PNNL-13417

Simultaneously Extracted Metals/ Acid-Volatile Sulfide and Total Metals in Surface Sediment from the Hanford Reach of the Columbia River and the Lower Snake River

G. W. Patton
E.A. Crecelius

January 2001

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RL01830

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Summary

Metals have been identified as contaminants of concern for the Hanford Reach because of upriver mining, industrial activities, and past nuclear material production at the U.S. Department of Energy's Hanford Site (DOE 1998; Johnson 1999). This study was undertaken to better understand the occurrence and fate of metals in sediment disposition areas in the Columbia and Snake Rivers. Samples of surface sediment were collected in 1997, 1998, and 1999, along the Hanford Reach of the Columbia River, behind upriver (Priest Rapids) and downriver (McNary) dams on the Columbia River and behind Ice Harbor Dam on the Snake River. Samples were analyzed for simultaneously extracted metals/acid-volatile sulfide (SEM/AVS), total metals, total organic carbon, and particle grain size.

The SEM/AVS molar ratios are an indicator of the amount of metals present in the sediment pore-water. When SEM/AVS ratios are <1 the concentrations of metals in the sediment porewater are generally below toxic levels because of the low solubility of the metal sulfides. The AVS values ranged from 0.075 to 21 μmol/g for Columbia River sediment samples and from 0.033 to 2.4 μmol/g for Snake River sediment samples. Sediment samples from Priest Rapids Dam reservoir and the Hanford Reach have higher concentrations of AVS than sediment samples from McNary Dam and Ice Harbor Dam. An apportionment of AVS by divalent metals according to solubility product constant (K_{sp}) values revealed that sufficient AVS should exist in all locations to limit the porewater concentrations of cadmium, copper, lead, and mercury. In sediment samples from Priest Rapids Dam, the Hanford Reach, and Ice Harbor Dam, zinc values were of similar magnitude as the AVS concentrations. In sediment samples from McNary Dam, the zinc concentrations were higher than the AVS concentrations, indicating the potential for zinc and other metals to be available for biotic uptake in the sediment porewater.

The results for total metals revealed higher concentrations of cadmium, thallium, and zinc in Columbia River sediment compared to Snake River sediment. The size-fractionated samples revealed that the total amount of metal present in the bulk sediment was more influenced by the weight percentage of each size fraction than by concentration differences between size fractions.

The level of total organic carbon ranged from 0.29% to 4.3% for the Columbia River and Snake River samples. In both rivers, total organic carbon levels were similar for locations near the dams where the sediment was mostly composed of silt and clay.

A comparison of total metals results to selected sediment criteria levels indicated that cadmium, nickel, and zinc in Columbia River sediment were near or above some probable effect levels for toxicity. However, the Snake River sediment results were below the probable effect levels for all metals.

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1.0 Introduction

The Hanford Reach of the Columbia River (in the state of Washington) is the last free-flowing portion of the Columbia River above Bonneville Dam in the United States. This section of the river provides important spawning habitat for chinook salmon (*Oncorhynchus tshawystcha*) and many other species. In addition, this portion of the Columbia River has recently been established as a United States national monument (65 FR 114). Metals, organic pollutants, and radionuclides have been identified as potential contaminants of concern for the Hanford Reach. Upriver mining, industrial activities, and past nuclear materials production at the U.S. Department of Energy's Hanford Site have contributed contaminants to the river (DOE 1998; Johnson 1999). In the summers of 1997 through 1999, upper layer sediment samples were collected along the Hanford Reach of the Columbia River and from the slack water reservoirs created by Priest Rapids Dam upriver from Hanford (completed in 1959) and McNary Dam downriver from Hanford (completed in 1953) (Figure 1). In 1998 and 1999, sediment samples were also collected from behind Ice Harbor Dam (completed 1961) the first dam on the Snake River above its confluence with the Columbia River (see Figure 1). Sediment samples were analyzed for simultaneously extracted metals/acid-volatile sulfide (SEM/AVS), total metals, total organic carbon, and particle grain size.

There is an ongoing debate in the scientific literature on how to evaluate the potential for sediment contaminated with metals to cause injury to aquatic organisms. Because of variations in the bioavailability of contaminants in sediment, no Washington State or federal freshwater sediment criteria are available to assess the sediment quality of the Columbia and Snake Rivers (EPA 1996).

One school of thought is that bioavailability (i.e., uptake by organisms and subsequent toxicity) is controlled primarily by the dissolved metal concentration in the sediment porewater. Proponents of this theory contend that using SEM/AVS molar ratios to estimate sediment porewater concentrations for cadmium, copper, mercury, nickel, lead, and zinc (generally present as divalent species) provides a better indicator of sediment toxicity than total metals concentrations on a dry weight basis (DeWitt et al. 1996; Hansen et al. 1996). AVS is usually the dominant-binding phase for divalent metals in sediment. Metal sulfide precipitates are typically very insoluble and this limits the amount of dissolved metal available in the sediment porewater. For an individual metal, when the amount of AVS exceeds the amount of the SEM metal (i.e., the SEM/AVS molar ratio is below 1), the metal concentration in the sediment porewater will be low because of the limited solubility of the metal sulfide. For a suite of divalent metals, the sum of the SEM metals must be considered, with the assumption that the metal with the lowest K_{sp} value (least soluble) will form the most stable complex with the AVS (i.e., the lowest K_{sp} metal will "outcompete" the other metals and bind with the AVS).

The other school of thought uses an empirical approach that matches trace metal sediment chemistry to biological effect data to determine toxic effect levels (Persaud et al. 1992; WAC-173-204; Long 1995 et al.; Ingersoll et al. 1996; MacDonald et al. 1996). Dietary factors (i.e., sediment ingestion) are an important pathway of biotic uptake for the empirical approach (Lee et al. 2000). Recent articles have reported that although metal concentration in sediment porewater may be controlled by geochemical equilibration with metal sulfides, metal exposure and subsequent toxicity is most likely influenced by sediment ingestion (Long et al. 1998; Lee et al. 2000).

This paper describes sediment concentrations of total metals, SEM/AVS, total organic carbon, and particle size for upper layer sediment collected from the Columbia River for 1997 through 1999 and the Snake River for 1998 and 1999. The data will be used to evaluate the ecological risk to aquatic organisms using both the geochemical equilibration (i.e., SEM/AVS) and dietary uptake (total metals) methods.

2.0 Sample Collection and Analysis

Single samples of surface sediment from locations on the Columbia and Snake Rivers (0 to 15 cm depth) were collected using a Ponar dredge with a 235-cm^2 opening (see Figure 1 for locations). After triggering and retrieving the dredge, the sediment was rapidly placed into glass jars and sealed with Teflon caps with no airspace above the sediment. The sample jars were placed into an ice-filled cooler for transport to the laboratory. One sediment sample was collected at four Hanford Reach locations where sediment occurs. For each of the reservoirs, samples were collected at three to six locations. Samples were collected in August after the spring freshets.

Sample collection sites were located approximately 4 km above Priest Rapids Dam and approximately 3 km above McNary Dam. The collection sites consisted of four stations spaced on a transect line across the Columbia River, with two additional sampling locations at the boat exclusion booms near the dams. Sediment samples in the Hanford Reach were collected in sloughs at the old White Bluffs Ferry Landing, at the Old Hanford Townsite, at the F Reactor, and at a shoreline (non-slough) near the Richland, Washington, municipal water supply pumphouse. Snake River sediment was collected at three locations on a transect approximately 5 km above Ice Harbor Dam. Approximate water depths ranged from 4 to 25 m at Priest Rapids Dam, 1 to 2 m at the Hanford Reach, 7 to 25 m at McNary Dam, and 9 to 26 m at Ice Harbor Dam.

Sediment samples for SEM/AVS analysis were placed as collected into a cold hydrochloric acid solution. The evolved hydrogen sulfide (H_2S) gas from the sediment and acid mixture was captured and analyzed with a gas chromatograph using a photoionization detector, this procedure determines the AVS amount (Allen et al. 1991). The cold hydrochloric acid extracts from the samples were analyzed using inductively coupled plasma mass spectrometry (ICP-MS) for cadmium, copper, lead, nickel and zinc using EPA Method 200.8 (EPA 1991) and using cold vapor atomic absorption spectroscopy (CVAA) for mercury (Bloom and Crecelius 1983), this procedure determines the SEM amount.

Sediment samples for total metals analysis were digested using a total digestion technique based on EPA Method 200.4 (EPA 1991) that uses a combination of nitric, perchloric, and hydrofluoric acids to digest the sediment in a sealed Teflon® container. The extracts were analyzed using the same methods as note above for the SEM extracts. In addition to the six metal suite analyzed for SEM/AVS sample, the total metals samples were also analyzed for antimony, arsenic, beryllium, chromium, selenium, and thallium using the ICP-MS method described above. The total metal samples were also analyzed for silver using graphite furnace atomic absorption spectroscopy using EPA Method 200.9 (EPA 1991).

Quality control for both SEM/AVS and totals metals samples included replicate analysis, blanks, matrix spike recovery, blank spike recovery, and comparison to standard reference materials. Standard reference materials used were a freshwater sediment standard from National Institute of Standards and Technology (SRM 2704) and a National Research Council of Canada marine estuarine sediment standard (MESS 2).

Sediment samples were shipped to Quanterra Environmental Services, St. Louis for total organic carbon analysis using EPA Method 9060 (EPA 1986). The 1998 sediment samples were shipped to Soil Technologies, Bainbridge Island, Washington, where they were wet-sieved into 5 grain sizes using non-metal sieves. The size fractions are coarse sand (0.5 to 1.0 mm), medium sand (0.25 to 0.5 mm), fine sand (0.125 to 0.25 mm), very fine sand (0.0625 to 0.125 mm), and silt and clay (<0.004 to 0.0625 mm).

3.0 Results and Discussion

The results from the sediment sampling effort on the Columbia and Snake Rivers and a discussion of the findings are presented in Section 3.0. This section provides information on SEM/AVS, total metals, total organic carbon, sediment grain size relationships, results for quality control samples and statistical correlations between analytes. A comparison of the measured concentrations in Columbia and Snake River sediment to comparative sediment quality guidelines is also provided.

For this report, the concentrations of metals and sulfide in sediment are given in units of μmol analyte/g sediment. The molar-based units are required to allow for easy comparison between the pool of available sulfide (acid-volatile sulfide) to the pool of divalent metals (simultaneously extracted metals). Conversion to the more typically reported μg/g is made using Equation (1).

$$\frac{\mu\text{mol analyte}}{\text{g sediment}} \times \frac{\mu\text{g analyte}}{\mu\text{mol analyte}} = \frac{\mu\text{g analyte}}{\text{g sediment}} \qquad (1)$$

or

$$\mu\text{mol/g x molecular weight} = \mu\text{g/g}$$

(Note: molecular weight = g/mol = μg/μmol.)

For example, mercury has a molecular weight of 200.6. A mercury result of 0.0023 μmol Hg/g sediment can be converted to a gravimetric form by multiplying by 200.6 μg/μmol to obtain 0.46 μg Hg/g sediment.

3.1 Simultaneously Extracted Metals/Acid-Volatile Sulfide

The SEM/AVS results for the 1997 through 1999 sediment samples are given in Tables 1a, 2a, and 3a and average values are shown in Figures 2 and 3. Quality control sample results are presented in Table A.1.

3.1.1 SEM/AVS Quality Control Samples

The SEM/AVS samples had low blanks and detection limits compared to the environmental concentrations determined (Table A.1). Replicate samples results were less than 25% relative percent difference for all metals, except for mercury that had relative percent differences ranging from 17% to -33%. Mercury was near the detection limit for most samples and relative percent differences between replicate samples typically increase near the detection limit. No standard reference material was available for acid-volatile sulfide. Matrix spike and blank spike samples had excellent recoveries with values ranging from 89% to 117%. No corrections were made to the sample results because of the low blanks values and good analytical recoveries reported for the quality control samples.

3.1.2 SEM/AVS Sediment Sample Results

For 1997 samples, the AVS results were similar for sediment from the Priest Rapids Dam reservoir and the Hanford Reach with concentrations ranging from 1.2 to 21 µmol/g (see Figure 2). Sediment from the McNary Dam reservoir had lower concentrations of AVS with levels ranging from 0.075 to 2.6 µmol/g (see Figure 2). When comparing the pool of SEM metals to the AVS pool (i.e., SEM/AVS molar ratio), both the Priest Rapid Dam and Hanford Reach sediment should have sufficient sulfide to limit the interstitial porewater concentrations of the divalent metals tested (see Figure 3). However, sediment samples from McNary Dam had more divalent metal (primarily zinc) available than the sulfide (see Figure 3). Zinc had the highest metal concentration for all locations.

The SEM/AVS results for the 1998 samples were similar to 1997 samples (see Figure 2) except for the average AVS concentration for Priest Rapid Dam sediment, which had decreased by a factor of two. For 1998, the average AVS values were similar for sediment from the Priest Rapid Dam reservoir and the Hanford Reach. Individual concentrations ranged from 0.32 to 15 µmol/g. Sediment from the McNary Dam reservoir and the Ice Harbor Dam reservoir (Snake River) had lower concentrations of AVS with individual values ranging from 0.033 to 2.4 µmol/g. For 1998, the SEM/AVS molar ratios were close to unity for sediment samples from Priest Rapids Dam and the Hanford Reach, with zinc as the dominant metal (see Figure 3). For 1998, the SEM/AVS molar ratios for sediment from McNary Dam were above one, with zinc as the primary metal present (see Figure 3). Ice Harbor Dam sediment had similar concentrations of AVS as McNary Dam; however, the zinc concentrations for Ice Harbor Dam were an order of magnitude below the Columbia River sediment.

The SEM/AVS results for the 1999 samples were similar to 1998 (see Figure 2). For 1999, the average acid-volatile sulfide values were similar for sediment samples from the Priest Rapid Dam reservoir and the Hanford Reach, with individual concentrations ranging from 0.33 to 14 µmol/g. Sediment samples from the McNary Dam reservoir and the Ice Harbor Dam reservoir (Snake River) had lower average concentrations of acid-volatile sulfide, with individual values ranging from 0.081 to 3.2 µmol/g. For 1999, the SEM/AVS molar ratios were close to one in sediment samples from Priest Rapids Dam and above one for Hanford Reach samples, with zinc as the dominant metal (see Figure 3). For 1999, the SEM/AVS molar ratios for sediment from McNary Dam were above one, indicating a potential for some metals to be present in the sediment porewater, with zinc as the primary metal present (see Figure 3). Ice Harbor Dam sediment had similar average concentrations of acid-volatile sulfide as McNary Dam; however, the average zinc concentrations in sediment samples from Ice Harbor Dam were one-fifth the average concentration in Columbia River sediment samples (see Figure 3).

These results reveal an apparent difference in the acid-volatile sulfide concentrations in sediment from Priest Rapids Dam reservoir and the Hanford Reach, which have higher concentrations than McNary Dam and Ice Harbor Dam sediment. An apportionment of acid-volatile sulfide by divalent metals according to solubility values (Table 4) revealed that sufficient acid-volatile sulfide should exist in all locations to limit the porewater concentrations of cadmium, copper, lead, and mercury. In sediment samples from Priest Rapids Dam, the Hanford Reach, and Ice Harbor Dam, zinc values were of similar magnitude as the acid-volatile sulfide concentrations. In McNary Dam sediment samples, the zinc concentrations were higher than the available acid-volatile sulfide pool, indicating the potential for zinc and other metals to be available in the sediment porewater.

3.2 Total Metal Concentrations

The total metals results for the 1997 to 1999 sediment samples are given in Tables 1b, 2b, and 3b. The 1998 sediment results were only reported for size fractionated samples, and the values reported in Table 2b were calculated as weighted mean concentration using the metal concentration reported for each fraction. Average total metals concentrations are shown in Figure 4. Quality control results total metal sample are given in Table A.2.

3.2.1 Quality Control Sample Results for Total Metals

The total metals samples had low blanks and detection limits compared to the environmental concentrations determined. Replicate samples results were less than 25% relative percent difference for all metals, with the following exceptions:

- 1997 - Beryllium, cadmium, chromium, nickel and thallium were between 26% and 32% relative percent difference.
- 1997 - Selenium was 68% relative percent difference; however, the result was near the detection limit.
- 1998 - Silver was 26% and mercury was 79%; however, both metals were present at low concentrations.

The NIST standard reference material (SRM 2704) sample results agreed well with the certified values, with relative percent difference ranging from 0% to 20%. The National Research Council Canada standard reference material (MESS 2) sample results had reasonable agreement (<26% relativity percent difference) with the certified values for silver, arsenic, chromium, copper, nickel, thallium, and zinc. However, for the MESS 2 standard reference material the maximum relative percent differences for antimony, beryllium, cadmium, mercury, lead, and selenium ranged from 38% to 97%, with 1998 results for beryllium (66%), cadmium (61%), and lead (97%) being particularly high. Matrix spike and blank spike samples had analytical recoveries ranging from 60% to 140%, with the following exceptions: (1998; copper [47%], nickel [58%], and lead [53%]) (1999; chromium [52%] and zinc [193%]). The average zinc analytical recovery for multiple years was 116%. No corrections were made to the sample results because of the low blanks values and reasonable analytical recoveries reported for the quality control samples.

3.2.2 Total Metals Results for Sediment Samples

For the 1997 through 1999 sediment samples, there was little temporal variation for all metals (see Figure 4). However, there were large differences between locations for cadmium and zinc. Both cadmium and zinc showed higher average concentrations at Columbia River sites compared to Ice Harbor Dam (Snake River). The average concentration of cadmium in sediment collected at Priest Rapids Dam was approximately three times the average levels measured at McNary Dam and more than thirty times the levels measured at Ice Harbor Dam. Average zinc concentrations measured at Priest Rapids Dam were about twice a high as those from McNary Dam and were more than four times the levels measured at Ice Harbor Dam.

Mean lead concentrations were elevated at Priest Rapids Dam and the Hanford Reach compared to sediment from both McNary Dam and Ice Harbor Dam (see Figure 4). The average concentration of lead in sediment at Priest Rapid Dam was 2 to 3 times higher than sediment from Ice Harbor Dam. Average thallium concentrations were elevated for Columbia River sediment compared to Snake River sediment. Mean thallium concentrations for Priest Rapids Dam sediment were roughly three times higher that Ice Harbor Dam sediment.

Average silver concentrations were similar for Priest Rapids Dam and McNary Dam sediments; however, Ice Harbor Dam sediments were approximately one-third lower (see Figure 4). Silver concentrations in 1999 Hanford Reach sediment samples were elevated compared to 1997 and 1998 samples collected at the same locations, with both 100-F slough and Old Hanford Townsite sloughs showing elevated values.

Mean antimony, arsenic, beryllium, chromium, copper, nickel, and selenium concentrations were similar (within a factor of two) at all locations for all years (see Figure 4). Mercury was <0.002 μmol/g for all samples, with sediment samples from Priest Rapids Dam and McNary Dam having slightly elevated average values compared to sediment samples from the Hanford Reach and Ice Harbor Dam.

3.3 Statistical Correlations for Total Organic Carbon, AVS, and Total Metals

Statistical analyses were conducted on the results for total organic carbon and total metals presented in Tables 1 to 3 to provide correlation coefficients (r) between analytes (p-values <0.05 were judged to be significant). Correlation coefficients for sediment samples from Priest Rapids Dam, Hanford Reach, McNary Dam, and Ice Harbor Dam (Snake River) are given in Tables A.3 and A.4. Correlation between analytes provides an indication that the source (either background minerals or anthropogenic input) of the metals to the river sediment may be related.

Significant correlation was observed between (cadmium-zinc) at all four locations; this was the only metal group with significant correlations for all locations. There was significant correlation between (silver-arsenic), (silver-copper), (silver-nickel), (cadmium-copper), (chromium-antimony) and (copper-nickel) for all three reservoirs; however, these metal groups were not significantly correlated for the Hanford Reach. For all Columbia River locations there were significant correlations between (arsenic-lead), (arsenic-antimony), (chromium-nickel), (cadmium-nickel), (cadmium-thallium), and (lead-antimony).

3.4 Linear Regressions for Metals Results (SEM Metals versus Total Metals)

Linear regressions were calculated for SEM extraction results verses total metal extraction results (Table 5). There was significant correlation ($p < 0.05$) between the two extraction techniques for all metals except for mercury. Cadmium, copper, nickel, and zinc had regression coefficients (r) above 0.80

and lead had a coefficient of 0.77. The different extraction/digestions yielded similar values for cadmium and zinc (slope = 1.0 for both elements) and lead (slope = 0.70). Copper, nickel, and mercury had lower concentrations for the SEM analysis compared to the total metals analysis, indicating that these materials were more difficult to remove from the sediment matrix.

3.5 Total Organic Carbon

The total organic carbon content of sediments varied both spatially and temporally (Figure 5). In general, Priest Rapids Dam and McNary Dam had similar weight percentages with values (mean ± 1 standard deviation) of 1.7% ± 1.1% and 1.4 ± 0.72%, respectively. Hanford Reach and Ice Harbor Dam sediment had lower average total organic carbon percentages of 0.60% ± 0.34% and 1.0% ± 0.62%. The total organic carbon levels at Priest Rapids Dam varied by a factor of 20 for the four locations approximately 4 km upriver from the dam, while the two locations near the dam had values that varied by only a factor of 2. Within the Hanford Reach, there were large differences in total organic carbon values that reflected the variable depositional processes.

McNary Dam had lower total organic carbon concentrations for sediment samples collected near the Washington shore at both the upriver and near dam locations, compared to sediment collected on the Oregon side of the river. The cross-river difference in concentrations of total organic carbon in McNary Dam sediment were greater for the upriver location where results varied by a factor of 4 to 5, compared to the near-dam locations where the total organic carbon levels varied less than a factor of two. In Snake River sediment samples collected above Ice Harbor Dam, the total organic carbon concentrations were lower for the location near the Franklin County shore.

The total organic carbon values measured for this study were similar to bulk total organic carbon values reported by Blanton et al. (1995) for Columbia River sediment from these locations. Blanton et al. (1995) also reported an inverse relationship between sediment grain size and total organic carbon content for Columbia River sediment collected from Priest Rapids Dam to McNary Dam.

3.6 1998 Sediment Grain Size Relationships

Sediment samples collected in 1998 were sieved into five grain-size fractions. Figures 6 through 9 show the weight percentage of each fraction at the sampling locations. At all locations, coarse sand was either not present or a very minor component (<1% for 16 of 19 locations). The three locations with coarse sand above 1% were near the Yakima County shore at Priest Rapids Dam (3.4%), the 100-F slough (6.1%), and the Franklin County shore at Ice Harbor Dam (1.3%).

For sediment samples from the three reservoirs, medium sand was only a minor component; however, it was the dominant fraction for the 100-F slough sample and nearly one-third of the weight fraction from the White Bluffs slough. The Priest Rapids Dam had considerable variation between locations with fine sand having higher percentages for the upriver locations and silt and clay having the highest percentages for the samples collected near the dam. Medium sand and fine sand fractions dominated the Hanford Reach locations, with less than 10% of the sediment present as silt and clay. At Ice Harbor Dam, the samples from the Walla Walla County shore and mid-river were primarily silt and clay; however, the sample from the Franklin County shore was dominated by fine sand. McNary sediment was dominated by silt and clay with some contribution from very fine sand; expect for the sample from the Washington shore, which had similar percentages of fine sand, very fine sand, and silt and clay. These sediment grain size results were similar to those reported by Beasley et al. (1986) and Blanton et al. (1995).

3.7 1998 Total Metal Concentrations for Size Fractionated Samples

The total metals results for the 1998 size fractionated samples are given in Tables A.5, A.6, and A.7. For most locations and metals, the highest concentrations were found on the coarse sand and medium sand fractions although these fractions were only minor components of the sediments. Overall, the major factor controlling the amount of metals in the sediment was the weight percentage of each size fraction, because the differences in weight percentages of the size fractions were considerably larger than the concentration differences between size fractions. For example, the total metal results were normalized by multiplying the result (μmol/g size fraction) for each size fraction by the weight percentage (g size fraction/g dry sediment) of each fraction. Examples of these normalized results are presented in Figures 10 through 13 for cadmium and zinc, which are the two metals with the largest concentration differences between locations. In general, the other metals had weight percentage normalized results that showed similar trends as cadmium and zinc (i.e., amount of metal in the sediment was more influenced by weight percentage of the size fraction than by the difference in concentrations between grain sizes).

For example (Table A.5 and Figure 10), the Priest Rapids Dam (near Grant County shore) sample results for cadmium were 0.49 μmol/g as coarse sand (0.81% weight percent as coarse sand) and 0.066 μmol/g as fine sand (45% weight percent as fine sand). Although the coarse sand fraction contained a higher molar concentration of cadmium, the fact that it represented a small amount (0.81%) of the total sediment results in a relatively small contribution of cadmium to the total (bulk) sediment. Comparatively, the amount contributed to the total sediment by the more predominate fine sand fraction (45%) was greater, even though the molar concentration of cadmium in the fine fraction was much less than the coarse fraction.

At Priest Rapids Dam, cadmium and zinc were distributed across most size fractions. The upper sites at Priest Rapids Dam showed the metals had the highest amounts in the fine sand and medium sand fractions, though the sample at the Yakima County shore had an equal amount in both the silt and clay and fine sand fractions. For samples collected near the dam at Priest Rapids, the silt and clay fraction dominated the Yakima County side shore, while the Grant County side had significant amounts in the silt and clay, very fine sand, and fine sand fractions. The Hanford Reach samples had cadmium levels that were lower than Priest Rapids Dam with the bulk of the cadmium in the fine sand fractions. The Hanford Reach samples had zinc levels that were similar to those at Priest Rapids Dam. The White Bluffs slough had the highest weight percent normalized concentration for the Hanford Reach for both cadmium and zinc. Weight percentage normalized cadmium and zinc levels were low for all size fractions at Ice Harbor Dam, compared to Columbia River sediment, with the silt and clay fraction having the highest amounts. At McNary Dam, the bulk of the cadmium and zinc was found in the silt and clay fraction, with little difference between locations.

3.8 Total Metal Concentrations Versus Selected Sediment Quality Criteria

There are currently no freshwater sediment quality criteria available from the U.S. Environmental Protection Agency or Washington State to compare the sediment metals concentrations determined by this study (WAC 173-204; Bates and Cubbage 1995). However, some comparative guidelines for the protection and management of aquatic sediment quality have been developed by the Ontario Ministry of Environment Energy (Persaud et al. 1993) and interim sediment quality assessment values have been developed by Environment Canada (EC 1994). The Ontario and Environment Canada guidelines are listed in Table 6.

The Ontario sediment criteria are based on a screening level concentration approach that uses field data (contaminant concentrations and benthic biota abundance) and a ranking process to derive sediment criteria. Bates and Cubbage (1995) report that the screening level concentration approaches are advantageous because they are based on chronic population-level effects on indigenous benthic species; however, they are limited in that they do not establish a direct cause and effect relationship between an individual contaminant and biotic survival. The Ontario guidelines have two effect levels for metals:

1) lowest effect level (LEL) which indicates a metal concentration that can be tolerated by most benthic organisms
2) severe effect level (SEL) at which a pronounced impact to benthic organisms can be expected.

The Environment Canada interim sediment quality assessment values are based on a modified national status and trends program that uses data from multiple approaches such as equilibrium partitioning studies, spiked sediment toxicity studies, field sample bioassays, and sediment criteria from other regulatory agencies (Bates and Cubbage 1995). This approach for deriving sediment criteria has the advantage of using a wide range of data sources, but is limited because individual studies are not always comparable because of differing sediment geochemistry, biotic communities, and variability in analytical test methods. The Environment Canada values have two effect levels:

1) threshold effect level (TEL) below which adverse impacts to benthic organisms are rarely observed
2) probable effect level (PEL) where adverse effects to benthic organisms are frequently observed.

Sediment quality for the Columbia River and Snake River sediment samples were evaluated by comparing the average metal concentrations to the guidelines in Table 6. Sample results that were ≥75% of the criteria are reported in Table 6 as “near criteria” values. No sediment quality criteria were available for antimony, beryllium, selenium, or thallium.

3.8.1 Severe Effect Level and Probable Effect Level Comparison

For all Columbia River locations, the average concentrations of metals in sediments were below the Ontario severe effect levels. All average concentrations of metals in sediment from Columbia River locations were below the Environment Canada probable effect level, except for cadmium and zinc that were above the guidelines at Priest Rapids Dam. Nickel concentrations in sediment from Priest Rapids

Dam and McNary Dam were near the probable effect level. Zinc concentrations for sediment at the Hanford Reach and McNary Dam locations were near the probable effect level guidelines.

The average concentrations for metals in sediment from Ice Harbor Dam locations were below both Ontario severe effect levels and Environment Canada probable effect levels for all metals analyzed.

3.8.2 Lowest Effect Level and Threshold Effect Level Comparison

The average concentrations for metals in sediment from Columbia River locations exceeded or were near the Ontario lowest effect level for all metals, except for mercury and silver, which were below the criteria. Priest Rapids Dam sediment results exceeded or were near the Environment Canada threshold effect level for all metals (no threshold effect level was given for silver). Hanford Reach sediment results were above or near the threshold effect level criteria for all metals except copper and mercury. McNary Dam sediment results were above or near the threshold effect level criteria for all metals except lead and mercury.

The average concentration of metals in sediment from Ice Harbor Dam were above or near the lowest effect level criteria for arsenic, chromium, copper, nickel, and zinc. The Ice Harbor Dam sediment sample results approached or exceeded the threshold effect level criteria for arsenic, chromium, nickel, and zinc.

4.0 Conclusions

The SEM/AVS results reveal an apparent difference in the AVS concentrations in sediment from Priest Rapids Dam reservoir and the Hanford Reach, which have higher concentrations than sediment samples from McNary Dam and Ice Harbor Dam. An apportionment of AVS by divalent metals according to K_{sp} values, revealed that sufficient AVS should exist in all locations to limit the porewater concentrations of cadmium, copper, lead, and mercury. In sediment samples from Priest Rapids Dam, the Hanford Reach, and Ice Harbor Dam, zinc values were of similar magnitude as the AVS concentrations. In samples from McNary Dam, the zinc concentrations were higher than the available AVS concentrations, indicating the potential for zinc and other metals to be available as dissolved species in the sediment porewater.

The total metals results revealed higher concentrations of cadmium, thallium, and zinc in Columbia River sediment compared to Snake River sediment. Total organic carbon levels ranged from 0.029% to 4.3%. For both rivers, the level of total organic carbon in sediment was similar for locations near the dams where the sediment was mostly composed of silt and clay. The size-fractionated samples revealed that the total amount of metal present in the bulk sediment was more influenced by the weight percentage of each size fraction than by concentration differences between size fractions. A comparison of total metal concentration to selected sediment criteria levels indicated that cadmium, nickel, and zinc in Columbia River sediment were near or above some probable effect levels. However, the Snake River sediment results were below the probable effect levels for all metals.

Additional work is needed on the Columbia/Snake river system to understand the impact trace metal contamination has on surface sediment. Some areas where additional information is needed include understanding the uptake pathways for metals (sediment ingestion verses water uptake), seasonal variations in SEM/AVS, changes in SEM/AVS ratios with depth, oxidation/reduction effects in the upper layer of sediment, direct measurements of dissolved metals in sediment porewater, changes to SEM/AVS ratios with drought/flood cycles, and the role of total organic carbon in metal uptake by biota.

Table 1a. 1997 Results (dry weight basis) for Total Organic Carbon, Acid-Volatile Sulfides, and Simultaneously Extracted Metals

Location	TOC (percent)	AVS (µmol/g)	SEM Cd (µmol/g)	SEM Cu (µmol/g)	SEM Hg[(a)] (µmol/g)	SEM Ni (µmol/g)	SEM Pb (µmol/g)	SEM Zn (µmol/g)
Priest Rapids Dam (Columbia River)								
Near Grant County Shore	1.70	21.4	0.0319	0.246	*0.0000002*	0.100	0.096	4.62
1/3 From Grant County Shore	NS	NS	NS	NS	NS	NS	NS	NS
2/3 From Grant County Shore	0.77	10.6	0.0452	0.246	*0.0000002*	0.134	0.151	5.98
Near Yakima County Shore	1.17	18.5	0.0612	0.250	*0.0000002*	0.119	0.190	6.92
Grant County Shore Near Dam	NS	NS	NS	NS	NS	NS	NS	NS
Yakima County Shore Near Dam	NS	NS	NS	NS	NS	NS	NS	NS
Mean	1.21	16.83	0.0461	0.247	0.0000002	0.118	0.146	5.84
Standard Deviation	*0.47*	*5.59*	*0.0146*	*0.002*	*0.0000000*	*0.017*	*0.047*	*1.16*
Hanford Reach (Columbia River)								
White Bluffs Slough	0.71	9.03	0.0082	0.112	0.0000002	0.048	0.108	2.02
100-F Area Slough	0.10	1.18	0.0048	0.086	0.0000005	0.024	0.050	1.37
Old Hanford Townsite Slough	0.96	12.6	0.0284	0.109	0.0000012	0.058	0.113	5.74
Richland Pumphouse	0.47	2.69	0.0113	0.189	0.0000052	0.039	0.161	2.95
Mean	0.56	6.38	0.0132	0.124	0.0000018	0.042	0.108	3.02
Standard Deviation	*0.37*	*5.37*	*0.0105*	*0.045*	*0.0000023*	*0.014*	*0.046*	*1.92*
McNary Dam (Columbia River)								
Near Oregon Shore	1.68	1.64	0.0125	0.329	0.0000027	0.121	0.089	1.84
1/3 From Oregon Shore	1.46	2.00	0.0258	0.292	0.0000215	0.103	0.091	2.90
2/3 From Oregon Shore	1.55	2.57	0.0224	0.297	0.0000070	0.114	0.105	3.35
Near Washington Shore	0.30	0.0747	0.0063	0.107	0.0000243	0.046	0.045	1.07
Oregon Shore Near Dam	NS	NS	NS	NS	NS	NS	NS	NS
Washington Shore Near Dam	NS	NS	NS	NS	NS	NS	NS	NS
Mean	1.25	1.57	0.0168	0.256	0.0000139	0.096	0.083	2.29
Standard Deviation	*0.64*	*1.07*	*0.0090*	*0.101*	*0.0000106*	*0.034*	*0.026*	*1.03*
Ice Harbor Dam (Snake River)								
Franklin County Shore	NS	NS	NS	NS	NS	NS	NS	NS
Mid River	NS	NS	NS	NS	NS	NS	NS	NS
Walla Walla County Shore	NS	NS	NS	NS	NS	NS	NS	NS
Mean	NS	NS	NS	NS	NS	NS	NS	NS
Standard Deviation	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*

NS = Not sampled.
NA = Not applicable (All values were below the detection limit).
(a) The mercury detection limit was *0.0000002 mmol/g*; results reported at this exact value were all below the detection limit.

Table 1b. 1997 Results for Total Metals (dry weight basis)

Location µmol/g (dry wt.)	Ag	As	Be	Cd	Cr	Cu	Hg	Ni	Pb	Sb	Se	Tl	Zn
Priest Rapids Dam (Columbia River)													
Near Grant County Shore	0.00182	0.0937	0.132	0.0324	1.242	0.612	NS	0.583	0.130	0.00808	0.0065	0.0077	5.64
1/3 From Grant County Shore	NS	NS		NS		NS	NS	NS	NS	NS	NS	NS	NS
2/3 From Grant County Shore	0.00144	0.0833	0.124	0.0384	1.410	0.467	NS	0.608	0.173	0.00649	0.0041	0.0043	6.91
Near Yakima County Shore	0.00178	0.0985	0.126	0.0610	1.315	0.630	NS	0.625	0.205	0.00704	0.0028	0.0074	7.59
Grant County Shore Near Dam	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Yakima County Shore Near Dam	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Mean	**0.0017**	**0.0918**	**0.128**	**0.0440**	**1.323**	**0.570**	**NS**	**0.600**	**0.017**	**0.0072**	**0.0045**	**0.0065**	**6.70**
Standard Deviation	***0.0002***	***0.0078***	***0.004***	***0.0150***	***0.084***	***0.089***	***NS***	***0.021***	***0.037***	***0.0008***	***0.0019***	***0.0019***	***0.99***
Hanford Reach (Columbia River)													
White Bluffs Slough	0.00081	0.0614	0.152	0.0089	1.029	0.313	NS	0.354	0.155	0.00854	0.0046	0.0039	3.29
100-F Area Slough	0.00043	0.0539	0.142	0.0052	1.098	0.291	NS	0.291	0.083	0.00494	0.0228	0.0033	2.58
Old Hanford Townsite Slough	0.00079	0.1084	0.134	0.0306	1.279	0.364	NS	0.474	0.147	0.00615	0.0020	0.0139	6.67
Richland Pumphouse	0.00115	0.0834	0.114	0.0087	0.796	0.304	NS	0.249	0.172	0.00623	0.0023	0.0023	3.40
Mean	**0.0008**	**0.0768**	**0.136**	**0.0130**	**1.051**	**0.320**	**NS**	**0.340**	**0.140**	**0.0065**	**0.0079**	**0.0059**	**4.00**
Standard Deviation	***0.0003***	***0.0245***	***0.016***	***0.0120***	***0.200***	***0.032***	***NS***	***0.098***	***0.039***	***0.0015***	***0.0100***	***0.0054***	***1.80***
McNary Dam (Columbia River)													
Near Oregon Shore	0.00397	0.1275	0.175	0.0130	1.267	0.634	NS	0.525	0.123	0.00810	0.0078	0.0033	3.33
1/3 From Oregon Shore	0.00171	0.1173	0.154	0.0273	1.250	0.548	NS	0.503	0.127	0.00754	0.0062	0.0040	4.47
2/3 From Oregon Shore	0.00199	0.1032	0.154	0.0210	1.292	0.557	NS	0.523	0.132	0.00742	0.0034	0.0052	4.53
Near Washington Shore	0.00066	0.0629	0.132	0.0064	0.958	0.258	NS	0.327	0.079	0.00510	0.0034	0.0035	2.19
Oregon Shore Near Dam	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Washington Shore Near Dam	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Mean	**0.0021**	**0.1027**	**0.154**	**0.0170**	**1.192**	**0.500**	**NS**	**0.470**	**0.120**	**0.0070**	**0.0052**	**0.0040**	**3.60**
Standard Deviation	***0.0014***	***0.0284***	***0.018***	***0.0092***	***0.157***	***0.160***	***NS***	***0.095***	***0.024***	***0.0013***	***0.0022***	***0.0008***	***1.10***
Ice Harbor Dam (Snake River)													
Franklin County Shore	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Mid River	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Walla Walla County Shore	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Mean	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Standard Deviation	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***
NS = Not sampled.													

Table 2a. 1998 Results (dry weight basis) for Total Organic Carbon, Acid-Volatile Sulfides, and Simultaneously Extracted Metals

Location	TOC (percent)	AVS (µmol/g)	SEM Cd (µmol/g)	SEM Cu (µmol/g)	SEM Hg (µmol/g)	SEM Ni (µmol/g)	SEM Pb (µmol/g)	SEM Zn (µmol/g)
Priest Rapids Dam (Columbia River)								
Near Grant County Shore	4.34	15.4	0.0666	0.171	0.0000082	0.097	0.111	7.36
1/3 From Grant County Shore	1.25	4.62	0.0639	0.163	0.0000088	0.095	0.119	7.42
2/3 From Grant County Shore	0.59	1.73	0.0259	0.232	0.0000201	0.137	0.130	4.85
Near Yakima County Shore	1.56	7.60	0.0503	0.399	0.0000184	0.152	0.152	5.81
Yakima County Shore Near Dam	1.85	3.64	0.0475	0.393	0.0000137	0.184	0.244	5.99
Grant County Shore Near Dam	2.96	9.66	0.0801	0.398	0.0000126	0.156	0.211	9.34
Mean	**2.09**	**7.11**	**0.0557**	**0.293**	**0.0000137**	**0.137**	**0.161**	**6.80**
Standard Deviation	***1.35***	***4.97***	***0.0188***	***0.116***	***0.0000049***	***0.035***	***0.054***	***1.59***
Hanford Reach (Columbia River)								
White Bluffs Slough	0.924	7.75	0.0292	0.198	0.0000091	0.062	0.174	7.94
100-F Area Slough	0.029	0.320	0.0033	0.103	0.0000189	0.026	0.044	1.26
Old Hanford Townsite Slough	0.551	2.20	0.0044	0.083	0.0000064	0.071	0.038	1.29
Richland Pumphouse	0.412	6.61	0.0079	0.145	0.0000115	0.037	0.138	2.60
Mean	**0.48**	**4.22**	**0.0112**	**0.132**	**0.0000115**	**0.049**	**0.099**	**3.27**
Standard Deviation	***0.37***	***3.53***	***0.0122***	***0.051***	***0.0000053***	***0.021***	***0.068***	***3.17***
McNary Dam (Columbia River)								
Near Oregon Shore	1.43	0.269	0.0153	0.301	0.0000535	0.109	0.085	2.47
1/3 From Oregon Shore	1.81	1.58	0.0192	0.300	0.0000617	0.109	0.091	2.71
2/3 From Oregon Shore	1.00	1.66	0.0206	0.259	0.0000600	0.115	0.101	4.39
Near Washington Shore	0.486	0.131	0.0157	0.158	0.0002173	0.058	0.080	2.04
Oregon Shore Near Dam	1.51	1.93	0.0124	0.255	0.0000124	0.109	0.079	2.09
Washington Shore Near Dam	1.02	0.144	0.0164	0.267	0.0001800	0.122	0.091	2.74
Mean	**1.21**	**0.95**	**0.0166**	**0.256**	**0.0000975**	**0.104**	**0.088**	**2.74**
Standard Deviation	***0.47***	***0.85***	***0.0029***	***0.052***	***0.0000813***	***0.023***	***0.008***	***0.86***
Ice Harbor Dam (Snake River)								
Franklin County Shore	0.31	2.43	0.0008	0.203	0.0000174	0.093	0.025	0.28
Mid River	1.13	0.0334	0.0004	0.247	0.0000650	0.086	0.039	0.32
Walla Walla County Shore	1.51	0.697	0.0012	0.238	0.0000170	0.091	0.041	0.37
Mean	**0.98**	**1.05**	**0.0008**	**0.230**	**0.0000331**	**0.090**	**0.035**	**0.32**
Standard Deviation	***0.61***	***1.23***	***0.0004***	***0.023***	***0.0000276***	***0.003***	***0.009***	***0.04***

Table 2b. 1998 Results for Total Metals Samples (dry weight basis)

Location µmol/g (dry wt.)	Ag	As	Be	Cd	Cr	Cu	Hg	Ni	Pb	Sb	Se	Tl	Zn
Priest Rapids Dam (Columbia River)													
Near Grant County Shore	0.00069	0.0481	0.066	0.0550	0.990	0.522	0.000548	0.507	0.114	0.0050	0.00688	0.0077	7.23
1/3 From Grant County Shore	0.00050	0.0364	0.073	0.0481	0.942	0.404	0.000460	0.461	0.127	0.0042	0.00630	0.0053	6.84
2/3 From Grant County Shore	0.00073	0.0428	0.104	0.0192	1.009	0.372	0.000313	0.486	0.122	0.0032	0.00580	0.0032	4.60
Near Yakima County Shore	0.00120	0.0548	0.106	0.0486	1.111	0.685	0.000641	0.611	0.173	0.0054	0.00573	0.0088	6.71
Grant County Shore Near Dam	0.00193	0.0705	0.127	0.0783	1.331	0.890	0.000993	0.720	0.236	0.0076	0.00828	0.0098	9.70
Yakima County Shore Near Dam	0.00198	0.0637	0.083	0.0536	1.471	0.796	0.000855	0.834	0.239	0.0090	0.00917	0.0055	7.96
Mean	**0.00117**	**0.0527**	**0.093**	**0.0505**	**1.142**	**0.612**	**0.000635**	**0.603**	**0.169**	**0.00574**	**0.00703**	**0.00671**	**7.17**
Standard Deviation	***0.00065***	***0.0128***	***0.023***	***0.0189***	***0.212***	***0.212***	***0.000253***	***0.148***	***0.057***	***0.00217***	***0.00141***	***0.00246***	***1.67***
Hanford Reach (Columbia River)													
White Bluffs Slough	0.00077	0.0590	0.150	0.0298	1.390	0.559	0.000412	0.442	0.223	0.0051	0.01084	0.0093	8.56
100-F Area Slough	0.00018	0.0359	0.069	0.0033	0.588	0.312	0.000111	0.238	0.067	0.0028	0.00597	0.0026	2.38
Old Hanford Townsite Slough	0.0005965	0.0360	0.173	0.0072	0.946	0.259	0.000755	0.384	0.089	0.0031	0.00584	0.0051	2.25
Richland Pumphouse	0.00133	0.1607	0.104	0.0082	0.833	0.464	0.000161	0.301	0.444	0.0088	0.00603	0.0025	5.55
Mean	**0.00072**	**0.0729**	**0.124**	**0.0121**	**0.939**	**0.398**	**0.000360**	**0.341**	**0.205**	**0.00496**	**0.00717**	**0.00489**	**4.69**
Standard Deviation	***0.00047***	***0.0595***	***0.047***	***0.0120***	***0.336***	***0.138***	***0.000294***	***0.090***	***0.173***	***0.00278***	***0.00245***	***0.00321***	***3.00***
McNary Dam (Columbia River)													
Near Oregon Shore	0.00124	0.0807	0.136	0.0128	1.079	0.562	0.000411	0.503	0.102	0.0063	0.00472	0.0033	3.27
1/3 From Oregon Shore	0.00177	0.1019	0.114	0.0283	1.122	0.642	0.000637	0.512	0.129	0.0076	0.00449	0.0041	5.00
2/3 From Oregon Shore	0.00090	0.0818	0.078	0.0155	1.029	0.418	0.000583	0.455	0.107	0.0058	0.00639	0.0036	4.30
Near Washington Shore	0.00058	0.0632	0.133	0.0108	0.909	0.306	0.000413	0.351	0.088	0.0047	0.00447	0.0033	3.44
Oregon Shore Near Dam	0.00144	0.1097	0.179	0.0172	1.007	0.531	0.000467	0.484	0.120	0.0057	0.00616	0.0043	3.77
Washington Shore Near Dam	0.00116	0.1038	0.175	0.0208	1.014	0.495	0.000768	0.483	0.064	0.0050	0.00597	0.0042	4.58
Mean	**0.00118**	**0.0902**	**0.136**	**0.0176**	**1.027**	**0.492**	**0.000547**	**0.465**	**0.101**	**0.00587**	**0.00537**	**0.00379**	**4.06**
Standard Deviation	***0.00041***	***0.0178***	***0.038***	***0.0063***	***0.072***	***0.117***	***0.000142***	***0.059***	***0.023***	***0.00103***	***0.00090***	***0.00045***	***0.68***
Ice Harbor Dam (Snake River)													
Franklin County Shore	0.00036	0.0918	0.149	0.0011	0.885	0.314	0.000048	0.311	0.062	0.0059	0.00447	0.0018	1.33
Mid River	0.00067	0.0983	0.154	0.0017	0.903	0.479	0.000216	0.391	0.075	0.0053	0.00574	0.0020	1.85
Walla Walla County Shore	0.00070	0.1055	0.152	0.0017	0.863	0.480	0.000501	0.375	0.071	0.0055	0.00600	0.0020	1.76
Mean	**0.00058**	**0.0985**	**0.152**	**0.0015**	**0.883**	**0.424**	**0.000255**	**0.359**	**0.069**	**0.00557**	**0.00540**	**0.00194**	**1.65**
Standard Deviation	***0.00019***	***0.0068***	***0.003***	***0.0003***	***0.020***	***0.095***	***0.000229***	***0.042***	***0.007***	***0.00032***	***0.00082***	***0.00012***	***0.28***
Weighted mean conc. using metal concentration in each sieve fraction.													

Table 3a. 1999 Results (dry weight basis) for Total Organic Carbon, Acid-Volatile Sulfides, and Simultaneously Extracted Metals

Location	TOC (percent)	AVS (µmol/g)	SEM Cd (µmol/g)	SEM Cu (µmol/g)	SEM Hg (µmol/g)	SEM Ni (µmol/g)	SEM Pb (µmol/g)	SEM Zn (µmol/g)
Priest Rapids Dam (Columbia River)								
Near Grant County Shore	3.27	4.70	0.0695	0.204	0.0000123	0.086	0.126	6.56
1/3 From Grant County Shore	0.21	2.44	0.0193	0.069	0.0000069	0.030	0.061	2.56
2/3 From Grant County Shore	1.08	3.11	0.0278	0.229	0.0000159	0.116	0.179	4.57
Near Yakima County Shore	1.22	8.15	0.0629	0.257	0.0000135	0.127	0.334	8.18
Grant County Shore Near Dam	2.30	13.68	0.0901	0.480	0.0000163	0.123	0.284	9.32
Yakima County Shore Near Dam	1.44	6.88	0.0653	0.433	0.0000170	0.170	0.260	7.24
Mean	**1.59**	**6.49**	**0.0558**	**0.279**	**0.0000136**	**0.109**	**0.207**	**6.41**
Standard Deviation	***1.06***	***4.14***	***0.0269***	***0.153***	***0.0000038***	***0.047***	***0.103***	***2.47***
Hanford Reach (Columbia River)								
White Bluffs Slough	0.51	2.25	0.0137	0.165	0.0000044	0.042	0.186	4.33
100-F Area Slough	0.84	0.33	0.0080	0.152	0.0000427	0.032	0.118	1.92
Old Hanford Townsite Slough	1.08	5.27	0.0309	0.152	0.0000120	0.080	0.146	6.13
Richland Pumphouse	NS	NS	NS	NS	NS	NS	NS	NS
Mean	**0.81**	**2.62**	**0.0175**	**0.156**	**0.0000197**	**0.051**	**0.150**	**4.13**
Standard Deviation	***0.28***	***2.49***	***0.0119***	***0.007***	***0.0000203***	***0.025***	***0.034***	***2.11***
McNary Dam (Columbia River)								
Near Oregon Shore	2.59	1.71	0.0134	0.246	0.0000270	0.108	0.091	1.92
1/3 From Oregon Shore	2.87	3.22	0.0284	0.286	0.0000134	0.113	0.132	3.38
2/3 From Oregon Shore	2.22	0.16	0.0139	0.244	0.0000736	0.105	0.100	2.21
Near Washington Shore	0.59	0.08	0.0114	0.150	0.0000746	0.070	0.083	1.91
Oregon Shore Near Dam	1.61	0.38	0.0138	0.264	0.0000833	0.101	0.097	1.86
Washington Shore Near Dam	0.92	0.16	0.0167	0.257	0.0000777	0.106	0.113	2.54
Mean	**1.80**	**0.95**	**0.0162**	**0.241**	**0.0000583**	**0.101**	**0.102**	**2.30**
Standard Deviation	***0.92***	***1.27***	***0.0062***	***0.047***	***0.0000300***	***0.015***	***0.017***	***0.59***
Ice Harbor Dam (Snake River)								
Franklin County Shore	0.17	0.08	0.0007	0.073	0.0000155	0.043	0.031	0.17
Mid River	1.40	1.28	0.0021	0.207	0.0000367	0.101	0.049	0.51
Walla Walla County Shore	1.56	2.42	0.0015	0.194	0.0000175	0.086	0.046	0.39
Mean	**1.04**	**1.26**	**0.0014**	**0.158**	**0.0000233**	**0.077**	**0.042**	**0.36**
Standard Deviation	***0.76***	***1.17***	***0.0007***	***0.074***	***0.0000117***	***0.031***	***0.010***	***0.17***
NS = Not sampled.								

Table 3b. 1999 Results for Total Metals Samples (dry weight basis)

Location µmol/g (dry wt.)	Ag	As	Be	Cd	Cr	Cu	Hg	Ni	Pb	Sb	Se	Tl	Zn
Priest Rapids Dam (Columbia River)													
Near Grant County Shore	0.00095	0.1153	0.156	0.0617	0.997	0.418	0.000578	0.425	0.135	0.0056	0.00598	0.00723	6.72
1/3 From Grant County Shore	0.00012	0.0543	0.177	0.0189	0.805	0.269	0.000289	0.307	0.086	0.0032	0.00598	0.00589	3.69
2/3 From Grant County Shore	0.00143	0.0897	0.181	0.0356	1.536	0.475	0.000634	0.587	0.286	0.0074	0.00598	0.00395	7.69
Near Yakima County Shore	0.00169	0.1314	0.187	0.0592	1.388	0.531	0.000922	0.594	0.303	0.0068	0.00598	0.00481	8.84
Grant County Shore Near Dam	0.00282	0.1247	0.178	0.0770	1.540	0.767	0.001062	0.721	0.233	0.0087	0.00598	0.00928	9.51
Yakima County Shore Near Dam	0.00336	0.1329	0.196	0.0664	1.621	0.716	0.001199	0.786	0.253	0.0085	0.00598	0.00644	8.50
Mean	**0.0017**	**0.1081**	**0.1793**	**0.0531**	**1.314**	**0.529**	**0.000781**	**0.570**	**0.216**	**0.0067**	**0.00598**	**0.00627**	**7.49**
Standard Deviation	***0.0012***	***0.0307***	***0.0132***	***0.0216***	***0.334***	***0.187***	***0.000340***	***0.179***	***0.087***	***0.0021***	***0.00000***	***0.00188***	***2.10***
Hanford Reach (Columbia River)													
White Bluffs Slough	0.00052	0.0953	0.191	0.0115	0.991	0.423	0.000290	0.300	0.190	0.0063	0.00598	0.00306	5.11
100-F Area Slough	0.00748	0.0880	0.217	0.0131	1.442	0.361	0.000313	0.396	0.157	0.0062	0.00598	0.00370	4.21
Old Hanford Townsite Slough	0.00538	0.0768	0.201	0.0097	1.139	0.245	0.000281	0.386	0.100	0.0047	0.00598	0.00529	2.86
Richland Pumphouse	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Mean	**0.00446**	**0.0867**	**0.203**	**0.0114**	**1.191**	**0.343**	**0.000294**	**0.361**	**0.149**	**0.0057**	**0.00598**	**0.00402**	**4.06**
Standard Deviation	***0.00357***	***0.0093***	***0.013***	***0.0017***	***0.230***	***0.090***	***0.000016***	***0.053***	***0.045***	***0.0009***	***0.00000***	***0.00115***	***1.13***
McNary Dam (Columbia River)													
Near Oregon Shore	0.00131	0.1193	0.202	0.0126	1.138	0.513	0.000565	0.487	0.118	0.0073	0.00598	0.00368	3.09
1/3 From Oregon Shore	0.00230	0.1209	0.217	0.0293	1.210	0.537	0.000813	0.494	0.153	0.0079	0.00598	0.00531	4.77
2/3 From Oregon Shore	0.00150	0.1085	0.206	0.0139	1.175	0.468	0.000552	0.502	0.128	0.0067	0.00598	0.00424	3.69
Near Washington Shore	0.00068	0.0800	0.198	0.0102	1.050	0.322	0.000522	0.398	0.113	0.0056	0.00598	0.00396	3.19
Oregon Shore Near Dam	0.00161	0.1281	0.215	0.0135	1.169	0.524	0.000616	0.497	0.123	0.0071	0.00598	0.00387	3.29
Washington Shore Near Dam	0.00133	0.0945	0.178	0.0197	1.050	0.451	0.000648	0.426	0.136	0.0070	0.00598	0.00381	4.31
Mean	**0.00146**	**0.1086**	**0.202**	**0.0165**	**1.132**	**0.469**	**0.000619**	**0.467**	**0.128**	**0.0069**	**0.00661**	**0.00415**	**3.72**
Standard Deviation	***0.00053***	***0.0183***	***0.014***	***0.0070***	***0.068***	***0.079***	***0.000105***	***0.044***	***0.014***	***0.0008***	***0.00155***	***0.00060***	***0.68***
Ice Harbor Dam (Snake River)													
Franklin County Shore	0.00013	0.0845	0.218	0.0008	0.899	0.260	0.000171	0.307	0.068	0.0058	0.00598	0.00193	1.32
Mid River	0.00068	0.1150	0.231	0.0012	0.996	0.450	0.000441	0.382	0.069	0.0068	0.00598	0.00202	1.43
Walla Walla County Shore	0.00089	0.1096	0.218	0.0013	0.987	0.468	0.000358	0.388	0.071	0.0064	0.00598	0.00214	1.47
Mean	**0.00057**	**0.1030**	**0.222**	**0.0011**	**0.961**	**0.393**	**0.000324**	**0.359**	**0.069**	**0.0063**	**0.00598**	**0.00203**	**1.41**
Standard Deviation	***0.00039***	***0.0163***	***0.008***	***0.0003***	***0.054***	***0.115***	***0.000138***	***0.045***	***0.002***	***0.0005***	***0.00000***	***0.00010***	***0.08***
NS = Not sampled.													

Table 4. Solubility Product Constants (K_{sp}) for Metal Sulfides

Metal-Sulfide	K_{sp}	Temp. ^oC	Reference
CdS	8.0×10^{-27}	18-25	Lange's Handbook, 14th Edition[(a)]
CdS	3.6×10^{-29}	18	CRC Handbook, 63rd Edition[(b)]
CuS	6.3×10^{-36}	18-25	Lange's Handbook, 14th Edition
CuS	8.5×10^{-45}	18	CRC Handbook, 63rd Edition
FeS	6.3×10^{-18}	18-25	Lange's Handbook, 14th Edition
FeS	3.7×10^{-19}	18	CRC Handbook, 63rd Edition
HgS (red)	4.0×10^{-53}	18-25	Lange's Handbook, 14th Edition
HgS (black)	1.6×10^{-52}	18-25	Lange's Handbook, 14th Edition
HgS	4×10^{-53} to 2×10^{-49}	18	CRC Handbook, 63rd Edition
Alpha-NiS	3.2×10^{-19}	18-25	Lange's Handbook, 14th Edition
Beta-NiS	1.0×10^{-24}	18-25	Lange's Handbook, 14th Edition
Gamma-NiS	2.0×10^{-26}	18-25	Lange's Handbook, 14th Edition
NiS	1.4×10^{-24}	18	CRC Handbook, 63rd Edition
PbS	8.0×10^{-28}	18-25	Lange's Handbook, 14th Edition
PbS	3.4×10^{-28}	18	CRC Handbook, 63rd Edition
Alpha-ZnS	1.6×10^{-24}	18-25	Lange's Handbook, 14th Edition
Beta-ZnS	2.5×10^{-22}	18-25	Lange's Handbook, 14th Edition
ZnS	1.1×10^{-23}	18	CRC Handbook, 63rd Edition

(a) Dean 1992.
(b) Weast 1982.

Table 5. Linear Regressions for Metals Extracted by SEM Method Versus Metals Extracted by Total Metals Method

Element	r	Slope (m)	Intercept (b)	n	p Value
Cd	0.93	1.01	0.00094	48	<0.01
Cu	0.89	0.56	-0.038	48	<0.01
Hg	0.0037	0.00036	0.000031	18	0.99
Ni	0.86	0.24	-0.021	48	<0.01
Pb	0.77	0.70	0.017	48	<0.01
Zn	0.90	1.00	-1.01	48	<0.01

y = SEM metals extraction result (µg/g dry weight).
x = Total metals extraction result (µg/g dry weight).

Table 6. Average Sediment Results Compared to Selected Sediment Quality Criteria

Metal/Location	Apportioned SEM/AVS > 1	Ontario Criteria > Lowest Effect Level	Ontario Criteria > Severe Effect Level	Environment Canada Criteria > Threshold Effect Level	Environment Canada Criteria > Probable Effect Level
Priest Rapids Dam					
Arsenic	*NA*	YES	NO	YES	NO
Cadmium	NO	YES	NO	YES	YES
Chromium	*NA*	YES	NO	YES	NO
Copper	NO	YES	NO	YES	NO
Lead	NO	YES	NO	YES	NO
Mercury	NO	NO	NO	Near Criteria	NO
Nickel	NO	YES	NO	YES	Near Criteria
Silver	*NA*	NO	*NS*	*NS*	*NS*
Zinc	Near Criteria	YES	NO	YES	YES
Hanford Reach					
Arsenic	*NA*	Near Criteria	NO	Near Criteria	NO
Cadmium	NO	YES	NO	YES	NO
Chromium	*NA*	YES	NO	YES	NO
Copper	NO	YES	NO	NO	NO
Lead	NO	YES	NO	Near Criteria	NO
Mercury	NO	NO	NO	NO	NO
Nickel	NO	YES	NO	YES	NO
Silver	*NA*	NO	*NS*	*NS*	*NS*
Zinc	Near Criteria	YES	NO	YES	Near Criteria
Ice Harbor Dam (1998 and 1999 only)					
Arsenic	*NA*	YES	NO	YES	NO
Cadmium	NO	NO	NO	NO	NO
Chromium	NA	YES	NO	YES	NO
Copper	NO	YES	NO	NO	NO
Lead	NO	NO	NO	NO	NO
Mercury	NO	NO	NO	NO	NO
Nickel	NO	YES	NO	YES	NO
Silver	*NA*	NO	*NS*	*NS*	*NS*
Zinc	NO	Near Criteria	NO	Near Criteria	NO
McNary Dam					
Arsenic	*NA*	YES	NO	YES	NO
Cadmium	NO	YES	NO	YES	NO
Chromium	NA	YES	NO	YES	NO
Copper	NO	YES	NO	Near Criteria	NO
Lead	NO	Near Criteria	NO	NO	NO
Mercury	NO	NO	NO	NO	NO
Nickel	NO	YES	NO	YES	Near Criteria
Silver	*NA*	NO	*NS*	*NS*	*NS*
Zinc	YES	YES	NO	YES	Near Criteria
Criteria Values (µmol/g dry wt.)					
Arsenic	NA	0.08	0.44	0.079	0.23
Cadmium	SEM/AVS < 1	0.0053	0.089	0.0053	0.031
Chromium	NA	0.5	2.1	0.72	1.7
Copper	SEM/AVS < 1	0.25	1.7	0.56	3.1
Lead	SEM/AVS < 1	0.15	1.2	0.17	0.44
Mercury	SEM/AVS < 1	0.0010	0.010	0.00087	0.0024
Nickel	SEM/AVS < 1	0.27	1.3	0.31	0.61
Silver	NA	0.005	NS	NS	NS
Zinc	SEM/AVS < 1	1.8	13	1.9	4.8

No sediment criteria were available for antimony, beryllium, selenium, or thallium.
NA = Not analyzed for this study.
NS = No available sediment criteria.

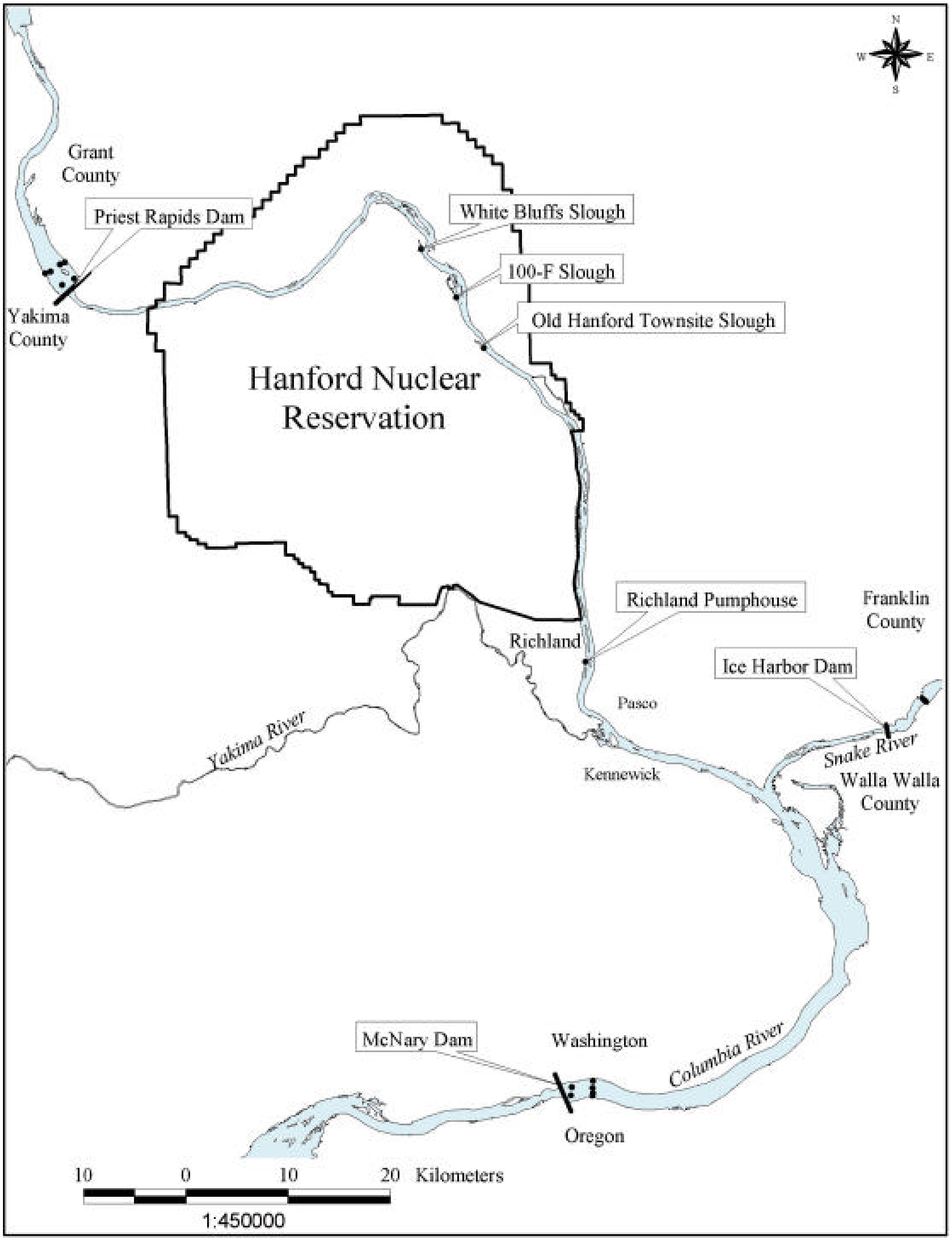


Figure 1. Sediment Sampling Locations for 1997 through 1999. The Hanford Reach is the free-flowing section of the Columbia River between Priest Rapids Dam and McNary Dam. Ice Harbor Dam is located on the Snake River in the state of Washington.

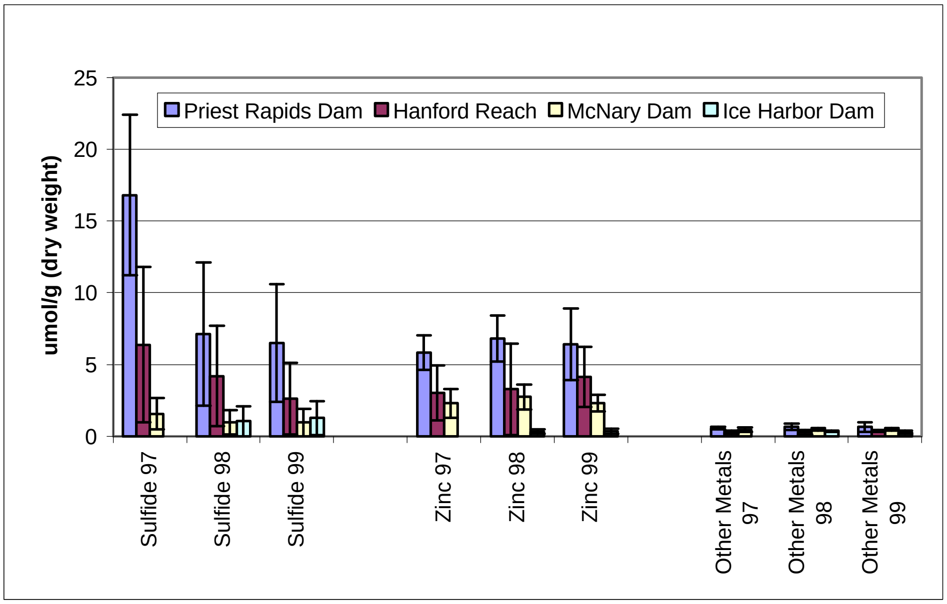


Figure 2. Average Concentrations (±1 standard deviation) of Acid-Volatile-Sulfide, Simultaneously Extracted Zinc, and Sum of Other Simultaneously Extracted Metals (Cd, Cu, Hg, Ni, and Pb) in Columbia and Snake River Sediment

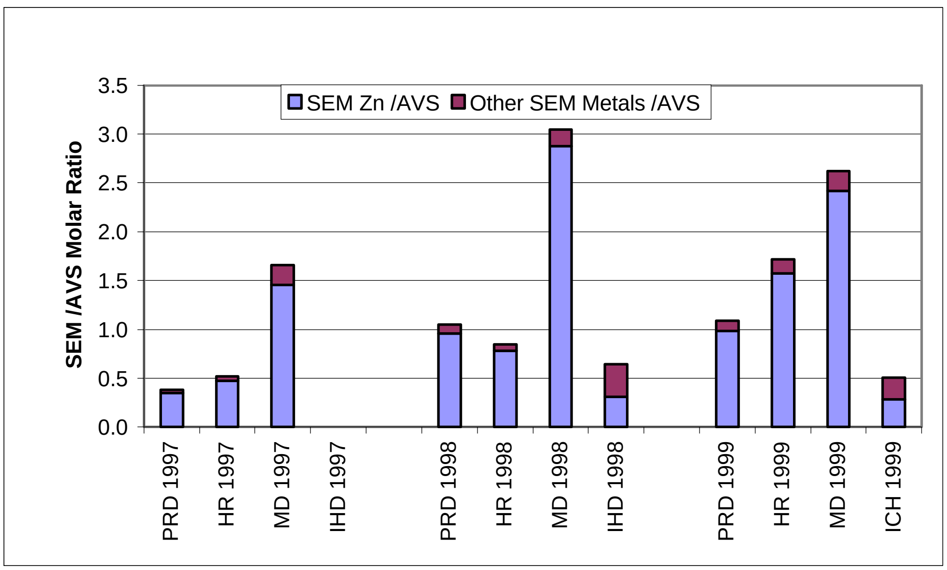
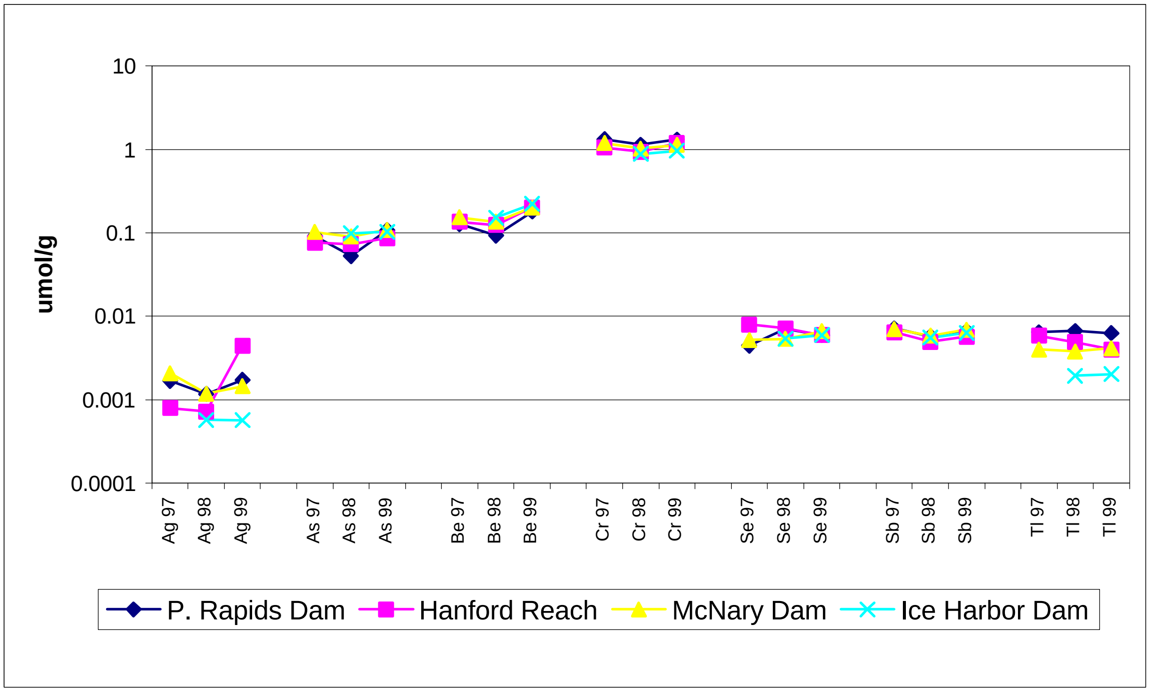


Figure 3. Ratios of Average Concentrations of Simultaneously Extracted Zinc and Average Sum of Other Simultaneously Extracted Metals (Cd, Cu, Hg, Ni, and Pb) to the Average Concentrations of Acid-Volatile Sulfide in Columbia and Snake River Sediment



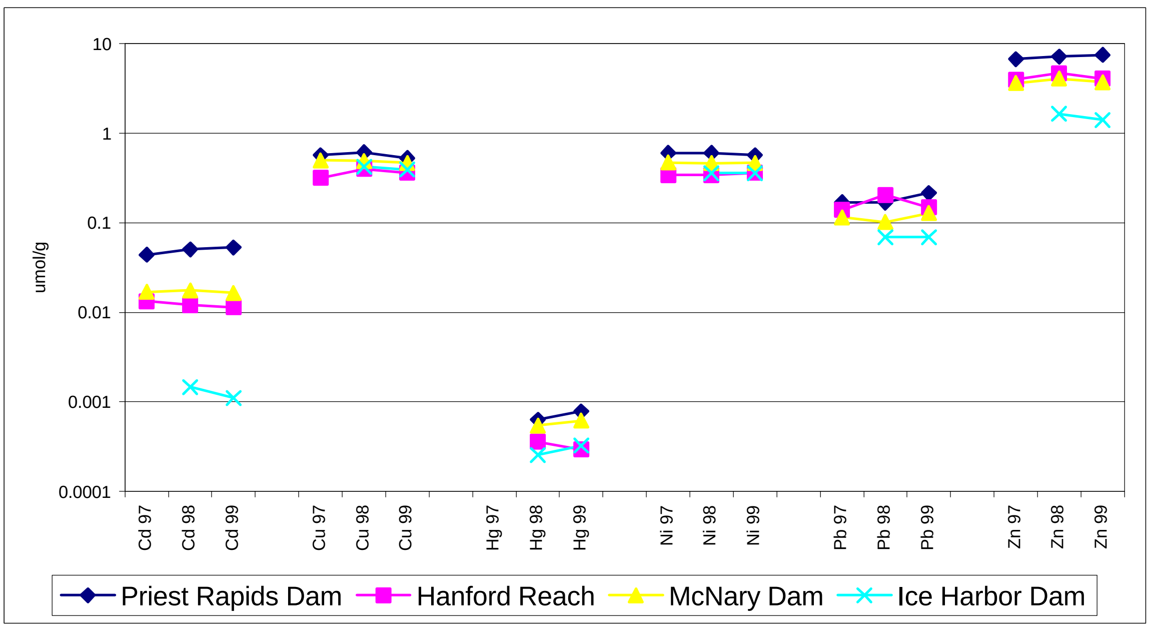


Figure 4. Average Dry Weight Metal Concentrations for 1997 to 1999 for Columbia and Snake River Sediment

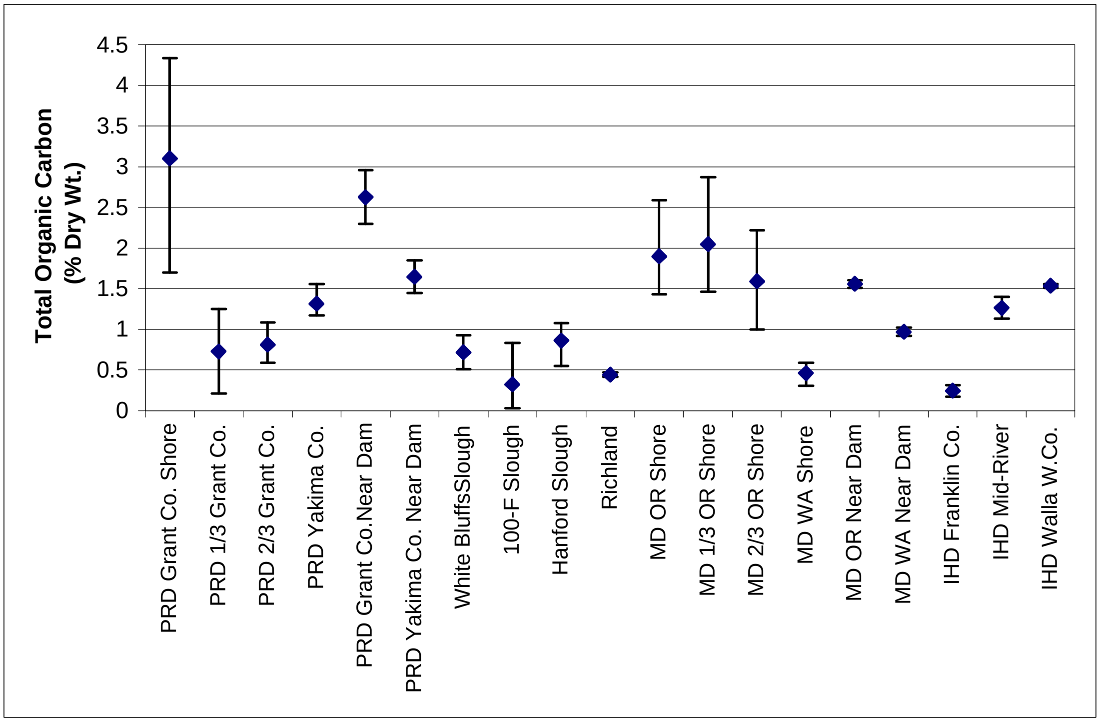


Figure 5. Average Total Organic Carbon Content at all Sediment Sampling Locations (PRD = Priest Rapids Dam, MD = McNary Dam, and IHD = Ice Harbor Dam)

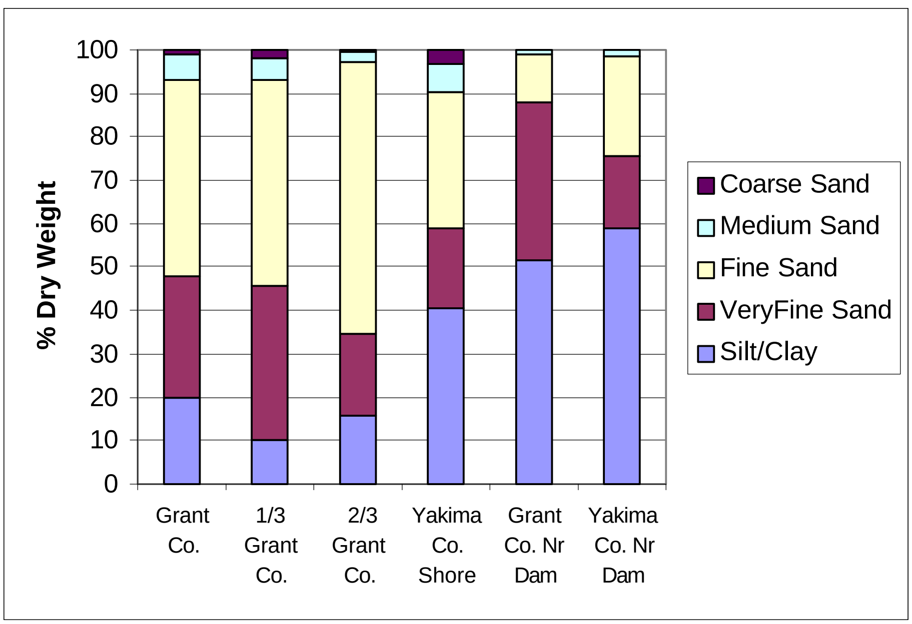


Figure 6. Percent Total Mass (dry weight) for Five Sediment Grain Size Fractions at Priest Rapids Dam Sediment Sampling Locations (1998)

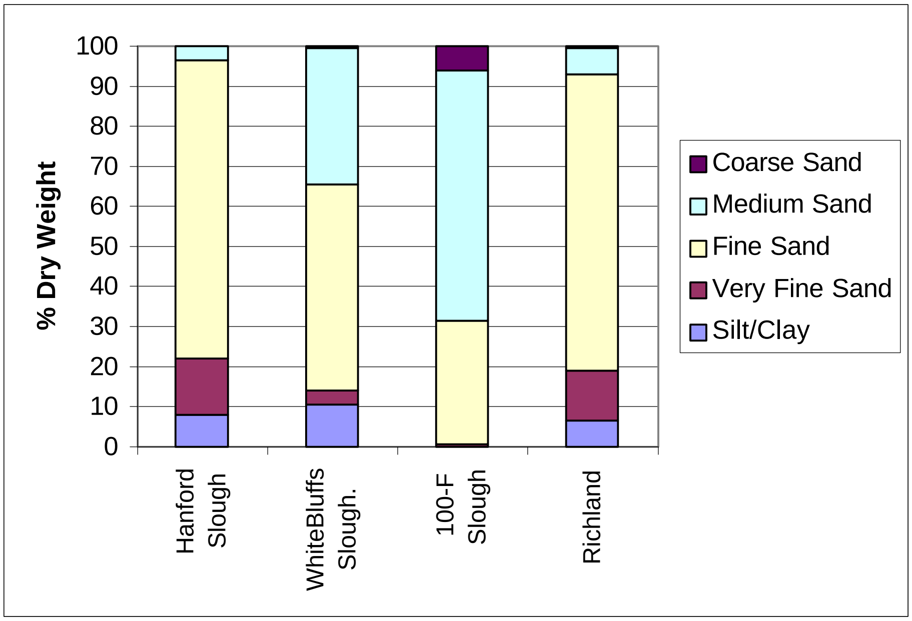


Figure 7. Percent Total Mass (dry weight) for Five Sediment Grain Size Fractions at Hanford Reach Sediment Sampling Locations (1998)

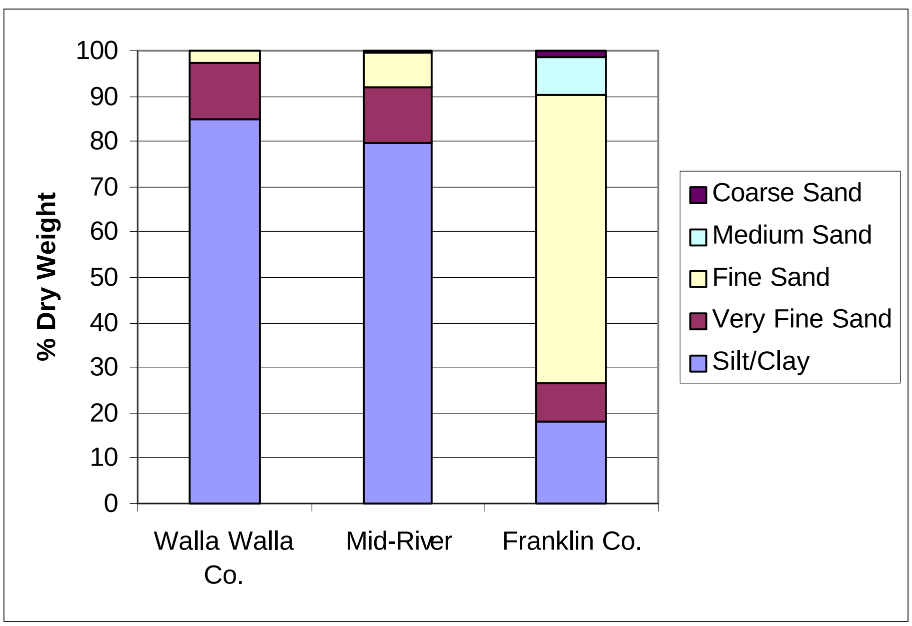


Figure 8. Percent Total Mass (dry weight) for Five Sediment Grain Size Fractions at Ice Harbor Dam Sediment Sampling Locations (1998)

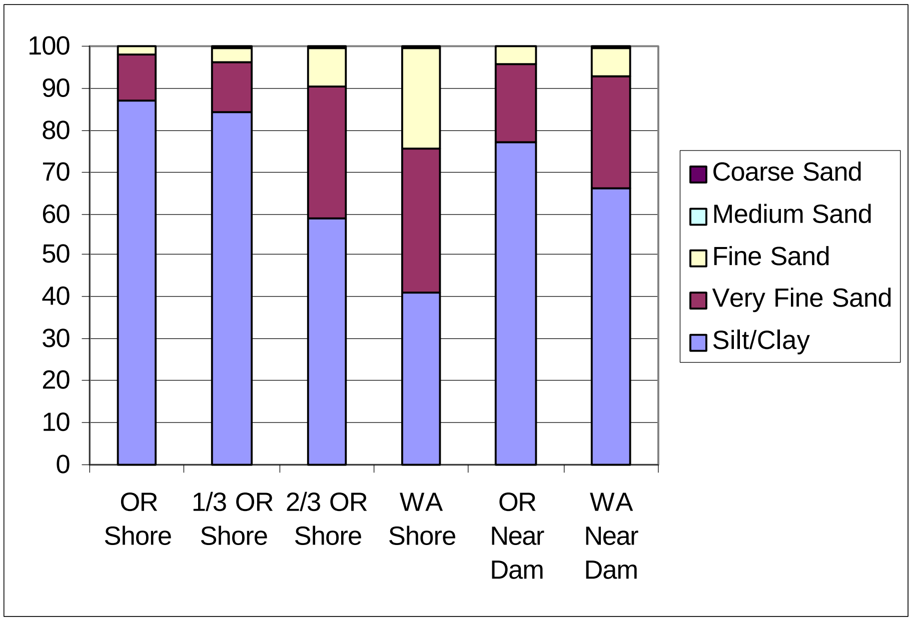


Figure 9. Percent Total Mass (dry weight) for Five Sediment Grain Size Fractions at McNary Dam Sediment Sampling Locations (1998)

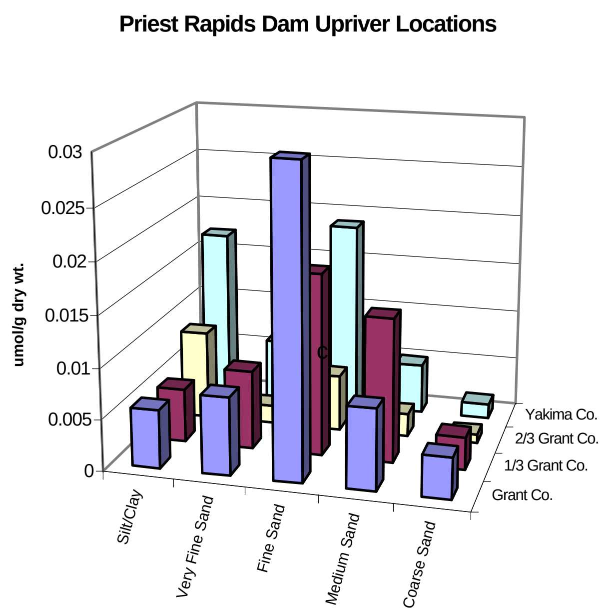


Figure 10. Normalized Cadmium Concentrations (μmol/g dry sediment) for Size Fractionated Sediment Samples at Upriver Locations at Priest Rapids Dam (1998)

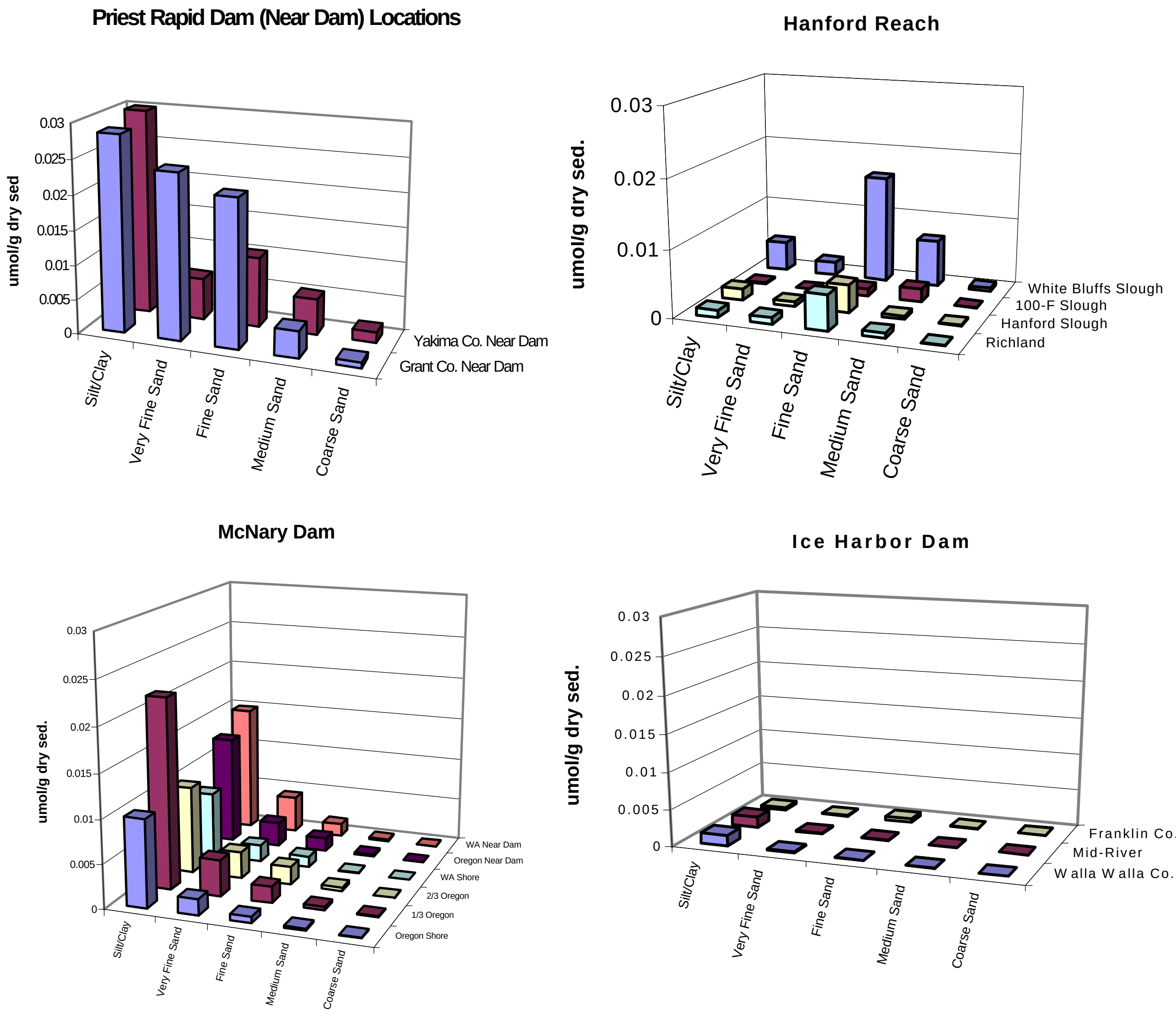


Figure 11. Normalized Cadmium Concentrations (μmol/g dry sediment) for Size Fractionated Sediment Samples (1998). a) locations near the dam at Priest Rapids Dam, b) Hanford Reach locations, c) Ice Harbor Dam locations, and d) locations at McNary Dam

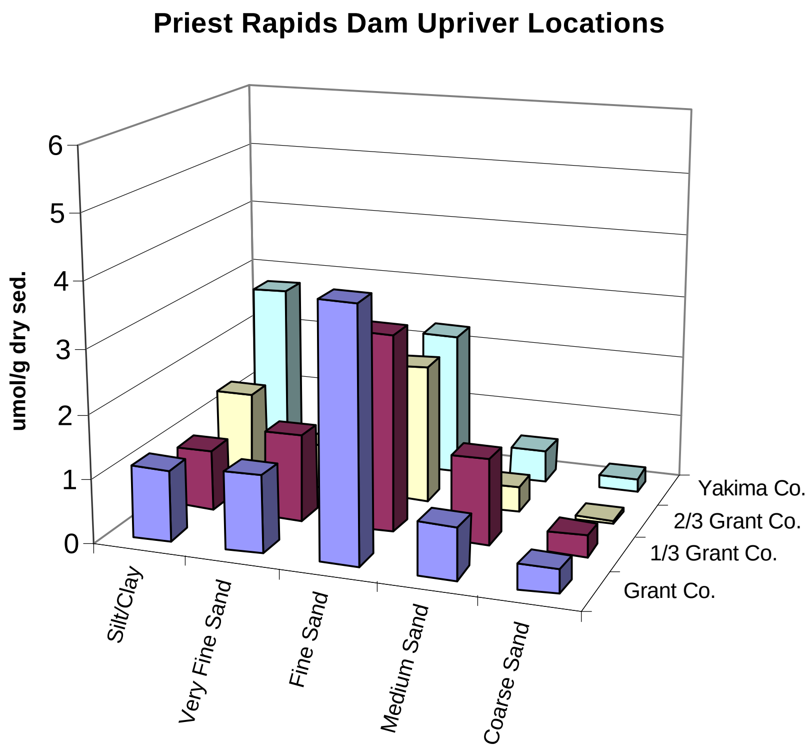


Figure 12. Normalized Zinc Concentrations (μmol/g dry sediment) for Size Fractionated Sediment Samples at Upriver Locations at Priest Rapids Dam (1998)

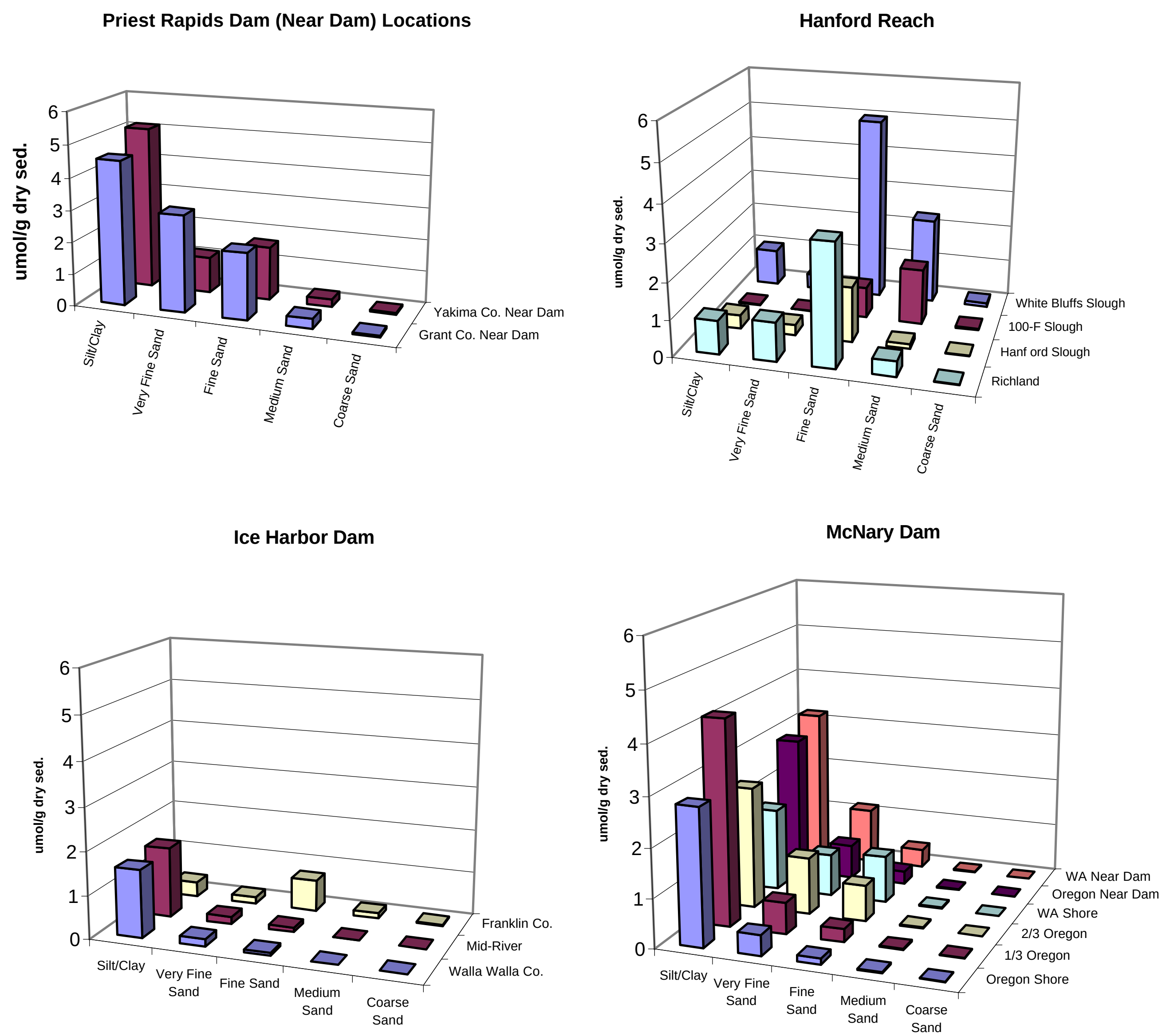


Figure 13. Normalized Zinc Concentrations (μmol/g dry sediment) for Size Fractionated Sediment Samples (1998). a) locations near the dam at Priest Rapids Dam, b) Hanford Reach locations, c) Ice Harbor Dam locations, and d) locations at McNary Dam.

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Appendix

Analytical and Statistical Data

Table A.1. Quality Control Sample Results for Simultaneously Extracted Metals (SEM)/Acid-Volatile Sulfide (AVS)

1997	AVS	SEM Cd	SEM Cu	SEM Hg	SEM Ni	SEM Pb	SEM Zn
Blank (µmol/g)	0.0220	0.00000954	0.000352	0.00000268	0.000137	0.0000650	0.0506
Detection Limit (µmol/g)	(a)	NA	NA	NA	NA	NA	NA
Replicate (RPD)	7%	4%	5%	-33%	4%	1%	1%
Matrix Spike Results							
Percent Recovery	NS	101%	101%	NS	101%	95%	94%
Percent Recovery	NS	101%	103%	NS	103%	93%	102%
1998	AVS	SEM Cd	SEM Cu	SEM Hg	SEM Ni	SEM Pb	SEM Zn
Blank (µmol/g)	NS	0.0000	0.0010	0.000003	0.000690	0.00019	0.0127
Blank (µmol/g)	NS	0.0000	0.0018	0.000003	0.00180	0.00047	0.0685
Detection Limit (µmol/g)	0.02	0.00002	0.00009	0.0000003	0.00002	0.00004	0.0002
Replicate (RPD)	2.8%	2.6%	0.3%	1.0%	0.2%	2.3%	2.3%
Replicate (RPD)	NS	0.4%	11.1%	10.0%	7.2%	17.3%	16.4%
Matrix Spike Results							
Percent Recovery	NS	100%	100%	99%	101%	97%	97%
Percent Recovery	NS	102%	101%	102%	102%	98%	98%
Percent Recovery	NS	102%	102%	104%	103%	97%	97%
Percent Recovery	NS	102%	105%	107%	104%	99%	99%
1999	AVS	SEM Cd	SEM Cu	SEM Hg	SEM Ni	SEM Pb	SEM Zn
Blank (µmol/g)	-0.03	0.0000	0.001	0.0009	0.3	0.3	0.008
Detection Limit (µmol/g)	0.009	0.01	0.02	0.0005	0.03	0.005	0.05
Replicate Analysis Results							
RPD	8%	2%	13%	27%	1%	3%	6%
RPD	9%	10%	7%	27%	15%	0%	4%
RPD	0%	18%	4%	NA	10%	4%	0%
RPD	13%	23%	5%	17%	5%	3%	6%
Blank Spike Results							
Percent Recovery	102%	100%	94%	103%	93%	117%	92%
Percent Recovery	105%	100%	95%	102%	94%	114%	96%

(a) AVS instrument detection limit of 0.0089 µmol.
NA = Not available.
NS = Not sampled.
RPD = Relative % difference.

Table A.2. Quality Control Sample Results for Total Metals

1997	Ag	As	Be	Cd	Cr	Cu	Hg	Ni	Pb	Sb	Se	Tl	Zn
Blank (µmol/g)	0.00014	0.0022	0.014	0.00022	0.0025	0.0027	NA	0.0014	0.00019	0.00047	0.0026	0.000073	0.0109
Detection Limit (µmol/g)	0.00005	0.0017	0.014	0.00022	0.0025	0.0027	NA	0.0012	0.00019	0.00016	0.0228	0.000073	0.0092
Replicate (RPD)	11%	1%	30%	26%	32%	20%	NA	27%	21%	3%	68%	28%	24%
Standard Reference Material Data													
Percent difference 2704 (NIST)	NA	19%	NA	6%	4%	3%	NA	1%	2%	19%	NA	3%	1%
Percent difference MESS 2	9%	2%	3%	5%	6%	26%	NA	3%	6%	20%	51%	9%	12%
Matrix Spike Results													
Percent Recovery	117%	114%	91%	105%	94%	136%	NA	138%	80%	106%	100%	96%	140%
Percent Recovery	111%	104%	88%	106%	101%	134%	NA	123%	81%	107%	111%	98%	138%
1998	Ag	As	Be	Cd	Cr	Cu	Hg	Ni	Pb	Sb	Se	Tl	Zn
Blank (µmol/g)	0.00070	0.0134	0.152	0.00106	0.0041	0.0029	0.000017	0.0052	0.00041	0.00093	0.0203	0.000279	0.0709
Detection Limit (µmol/g)	0.00006	0.0134	0.067	0.00080	0.0038	0.0003	0.000008	0.0007	0.00010	0.00016	0.0203	0.000010	0.0046
Replicate (RPD)	26%	4%	1%	2%	3%	7%	79%	0%	0%	2%	NA	2%	0.0140
Standard Reference Material Data													
Percent difference (2704 NIST)	NA	1%	NA	2%	10%	2%	0%	1%	6%	9%	NA	2%	1%
Percent difference (MESS 2)	6%	10%	66%	61%	6%	7%	14%	1%	97%	38%	2%	4%	5%
Matrix Spike Results													
Percent Recovery	86%	95%	87%	91%	82%	117%	94%	111%	61%	104%	128%	96%	NA
Percent Recovery	88%	84%	77%	85%	NA	47%	NA	58%	53%	96%	93%	88%	NA
1999	Ag	As	Be	Cd	Cr	Cu	Hg	Ni	Pb	Sb	Se	Tl	Zn
Blank (µmol/g)	0.00012	0.0134	0.067	0.00080	0.0038	0.0003	0.000183	0.0010	0.00010	0.00016	0.0060	0.000010	0.4754
Detection Limit (µmol/g)	0.00012	0.0134	0.067	0.00080	0.0038	0.0003	0.000007	0.0007	0.00010	0.00016	0.0060	0.000010	0.0046
Standard Reference Material													
Percent Difference 2704	NA	3%	NA	0%	3%	2%	12%	1%	4%	4%	NA	2%	3%
Percent Difference 2704	NA	6%	NA	4%	6%	20%	8%	11%	13%	0%	NA	10%	6%
Standard Reference Material													
Percent difference MESS-2	17%	1%	4%	17%	3%	14%	39%	8%	3%	9%	17%	2%	12%
Percent difference MESS-2	5%	6%	14%	27%	2%	13%	36%	6%	3%	12%	17%	7%	9%
Blank Spike Results													
Percent Recovery	119%	99%	103%	102%	52%	94%	98%	100%	105%	88%	94%	97%	193%
Percent Recovery	NA	NA	NA	NA	76%	93%	NA	99%	103%	NA	NA	NA	68%
Matrix Spike Results													
Percent Recovery	91%	102%	109%	102%	101%	80%	106%	91%	101%	105%	103%	103%	119%
Percent Recovery	NA	NA	NA	NA	97%	81%	NA	91%	98%	NA	NA	NA	90%
Percent Recovery	120%	111%	109%	101%	114%	84%	110%	90%	81%	102%	89%	93%	98%
Percent Recovery	NA	NA	NA	NA	97%	80%	NA	91%	91%	NA	NA	NA	83%
Replicate (RPD)	9%	4%	2%	2%	2%	0%	4%	0%	1%	3%	NA	0%	0%

NA = Not analyzed.
RPD = Relative % difference.

Table A.3. Correlation Between Total Organic Carbon, Acid-Volatile Sulfide, and Total Metals

Priest Rapids Dam (1997 to 1999, All Locations)

	Ag	**As**	**Be**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Se**	**Sb**	**Tl**	**Zn**	**TOC**	**AVS**
Ag	1.00														
As	0.72	1.00													
Be	0.44	0.78	1.00												
Cd	0.63	0.51	0.12	1.00											
Cr	**0.89**	0.65	0.42	0.47	1.00										
Cu	0.77	0.29	-0.02	0.73	0.65	1.00									
Hg	**0.95**	0.72	0.40	**0.83**	**0.86**	**0.83**	1.00								
Ni	**0.87**	0.38	0.05	0.60	**0.86**	**0.89**	**0.86**	1.00							
Pb	0.70	0.61	0.47	0.52	**0.87**	0.57	0.79	0.72	1.00						
Se	0.06	-0.25	-0.23	0.17	0.02	0.38	0.28	0.29	0.11	1.00					
Sb	**0.88**	0.63	0.30	0.59	**0.89**	**0.80**	**0.90**	**0.87**	0.72	0.22	1.00				
Tl	0.32	0.15	-0.02	0.65	0.03	0.63	0.44	0.26	-0.03	0.17	0.32	1.00			
Zn	0.72	0.53	0.19	**0.89**	0.73	0.76	**0.89**	0.75	**0.80**	0.21	0.73	0.40	1.00		
TOC	0.09	0.06	-0.29	0.60	-0.05	0.38	0.25	0.14	-0.05	0.41	0.20	0.61	0.43	1.00	
AVS	0.32	0.27	-0.10	0.29	0.19	0.36	0.46	0.22	-0.04	-0.29	0.39	0.54	0.22	0.34	1.00

(n = 15, except for Hg where n =12)
(Bold indicates a significant correlation, p-value <0.05)

Hanford Reach (1998 to 1999, All Locations)

	Ag	**As**	**Be**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Se**	**Sb**	**Tl**	**Zn**	**TOC**	**AVS**
Ag	1.00														
As	**0.88**	1.00													
Be	0.03	0.30	1.00												
Cd	0.74	0.50	-0.53	1.00											
Cr	0.49	0.66	0.80	-0.16	1.00										
Cu	**0.94**	**0.83**	-0.11	**0.88**	0.31	1.00									
Hg	0.68	**0.81**	0.28	0.52	0.34	0.73	1.00								
Ni	**0.93**	**0.83**	0.07	0.79	0.46	**0.97**	0.71	1.00							
Pb	0.55	0.33	0.05	0.66	0.14	0.68	0.49	0.76	1.00						
Se	0.36	0.41	0.55	0.25	0.35	0.44	0.74	0.55	0.75	1.00					
Sb	0.22	0.55	0.78	-0.44	**0.87**	0.01	0.25	0.11	-0.32	0.10	1.00				
Tl	0.78	0.68	0.46	0.47	0.60	0.73	0.70	**0.83**	0.78	**0.80**	0.24	1.00			
Zn	0.53	0.28	-0.54	**0.94**	-0.30	0.75	0.40	0.69	0.77	0.33	-0.62	0.39	1.00		
TOC	**0.95**	**0.92**	0.12	0.75	0.45	**0.95**	**0.86**	**0.94**	0.61	0.56	0.22	**0.82**	0.57	1.00	
AVS	0.31	0.32	0.08	-0.16	0.39	0.02	-0.10	-0.04	-0.55	-0.51	0.57	-0.04	-0.48	0.12	1.00

(n = 11, except for Hg where n = 7)
(Bold indicates a significant correlation, p-value <0.05)

Table A.4. Correlation Between Total Organic Carbon, Acid-Volatile Sulfide, and Total Metals

McNary Dam (1997 to 1999, All Locations)

	Ag	**As**	**Be**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Se**	**Sb**	**Tl**	**Zn**	**TOC**	**AVS**
Ag	1.00														
As	0.72	1.00													
Be	0.27	0.60	1.00												
Cd	0.34	0.47	0.01	1.00											
Cr	0.76	0.76	0.35	0.46	1.00										
Cu	0.74	0.76	0.13	0.61	0.71	1.00									
Hg	0.60	0.56	0.30	0.75	0.47	0.33	1.00								
Ni	0.66	**0.80**	0.23	0.55	0.78	**0.94**	0.35	1.00							
Pb	0.51	0.58	0.37	0.52	0.69	0.51	0.24	0.52	1.00						
Se	0.36	0.64	0.48	-0.02	0.27	0.29	0.26	0.35	0.24	1.00					
Sb	0.78	0.76	0.30	0.54	**0.89**	0.77	0.43	0.73	**0.82**	0.30	1.00				
Tl	0.20	0.40	0.36	0.65	0.47	0.28	0.73	0.39	0.52	-0.14	0.35	1.00			
Zn	0.23	0.33	-0.13	**0.91**	0.33	0.52	0.71	0.52	0.40	-0.04	0.37	0.61	1.00		
TOC	0.54	0.77	0.49	0.47	0.66	0.68	0.39	0.74	0.66	0.26	0.74	0.49	0.33	1.00	
AVS	0.53	0.52	0.02	0.64	0.60	0.56	0.38	0.54	0.61	-0.02	0.62	0.62	0.52	0.62	1.00

(n = 16, except for Hg where n =12)
(Bold indicates a significant correlation, p-value <0.05)

Ice Harbor Dam (1998 to 1999, All Locations)

	Ag	**As**	**Be**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Se**	**Sb**	**Tl**	**Zn**	**TOC**	**AVS**
Ag	1.00														
As	**0.88**	1.00													
Be	0.03	0.30	1.00												
Cd	0.74	0.50	-0.53	1.00											
Cr	0.49	0.66	0.80	-0.16	1.00										
Cu	**0.94**	**0.83**	-0.11	**0.88**	0.31	1.00									
Hg	0.68	**0.81**	0.28	0.52	0.34	0.73	1.00								
Ni	**0.93**	**0.83**	0.07	0.79	0.46	**0.97**	0.71	1.00							
Pb	0.55	0.33	0.05	0.66	0.14	0.68	0.49	0.76	1.00						
Se	0.36	0.41	0.55	0.25	0.35	0.44	0.74	0.55	0.75	1.00					
Sb	0.22	0.55	0.78	-0.44	**0.87**	0.01	0.25	0.11	-0.32	0.10	1.00				
Tl	0.78	0.68	0.46	0.47	0.60	0.73	0.70	**0.83**	0.78	**0.80**	0.24	1.00			
Zn	0.53	0.28	-0.54	**0.94**	-0.30	0.75	0.40	0.69	0.77	0.33	-0.62	0.39	1.00		
TOC	**0.95**	**0.92**	0.12	0.75	0.45	**0.95**	**0.86**	**0.94**	0.61	0.56	0.22	**0.82**	0.57	1.00	
AVS	0.31	0.32	0.08	-0.16	0.39	0.02	-0.10	-0.04	-0.55	-0.51	0.57	-0.04	-0.48	0.12	1.00

(n = 6)
(Bold indicates a significant correlation, p-value <0.05)

Table A.5. Total Metals Results (dry weight basis) for 1998 Size Fractionated Sediment Samples (μmol/g)

Location	Size	Weight %	Ag	As	Be	Cd	Cr	Cu	Hg	Ni	Pb	Sb	Se	Tl	Zn
Priest Rapids Dam (Columbia River)															
Near Grant County Shore	CS	0.81	0.002030	0.5576	0.055	0.4928	0.451	2.002	0.003555	0.603	0.4991	0.02074	0.0379	0.03715	44.06
Near Grant County Shore	MS	6.04	0.000936	0.1029	0.023	0.1300	0.227	0.910	0.002243	0.273	0.1734	0.00657	0.0141	0.01109	12.98
Near Grant County Shore	FS	45.20	0.000471	0.0334	0.073	0.0662	0.731	0.507	0.000412	0.513	0.1068	0.00441	*0.0060*	0.01005	8.46
Near Grant County Shore	VFS	28.30	0.000349	0.0327	0.077	0.0268	1.277	0.308	0.000306	0.424	0.0857	0.00415	*0.0060*	0.00503	4.16
Near Grant County Shore	SC	19.60	0.001557	0.0663	0.050	0.0291	1.433	0.686	0.000563	0.680	0.1387	0.00649	0.0068	0.00382	5.52
1/3 From Grant County Shore	CS	1.75	0.000319	0.0826	0.075	0.1836	0.439	0.623	0.000912	0.343	0.1823	0.00586	0.0060	0.01440	18.36
1/3 From Grant County Shore	MS	5.17	0.000745	0.1267	0.071	0.2722	0.455	1.135	0.001560	0.418	0.3421	0.00957	0.0106	0.01574	24.78
1/3 From Grant County Shore	FS	47.30	0.000355	0.0259	0.068	0.0377	0.583	0.329	0.000431	0.426	0.1133	0.00315	0.0060	0.00533	6.36
1/3 From Grant County Shore	VFS	35.67	0.000251	0.0274	0.075	0.0216	1.287	0.251	0.000255	0.416	0.0862	0.00349	0.0060	0.00349	3.70
1/3 From Grant County Shore	SC	10.09	0.001984	0.0634	0.094	0.0521	1.747	0.888	0.000678	0.826	0.2194	0.00830	0.0070	0.00473	9.00
2/3 From Grant County Shore	CS	0.21	0.001798	0.3665	0.130	0.3946	0.816	1.681	0.003061	0.755	0.4396	0.01327	0.0196	0.02136	22.18
2/3 From Grant County Shore	MS	2.66	0.000955	0.1444	0.129	0.0865	0.997	0.905	0.000788	0.832	0.2375	0.00617	0.0057	0.01097	14.03
2/3 From Grant County Shore	FS	62.70	0.000401	0.0265	0.109	0.0088	0.680	0.228	0.000194	0.347	0.0800	0.00203	0.0057	0.00250	3.36
2/3 From Grant County Shore	VFS	18.70	0.000334	0.0345	0.082	0.0096	1.504	0.269	0.000210	0.520	0.0886	0.00238	0.0057	0.00257	3.67
2/3 From Grant County Shore	SC	15.70	0.002475	0.0963	0.103	0.0556	1.742	0.966	0.000793	0.940	0.3055	0.00853	0.0061	0.00522	8.82
Near Yakima County Shore	CS	3.40	0.000179	0.0395	0.088	0.0429	0.562	0.378	0.000623	0.328	0.0960	0.00181	0.0057	0.01311	6.46
Near Yakima County Shore	MS	6.53	0.000441	0.1096	0.121	0.0759	0.423	0.488	0.000613	0.362	0.1482	0.00334	0.0057	0.01714	7.78
Near Yakima County Shore	FS	31.30	0.000436	0.0388	0.092	0.0603	0.646	0.540	0.000588	0.427	0.1423	0.00316	0.0057	0.01123	7.09
Near Yakima County Shore	VFS	18.30	0.000606	0.0357	0.126	0.0341	0.988	0.449	0.000608	0.492	0.1342	0.00439	0.0057	0.00724	5.91
Near Yakima County Shore	SC	40.50	0.002262	0.0681	0.105	0.0422	1.681	0.960	0.000703	0.870	0.2239	0.00818	0.0057	0.00590	6.62
Grant County Shore Near Dam	CS	0.10	0.003504	0.4070	0.045	0.7544	0.686	2.625	0.009871	0.532	0.7375	0.02695	0.0285	0.02735	56.91
Grant County Shore Near Dam	MS	0.70	0.004023	0.5016	0.088	0.5552	0.987	2.804	0.006082	0.695	0.7491	0.02595	0.0348	0.02721	42.37
Grant County Shore Near Dam	FS	11.00	0.001752	0.0975	0.075	0.1936	0.935	1.147	0.002134	0.726	0.3284	0.00903	0.0095	0.02066	18.36
Grant County Shore Near Dam	VFS	36.40	0.000899	0.0716	0.130	0.0657	0.973	0.544	0.000748	0.537	0.1664	0.00490	0.0057	0.01010	8.08
Grant County Shore Near Dam	SC	51.80	0.002670	0.0574	0.138	0.0549	1.673	1.049	0.000838	0.848	0.2578	0.00897	0.0094	0.00691	8.47
Yakima County Shore Near Dam	CS	0.16	0.005164	0.5228	0.052	0.9769	0.975	3.712	0.005035	0.818	0.5816	0.03659	0.0441	0.01934	31.97
Yakima County Shore Near Dam	MS	1.39	0.003273	0.1672	0.058	0.3775	0.981	2.261	0.002453	0.742	0.3835	0.02044	0.0213	0.01318	16.22
Yakima County Shore Near Dam	FS	22.90	0.000904	0.0407	0.067	0.0446	1.062	0.527	0.000613	0.685	0.1599	0.00606	0.0066	0.00531	7.09
Yakima County Shore Near Dam	VFS	16.60	0.000916	0.0393	0.084	0.0367	1.437	0.547	0.000633	0.789	0.1673	0.00655	0.0069	0.00541	6.61
Yakima County Shore Near Dam	SC	59.00	0.002651	0.0757	0.089	0.0517	1.651	0.927	0.000962	0.905	0.2861	0.01050	0.0104	0.00538	8.41

Italicized numbers were undetected at the given value.

CS = Coarse Sand; MS = Medium Sand; FS = Fine Sand; VFS = Very Fine Sand; SC = Silt and Clay.

Table A.6. Total Metals Results (dry weight basis) for 1998 Size Fractionated Sediment Samples (μmol/g)

Location	Size	Weight %	Ag	As	Be	Cd	Cr	Cu	Hg	Ni	Pb	Sb	Se	Tl	Zn
Hanford Reach (Columbia River)															
White Bluffs Slough	CS	0.49	0.002549	0.2564	0.138	0.1038	1.374	1.687	0.001286	0.717	0.5464	0.00881	0.0191	0.01636	20.80
White Bluffs Slough	MS	34.00	0.000522	0.0641	0.158	0.0205	0.785	0.504	0.000294	0.313	0.1809	0.00442	0.0198	0.00953	6.64
White Bluffs Slough	FS	51.40	0.000696	0.0518	0.149	0.0311	1.795	0.548	0.000408	0.493	0.2265	0.00526	*0.0057*	0.00993	9.41
White Bluffs Slough	VFS	3.75	0.001975	0.0841	0.145	0.0526	1.567	0.864	0.000838	0.686	0.3554	0.00755	0.0132	0.00611	10.39
White Bluffs Slough	SC	10.30	0.001455	0.0602	0.138	0.0426	1.312	0.633	0.000628	0.516	0.2792	0.00570	*0.0057*	0.00677	9.45
100-F Area Slough	CS	6.07	0.000080	0.0133	0.017	0.0008	0.058	0.110	0.000085	0.050	0.0136	0.00054	*0.0060*	0.00082	0.73
100-F Area Slough	MS	62.20	0.000158	0.0338	0.067	0.0031	0.509	0.279	0.000118	0.232	0.0638	0.00210	*0.0060*	0.00277	2.38
100-F Area Slough	FS	31.20	0.000248	0.0438	0.081	0.0033	0.819	0.411	0.000096	0.280	0.0815	0.00465	*0.0060*	0.00256	2.65
100-F Area Slough	VFS	0.33	0.000382	0.0386	0.065	0.0075	2.623	0.433	0.000191	0.440	0.0813	0.00428	*0.0060*	0.00178	3.17
100-F Area Slough	SC	0.19	0.001622	0.1476	0.079	0.1072	1.608	1.054	0.001186	0.689	0.2976	0.01232	0.0068	0.00470	11.10
Old Hanford Townsite Slough	CS	0.15	0.001965	0.5507	0.120	0.0980	0.704	1.380	0.001102	0.503	0.2740	0.01395	0.0223	0.01868	10.29
Old Hanford Townsite Slough	MS	3.52	0.000553	0.0929	0.154	0.0141	0.657	0.430	0.000239	0.601	0.1154	0.00410	0.0063	0.01512	3.79
Old Hanford Townsite Slough	FS	74.38	0.000509	0.0307	0.185	0.0056	0.811	0.223	0.000952	0.352	0.0808	0.00267	*0.0057*	0.00523	1.97
Old Hanford Townsite Slough	VFS	13.90	0.000562	0.0281	0.124	0.0048	1.388	0.189	0.000054	0.364	0.0710	0.00261	*0.0057*	0.00272	2.00
Old Hanford Townsite Slough	SC	8.07	0.001455	0.0643	0.151	0.0210	1.557	0.619	0.000356	0.624	0.1766	0.00678	0.0066	0.00361	4.50
Richland Pumphouse	CS	0.29	0.001956	1.2673	0.095	0.0293	0.784	0.954	0.000454	0.332	1.7269	0.02315	0.0067	0.00320	6.98
Richland Pumphouse	MS	6.80	0.001001	0.3241	0.124	0.0116	0.704	0.504	0.000187	0.269	0.5213	0.00858	0.0066	0.00343	6.04
Richland Pumphouse	FS	74.10	0.000746	0.0938	0.092	0.0070	0.744	0.351	0.000091	0.262	0.2928	0.00571	*0.0057*	0.00233	4.32
Richland Pumphouse	VFS	12.40	0.002586	0.2384	0.136	0.0080	1.176	0.668	0.000249	0.425	0.7413	0.01485	*0.0057*	0.00266	8.30
Richland Pumphouse	SC	6.40	0.005952	0.5619	0.163	0.0170	1.329	1.318	0.000758	0.548	1.4769	0.03314	0.0095	0.00318	13.89
Ice Harbor Dam (Snake River)															
Franklin County Shore	CS	1.30	0.000416	0.1694	0.179	0.0009	1.082	0.414	0.000028	0.424	0.0780	0.00805	*0.0045*	0.00233	2.03
Franklin County Shore	MS	8.51	0.000246	0.1135	0.144	0.0008	0.680	0.277	*0.000008*	0.296	0.0693	0.00612	*0.0045*	0.00225	1.37
Franklin County Shore	FS	63.50	0.000222	0.0644	0.145	0.0008	0.821	0.228	*0.000008*	0.254	0.0528	0.00460	*0.0045*	0.00155	1.11
Franklin County Shore	VFS	8.56	0.000711	0.1447	0.159	0.0016	1.048	0.514	*0.000008*	0.429	0.0776	0.00876	*0.0045*	0.00213	1.77
Franklin County Shore	SC	18.10	0.000737	0.1474	0.158	0.0019	1.113	0.532	0.000228	0.457	0.0828	0.00902	*0.0045*	0.00225	1.84
Mid River	CS	0.02	0.001891	0.2264	0.219	0.0173	0.711	1.006	0.019044	0.428	0.0688	0.01520	0.0227	0.00154	3.14
Mid River	MS	0.21	0.001752	0.2547	0.136	0.0112	1.033	0.924	0.001665	0.527	0.0881	0.01290	0.0130	0.00250	2.18
Mid River	FS	7.61	0.000434	0.0855	0.073	0.0012	0.757	0.283	0.000170	0.297	0.0546	0.00505	*0.0057*	0.00181	1.28
Mid River	VFS	12.30	0.000441	0.0557	0.090	0.0008	0.815	0.256	0.000135	0.296	0.0502	0.00343	*0.0057*	0.00163	1.35
Mid River	SC	79.80	0.000723	0.1057	0.172	0.0018	0.930	0.530	0.000224	0.414	0.0806	0.00562	*0.0057*	0.00210	1.98
Walla Walla County Shore	CS	0.00	0.001687	0.1769	*0.014*	0.0008	*0.004*	3.371	0.002298	0.267	0.0475	0.00978	*0.0060*	0.00013	1.07
Walla Walla County Shore	MS	0.13	0.001400	0.1479	0.070	0.0052	0.586	1.119	0.001680	0.452	0.0733	0.01106	0.0137	0.00174	2.58
Walla Walla County Shore	FS	2.44	0.000790	0.1095	0.091	0.0022	0.867	0.614	0.000419	0.459	0.0693	0.00691	0.0071	0.00228	2.58
Walla Walla County Shore	VFS	12.40	0.000570	0.0849	0.114	0.0014	0.858	0.487	0.000217	0.396	0.0601	0.00558	*0.0060*	0.00204	1.34
Walla Walla County Shore	SC	85.00	0.000716	0.1083	0.160	0.0017	0.864	0.474	0.000543	0.369	0.0724	0.00541	*0.0060*	0.00199	1.79

Italicized numbers were undetected at the given value.
CS = Coarse Sand; MS = Medium Sand; FS = Fine Sand; VFS = Very Fine Sand; SC = Silt and Clay.

Table A.7. Total Metals Results (dry weight basis) for 1998 Size Fractionated Sediment Samples (μmol/g)

Location	Size	Weight %	Ag	As	Be	Cd	Cr	Cu	Hg	Ni	Pb	Sb	Se	Tl	Zn
McNary Dam (Columbia River)															
Near Oregon Shore	CS	0.06	0.002586	0.3090	0.204	0.1580	0.359	1.937	0.002278	0.650	0.2158	0.02843	0.0286	0.00881	19.43
Near Oregon Shore	MS	0.15	0.003532	0.3357	0.150	0.1429	0.979	1.972	0.003395	0.668	0.2403	0.02420	0.0315	0.00984	16.98
Near Oregon Shore	FS	1.66	0.001761	0.1229	0.136	0.0405	1.183	0.966	0.001027	0.705	0.1464	0.00899	0.0067	0.00715	7.25
Near Oregon Shore	VFS	11.00	0.001289	0.0627	0.129	0.0168	0.861	0.469	0.000472	0.466	0.0951	0.00600	*0.0045*	0.00377	3.73
Near Oregon Shore	SC	87.20	0.001224	0.0815	0.136	0.0115	1.104	0.562	0.000385	0.503	0.1012	0.00627	0.0046	0.00309	3.11
1/3 Oregon Shore	CS	0.21	0.000693	0.0522	0.015	0.0555	*0.004*	0.437	0.002378	0.103	0.0359	0.00335	*0.0045*	0.00131	4.27
1/3 Oregon Shore	MS	0.28	0.003235	0.2547	0.125	0.1336	1.145	1.331	0.002228	0.622	0.1866	0.01357	0.0116	0.00604	9.49
1/3 Oregon Shore	FS	3.51	0.001520	0.1877	0.110	0.0534	0.990	0.698	0.001092	0.570	0.1355	0.00832	*0.0045*	0.00553	7.27
1/3 Oregon Shore	VFS	11.70	0.001020	0.1210	0.111	0.0352	0.988	0.477	0.000603	0.510	0.1111	0.00654	*0.0045*	0.00495	5.40
1/3 Oregon Shore	SC	84.30	0.001882	0.0953	0.114	0.0259	1.149	0.660	0.000613	0.511	0.1308	0.00771	*0.0045*	0.00393	4.84
2/3 Oregon Shore	CS	0.01	0.002364	0.1415	*0.014*	0.1381	*0.004*	1.640	0.008874	0.456	0.1318	0.00986	*0.0060*	0.00561	9.43
2/3 Oregon Shore	MS	0.19	0.005525	0.4567	0.088	0.2194	1.440	2.592	0.005384	0.850	0.3276	0.02015	0.0323	0.01039	14.51
2/3 Oregon Shore	FS	9.34	0.000918	0.0925	0.088	0.0222	0.944	0.505	0.000892	0.553	0.1272	0.00954	0.0069	0.00595	7.69
2/3 Oregon Shore	VFS	31.40	0.000623	0.0426	0.061	0.0096	0.751	0.272	0.000318	0.358	0.0840	0.00444	0.0069	0.00335	3.62
2/3 Oregon Shore	SC	59.00	0.001029	0.0997	0.085	0.0169	1.189	0.474	0.000658	0.491	0.1153	0.00595	*0.0060*	0.00342	4.10
Near Washington Shore	CS	0.02	0.000312	0.0198	0.038	0.0210	0.081	0.251	0.004567	0.100	0.0229	0.00182	*0.0045*	0.00062	3.03
Near Washington Shore	MS	0.63	0.000311	0.0408	0.110	0.0151	0.473	0.322	0.001845	0.234	0.0687	0.00317	*0.0045*	0.00350	3.46
Near Washington Shore	FS	23.90	0.000354	0.0371	0.150	0.0053	0.519	0.189	0.000288	0.233	0.0650	0.00332	*0.0045*	0.00321	3.91
Near Washington Shore	VFS	34.50	0.000312	0.0428	0.120	0.0055	0.777	0.194	0.000251	0.276	0.0649	0.00378	*0.0045*	0.00268	2.44
Near Washington Shore	SC	41.00	0.000936	0.0959	0.135	0.0183	1.254	0.468	0.000598	0.485	0.1209	0.00628	*0.0045*	0.00384	4.01
Oregon Shore Near Dam	CS	0.02	0.002883	0.2523	*0.014*	0.2203	0.322	1.796	0.003136	0.554	0.1462	0.00324	*0.0060*	0.00665	5.74
Oregon Shore Near Dam	MS	0.23	0.003171	0.3039	0.159	0.1125	1.021	1.384	0.002353	0.662	0.1812	0.01052	0.0171	0.00643	5.98
Oregon Shore Near Dam	FS	4.01	0.001836	0.1974	0.163	0.0391	1.069	0.749	0.000857	0.647	0.1644	0.00956	0.0101	0.00751	6.53
Oregon Shore Near Dam	VFS	18.90	0.000911	0.0933	0.168	0.0148	0.878	0.372	0.000342	0.422	0.1044	0.00500	*0.0060*	0.00424	3.62
Oregon Shore Near Dam	SC	76.90	0.001539	0.1085	0.182	0.0164	1.035	0.555	0.000471	0.489	0.1210	0.00571	*0.0060*	0.00408	3.65
Washington Shore Near Dam	CS	0.00	0.001493	0.1587	*0.014*	0.2332	0.618	1.319	NA	0.577	0.1388	0.00253	*0.0060*	0.00635	9.76
Washington Shore Near Dam	MS	0.29	0.001150	0.1847	0.145	0.0658	1.123	0.832	0.002189	0.574	0.3787	0.01970	0.0067	0.00756	8.10
Washington Shore Near Dam	FS	6.80	0.000901	0.0948	0.168	0.0221	0.946	0.366	0.001022	0.426	0.1197	0.00388	*0.0060*	0.00495	5.44
Washington Shore Near Dam	VFS	27.10	0.000651	0.0741	0.143	0.0157	0.816	0.321	0.000400	0.394	0.1083	0.00352	*0.0060*	0.00399	4.08
Washington Shore Near Dam	SC	65.80	0.001400	0.1165	0.189	0.0225	1.102	0.579	0.000887	0.525	0.1485	0.00571	*0.0060*	0.00414	4.69

Italicized numbers were undetected at the given value.

CS = Coarse Sand; MS = Medium Sand; FS = Fine Sand; VFS = Very Fine Sand; SC = Silt and Clay.

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