-24	**DRY 0-10**	**11.0**		1.00	0.163	09/12/12	10/15/12	B12J079
1210038-30	**CEDAR 1-6**	**28.2**		1.57	0.256	09/11/12	10/15/12	B12J079
1210038-31	**CEDAR 7-9**	**25.2**		1.00	0.163	09/11/12	10/15/12	B12J079
1210038-32	**CEDAR 10**	**25.6**		1.00	0.163	09/11/12	10/15/12	B12J079
1210038-34	**CEDAR 12**	**5.82**		0.998	0.162	09/11/12	10/15/12	B12J079

QC Results for Batch ID: B12J079

Method Blank	Sample ID	Result	Qualifer	RL	MDL	Analyzed
B12J079-BLK1	Blank	0.100	U	0.100	0.016	10/15/12

Sample #	QC Sample	Result	Spike Level	Source Sample	Source Result	%Rec	%Rec Limits	RPD	RPD Limit
B12J079-BS1	LCS	41.4	40			103	85-115		
B12J079-DUP1	Duplicate	5.79		1210038-34	5.82			0.6	20
B12J079-MS1	Matrix Spike	68.7	40.1	1210038-32	25.6	108	75-125		
B12J079-MSD1	Matrix Spike Dup	66.9	40	1210038-32	25.6	103	75-125	3	20
B12J079-SRM1	Reference	176	168			105	83.3-117.3		

Authorized by: DM **Release Date:** 11/19/12

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Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Arsenic

Project Name: NE Washington Sediments

Work Order: 1210038 **Analyte:** Arsenic **Matrix:** Sediment/Soil
Project Officer: Johnson, Art **Method:** EPA200.8 **Units:** mg/Kg dw
Date Collected: 09/11/2012 **Date Analyzed:** 11/06/2012

Sample #	Sample ID	Result	Qualifier	RL	MDL	Collected	Analyzed	Batch ID
1210038-33	CEDAR 11	7.78		0.990	0.161	09/11/12	11/06/12	B12J174
1210038-35	CEDAR 13	11.3		0.996	0.162	09/11/12	11/06/12	B12J174
1210038-36	CEDAR 14	20.5		0.994	0.162	09/11/12	11/06/12	B12J174
1210038-37	CEDAR 15-16	22.3		1.00	0.163	09/11/12	11/06/12	B12J174
1210038-38	CEDAR 17-18	17.2		1.57	0.256	09/11/12	11/06/12	B12J174
1210038-39	CEDAR 19-20	14.8		1.59	0.258	09/11/12	11/06/12	B12J174
1210038-40	CEDAR 23-24	16.5		1.53	0.249	09/11/12	11/06/12	B12J174
1210038-41	CEDAR 27-28	20.8		1.00	0.163	09/11/12	11/06/12	B12J174
1210038-42	CEDAR 31-32	20.0		1.00	0.163	09/11/12	11/06/12	B12J174
1210038-43	CEDAR 35-36	26.7		0.996	0.162	09/11/12	11/06/12	B12J174
1210038-44	CEDAR 37-38	25.9		1.00	0.163	09/11/12	11/06/12	B12J174
1210038-50	Elbow	14.5		1.00	0.163	10/09/12	11/06/12	B12J174
1210038-51	Dilly	13.9		1.00	0.163	10/09/12	11/06/12	B12J174
1210038-52	Bowen	26.0		1.00	0.163	10/09/12	11/06/12	B12J174
1210038-53	Peterson	5.95		1.00	0.163	10/10/12	11/06/12	B12J174
1210038-55	Bodie	1.08		1.00	0.163	10/10/12	11/06/12	B12J174
1210038-56	Elbow10-20	18.9	J	1.00	0.163	10/09/12	11/06/12	B12J174
1210038-57	Elbow20-30	16.5	J	1.00	0.163	10/09/12	11/06/12	B12J174
1210038-58	Elbow30-40	15.2	J	1.00	0.163	10/09/12	11/06/12	B12J174
1210038-59	Elbow 0-10	17.4	J	1.00	0.163	10/09/12	11/06/12	B12J174

QC Results for Batch ID: B12J174

Method Blank	Sample ID	Result	Qualifer	RL	MDL	Analyzed
B12J174-BLK1	Blank	0.100	U	0.100	0.016	11/06/12

Sample #	QC Sample	Result	Spike Level	Source Sample	Source Result	%Rec	%Rec Limits	RPD	RPD Limit
B12J174-BS1	LCS	42.2	40			105	85-115		
B12J174-DUP1	Duplicate	26.8		1210038-43	26.7			0.5	20
B12J174-DUP2	Duplicate	13.7		1210038-51	13.9			2	20
B12J174-MS1	Matrix Spike	51.4	39.8	1210038-33	7.78	110	75-125		
B12J174-MSD1	Matrix Spike Dup	51.0	39.9	1210038-33	7.78	108	75-125	0.7	20
B12J174-SRM1	Reference	176	168			105	83.3-117.3		

Authorized by: DM **Release Date:** 11/19/12

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Cadmium

Project Name: NE Washington Sediments

Work Order: 1210038 | **Analyte: Cadmium** | **Matrix: Sediment/Soil**
Project Officer: Johnson, Art | **Method: EPA200.8** | **Units: mg/Kg dw**
Date Collected: 09/11/2012 | **Date Analyzed: 10/15/2012**

Sample #	Sample ID	Result	Qualifier	RL	MDL	Collected	Analyzed	Batch ID
1210038-01	**CEDAR 1**	**7.51**		1.00	0.034	09/11/12	10/15/12	B12J079
1210038-02	**CEDAR 2**	**11.3**		0.996	0.034	09/11/12	10/15/12	B12J079
1210038-03	**CEDAR 3**	**9.71**		0.994	0.033	09/11/12	10/15/12	B12J079
1210038-04	**CEDAR DUP**	**11.2**		0.998	0.034	09/11/12	10/15/12	B12J079
1210038-10	**SILVER 0-10**	**16.8**		1.00	0.034	09/11/12	10/15/12	B12J079
1210038-11	**SILVER 10-20**	**25.7**		0.994	0.033	09/11/12	10/15/12	B12J079
1210038-12	**SILVER 20-30**	**0.422**		0.100	0.003	09/11/12	10/15/12	B12J079
1210038-13	**SILVER 30-50**	**0.160**		0.099	0.003	09/11/12	10/15/12	B12J079
1210038-15	**PHALON 0-10**	**8.71**		0.996	0.034	09/12/12	10/15/12	B12J079
1210038-16	**PHALON 10-20**	**4.50**		0.994	0.033	09/12/12	10/15/12	B12J079
1210038-17	**PHALON 20-30**	**4.50**		0.994	0.033	09/12/12	10/15/12	B12J079
1210038-18	**PHALON 30-50**	**5.28**		1.01	0.034	09/12/12	10/15/12	B12J079
1210038-20	**PHILLIPS 0-10**	**10.5**		1.00	0.034	09/11/12	10/15/12	B12J079
1210038-21	**PHILLIPS 10-20**	**7.49**		1.00	0.034	09/11/12	10/15/12	B12J079
1210038-22	**PHILLIPS 20-30**	**0.593**		0.100	0.003	09/11/12	10/15/12	B12J079
1210038-24	**DRY 0-10**	**4.50**		1.00	0.034	09/12/12	10/15/12	B12J079
1210038-30	**CEDAR 1-6**	**8.48**		1.57	0.053	09/11/12	10/15/12	B12J079
1210038-31	**CEDAR 7-9**	**12.9**		1.00	0.034	09/11/12	10/15/12	B12J079
1210038-32	**CEDAR 10**	**12.2**		1.00	0.034	09/11/12	10/15/12	B12J079
1210038-34	**CEDAR 12**	**0.780**		0.100	0.003	09/11/12	10/15/12	B12J079

QC Results for Batch ID: B12J079

Method Blank	Sample ID	Result	Qualifer	RL	MDL	Analyzed
B12J079-BLK1	Blank	0.100	U	0.100	0.003	10/15/12

Sample #	QC Sample	Result	Spike Level	Source Sample	Source Result	%Rec	%Rec Limits	RPD	RPD Limit
B12J079-BS1	LCS	40.3	40			101	85-115		
B12J079-DUP1	Duplicate	0.773		1210038-34	0.780			1	20
B12J079-MS1	Matrix Spike	52.4	40.1	1210038-32	12.2	100	75-125		
B12J079-MSD1	Matrix Spike Dup	51.3	40	1210038-32	12.2	98	75-125	2	20
B12J079-SRM1	Reference	103	103			100	83.6-115.5		

Authorized by: Dm **Release Date:** 11/19/12

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Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Cadmium

Project Name: NE Washington Sediments

Work Order: 1210038 **Analyte:** Cadmium **Matrix:** Sediment/Soil
Project Officer: Johnson, Art **Method:** EPA200.8 **Units:** mg/Kg dw
Date Collected: 09/11/2012 **Date Analyzed:** 11/06/2012

Sample #	Sample ID	Result	Qualifier	RL	MDL	Collected	Analyzed	Batch ID
1210038-33	CEDAR 11	2.61		0.990	0.033	09/11/12	11/06/12	B12J174
1210038-35	CEDAR 13	0.567		0.100	0.003	09/11/12	11/07/12	B12J174
1210038-36	CEDAR 14	0.701		0.099	0.003	09/11/12	11/07/12	B12J174
1210038-37	CEDAR 15-16	1.31		1.00	0.034	09/11/12	11/06/12	B12J174
1210038-38	CEDAR 17-18	0.524		0.157	0.005	09/11/12	11/07/12	B12J174
1210038-39	CEDAR 19-20	0.319		0.159	0.005	09/11/12	11/07/12	B12J174
1210038-40	CEDAR 23-24	0.492		0.153	0.005	09/11/12	11/07/12	B12J174
1210038-41	CEDAR 27-28	0.827		0.100	0.003	09/11/12	11/07/12	B12J174
1210038-42	CEDAR 31-32	0.789		0.100	0.003	09/11/12	11/07/12	B12J174
1210038-43	CEDAR 35-36	1.46		0.996	0.034	09/11/12	11/06/12	B12J174
1210038-44	CEDAR 37-38	1.27		1.00	0.034	09/11/12	11/06/12	B12J174
1210038-50	Elbow	2.94		1.00	0.034	10/09/12	11/06/12	B12J174
1210038-51	Dilly	1.98		1.00	0.034	10/09/12	11/06/12	B12J174
1210038-52	Bowen	7.20		1.00	0.034	10/09/12	11/06/12	B12J174
1210038-53	Peterson	0.774		0.100	0.003	10/10/12	11/07/12	B12J174
1210038-55	Bodie	0.517		0.100	0.003	10/10/12	11/07/12	B12J174
1210038-56	Elbow10-20	3.48	J	1.00	0.034	10/09/12	11/06/12	B12J174
1210038-57	Elbow20-30	1.67	J	1.00	0.034	10/09/12	11/06/12	B12J174
1210038-58	Elbow30-40	1.76	J	1.00	0.034	10/09/12	11/06/12	B12J174
1210038-59	Elbow 0-10	3.07	J	1.00	0.034	10/09/12	11/06/12	B12J174

QC Results for Batch ID: B12J174

Method Blank	Sample ID	Result	Qualifer	RL	MDL	Analyzed
B12J174-BLK1	Blank	0.100	U	0.100	0.003	11/06/12

Sample #	QC Sample	Result	Spike Level	Source Sample	Source Result	%Rec	%Rec Limits	RPD	RPD Limit
B12J174-BS1	LCS	41.1	40			103	85-115		
B12J174-DUP1	Duplicate	1.49		1210038-43	1.46			2	20
B12J174-DUP2	Duplicate	1.93		1210038-51	1.98			2	20
B12J174-MS1	Matrix Spike	43.5	39.8	1210038-33	2.61	103	75-125		
B12J174-MSD1	Matrix Spike Dup	42.8	39.9	1210038-33	2.61	101	75-125	2	20
B12J174-SRM1	Reference	101	103			98	83.6-115.5		

Authorized by: Dm **Release Date:** 11/19/12

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Lead

Project Name: NE Washington Sediments

Work Order: 1210038 | **Analyte: Lead** | **Matrix: Sediment/Soil**
Project Officer: Johnson, Art | **Method: EPA200.8** | **Units: mg/Kg dw**
Date Collected: 09/11/2012 | **Date Analyzed: 10/15/2012**

Sample #	Sample ID	Result	Qualifier	RL	MDL	Collected	Analyzed	Batch ID
1210038-01	**CEDAR 1**	**308**		1.00	0.066	09/11/12	10/15/12	B12J079
1210038-02	**CEDAR 2**	**478**		0.996	0.066	09/11/12	10/15/12	B12J079
1210038-03	**CEDAR 3**	**405**		0.994	0.066	09/11/12	10/15/12	B12J079
1210038-04	**CEDAR DUP**	**469**		0.998	0.066	09/11/12	10/15/12	B12J079
1210038-10	**SILVER 0-10**	**545**		1.00	0.066	09/11/12	10/15/12	B12J079
1210038-11	**SILVER 10-20**	**864**		0.994	0.066	09/11/12	10/15/12	B12J079
1210038-12	**SILVER 20-30**	**13.2**		0.996	0.066	09/11/12	10/15/12	B12J079
1210038-13	**SILVER 30-50**	**2.89**		0.992	0.066	09/11/12	10/15/12	B12J079
1210038-15	**PHALON 0-10**	**203**		0.996	0.066	09/12/12	10/15/12	B12J079
1210038-16	**PHALON 10-20**	**19.5**		0.994	0.066	09/12/12	10/15/12	B12J079
1210038-17	**PHALON 20-30**	**4.71**		0.994	0.066	09/12/12	10/15/12	B12J079
1210038-18	**PHALON 30-50**	**6.11**		1.01	0.067	09/12/12	10/15/12	B12J079
1210038-20	**PHILLIPS 0-10**	**371**		1.00	0.067	09/11/12	10/15/12	B12J079
1210038-21	**PHILLIPS 10-20**	**263**		1.00	0.066	09/11/12	10/15/12	B12J079
1210038-22	**PHILLIPS 20-30**	**9.31**		1.00	0.066	09/11/12	10/15/12	B12J079
1210038-24	**DRY 0-10**	**33.6**		1.00	0.067	09/12/12	10/15/12	B12J079
1210038-30	**CEDAR 1-6**	**295**		1.57	0.104	09/11/12	10/15/12	B12J079
1210038-31	**CEDAR 7-9**	**459**		1.00	0.066	09/11/12	10/15/12	B12J079
1210038-32	**CEDAR 10**	**704**		1.00	0.067	09/11/12	10/15/12	B12J079
1210038-34	**CEDAR 12**	**17.0**		0.998	0.066	09/11/12	10/15/12	B12J079

QC Results for Batch ID: B12J079

Method Blank	Sample ID	Result	Qualifer	RL	MDL	Analyzed
B12J079-BLK1	Blank	0.100	U	0.100	0.007	10/15/12

Sample #	QC Sample	Result	Spike Level	Source Sample	Source Result	%Rec	%Rec Limits	RPD	RPD Limit
B12J079-BS1	LCS	42.5	40			106	85-115		
B12J079-DUP1	Duplicate	16.5		1210038-34	17.0			3	20
B12J079-MS1	Matrix Spike	758	40.1	1210038-32	704	135	75-125		
B12J079-MSD1	Matrix Spike Dup	733	40	1210038-32	704	72	75-125	3	20
B12J079-SRM1	Reference	83.3	76.9			108	81.3-118.7		

Authorized by: DM **Release Date:** 11/19/12

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Lead

Project Name: NE Washington Sediments

Work Order: 1210038 | **Analyte: Lead** | **Matrix: Sediment/Soil**
Project Officer: Johnson, Art | **Method: EPA200.8** | **Units: mg/Kg dw**
Date Collected: 09/11/2012 | **Date Analyzed: 11/06/2012**

Sample #	Sample ID	Result	Qualifier	RL	MDL	Collected	Analyzed	Batch ID
1210038-33	**CEDAR 11**	**135**		0.990	0.066	09/11/12	11/06/12	B12J174
1210038-35	**CEDAR 13**	**3.20**		0.996	0.066	09/11/12	11/06/12	B12J174
1210038-36	**CEDAR 14**	**3.95**		0.994	0.066	09/11/12	11/06/12	B12J174
1210038-37	**CEDAR 15-16**	**13.2**		1.00	0.067	09/11/12	11/06/12	B12J174
1210038-38	**CEDAR 17-18**	**3.86**		1.57	0.104	09/11/12	11/06/12	B12J174
1210038-39	**CEDAR 19-20**	**1.42**		0.159	0.011	09/11/12	11/07/12	B12J174
1210038-40	**CEDAR 23-24**	**2.08**		1.53	0.102	09/11/12	11/06/12	B12J174
1210038-41	**CEDAR 27-28**	**3.01**		1.00	0.067	09/11/12	11/06/12	B12J174
1210038-42	**CEDAR 31-32**	**2.30**		1.00	0.066	09/11/12	11/06/12	B12J174
1210038-43	**CEDAR 35-36**	**2.26**		0.996	0.066	09/11/12	11/06/12	B12J174
1210038-44	**CEDAR 37-38**	**2.21**		1.00	0.067	09/11/12	11/06/12	B12J174
1210038-50	**Elbow**	**70.1**		1.00	0.066	10/09/12	11/06/12	B12J174
1210038-51	**Dilly**	**75.1**		1.00	0.066	10/09/12	11/06/12	B12J174
1210038-52	**Bowen**	**262**		1.00	0.066	10/09/12	11/06/12	B12J174
1210038-53	**Peterson**	**12.5**		1.00	0.066	10/10/12	11/06/12	B12J174
1210038-55	**Bodie**	**16.2**		1.00	0.066	10/10/12	11/06/12	B12J174
1210038-56	**Elbow10-20**	**106**	**J**	1.00	0.067	10/09/12	11/06/12	B12J174
1210038-57	**Elbow20-30**	**10.1**	**J**	1.00	0.066	10/09/12	11/06/12	B12J174
1210038-58	**Elbow30-40**	**13.5**	**J**	1.00	0.066	10/09/12	11/06/12	B12J174
1210038-59	**Elbow 0-10**	**82.5**	**J**	1.00	0.066	10/09/12	11/06/12	B12J174

QC Results for Batch ID: B12J174

Method Blank	Sample ID	Result	Qualifer	RL	MDL	Analyzed
B12J174-BLK1	Blank	0.100	U	0.100	0.007	11/06/12

Sample #	QC Sample	Result	Spike Level	Source Sample	Source Result	%Rec	%Rec Limits	RPD	RPD Limit
B12J174-BS1	LCS	42.4	40			106	85-115		
B12J174-DUP1	Duplicate	2.27		1210038-43	2.26			0.2	20
B12J174-DUP2	Duplicate	73.8		1210038-51	75.1			2	20
B12J174-MS1	Matrix Spike	182	39.8	1210038-33	135	118	75-125		
B12J174-MSD1	Matrix Spike Dup	177	39.9	1210038-33	135	107	75-125	2	20
B12J174-SRM1	Reference	84.9	76.9			110	81.3-118.7		

Authorized by: DM **Release Date:** 11/19/12

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Zinc

Project Name: NE Washington Sediments

Work Order: 1210038 | **Analyte: Zinc** | **Matrix: Sediment/Soil**
Project Officer: Johnson, Art | **Method: EPA200.8** | **Units: mg/Kg dw**
Date Collected: 09/11/2012 | **Date Analyzed: 10/15/2012**

Sample #	Sample ID	Result	Qualifier	RL	MDL	Collected	Analyzed	Batch ID
1210038-01	**CEDAR 1**	**259**		50.0	2.18	09/11/12	10/15/12	B12J079
1210038-02	**CEDAR 2**	**403**		49.8	2.17	09/11/12	10/15/12	B12J079
1210038-03	**CEDAR 3**	**339**		49.7	2.16	09/11/12	10/15/12	B12J079
1210038-04	**CEDAR DUP**	**384**		49.9	2.17	09/11/12	10/15/12	B12J079
1210038-10	**SILVER 0-10**	**947**		50.0	2.18	09/11/12	10/15/12	B12J079
1210038-11	**SILVER 10-20**	**619**		49.7	2.16	09/11/12	10/15/12	B12J079
1210038-12	**SILVER 20-30**	**63.6**		49.8	2.17	09/11/12	10/15/12	B12J079
1210038-13	**SILVER 30-50**	**31.5**		4.96	0.216	09/11/12	10/15/12	B12J079
1210038-15	**PHALON 0-10**	**223**		49.8	2.17	09/12/12	10/15/12	B12J079
1210038-16	**PHALON 10-20**	**119**		49.7	2.16	09/12/12	10/15/12	B12J079
1210038-17	**PHALON 20-30**	**127**		49.7	2.16	09/12/12	10/15/12	B12J079
1210038-18	**PHALON 30-50**	**137**		50.3	2.19	09/12/12	10/15/12	B12J079
1210038-20	**PHILLIPS 0-10**	**670**		50.1	2.18	09/11/12	10/15/12	B12J079
1210038-21	**PHILLIPS 10-20**	**351**		50.0	2.18	09/11/12	10/15/12	B12J079
1210038-22	**PHILLIPS 20-30**	**69.6**		50.0	2.18	09/11/12	10/15/12	B12J079
1210038-24	**DRY 0-10**	**27.0**		5.01	0.218	09/12/12	10/15/12	B12J079
1210038-30	**CEDAR 1-6**	**472**		78.6	3.42	09/11/12	10/15/12	B12J079
1210038-31	**CEDAR 7-9**	**386**		50.0	2.18	09/11/12	10/15/12	B12J079
1210038-32	**CEDAR 10**	**502**		50.1	2.18	09/11/12	10/15/12	B12J079
1210038-34	**CEDAR 12**	**21.0**		4.99	0.217	09/11/12	10/15/12	B12J079

QC Results for Batch ID: B12J079

Method Blank	Sample ID	Result	Qualifer	RL	MDL	Analyzed
B12J079-BLK1	Blank	5.00	U	5.00	0.218	10/15/12

Sample #	QC Sample	Result	Spike Level	Source Sample	Source Result	%Rec	%Rec Limits	RPD	RPD Limit
B12J079-BS1	LCS	42.8	40			107	85-115		
B12J079-DUP1	Duplicate	20.9		1210038-34	21.0			0.6	20
B12J079-MS1	Matrix Spike	554	40.1	1210038-32	502	131	75-125		
B12J079-MSD1	Matrix Spike Dup	538	40	1210038-32	502	91	75-125	3	20
B12J079-SRM1	Reference	306	276			111	82.2-117.8		

Authorized by: DM

Release Date: 11/19/12

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Zinc

Project Name: NE Washington Sediments

Work Order: 1210038 | **Analyte:** Zinc | **Matrix:** Sediment/Soil
Project Officer: Johnson, Art | **Method:** EPA200.8 | **Units:** mg/Kg dw
Date Collected: 09/11/2012 | **Date Analyzed:** 11/06/2012

Sample #	Sample ID	Result	Qualifier	RL	MDL	Collected	Analyzed	Batch ID
1210038-33	CEDAR 11	60.4		49.5	2.15	09/11/12	11/06/12	B12J174
1210038-35	CEDAR 13	28.4		4.98	0.217	09/11/12	11/07/12	B12J174
1210038-36	CEDAR 14	80.1		49.7	2.16	09/11/12	11/06/12	B12J174
1210038-37	CEDAR 15-16	171		50.2	2.18	09/11/12	11/06/12	B12J174
1210038-38	CEDAR 17-18	78.8		78.6	3.42	09/11/12	11/06/12	B12J174
1210038-39	CEDAR 19-20	51.7		7.94	0.345	09/11/12	11/07/12	B12J174
1210038-40	CEDAR 23-24	55.0		7.65	0.333	09/11/12	11/07/12	B12J174
1210038-41	CEDAR 27-28	78.5		50.1	2.18	09/11/12	11/06/12	B12J174
1210038-42	CEDAR 31-32	82.3		50.0	2.18	09/11/12	11/06/12	B12J174
1210038-43	CEDAR 35-36	112		49.8	2.17	09/11/12	11/06/12	B12J174
1210038-44	CEDAR 37-38	104		50.1	2.18	09/11/12	11/06/12	B12J174
1210038-50	Elbow	99.0		50.0	2.18	10/09/12	11/06/12	B12J174
1210038-51	Dilly	64.0		50.0	2.18	10/09/12	11/06/12	B12J174
1210038-52	Bowen	256		50.0	2.18	10/09/12	11/06/12	B12J174
1210038-53	Peterson	71.6		50.0	2.18	10/10/12	11/06/12	B12J174
1210038-55	Bodie	62.0		50.0	2.18	10/10/12	11/06/12	B12J174
1210038-56	Elbow10-20	122	J	50.1	2.18	10/09/12	11/06/12	B12J174
1210038-57	Elbow20-30	93.9	J	50.0	2.18	10/09/12	11/06/12	B12J174
1210038-58	Elbow30-40	100	J	50.0	2.18	10/09/12	11/06/12	B12J174
1210038-59	Elbow 0-10	102	J	50.0	2.18	10/09/12	11/06/12	B12J174

QC Results for Batch ID: B12J174

Method Blank	Sample ID	Result	Qualifer	RL	MDL	Analyzed
B12J174-BLK1	Blank	5.00	U	5.00	0.218	11/06/12

Sample #	QC Sample	Result	Spike Level	Source Sample	Source Result	%Rec	%Rec Limits	RPD	RPD Limit
B12J174-BS1	LCS	43.6	40			109	85-115		
B12J174-DUP1	Duplicate	111		1210038-43	112			1	20
B12J174-DUP2	Duplicate	63.0		1210038-51	64.0			2	20
B12J174-MS1	Matrix Spike	102	39.8	1210038-33	60.4	104	75-125		
B12J174-MSD1	Matrix Spike Dup	101	39.9	1210038-33	60.4	103	75-125	0.2	20
B12J174-SRM1	Reference	300	276			109	82.2-117.8		

Authorized by: DM

Release Date: 11/19/12

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Mercury

Project Name: NE Washington Sediments

Work Order: 1210038 | **Analyte: Mercury** | **Matrix: Sediment/Soil**
Project Officer: Johnson, Art | **Method: EPA245.5** | **Units: mg/Kg dw**
Date Collected: 09/11/2012 | **Date Analyzed: 10/03/2012**

Sample #	Sample ID	Result	Qualifier	RL	MDL	Collected	Analyzed	Batch ID
1210038-01	**CEDAR 1**	**0.102**		0.0078	0.0011	09/11/12	10/03/12	B12J033
1210038-02	**CEDAR 2**	**0.130**		0.0080	0.0012	09/11/12	10/03/12	B12J033
1210038-03	**CEDAR 3**	**0.147**		0.0086	0.0013	09/11/12	10/03/12	B12J033
1210038-04	**CEDAR DUP**	**0.143**		0.0087	0.0013	09/11/12	10/03/12	B12J033
1210038-10	**SILVER 0-10**	**0.275**		0.0091	0.0013	09/11/12	10/03/12	B12J033
1210038-11	**SILVER 10-20**	**0.280**		0.0105	0.0015	09/11/12	10/03/12	B12J033
1210038-12	**SILVER 20-30**	**0.0273**		0.0042	0.0006	09/11/12	10/03/12	B12J033
1210038-13	**SILVER 30-50**	**0.0130**		0.0030	0.0004	09/11/12	10/03/12	B12J033
1210038-20	**PHILLIPS 0-10**	**0.153**		0.0056	0.0008	09/11/12	10/03/12	B12J033
1210038-21	**PHILLIPS 10-20**	**0.0925**		0.0048	0.0007	09/11/12	10/03/12	B12J033
1210038-22	**PHILLIPS 20-30**	**0.0480**		0.0037	0.0005	09/11/12	10/03/12	B12J033
1210038-30	**CEDAR 1-6**	**0.208**		0.0213	0.0031	09/11/12	10/03/12	B12J033
1210038-31	**CEDAR 7-9**	**0.157**		0.0098	0.0014	09/11/12	10/03/12	B12J033
1210038-32	**CEDAR 10**	**0.137**		0.0063	0.0009	09/11/12	10/03/12	B12J033
1210038-33	**CEDAR 11**	**0.0325**		0.0030	0.0004	09/11/12	10/03/12	B12J033
1210038-34	**CEDAR 12**	**0.0270**		0.0036	0.0005	09/11/12	10/03/12	B12J033
1210038-35	**CEDAR 13**	**0.0466**		0.0060	0.0009	09/11/12	10/03/12	B12J033
1210038-36	**CEDAR 14**	**0.0666**		0.0108	0.0016	09/11/12	10/03/12	B12J033
1210038-37	**CEDAR 15-16**	**0.0684**		0.0151	0.0022	09/11/12	10/03/12	B12J033
1210038-38	**CEDAR 17-18**	**0.0466**		0.0291	0.0042	09/11/12	10/03/12	B12J033

QC Results for Batch ID: B12J033

Method Blank	Sample ID	Result	Qualifer	RL	MDL	Analyzed
B12J033-BLK1	Blank	0.0036	U	0.0036	0.0005	10/03/12

Sample #	QC Sample	Result	Spike Level	Source Sample	Source Result	%Rec	%Rec Limits	RPD	RPD Limit
B12J033-BS1	LCS	0.069	0.072			96	85-115		
B12J033-DUP1	Duplicate	0.026		1210038-34	0.0270			5	20
B12J033-MS1	Matrix Spike	0.248	0.151	1210038-01	0.102	97	75-125		
B12J033-MSD1	Matrix Spike Dup	0.245	0.155	1210038-01	0.102	92	75-125	1	20

Authorized by: Dm **Release Date:** 11/19/12

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Mercury

Project Name: NE Washington Sediments

Work Order: 1210038 | **Analyte: Mercury** | **Matrix: Sediment/Soil**
Project Officer: Johnson, Art | **Method: EPA245.5** | **Units: mg/Kg dw**
Date Collected: 09/12/2012 | **Date Analyzed: 10/05/2012**

Sample #	Sample ID	Result	Qualifier	RL	MDL	Collected	Analyzed	Batch ID
1210038-15	**PHALON 0-10**	**0.138**		0.0048	0.0007	09/12/12	10/05/12	B12J054
1210038-16	**PHALON 10-20**	**0.0505**		0.0040	0.0006	09/12/12	10/05/12	B12J054
1210038-17	**PHALON 20-30**	**0.0360**		0.0039	0.0006	09/12/12	10/05/12	B12J054
1210038-18	**PHALON 30-50**	**0.0339**		0.0042	0.0006	09/12/12	10/05/12	B12J054
1210038-24	**DRY 0-10**	**0.0567**		0.0038	0.0006	09/12/12	10/05/12	B12J054
1210038-39	**CEDAR 19-20**	**0.0381**		0.0317	0.0046	09/11/12	10/05/12	B12J054
1210038-40	**CEDAR 23-24**	**0.0507**		0.0273	0.0040	09/11/12	10/05/12	B12J054
1210038-41	**CEDAR 27-28**	**0.0530**		0.0156	0.0023	09/11/12	10/05/12	B12J054
1210038-42	**CEDAR 31-32**	**0.0358**		0.0152	0.0022	09/11/12	10/05/12	B12J054
1210038-43	**CEDAR 35-36**	**0.0420**		0.0125	0.0018	09/11/12	10/05/12	B12J054
1210038-44	**CEDAR 37-38**	**0.0364**		0.0117	0.0017	09/11/12	10/05/12	B12J054

QC Results for Batch ID: B12J054

Method Blank	Sample ID	Result	Qualifer	RL	MDL	Analyzed
B12J054-BLK1	Blank	0.0036	U	0.0036	0.0005	10/05/12

Sample #	QC Sample	Result	Spike Level	Source Sample	Source Result	%Rec	%Rec Limits	RPD	RPD Limit
B12J054-BS1	LCS	0.072	0.072			100	85-115		
B12J054-DUP1	Duplicate	0.038		1210038-43	0.0420			9	20
B12J054-MS1	Matrix Spike	0.112	0.0861	1209076-04	0.016	110	75-125		
B12J054-MSD1	Matrix Spike Dup	0.096	0.0744	1209076-04	0.016	107	75-125	15	20

Authorized by: Dm **Release Date:** 11/19/12

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Mercury

Project Name: NE Washington Sediments

Work Order: 1210038 | **Analyte: Mercury** | **Matrix: Sediment/Soil**
Project Officer: Johnson, Art | **Method: EPA245.5** | **Units: mg/Kg dw**
Date Collected: 10/09/2012 | **Date Analyzed: 10/26/2012**

Sample #	Sample ID	Result	Qualifier	RL	MDL	Collected	Analyzed	Batch ID
1210038-50	**Elbow**	**0.133**		0.0160	0.0023	10/09/12	10/26/12	B12J234
1210038-51	**Dilly**	**0.0431**		0.0073	0.0011	10/09/12	10/26/12	B12J234
1210038-52	**Bowen**	**0.0932**		0.0064	0.0009	10/09/12	10/26/12	B12J234
1210038-53	**Peterson**	**0.0642**		0.0059	0.0009	10/10/12	10/26/12	B12J234
1210038-56	**Elbow10-20**	**0.116**	**J**	0.0055	0.0008	10/09/12	10/26/12	B12J234
1210038-57	**Elbow20-30**	**0.0632**	**J**	0.0061	0.0009	10/09/12	10/26/12	B12J234
1210038-58	**Elbow30-40**	**0.0476**	**J**	0.0044	0.0006	10/09/12	10/26/12	B12J234
1210038-59	**Elbow 0-10**	**0.178**	**J**	0.0104	0.0015	10/09/12	10/26/12	B12J234

QC Results for Batch ID: B12J234

Method Blank	Sample ID	Result	Qualifer	RL	MDL	Analyzed
B12J234-BLK1	Blank	0.0036	U	0.0036	0.0005	10/26/12

Sample #	QC Sample	Result	Spike Level	Source Sample	Source Result	%Rec	%Rec Limits	RPD	RPD Limit
B12J234-BS1	LCS	0.071	0.072			99	85-115		
B12J234-DUP1	Duplicate	0.044		1210038-51	0.0431			2	20
B12J234-MS1	Matrix Spike	1.33	0.071	1210060-08	1.22	154	75-125		
B12J234-MSD1	Matrix Spike Dup	1.29	0.0726	1210060-08	1.22	92	75-125	3	20

Authorized by: DM **Release Date:** 11/19/12

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Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Mercury

Project Name: NE Washington Sediments

Work Order: 1210038
Project Officer: Johnson, Art
Date Collected: 10/10/2012

Analyte: Mercury
Method: EPA245.5
Date Analyzed: 11/01/2012

Matrix: Sediment/Soil
Units: mg/Kg dw

Sample #	Sample ID	Result	Qualifier	RL	MDL	Collected	Analyzed	Batch ID
1210038-55	**Bodie**	**0.0124**	**J**	0.0030	0.0004	10/10/12	11/01/12	B12J291

QC Results for Batch ID: B12J291

Method Blank	Sample ID	Result	Qualifer	RL	MDL	Analyzed
B12J291-BLK1	Blank	0.0036	U	0.0036	0.0005	11/01/12

Sample #	QC Sample	Result	Spike Level	Source Sample	Source Result	%Rec	%Rec Limits	RPD	RPD Limit
B12J291-BS1	LCS	0.071	0.072			99	85-115		
B12J291-MS1	Matrix Spike	0.047	0.0586	1210038-55	0.012	59	75-125		
B12J291-MSD1	Matrix Spike Dup	0.058	0.0577	1210038-55	0.012	79	75-125	21	20

Authorized by: DM

Release Date: 11/19/12

Manchester Environmental Laboratory

7411 Beach Drive East, Port Orchard, Washington 98366

December 24, 2012

Subject:	N.E. Wash Sediments
LIMS ID:	1210038
Laboratory:	Analytical Resources, Inc., ARI
Project Officer:	Art Johnson
By:	Karin Feddersen

Grain Size

Analytical Methods

These samples were analyzed for Grain Size following Puget Sound Estuary Program protocols, and reported as Gravel, Sand, Silt, and Clay.

The samples contained organic woody or other organic matter, which may have affected the grain size distribution results. Therefore the results have been qualified as estimates in all analyses.

Holding Times

Samples were sent on ice and arrived at 0.5°C, within criteria of above freezing and below 6°C.

All samples were analyzed within the recommended holding time of 6 months days from collection, based upon dates entered on the Laboratory Analyses Require form.

Method QA/QC

ARI performed a "QA ratio" check to determine how closely the total masses match between two different aliquots: the mass of the sample used for moisture content analysis vs. the mass calculated from the sieve and pipette portions of the test, using a separate aliquot.

The numerator in the ratio is the calculated weight of the total solids. The denominator is the total coarse mass measured from sieving plus the total fine mass measured during the pipette analysis.

If the moisture content sample is not exactly the same as the test sample, then the QA can be outside criteria. When the sample contains large particles, especially if the particles are organic, and irregular like debris, it is difficult to get the moisture contents to be exactly the same. This is especially difficult with limited volume since as smaller samples are less representative samples.

The PSEP method states: "The total amount of fine-grained material used for pipette analysis should be 5-25 g. If more material is used, particles may interfere with each other during settling and the possibility of flocculation may be enhanced. If less material is used, the experimental error in weighing becomes unacceptably large."

Due to the organic content in the samples, estimating the dry weight of fines in each sample was difficult. Several sample analyses had to be repeated to obtain the required amount of fines. According to ARI, due to the high moisture content of one sample, 1210038-50, there was insufficient sample volume available to repeat the analysis. In addition, the sample was composed entirely of organic matter, which is an inappropriate matrix for this analysis.

Triplicate Samples

Triplicate analyses were performed on 1210038-14, which was chosen by the client. The standard deviation was outside ARI's criteria. However, due to the high moisture content, there was insufficient sample volume available to repeat the analyses.

Data Qualifier Codes

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

Washington State Department of Ecology
PBT Sediment Cores 2012; part 2

Percent Retained in Each Fraction

Major Components of Apparent Grain Size Distribution by PSEP Methodology

Sample Number	Gravel (>2,000)	Sand (2,000< x <62.5)	Silt (62.5< x <4)	Clay (<4)
1210038-14	0.0	25.5 J	51.3 J	23.2 J
1210038-14	0.0	18.8	55.0	26.3
1210038-14	0.0	12.0	58.1	29.8
1210038-05	0.0	22.2	31.4	46.4
1210038-06	0.0	6.0	52.6	41.4
1210038-07	43.6 J	17.7	18.7	20.0
1210038-19	34.4 J	23.0	21.2	21.5
1210038-23	0.0	70.4	18.9	10.8
1210038-24	0.0	29.8	40.3	29.9
1210038-50	36.5 J	34.0	10.6	18.9
1210038-51	0.0	57.9	32.1	10.0
1210038-52	0.0	38.7	53.1	8.2
1210038-53	0.1 J	62.1	32.5	5.3
1210038-55	0.0	40.2	51.8	8.0

1. Testing performed according to PSEP "Apparent Grain Size Distribution" protocol, with modifications for determination of only the major components

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Washington State Department of Ecology
PBT Sediment Cores 2012; part 2

QA Summary

Sample Number	ARI Number	Gravel (>2,000)	Sand (2,000< x <62.5)	Silt (62.5< x <4)	Clay (<4)	Total Fines
1210038-14	D-1	0.0	25.5 J	51.3 J	23.2 J	74.5 J
1210038-14	D-2	0.0	18.8	55.0	26.3	81.2
1210038-14	D-3	0.0	12.0	58.1	29.8	88.0
Average		0.00	18.75	54.82	26.42	81.25
STDEV		0.00	5.49	2.78	2.72	5.50
%RSD			29.30	5.08	10.28	15.36

Sample Number	Date Sampled	Date Extracted	Date Completed	QA Summary		
				Amount Fines	Data Qualifiers	QA Ratio (95-105)
1210038-14	10/18/2012	10/23/2012	10/31/2012	2.76 J	SS	100.8
1210038-14	10/18/2012	10/23/2012	10/31/2012	2.86	SS	104.4
1210038-14	10/18/2012	10/23/2012	10/31/2012	2.81	SS	100.3
1210038-05	10/18/2012	10/29/2012	10/31/2012	7.68		102.6
1210038-06	10/18/2012	10/24/2012	10/31/2012	6.49		100.2
1210038-07	10/18/2012	10/29/2012	10/31/2012	2.12	SS	97.7
1210038-19	10/18/2012	10/24/2012	10/31/2012	2.94	SS	98.9
1210038-23	10/18/2012	10/24/2012	10/31/2012	1.84	SS	99.4
1210038-24	10/18/2012	10/24/2012	10/31/2012	14.42		98.5
1210038-50	10/18/2012	10/24/2012	10/31/2012	0.67	SS, SM	29.2
1210038-51	10/18/2012	10/29/2012	10/31/2012	6.50		100.1
1210038-52	10/18/2012	10/29/2012	10/31/2012	9.03		102.8
1210038-53	10/18/2012	10/29/2012	10/31/2012	6.23		103.4
1210038-55	10/18/2012	10/24/2012	10/31/2012	12.27		101.4

Notes:

1. The PSEP limits for amount of fines are between 5 and 25 g
2. ARI Data Qualifier, see attached sheet
3. ARI Internal QA limits = 95-105% STDEV

VO32

Manchester Environmental Laboratory
7411 Beach Drive E, Port Orchard, Washington 98366

Case Narrative

November 6, 2012

Project: General Chemistry NE Washington Sediments

Work Order: 1210038

Project Manager: Johnson, Art

By: Dean Momohara

Summary

The laboratory analyzed the samples following Standard Methods 2540G for percent solids and PSEP-TOC for total organic carbon @ 70°.

All analyses requested were evaluated by established regulatory quality assurance guidelines.

Sample Information

The samples were received at the Manchester Laboratory on 9/27/2012 and 10/17/2012. All coolers were received within the proper temperature range of 0°C - 6°C. The samples were received in good condition. The samples for PSEP-TOC analysis were frozen prior to analysis. Sample 06 for TOC was not analyzed. Samples 05 and 07 were collected in the wrong container. Forty five samples were received and assigned laboratory identification numbers 01 to 05, 07, 10 to 24, 30 to 44, 50 to 53 and 55 to 59.

Holding Times

All analyses were performed within their hold times except for percent solids and TOC. All samples for percent solids and samples 05, 07, 14, 19, 23 and 24 for TOC were received and analyzed out of hold time. The results were qualified as estimates.

Calibration

The instrument was calibrated following the appropriate method. All initial and continuing calibration verification checks were within the acceptance limits.

All initial and continuing blank checks were within the acceptance limits. The r-value was within the acceptance limits. All standard residuals were within acceptance limits. Oven drying temperatures were monitored before and after drying.

Method Blanks

No analytically significant levels of analyte were detected in the method blanks associated with these samples.

Laboratory Control Samples

All laboratory control sample recoveries were within the acceptance limits.

Replicates

The associated duplicate relative percent difference(s) and duplicate relative standard deviation (solid TOC analysis) of samples with concentrations greater than 5 times the reporting limit were within the acceptance limits.

Matrix Spikes

NA

Other Quality Assurance Measures and Issues

U - The analyte was not detected at or above the reported result.

J - The analyte was positively identified. The associated numerical result is an estimate.

bold - The analyte was present in the sample. (Visual Aid to locate detected compounds on report sheet.)

Please call Dean Momohara at (360) 871-8808 to further discuss this project.

cc: Project File

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Percent Solids

Project Name: NE Washington Sediments

Work Order: 1210038 | **Analyte: Solids** | **Matrix: Sediment/Soil**
Project Officer: Johnson, Art | **Method: SM2540G** | **Units: %**
Date Collected: 09/11/2012 | **Date Analyzed: 09/27/2012**

Sample #	Sample ID	Result	Qualifier	RL	MDL	Collected	Analyzed	Batch ID
1210038-01	CEDAR 1	9.2	J	0.001		09/11/12	09/27/12	B12J008
1210038-02	CEDAR 2	9.0	J	0.001		09/11/12	09/27/12	B12J008
1210038-03	CEDAR 3	8.2	J	0.001		09/11/12	09/27/12	B12J008
1210038-04	CEDAR DUP	8.2	J	0.001		09/11/12	09/27/12	B12J008
1210038-10	SILVER 0-10	7.9	J	0.001		09/11/12	09/27/12	B12J008
1210038-11	SILVER 10-20	6.8	J	0.001		09/11/12	09/27/12	B12J008
1210038-12	SILVER 20-30	16.1	J	0.001		09/11/12	09/27/12	B12J008
1210038-13	SILVER 30-50	23.4	J	0.001		09/11/12	09/27/12	B12J008
1210038-15	PHALON 0-10	15.1	J	0.001		09/12/12	09/27/12	B12J008
1210038-16	PHALON 10-20	18.0	J	0.001		09/12/12	09/27/12	B12J008
1210038-17	PHALON 20-30	18.2	J	0.001		09/12/12	09/27/12	B12J008
1210038-18	PHALON 30-50	17.0	J	0.001		09/12/12	09/27/12	B12J008
1210038-20	PHILLIPS 0-10	13.0	J	0.001		09/11/12	09/27/12	B12J008
1210038-21	PHILLIPS 10-20	14.6	J	0.001		09/11/12	09/27/12	B12J008
1210038-22	PHILLIPS 20-30	19.6	J	0.001		09/11/12	09/27/12	B12J008
1210038-24	DRY 0-10	30.1	J	0.001		09/12/12	09/27/12	B12J008
1210038-30	CEDAR 1-6	3.4	J	0.001		09/11/12	09/27/12	B12J008
1210038-31	CEDAR 7-9	7.3	J	0.001		09/11/12	09/27/12	B12J008
1210038-32	CEDAR 10	11.1	J	0.001		09/11/12	09/27/12	B12J008
1210038-33	CEDAR 11	23.1	J	0.001		09/11/12	09/27/12	B12J008

QC Results for Batch ID: B12J008

Method Blank	Sample ID	Result	Qualifer	RL	MDL	Analyzed
B12J008-BLK1	Blank	0.001	U	0.001		09/27/12

Sample #	QC Sample	Result		Spike Level	Source Sample	Source Result		%Rec	%Rec Limits	RPD	RPD Limit
B12J008-DUP1	Duplicate	16.0	J		1210038-12	16.1	J			0.5	20
B12J008-DUP2	Duplicate	3.8	J		1210038-30	3.4	J			11	20

Authorized by: DM **Release Date:** 10/29/12

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Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Percent Solids

Project Name: NE Washington Sediments

Work Order: 1210038 **Analyte:** Solids **Matrix:** Sediment/Soil
Project Officer: Johnson, Art **Method:** SM2540G **Units:** %
Date Collected: 09/11/2012 **Date Analyzed:** 09/27/2012

Sample #	Sample ID	Result	Qualifier	RL	MDL	Collected	Analyzed	Batch ID
1210038-34	CEDAR 12	20.0	J	0.001		09/11/12	09/27/12	B12J009
1210038-35	CEDAR 13	11.5	J	0.001		09/11/12	09/27/12	B12J009
1210038-36	CEDAR 14	6.7	J	0.001		09/11/12	09/27/12	B12J009
1210038-37	CEDAR 15-16	4.8	J	0.001		09/11/12	09/27/12	B12J009
1210038-38	CEDAR 17-18	2.5	J	0.001		09/11/12	09/27/12	B12J009
1210038-39	CEDAR 19-20	2.2	J	0.001		09/11/12	09/27/12	B12J009
1210038-40	CEDAR 23-24	2.7	J	0.001		09/11/12	09/27/12	B12J009
1210038-41	CEDAR 27-28	4.6	J	0.001		09/11/12	09/27/12	B12J009
1210038-42	CEDAR 31-32	4.4	J	0.001		09/11/12	09/27/12	B12J009
1210038-43	CEDAR 35-36	5.4	J	0.001		09/11/12	09/27/12	B12J009
1210038-44	CEDAR 37-38	5.6	J	0.001		09/11/12	09/27/12	B12J009

QC Results for Batch ID: B12J009

Method Blank	Sample ID	Result	Qualifer	RL	MDL	Analyzed
B12J009-BLK1	Blank	0.001	U	0.001		09/27/12

Sample #	QC Sample	Result		Spike Level	Source Sample	Source Result		%Rec	%Rec Limits	RPD	RPD Limit
B12J009-DUP1	Duplicate	20.0	J		1210038-34	20.0	J			0.07	20
B12J009-DUP2	Duplicate	5.4	J		1210038-43	5.4	J			0.4	20

Authorized by: Dr **Release Date:** 10/29/12

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Total Organic Carbon (70 C)

Project Name: NE Washington Sediments

Work Order: 1210038
Project Officer: Johnson, Art
Date Collected: 09/11/2012

Analyte: Total Organic Carbon
Method: PSEP-TOC
Date Analyzed: 10/12/2012

Matrix: Sediment/Soil
Units: %

Sample #	Sample ID	Result	Qualifier	RL	MDL	Collected	Analyzed	Batch ID
1210038-05	**CEDAR 0-10**	**10.8**	**J**	0.10	0.03	09/11/12	10/12/12	B12J071
1210038-07	**CEDAR 15-38**	**27.9**	**J**	0.10	0.03	09/11/12	10/12/12	B12J071
1210038-14	**SILVER 0-50**	**17.1**	**J**	0.10	0.03	09/11/12	10/12/12	B12J071
1210038-19	**PHALON 0-50**	**26.9**	**J**	0.10	0.03	09/12/12	10/12/12	B12J071
1210038-23	**PHILLIPS 0-30**	**31.3**	**J**	0.10	0.03	09/11/12	10/12/12	B12J071
1210038-24	**DRY 0-10**	**15.4**	**J**	0.10	0.03	09/12/12	10/12/12	B12J071

QC Results for Batch ID: B12J071

Method Blank	Sample ID	Result	Qualifer	RL	MDL	Analyzed
B12J071-BLK1	Blank	0.10	U	0.10	0.03	10/12/12

Sample #	QC Sample	Result	Spike Level	Source Sample	Source Result		%Rec	%Rec Limits	RPD	RPD Limit
B12J071-DUP1	Duplicate	16.8		1210038-14	17.1	J			1	20
B12J071-DUP2	Duplicate	17.8		1210038-14	17.1	J			4	20
B12J071-SRM1	Reference	2.92	2.99				98	75-125		

Authorized by: Dr

Release Date: 10/29/12

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Total Organic Carbon (70 C)

Project Name: NE Washington Sediments

Work Order: 1210038
Project Officer: Johnson, Art
Date Collected: 10/09/2012

Analyte: Total Organic Carbon
Method: PSEP-TOC
Date Analyzed: 10/25/2012

Matrix: Sediment/Soil
Units: %

Sample #	Sample ID	Result	Qualifier	RL	MDL	Collected	Analyzed	Batch ID
1210038-50	**Elbow**	**27.1**		0.10	0.03	10/09/12	10/25/12	B12J186
1210038-51	**Dilly**	**10.2**		0.10	0.03	10/09/12	10/25/12	B12J186
1210038-52	**Bowen**	**7.04**		0.10	0.03	10/09/12	10/25/12	B12J186
1210038-53	**Peterson**	**19.2**		0.10	0.03	10/10/12	10/25/12	B12J186
1210038-55	**Bodie**	**9.10**		0.10	0.03	10/10/12	10/25/12	B12J186

QC Results for Batch ID: B12J186

Method Blank	Sample ID	Result	Qualifer	RL	MDL	Analyzed
B12J186-BLK1	Blank	0.10	U	0.10	0.03	10/25/12

Sample #	QC Sample	Result	Spike Level	Source Sample	Source Result	%Rec	%Rec Limits	RPD	RPD Limit
B12J186-DUP1	Duplicate	11.1		1210038-51	10.2			8	20
B12J186-DUP2	Duplicate	10.7		1210038-51	10.2			5	20
B12J186-SRM1	Reference	2.74	2.99			92	75-125		

Authorized by: Dn

Release Date: 10/29/12

Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Percent Solids

Project Name: NE Washington Sediments

Work Order: 1210038 **Analyte: Solids** **Matrix: Sediment/Soil**
Project Officer: Johnson, Art **Method: SM2540G** **Units: %**
Date Collected: 10/09/2012 **Date Analyzed: 10/17/2012**

Sample #	Sample ID	Result	Qualifier	RL	MDL	Collected	Analyzed	Batch ID
1210038-50	**Elbow**	**4.7**	**J**	0.001		10/09/12	10/17/12	B12J187
1210038-51	**Dilly**	**10.2**	**J**	0.001		10/09/12	10/17/12	B12J187
1210038-52	**Bowen**	**11.9**	**J**	0.001		10/09/12	10/17/12	B12J187
1210038-53	**Peterson**	**12.8**	**J**	0.001		10/10/12	10/17/12	B12J187
1210038-55	**Bodie**	**39.8**	**J**	0.001		10/10/12	10/17/12	B12J187

QC Results for Batch ID: B12J187

Method Blank	Sample ID	Result	Qualifer	RL	MDL	Analyzed
B12J187-BLK1	Blank	0.001	U	0.001		10/17/12

Sample #	QC Sample	Result	Spike Level	Source Sample	Source Result		%Rec	%Rec Limits	RPD	RPD Limit
B12J187-DUP1	Duplicate	12.8		1210038-53	12.8	J			0.1	20

Authorized by: DM **Release Date:** 11/5/12

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Washington State Department of Ecology
Manchester Environmental Laboratory
Final Analysis Report for
Percent Solids

Project Name: NE Washington Sediments

Work Order: 1210038 | **Analyte: Solids** | **Matrix: Sediment/Soil**
Project Officer: Johnson, Art | **Method: SM2540G** | **Units: %**
Date Collected: 10/09/2012 | **Date Analyzed: 10/29/2012**

Sample #	Sample ID	Result	Qualifier	RL	MDL	Collected	Analyzed	Batch ID
1210038-56	**Elbow10-20**	**13.3**	**J**	0.001		10/09/12	10/29/12	B12J288
1210038-57	**Elbow20-30**	**12.4**	**J**	0.001		10/09/12	10/29/12	B12J288
1210038-58	**Elbow30-40**	**16.0**	**J**	0.001		10/09/12	10/29/12	B12J288
1210038-59	**Elbow 0-10**	**7.2**	**J**	0.001		10/09/12	10/29/12	B12J288

QC Results for Batch ID: B12J288

Method Blank	Sample ID	Result	Qualifer	RL	MDL	Analyzed
B12J288-BLK1	Blank	0.001	U	0.001		10/29/12

Sample #	QC Sample	Result		Spike Level	Source Sample	Source Result		%Rec	%Rec Limits	RPD	RPD Limit
B12J288-DUP1	Duplicate	12.4	J		1210038-57	12.4	J			0.3	20

Authorized by: LM

Release Date: 11/1/12

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Manchester Environmental Laboratory

7411 Beach Drive East, Port Orchard, Washington 98366

December 18, 2012

Subject:	**NE Washington Sediments**
Ecology LIMS ID:	1210038
Laboratory:	Eberline Analytical
Project Officer:	Art Johnson
By:	Karin Feddersen

Lead-210 from Polonium-210

Summary

These samples were analyzed using Eberline's method EML Po-2 Modified, and reported on a dry weight basis. See Eberline's case narrative for more details.

Calibration

The instrument efficiency, selectivity, and specificity were confirmed daily.

Tracer

The isotope polonium-208 is used as a tracer compound to measure recovery in each sample. In addition, individual tracer recoveries are used to calculate results.

Two samples had poor recovery and were recounted on 11/12/12.

Blanks

No activity was detected in any of the method blanks above the reporting level.

Laboratory Control Sample (LCS)

An LCS was counted with each batch. Recoveries were 83.2% and 84.5%.

Eberline Analytical Final Report of Analysis

Report To:		Work Order Details:
Karin Feddersen	SDG:	12-10136 REVISED
WA State Dept of Ecology Manchester Lab	Purchase Order:	13-25692
7411 Beach Drive East	Analysis Category:	ENVIRONMENTAL
Port Orchard, WA 98366	Sample Matrix:	SO

Lab ID	Sample Type	Client ID	Sample Date	Receipt Date	Analysis Date	Batch ID	Analyte	Method	Result	CU	CSU	MDA	Report Units
12-10136-01	LCS	KNOWN	10/25/12 00:00	10/25/2012	11/7/2012	12-10136	Lead-210	EML Po-2 Modified	7.49E+00	2.77E-01			pCi/g
12-10136-01	LCS	SPIKE	10/25/12 00:00	10/25/2012	11/7/2012	12-10136	Lead-210	EML Po-2 Modified	6.24E+00	1.00E+00	1.11E+00	1.43E-01	pCi/g
12-10136-01	LCS	KNOWN	10/25/12 00:00	10/25/2012	11/12/2012	12-10136	Lead-210	EML Po-2 Modified	7.49E+00	2.77E-01			pCi/g
12-10136-01	LCS	SPIKE	10/25/12 00:00	10/25/2012	11/12/2012	12-10136	Lead-210	EML Po-2 Modified	6.33E+00	1.06E+00	1.16E+00	1.61E-01	pCi/g
12-10136-02	MBL	BLANK	10/25/12 00:00	10/25/2012	11/7/2012	12-10136	Lead-210	EML Po-2 Modified	2.64E-03	9.53E-03	9.53E-03	2.15E-02	pCi/g
12-10136-02	MBL	BLANK	10/25/12 00:00	10/25/2012	11/12/2012	12-10136	Lead-210	EML Po-2 Modified	4.15E-04	9.52E-03	9.52E-03	2.42E-02	pCi/g
12-10136-03	DUP	1210038-31	09/11/12 00:00	10/25/2012	11/12/2012	12-10136	Lead-210	EML Po-2 Modified	1.73E+00	2.41E-01	2.74E-01	2.22E-02	pCi/g
12-10136-04	TRG	1210038-30	09/11/12 00:00	10/25/2012	11/7/2012	12-10136	Lead-210	EML Po-2 Modified	8.56E+00	8.97E-01	1.11E+00	2.55E-02	pCi/g
12-10136-05	DO	1210038-31	09/11/12 00:00	10/25/2012	11/12/2012	12-10136	Lead-210	EML Po-2 Modified	1.44E+00	2.07E-01	2.34E-01	2.31E-02	pCi/g
12-10136-06	TRG	1210038-32	09/11/12 00:00	10/25/2012	11/7/2012	12-10136	Lead-210	EML Po-2 Modified	1.79E+00	2.49E-01	2.83E-01	1.78E-02	pCi/g
12-10136-07	TRG	1210038-33	09/11/12 00:00	10/25/2012	11/7/2012	12-10136	Lead-210	EML Po-2 Modified	5.20E-01	1.18E-01	1.24E-01	3.13E-02	pCi/g
12-10136-08	TRG	1210038-34	09/11/12 00:00	10/25/2012	11/7/2012	12-10136	Lead-210	EML Po-2 Modified	7.16E-01	1.49E-01	1.59E-01	3.60E-02	pCi/g
12-10136-09	TRG	1210038-35	09/11/12 00:00	10/25/2012	11/7/2012	12-10136	Lead-210	EML Po-2 Modified	6.65E-01	1.25E-01	1.35E-01	1.69E-02	pCi/g
12-10136-10	TRG	1210038-36	09/11/12 00:00	10/25/2012	11/7/2012	12-10136	Lead-210	EML Po-2 Modified	6.45E-01	1.43E-01	1.51E-01	3.28E-02	pCi/g
12-10136-11	TRG	1210038-37	09/11/12 00:00	10/25/2012	11/12/2012	12-10136	Lead-210	EML Po-2 Modified	4.88E-01	1.10E-01	1.16E-01	2.69E-02	pCi/g
12-10136-12	TRG	1210038-38	09/11/12 00:00	10/25/2012	11/7/2012	12-10136	Lead-210	EML Po-2 Modified	5.06E-01	1.15E-01	1.21E-01	2.32E-02	pCi/g
12-10136-13	TRG	1210038-39	09/11/12 00:00	10/25/2012	11/7/2012	12-10136	Lead-210	EML Po-2 Modified	3.90E-01	1.39E-01	1.42E-01	5.72E-02	pCi/g
12-10136-14	TRG	1210038-40	09/11/12 00:00	10/25/2012	11/7/2012	12-10136	Lead-210	EML Po-2 Modified	4.93E-01	1.16E-01	1.22E-01	2.49E-02	pCi/g
12-10136-15	TRG	1210038-41	09/11/12 00:00	10/25/2012	11/7/2012	12-10136	Lead-210	EML Po-2 Modified	2.03E-01	6.17E-02	6.36E-02	1.83E-02	pCi/g
12-10136-16	TRG	1210038-42	09/11/12 00:00	10/25/2012	11/7/2012	12-10136	Lead-210	EML Po-2 Modified	3.02E-01	7.75E-02	8.08E-02	1.81E-02	pCi/g
12-10136-17	TRG	1210038-43	09/11/12 00:00	10/25/2012	11/7/2012	12-10136	Lead-210	EML Po-2 Modified	2.73E-01	6.94E-02	7.24E-02	1.89E-02	pCi/g
12-10136-18	TRG	1210038-44	09/11/12 00:00	10/25/2012	11/7/2012	12-10136	Lead-210	EML Po-2 Modified	2.73E-01	6.53E-02	6.85E-02	1.44E-02	pCi/g

CU=Counting Uncertainty;CSU=Combined Standard Uncertainty (2-sigma);MDA=Minimal Detected Activity;LCS=Laboratory Control Sample; MBL=Blank; DUP=Duplicate; TRG=Normal Sample; DO=Duplicate Original

Appendix C. Metals, Lead-2010, and Percent Solids Data for Cedar Lake Box Core Collected September 11, 2012

(dry weight basis)

Sample No. (1210038-)	Depth Increment (cm)	Lead (mg/Kg)	Zinc (mg/Kg)	Arsenic (mg/Kg)	Cadmium (mg/Kg)	Antimony (mg/Kg)	Mercury (mg/Kg)	Pb-210 (pCi/g)	Solids (%)
30	1-6	295	472	28	8.5	9.5	0.21	8.558	3.4
31	7-9	459	386	25	13	16	0.16	1.586	7.3
32	9-10	704	502	26	12	16	0.14	1.786	11.1
33	10-11	135	60	7.8	2.6	2.7	0.03	0.520	23.1
34	11-12	17	21	5.8	0.78	0.57	0.03	0.716	20
35	12-13	3.2	28	11	0.57	0.85	0.05	0.665	11.5
36	13-14	3.95	80	21	0.70	1.4	0.07	0.645	6.7
37	14-16	13.2	171	22	1.3	1.9	0.07	0.488	4.8
38	16-18	3.86	79	17	0.52	1.2	0.05	0.506	2.5
39	18-20	1.42	52	15	0.32	1.0	0.04	0.390	2.2
40	22-24	2.08	55	17	0.49	1.6	0.05	0.493	2.7
41	26-28	3.01	79	21	0.83	1.8	0.05	0.203	4.6
42	30-32	2.3	82	20	0.79	1.4	0.04	0.302	4.4
43	34-36	2.26	112	27	1.5	2.8	0.04	0.273	5.4
44	36-38	2.21	104	26	1.3	2.6	0.04	0.273	5.6

Appendix D. Estimates of Sedimentation Rates in Cedar, Black, and Wenatchee Lakes

Cedar Lake*		Black Lake†		Wenatchee Lake**	
Year	Sedimentation Rate ($g/cm^2/yr$)	Year	Sedimentation Rate ($g/cm^2/yr$)	Year	Sedimentation Rate ($g/cm^2/yr$)
2000	0.007	2006	0.013	2007	0.054
1968	0.016	2000	0.022	2003	0.050
1959	0.010	1996	0.014	1999	0.075
1937	0.030	1992	0.019	1990	0.052
1925	0.012	1988	0.019	1978	0.049
1913	0.009	1980	0.024	1963	0.031
1904	0.007	1974	0.041	1938	0.021
1890	0.008	1969	0.033	1902	0.020
1883	0.006	1957	0.017	1881	0.020
1877	0.009	- -	- -	- -	- -
1855	0.003	- -	- -	- -	- -

*present study
†Furl and Roberts (2010)
**Furl and Roberts (2011)

Appendix E. Brief Summary of Smelter Histories

Trail Smelter

The following Trail operations historical summary primarily is adapted from Queneau (2010).

Trail BC smelter operations have been underway almost continuously since 1896. Initially one blast furnace and four reverberatory furnaces were operated to treat copper-gold ores. By 1898, three 600-ton per day (tpd) furnaces and 48 roasters were installed. Around 1900, the smelting of lead sulfide ores began. Lead production and improved processes progressed steadily, and by 1906 production capacity reached 75 standard tpd. Electrolytic zinc and copper refineries came on line in 1916. Cadmium recovery began in 1927. In 1931, Trail's fuming furnace processed 150,000 tons of blast furnace slag. Also in 1931, operations expanded to include the manufacturing of ammonium sulfate and ammonium phosphate fertilizer. Prior to the installation of baghouses in 1951, to better recover dust and condensed fume from lead blast-furnace offgas, a greater portion of the cadmium and arsenic had been exhausted to atmosphere.

By the early 1970s, Trail operations were aging and in need of major upgrade. For example, much of the lead smelter was essentially 40 to 50 years old, dating back to the 1930s. The path to major modernization across the operations proceeded through the 1980s and 1990s, and continues today. In 1997, the Kivcet lead smelter was commissioned, reaching full operation by 1999. The Kivcet process was shown to decrease stack emissions of particulates, lead, arsenic, mercury, fluoride, and SO_2 by 68 to 98%.

Queneau (2010) estimated and extrapolated limited available records for the period of 1921 to 2005 to develop a minimum estimate of selected metals released into the air from the Trail smelter stacks: zinc – 38,465 tons; lead – 22,688 tons; arsenic – 1,225 tons; cadmium – 1,103 tons; mercury – 97 tons. By applying Trail feed tonnage information organized by Queneau, a simplified minimum daily feedstock tonnage average of over 1,550 tpd for the lead and zinc operations can be estimated over 84 years. In total, the feedstock for over eight decades of operation approached 48.5 million tons.

Today the Trail operations are described as one of the world's largest fully integrated zinc and lead smelters, producing refined zinc, lead, and a variety of precious and specialty metals, chemicals, and fertilizer products (www.teck.com/Generic.aspx?PAGE=Teck Site/Diversified Mining Pages/Zinc Pages/Trail&portalName=tc).

LeRoi/Northport Smelter

In contrast to the successful 116-year history of the Trail operations, LeRoi Mining Company was significantly smaller and experienced a short, intermittent operations life. Much of the following summary is borrowed and adapted from reports authored by Quivik (2010) and McNulty (2011).

The LeRoi smelter in Northport, Washington was built as a copper smelter in 1897 and 1898. The smelter's capacity is reported to have been up to 450 tpd. In 1905, the smelter lost its principle supplier of ore (LeRoi Mine) to the Trail smelter. Prior to closing in 1909, the smelter continued to operate at a reduced rate. Thus the records indicate that this original smelter operated for about nine years at various levels before shutdown.

The facility sat idle until 1916 when, during the World War I era, it was converted to a lead smelter by the Day family. The Northport Smelting and Refining Company built additional workings at the original LeRoi site. Two furnaces, each with a capacity to treat about 250 tons of materials, were "blown in" at that time. A third was installed, but never used. The smelter operated from early 1916 through 1918, then about half of 1919 through 1920. In 1921 it operated for about three months before closing permanently. Thus, the lead smelter operated for roughly three years before final abandonment. The smelter was sold to Asarco in 1922 and underwent partial dismantling in 1923.

References

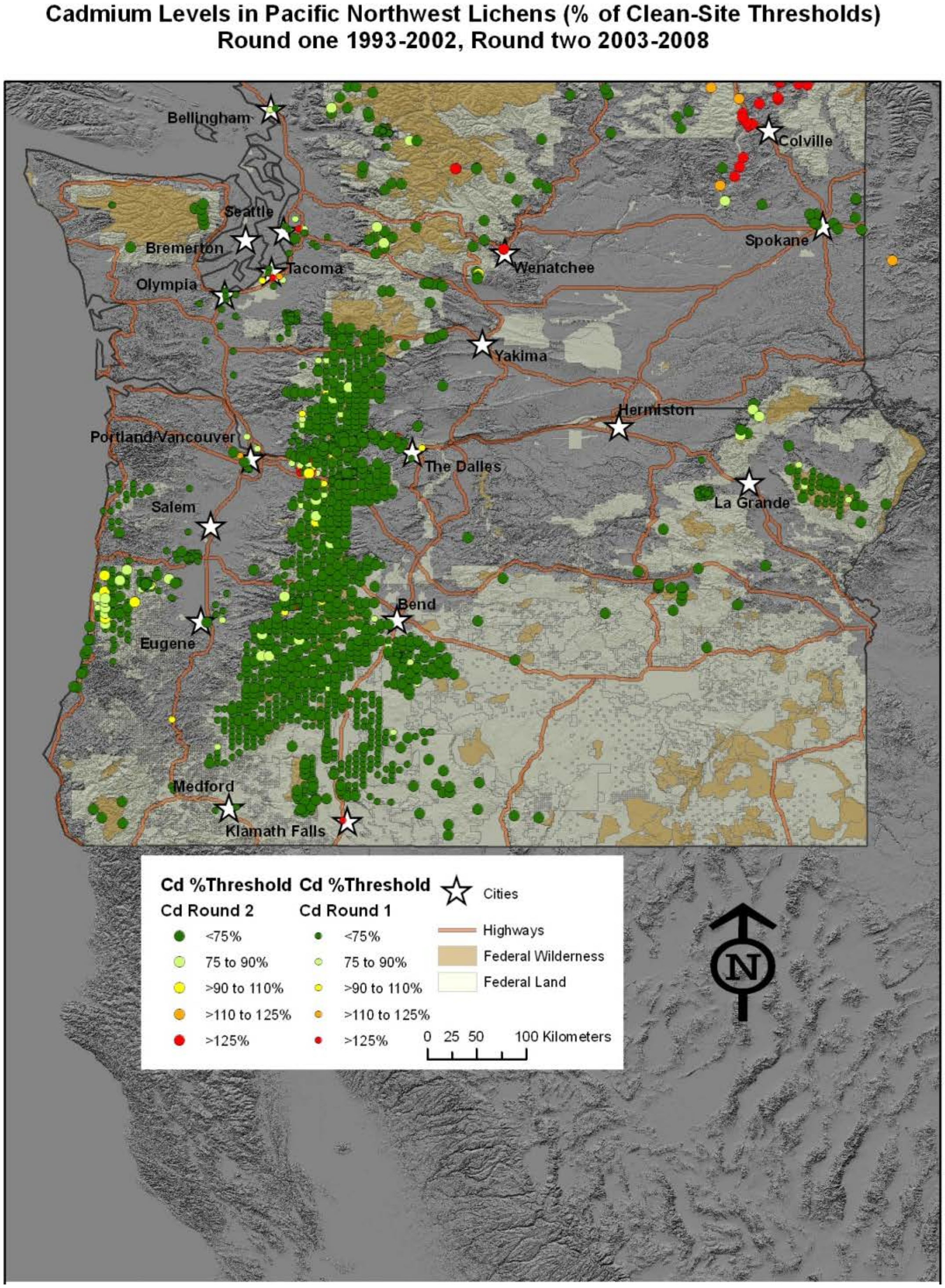
McNulty, Terence P., 2011. Expert Report, Pakootas v. Teck Cominco Metals Ltd., January 14, 2011.

Queneau, Paul B., 2010. Expert Opinion, Pakootas, et al. v. Teck Cominco Metals, September 15, 2010.

Quivik, Fredric L., 2010. History of Mining, Milling, and Smelting in NE Washington, Expert Report, November 19, 2010, Pakootas v. Teck Cominco Metals CV-04-0256-LRS.

Appendix F. Cadmium Concentrations in Pacific Northwest Lichens as Percent of Clean-Site Threshold Values

provided by Linda Geiser, U.S. Forest Service, Corvallis OR.



Appendix G. Acronyms and Abbreviations

BC	British Columbia, Canada
CRS	Constant rate of supply
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EAP	Environmental Assessment Program (Ecology)
EPA	U.S. Environmental Protection Agency
MEL	Manchester Environmental Laboratory (Ecology)
PEC	Probable effect concentration
RPD	Relative percent difference
RSD	Relative standard deviation
SOP	Standard operating procedures
SO_2	Sulfur dioxide

Units of Measurement

cm	centimeter, a unit of length equal to 1/100 meter
ft	feet
g	gram, a unit of mass
g/cm^2/year	grams per square centimeter per year
mg/Kg	milligrams per kilogram (parts per million)
pCi	picocuries, a unit of radioactive decay
tpd	tons per day
ug	microgram, a unit of mass equal to 1/1,000,000 gram
ug/cm^2/year	microgram per square centimeter per year