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# Environmental Monitoring of Columbia River Sediments: Grain-Size Distribution and Contaminant Association

M. L. Blanton
W. W. Gardiner
R. L. Dirkes

April 1995

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

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Pacific Northwest Laboratory
Richland, Washington 99352

# Summary

Hanford Site-derived pollutants are transported in surface waters in the particulate or dissolved form. Particulate transport is facilitated by sorption to minerally or organically derived material. In fluvial systems, particulate transport is based on particle size, particle density, and water velocity. Contaminants associated with minerals are transported and deposited differently than those contaminants associated with organic carbon. In the Columbia River, sediment grain size and organic content can vary greatly from one location to another, resulting in significant differences in contaminant partitioning and transport. Previous evaluations of Columbia River sediments were typically performed on samples of bulk sediment and did not consider the physical (i.e., grain-size distribution) or chemical (i.e., organic carbon content) characteristics of a given site.

A study to determine the characteristics associated with contaminant absorption was developed with the following objectives: 1) document the differences in sediment grain size and organic content and 2) determine associations between grain size, organic matter, and contaminants in sediments occurring at six established monitoring sites. Sediments at the six monitoring-site locations were analyzed for grain size, total organic carbon (TOC) content, radionuclides, metals, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, and pesticides. This study demonstrated the utility of sediment grain characterization and TOC analysis in interpreting sediment-monitoring data.

Grain size and organic content varied greatly among samples. Sediment from the Priest Rapids Dam monitoring sites were predominantly fine and very fine silt. Samples collected from the Hanford Reach monitoring sites were dominated by medium and fine sand, with the exception of White Bluffs Slough sediment that had nearly equal amounts of fine sand, very fine sand, and silt. The McNary Dam monitoring sites were characterized by very fine sand on the Washington shore and silt and clay on the Oregon shore. The TOC content among all sites ranged from 0.03% to 1.82%, with the higher TOC content generally associated with finer-grained sediment.

This study found the majority of radionuclide concentrations to be below minimum detection levels at all sites, with the exception of $^{137}Cs$ and $^{238}U$. While the highest concentrations of $^{137}Cs$ and $^{238}U$ were found in sediments from the McNary Dam monitoring sites, concentrations measured at the other three sites did not differ greatly. All metals were detected in each sediment sample. Sediment from the McNary Dam monitoring sites had the highest concentrations of metals, with the exception of barium, lead, and zinc. A transect across the McNary Dam monitoring sites revealed gradually increasing metals concentrations toward the Oregon shore, with a direct correlation between grain size and TOC content with metals concentrations. Organics (i.e., polycyclic aromatic hydrocarbons, polychlorinated biphenyls, and pesticides) were undetected in nearly all sediments.

Metals concentrations by grain sizes in one sample analyzed were highest in the medium sand and clay fractions. Because this sample was composed of 1% medium sand and 33% clay, the metals are likely partitioned in the clay fraction, rather than in the medium sand. In addition, the medium sand fraction may be dominated by woody debris, increasing the TOC content and possibly skewing the metals partitioning.

The results of this study show that, among the Columbia River monitoring sites sampled, grain size and TOC vary greatly. In addition, metals concentrations appear to be associated with both finer-grain-size fractions and TOC. This trend was seen in bulk sediment samples, as well as the fractioned sample. Variations in sediment grain size and TOC within the Columbia River sediments and the differential partitioning of metals to fine-grained sediments can impact the fate and effect of Hanford Site-derived pollutants. Sediment grain characterization and TOC analysis should be included in interpretations of sediment-monitoring data and in choosing monitoring-site locations.

The results of this study will aid the Surface Environmental Surveillance Project in communicating to the public why differences occur in concentrations of contaminants in sediments throughout the Columbia River and in enabling direct comparisons between sediment-monitoring sites to account for grain size and TOC effects on sediment contaminant sorption when reporting monitoring results.

# Acknowledgments

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# Introduction

The Hanford Site, located in south-central Washington state, is approximately 1450 $km^2$ of semiarid shrub and grasslands located approximately 11 km north of the confluence of the Yakima and Columbia rivers. The Hanford Site, for many years, was dedicated to the production of plutonium for national defense and to the management of the resulting wastes. Defense production produced approximately 1.4 billion $m^3$ of hazardous or radioactive liquids and solids (EPA 1989a). Between 1944 and 1970, the mid-Columbia River received radioactive waste and, to a lesser extent, hazardous contaminants as a consequence of plutonium production. With the shutdown of the once-through production reactors in 1966 through 1971, the radionuclide burden in Columbia River sediments decreased as the result of radioactive decay, subsequent deposition of uncontaminated material, and downriver transport of contaminated sediments. However, discharges of some radionuclides and nonradiological chemicals still occur through seepage of contaminated groundwater into the river. It is expected that some of this material is either deposited directly to the river bottom or is sorbed to the sediment material and then deposited onto the river bottom. Also, radionuclides in solution can be transported out of the river system and into the Pacific Ocean.

This report documents the results of a study conducted by Pacific Northwest Laboratory[a] for the U.S. Department of Energy as part of the Hanford Site-wide Surface Environmental Surveillance Project (SESP). The SESP is responsible for assessing onsite and offsite environmental impacts and estimating offsite human health exposures. The project monitors air, surface water, sediment, agricultural products, vegetation, soil, and wildlife. In addition, the project conducts independent onsite surveillance to evaluate the effectiveness of Hanford Site effluent controls and, to this end, established six sediment-monitoring sites on the Columbia River between Priest Rapids and McNary dams (Figure 1). The sites are routinely sampled and analyzed as part of the surface-water-monitoring program. The objectives of the SESP sediment surveillance activities are to 1) verify that doses resulting from Hanford Site operations through the surface-water pathway remain low, 2) provide an indication of changes in environmental conditions that potentially increase or decrease the chance of public exposures, and 3) provide public assurance that the radiological and nonradiological chemical conditions and potential exposure pathways are understood and receive appropriate attention.

In fluvial systems, nutrients and toxic constituents are distributed and cycled through various environmental media. A clear understanding of how contaminants are distributed once they have entered aquatic systems is extremely important to meet the above-stated objectives. Research on the fate and transport of contaminants has shown that both grain size and total organic carbon (TOC) content of sediments greatly influence the sorption of contaminants onto sediments. However, the use of such information in interpreting data from surveillance programs is not in wide practice. There can be wide variability in streambed sediment characteristics along the Columbia River, making direct comparisons of sediment-monitoring results from one location to another difficult without understanding the effects such characteristics have on contaminant sorption. Without such understanding, the ultimate fate and transport of Hanford Site-derived contaminants and the potential exposure of contaminants to wildlife and humans will be difficult to discern.

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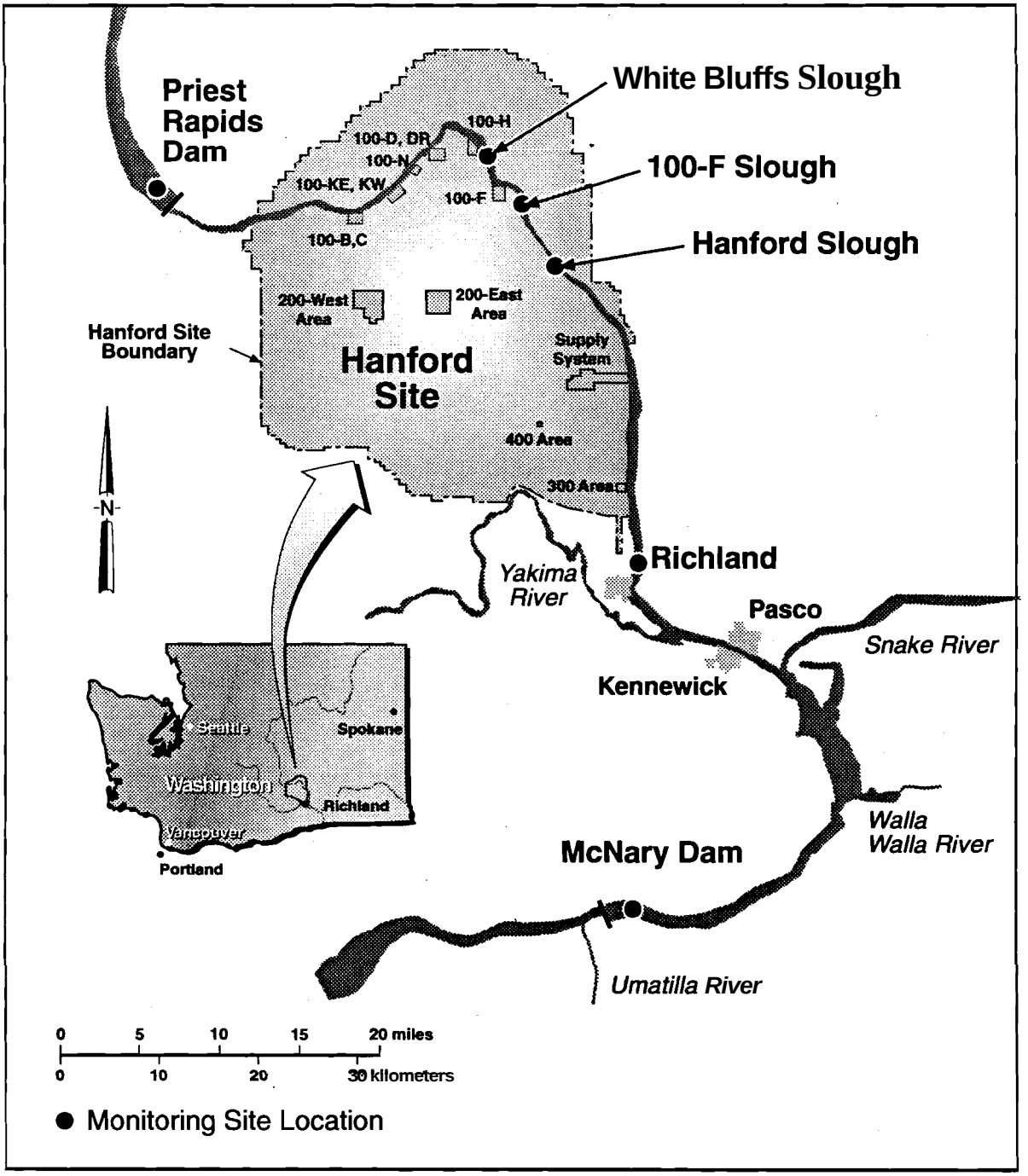


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**Figure 1. Surface Environmental Surveillance Project Routine Sediment-Monitoring Sites**

The objectives of this study were as follows:

- document the differences in sediment grain size and TOC content of sediments occurring at the six sediment-monitoring sites along the Columbia River

- determine associations between grain size, organic matter, and contaminants in sediments occurring at the six sediment-monitoring sites.

Sediments at the monitoring-site locations (see Figure 1) were analyzed for grain size, TOC, radionuclides, metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and pesticides. In addition, one sample was separated into grain-size fractions, and each grain-size fraction underwent metals and TOC analyses to discern associations between contaminant and grain-size fraction.

This report contains discussions of the study area background; the materials and methods used in the analyses; the results of grain size and TOC, radionuclides, metals, and organics analyses; the conclusions drawn from the analyses; and the references cites herein. Appendix A provides the quality assurance/quality control summary, and Appendix B gives the results for the radionuclide analyses.

# Study Area Background

This section briefly describes the hydrologic characteristics of the Columbia River and the factors that influence sediment and contaminant transport and fate.

## Hydrologic Setting

The Columbia River is the fifth largest river (by volume) in North America and is the largest river in the Pacific Northwest. Water quality between Grand Coulee Dam and the mouth of the river is classified as Class A (excellent) by the State of Washington Department of Ecology (DOE 1988). The Columbia River flow is regulated by 11 dams within the United States, 7 of which are upstream of the Hanford Site and 4 downstream. The nearest upstream dam from the Hanford Site boundary is Priest Rapids Dam, which is approximately 9 km away. The first downstream dam is McNary Dam, which is approximately 112 km from the Hanford Slough (see Figure 1). The portion of the river downstream of Priest Rapids Dam to the head of Lake Wallula (near the city of Richland) is called the Hanford Reach and is the only remaining "free-flowing" section of the river within the system above Bonneville Dam. This portion of the river has some unique aspects as a result of being unimpounded; in particular, the reach is the largest track of chinook salmon-spawning habitat left on the river that is still used.

Although the Hanford Reach is considered to be free flowing, the flow is regulated and varies markedly because of the relatively small storage capacity and operational practices of Priest Rapids Dam. The average annual flow in the Hanford Reach is approximately 3400 $m^3/s$, based on approximately 65 years of historical data (DOE 1987). Typical daily flow rates in the Hanford Reach during summer, fall, and winter range from 1000 to 7100 $m^3/s$; during spring runoff periods, flows can reach 12,700 $m^3/s$ (Weiss 1993). Peak water (and sediment) discharge at the Columbia River mouth typically occurs during late spring and early summer as a result of snow melt in the foothills of the Cascade Range and in lower elevations of the Columbia River plateau (Hedges et al. 1984). Suspended sediment in the Hanford Reach is low, ranging from 1 to 7 mg/L (Friant and Brandt 1993).

The primary contributor of suspended sediment to the Columbia River is the Snake River (Whetten et al. 1969); however, the Yakima and Walla Walla rivers are also significant sources. Sediment contributions from these sources are highly seasonal and related to water-discharge patterns. Haushild (1980) reported that sand, silt, and clay are deposited in and near the mouth of the Yakima River (confluence with the Columbia River) toward the upstream end of Lake Wallula (i.e., the reservoir behind McNary Dam). This is in contrast to the armored, gravel streambed in the lower reach of the Snake River. Work by Hedges et al. (1984) examined the sedimentary organic matter at 16 sites along the Columbia River and selected tributaries for a total of 19 samples that were collected and analyzed from upstream of Grand Coulee Dam to the mouth of the Columbia River. The weight percentages of organic carbon in the 19 sediment samples ranged from 0.24% to 3.25%. and no correlation existed between TOC content and site location. Researchers noted that the TOC content of sediments behind individual reservoirs was extremely variable, averaging ±40% variation within the three individual test sites (Grand Coulee, Wells, and Oregon City dams). They did find a trend toward higher TOC content in finer-grained sediments. Sedimentation rates at certain sites behind McNary Dam have been postulated to be as high as 30 cm/yr (Robertson et al. 1973). Subsequent studies by

Beasley et al. (1986) reported sedimentation rates to average 7 ± 3 cm/yr along the Oregon shore, 4 ± 2 cm/yr at midchannel, and 2 ± 1 cm/yr for the Washington shore (values rounded to nearest whole number). Sediment accumulates faster on the Oregon shore than the Washington shore because sediment input from the Snake and Walla Walla rivers is constrained to the near shore (Oregon side).

Characteristics of the Columbia River streambed from the Hanford Reach downstream to The Dalles Dam was described by Haushild (1980) as "mostly armored with gravel and cobbles." This description would also adequately describe the streambed at Priest Rapids Dam. However, one result of the placement of dams along the Columbia River is the restriction of both suspended and bedload sediments behind the dams. This results in a short-term accumulation of sands and finer-grain-size classes behind the dams (Whetten et al. 1969). Based on visual observations from past sediment-monitoring samples taken for the SESP, characteristics of the top 1- to 5-cm portion of the bed sediment at Priest Rapids Dam appeared to be dominated by coarse to fine sands and silts. This is in contrast to visual observations made at the Hanford Reach monitoring sites, where cobble, coarse, and fine-sand-bed sediments were found and at the McNary Dam monitoring sites, where silt and clay sediments were found. From past sediment-sampling activities, it was clear that the sediment characteristics at individual monitoring-site locations were quite different, thus giving rise to this study (i.e., how the differences in sediment characteristics could be affecting contaminant sorption and subsequent data interpretation).

## Sorption of Contaminants by Sediments

The term sorption is used in this report to describe the accumulation of dissolved substances by solid particles. Sorption of anthropogenic contaminants onto suspended and bed sediments plays a major role in determining contaminant fate in fluvial systems. No simple relationship exists between sediment grain-size fraction and associated contaminant load. In general, pollutants and nutrients discharged into fluvial systems are associated with the finer sediment fractions. In terms of contaminant loading, larger grain-size fractions tend to have a dilution effect (Literathy et al. 1987). This inverse relationship between particle size and sorption (i.e., finer grain sizes having an increased concentration of metals and organics) has been noted by previous researchers (Lotse et al. 1968; Richardson and Epstein 1971; Gibbs 1973). Higher concentrations of metals have been shown to accumulate in the finer-grain-size fractions; this phenomenon has been attributed to the higher surface-area to grain-size ratio of the finer-grain sizes (Gibbs 1973; Sinex and Helz 1981). Another major factor in determining a solid's sorptive potential for both organics and inorganics is the TOC content of the sediment (Lambert 1967; Richardson and Epstein 1971; Karickhoff et al. 1978; Suzuki et al. 1979). Studies have also demonstrated an association between TOC with finer-grain-size fractions of <0.062 mm (i.e., silts and clays). Nelson et al. (1966) separated Columbia River sediment samples into various grain-size fractions, ranging from "<0.074 mm" to ">10 mm" while measuring $^{65}Zn$ and $^{60}Co$ activities in each fraction. The $^{65}Zn/^{60}Co$ activity ratios showed a decreasing trend with increasing particle size; activity ratios ranged from 24 (in the <0.074-mm grain size) to 6 for the very coarse material. A study by Tada and Suzuki (1982) found the main factor controlling adsorption of metal was organic matter content of the sediments. Metal concentrations (zinc, lead, chromium, copper, nickel, and mercury) in the western basin of Ontario were found to be associated with clay and silt-size grain fractions (Mudroch 1983). A study by Richardson and Epstein (1971) demonstrated that two hydrophobic compounds, 4,4-DDT and methoxychlor, were associated with

the finer particle sizes (clay), whereas the more soluble endosulfan preferred coarser material. Lambert and colleagues found that the sorption of neutral pesticides (organic) was strongly associated with the organic matter content of the soil (Lambert et al. 1965; Lambert 1967).

The above information indicates that direct comparison of radiological monitoring data, as well as those for metals and organics, should take into account the effects that grain size have on sorption. Both grain size and TOC content of sediments should be considered when interpreting results. Literathy et al. (1987) noted that comparisons of sediment contamination between sites would be impossible without taking into consideration and correcting for sediment grain-size effects.

# Materials and Methods

This section provides a description of the materials and methods used in this study for sample collection, grain size, TOC, radionuclides, metals, and organics analyses. Detailed information on each of the above methods along with corresponding information on quality assurance and quality control information is provided in Appendix A.

## Sample Collection

Surficial sediment samples (0 to 5 cm) were collected at 12 stations from the 6 SESP monitoring sites along the Columbia River (see Figure 1). At the monitoring sites at McNary and Priest Rapids dams, transects with four stations each were established across the river: Priest Rapids Dam Grant County shore, 1/3 distance from Grant County shore, 213 distance from Grant County shore, and opposite Yakima County shore. The same designations are used for McNary Dam across the river, starting on the Oregon shore: McNary Dam Oregon shore, 113 distance from Oregon shore, 2/3 distance from Oregon shore, and opposite Washington shore. At the Hanford Reach monitoring sites (White Bluffs Slough, 100-F Slough, Hanford Slough, and Richland Pumphouse), a single near-shore sample (Hanford Site shoreline) was collected. A single grab sample was taken at each sampling point using a Petite Ponar Grab Sampler (235-cm2 opening). One field replicate was taken at the McNary Dam site. Approximately 500 g of sediment were collected and placed into clean plastic bags for radiochemical analysis. Sediments for radiochemical analysis were placed on ice and shipped overnight to the analytical laboratory. Approximately 1 gal (by volume) of sediment was collected for nonradiochemical analysis; placed in solvent-rinsed, acid-cleaned glass jars; packaged in shipping crates with ice packs; and shipped overnight to the analytical laboratory. At the laboratory, samples were homogenized, using stainless steel mixing bowls and utensils, then subsampled for grain size, TOC, metals, PAHs, PCBs, and pesticides analysis.

## Grain Size and Total Organic Carbon Analysis

Two grain-size analyses were performed on each sample: one with organic digestion and one without organic digestion. Two TOC analyses were also performed: one on each sediment batch sample and one on each sample grain-size fraction. Grain-size analysis was performed following procedure PSEP (1986); TOC analysis was performed using a method similar to ASTM (1985). The reference detection limits were 1.0% for grain-size analysis and 0.1% for TOC analysis. Sediments were fractioned into grain sizes using the Wentworth grade of classification (EPA 1989b) presented below:

| Wentworth Classification | Grade Limits (mm) |
|---|---|
| Coarse sand | 1.000 to 0.500 |
| Medium sand | 0.500 to 0.250 |
| Fine sand | 0.250 to 0.125 |
| Very fine sand | 0.125 to 0.062 |
| Silt | 0.062 to 0.004 |
| Clay | < 0.004 |

When reporting grain-size distribution and TOC results for a given station, the "proportion" of TOC contribution was calculated by taking the TOC concentration for a given grain-size fraction multiplied by the relative contribution of that fraction to the whole sediment. This TOC proportion was used in generating several figures provided in the next section.

## Radionuclide Analysis

Radionuclide analysis consisted of a gamma scan, $^{90}Sr$, uranium ($^{235}U/^{238}U$), and isotopic plutonium. Gamma-emitting radionuclides were counted on either a germanium (lithium) (GE[Li]) or an Intrinsic (hyperpure) Germanium (HPGE) detector system. Strontium was precipitated from the sample as strontium oxalate, converted and precipitated as a carbonate, and counted on a low-background, gas-flow proportional counter for beta activity. The sample was counted directly for $^{235}U$ and $^{238}U$ by a low-energy photon-detection system. For plutonium isotopic analysis, the plutonium was coprecipitated with calcium oxalate, dissolved, loaded onto an anion-exchange resin column, eluted, plated, and counted on an alpha spectrometer.

## Metals Analysis

Bulk sediment samples from each site were analyzed for 11 metals. Eight metals (arsenic, barium, chromium, copper, manganese, lead, nickel, and zinc) were analyzed by energy-dispersive X-ray fluorescence using a Pacific Northwest Laboratory standard operating procedure. Mercury was analyzed using cold-vapor atomic absorption spectroscopy (Bloom and Crecelius 1983). Beryllium and cadmium were analyzed by inductively coupled plasma-mass spectrometry and Method 200.8 (EPA 1991). One sample from the McNary Dam monitoring site (213 from shore sample) was separated into grain-sizes fractions (Wentworth grade of classification) and each grain-size fraction underwent metals analysis.

## Organics Analysis

The analyses for PAHs followed Method 8270 (EPA 1986). Analyses for pesticides and PCBs followed Method 8080 (EPA 1986). The extractions for PAHs. PCBs, and pesticides were performed simultaneously using methylene chloride. The target detection limit for all PAHs and PCBs analyzed was 20 µg/kg. The minimum detection limit (MDL) for all organics was 2.0 µg/kg, with the exception of the multipeak compounds technical chlordane and toxaphene that were 30 µg/kg each.

# Results and Discussion

Sediments collected from each of the 12 stations at the 6 SESP monitoring sites were analyzed for grain size (with and without organic material), TOC, radionuclides, metals, PAHs, PCBs, and organics. The results and discussion are presented in this section for both individual monitoring sites and regional means. Regional means include the sampling stations in the Priest Rapids and McNary dams transects, as well as the Hanford Reach. The following discussion focuses on identifying differences in sediment grain size and organic content of sediments at monitoring-site locations and determining the associations among the contaminants, grain size, and TOC. It is important to note that the intent of this study was not to characterize the extent of anthropogenic contaminant loading to Columbia River sediments, but to determine the utility of sediment grain size and TOC data in interpreting monitoring data results.

In terms of contaminant burdens in sediments, this section will focus primarily on the radionuclides and metals results because much of the data for the PAHs, PCBs, and organics were below the MDLs. Thus, the ability to discern possible grain-size and TOC effects would be difficult and also because the release of such contaminants (PAHs, PCBs, and organics) was not a dominant component of the Hanford Site waste stream. Although much of the radionuclide results were also below the MDLs, a discussion of the results is warranted because of the quantity of historical releases and the public interest surrounding this form of contamination.

## Grain Size and Total Organic Carbon

Sediment grain-size distributions varied greatly among sampling sites (Table 1). Grain-size analysis was performed for both untreated (with organic material) and peroxide-treated (without organic material) sediments, with the intention of being able to discern which fractions were dominated by organic material (see Table 1). Grain-size distribution varied, with all grain-size fractions dominating at least one monitoring site, with the exception of the clay-size fraction. Small shifts in grain-size proportion occurred between fine/very fine sand and silt/clay fractions. Shifts in grain-size fractions in treated and untreated samples may have been caused by intersample variability (unknown) or by a decrease in particle size because of the removal of organics. A larger number of replicates would be needed to determine if perceived shifts found in this study were not an artifact of the precision of the laboratory method.

An inverse relationship between grain size and TOC (in that as the amount of sand in sediment increases, the amount of TOC decreases) is evident from monitoring-site data, with the exception of Priest Rapids Dam Grant County shore station. At the Priest Rapids Dam Grant County shore station, a higher TOC concentration existed than expected based on grain-size distribution. This also occurs to a lesser extent at the White Bluffs and Hanford Slough locations. This inverse sand/TOC relationship can be seen in the TOC/sand regression plot (Figure 2). All monitoring sites, except Priest Rapids Dam Grant County shore station, were included in the simple linear regression calculation ($Y = 1.913 - 0.017 * X$; $R^2 = 0.747$). The Priest Rapids Dam Grant County shore station was excluded as an outlier because of the presence of large woody debris apparent in the sand grain-size fractions resulting in higher concentrations of TOC to occur in this grain-size fraction.

Table 1. Sediment Grain-Size Distribution by Monitoring Site

| | | Dry Weight %[a] | | | | | |
|---|---|---|---|---|---|---|---|
| | Bulk TOC, % | Coarse Sand, 1.000 to 0.500mm | Medium Sand. 0.500 to 0.250mm | Fine Sand, 0.250 to0.125mm | Very Fine Sand, 0.125 to 0.062mm | Silt. 0.062 to 0.004mm | Clay, <0.004mm |
| PRD Grant County Shore | 1.82 | 5 (3) 11.28 | 4 (3) 7.01 | 41 (21) 0.97 | 32 (47) 0.36 | 15 (17) 1.15 | 5 (9) 7.11 |
| PRD Grant 1/3 | 0.59 | 10 (8) 2.88 | 5 (3) 2.43 | 40 (51) 0.24 | 36 (27) 0.11 | 6 (6) 1.30 | 3 (5) 5.28 |
| PRD Grant 2/3 | 0.09 | 40 (43) 0.05 | 29 (23) 0.02 | 21 (19) 0.07 | 6 (9) 0.14 | 4 (6)[b] 0.63 | (b) 2.41 |
| PRD Yakima County Shore | 0.69 | 10 (10) 1.14 | 4 (3) 2.27 | 25 (15) 2.52 | 29 (37) 0.19 | 27 (28) 0.31 | 7 (8) 3.58 |
| White Bluffs | 1.11 | 3 (0) 8.30 | 2 (1) | 28 (24) 0.57 | 35 (40) 0.29 | 25 (23) 1.14 | 4 (9) 6.34 |
| 100-F Slough | 0.08 | 7 (8) 0.02 | 63 (59) 0.01 | 25 (27) 0.01 | 3 (5) 0.05 | 2 (4)[b] 1.40 | (b) 3.52 |
| Hanford Slough | 1.08 | 4 (1) 8.89 | 7 (5) 3.00 | 59 (49) 0.23 | 18 (27) 0.53 | 11 (10) 3.81 | 4 (8) 7.57 |
| Richland Pumphouse | 0.03 | 0 (0) | 1 (1) 0.12 | 94 (90) 0.03 | 5 (8) 0.03 | 0 (1)[b] 1.66 | (b) 6.26 |
| McNary Oregon Shore | 1.39 | 9 (8) 0.69 | 1 (1) 6.61 | 5 (3) 1.32 | 24 (24) 0.49 | 49 (44) 0.55 | 13 (18) 4.05 |
| McNary Oregon 1/3 | 1.75 | 0 (0) ND | 0 (0) ND | 3 (0) 9.59 | 6 (4) 2.71 | 67 (61) 0.68 | 21 (30) 3.86 |
| McNary Oregon 2/3 | 1.05 | 1 (0) 0.0 | 0 (0) 9.12 | 3 (2) 4.89 | 36 (49) 0.28 | 48 (46) 0.28 | 11 (15) 3.86 |
| McNary Washington Shore | 0.28 | 1 (0) 18.88 | 6 (6) 0.20 | 20 (41) 0.01 | 55 (34) ND | 15 (13) 0.30 | 4 (4) 4.12 |
| McNary Washington Rep. | 0.29 | 1 (0) 15.90 | 7 (6) 0.57 | 35 (34) 0.01 | 41 (41) 0.01 | 13 (12) 0.20 | 4 (5) 4.00 |

(a) = Rounded to nearest whole number.
(b) = Combined silt/clay fraction results.
— = Values are the percent total organic carbon (TOC) for a given grain size.
( ) = Without organic material.
ND = Not detected.
PRD = Priest Rapids Dam.
Rep. = Replicate sample.

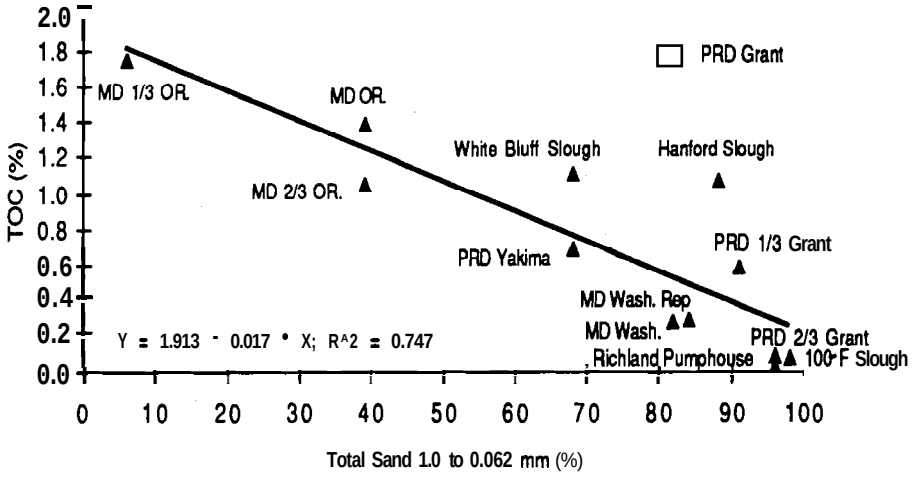


Figure 2. Simple Linear Regression of Sampling Stations. All monitoring sites are included in the regression analysis, with the exception of Priest Rapids Dam Grant County shore station (denoted as □). Regression analysis demonstrates a significant inverse relationship ($P<0.001$) between grain size and TOC content, in that as the amount of sand increases, the amount of TOC content decreases.

The grain-size distribution at the Priest Rapids Dam monitoring site revealed a fairly consistent grain-size profile; primarily fine sand and very fine sand (Figures 3 through 6). However, one sample from this monitoring site was composed predominantly of coarse, medium, and fine sand. Bulk sediment TOC levels varied greatly, ranging from 0.09% to 1.82%. Visually, samples from this site appeared to have heavy amounts of large, medium, and fine woody and nonwoody plant debris. The TOC was not strongly associated with a particular grain-size class, possibly because of the large amounts of debris.

To make any statements about the downriver profile of sediment grain size in the Hanford Reach would require an extensive sampling effort and was beyond the scope of this study. However, based on the samples taken at the four sampling locations, there were no obvious downriver trends in grain-size distribution. The four sampling locations in the Hanford Reach varied greatly, and appeared to be heavily influenced by local factors. The Hanford Reach was predominantly composed of coarse, medium, and fine sand (Figures 7 through 10). While the bulk sediment TOC levels varied greatly (0.03% to 1.11%) among the four sampling locations, they did correspond to grain-size composition, in that higher TOC levels were associated with fine-grain-dominated sediments (White Bluffs and Hanford Slough). The Richland Pumphouse sample was composed of 94% fine sand, and TOC levels were nearly nonexistent.

A trend in grain-size distribution was evident at the McNary Dam monitoring sites. The McNary Dam Oregon shore sample was predominantly silt, while the opposite Washington shore sediments were predominantly very fine sand. The majority of TOC in all four transect samples was associated with the clay grain-size fraction (Figures 11 through 14). The trend in grain size at the McNary Dam monitoring sites is consistent with previous observations (Beasley et al. 1986). The opposite Washington shore sample was dominated by sand and gravel similar to that of the Hanford Reach. The high sediment loads of the Snake and Walla Walla rivers, combined with the low flow

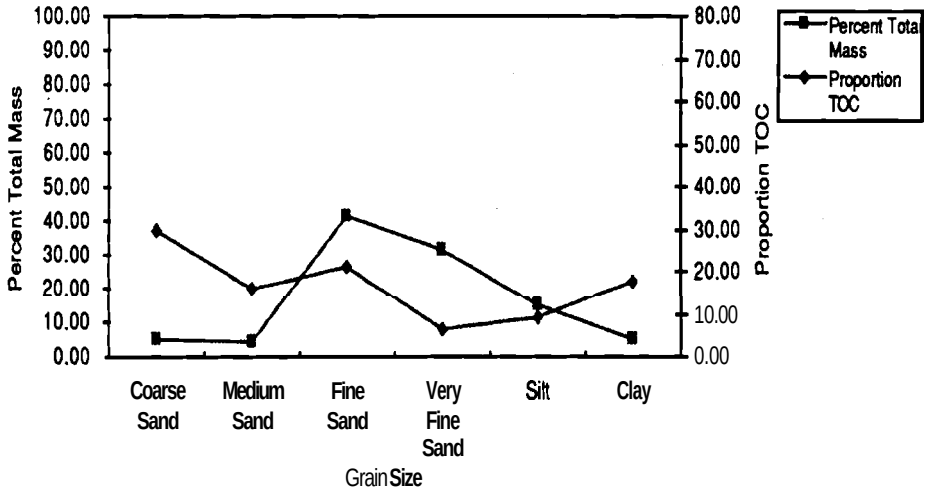


**Figure 3. Grain Size and Total Organic Carbon in Sediment from Priest Rapids Dam Grant County Shore Sample**

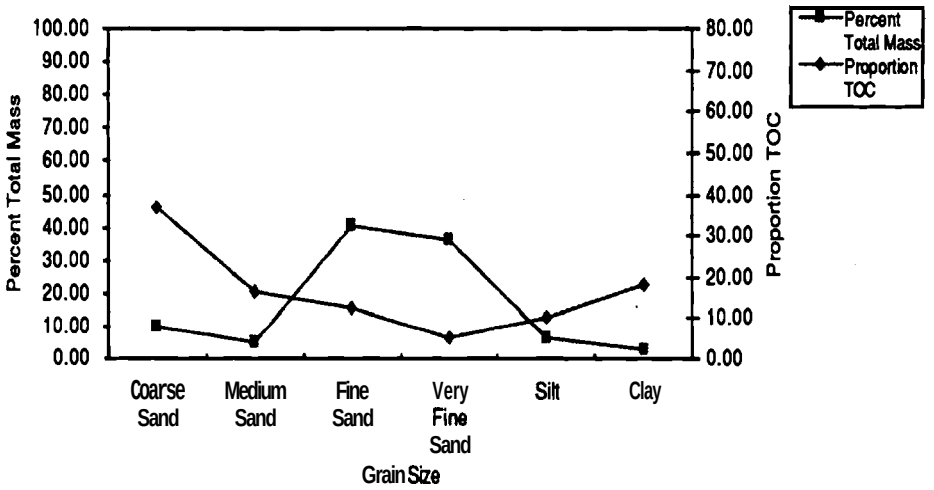


**Figure 4. Grain Size and Total Organic Carbon in Sediment from Priest Rapids Dam 1/3 Distance from Grant County Shore Sample**

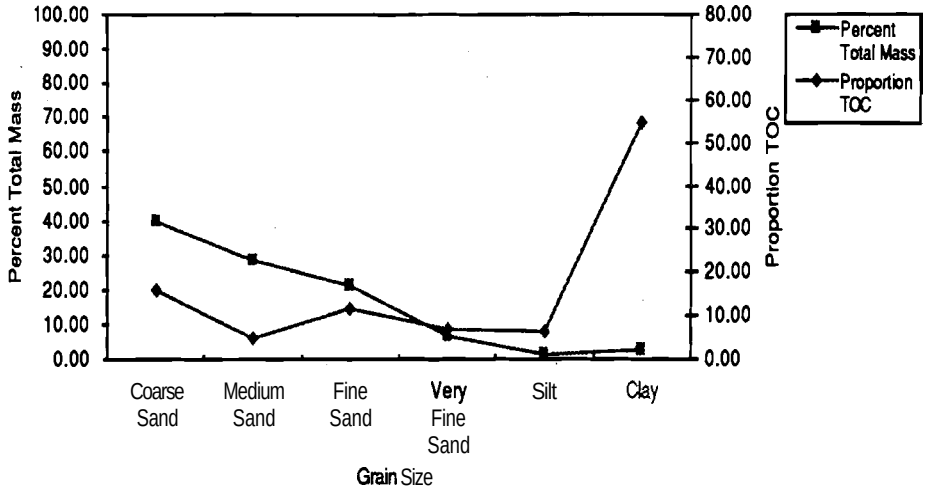


**Figure 5. Grain Size and Total Organic Carbon in Sediment from Priest Rapids Dam 2/3 Distance from Grant County Shore Sample**

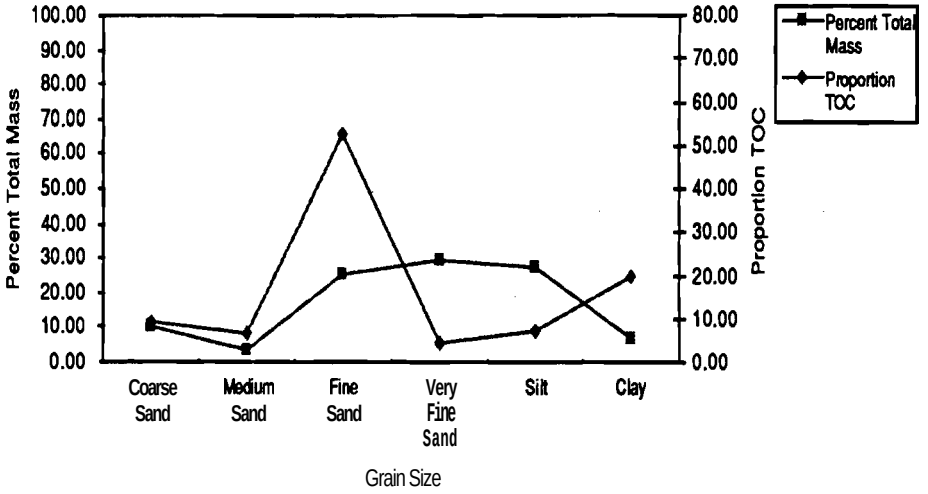


**Figure 6. Grain Size and Total Organic Carbon in Sediment from Priest Rapids Dam Opposite Yakima County Shore Sample**

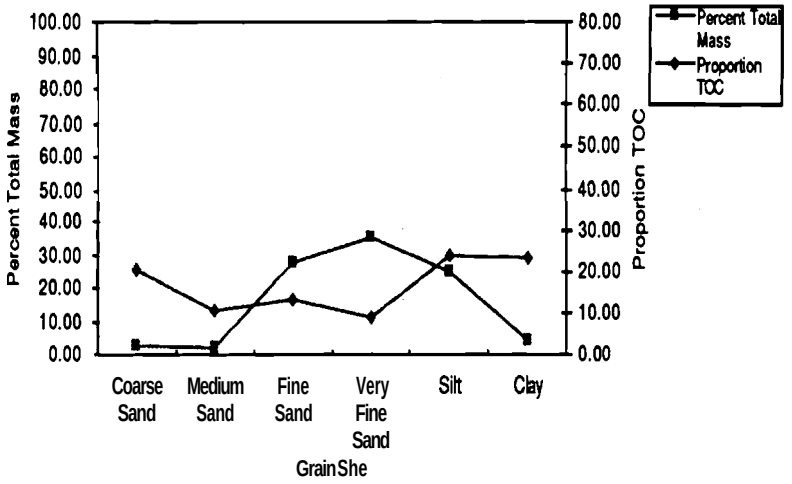


**Figure 7.** Grain Size and Total Organic Carbon in Sediment from White Bluffs Slough Sample

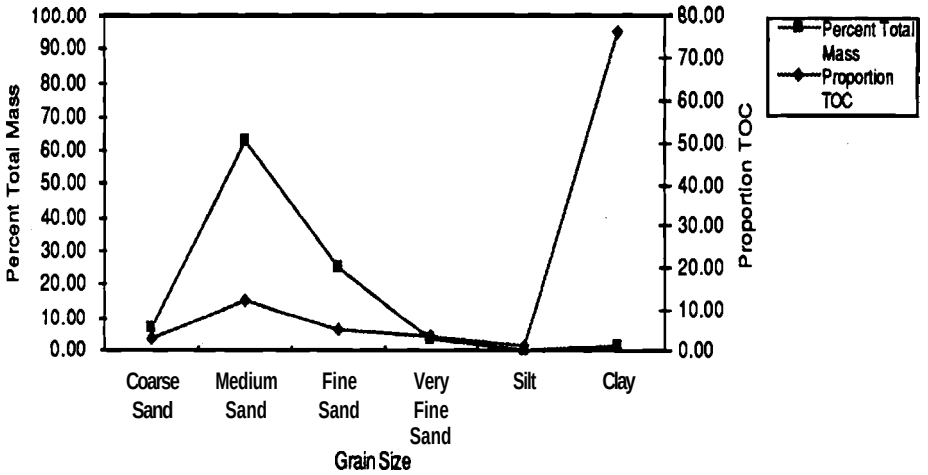


**Figure 8.** Grain Size and Total Organic Carbon in Sediment from 100-F Slough Sample

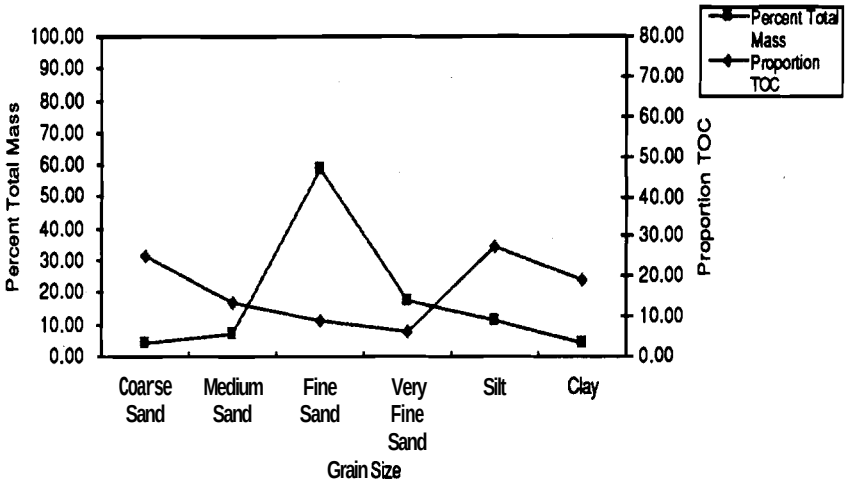


**Figure 9.** Grain Size and Total Organic Carbon in sediment from Hanford Slough Sample

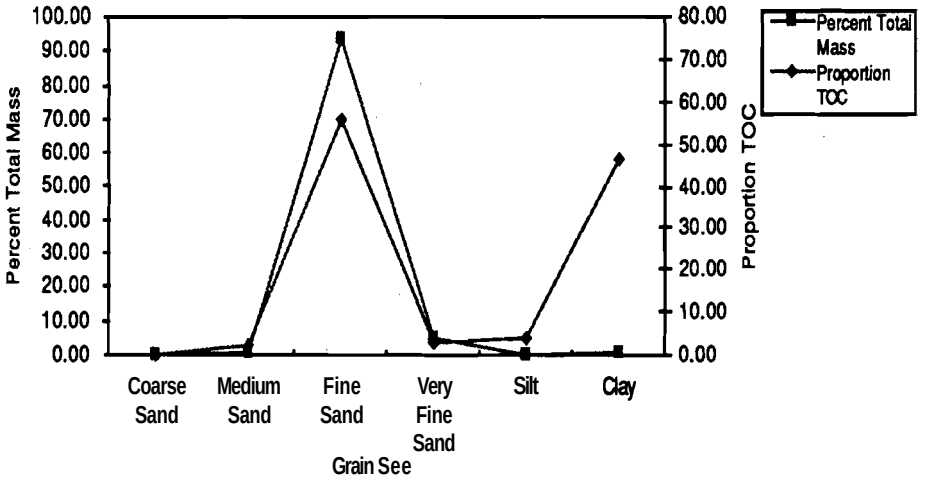


**Figure 10.** Grain Size and Total Organic Carbon in Sediment from **Richland** Pumphouse Sample

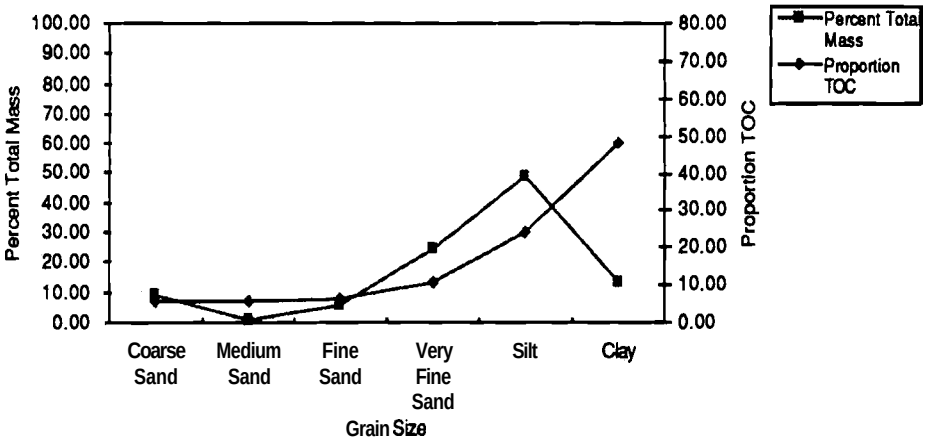


**Figure 11. Grain Size and Total Organic Carbon in Sediment from McNary Dam Oregon Shore Sample**

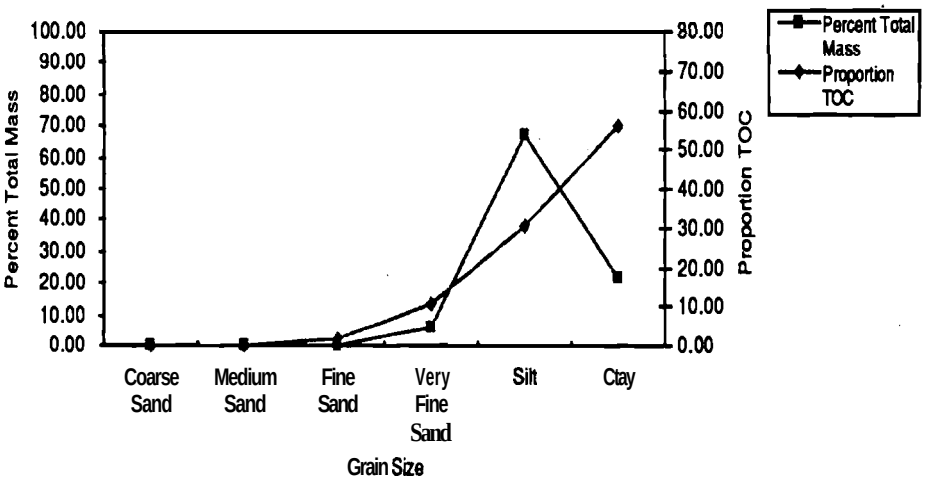


**Figure 12. Grain Size and Total Organic Carbon in Sediment from McNary Dam 1/3 Distance from Oregon Shore Sample**

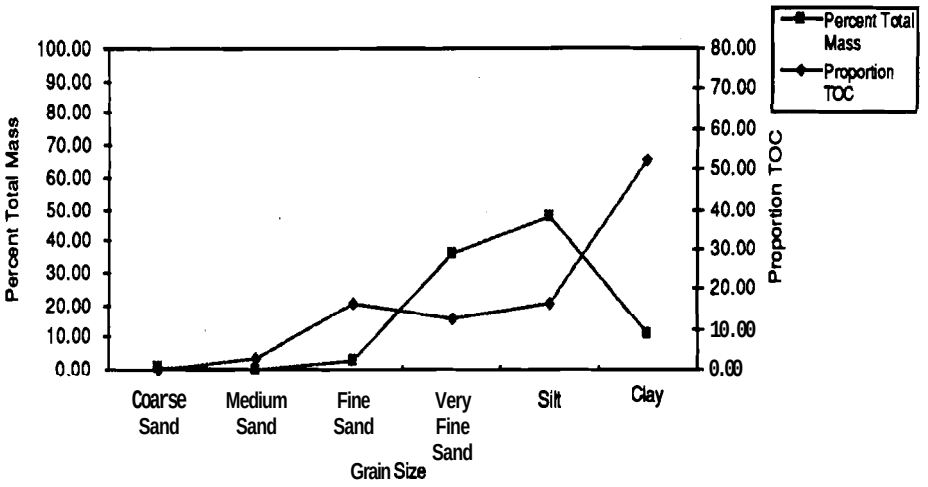


**Figure 13.** Grain Size and Total Organic Carbon in Sediment from McNary Dam 2/3 Distance from Oregon Shore Sample

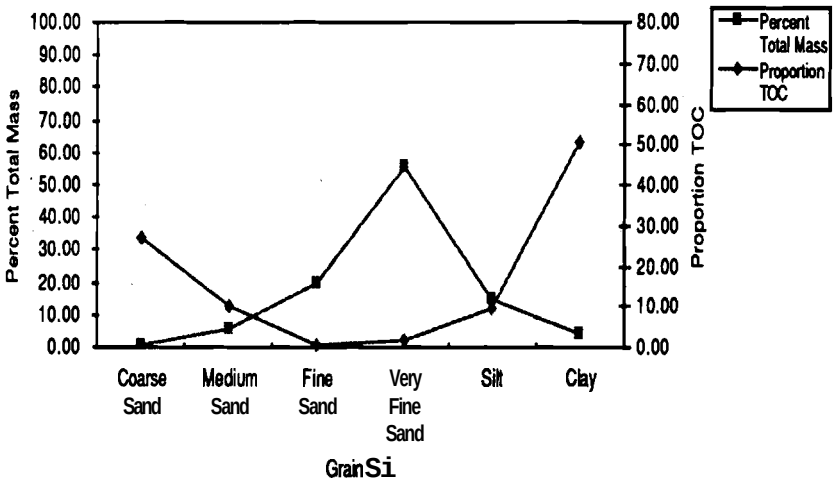


**Figure 14.** Grain Size and Total Organic Carbon in Sediment from McNary Dam Opposite Washington Shore Sample

rates in the McNary reservoir, are largely responsible for differences in sedimentation rates between the Oregon and Washington shore samples (i.e., Oregon shore has higher sediment accumulation rates than the Washington shore).

When comparing three monitoring sites (Priest Rapids Dam, Hanford Reach, and McNary Dam) in terms of grain-size fractions, the McNary Dam site is the most dissimilar, having a higher percent of silts and clays than Priest Rapids Dam or Hanford Reach, which were predominantly sand. In the TOC analysis of fractioned sediments, the greatest proportion of TOC occurred in the fine silt and clay grain sizes.

## Radionuclides

The MDLs were met for all radionuclides, and blanks were uncontaminated. The Richland Pumphouse sediment sample was lost during sediment preparation; therefore, no radionuclide results for this monitoring site are reported and average radionuclide concentrations for the Hanford Reach do not include this sample. As stated earlier, radionuclide concentrations were low at all sites, when compared to background levels at Priest Rapids Dam, with many radionuclides occurring below the MDLs. When comparing regional mean radionuclide concentrations, no appreciable differences existed in all the samples; however, concentrations of $^{137}Cs$, $^{238}U$, and $^{60}Co$ were highest in the McNary Dam sediments. Results for radionuclides not represented in Figure 15 were generally

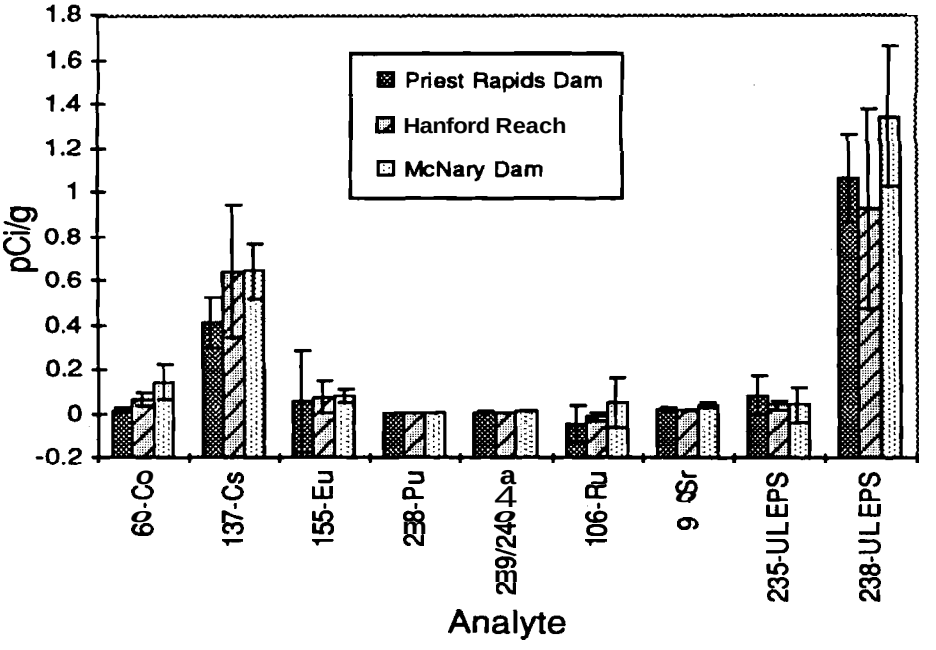


**Figure 15.** Selected Radionuclide Results from Six Historical Monitoring Sites Along the Columbia River from Priest Rapids Dam to McNary Dam (error bars are one standard deviation about the mean)

below MDLs. Radionuclides presented in Figure 15 are those that were perceived to have the most public concern, and many of which were also below the MDLs. For example, $^{60}Co$, $^{155}Eu$, $^{238}Pu$, and $^{238}U$ results were below MDLs in some of the samples analyzed. All of the $^{235}U$ results were below MDLs, and all but two samples were below the $^{238}Pu$ MDL. Appendix B provides the results for all radionuclide analyses.

All samples had $^{137}Cs$ and $^{90}Sr$ concentrations above MDLs, and both radionuclides can be attributed to past Hanford Site production activities as well as atmospheric fallout from weapons testing. The average concentration of $^{137}Cs$ occurring along the Hanford Reach is indistinguishable from the average McNary Dam concentration; however, both the Hanford Reach and McNary Dam average $^{137}Cs$ concentrations were sightly higher than those from Priest Rapids Dam. There were no differences in regional mean $^{90}Sr$ concentrations.

Concentrations of $^{238}U$ are naturally occurring in sediments, and the Columbia River has a naturally elevated level of uranium compared to samples collected onsite and in other remote "control" areas (Price and Kinnison 1982). The elevated levels of $^{238}U$ are a direct result of the natural background levels. Based on the limited data set of this study, concentrations of $^{238}U$ for Priest Rapids Dam (mean 1.0, standard deviation 0.22), Hanford Reach (mean 0.92, standard deviation 0.45), and McNary Dam (mean 1.35, standard deviation 0.29) are essentially the same.

In March 1994, the State of Washington Department of Health issued a special report that evaluated radioactivity in Columbia River sediments and their associated health effects (Wells 1994). In that report, dose estimates were made for the "maximally exposed individual," using maximum measured concentrations of artificial radioactivity in surface sediments of the Columbia River. The report calculated doses from buried sediments and other scenarios as well. The concentrations of radionuclides used in the dose calculations of the Wells (1994) report were higher than the concentrations measured in this study; at times, radionuclide concentrations differed by orders of magnitude. The maximally exposed individual dose was reported to be 0.13 mrem/yr for surficial sediments. To place this into perspective, the average natural background doses in the U.S. (excluding medical and radon exposures) is approximately 100 mrem/yr. With the inclusion of naturally occurring radon exposure, the natural background dose is elevated to approximately 300 mrem/yr. Thus, the dose calculation by the Wells (1994) report are less than 1% of the natural background exposure dose. The Wells (1994) report concluded that, "calculated doses and attendant risks from exposure to artificial radioactivity in Columbia River sediments are small for every section of the river." The measured concentrations of radionuclides in sediments from analyses in our study were below those used in the Wells (1994) report and, therefore, do not contradict their conclusions.

## Metals

Eleven metals were analyzed for this study (Table 2). All 11 metals were detected above the MDLs. The highest concentrations were generally found at the McNary Dam monitoring sites, followed by those at Priest Rapids Dam. The four Hanford Reach sampling sites had the lowest metals concentrations. A trend of increasing metals concentrations was observed along the McNary Dam monitoring sites (Figure 16), with the lowest concentrations measured in the opposite Washington shore sample. This trend was true of all metals, except barium, beryllium, and

**Table 2. Results of Metal Analysis for Bulk and Fractioned Samples Compared to Sediment Quality Standards (mg/kg dry weight)[a]**

| | Moisture (%) | As | Ba | Be | Cd | Cr | Cu | Hg | Mn | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Method | | ICP/MS | ICP/MS | ICP/MS | ICP/MS | ICP/MS | XRF | CVAA | ICP/MS | XRF | XRF | XRF |
| Detection limit | | 0.4 | 0.1 | 0.3 | 0.02 | 0.5 | 5 | 0.01 | 0.3 | NA | 5 | 3 |
| PRD Gr. Shore | 49.5 | 4.3 | 734 | 1.36 | 6.23 | 54 | 37.9 | 0.099 | 613 | 32.8 | 41 | 620 |
| PRD 1/3 Gr. Shore | 35.2 | 7.5 | 777 | 1.22 | 5 | 60 | 25.6 | 0.068 | 660 | 29.4 | 37.3 | 558 |
| PRD 2/3 Gr. Shore | 18.9 | 3 | 730 | 1.19 | 1.19 | 49 | 19.6 | 0.028 | 773 | 21.6 | 24.6 | 231 |
| PRD Yakima Shore | 33.5 | 9.3 | 653 | 1.16 | 4.32 | 46 | 37.1 | 0.102 | 900 | 35.1 | 52.4 | 485 |
| 100-F Slough | 22.8 | 4.9 | 727 | 1.31 | 0.613 | 35 | 25.4 | 0.014 | 868 | 18.4 | 26.1 | 215 |
| Richland Pumphouse | 23.3 | 6.8 | 825 | 1.38 | 0.891 | 30 | 17.8 | 0.015 | 389 | 15.8 | 38.9 | 228 |
| White Bluffs Slough | 45.7 | 11 | 780 | 1.25 | 2.11 | 51 | 37.2 | 0.073 | 502 | 28.3 | 76 | 533 |
| Hanford Slough | 46.9 | 7.9 | 744 | 1.19 | 2.02 | 50 | 23.9 | 0.048 | 567 | 21.2 | 34.4 | 313 |
| MD OR Shore | 51.9 | 12 | 755 | 1.61 | 3.71 | 58 | 45.7 | 0.145 | 779 | 31.6 | 29.8 | 354 |
| MD 1/3 OR Shore | 62.2 | 12 | 617 | 1.42 | 3.64 | 53 | 51.6 | 0.149 | 861 | 36.3 | 37.5 | 384 |
| MD 2/3 OR Shore | 48.5 | 9.3 | 734 | 1.61 | 2.53 | 70 | 35 | 0.164 | 1040 | 27 | 34.4 | 389 |
| MD WA Shore | 28.8 | 5 | 686 | 1.33 | 1.33 | 34 | 14 | 0.069 | 771 | 20.7 | 25.3 | 217 |
| MD WA Shore Rep. | 29 | 7.4 | 670 | 1.32 | 1.36 | 35 | 18.6 | 0.074 | 774 | 19.4 | 22.1 | 211 |
| Fractioned Sample | | | | | | | | | | | | |
| MD 2/3-MS | NA | 23 | 838 | 1.07 | 18.4 | 52 | 120 | 0.849 | 2300 | 37.7 | 192 | 739 |
| MD 2/3-FS | NA | 7.3 | 779 | 1.41 | 2.28 | 47 | 27.3 | 0.130 | 976 | 29.3 | 39.1 | 395 |
| MD 2/3-VFS | NA | 7.0 | 793 | 1.39 | 1.97 | 48 | 25.0 | 0.121 | 842 | 20.6 | 34.1 | 351 |
| MD 2/3-Silt | NA | 7.8 | 663 | 1.45 | 2.46 | 91 | 28.8 | 0.436 | 922 | 33.5 | 31.9 | 306 |
| MD 2/3-Clay | NA | 27.9 | 609 | 2.65 | 5.80 | 85 | 99.9 | 0.127 | 2410 | 58.5 | 109 | 746 |
| Provincial Sediment Standards Quality Guidelines[a] | | | | | | | | | | | | |
| No effect | NA | (b) | (b) | (b) | (b) | (b) | (b) | (b) | (b) | (b) | (b) | (b) |
| Lowest effect | NA | 6 | (b) | (b) | 0.6 | 26 | 16 | 0.2 | 460 | 16 | 31 | 120 |
| Severe effect | NA | 33 | (b) | (b) | 10 | 110 | 110 | 2 | 1100 | 75 | 250 | 820 |
| Sediment Quality Guidelines [a] | NA | 17 | (b) | (b) | 2.5 | 100 | 85 | 0.6 | 1200 | 92 | 55 | 143 |

(a) From Bennett and Cubbage (1991).
(b) No established guideline.
CVAA = Cold-vapor atomic absorption spectroscopy.
FS = Fine sand.
ICP/MS = Inductively coupled plasma-mass spectrometry.
MD OR = McNary Dam Oregon.
MD WA = McNary Dam Washington.
MS = Medium sand.
NA = Not applicable.
PRD = Priest Rapids Dam.
PRD Gr. = Priest Rapids Dam Grant County Shore.
Rep. = Replicate sample.
VFS = Very fine sand.
XRF = X-ray fluorescence.

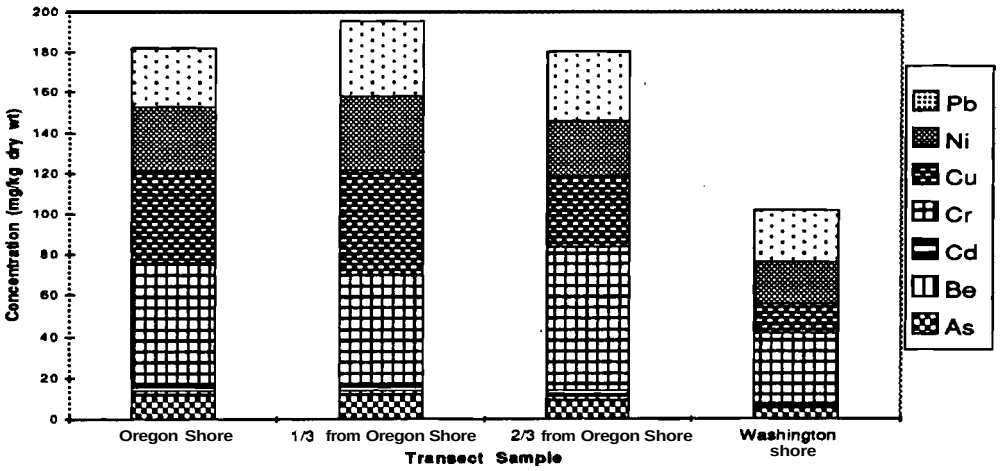


Figure 16. Concentration of Selected Metals at McNary Dam Monitoring Sites

manganese. A similar trend was not seen for the Priest Rapids Dam monitoring sites. When comparing the regional mean concentrations (Figure 17), the McNary Dam monitoring sites had the highest metals concentrations, with the exception of lead, zinc, and barium that were highest at Priest Rapids Dam and were not included in Figure 17.

The pattern of heavy metal distribution from Priest Rapids to McNary dams was associated with the finer sediment grain sizes and TOC. Results of sediments analyzed for metals by grain-size fraction found the highest metal concentrations occumng in the medium sand and clay grain-size fractions (see Table 2). These fractions also had the highest TOC content. This analysis (metals by grain-size fraction) was performed on the McNary Dam 2/3 distance from shore sample. The corresponding grain-size and TOC information was presented in Figure 13. The silt and very fine-sand fractions were the dominant grain-size fraction, composing over 90% of the sample. The medium-sand fraction composed less than 3% of the sample but had the highest TOC. The occurrence of TOC in the medium-sand fraction was likely caused by the presence of woody debris. The clay fraction was only 10% of the mass and had a very high TOC proportion. The concentration of selected metals by grain-size fraction is provided in Figure 18.

The results of this study show a very strong correlation with TOC and grain-size effect with metals concentration in the one sample analyzed and support previous research presented in the introduction to this report.

A comparison of metal results of this study, compared to the two sediment water-quality guidelines was provided in Table 2. There is currently no U.S. Environmental Protection Agency-approved sediment water-quality standards, but the two guidelines come from 1) Provincial Sediment

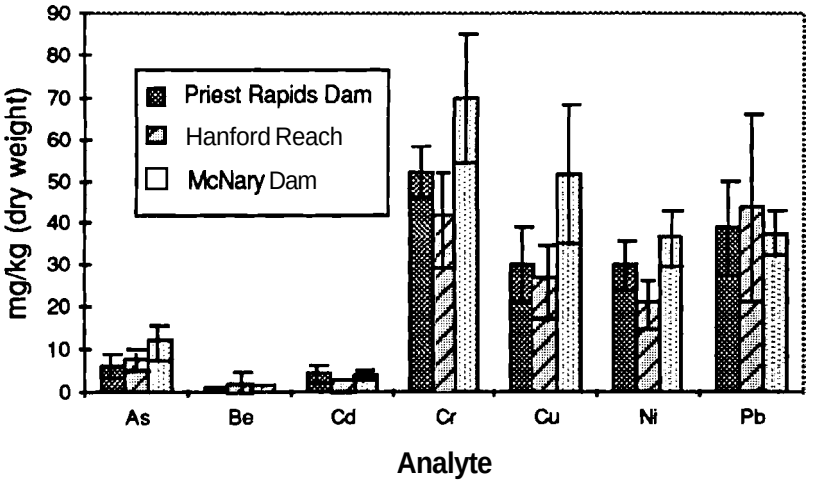


**Figure 17.** Average Concentration of Selected Metals from Priest Rapids Dam to McNary Dam (error bars are one standard deviation about the mean)

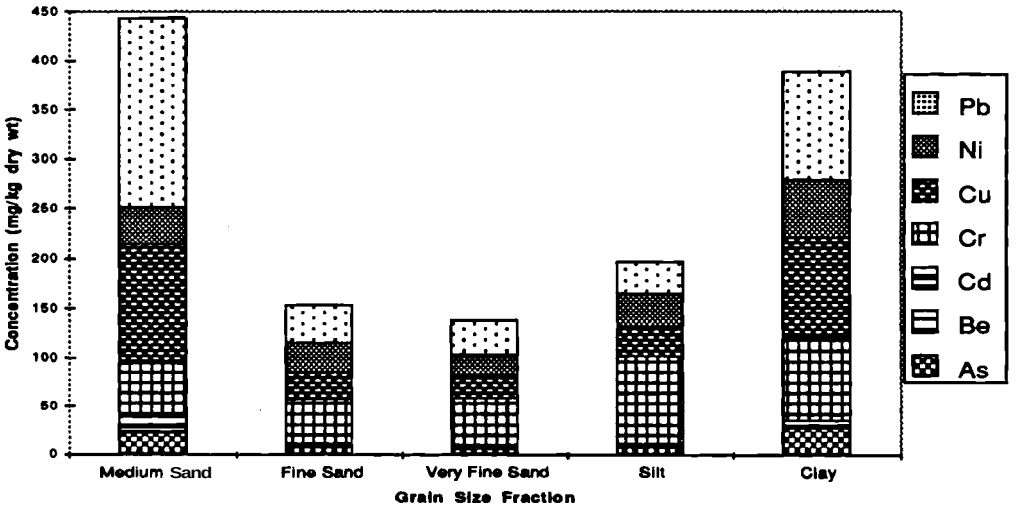


**Figure 18.** Selected Metals Results by Grain-Size Fraction from the McNary Dam 2/3 Distance from Oregon Shore Sample

Quality Guidelines (PSQG), developed by the Ontario Ministry of the Environment, revised in May 1991 and 2) Sediment Quality Guidelines (SQG), developed by Beak Consultants in 1988 for the Ontario Ministry of the Environment (Bennett and Cubbage 1991). The PSQGs define three levels of chronic, long-term effects for benthic organisms:

- No-Effect Level. No toxic effects have been observed on aquatic organisms, no expected food-chain biomagnification, and all water-quality guidelines will be met.

- Lowest-Effect Level. Indicates a level of sediment contamination that can be tolerated by most benthic organisms.

- Severe-Effect Level. Pronounced disturbance of sediment-dwelling organisms can be expected, with concentrations being detrimental to the majority of benthic species (Bennett and Cubbage 1991).

Using these levels for comparison, concentrations of metals in all samples were generally higher than the Lowest-Effect Level, with the exception of mercury (also, arsenic and lead were sometimes below this mark). No samples had metals concentrations above the Severe-Effect Level. Mercury concentrations were below all SQGs listed in Table 2.

A full description of all the guidelines is provided in Bennett and Cubbage (1991). In general, the SQGs used "background" values as bases for setting standards for metals. Using these guidelines for comparisons to the results from this study, lead, zinc, and cadmium were found to be higher: lead in the White Bluffs sample, zinc in all samples, and cadmium in McNary Dam 1/3 and 2/3 distance from shore samples and Priest Rapids Dam 1/3 distance and opposite Yakima County shore samples.

There are no currently established State of Washington sediment water-quality guidelines. The State of Washington Department of Ecology is currently in the process of developing criteria for contaminated freshwater sediments. For this reason, none were provided in this report. However, several sediment water-quality guidelines have been provided for comparison purposes. Of the guidelines provided, none have a standard for beryllium. It would go beyond the intent of this report to provide a discussion of the merits of each sediment water-quality guideline and to conduct an assessment of the potential environmental impact that observed metals concentrations may have on the environment or to try and determine the source of contaminants and answer questions concerning bioavailability of contaminants.

## Organics

Concentrations of PAHs were generally low for all samples, with no above-MDLs for any PAH compound in the McNary Dam opposite Washington shore sample, Priest Rapids Dam 2/3 distance from shore sample, 100-F Slough sample, and Richland Pumphouse sample. Fluoranthene and pyrene were the most commonly detected PAH compound. The Priest Rapids Dam opposite Yakima County shore sample had the highest level of PAHs, including fluoranthene, pyrene, benz(a)anthracene, chrysene, and benzo(b)fluoranthene (Table 3).

Our results indicate that physicochemical characteristics can vary among Columbia River monitoring sites and regions. Furthermore, our research, as well as previous studies, indicates that sediment physicochemical properties can affect sediment contaminant burdens. Grain size and TOC can act as confounding factors, potentially causing inappropriate comparisons resulting in erroneous conclusions (i.e., fine-grained test sediment versus coarse sand reference). Several sediment-evaluation programs include grain size and/or TOC when selecting appropriate reference sites or when comparing test sites (dredged-material evaluations [EPA/USACE 1991, 1994]; National Status and Trends-Mussel Watch Monitoring Program [NOAA 1993]; and EPA Superfund evaluations [White et al. 19941). Grain size and TOC should be included in future Columbia River sediment-monitoring and -evaluation programs.

Based on the results of this study and literature review, the following conclusions can be made:

- sediment grain size and TOC influence contaminant fate and transport (in general, sediments with higher TOC content and finer grain-size distribution can have higher contaminant burdens than sediments from a given river section that have less TOC and greater amounts of coarse-grained sediments)

- physiochemical sediment characteristics are highly variable among monitoring sites along the Columbia River

- sediment grain characterization and TOC analysis should be included in interpretations of sediment-monitoring data.

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# Appendix A

# Quality Assurance/Quality Control Summary

# Appendix A

# Quality Assurance/Quality Control Summary

**Parameter: Radionuclide Analysis**
**Matrix: Sediment**

QA/QC Data Quality Objectives (pCi/g)

Radiochemical analysis consists of a gamma scan, $^{90}Sr$ analysis, uranium isotopic analysis, and plutonium isotopic analysis. Gamma-emitting radionuclides are counted on either a germanium lithium (Ge[Li]) or an Intrinsic (hyperpure) Germanium (HPGE) detector system. Strontium is precipitated from the sample as strontium oxalate, converted and precipitated as a carbonate, and counted on a low-background, gas-flow proportional counter for beta activity. The sample is counted directly for $^{235}U$ and $^{238}U$ by a low-energy photon-detection system (LEPS) for uranium isotopic analysis. For plutonium isotopic analysis, the plutonium is coprecipitated with calcium oxalate, dissolved, loaded onto an anion-exchange resin column, eluted, plated, and counted on an alpha spectrometer.

The reporting laboratory lost the Richland Pumphouse sediment sample during sediment preparation.

Detection Limits

| Analyte | Method | Accuracy | Minimum Detection Limit (pCi/g) |
|---|---|---|---|
| $^{60}Co$ | Ge(Li) or HPGE | ±20% | 0.02 |
| $^{137}Cs$ | Ge(Li) or HPGE | ±20% | 0.02 |
| $^{154}Eu$ | Ge(Li) or HPGE | ±20% | 0.05 |
| $^{155}Eu$ | Ge(Li) or HPGE | ±20% | 0.05 |
| $^{106}Ru$ | Ge(Li) or HPGE | ±20% | 0.17 |
| $^{238}Pu$ | Anion Exchange Separation and Alpha Energy Analysis Spectrometer | ±25% | 0.0006 |
| $^{239/240}Pu$ | Anion Exchange Separation and Alpha Energy Analysis Spectrometer | ±25% | 0.0006 |
| $^{90}Sr$ | Oxalate and Carbonate Precipitation Separation and Gas-Flow Proportional Counter | ±30% | 0.005 |
| U-iso | LEPS | ±20% | 1 |

**Parameter: Grain Size**
**Matrix: Sediment**

Method: Samples were analyzed both with and without organic material using a method similar to ASTM-D 2217. Samples for "without organics" analysis were treated with $H_2O_2$ on April 22, 1994, and wet washed over a series of stainless-steel sieves (#35, #60, #120, #230, #400) by May 8, 1994.

The fine fractions (silt, clay) were subdivided using a pipette technique, based on the differential settling rates of each particle. The silt/clay slurry was mixed with a deflocculent (2% HCl) in a 1-L graduated cylinder and was then allowed to settle. Silt and clay subsamples were removed based on settling velocities. The sand fractions were then subsampled, air dried, and weighed. The silt and clay fractions were treated with 2% HCl as a deflocculent, then subsampled and weighed. Remaining sediments were sealed in the glass containers and sent to the testing laboratory for TOC analysis. All "with organics" analyses were completed by May 8, 1994.

Samples for "with organics" analysis were treated in the same manner listed above; however, they were not treated with $H_2O_2$.

Holding Times: All samples were received from M. Blanton by April 16, 1994, subsampled in the laboratory on April 18, 1994, and received by the testing laboratory on April 19, 1994. All samples were analyzed by May 8, 1994, within the specified 6-month holding period.

Detection Limit: .The detection limit of 1.0% was met for all samples.

Blanks: Not applicable in these analyses.

Laboratory Control Standards: Not applicable in these analyses.

Matrix Spike/Matrix Spike Duplicate: Not applicable in these analyses.

Replication: One field replicate analysis was run. Totals of coarse sand, medium sand, very fine sand, silt, and clay fractions produced relative percent differences ranging from 0% to 55%. Fine sand and very fine sand relative percent differences exceeded the ±20% limit specified in the QA plan; however, because these are field replicates, it is difficult to discern whether this variation was generated in the field or in the laboratory.

Stand Reference Material: Not applicable for this analyses.

Parameter: Total Organic Carbon
Matrix: Sediment

Method: Samples were analyzed both as whole sediments and in the fractioned form, according to the EPA Edison, New Jersey laboratory procedure (EPA 1986a). This procedure involves combustion and quantitation of evolved carbon dioxide using a LECO analyzer. Total organic carbon content was reported as a percentage of dry weight of the acidified sample.

Holding Times: All samples were analyzed within the specific 6-month holding period.

Detection Limits: The target detection limit of 0.1% was met for all samples.

Method Blanks: The method blanks that were analyzed (n=4) had concentrations ranging from 0.003% to 0.004%. Because these are less than the detection limit, no blank correction was required.

Matrix Spikes: Not applicable in these analyses.

Replicates: The relative percent difference (RPD) for duplicate sample analysis was 0% and 5%, less than the QC limits of f 10%. The RPD for the field replicates was 4%, also within the 10% QC limit.

Standard Reference Material: MESS-1, obtained from the National Research Council of Canada (NRCC), was analyzed with the sediment samples. The standard reference material was measured at 2.56%, which agrees with the certified value of 2.6% ±0.2%.

Parameter: Metals
Matrix: Sediment

QA/QC Data Quality Objectives (mg/kg dry weight)

| Reference | Method | Range of Recovery | SRM Accuracy | Target Detection Limit (mg/kg) | Achieved Detection Limit (mg/kg) |
|---|---|---|---|---|---|
| Arsenic | XRF | NA | ±25% | 0.4 | 2.5 |
| Barium | XRF | NA | ±25% | 0.1 | 100 |
| Beryllium | ICP-MS | 75%-125% | ±30% | 0.3 | 0.279 |
| Cadmium | ICP-MS | 75%-125% | ±30% | 0.02 | 0.659 |
| Chromium | XRF | NA | ±25% | 0.5 | 33 |
| Copper | XRF | NA | ±25% | 5 | 5.5 |
| Lead | XRF | NA | ±25% | 5 | 6.2 |
| Manganese | XRF | NA | ±25% | 0.3 | 100 |
| Mercury | CVAA | 75%-125% | ±30% | 0.01 | 0.001 |
| Nickel | XRF | NA | ±25% | NA | 7.5 |
| Zinc | XRF | NA | ±25% | 3 | 7.8 |

Method: A total of 11 metals were analyzed for: arsenic (As), barium (Ba), beryllium (Be), cadmium (Cd), chromium (Cr), copper (Cu), manganese (Mn), mercury (Hg), nickel (Ni), lead (Pb), and zinc (Zn). Eight metals (As, Ba, Cr, Cu, Mn, Pb, Ni, and Zn) were analyzed by energy-dispersive x-ray fluorescence (XRF) following the method in established Pacific Northwest Laboratory operating procedures. Hg was analyzed using cold-vapor atomic absorption spectroscopy (CVAA) according to the method of Bloom and Crecelius (1983). Two metals (Be and Cd) were analyzed by inductively coupled plasma mass spectrometry (ICP-MS) and EPA Method 200.8 (EPA 1991).

To prepare the sediment for analysis, samples were freeze dried and blended in a Spex mixer-mill. The XRF analysis was performed on a 0.5-g aliquot of dried, ground material pressed into a pellet with a diameter of 2 cm. For ICP-MS and CVAA analyses, 0.2- to 0.5-g aliquots of dried homogeneous sample were digested using a mixture of nitric/perchloric and hydrofluoric acids. One sample (SESP-8-MS) had only approximately 0.16 g total and the same aliquot was first analyzed by XRF. This same sample aliquot will be digested for Be, Cd, and Hg analyses separately. Detection limits for this sample are slightly elevated because of the limited amount of sample.

Holding Time: The first 13 samples were received from M. Blanton on April 16, 1994, subsampled and received by the laboratory on April 20, 1994. An additional 5 samples were received from another laboratory on May 5, 1994. One additional sample, McNary 2/3 coarse sand was listed on the chain of custody but was not sent because of insufficient sample. Samples were logged into the laboratory's log-in system, frozen to -80°C, and subsequently freeze dried within approximately 7 days of sample receipt. Samples were all analyzed within 180 days of collection. The following summarizes all analysis dates:

Sample digestion May 19, 1994
XRF analysis May 13, 1994
ICP-MS May 20, 1994
CVAA-Hg May 19, 1994.

Detection Limits: Samples are reported in mg/kg dry weight. Detection limits reported for XRF analyses are based on the standard deviation of 7 replicate analyses of a sediment standard reference material multiplied by the student t value at the 99th percentile. The detection limits reported for the ICP-MS values are based on 3 times the standard deviation of 3 replicate analyses of the low standard. Method detection limits exceeded target detection limits for most metals. This does not appear to affect results, because all sediment values greatly exceed the method detection limit.

Method Blanks: One method blank was analyzed for Be, Cd, and Hg. No metals were detected in the method blank. Method blanks are not analyzed by XRF; therefore, no blank results are reported for XRF metals.

Blank Spikes: One procedural blank was spiked with Be, Cd, and Hg. Blank spike recoveries ranged from 76% to 85%. All recoveries were within the QC limits of 75% to 125%. Because no procedural blanks are analyzed by XRF, no blank spike recovery data are possible for XRF analyses.

Matrix Spikes: A matrix spike was not run with 'these sediments; however, the blank spike results indicate acceptable percent recovery.

Standard Reference Material 1646 (estuarine sediment from the National Institute of Standards and Technology [NIST]) was analyzed for all metals. Results for all metals analyzed by ICP-MS were within ±30% of mean certified value and all metals analyzed by XRF were within ±25%, indicating good accuracy. One additional SRM, BEST-1, an estuarine sediment, was analyzed for Hg only. Results were within ±30% of the certified mean.

**Parameter:** PAHs
**Matrix: Sediment**

QA/QC Data Quality Objectives (µg/kg dry wt)

| Reference | Method | Range of Recovery | SRM Accuracy | Target Detection Limit (µg/kg) | Achieved Detection Limit (µg/kg) |
|---|---|---|---|---|---|
| Naphthalene | Modified 8270 | 40%-120% | ±50% | 20 | 2.90 |
| Acenaphthylene | Modified 8270 | 40%-120% | ±50% | 20 | 2.33 |
| Acenaphthene | Modified 8270 | 40%-120% | ±50% | 20 | 3.04 |
| Fluorene | Modified 8270 | 40%-120% | ±50% | 20 | 2.51 |
| Phenanthrene | Modified 8270 | 40%-120% | ±50% | 20 | 2.53 |
| Anthracene | Modified 8270 | 40%-120% | ±50% | 20 | 2.46 |
| Fluoranthene | Modified 8270 | 40%-120% | ±50% | 20 | 2.28 |
| Pyrene | Modified 8270 | 40%-120% | ±50% | 20 | 2.75 |
| Benzo[a]anthracene | Modified 8270 | 40%-120% | ±50% | 20 | 2.71 |
| Chrysene | Modified 8270 | 40%-120% | ±50% | 20 | 3.33 |
| Benzo[b]fluoranthene | Modified 8270 | 40%-120% | ±50% | 20 | 2.51 |
| Benzo[k]fluoranthene | Modified 8270 | 40%-120% | ±50% | 20 | 2.97 |
| Benzo[a]pyrene | Modified 8270 | 40%-120% | ±50% | 20 | 2.32 |
| Indeno[1,2,3-C,d] pyrene | Modified 8270 | 40%-120% | ±50% | 20 | 2.01 |
| Dibenz[a,h]anthracene | Modified 8270 | 40%-120% | ±50% | 20 | 2.04 |
| Benzo[g,h,i]perylene | Modified 8270 | 40%-120% | ±50% | 20 | 1.69 |

Method: Analyses of PAH compounds followed EPA SW-846 Method 8270 (EPA 1986b). Sediment was extracted two to three times consecutively using a roller technique. The extracts were dried over sodium sulfate, passed through a cleanup column, and concentrated in preparation of further cleanup by liquid chromatography. Samples were analyzed via high-resolution capillary gas chromatography/mass spectrophotometry (GC/MS). A data system provided for identification and measurement of the selected PAHs, using a selective ion mode (SIM). In the SIM, each PAH compound was monitored simultaneously for the presence of a parent ion and a confirming second ion.

Holding Times: Sediment samples were collected from April 11 to April 15, 1994, and subsampled at the laboratory on April 18, 1994. Samples amved on April 20, 1994, were extracted on May 16, 1994, and analyzed from May 20 to May 21, 1994. The 30-day holding time prior to extraction was exceeded by 6 days; the 40-day holding time between extraction and analysis was not exceeded.

Blanks: The samples were run as one batch and the criterion of one blank was met. HPAHs and LPAHs were not detected above the target detection limit of 20 µg/kg.

Detection Limits: The detection limit goal of 30 µg/kg was met for all PAH compounds.

Laboratory Control Standards: The criterion for a surrogate internal standard per sample was met. Three surrogate standards were evaluated: d8 naphthalene, d10 acenapthalene, and d12 chrysene.

Surrogate recoveries were within the QA plan goals of 50% to 150%, with the exception of McNary 2/3. Two of the three compounds were recovered below the 50% minimum acceptance criteria.

Matrix Spike/Matrix Spike Duplicate: The criterion of one matrix spike sample was met. The 40% to 120% criteria for spike recovery was met for all PAHs, ranging from 59% to 77%.

Standard Reference Materials: The NIST 1941a certified sediment standard reference material was processed with the analytical batch. The percent difference (PD) for the PAH in the SRM ranged from 0% to 57% and averaged 32% relative to the certified values. QA limits specify that the observed value for an SRM must be within 30% of the certified value; however, this criterion historically has been established for surrogate-corrected data. A reasonable PD goal for uncorrected data, such as those reported here, should be the same as that for surrogate recovery goals—in this case, 50% PD. We have applied this goal to the NIST standard reference material.

Parameter: **PCBs/Pesticides**
Matrix: Sediment

QA/QC Data Quality Objectives: (µg/kg dry wt)

| Reference | Method | Range of Recovery | SRM Accuracy | Target Detection Limit (µg/kg) | Achieved Detection Limit (µg/kg) |
|---|---|---|---|---|---|
| Aldrin | Modified 8080 | 40%-120% | ±50% | 2.0 | 0.85 |
| A-BHC | Modified 8080 | 40%-120% | ±50% | 2.0 | 0.56 |
| B-BHC | Modified 8080 | 40%-120% | ±50% | 2.0 | 0.82 |
| Lindane | Modified 8080 | 40%-120% | ±50% | 2.0 | 0.65 |
| D-BHC | Modified 8080 | 40%-120% | ±50% | 2.0 | 0.75 |
| 4.4-DDD | Modified 8080 | 40%-120% | ±50% | 2.0 | 1.02 |
| 4,4-DDE | Modified 8080 | 40%-120% | ±50% | 2.0 | 0.82 |
| 4,4-DDT | Modified 8080 | 40%-120% | ±50% | 2.0 | 0.88 |
| Dieldrin | Modified 8080 | 40%-120% | ±50% | 2.0 | 0.80 |
| Endosulfan I | Modified 8080 | 40%-120% | ±0% | 2.0 | 0.90 |
| Endosulfan II | Modified 8080 | 40%-120% | ±50% | 2.0 | 0.82 |
| Endosulfan sulfate | Modified 8080 | 40%-120% | ±50% | 2.0 | 0.78 |
| Endrin | Modified 8080 | 40%-120% | ±50% | 2.0 | 0.93 |
| Endrin aldehyde | Modified 8080 | 40%-120% | ±50% | 2.0 | 0.90 |
| Heptachlor | Modified 8080 | 40%-120% | ±50% | 2.0 | 0.90 |
| Heptachlor epoxide | Modified 8080 | 40%-120% | ±50% | 2.0 | 0.83 |
| Technical chlordane | Modified 8080 | 40%-120% | ±50% | 30 | 28.25 |
| Toxaphene | Modified 8080 | 40%-120% | ±50% | 30 | 28.25 |
| Aroclor 1242 | Modified 8080 | 40%-120% | ±50% | 20 | 28.25 |
| Aroclor 1248 | Modified 8080 | 40%-120% | ±50% | 20 | 28.25 |
| Aroclor 1254 | Modified 8080 | 40%-120% | ±50% | 20 | 28.25 |
| Aroclor 1260 | Modified 8080 | 40%-120% | ±50% | 20 | 28.25 |

Method: Analysis of pesticide and PCB compounds followed EPA SW-846 Method 8080 (EPA 1986b). Sediments were extracted simultaneously with the PAH samples using methylene chloride. A portion of the methylene chloride was exchanged to hexane, and interferences were removed by passing the extract through a column packed with 10 g of 2% activated alumina and 20 g of 2% deactivated silica. Additional cleanup treatment was performed using high-performance liquid chromatography (HPLC). Analytical quantification was performed using gas chromatography with electron capture detector (GC-ECD) analysis.

Holding Times: Sediment samples were collected from April 11 to April 15, 1994, and subsampled at the laboratory on April 18, 1994. Samples amved at the analysis laboratory on April 20, 1994, were extracted on May 16, 1994, and analyzed from May 24 to May 25, 1994. The 30-day holding time prior to extraction was exceeded by 6 days; the 40-day holding time between extraction and analysis was not exceeded.

Blanks: The samples were run as one batch and the criterion of one blank was met. Pesticides and PCBs were not detected above the target detection limits.

Detection Limits: The detection limit goals were met for all pesticide and PCB compounds, except for Arochlor 1242, 1248, 1254, 1260.

Laboratory Control Standards: The criterion of a surrogate internal standard per sample was met. Three surrogate standards were evaluated: DBOFB, CL5 (103). and CL5 (112). Surrogate recoveries were within the QA plan goals of 50% to 150%.

Matrix Spike/Matrix Spike Duplicate: The criterion of one matrix spike sample was met. The 40% to 120% criteria for spike recovery was met for all PAHs, ranging from 54% to 100%.

Standard Reference Materials: The certified NIST 1941a sediment standard reference material was processed with the analytical batch. The percent difference (PD) for the pesticides and PCB in the standard reference material ranged from 33% to 44%, and averaged 37% relative to the certified values. Quality assurance limits specify that the observed value for a standard reference material must be within 30% of the certified value; however, this criterion historically has been established for surrogate-corrected data. A reasonable PD goal for uncorrected data, such as those reported here, should be the same as that for surrogate recovery goals — in this case, 50% PD. We have applied this goal to the NIST standard reference material.

# References


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# Appendix B

# Results of Radionuclide Analyses

# Appendix B
# Results of Radionuclide Analyses

| Site | Constituent | Concentration | 2 Sigma Counting Error |
|---|---|---|---|
| PRD-Grant County Shore | Be-7 | 5.67E-02 | 1.81E-01 |
| PRD-Grant County Shore | CePr-144 | -2.04E-02 | 1.88E-01 |
| PRD-Grant County Shore | Co-60 | 2.98E-02 | 1.69E-02 |
| PRD-Grant County Shore | Cs-134 | 1.53E-03 | 1.62E-02 |
| PRD-Grant County Shore | Cs-137 | 3.87E-01 | 5.49E-02 |
| PRD-Grant County Shore | Eu-154 | 3.89E-02 | 5.21E-02 |
| PRD-Grant County Shore | Eu-155 | 8.52E-02 | 5.04E-02 |
| PRD-Grant County Shore | K-40 | 1.58E+01 | 1.75E+00 |
| PRD-Grant County Shore | Pu-238 | 2.77E-04 | 2.58E-04 |
| PRD-Grant County Shore | Pu-239/240 | 5.43E-03 | 1.19E-03 |
| PRD-Grant County Shore | Ru-106 | -6.91E-02 | 1.58E-01 |
| PRD-Grant County Shore | Sb-125 | -2.70E-02 | 5.08E-02 |
| PRD-Grant County Shore | Sr-90 | 2.14E-02 | 7.84E-03 |
| PRD-Grant County Shore | U-235 LEPS | 1.39E-01 | 9.38E-02 |
| PRD-Grant County Shore | U-238 LEPS | 8.97E-01 | 3.24E-01 |
| PRD-Grant County Shore | Zn-65 | -5.98E-02 | 4.54E-02 |
| PRD-Grant County Shore | ZrNb-95 | -7.18E-02 | 5.26E-02 |
| PRD-1/3 Grant Shore | Be-7 | 4.18E-02 | 1.70E-01 |
| PRD-1/3 Grant Shore | CePr-144 | 6.41E-03 | 1.78E-01 |
| PRD-1/3 Grant Shore | Co-60 | 1.11E-02 | 1.62E-02 |
| PRD-1/3 Grant Shore | Cs-134 | -4.12E-02 | 1.59E-02 |
| PRD-1/3 Grant Shore | Cs-137 | 3.75E-01 | 4.64E-02 |
| PRD-1/3 Grant Shore | Eu-154 | 5.20E-03 | 5.22E-02 |
| PRD-1/3 Grant Shore | Eu-155 | 5.55E-02 | 5.41E-02 |
| PRD-1/3 Grant Shore | K-40 | 1.46E+01 | 1.57E+00 |
| PRD-1/3 Grant Shore | Pu-238 | 1.49E-05 | 1.08E-04 |
| PRD-1/3 Grant Shore | Pu-239/240 | 9.48E-03 | 1.46E-03 |
| PRD-1/3 Grant Shore | Ru-106 | -1.50E-01 | 1.42E-01 |
| PRD-1/3 Grant Shore | Sb-125 | -1.16E-03 | 4.37E-02 |
| PRD-1/3 Grant Shore | Sr-90 | 2.12E-02 | 7.27E-03 |
| PRD-1/3 Grant Shore | U-235 LEPS | 1.64E-01 | 7.20E-02 |
| PRD-1/3 Grant Shore | U-238 LEPS | 1.36E+00 | 3.21E-01 |
| PRD-1/3 Grant Shore | Zn-65 | -2.92E-01 | 6.27E-02 |
| PRD-1/3 Grant Shore | ZrNb-95 | 3.45E-02 | 4.34E-02 |
| PRD-2/3 Grant Shore | Be-7 | 2.96E-03 | 1.17E-01 |
| PRD-2/3 Grant Shore | CePr-144 | 1.07E-02 | 1.25E-01 |
| PRD-2/3 Grant Shore | Co-60 | 8.72E-04 | 1.25E-02 |
| PRD-2/3 Grant Shore | Cs-134 | 1.96E-03 | 1.01E-02 |
| PRD-2/3 Grant Shore | Cs-137 | 3.08E-01 | 4.00E-02 |
| PRD-2/3 Grant Shore | Eu-154 | 1.80E-02 | 3.71E-02 |
| PRD-2/3 Grant Shore | Eu-155 | 4.48E-02 | 3.27E-02 |
| PRD-2/3 Grant Shore | K-40 | 1.33E+01 | 1.43E+00 |
| PRD-2/3 Grant Shore | Pu-238 | 3.22E-04 | 2.59E-04 |

| Site | Constituent | Concentration | 2 Sigma Counting Error |
|---|---|---|---|
| PRD-2/3 Grant Shore | Pu-239/240 | 4.52E-03 | 1.07E-03 |
| PRD-2/3 Grant Shore | Ru-106 | 5.10E-02 | 9.57E-02 |
| PRD-2/3 Grant Shore | Sb-125 | 0.00E+00 | 3.12E-02 |
| PRD-2/3 Grant Shore | Sr-90 | 5.36E-03 | 3.87E-03 |
| PRD-2/3 Grant Shore | U-235 LEPS | -2.66E-02 | 7.12E-02 |
| PRD-2/3 Grant Shore | U-238 LEPS | 9.88E-01 | 2.95E-01 |
| PRD-2/3 Grant Shore | Zn-65 | -1.49E-02 | 3.08E-02 |
| PRD-2/3 Grant Shore | ZrNb-95 | -8.86E-02 | 3.62E-02 |
| PRD-Yakima County Shore | Be-7 | -1.39E-01 | 1.88E-01 |
| PRD-Yakima County Shore | CePr-144 | -9.31E-02 | 1.94E-01 |
| PRD-Yakima County Shore | Co-60 | 9.65E-03 | 1.79E-02 |
| PRD-Yakima County Shore | Cs-134 | -4.37E-02 | 1.83E-02 |
| PRD-Yakima County Shore | Cs-137 | 5.75E-01 | 6.70E-02 |
| PRD-Yakima County Shore | Eu-154 | -6.22E-02 | 5.97E-02 |
| PRD-Yakima County Shore | Eu-155 | 3.20E-02 | 5.83E-02 |
| PRD-Yakima County Shore | K-40 | 1.31E+01 | 1.43E+00 |
| PRD-Yakima County Shore | Pu-238 | 1.68E-04 | 1.67E-04 |
| PRD-Yakima County Shore | Pu-239/240 | 9.52E-03 | 1.57E-03 |
| PRD-Yakima County Shore | Ru-106 | -3.55E-02 | 1.48E-01 |
| PRD-Yakima County Shore | Sb-125 | -1.50E-03 | 4.85E-02 |
| PRD-Yakima County Shore | Sr-90 | 2.46E-02 | 6.81E-03 |
| PRD-Yakima County Shore | U-235 LEPS | 5.49E-02 | 8.81E-02 |
| PRD-Yakima County Shore | U-238 LEPS | 1.01E+00 | 2.57E-01 |
| PRD-Yakima County Shore | Zn-65 | -3.35E-01 | 6.90E-02 |
| PRD-Yakima County Shore | ZrNb-95 | 4.66E-02 | 4.57E-02 |
| White Bluffs Slough | Be-7 | -1.07E-01 | 2.08E-01 |
| White Bluffs Slough | CePr-144 | 8.90E-02 | 1.98E-01 |
| White Bluffs Slough | Co-60 | 7.06E-02 | 2.40E-02 |
| White Bluffs Slough | Cs-134 | -3.67E-02 | 1.78E-02 |
| White Bluffs Slough | Cs-137 | 9.68E-01 | 1.06E-01 |
| White Bluffs Slough | Eu-152 | 6.43E-01 | 1.28E-01 |
| White Bluffs Slough | Eu-154 | 2.09E-02 | 5.82E-02 |
| White Bluffs Slough | Eu-155 | 4.05E-02 | 6.10E-02 |
| White Bluffs Slough | K-40 | 1.71E+01 | 1.83E+00 |
| White Bluffs Slough | Pu-238 | 2.03E-04 | 1.58E-04 |
| White Bluffs Slough | Pu-239/240 | 4.08E-03 | 7.89E-04 |
| White Bluffs Slough | Ru-106 | -2.96E-02 | 1.58E-01 |
| White Bluffs Slough | Sb-125 | -1.05E-02 | 4.98E-02 |
| White Bluffs Slough | Sr-90 | 1.66E-02 | 5.47E-03 |
| White Bluffs Slough | U-235 LEPS | 3.20E-02 | 9.85E-02 |
| White Bluffs Slough | U-238 LEPS | 9.41E-01 | 3.16E-01 |
| White Bluffs Slough | Zn-65 | -3.60E-01 | 7.44E-02 |
| White Bluffs Slough | ZrNb-95 | 5.64E-02 | 5.13E-02 |
| 100-F Sbugh | Be-7 | -6.37E-02 | 1.35E-01 |
| 100-F Sbugh | CePr-144 | 4.00E-02 | 1.41E-01 |
| 100-F Slough | Co-60 | 3.17E-02 | 1.53E-02 |

| Site | Constituent | Concentration | 2 Sigma Counting Error |
|---|---|---|---|
| 100-F Slough | Cs-134 | -8.65E-02 | 1.68E-02 |
| 100-F Slough | Cs-137 | 3.85E-01 | 4.50E-02 |
| 100-F Slough | Eu-154 | 5.97E-02 | 4.36E-02 |
| 100-F Slough | Eu-155 | 2.35E-02 | 4.21E-02 |
| 100-F Slough | K-40 | 1.28E+01 | 1.36E+00 |
| 100-F Slough | Pu-238 | 8.96E-05 | 1.23E-04 |
| 100-F Slough | Pu-239/240 | 1.47E-03 | 4.90E-04 |
| 100-F Slough | Ru-106 | 7.35E-03 | 1.07E-01 |
| 100-F Slough | Sb-125 | 2.03E-03 | 3.37E-02 |
| 100-F Slough | Sr-90 | 1.30E-02 | 5.21E-03 |
| 100-F Slough | U-235 LEPS | 5.40E-02 | 6.85E-02 |
| 100-F Slough | U-238 LEPS | 1.37E+00 | 3.04E-01 |
| 100-F Slough | Zn-65 | -2.11E-01 | 4.53E-02 |
| 100-F Slough | ZrNb-95 | 1.08E-02 | 3.43E-02 |
| Hanford Slough | Be-7 | 8.48E-02 | 2.48E-01 |
| Hanford Slough | CePr-144 | 3.72E-02 | 2.43E-01 |
| Hanford Slough | Co-60 | 9.04E-02 | 2.94E-02 |
| Hanford Slough | Cs-134 | -6.43E-02 | 2.39E-02 |
| Hanford Slough | Cs-137 | 5.64E-01 | 6.89E-02 |
| Hanford Slough | Eu-152 | 4.44E-01 | 1.45E-01 |
| Hanford Slough | Eu-154 | 6.48E-02 | 7.85E-02 |
| Hanford Slough | Eu-155 | 1.60E-01 | 7.69E-02 |
| Hanford Slough | K-40 | 1.71E+01 | 1.86E+00 |
| Hanford Slough | Pu-238 | 1.61E-04 | 1.60E-04 |
| Hanford Slough | Pu-239/240 | 5.66E-03 | 1.08E-03 |
| Hanford Slough | Ru-106 | -2.03E-02 | 2.00E-01 |
| Hanford Slough | Sb-125 | -2.05E-02 | 6.16E-02 |
| Hanford Slough | Sr-90 | 1.66E-02 | 5.21E-03 |
| Hanford Slough | U-235 LEPS | 4.40E-02 | 6.61E-02 |
| Hanford Slough | U-238 LEPS | 4.63E-01 | 2.72E-01 |
| Hanford Slough | Zn-65 | -5.56E-01 | 1.02E-01 |
| Hanford Slough | ZrNb-95 | 6.69E-02 | 6.61E-02 |
| McNary-Oregon Shore | Be-7 | 1.01 E-01 | 1.58E-01 |
| McNary-Oregon Shore | CePr-144 | -3.78E-02 | 1.46E-01 |
| McNary-Oregon Shore | Co-60 | 2.01E-01 | 3.75E-02 |
| McNary-Oregon Shore | Cs-134 | -1.31E-02 | 1.29E-02 |
| McNary-Oregon Shore | Cs-137 | 6.65E-01 | 8.02E-02 |
| McNary-Oregon Shore | Eu-152 | 8.51E-01 | 1.45E-01 |
| McNary-Oregon Shore | Eu-154 | 1.50E-01 | 5.05E-02 |
| McNary-Oregon Shore | Eu-155 | 3.51E-02 | 3.69E-02 |
| McNary-Oregon Shore | K-40 | 1.46E+01 | 1.57E+00 |
| McNary-Oregon Shore | Pu-238 | 4.24E-04 | 2.39E-04 |
| McNary-Oregon Shore | Pu-239/240 | 1.24E-02 | 1.74E-03 |
| McNary-Oregon Shore | Ru-106 | 6.97E-02 | 1.24E-01 |
| McNary-Oregon Shore | Sb-125 | 2.21E-02 | 3.81E-02 |
| McNary-Oregon Shore | Sr-90 | 4.88E-02 | 1.10E-02 |

| Site | Constituent | Concentration | 2 Sigma Counting Error |
|---|---|---|---|
| McNary-Oregon Shore | U-235 LEPS | 6.47E-03 | 9.80E-02 |
| McNary-Oregon Shore | U-238 LEPS | 9.06E-01 | 2.98E-01 |
| McNary-Oregon Shore | Zn-65 | -1.25E-01 | 4.35E-02 |
| McNary-Oregon Shore | ZrNb-95 | -6.10E-02 | 4.21E-02 |
| McNary-1/3 Oregon Shore | Be-7 | 2.06E-01 | 2.39E-01 |
| McNary-1/3 Oregon Shore | CePr-144 | -1.36E-01 | 2.09E-01 |
| McNary-1/3 Oregon Shore | Co-60 | 5.96E-02 | 2.86E-02 |
| McNary-1/3 Oregon Shore | Cs-134 | 2.60E-03 | 2.01E-02 |
| McNary-1/3 Oregon Shore | Cs-137 | 4.79E-01 | 7.04E-02 |
| McNary-1/3 Oregon Shore | Eu-154 | -9.56E-02 | 7.88E-02 |
| McNary-1/3 Oregon Shore | Eu-155 | 9.31E-02 | 5.33E-02 |
| McNary-1/3 Oregon Shore | K-40 | 1.40E+01 | 1.68E+00 |
| McNary-1/3 Oregon Shore | Pu-238 | 1.01E-03 | 1.22E-03 |
| McNary-1/3 Oregon Shore | Pu-239/240 | 7.82E-03 | 3.24E-03 |
| McNary-1/3 Oregon Shore | Ru-106 | 1.83E-01 | 1.79E-01 |
| McNary-1/3 Oregon Shore | Sb-125 | -2.43E-02 | 6.01E-02 |
| McNary-1/3 Oregon Shore | Sr-90 | 4.26E-02 | 1.01E-02 |
| McNary-1/3 Oregon Shore | U-235 LEPS | -5.88E-02 | 8.79E-02 |
| McNary-1/3 Oregon Shore | U-238 LEPS | 1.31E+00 | 3.26E-01 |
| McNary-1/3 Oregon Shore | Zn-65 | -9.90E-02 | 5.84E-02 |
| McNary-1/3 Oregon Shore | ZrNb-95 | -7.28E-02 | 6.67E-02 |
| McNary-2/3 Oregon Shore | Be-7 | 4.39E-02 | 2.53E-01 |
| McNary-2/3 Oregon Shore | CePr-144 | -1.16E-01 | 2.47E-01 |
| McNary-2/3 Oregon Shore | Co-60 | 2.21E-01 | 3.99E-02 |
| McNary-2/3 Oregon Shore | Cs-134 | -6.08E-02 | 2.48E-02 |
| McNary-2/3 Oregon Shore | Cs-137 | 7.76E-01 | 8.99E-02 |
| McNary-2/3 Oregon Shore | Eu-152 | 8.68E-01 | 1.70E-01 |
| McNary-2/3 Oregon Shore | Eu-154 | 8.89E-03 | 8.29E-02 |
| McNary-2/3 Oregon Shore | Eu-155 | 8.17E-02 | 8.04E-02 |
| McNary-2/3 Oregon Shore | K-40 | 1.71E+-01 | 1.88E+00 |
| McNary-2/3 Oregon Shore | Pu-238 | 1.00E-04 | 4.19E-04 |
| McNary-2/3 Oregon Shore | Pu-239/240 | 1.35E-02 | 4.03E-03 |
| McNary-2/3 Oregon Shore | Ru-106 | -9.64E-02 | 2.08E-01 |
| McNary-2/3 Oregon Shore | Sb-125 | -8.03E-04 | 6.40-E-02 |
| McNary-2/3 Oregon Shore | Sr-90 | 4.05E-02 | 9.60E-03 |
| McNary-2/3 Oregon Shore | U-235 LEPS | 1.21E-01 | 7.27E-02 |
| McNary-2/3 Oregon Shore | U-238 LEPS | 1.61E+00 | 3.31E-01 |
| McNary-2/3 Oregon Shore | Zn-65 | -5.55E-01 | 1.08E-01 |
| McNary-2/3 Oregon Shore | ZrNb-95 | 3.14E-02 | 6.77E-02 |
| McNary-Wash. Shore | Be-7 | 1.21E-01 | 1.74E-01 |
| McNary-Wash. Shore | CePr-144 | -6.59E-02 | 1.82E-01 |
| McNary-Wash. Shore | Co-60 | 9.11E-02 | 2.18E-02 |
| McNary-Wash. Shore | Cs-134 | -4.25E-02 | 1.67E-02 |
| McNary-Wash. Shore | Cs-137 | 6.49E-01 | 7.32E-02 |
| McNary-Wash. Shore | Eu-152 | 5.50E-01 | 1.20E-01 |
| McNary-Wash. Shore | Eu-154 | 2.89E-02 | 5.86E-02 |

| Site | Constituent | Concentration | 2 Sigma Counting Error |
|---|---|---|---|
| McNary-Wash. Shore | Eu-155 | 1.10E-01 | 5.72E-02 |
| McNary-Wash. Shore | K-40 | 1.65E+01 | 1.75E+00 |
| McNary-Wash. Shore | Pu-238 | 8.63E-04 | 6.21E-04 |
| McNary-Wash. Shore | Pu-239/240 | 9.81E-03 | 2.28E-03 |
| McNary-Wash. Shore | Ru-106 | 3.59E-02 | 1.42E-01 |
| McNary-Wash. Shore | Sb-125 | 2.63E-02 | 4.57E-02 |
| McNary-Wash. Shore | Sr-90 | 1.68E-02 | 5.56E-03 |
| McNary-Wash. Shore | U-235 LEPS | 8.33E-02 | 7.29E-02 |
| McNary-Wash. Shore | U-238 LEPS | 1.53E+00 | 3.24E-01 |
| McNary-Wash. Shore | Zn-65 | -4.31E-01 | 7.71E-02 |
| McNary-Wash. Shore | ZrNb-95 | 7.61E-02 | 4.72E-02 |

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