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Prepared by

CH2MHILL

ecology and environment, inc.
International Specialists in the Environment

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SECTION 5

Preliminary Sediment Conceptual Site Model

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This section presents the updated preliminary CSM for contaminated sediment in the UCR. It includes descriptions of known and potential sources of contamination, the river/reservoir hydraulic relationship, the nature and extent of COIs, and an evaluation of fate and transport of COIs. The information presented here builds on information about the CSM presented in the A&R Document (CH2M HILL, 2004b).

This preliminary sediment CSM provides a broad-scale framework for assessing UCR sediment contamination. It is anticipated that future studies conducted during the RI/FS will augment this understanding and will supply additional detail within specific areas or locations. Data gaps are summarized at the end of each of the following subsections. Filling these data gaps may be useful to further refine the sediment conceptual site model; however, a determination of whether the data gaps constitute data needs for the RI/FS will be evaluated through subsequent application of the DQO process.

5.1 Sources of Contamination

Known and potential sources of contamination in UCR sediments were identified in the ESI conducted for a portion of the UCR (Ecology and Environment [E&E], 2003). These known and potential sources of contamination were evaluated as part of the development of the RI/FS preliminary sediment CSM in accordance with the DQOs developed for source identification detailed in the QAPP and summarized in Section 2 of this document. The source identification process entailed evaluation of available information on releases from upstream industry and operations, process and historical information from the facilities, and review of applicable industry-related literature. Results of that evaluation are summarized in the A&R Document. The source identification process also involved review of Phase I RI sediment sampling results. Evaluation of the data from the Phase I RI sediment sampling program did not result in identification of new sources of sediment contaminants. The Phase I sediment sampling results support the previous evaluation of contaminant sources presented in the A&R Document.

The known and potential sources include mining and milling operations, smelting operations, pulp and paper production, sewage treatment plants, and other industrial activities. These known and potential sources are briefly summarized in the following subsections.

5.1.1 Mining, Milling, and Smelting

Numerous mining and milling operations have operated since the late 1800s within the drainage area of the UCR in the U.S. and Canada. Although claims were staked earlier, development of mineral resources in the area did not become economically feasible until approximately the 1890s, when ore concentration processes were introduced. Ores were concentrated in mills built at or in the vicinity of the mines and transported to smelters for further refining. Mining and ore processing wastes containing arsenic, cadmium, copper, lead, mercury, and zinc were generated during these operations (E&E, 2000). In addition to hard rock mines, placer gold mining using mercury amalgamation reportedly occurred within the drainage of Big Sheep Creek, a tributary to the Columbia River (USEPA, 1991).

5.1.1.1 Former Le Roi/Northport Smelter

The Le Roi/Northport smelter is a former smelter located on the east bank of the Columbia River just northeast of the town center of Northport, Washington. Smelter operations began in 1896 by processing copper and gold ores. By 1908 it was processing 500 tons of ore per day. It closed in 1909 because of competition with the Cominco smelter (see Section 5.1.1.2). It restarted in 1914 and processed lead ores sporadically until 1922. The smelter produced slag, which was reportedly placed in piles for disposal or discharged directly to the river by underground launders. Contaminants detected at significant concentrations in soil samples collected at the smelter site include arsenic, cadmium, copper, lead, mercury, and zinc (E&E, 2003). The site was the subject of an USEPA soil removal action during the summer of 2004.

5.1.1.2 Cominco Smelter

The Cominco smelter is located approximately 10 river miles upstream from the U.S.-Canada border in Trail, B.C., Canada. Smelter operations have been underway in Trail since 1896. The smelter is owned by a company which became known as Consolidated Mining and Smelting Company of Canada, Ltd., in 1906, was officially renamed Cominco in 1966, and merged with Teck Ltd. to become Teck Cominco Metals, Ltd., in 2001 (also referred to as “Cominco” in this document).

The facility primarily produced lead and silver during the first decade of operation, with zinc production initiated in 1915. Plants for production of nitrogen- and phosphorus-based fertilizers were built in 1930. Although the smelter was originally built to process materials from local mines, it currently processes ore concentrates obtained from mining operations throughout the world. In addition to lead, zinc, cadmium, silver, gold, bismuth, antimony, indium, germanium, and arsenic, this facility produces sulfuric acid and liquid sulfur dioxide. It also produced ammonia, ammonium sulfate, and phosphate fertilizers until August 1994, at which time production of the phosphorus-based fertilizer was terminated. The fertilizer plant was found to be a major source of mercury at the Trail operations largely because mercury is a constituent of the phosphate rock obtained from the Warm Springs Mine, Montana. The smelter complex has discharged liquid effluent and water-granulated fumed slag into the Columbia River and has experienced a number of accidental spills and releases to the river. Another source of contamination to the Columbia River is the Stoney Creek drainage located just north of the smelter.

Liquid Effluent Discharges

Available information about liquid effluent discharges from Cominco to the Columbia River was presented in the A&R Document and is briefly summarized below.

Cominco first applied for permits to discharge industrial effluent to the Columbia River in 1973. In 1978, the Province of B.C. issued effluent discharge permit PE-2753 for metallurgical plant operations (Province of B.C. Environment, 1991a). Aqueous discharges of various constituents, including lead, zinc, cadmium, arsenic, mercury, antimony, copper, manganese, ammonia, phosphate, and fluoride were monitored under the permit.

Information on pre-1977 discharges from Cominco to the Columbia River is not available. Since 1977, Cominco has monitored and reported discharges from permitted outfalls, as well as spills and leaks. This includes calculated average daily discharge data (by year) for outfalls discharging into the Columbia River.

Available discharge data for the period 1977 through 1996 were compiled from a combination of information sources (Evergreen State College, 1993; Cominco, 1995; Cominco, 1997). Dissolved metals effluent data are available for arsenic, cadmium, lead and zinc for 1977 through 1996, and total metals data are available for arsenic, cadmium, lead, and zinc for 1991 through 1996. Total mercury data are available for 1977 through 1996. Mercury loading data for the metallurgical operations are available for the period 1977 through 1996, but, for the fertilizer operations, mercury data are available only for the period 1980 through 1996. Discharge data for dissolved fluoride, nitrate, and phosphate from the fertilizer operations also are available for the period 1980 through 1996. Except for mercury, the available data are presented only in histogram format; mercury data are available in tabular format (1980 to 1994) and histogram format (1977 to 1996) (Evergreen State College, 1993; Cominco, 1995; Cominco, 1997).

Environment Canada provides data regarding surface water discharges to the Columbia River for Cominco for 1994 through 2002 via the National Pollutant Release Inventory (NPRI) (Environment Canada, 2004). Surface water discharge is defined to include discharges, spills, and leaks (Environment Canada, 2004). Discharge data are provided for total metals in metric tons per year.

Comparison between the Environment Canada (2004) data and Cominco (1997) data for the years of data overlap (1994 through 1996) reveals apparent discrepancies in reported discharge loading values. It is not clear how discharge values were calculated by Environment Canada (2004) and Cominco (Evergreen State College, 1993; Cominco, 1995; Cominco, 1997).

Data for selected constituent discharges to the Columbia River are summarized below. Numerical values of the graphically presented Cominco data (Evergreen State College, 1993; Cominco, 1995; Cominco, 1997) are estimated. No attempt was made in this evaluation to convert daily and yearly discharge units to compare the Cominco data and the Environment Canada data. It should be noted that the permitted liquid effluent discharges discussed below may not be representative of the magnitude or frequency of discharges from the facility between 1896 and 1978, prior to the establishment of monitoring requirements under the effluent discharge permit. It also should be noted that the chemical form (e.g., particulate, colloidal, sorbed, complexed, dissolved) of the liquid constituents is not known based on available information.

- **Lead.** Dissolved lead loading decreased between 1980 and 1996, from a high of approximately 205 kilograms per day (kg/day) to as low as approximately 12 kg/day (Cominco, 1995; Cominco, 1997). After 1991, total lead effluent ranged between approximately 85 kg/day (in 1994) and 235 kg/day in 1992 (Cominco, 1995; Cominco, 1997). Annual discharges of lead and its compounds decreased between 1994 and 2002 from 149 metric tons in 1994 to as low as 1.76 metric tons in 2001 (Environment Canada, 2004).

- **Zinc.** Dissolved zinc loading decreased steadily (1980 to 1994), from approximately 7,400 kg/day to several hundred kg/day. After 1991, total zinc decreased (data only for 1991 to 1994) from approximately 500 to 200 kg/day (Cominco, 1995; Cominco, 1997). Annual discharges of zinc and its compounds decreased steadily from 4,444 metric tons in 1994 to as low as 18.38 metric tons in 2001 (Environment Canada, 2004).
- **Cadmium.** Dissolved cadmium loading decreased steadily (1980 to 1994) from a high of approximately 64 kg/day (in 1982) to approximately 3 kg/day. Total cadmium decreased (data only for 1991 to 1994) from a high of approximately 13 kg/day to a low of approximately 4 kg/day (Cominco, 1995; Cominco, 1997). Annual discharges of cadmium and its compounds decreased steadily from 6 metric tons in 1994 to as low as 0.17 metric ton in 2001 (Environment Canada, 2004).
- **Arsenic.** Dissolved arsenic loading generally decreased (1980 to 1994) from a high of approximately 18 kg/day to a low of approximately 4 kg/day. Total arsenic exhibited no trend (data only for 1991 to 1994), ranging from approximately 6 kg/day to 10 kg/day (Cominco, 1995; Cominco, 1997). Annual discharges of arsenic and its compounds decreased steadily from 41.5 metric tons in 1994 to as low as 0.52 metric ton in 2000 (Environment Canada, 2004).
- **Mercury.** Total mercury loading generally decreased (1980 to 1994), ranging from 7.24 to 0.39 kg/day. Results were analyzed separately for metallurgical and fertilizer operations. Average discharges from the two operations were approximately equal over the reporting period (Cominco, 1995; Cominco, 1997). Annual discharges of mercury and its compounds decreased steadily from 0.14 metric ton in 1994 to as low as 0.0126 metric ton in 2002 (Environment Canada, 2004).
- **Antimony.** Annual discharges of antimony and its compounds for the period 1994 to 2002 ranged from a low of 2.25 metric tons in 2000 to a high of 7.92 metric tons in 1995 (Environment Canada, 2004).
- **Copper.** Annual discharges of copper and its compounds decreased from a high of 898 metric tons in 1994 to 0.31 metric tons in 2002 (Environment Canada, 2004).
- **Manganese.** Annual discharges of manganese and its compounds decreased from a high of 16.95 metric tons in 1995 to 0.54 metric tons or less for the period from 1997 through 2002 (Environment Canada, 2004).
- **Ammonia.** Dissolved NH_3/N loading generally decreased after 1989. Discharges (1980 to 1994) ranged from approximately 2,900 kg/day to less than 1,000 kg/day (Cominco, 1995; Cominco, 1997). Annual discharges of total ammonia generally decreased over the period 1994 to 2002 ranging from a high of 500.4 metric tons in 1995 to a low of 89.4 metric tons in 2001 (Environment Canada, 2004).
- **Phosphate.** Total PO_4/P loading generally decreased after 1988. Discharges (1980 to 1994) ranged from approximately 7,000 kg/day to 1,500 kg/day. Ortho PO_4/P generally comprised most of the total PO_4/P (Cominco, 1995; Cominco, 1997).
- **Fluoride.** Dissolved fluoride loading generally decreased (1980 to 1994) from a high of approximately 9,500 kg/day to less than 1,000 kg/day (Cominco, 1995; Cominco, 1997).

Water-Granulated Fumed Slag Discharges

Slag has been generated as part of the smelting processes at the Trail facility over most of its history. Blast furnace slag, generated by the lead smelters, contained appreciable quantities of zinc and lead (Cominco, 1991). Because of the remaining high metals concentrations, the blast furnace slag was reportedly never discharged directly into the Columbia River (Ministry of Environment, Lands and Parks [MELP], 1990).

Since 1930, blast furnace slag has been fumed to recover residual zinc and lead (Cominco, 1991). Following fuming, the molten slag was tapped and granulated with water. This water-granulated fumed slag generally consists of black, glassy material, the bulk of which has the texture of sand. The particles are highly angular. A small proportion consists of fines that have a broken eggshell or needle-like morphology (Cominco, 1991). From the beginning of the slag fuming process in 1930, the water-granulated fumed slag was discharged to the Columbia River. From 1973 to 1995, water-granulated fumed slag was discharged to the Columbia River under effluent permit PE-2753. In 1995, the permit to discharge water-granulated fumed slag to the river expired, and the water-granulated fumed slag has since been collected onsite (MacDonald Environmental Sciences, Ltd. [MESL], 1997). In 1994, Cominco evaluated potential uses of water-granulated fumed slag. These included its use in the manufacture of cement; in concrete aggregate (less than or equal to 4 mesh component); as a pozzolanic additive, as partial replacement for Portland cement; in "Slagcrete" (combining water-granulated fumed slag, sulfur, and a proprietary ingredient); and for paving (Cominco, 1994).

Information documenting the quantity of water-granulated fumed slag discharged by Cominco to the Columbia River has not been located. However, the water-granulated fumed slag discharge may be estimated based on the amount of lead produced (Cominco, 1990). Cominco has reported that the weight of blast furnace slag generated is equal to approximately 140 percent of the weight of lead produced, and the weight of water-granulated fumed slag generated and discharged to the Columbia River is equal to approximately 85 percent of the weight of blast furnace slag generated (Cominco, 1990). Based on these ratios and lead production information, it is estimated that more than 13,000,000 tons of water-granulated fumed slag were generated and discharged to the Columbia River. Since completion of Grand Coulee Dam in 1940, it is estimated that approximately 10,000,000 tons of water-granulated fumed slag were generated and discharged to the Columbia River.

The chemical and physical nature of the water-granulated fumed slag may vary depending on the chemical composition of the fumed slag material and the granulation process. The composition of the fumed slag material will have varied over the period of operations as a result of variations in ore concentrate composition, the specific processes employed to recover metal values and remove impurities, and the effectiveness of those processes over time. In 1991, Cominco reported that chemical analyses were conducted on each fumed slag batch to provide information on chemical composition. Slag tapping was reportedly initiated at a point beyond that warranted by economic parameters in order to minimize the amount of metals released into the environment (Cominco, 1991).

Several studies were conducted between 1974 and 1992 by Cominco (Cominco, 1990, 1991), by B.C. Ministry of Environment (MEPBC, 1979), and Fisheries and Oceans Canada (BFO, 1992) to evaluate the bulk chemistry, leachability under various laboratory conditions, grain size distribution, and various physical properties of water-granulated fumed slag. The results are summarized in the A&R Document. Based on the available grain size data presented in the studies listed above, water-granulated fumed slag consists predominantly of fine to coarse sand, with silt-size (0.074 mm) or smaller particles comprising up to 0.6 percent of the total. Also according to these studies, the following metals have been detected in bulk samples of water-granulated fumed slag:

- Antimony at concentrations ranging from less than 25 mg/kg (below detection limits) to 326 mg/kg
- Cadmium at concentrations ranging from less than 1 mg/kg (below detection limits) to 300 mg/kg
- Chromium at concentrations ranging from 210 to 311 mg/kg
- Copper at concentrations ranging from 1,800 to 11,900 mg/kg
- Iron at concentrations ranging from 279,000 to 339,000 mg/kg
- Lead at concentrations ranging from 14 to 6,650 mg/kg
- Manganese at concentrations ranging from 5,330 to 11,500 mg/kg
- Nickel at concentrations ranging from 17.2 to 41.1 mg/kg
- Zinc at concentrations ranging from 19,900 to 48,200 mg/kg

Arsenic was analyzed in two of the previous studies (Cominco, 1990; BFO, 1992), but was not detected above the detection limits (30 mg/kg and 100 mg/kg, respectively).

Fine-grained fractions of water-granulated fumed slag also were analyzed in one of the studies (Cominco, 1991). Results indicate that lead is present in the finer grained fractions of water-granulated fumed slag at concentrations higher than in the associated bulk sample.

Each of these metals (antimony, arsenic, cadmium, chromium, copper, iron, lead, manganese, nickel, and zinc) has been identified as a COI in UCR sediment based on the process described in Section 4. The other two metal COIs identified for the site are mercury and uranium. Mercury was analyzed in water-granulated fumed slag in only one of the previous studies (BFO, 1992) and was not detected above the detection limit of 0.005 mg/kg. None of the previous studies analyzed uranium in water-granulated fumed slag.

Of the metal COIs identified for the UCR sediment, some of the metals detected in water-granulated fumed slag samples—antimony, chromium, copper, iron, manganese, and zinc—display broadly similar trends in their distribution within UCR sediment, as discussed in sections that follow. On the basis of these observations, these metals are referred to as ″coarse-grained slag-associated metals″ in this document. Arsenic, although not detected in water-granulated fumed slag samples (detection limits of 30 mg/kg and 100 mg/kg), also is considered a coarse-grained slag associated metal in this document based on broadly similar trends in distribution. Lead has been reported at widely varying concentrations in samples of water-granulated fumed slag. As described in Section 5.4, the distribution of lead is similar in some, though not all, respects to the distribution of coarse-grained slag-associated metals. Above Marcus Flats, the distribution of lead is broadly similar to the coarse-grained slag-associated metals listed above; below Marcus Flats, the distribution of lead in sediments shares fewer similarities with the coarse grained slag-associated metals listed above. Therefore, lead is treated in this evaluation as both a coarse-grained, slag-associated metal and as an "other metal."

As stated above, the chemical and physical characteristics of the water-granulated fumed slag likely have varied over the period of time the material has been discharged into the Columbia River, as indicated by variations in the chemical composition of the fumed slag material and the granulation process. The chemical characteristics of the fumed slag would be expected to vary based upon composition or the ores processed, the smelting and refining processes used to recover metal values and remove impurities, and the effectiveness of those processes. Specific information regarding these variations was not available for evaluation.

As indicated in the discussion of liquid effluent discharges above, COIs identified as coarse-grained slag associated metals have also been discharged to the UCR in liquid effluent. Thus, identification of a COI in the UCR as a coarse-grained slag associated metal in this document is not intended to exclude from consideration other chemical forms of that COI. Identification of a metal COI as a coarse-grained slag-associated metal is intended primarily to aid in the understanding of broad-scale distributions of these metal COIs in the UCR.

Other Possible Sources

In addition to the discharges described above, several other possible sources of contamination at Cominco have been identified. These possible sources include the following:

- Spills, bypasses, and emergency releases, including a single 6,300-pound spill of mercury in March 1980
- Groundwater and surface water runoff associated with waste dumping and operational practices in the vicinity of Stoney Creek
- Groundwater discharge
- Discharges to the air
- Runoff impacted by particulates deposited as a result of air discharges from stacks

More information about these possible sources is provided in the A&R Document.

5.1.2 Celgar Pulp Company

Since 1960, the Celgar Pulp Mill, an integrated wood mill and bleach kraft pulp mill, has operated in Castlegar, B.C., approximately 30 river miles upstream from the U.S.-Canada border. The mill began operations as the Celgar Pulp Company (Celgar) (U.S. Geological Survey [USGS], 1994). Celgar Pulp Company was in bankruptcy in 2004 (Environment Canada, 2004), but was reported to have operated continuously since 1960 (Celgar, 2004). The Celgar pulp mill currently is owned and operated by the Zellstoff Celgar Limited Partnership (Environment Canada, 2006). Between the time the mill began operation and mid-1993, the mill used elemental chlorine in its bleaching process (USGS, 1994). Celgar was identified as a source of dioxin/furan discharges to the Columbia River prior to modernization (Evergreen State College, 1993; USGS, 1994). More information about effluent discharges from the plant is provided in the A&R Document.

5.1.3 Potential Sources of PCBs in UCR Sediments

In general, PCBs may be found in electrical insulators, transformers and capacitors, inks, paints, lubricants, and plastics (USGS, 2000). Several sources of PCB releases have been identified within the Spokane River, a tributary to Lake Roosevelt. Many of these sources are in the vicinity of Spokane, Washington, located about 65 river miles upstream from the confluence with Lake Roosevelt (Ecology, 1995).

Specific locations in the Columbia River system where the presence of PCBs has been identified include the Cominco Smelter operations at Trail and Celgar. In March of 2001, Cominco documented a 10-liter PCB oil spill. The spill reportedly did not reach the Columbia River. However, it indicates the existence of PCBs at that location (Environment Canada, 2003). As of 1993, Celgar was still storing PCBs onsite, reporting the storage of five PCB containers at its facility (Celgar, 1993).

5.1.4 Other Potential Sources of Contamination

Other potential sources of contaminants include municipal storm sewers and nonpoint sources. The ESI report (E&E, 2003) identified the presence of 54 storm sewers from the City of Trail, B.C., that drain into the Columbia River. It also identified effluents from the municipal sewage treatment plants at Castlegar, B.C., and Trail, B.C., that discharge directly into the Columbia River, and effluent from municipal sewage treatment plants at Colville, Washington, and Chewelah, Washington, that discharge into the Colville River.

5.1.5 Data Gaps

Data gaps pertaining to known and potential sources of contaminants in UCR sediments have been identified. Whether these data gaps constitute data needs for the RI/FS will be evaluated through the DQO process or future RI/FS phases. These data gaps are as follows:

- Additional information on the chemical and physical properties of liquid effluent discharged from Cominco
- Additional information on historic discharges from Cominco, including pre-1977 discharges
- Additional information on the chemical and physical characteristics of the water-granulated fumed slag over the period of time the material has been discharged into the Columbia River
- Additional information on other liquid and solid discharges from Cominco and associated operations and facilities, including Stoney Creek, over its history
- Information on current and anticipated future discharges from Cominco and associated operations and facilities, including Stoney Creek

5.2 River/Reservoir Hydraulic Relationship and Sediment Grain Size

This section presents an evaluation of the hydraulic characteristics of the combined river/reservoir UCR system and of sediment grain size. The relationship between hydraulic characteristics and sediment grain size is fundamental for understanding the processes that affect the distribution of sediment grain size and contaminated sediments within the UCR since the construction of Grand Coulee Dam in 1940. This section provides an overview of this relationship to help lay the framework for the interpretation of the nature and extent of contaminated sediment discussed in Section 5.4 and fate and transport of contaminated sediment discussed in Section 5.5. Additional discussion of the relationship between the river and reservoir may be found in the A&R Document.

5.2.1 River/Reservoir Hydraulic Relationship

This section describes the relationship between Lake Roosevelt water levels measured at Grand Coulee Dam and Columbia River flows measured at the international border station (USGS Station 12399500). It describes annual reservoir level changes, river flows at the international border station, the cyclical relationship between reservoir levels at Grand Coulee Dam and river flows at the international border station, and the average cross-sectional flow velocity through the reservoir. This information contributes to the understanding of how water and sediment move through the UCR.

5.2.1.1 Reservoir Levels

Figure 5-1 shows Lake Roosevelt water elevations for 1992, 1997, and 2002. These three years illustrate how the reservoir level fluctuates between a full pool elevation of 1,290 feet (U.S. Bureau of Reclamation [USBR] 1937 vertical datum) and an annual low pool elevation that can be as low as 1,208 feet during a wet year (1997) or as high as 1,263 feet during a dry year (1992). Elevation 1,208 is the lowest level to which the USBR prefers to draw down the reservoir. Water level drawdown for flood control typically begins in January and reaches maximum drawdown in May. After spring drawdown, the reservoir refills relatively rapidly during snowmelt and spring runoff. Typically the reservoir is filled to near full pool (near elevation 1,290) by the Fourth of July weekend and maintained within 10 feet of full pool (between 1,280 and 1,290 feet) through the summer and fall.

Figure 5-2 plots the percentage of time the reservoir level has been at or lower than a given elevation. The plot was made by using the daily water level records kept by the USBR for the period between July 1, 1940, and August 4, 2004. The total number of days that the reservoir has been at or lower than a specific elevation is also shown. Two periods of record are shown: the complete 1940 to 2004 time period, and the last 20 years (1984 to 2004). The 1984 to 2004 time period is the time period since completion of Revelstoke Dam, the last major dam built on the Columbia River system that influences control of spring runoff above Grand Coulee Dam.

Figure 5-2 shows that the reservoir level has been maintained above 1,208 feet on a continual basis over the last 20 years. The 60-year data set shows that the reservoir water surface has been lower than 1,208 feet for only a small percentage of its history. This corresponds to times when either major work was occurring at the dam, such as the 1974 completion of the third powerhouse, or during the early operational years when water levels were varied more widely than under current management practices. Figure 5-2 also shows that the reservoir level has been above 1,240 feet about 90 percent of the time. Put another way, the water surface has been below 1,240 feet 10 percent of the time since 1940. Since 1984 the water surface has been below about 1,250 feet 10 percent of the time. Looked at from the perspective of bank exposure, the upper portion of the bank is exposed a greater percentage of the time than the lower portions. This portion also receives the most exposure to rain, snowmelt, wave action, and the rising and falling reservoir water level. This exposure results in the hydraulic washing of fine-grained sediment, such as silt- and clay-sized particulates, with resultant migration of the fine-grained sediment from higher elevations on the bank to lower elevations. Fine-grained contaminants and contaminants that are attached to or incorporated within the fine-grained sediment are similarly transported to lower bank elevations.

5.2.1.2 Inflow to Lake Roosevelt

The Columbia River, Spokane River, and Kettle River contribute 99 percent of the flow entering Lake Roosevelt. On average, the Columbia River represents 89 percent of the flow to the lake, the Spokane River provides 7 percent, and the Kettle River provides 3 percent. The remaining 1 percent is provided by numerous small streams and the Colville and the Sanpoil Rivers (Stober et al., 1981). The Pend Oreille River, which flows into the mainstem of the Columbia River just north of the U.S.-Canada border, contributes 27 percent of the mean annual flow in the Columbia River at that location (Ecology, 1997). Outflow from Lake Roosevelt occurs via flow through the dam to the Columbia River or through a pumped discharge to Banks Lake (the pumps are adjacent to Grand Coulee Dam) for irrigation storage (Welch et al., 1992).

USGS has operated the international border Columbia River flow gage continuously since March 1, 1938. The average river flow since 1938 has been about 100,000 cubic feet per second (cfs). The highest flow ever recorded is 680,000 cfs, which occurred in June 1894. The second highest flow was 550,000 cfs in June 1948, and the third highest flow was 492,000 cfs in June 1961. The highest flow to occur in the last 20 years (1984 to 2004) was 305,000 cfs in June 1997. The general effect of the upriver dams is a reduction in peak flow (because water is intentionally held to reduce peak flows) and an increase in median flow (because the stored water is released more gradually).

5.2.1.3 Reservoir Level and River Flow

The reservoir level is managed to provide storage for the high spring flows. The reservoir water level rises as Columbia River and tributary flows increase. This is shown in Figure 5-3, which is a plot of Columbia River daily mean streamflow measured at the border and reservoir water level for the 1997 water year, a wet year. The peak flow occurred when the reservoir was near elevation 1,267.

Another effect of the reservoir management practices is that peak annual Columbia River flows tend to occur at higher reservoir levels than at lower. This is because peak annual flow typically occurs in mid- to late-spring when snowmelt runoff is highest, and which occurs well after the annual reservoir fill cycle has begun. Figure 5-4 is a plot of the highest recorded river flow since 1940 to have occurred at various reservoir water levels. The period of record is from July 1940 to August 2004. The plotted data consist of the highest recorded flow to have occurred within discreet 10-foot reservoir level increments beginning at 1,120 to 1,130 feet and ending at 1,280 to 1,290 feet. The flows are plotted at the midpoint of the 10-foot increment; e.g., at 1,125 feet and 1,285 feet. The trend of higher flow occurring at higher reservoir level is apparent for the complete period of record from July 1940 to August 2004. Since October 1, 1984, the highest flows occurred in water year 1997 and are of lower magnitude than the complete time period due to the combined upstream water storage effect of the dams on the Columbia River and its tributaries built after Grand Coulee Dam. This data set, and the same data set excluding the 1997 water year data, shows a trend of increasing maximum flow up to the 1,260- to 1,270-foot range, then lesser flows at higher water levels. The post-1984 data set likely more typifies current reservoir operations and is likely more representative of future operations.

The timing of peak river flow and reservoir water levels is important because of its impact on sediment transport. Transport of sediment longitudinally at any point along the UCR will be highest when the water velocity is highest, and the highest water velocities occur when the flow area is low and the flow rate is high, as discussed in Section 5.2.1.4.

5.2.1.4 Reservoir Flow Velocity

As discussed above, reservoir pool level and flow rate are determined by a combination of snowpack/snowmelt and reservoir management practices at Grand Coulee Dam and upstream dams. Another related reservoir element of importance to the RI/FS is flow velocity. Flow velocity variations in the reservoir play a large role in determining the nature and extent and fate and transport of contaminated sediments within the UCR. Flow velocity at any given location in the reservoir is a function of reservoir level and river flow. Other important factors determining flow velocity include turbulence, differential momentum, proximity to the sides and bottom, surface roughness of the sides and bottom, channel shape and orientation, secondary currents, density currents, inflow from numerous tributaries along the reservoir, and many other factors that make precise calculation of actual flow velocity difficult.

Determination of actual flow velocities throughout the UCR is beyond the scope of Phase I of the RI. However, in order to help with the understanding of broad-scale sediment transport within the UCR, an initial simplified assessment was performed using average flow velocities across transects. Average flow velocity at any transect across the reservoir is a function of both flow rate and reservoir level. For any given reservoir level and location along the length of the UCR, there is a unique cross-sectional configuration and cross-sectional area through which the reservoir flow occurs.

Figures 5-5, 5-6, and 5-7 present the results of the simplified analysis of historical average cross-sectional water flow velocity in Lake Roosevelt at three reservoir levels (elevations 1,290 1,255, and 1,208) (CH2M HILL, 2004b). Figure 5-5 depicts full pool, 1,290 feet. Figure 5-6 depicts the minimum maintenance level of 1,255 feet for routine dam drum gate maintenance. This elevation was chosen because it is an intermediate level between full pool and the typical lowest pool level of 1,208 feet. Figure 5-7 depicts the reservoir level at 1,208 feet. Each figure shows the calculated average reservoir cross-sectional area by river mile for the selected pool level in square feet (sq ft) (y-axis left scale) and the average cross-sectional flow velocity in feet per second (fps) (y-axis right scale) for a range of river flow rates for each river mile beginning at the U.S.-Canada border (RM 744) and descending downriver to RM 668. The range of flow rates for each plot reflects the historical range of flows that have occurred when the reservoir was at each of the three water levels (1,290, 1,255, and 1,208 feet). The calculated flow velocities represent the average velocity through a cross section taken perpendicular to the reservoir centerline at each river mile. They were calculated by dividing the river flow rate by the cross-sectional area (that is, use of the continuity equation assuming a constant water surface level).

The calculated average cross-sectional flow velocities provide only general estimates of the actual river flow velocity at each point within any of the cross sections. In general, the velocity in any cross section will be higher than the average calculated value near the middle of the channel, and lower at the sides and bottom. Velocities will also be higher on the outside of bends compared to the inside of bends. Although the calculated average flow velocities are subject to these uncertainties, they provide insight into how the reservoir flow velocity changes from upriver to downriver, and from high to low flow on a broad scale.

Transportation of sediments by flowing water is governed by many factors, the most important of which are flow velocity and sediment grain size. Other factors include grain density, grain shape, sediment sorting, riverbed morphology, and turbulence. Determination of actual flow velocities and the other principal factors that determine sediment transport in the UCR was not within the scope of Phase I of the RI/FS. However, in order to perform a first-pass analysis of sediment transport to assist with interpretation of the nature and extent and fate and transport components of the preliminary sediment CSM, a generalized relationship between average flow velocity and grain size was estimated. For this purpose, as a general approximation, movement of sand-sized sediment is considered to be unlikely within the system at average cross-sectional flow velocities of less than 2 to 3 fps. An average cross-sectional flow velocity band from 2 fps to 3 fps has been placed on Figures 5-5, 5-6, and 5-7 to provide a general indication of where further downriver movement of sand-sized bed sediment (such as water-granulated fumed slag) is unlikely at the indicated pool level. As with all flow rates shown in the figures, the velocity band of 2 to 3 fps is an average cross-sectional velocity for each river mile transect represented. The actual velocity near the sediment interface at the bottom of the river would typically be significantly less than the average cross-sectional flow velocity.

The reservoir flow velocity and its frequency of occurrence significantly influence the longitudinal movement of sediment within the reservoir along with the distribution of sediment grain size and associated contaminants. Based on the results of the simplified average cross-sectional flow velocity analysis, transport of sand-sized material is expected to be very limited in the UCR downstream from Marcus Flats, as illustrated in Figures 5-5, 5-6, and 5-7. The results also suggest that movement of such sediment has largely not occurred since 1940. The actual distribution of sand-sized sediment found within the UCR, based on the results of the 2005 sampling program, generally agrees with this prediction and is discussed in the next section.

5.2.2 Grain Size Distribution

Section 5.2.2 describes observed variations and patterns in sediment grain size based on the particle size analysis results from the UCR 2005 Phase I sediment investigation. Observations of longitudinal, transverse, and vertical grain size variations and patterns are important to the overall understanding of sediment transport, distribution of COIs, variations in sedimentation rates, and the potential association between selected COIs and certain grain size classes.

The UCR 2005 Phase I sediment sampling program included collection of sediment samples from throughout the entire UCR river and reservoir system. As discussed in Section 5.2.1, variations in the flow velocity and reservoir pool elevation and/or river stage influence and control the transport and deposition of bed sediment throughout the UCR. Information on sediment grain size variation gained from the Phase I sampling program greatly aids in the overall understanding of the nature and extent of certain COIs and their associated fate and transport under different hydraulic conditions that can be expected based upon the historical flow and stage data.

Only a limited body of particle size data has been generated by previous investigations. Although some particle size data for beach, side-bank, and side-channel sediments have been generated, few representative data are available from the mid-channel portions of the UCR. A significant data gap from the previous investigations also was identified with respect to the longitudinal, transverse, and vertical variations in sediment grain size throughout the system.

Particle size data were identified as an essential component of the Phase I sediment sampling program through the DQO process. In particular, the QAPP identified the need for additional particle size data to better assess the potential for transport and deposition of contaminated sediments in the UCR system. Particle size data also are useful for understanding specific hydraulic processes that control the nature and extent of COIs. For the Phase I investigation, particle size analysis included quantification of sediment sizes ranging from pebble gravel to colloid. Particles sizes for each specific size class are as follows:

- Gravel: 4.75 mm and greater
- Sand: 4.74 mm to 0.075 mm
- Silt: 0.074 mm to 0.005 mm
- Clay: 0.004 to 0.001 mm
- Colloid: <0.001 mm

Although the grain size classes established for the UCR sediment investigation differ slightly from standard Wentworth scale convention (Wentworth, 1922) due to soil testing laboratory considerations, the deviations in grain sizes (namely for sand and silt) are minor and do not significantly affect the overall assessment, interpretation, and comparability of the Phase I sediment data. Although larger sediment sizes (large gravel, cobbles, boulders) are present throughout the site, the selected grain size range represents the typical size range that was readily recoverable using the methods employed by this study (i.e., van Veen and Ponar), and which coincided with the size fractions where COIs were believed to be most concentrated. As discussed in Section 5.4, a subset of sediment samples collected from specific beaches in the UCR were segregated by grain size (75 micrometers [µm] to 2 millimeters [mm], and <75 µm) for separate chemical analysis to assess the distribution of COIs in the respective coarse-grained and fine-grained size fractions. Sections 5.4.1.4 and 5.4.2.4 discuss the observed relationship between sediment grain size and COI concentrations in the selected beach samples.

One important grain size observation from historical sampling efforts was the presence of black, glassy, sand-sized material interpreted to comprise water-granulated fumed slag in sediment samples collected from the upper portions of the UCR system, particularly in the reaches above Marcus Flats. Sand-sized sediment containing a high percentage of water-granulated fumed slag has been observed in various locations along the river (e.g., the black sand beach, and the large point bar sediment deposit located just upstream from Sheep Creek). As described in the A&R Document, water-granulated fumed slag from the Cominco Smelter consists primarily of black, glassy sand-sized particles with less than 1 percent by weight of silt-sized or smaller particles.

Understanding the grain size characteristics of water-granulated fumed slag and the associated potential for mobilization and transport of this material in the UCR system was an important part of the assessment presented in Section 5.2.1. The discussion of particle size observations and relationships that follow in this section, used in conjunction with the information presented in Section 5.2.1, highlights on a broad scale how the river system hydrodynamics have had a direct impact on the distribution water-granulated fumed slag in UCR bottom and side-bank sediments. Due to the low percentage (<10 percent) of gravel-sized material in most of the sediment samples, the grain size discussions that follow focus largely on observed broad-scale variations in the sand, silt, clay, and colloid size fractions of sediment.

5.2.2.1 Longitudinal Variations in Particle Size Distribution

Figure 5-8 presents plots of grain size variations (gravel, sand, fines [< 75 µm] for sediment samples collected from mid-channel, left-bank, and right-bank locations along the entire project area (U.S.-Canada border to Grand Coulee Dam). The fines fraction consists of silt, clay, and colloids. The distribution of silt, clay, and colloids within the fines fraction for mid-channel samples is also displayed in Figure 5-8.

The following broad-scale points and observations can be drawn from these longitudinal plots:

- The percentage of sand in the mid-channel samples drops off abruptly below Marcus Flats (approximately RM 706), suggesting the importance of Marcus Flats as a zone of transition from a predominantly riverine system capable of transporting sand to a lower velocity reservoir system in which sand-sized and coarser sediment tends to be deposited. It should be noted, nonetheless, that sand-sized sediment is present in mid-channel samples below Marcus Flats, and it is possible that some of this sand was transported downstream from the Marcus Flats area during very low reservoir drawdowns, high river flow rates, or prior to construction of Grand Coulee Dam.

- The percentage of fine-grained (<75 µm) sediment in mid-channel samples is notably lower (typically <20 percent) above Marcus Flats than below, and rises abruptly to 70 percent or greater in the mid- and lower-reservoir reaches below Marcus Flats. This observation is consistent with the understanding that this portion of the reservoir is dominated by lower velocity flows, which allow for the deposition of fine-grained sediment.

- After peaking just below Marcus Flats, the percentage of silt in mid-channel samples declines progressively downstream toward the dam, suggesting gradual settlement and deposition of this particular size fraction over the lower 100 miles of the reservoir.
- Mid-channel samples collected above Marcus Flats contained little or no measurable quantity of clay or colloids based on laboratory particle size analysis. Below Marcus Flats, the percentage of clay and colloids increases steadily with distance downstream, with as much as 60 to 70 percent of the sediment collected in the lower reaches of the reservoir composed of clay and colloids.
- Side-bank samples (defined as either the left- or right-most sample from each sample transect) consistently exhibit a higher percentage of sand (typically 50 to 90 percent) than the mid-channel samples throughout the entire length of the project area.
- Comparison of the trends for the right bank and left bank sand and fines (<75 μm) fractions indicates a similar sediment size distribution in the two banks. Of particular note is the apparent decrease in the percentage of sand, and increase in the percentage of finer grained sediments in the mid-reservoir area between approximately RM 725 and RM 675.
- Side-bank samples collected throughout the study area typically contained less than 20 percent gravel. As discussed above, sampling protocols used for the Phase I sediment sampling program selectively avoided collection of coarse-grained sediment. Side-bank sediments throughout the UCR commonly contain a larger percentage of gravel and larger material than is represented by the grain size distribution information presented in the samples.

The abrupt decrease in mid-channel sand content below Marcus Flats highlights and supports some of the observations and conclusions presented in Section 5.2.1; namely, that Marcus Flats marks the transition from predominantly riverine to reservoir conditions. Calculated average flow rates decrease markedly within Marcus Flats and, based on the preliminary analysis of sediment transport discussed in Section 5.2.1.4, favor the deposition of sand. The observed peak in silt-sized material just below Marcus Flats is thought to be caused by both the reduction in river flow velocity (sufficient to promote silt deposition) and additional contributions of silt-sized sediment from the Kettle River, whose confluence with the Columbia River is located at Marcus Flats, and the Colville River, whose confluence with the Columbia River lies just downstream from Marcus Flats. The progressive increase in the percentage of clay and colloid-sized sediment in mid-channel samples downstream from Marcus Flats demonstrates that sedimentation in this portion of the river is dominated by settlement and deposition of fine-grained sediment particles. Sections 5.4.1.1 and 5.4.2.1 discuss the observed relationship between sediment grain size and observed concentrations for selected COIs. Section 5.5 further discusses the fate and transport implications of sediment particle size, including the role that particle size (and TOC content) has on the sorption and binding affinity of selected COIs found in UCR sediment.

5.2.2.2 Transverse Changes in Particle Size Distribution

Transverse variations in particle size distribution also were evaluated at selected river reaches (i.e., high-density focus area transects) to identify any observable particle size changes across the river channel. Figures 5-9 through 5-14 present cross sections of the river channel that show the locations of the high-density transect samples. Historical sampling efforts tended to collect samples only from the side-bank or side-channel areas of the river. The high-density focus area transects that were established as part of the Phase I sediment sampling program included from five to nine samples along a given transect, rather than the usual left bank, middle, right bank samples collected from typical transects. The expanded focus area transect samples provided a greater ability to observe variations in particle size distribution as a function of sample depth and/or elevation at discrete locations within the river/reservoir system.

At several upriver sampling stations, no mid-channel samples were collected. Sediment samples from this reach were largely unattainable due to the high river flow velocities and/or the presence of predominantly coarser grained sediment (gravels, cobbles, boulders) that could not be sampled with the methods of collection employed by this study. Transverse profiles for these up-river reaches, if constructed, would include coarser grained sediments throughout most of the mid-channel area. Sand-sized material, including some percentage of water-granulated fumed slag, is expected to be present locally in the mid-channel area, where it would be lodged in the interstices between the larger sized sediment, or present in small, localized eddies behind larger boulders and other obstructions. Side-bank samples from this area would vary, but typically would be dominated by sand and gravel-to-cobble sized material.

Figure 5-15 presents observed variations in the percentage of fines (silt, clay, colloids) and sand at three selected transects: RM 706 (Marcus Flats), RM 678 (mid-reservoir) and RM 605 (lower reservoir). These plots help to highlight some important observations regarding transverse changes in particle size distribution at specific locations.

In the vicinity of Marcus Flats (approximately RM 706), the transverse profiles (Figures 5-15) show that the mid-channel area is dominated by sand-sized sediment, with very little fine-grained material. The highest percentage of sand is observed in the sample collected from the old river channel. Side-bank samples typically contain from 60 to 70 percent fines, composed mainly of silt and clay. These observations reinforce the fact that, as mentioned above, the mid-channel area in this reach of the river (and upstream) is dominated by sand-sized and coarser sediment. Sample RM 706X4 was described in the field sample log as being a "black medium sand…slag-like material appears to be present." This description is consistent with the sediment chemistry information (discussed in Section 5.4.1) that found the sediments from RM 706X4 to be enriched in coarse-grained slag-associated metals.

The particle size observations for samples collected along the expanded transects at RM 678 and RM 605 (Figure 5-15) are notably similar to each other, but very different than those at RM706 in Marcus Flats. Mid-channel sediment samples along these transects show a high percentage of fines (>97 percent), and a low percentage of sand (typically <2 percent). Based on the results of the simplified average cross-sectional flow velocity analysis, transport of sand-sized material is expected to be limited in the UCR downstream from Marcus Flats, a finding that is consistent with grain size observations. The percentage of fine-grained sediment fractions at RM 678 and RM 605 is notably similar, further demonstrating the relative consistency in the processes controlling sediment deposition in this portion of the reservoir. One noteworthy difference is the progressive increase in the colloidal fraction from RM 678 to RM 605. The general similarity in overall proportion of fine-grained sediment in these transect profiles, although 73 miles apart, attests to the dominant sediment depositional regime in the middle and lower reservoir area below Marcus Flats.

A comparison of the side-bank samples collected from the normal and high-density transects with samples from the mid-channel area further highlights another important sediment transport and distribution phenomenon: soil washing and remobilization of fines. As described in Section 5.2.1, selective washing and remobilization of fine-grained sediments from the side bank areas of the reservoir due to the combined effects of rising and falling reservoir water level, wave action, and exposure to rainfall and localized sheet runoff is thought to be an ongoing process that further contributes to the concentration of finer grained sediments into the lower, deeper portions of the reservoir.

5.2.2.3 Tributary Particle Size Distribution

As described in Section 2.2.3, sediment samples were collected from the mouths of six major UCR tributaries. Sediment samples specifically were collected from the mid-channel tributary mouth area at the immediate confluence with the UCR, and a short distance downstream (typically within 0.5 miles) from the tributary mouths. Figure 5-16 presents a comparative distribution of particle sizes (gravel, sand, and fines [<75 µm]) for tributary samples collected during the Phase I investigation. Figure 5-16 also presents additional refinement on the distribution of the fine-grained particles sizes (silt, clay, and colloids) in these same samples. In general, the size distribution data indicate that coarser grained sediments (sands and gravel) are more predominant in the mouths (T1 samples) and proximal delta areas (T2 samples) of the upstream tributaries such as Sheep Creek and Onion Creek. In contrast, tributary samples from the mid- and lower-reservoir areas such as the Sanpoil River, Spokane River, and Colville River were dominated by finer grained sediments (silt, clay, and colloids). From this observation, it can be concluded that the sediment distribution in the vicinity of the tributary mouths is influenced by the degree to which the tributaries, at their confluence with the UCR, are free-flowing rivers or are part of the reservoir. The tributary samples from the mouth of the Kettle River (RM 706) were dominated by fines near the mouth (T1) and by sands in the proximal delta area (T2). Sections 5.4.1.5 and 5.4.2.5 provide additional discussion of the observed COI concentrations in the tributary samples as compared to nearby samples within the UCR.

5.2.2.4 Vertical Changes in Particle Size Distribution

The van Veen sampler provided subaqueous sediment samples from the upper 6 inches or so of the sediment column. Additional information on sediment characteristics at greater depths within the sediment column, including particle size variations with depth, was obtained from UCR core samples. The DQO for subsurface sediment was developed in response to the uncertainties associated with potential scour/redistribution of contaminated sediment, the depth to which sediment contamination may exist, the influence that sediment grain size can have on the nature and extent of COIs, and the environmental fate and transport of subsurface sediments.

The Vibracore drilling method was used to obtain sediment core samples from mid-channel and submerged side-bank locations of the reservoir bed at nine discrete locations. Due to equipment constraints associated with the Vibracore method, cores were not obtained from areas in the reservoir having a depth of 200 feet or more. The recovered cores, ranging in length from 5 to 9 feet, were segregated into discrete depth intervals for subsequent analytical testing. Because of the vibratory action of the Vibracore drilling method, it is suspected that some of the core samples from locations having a high percentage of fines (<75 µm) may have become slightly agitated during collection. The unavoidable vibratory agitation potentially liquefied and resuspended the uppermost portions (upper 0.5 to 1.0 foot) of the loose and highly liquid sediment column. At one core location (RM 622), uniform sandy sediment was encountered throughout the full length of the core. It is uncertain whether the RM622 core sample provides a representative indication of sediment conditions in this portion of the reservoir and accurately portrays the vertical distribution of in-place sediment immediately below the sediment/water interface. The RM622 core is located next to a steep side bank, and landslides have been mapped upslope from this location (see Figure 2- 10). Section 5.4.1.3 further discusses the observed metal concentrations in the RM 622 core.

The following depth intervals were selected from each core for preparation of individual samples:

- 0 to 0.5 foot
- 0.5 to 1.0 foot
- 1.0 to 3.0 feet
- 3.0 to 5.0 feet
- 5.0 to 7.0 feet
- 7.0 to 9.0 feet

Samples from RM 708, 704, 692, 676, and 661 were collected from the mid-channel portion of the river where the bottom sediment interface was at a depth of 200 feet or less. Core samples collected farther downstream (RM 644, 637, 622, and 605) were collected from submerged side-bank areas where the sediment interface was at a depth less than 200 feet.

Core samples had been proposed for RM 723, 734, and 742. These samples were not collected, however, because of the coarse-grained nature of the bed sediments and the elevated river flow velocities that prevented the establishment of a stable drilling platform for the Vibracore drilling equipment. It is inferred, based on visual observations of the river bottom by the field sampling team and the lack of mid-channel samples attained by the van Veen sampler, that the upper several feet of the sediment column in the mid-channel portion of the river at and above RM 723 consists predominantly of gravel, cobbles, and boulders.

Figure 5-17 presents particle size versus depth plots for the following three distinct areas of the river/reservoir system:

- The mid-channel area of Marcus Flats
- The mid-channel area of the middle reservoir below Marcus Flats where core samples were collected in water depths less than 200 feet
- The side terrace areas of the old river channel, slightly away from mid-channel, where reservoir water depths are less than 200 feet

At RM 708, the most upstream core sample location, 7 feet of relatively uniform, black sand was observed. A similar sediment distribution pattern was observed slightly downstream at RM 704. The RM 704 and 708 cores demonstrate that the mid-channel portion of Marcus Flats is a primary depositional zone for sandy, water-granulated fumed slag-enriched sediment. This observation further reinforces the sediment transport and deposition concepts discussed in Section 5.2.1; namely, that Marcus Flats tends to act as a significant transition zone within which deposition of sandy sediment (including water-granulated fumed slag) is predicted due to changes in the flow channel configuration and associated changes in flow velocity.

The cores from RM 676 (Gifford/Inchelium area) and RM 661 (Hunters) show a similar particle size distribution pattern with depth. Sediment from both of these locations is composed predominantly of finer grained material (<75 µm) over the entire 7-foot length of the core. Both cores showed a fairly uniform distribution of fines (approximately 80 to 90 percent) and approximately 10 to 20 percent sand. At RM 676, a small amount (<10 percent) of gravelly material also was present in the lower portion of the core.

Table 5-1 summarizes the distribution of silt, clay, and colloids in the core samples from RM 676 and RM 661. It can be seen that the fine-grained fraction at RM 661 contains a higher percentage of silt than RM 676, and a lower percentage of clay and colloids. The comparative distribution of fines in the RM 676 core is reasonably consistent with the fines distribution observed along the nearby expanded transect at RM 678, particularly the four mid-channel samples RM 678X2 through RM 678X5. The distribution of fines in these two cores, however, is somewhat in contrast with the observed longitudinal distribution of fines in the mid-channel transect samples (see Figure 5-8), which shows a progressive increase in the percentage of clay and colloids and a corresponding decrease in the percentage of silt with increasing distance downriver. The greater percentage of silt-sized material in the RM 661 sample may be attributable to local sediment influx from nearby Nez Perce Creek, enhanced mobilization of silt-sized material from washing of side-bank areas, or other sediment depositional processes such as landslide contributions.

Core samples from RM 644 and RM 637 were collected from side terrace areas of the old river channel, and not from the deepest, mid-channel portion of the reservoir. The RM 644 core extended to a depth of 7 feet, and the RM 637 core extended only to a depth of 5 feet. The observed vertical variations in grain size are somewhat similar at these two locations. The upper 1 to 3 feet of the sediment column consists predominantly of fines, underlain by sandy material. As discussed in Sections 5.4.1.3 and 5.4.2.3, the concentration of COI metals in these deeper, sandier horizons at RM 644 and RM 637 are significantly lower than concentrations observed in the finer grained sediments in the uppermost portions of the sediment column. These observations suggest that the sandier sediments encountered in the lower portions of these cores may represent pre-reservoir side-bank material.

5.2.3 Data Gaps

Several data gaps are recognized to exist with respect to the overall understanding of the UCR river/reservoir hydraulics and sediment transport, based on review of the findings from the Phase I sediment investigation. Whether these data gaps constitute data needs for the RI/FS will be evaluated through the DQO process during future RI/FS phases. The data gaps are as follows:

- Geomorphological features and environments that are present in the UCR floodplain (both submerged and exposed portions) have not been mapped or evaluated in detail. Additional categorization and mapping of specific geomorphological features and landform positions may be required to better understand the potential influence these features could have on river hydrodynamics and the distribution of COIs.

- An analysis of changes in the areal extent of exposed reservoir side-bank areas under various pool operating levels has not been conducted. Such an analysis may be important to better address possible concerns associated with wind-borne mobilization of COIs in fine grained sediment.

- Calculation of average cross-sectional flow velocity provides only a limited broad understanding of sediment transport within the UCR. In order to better assess the characteristics of sediment transport in the UCR, to identify active areas of sediment scour and/or deposition and the rate to which they occur, and to provide a more detailed understanding of local-scale variations in river hydrodynamics, additional data collection and analysis may be required (e.g., high-resolution bathymetry, cross-sectional Doppler flow velocity profiling, sediment sub-bottom profiling, supplemental grain size analysis, and sediment transport modeling).

- Little is known regarding the existing sediment load entering the UCR system. In particular, there is considerable uncertainty regarding the sediment flux (suspended and bedload transport) from UCR tributaries versus the Columbia River itself at the U.S.-Canada border. Sediment loading information is important for understanding sediment transport and accumulation. Additional sediment load information for the Columbia River and its major tributaries may need to be gathered to support any detailed sediment transport analysis or modeling.

- In general, a large proportion of sediment transport in riverine systems occurs under episodic extreme events. The UCR reservoir is a component of a managed system in which reservoir level and river flow are largely controlled by operation of Grand Coulee Dam and dams located upstream on the Columbia River and tributaries, which greatly reduces the extremes of flow events that would otherwise strongly affect sediment transport within the UCR. Nonetheless, it is recognized that, even within the managed UCR system, extremes of flow and reservoir level may occur. The degree to which these extremes may affect sediment transport in the UCR have not been addressed by the first-pass analyses presented in this document.

- The potential role that wave action and seasonal reservoir fluctuations have on the mobilization of fine-grained sediment (possibly containing COIs) from side-bank portions of the reservoir is not well understood. Similarly, for the more riverine portion of the UCR site near the U.S.-Canada border, uncertainty remains regarding the degree to which fine-grained sediment in river side-bank areas (containing variable concentrations of COIs) is scoured and eroded during high-flow or low-stage conditions.

5.3 Total Organic Carbon Distribution

This section summarizes the results of TOC sample analyses and the distribution of TOC in the UCR. The concentration of TOC was determined for every sediment sample. TOC refers to the total amount of organic carbon in the sediment and does not include mineralized carbon present as carbonates or bicarbonates. Concentrations of organic contaminants (particularly nonpolar, nonionizable chemicals) and the toxicity of these contaminants in sediments have been observed to correlate with organic carbon content of the sediments. Nonpolar contaminants in sediments or water preferentially partition into the organic material in sediments because of the similar chemical nature of the organic material to the nonpolar organic contaminants (Michelsen, 1992). As discussed in Section 4, the Colville Confederated Tribes use a TOC-normalized approach to determine sediment cleanup levels for organics.

Previous UCR sediment investigations also analyzed for TOC. Figure 5-18 shows the results from the previous studies plotted with respect to river mile longitudinally along the UCR. Figure 5-18 also shows the USEPA 2005 TOC data from the Phase I sediment sampling**.** As described in the A&R Document, previous studies have shown similar longitudinal patterns between TOC and cadmium and mercury. Insufficient organic COI data were available from previous studies to evaluate with respect to TOC content.

5.3.1 Longitudinal Changes in TOC Distribution

Figure 5-19 shows USEPA 2005 TOC concentrations longitudinally along the UCR and differentiates between samples collected from the right or left banks and mid-channel locations. It is apparent that the distribution of TOC is similar to that of the fine sediment as described in Section 5.2 and illustrated in Figure 5-9. Downstream from Marcus Flats, concentrations of TOC are much higher at mid-channel locations than on the left and right banks. Mid-channel TOC concentrations appear to follow a trend similar to that for the distribution of silt (Figure 5-8), particularly with respect to the relatively high concentrations near RM 695. This may be partially attributable to TOC input from the Kettle (mouth near RM 706) and Colville Rivers (mouth near RM 698), and from the Upper Columbia River. TOC input from the Spokane River, which enters the UCR at RM 639, and from Hawk Creek (RM 634) may contribute to the gradual mid-channel UCR rise in TOC downstream of RM 645. Although previous studies did not preferentially sample the mid-channel, the plots of longitudinal distribution of TOC from these studies are generally comparable with the plots of USEPA 2005 data (Figure 5-18).

5.3.2 Transverse Variations in TOC Distribution

Figure 5-20 presents observed variations in the concentration of TOC at three selected transects: RM 706 (Marcus Flats), RM 678 (mid-reservoir), and RM 605 (lower reservoir). The concentrations vary across each transect in a manner similar to the percentages of fine-grained sediment discussed in Section 5.2, which is expected given the UCR sediment TOC is likely associated with slow-settling particles. At RM 706, TOC is found at significantly higher concentrations outside the old river channel compared to within, which is dominated by sand-sized sediment. Below Marcus Flats at RM 678, and also much farther downstream at RM 605, the reverse is apparent, as also discussed previously for fine-grained sediment.

5.3.3 Vertical Variations in TOC Distribution

The vertical distribution of TOC in core samples are presented in Table 5-2. Similar to mid-channel surface sediment, the core with the highest TOC concentration (RM 692) was collected downstream from Marcus Flats and below the confluence of the Kettle and Colville Rivers. TOC in the core from RM 692 varied from a high of 32,200 mg/kg in the upper 6-inch horizon to a low of 4,020 mg/kg in the 3- to 5-foot horizon. Downstream cores had lower TOC, with concentrations varying between about 12,000 and 600 mg/kg, and with the highest concentrations occurring predominantly in the upper horizons.

5.3.4 Data Gaps

Data gaps pertaining to the distribution of TOC in UCR sediments have been identified. Whether these data gaps constitute data needs for the RI/FS will be evaluated through the DQO process during future RI/FS phases. These data gaps are summarized as follows:

- Sources or conditions that influence the spatial variations in TOC concentrations in UCR sediment are not well understood. Additional TOC sediment data may be required to better characterize TOC variations and sources and the role TOC plays within the fate and transport of sediment contaminants.

5.4 Nature and Extent of COIs in Sediment

This section describes the current understanding, based on the 2005 Phase I sediment sampling, of the distribution of individual COIs throughout the UCR and Lake Roosevelt. The distributions of the COIs were evaluated as part of the development of the RI/FS preliminary sediment CSM in accordance with the DQOs developed for nature and extent of contamination detailed in the QAPP and summarized in Section 2 of this report. The nature and extent evaluation considers the longitudinal, transverse, and vertical distributions of the COIs according to the sitewide scale of the Phase I sediment sampling program, which was designed to provide a general overview of the distributions of sediment COIs within the UCR. Consequently, the distribution information presented in this subsection does not account for smaller scale variations in COI distribution that may be present in the UCR. Section 5.4.1 discusses the distribution of metals COIs, and Section 5.4.2 discusses the distribution of organic COIs.

5.4.1 Distribution of Metals

This section describes the general longitudinal, transverse, and vertical distributions of metals, and also provides details about the distributions of metals in the focus areas, at beaches, and in the vicinity of tributaries.

One important element in understanding the general distributions of metals in UCR sediments is the relationships between the metal COIs identified in Section 5.1 and coarse-grained sediment and between other metals and finer grained and organic-carbon-rich sediment. This is because, as described in Section 5.1, the sources of metal COI sediment contamination released from Cominco originated primarily as either a component of liquid effluent (possibly including fine particulate, colloidal, sorbed, complexed, and/or dissolved forms) or as coarser particulates discharged into the water (e.g., water-granulated fumed slag). As noted in Sections 5.2 and 5.3, the distributions of different sediment sizes and TOC concentrations are influenced by river and reservoir hydrodynamic processes. The coarse-grained bed sediment and water-granulated fumed slag are predominant in the hydrodynamically more active upper reaches of the UCR, and sediment that is finer grained and richer in TOC is predominant in the quiescent lower reaches of the UCR.

Copper, iron, manganese, and zinc are strongly associated with water-granulated fumed slag, as discussed in Section 5.1. The highest concentrations of these coarse-grained slag-associated metals occur predominantly in the portion of the river upstream from Marcus Flat above RM 700, where coarse-grained materials predominate. Antimony, arsenic, chromium, and lead also appear to be associated with water-granulated fumed slag based on chemical analyses of water-granulated fumed slag (BFO, 1992**;** Cominco, 1990) and/or distribution patterns that are similar to copper, iron, manganese, and zinc, as described in Section 5.4.1.1. Uranium concentrations also appear to follow a similar trend, but the high percentage of nondetect results with elevated reporting limits, described in Section 2, hinders a more complete understanding of distribution patterns relative to screening levels.

Although antimony, arsenic, chromium, copper, iron, lead, manganese, and zinc are components of water-granulated fumed slag, they likely were also discharged into the UCR as dissolved-phase metals associated with liquid effluent and/or other nonslag solid-phase discharges. Cominco began operation of an effluent treatment plant in 1951. The results of various metals extraction tests performed on water-granulated fumed slag, listed in Tables 4-3 through 4-5 of the A&R Document (CH2M HILL, 2004b), show that cadmium, copper, lead, zinc, and other metals can be removed from water-granulated fumed slag by rinsing/leaching.

Visual evidence and grain size information from historical sediment sampling indicate that black, sand-sized material indicative of coarse-grained water-granulated fumed slag, was not visually evident in the surficial bed sediment collected downstream from Marcus Flats. Furthermore, grain-size analysis results also indicate that mid-channel UCR sediment samples collected downstream from Marcus Flats contain relatively less coarse-grained materials than samples collected from within, and upstream from, Marcus Flats. In the middle and lower reaches of the reservoir, finer grained sediments (consisting of silt, clay, and/or organic particulates) are more dominant and typically contain a higher TOC concentration. Metals such as mercury and cadmium (and to lesser degrees lead and nickel) appear to be less correlated with sediment affected by the coarse-grained water-granulated fumed slag, and are instead associated more with the finer grained sediments.

Figure 5-21 presents the longitudinal distribution of each metal in Phase I surface sediment samples. These plots clearly show the differing distributions for the coarse-grained slag-associated metals and the other metals.

5.4.1.1 Longitudinal Distribution

This section describes the longitudinal distributions of the coarse-grained slag-associated metals and the other metal COIs along the length of the UCR. The evaluations discussed in this section are based on the results for samples collected at transect, beach, and tributary locations listed in Appendix C, Table C-6. Each of the samples was assigned to a longitudinal distribution subgroup based on its position relative to the UCR channel (i.e., left bank, mid-channel, right bank) in order to identify possible distribution patterns and trends along the longitudinal axes of these channel positions.

The longitudinal distributions of metallic COIs along the length of the UCR are shown in Figure 5-21. For each sample, the figures indicate the detected chemical concentration on the y-axis and the sample location by river mile on the x-axis. Different symbol shapes are used to indicate sample subgroupings (i.e., beach and tributary), which are discussed in further detail in subsequent sections. Symbols for samples collected along the same longitudinal axis share a common color: blue for left-bank samples; green for right-bank samples; and pink for mid-channel samples. Only detected concentrations are indicated; samples where the indicated chemical was not detected are not shown on the graphs.

The following conclusions about the distribution of metals were derived from review of Figure 5-21 and integration of grain size distribution information presented in Section 5.2.2:

- Concentrations of coarse-grained slag-associated metals are generally highest near the U.S.-Canada border and lowest near Grand Coulee Dam. In right- and left-bank samples, concentrations of most coarse-grained slag-associated metals decline sharply between RM 720 and RM 725, located upstream from Marcus Flats. In the mid-channel samples, elevated concentrations of coarse-grained slag-associated metals extend several miles farther downstream to Marcus Flats, as shown in the distribution graph for zinc.
- Concentrations of cadmium, mercury, and nickel are generally higher in the reservoir section than the river above Northport at RM 734. The cadmium and mercury plots have similar patterns, which are also similar to the TOC plots described in Section 5.3.
- The longitudinal distribution of lead differs from those of cadmium, mercury, and nickel and from the other coarse-grained slag-associated metals. Like the other coarse-grained slag-associated metals, lead concentrations are elevated in samples above Marcus Flats. However, elevated concentrations of lead continue in mid-channel samples well past Marcus Flats into portions of the system dominated by reservoir depositional processes. Lead has been documented to be a component of water-granulated fumed slag, which may explain its distribution above Marcus Flats (i.e., associated with coarse-grained slag), and can also be subject to aqueous-phase transport and association with organic carbon and suspended sediments, which may explain its distribution below Marcus Flats (i.e., associated with finer grained material).
- The river upstream from Marcus Flats is faster flowing, particularly during reservoir drawdown, and typically the bed sediment consists of coarser grained materials. The hydrodynamics of the system influence transport and deposition of different grain size materials. Above the vicinity of Onion Creek (RM 734), the mid-channel of the river is dominated by cobbles and boulders; sand and coarse-grained slag-associated metals occur predominantly along the shore in eddies, point bars, and beaches. Finer grained material is carried downstream. Between Onion Creek and Marcus Flats, coarse-grained slag-associated metals are present in both mid-channel and bank samples, suggesting broader deposition of sand-sized materials in this portion of the river.
- Marcus Flats appears to be a transition area for coarse-grained slag-associated metals and other metals. Sediment transport and deposition in the Marcus Flats area is affected by the hydrodynamics of the river (both existing and historical) and by water level

changes in Lake Roosevelt. In areas such as the former river channel with faster flow velocities (at times of low pool elevations), coarse-grained materials and coarse-grained slag-associated metals are present. Finer grained materials and other metals such as mercury are found in portions of Marcus Flats that are typically covered by the quiet waters of Lake Roosevelt at times of high pool elevations.

- Downstream from Marcus Flats, metals distribution is a function of reservoir deposition of finer-grained sediment that is transported as suspended load to Lake Roosevelt. Sifting and washing processes along the banks of the lake also carry finer grained materials into the lake, leaving coarse-grained materials behind. Landslides and slumping along the lake shore also serve to redistribute sediments and may locally influence the distribution of metals.

5.4.1.2 Transverse Distribution of Metals

The Phase I sediment sampling program included collection of sediment samples along a number of transects that cross the river and reservoir. Previous sampling programs did not collect cross-channel (transverse) sediment samples along transects. The need for this type of information was identified through the DQO process as an essential component of the Phase I sediment sampling program. The establishment of regularly spaced transects by river mile was the fundamental approach for establishment of sample locations to characterize the distribution of COIs in UCR sediment.

Transect samples are described in Section 2.2, and the locations sampled are shown in Figures 2-2 to 2-12. Typical transects included three samples: one on the left bank, one in the middle of the old river channel, and one on the right bank. A higher number of sample locations was established for the center transect of each of the six focus areas to better define the transverse variability of sediment contamination. These transects are referred to as high-density focus area transects and are located at RM 742, 723, 706, 678, 642, and 605. An additional high-density transect was established at RM 637, 2 miles downstream from the Spokane River confluence. The high-density transects provided a greater ability to observe variations in sediment metal distribution as a function of sample depth and/or elevations compared to the standard transect samples at discrete locations.

Transverse variations in metal concentration were analyzed by dividing the site into three subareas that were defined based on the conclusions from the longitudinal distribution evaluation. These areas consist of the portions of the UCR upstream from Marcus Flats (upstream from RM 707), within Marcus Flats (between RM 707 and 702), and downstream from Marcus Flats (downstream from RM 702). Coarse-grained slag-associated metals are discussed separately from the other metals.

In the discussion of the transverse distribution of metals, general descriptive terms are used to identify specific locations within the reservoir transect. These terms include the following:

- Side bank: Sample stations located at the outer ends of the transects; side-bank samples typically lie above elevation 1208 and are above the pre-reservoir Holocene river channel/floodplain.

- Side channel: Sample stations located between the mid-channel sample and the side-bank areas, but still in the deeper portions of the river/reservoir at elevations below 1208.
- Mid-channel: Sample station (or stations) located at the deepest portion of the transect within the original pre-reservoir river channel.

Above Marcus Flats (Upstream from RM 708)

The transverse distribution of sediment metal concentrations upstream from Marcus Flats is quite, variable as indicated in the plots of longitudinal metal concentration presented previously. This is especially the case for coarse-grained slag-associated metals.

Coarse-Grained Slag-Associated Metals

The concentration of coarse-grained slag-associated metals (antimony, arsenic, chromium, copper, iron, lead, manganese, and zinc) in the samples containing sand-sized water-granulated fumed slag varies significantly within the UCR between the U.S.-Canada border and Marcus Flats. As previously discussed, sediment samples from mid-channel upstream from RM 729 were unattainable due to the high river flow velocities and/or the presence of coarse-grained sediment (gravels, cobbles, boulders) that could not be sampled with the methods of collection employed by this study. Sand-sized material, including some percentage of water-granulated fumed slag, is expected to be present in the mid-channel region, where it would be lodged in the interstices between the larger sized sediment, or localized in small, localized eddies behind larger boulders and other obstructions. Mid-channel river velocities are periodically high enough in this area to transport water-granulated fumed slag downstream.

The variability in metals concentration above RM 729 is largely attributable to the relative proportion of coarse-grained water-granulated fumed slag and native sediment (having a naturally lower concentration of the coarse-grained slag-associated metals) that is present in the sediment from that particular area. The actual amount of coarse-grained water-granulated fumed slag that is present in a given area depends on many factors, including the proximity to a tributary depositing cleaner sediment, location within the channel (i.e., in a backwater area or closer to mid-channel), and proximity to bank erosion and/or bank slump areas.

Below RM 729 and above RM 707, mid-channel samples were attainable at 50 percent of the planned locations. With the exception of the sample 718X2, all mid-channel samples that could be obtained downstream from RM 729 had notably higher coarse-grain slag-associated metal concentrations than the corresponding left or right bank samples collected along the same transect. The sample from 718X2 was collected on the outermost edge of the old river channel (see Figure 2-4) and may not be representative of the main mid-channel corridor, where coarse-grained water-granulated fumed slag preferentially accumulates and is mobilized as bedload sediment.

Table 5-3 provides a summary of zinc concentrations in mid-channel samples between RM 729 and RM 710. The elevated zinc concentration in these mid-channel sediment samples demonstrate that coarse-grained water-granulated fumed slag is preferentially distributed and transported within the present-day main flow channel (thalweg). Sandy water-granulated fumed slag-enriched sediment is most likely to settle and accumulate in areas of the old river channel where flow velocities are locally reduced due to channel morphology or eddy areas that develop behind submerged obstructions. These localized accumulations of water-granulated fumed slag-enriched sediment most likely become mobilized and transported as bedload during seasonal or episodic high-flow periods when flow velocities are highest.

Other Metals

The concentrations of cadmium, lead, mercury, and nickel in sediment also vary within the UCR between the U.S.-Canada border and Marcus Flats. However, these metals show a less distinct and discernable concentration difference between the mid-channel and side-bank samples than is observed for the coarse-grained slag-associated metals. In addition, the concentrations of these metals are comparatively lower than the concentrations of the major coarse-grained slag-related metals.

Within Marcus Flats (Between RM 708 and RM 701)

The transverse distribution of sediment metal concentrations within the vicinity of Marcus Flats is distinct and variable, particularly for the coarse-grained slag-associated metals. The transverse distribution of other metals is less apparent. Notable observations are highlighted and discussed below.

Coarse-Grained Slag-Associated Metals

Coarse-grained slag-associated metals within the Marcus Flats area display transverse variability that appears to be strongly tied to the sediment transport and depositional characteristics of this unique hydraulic feature of the UCR. More specifically, the observed concentration pattern for these metals provides some important insights into the apparent distribution and fate of coarse-grained water-granulated fumed slag that is transported into this area under past and present reservoir conditions. Figure 5-22 displays the cross-channel variations in coarse-grained slag associated metal concentrations along the expanded transect in Focus Area 3. The concentration pattern in these figures illustrates that the coarse-grained slag-associated metals are preferentially enriched in the single sample (RM 706X4) collected from the area of the old river channel. The other transect samples collected within Marcus Flats (RM 708, RM 707, RM 705, and RM704) show a similar concentration pattern, with the mid-channel “X2” sample consistently showing preferential metals enrichment. For certain metals such as zinc and copper, the concentrations of mid-channel and side-bank sediments differ by as much as two orders of magnitude. Section 5.4.1.3 provides additional discussion on the importance of the old river channel within Marcus Flats as a primary depositional area for coarse-grained water-granulated fumed slag.

Other Metals

For the case of cadmium and mercury, the highest concentrations are present in the side-bank samples (RM706X1 and 706X2). The lead concentration pattern along this same transect shows some general similarity to the other slag-associated metals (i.e., relatively higher concentrations in the mid-channel sample from the old pre-reservoir channel). However, lead concentrations in the X1 and X2 transect samples also were a factor of 3 to 4 higher than the other corresponding transect samples (excluding the mid-channel sample RM706X4), similar to what is observed for cadmium and mercury. No pattern is discernable for nickel. Although sediment from the side-bank and nearshore areas is recognizably finer grained than the mid-channel sample (see Figure 5-15), sediment grain size considerations alone do not appear to explain the observed concentration pattern for cadmium, mercury, nickel or lead. It is also worth noting that station RM706X7 is located close to the mouth of the Kettle River; river hydraulics (i.e., eddy currents) in this portion of Marcus Flats may affect the distribution and mobilization of COIs in sediment.

Below Marcus Flats (Downstream from RM 701)

Review of the longitudinal and transverse grain size information discussed in Section 5.2.2 demonstrates that silt, clay, and colloids are the predominant mid-channel sediment sizes observed throughout the lower 100 miles of the reservoir. Sediment samples (transect grabs and cores) collected downstream from Marcus Flats showed no visual evidence of black, coarse-grained water-granulated fumed slag. Review of the longitudinal distribution of metals in sediments from the middle and lower reservoir area (Section 5.4.1.1) indicates that concentrations of coarse-grained slag-associated metals decrease progressively with increasing distance downstream from Marcus Flats.

The conceptual model describing sediment deposition in the reservoir area below Marcus Flats is that finer grained sediments are gradually settling out (in general conformance with the principles of Stokes' Law) based on the size and shape of the sediment particles and the flow velocity in the reservoir. The Phase I sediment investigation did not specifically attempt to quantify sediment deposition rates in the middle and lower reservoir area, or to quantify the proportion of sediment contributed by local tributaries versus through-flow contributions (as suspended sediment) from the Columbia River at the U.S.-Canada border. The Phase I investigation did, however, include the collection of samples along a series of high-density transects (included within each focus area) to better understand the nature and extent of metal contaminants across the width of the reservoir. Evaluation of the transverse distribution of sediment contamination in the lower reservoir area enhances the understanding of how metal COIs are distributed in the lower reservoir areas and helps identify the depositional processes that most likely influence the distribution of these contaminants in UCR sediments.

The transverse distribution of sediment metal concentrations downstream from Marcus Flats is characteristically different from the patterns observed in Marcus Flats. The discussion that follows focuses on a reduced suite of coarse-grained slag-associated indicator metals (defined for the purpose of this evaluation as zinc, arsenic, and manganese) and other metals (cadmium, mercury, and lead) to highlight, compare, and contrast the transverse distributions of these different COIs.

Coarse-Grained Slag-Associated Metals

Figures 5-23a, 5-24, and 5-25 display transverse variations in concentrations of the coarse-grained slag-associated indicator metals zinc, arsenic, and manganese at three high-density transects downstream from Marcus Flats: RM 678, 642, and 605. The transects at RM 678 and 642 included seven separate samples across the channel, whereas nine samples were collected at RM 605. Side-bank samples are represented by the "X1" and "X7" samples at the two upstream transects; at RM 605, the transect includes three side-bank samples (X7, X8, and X9), two of which were collected from shallow water along a broad, gently sloping beach/side-bank area.

In general, the concentration distribution pattern is similar for all three metals and generally mimics the corresponding transverse plots of fine-grained sediment (<75 μm) (see

Figure 5-15) presented in Section 5.2.2. Although some concentration variability does occur in the deeper side-channel and mid-channel samples, the differences are within a factor of two. Minor differences in sample collection (e.g., inadvertent variations in the actual depth of sample recovery within the sediment column, particularly in areas containing a high percentage of soft, fine-grained sediment) can affect the characterization and understanding of apparent transverse concentration variations.

As previously described in Section 5.4.1.1, there is a general similarity in the observed concentrations of most of the coarse-grained slag-associated metals over the lower 75 miles of the reservoir. Comparison of zinc, arsenic, and manganese concentrations at RMs 678, 642, and 605 shows little difference between the metals. Table 5-4 provides a summary of average concentrations of the mid-channel and side-channel samples from the three transect locations. The overall similarity in both the transverse and longitudinal concentration patterns demonstrates that transport and deposition of COI metals in the reservoir area below Marcus Flats is relatively uniform and is controlled primarily by the natural hydrodynamic dispersion and settling of fine suspended particulates (clays, colloids, fine organic carbon-enriched detritus) with which these trace metals likely are sorbed or otherwise associated (e.g., possible fine particulate components of liquid effluent) in this portion of the site, rather than being associated with coarse-grained water-granulated fumed slag particles. The discussion below demonstrates that transverse concentrations of other metals are very similar to the coarse-grained slag associated metals, which further supports the concept that the principal source of all the metals is likely associated with liquid effluent discharges or rinsing/leaching of water-granulated fumed slag.

Other Metals

Figures 5-23b, 5-24, and 5-25 also display transverse variations in cadmium, mercury, and lead concentrations at the same three high-density transects (RM 678, RM 642, and RM 605) discussed above. Overall, the transverse distributions of these metals in the reservoir area below Marcus Flats show marked similarity to the concentration patterns observed for the coarse-grained slag-associated metals. As noted above for the coarse-grained slag-associated metals, some concentration variability does occur between the deeper side-channel and mid-channel samples, but the differences typically are within a factor of two. Likewise, average concentrations of the other metals (Table 5-5) remain relatively similar, differing by less than a factor of two over the entire 70-mile interval spanned by these three transects.

As described in Section 5.2, the side-bank samples from these transects are characteristically more coarse-grained than the associated side-channel and mid-channel samples due to the washing effect of reservoir level fluctuations combined with wave action and sub-aerial erosion processes. As shown in the transverse distribution plots, COI metal concentrations in the side-bank samples are consistently lower than concentrations observed in the deeper side-channel and mid-channel samples. A direct correlation appears to exist between the concentration of certain COI metals concentrations and the corresponding percentage of fine-grained sediment and/or the TOC concentration that is present in the samples. Figures 5-26, 5-27, and 5-28 present a series of correlation plots that compare the measured concentrations of mercury and cadmium in mid-channel and side-channel transect samples collected below Marcus Flats to the amounts of clay, colloids, and TOC in these same samples. The figures include a program-defined trendline through the data set to help highlight apparent correlation trends. The data in Figures 5-26 and 5-27 suggest that the cadmium concentration displays a slight to moderate association with increasing TOC concentration and colloid percentage. Figure 5-28 also shows that a slight to moderate association may exist between the mercury concentration and measured TOC concentration. These relationships are expected, given the known sorption affinity that these metals typically have for fine-grained sediment and organic carbon.

5.4.1.3 Vertical Distribution of Metals

The DQO process for the Phase 1 sediment investigation identified the need for additional information on the vertical distribution of COI metals in UCR sediments. Specifically, the DQO for subsurface sediment was developed in response to the uncertainties associated with the vertical distribution of COIs in UCR sediment, the potential for scour/ redistribution of contaminated sediment, and the potential environmental fate and transport of these contaminants.

Historical information on the vertical distribution of metal contaminants in UCR sediments is limited. Previous UCR sediment studies by Ecology and USGS included collection of shallow core samples (typically <4 feet long) from a limited number of locations within the reservoir. The Ecology core sample was collected in 1986 from the area of Frenchman Rocks (RM 692). In 2002, the USGS collected core samples from five locations (RMs 705, 692, 668, 643, and 624) within Lake Roosevelt. The purpose of the USGS study was to evaluate the trace-element concentrations within the accumulated bed sediments of Lake Roosevelt and evaluate whether metallurgical slag was present. A discussion of methods, findings, and conclusions from the recent USGS investigation are presented in *Vertical Distribution of Trace Element Concentrations and Occurrence of Metallurgical Slag Particles in Accumulated Bed Sediments of Lake Roosevelt, Washington, September 2002* (USGS, 2005).

As discussed in earlier sections, nine core samples were collected between Marcus Flats (RM 708) and the area just upriver from Grand Coulee Dam (RM 605) as part of the Phase I sediment investigation. The core locations are shown in Figures 2-5 through 2-12. Figures 5-29 through 5-36 show the locations of these cores on cross-sectional transect plots of the river channel to better depict the core location with respect to river channel morphology. Section 5.2.2 provides additional discussion on the methods of core sample collection, potential disruption/liquefaction of the uppermost sediment horizon (particularly in mid- and lower reservoir areas containing soft, weakly consolidated clay- and colloid-enriched sediment) caused by Vibracore operations, and the sample depth intervals that were established to assess the vertical distribution of COIs and variations in grain size. Section 5.2.2 also describes river conditions above Marcus Flats that prevented the collection of sediment core samples.

The vertical distributions of arsenic, cadmium, lead, mercury, iron, and zinc at the nine core locations are summarized in Table 5-6. The distribution information illustrates the following important concepts regarding the vertical and longitudinal distribution of COIs in UCR sediments:

- Coarse-grained slag associated metals such as zinc and iron are notably enriched in the Marcus Flats core samples (RM 708 and 704). As discussed in Section 5.2.2, black, sand-sized water-granulated fumed slag particles were visually evident throughout the full 7 foot length of the Marcus Flats cores. The concentration of zinc and iron in the most upstream core collected above Marcus Flats core suggests that the sediment in the pre-reservoir river channel may contain as much as 50 percent water-granulated fumed slag, based on a comparison to the typical metal concentrations in water-granulated fumed slag (BFO, 1972; Cominco, 1990).

- Differences in the concentration and vertical distribution of coarse-grained slag-associated metals such as iron and zinc in the core samples from RM 708 and RM 704 (Marcus Flats) indicate variability in the depositional environment of the pre-reservoir river channel.
- Concentrations of the coarse-grained slag-associated metals iron and zinc decline by approximately an order of magnitude between Marcus Flats and RM676.
- Cores obtained from RMs 692 and 676 show elevated concentrations of coarse-grained slag-associated metals, but no visual evidence of sand-sized water-granulated fumed slag. Concentrations of coarse-grained slag-associated metals were highest in the deeper intervals of these cores (5 to 7 feet below the top of core).
- The core from RM 676 contained the highest concentrations of arsenic, cadmium, lead, and mercury. Of these metals, arsenic is considered a coarse-grained slag-associated metal. The other metals have been associated with aqueous effluent discharges from the Cominco smelter and generally exhibit an affinity for sediments and/or organic matter. These metals show a lower degree of concentration variability throughout the site as compared to the more coarse-grained slag-associated metals. The highest concentrations in the RM 676 core typically occur in the 3- to 5-foot or 5- to 7-foot core interval samples. Given their general fate and transport characteristics, it is expected that these metals would be preferentially sorbed to fine-grained organic or inorganic particulates (i.e., clays, colloids, or organic detritus).
- Cores from the lower portion of the site (RM 661 and below) did not contain visual evidence of water-granulated fumed slag, and elevated metals concentrations appear to be associated with the soft, clay- and colloid-enriched layer nearer the top of these cores.
- Sediment samples from the RM 622 core consistently contain the lowest observed concentrations of COI metals as compared to the other eight cores. As discussed in Section 5.2.2.4, it is uncertain whether the RM622 core sample provides a representative indication of sediment conditions in this portion of the reservoir and accurately portrays the vertical distribution of in-place sediment immediately below the sediment/water interface. As shown in Figure 5-30, the RM622 core is located next to a steep side bank, and landslides (identified by USBR) have been mapped upslope from this location (see Figure 2-10). It is possible that the materials at this core location may consist of clean bank slump sediments that have been recently introduced into the reservoir.

Figures 5-37, 5-38, and 5-39 display vertical variations in COI concentrations for selective metals (arsenic, lead, mercury, and zinc) at three individual core locations (RM 704, 676, and 605) representing sediment conditions in Marcus Flats, the mid-reservoir, and the lower reservoir, respectively. These plots further illustrate and reinforce some of the key concepts discussed above regarding the vertical distribution of COI metals in UCR sediments.

5.4.1.4 Distribution of Metals on Beaches

The term “beach” as used in this report and the Phase I Sediment QAPP describes areas that are located between the high- and low-water marks along the shores of the river and reservoir and may be subject to high use by human receptors. A total of 15 separate beach areas were selected for sampling in order to provide a sufficient number of representative samples to assess conditions in these high-use areas. The following beaches were sampled:

- Black Sand Beach—RM 742, East Side
- Northport City Boat Launch—RM 735, East Side
- Dalles Orchard—RM 730, East Side
- North Gorge Campground—RM 718, East Side
- Marcus Island Campground—RM 708, East Side
- Kettle Falls Swim Beach—RM 700, East Side
- Haag Cove—RM 697, West Side
- French Rocks Boat Launch—RM 690, West Side
- Cloverleaf Beach—RM 675, East Side
- AA Campground—RM 673, East Side
- Rogers Bar Campground—RM 658, West Side
- Columbia Campground—RM 642, East Side
- Lincoln Mill Boat Ramp—RM 633, East Side
- Keller Ferry No. 2—RM 615, East Side
- Spring Canyon Campground—RM 600, South Side

Three of the beaches—Northport City Boat Launch, Kettle Falls Swim Beach, and Columbia Campground Beach—were identified as areas of interest based on recreational use, where more detailed discrete and composite sampling was conducted, including collection of samples for size-fractionation analysis. Conditions at the other 12 beaches are represented by elevation-based composite samples.

Longitudinal Trends

Concentrations of COI metals in beach samples were plotted by river mile to evaluate longitudinal trends for beaches along the length of the UCR site (Figure 5-40).

The beach longitudinal trends for antimony, chromium, copper, iron, manganese, uranium, and zinc are similar to those observed in the overall longitudinal trend analysis for coarse-grained slag-associated metals described in Section 5.4.1.1; beaches with the highest concentrations of these metals are located above Marcus Flats. The plot for arsenic is similar, but also shows a slight increase in concentrations in the lower portion of site. The highest concentrations of cadmium, lead, mercury, and nickel extend farther downstream to the vicinity of the AA Campground Beach at RM 673.

Elevation-Based Trends

The beach sampling program was also set up to evaluate possible relationships between elevation and chemical concentrations at the selected beaches, with three elevation-based composite samples being collected at each beach. Table 5-7 summarizes the distribution of metals in discrete grab and elevation-based composite samples collected at beaches. The following elevation-based trends were observed in samples collected from the beaches:

- Black Sand Beach. Concentrations of most metals are lower in the samples collected from the middle and lower parts of the beach (elevation 1293). This trend was not observed on any of the other beaches above Marcus Flats.
- Northport City Boat Launch. Concentrations of all metals are higher in samples collected from the middle and lower parts of the beach.
- Dalles Orchard and North Gorge Campground. Concentrations of coarse-grained slag associated metals are higher in samples collected from the middle and lower parts of the beach. Concentrations of other metals do not appear to vary across the different elevations at the beach.
- Marcus Island Campground. Concentrations of copper, iron, and zinc are higher in samples collected from the middle and lower parts of the beach. Concentrations of cadmium, lead, and mercury also are higher in the lower portions of the beach.
- Kettle Falls Swim Beach, Haag Cove, French Rocks Campground, and Cloverleaf Beach. Concentrations of most metals tend to increase in samples collected from the middle and lower portions of the beach.
- AA Campground. No clear trends in concentrations were observed. This is likely because of the beach layout; sample locations were established in known “high use” portions of the beach/inlet area at elevations between approximately 1270 and 1290 feet, laid out in a general grid-like pattern. As such, the AA Campground beach samples do not wholly coincide with the typical beach sampling protocol involving collection of samples from three discrete elevations (1285, 1270, and 1255 feet).
- Rogers Bar Campground. Concentrations of all metals decline somewhat in the lower portions of the beach.
- Columbia Campground. Concentrations of most metals are higher in samples collected from the middle and lower portions of the beach.
- Lincoln Mill Boat Ramp. Concentrations of most metals decline in the lower portions of the beach.
- Keller Ferry No.2 and Spring Canyon Campground. No clear trends in concentrations were observed.

Comparison of Beach Results to Nearby Bank Sample Results

The average concentration of metals at each beach are compared in Table 5-8 to concentrations at nearby (i.e., within 3 miles up or downstream) individual transect sample locations. For the most part, the average concentration of metals at the beaches is bracketed within the range of concentrations detected in the nearby transect bank samples. A statistical evaluation of potential beach/bank relationships was not conducted because of the limited number of bank samples associated with each beach (typically fewer than four) and the variability of detected results for the nearby transect samples.

Grain-Size Trends

Selected beach composite samples were analyzed for particle size fractionation of metals. Figures 5-41 illustrates analytical results for select COI metals (arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, and zinc) in particle size fractions of <75 µm and 75 µm to 2 mm for samples collected at the Columbia Campground (RM 642), Kettle Falls Swim Beach (RM 700), and Northport City Beach (RM 735).

In general, all the metal COIs were detected at higher concentrations in the finer grained fraction (<75 µm) in the downstream beaches (Columbia Campground and Kettle Falls Swim Beach). However, in the Northport City Beach sample, chromium, copper, iron, manganese, and zinc were detected at higher concentrations in the coarser fraction (75 µm to 2 mm) than in the <75 um fraction. This finding is consistent with the observation that these metals are associated with coarse-grained water-granulated fumed slag deposited locally in the upper reach such as the Northport City Beach. The coarse fraction of the downstream beach samples thus likely consists of pre-reservoir bank sediment (terrace deposits) or re-worked colluvial material. At the downstream beaches, the fine grained materials with comparatively higher metals concentrations likely were deposited under reservoir conditions and subjected to limited sifting and washing effects described above. The higher concentrations of metal COIs in the finer fraction at the downstream beaches is consistent with the general tendency of the metal COIs to associate with fine-grained sediment and TOC.

5.4.1.5 Distribution of Metals at Tributary Mouths

Tributary sediment samples were collected within the UCR near the mouths of six major tributaries (Sanpoil River, Spokane River, Colville River, Kettle River, Onion Creek, and Big Sheep Creek) to better understand the role that tributaries from larger watersheds in the study area may play as potential sources of COIs, and to assess potential COI dilution or enrichment effects on main UCR river channel sediments immediately downstream from the tributary mouths. Sediment conditions at the tributary mouths may be complex and dynamic due to chemical, hydraulic, and other physical processes that may be active in these environments. The evaluation of the Phase I tributary mouth surface sediment sample results is limited to a comparison of the tributary mouth samples results to nearby mid-channel sample results. These sample results are illustrated in Figure 5-22. Results of the limited evaluation of potential impacts of the major tributaries are as follows:

- **Big Sheep Creek.** Arsenic and cadmium concentrations were lower, while chromium, copper, lead, manganese, and zinc concentrations were much lower, in Big Sheep Creek tributary samples than in nearby mid-channel samples.
- **Onion Creek.** Antimony and uranium concentrations were lower, while chromium, copper, lead, manganese, and zinc concentrations were much lower, in Onion Creek tributary samples than in nearby mid-channel samples. Nickel and mercury concentrations were not appreciably different.
- **Kettle River. A**ntimony, arsenic, cadmium, chromium were lower; copper, lead, manganese, and zinc concentrations were much lower; and nickel concentrations were higher in the Kettle River tributary than in nearby mid-channel samples. Mercury concentrations were not demonstrably different.
- **Colville River.** Arsenic, chromium, copper, lead, and zinc concentrations were lower, and nickel concentrations were slightly higher, in Colville River tributary samples than

nearby mid-channel samples. Cadmium, manganese, and mercury concentrations were not demonstrably different.

- **Spokane River.** Mercury concentrations were lower in the Spokane River tributary samples than in nearby mid-channel samples. No demonstrable difference was noted for the other metal COIs.
- **Sanpoil River.** Mercury concentrations were lower in the Sanpoil River tributary samples than in nearby mid-channel samples. No demonstrable difference was noted for the other metal COIs.

In summary, based on this limited analysis of potential impacts from major tributaries, none of the tributaries appear to contribute to loading of metal COIs in mid-channel sediments, with the possible exception of nickel from the Colville River and Kettle River. In general, it appears that tributary sediment contributions tend to dilute concentrations of the other metal COIs in mid-channel sediments.

5.4.2 Distribution of Organics

The organic COIs identified as a result of the Phase I sampling are listed in Table 4-1. The longitudinal, transverse, and vertical distributions of the organic COIs, as well as distributions on beaches, are briefly summarized by analytical group (e.g., dioxins/furan, pesticides, PCBs) in the following subsections.

5.4.2.1 Dioxins/Furans

Dioxin/furan analysis was conducted only on samples collected at beach and core locations. All 17 dioxin/furan congeners were detected in Phase I sediment core and beach samples. Of these, 2,3,7,8-tetrachlorodibenzofuran (2,3,7,8-TCDF) is the congener with the greatest number of detects and the greatest number of exceedances of criteria (Table 4-1). Results for 2,3,7,8-TCDF are presented below. The longitudinal distribution, areal distribution on beaches, and vertical distribution of 2,3,7,8-TCDF in cores are discussed below. Trends for 2,3,7,8-TCDF concentrations associated with size-fractionated beach samples, and trends for TOC, clay, and colloids in beach and core samples, also are discussed below.

Longitudinal Distribution in Beaches and Cores

2,3,7,8-TCDF was detected in samples from 11 beaches, with the highest concentrations detected in samples from Marcus Island (RM 708), North Gorge (RM 718), and Haag Cove (RM 697). The longitudinal distribution of 2,3,7,8-TCDF in beach sediment samples is summarized in Table 5-9. 2,3,7,8-TCDF was also detected in samples from three cores collected at RM 605, RM 637, and RM 692. The highest concentrations in beach samples were detected in samples from RM 708 (Marcus Island), RM 697 (Haag Cove), and RM 718 (North Gorge). The highest concentrations in core samples were detected in cores collected at RM 637 and RM 692.

Areal Distribution on Beaches

For beaches below Marcus Flats, 2,3,7,8-TCDF concentrations in beach samples were generally highest in B3 samples, which were collected at the lowest elevations, and decreased with increase in elevation. Distribution of 2,3,7,8-TCDF with respect to elevation in beach sediment samples is summarized in Table 5-10.

Vertical Distribution in Cores

2,3,7,8-TCDF exhibited generally decreasing concentrations with depth for the cores collected at RM605, RM637, RM661, and RM692, with the highest concentrations consistently detected in samples from the upper one foot of the core except for the core collected at RM 704, in which concentrations were low for all sample depths. The relationship of 2,3,7,8-TCDF concentrations and sample depth for cores is presented in Table 5-10. The comparatively low concentrations in samples from all depths in the core from RM 704 may be attributable to the comparatively high proportion of sand and low proportions of silt and finer particles throughout the core. The association of particle size and 2,3,7,8-TCDF concentrations in core samples is discussed further below.

Size Fractionation

Samples from beaches at RM 642, RM 700, and RM 735 were analyzed for particle size fractionation of dioxins/furans. As indicated in Table 5-11, 2,3,7,8-TCDF concentrations for the <75 um particle size fractions were notably higher than those for the 75 µm–2 mm size fractions for each of the beaches.

Association with TOC, Clay, and Colloids

As discussed in Section 5.3, nonpolar organic compounds such as dioxins/furans exhibit an affinity for organic matter in sediments. The concentrations of 2,3,7,8-TCDF in Phase I sediment samples shows a general association with concentrations of TOC in sediment. For example, in the core collected from RM 692, TOC exhibited the highest concentrations in the upper 6-inch interval, and decreased downward (Table 5-2). A similar downward decrease in 2,3,7,8-TCDF concentrations is observed in the core, as discussed above and presented in Table 5-10. A similar association between 2,3,7,8-TCDF and TOC is observed in samples from cores collected from RM 605, RM 637, and RM 661, and in beach samples. Figure 5-42 shows 2,3,7,8-TCDF concentrations versus TOC concentrations for all beach composite samples and core samples in which 2,3,7,8-TCDF was detected.

As discussed in Sections 5.2 and 5.3, the distribution of TOC concentrations in the Phase I sediment samples is similar to the distribution of clay and colloid fractions of sediment, likely because TOC is associated with these slow-settling sediments. As illustrated in Figure 5-43, there is also a general association of 2,3,7,8-TCDF concentrations and clay/colloid content in sediment, particularly for core samples.

5.4.2.2 PCBs

The PCB Aroclors identified as COIs are Aroclor-1016 and Arochlor-1260, each of which was detected once at a concentration exceeding its respective screening level. The detected exceedances occurred at the same sample location, RM 687A1, located 13 miles downstream from Marcus Flats. PCBs were detected at low concentrations in bed sediment samples collected from nearby locations during previous investigations by Ecology in 1990 (Ecology, 1991) and USEPA (E&E, 2003). In 1990, PCBs (as tetra-, penta-, and hexachlorinated biphenyls) were detected at low concentrations in a single sample collected near French Point Rocks, near RM 690 (Ecology, 1991). In 2001, PCBs (Aroclors 1254 and 1260) were detected at low concentrations in a single sample collected at RM 688 (E&E, 2003). The observation that detection of PCBs has been limited to the general area between RMs 687 and 690 suggests the possibility of a local PCB source or a nearby source or localized zone of accumulation.

5.4.2.3 Pesticides

Several pesticides, including 2,4′-DDE, 2,4′-DDT, 4,4′-DDD, 4,4′-DDE, 4,4′-DDT, and aldrin, were identified as COIs in sediments (see Table 4-1). Of these, the pesticides that exhibited the greatest number of screening criteria exceedances were 2,4′-DDE, 2,4′-DDT, 4,4′-DDE, and 4,4′-DDT. Longitudinal profiles of concentrations of these pesticides in sediment are illustrated in Figure 44. The highest concentrations of these pesticides were detected in beach samples collected at Columbia Beach (RM 642), possibly indicating a nearby local source of these pesticides. Of the samples collected at Columbia Beach, the discrete sample B3R (corresponding to the lowest elevation and right-hand side) contained the highest concentrations of all four pesticides.

5.4.2.4 PAHs

PAHs identified as COIs in sediments are benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, dibenzo(a,h)anthracene, indeno[1,2,3-cd]pyrene, and chrysene (see Table 4-1). Of these PAHs, chrysene exhibited the greatest number of detects and exceedances of sample-specific carbon-adjusted CCT values. A longitudinal profile of concentrations of chrysene in sediment is illustrated in Figure 5-45. Chrysene was detected in beach, core, and river group sediment samples throughout the UCR, with most concentrations below 10 micrograms per kilogram (µg/kg). The highest chrysene concentrations were detected in beach or bank samples from RM 740 (left bank), RM 735 (Northport City Beach), RM 730 (Onion Creek tributary sample), RM 708 (Marcus Island Campground Beach), RM 678 (left bank), and RM 628 (right bank). In general, the bank and beach samples exhibit the highest chrysene concentrations overall, although mid-channel samples tend to have higher concentrations than the adjacent transect samples between RM 695 and RM 678. No sources of chrysene or other PAH COIs have been identified in the UCR.

5.4.3 Data Gaps

Data gaps pertaining to the nature and extent of metal and organic COIs in UCR sediments have been identified. Whether these data gaps constitute data needs for the RI/FS will be evaluated through the DQO process or future RI/FS phases. These data gaps are as follows:

- Limited data are available from previous UCR sediment studies to perform a robust and defensible analysis of temporal changes in COI concentrations. Evaluation of temporal changes in COI concentrations, although not specifically included as a DQO of the Phase I sediment sampling program, likely will be necessary as part of future RI/FS phases.
- Analytical uncertainties resulted in incomplete characterization of antimony and uranium as part of the Phase I sediment investigation. Additional antimony and uranium data may be required to more fully assess the nature, extent and magnitude of these constituents in UCR sediment.
- The observed concentration pattern for nickel suggests a possible natural geologic source within the limits of the UCR watershed system. Additional evaluation of nickel in UCR sediments may be necessary to determine whether concentrations in UCR sediment are more attributable to natural or anthropogenic sources.

- Certain sediment samples were unattainable during the Phase I sediment investigation, especially mid-channel samples from the riverine and reservoir reaches above Marcus Flats. The absence of sediment samples from these areas limits the understanding of how sediment COIs are distributed in these portions of the UCR. Additional sediment samples may need to be collected (perhaps using different methods of sediment collection) to more fully characterize the distribution of COIs in this portion of the UCR.

- The evaluation and discussion of the findings from the Phase I sediment investigation was focused, by necessity, on a limited suite of COIs that served as primary indicator constituents. Additional analysis and evaluation of the Phase I data set (inorganics and organics) could be performed, if determined to be important for purposes of risk assessment, remedy selection, or ARARs analysis, to better understand, or further refine, the nature and extent of various trace elements and COIs in UCR sediment that were not discussed in detail herein.

- Results from the Phase I sediment investigation suggested that transport of sand-sized sediment—including water-granulated fumed slag—was limited in areas downstream from Marcus Flats, whereas within Marcus Flats considerable quantities of slag were evident in the mid-channel core and grab samples. Other large accumulations of slag have been documented in other areas of the UCR upstream from Marcus Flats. Additional investigation of the lateral and vertical extent of slag-impacted sediment, both upstream and downstream from, as well as within Marcus Flats, may be necessary to better refine the primary depositional zones for slag, and the extent over which the larger sized slag particles are distributed.

- The spacing of the Phase I sediment samples is appropriate for gaining a general understanding of longitudinal, transverse, and vertical distribution of COIs in sediment from throughout the UCR study area. Additional characterization samples may be needed to further refine locations of greatest sediment contamination by mass and concentration.

- The various factors that influence the spatial concentration patterns for mercury and cadmium in the Marcus Flats area sediments are not well understood based on available source information, river/reservoir hydrodynamics, and the existing distribution of sediment samples. Refining the overall understanding of mercury and cadmium in UCR sediment is important to the sediment CSM and to future risk assessment efforts. Additional characterization samples from the Marcus Flats area may be necessary to better refine the nature and extent of these constituents, and to identify what factors may be controlling their distribution in this area.

- Metal COIs, including coarse-grained slag-associated metals and other metals, are documented to have been discharged into the UCR in liquid effluent. The chemical and physical characteristics of the metals in liquid effluent are not known based on review of available data. Additional information on the characteristics of the liquid effluent discharges may be required to better understand the nature and extent, as well as fate and transport and potential risk, of these COIs.

- The Phase I sediment investigation did not include a DQO related to the determination of background levels of COIs. Establishing background concentrations for selected COIs may be important, especially for purposes of risk assessment and/or when considering any possible future remedial actions.
- The Spokane River potentially has an influence on the concentrations of certain COIs that are measured in UCR sediments. However, ascribing a definitive cause/effect relationship to certain COIs without having a corresponding set of comparable data for the Spokane Arm of Lake Roosevelt limits the ability to assess this possible relationship. Additional evaluation of the Spokane River as a potential source of COIs to the lower reaches of the UCR reservoir may be necessary.
- Dioxin and furan data are limited to cores and beaches and thus provide only limited spatial coverage. Additional sampling and analysis for dioxins and furans may be necessary to provide a more complete characterization of these organic constituents in sediment samples from throughout the UCR.
- Organic COIs have been detected in UCR sediment but have not been attributed to a particular source. Additional evaluation of organic COIs in UCR sediments may be necessary to determine whether concentrations in UCR sediment appear to be related to a specific source, or possibly due to other causes (e.g., atmospheric deposition of combustion byproducts).

5.5 Fate and Transport of COIs in Sediment

Section 4.4 of the A&R Document (CH2M HILL, 2004b) provided a detailed description of proposed hypotheses regarding the fate and transport of contaminants within the UCR. The fate and transport concepts described in the A&R Document were based on a review of historical data and an assessment of hydraulic relationships that exist between the river and reservoir; in particular, flow velocities in the river under different stage and discharge conditions.

Overall, the observations and findings from the Phase I sediment sampling program support the fate and transport concepts presented in the A&R Document. The data and findings from the Phase I sediment sampling have, however, helped to refine the understanding of the physical characteristics, chemical processes, and hydraulic factors that affect the fate and transport of environmental contaminants in the UCR. This section summarizes the current conceptual model concepts concerning fate and transport.

5.5.1 Contaminant Transport Mechanisms

Environmental contaminants in the UCR system are thought to be present in one of three primary forms: solid phase, particulate sorbed, or dissolved phase. The solid-phase form would include, for example, water-granulated fumed slag from the Cominco smelter that contains various trace metals, metalloids, and common earth-crust metals such as aluminum and iron. These contaminants would be present within the mineral matrix of the sand-sized or finer water-granulated fumed slag material. Other possible solid-phase forms of COIs could potentially include fine particulates associated with liquid effluent discharges. Particulate-sorbed contaminants include both inorganic and organic constituents that are preferentially bound to fine-grained solid-phase materials (clay, colloids, organic carbon-enriched detritus) that are present in the UCR system. Dissolved-phase contaminants would either remain in solution from their source of origin, or become leached or dissolved from a solid-phase material.

The A&R Document described the following four general transport mechanisms for mobilization of contaminants within the UCR:

- Solution transport
- Suspended transport
- Surface transport
- Bed transport

In brief, **solution transport** involves the movement of dissolved contaminants in UCR surface water until chemical conditions result in precipitation, or sorption to particulates, or sorption to hydroxides or oxyhydroxides that are present on some mineral surfaces, or biological uptake. The Cominco smelter, its fertilizer plants, and other facility operations are known to have contributed aqueous discharges to the Columbia River. The Phase I sediment investigation did not directly investigate the concentration of contaminants in Columbia River surface water. However, results from the Phase I sediment sampling program provide some inferences regarding possible mechanisms by which these aqueous-phase metals were transported, dispersed, and deposited into the UCR sediments—especially where they are found in greater concentrations within the finer grained sediments below Marcus Flats.

Suspended transport involves movement of silt- to clay-sized particles of source material such as water-granulated fumed slag, and/or mineral-based or organic particulates to which contaminants are bound via sorption or other surface-binding mechanism. Previous UCR investigations have included sampling and analysis programs to evaluate the concentration of organic and inorganic contaminants in suspended particulates from the river. The Phase I investigation did not directly investigate suspended transport of contaminants. However, inferences regarding the transport and deposition of fine-grained suspended particulates have been drawn from the Phase I investigation findings. In particular, it appears evident that much of the contamination found in the finer grained (<200 mesh) sediments from the mid-channel portions of the reservoir downstream from Marcus Flats was, and continues to be, transported there in association with suspended particulate material. Flow velocities below Marcus Flats become low enough to allow settlement and deposition of these particulate-bound contaminants. As discussed below, suspended transport is the primary transport mechanism for the very fine-grained fraction of water-granulated fumed slag and for contaminants associated with very fine-grained particulates, such as those found in the Middle Reservoir and Lower Reservoir reaches.

Surface transport involves the movement of small aggregated mats of water-granulated fumed slag or woody, fibrous materials containing water-granulated fumed slag and/or organic contaminants along the water surface. In this form, the contaminants are transported along the water surface and tend to remain there because of water surface tension. When the surface tension is broken, the floating particulate materials will sink or become suspended in the water column. The Phase I investigation did not directly investigate surface transport of contaminants; however, some small floating mats appearing to contain fine, black water-granulated fumed slag material were observed along the river's edge in selected up-river locations (above Northport) by field personnel and other investigators during the course of the Phase I field investigation and planning efforts. The mechanism(s) that currently contribute to the formation of these small, floating mats of material are not well understood.

Bed transport involves the movement of sediment along the bottom of the river or reservoir through the processes of traction or saltation. As described in previous sections, visual observations and chemical data demonstrate that water-granulated fumed slag has been preferentially deposited in the upper, free-flowing reaches of the Columbia River and is present in considerable quantity in the old river channel in the vicinity of Marcus Flats. The fate and transport of water-granulated fumed slag depends on its particle size, density (specific gravity), shape, and chemical stability in the river and reservoir environment. Section 5.2.1.4 provides detailed discussion of the flow velocity considerations that influence the mobilization and transport of sand-sized bed sediment under various river flow and reservoir stage conditions.

Findings and observations from the Phase I sediment investigation support the belief that these four processes serve as the dominant mechanisms affecting the transport of contaminants within the UCR system. Section 4.4 in the A&R Document provides a detailed discussion of the fate and transport characteristics of specific COIs (metals and organic constituents) that are present in UCR sediment.

5.5.2 Primary Processes Affecting the Fate and Transport of Sediment COIs

Section 5.5.1 gave a general overview of the primary UCR sediment transport mechanisms, based primarily on the analysis presented in the A&R Document. This section provides additional discussion of specific physical and chemical processes and anthropogenic activities that further affect the fate and transport of COIs in UCR sediment. The particular processes and activities discussed below include:

- Grand Coulee Dam Operations and Regional Management of Columbia River Discharge. Discusses the role and importance of river flow and stage, bank slumping and side-bank washing on the mobilization and distribution of sediment COIs.
- Reduction of Known Upstream Sources of Sediment COIs. Discusses how documented changes in COI source contributions and loading to the UCR affect the fate and transport of these constituents.
- Water-Granulated Fumed Slag Distribution, Accumulation, and Potential Remobilization. Discusses the current understanding of water-granulated fumed slag distribution within UCR sediments, and the potential for future remobilization of the coarse-grained water-granulated fumed slag, and/or coarse-grained slag-associated metal COIs.
- Sediment Accretion and Burial. Discusses how certain reaches of the river/reservoir system serve as a sediment "sink" wherein certain COIs would tend to accumulate and have limited propensity for remobilization and transport.
- Benthic Flux and Biological Uptake and Conversion. Discusses the possible role that benthic flux and biological uptake/conversion may play in remobilizing COIs that are

buried in the near-surface sediment column, and/or become chemically transformed or mobilized by biological processes or biological uptake.

- Effects of TOC on Sorption and Contaminant Mobility. Discusses the possible association of specific COIs with TOC in sediment, and the effect that TOC can have on bioavailability of sorbed constituents.

5.5.2.1 Grand Coulee Dam Operations and Regional Management of Columbia River Discharge

With the construction of Grand Coulee Dam, a large reach of the Columbia River was transformed from a free-flowing riverine system to a managed reservoir system that displays a more lacustrine-like hydraulic environment for much of its length between Grand Coulee dam and the U.S.-Canada border. Creation of a reservoir environment changed the pre-reservoir sedimentation processes and patterns and produced other associated effects that influence the fate and transport of inorganic and organic COIs. Some of the natural and operation-dependent conditions that directly affect sediment transport, mobilization, and deposition are briefly discussed below.

Stage and Discharge

Discharge rates and stage height within the UCR are strongly influenced by the operation of U.S. and Canadian dams. Ongoing operations at Grand Coulee Dam since 1984 and associated hydraulic controls exerted by Canadian dams on the Columbia and Pend Oreille Rivers have maintained a fairly controlled set of stage and discharge conditions in Lake Roosevelt and in the riverine reaches immediately upstream from the reservoir. Seasonal changes in stage and discharge are influenced primarily by seasonal hydrologic conditions, flood control, power demand requirements, and fish management strategies. Section 5.2 discusses river/reservoir hydraulic relationships and the role that managed reservoir levels and flows have on the potential mobilization and transport of sediment within the UCR. These existing operational conditions exert considerable control over the current distribution, transport and deposition of sediment within the UCR river/reservoir system and influence the eventual fate and transport of associated contaminants, both in sediment and in solution.

An example of how flow velocity changes influence the distribution and transport of COIs in UCR sediment is in the observed quantity of coarse-grained (sand-sized) water-granulated fumed slag that has been deposited within the pre-reservoir river channel through Marcus Flats. Section 5.2 discusses how changes in river flow velocity will affect where certain particle sizes are deposited within the UCR. Section 5.2.2 specifically describes longitudinal, transverse, and vertical variations in sediment grain size, including a discussion of observations within Marcus Flats. While variations in river flow velocity are seen to exert a significant influence on the longitudinal distribution of sediment COIs in the river/reservoir system, seasonal changes in the reservoir pool elevation also can affect the vertical distribution and transport of COIs. In particular, higher elevation side-bank and beach areas are known to be submerged less frequently (see Figures 5-2 through 5-4) and therefore would be less able to accumulate finer-grained suspended sediment and associated COIs. Evidence from the Phase I sediment study also suggests that routine operational changes in the reservoir pool elevation contributes to the transport and movement of COIs from the side-bank areas (i.e., side-bank washing) into deeper portions of the reservoir.

Bank Slumps

Normal operational changes in the Lake Roosevelt pool level have caused bank slumps and landslides to occur along many portions of the reservoir shoreline. The more significant bank slump and landslide areas have been mapped by USBR. The locations of these areas are shown in Figures 2-3 through 2-12. Many of the larger slumps occurred in the early years immediately following establishment of Lake Roosevelt. These slumps and landslides typically occurred as a result of lowering of the reservoir pool level and inability of the nearshore sediments to dewater at the same rate, resulting in slope failure of the saturated sediments/soils.

One effect of the slope failures is the transportation of "clean" native sediment/soil from the upland side banks into the reservoir. The frequency and magnitude of bank slumpage is believed to have declined significantly as a result of current reservoir management practices. As a result, the influx of "clean" sediment is thought to be considerably less today than occurred during the first decade or so of reservoir operations. Recent studies by the USGS (USGS, 2005) identified sediment horizons in selected core samples within the reservoir that were inferred to represent materials that likely originated from historical bank slumps. From a fate and transport perspective, bank slump sediments can either cover and bury earlier sediments known to contain COIs, or could disrupt and remobilize COIs that are present in the soft, fine-grained horizon near the top of the sediment column.

Side-Bank Washing

In addition to promoting possible bank instability as discussed above, reservoir level fluctuations, coupled with wave action on the side banks and beaches and sub-aerial erosional processes contribute to the washing and mobilization of fine-grained sediment particles from these areas. In particular, as the reservoir is raised and lowered over its current operational range (approximately 1208 to 1290 feet), the finer grained sediment fraction (containing either elevated or comparatively low concentrations of COIs) is preferentially washed and eroded from these reservoir side-bank areas. Once eroded and mobilized, these finer-grained sediments will settle into deeper levels of the reservoir. In side-bank areas where finer-grained sediments are present and contain measurable concentrations of COIs, this washing and erosion process can influence the mobilization and distribution of COIs.

Seasonal exposure of the bank areas during periods of reservoir drawdown also can affect volatilization and/or ultraviolet (UV) degradation of any organic constituents that may be present in the side-bank areas of the reservoir.

Given the understanding of current and historical reservoir management practices, there appears to be little potential for large-scale broadcasting of sand-sized or finer contaminated sediment into higher elevation side-bank areas, particularly in the reservoir areas below Marcus Flats. Airborne transport of dust-related contaminants from exposed beach and side-bank areas during intermittent high wind events is a potential concern that is being addressed by other investigations and studies. Under current reservoir management practices, reservoir levels would typically remain at a pool level below 1270 during seasonal high-flow conditions (see Figures 5-3 and 5-4). As a result, contamination of the upper 20 feet of the side-bank area due to large-scale broadcasting of contaminated suspended sediments would not be expected. Similarly, evidence from Phase I transect samples indicates that side-bank sediment samples collected between elevation 1290 and 1250 typically show much lower concentrations of COIs compared to sediment samples collected from a lower elevations within the reservoir below Marcus Flats.

5.5.2.2 Reduction of Known Upstream Sources of Sediment COIs

According to a summary report prepared by consultants to Cominco, the routine discharge of water-granulated fumed slag into the Columbia River was discontinued in mid-1995. According to Celgar, in the process of modernization, which included reduction of chlorine usage, the plant reduced discharges of furans and by 1993 had reduced dioxin and furan concentrations in effluent to below minimum detection limits (E&E, 2003).

Liquid effluent discharges from Cominco have reportedly been significantly reduced since the early 1980s. Section 5.1 provides an overview of these various operations and historical source contributions to the Columbia River. The reported reduction in contaminant contributions from these sources could have a positive effect on the loading and distribution of COIs into the UCR. The Phase I investigation did not specifically address sediment loading rates at or below the border. Uncertainty still remains over the quantity of water-granulated fumed slag that remains within the river system between the Trail facility and the U.S.-Canada border, and the degree to which this sediment is susceptible to scour and remobilization during future high-flow discharge events.

Reduction in effluent discharges from the Celgar facility also would be expected to reduce the dioxin and dibenzofuran contaminant load to the Columbia River.

5.5.2.3 Water-Granulated Fumed Slag Distribution, Accumulation, and Potential Remobilization

As described in Section 5.1.1.2, an estimated 13,000,000 tons of water-granulated fumed slag was generated and discharged to the Columbia River from the Cominco smelter, with about 10,000,000 tons being discharged since construction of Grand Coulee Dam. Lesser quantities of water-granulated fumed slag have been discharged to the Columbia River from the former Le Roi/Northport smelter. The size of the water-granulated fumed slag generated by the Cominco smelter allowed it to be transported (as bedload and suspended load) downriver and become dispersed with other naturally derived UCR sediments. Black, glassy, sand-sized material, having the appearance of water-granulated fumed slag, was observed in some beach, core, transect and bioassay sediment samples collected as part of the Phase I sampling program. Some small quantities of black, ferromagnesian minerals (e.g., amphiboles, pyroxenes) also are expected to be present in the UCR sediments from erosion of bedrock within the drainage system and can show some general similarities to water-granulated fumed slag. However, water-granulated fumed slag is readily differentiated from ferromagnesian minerals based on chemical composition, specific gravity, particle shape, optical and magnetic properties, and weathering characteristics.

Coarse-grained water-granulated fumed slag was visually evident in various samples collected as far downstream as Marcus Flats, where core samples from RM 708 and 704 encountered up to 7 feet of water-granulated fumed slag-impacted sediment. Below Marcus Flats, coarse-grained water-granulated fumed slag was not visually evident in any of the Phase I sediment samples collected. These observations and findings support the observation that coarse-grained water-granulated fumed slag is primarily distributed throughout the upper 40 miles of the UCR. The water-granulated fumed slag, however, is not evenly or uniformly distributed, either longitudinally or transversely, in this reach due to river morphology and hydrodynamic considerations. Primary accumulation areas within the UCR for sand-sized water-granulated fumed slag include the following:

1. Side-bank beach and point bar areas in the upriver reaches (e.g., Black Sand Beach at RM 742; large point bar deposit at RM 738) deposited during historical high river flow events
2. Marcus Flats, concentrated in the old river channel
3. Dispersed to an unknown depth within the interstices of the coarse, cobbly sediments in the old river channel upstream from approximately RM 729 (Onion Creek)
4. Localized accumulations within the old river channel downstream from approximately RM 729 to approximately RM 710 (near the entrance to Marcus Flats)
5. Within the old river channel downstream from Marcus Flats, but buried at depth by finer-grained post-reservoir sediments that have accumulated since construction of Grand Coulee Dam

Historical information indicates that, at the point of discharge, 90 percent or more of the Cominco water-granulated fumed slag consisted of sand-sized (fine to coarse sand) material (Table 4-1 of the A&R Document). This size fraction would move predominantly via bed transport mechanisms and would be subject to the sediment transport limitations and conditions described above and in Section 5.2. The finer grained water-granulated fumed slag particles (smaller than sand size), which consists of less than one percent by weight of the water-granulated fumed slag according to historical information, would display potentially greater longitudinal and transverse mobilization in the UCR system. Water-granulated fumed slag-associated particles that are silt-sized or finer likely would be transported further downstream from Marcus Flats, and would settle to the reservoir bottom at locations governed by their size and density. Additional sources or mechanisms contributing to the dispersion of coarse-grained slag-associated metals in these finer grained sediments below Marcus Flats include (1) natural influx from local tributary sources, and (2) ongoing remobilization, transport, and deposition of these metals, as true fine-grained particles of water-granulated fumed slag, or as metal ions sorbed to suspended particles, or as fine-grained particulates discharged as a component of liquid effluent.

Although these topics were not addressed by the Phase I sediment sampling program, USGS has recently conducted an evaluation of the role that weathering and decrepitation may play on the potential for remobilization of metals from coarser grained water-granulated fumed slag (USGS, 2005). Findings from the USGS study may help better define the degree to which coarse-grained water-granulated fumed slag can or will serve as an ongoing source of metals contamination to the UCR via resuspension and transport of weathering products from the water-granulated fumed slag particle surface and/or direct solubilization of metal ions into ambient water. However, the degree and rate which these processes are occurring throughout the UCR is unknown.

5.5.2.4 Sediment Accretion and Burial

Previous discussions have touched upon general areas within the UCR river and reservoir where active sediment scouring, side-bank washing, deposition, and accumulation are expected to occur. Sand-sized sediment (containing appreciable quantities of water-granulated fumed slag) is known to have accumulated in the old pre-reservoir river channel area within Marcus Flats. Deposition of the sand-sized material in this area results primarily from the reduction in river flow velocity below what is needed to sustain bedload transport of most sand-sized material. The transverse grain size plots (see Figure 5-15) also indicate that some fine-grained sediment is deposited in the side-channel and side-bank areas within Marcus Flats. The long-term potential for erosion and transportation of these finer grained sediments within Marcus Flats is not known. Compared to the coarser grained sandy sediments from the mid-channel area, these finer grained Marcus Flats side-bank and side-channel samples have considerably lower concentrations of COIs, reducing the potential concern over remobilization and transport of COIs from these sediments.

In areas downstream from Marcus Flats, fine-grained sediment (silt size and finer) is actively accumulating in the quiescent reservoir areas. Little resuspension and mobilization of the fine-grained sediment is believed to occur in this portion of the reservoir, particularly in areas that are submerged at all times. Bank slumps or bioturbation may cause some remobilization of fine-grained sediments, and bank washing likely remobilizes some fine-grained materials from side-bank areas that are periodically exposed. Existing bottom sediment in the middle and lower reservoir areas is expected to become progressively buried through the steady, ongoing influx and deposition of new fine-grained sediment. A reduction in sediment COI concentrations within the uppermost portion of the sediment column (where biological exposure is most likely to occur) would be expected to occur over time if the influx of COIs in the suspended sediment fraction were to decrease.

5.5.2.5 Benthic Flux and Biological Uptake and Conversion

The Phase I sampling program did not investigate or characterize in-situ sediment pore water concentrations or the possible remobilization of sediment-bound COIs by benthic flux. Benthic flux represents the transport of dissolved chemical species across the solid-liquid interface at the bottom of aquatic systems. The flux of solutes can be either positive (into the water column from the sediment) or negative (out of the water column into the sediment) and can vary over multiple temporal and spatial scales (USGS Toxic Substances Hydrology Program website definition).

COIs that are present in UCR sediment are potentially subject to geochemical processes that can affect their long-term stability, mobility, recalcitrance, and bioavailability. Reservoir pool fluctuations and other natural hydraulic and/or chemical processes that occur within the reservoir environment may affect sediment porewater and the associated benthic flux. The potential role that benthic flux plays on the mobilization of COIs into the water column from the bottom sediment is not known and was not investigated as part of the Phase I sediment sampling. It is known, for example, that physical and chemical processes and reactions within the sediment column can create chemical gradients that may encourage the diffusion of metals and metalloids upward toward the sediment-water interface, thereby increasing the potential for release into the overlying water. For example, a recent study by Toevs et al. (2006) has documented these conditions in metal-affected sediments from Lake Coeur d'Alene in northern Idaho. Biological uptake of COIs and in-place chemical conversion of certain metals (e.g., mercury methylation) can also affect the fate and transport of selected sediment-bound constituents.

The eventual fate of contaminants buried in sediment will differ depending on the constituent and site of deposition. Some constituents are expected to remain effectively immobilized and chemically stable in the sediment column for long time periods. Conversely, some constituents may be more chemically active and influenced by physical and chemical processes and/or biological uptake mechanisms that cause them to experience a shorter residence time in the sediment column.

The Phase I bioassay testing program used both burrowing macroinvertebrates (*Hyalella azteca* and *Chironomus tentans*) and an aquatic macroinvertebrate (*Ceriodaphnia dubia*) to assess the possible impact that exposure to UCR sediment could have on the growth, development, and mortality of these organisms. A detailed discussion of the results from the bioassay testing is presented in a separate technical memorandum, including the results of the bioassay water (porewater) associated with the sediment samples used for the tests (CH2M HILL, 2006b).

5.5.2.6 Effects of TOC and Sediment Fines on Sorption and Contaminant Mobility

The sorption affinity and bioavailability of certain organic and inorganic constituents can be strongly influenced by the concentration of TOC and/or the percentage of clay/colloid-sized material that is present in the sediment. Section 5.3 describes the distribution of TOC in UCR sediments. Section 5.2.2 discusses observed variations in sediment grain size throughout the UCR study area.

The concentrations of organic contaminants (particularly, nonpolar, nonionizable chemicals) and the toxicity of these contaminants in sediments have been observed to correlate with organic carbon content in sediments. For example, the CCT human health sediment screening values presented in Table 3-1 are carbon normalized. Carbon normalizing the screening values takes into account the fact that higher concentrations of TOC in sediment result in lower anticipated bioavailability and toxicity. As discussed in Section 5.3, nonpolar contaminants in sediments or water preferentially partition into the organic material in sediments because of the similar chemical nature of the organic material to the nonpolar organic contaminants. Humic acid is often a significant component of these organic materials. Humic acid is known to act as a complexing agent with various heavy metals.

Figure 5-19 shows the longitudinal distribution of TOC within mid-channel and side-bank samples. Figure 5-20 shows the transverse distribution of TOC at three selected high-density transects: RM 706 (Marcus Flats), RM 678 (mid-reservoir), and RM 605 (lower reservoir). These plots indicate that TOC varies both longitudinally and transversely. These observed variations in TOC show some direct correlation to the concentrations of some COIs. Figures 5-26, 5-27, and 5-28 present correlation plots for cadmium, mercury, and TOC. The data suggest that the cadmium concentration displays a slight to moderate association with increasing TOC; a slight to moderate association also appears to exist between the mercury concentration and measured TOC content.

Section 5.4.2 provides additional discussion on the role that TOC plays in the occurrence and distribution of organic contaminants in UCR sediment. In particular, as shown in Figure 5-42, the concentration of 2,3,7,8-TCDF appears to show a strong positive association with TOC. A similar type of general association between 2,3,7,8-TCDF and clay/colloid content also was observed (see Figure 5-43). These apparent positive associations between

TOC and/or the percentage of sediment fines and the concentrations of selected organic and inorganic COIs are consistent with the known affinity that these constituents have for organic matter and fine-grained sediments. The degree to which the COIs are associated with, and bound to, the organic matter and/or mineral matrices in the sediments will potentially affect the long-term stability and bioavailability of these constituents in the UCR environment.

5.5.3 Data Gaps

Data gaps pertaining to the fate and transport of metal and organic COIs in UCR sediments have been identified. Whether these data gaps constitute data needs for the RI/FS will be evaluated through the DQO process or future RI/FS phases. These data gaps are as follows:

- Uncertainties remain with respect to the chemical processes that affect the potential remobilization and/or solubilization of COIs that occur in association with the fine-grained sediment fraction. Although processes such as chemical oxidation, desorption, dissolution of contaminants, and benthic flux may be influencing the fate and transport of COIs in UCR sediment, specific details regarding these mechanisms are lacking, and investigation of them was not a DQO of the Phase I sediment investigation program. Additional information on metals remobilization may be necessary to better understand the importance of these mechanisms on the fate and transport of COIs in UCR sediment.

- Uncertainties remain with respect to the chemical processes and kinetics that affect the weathering/degradation of water-granulated fumed slag in the UCR environment. Evaluation of slag weathering was not a DQO of the Phase I sediment investigation program; initial investigations of this process have been conducted by USGS. Additional information on slag weathering may be necessary to better understand the importance of this process on the fate and transport of COIs in UCR sediment.

- Metal COIs, including coarse-grained slag-associated metals and other metals, are documented to have been discharged into the UCR in liquid effluent. The chemical and physical characteristics of the metals in liquid effluent are not known based on review of available data. Additional information on the characteristics of the liquid effluent discharges may be required to better understand the fate and transport of these COIs.

- Tributary mouth areas can be complex and dynamic due to a variety of hydraulic, chemical, and physical processes that occur in these localized environments. Information collected during the Phase I sediment investigation provided important information on the apparent nature and extent of COIs in the immediate vicinity of major tributary mouths. Additional data collection may be required to address specific fate and transport considerations or risk assessment concerns associated with tributary mouth areas.

- Consistent with project DQOs, the spacing of the Phase I sediment samples was designed, at large, to provide a general understanding of longitudinal, transverse, and vertical distribution of COIs in sediment from throughout the UCR study area. As discussed in Section 5.4.3, additional characterization samples may be needed to further refine locations of greatest sediment contamination by mass and concentration at a smaller scale of resolution if determined to be important for purposes of risk assessment or remedy selection. Similarly, if it appears that high chemical variability occurs over small lateral or vertical distances, additional investigation also may be necessary to better assess local-scale variations in fate and transport processes.

- The sediment CSM discusses the potential role of liquid-phase sorption/desorption to fine-grained sediments and TOC. The Phase I investigation did not include specific DQOs that were intended to address the degree to which liquid-phase COIs are sorbed to clay minerals and/or plankton. The specific role that suspended clay minerals and/or organic debris play in controlling the fate and transport of COIs in the UCR environment may need to be further evaluated.
- Findings from the Phase I sediment investigation suggest a slight to moderate positive association between the concentration of certain COIs and the associated TOC and sediment fines percentages. Additional information on the role that TOC and fine-grained particulates have on contaminant mobility and bioavailability may be necessary.
- Little information is available on sediment deposition rates within the UCR system. Establishing sediment deposition rates at several different locations within the system may be useful for understanding variations in sediment transport and the fate and transport of COIs. Age dating of sediments may also be useful to better understand variations in sedimentation rates and magnitudes.

TABLE 5-1

Range of Fine-Grained Size Fraction Percentages in Cores from RM 676 and RM 661

Upper Columbia River RI/FS

Particle Size Fraction	Size Fraction Percentages	
	RM 676	**RM 661**
Silt	44-56	66-80
Clay	26-30	9-14
Colloids	8-16	4-9

TABLE 5-2
Vertical Distribution of Total Organic Carbon in Phase I Core Samples
Upper Columbia River RI/FS

	TOC Concentration (mg/kg)								
Depth (ft)	**RM 605 Core**	**RM 622 Core**	**RM 637 Core**	**RM 644 Core**	**RM 661 Core**	**RM 676 Core**	**RM 692 Core**	**RM 704 Core**	**RM 708 Core**
0 - 0.5		1,740	11,800	7,880	7,010	10,100	32,200	534	899
0 - 1	11,400	2,470	10,300	3,700	4,290	7,190	24,800	261	2,050
1 - 3	5,140	2,730	4,070	632	3,990	6,340	16,500	833	2,770
3 - 5	1,770	3,960	2,560	1,090	1,770	7,560	4,030	778	991
5 - 7		1,790		626	1,120	5,530	17,400	918	842
7 - 9		937						2,120	

ft = feet
RM = river mile

TABLE 5-3
Summary of Left-, Mid-Channel, and Right-Bank Zinc Concentrations Between RM 729 and RM 710
Upper Columbia River RI/FS

Sample River Mile	Left-Bank Zinc (mg/kg)	Mid-Channel Zinc (mg/kg)	Right-Bank Zinc (mg/kg)
729	1,250	16,600	1,800
726	2,470	14,800	2,730
724	93	19,200	8,410
722	1,000	20,100	809
721	210	19,200	1,520
718	1,180	1,240	545
710	392	13,600	182

mg/kg = milligrams per kilogram

TABLE 5-4

Average Concentration of Selected Coarse-Grained Slag-Associated Metals at Selected High-Density Transects Below Marcus Flats

Upper Columbia River RI/FS

Transect Location	**Average Zinc (mg/kg)**	**Average Arsenic (mg/kg)**	**Average Manganese (mg/kg)**
RM 678[a]	783	13.8	837
RM642[b]	663	10.1	891
RM605[c]	712	9.5	1266

[a] Mid-channel and side-channel samples at RM 687 include X2, X3, X4, and X5.
[b] Mid-channel and side-channel samples at RM 642 include X2, X3, X4, X5, and X6.
[c] Mid-channel and side-channel samples at RM 605 include X2, X3, X4, X5, and X6 and the X5 duplicate.

mg/kg = milligrams per kilogram

TABLE 5-5
Average Concentration of Other Metals at Selected High-Density Transects Below Marcus Flats
UCR Phase I Sediment Data Evaluation Report

Transect Location	Average Cadmium (mg/kg)	Average Mercury (mg/kg)	Average Lead (mg/kg)
RM 678[a]	6.5	1.6	331
RM642[b]	5.9	1.2	237
RM605[c]	5.8	0.9	186

[a] Mid-channel and side-channel samples at RM 687 include X2, X3, X4, and X5.
[b] Mid-channel and side-channel samples at RM 642 include X2, X3, X4, X5, and X6.
[c] Mid-channel and side-channel samples at RM 605 include X2, X3, X4, X5, and X6 and the X5 duplicate.

mg/kg = milligrams per kilogram

TABLE 5-6
Vertical Distribution of Metals Detected in Phase I Core Samples
Upper Columbia River RI/FS

Arsenic (mg/kg)

Depth (ft)	RM 605 Core	RM 622 Core	RM 637 Core	RM 644 Core	RM 661 Core	RM 676 Core	RM 692 Core	RM 704 Core	RM 708 Core
0 - 0.5	--	6.6	9.9	15.9	8.1	9	5.3	5.8	12.8
0 - 1	15.5	6	12.7		6.9	17.5	4.4	6.1	11
1 - 3	4.8	6	2.4		8.9	14.3	2.9	5.3	2.9
3 - 5	4.6	7.4	3.1		7.4	17.8	7.5	7.7	3.2
5 - 7		5.8			7.1	17.3	9	10.3	0.95
7 - 9		6.3						8.8	

Cadmium (mg/kg)

Depth (ft)	RM 605 Core	RM 622 Core	RM 637 Core	RM 644 Core	RM 661 Core	RM 676 Core	RM 692 Core	RM 704 Core	RM 708 Core
0 - 0.5	--	0.08	5.4	12.7	3.6	5.5	8	0.25	4.4
0 - 1	11.3		9.3	0.34	3.8	14.2	5	0.23	4.4
1 - 3	0.43	0.053	0.09	0.1	4.9	13.2	5.4	0.38	3.9
3 - 5	0.11	0.051	0.079		1.6	14.1	3.6		3.5
5 - 7		0.05		0.058	0.46	17.9	9.8		4.4
7 - 9								0.47	

Iron (mg/kg)

Depth (ft)	RM 605 Core	RM 622 Core	RM 637 Core	RM 644 Core	RM 661 Core	RM 676 Core	RM 692 Core	RM 704 Core	RM 708 Core
0 - 0.5	--	13700	33100	34500	24400	29400	28700	128000	256000
0 - 1	34000	15400	26900	13700	19700	28800	27000	127000	266000
1 - 3	18700	14200	14700	14300	22000	29300	22300	119000	168000
3 - 5	17300	15300	13600	15600	23100	30000	40100	127000	227000
5 - 7		13900		12500	20100	30400	31200	126000	206000
7 - 9		13400						128000	

Lead (mg/kg)

Depth (ft)	RM 605 Core	RM 622 Core	RM 637 Core	RM 644 Core	RM 661 Core	RM 676 Core	RM 692 Core	RM 704 Core	RM 708 Core
0 - 0.5	--	9	180	841	162	330	288	382	1150
0 - 1	462	6.7	261	10.8	165	690	214	378	1140
1 - 3	20	6.5	7.9	5.4	234	1010	216	431	471
3 - 5	8.9	7.1	6.2	5.3	96.2	1050	550	439	524
5 - 7		6.6		4.4	22.6	1230	367	542	633
7 - 9		5.2						498	

Mercury (mg/kg)

Depth (ft)	RM 605 Core	RM 622 Core	RM 637 Core	RM 644 Core	RM 661 Core	RM 676 Core	RM 692 Core	RM 704 Core	RM 708 Core
0 - 0.5	--	0.036	0.81	1.5	0.47	1.5	1.6	0.015	0.035
0 - 1	1		0.83	0.022	0.6	2.4	0.52	0.011	0.021
1 - 3	0.052			0.005	0.6	2.7	1.7	0.016	0.029
3 - 5	0.009			0.006	0.4	3.2	0.063	0.015	0.013
5 - 7				0.007	0.049	2.3	0.98	0.013	0.027
7 - 9								0.013	

Zinc (mg/kg)

Depth (ft)	RM 605 Core	RM 622 Core	RM 637 Core	RM 644 Core	RM 661 Core	RM 676 Core	RM 692 Core	RM 704 Core	RM 708 Core
0 - 0.5	--	38.4	635	1230	457	1040	1120	11700	23500
0 - 1	1210	37.5	927	55.2	439	1710	981	11700	24800
1 - 3	80.5	35.3	46.1	30.9	545	1890	1450	11100	13800
3 - 5	48.3	39.8	37.1	35.8	193	2120	4020	12100	18100
5 - 7		35.5		32.8	75.3	1960	1530	12500	17300
7 - 9		30						12600	

-- Sample was not collected at the indicated sample depth

TABLE 5-7
Summary of Metals Results by Position on Beach
Upper Columbia River RI/FS

Beach/River Mile	Concentration (mg/kg)											
	Black Sand Beach RM 742			**Northport Boat RM 735[a]**			**Dalles Orchard RM 729**			**North Gorge RM 718**		
Position	**Lower**	**Middle**	**Upper**	**Lower**	**Middle**	**Upper**	**Lower**	**Middle**	**Upper**	**Lower**	**Middle**	**Upper**
Analyte												
Antimony	18.6	52.3	47.7	22.93	27.23	21.53	24.8	32.4	11.2	6.4	3.6	--
Arsenic	16.1	25.2	27.3	17.33	14.33	10.67	18.1	22.5	13.7	10.7	9.6	5
Cadmium	1	1.2	1.4	2.99	2.39	2.25	2.1	1.9	2.5	4.2	4.2	1.1
Chromium	101	123	128	68.43	66.20	50.73	71.9	77.6	51.3	24.9	22.8	15.1
Copper	1620	2240	2350	1382	1182	833	1300	1380	802	216	132	22.9
Iron	197000	187000	211000	113367	108233	75267	108000	110000	82100	29500	23500	16000
Lead	276	231	266	309	256	186	205	190	214	216	223	68.8
Manganese	3080	3680	3680	2138	2004	1446	2110	2200	1660	434	270	171
Mercury	0.028	0.03	0.65	0.10	0.10	0.07	0.034	0.044	0.073	0.37	0.4	0.068
Nickel	9.3	12.1	12.4	13.33	13.03	12.80	10.4	12.1	10.4	15.3	17.2	9.6
Uranium	64.8	84.3	81.6	--	--	--	--	--	--	14.2	11.2	5.7
Zinc	14900	15200	16900	9623	8543	5947	8700	8410	6560	1700	1060	352

Beach/River Mile	Marcus Island RM 708			Kettle Falls Swim RM 700[a]			Haag Cove RM 697			French Rocks RM 690		
Position	**Lower**	**Middle**	**Upper**	**Lower**	**Middle**	**Upper**	**Lower**	**Middle**	**Upper**	**Lower**	**Middle**	**Upper**
Analyte												
Antimony	--	2	--	--	--	--	1.8	1.8	--	--	--	--
Arsenic	6.5	8.6	-	1.87	1.27	1.57	2.3	1.4	1	2.6	2.4	2.4
Cadmium	7.3	5.6	1.6	0.26	0.16	0.15	7.8	4.4	0.32	0.45	0.33	0.51
Chromium	19.7	19.9	14	22.93	9.77	9.80	24.8	14.6	5.6	12.7	12.4	12.8
Copper	50.3	57.8	14.1	17.60	9.50	10.13	34	16.5	4.2	13.8	14.5	10.9
Iron	17600	23400	12700	17433	9647	9530	18100	11800	5180	12000	9960	11000
Lead	297	202	52.3	8.9	6.0	5.2	222	136	16.5	21.9	18.7	20.7
Manganese	214	246	170	381	151	177	267	158	111	260	171	208
Mercury	0.81	0.47	0.078	0.01	--	--	0.8	0.29	--	0.03	0.019	--
Nickel	16.3	16.8	12.9	18.73	7.77	7.77	19.7	11.2	4.1	10.9	9.6	15
Uranium	--	6.7	7.5	--	--	--	--	--	--	--	8.4	--
Zinc	915	620	186	55.4	36.2	34.0	700	391	53.8	97.1	67.2	91.8

Beach/River Mile	Cloverleaf Branch RM 675			AA Campground RM 673			Rogers Bar RM 658			Columbia RM 642[a]		
Position	**Lower**	**Middle**	**Upper**	**Lower**	**Middle**	**Upper**	**Lower**	**Middle**	**Upper**	**Lower**	**Middle**	**Upper**
Analyte												
Antimony	1.6	1.1	1	1.1	1.5	1.2	--	--	--	0.79	0.96	1.04
Arsenic	7	3.6	2.3	3.6	5.3	4.1	--	1.9	2.2	4.70	5.40	3.83
Cadmium	2.4	0.63	3.1	1	0.74	0.17	0.056	0.11	0.22	1.63	0.45	0.33
Chromium	28	17.7	19.5	18	24.2	14.8	5.7	13.2	9.6	16.93	14.27	12.13
Copper	28.7	16.1	14.8	14.7	20	12.1	4.9	9	7.4	19.07	11.40	8.70
Iron	22600	15200	13300	16000	21100	14800	4930	9800	9720	16700	15933	14400
Lead	102	15.8	51.1	33.7	19.7	6.7	3.1	5.4	5.1	58.20	18.47	10.57
Manganese	526	194	145	167	383	248	95.3	157	134	283	190	167
Mercury	0.21	0.03	0.062	0.053	0.031	0.01	--	--	--	0.14	0.03	0.02
Nickel	23.8	15.9	14	15.5	21.1	12.8	5.1	10.2	9	14.57	11.77	10.23
Uranium	--	--	--	--	--	--	--	--	--	9.50	--	--
Zinc	295	90.3	220	158	118	48.9	21.3	33	47.4	233.33	142.67	119.90

Beach/River Mile	Lincoln Mill RM 633			Keller Ferry RM 615			Spring Canyon RM 600		
Position	**Lower**	**Middle**	**Upper**	**Lower**	**Middle**	**Upper**	**Lower**	**Middle**	**Upper**
Analyte									
Antimony	--	--	--	--	--	--	--	--	--
Arsenic	5.9	6.7	5.9	4.7	4.9	4	10.3	7.5	8.5
Cadmium	--	--	--	--	--	--	--	--	--
Chromium	6.2	9.1	9.6	12.5	11.2	9.8	9.6	9.7	9
Copper	7.3	10	11.5	9.1	8.6	6.7	7.1	5.5	6.5
Iron	10200	12600	14200	15600	15500	13100	15400	14900	14300
Lead	4.4	4.7	6.2	5.9	6.3	4.5	6.7	7.1	6.1
Manganese	217	224	334	248	230	214	227	208	226
Mercury	--	--	--	--	--	--	--	--	--
Nickel	6.1	7.8	8.5	10.1	9.4	8.5	8.2	7.5	7.5
Uranium	6.3	6.4	6.9	5.4	4.6	--	--	5.2	--
Zinc	26.5	30.1	35.5	39.2	44.2	36.9	48	54.6	39.7

[a] Selected beach and concentrations listed are averages for discrete grab and composite samples.
-- = metal was not detected
mg/kg = milligrams per kilogram

TABLE 5-8
Comparison of Average Concentrations of Metals at Beaches to Metals Concentrations in Nearby Transect Samples
Upper Columbia River RI/FS

Concentration (mg/kg)

Black Sand Beach RM742

	Black Sand Beach Avg	RM739X1	RM740A1(X1)	RM741X1	RM742A1(X1)	RM743A1(X1)	RM744A1(X1)
Antimony	40	23.2 J	6.2 J	21.8 J	19 J	20.7 J	21.2 J
Arsenic	23	14.7	5.2	9.9	6.3	8.7	6.9
Cadmium	1	3	2	1.9	3.4	2	1.5
Chromium	117	64.8 J	21.5	29.2	29.6	28.5	26.4
Copper	2070	1050	181	449	399	356	390
Iron	198333	86400 D	25200	42100	39200	42500	35800
Lead	258	273	118 J	172	182 J	201 J	141
Manganese	3480	1630	429	805	745	616	718
Mercury	0.24	0.12 J	0.14 J	0.095 J	0.16	0.17	0.15
Nickel	11	13	11	9	10.6	11.1	9.7
Uranium	77	6.8 J	9.4 J	19.2 J	25.3 U	25.9 U	11.4 J
Zinc	15667	7240 D	1480	3250	2920	2560	2480

Northport Boat Launch RM735

	Northport Boat Launch Avg	RM733A1(X1)	RM735X1	RM736A1(X1)	RM737X1	RM738X1
Antimony	24	17.4 J	29.1 J	5.1 J	42.9 J	20.2 J
Arsenic	14	6.6	15.9	4.8	30.8	9.5
Cadmium	3	2.9	1.8	4.3	1.2	1.3
Chromium	62	38.6	42.3	20.7	74.5	26.8
Copper	1132	641	650	129	1270	281
Iron	98956	88400 D	53400	27400	109000 D	30900
Lead	250	1390	134	214	196	107
Manganese	1862	2490 J	1130	378	2000	600
Mercury	0.09	0.083 J	0.087 J	0.33 J	0.075 J	0.057 J
Nickel	13	9.5	10	15.1	11.7	12.4
Uranium	-	19.6 U	8.7 U	28.3 U	27	24 U
Zinc	8038	8200 D	4150	1760	9020 D	1900

Dalles Orchard RM 729

	Dalles Orchard Avg	RM726X1	RM727A1(X1)	RM728X1	RM729A1(X1)	RM730X1	RM731X1	RM732X1
Antimony	23	16.2 J	5.6 J	53.9 J	9.9 J	1.1 UR	8.9 J	37.8 J
Arsenic	18	10.6	9.1	20.3	2	2.8 U	8.9	32.6
Cadmium	2	2	3	0.8	1.1	0.52	2.2	0.44 J
Chromium	67	28.5	20.1	84.5	14.5	12.9	20.7	97.4
Copper	1161	369	126	1420	183	26	202	1710
Iron	100033	36500	24900	112000 D	16200	12000	27300 J	159000 JD
Lead	203	130	170	195	68.4	33.6	146	476
Manganese	1990	698	374	2380	371 J	208	443	3100 D
Mercury	0.05	0.2	0.37 J	0.06 J	0.06 J	0.2	0.68	0.099 J
Nickel	11	12.7	12.6	11.3	6.3	9.4	12.4	12.5
Uranium	--	26.9 U	24.5 U	57.6	24.1 U	4.6 J	4.8 J	20.4 UJ
Zinc	7890	2470	1310	9180 J	1250	249	1710	13800 D

North Gorge RM 718

	North Gorge Avg	RM715X1	RM718X1	RM721X1
Antimony	5	2.7 J	2.5 UR	1.3 UR
Arsenic	8	8.9	12.6	4.3
Cadmium	3	5.6	6.7	0.76
Chromium	21	25.9	21.2	15.7
Copper	124	105	61.3	31.8
Iron	23000	24000	24000	13800
Lead	169	275	335	36.6
Manganese	292	315	326	272
Mercury	0.28	1.1	0.59 J	0.032 J
Nickel	14	20.9	19.8	15
Uranium	10	23.2 J	22.7 U	18.3 U
Zinc	1037	971	1180	210

TABLE 5-8
Comparison of Average Concentrations of Metals at Beaches to Metals Concentrations in Nearby Transect Samples
Upper Columbia River RI/FS

Marcus Island RM 708

	Marcus Island Avg	**RM705X1**	**RM706A1(X1)**	**RM707X1**	**RM708X1**	**RM710X1**
Antimony	2	1.8 J	3.8 UJ	0.72 UR	2.4 J	1.4 UR
Arsenic	8	26.2	4.5	8.8	9.4	7.2
Cadmium	5	1.6	3.8	0.54	1.8	4.5
Chromium	18	68.5	21.3	18	21.5	25.2
Copper	41	52.8	78.8	20	48.8	39.9
Iron	17900	30100	18800	18900	20900 J	19000 J
Lead	184	59.9	197	35.9	84.4	171
Manganese	210	534	317	205	347	261
Mercury	0.45	0.14	0.66	0.068 J	0.2	0.46
Nickel	15	52.8	15.5	18.4	18.7	20
Uranium	7	10 J	9.6 J	7.5 J	30.1 UJ	26.3 UJ
Zinc	574	260 J	764	157	351	392

Kettle Falls Swim RM 700

	Kettle Falls Avg	**RM698A1(X1)**	**RM701X1**
Antimony	--	3.5 J	6.5 UR
Arsenic	2	7.9	1.8
Cadmium	0	5.3	0.29 J
Chromium	14	34.9	9.8
Copper	12	164	13.4
Iron	12203	29800	9350
Lead	7	309	9.6
Manganese	236	417	171
Mercury	0.01	0.87	0.005 J
Nickel	11	25.3	8.1
Uranium	--	11.5 J	21.6 UJ
Zinc	42	954	45.4

Haag Cove RM 697

	Haag Cove Avg	RM695X3	RM698X3
Antimony	2	5.8 UJ	6.8 UR
Arsenic	2	1.7	1.2
Cadmium	4	0.26 J	0.13 J
Chromium	15	9.7	5.5
Copper	18	7.5	4.5
Iron	11693	8020	5550
Lead	125	13.7	2.6
Manganese	179	123	137
Mercury	0.55	0.0099 J	0.12 U
Nickel	12	7.3	4.1 J
Uranium	--	19.3 U	22.6 UJ
Zinc	382	56.1 J	16

French Rocks RM 690

	French Rocks Avg	**RM689A1(X3)**
Antimony		7.4 UJ
Arsenic	2	2.1
Cadmium	0.43	0.13 J
Chromium	13	16.9
Copper	13	14.7
Iron	10987	15000
Lead	20	12.3
Manganese	213	319
Mercury	0.02	0.034 J
Nickel	12	15.1
Uranium	8	24.8 U
Zinc	85	62.6

TABLE 5-8
Comparison of Average Concentrations of Metals at Beaches to Metals Concentrations in Nearby Transect Samples
Upper Columbia River RI/FS

Cloverleaf Branch RM 675

	Cloverleaf Branch Avg	RM676X1	RM677X1
Antimony	1.2	0.49 UR	1.2 UR
Arsenic	4	2.6 U	7.4
Cadmium	2	0.14 J	0.12 J
Chromium	22	8.4	20.3
Copper	20	7.6	19.8
Iron	17033	7690	16800
Lead	56	3	7.9
Manganese	288	126	245
Mercury	0.10	0.1 U	0.11 U
Nickel	18	7.7	22.2
Uranium	--	20.5 U	6.4 U
Zinc	202	25.9	41.6

AA Campground RM 673

	AA Campground Avg	RM670X3	RM673X3
Antimony	1.3	1.2 UJ	6.4 UR
Arsenic	4	2.4	4.2
Cadmium	0.6	0.26 J	0.12 J
Chromium	19	16.6	22.9
Copper	16	11.1	18.4
Iron	17300	14600	17900
Lead	20	9.6	6
Manganese	266	183	333
Mercury	0.03	0.007 J	0.017 J
Nickel	16	12.3	20.1
Uranium	--	11.6 J	21.5 U
Zinc	108	58.5	40.3

Rogers Bar RM 658

	Rogers Bar Avg	RM655X3	RM658A1(X3)	RM661X3
Antimony	--	6 UR	7.7 UR	0.91 UJ
Arsenic	2	11.2	5	7.7
Cadmium	0.13	0.5 U	0.41 J	0.48 U
Chromium	10	19.1	30.5	38.9
Copper	7	15.8	23.1	28.2
Iron	8150	19600	23400	22600
Lead	5	10	19.4 J	8.9
Manganese	129	320	563	391
Mercury	--	0.006 J	0.015 J	0.012 J
Nickel	8	18.5	27.4	35.5
Uranium	--	9.6 J	25.6 UJ	8.6 J
Zinc	34	44.6	88.6	62.3

Columbia RM 642

	Columbia Campground Avg	RM641A1(X1)	RM642A1(X1)	RM643X1	RM644X1
Antimony	0.93	11.3 UR	7.3 UR	5.1 UR	5.6 UJ
Arsenic	5	3.4	4.1	0.76 U	7.6
Cadmium	0.80	2.4	2.1	0.2 J	0.52
Chromium	14	24.1	17.9	8.4	8.6
Copper	13	28	19.9	9.5	9.4
Iron	15678	20500	16900	26600	27500
Lead	29	67.7 J	82.4 J	9.6	12
Manganese	214	379	314	516	610 J
Mercury	0.06	0.34	0.23	0.012 J	0.1 UR
Nickel	12	20.5	14.8	6.6	6.1
Uranium	10	37.7 UJ	24.3 UJ	17 U	18.7 U
Zinc	165	355	292	83.1	83.2

TABLE 5-8

Comparison of Average Concentrations of Metals at Beaches to Metals Concentrations in Nearby Transect Samples

Upper Columbia River RI/FS

Lincoln Mill RM 633

	Lincoln Mill Avg	RM631X1
Antimony	--	5.8 UR
Arsenic	6	6.3
Cadmium	--	0.48 U
Chromium	8	8.2
Copper	10	7.3
Iron	12333	13800
Lead	5	5.2
Manganese	258	254
Mercury	--	0.096 U
Nickel	7	7.1
Uranium	7	19.2 U
Zinc	31	38.8

Keller Ferry RM 615

	Kellers Ferry Avg	RM613X1	RM616X1
Antimony	--	6.3 UR	7.8 UR
Arsenic	5	14.6	3.9
Cadmium	--	0.53 U	0.64 J
Chromium	11	17.2	16.9
Copper	8	16.4	20.1
Iron	14733	21700	20000
Lead	6	12.1	13.9
Manganese	231	444	324
Mercury	--	0.005 J	0.026 U
Nickel	9	15.8	15.1
Uranium	5	21.1 U	26.1 UJ
Zinc	40	60.5	101 J

Spring Canyon RM 600

	Spring Canyon Avg	RM600X1	RM603A1(X1)
Antimony	--	5.3 UR	5.6 UR
Arsenic	9	5.2	6
Cadmium	--	0.038 J	0.23 J
Chromium	9	9.9	14
Copper	6	9.6	11.8
Iron	14867	14200	24900
Lead	7	5.3	11.1
Manganese	220	277	457
Mercury	--	0.009 U	0.017 J
Nickel	8	8.8	12.7
Uranium	5	17.6 UJ	18.6 U
Zinc	47	38.8 J	94.2

-- = metal was not detected
mg/kg = milligrams per kilogram
U = analyte was not detected
J = estimated value
D = dilution
UJ = analyte was not detected, reporting limit estimated
UR = analyte was not detected, reporting limit rejected

TABLE 5-9

Concentrations of 2,3,7,8-TCDF in Composite Beach Samples by Position on Beach

Upper Columbia River RI/FS

Beach	River Mile	2,3,7,8-Tetrachlorodibenzofuran (pg/g)		
		Lower	Middle	Upper
Spring Canyon Campground	600	0.204 U	0.0952 U	0.101 U
Keller Ferry No. 2	615	0.0961 U	0.161 U	0.0917 U
Lincoln Mill Boat Launch	633	0.0725 U	0.0569 U	0.106 U
Columbia Campground	642	3.99	0.677	0.311 J
Rogers Bar Campground	658	0.12 U	0.0665 U	0.104 U
AA Campground	673	1.2	0.778	0.0843 U
Cloverleaf Beach	675	1.93	0.718	1.42
French Rocks Boat Launch	690	1.45	1.19	0.649
Haag Cove	697	16.1	8.7	0.295 J
Kettle Falls Swim Beach	700	0.0817 U	0.0777 U	0.0723 J
Marcus Island Campground	708	23.7	18.4	1.15
North Gorge Campground	718	14.2	15.4	3.85
Dalles Orchard	729	0.564	0.575	0.67
Northport City Boat Launch	735	0.774	0.571	0.751
Black Sand Beach	742	0.235 J	0.428	0.36

U = not detected
J = estimated value
pg/g - picograms per gram (parts per trillion)

TABLE 5-10

Vertical Distribution of 2,3,7,8-TCDF in Core Samples

Upper Columbia River RI/FS

	2,3,7,8-TCDF Concentration (pg/g)				
Depth (ft)	**RM 605 Core**	**RM 637 Core**	**RM 661 Core**	**RM 692 Core**	**RM 704 Core**
0 - 0.5	NS	52.5	17.4	28	0.44
0 - 1	27	19.5	18.5	14.4	0.451
1 - 3	0.143	0.204	1.45	52.3	0.419
3 - 5	ND	0.0759	0.15	4.04	0.45
5 - 7	NS	NS	ND	3.66	0.446
7 - 9	NS	NS	NS	NS	0.402

ft = feet

pg/g = picograms per gram

TABLE 5-11

Distribution of 2,3,7,8-TCDF in Size-Fractionated Beach Samples

Upper Columbia River RI/FS

Beach	**Sample**	**Fraction**	**Result**	**Qual**	**Unit**
Columbia Campground	RM642BSF	<75 um	3.97		PG/G
	RM642BSF	>75 um	1.24		PG/G
	RM642BSF	whole	1.43		PG/G
Kettle Falls Swim Beach	RM700BSF	<75 um	0.263	J	PG/G
	RM700BSF	>75 um	0.12	J	PG/G
	RM700BSF	whole	0.0839	U	PG/G
Northport City Boat Launch	RM735BSF	<75 um	1.61		PG/G
	RM735BSF	>75 um	0.745	J	PG/G
	RM735BSF	whole	0.77		PG/G

um = micrometer

pg/g = picograms per gram

FIGURE 5-1
Lake Roosevelt Water Elevations
Upper Columbia River RI/FS

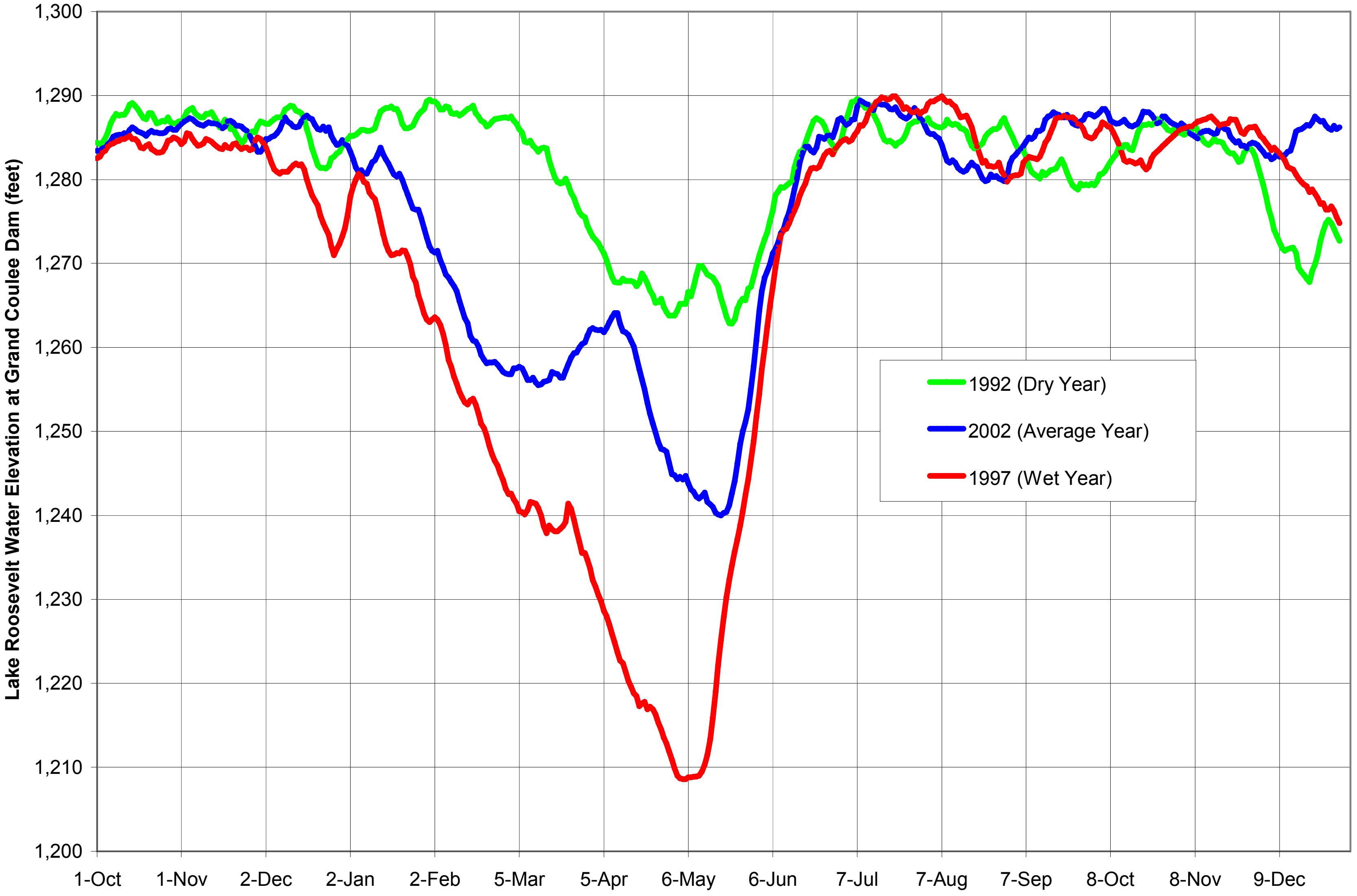

FIGURE 5-2

Percent Time When Lake Roosevelt Water Elevations are at or Below Indicated Levels (7/1/1940 – 8/4/2004)

Upper Columbia River RI/FS

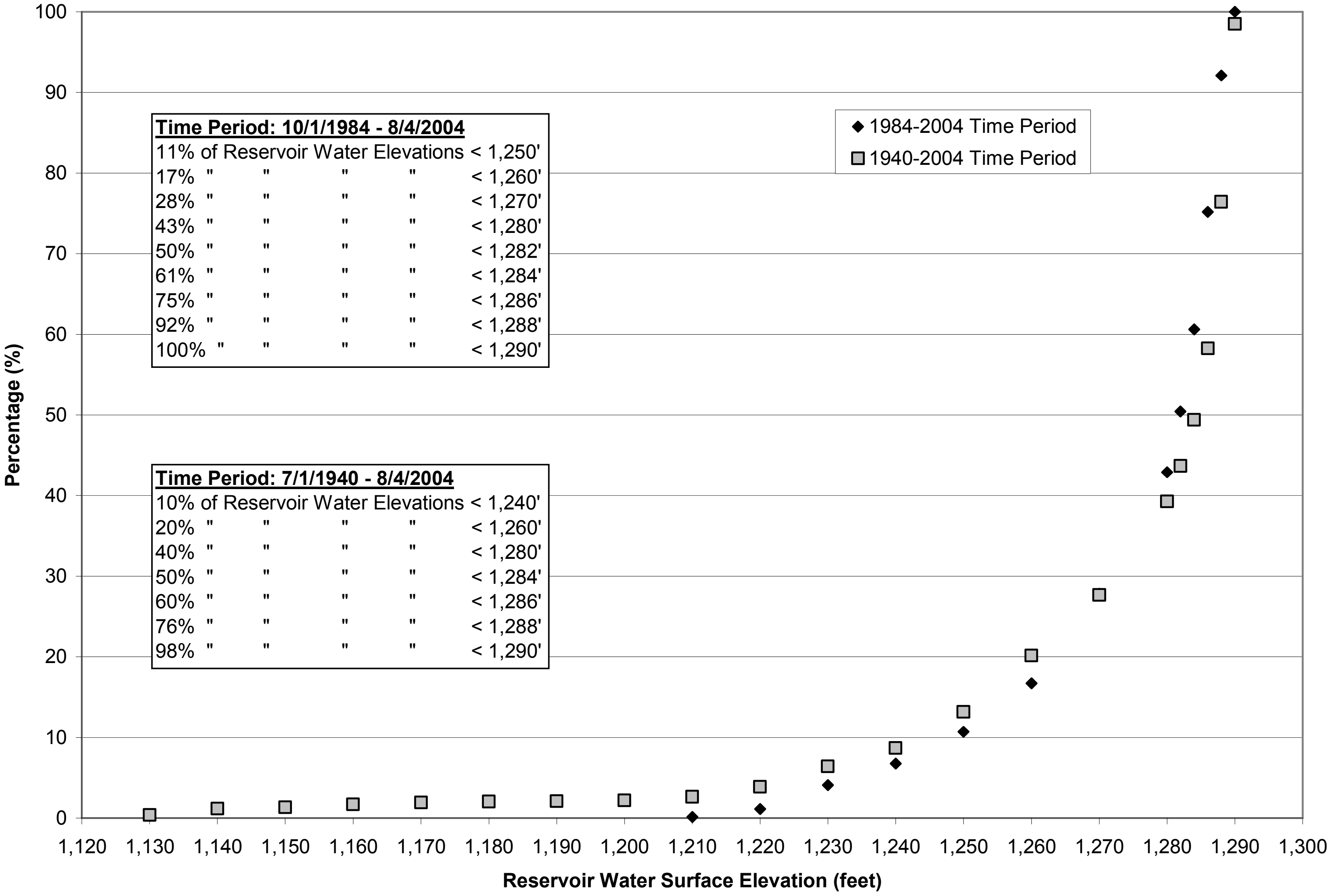

FIGURE 5-3

Columbia River Daily Mean Streamflow and Lake Roosevelt Water Surface Elevation for Water Year 1997 (October 1, 1996 – September 30, 1997)

Upper Columbia River RI/FS

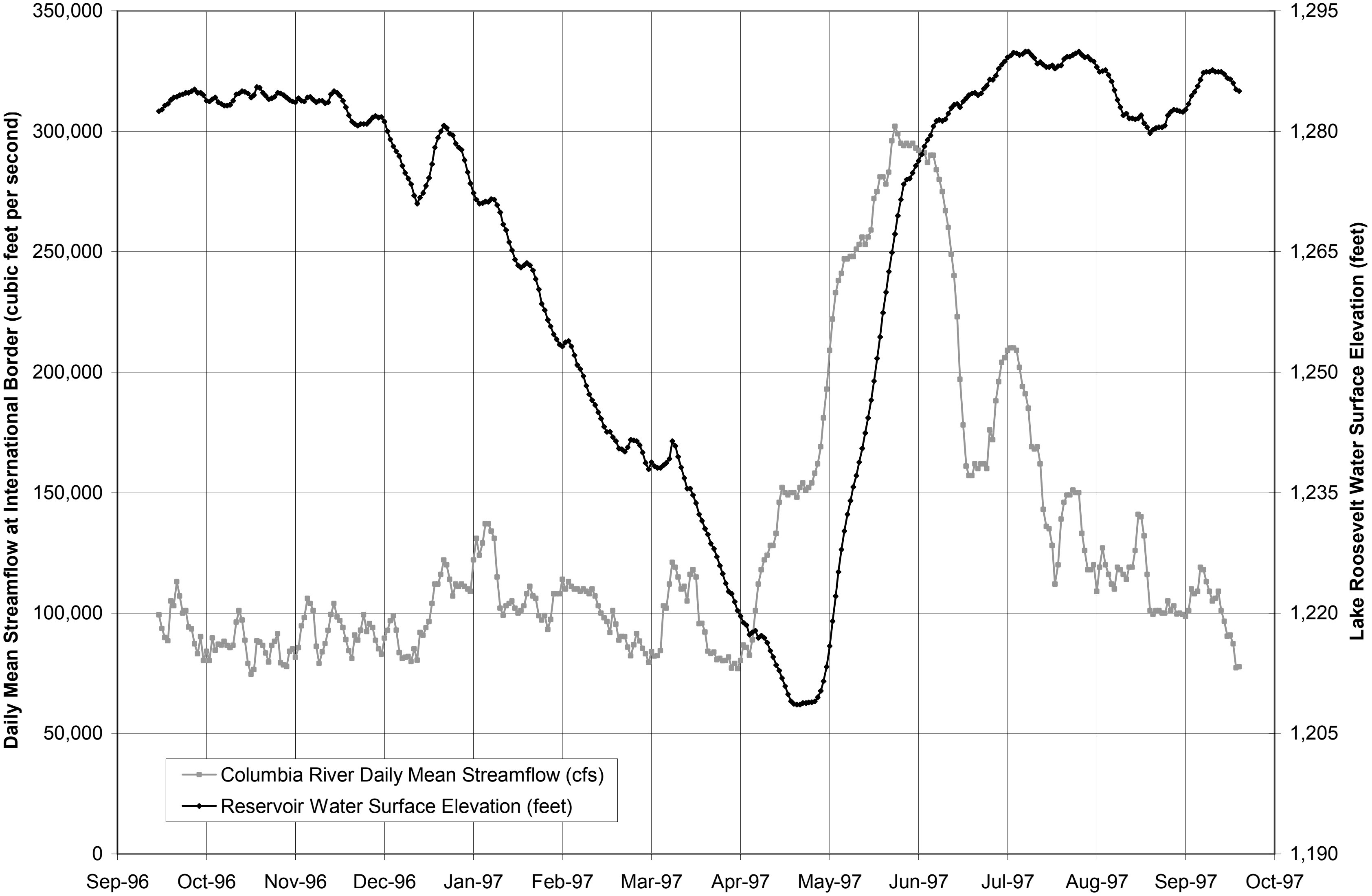

FIGURE 5-4

Highest Columbia River Flow at the International Border at Various 10-Foot Range Reservoir Water Levels

Upper Columbia River RI/FS

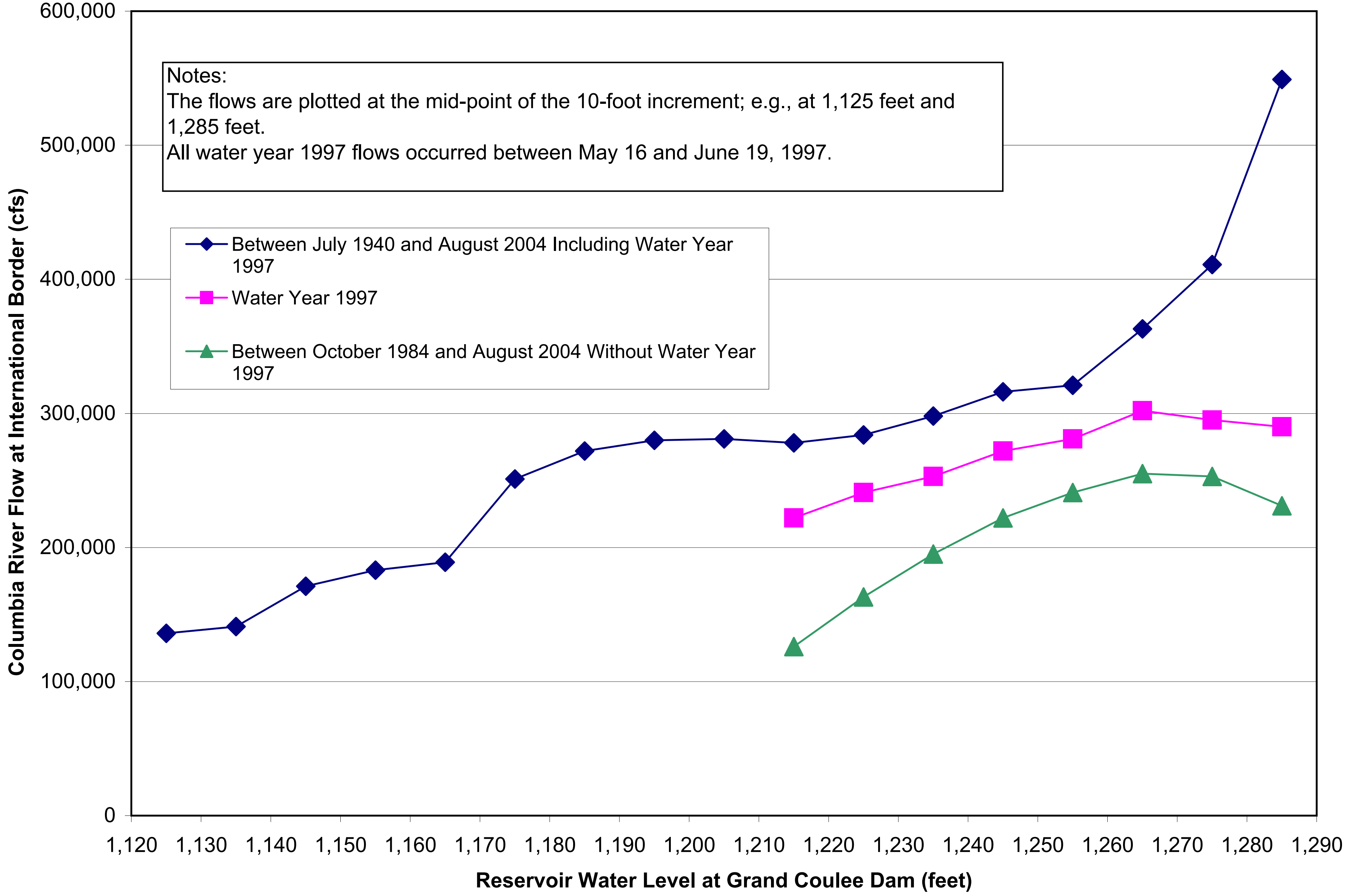

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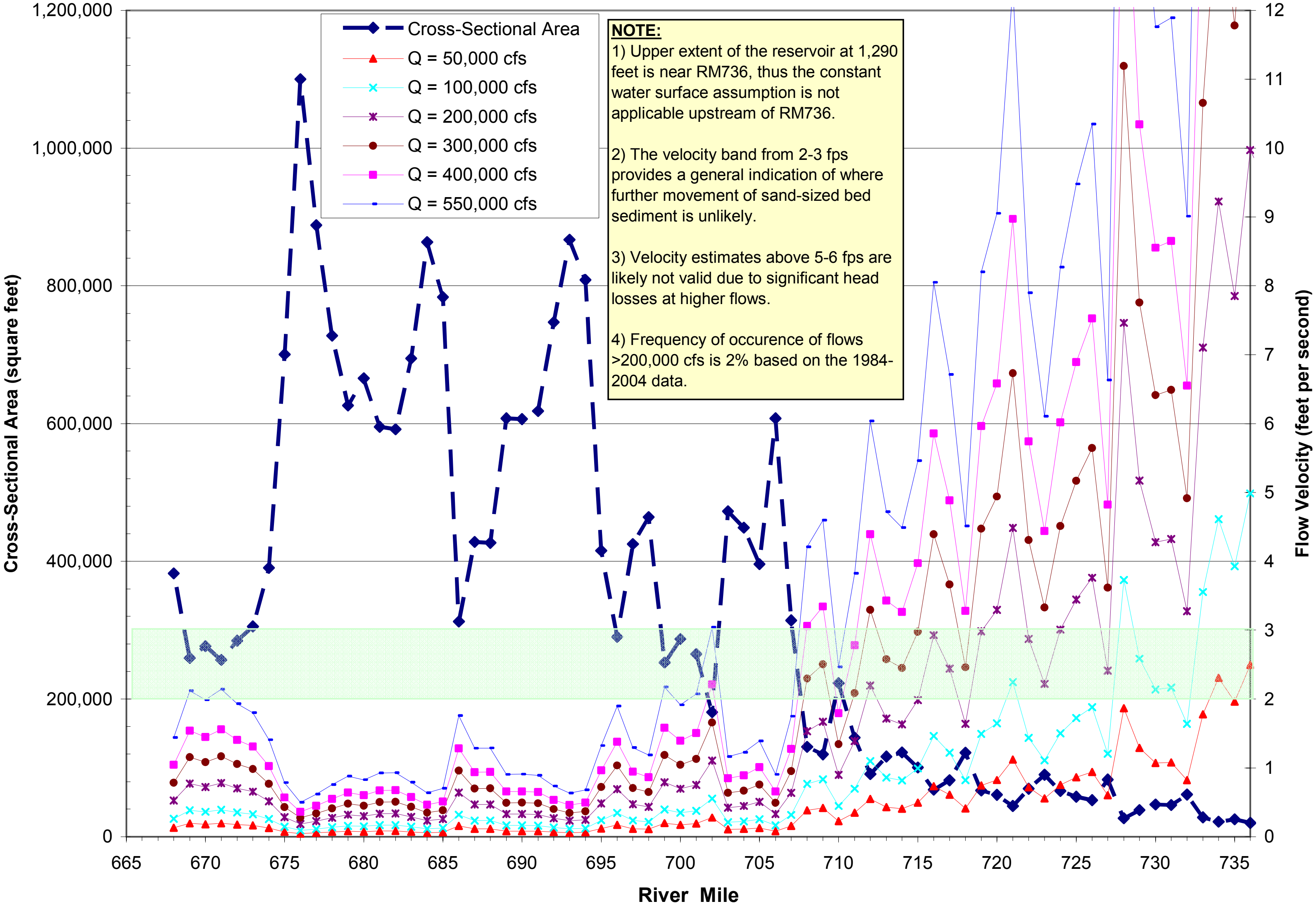
FIGURE 5-5

Cross-Sectional Flow Velocity Estimates at Each River Mile (pool elevation at 1,290 feet)

Upper Columbia River RI/FS



NOTE:

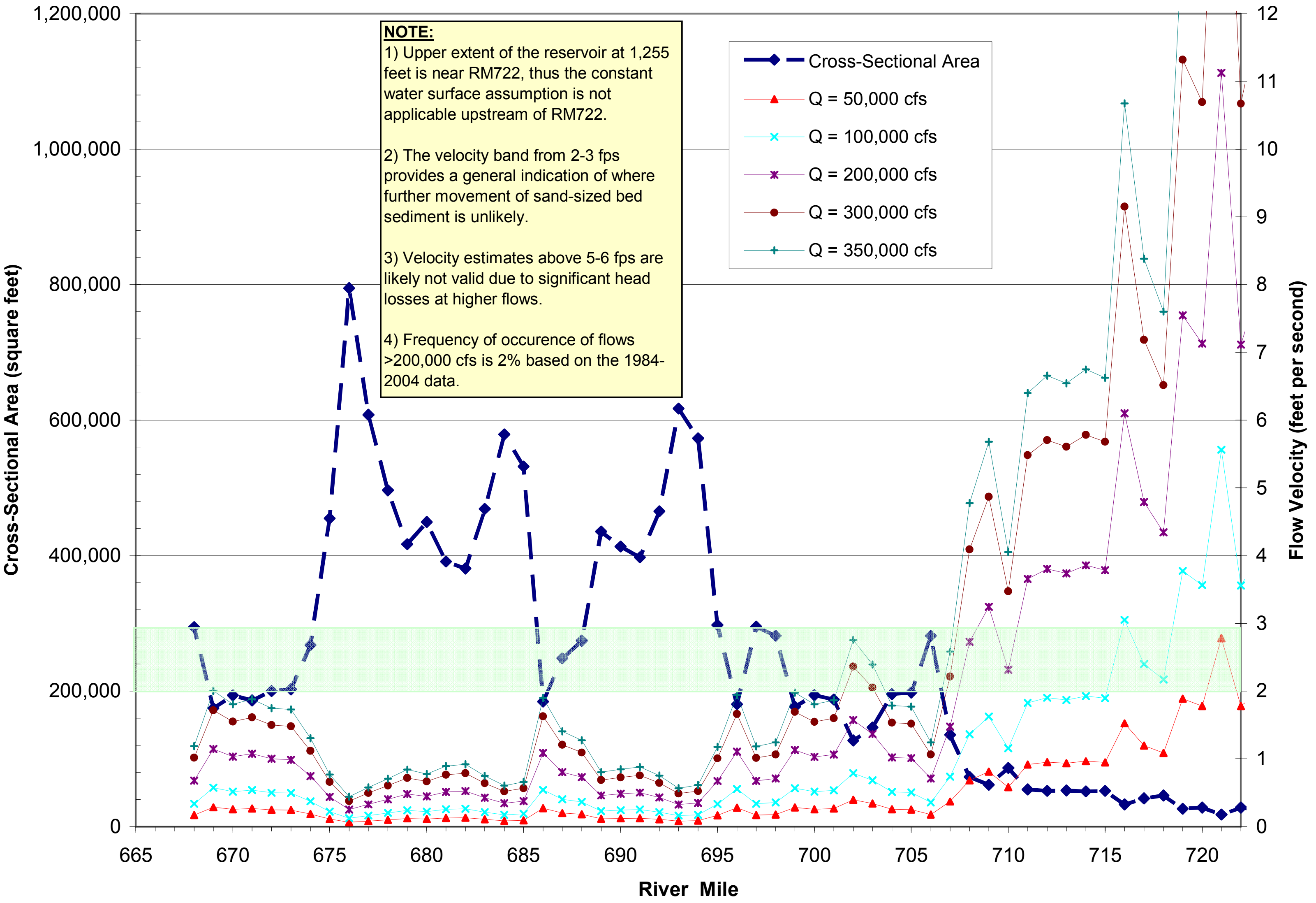
1) Upper extent of the reservoir at 1,290 feet is near RM736, thus the constant water surface assumption is not applicable upstream of RM736.

2) The velocity band from 2-3 fps provides a general indication of where further movement of sand-sized bed sediment is unlikely.

3) Velocity estimates above 5-6 fps are likely not valid due to significant head losses at higher flows.

4) Frequency of occurence of flows >200,000 cfs is 2% based on the 1984-2004 data.

FIGURE 5-6
Cross-Sectional Flow Velocity Estimates at Each River Mile (pool elevation at 1,255 feet)
Upper Columbia River RI/FS


NOTE:
1) Upper extent of the reservoir at 1,255 feet is near RM722, thus the constant water surface assumption is not applicable upstream of RM722.

2) The velocity band from 2-3 fps provides a general indication of where further movement of sand-sized bed sediment is unlikely.

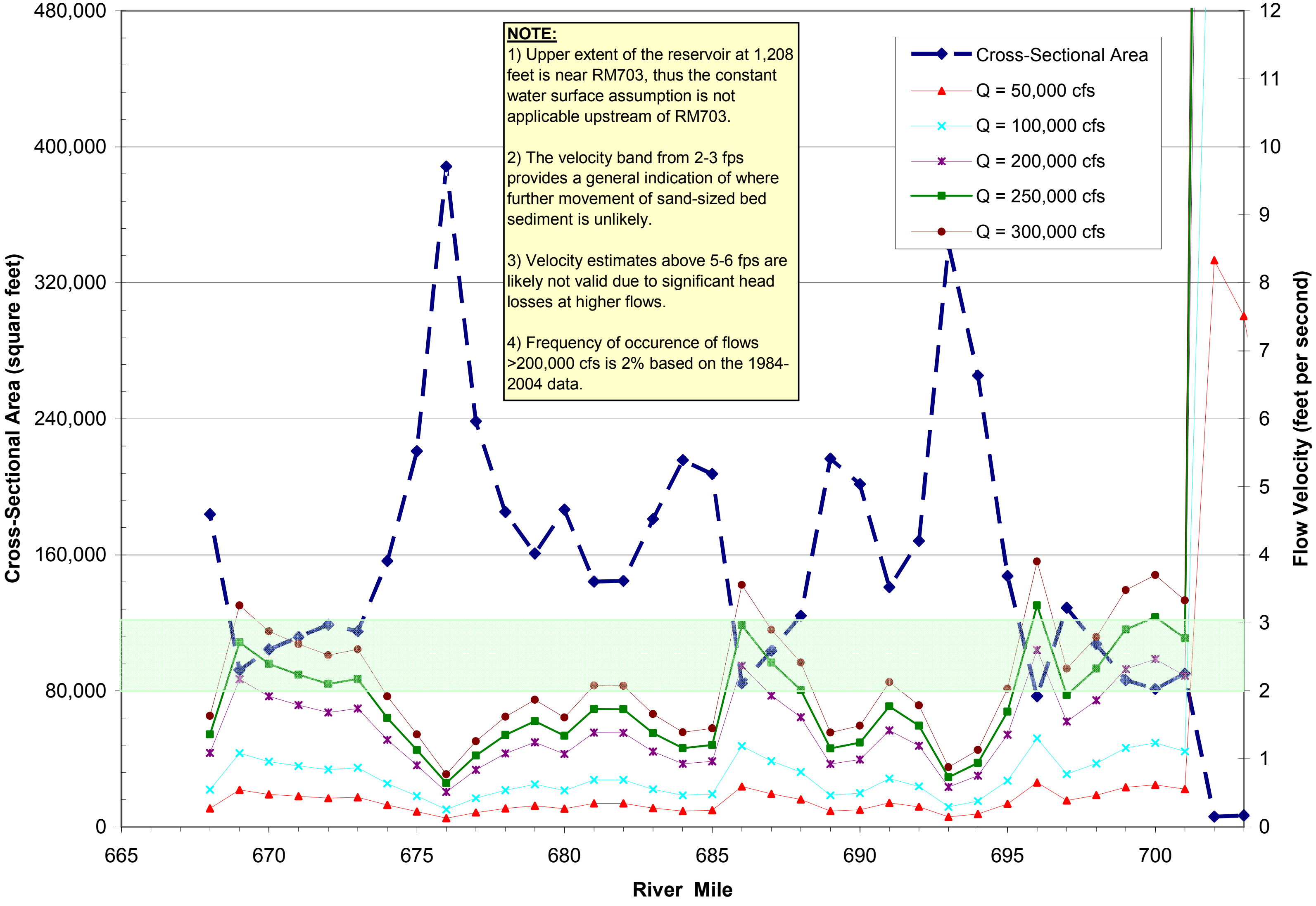
3) Velocity estimates above 5-6 fps are likely not valid due to significant head losses at higher flows.

4) Frequency of occurence of flows >200,000 cfs is 2% based on the 1984-2004 data.

FIGURE 5-7

Cross-Sectional Flow Velocity Estimates at Each River Mile (pool elevation at 1,208 feet)

Upper Columbia River RI/FS



NOTE:

1) Upper extent of the reservoir at 1,208 feet is near RM703, thus the constant water surface assumption is not applicable upstream of RM703.

2) The velocity band from 2-3 fps provides a general indication of where further movement of sand-sized bed sediment is unlikely.

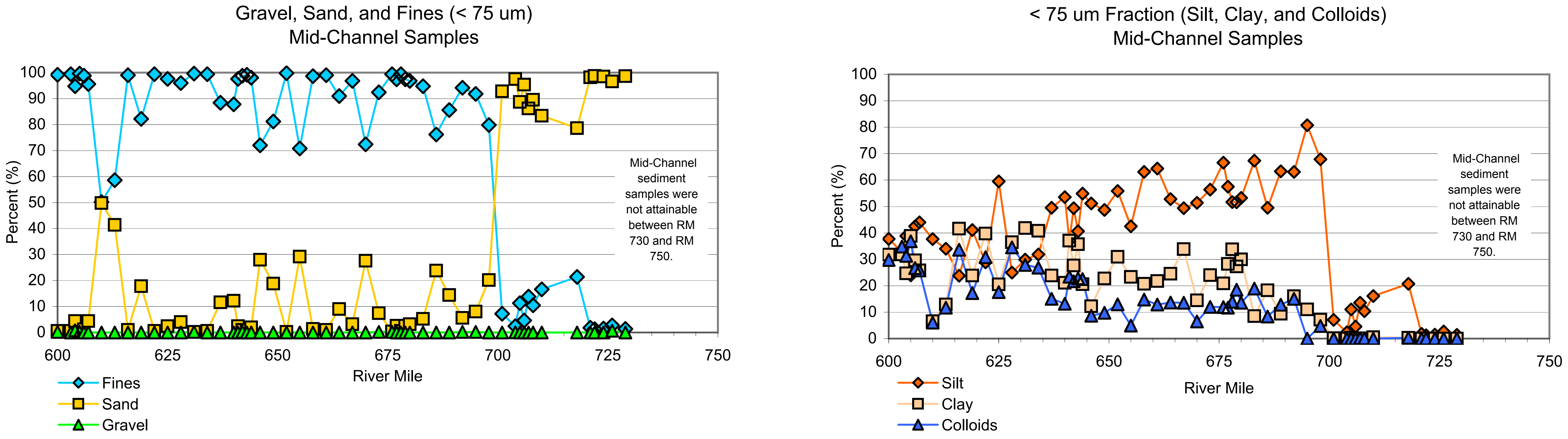
3) Velocity estimates above 5-6 fps are likely not valid due to significant head losses at higher flows.

4) Frequency of occurence of flows >200,000 cfs is 2% based on the 1984-2004 data.

Figure 5-8

Distributions of Gravel, Sand, and Finer Grained Sediment in Mid-Channel, Left-Bank, and Right-Bank Sediment Samples - 2005 Phase I Sediment Samples

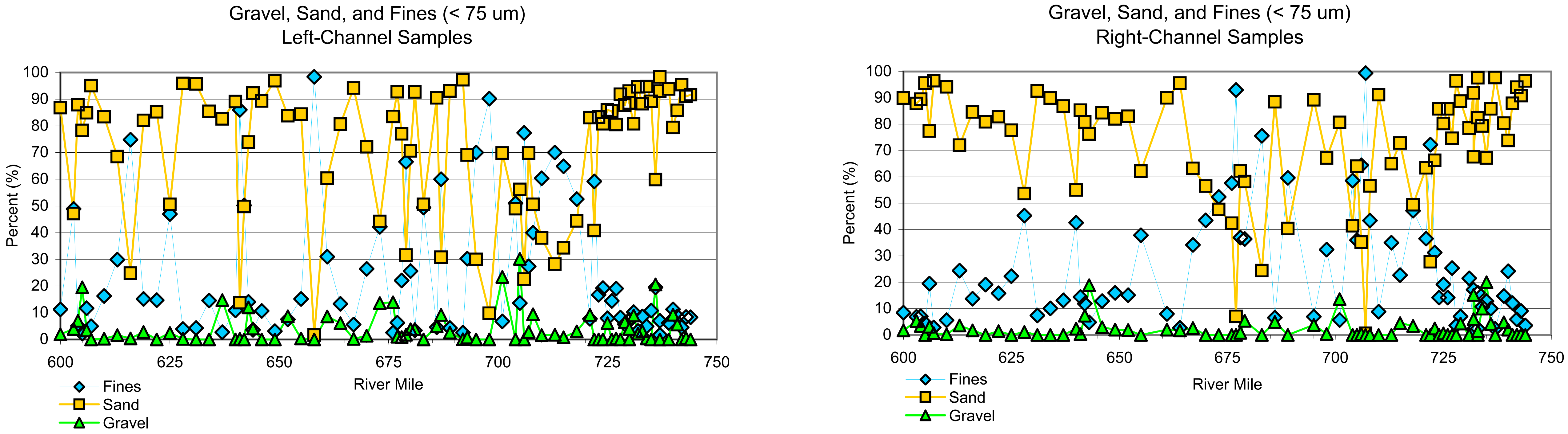
Upper Columbia River RI/FS


Gravel, Sand, and Fines (< 75 um)
Mid-Channel Samples

Mid-Channel sediment samples were not attainable between RM 730 and RM 750.

< 75 um Fraction (Silt, Clay, and Colloids)
Mid-Channel Samples

Mid-Channel sediment samples were not attainable between RM 730 and RM 750.


Gravel, Sand, and Fines (< 75 um)
Left-Channel Samples

Gravel, Sand, and Fines (< 75 um)
Right-Channel Samples

UCR_Sediment_DE_Figure_5-8_REV.xls

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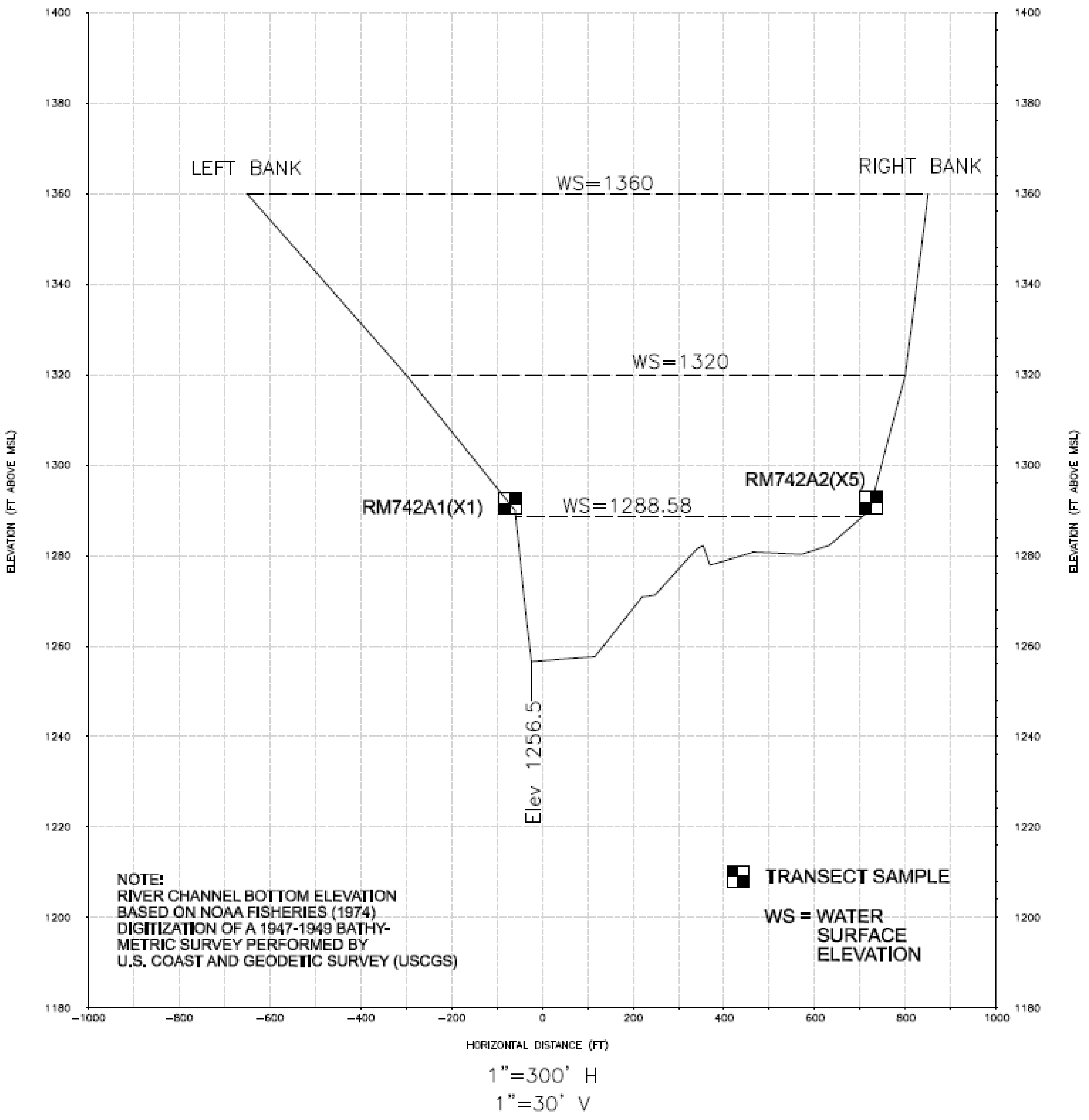


Figure 5-9
Channel Cross-Section and Sampling Locations at RM 742
Upper Columbia River RI/FS

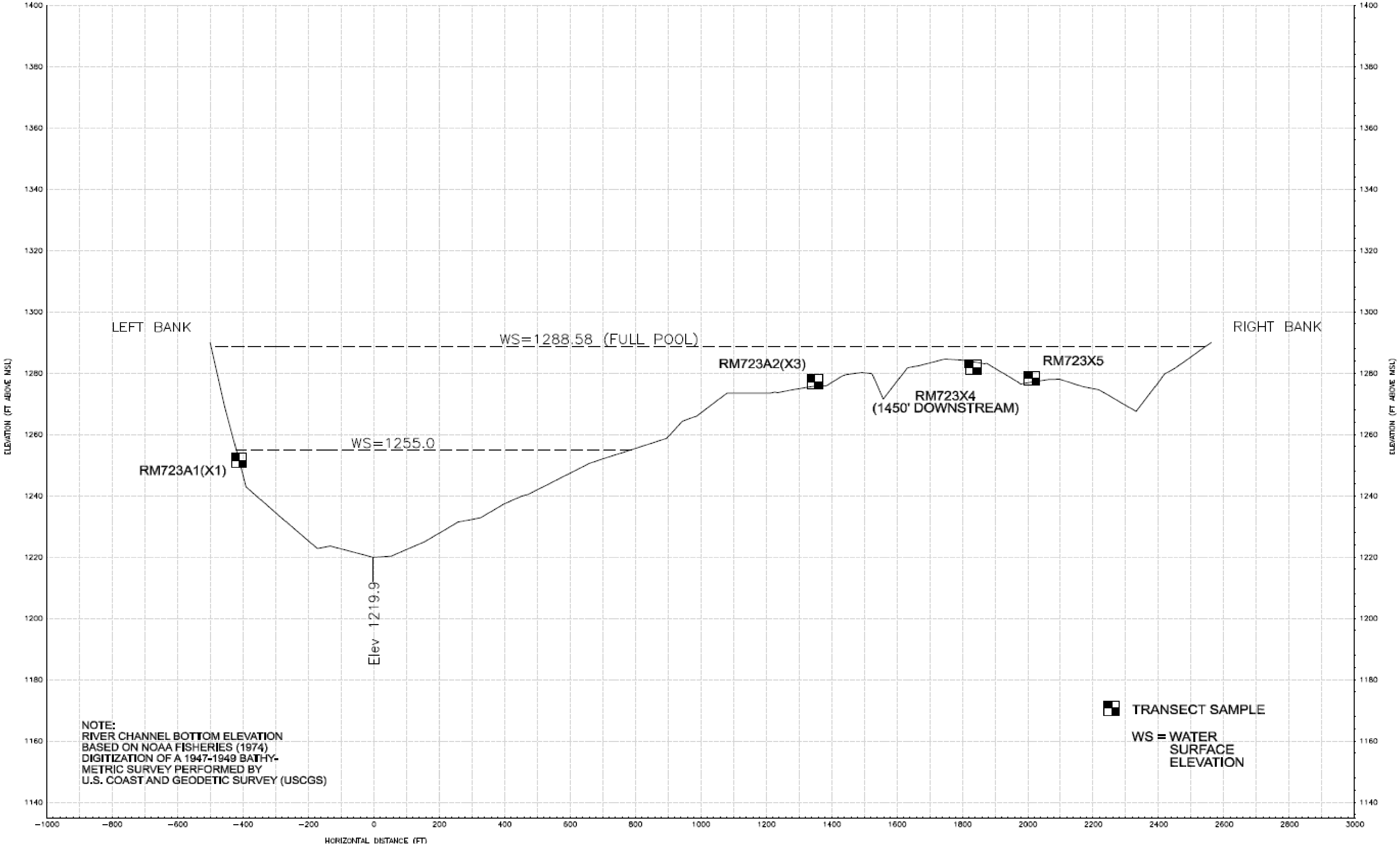


Figure 5-10
Channel Cross-Section and Sampling Locations at RM 723
Upper Columbia River RI/FS

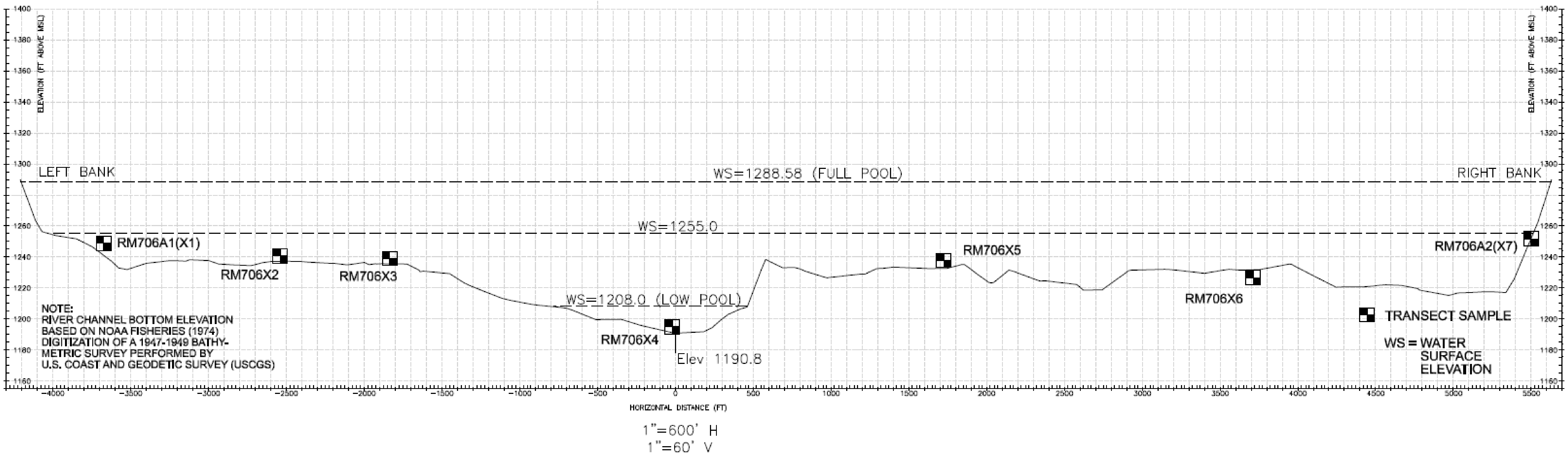


Figure 5-11
Channel Cross-Section and Sampling Locations at RM 706
Upper Columbia River RI/FS

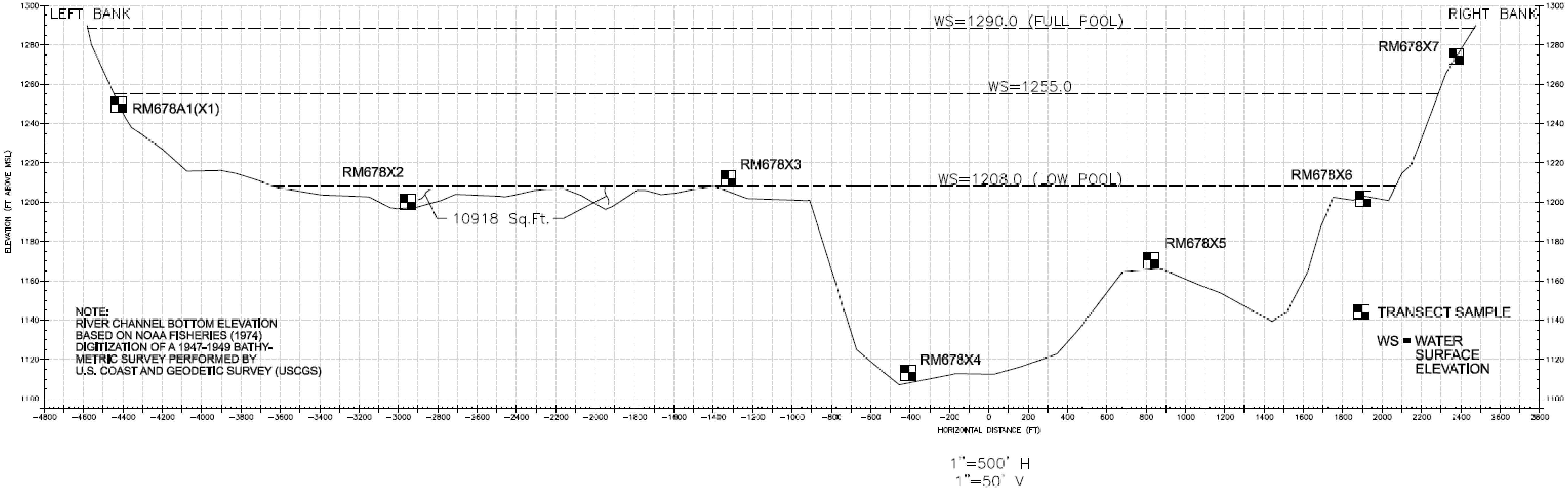


Figure 5-12
Channel Cross-Section and Sampling Locations at RM 678
Upper Columbia River RI/FS

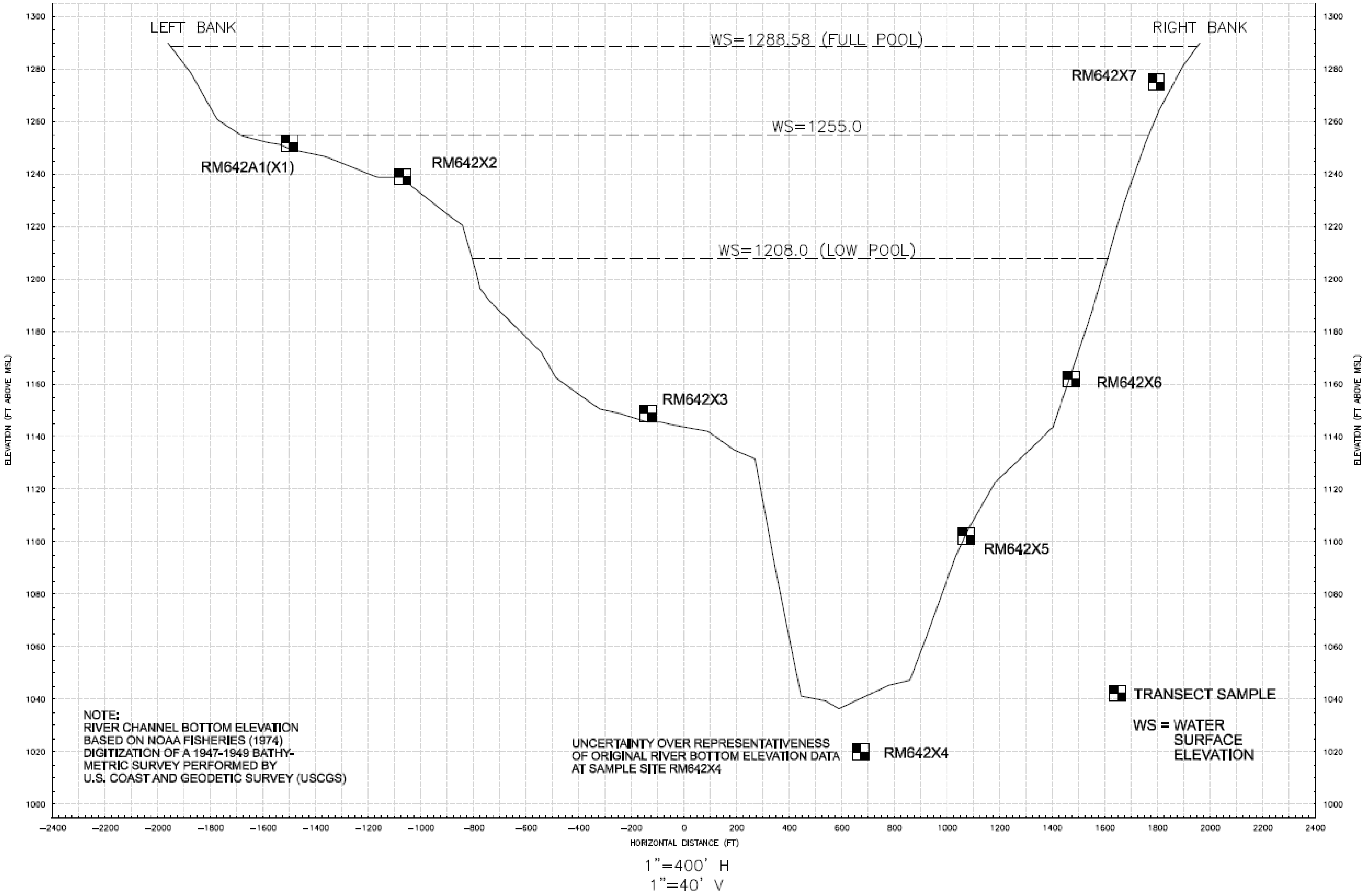


Figure 5-13
Channel Cross-Section and Sampling Locations at RM 642
Upper Columbia River RI/FS

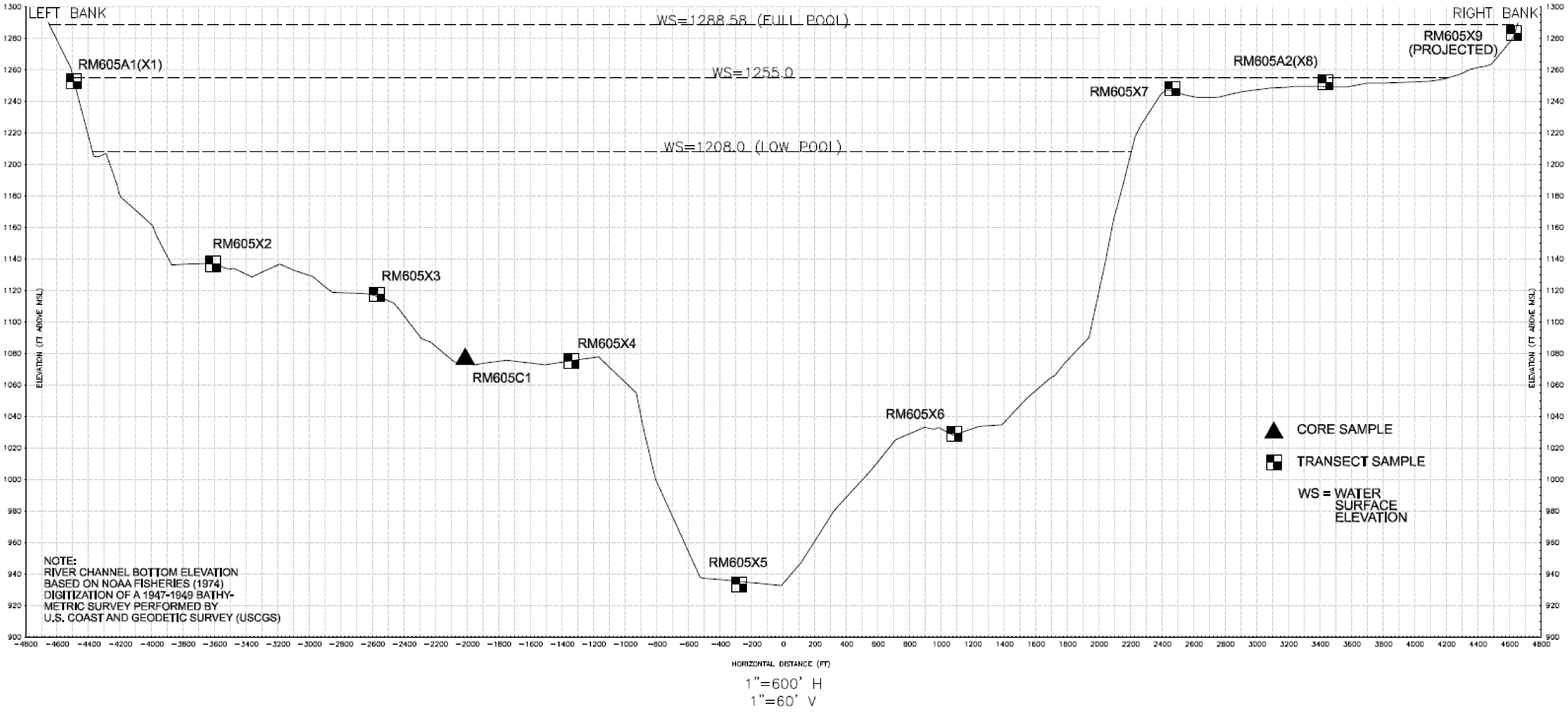


Figure 5-14
Channel Cross-Section and Sampling Locations at RM 605
Upper Columbia River RI/FS

FIGURE 5-15
Transverse Distributions of Grain Size and Elevation, River Miles 706, 678, and 605 - Phase I Surface Sediment Samples
Upper Columbia River RI/FS

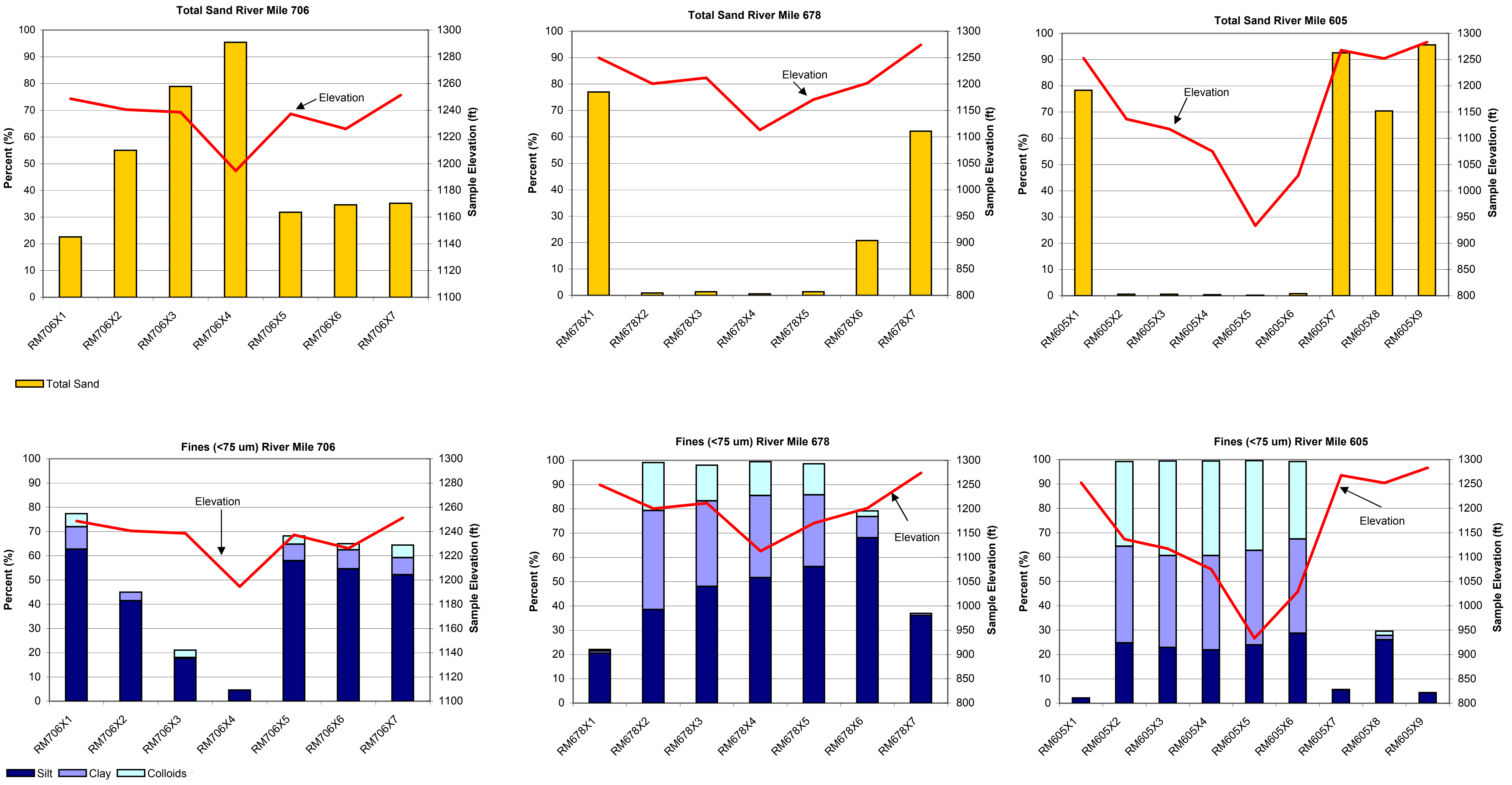
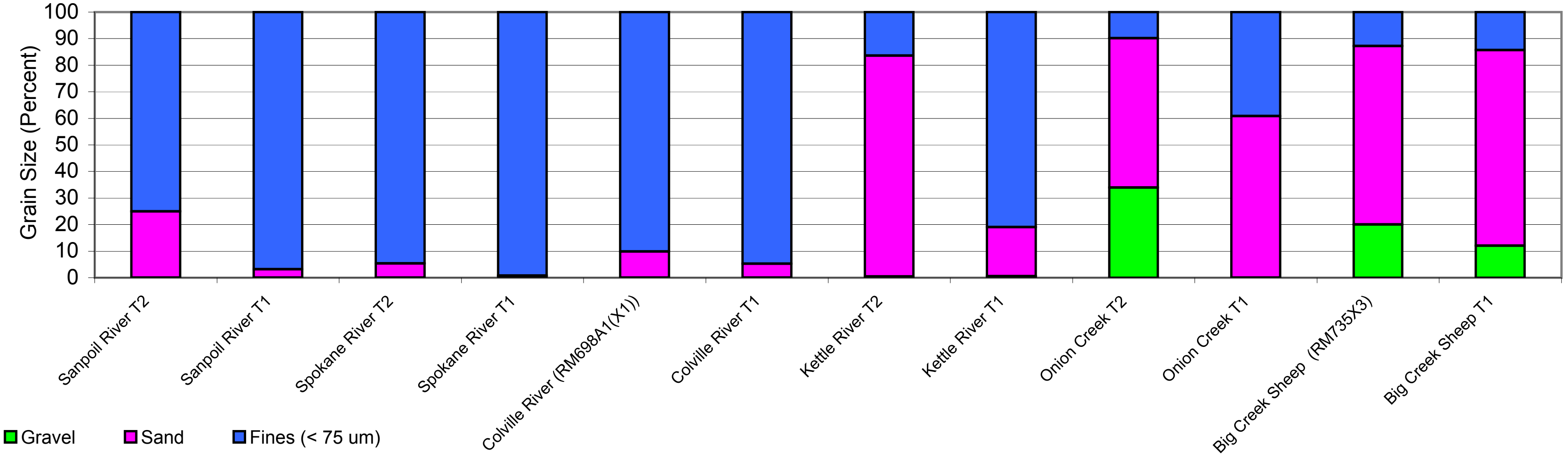


FIGURE 5-16
Comparison of Tributary Sample Particle Size Distributions - Phase I Surface Sediment Samples
Upper Columbia River RI/FS

Gravel, Sands, and Fines



Silt, Clay, and Colloids

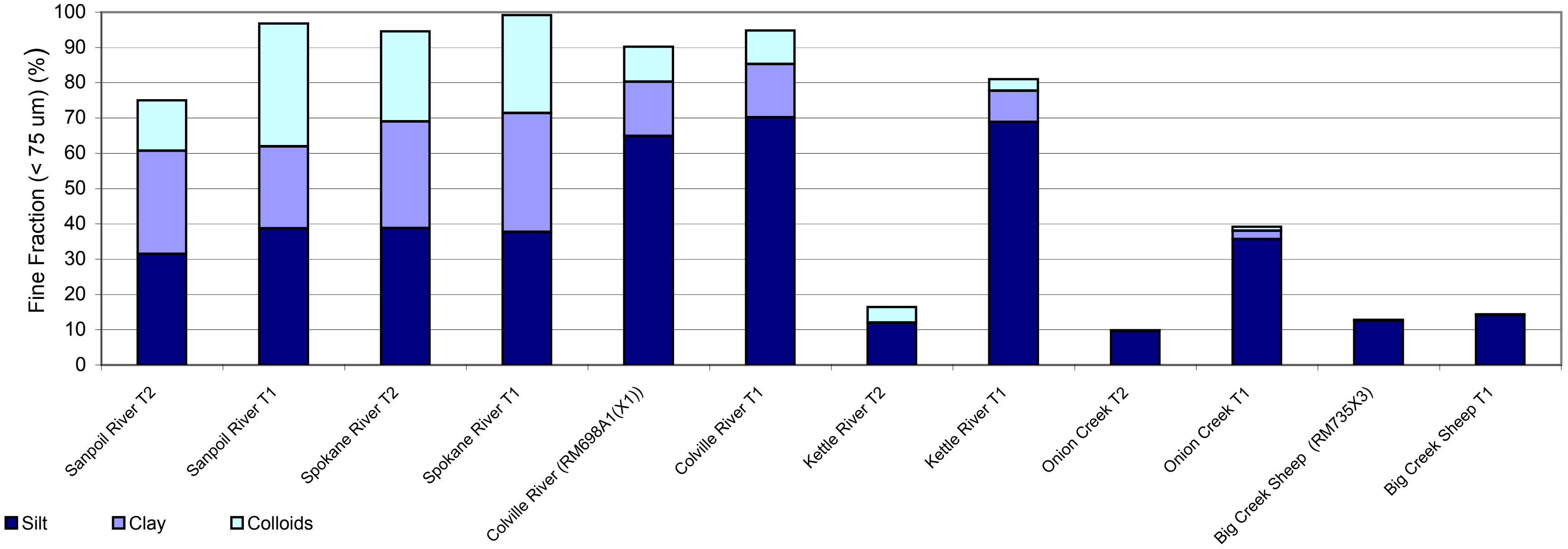


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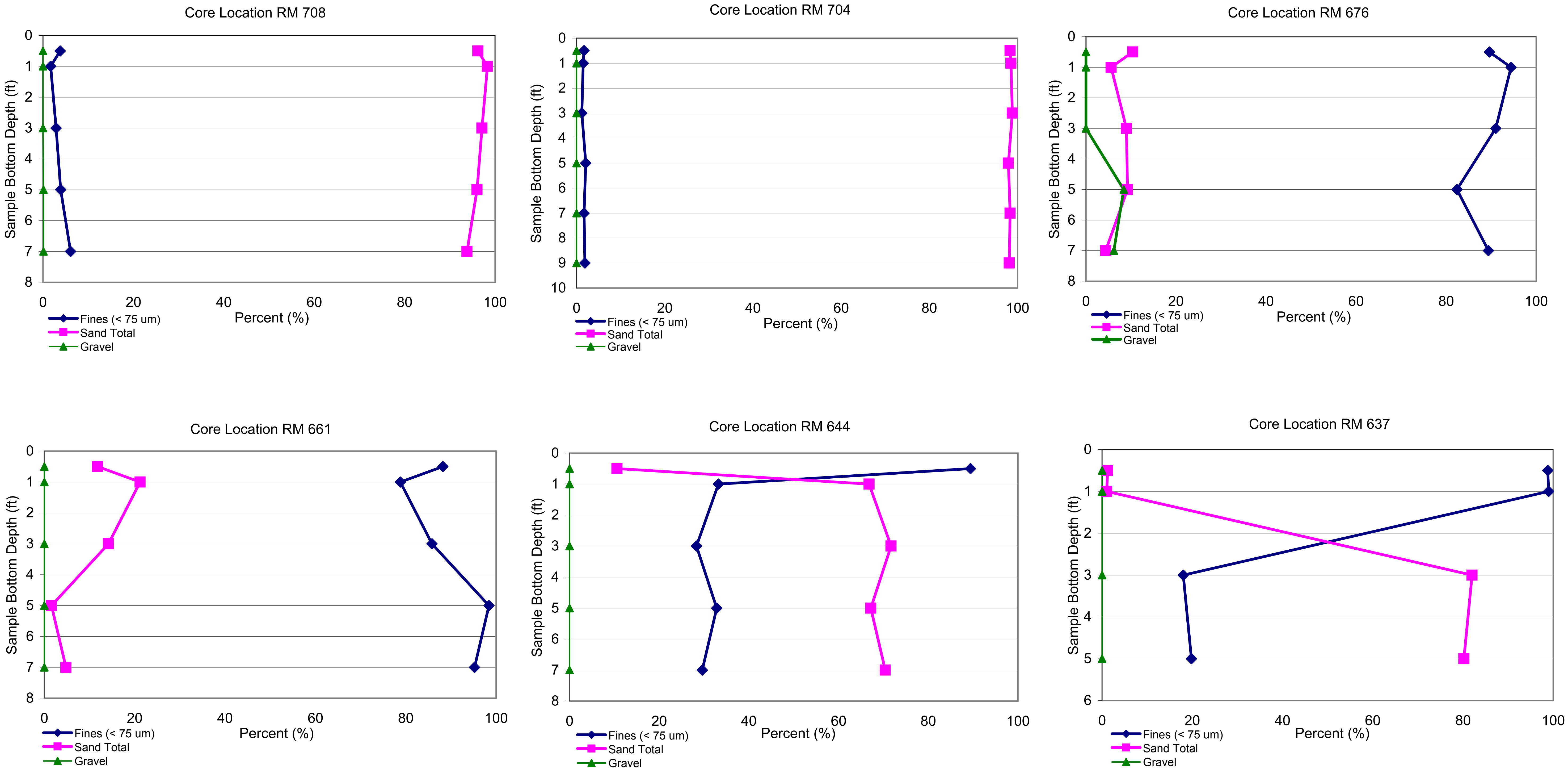
FIGURE 5-17
Grain Size Distributions in Core Samples Collected at RM 708, 704, 676, 661, 644, and 637 - 2005 Phase I Sediment Core Samples
Upper Columbia River RI/FS



UCR_Sediment_DE_Figure_5-17_REV.xls

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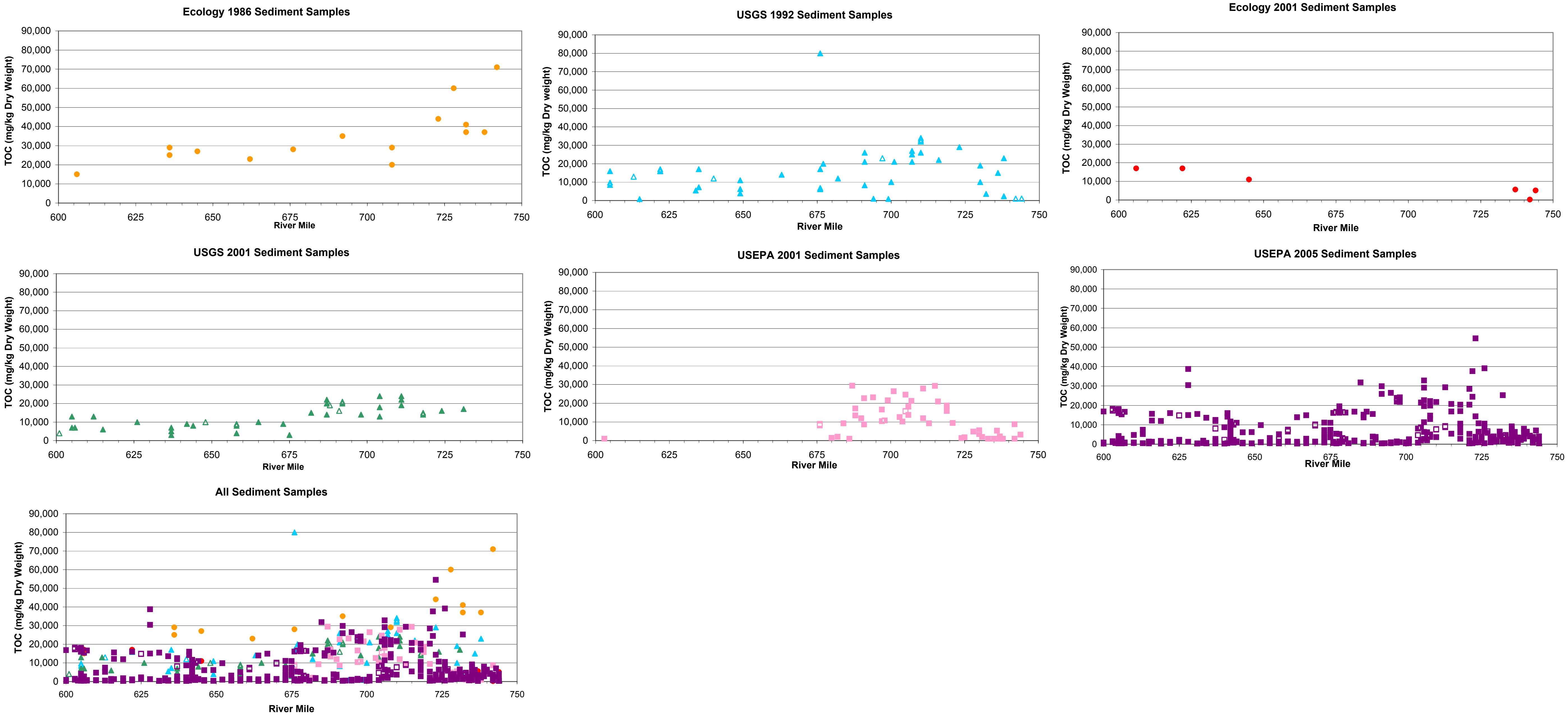
FIGURE 5-18
Distributions of TOC by Investigation
Upper Columbia River RI/FS



Notes:
The river mile is the measurement upstream from the Mouth of the Columbia River.
Ecology 1986 = An Assessment of Metals contamination in Lake Roosevelt
USGS 1992 = Sediment Quality Assessment of Franklin Roosevelt Lake and the Upstream Reach of the Columbia Rver (UCR 243)
USGS 2001 = Concentration and Distribution of Slag-Related Trace elements and Mercury in Fine-Grained Beach and Bed Sediments in Lake Roosevelt (UCR 002)
USEPA 2001 = Upper Columbia Preliminary Assessment and Site Investigations and Expanded Site Inspection (UCR 247)
Ecology 2001 = Reassessment of Toxicity of Lake Roosevelt Sediments
USEPA 2005 = Phase I Sediment Sampling
USEPA 2001 and USEPA 2005 reported TOC concentrations as mg/kg dry weight. All other studies reported TOC in % dry weight. These values were converted to mg/kg dry weight.

FIGURE 5-19

Longitudinal Distribution of Total Organic Carbon by River Mile - Phase I Mid-Channel, Right Bank, and Left Bank Surface Sediment Samples

Upper Columbia River RI/FS

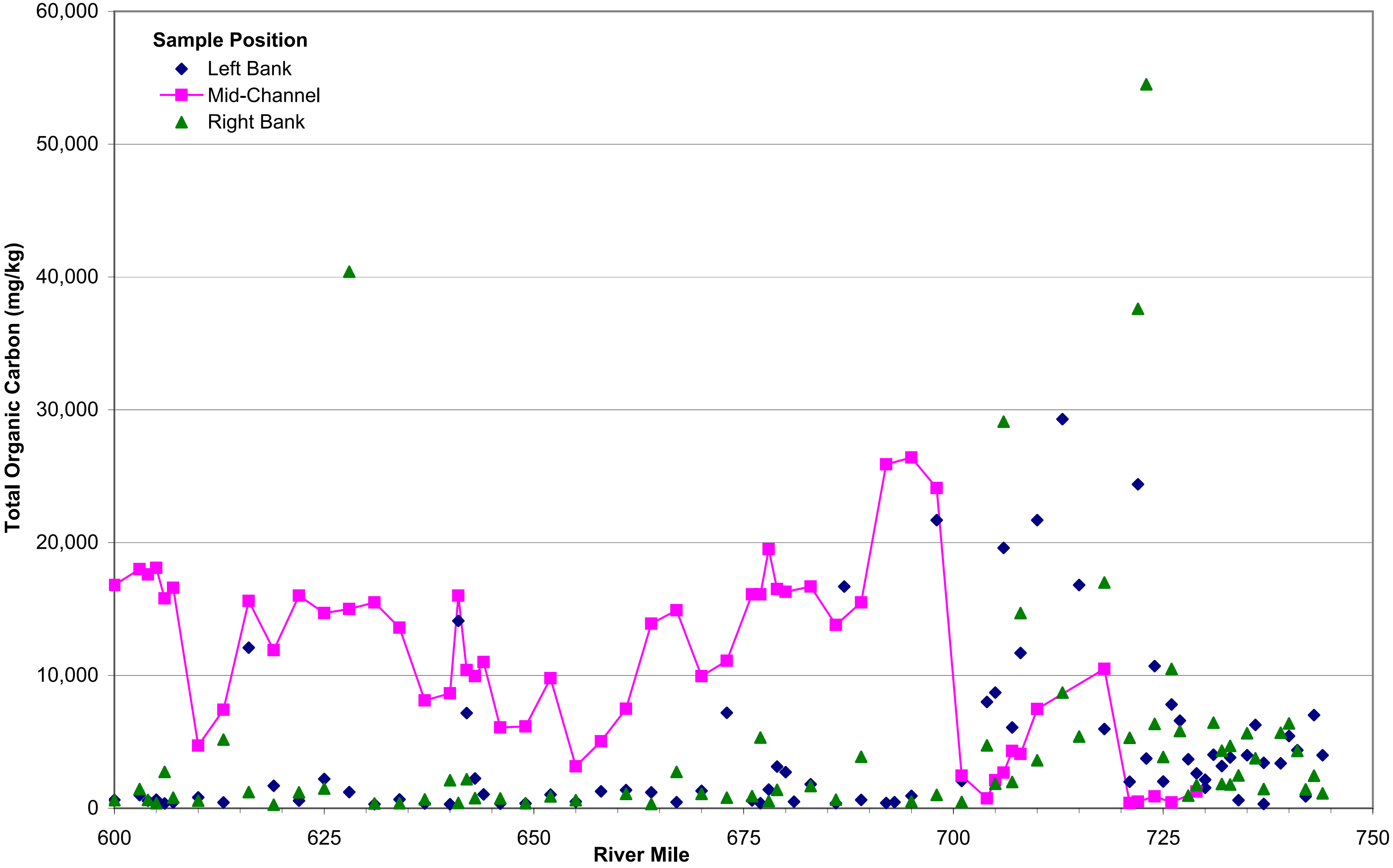


FIGURE 5-20
Transverse Distributions of TOC and Elevations at RM 706, 678, and 605 - 2005 Phase I Surface Sediment Samples
Upper Columbia River RI/FS

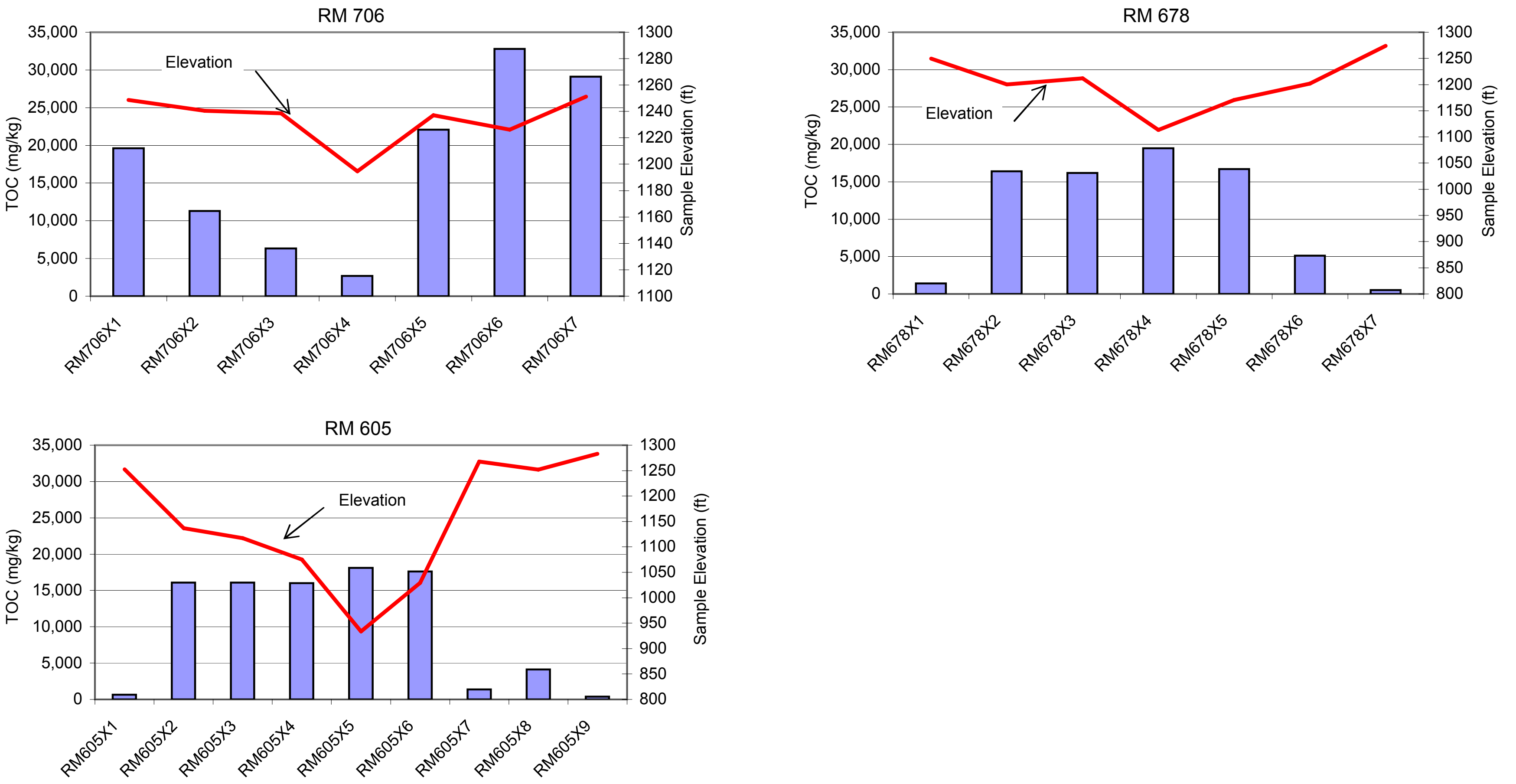


FIGURE 5-21
Longitudinal Distribution of Metals by River Mile - Phase I Surface Sediment
Upper Columbia River RI/FS

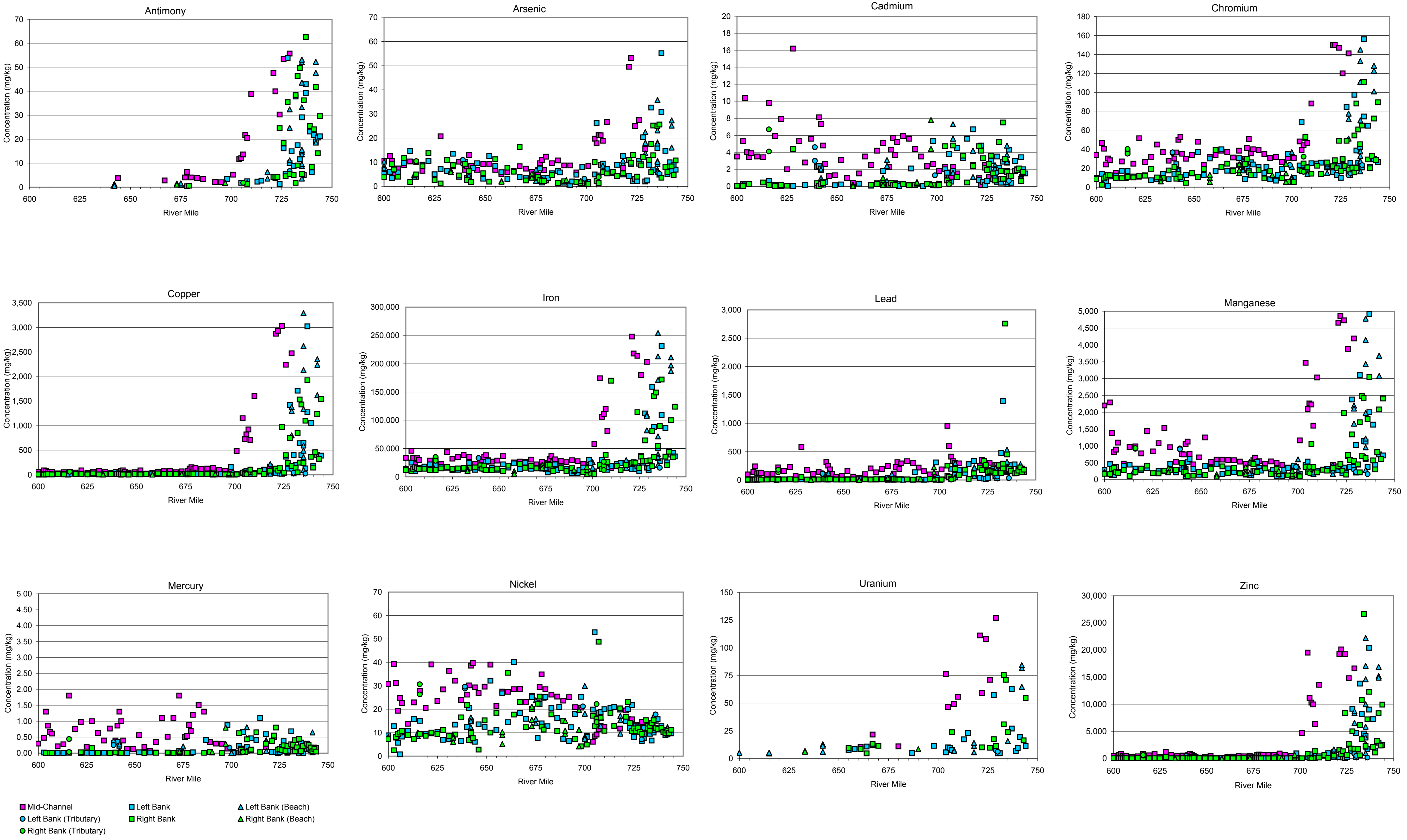


FIGURE 5-22a

Transverse Distribution of Metals and Sample Elevation - Focus Area 3 (RM 706) - 2005 Phase I Surface Sediment Samples

Upper Columbia River RI/FS

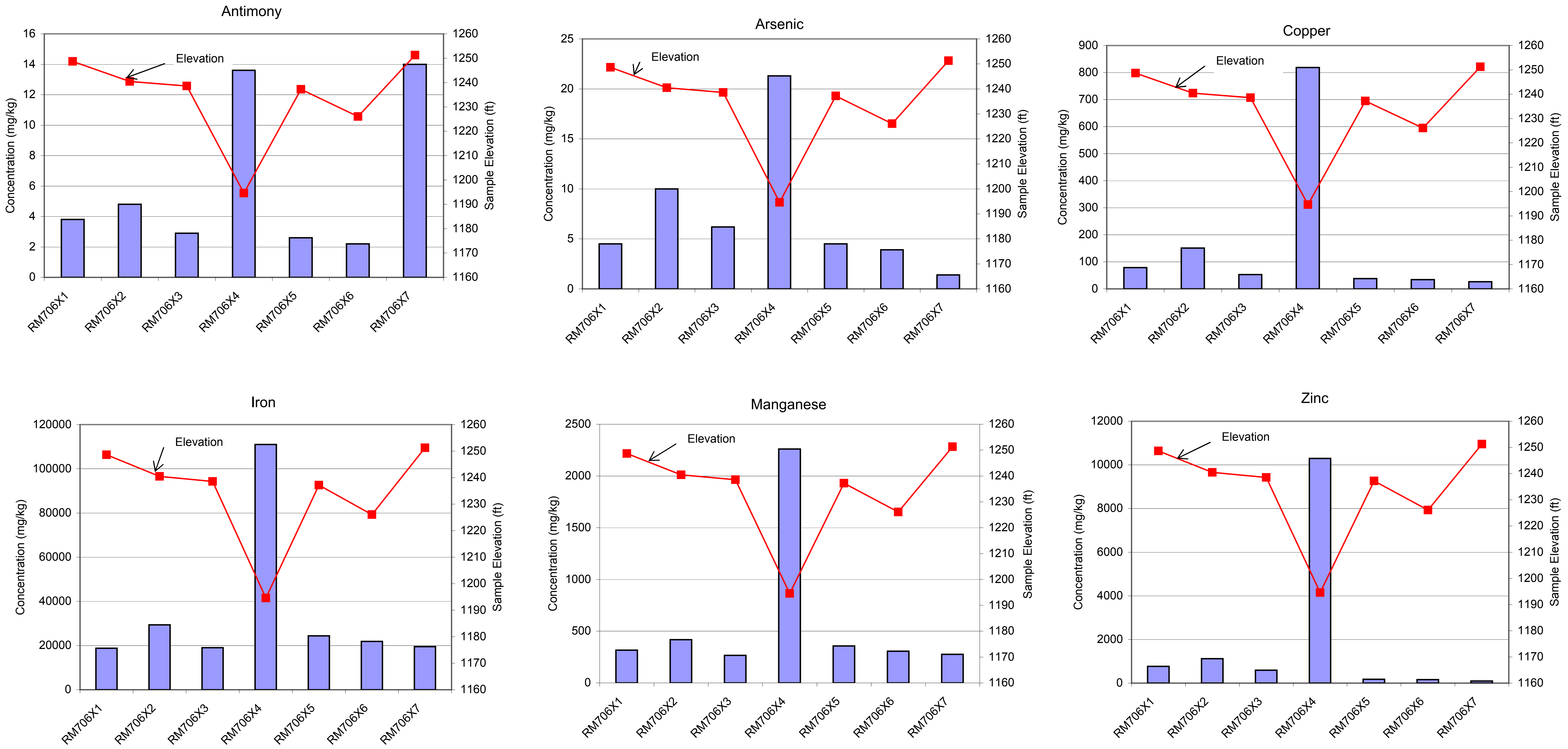


FIGURE 5-22b

Transverse Distribution of Metals and Sample Elevation - Focus Area 3 (RM 706) - 2005 Phase I Surface Sediment Samples

Upper Columbia River RI/FS

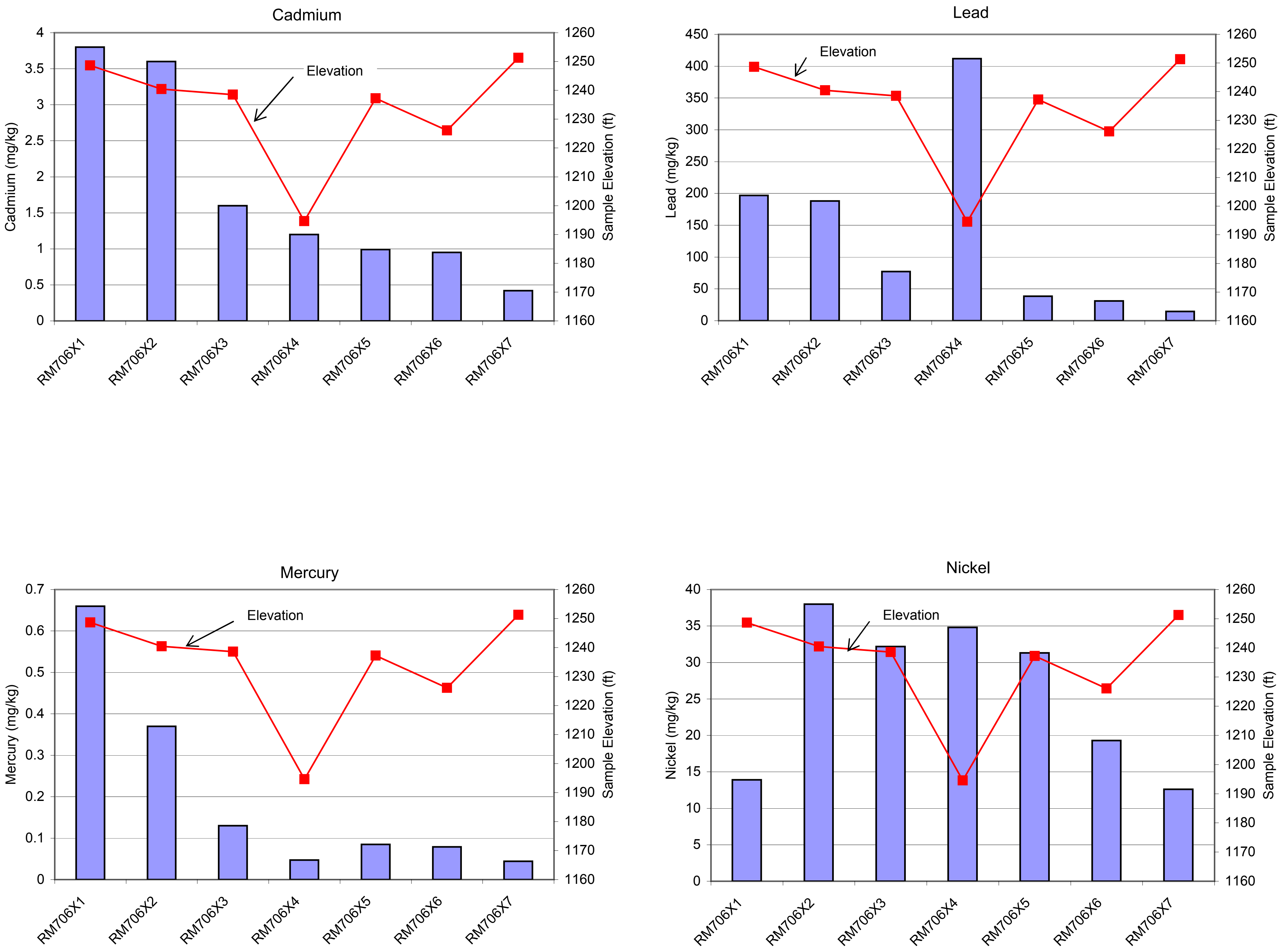


FIGURE 5-23
Transverse Distribution of Metals and Sample Elevation - Focus Area 4 (RM 678) - 2005 Phase I Surface Sediment Samples
Upper Columbia River RI/FS

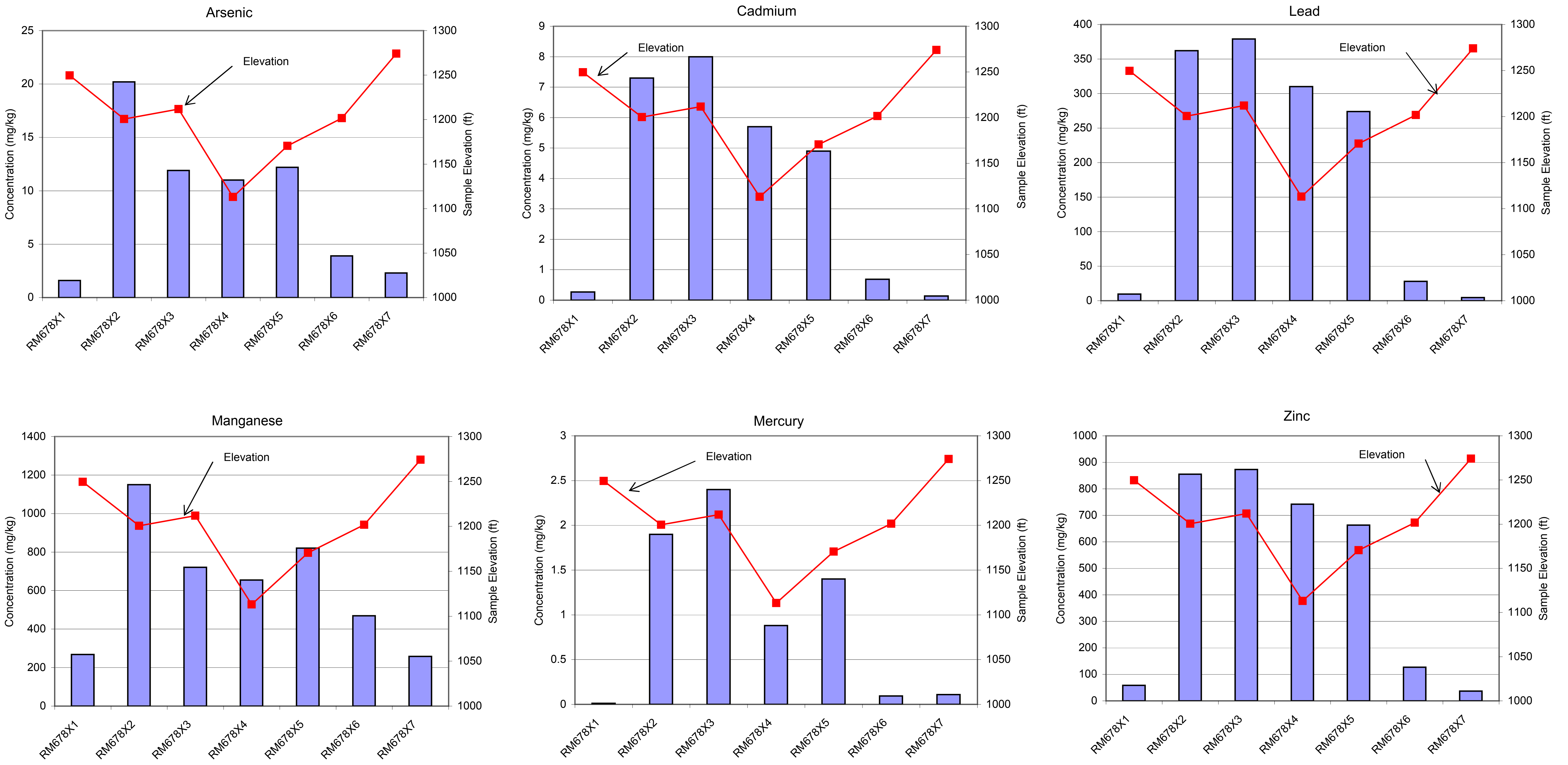
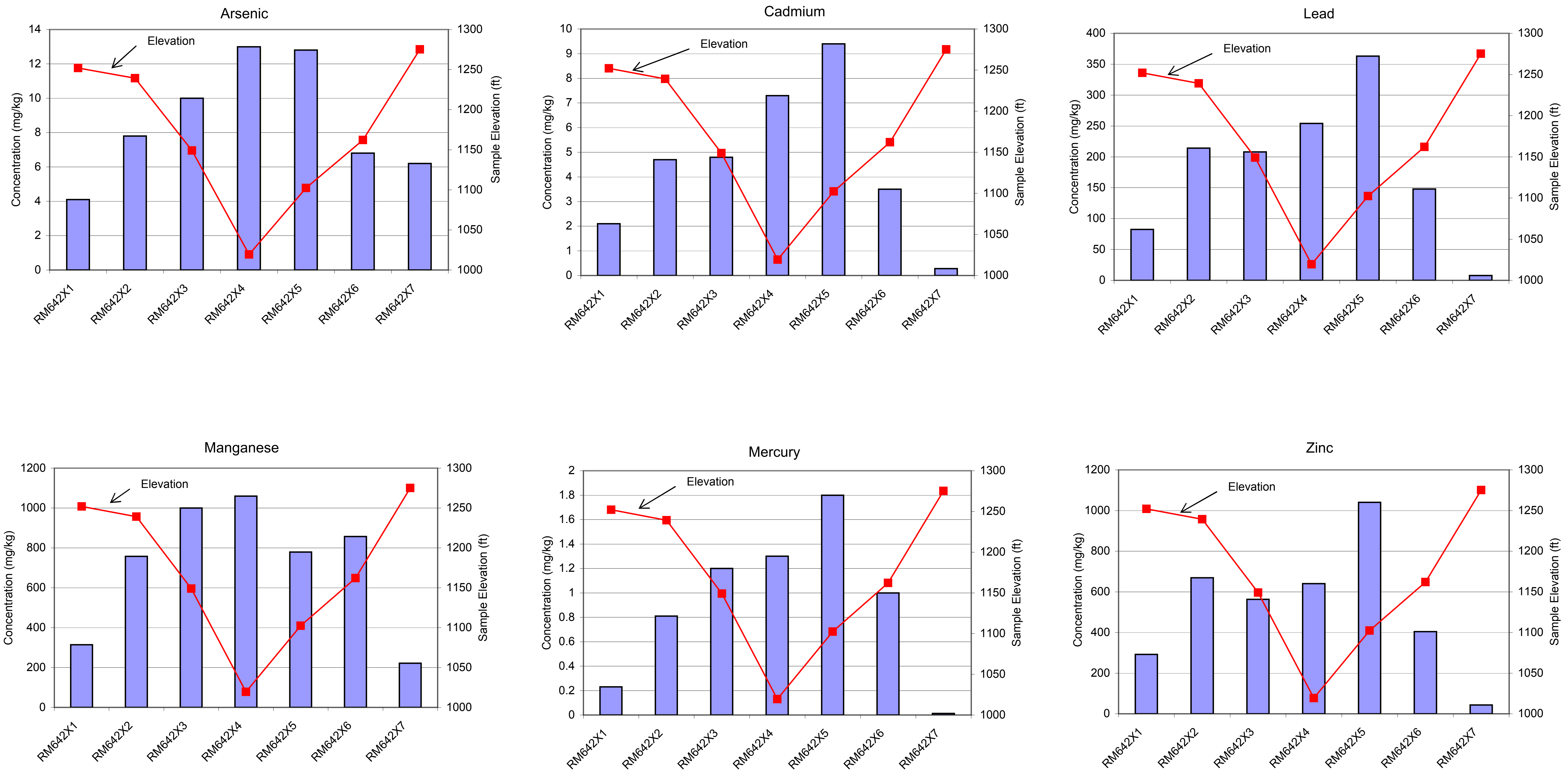


FIGURE 5-24
Transverse Distribution of Metals and Sample Elevation - Focus Area 5 (RM 642) - 2005 Phase I Surface Sediment Samples
Upper Columbia River RI/FS



UCR_Sediment_DE_Figure_5-22a_to_5-25_REV.xls

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FIGURE 5-25
Transverse Distribution of Metals and Sample Elevation - Focus Area 5 (RM 605) - 2005 Phase I Surface Sediment Samples
Upper Columbia River RI/FS

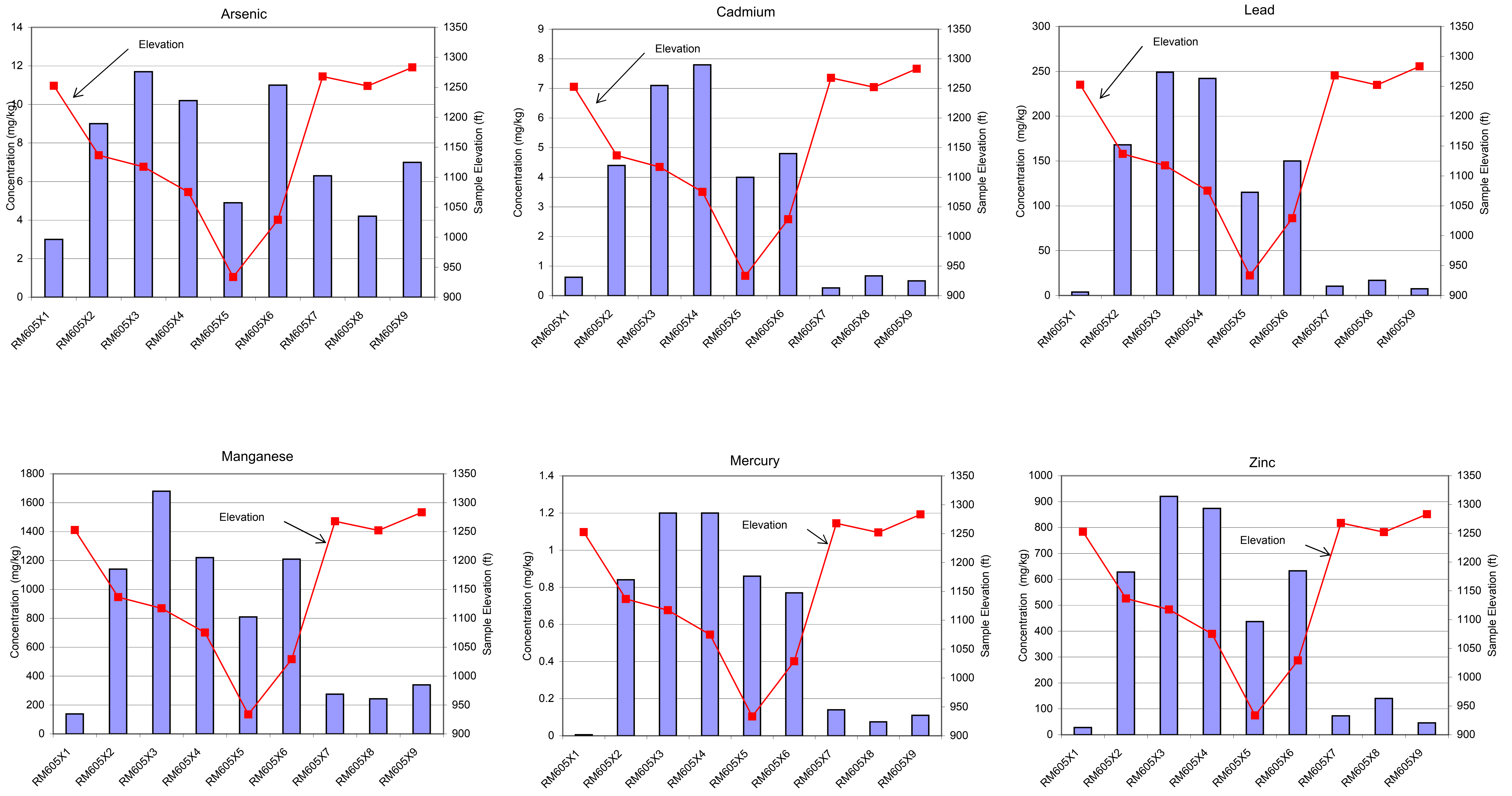
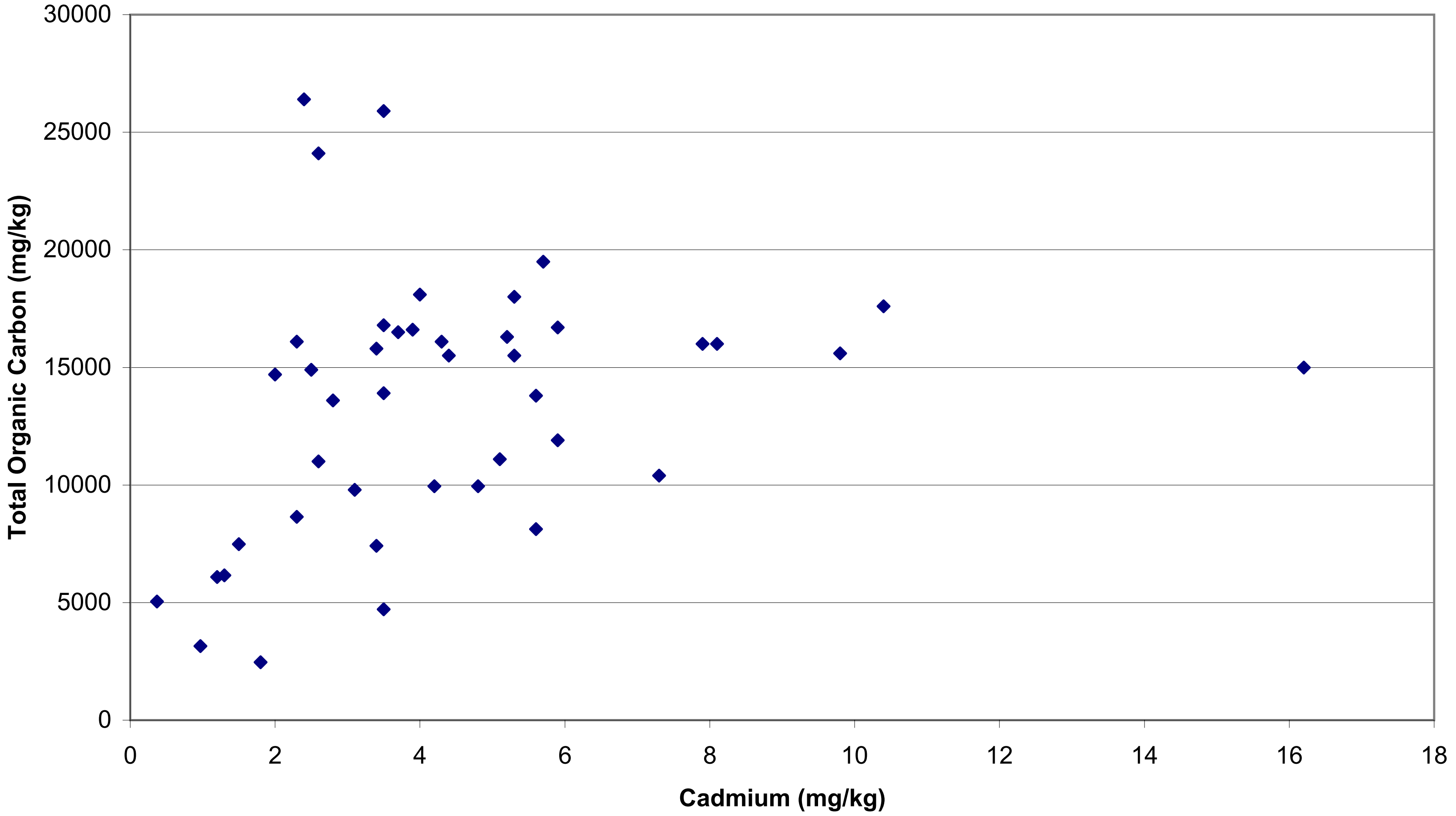


FIGURE 5-26

Cadmium Correlation with TOC in Mid-channel Samples Collected Below Marcus Flats - Phase I Surface Sediment Samples

Upper Columbia River RI/FS



UCR_Sediment_DE_Figure_5-26_to_5-28_REV.xls

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FIGURE 5-27

Cadmium Correlation with TOC in Mid-channel Samples Collected Below Marcus Flats - Phase I Surface Sediment Samples

Upper Columbia River RI/FS

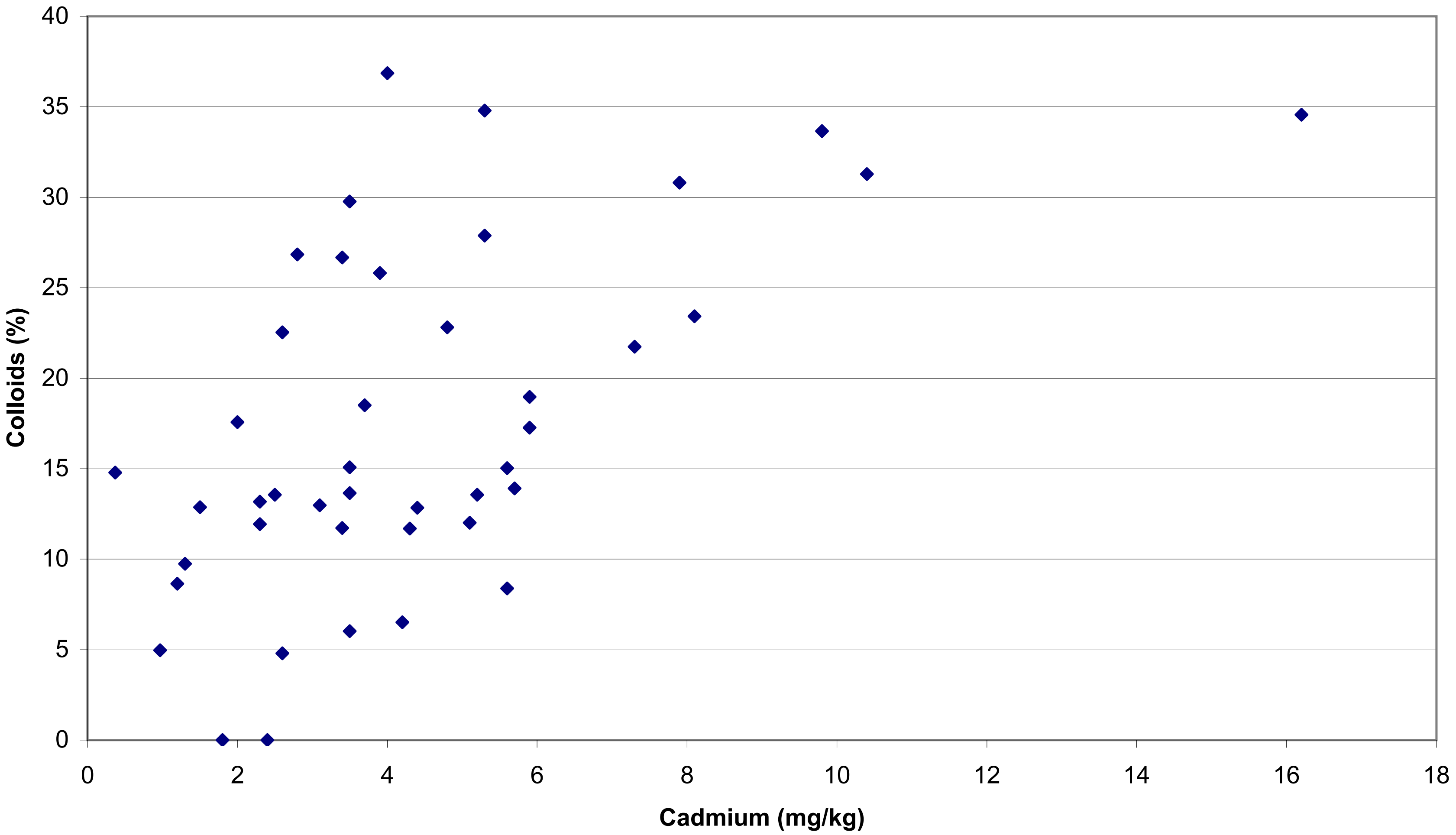
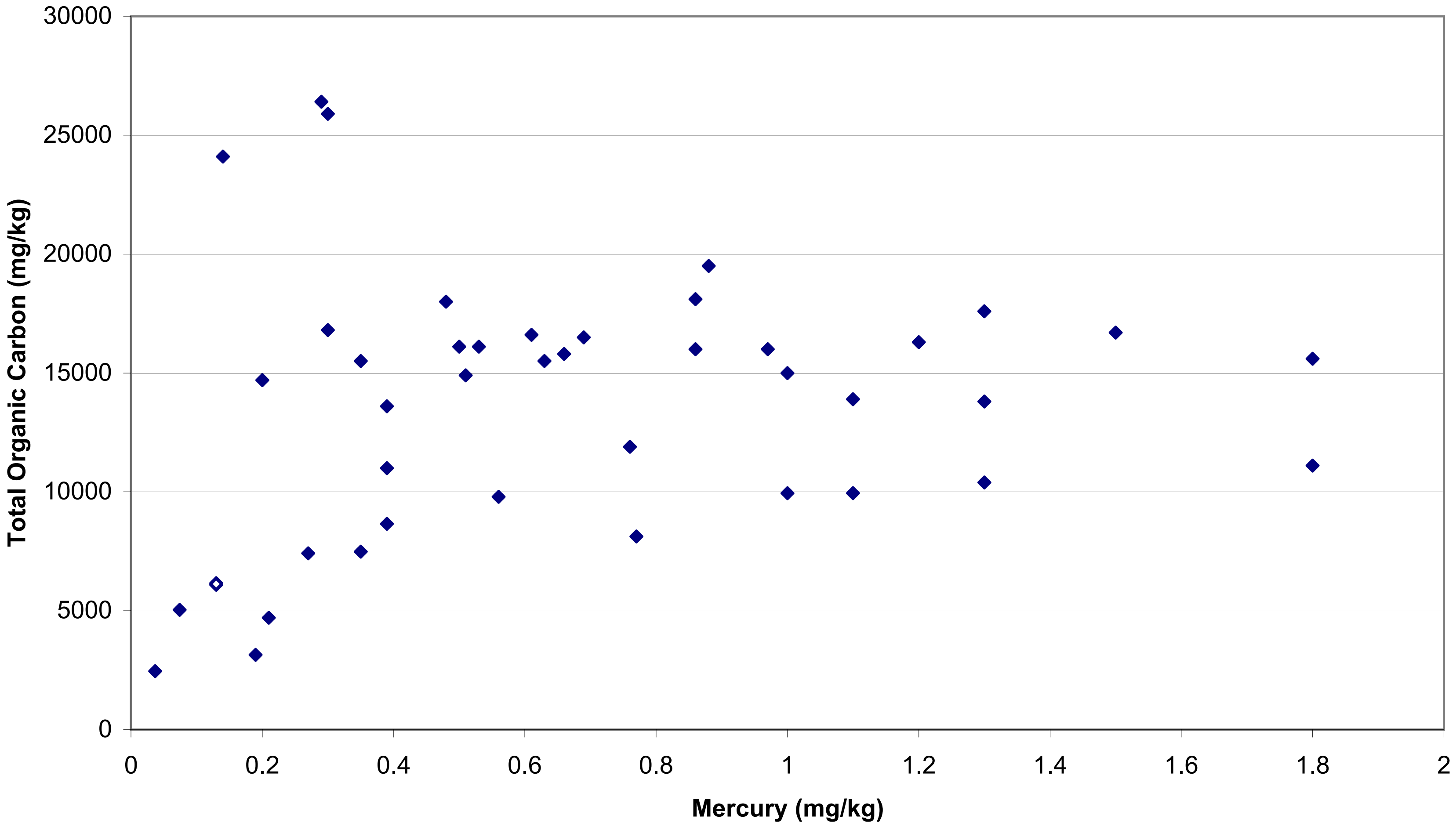


FIGURE 5-28
Mercury Correlation with TOC in Mid-channel Samples Collected Below Marcus Flats - Phase I Surface Sediment Samples
Upper Columbia River RI/FS



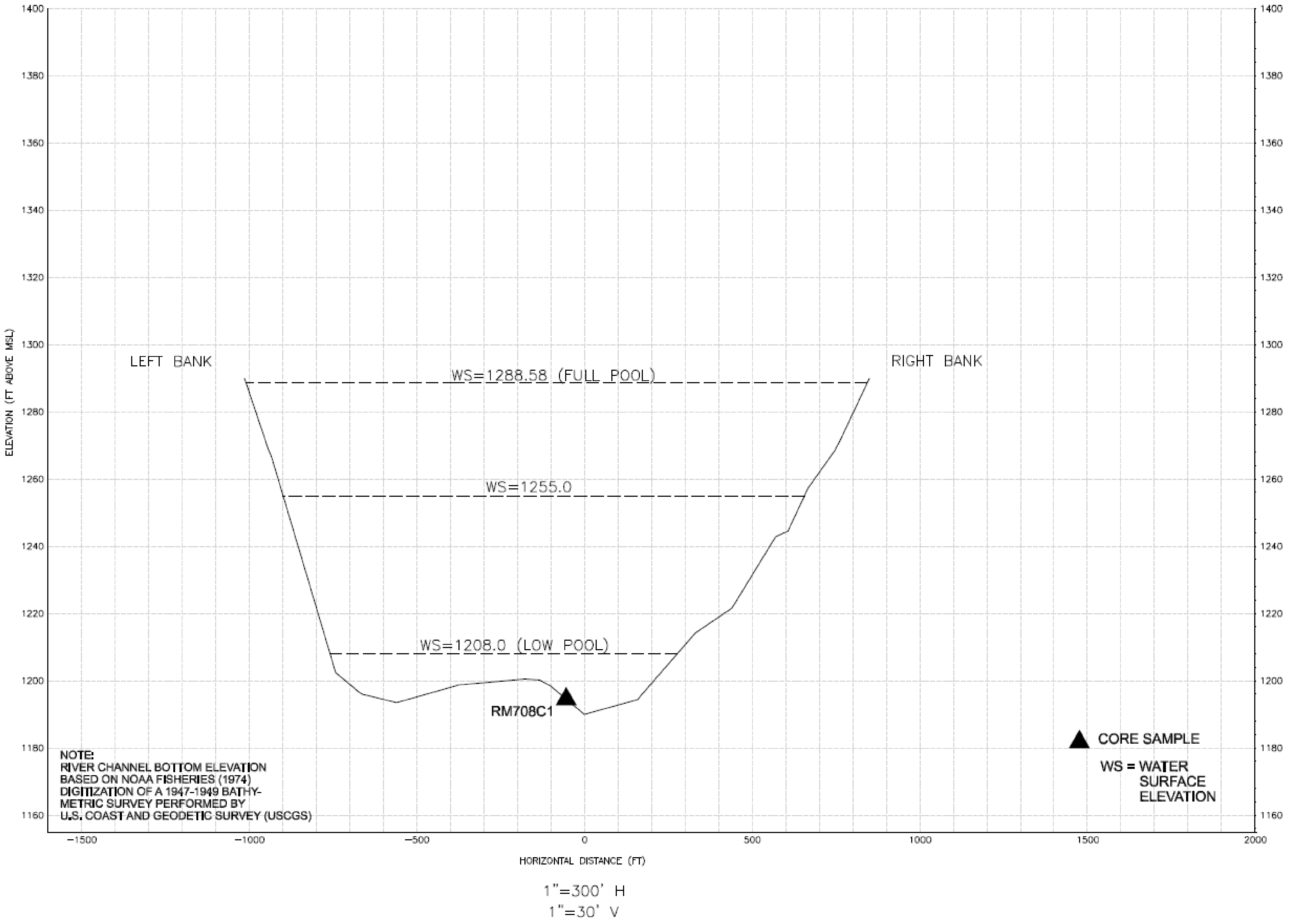


Figure 5-29
Channel Cross-Section and Sampling Locations at RM 708
Upper Columbia River RI/FS

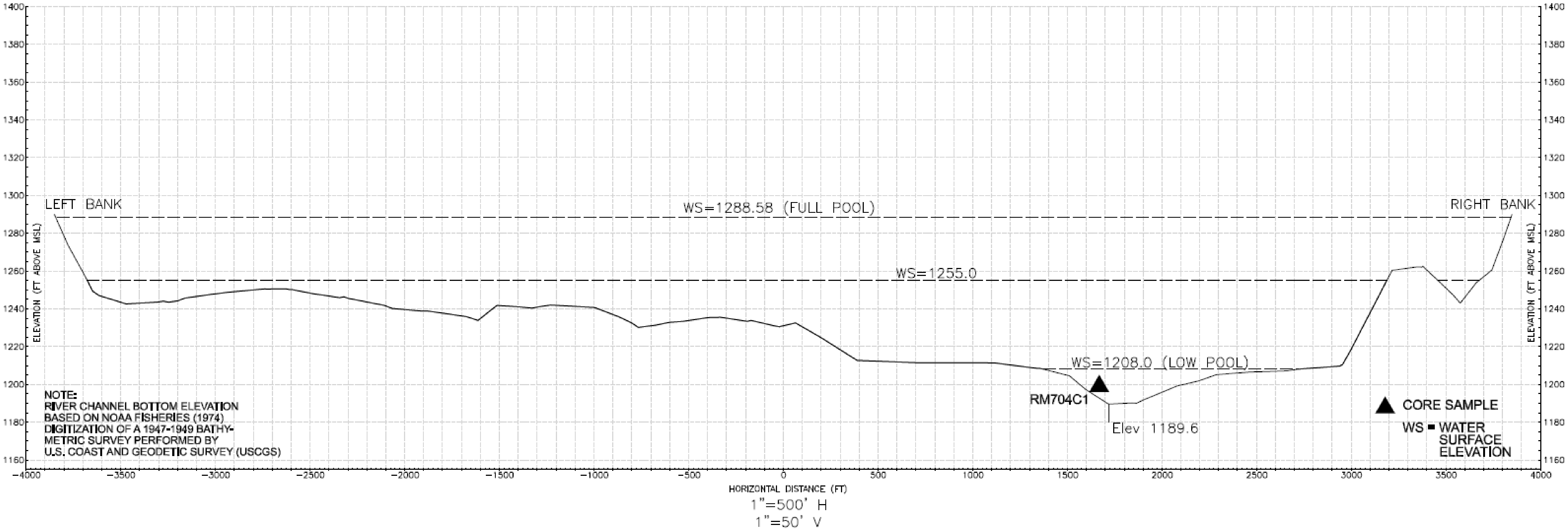


Figure 5-30
Channel Cross-Section and Sampling Locations at RM 704
Upper Columbia River RI/FS

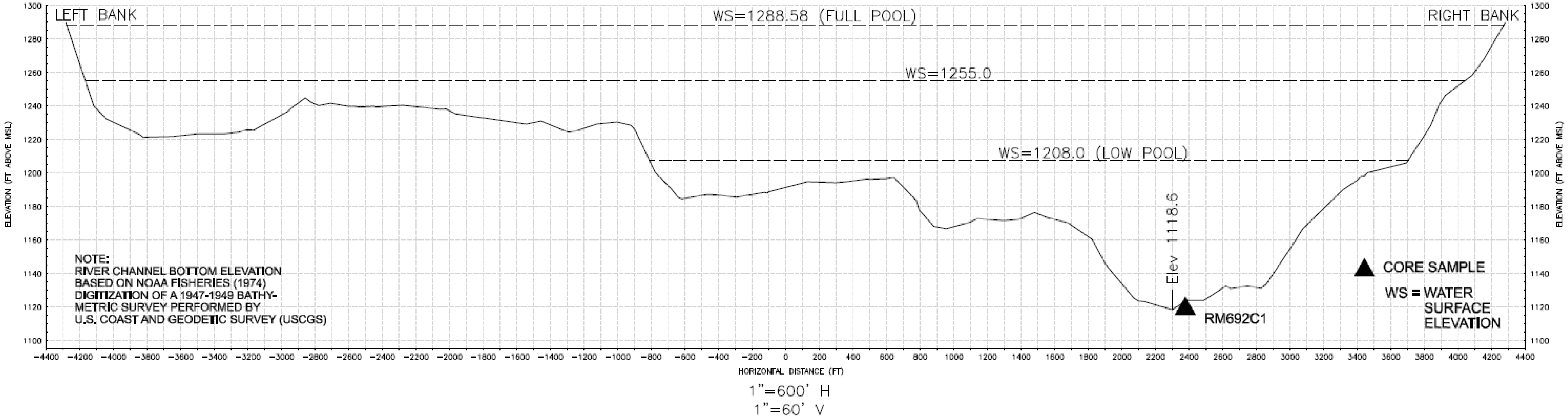


Figure 5-31
Channel Cross-Section and Sampling Locations at RM 692
Upper Columbia River RI/FS

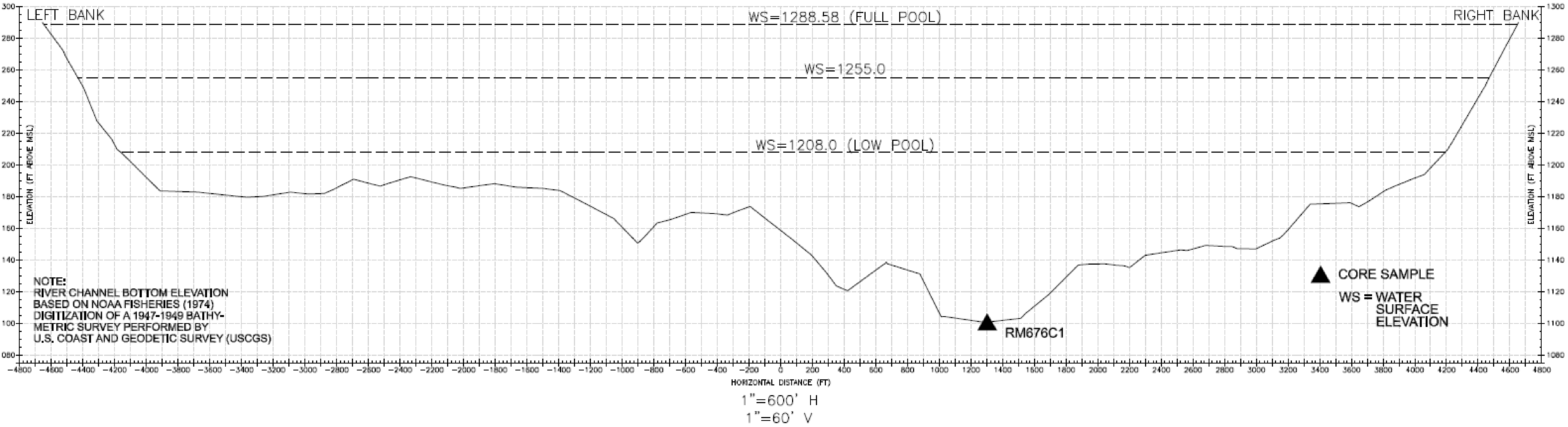
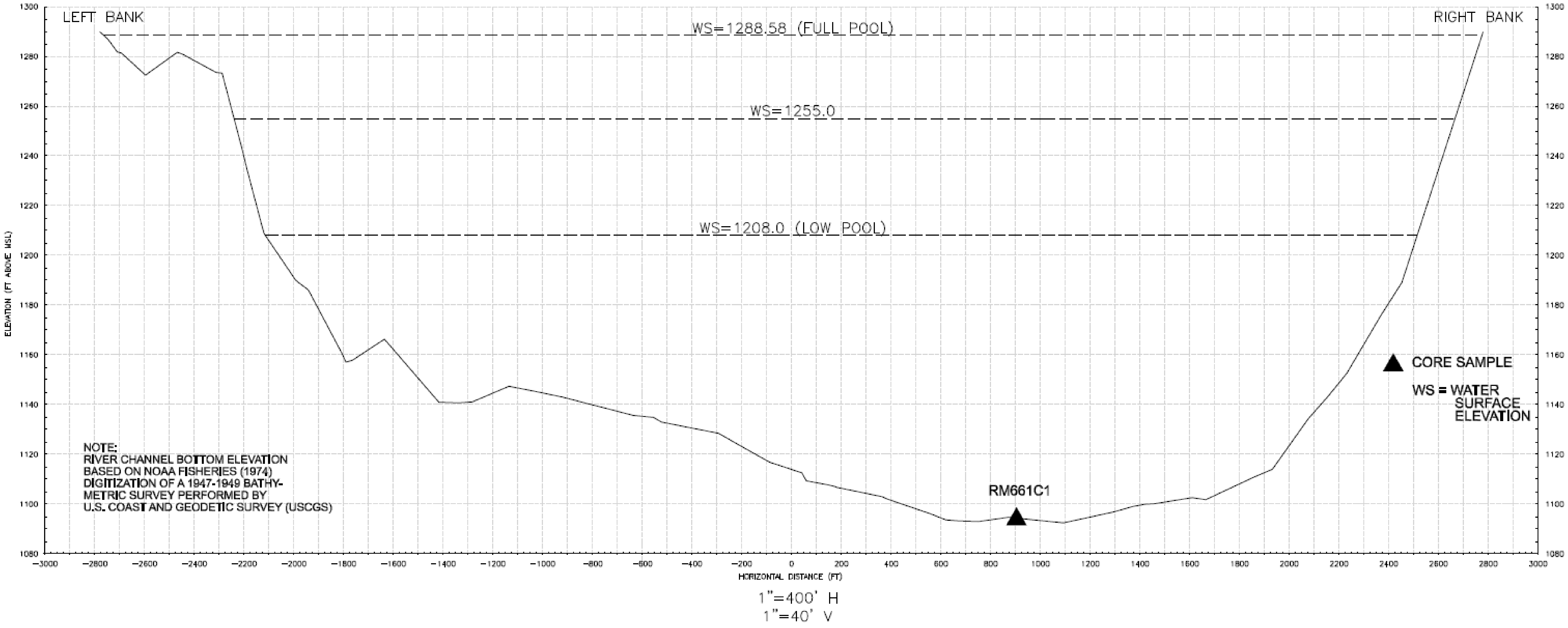
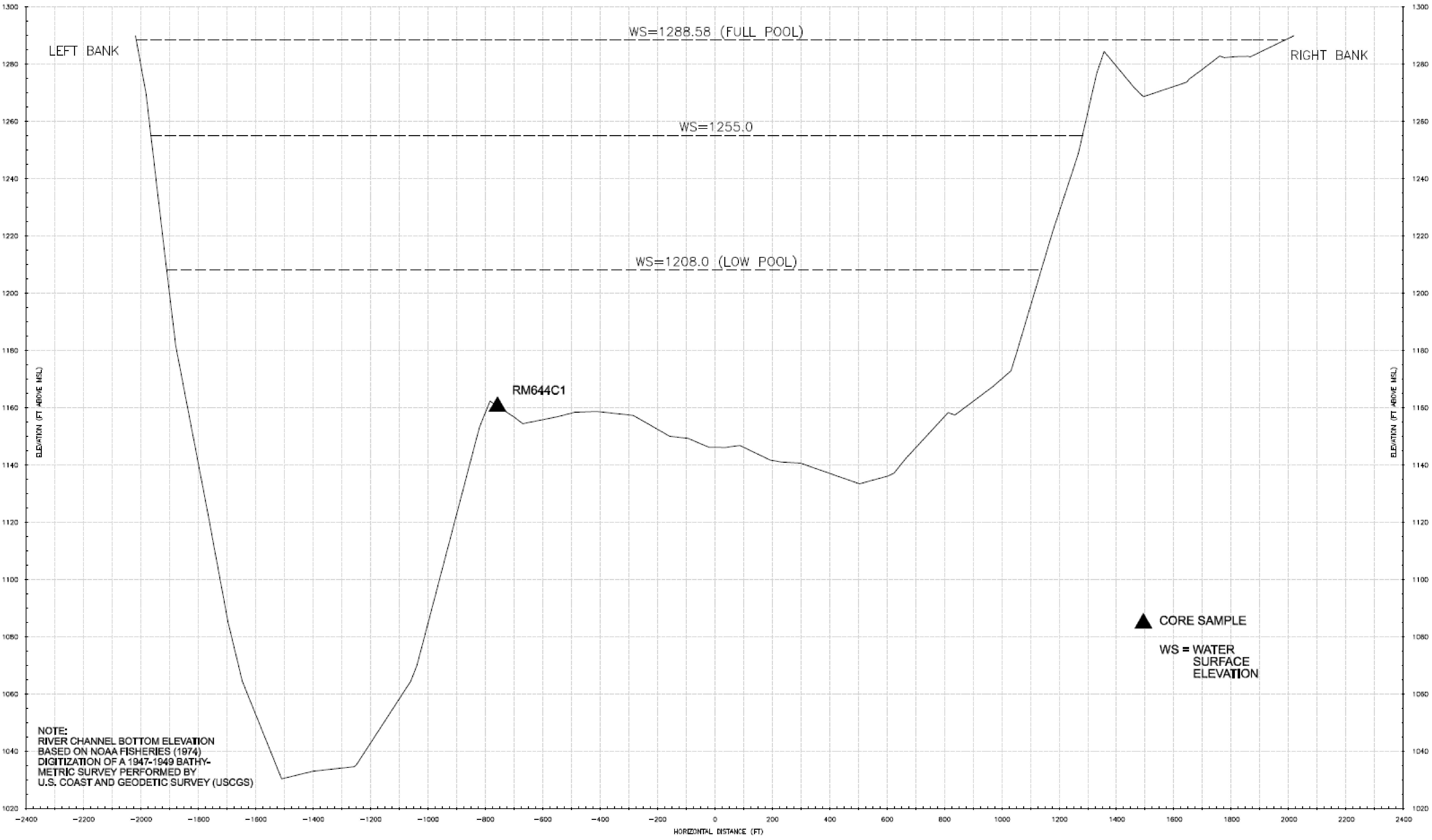


Figure 5-32
Channel Cross-Section and Sampling Locations at RM 676
Upper Columbia River RI/FS



NOTE:
RIVER CHANNEL BOTTOM ELEVATION BASED ON NOAA FISHERIES (1974) DIGITIZATION OF A 1947-1949 BATHYMETRIC SURVEY PERFORMED BY U.S. COAST AND GEODETIC SURVEY (USCGS)

Figure 5-33
Channel Cross-Section and Sampling Locations at RM 661
Upper Columbia River RI/FS



NOTE:
RIVER CHANNEL BOTTOM ELEVATION BASED ON NOAA FISHERIES (1974) DIGITIZATION OF A 1947-1949 BATHYMETRIC SURVEY PERFORMED BY U.S. COAST AND GEODETIC SURVEY (USCGS)

Figure 5-34
Channel Cross-Section and Sampling Locations at RM 644
Upper Columbia River RI/FS

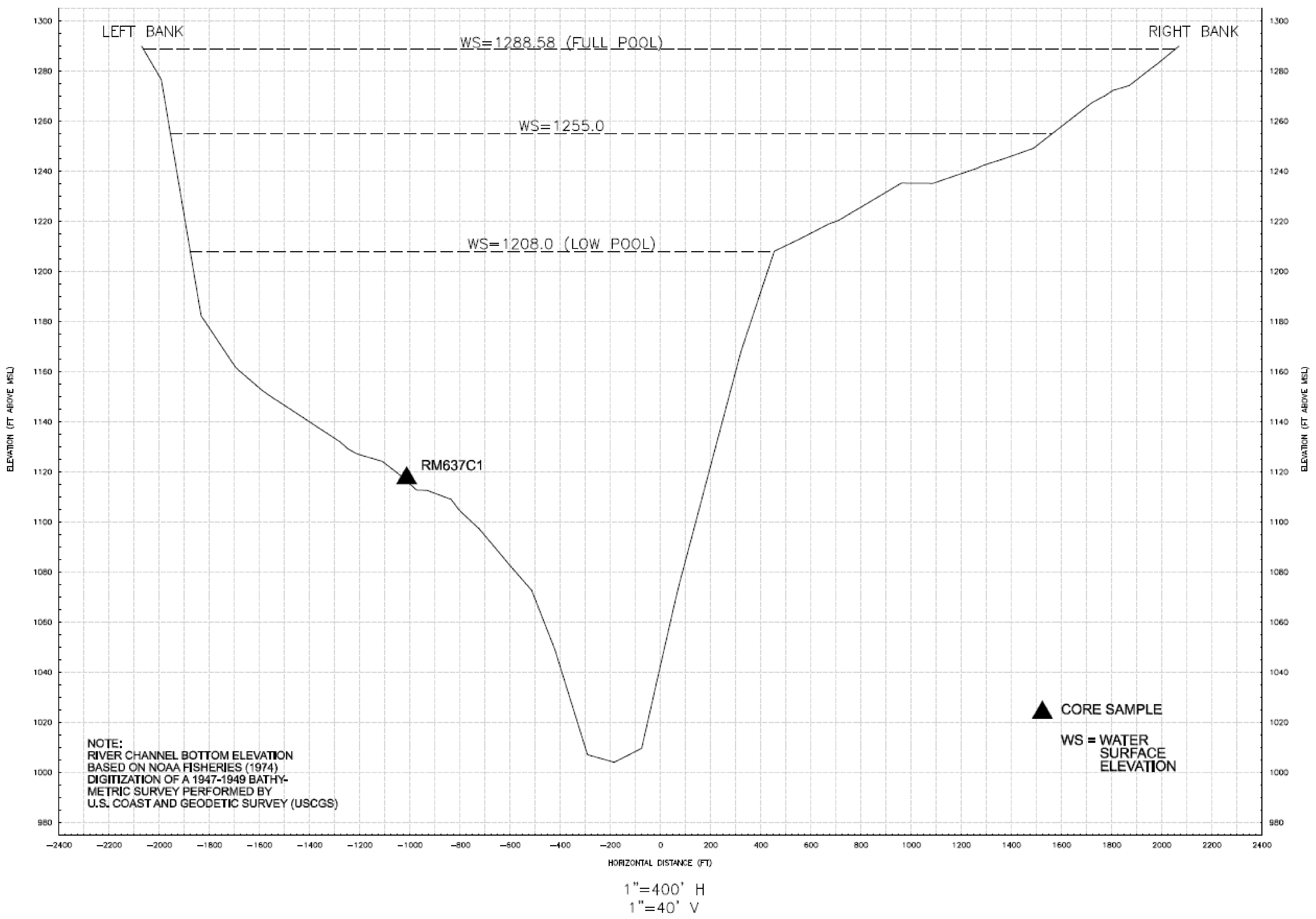
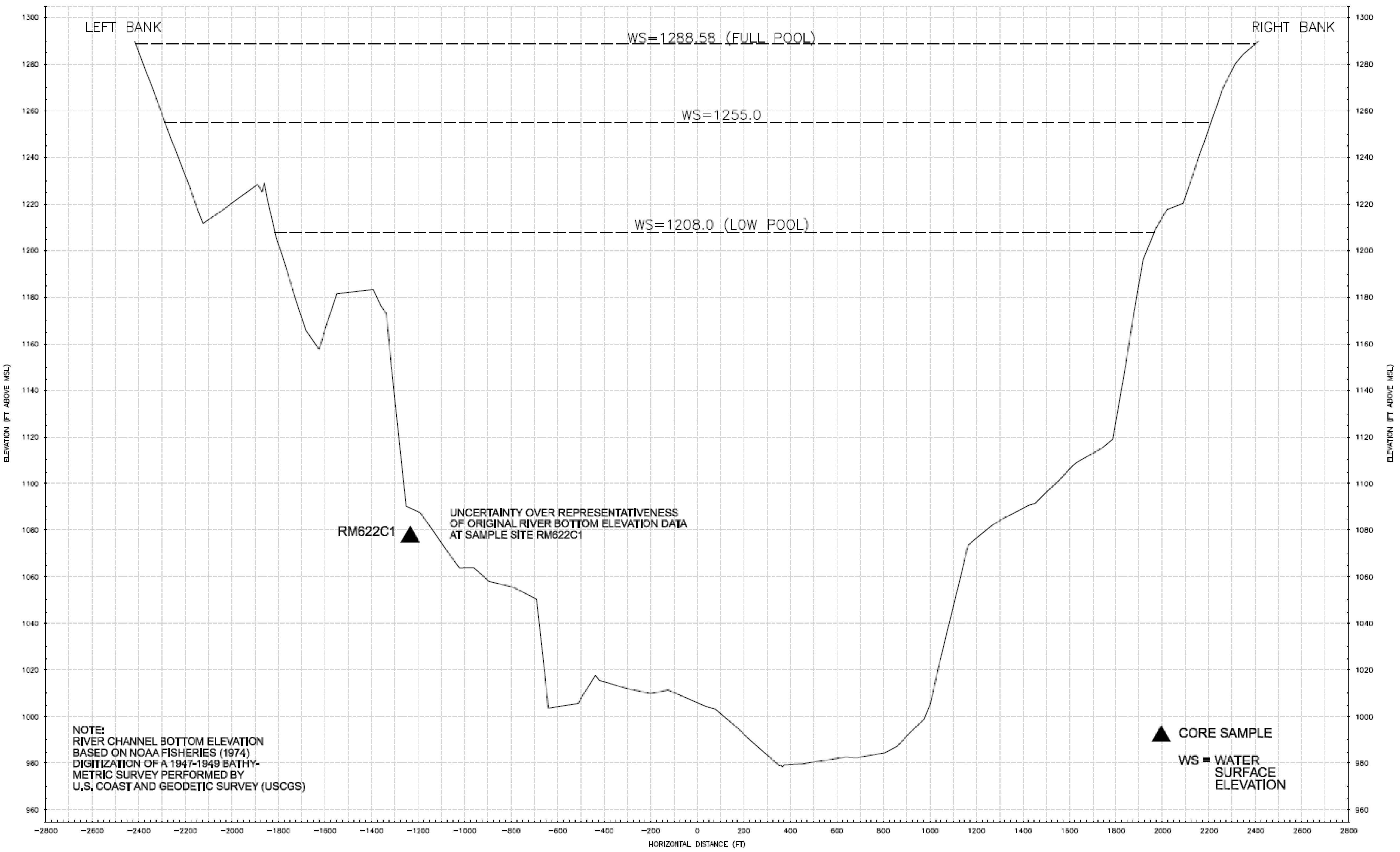


Figure 5-35
Channel Cross-Section and Sampling Locations at RM 637
Upper Columbia River RI/FS



UNCERTAINTY OVER REPRESENTATIVENESS
OF ORIGINAL RIVER BOTTOM ELEVATION DATA
AT SAMPLE SITE RM622C1

NOTE:
RIVER CHANNEL BOTTOM ELEVATION
BASED ON NOAA FISHERIES (1974)
DIGITIZATION OF A 1947-1949 BATHYMETRIC SURVEY PERFORMED BY
U.S. COAST AND GEODETIC SURVEY (USCGS)

▲ CORE SAMPLE

WS = WATER SURFACE ELEVATION

Figure 5-36
Channel Cross-Section and Sampling Locations at RM 622
Upper Columbia River RI/FS

FIGURE 5-37
Vertical Distribution of Metals in 2005 Phase I Sediment Core Samples RM 704
Upper Columbia River RI/FS

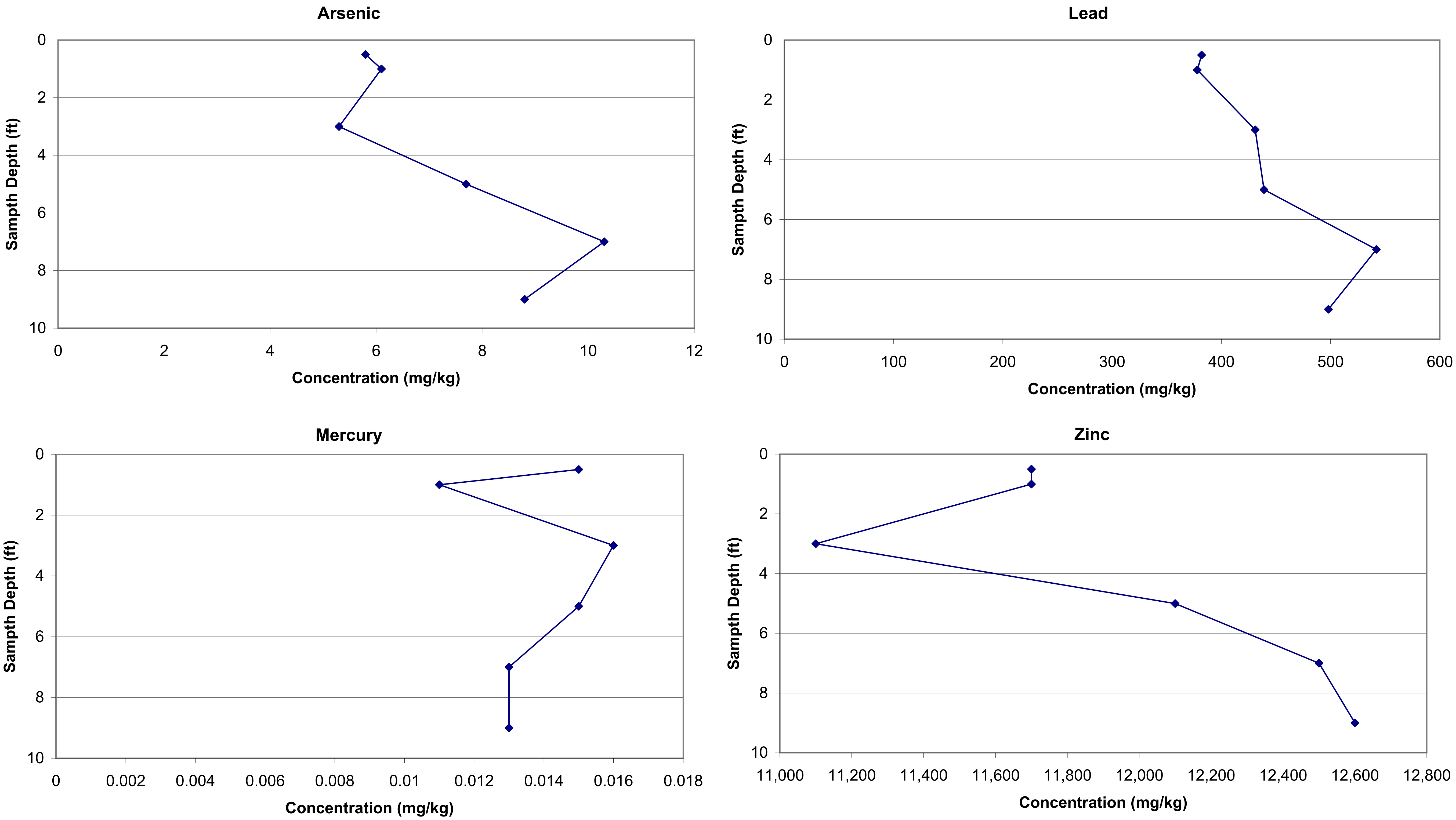


FIGURE 5-38

Vertical Distribution of Metals in 2005 Phase I Sediment Core Samples RM 676

Upper Columbia River RI/FS

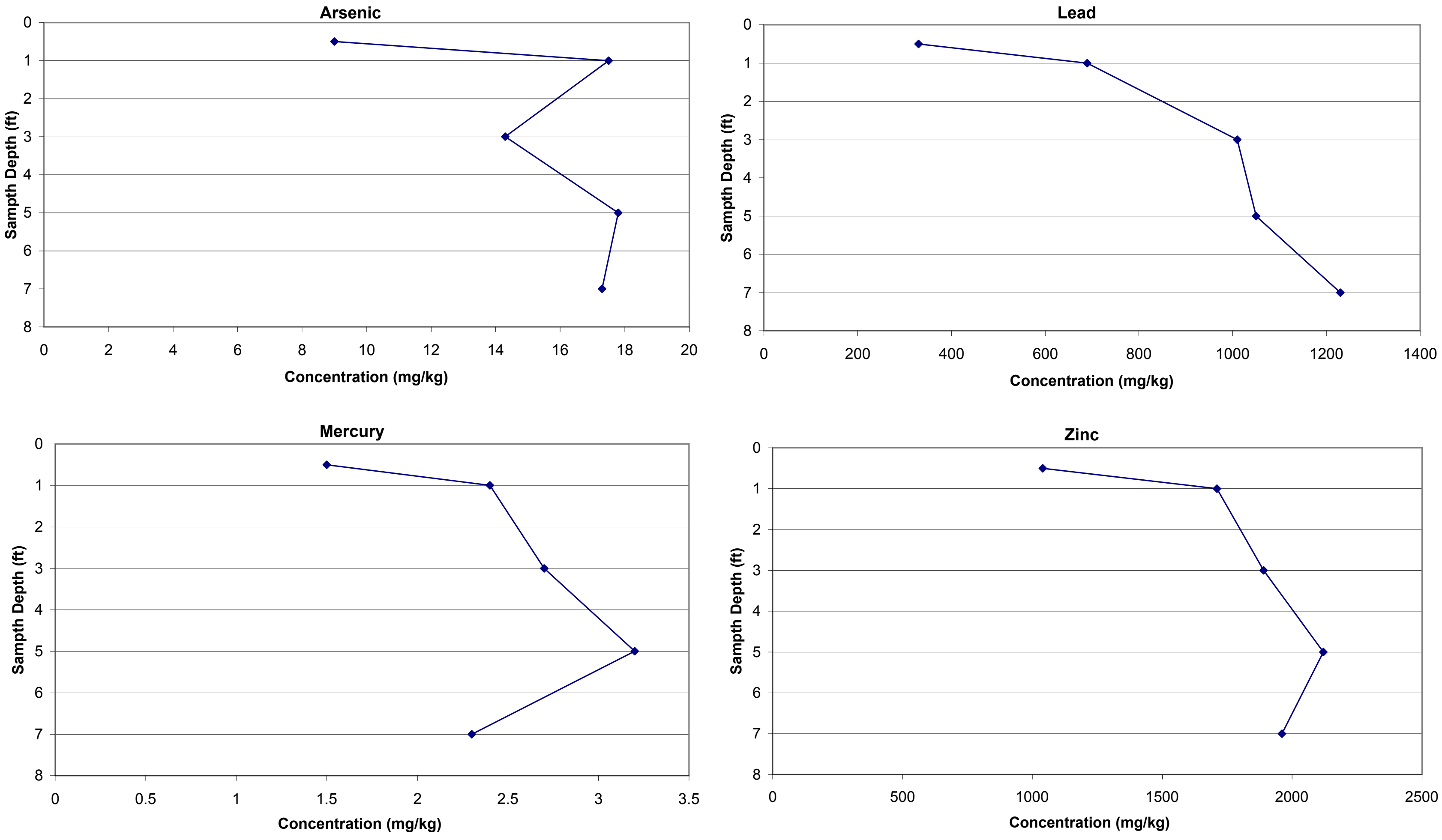


FIGURE 5-39
Vertical Distribution of Metals in 2005 Phase I Sediment Core Samples RM 605
Upper Columbia River RI/FS

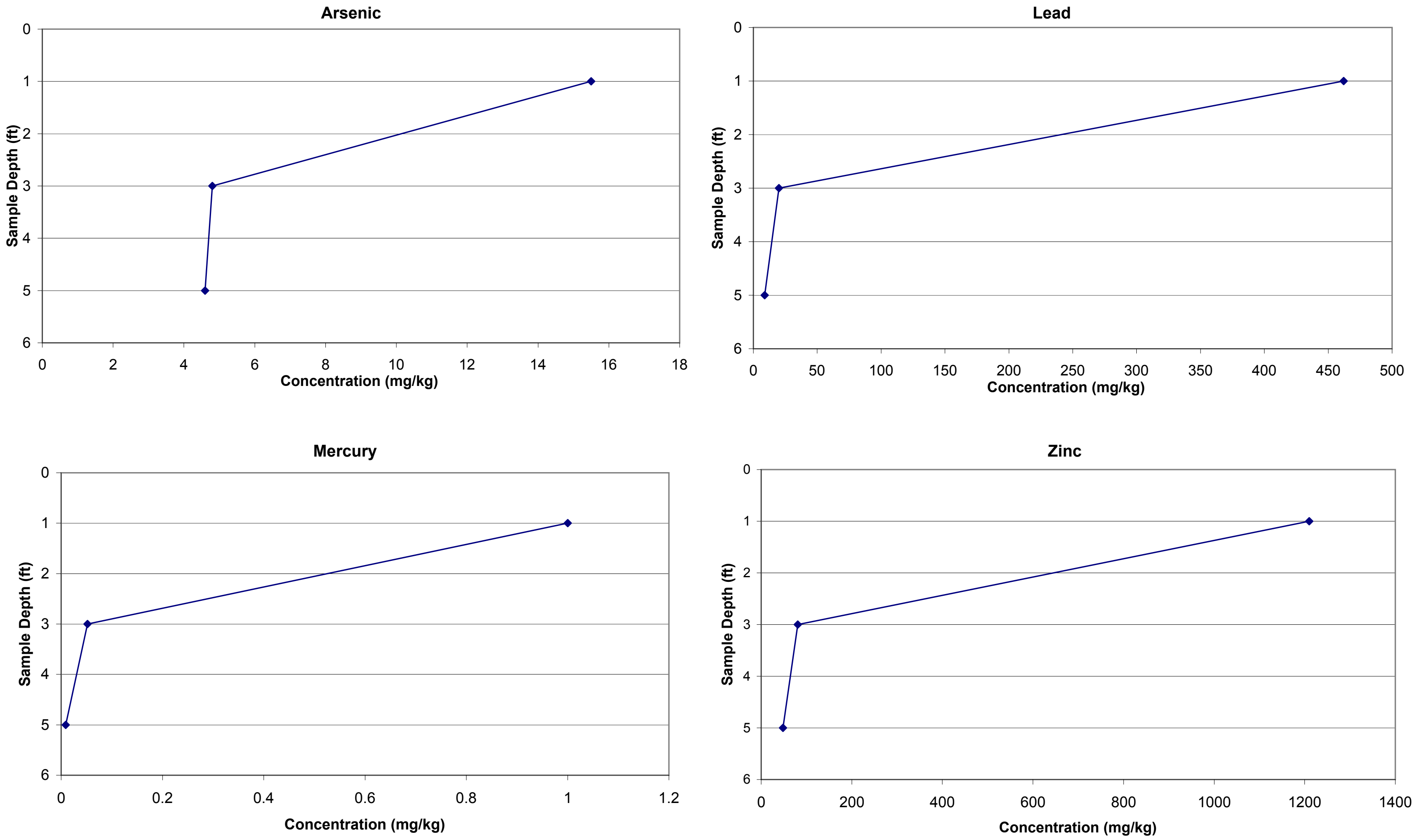


FIGURE 5-40a
Longitudinal Distribution of Metals in 2005 Phase I Beach Samples
Upper Columbia River RI/FS

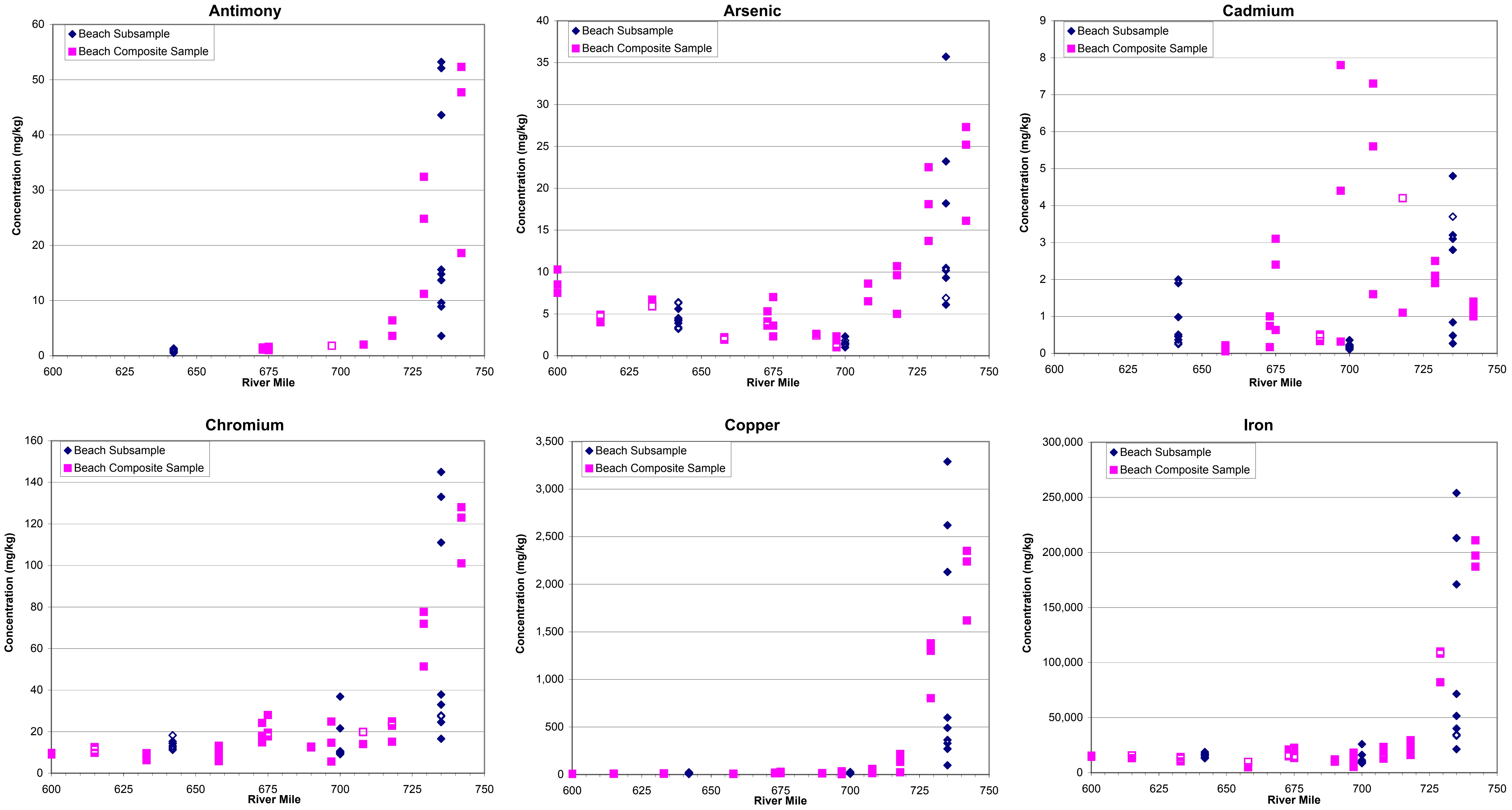


FIGURE 5-40b
Longitudinal Distribution of Metals in Phase I Beach Samples
Upper Columbia River RI/FS

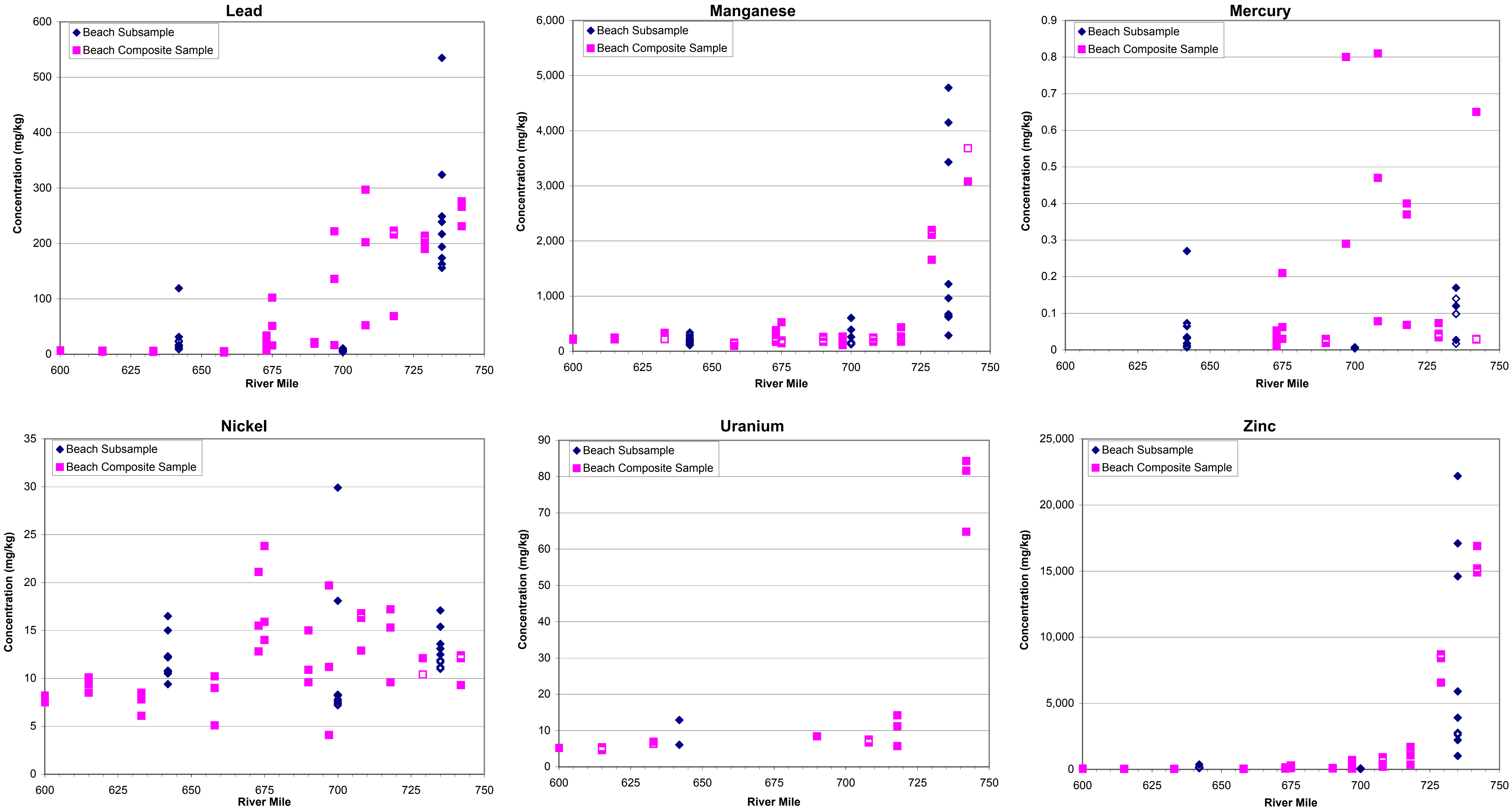


FIGURE 5-40a
Longitudinal Distribution of Metals in 2005 Phase I Beach Samples
Upper Columbia River RI/FS

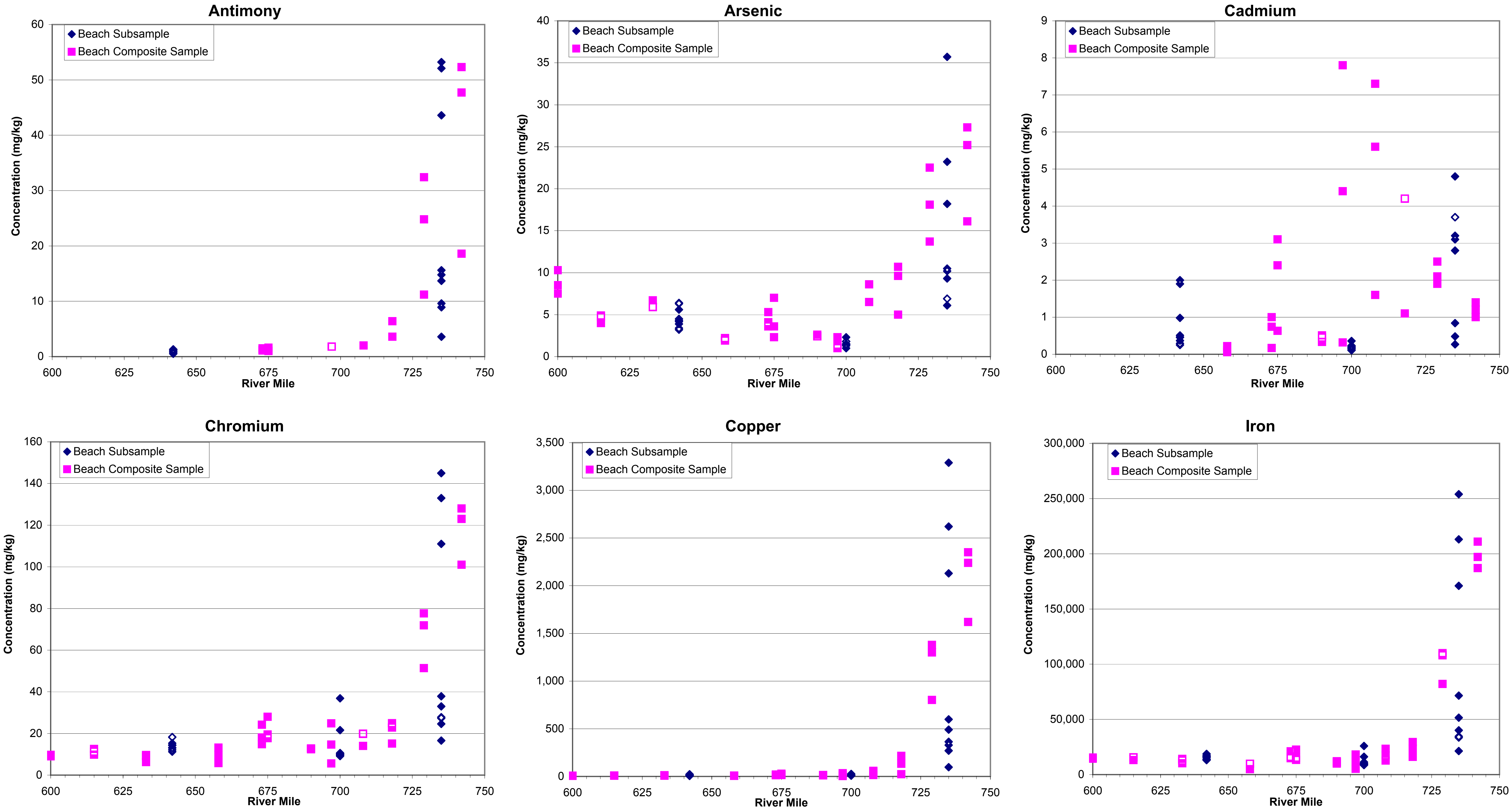


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FIGURE 5-40b
Longitudinal Distribution of Metals in Phase I Beach Samples
Upper Columbia River RI/FS

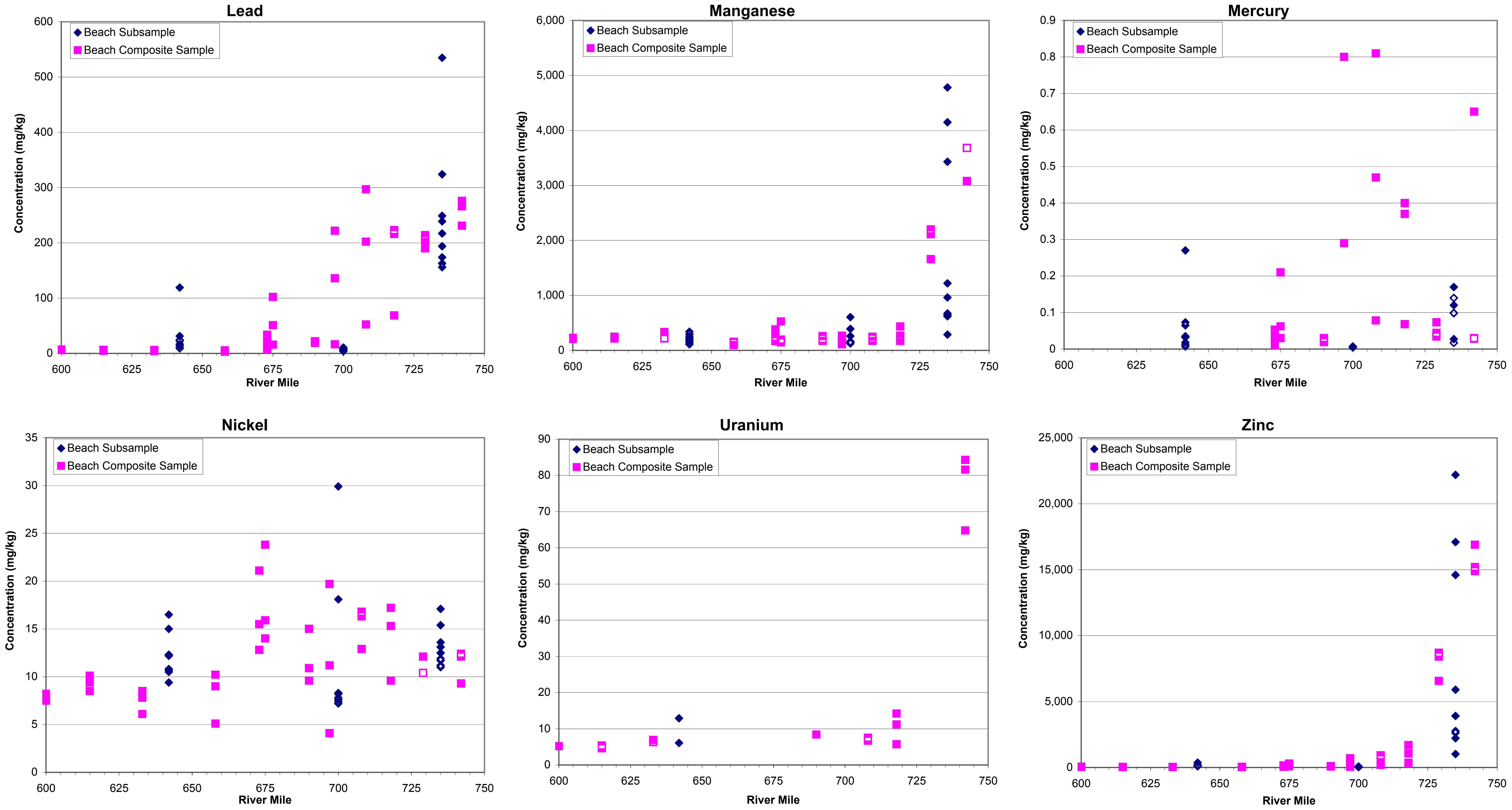

FIGURE 5-41
Distribution of Metals in Size Fractionated Sediment Samples - 2005 Phase I Composite Beach Samples
Upper Columbia River RI/FS

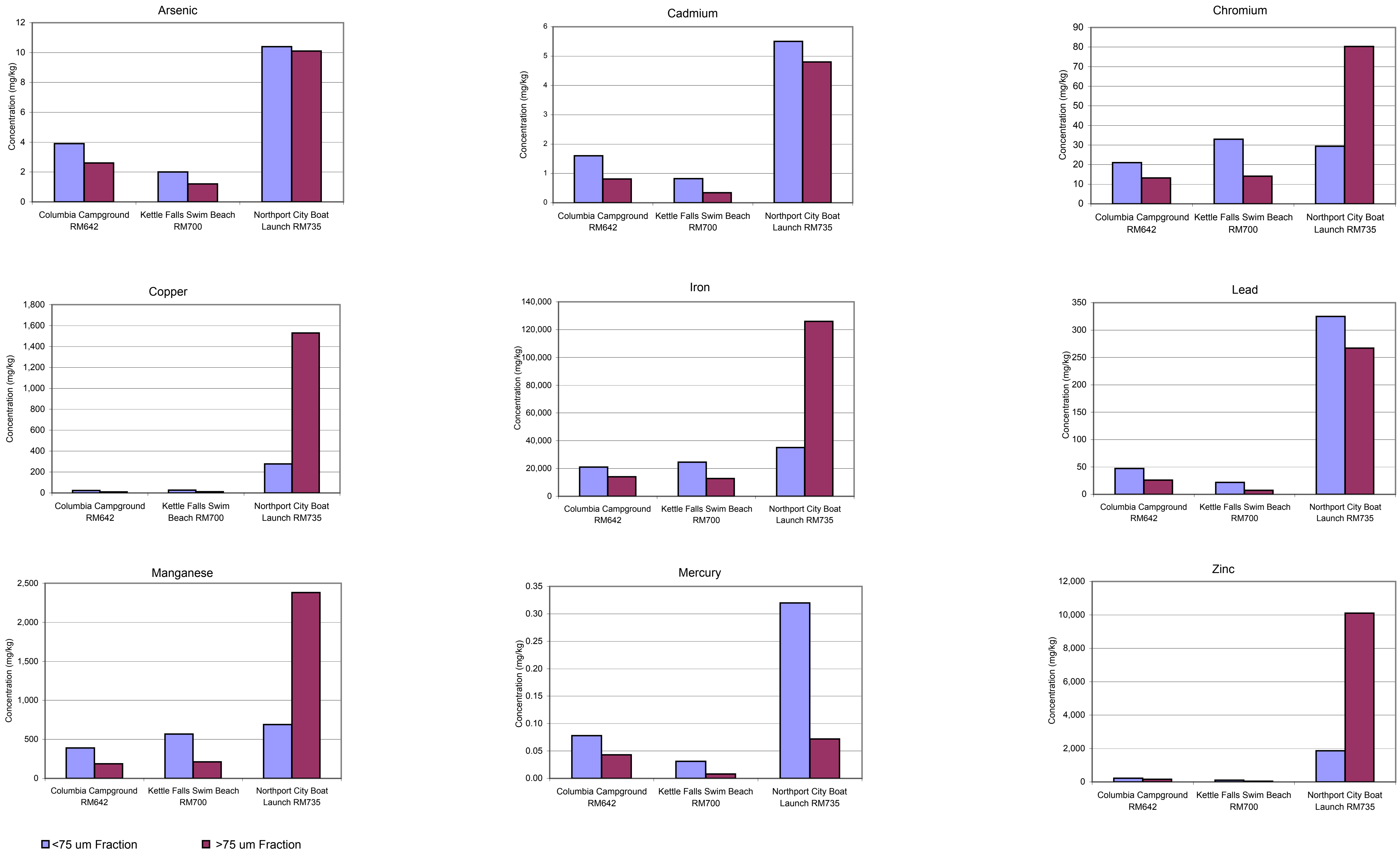

FIGURE 5-42

2,3,7,8-TCDF Correlation with TOC - Phase I Beach Composite and Sediment Core Samples

Upper Columbia River RI/FS

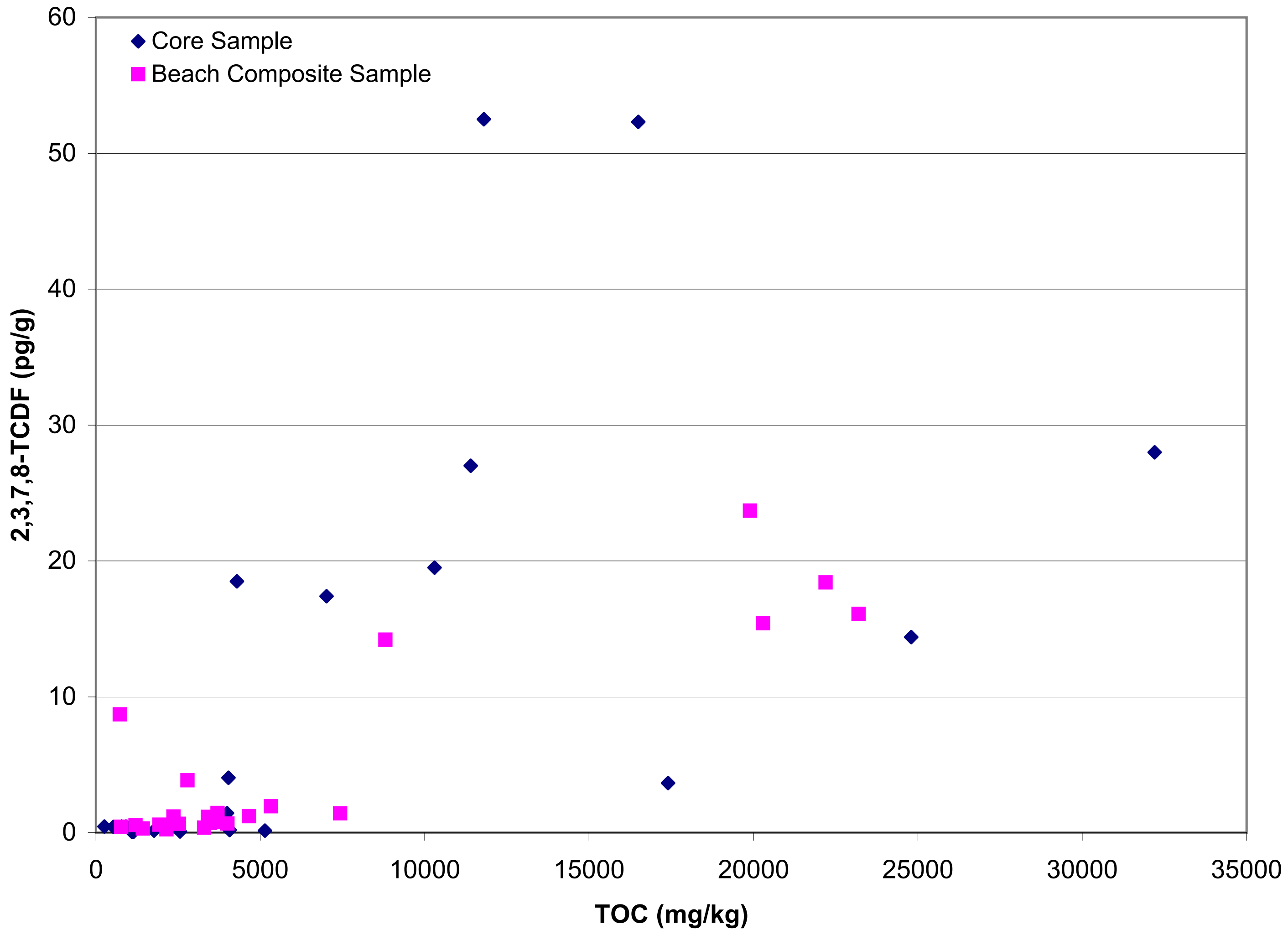

FIGURE 5-43

2,3,7,8-TCDF Correlation with Percent Colloid and Clay Fractions- Phase I Beach Composite and Sediment Core Samples

Upper Columbia River RI/FS

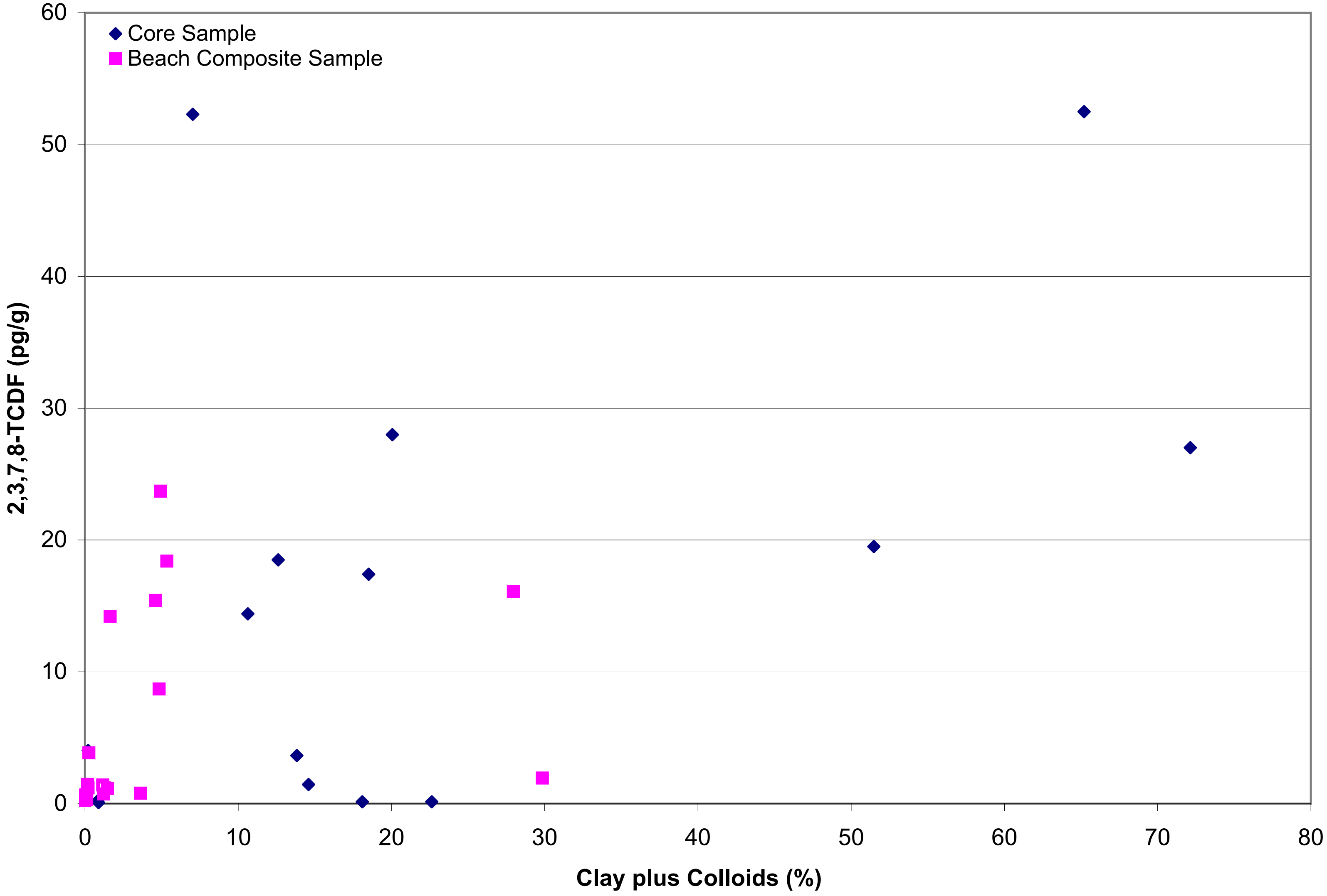

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FIGURE 5-44
Longitudinal Distribution of Pesticides by River Mile - 2005 Phase I Surface Sediment Samples
Upper Columbia River RI/FS

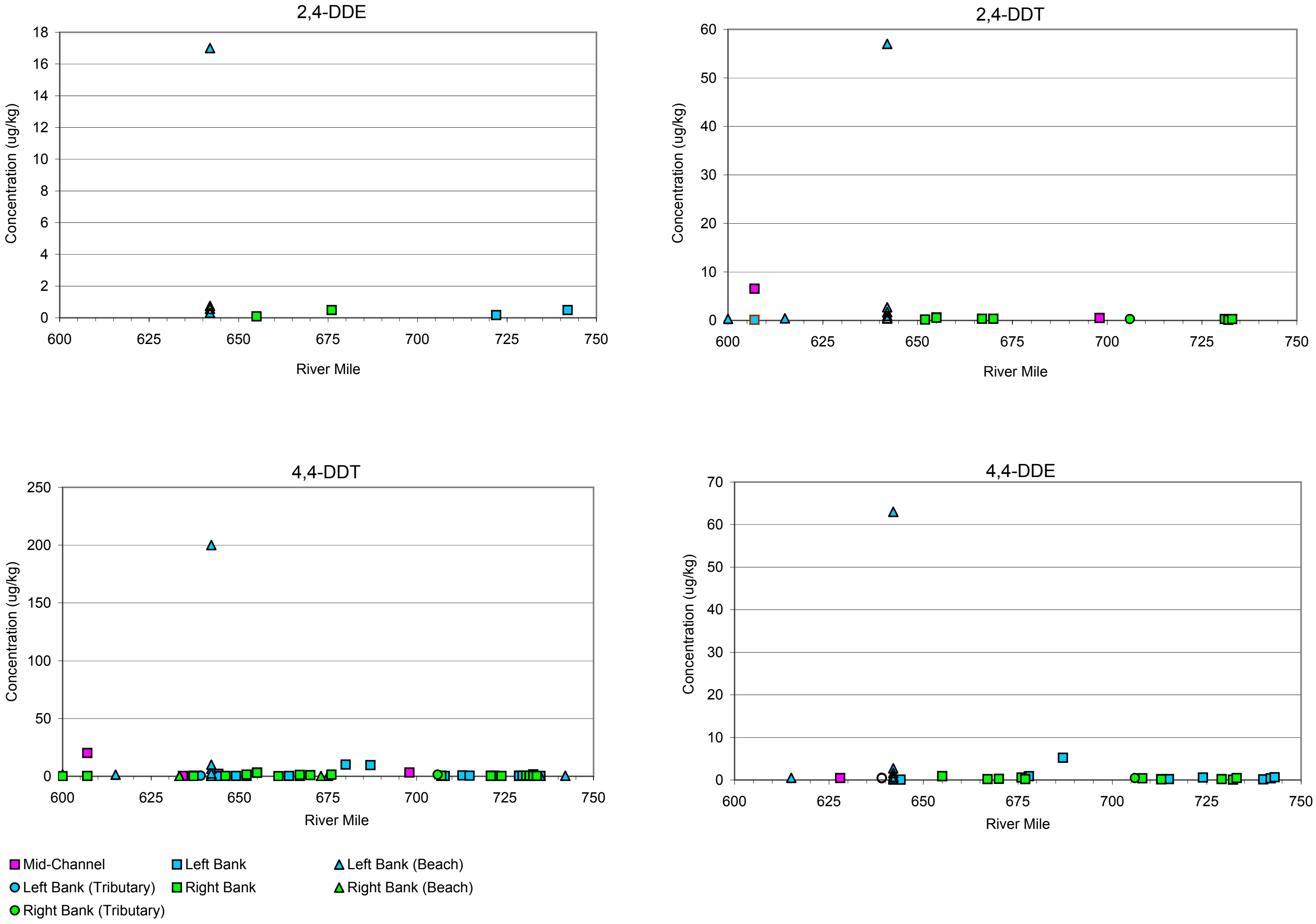

FIGURE 5-45
Longitudinal Distribution of Chrysene by River Mile - 2005 Phase I Surface Sediment Samples
Upper Columbia River RI/FS