US Army Corps of Engineers®
Portland District

SEDIMENT QUALITY REPORT

CHIEF JOSEPH RESERVOIR, RUFUS WOODS LAKE
COLUMBIA RIVER BASIN
COLUMBIA RIVER, IDAHO

Chief Joseph Reservoir, Rufus Woods Lake

Sediment Quality Report
August 2020

EXECUTIVE SUMMARY

The Columbia River drains about 668,000 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.

The U.S. Army Corps of Engineers Seattle District (Corps) operates one dam on the middle Columbia River, Chief Joseph Dam. Chief Joseph Dam and Rufus Woods Lake, the reservoir formed by Chief Joseph Dam, are located immediately downstream of Grand Coulee Dam and Lake Roosevelt. Sediment contamination exists in the Columbia River upstream of Grand Coulee Dam (U.S. Geological Survey [USGS] 1994; Washington State Department of Ecology [Ecology] 2001; USGS 2005). Elevated concentrations of arsenic, cadmium, copper, lead, mercury, and zinc have been measured in Lake Roosevelt sediments. The Teck Resources Limited (Teck) lead-zinc smelter, located on the Columbia River about 16 kilometers 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) (USGS 1994). In addition, historical mining activities in the watershed are also a possible source of metals to Lake Roosevelt and the upper Columbia River (Ecology 2001). Sediment contamination in Lake Roosevelt is of concern because Rufus Woods Lake is located immediately downstream and transport of contaminated sediments from Lake Roosevelt may be impacting sediment quality in Rufus Woods Lake.

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ACRONYMS

Acronym	Description
µg/kg	Micrograms Per Kilogram
Corps	U.S. Army Corps of Engineers
DFO	Department of Fisheries And Oceans Canada
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
mg/kg	Milligrams Per Kilogram
PBDEs	Polybrominated Diphenyl Ethers
PCBs	Polychlorinated Biphenyls
SEF	Sediment Evaluation Framework
Teck	Teck Resources Limited
TMDL	Total Maximum Daily Load
TOC	Total Organic Carbon
USGS	U.S. Geological Survey
Washington State DNR	Washington State Department of Natural Resources

SECTION 1 - INTRODUCTION

1.1 STUDY AREA

The Columbia River drains about 668,000 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.

The U.S. Army Corps of Engineers Seattle District (Corps) operates one dam on the middle Columbia River, Chief Joseph Dam. Chief Joseph Dam and Rufus Woods Lake, the reservoir formed by Chief Joseph Dam, are located immediately downstream of Grand Coulee Dam and Lake Roosevelt. Sediment contamination exists in the Columbia River upstream of Grand Coulee Dam (U.S. Geological Survey [USGS] 1994; Washington State Department of Ecology [Ecology] 2001; USGS 2005). Elevated concentrations of arsenic, cadmium, copper, lead, mercury, and zinc have been measured in Lake Roosevelt sediments. The Teck Resources Limited (Teck) lead-zinc smelter, located on the Columbia River about 16 kilometers 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) (USGS 1994). In addition, historical mining activities in the watershed are also a possible source of metals to Lake Roosevelt and the upper Columbia River (Ecology 2001). Sediment contamination in Lake Roosevelt is of concern because Rufus Woods Lake is located immediately downstream and transport of contaminated sediments from Lake Roosevelt may be impacting sediment quality in Rufus Woods Lake.

A summary of sediment quality data collected by the Corps in 2004 and 2011 in Rufus Woods Lake will be presented.

SECTION 2 - BACKGROUND

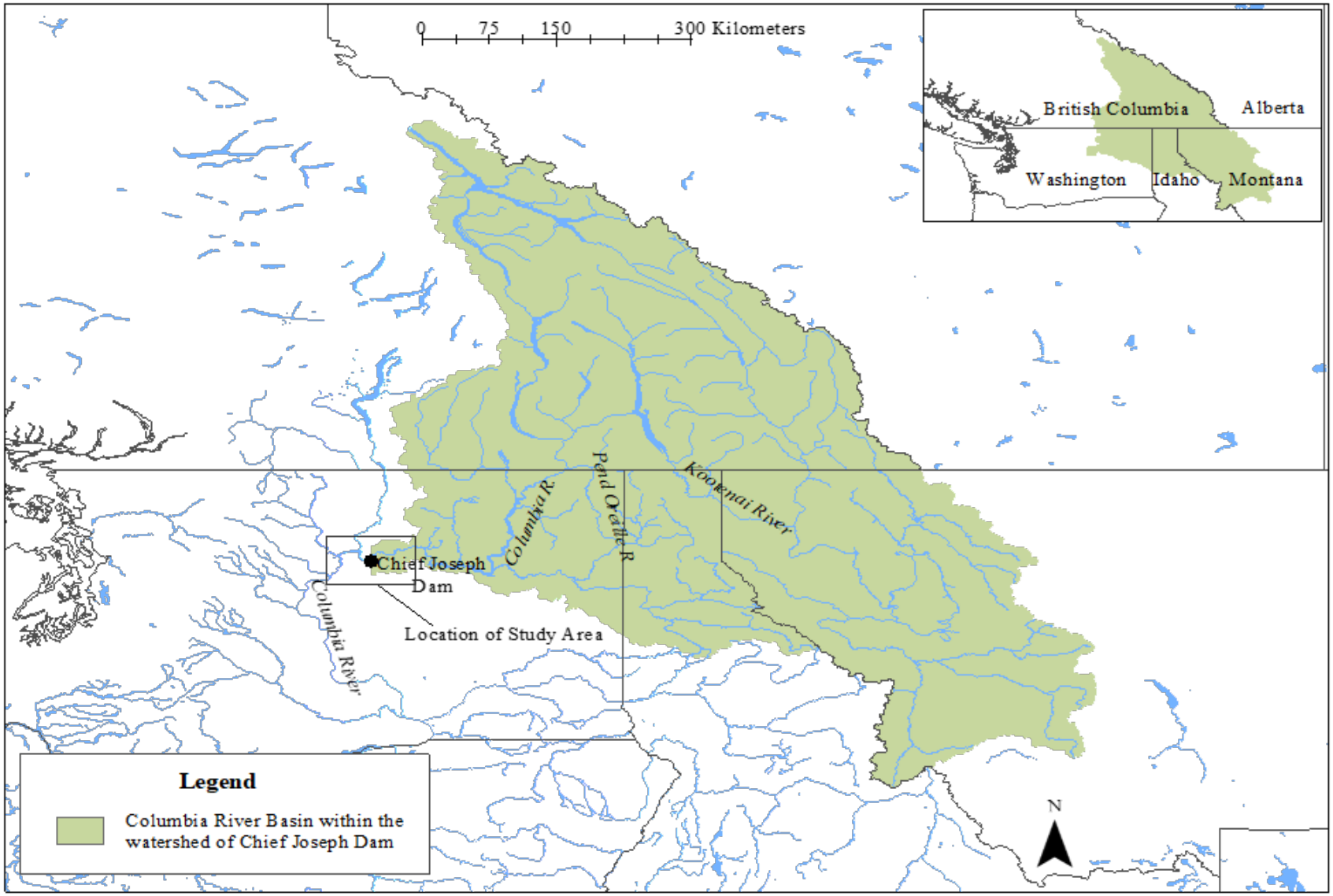
2.1 SITE CHARACTERIZATION

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 2-1). The Kootenai River (spelled Kootenay in Canada) and the Pend Oreille River enter the Columbia River north of the U.S.-Canada 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 project located at River Kilometer 959. Downstream of Grand Coulee Dam, the river enters Rufus Woods Lake, the 80-kilometer-long reservoir formed by Chief Joseph Dam, a Corps project.

Chief Joseph Dam is a run-of-river dam located at River Kilometer 877 on the Columbia River in Washington, about 82 kilometers downstream of Grand Coulee Dam. The dam is a concrete gravity dam, over 1.8 kilometers long, 72 meters high, with 19 spillway bays that abut the right bank. The powerhouse, which consists of 27 main generators with a hydraulic capacity of 6,201 cubic meters per second, is oriented in an east-west direction about 90 degrees to the spillway. The spillway has a total length of 343 meters with a design discharge capacity of 33,980 cubic meters per second. A 3.81-meter deflector was completed across the entire spillway in 2009 to reduce the production of dissolved gas during spillway operations.

Chief Joseph Dam was originally designed with a normal full pool at 288.3 meters and a normal minimum pool at 286.5 meters. During the 1970s, the powerhouse was expanded and the normal pool operating range was raised by 3 meters to a minimum pool of 289.5 meters and a maximum pool of 291.3 meters. Rufus Woods Lake has a gross storage capacity of 0.731 cubic kilometers, a maximum depth of about 70 meters, and a mean water retention time of about 3 days.

Figure 2-1. Location of Chief Joseph Dam and Watershed



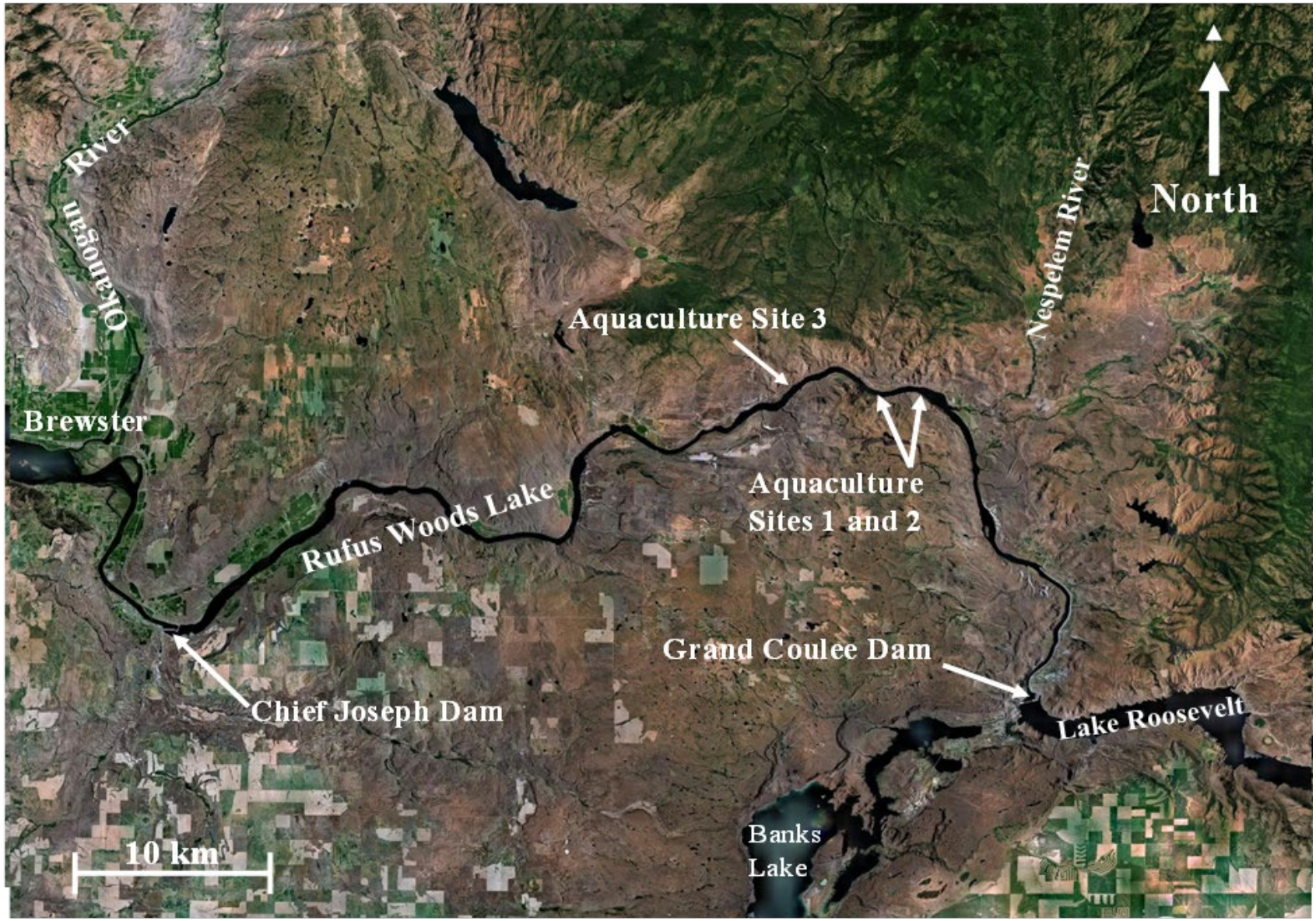
2.2 CLIMATE AND GEOLOGY

The climate in the vicinity of Chief Joseph Dam 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 (Corps 2009a).

Chief Joseph Dam and Rufus Woods Lake are within the high-steppe, semiarid desert region of central Washington (Figure 2-2). The Columbia River at Rufus Woods Lake 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 (Washington State Department of Natural Resources [DNR] 2004). The Okanogan Highlands are characterized by rounded mountains and narrow valleys, and are dominated by metasedimentary rocks and granite. The Highlands consist of moderately steep forested slopes that rise up to more than 2,000 meters in elevation. 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 (Washington State DNR 2004).

Rufus Woods Lake is in a steep-sided canyon of the Columbia River. Slopes rise more than 300 meters directly from the lake to the Okanogan Highlands on the north side, while on the south side, the slopes rise up gradually in a series of terraces and benches to the Columbia Plateau. The majority of the immediate watershed is dry and dominated by shrub-steppe vegetation with few trees (Corps 2009a). Side canyons and draws in the watershed support isolated stands of coniferous and deciduous trees. Irrigated orchards exist on the upland benches near the dam. Elevations range from about 236 meters at the Columbia River immediately downstream of Chief Joseph Dam to over 2,000 meters in the mountainous terrain that rise up from the water in the mid- to upper reaches of the reservoir.

Figure 2-2. Location of Rufus Woods Lake, Washington



2.3 SEDIMENT LOADINGS

Sediment loadings to the Columbia River upstream of Chief Joseph Dam have been substantially altered. First, by the completion of Grand Coulee Dam and the formation of Lake Roosevelt in 1941, and then subsequently by the completion of numerous upstream dams and reservoirs in Canada and the United States. Currently, the majority of sediment loadings to the Columbia River system are trapped and stored by these upstream reservoirs, and only a very small percent of the sediment loading is transported downstream to Lake Roosevelt (USGS 1994). Because of the size and depth of Lake Roosevelt, little sediment moves downstream to Rufus Woods Lake (Corps 2009a).

The Corps reports little sediment accumulation in Rufus Woods Lake since the construction of Chief Joseph Dam (Corps 2009a). There are no major sediment bearing tributaries to the reservoir and, as noted above, Grand Coulee Dam effectively traps and limits the transport of sediment downstream. The banks of Rufus Woods Lake are subject to erosion, and landslides and sloughing of steep banks on the steep nearshore terrain likely contribute some sediment to the reservoir.

2.4 LAND USE

The Columbia River watershed upstream of Chief Joseph Dam and Rufus Woods Lake encompasses about 195,000 square kilometers of northeastern Washington, northwestern Montana, northern Idaho, and southeastern British Columbia. Of that total upstream watershed, about 191,000 square kilometers are located upstream of Grand Coulee Dam, with the immediate Rufus Woods Lake watershed only totaling about 4,000 square kilometers. The Columbia River watershed is a sparsely populated mountainous area. Major population centers are concentrated near Missoula and Butte in Montana, near Sandpoint and Coeur d'Alene in Idaho, near Spokane in Washington, and near Cranbrook and Castlegar in British Columbia. For the immediate Rufus Woods Lake watershed, there are only a few small towns and communities such as Coulee Dam, Elmer City, and Nespelum, located along the reservoir (Corps 2009a).

The economy of the Columbia River watershed relies heavily on forest products, mining, hydropower, recreation (tourism), technology, retail trade, and agriculture. The principal industries in the immediate Rufus Woods Lake watershed are fruit, wheat, cattle ranching, forest products, aquaculture, and service industries. Fruit orchards are located on side slopes immediately adjacent to the reservoir. Cattle ranching and dry-land wheat farming are important industries in the arid areas inland from the reservoir (Corps 2009a).

2.5 CONTAMINANT SOURCES

Historical and current point and non-point source discharges of contaminants that may impact water and sediments in the Columbia River and Rufus Woods Lake exist in the watershed. Mining has been active in the watershed in both the United States and Canada since the late 1880s. In general, zinc and lead were the main metals mined in

the watershed along with copper, gold, silver, tin, tungsten, and molybdenum (Mills 1977; U.S. Environmental Protection Agency [EPA] 2008a). Mining in the watershed has declined, and actions have been taken to reduce the loading of contaminants from historical and active mines, including treatment and recycling of waste rock and tailings pile runoff, and restoration of abandoned mines.

Two major sources of contamination to the water and sediments upstream of Rufus Wood Lake are the Teck smelter in Trail, British Columbia, about 15 kilometers upstream of the U.S.-Canada border, and the Zellstoff Celgar Ltd. bleached kraft pulp mill located in Castlegar, British Columbia, about 50 kilometers upstream of the U.S.-Canada (EPA 2008a). The Teck facility is a lead and zinc smelter that has been in operation since 1896 (G3 Consulting 2001). The smelter was originally a copper smelter but was converted to lead and zinc in 1909 and today is one of the world's largest metallurgical complexes. Historically, the Teck facility discharged large quantities of slag material (the byproduct of the smelting furnaces) containing various quantities of trace and major metals to the Columbia River, as well as discharging processed wastewater containing arsenic, cadmium, lead, mercury, and zinc directly to the river. The facility also operated an ammonia phosphate fertilizer plant that discharged about 2.2 metric tons per day of phosphate into the river. The operation of the phosphate plant was discontinued in 1994, while the routine discharge of slag and smelter wastewater to the river was discontinued in mid-1995 (EPA 2008).

The Zellstoff pulp mill used chlorine in the bleaching process from 1961 until mid-1993. Chlorine reacts with compounds in the wood resulting in discharged effluent containing organic compounds, including dioxins and furans (USGS 1994). Starting in 1991, the plant modernized its facilities, including the installation of a chlorine dioxide bleach plant and secondary treatment facility. Consequently, the discharge of chlorinated organic chemicals such as dioxin to the Columbia River has been greatly reduced (EPA 2008a).

Rainbow trout (*Oncorhynchus mykiss*) fish farming began in Rufus Woods Lake in 1989 with a small operation located along the south shore of the lake in Douglas County. Currently, there are four aquaculture facilities located in Rufus Woods Lake along the north shore on the Colville Confederated Tribes Indian Reservation. Pacific Aquaculture owns three of these facilities. Two were upgraded in 2008, and one was recently built and became operational in 2016. Faith Frontier Ministries owns the fourth facility, which has been in operation since 1995 (EPA 2012a). The potential effects of aquaculture on fresh water and sediment quality are largely related to waste produced by the facilities via fish feed and feces (Environment Canada 2009). In addition, contaminants such as antibiotics, pesticides, herbicides, fungicides, and heavy metals are also of concern to surrounding waters and sediments (Department of Fisheries and Oceans Canada [DFO] 2006; Environment Canada 2009).

Numerous communities in British Columbia, Montana, Idaho, and Washington continue to discharge secondary treated water to the Columbia River and major tributaries such as the Pend Oreille River and Kootenai River. Moreover, there are numerous small community wastewater systems and individual septic systems in the immediate Rufus Woods Lake watershed. In addition, there are numerous fruit orchards and cattle

ranches in the immediate watershed that may be sources of nutrients and organic contaminants to the reservoir.

2.6 AQUACULTURE FACILITIES

Rainbow trout fish farming began in Rufus Woods Lake in 1989 with a small operation located along the south shore of the lake in Douglas County. These farms were acquired by Columbia River Fish Farms and moved to the north shore on the Colville Confederated Tribes Indian Reservation, downstream of Grand Coulee Dam near the confluence of the Nespelum River, in 1991 and 1997. These two aquaculture facilities were acquired by Pacific Seafood in the fall of 2008 and renamed Pacific Aquaculture Inc. Site 1 and Site 2 (EPA 2011). The facilities were initially in a state of disarray but were upgraded by Pacific Aquaculture and had a combined harvest of about 3.63 million kilograms of trout per year in 2011 (EPA 2012a). A smaller aquaculture facility called Chief Joseph Fish Farm is owned by Faith Frontier Ministries and located approximately 16 kilometers downstream of the Pacific Aquaculture facilities. Chief Joseph Fish Farm has been in operation since 1995 and had an annual production of about 0.77 million kilograms of trout per year in 2011 (EPA 2012a).

The two Pacific Aquaculture fish farm locations are shown in Figure 2-2. Site 1 is the farthest downstream, located at River Kilometer 932.6, about 25 kilometers downstream of Grand Coulee Dam. The net pens at Site 1 consists of 20 steel net pens, each 25 meters by 25 meters in size, arranged in an array approximately 275 meters long and 55 meters wide (EPA 2012a). The site also contains on-shore fish production/waste facilities. Site 2 is upstream of Site 1 and is located at River Kilometer 936.3, about 22.5 kilometers downstream of Grand Coulee Dam. The net pens at Site 2 consists of 20 steel net pens, each 25 meters by 25 meters in size, arranged in an array approximately 275 meters long and 55 meters wide (EPA 2012a). Annual production was reported by the EPA (2012a) to be 2.27 million kilograms at Site 1, and 1.36 million kilograms at Site 2. A third site (Site 3) was recently built by Pacific Aquaculture and became fully operational in 2016. The new Site 3 is located at River Kilometer 927.8, about 4.8 kilometers downstream of Site 1, and consists of 20 steel net pens, each 30 meters by 30 meters in size and arranged in an array approximately 335 meters long by 67 meters wide. Annual production at Site 3 is estimated at 2.72 million kilograms (EPA 2012a).

In recent years, the environmental impacts of aquaculture on marine and freshwater ecosystems have received increasing attention (DFO 2006; Black 2008; Environment Canada 2009; Zivic et al. 2009). Waste produced by fish farms that can impact water and sediment quality includes nutrients, feces, feed pellets, and organic matter (Environment Canada 2009). In addition, contaminants such as antibiotics, pesticides, herbicides, fungicides, and heavy metals are also of concern to surrounding waters and sediments (DFO 2006; Environment Canada 2009). The influx of aquaculture waste products and contaminants into the surrounding waters and sediments has resulted in an overall concern regarding the environmental impact of aquaculture on water and sediment quality.

Phosphorus, nitrogen, carbon, and zinc are the primary constituents of concern released to surface waters and sediments from aquaculture (Beveridge 2004; Podemski and Blanchfield 2006; Mugg et al. 2007). The primary sources of these constituents are fecal material and uneaten feed. Copper may also be a constituent of concern if the aquaculture facility uses an anti-fouling agent on the net pens (Mugg et al. 2007). Dissolved carbon, phosphorus, nitrogen, and zinc may be released directly to the water column by the solubilization from feed and feces, and through gill and urinary excretion (Beveridge 2004; Mugg et al. 2007; Azevedo et al. 2011). Uneaten feed and fecal material are usually in the form of solid wastes that settle to the bottom. The greatest accumulation of wastes and corresponding sediment impact is generally either directly under the cages or immediately downstream near the cages (Cornel and Whoriskey 1993; Troell and Berg 1997). Settling velocities of fish feed and feces along with current speed and water depth are important factors in determining how far downstream waste solids may be re-suspended and transported before they are deposited in the sediments (Black 2008). Sediments beneath freshwater aquaculture cages have shown enrichment in phosphorus, nitrogen, carbon, copper, and zinc (Troell and Berg 1997; Rooney and Podemski 2010).

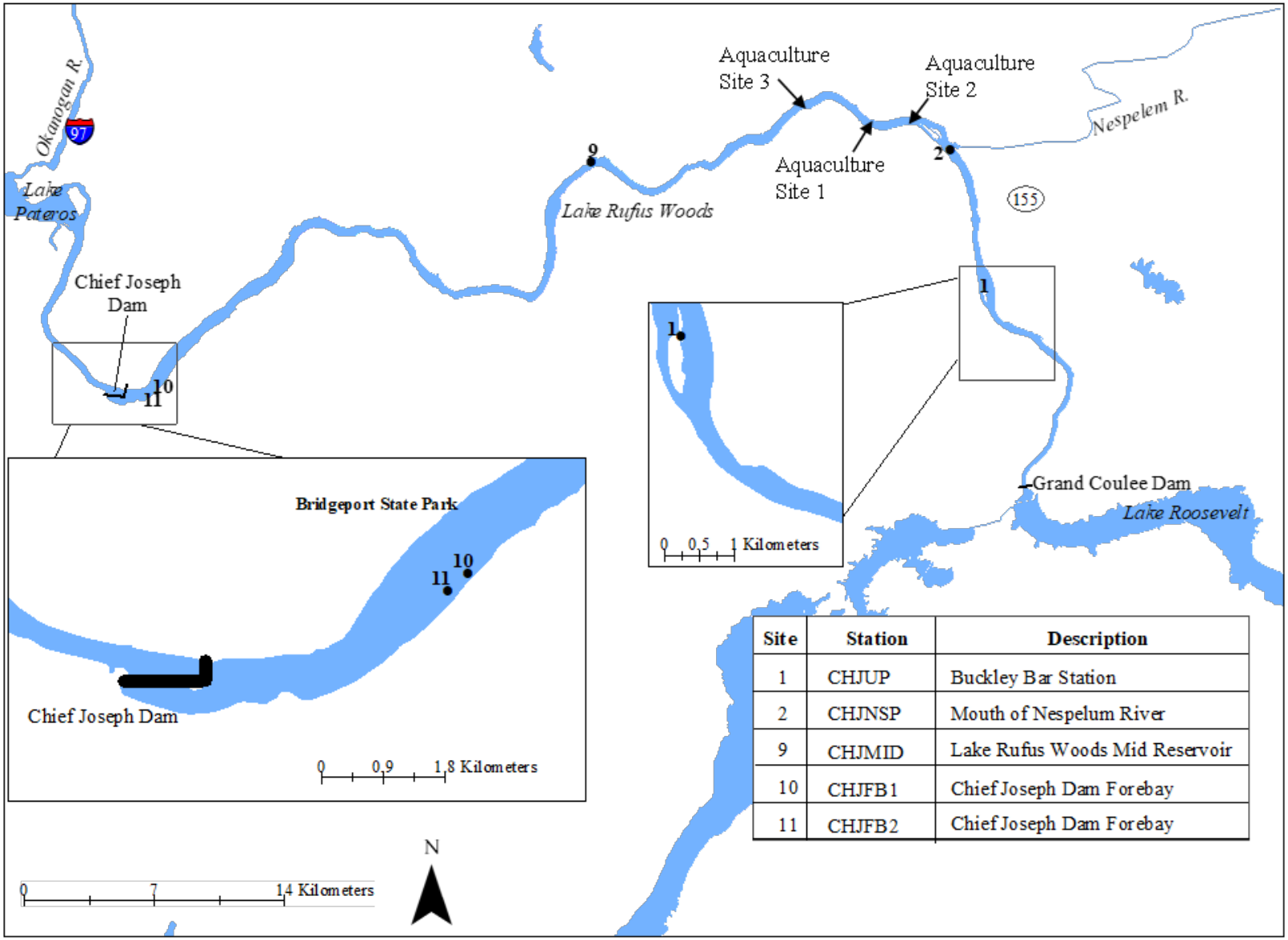
2.7 SEDIMENT CHARACTERIZATION STUDIES

2.7.1 U.S. Army Corps of Engineers 2004 Study

The Corps 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 (1) evaluate existing sediment quality throughout Rufus Woods Lake to determine whether significant longitudinal differences exist, and (2) compare Rufus Woods Lake sediment quality to known sediment quality upstream in Lake Roosevelt and background sediment quality in the Columbia River at Lower Arrow Lake, British Columbia.

The target locations for the 2004 sediment sampling were from natural depositional zones within Rufus Woods Lake from Chief Joseph Dam upstream to Grand Coulee Dam. Sediment sampling station locations and details are summarized in Table 2-1 with general sampling locations shown in Figure 2-3. Sediment quality parameters monitored are presented in Table 2-2. Sediments were collected using a stainless steel Van Veen grab sampler. Grab samples were 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. Each sediment station sample was a composite of three grabs collected from the top 10 centimeters using a stainless steel spoon (making sure not to touch the sampler sidewalls) and composited in a stainless steel bowl. Samples were analyzed for particle size, total solids, organic carbon, and eight metals.

Figure 2-3. Locations of 2004 Sediment Monitoring Stations in Rufus Woods Lake, Washington



Site	Station	Description
1	CHJUP	Buckley Bar Station
2	CHJNSP	Mouth of Nespelum River
9	CHJMID	Lake Rufus Woods Mid Reservoir
10	CHJFB1	Chief Joseph Dam Forebay
11	CHJFB2	Chief Joseph Dam Forebay

Table 2-1. Sediment Sampling Station Locations and Details for 2004 Assessment

Site ID Number	Station Name	Sample Date	Sample Time	Latitude (NAD 83)	Longitude (NAD 83)	Number of Samples Composited	Water Depth Range (m)	Approx. River km	Approximate Station Location
1	CHJUP-5S	11/5/2004	1200	48° 3' 38.268"	-119° 0' 52.416"	3	6.1 to 7.0	946.3	Buckley Bar
2	CHJNSP-4S	11/5/2004	1300	48° 7' 43.5"	-119° 2' 39.696"	3	11.3 to 13.1	937.4	Mouth of Nespelum River
9	CHJMID-3S	11/5/2004	1420	48° 6' 59.472"	-119° 18' 6.624"	3	9.8 to 15.2	914.1	Mid-Reservoir Location
10	CHJFB-1S	11/4/2004	1550	48° 0' 57.312"	-119° 35' 41.604"	3	13.1 to 19.8	888.1	Forebay Near Bridgeport State Park
11	CHJFB-2S	11/4/2004	1630	48° 0' 57.78"	-119° 35' 41.676"	3	14.9 to 18.3	888.1	Forebay Near Bridgeport State Park

Table 2-2. Methods, Detection Limits, Containers, Preservation Techniques and Holding Times for the 2004 and 2011 Sediment Quality Analyses

Chemical	Matrix	Method Number [1/]	Detection Limit/Unit	Container and Preservation	Holding Time	Sample Code [2/]
Arsenic	Sediment	EPA 7060	1.0 mg/kg	P/G, 4°C	6 months	A
Cadmium	Sediment	EPA 6010	0.2 mg/kg	P/G, 4°C	6 months	A
Chromium	Sediment	EPA 6010	0.5 mg/kg	P/G, 4°C	6 months	A
Copper	Sediment	EPA 6010	0.5 mg/kg	P/G, 4°C	6 months	A
Lead	Sediment	EPA 6020	0.1 mg/kg	P/G, 4°C	6 months	A
Lithium	Sediment	EPA 6010	1.0 mg/kg	P/G, 4°C	6 months	B
Mercury	Sediment	EPA 6020	0.01 mg/kg	P/G, 4°C	28 days	A
Nickel	Sediment	EPA 6010	0.25 mg/kg	P/G, 4°C	6 months	A
Zinc	Sediment	EPA 6010	0.25 mg/kg	P/G, 4°C	6 months	A
Total organic carbon	Sediment	EPA 9060	100 mg/kg	P/G, 4°C	28 days	A
Total solids	Sediment	EPA 160.3	0.1 %	P/G, 4°C	14 days	A
Particle size	Sediment	—	—	P/G, 4°C	6 months	A
Total phosphorus	Sediment	EPA 365.1	0.2 mg/kg	P/G, 4°C	28 days	B
Total nitrogen	Sediment	EPA 351.1	1.0 mg/kg	P/G, 4°C	28 days	B
Ammonia	Sediment	EPA 350.1	2.0 mg/kg	P/G, 4°C	7 days	B
Polychlorinated biphenyls (PCBs)	Sediment	EPA 8082	20 µg/kg	G, 4°C	7 days	C
polybrominated diphenyl ethers (PBDEs)	Sediment	EPA 8082	0.5 µg/kg	G, 4°C	7 days	C
Pesticides	Sediment	EPA 8082	0.5–5.0 µg/kg	G, 4°C	7 days	C

Note: mg/kg = milligrams per kilogram; µg/kg = micrograms per kilogram; P/G = polyethylene or glass.
1/ SM method numbers are from Greenberg, Eaton, and Clesceri (2000); EPA method numbers are from EPA (1983, 1984, and 1992).
2/ A= Analyzed for all sampling stations in 2004 and 2011; B = Analyzed for all sampling stations in 2011; C = Analyzed only for stations CHJUP-S1-T1, CHJNSP-S2-T1, CHJMID-S5-T1, and CHJFB-S7-T1 in 2011.

2.7.2 U.S. Army Corps of Engineers 2011 Study

The Corps conducted a second sediment quality study in the Columbia River above Chief Joseph Dam during 2011. Sediment sampling was designed to provide information on the distribution of contaminants of concern in Rufus Woods Lake by focusing sampling on suspected source areas, areas where sediments would be expected to accumulate, and areas sampled in 2004. The target locations for the 2011 sediment sampling were (1) natural depositional zones within Rufus Woods Lake from Chief Joseph Dam upstream to Grand Coulee Dam previously sampled in 2004, and (2) areas upstream and downstream of aquaculture facilities where sediments could possibly accumulate in current sheltered areas or depressions. Sediment sampling station locations and details are summarized in Table 2-3, with general sampling locations shown in Figure 2-4. Sediment quality parameters monitored are presented in Table 2-2. As seen in Table 2-2, there were no differences in the methodology and detection limits between the 2004 and 2011 studies.

Table 2-3. Sediment Sampling Station Locations and Details for 2011 Assessment

Site ID Number	Station Name	Date and Time	Latitude (NAD 83)	Longitude (NAD 83)	Number of Samples Composited	Water Depth Range (m)	Approximate River km	Approximate Station Location	Location Sampled in 2004
1	CHJUP-S1-T1	11/2/11 10:00	48° 03' 43.9"	-119° 01' 04.1"	5	5.8 to 8.8	946.3	Buckley Bar	Yes
2	CHJNSP-S2-T1	11/2/11 11:44	48° 07' 49.1"	-119° 02' 43.9"	3	12.8 to 13.4	937.4	Mouth of Nespelum River	Yes
3	CHJFF-S3-T1	11/3/11 13:57	48° 08' 27.9"	-119° 03' 45.6"	3	4.3 to 7.3	936.2	335 meters downstream of Aquaculture Site #2	No
4	CHJFF-S3-T2	11/3/11 14:55	48° 08' 16.0"	-119° 03' 38.5"	3	6.7 to 7.0	935.8	580 meters downstream of Aquaculture Site #2	No
5	CHJFF-S4-T1	11/2/11 13:22	48° 08' 19.5"	-119° 05' 59.3"	3	14.6 to 17.1	932.6	45 meters downstream of Aquaculture Site #1	No
6	CHJFF-S4-T2	11/2/11 15:00	48° 08' 22.1"	-119° 06' 03.6"	3	7.6 to 8.2	936.3	150 meters downstream of Aquaculture Site #1	No
7	CHJFF-S4-T3	11/3/11 12:07	48° 08' 19.8"	-119° 06' 00.2"	2	15.2 to 17.1	932.6	75 meters downstream of Aquaculture Site #1	No
8	CHJFF-S4-T4	11/3/11 12:43	48° 08' 45.9"	-119° 06' 44.2"	3	9.8 to 10.4	931.3	1220 meters downstream of Aquaculture Site #1	No
9	CHJMID-S5-T1	11/3/11 16:00	48° 07' 02.4"	-119° 18' 04.9"	4	5.8 to 8.5	914.1	Mid-Reservoir location	Yes
10	CHJFB-S7-T1	11/1/11 14:46	48° 00' 58.8"	-119° 35' 44.8"	3	13.1 to 16.5	881.1	Forebay Near Bridgeport State Park	Yes
11	CHJFB-S7-T2	11/1/11 15:30	48° 00' 58.2"	-119° 35' 45.0"	3	16.5 to 16.8	881.1	Forebay Near Bridgeport State Park	Yes

Figure 2-4. Locations of 2011 Sediment Monitoring Stations in Rufus Woods Lake, Washington

In general, sediments were collected at the five locations sampled in 2004 that were located downstream of islands or in backwater slow current areas that favored accumulations of fine particle-sized sediments. For the 2011 study, sediment samples were also collected at six additional stations located downstream of the aquaculture facilities. Because of the depth and velocity in the river downstream of the facilities, it was difficult to locate low velocity zones or depressional areas where sediments may collect. Consequently, most sediments collected downstream of aquaculture facilities were collected from high velocity zones with little fine particle-sized sediments.

Sediments were collected using a stainless steel Van Veen grab sampler. Grab samples were 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 cm. Each sediment station sample was a composite of three grabs collected from the top 10 cm using either a stainless steel spoon and compositing bowl (for organics analysis) or HDPE spoon and compositing bucket (metals and nutrients analysis). Samples were analyzed for particle size, total solids, organic carbon, nutrients, polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), pesticides, and nine different metals.

2.8 CONTAMINANTS OF CONCERN

Many pollutants tend to be associated with particles that settle out onto bottom sediments. At great enough concentrations, these compounds may be harmful to benthic organisms and may bio accumulate in fish and other aquatic organisms. Sediment samples were analyzed for metals, nutrients, organochlorine pesticides, polychlorinated biphenyls (PCBs), and polybrominated diphenyl ethers (PBDEs).

2.8.1 Metals

Metals of concern include arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc. Sources of these metals exist upstream of Grand Coulee Dam from historical mining and smelter activities in British Columbia. Elevated concentrations of metals can be toxic to benthic and aquatic organisms and bio accumulate.

2.8.2 Nutrients

Nutrients of concern that are found in sediments include phosphorus and nitrogen compounds, including ammonia. Elevated concentrations of phosphorus and nitrogen compounds in sediments may be an indication of an upstream source of these nutrients to the ecosystem. Additionally, elevated phosphorus concentrations may result in increased algal growth leading to eutrophication or nutrient enrichment of surface waters. High ammonia concentrations in sediments can be toxic to benthic organisms.

2.8.3 Organochlorine Pesticides

Organochlorine pesticides are chlorinated hydrocarbons used extensively as pesticides in the 1940s through the 1970s. Most organochlorine pesticides are no longer sold in

the United States. However, many of these pesticides are extremely persistent in the environment. Pesticides, such as DDT (Dichlorodiphenyltrichloroethane), that were banned years ago are still found in the environment. Since the early 1970s organochlorine pesticides, such as DDT, have been shown to be harmful to aquatic invertebrates, fish, birds, and mammals (USGS 1996).

2.8.4 Polychorinated Biphenyls

PCBs were developed in the 1940s and used in the manufacturing of transformers, capacitors and many other heat transfer devices. 1n 1979, their manufacture and import was banned in the United States due to evidence of the chemical compounds toxicity to humans and animals, persistence in the environment, and tendency to bioaccumulate. PCBs are mixtures of different congeners of chlorobiphenyls. Consequently, many forms of PCBs exist and they are generally referred to by their commercial mixture names called Aroclors (EPA 2012b).

2.8.5 Polybrominated Diphenyl Ethers

PBDEs are classes of bromated hydrocarbons that are used as flame retardants in numerous products, including furniture, plastics, electrical equipment, wire insulation, textiles, and other household products (EPA 2012c). PBDEs exist as mixtures of many different chemicals called congeners that have unique molecular structures. Each congener is given a number to identify it from other PBDE congeners. PBDEs can enter the environment through many different pathways including emissions from manufacturing, recycling wastes, and leaching from waste disposal sites. Although the use of PBDEs has been banned in many European countries due to the chemical persistence in the environment and tendency to bioaccumulate, use in the United States continues to be widespread.

2.9 EXISTING 303(D) AND Total Maximum Daily Loads

Rufus Woods Lake was identified by Ecology as water quality impaired and not fully supporting aquatic life in the Ecology 2016 Integrated Report (Ecology 2018). Consequently, Rufus Woods Lake was included in the 2016 Ecology Clean Water Act 303(d) Category 5 (impaired) list for flow, dissolved oxygen and temperature. The 303(d) Category 5 list is defined by EPA as waters with one or more beneficial uses being impaired or threatened, and a total daily maximum load (TMDL) is required to address the impairment or threat. For Rufus Woods Lake, a TMDL is needed for dissolved oxygen and temperature. Rufus Woods Lake currently has an EPA-approved TMDLs for total dissolved gas.

Rufus Woods Lake is located immediately downstream of Grand Coulee Dam and Lake Roosevelt, and nearly all the inflow to Rufus Woods Lake comes from Lake Roosevelt. As such, water or sediment quality impairments upstream of Grand Coulee Dam are of concern to Rufus Woods Lake. Lake Roosevelt and the Columbia River upstream of Grand Coulee Dam have been identified by Ecology as water and sediment quality impaired and not fully supporting aquatic life in the Ecology 2016 Integrated Report

(Ecology 2018). This assessment listed Lake Roosevelt at Grand Coulee Dam as a Class 2 waterbody of concern due to sediment metal concentrations. Sediment contamination in Lake Roosevelt is of concern because Rufus Woods Lake is located immediately downstream, and transport of contaminated sediments from Lake Roosevelt may be impacting sediment quality in Rufus Woods Lake.

2.10 FRESHWATER SEDIMENT SCREENING LEVELS

The Pacific Northwest Sediment Evaluation Framework (SEF) manual provides a regional framework for assessing, characterizing, and evaluating sediments in the Pacific Northwest (Northwest Regional Sediment Evaluation Team Agencies 2016). The SEF developed freshwater sediment quality guidelines for evaluating sediment chemical analytical results based on screening levels and bioaccumulation criteria.

2.11 DATA ANALYSIS

Sediment contaminant concentrations are often closely related with grain size, with increasing concentrations associated with finer particle size sediments. Consequently, it can be difficult to determine any conclusions from sediment contaminant concentrations between samples without accounting for the effects of grain size differences. However, normalizing data based on grain size may not always be effective (Yates et al. 2005). Consequently, numerous researchers have used reference elements to normalize metals (Carvalho and Schropp 2002; Yates et al. 2005) and other contaminants (Herut and Sandler 2006) to allow comparisons of sediment data. Many reference elements have been used for chemical normalization, including aluminum, iron, total organic carbon, and lithium. Yates et al. (2005) concluded that for the northern latitude regions dominated by glaciations, lithium normalization is the preferred method.

2.12 CONCEPTUAL SITE MODEL

A conceptual site model was not developed for sediments in Rufus Woods Lake. There are no known dredging operations in the reservoir. Consequently, any contaminants in the sediments are not anticipated to be released to the water during dredging, in water disposal, or other disposal operations.

SECTION 3 - RESULTS AND DISCUSSION

Sediment quality results from 2004 and 2011 in Rufus Woods Lake are summarized below for physical and chemical testing, correlations and trends, and for longitudinal distributions. General locations for the 2004 and 2011 sediment stations are shown in Figure 2-3 and Figure 2-4. Sediment chemistry results are compared to Pacific Northwest Regional Sediment Evaluation Framework screening levels.

3.1 PHYSICAL AND CHEMICAL TESTING

3.1.1 Conventionals

Table 3-1 shows results for grain size, percent solids, and total organic carbon (TOC) for sediment samples collected in Rufus Woods Lake in 2004 and 2011. In general, grain size analyses indicates that the forebay sediments (Sites 10 and 11) were dominated by clay/silt fractions, mid-reservoir sediments (Sites 2 and 9) were a mix of sand and clay/silt fractions, while up-reservoir sediments (Site 1) were dominated by sand fractions. Sediments located downstream of the aquaculture facilities (Sites 3, 4, 5, 6, 7, and 8) were dominated by sand fractions, with lesser percentages of gravel. Sites 4 and 7 contained the greatest percentage of gravels at 16 and 32 percent, respectively. In general, the sites located downstream of the aquaculture facilities contained the highest percentages of gravels and lowest percentages of clay/silt fractions. Percent solids ranged from a low of about 42 to 45 percent at the forebay sediment stations (Sites 10 and 11) to a high of about 81 percent at Site 7 located about 75 meters downstream of Aquaculture Site #1. Table 3-1 also presents selected upstream sediment data representing both the sediment quality immediately upstream of Rufus Woods Lake in Grand Coulee Dam's forebay, as well as background reference sediment quality collected in Lower Arrow Lake, British Columbia (USGS 1994; Ecology 2001; USGS 2004). In general, grain sizes varied between studies with most sites dominated by a mixture of sand and silt/clay fractions.

TOC concentrations, measured in Rufus Woods Lake sediments in 2011, are summarized in Table 3-2 and presented in Figure 3-1. TOC concentrations were low at all sites and ranged from 2,086 to 20,710 mg/kg (i.e., 0.2 to 2.1 percent). TOC concentrations showed no spatial pattern with elevated TOC concentrations located both upstream and downstream of aquaculture facilities (

Figure 3-1). This range of TOC concentrations was similar to upstream and background data ((2000 to 13000 mg/kg [i.e. 0.2 to 1.3 percent]).Because grain size and TOC can correlate to concentration of metals and other contaminants, these parameters are of interest when comparing sites because differences in contaminant concentrations may largely be attributed to differences in grain sizes and TOC concentrations rather than the presence or absence of contamination.

Table 3-1. Sediment Metals and Conventionals Data Collected in Lake Rufus Woods, 2004 and 2011

Site No.	Sample Number	Station Location	River Mile	Date	Time	Aluminum (mg/kg)	Arsenic (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Lithium (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) (%)	Silt/Clay (< 0.075 mm) (%)	Mean Particle Size (mm)
Lake Rufus Woods Sediment Sample Data 2011																					
1	CHJUP-S1-T1	Buckley Bar	588	11/2/2011	10:00	6253	1.28	0.857	11.3	14.8	19.1	10.3	0.029	8.47	202	5182	69.02	0.90	94.24	4.86	0.1696
2	CHJNSP-S2-T1	Nespelum River	582.5	11/2/2011	11:44	6820	1.53	0.644	11.0	7.40	11.6	10.6	<0.033	8.22	118	20710	60.27	0.45	64.92	34.63	0.0992
3	CHJFF-S3-T1	500' Downstream Aquaculture #2	581.7	11/3/2011	13:57	4902	0.717	0.657	9.04	5.91	5.59	7.59	<0.028	7.02	86.8	6364	71.64	2.27	96.16	1.58	0.2496
4	CHJFF-S3-T2	1800' Downstream Aquaculture #2	581.5	11/3/2011	14:55	4774	1.36	0.663	11.5	10.2	10.6	7.37	<0.028	6.13	114	14930	65.61	16.33	81.66	2.02	0.7428
5	CHJFF-S4-T1	200' Downstream Aquaculture #1	579.5	11/2/2011	13:22	3133	0.664	0.282	7.38	6.53	6.89	5.01	0.048	4.92	64.8	6985	75.1	4.46	95.35	0.19	0.4313
6	CHJFF-S4-T2	500' Downstream Aquaculture #1	579.4	11/2/2011	15:00	4275	0.621	0.397	9.71	5.45	4.97	7.10	<0.025	6.86	77.3	2086	73.83	2.24	96.95	0.81	0.2774
7	CHJFF-S4-T3	100' Downstream Aquaculture #1	579.5	11/3/2011	12:07	3418	0.669	0.370	7.60	11.7	8.33	5.75	<0.025	4.52	88.0	4688	80.97	31.57	68.26	0.17	1.2095
8	CHJFF-S4-T4	4000' Downstream Aquaculture #1	578.7	11/3/2011	12:43	3570	0.611	0.522	6.15	4.99	8.48	5.71	<0.026	4.34	102	12010	73.86	0.93	96.91	2.16	0.1878
9	CHJMID-S5-T1	Mid Reservoir	568	11/3/2011	16:00	6030	0.919	1.16	9.68	6.28	11.4	10.0	<0.030	7.01	166	5777	64.58	0.06	73.16	26.79	0.0833
10	CHJFB-S7-T1	Chief Joseph Dam Forebay	547.5	11/1/2011	14:46	12735	2.86	**2.98**	17.8	23.6	51.8	16.2	0.169	14.3	305	14700	42.12	0.00	36.75	63.25	0.0433
11	CHJFB-S7-T2	Chief Joseph Dam Forebay	547.5	11/1/2011	15:30	12866	2.89	**3.00**	17.8	23.7	50.3	17.2	0.135	14.2	283	14690	42.48	0.00	38.63	61.37	0.0458
Lake Rufus Woods Sample Data 2004[1]																					
	1	Chief Joseph Dam Forebay	547.5	11/4/2004	16:30	—	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	547.5	11/4/2004	15:50	—	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	14:20	—	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	13:00	—	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	12:00	—	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)[2]																					
	71	Grand Coulee Dam RB	596	10/16/1992	16:45	—	**18.00**	**6.20**	—	61.00	190.00	—	**0.800**	—	730	13000	—	—	—	95.00	—
	1	Lower Arrow Lake*	787	10/10/1992	9:00	—	2.00	0.50	—	7.00	28.00	—	<0.05	—	49	7000	—	—	—	10.00	—
	2	Lower Arrow Lake*	787	10/10/1992	10:30	—	1.50	0.50	—	7.00	32.00	—	<0.05	—	60	8000	—	—	—	9.00	—
Upstream Sediment Sample Data (USGS 2004)[3]																					
	—	Upstream Reference Site	760	1995	—	2820	1.14	0.17	8.7	10.10	8.48	7.72	<0.05	7.1	58	—	—	—	—	—	—
	—	Upstream Reference Site	760	1999	—	3290	1.00	0.15	16.60	13.20	8.29	5.21	<0.05	7.3	40	—	—	—	—	—	—
Upstream Sediment Sample Data (WDOE 2001)[4]																					
	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	—
Downstream Sediment Sample Data (EPA 2008)[5]																					
	—	Mean Concentration of 45 samples	420-292	10/1/2004	—	—	5.07	1.09	14.37	17.10	12.43	—	0.040	15.1	143	—	—	—	—	—	—
WDOE Sediment Management Standards (WDOE 2013)[6]																					
	Freshwater Sediment Cleanup Objective (SCO)					—	14	2.1	72	400	360	—	0.66	26	3200	—	—	—	—	—	—
	Freshwater Sediment Cleanup Screening Level (CSL)					—	120	5.4	88	1200	>1300	—	0.80	110	>4200	—	—	—	—	—	—
Confederated Tribes of the Colville Reservation (2005)[7]																					
	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 Cleanup Objective (SCO) while values in bold and shaded are in excess of the Freshwater Sediment Cleanup Screening Level (SCL)

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. Corps 2009a. Sediment Quality Assessment of Lake Rufus Woods and Chief Joseph Dam, 2004
2. USGS 1994. Sediment Quality Assessment of Franklin D. Roosevelt Lake and the Upstream Reach of the Columbia River, Washington 1992
3. USGS 2004. Vertical Distribution of Trace Elements and Metallurgical Slag in Sediments, Lake Roosevelt, Washington 2002
4. WDOE 2001. Reassessment of Toxicity of Lake Roosevelt Sediments
5. EPA 2008. Sediment Quality in the Mid-Columbia River between Vantage, Washington and McNary Dam
6. Ecology 2013. Sediment Management Standards (SMS) Chapter 173-204 WAC
7. Colville Tribe 2005. Colville Tribal Law and Order Code. Chapter 4-16 Hazardous Substance Control.

3.1.2 Nutrients

Phosphorus is present in sediments in both inorganic and organic forms. Inorganic forms include iron, aluminum, and calcium bound phosphorus as well as exchangeable phosphorus in the pore water. Organic forms include fulvic and humic acid phosphorus and dissolved organic phosphorus (Moore et al. 1998). The ability for sediments to sorb (retain) and desorb (release) phosphorus is largely determined by the individual sediment characteristics and chemical composition. Nitrogen in lake sediments is present largely in the organic form and is generally believed to be largely unavailable. Readily available forms of nitrogen in sediments are found in the porewater as both ammonium and organic nitrogen, as well as exchangeable ammonium on the sediment (EPA 1974). For sediments collected in Rufus Woods Lake in 2011, only total phosphorus was measured, and phosphorus adsorption/desorption studies were not conducted. Organic nitrogen was determined from total Kjeldahl nitrogen concentrations. Inorganic nitrogen was determined from ammonia (NH_4^+-N + NH_3-N) concentrations that include ammonium.

Nutrient concentrations, measured in Rufus Woods Lake sediments in 2011, are summarized in Table 3-2 and presented in Figure 3-1. Total phosphorus concentrations in sediments ranged from 790 mg/kg at Site 6 (150 meters downstream of Aquaculture Site #1) to 2,801 mg/kg at Site 7 (75 meters downstream of Aquaculture Site #1). Sediment phosphorus concentrations were greatest both immediately downstream of Aquaculture Site #1 (Sites 5 and 7) and in the forebay (Sites 10 and 11). The elevated phosphorus at Sites 5 and 7 (downstream of Aquaculture Site #1) is interesting because the sediments were dominated by gravels and sand with very little silt/clay fractions (0.19 and 0.17 percent, respectively). Phosphorus chemistry suggests that sediment concentrations should be somewhat correlated to particle size. As such, the elevated concentrations in sediments containing little silt/clay immediately downstream of Aquaculture Site #1 suggests that the aquaculture facilities may be a source of phosphorus to the sediments.

Figure 3-1. Longitudinal Distribution of Sediment Nutrients and Total Organic Carbon in Rufus Woods Lake from the 2011 study.

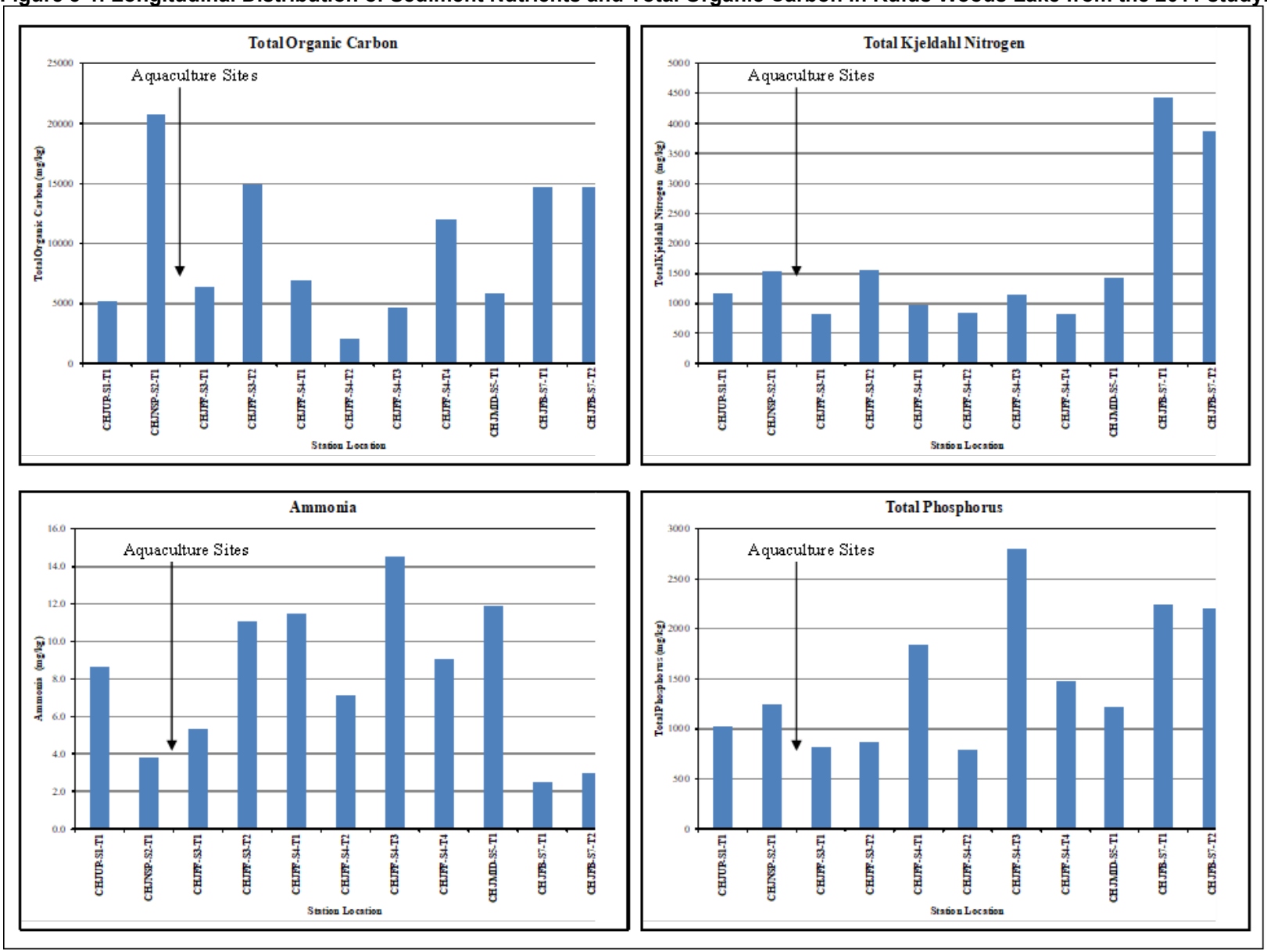


Table 3-2. Sediment Nutrient Data Collected in Lake Rufus Woods, Chief Joseph Dam in 2011

Site No.	Sample Number	Station Location	River km	Date	Time	Total Phosphorus (mg/kg)	Total Kjeldhal Nitrogen (mg/kg)	Ammonia (mg/kg)	Total Organic Carbon (mg/kg)	Solids (%)	Gravel (> 2 mm) (%)	Sand (2 - 0.075 mm) (%)	Silt/Clay (< 0.075 mm) (%)	Mean Particle Size (mm)
Lake Rufus Woods Sediment Sample Data 2011														
1	CHJUP-S1-T1	Buckley Bar	946.3	11/2/2011	10:00	1018	1170	8.67	5182	69.02	0.90	94.24	4.86	0.1696
2	CHJNSP-S2-T1	Nespelum River	937.4	11/2/2011	11:44	1248	1545	3.77	20710	60.27	0.45	64.92	34.63	0.0992
3	CHJFF-S3-T1	335m downstream Aquaculture #2	936.2	11/3/2011	13:57	821	825	5.30	6364	71.64	2.27	96.16	1.58	0.2496
4	CHJFF-S3-T2	580m downstream Aquaculture #2	935.8	11/3/2011	14:55	869	1552	11.1	14930	65.61	16.33	81.66	2.02	0.7428
5	CHJFF-S4-T1	45m downstream Aquaculture #1	932.6	11/2/2011	13:22	1849	988	11.5	6985	75.10	4.46	95.35	0.19	0.4313
6	CHJFF-S4-T2	150m downstream Aquaculture #1	936.3	11/2/2011	15:00	790	845	7.12	2086	73.83	2.24	96.95	0.81	0.2774
7	CHJFF-S4-T3	75m downstream Aquaculture #1	932.6	11/3/2011	12:07	2801	1149	14.5	4688	80.97	31.57	68.26	0.17	1.2095
8	CHJFF-S4-T4	1220m downstream Aquaculture #1	931.3	11/3/2011	12:43	1476	824	9.06	12010	73.86	0.93	96.91	2.16	0.1878
9	CHJMID-S5-T1	Mid Reservoir	914.1	11/3/2011	16:00	1227	1425	11.9	5777	64.58	0.06	73.16	26.79	0.0833
10	CHJFB-S7-T1	Chief Joseph Dam Forebay	881.1	11/1/2011	14:46	2250	4438	2.48	14700	42.12	0.00	36.75	63.25	0.0433
11	CHJFB-S7-T2	Chief Joseph Dam Forebay	881.1	11/1/2011	15:30	2211	3858	3.02	14690	42.48	0.00	38.63	61.37	0.0458

Total Kjeldahl nitrogen concentrations ranged from 824 mg/kg at Site 8 (1,220 meters downstream of Aquaculture Site #1) to 4,438 mg/kg at Site 10 (Chief Joseph Dam forebay). Total Kjeldahl nitrogen concentrations were substantially greater at the forebay (Sites 10 and 11) than any other location sampled. Ammonia concentrations in the sediments ranged from 2.48 mg/kg at Site 10 (Chief Joseph Dam forebay) to 14.5 mg/kg at Site 7 (75 meters downstream of Aquaculture Site #1). Ammonia concentrations were substantially greater at sites downstream of Aquaculture facilities (Sites 4, 5, and 7) and at the mid-reservoir station (Site 9) than at other locations, suggesting that the aquaculture facilities may be a source of ammonia to the sediments.

To compare the relative spatial distribution of nutrients in Rufus Woods Lake, sites were ranked according to concentrations of each nutrient and organic carbon, and then the sites were ranked by the average of each individual nutrient/carbon rank (Table 3-3). Total organic carbon was combined with nutrients because of the important role organic carbon plays in nutrient cycling, sediment enrichment and trophic status in water bodies (Williamson et al. 1999; Pelletier et al. 2011). Ranks are shown by location in Figure 3-2. In general, the nutrient ranking methods show that the highest concentrations of nutrients are at the forebay (Sites 10 and 11), downstream of the aquaculture facilities (Sites 4, 5, and 7), and near the Nespelum River (Site 2). Several stations located downstream of aquaculture facilities (Sites 3 and 6) had the lowest nutrient ranking, which shows the random spatial distribution of sediment nutrients in Rufus Woods Lake. Figure 3-2 shows the correlation of the nutrients rank index with percent silt/clay fraction in sediments. The relationship is low (r^2=0.26), suggesting that either the clay/silt fractions are not well correlated to nutrient concentrations or that those sites with low silt/clay percentages but elevated nutrients were enriched. In addition, the random spatial distribution of sediment nutrients in Rufus Woods Lake points to few, if any, reservoir management implications.

Table 3-3. Nutrient Concentrations and Nutrient Rank Index Calculations

			Concentrations in mg/kg				Rank of Sites by Concentrations				Mean of	Overall	Rank
Site No.	**SAMPLE ID**	**Date and Time**	**TP[3]**	**TKN[3]**	**NH4[3]**	**TOC[3]**	**TP[3]**	**TKN[3]**	**NH4[3]**	**TOC[3]**	Ranks	Rank[1]	Index[2]
1	(CHJUP-S1-T1)	11/2/11 10:00	1018	1170	8.67	5182	8	6	6	9	7	9	2.3
2	(CHJNSP-S2-T1)	11/2/11 11:44	1248	1545	3.77	20710	6	4	9	1	5	5	4.5
3	(CHJFF-S3-T1)	11/3/11 13:57	821	825	5.30	6364	10	10	8	7	9	10	0.8
4	(CHJFF-S3-T2)	11/3/11 14:55	869	1552	11.1	14930	9	3	4	2	5	2	5.0
5	(CHJFF-S4-T1)	11/2/11 13:22	1849	988	11.5	6985	4	8	3	6	5	6	4.3
6	(CHJFF-S4-T2)	11/2/11 15:00	790	845	7.12	2086	11	9	7	11	10	11	0.1
7	(CHJFF-S4-T3)	11/3/11 12:07	2801	1149	14.5	4688	1	7	1	10	5	3	4.8
8	(CHJFF-S4-T4)	11/3/11 12:43	1476	824	9.06	12010	5	11	5	5	7	8	3.0
9	(CHJMID-S5-T1)	11/3/11 16:00	1227	1425	11.9	5777	7	5	2	8	6	7	4.0
10	(CHJFB-S7-T1)	11/1/11 14:46	2250	4438	2.48	14700	2	1	11	3	4	1	5.3
11	(CHJFB-S7-T2)	11/1/11 15:30	2211	3858	3.02	14690	3	2	10	4	5	3	4.8

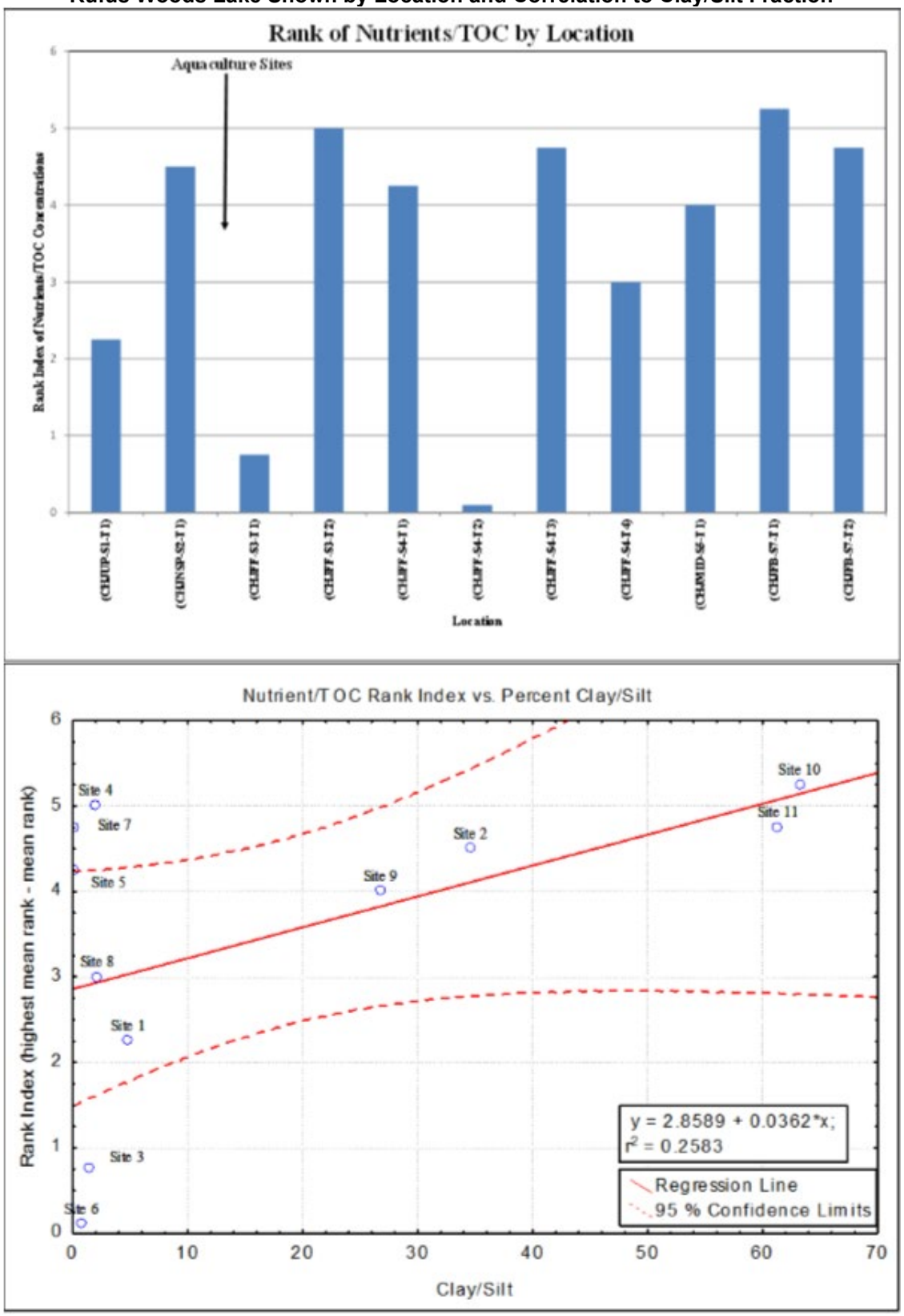
Notes:

[1]Overall rank represents the rank of the mean of ranks. Lower rank numbers represent higher concentrations.

[2]Rank index calculated as: Highest mean rank - mean ranks for different sites. This ranking results in the site with the highest concentrations having the highest rank index value.

[3]Abbreviations: TP-Total Phosphorus, TKN-Total Kjeldhal Nitrogen, NH4-Ammonia, TOC-Total Organic Carbon.

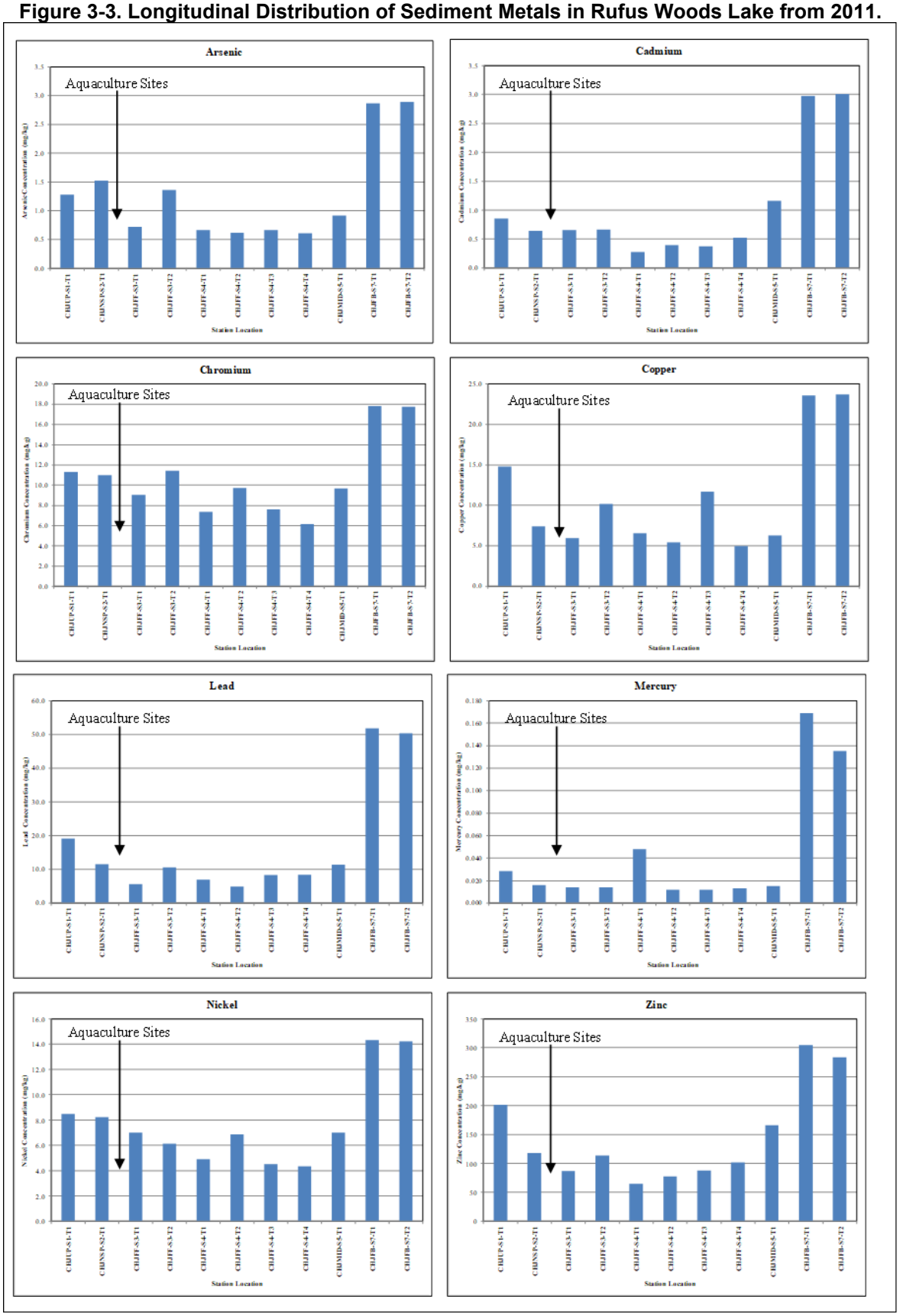
Figure 3-2. Rank Index of Nutrients in Sediments Collected from Rufus Woods Lake Shown by Location and Correlation to Clay/Silt Fraction



3.1.3 Metals

Metals concentrations in Rufus Woods Lake for the 2004 and 2011 sediment studies are summarized in Table 3-1, with 2011 data presented in Figure 3-3. Because the methodology and detection limits were similar between 2004 and 2011, observed differences in metal concentrations could be attributed to differences in silt/clay fractions between the different years. The forebay stations (Sites 10 and 11) had the highest concentration of all metals with moderate metals concentrations at the mid-reservoir station (Site 9) and up-reservoir stations (Sites 1 and 2), and lowest metal concentrations at stations located downstream of the aquaculture facilities (Sites 3 through 8). Sediment metals concentrations in Rufus Woods Lake measured at the forebay, mid-reservoir, Nespelum, and Buckley Bar stations (Sites 11, 10, 9, 2, and 1, respectively) in 2011 were similar to concentrations measured at those stations in 2004 (Table 3-1). Sediment metals concentrations in Rufus Woods Lake were less than concentrations measured by the USGS (1994) at Grand Coulee Dam forebay but greater than concentrations measured by Ecology (2001) at Grand Coulee Dam forebay (Table 3-1). Additionally, Rufus Woods Lake metal concentrations were substantially greater than background and/or reference site metal concentrations for the Columbia River collected by both the USGS (1994) and Ecology (2001) in Lower Arrow Lake, and by the USGS (2004) at a reference site located upstream of Trail, British Columbia. In general, metal concentrations at stations sampled in 2004 and 2011 are relatively low with no concentration exceeding the SEF screening level 1 except for cadmium at the forebay stations (Sites 10 and 11) in both 2004 and 2011. This data suggests that adverse effects to the benthic community may be possible in the forebay sediments due to elevated cadmium concentrations.

Figure 3-3. Longitudinal Distribution of Sediment Metals in Rufus Woods Lake from 2011.



Sediment metal concentrations in Lake Rufus Woods were also compared to concentrations measured about 190 to 480 kilometers downstream in the middle Columbia River from Vantage, Washington to McNary Dam forebay (EPA 2008b) (Table 3-1). In general, the concentrations for many of the metals evaluated in Rufus Woods were similar to metal concentrations collected in the middle Columbia River by the EPA (2008b). The exceptions were for zinc, lead, mercury, and cadmium, which were substantially higher in Rufus Woods Lake at the Chief Joseph Dam forebay location (Sites 10 and 11) in 2004 and 2011. These metals are known to be elevated in the Columbia River upstream of Grand Coulee Dam from historical discharge of metal smelter waste slag into the river (USGS 1994; Ecology 2001).

To compare the relative spatial distribution of metals in 2011, sites were ranked according to concentrations of each metal, and then the sites were ranked by the average of each individual metal rank (Table 3-4). Ranks are shown by location in Figure 3-4. In general, the 2011 metals rank index shows that the highest concentrations of most metals are near the forebay (Sites 10 and 11) and downstream of Grand Coulee Dam (Sites 1 and 2). Locations downstream of the aquaculture facilities (Sites 3 through 8) had the lowest metals ranks. Figure 3-5 shows the correlation of the metals rank index with percent silt/clay fraction in sediments. The relationship is moderate ($r^2 = 0.72$) suggesting that metals concentrations in Rufus Woods Lake are likely correlated to clay/silt fractions. Metals are often correlated with clays and silts because these particle fractions have a greater surface area for metals to sorb onto and also are associated with depositional areas (Horowitz 1985).

Figure 3-4. Rank Index of Metals in Sediments Collected from Rufus Woods Lake in 2011. Shown by Location and Correlation to Clay/Silt Fraction

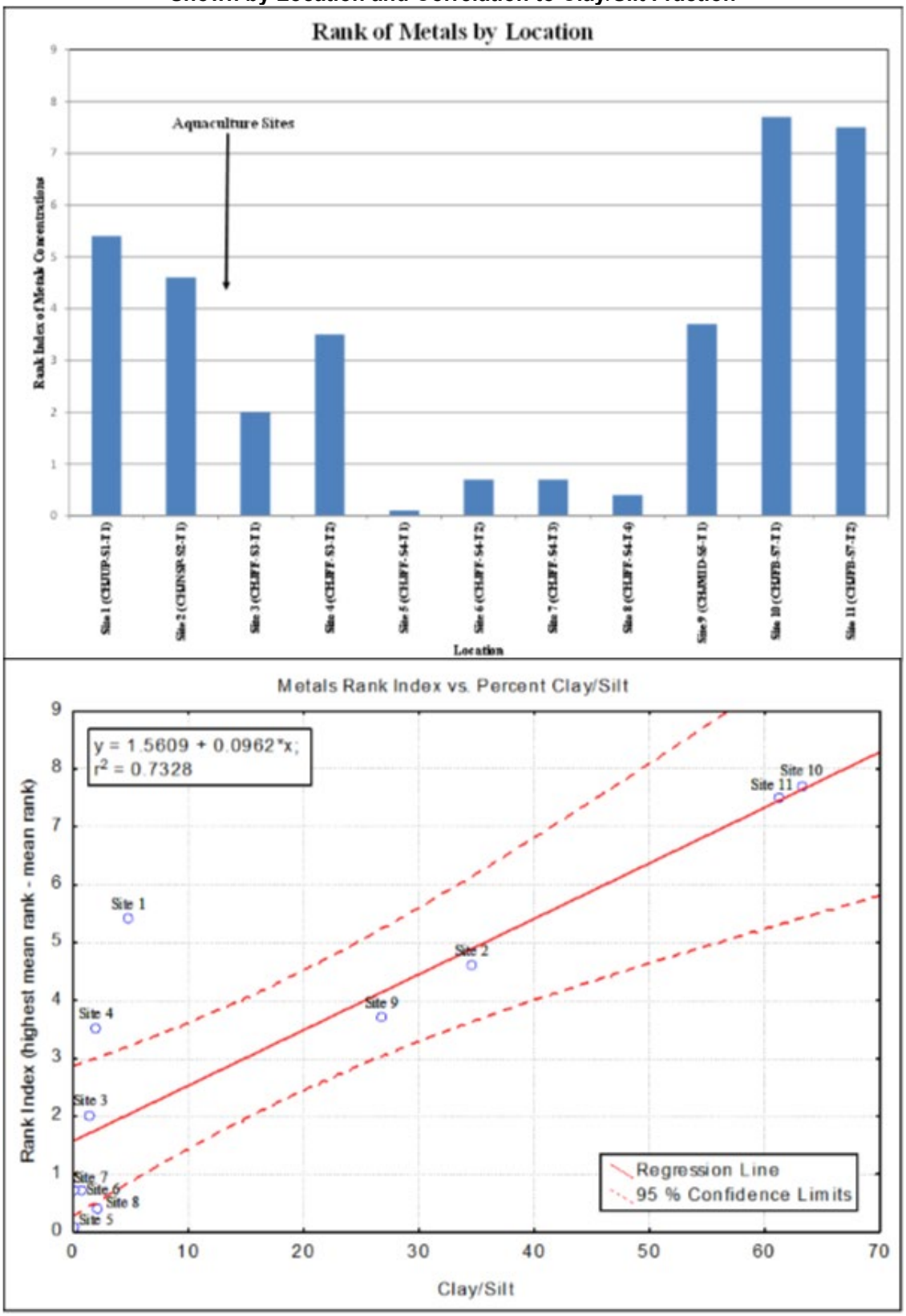


Table 3-4. Concentrations and Metals Rank Index Calculations for 2011 Data

			Concentrations in mg/kg										Rank of Sites by Concentrations										Mean of	Overall	Rank
Site No.	SAMPLE ID	Date and Time	Al[3]	As	Cd	Cr	Cu	Pb	Li	Ni	Hg	Zn	Al	As	Cd	Cr	Cu	Pb	Li	Ni	Hg	Zn	Ranks	Rank[1]	Index[2]
1	CHJUP-S1-T1	11/2/11 10:00	6253	1.28	0.857	11.3	14.8	19.1	10.3	8.47	0.029	202	4	5	4	4	3	3	4	3	4	3	3.7	3	5.4
2	CHJNSP-S2-T1	11/2/11 11:44	6820	1.53	0.644	11.0	7.40	11.6	10.6	8.22	<0.033	118	3	3	7	5	6	4	3	4	5	5	4.5	4	4.6
3	CHJFF-S3-T1	11/3/11 13:57	4902	0.717	0.657	9.04	5.91	5.59	7.59	7.02	<0.028	86.8	6	7	6	8	9	10	6	5	5	9	7.1	7	2.0
4	CHJFF-S3-T2	11/3/11 14:55	4774	1.36	0.663	11.5	10.2	10.6	7.37	6.13	<0.028	114	7	4	5	3	5	6	7	8	5	6	5.6	6	3.5
5	CHJFF-S4-T1	11/2/11 13:22	3133	0.664	0.282	7.38	6.53	6.89	5.01	4.92	0.048	64.8	11	9	11	10	7	9	11	9	3	11	9.1	11	0.0
6	CHJFF-S4-T2	11/2/11 15:00	4275	0.621	0.397	9.71	5.45	4.97	7.10	6.86	<0.025	77.3	8	10	9	6	10	11	8	7	5	10	8.4	8	0.7
7	CHJFF-S4-T3	11/3/11 12:07	3418	0.669	0.370	7.60	11.7	8.33	5.75	4.52	<0.025	88.0	10	11	10	9	4	8	9	10	5	8	8.4	8	0.7
8	CHJFF-S4-T4	11/3/11 12:43	3570	0.611	0.522	6.15	4.99	8.48	5.71	4.34	<0.026	102	9	8	8	11	11	7	10	11	5	7	8.7	10	0.4
9	CHJMID-S5-T1	11/3/11 16:00	6030	0.919	1.16	9.68	6.28	11.4	10.0	7.01	<0.030	166	5	6	3	7	8	5	5	6	5	4	5.4	5	3.7
10	CHJFB-S7-T1	11/1/11 14:46	12735	2.86	2.98	17.8	23.6	51.8	16.2	14.3	0.169	305	2	1	2	1	2	1	2	1	1	1	1.4	1	7.7
11	CHJFB-S7-T2	11/1/11 15:30	12866	2.89	3.00	17.8	23.7	50.3	17.2	14.2	0.135	283	1	2	1	2	1	2	1	2	2	2	1.6	2	7.5

Notes:

[1]Overall rank represents the rank of the mean of ranks. Lower rank numbers represent higher concentrations.

[2]Rank index calculated as: Highest mean rank - mean ranks for different sites. This ranking results in the site with the highest concentrations having the highest rank index value.

[3]Abbreviations: Al-Aluminum, As-Arsenic, Cd-Cadmium, Cr-Chromium, Pb-Lead, Li-Lithium, Ni-Nickel, Hg-Mercury, Zn-Zinc.

3.1.4 Organic Contaminants

Rufus Woods Lake sediments collected in 2011 were analyzed for several organic contaminants including organochlorine pesticides, PCBs, and PBDEs. Sediments were analyzed for both currently used organochlorine pesticides and “legacy” organochlorine pesticides such as DDTs (DDT, DDD, or DDE), that were largely banned in the early 1970s but are still found in the environment (USGS 1996). PCBs analyzed included the most common Aroclors. Aroclors are commercial mixtures of PCBs that were developed for their thermal stability and banned in the 1970s due to toxicity concerns (EPA 2012b). PBDEs are flame retardants that are present in many products and are being found in the environment (EPA 2012c). Organic contaminants were only measured at Sites 1, 2, 9, and 10. Concentrations of all organic contaminants at these four stations sampled in Lake Rufus Woods were less than the detection limits shown in Table 3-5.

Organic contaminant concentrations in Lake Rufus Woods were compared to concentrations measured about 190 to 480 kilometers downstream in the middle Columbia River from Vantage, Washington, to the McNary Dam forebay (EPA 2008). It should be noted that the detection limits for the EPA (2008b) study were generally lower, with PCBs 10 times lower (2 µg/kg), organochlorine pesticides from 5 to 10 times lower (0.1 µg/kg), and PBDEs similar (0.5 µg/kg). The EPA (2008b) study detected DDTs in 29 of 44 sediment samples; however, only 4 of 44 samples measured DDTs at concentrations greater than the Rufus Woods Lake 2011 detection limit of about 1.0 µg/kg. Other organochlorine pesticides were detected in only 4 of 44 samples collected, all at concentrations lower than the Rufus Woods Lake 2011 detection limits. Total PBDEs were detected in 60 percent of the sediment samples from the EPA middle Columbia River study (EPA 2008b) at concentrations greater than the Rufus Woods Lake 2011 detection limits. Similar to Rufus Woods Lake, no PCB Aroclors were detected in any sample collected in the middle Columbia River at detection limits less than Rufus Woods Lake. The lack of organochlorine pesticides, PCBs, or PBDEs in Rufus Woods Lake samples collected in 2011 may indicate that there are few sources of these contaminants to the lake. However, as previously noted, the sampling was limited (only four samples) and detection limits were higher than downstream studies (EPA 2008b). Therefore, further sampling is needed at lower detection limits in Rufus Woods Lake before any direct comparison can be made to the Lower Columbia River study (EPA 2008b). In addition, there is no fish tissue data in this reach to determine if organochlorine pesticides, PCBs, or PBDEs may be a concern in Rufus Woods Lake.

Table 3-5. Sediment Organics Data Collected in Lake Rufus Woods, Chief Joseph Dam during 2011

Compound	CHJFB-S7-T1 (ug/kg)	Q	CHJMID-S5-T1 (ug/kg)	Q	CHJNSP-S2-T1 (ug/kg)	Q	CHJUP-S1-T1 (ug/kg)	Q
Polychlorinated Biphenyls (PCB)								
Aroclor 1016	< 19	U	< 20	U	< 20	U	< 19	U
Aroclor 1242	< 19	U	< 20	U	< 20	U	< 19	U
Aroclor 1248	< 19	U	< 20	U	< 20	U	< 19	U
Aroclor 1254	< 19	U	< 20	U	< 20	U	< 19	U
Aroclor 1260	< 19	U	< 20	U	< 20	U	< 19	U
Aroclor 1221	< 19	U	< 20	U	< 20	U	< 19	U
Aroclor 1232	< 19	U	< 20	U	< 20	U	< 19	U
Aroclor 1262	< 19	U	< 20	U	< 20	U	< 19	U
Aroclor 1268	< 19	U	< 20	U	< 20	U	< 19	U
Polybrominated Diphenyl Ethers (PBDE)								
PBDE-17	< 0.5	U	< 0.5	U	< 0.5	U	< 0.5	U
PBDE-28	< 0.5	U	< 0.5	U	< 0.5	U	< 0.5	U
PBDE-47	< 0.5	U	< 0.5	U	< 0.5	U	< 0.5	U
PBDE-66	< 0.5	U	< 0.5	U	< 0.5	U	< 0.5	U
PBDE-71	< 0.5	U	< 0.5	U	< 0.5	U	< 0.5	U
PBDE-85	< 0.5	U	< 0.5	U	< 0.5	U	< 0.5	U
PBDE-99	< 0.5	U	< 0.5	U	< 0.5	U	< 0.5	U
PBDE-100	< 0.5	U	< 0.5	U	< 0.5	U	< 0.5	U
PBDE-138	< 0.5	U	< 0.5	U	< 0.5	U	< 0.5	U
PBDE-153	< 0.5	U	< 0.5	U	< 0.5	U	< 0.5	U
PBDE-154	< 0.5	U	< 0.5	U	< 0.5	U	< 0.5	U
PBDE-183	< 0.5	U	< 0.5	U	< 0.5	U	< 0.5	U
Organochlorine Pesticides								
alpha-BHC	< 1	Y	< 0.49	U	< 0.5	U	< 0.48	U
beta-BHC	< 0.48	U	< 0.49	U	< 0.5	U	< 0.48	U
delta-BHC	< 0.48	U	< 0.49	U	< 0.5	U	< 0.48	U
gamma-BHC (Lindane)	< 0.48	U	< 0.49	U	< 0.5	U	< 0.48	U
Heptachlor	< 0.48	U	< 0.49	U	< 0.5	U	< 0.48	U
Aldrin	< 0.48	U	< 0.49	U	< 0.5	U	< 0.48	U
Heptachlor Epoxide	< 0.97	U	< 0.98	U	< 0.99	U	< 0.96	U
Endosulfan I	< 0.48	U	< 0.49	U	< 0.5	U	< 0.48	U
Dieldrin	< 0.97	U	< 0.98	U	< 0.99	U	< 0.96	U
4,4'-DDE	< 0.97	U	< 0.98	U	< 0.99	U	< 0.96	U
Endrin	< 0.97	U	< 0.98	U	< 0.99	U	< 0.96	U
Endosulfan II	< 0.97	U	< 0.98	U	< 0.99	U	< 0.96	U
4,4'-DDD	< 0.97	U	< 0.98	U	< 0.99	U	< 0.96	U
Endosulfan Sulfate	< 0.97	U	< 0.98	U	< 0.99	U	< 0.96	U
4,4'-DDT	< 0.97	U	< 0.98	U	< 0.99	U	< 0.96	U
Methoxychlor	< 4.8	U	< 4.9	U	< 5	U	< 4.8	U
Endrin Ketone	< 0.97	U	< 0.98	U	< 0.99	U	< 0.96	U
Endrin Aldehyde	< 0.97	U	< 0.98	U	< 0.99	U	< 0.96	U
trans-Chlordane	< 0.48	U	< 0.49	U	< 0.5	U	< 0.48	U
cis-Chlordane	< 0.48	U	< 0.49	U	< 0.5	U	< 0.48	U
Toxaphene	< 97	U	< 98	U	< 99	U	< 96	U
Hexachlorobenzene	< 0.48	U	< 0.49	U	< 0.5	U	< 0.48	U
Hexachlorobutadiene	< 0.48	U	< 0.49	U	< 0.5	U	< 0.48	U

Notes:

U Undetected at reported detection limit

Y Undetected at the reported detection limit. Detection limit raised due to chromatographic interference

3.2 DATA ANALYSIS

Metals and nutrient data were further analyzed using statistical methods to determine what, if any, relationships exist among the data, and to better understand spatial patterns of contaminants in Rufus Woods Lake.

3.2.1 Correlations

Numerous measurements in Rufus Woods Lake appeared to be related to each other. A correlation matrix was constructed to better identify relationships between metals, nutrients, TOC, and grain size (Table 3-6). A Pearson-R correlation coefficient was used to determine relationships, with R values approaching positive 1 representing strong positive relationships, and R values approaching negative 1 representing strong negative relationships. Strong relationships existed between all metals with the majority being moderately to strongly correlated with the silt/clay percentage (positive correlation) and sand percentage (negative correlation), suggesting that the metals were associated with the finer particle size fractions. Spatial patterns of metals were consistent with these correlations, with the highest metals concentrations associated with higher percentages of silt/clay (see Figure 3-4).

Limited correlations existed for nutrients and all other parameters. Although total Kjeldahl nitrogen had a strong positive correlation to silt/clay percentage and several metals, total phosphorus and ammonia showed very few correlations. The lack of correlation for ammonia and total phosphorus with other parameters possibly suggests that another source of these nutrients, such as the aquaculture sites, exists in Rufus Woods Lake.

Table 3-6. Correlations Between Parameters in the 2011 Sediments from Rufus Woods Lake (Pearson coefficient n=11)

	Al	As	Cd	Cr	Cu	Pb	Li	Hg	Ni	Zn	TP	TKN	NH3	Percent Solids	TOC	Percent Gravel	Percent Sand	Percent Clay/Silt
Aluminum (Al)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Arsenic (As)	**0.97**	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cadmium (Cd)	**0.97**	**0.94**	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Chromium (Cr)	**0.96**	**0.97**	**0.93**	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Copper (Cu)	**0.88**	**0.91**	**0.89**	**0.89**	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lead (Pb)	**0.96**	**0.96**	**0.98**	**0.93**	**0.95**	—	—	—	—	—	—	—	—	—	—	—	—	—
Lithium (Li)	**0.99**	**0.95**	**0.95**	**0.95**	**0.85**	**0.93**	—	—	—	—	—	—	—	—	—	—	—	—
Mercury (Hg)	**0.90**	**0.89**	**0.93**	**0.86**	**0.89**	**0.96**	**0.83**	—	—	—	—	—	—	—	—	—	—	—
Nickel (Ni)	**0.99**	**0.95**	**0.95**	**0.97**	**0.87**	**0.94**	**0.98**	**0.89**	—	—	—	—	—	—	—	—	—	—
Zinc (Zn)	**0.94**	**0.91**	**0.95**	**0.90**	**0.91**	**0.95**	**0.95**	**0.86**	**0.92**	—	—	—	—	—	—	—	—	—
Total Phosphorus (TP)	0.34	0.38	0.42	0.25	0.56	0.49	0.28	0.54	0.27	0.35	—	—	—	—	—	—	—	—
Total Kjeldahl Nitrogen (TKN)	**0.96**	**0.97**	**0.97**	**0.94**	**0.91**	**0.97**	**0.91**	**0.95**	**0.93**	**0.91**	0.51	—	—	—	—	—	—	—
Ammonia (NH3)	-0.74	-0.69	-0.64	-0.70	-0.48	-0.63	-0.73	-0.61	**-0.78**	-0.57	0.08	-0.62	—	—	—	—	—	—
Percent Solids	**-0.97**	**-0.97**	**-0.94**	**-0.95**	**-0.80**	**-0.92**	**-0.96**	**-0.86**	**-0.95**	**-0.90**	-0.24	**-0.94**	0.75	—	—	—	—	—
Total Organic Carbon (TOC)	0.50	0.61	0.41	0.47	0.34	0.44	0.48	0.37	0.43	0.37	0.12	0.51	-0.53	-0.63	—	—	—	—
Percent Gravel	-0.40	-0.29	-0.35	-0.31	-0.05	-0.29	-0.43	-0.30	-0.44	-0.37	0.42	-0.23	0.65	0.46	-0.20	—	—	—
Percent Sand	**-0.87**	**-0.88**	**-0.86**	**-0.82**	**-0.82**	**-0.85**	**-0.84**	**-0.79**	**-0.81**	**-0.79**	-0.63	**-0.91**	0.48	**0.84**	-0.56	0.01	—	—
Percent Clay/Silt	**0.95**	**0.92**	**0.92**	**0.88**	0.77	**0.90**	**0.94**	**0.84**	**0.91**	**0.87**	0.41	**0.93**	-0.69	**-0.96**	0.59	-0.41	**-0.92**	—
Mean Particle Size	-0.54	-0.42	-0.48	-0.43	-0.18	-0.42	-0.57	-0.39	-0.56	-0.50	0.33	-0.35	0.72	0.58	-0.28	**0.98**	0.17	-0.55

Notes:

0.92 = Number is significant at $p<0.05$ (Bonferroni Corrected)

3.3 LONGITUDINAL AND SPATIAL DISTRIBUTIONS

3.3.1 Metals

In general, metals showed a consistent pattern of having moderate concentrations in the upper part of Rufus Woods Lake upstream of the aquaculture facilities (Sites 1 and 2), low concentrations in areas immediately downstream of aquaculture facilities (Sites 3-8), and high concentrations in the middle and lower part of Rufus Woods Lake (Sites 9-11) (See Figure 3-3). Arsenic, cadmium, lead, nickel, and zinc concentrations showed the strongest longitudinal trend of being moderately high at Sites 1 and 2 below Grand Coulee Dam, decreasing in concentration downstream at Sites 3 through 8 below the aquaculture facilities, and then increasing in concentration further downstream at Sites 9, 10, and 11 near Chief Joseph Dam. Concentrations of chromium, copper, and mercury showed little spatial pattern and no obvious trends in Rufus Woods Lake. This data suggests that aquaculture facilities are not a source of metals to the sediments. Rather, sediment metal concentrations in Rufus Woods Lake appear to be influenced by historical sources upstream of Grand Coulee Dam.

3.3.2 Nutrients and Total Organic Carbon

Little longitudinal or spatial patterns were observed for nutrients and TOC, with the possible exception of ammonia and total Kjeldahl nitrogen (See Figure 3-1). Ammonia concentrations were greatest downstream of the aquaculture facilities (Sites 3 through 8) and at the mid-reservoir station (Site 9). Lower concentrations of ammonia were measured both upstream of the aquaculture facilities (Sites 1 and 2) and farther downstream at the Chief Joseph Dam forebay (Sites 10 and 11). For total Kjeldahl nitrogen, a pattern similar to that seen for metals was observed with moderate concentrations in the upper part of Rufus Woods Lake upstream of the aquaculture facilities (Sites 1 and 2), low concentrations in areas immediately downstream of aquaculture facilities (Sites 3 through 8), and high concentrations in the middle and lower part of Rufus Woods Lake (Sites 9 through 11). TOC and total phosphorus showed no obvious trends. This data suggests that the aquaculture facilities may be a source of ammonia to the sediments.

3.3.3 Organics

Concentrations of organic contaminants were below detection limits at all sites sampled (Sites 1, 2, 9, and 11). These sites represent a large area of Rufus Woods Lake from downstream of Grand Coulee Dam (Site 1), the mouth of the Nespelum River (Site 2), mid-reservoir (Site 9), and the Chief Joseph Dam forebay (Site 10). Sites located immediately downstream of the aquaculture facilities were not analyzed for organic contaminants due to the limited amount of sediment collected at these locations.

SECTION 4 - CONCLUSIONS AND RECOMMENDATIONS

A moderate amount of sediment data exists in Lake Roosevelt upstream of Grand Coulee Dam, while only limited sediment data exists in Rufus Woods Lake upstream of Chief Joseph Dam. For Rufus Woods Lake, the Corps conducted two separate sediment quality studies in 2004 and 2011. Sediment quality data has been collected numerous times upstream of Grand Coulee Dam in Lake Roosevelt by Ecology and the USGS.

4.1 RUFUS WOODS LAKE

Sediment data collected by the Corps in 2004 and 2011 yielded the following conclusions:

The forebay stations (Sites 10 and 11) had the highest concentration of all metals with moderate metals concentrations at the mid-reservoir station (Site 9) and up-reservoir stations (Sites 1 and 2), and lowest metal concentrations at stations located downstream of the aquaculture facilities (Sites 3 through 8).

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

Sediment metal concentrations in Rufus Woods Lake were similar to metal concentrations collected in the middle Columbia River between Vantage, Washington, and the McNary Dam forebay. The exceptions were for zinc, lead, mercury, and cadmium, which were 2 to 5 times greater in Rufus Woods Lake at the Chief Joseph Dam forebay location (Sites 10 and 11).

Concentrations of all organic contaminants at stations in Lake Rufus Woods were less than the detection limits.

The majority of metals were correlated with the silt/clay percentage, suggesting that metals in Rufus Woods Lake were associated with the finer particle size fractions. Limited correlations existed for nutrients and all other parameters. The lack of correlation for ammonia and total phosphorus with most other parameters suggest that another source, such as the aquaculture sites, exists in Rufus Woods Lake.

In general, metals showed a consistent pattern of having moderate concentrations in the upper part of Rufus Woods Lake upstream of the aquaculture facilities, lower concentrations in areas immediately downstream of aquaculture facilities, and higher concentrations in the middle and lower parts of Rufus Woods Lake. This data suggests that the fish farms were not a new source of metals to Rufus Woods Lake.

Little longitudinal or spatial patterns were observed for nutrients and TOC, with the possible exception of ammonia and total Kjeldahl nitrogen. Ammonia concentrations were greatest downstream of the aquaculture facilities and at the mid-reservoir station, suggesting that the aquaculture facilities may be a source of ammonia to the sediments.

Elevated total phosphorus concentrations were measured downstream of the aquaculture facilities in sediments containing very little silt/clay fractions. Phosphorus chemistry suggests that sediment concentrations should be somewhat correlated to particle size. Consequently, the aquaculture facilities may be a source of phosphorus to these silt/clay starved sediments.

4.2 RECOMMENDATIONS

A more detailed sediment sampling program should be conducted in Rufus Woods Lake immediately downstream of Grand Coulee Dam focusing on backwater areas that may collect sediments. Additional sediment data collected in the upstream reaches of Rufus Woods Lake would allow for a better assessment of possible source(s) of nutrients, metals, and organics to the sediments. Also, additional sediment sampling downstream of aquaculture sites should be conducted in an attempt to collect samples with greater silt/clay fractions that are more representative of the Rufus Wood Lake system. Detection limits for organic contaminants at all sites should be lowered to achieve more meaningful data.

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