U.S. Army Corps
of Engineers
Seattle District

Sediment Quality Assessment of Lake Rufus Woods and Chief Joseph Dam, 2004

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Introduction

The Columbia River drains over 670,000 square kilometers of the Pacific Northwest in the United States and Canada. The Snake, Kootenai, and Pend Oreille-Clark Fork systems are the largest tributaries of the Columbia River. The hydrology of the Columbia River system has been modified during the past 100 years due to the construction of numerous hydroelectric, irrigation, flood control, and transportation projects. The construction of these projects on the mainstem of and tributaries of the Columbia River created numerous reservoirs that have resulted in a significant alteration of the natural flow regime, river geometry, river velocity, and water residence time in the Columbia River. A consequence of the creation of reservoirs is that the sediment transport patterns of the Columbia River system have been altered resulting in increased sedimentation in the reservoirs formed by the dams.

Sediment contamination exists in the Columbia River upstream of Grand Coulee Dam in Lake Roosevelt (USGS 1994, Ecology 2001, USGS 2005). Elevated concentrations of arsenic, cadmium, copper, lead, mercury, and zinc have been measured in these sediments. The Teck Cominco lead-zinc smelter, located on the Columbia River about 10 miles north of the Canadian Border in Trail, British Columbia, is the primary source for the contaminated sediments. The smelter deposited large amounts of slag material (black sand sized material containing arsenic, copper and zinc) to the Columbia River and lesser amounts of non-slag effluent (dissolved and fine-grained suspended material containing arsenic, cadmium, lead, mercury, and zinc) to the Columbia River (USGS 1994). In addition, mining activities in the watershed are also a possible source of metals to Lake Roosevelt (Ecology 2001).

Elevated concentrations of arsenic, copper and zinc were largely associated with sandy sediments found in the upper reaches of Lake Roosevelt near the Canadian Border (USGS 1994). Slag particles from the smelter were the source of metal contamination to for these sediments (USGS 1994). Concentrations of these metals were greatest in the upper reaches of Lake Roosevelt near the Canadian Border with decreasing concentrations downstream towards Grand Coulee Dam (USGS 1994, Ecology 2001). Concentrations of cadmium, lead, and mercury were associated with finer sediment particles and were greatest in the middle and lower reaches of Lake Roosevelt (USGS 1994, Ecology 2001). The USGS (1994) concluded that cadmium, lead, and mercury were likely associated with non-slag effluent material discharged to the Columbia River. Ecology (2001) noted that mercury concentrations were highly correlated with clay fractions in the lower reaches of Lake Roosevelt.

The sediment quality in the Columbia River is of concern because sediment contamination has an impact on fish survivability, edible fish tissue toxicity, the benthic community, and other aquatic processes. The State of Washington Department of Ecology (WDOE) 2008 Water Quality Assessment 305(b) report and 303(d) list was approved by the Environmental Protection Agency (EPA) on January 29, 2009. This assessment listed Lake Roosevelt at Grand Coulee Dam as a Class 2 waterbody of concern due to sediment metal concentrations.

The Seattle District Corps of Engineers (COE) operates one dam on the mainstem Columbia River, Chief Joseph Dam. Chief Joseph Dam and Lake Rufus Woods, the reservoir formed by Chief Joseph Dam, are located immediately downstream of Grand Coulee Dam and Lake Roosevelt. To address the concerns over possible sediment contamination in the Columbia River downstream of Grand Coulee Dam and to actively participate in possible future Columbia River sediment TMDLs, the COE designed a sediment study to quantify more precisely the quality of sediments in the reservoir formed by Chief Joseph Dam. Baseline sediment quality data will allow the COE to share data and work together with other state and federal agencies to develop a more comprehensive understanding of sediment concerns in the Columbia River. In addition, baseline sediment quality data will help the Seattle District better define the relationship between Chief Joseph Dam operations and the sediment deposition in the Columbia River.

Purpose and Scope

The Seattle District Corps of Engineers conducted a sediment quality study in the Columbia River above Chief Joseph Dam during 2004. The purpose of the study was to collect baseline sediment quality data in Lake Rufus Woods to determine the spatial gradients in sediment quality in the Columbia River downstream of Grand Coulee Dam and upstream of Chief Joseph Dam. The major objectives of this study were to:

- Determine baseline sediment quality for Lake Rufus Woods, the reservoir behind Chief Joseph Dam
- Evaluate existing sediment quality throughout Lake Rufus Woods to determine whether significant longitudinal differences exist
- Evaluate sediment quality for Lake Rufus Woods and compare to known sediment quality upstream in Lake Roosevelt at Grand Coulee Dam and to background sediment quality in the Columbia River at Lower Arrow Lake, British Columbia

These objectives were addressed by collecting sediment samples at five (5) stations in Lake Rufus Woods. The study was conducted in November 2004 and focused on the Columbia River from Grand Coulee Dam downstream to Chief Joseph Dam.

Methods and Materials

Site Characterization

The Columbia River originates in the Rocky Mountains of British Columbia at an elevation exceeding 3,000 meters and flows northward for several hundred kilometers before flowing southward through a series of lakes and reservoirs toward the state of Washington (Figure 1). The Kootenai River and the Pend Oreille River enter the Columbia River north of the international border, and the Columbia River flows into Lake Roosevelt immediately south of the border. Lake Roosevelt is the 210 kilometer long reservoir formed by Grand Coulee Dam, a Bureau of Reclamation (BOR) project located at river kilometer 960. Downstream of Grand Coulee Dam the river enters Rufus Woods Lake, the 80 kilometer long reservoir formed by Chief Joseph Dam, a COE project. Chief Joseph Dam is a run-of-river dam located at river kilometer 876 on the Columbia River in Washington, about 84 kilometers downstream of Grand Coulee Dam. The dam is a concrete gravity dam, 72 meters high, with 19 spillway bays which abut the right bank. Rufus Woods Lake has a gross storage capacity of 728 million cubic meters, a maximum depth of about 70 meters, and a mean water residence time of about 3 days. This study was conducted in the Columbia River from Grand Coulee Dam downstream to Chief Joseph Dam (Figure 2).

The study area lies within the high-steppe, semiarid desert region of central Washington (Figure 2). The Columbia River in the study area forms the boundary between two distinct geologic provinces in the State of Washington, the Okanogan Highlands to the north and the Columbia Plateau to the south (WDNR 2004). The Okanogan Highlands are characterized by rounded mountains and narrow valleys, and are dominated by metasedimentary rocks. The Columbia Plateau is characterized by incised rivers, extensive plateaus, and anticlinal ridges. The Plateau region is dominated by basalt flows laid down by successive volcanic eruptions during the Miocene (WDNR 2004). Elevations range from about 236 meters at the Columbia River immediately downstream of Chief Joseph Dam to over 1,000 meters in the mountainous terrain that rise up from the water in the mid to upper reaches of the reservoir. Land use in the study area is dominated by rangeland, irrigated cropland, and orchards (USCOE 1985)

The climate of the study area is influenced by easterly moving weather systems from the Pacific Ocean. Winters are generally cool with November through March being the wettest months. Summers are warm and dry with little to no precipitation falling from June through September. The mean annual precipitation in the vicinity of the dam is about 25 centimeters. Total annual snowfall varies with elevation throughout the study area, with about 40 centimeters near the dam. The mean annual temperature at the dam is 10°C, with extremes recorded in the vicinity of the dam of – 30°C and 43°C (USCOE 1985).

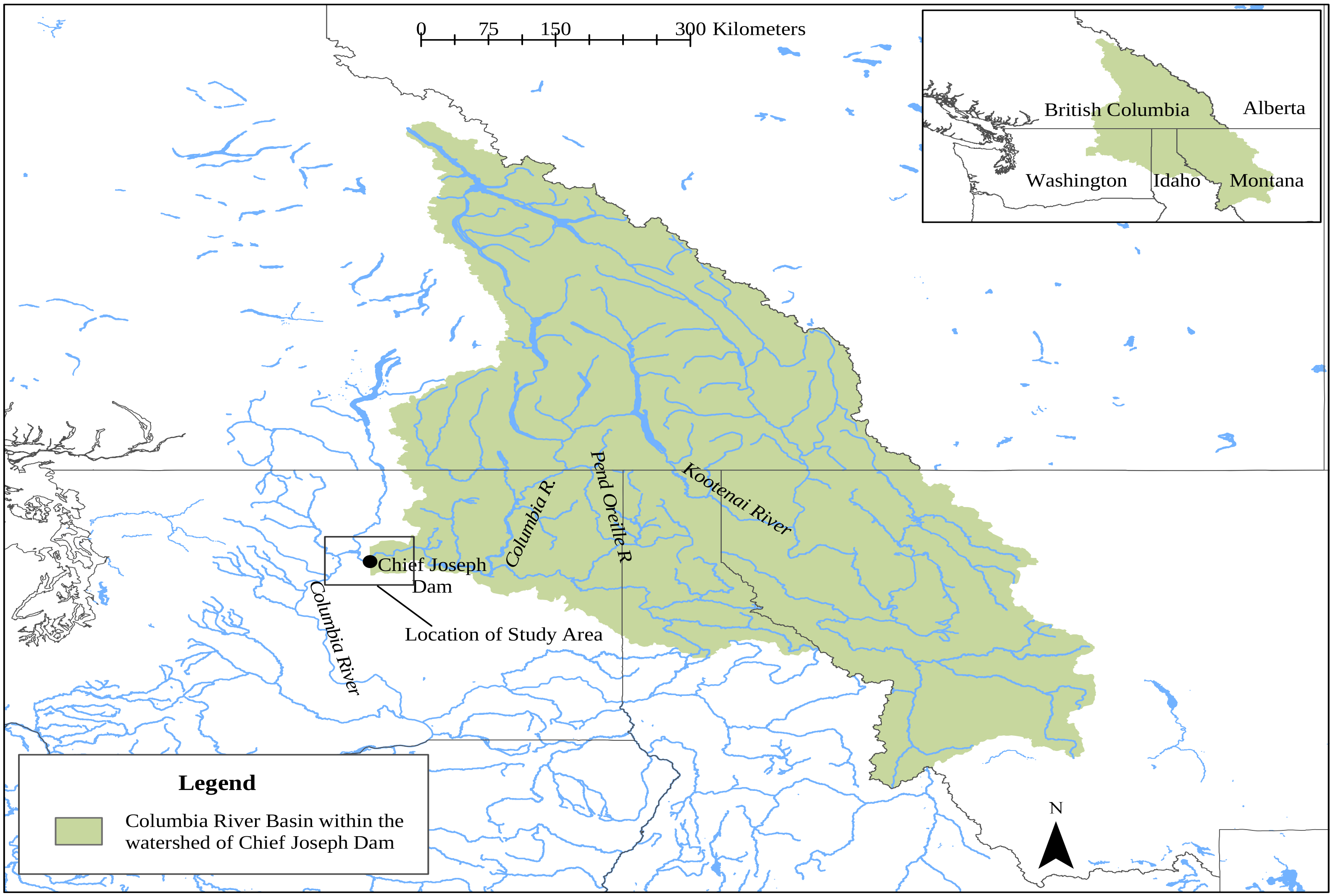
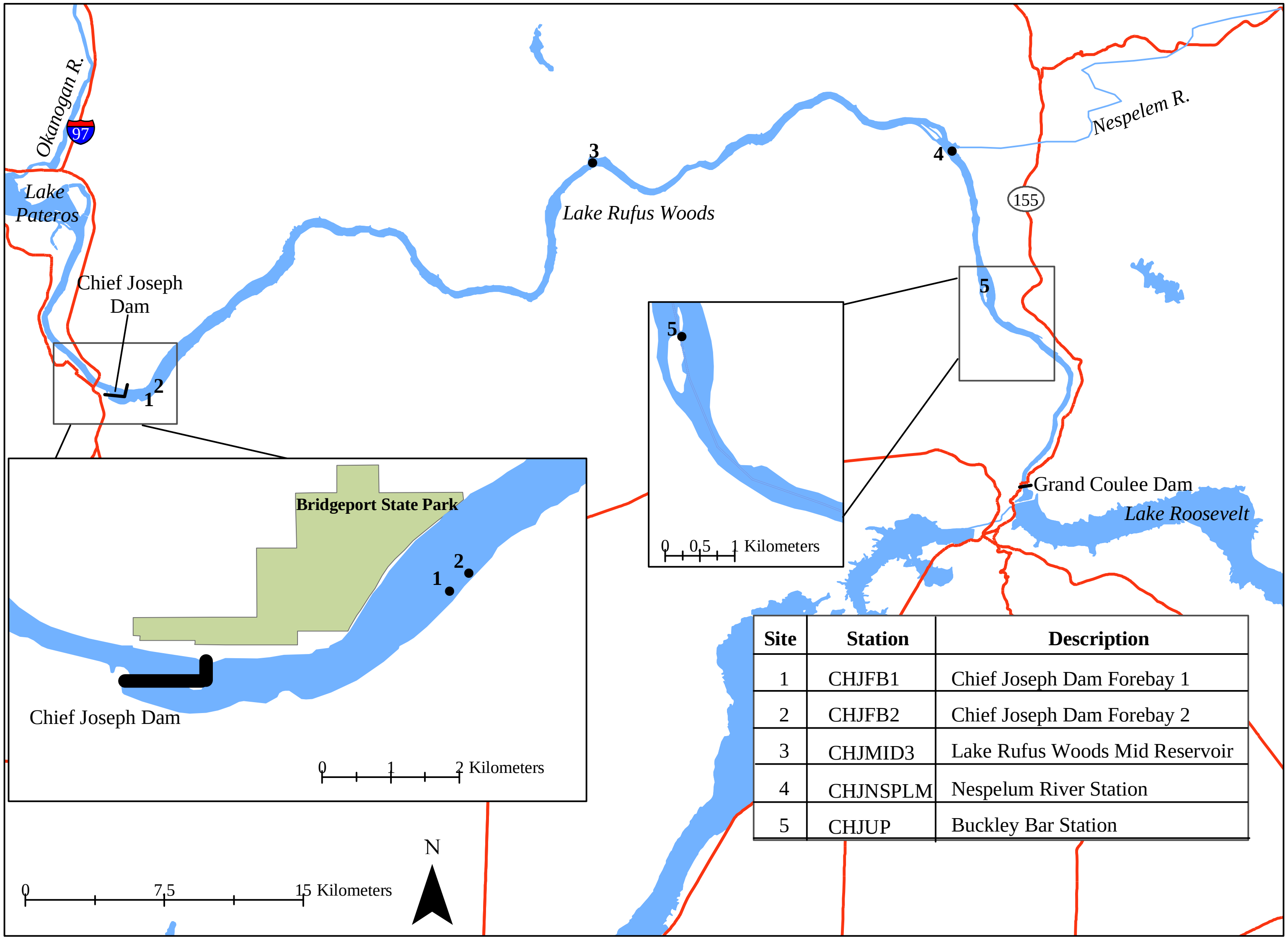


Figure 1. Location of Chief Joseph Dam and watershed.



Site	Station	Description
1	CHJFB1	Chief Joseph Dam Forebay 1
2	CHJFB2	Chief Joseph Dam Forebay 2
3	CHJMID3	Lake Rufus Woods Mid Reservoir
4	CHJNSPLM	Nespelum River Station
5	CHJUP	Buckley Bar Station

Figure 2. Locations of sediment monitoring stations in Lake Rufus Woods, at Chief Joseph Dam, Washington.

Sampling Design

Trace metals occur naturally in river and lake sediments from the weathering of rocks and mineral soils in the watershed. However, metals can also be introduced by human activities which result in contaminated sediments being transported down gradient to receiving water bodies. The target locations for sediment sampling were from natural depositional zones within Lake Rufus Woods from Chief Joseph Dam upstream to Grand Coulee Dam. Sediment sampling station locations and details are summarized in Table 1 with general sampling locations shown in Figure 2. Sediment quality parameters monitored are presented in Table 2.

All sediment sampling locations were marked directly onto a 1:24,000-scale USGS topographic map as well as a smaller-scale field drawn site map, and the latitude and longitude was obtained using a Garmin GPS-V global positioning satellite (GPS) receiver system, typically with an accuracy less than ± 10 meters. Where the GPS instrument would not give a location due to a lack of available satellites or instrument error, an estimated sampling position was recorded in the field notebook and on the site map. This estimated location was transferred to a digitized orthophoto using Arcview software where a latitude and longitude were obtained with an estimated accuracy of less than ± 30 meters.

Sediment Sampling Procedure

All sediment sampling was performed by two field technicians wearing new powderless vinyl gloves and practicing clean hands-dirty hands field techniques as follows:

- All sampling equipment was thoroughly cleaned and decontaminated following PSEP protocols (USEPA 1997). The equipment was cleaned by washing in Liquinox detergent, followed by a tap water rinse, a 10 percent nitric acid rinse, and a final rinse using deionized water.
- Sediment samples were collected using a 0.1 square meter (m^2) stainless steel van Veen grab sampler. Stainless steel spoons and bowls were used to transfer and homogenize sediment samples.
- All sampling equipment, except the van Veen grab sampler, was dedicated to each sampling location and kept in a plastic bag (e.g. Ziploc) until used.
- Between sample cleaning of the van Veen grab sampler consisted of brushing and rinsing with on-site water.
- A clean plastic sheet was placed on the boat and all decontaminated equipment and sampling containers were placed on the plastic sheet and covered with clean plastic when not in use.

Table 1. Sediment sampling station locations and details.

			Sample	Sample	River	Water Depth	Sample Location (NAD-83)	
Site No.	Sample ID	Site Name	Date	Time	Mile	Range (ft)	Latitude	Longitude
Sediment Samples								
1	CHJFB1-1S	Chief Joseph Dam Forebay 1	11/4/2004	1550	546.5	43 to 65	48.01592	-119.59489
2	CHJFB2-2S	Chief Joseph Dam Forebay 2	11/4/2004	1630	546.5	49 to 60	48.01605	-119.59491
3	CHJMID3-3S	Lake Rufus Woods Mid Reservoir	11/5/2004	1420	568	32 to 50	48.06063	-119.01456
4	CHJNSPLM-4S	Nespelum River Station	11/5/2004	1300	582	37 to 43	48.12875	-119.04436
5	CHJUP-5S	Buckley Bar Station	11/5/2004	1200	588	20 to 23	48.11652	-119.30184

Table 2. Methods, detection limits, containers, preservation techniques and holding times for sediment quality analyses.

	Matrix	Method Number [a]	Detection Limit/Unit	Container and Preservation	Holding Time
Laboratory Chemical Parameters					
Arsenic	Sediment	EPA 7060	1.5 mg/kg	P/G, 4º C	6 Months
Cadmium	Sediment	EPA 6010	0.2 mg/kg	P/G, 4º C	6 Months
Chromium	Sediment	EPA 6010	0.5 mg/kg	P/G, 4º C	6 Months
Copper	Sediment	EPA 6010	0.5 mg/kg	P/G, 4º C	6 Months
Lead	Sediment	EPA 7421	0.1 mg/kg	P/G, 4º C	6 Months
Mercury	Sediment	EPA 7471	0.01 mg/kg	P/G, 4º C	28 Days
Nickel	Sediment	EPA 6010	0.25 mg/kg	P/G, 4º C	6 Months
Zinc	Sediment	EPA 6010	0.25 mg/kg	P/G, 4º C	6 Months
Total Organic Carbon	Sediment	EPA 9060	100 mg/kg	P/G, 4º C	28 Days
Total Solids	Sediment	EPA 160.3	0.1 %	P/G, 4º C	14 Days
Particle Size	Sediment	—	—	P/G, 4º C	6 Months

[a] SM method numbers are from APHA et al. (2000); EPA method numbers are from U.S. EPA (1983, 1984, and 1992).
mg/kg Milligrams per kilogram
P/G Polyethylene or glass

- Each sediment station sample was a composite of three grabs. A grab sample was considered acceptable if 1) overlying water was present and of low turbidity, 2) the sampler was not overflowing, 3) the sediment surface was undisturbed, and 4) sampler penetration exceeded 10 centimeters (cm).

- Upon retrieval of an acceptable sample, the overlying water was siphoned off and the top 10 cm was retained for analysis. Material touching the sidewall of the grab sampler was not retained.

- Samples were composited in a decontaminated stainless steel bowl, transferred to laboratory cleaned sample containers, appropriately labeled, immediately placed on ice in a cooler and delivered to the laboratory following proper chain of custody procedures.

- Each sample was analyzed for the parameters shown in Table 2.

Quality Assurance Procedures

Quality assurance of sediment quality samples followed procedures set forth in the *Scope of Work: Sediment Quality Sampling at Chief Joseph Dam 2004* (USCOE 2003). Data were validated according to the sampling and analysis plan, and quality control data provided by the laboratory were combined with results of field duplicates to check the precision and accuracy of the data. Data validation results are presented in **Appendix A** at the end of this report. Values qualified as estimates were used in the evaluation.

Freshwater Sediment Standards

The Washington State Department of Ecology (WDOE) has not yet promulgated freshwater sediment standards. However, WDOE has been developing a set of freshwater sediment quality values (SQVs) to be used in WDOE's sediment management programs (Michelsen 2003). The proposed SQVs are separated into sediment quality standards (SQS) and cleaning screening levels (CSL). Sediments with contaminant concentrations less than the SQS values should have little to no effect on biological organisms, while sediments with concentrations greater than the CSL require further study and may warrant cleanup. The proposed WDOE freshwater sediment guidelines are presented in Table 3.

The Confederated Tribes of the Colville Reservation has adopted minimum numerical cleanup levels for contamination in freshwater sediments caused by listed hazardous substances. These cleanup levels are designed for the protection of sediment dwelling organisms. The current Colville Tribe sediment cleanup levels are presented in Table 3.

Table 3. Soil, sediment and water quality criteria and guidelines.

Parameters	WDOE Freshwater Sediment Quality Standard (SQS)[1] (mg/kg)	WDOE Freshwater Sediment Cleanup Screening Level (CSL)[1] (mg/kg)	Colville Tribe Sediment Cleanup Level[2] (mg/kg)
Arsenic	20	51	9.79
Cadmium	0.6	1	0.99
Chromium	95	100	43.4
Copper	80	830	31.6
Lead	335	430	35.8
Mercury	0.5	0.75	0.18
Nickel	60	70	22.7
Zinc	140	160	121

Notes:
1. Washington Department of Ecology (Michelsen 2003).
2. Confederated Tribes of the Colville Reservation (2005)

Results and Discussion

Sediment quality results are summarized below for physical and chemical testing and for longitudinal distributions. Sediment chemistry results are compared to Washington State Department of Ecology Freshwater Sediment Guidelines and to Confederated Tribes of the Colville Reservation Freshwater Sediment Cleanup Levels.

Physical and Chemical Testing

Conventionals

Table 4 shows results for percent solids, total organic carbon (TOC) and grain size. Grain size analyses indicate that Sites 1, 2 and 4 were dominated by clay/silt fractions (84, 86 and 87 percent, respectively), while Sites 3 and 5 were dominated by sand fractions (72 to 96 percent, respectively). TOC concentrations were low at all sites and ranged from 1932 mg/kg to 13590 mg/kg (i.e. 0.2 to 1.4 percent). TOC concentrations were correlated to grain size with the highest TOC concentrations measured at those sites dominated by the clay/silt fraction (Sites 1, 2 and 4). Because grain size and TOC typically correlate to concentration of metals these parameters are of interest when comparing sites because differences in metal concentrations may largely be attributed to differences in grain sizes and TOC concentrations rather than the presence or absence of contamination.

Metals

Metals concentrations in Lake Rufus Woods sediments are summarized in Table 4. The forebay sites (Sites 1 and 2) had the highest concentration of all metals with lower metals concentrations at the mid reservoir site (Site 3) and up reservoir sites (Sites 4 and 5). Metals concentrations exceeded Washington Department of Ecology Freshwater Sediment Cleanup Screening Level (CSL) criteria for Cadmium (Sites 1, 2, 3, and 4) and Zinc (Sites 1 and 2). Additionally, Sediment Quality Standard (SQS) criteria were exceeded for Cadmium (Site 5) and for Zinc (Sites 3 and 5). Colville Tribe sediment cleanup levels were exceeded for Cadmium (Sites 1, 2, 3, and 4), Lead (Sites 1, 2, and 3), Mercury (Site 1), and Zinc (Sites 1, 2, 3, and 5).

Sediment metals concentrations in Lake Rufus Woods were less than concentrations measured by the USGS (1994) at Grand Coulee Dam but greater than concentrations measured at Grand Coulee Dam by WDOE (2001). Lake Rufus Woods metal concentrations were substantially greater than background and/or reference site metal concentrations for the Columbia River collected by both the USGS (1994) and WDOE (2001) in Lower Arrow Lake.

Table 4. Sediment quality data collected in Lake Rufus Woods, Chief Joseph Dam during 2004.

Site No.	Location	River Mile	Date	Time	Arsenic (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Mercury (mg/kg)	Nickel (mg/kg)	Zinc (mg/kg)	Total Organic Carbon (mg/kg)	Solids (%)	Gravel (> 2 mm) (%)	Sand (2 - 0.075 mm) (%)	Clay/Silt (< 0.075 mm) (%)	Mean Particle Size (mm)
Lake Rufus Woods Sediment Sample Data																		
1	Chief Joseph Dam Forebay	546.5	11/4/2004	1630	6.10	**3.20**	11.40	19.50	102.0	0.205	11.90	**265**	13325	45.32	0.00	15.89	84.11	0.0410
2	Chief Joseph Dam Forebay	546.5	11/4/2004	1550	6.08	**3.97**	11.10	22.90	57.0	0.175	11.40	**227**	13590	42.81	0.00	14.14	85.86	0.0446
3	Mid Reservoir	568	11/5/2004	1420	3.55	**1.54**	6.51	9.72	47.20	0.064	7.02	**140**	2203	68.40	0.05	72.04	27.92	0.0879
4	Nespelum River	582	11/5/2004	1300	4.06	**1.00**	8.50	9.59	15.90	0.033	9.14	70.9	13195	55.28	0.00	12.51	87.49	0.0391
5	Buckley Bar	588	11/5/2004	1200	2.74	**0.78**	5.47	18.40	33.80	0.017	5.68	**144**	1932	70.41	0.00	95.94	4.06	0.1863
Upstream Sediment Sample Data (USGS 1994)[1]																		
71	Grand Coulee Dam RB	596	10/16/1992	1645	18.00	**6.20**	—	61.00	190.00	**0.800**	—	**730**	13000	—	—	—	95.00	—
1	Lower Arrow Lake*	787	10/10/1992	900	2.00	0.50	—	7.00	28.00	<0.05	—	49	7000	—	—	—	10.00	—
2	Lower Arrow Lake*	787	10/10/1992	1030	1.50	0.50	—	7.00	32.00	<0.05	—	60	8000	—	—	—	9.00	—
Upstream Sediment Sample Data (WDOE 2001)[2]																		
9	Grand Coulee Dam Forebay	596	5/9/2001	—	9.20	**1.80**	—	11.00	17.00	0.030	—	86	3000	70.80	0.60	92.30	7.20	—
10	Lower Arrow Lake*	782	5/7/2001	—	2.00	0.46		4.00	12.00	0.004	—	27	2000	77.40	12.60	84.30	0.00	—
WDOE Sediment Criteria Information (Michelsen 2003)[3]																		
Freshwater Sediment Quality Standard (SQS)					20	0.6	95	80	335	0.50	60	140	—	—	—	—	—	—
Freshwater Sediment Cleanup Screening Level (CSL)					51	1.0	100	830	430	0.75	70	160	—	—	—	—	—	—
Confederated Tribes of the Colville Reservation (2005)[4]																		
Freshwater Sediment Cleanup Level					9.79	0.99	43.4	31.6	35.8	0.18	22.7	121	—	—	—	—	—	—

Notes

Sediment sample values in bold are in excess of the WDOE Freshwater Sedement SQS while values in bold and shaded are in excess of the Freshwater Sediment CSL

Sediment sample values underlined are in excess of the Colville Tribe Sediment Cleanup Level

* Background sediment sample represented by data collected at Lower Arrow Lake, British Columbia

1. USGS 1994. Sediment Quality Assessment of Franklin D. Roosevelt Lake and the Upstream Reach of the Columbia River, Washington 1992
2. WDOE 2001. Reassessment of Toxicity of Lake Roosevelt Sediments
3. Michelsen 2003. Development of Freshwater Sediment Quality Values for Use in Washington State, Phase II Report
4. Colville Tribe 2005. Colville Tribal Law and Order Code. Chapter 4-16 Hazardous Substance Control.

Longitudinal Distribution of Metals

In general, concentrations of metals increased from upstream stations (Sites 4 and 5) to downstream stations (Sites 1 and 2) (Figure 3). Arsenic, cadmium, lead, mercury, nickel, and zinc concentrations showed a longitudinal trend of increasing from Site 5 at Grand Coulee Dam downstream to Sites 1 and 2 at Chief Joseph Dam. However, concentrations of chromium, copper and nickel showed little pattern between upstream and downstream sites.

Metal concentrations were generally correlated to grain size and total organic carbon concentrations (Table 4). Except for Site 4 (Nespelum River Station), upstream and mid reservoir sites were dominated by sand fractions with low organic carbon concentrations. Downstream sites near Chief Joseph Dam were dominated by silt/clay fractions with moderate organic carbon concentrations (Table 4). As seen in Table 4 and Figure 3, the sites with the greatest percent silt/clay fraction and total organic carbon (Sites 1 and 2) tended to be the sites with the highest metal concentrations.

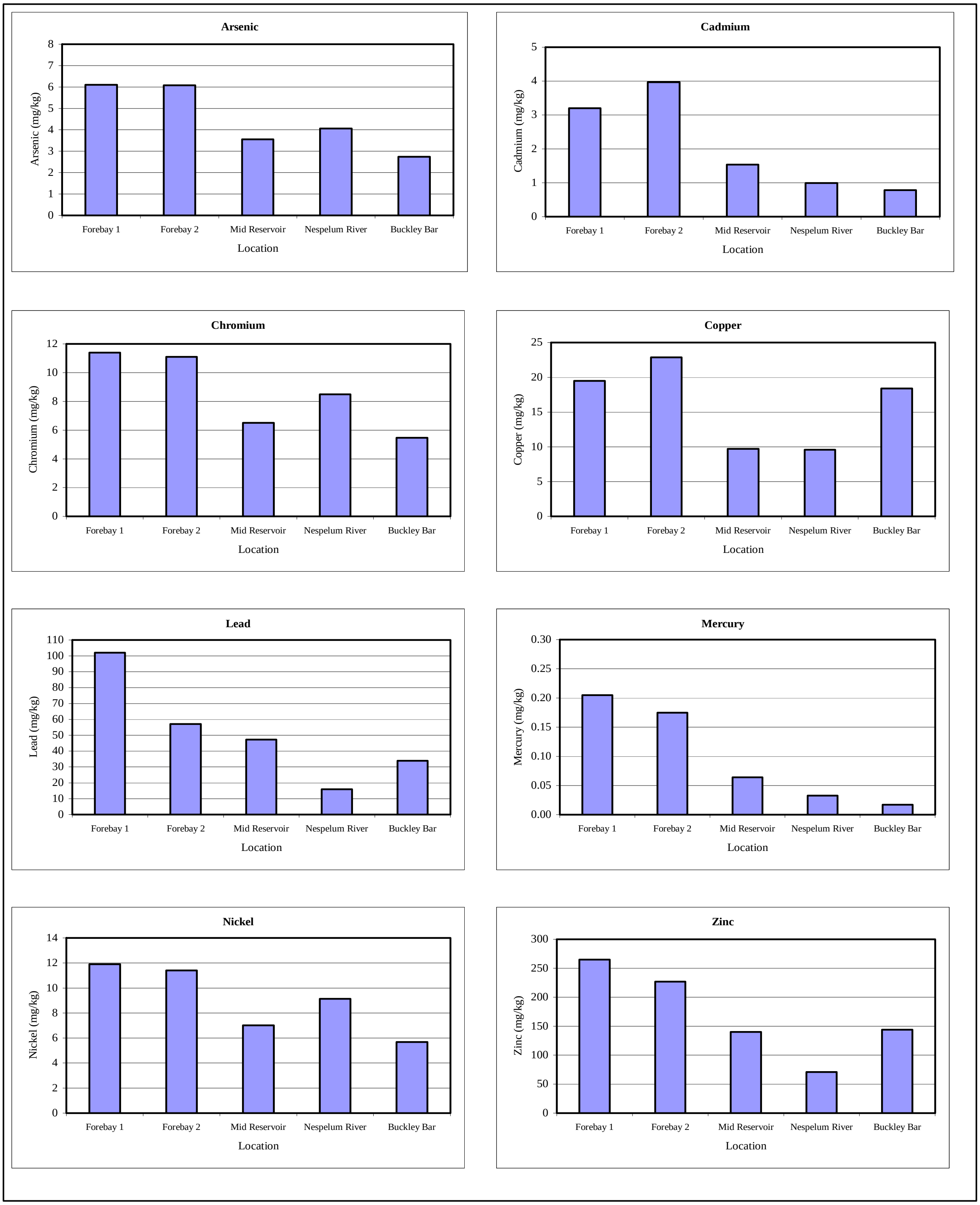


Figure 3. Longitudinal distribution of sediment metals in Lake Rufus Woods, Chief Joseph Dam.

Conclusions

Sediment metal concentrations in Lake Rufus Woods were less than concentrations measured upstream of Grand Coulee Dam in Lake Roosevelt but greater than background concentrations measured in the upper Columbia River at Lower Arrow Lake. Concentrations of arsenic, cadmium, lead, mercury, nickel, and zinc showed a longitudinal trend of increasing from Site 5 below Grand Coulee Dam downstream to Sites 1 and 2 above Chief Joseph Dam. This downstream increase in metals concentrations in Lake Rufus Woods is likely correlated to grain size differences between sample locations. Upstream sediments collected below Grand Coulee Dam were dominated by sand fractions while downstream sediments collected at Chief Joseph Dam were dominated by silt/clay fractions.

Lake Rufus Woods sediments exceeded WDOE freshwater sediment cleanup screening levels for cadmium and zinc and the Colville Tribe sediment cleanup levels for cadmium, lead, mercury, and zinc at several locations. The greatest numbers of exceedances were measured for sediments collected at the forebay of Chief Joseph Dam.

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Appendix A

Quality Assurance Report

This report presents results from the quality assurance review of soil, sediment, and water quality data collected for the Sediment Quality Assessment of Lake Rufus Woods. Data assessment procedures used in this quality assurance review are based on the following eight control elements:

- Completeness
- Methodology
- Holding times
- Detection limit
- Blanks
- Duplicates
- Matrix spikes
- Control samples

No problems were associated with the data collected in connection with this project. The following sections provide specific details for each of the quality control elements reviewed and any resultant corrective action required.

Completeness

Completeness was assessed by comparing valid sample data values with total number of sample values. Because the number of valid sample data divided by the total number of samples was greater than the quality assurance objective of 95 percent, no corrective actions were required to address problems related to completeness.

Methodology

Methodology was assessed by examining field notebooks, sampling data sheets, and laboratory reports for deviations from the monitoring plan and quality assurance plan. Subsequent to this review, it was concluded that there were no significant deviations in methodology that required corrective action.

Holding Times

Holding times were assessed by comparing analytical dates to sample collection dates. Corrective action was to be implemented for all values that exceeded the maximum holding times required by U.S. EPA. Subsequent to this review, it was concluded that there were no holding time problems that required corrective action.

Blanks

Preparation blanks, which are composed of reagent water that is prepared as a sample, were analyzed with collected samples, and the results were reported in each laboratory report. If a blank value exceeded the detection limit, corrective actions were to be implemented for the associated samples. Because all blanks were below the method detection limit for their respective analytes, no corrective actions were required for this quality control element.

Detection Limits

Laboratory data were reported with a method detection limit (MDL) and a reporting detection limit (RDL). The laboratory MDL represents the minimum concentration of a constituent that can be detected. All data values that were below the MDL were qualified as below detection with a < symbol next to the reported detection limit.

Duplicates

Laboratory duplicates are two aliquots of a sample processed concurrently and identically. Corrective action was implemented for all laboratory duplicates with a relative percent difference (RPD) greater than 25 percent. Duplicate problems were encountered in the following analyses:

- A RPD of 62.5 percent was measured for cadmium. No corrective action taken because other quality control elements indicated the data were acceptable.

- A RPD of 33.97 percent was measured for copper. No corrective action taken because other quality control elements indicated the data were acceptable.

Matrix Spikes

Matrix spikes are used as an indicator of matrix effects on sample recovery and precision. If a percent recovery from a matrix spike was not within 75 to 125 percent for metals or a pre-determined laboratory range for organics, corrective actions were implemented where necessary. No matrix spike problems were encountered.

Control Samples

Control samples refer to check standards, blank spikes, or standard reference materials. If the percent recovery for a control standard was not within 80 to 120 percent for metals and a pre-determined laboratory range for organics, corrective actions were implemented, where necessary. All control sample recoveries were within acceptable limits.