EXPERT REPORT OF VICTOR J. BIERMAN, JR.

Joseph A. Pakootas, et al., Plaintiffs
and
State of Washington

v.

Teck Cominco Metals, Ltd., Defendant

Case No. CV-04-0256-LRS
United States District Court for Eastern District of Washington

September 17, 2010

Victor J. Bierman, Jr., Ph.D., BCEEM

LimnoTech
Water | Environment | Scientists | Engineers

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ABBREVIATIONS

cfs	Cubic feet per second
cms	Cubic meters per second
CRIEMP	Columbia River Integrated Environmental Monitoring Program
dyne/cm^2	Dynes per square centimeter
EPA	U.S. Environmental Protection Agency
GIS	Geographical information system
HEC-RAS	Hydraulic Engineering Center-River Analysis System
mg/kg	Milligrams per kilogram
mm	Millimeters
m^3/s	Cubic meters per second
NAD83	North American Datum 1983
PEP	Provincial Emergency Program
QA/QC	Quality assurance and quality control
RI/FS	Remedial Investigation and Feasibility Study
RM	River mile
UCR	Upper Columbia River
µg/L	Micrograms per liter
USGS	U.S. Geological Survey
WQO	Water Quality Objectives
1D	One-dimensional
3D	Three-dimensional

DECLARATION

My name is Victor J. Bierman, Jr., and I am a Senior Scientist at LimnoTech, an environmental science and engineering consulting firm whose home office is located in Ann Arbor, Michigan. I earned an A.B. in Science from Villanova University, and an M.S. in Physics and a Ph.D. in Environmental Engineering from the University of Notre Dame. I am a former U.S. EPA National Expert in Environmental Exposure Assessment and a former Associate Professor in the Department of Civil Engineering at the University of Notre Dame. I am a Board Certified Environmental Engineering Member, by Eminence, of the American Academy of Environmental Engineers. I have 37 years of experience in the development and application of water quality models for toxic chemical transport and fate, and eutrophication.

As a LimnoTech Senior Scientist, I conduct research and development on projects for federal, state and regional government clients. I also provide scientific peer review and expert testimony on a variety of environmental issues for government agencies, and industrial, regulatory and private clients.

My work with toxic chemicals focuses on transport, fate, partitioning and bioaccumulation of organic chemicals and metals. I have conducted studies in major river systems, estuaries, and the Great Lakes, and remedial investigations at U.S. EPA Superfund sites. These studies have included the Hudson, Fox and Kalamazoo Rivers, Green Bay and Saginaw Bay in the Great Lakes, the Columbia River, and the Delaware and Potomac River estuaries.

My full resume is contained in Appendix A.

I was asked to provide expert testimony on the transport and fate of the defendant's waste discharges from their facility at Trail, British Columbia, on the Upper Columbia River (UCR). I investigated river hydraulics and sediment transport potential in the UCR and Lake Roosevelt and formed the opinion that metals in the slag and liquid waste discharged from the Teck Cominco facility at Trail, British Columbia, move downstream and have come to be located in

the United States. I also investigated observed data for metals concentrations in the water and sediments of the UCR and Lake Roosevelt to confirm and support this opinion.

I provided all of the materials I considered in forming my opinions in this expert report to Ms. Kristie E. Carevich, Assistant Attorney General, State of Washington, in electronic form on September 17, 2010.

LimnoTech was compensated at an hourly rate of $250.00 for the time I spent on this project.

EXPERT TESTIMONY IN THE PAST FOUR YEARS

State of Oklahoma, et al., v. Tyson Foods, Inc., et al. 2006-2010. I provided expert testimony pertaining to transport and fate of phosphorus from land application of poultry litter in the Illinois River Watershed, Arkansas. I prepared a written expert report, was deposed, and testified at trial in U.S. District Court for the Northern District of Oklahoma.

STUDY AREA

The Columbia River flows from northern British Columbia, generally south through eastern Washington, and then west, forming part of the border between Washington and Oregon, and then eventually flows into the Pacific Ocean. Lake Roosevelt was formed on the Columbia River by the Grand Coulee Dam which was brought into service in 1942. The portion of the river addressed in my expert report, and referred to as the Upper Columbia River (UCR) and Lake Roosevelt, extends from Lower Arrow Lake, British Columbia, to Grand Coulee Dam (Figure 1). Figure 2 shows an expanded view of the Canadian portion and the northern section of the U.S. portion between the Canada-United States border (international border) and Marcus Flats.

The study area is divided into five large-scale reaches:

- Canada Reach
- Northport Reach
- Upper Reservoir Reach
- Middle Reservoir Reach
- Lower Reservoir Reach.

These reaches are shown in Figures 3-7, respectively, and their River Mile (RM) boundaries are listed in Table 1, along with the locations of various landmarks. All RM boundaries in my expert report are based on the U.S. Geological Survey (USGS) system to the international border and then extended into Canada.

Also listed in Table 1 are the RM boundaries for the six numbered reaches in the Upper Columbia River Work Plan for the Remedial Investigation and Feasibility Study (RI/FS Work Plan) (U.S. EPA and Teck Cominco 2008a, 2008b). Reaches 1 and 2 correspond, respectively, to the Northport and Upper Reservoir Reaches in Figures 4 and 5. Reaches 3-6 correspond to sub-sections of the Middle and Lower Reservoir Reaches in Figures 6 and 7. The Canada Reach (Figure 3) is outside the study area of the RI/FS Work Plan. Lake Roosevelt comprises Reaches

2-6 and extends approximately 135 miles upstream from Grand Coulee Dam, reaching to within 15 miles of the international border.

Figure 3 shows an expanded view of the study area above the international border. Hugh Keenleyside Dam at the outlet of Lower Arrow Lake is approximately 35 miles upstream of the border near RM 780. Birchbank is located approximately 19 miles downstream at RM 761. The Teck Cominco facility at Trail, British Columbia, is located approximately 5 miles downstream of Birchbank near RM 756. Waneta is located approximately 10 miles downstream of Teck Cominco near RM 746. The Pend Oreille River enters the Columbia River approximately one mile downstream of Waneta and 0.50 mile upstream of the international border which is located at RM 745.

MOVEMENT OF WATER, SOLIDS AND METALS IN THE UPPER COLUMBIA RIVER

To understand the movement of metals in the UCR and Lake Roosevelt, it is necessary to understand the movement of water and sediment particles (solids) in the river. Flow of sediment solids through a river basin is a natural phenomenon. These solids come from the watershed, tributaries, bank erosion and landslides. Portions of metals are dissolved in the river water and other portions are partitioned (attached) to these river solids. One portion of the metals follows the river water and another portion follows the river solids. In turn, the movement and transport of solids is strongly influenced by the flow velocity of the river. Consequently, movement and transport of metals in the UCR and Lake Roosevelt depend on the interplay of river hydraulics, sediment transport, and various physical-chemical processes that control how metals partition (attach) to solids.

The Teck Cominco facility at Trail, British Columbia, discharged granulated slag into the UCR until mid-1995 and it also discharges liquid waste (Queneau 2010). Metals were in the slag solids and are also in the liquid waste. These metals include antimony, arsenic, cadmium, chromium, copper, lead, manganese, mercury and zinc. The liquid waste contains metals dissolved in the liquid waste and metals partitioned to particles in the waste (Queneau 2010; U.S. EPA 2006; Teck Cominco 1997). Metals in the liquid waste do not look the same after they are discharged to the UCR because they become re-distributed between metals dissolved in the river water and metals partitioned to river solids, primarily fine-grained particles (e.g., Horowitz 1991; Stumm and Morgan 1996; Owens et al. 2005). Metals could also have partitioned to fine-grained slag particles. The amount of river solids is much greater than the amount of solid particles in the original liquid waste. River solids are less dense than granulated slag solids and most of them are smaller. I will refer to river solids as "non-slag" solids to distinguish them from the granulated slag solids discharged by Teck Cominco.

Metals discharged by Teck Cominco before mid-1995 move down the UCR associated with slag solids, partitioned to non-slag river solids, and dissolved in the river water. Metals discharged by Teck Cominco after mid-1995 move down the river partitioned to non-slag river solids and

dissolved in the river water. During both periods of time, movement and transport of metals in the UCR depend on river hydraulics, sediment transport, and processes that control how metals partition to solids.

In the upstream portion of the UCR, the river water flows fast and has high energy. As the water flows downstream it slows down and loses energy due to the backwater influence of Grand Coulee Dam and because the river becomes wider. Sediment transport is strongly influenced by the flow velocity of the river and the size of the sediment particles. At the high river velocities in the upper reaches of the river, slag particles and non-slag river particles can both remain mobile and be transported by the water. As velocities decline in the middle reach of the river, most of the larger slag particles cannot remain mobile and begin to settle out of the water column and deposit in the sediment bed at the bottom of the river. As velocities decline further, only the fine-grained slag and non-slag river particles can remain mobile and be transported. Finally, when velocities approach their lowest values in the lower reaches, even these fine-grained particles cannot remain mobile and settle out of the water column and into the sediment bed.

This interplay of river hydraulics and sediment transport is a dynamic process in which particles are "sorted" from upstream to downstream in order of decreasing size. As the water moves downstream and loses energy, metals associated with solids settle out along the way and are deposited to the sediment bed in the UCR and Lake Roosevelt. This is why not all of the metals go out Grand Coulee Dam. The spatial distribution of a particular metal down the river, and its distribution between the water column and sediment bed, depend on how fast the river water moves, the sizes of the solids with which it is associated, and how strongly it partitions to these solids (e.g., Owens et al. 2005; Foster and Charlesworth 1996).

I investigated river hydraulics and sediment transport potential in the UCR and Lake Roosevelt and formed the opinion that metals in the slag and liquid waste discharged from the Teck Cominco facility at Trail, British Columbia, move downstream and have come to be located in the United States. I also investigated observed data for metals concentrations in the water and sediments of the UCR and Lake Roosevelt to confirm and support this opinion.

METHODS FOR DATA REVIEW

Although the Remedial Investigation and Feasibility Study (RI/FS) for the UCR is still ongoing, there exists a large body of data collected by provincial, federal and state agencies, consulting companies, and Teck Cominco. These data are sufficient to draw conclusions and form opinions about the movement and downstream transport of metals discharged by Teck Cominco at Trail, British Columbia.

I relied upon 16 different datasets in forming my opinions in this expert report. These data included the water column and the sediments at the bottom of the UCR and Lake Roosevelt. The parameters included metals (antimony, arsenic, cadmium, chromium, copper, lead, manganese, mercury and zinc), solids, organic carbon and grain size. These data represent the Canadian and U.S. portions of the study area from Lower Arrow Lake, British Columbia, to Grand Coulee Dam. Appendix B contains an annotated bibliography which describes each of these 16 datasets, including the field and laboratory quality assurance and quality control (QA/QC) procedures used by the reporting agencies.

Before using any of these datasets, I conducted my own independent review of the data themselves and their associated sampling locations. My review involved comparison of the reported data and geographical information system (GIS) information in each dataset to at least one independent source, usually a published report containing the data in tabulated form. In addition to comparing the reported value of each result, tallies of the total number of locations, samples and results were all compared for consistency so that potential missing data or duplicated data could be investigated. The GIS information was compared to published coordinates and/or maps in one or more independent sources, usually published reports. Each sampling location was inspected against an independent data source and the location description to confirm that the mapped location was correct. The GIS information for all datasets was standardized in a consistent coordinate system, the North American Datum 1983 (NAD83). Appendix C contains detailed results of my data and GIS reviews, and the specific sources for each of the 16 datasets.

OPINION 1

Metals in the slag and liquid waste discharged by Teck Cominco into the Columbia River at Trail, British Columbia, move downstream and are transported to the United States.

Metals discharged by Teck Cominco move down the river associated with slag solids (pre-1995), partitioned to non-slag river solids, and dissolved in the river water. The first step in my investigation was to show that there is only one possible flow pathway from the Teck Cominco facility to the United States and that there are no dams along this pathway to trap slag or non-slag river solids. I then went on to investigate observed data for metals in the river to show that metals discharged by Teck Cominco move downstream and are transported to the United States.

A. Hydraulics and Transport

The Columbia River is the principal inflow to Lake Roosevelt and contributes flow from a large drainage basin area in Canada and the United States. In addition to the Columbia River, six other major rivers flow directly into the UCR and Lake Roosevelt: the Kootenay, Pend Oreille (U.S. spelling), Kettle, Colville, Spokane and Sanpoil rivers (Figure 1). The Pend Oreille River flows into the main stem of the Columbia River just north of the international border (Figure 3).

There is a single flow path directly from Teck Cominco at Trail, British Columbia, to the United States. Metals dissolved in the river water move downstream and are transported directly to the international border.

Dams can impede the downstream transport of slag and non-slag river solids, and any associated metals, by trapping and retaining them behind the dams. However, there are no dams to trap these solids between the Teck Cominco facility at Trail, British Columbia, and the United States.

Figure 8 shows the locations and dates of construction for all dams on the UCR and Lake Roosevelt. Figure 9 shows an expanded view of the UCR in the vicinity of the international border, including an inset for the Waneta Dam on the Pend Oreille River. The downstream transport of metals discharged by the Teck Cominco facility via slag or non-slag river solids is unimpeded by the presence of any dams between Trail, British Columbia, and the United States.

B. Observed Data for Metals in the River

I went on to investigate two different sets of observed data in the river to show that metals discharged by Teck Cominco move downstream and are transported to the United States. The first dataset included measurements for two spill events from the Teck Cominco facility reported by Mr. Bill Duncan, Senior Biologist for Teck Cominco. Both datasets included measurements from routine water quality monitoring conducted by the British Columbia Ministry of the Environment at Birchbank and Waneta.

The Birchbank monitoring station is located 5.90 miles upstream of the Teck Cominco facility at Trail, British Columbia, and the Waneta station is located 9.57 miles downstream of the facility (Figure 3). The confluence of the Pend Oreille River is 1.15 miles below the Waneta station and the international border is 0.50 miles below the confluence. The total distance between the Teck Cominco facility and the international border is 11.21 miles.

The spill event data show that metals discharged by Teck Cominco at Trail, British Columbia, move downstream and are transported to the United States. The routine water quality monitoring data show that the movement and downstream transport of metals from Teck Cominco to the United States is not limited to isolated spill events, but occurred historically during the period of active slag discharge and continued even after significant changes to the discharges from the Teck Cominco facility.

1. Observed Data for Spill Events

i. Teck Cominco Spill Emergency Protocol

As part of the British Columbia's Provincial Emergency Program (PEP), Teck Cominco has reported spill events at its Trail, British Columbia, facility (e.g., Duncan 2008a, 2008b, 2007a, 2007b). The Teck Cominco spill emergency protocol involves triggering of automatic samplers downstream at Waneta in response to a spill event. The operating premise of this protocol is that spills of substances at the Trail facility are transported downstream to Waneta, and that the travel times for these spills can be estimated from river flows and a HEC-RAS hydraulic model developed by BC Hydro and Power Authority (Duncan 2008c). As evidence of this premise, Duncan (2008c) specifically proposed a sampling campaign to test this spill response protocol by adding lithium as a tracer to a Teck Cominco outfall to simulate a spill event, and then gathering monitoring data at Waneta to calibrate the HEC-RAS model for various flow conditions in the river.

ii. Spill Event on April 7, 2008

On April 7, 2008, a spill event began at 8:01 AM from the Teck Cominco Comb III outfall (Duncan 2008b). The spill included arsenic, cadmium, copper, lead, thallium and zinc. The event was reported to the British Columbia PEP and assigned the file number DGIR No. 800072. Water samples were collected at the Waneta Water Quality Objectives (WQO) station with an automated sampler that was manually triggered. Four of these samples (10:20 AM; 10:50 AM; 11:20 AM; and 12:00 PM) were analyzed. Based on the HEC-RAS model (Duncan 2008c) and flow conditions at Birchbank at the time of the spill (1,050 m^3/s or 37,080 cfs), the travel time from the Trail facility to Waneta was estimated to be approximately 200 minutes (3.3 hours).

Figures 10-12 show illustrative results for total water column concentrations of zinc, lead and cadmium collected at Waneta with the automated sampler, along with ambient concentrations in the river from routine monitoring data at Birchbank (Station ID BC08NE0005) and Waneta (Station ID BC08NE0001). Monitoring data were collected approximately biweekly at Birchbank and approximately weekly at Waneta (Environment

Canada 2010). All of these total concentrations included metals dissolved in the river water and partitioned to non-slag river solids.

The top panel in each figure shows ambient concentrations in the river at Birchbank for approximately one month before and after the reported spill. The middle panel in each figure shows ambient concentrations in the river at Waneta for approximately one month before and after the reported spill, along with concentrations measured in the four samples taken at Waneta approximately three hours after the reported spill. The bottom panel in each figure shows results from these four samples at Waneta on an expanded time scale. Open symbols represent reported non-detect values plotted at the detection limit.

For all three metals, the ranges of concentrations measured at Waneta approximately three hours after the reported spill are higher than ambient concentrations in the river upstream and downstream of the Teck Cominco facility at Trail, British Columbia. All ambient concentrations of total zinc are below 2.4 µg/L and the four concentrations measured at Waneta approximately three hours after the spill range from 5.8 to 27 µg/L (Figure 10). All ambient concentrations of total lead are below 0.53 µg/L and the four concentrations measured at Waneta approximately three hours after the spill range from 0.90 to 2.7 µg/L (Figure 11). Finally, all ambient concentrations of total cadmium are below 0.07 µg/L and the four concentrations measured at Waneta approximately three hours after the spill range from 0.10 (detection limit) to 0.50 µg/L (Figure 12).

iii. Spill Event on May 28, 2008

On May 28, 2008, another spill event began at 4:45 PM from the Teck Cominco Combined III outfall (Duncan 2008a). The spill included arsenic, cadmium, copper, lead, thallium and zinc. This event was reported to the British Columbia PEP and assigned the file number DGIR No. 800593. Twenty-four (24) samples were collected with the automated sampler at Waneta between 7:30 PM and 11:20 PM and all 24 samples were analyzed. Based on the HEC-RAS model (Duncan 2008c) and flow conditions at Birchbank at the time of the spill (3,095 m^3/s or 109,299 cfs), the travel time from the Trail facility to

Waneta was estimated to be approximately 135 minutes (2.25 hours). Figures 13-15 show illustrative results for total water column concentrations of zinc, lead and cadmium using the same format as in Figures 10-12. Again, all of these total concentrations included metals dissolved in the river water and partitioned to non-slag river solids.

For all three metals, concentrations measured at Waneta approximately two to four hours after the reported spill are higher than ambient concentrations in the river upstream and downstream of the Teck Cominco facility at Trail, British Columbia. All ambient concentrations of total zinc are less than 3.7 µg/L and the concentrations measured at Waneta two to four hours after the spill range from 2.6 to 33 µg/L (Figure 13). Only two of the 24 samples for the spill event are less than 3.7 µg/L. All ambient concentrations of total lead are below 0.68 µg/L and the concentrations measured at Waneta two to four hours after the spill range from 0.80 to 29 µg/L (Figure 14). Finally, all ambient concentrations of total cadmium are below 0.05 µg/L and the concentrations measured at Waneta two to four hours after the spill range from 0.10 (detection limit) to 1.0 µg/L (Figure 15).

Subsequent to the above analyses of the automated samples at Waneta, the remaining volumes in these samples were acid-preserved and then re-analyzed for metals. Total zinc ranged from 2.6 to 33 µg/L in the original raw samples, but ranged from 5.3 to 42 µg/L in the acid-preserved samples. Total lead ranged from 0.80 to 29 µg/L in the original raw samples, but ranged from 6.9 to 66 µg/L in the acid-preserved samples. Total cadmium concentrations in the acid-preserved samples were approximately the same as those in the original raw samples.

iv. Summary of Evidence from Spill Event Data

These observed spill event data are strong evidence that metals discharged by Teck Cominco at Trail, British Columbia, move downstream and are transported to Waneta. I inferred that these metals continue to move downstream and are transported to the United States because there is only one possible flow path from Waneta to the international

border. Furthermore, the distance between the Teck Cominco facility at Trail, British Columbia, and the Waneta sampling station is 9.57 miles, which is already 85 percent of the total distance between Teck Cominco and the international border (11.21 miles). The average travel time between Teck Cominco and Waneta for the above two spill events was 168 minutes (2.79 hours), which corresponds to an average travel velocity of 3.43 miles per hour. At this rate, metals require only another 29 minutes to travel the remaining 1.64 miles from Waneta to the international border, along the only possible flow path.

The average travel velocity of 3.43 miles per hour between the Teck Cominco facility at Trail, British Columbia, and the international border was corroborated by independent modeling analyses. The river flows for the above two spill events were 1,050 m^3/s (37,080 cfs) and 3,095 m^3/s (109,299 cfs). For the average of these two flows (2,072 m^3/s or 73,190 cfs), the time of travel calculations by McLean (2010) produce an average travel velocity of 3.31 miles per hour between these two locations, which is within three percent of the value I assumed.

2. Observed Data from Water Quality Monitoring

Next, I went on to investigate observed water quality monitoring data collected by the British Columbia Ministry of the Environment at Birchbank and Waneta. These data show that the movement and downstream transport of metals from the Teck Cominco at Trail, British Columbia, to the United States is not limited to isolated spill events, but occurred historically during the period of active slag discharge and continued even after significant changes to the discharges from the Teck Cominco facility.

i. Water Column Monitoring Data

Monitoring is conducted approximately bi-weekly at Birchbank (Station ID BC08NE0005) and approximately weekly at Waneta (Station ID BC08NE0001) as part of the British Columbia Provincial Monitoring Program (Environment Canada 2010). Analyses were conducted for total water column concentrations of antimony, arsenic, cadmium,

chromium, copper, lead, manganese and zinc. These total concentrations included the metals associated with slag (pre-1995), metals partitioned to non-slag river solids, and metals dissolved in the river water.

I investigated data from two time periods, 1983-1985 and 2003-2009. The first period (1983-1985) was selected because it is prior to the cessation of active slag discharge from the Teck Cominco facility in 1995. It is also the first period for which water column metals data are available to conduct upstream and downstream analyses using an internally consistent dataset collected by a single agency.

The second period (2003-2006) was selected for several reasons. First, it is after several significant changes to the discharges from the Teck Cominco facility, including the cessation of active slag discharge in 1995, the operation of a new KIVCET lead smelter in 1999, and installation of a seepage collection system in the Stoney Creek watershed in 1997-1998 (G3 Consulting 2001). Second, the reported detection limits were lower than those during 1996-2002 because there was higher sensitivity and more consistency in the analytical methods. This minimized the number of reported non-detect values, especially for cadmium.

ii. Data Evaluation

I evaluated these data and showed that metals concentrations at Waneta, downstream of the Teck Cominco facility at Trail, British Columbia, are substantially higher than those upstream at Birchbank and they have distinctly different patterns. These comparisons were conducted using only detected metals concentrations so that differences in the number of non-detects and the uncertainty in their values did not influence comparisons of concentrations between locations.

Illustrative box and whisker plots (Figures 16-18) are presented for zinc, lead and cadmium. In the UCR, zinc is strongly associated with coarse-grained slag, lead is less strongly associated, and cadmium is primarily associated with finer-grained sediments

(U.S. EPA 2006). On the box and whisker plots, the median is indicated by a horizontal line, the arithmetic average by an "x," the 25^{th} and 75^{th} percentiles by the upper and lower boundaries of the box, the 5^{th} and 95^{th} percentiles by the "whiskers," and individual data points that lie outside the "whiskers" by open circles.

Figure 16 shows box and whisker plots for total zinc concentrations at Birchbank and Waneta during 1983-1985 (top panel) and 2003-2009 (bottom panel). Median total zinc concentrations at Waneta, downstream of the Teck Cominco facility at Trail, are higher than those upstream at Birchbank during both time periods.

Figure 17 shows the corresponding box and whisker plots for total lead concentrations. Median total lead concentrations at Waneta, downstream of the Teck Cominco facility at Trail, are higher than those upstream at Birchbank during both time periods.

Figure 18 shows the corresponding box and whisker plots for total cadmium concentrations for 2003-2009. Median total cadmium concentrations at Waneta, downstream of the Teck Cominco facility at Trail, are higher than those upstream at Birchbank during 2003-2009. There is an insufficient number of detected cadmium data at Birchbank for 1983-1985 to construct box and whisker plots. It should be noted that detection limits for cadmium were higher during 1983-1985 than during 2003-2009.

Cumulative frequency distribution (CFD) plots are also presented for zinc, lead and cadmium (Figures 19-21). Cumulative frequency distributions are another way to illustrate the sharp differences in metals concentrations upstream and downstream of the Teck Cominco facility. They show the percent of observations in a group that are less than or equal to a particular value. They are a "running total" of the frequencies of occurrence of a particular value. The CFDs presented here are useful for visualizing differences in how the concentrations for each metal are distributed at Birchbank versus Waneta.

For example, Figure 19 shows CFDs for total zinc concentrations at Birchbank and Waneta during 1983-1985 (top panel) and 2003-2009 (bottom panel). During 1983-1985, one

percent of the observations at Birchbank are less than or equal to 1 µg/L, and one percent of the observations at Waneta are less than or equal to 3 µg/L. At Birchbank, 50 percent of the observations are less than or equal to 3 µg/L and 50 percent of the observations are greater than 3 µg/L. This means that 3 µg/L is the median concentration at Birchbank. Likewise, 16 µg/L is the median concentration at Waneta. Finally, 100 percent of the observations at Birchbank are less than or equal to 17 µg/L, and 100 percent of the observations at Waneta are less than 111 µg/L. The distribution of observations at Waneta is clearly distinct from the distribution at Birchbank because the respective CFDs do not overlap or intersect over the entire range of observed concentrations.

Figure 19 shows clear distinctions in the distributions of observed zinc concentrations between Birchbank and Waneta for both 1983-1985 and 2003-2009. Median zinc concentrations downstream at Waneta are substantially higher than those upstream at Birchbank. In addition, the cumulative distributions of observations at Waneta are greater than those at Birchbank over the entire range of observed concentrations. It should be noted that the separations between these distributions are actually greater than they appear because of the log scale used for zinc concentrations on the vertical axes.

Figure 20 shows CFDs for total lead concentrations at Birchbank and Waneta during 1983-1985 (top panel) and 2003-2009 (bottom panel). Median lead concentrations downstream at Waneta are substantially higher than those upstream at Birchbank. The cumulative distributions at Waneta are greater than those at Birchbank over the entire range of observed concentrations.

Figure 21 shows CFDs for total cadmium concentrations at Birchbank and Waneta during 2003-2009. Median cadmium concentrations downstream of Waneta are substantially higher than those upstream at Birchbank. The cumulative distributions at Waneta are greater than those at Birchbank over the entire range of observed concentrations.

Cumulative frequency distributions for all other metals are contained in Appendix D. Results for antimony and chromium are presented for only 2003-2009 because insufficient

data are available for 1983-1985. There are eight different combinations of metals and time periods for which comparisons can be made between Birchbank and Waneta. For all eight of these combinations, median concentrations downstream of Teck Cominco at Waneta are higher than those upstream at Birchbank. For seven of these eight combinations, cumulative distributions downstream at Waneta are greater than those upstream at Birchbank. The only exception is for chromium in 2003-2009 because the upstream and downstream distributions overlap between the 10^{th} and 40^{th} percentiles (Figure D-3).

Combining the CFD results for all metals (including zinc, lead and cadmium), there are 13 different combinations of metals and time periods for which comparisons can be made between Birchbank and Waneta. For all 13 of these combinations, median concentrations downstream of Teck Cominco at Waneta are higher than those upstream at Birchbank. For 12 of these 13 combinations, cumulative distributions downstream of Waneta are greater than those upstream at Birchbank.

iii. Summary of Evidence from Water Column Monitoring Data

These observed water quality monitoring data strongly confirm the above results from evaluation of the observed spill event data. That is, metals discharged by Teck Cominco at Trail, British Columbia, move downstream and are transported to the United States. In addition, these observed monitoring data are strong evidence that the movement and downstream transport of metals from Teck Cominco to the United States is not limited to isolated spill events, but occurred historically during a period of active slag discharge (1983-1985) and continued during 2003-2009 even after significant changes to the discharges from the Teck Cominco facility between 1995 and 1998.

OPINION 2

Metals in the slag and liquid waste discharged by Teck Cominco into the Columbia River at Trail, British Columbia, have come to be located in the Upper Columbia River and Lake Roosevelt.

Metals in the slag and liquid waste discharged by Teck Cominco at Trail, British Columbia, move downstream and are transported to the United States. These metals move down the river associated with slag solids (pre-1995), partitioned to non-slag river solids, and dissolved in the river water. As the water moves further downstream and loses energy, slag and non-slag river solids settle out along the way and deposit metals to the sediment bed in the UCR and Lake Roosevelt.

I investigated the transport potential for solids in the river to show that both slag solids and non-slag river solids are deposited to the sediment bed in the UCR and Lake Roosevelt. Next, I investigated observed data for metals in the sediments to show that metals discharged by Teck Cominco at Trail, British Columbia, are also deposited to the sediment bed and have come to be located in the UCR and Lake Roosevelt.

A. Hydraulics and Sediment Transport Potential

Another expert in this case (McLean 2010) has shown that slag discharged by Teck Cominco at Trail, British Columbia, before 1995 and non-slag river solids move downstream and are transported to the international border.

HydroQual Inc., Teck Cominco's own consultant for the RI/FS Work Plan, developed two different mathematical models for the UCR that both start at the international border, a one-dimensional (1D) hydraulic model and a three-dimensional (3D) hydrodynamic model (U.S. EPA and Teck Cominco 2008b, Appendix C). In reference to results from their 3D hydrodynamic model, HydroQual suggested that the upstream portions of the UCR nearest to the

international border are largely transport zones for most particle types and that the river has enough energy to transport all size classes of solids. They went on to conclude that other areas of the UCR through Marcus Flats (and likely further downstream) are largely deposition zones.

I investigated the continued downstream movement and transport of solids from the international border to the UCR and Lake Roosevelt using results from the 1D hydraulic model developed by HydroQual (U.S. EPA and Teck Cominco 2008b, Appendix C). HydroQual applied the U.S. Army Corps of Engineers HEC-RAS 4.0 (Hydraulic Engineering Center – River Analysis System) computer model (U.S. Army Corps of Engineers 2008) to the area from the international border (RM 745) to Grand Coulee Dam (RM 596). HEC-RAS simulates 1D hydrodynamics and sediment transport potential for non-cohesive sediments. These are sediments in which the particles do not stick together. A typical example is sand.

HEC-RAS was developed by the U.S. Department of Defense, Army Corps of Engineers, to manage the rivers, harbors, and other public works under their jurisdiction. It is peer-reviewed, in the public domain, and has found wide acceptance by government agencies and private firms. I reviewed the HydroQual HEC-RAS model and found it acceptable for my investigation of reach-scale sediment transport potential.

HydroQual conducted preliminary (uncalibrated) HEC-RAS simulations for upstream flows ranging from 2,000 to 14,000 m^3/s (71,000 to 495,000 cfs) and downstream water elevations of 368 m (1,210 ft) (low pool) and 393 m (1,290 ft) (high pool). These flows and water elevations represent a range of conditions that occurred since construction of the Grand Coulee Dam began in 1938. For these simulations, HydroQual used a Manning's *n* value of 0.040. Manning's *n* is a flow resistance coefficient and is the principal parameter used to calibrate the HEC-RAS model. The value of 0.040 is reasonable and appropriate for the conditions in the UCR. In addition, HydroQual conducted sensitivity analyses for Manning's *n* values that represented a range of river conditions from smooth bed and high depth (0.020) to rough bed and low depth (0.080) and found that model results in most locations were not highly sensitive to these changes in conditions.

I conducted an analysis of reach-scale sediment transport potential using the HydroQual HEC-RAS results for flows of 2,000 and 4,000 m^3/s (71,000 and 142,000 cfs). These flows correspond approximately to the 20^{th} and 90^{th} percentiles, respectively, of daily average flows measured at the international border from 1973 to the present, and to the 55^{th} and 78^{th} percentiles, respectively, of all daily average flows measured from 1938 to the present (Figure 22).

To estimate slag transport potential, I used the critical boundary shear stresses for initiation of erosion for the five size fractions of granulated slag in Table C2 of the RI/FS Work Plan (U.S. EPA and Teck Cominco 2008b, Appendix C). These size fractions ranged from 4 mm (granule) to less than or equal to 0.25 mm (fine sand and smaller), and were assumed to have a solids density of 3.50 g/cm^3. Boundary shear stress is a measure of the force exerted by river flow on the surface of the sediment bed. For the river to transport a particle, the boundary shear stress must exceed the critical shear stress required for the particle to begin moving. Critical shear stress increases with the size of the particle. The critical boundary shear stresses in Table C2 of the RI/FS Work Plan are reproduced in Table 2.

I also used results from the HydroQual HEC-RAS model to investigate the transport potential of non-slag solids in the size range 0.125 mm (very fine sand) and smaller, and with solids densities of 2.65 g/cm^3. This particle category includes non-slag river solids in the UCR and Lake Roosevelt. My estimate of the critical boundary shear stress for these particles (1.7 $dyne/cm^2$) was based on the Shields diagram as given in analytical and graphical form by van Rijn (1984). This value of the critical boundary shear stress is at the lower limit of the Shields diagram and applies to non-slag particles in the size range between 0.125 and 0.063 mm. Particles smaller than 0.063 mm are considered to be silt- and clay-size particles. These are the non-slag particles in rivers to which most of the metals are partitioned (e.g., Owens et al. 2005; Horowitz 1991; Förstner 1990).

Because critical shear stress is proportional to particle size, slag particles larger than 4 mm (pebble and larger) have a critical shear stress greater than 50 $dynes/cm^2$ and slag particles smaller than 0.25 mm (fine sand and smaller) have a critical shear stress less than 2.5 $dynes/cm^2$

(Table 2). At critical boundary shear stresses less than this value, slag particles with sizes smaller than 0.25 mm begin to deposit out of the water column and into the sediment bed because not all of them can be mobilized and transported. Non-slag particles smaller than 0.125 - 0.063 mm (very fine sand) have a critical shear stress less than 1.7 dyne/cm^2. At a critical boundary shear stress of 1.7 dyne/cm^2, non-slag particles with sizes of 0.125 mm and smaller can be mobilized and transported. At critical boundary shear stresses less than this value, non-slag particles with sizes smaller than 0.063 mm begin to deposit out of the water column and into the sediment bed.

Figures 23 and 24 show shear stresses computed by the HEC-RAS model as a function of river mile for low pool (368.6 m) and flows of 2,000 and 4,000 m^3/s, respectively. Each of the particle size classes is color-coded as described in the figure legend. The color at each river mile corresponds to the largest particle size that can be transported in the water column. All particles smaller than this size can also be transported in the water column, but all particles larger than this size are deposited to the sediment bed. The purple triangles correspond to computed shear stresses less than 1.7 dyne/cm^2, the value at which non-slag particles with sizes smaller than 0.063 mm begin to deposit out of the water column and into the sediment bed.

The results in Figures 23 and 24 indicate that for both flows, shear stresses between the international border and Northport are large enough to mobilize and transport most of the granulated slag in the largest size fraction (granule) and all of the granulated slag in the four smaller size fractions (very coarse sand, coarse sand, medium sand, and fine sand and smaller). Results also indicate that most of the granulated slag continued to be transported downstream through the Upper Reservoir Reach to the uppermost portion of the Middle Reservoir Reach. The smallest granulated slag size fraction (fine sand and smaller) began to deposit in the Middle Reservoir Reach at the lower flow and in the uppermost portion of the Lower Reservoir Reach at the higher flow. At a given river mile, more of the granulated slag was transported downstream at higher flow than at lower flow, but the differences are not substantial between the international border and Northport. Non-slag river particles smaller than 0.063 mm begin to deposit around the upper portion of the Middle Reservoir Reach, but much more of the Middle Reservoir Reach is depositional at the lower flow than at the higher flow. Most of the Lower Reservoir Reach is

depositional for the smallest granulated slag size fraction (fine sand and smaller) and non-slag river particles less than 0.063 mm.

Figures 25 and 26 show the results for low pool in the form of maps. For both flows, most of the granulated slag was transported downstream to Marcus Flats but less was transported further downstream. Marcus Flats extends approximately from RM 708 through RM 703. At the lower flow, most of the river below Marcus Flat is a deposition zone for slag particles and non-slag river particles smaller than 0.063 mm. At the higher flow, some slag was transported through the Middle Reservoir Reach and some deposition began to occur, but the Lower Reservoir Reach is primarily a deposition zone for the smallest granulated slag size fraction (fine sand and smaller) and non-slag river particles smaller than 0.063 mm.

Results for high pool (392.2 m) (Figures 27 and 28) indicate that some of the granulated slag in the two largest size fractions (granule and very coarse sand) began to deposit between the international border and Northport, but most of the slag in the three smaller size fractions (coarse sand, medium sand, and fine sand and smaller) was transported downstream past Northport through the Upper Reservoir Reach. At a given river mile, more of the granulated slag was transported downstream at higher flow than at lower flow, but most of the slag particles had begun to deposit before the uppermost portion of the Middle Reservoir Reach. Non-slag river particles smaller than 0.063 mm begin to deposit in the uppermost portion of the Middle Reservoir Reach. Most of the Middle Reservoir Reach and all of the Lower Reservoir Reach are deposition zones for the smallest granulated slag size fraction (fine sand and smaller) and non-slag river particles smaller than 0.063 mm.

Figures 29 and 30 show the results for high pool in the form of maps. Most of the granulated slag was transported downstream to Northport and some of it continued to be transported downstream to just above Marcus Flats, especially at the higher flow. Most of the slag began to deposit in the vicinity of Marcus Flats. For both flows, most of the river below Marcus Flats is a deposition zone for the smallest granulated slag size fraction (fine sand and smaller) and non-slag river particles smaller than 0.063 mm.

To summarize, metals in the slag and liquid waste discharged by Teck Cominco at Trail, British Columbia, move downstream and are transported to the United States. These metals move down the river associated with slag solids (pre-1995), partitioned to non-slag river solids, and dissolved in the river water. My modeling analysis of solids transport potential is strong evidence that as the water moves downstream of the international border and loses energy, both slag solids (pre-1995) and non-slag river solids settle out along the way and are deposited to the sediment bed in the UCR and Lake Roosevelt. Because metals discharged by Teck Cominco at Trail, British Columbia, are associated with both of these types of solids, metals discharged by Teck Cominco are also deposited to the sediment bed and come to be located in the UCR and Lake Roosevelt.

B. Observed Data for Metals in Surface Sediments

Next, I investigated observed data for metals in the surface sediments to confirm my modeling results and show that metals discharged by Teck Cominco at Trail, British Columbia, are deposited to the sediment bed and come to be located in the UCR and Lake Roosevelt. Although the RI/FS is still ongoing, there exists a large body of data collected by provincial, federal and state agencies, consulting companies, and Teck Cominco. These data are sufficient to draw conclusions and form opinions about the movement and downstream transport and fate of the metals discharged by Teck Cominco.

1. Surface Sediment Metals Data

I investigated surface sediment metals concentrations for the UCR and Lake Roosevelt using data from 13 different studies:

- Baturin (1993)
- Bortleson et al. (2001)
- Columbia Environmental Consulting (2002)
- Cox et al. (2005)
- Era and Serdar (2001)
- Hatfield Consultants (2008)

- Johnson et al. (1989; 1990)
- Johnson (1991)
- Majewski et al. (2003)
- Paulson et al. (2006)
- U.S. EPA and Teck Cominco (2008a, 2008b)
- U.S. EPA (2003)
- U.S. EPA (2002)

These studies included sampling locations in Canada and the United States from Lower Arrow Lake, British Columbia, to Grand Coulee Dam. Depending on the metal, there were between 186 and 386 locations with reported detected surface sediment concentrations. There were 7 to 20 locations upstream of Teck Cominco at Trail, British Columbia, and 9 to 10 locations between Teck Cominco and the international border. There were between 170 and 356 locations from the international border to Grand Coulee Dam.

Surface sediment concentrations were considered to include all reported measurements between 0 and 15 cm depth. Data from two time periods were investigated, a 12-year period (1984-1995) of active slag discharge from the Teck Cominco facility at Trail, British Columbia, and another 12-year period (1996-2007) after cessation of active slag discharge in 1995.

2. Data Evaluation

I evaluated these data to show that metals concentrations in the sediments downstream of the Teck Cominco facility at Trail, British Columbia, are substantially higher than those upstream and they have distinctly different patterns. These comparisons were conducted using only detected metals concentrations so that differences in the number of non-detects and the uncertainty in their values did not influence comparisons of concentrations between these areas.

Illustrative spatial scatter plots are presented for zinc, lead and cadmium showing surface sediment metals concentrations along the entire flow path of the UCR from Lower Arrow Lake to Grand Coulee Dam for each time period. These concentrations are also shown in the form of maps. Illustrative cumulative frequency distributions (CFDs) are also presented for zinc, lead and cadmium to show the clear distinctions in the distributions of metals concentrations upstream and downstream of the Teck Cominco facility at Trail, British Columbia.

Figures 31 and 32 show total zinc concentrations in surface sediment versus river mile for 1984-1995 and 1996-2007, respectively. For each time period, concentrations are relatively low upstream of Teck Cominco at Trail, British Columbia, and increase substantially in the Canadian reach immediately downstream of Teck Cominco. For 1984-1995, concentrations continue to increase below the international border and then begin to decline at approximately RM 730. For 1996-2007, concentrations remain higher below the international border before beginning to decline at approximately RM 705.

Figures 33 and 34 show these results for zinc in the form of maps. In particular, the insets show reported results for all locations between Lower Arrow Lake and Northport. For both time periods, a sharp transition in surface sediment zinc concentrations is evident between upstream and downstream of the Teck Cominco facility at Trail, British Columbia.

Figures 35 and 36 show the spatial scatter plots for total lead concentrations. Again, for each time period, concentrations are relatively low upstream of Teck Cominco at Trail, British Columbia, and increase substantially in the Canadian reach immediately downstream of Teck Cominco. For 1984-1995, concentrations remain approximately level and then begin to decline around RM 660. For 1996-2007, concentrations continue to increase below the international border and then begin to decline at approximately RM 690.

Figures 37 and 38 show these results for lead in the form of maps. Again, for both time periods, a sharp transition in surface sediment lead concentrations is evident between upstream and downstream of the Teck Cominco facility at Trail, British Columbia.

Figures 39 and 40 show the spatial scatter plots for total cadmium concentrations. Again, for both time periods, concentrations are relatively low upstream of Teck Cominco, at Trail, British Columbia, and increase substantially in the Canadian reach immediately downstream of Teck Cominco. For 1984-1995 and 1996-2007, concentrations remain at high levels from the international border to Grand Coulee Dam.

Figures 41 and 42 show these results for cadmium in the form of maps. Again, for both time periods, a sharp transition in surface sediment cadmium concentrations is evident between upstream and downstream of the Teck Cominco facility at Trail, British Columbia.

Cumulative frequency distributions (CFDs) are another way to visualize these sharp differences between metals concentrations upstream and downstream of the Teck Cominco facility. Figures 43-45 show CFDs for zinc, lead and cadmium, respectively, for the reach upstream of Teck Cominco at Trail, British Columbia, and for two reaches immediately downstream, the reach between Teck Cominco and the international border, and the reach between the international border and Northport. The top panels in each figure show results for 1984-1995 and the bottom panels show results for 1996-2007.

Figure 43 shows clear distinctions in the distributions of observed zinc concentrations between the upstream reach and both downstream reaches for 1984-1995 and 1996-2007. Median zinc concentrations in the two downstream reaches are substantially higher than those in the upstream reach. In addition, the cumulative distributions of observations in each downstream reach are greater than those in the upstream reach over the entire range of observed concentrations. It should be noted that the separations between these distributions are actually greater than they appear because of the log scale used for zinc concentrations on the vertical axes.

Figure 44 shows clear distinctions in the distributions of observed lead concentrations between the upstream reach and both downstream reaches for 1984-1995 and 1996-2007. Median lead concentrations in the two downstream reaches are substantially higher than

those in the upstream reach. In addition, the cumulative distributions of observations in each downstream reach are greater than those in the upstream reach over the entire range of observed concentrations.

Figure 45 shows clear distinctions in the distributions of observed cadmium concentrations between the upstream reach and both downstream reaches for 1984-1995 and 1996-2007. Median cadmium concentrations in the two downstream reaches are substantially higher than those in the upstream reach. In addition, the cumulative distributions of observations in each downstream reach are greater than those in the upstream reach over the entire range of observed concentrations.

Cumulative frequency distributions for all other metals are contained in Appendix E. Results for antimony are presented for only 1996-2007 because insufficient data are available for 1984-1995. There are 22 different combinations of metals and reaches downstream of Teck Cominco for which CFDs can be compared to those upstream of Teck Cominco. For 21 of these 22 combinations, median concentrations downstream are higher and cumulative distributions are greater than those in the upstream reach over the entire range of observed concentrations. The only exception is for chromium in 1996-2007. Although median chromium concentrations in both downstream reaches are higher than the median concentration in the upstream reach, the distributions for the upstream reach and the first downstream reach overlap in the percentiles between 0 and 15, and between 95 and 100 (Figure E-3, bottom panel).

Combining the CFD results for all metals (including zinc, lead and cadmium), there are 34 different combinations of metals and reaches downstream of Teck Cominco for which CFDs can be compared to those upstream of Teck Cominco. For 33 of these 34 combinations, median concentrations downstream are higher and cumulative distributions are greater than those in the upstream reach over the entire range of observed concentrations.

3. Summary of Evidence from Surface Sediment Metals Data

Metals discharged by Teck Cominco at Trail, British Columbia, move down the river associated with slag solids (pre-1995), partitioned to non-slag river solids, and dissolved in the river water. My modeling analysis of solids transport potential showed that as the water moves downstream of the international border and loses energy, both slag solids (pre-1995) and non-slag river solids settle out along the way and are deposited to the sediment bed in the UCR and Lake Roosevelt. Because metals discharged by Teck Cominco at Trail, British Columbia, are associated with both of these types of solids, metals discharged by Teck Cominco are also deposited to the sediment bed and come to be located in the UCR and Lake Roosevelt.

My evaluation of the spatial distributions of observed surface sediment metals concentrations independently confirms my modeling analysis. The observed distributions of surface sediment metals concentrations from Lower Arrow Lake to the UCR and Lake Roosevelt are strong evidence that metals in the slag and liquid waste discharged by Teck Cominco at Trail, British Columbia, are the cause of substantial increases in the concentrations of these metals downstream of the Teck Cominco facility. They are also strong evidence that metals move downstream, are transported below the international border, settle out of the water column along the way, and are deposited in the sediment bed of the UCR and Lake Roosevelt.

Based on these independent lines of evidence, modeling analysis and observed sediment data, I conclude that metals in the slag and liquid waste discharged by Teck Cominco at Trail, British Columbia, have come to be located in the UCR and Lake Roosevelt.

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TABLES

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Table 1. River Mile Table for the Upper Columbia River and Lake Roosevelt Including U.S. EPA and USGS River Miles, Location and Landmark Descriptions, and RI/FS Work Plan Reach Segment Definitions

EPA River Mile	USGS River Mile	Location/Landmarks	Reach Segment Definition	RI/FS Reach Definition (Reach 1 to Reach 6)
790	791		Canada Reach	-
789	790		Canada Reach	-
788	789		Canada Reach	-
787	788		Canada Reach	-
786	787	Lower Arrow Lake	Canada Reach	-
785	786		Canada Reach	-
784	785		Canada Reach	-
783	784		Canada Reach	-
782	783		Canada Reach	-
781	782		Canada Reach	-
780	781		Canada Reach	-
779	780		Canada Reach	-
778	779		Canada Reach	-
777	778		Canada Reach	-
776	777	Castlegar	Canada Reach	-
775	776		Canada Reach	-
774	775		Canada Reach	-
773	774	Kootenay River	Canada Reach	-
772	773		Canada Reach	-
771	772		Canada Reach	-
770	771		Canada Reach	-
769	770		Canada Reach	-
768	769		Canada Reach	-
767	768		Canada Reach	-
766	767		Canada Reach	-
765	766		Canada Reach	-
764	765		Canada Reach	-
763	764		Canada Reach	-
762	763		Canada Reach	-
761	762		Canada Reach	-
760	761	At Birchbank	Canada Reach	-
759	760		Canada Reach	-
758	759		Canada Reach	-
757	758	At Trail	Canada Reach	-

EPA River Mile	USGS River Mile	Location/Landmarks	Reach Segment Definition	RI/FS Reach Definition (Reach 1 to Reach 6)
756	757		Canada Reach	-
755	756	Teck Cominco Facility	Canada Reach	-
754	755		Canada Reach	-
753	754		Canada Reach	-
752	753		Canada Reach	-
751	752		Canada Reach	-
750	751		Canada Reach	-
749	750		Canada Reach	-
748	749		Canada Reach	-
747	748		Canada Reach	-
746	747		Canada Reach	-
745	746	Near Waneta and Pend D'Oreille River	Canada Reach	-
744	745	At the US/Canadian Boundary	Northport Reach	Reach 1
743	744		Northport Reach	Reach 1
742	743	Black Sand Beach and U/S of Tom Bush Creek	Northport Reach	Reach 1
741	742		Northport Reach	Reach 1
740	741	U/S of Matthews Creek	Northport Reach	Reach 1
739	740	U/S of Scriver Creek	Northport Reach	Reach 1
738	739		Northport Reach	Reach 1
737	738	At the Mouth of Goodeve Creek	Northport Reach	Reach 1
736	737	At the Mouth of Deep Creek	Northport Reach	Reach 1
735	736	D/S of Big Sheep Creek	Northport Reach	Reach 1
734	735	At Northport	Northport Reach	Reach 1
733	734		Northport Reach	Reach 1
732	733	U/S of Fivemile Creek	Northport Reach	Reach 1
731	732	Near the Mouth of Squaw Creek	Northport Reach	Reach 1
730	731		Northport Reach/Upper Reservoir Reach	Reach 1
729	730	At the Mouth of Onion Creek	Upper Reservoir Reach	Reach 1/Reach 2
728	729		Upper Reservoir Reach	Reach 2
727	728		Upper Reservoir Reach	Reach 2
726	727	At Marble and Just D/S of Rattlesnake Creek	Upper Reservoir Reach	Reach 2
725	726		Upper Reservoir Reach	Reach 2
724	725		Upper Reservoir Reach	Reach 2
723	724		Upper Reservoir Reach	Reach 2
722	723	China Bend and At the Mouth of Ryan Creek	Upper Reservoir Reach	Reach 2

EPA River Mile	USGS River Mile	Location/Landmarks	Reach Segment Definition	RI/FS Reach Definition (Reach 1 to Reach 6)
721	722	U/S of Flat Creek and Fifteenmile Creek	Upper Reservoir Reach	Reach 2
720	721		Upper Reservoir Reach	Reach 2
719	720	D/S of Lodgepole Creek	Upper Reservoir Reach	Reach 2
718	719	Near North Gorge	Upper Reservoir Reach	Reach 2
717	718		Upper Reservoir Reach	Reach 2
716	717		Upper Reservoir Reach	Reach 2
715	716	At Bossburg	Upper Reservoir Reach	Reach 2
714	715		Upper Reservoir Reach	Reach 2
713	714	Snag Cove	Upper Reservoir Reach	Reach 2
712	713		Upper Reservoir Reach	Reach 2
711	712	Just D/S of Evans	Upper Reservoir Reach	Reach 2
710	711		Upper Reservoir Reach/Middle Reservoir Reach	Reach 2/Reach 3
709	710		Middle Reservoir Reach	Reach 3
708	709	U/S of Marcus Island	Middle Reservoir Reach	Reach 3
707	708	At Marcus	Middle Reservoir Reach	Reach 3
706	707	Just U/S of Kettle River Mouth	Middle Reservoir Reach	Reach 3
705	706	At the Mouth of Katy Creek	Middle Reservoir Reach	Reach 3
704	705		Middle Reservoir Reach	Reach 3
703	704	U/S of Martin Spring Creek	Middle Reservoir Reach	Reach 3
702	703		Middle Reservoir Reach	Reach 3
701	702		Middle Reservoir Reach	Reach 3
700	701	Near Kettle Falls	Middle Reservoir Reach	Reach 3
699	700	D/S of Sherman Creek	Middle Reservoir Reach	Reach 3
698	699	Just D/S of Colville River Mouth	Middle Reservoir Reach	Reach 3/Reach 4
697	698	Near Haag Cove and U/S of Cougar Canyon Creek	Middle Reservoir Reach	Reach 4
696	697		Middle Reservoir Reach	Reach 4
695	696	Just D/S of Rickey Creek	Middle Reservoir Reach	Reach 4
694	695	Just D/S of Roper Creek	Middle Reservoir Reach	Reach 4
693	694	At Bradbury Beach	Middle Reservoir Reach	Reach 4
692	693	At the Mouth of Martin Creek	Middle Reservoir Reach	Reach 4
691	692		Middle Reservoir Reach	Reach 4
690	691	U/S of French Rocks	Middle Reservoir Reach	Reach 4
689	690	U/S of Cuba Canyon	Middle Reservoir Reach	Reach 4
688	689		Middle Reservoir Reach	Reach 4

EPA River Mile	USGS River Mile	Location/Landmarks	Reach Segment Definition	RI/FS Reach Definition (Reach 1 to Reach 6)
687	688	Near Barnaby and Barnaby Island	Middle Reservoir Reach	Reach 4
686	687		Middle Reservoir Reach	Reach 4
685	686	At Rice	Middle Reservoir Reach	Reach 4
684	685		Middle Reservoir Reach	Reach 4
683	684		Middle Reservoir Reach	Reach 4
682	683		Middle Reservoir Reach	Reach 4
681	682		Middle Reservoir Reach	Reach 4
680	681	Near Mouth of Little Jim Creek	Middle Reservoir Reach	Reach 4
679	680	Just D/S of Daisy	Middle Reservoir Reach	Reach 4
678	678		Middle Reservoir Reach	Reach 4
677	677	U/S of Cobbs Creek	Middle Reservoir Reach	Reach 4
676	676	U/S of Hall Creek	Middle Reservoir Reach	Reach 4
675	675	At Inchelium and Gifford and the Mouth of Stranger Creek	Middle Reservoir Reach	Reach 4
674	674	D/S of Cloverleaf Beach	Middle Reservoir Reach	Reach 4
673	673	Near the Mouth of Deer Creek	Middle Reservoir Reach	Reach 4
672	672		Middle Reservoir Reach	Reach 4
671	671		Middle Reservoir Reach	Reach 4
670	670		Middle Reservoir Reach	Reach 4
669	669		Middle Reservoir Reach	Reach 4
668	668	U/S Stray Dog Canyon Creek	Middle Reservoir Reach	Reach 4
667	667		Middle Reservoir Reach	Reach 4
666	666		Middle Reservoir Reach	Reach 4
665	665		Middle Reservoir Reach	Reach 4
664	664	At the Mouth of Harvey Creek	Middle Reservoir Reach	Reach 4
663	663	U/S of Nez Perce Creek	Middle Reservoir Reach	Reach 4
662	662		Middle Reservoir Reach	Reach 4
661	661	U/S of Coyote Creek	Middle Reservoir Reach	Reach 4
660	660	U/S of Hunter Creek	Middle Reservoir Reach	Reach 4
659	659		Middle Reservoir Reach	Reach 4
658	658	D/S of Monaghan Creek	Middle Reservoir Reach	Reach 4
657	657		Middle Reservoir Reach	Reach 4
656	656		Middle Reservoir Reach	Reach 4
655	655		Middle Reservoir Reach	Reach 4
654	654	At Wilmont Bay	Middle Reservoir Reach	Reach 4
653	653		Middle Reservoir Reach	Reach 4
652	652		Middle Reservoir Reach	Reach 4

EPA River Mile	USGS River Mile	Location/Landmarks	Reach Segment Definition	RI/FS Reach Definition (Reach 1 to Reach 6)
651	651	Near Corkscrew Canyon Campground	Middle Reservoir Reach	Reach 4
650	650		Middle Reservoir Reach	Reach 4
649	649		Middle Reservoir Reach	Reach 4
648	648	Near the Mouth of Ninemile Creek	Middle Reservoir Reach	Reach 4
647	647		Middle Reservoir Reach	Reach 4
646	646		Middle Reservoir Reach	Reach 4
645	645	U/S of Sixmile Creek	Middle Reservoir Reach	Reach 4
644	644	U/S of Castle Rock Creek	Middle Reservoir Reach	Reach 4
643	643	D/S of Cottonwood Creek	Middle Reservoir Reach	Reach 4
642	642	Near the Mouth of Threemile Creek	Middle Reservoir Reach	Reach 4
641	641		Middle Reservoir Reach	Reach 4
640	640	At the Mouth of Louie Creek	Middle Reservoir Reach/Lower Reservoir Reach	Reach 4/Reach 5
639	639	At the Mouth of Spokane River	Lower Reservoir Reach	Reach 5
638	638		Lower Reservoir Reach	Reach 5
637	637		Lower Reservoir Reach	Reach 5
636	636	Near Seven Bays	Lower Reservoir Reach	Reach 5
635	635		Lower Reservoir Reach	Reach 5
634	634	At the Mouth of Hawk Creek	Lower Reservoir Reach	Reach 5
633	633		Lower Reservoir Reach	Reach 5
632	632	At Lincoln	Lower Reservoir Reach	Reach 5
631	631		Lower Reservoir Reach	Reach 5
630	630		Lower Reservoir Reach	Reach 5
629	629		Lower Reservoir Reach	Reach 5
628	628	At Sterling Point	Lower Reservoir Reach	Reach 5
627	627	U/S of Halverson Canyon Creek	Lower Reservoir Reach	Reach 5
626	626		Lower Reservoir Reach	Reach 5
625	625	At the Mouth of Jump Canyon	Lower Reservoir Reach	Reach 5
624	624		Lower Reservoir Reach	Reach 5
623	623		Lower Reservoir Reach	Reach 5
622	622	U/S of Redford Canyon	Lower Reservoir Reach	Reach 5
621	621		Lower Reservoir Reach	Reach 5
620	620	Near Jones Bay	Lower Reservoir Reach	Reach 5
619	619	Near Hanson Harbor	Lower Reservoir Reach	Reach 5
618	618	Near Goldsmith	Lower Reservoir Reach	Reach 5
617	617		Lower Reservoir Reach	Reach 5/Reach 6

EPA River Mile	USGS River Mile	Location/Landmarks	Reach Segment Definition	RI/FS Reach Definition (Reach 1 to Reach 6)
616	616	At the Mouth of the Sanpoil River	Lower Reservoir Reach	Reach 6
615	615		Lower Reservoir Reach	Reach 6
614	614	Keller Ferry	Lower Reservoir Reach	Reach 6
613	613		Lower Reservoir Reach	Reach 6
612	612	U/S of Speigle Canyon	Lower Reservoir Reach	Reach 6
611	611		Lower Reservoir Reach	Reach 6
610	610		Lower Reservoir Reach	Reach 6
609	609		Lower Reservoir Reach	Reach 6
608	608		Lower Reservoir Reach	Reach 6
607	607		Lower Reservoir Reach	Reach 6
606	606		Lower Reservoir Reach	Reach 6
605	605	D/S of Niles Canyon	Lower Reservoir Reach	Reach 6
604	604	D/S of Kwel Kwel Canyon	Lower Reservoir Reach	Reach 6
603	603	At Plum Point	Lower Reservoir Reach	Reach 6
602	602		Lower Reservoir Reach	Reach 6
601	601		Lower Reservoir Reach	Reach 6
600	600	Near Spring Canyon	Lower Reservoir Reach	Reach 6
599	599		Lower Reservoir Reach	Reach 6
598	598		Lower Reservoir Reach	Reach 6
597	597	Near Crescent Bay	Lower Reservoir Reach	Reach 6
596	596	Grand Coulee Dam	Lower Reservoir Reach	Reach 6

** "River Miles" listed above are based on the river miles provided in the following document:"Upper Columbia River, Work Plan for the Remedial Investigation and Feasibility Study, Volume I of II, Modified by USEPA, Based on a Draft Work Plan Provided By Teck Cominco American Incorporated, December 2008."*

Table 2. Estimated Critical Boundary Shear Stresses to Initiate Erosion for Various Size Fractions of Granulated Slag (From Table C2, Appendix C, U.S. EPA and Teck Cominco 2008b)

Particle Diameter (mm)	Wentworth Size Class	Critical Boundary Shear Stress ($dyne/cm^2$)	Percentage of Granulated Slag by Mass
>4		> 50	
	pebble & larger		n/a
4		50	
	granule		10%
2		20	
	very coarse sand		30%
1		7.8	
	coarse sand		30%
0.5		3.7	
	medium sand		25%
0.25		2.5	
	fine sand & smaller		5%
< 0.25		< 2.5	

Note: Values assume a granulated slag density of 3.50 g/cm^3 and that the particles have rounded shapes similar to natural quartz particles.

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FIGURES

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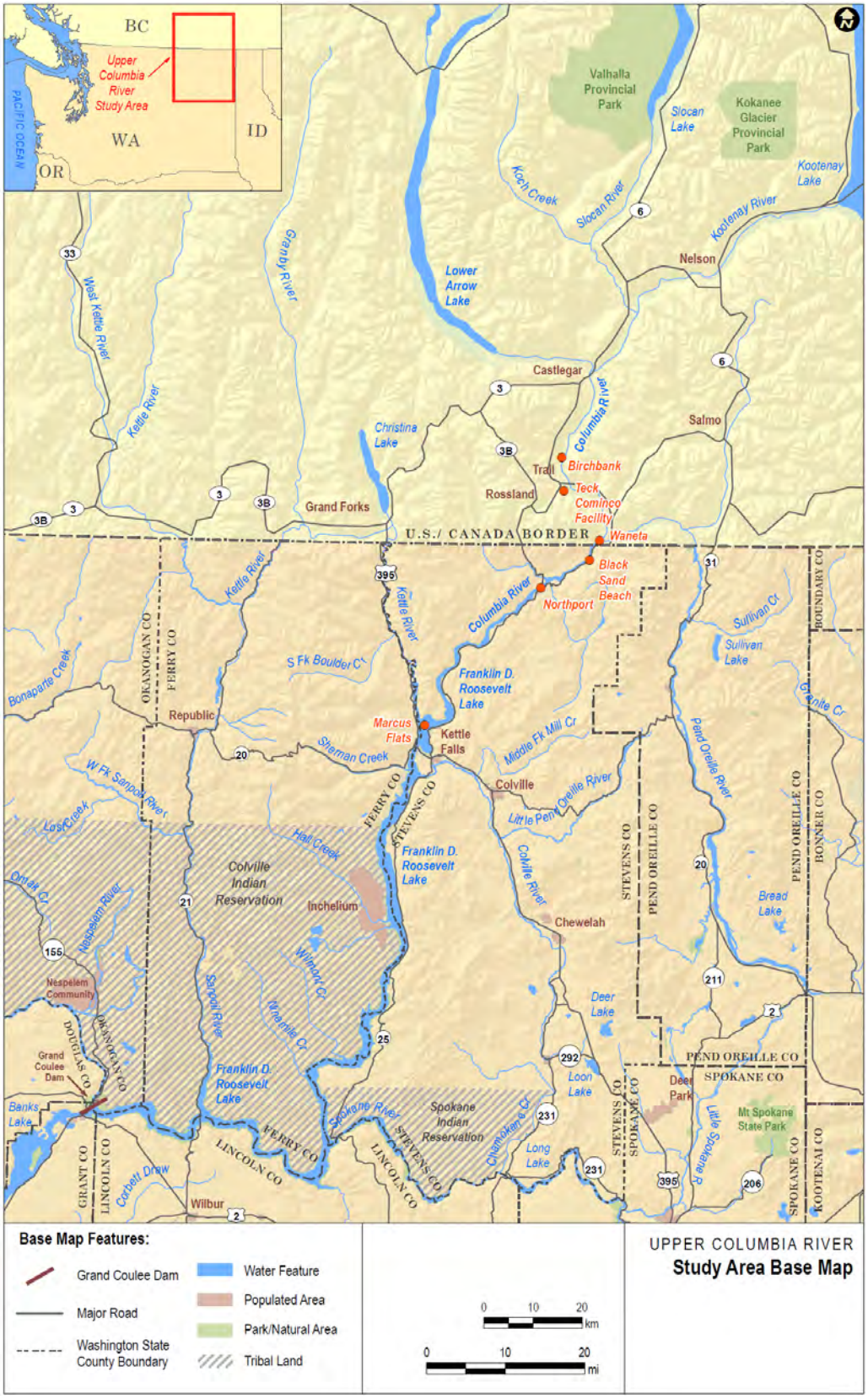


Figure 1. Map of Upper Columbia River and Lake Roosevelt

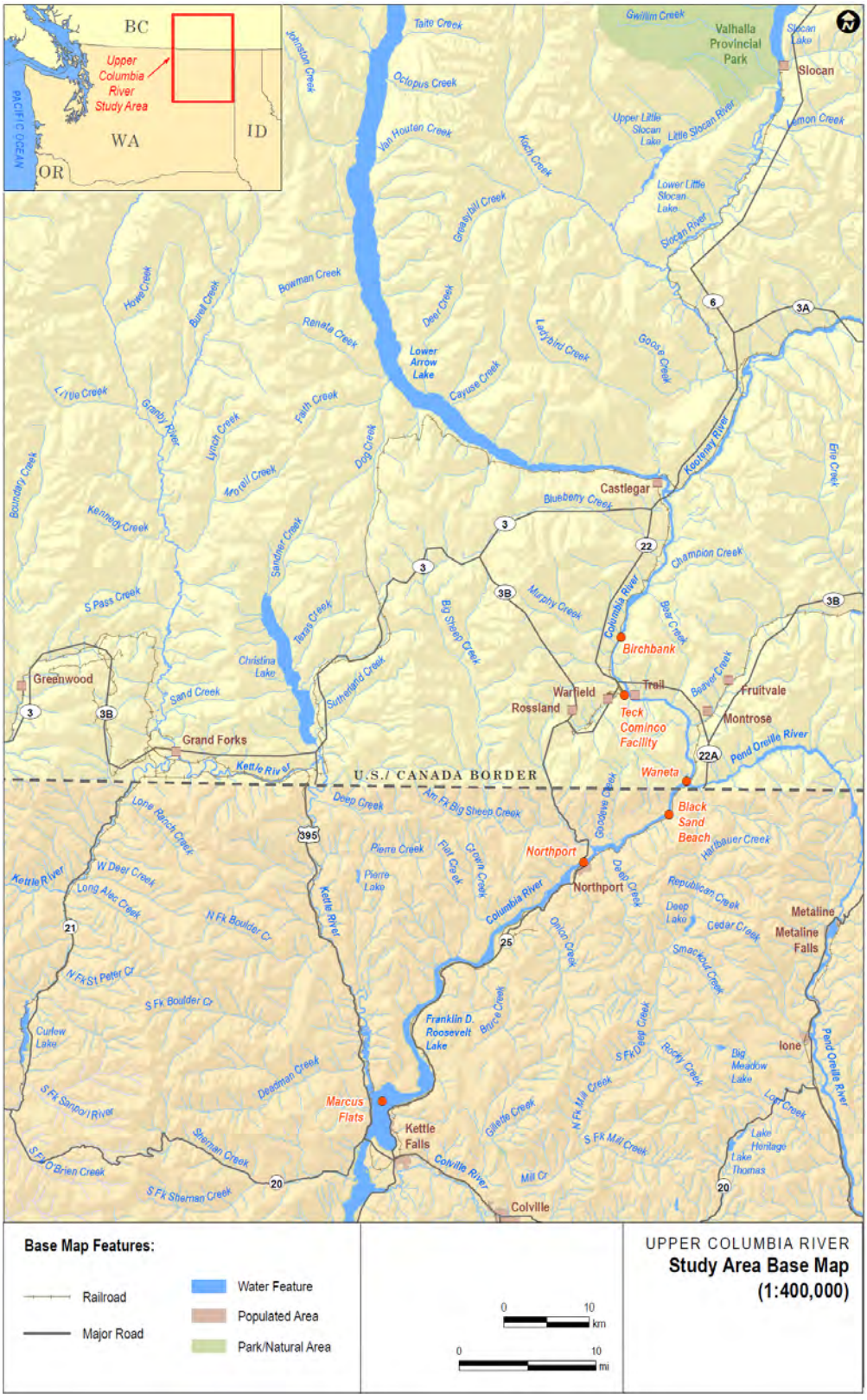


Figure 2. Map of Canadian Portion and Northern Section of the U.S. Portion of the Upper Columbia River and Lake Roosevelt

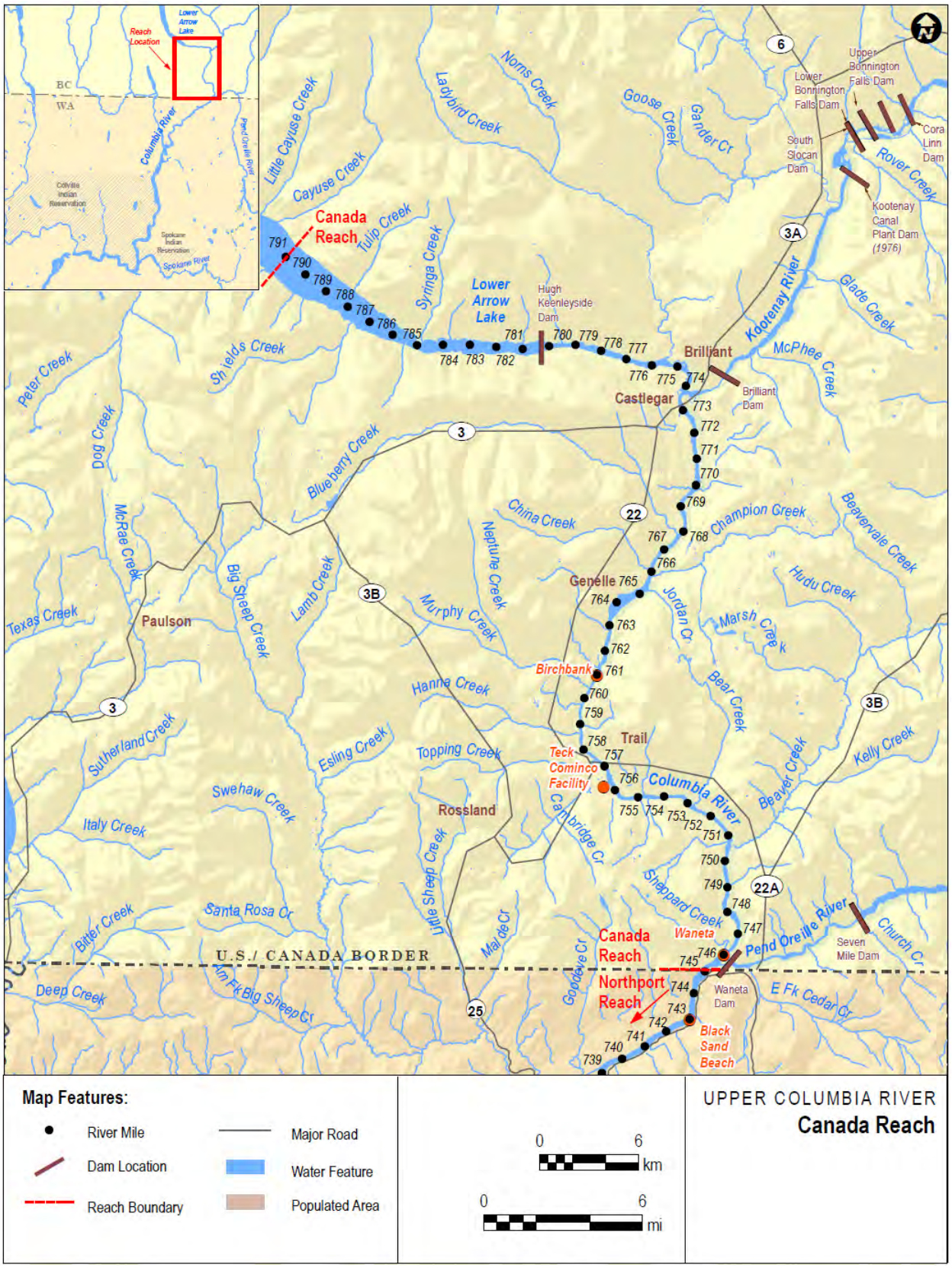


Figure 3. Map of the Canada Reach of the Upper Columbia River and Lake Roosevelt

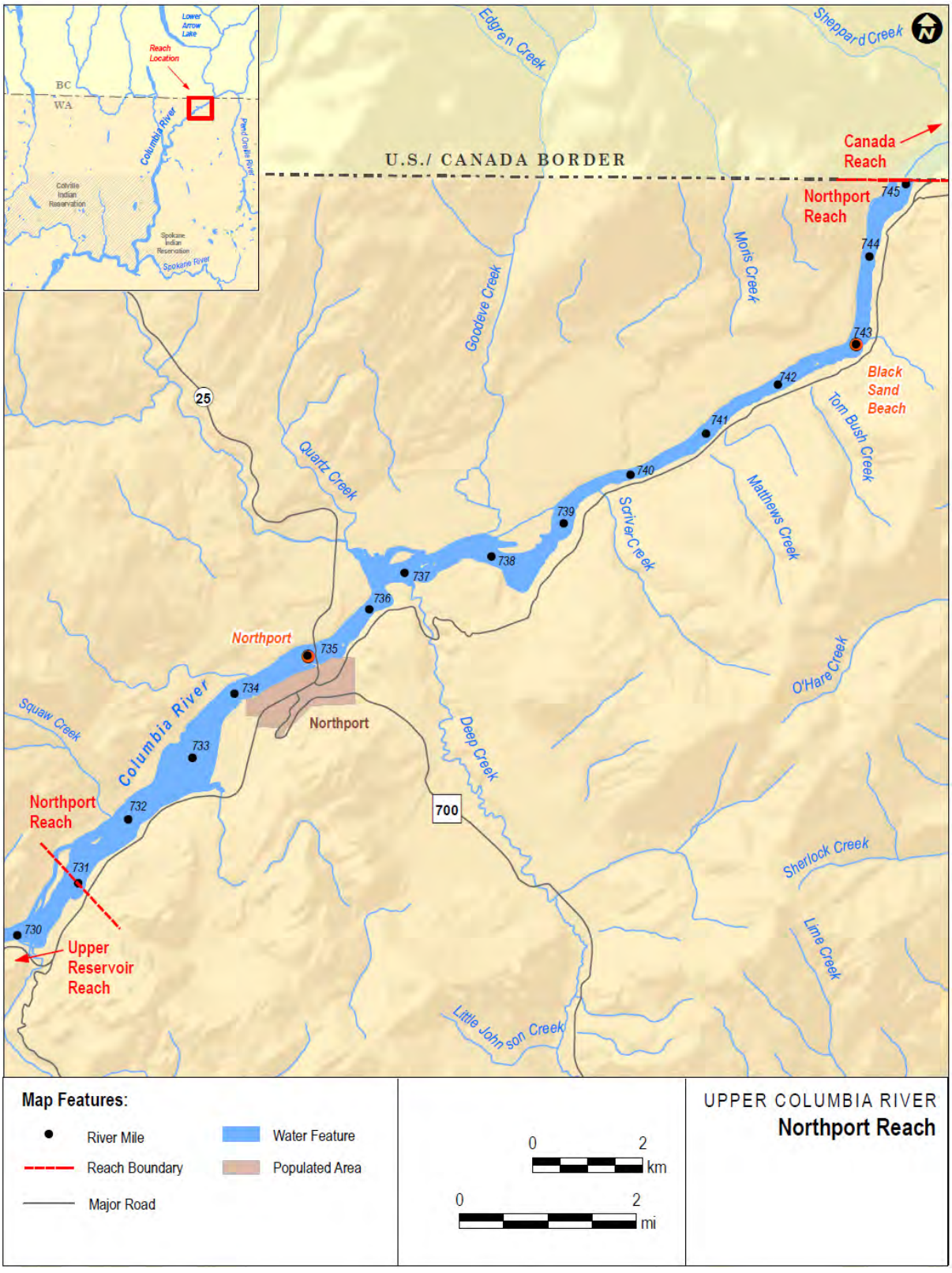


Figure 4. Map of the Northport Reach of the Upper Columbia River and Lake Roosevelt

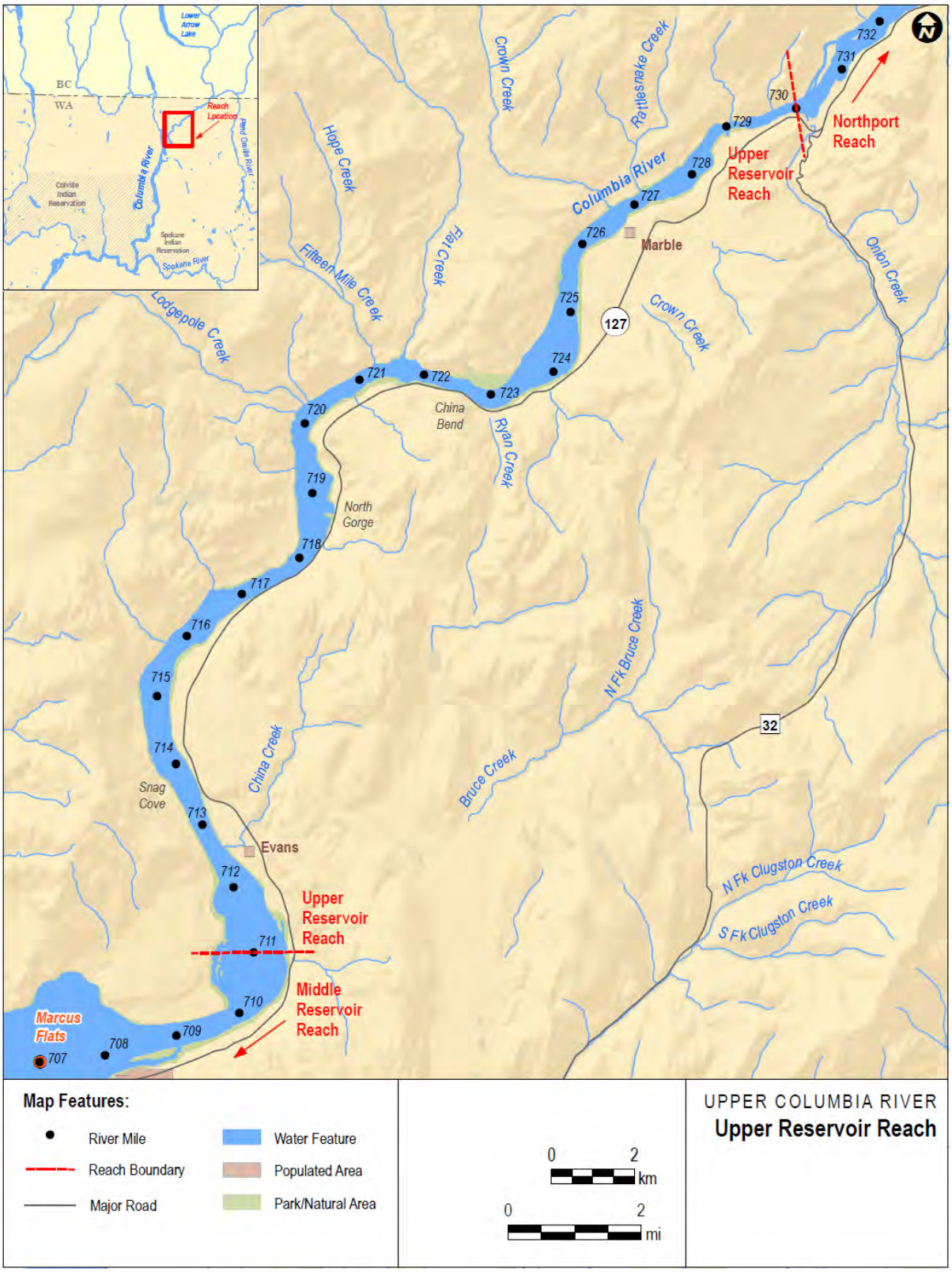


Figure 5. Map of the Upper Reservoir Reach of the Upper Columbia River and Lake Roosevelt

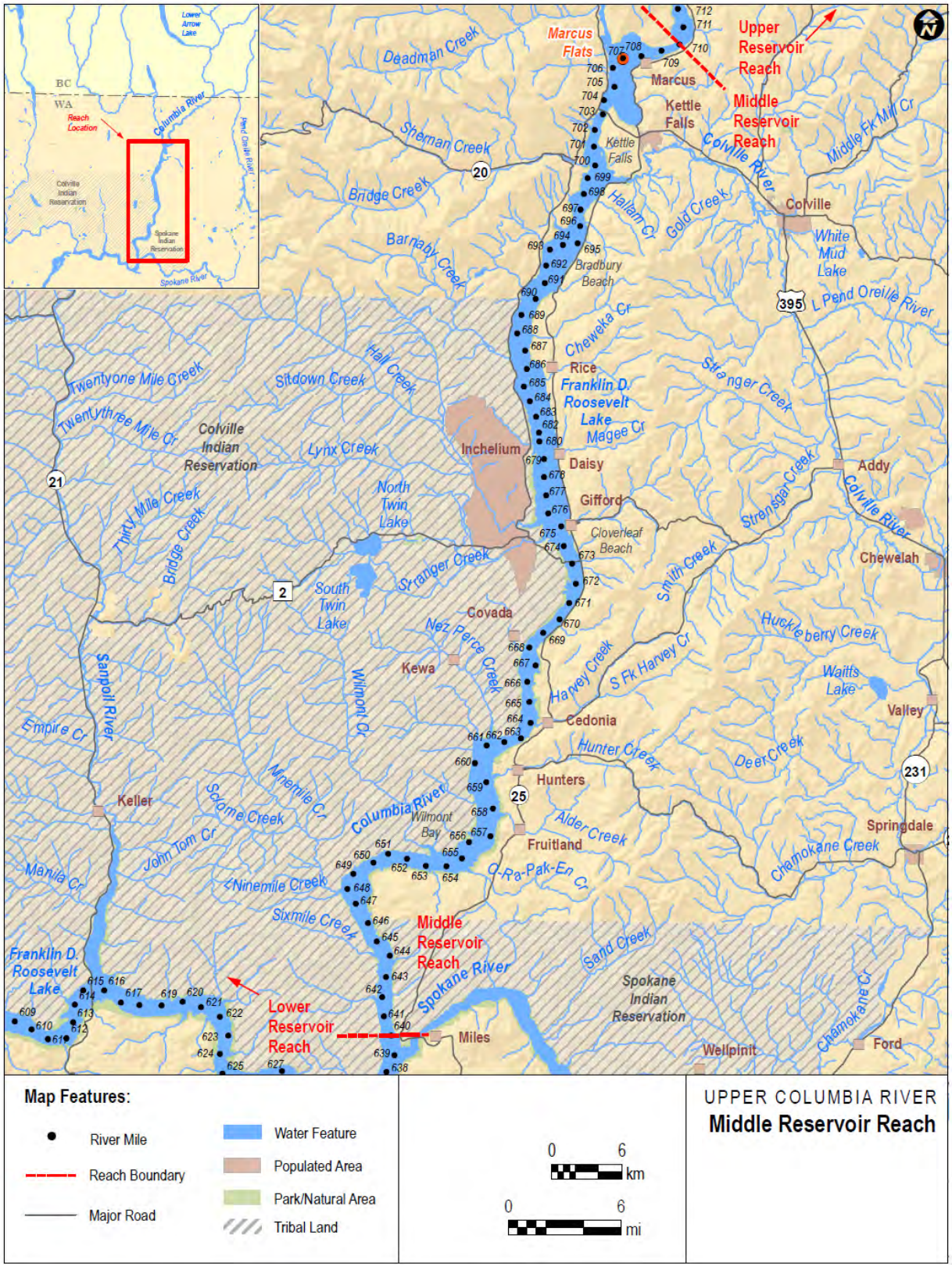


Figure 6. Map of the Middle Reservoir Reach of the Upper Columbia River and Lake Roosevelt

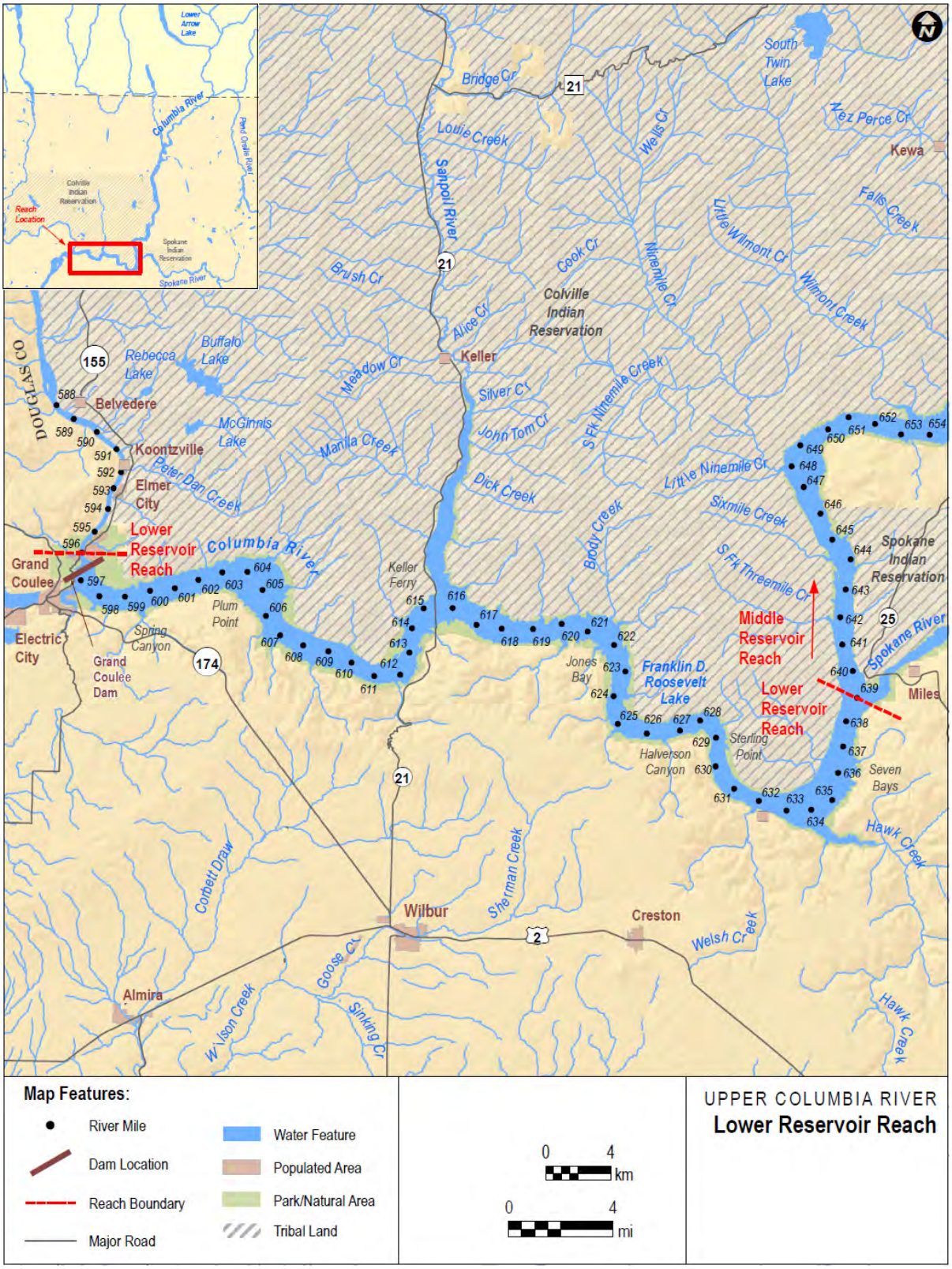


Figure 7. Map of the Lower Reservoir Reach of the Upper Columbia River and Lake Roosevelt

Figure 8. Map of Locations of Dams in the Upper Columbia River System and Lake Roosevelt

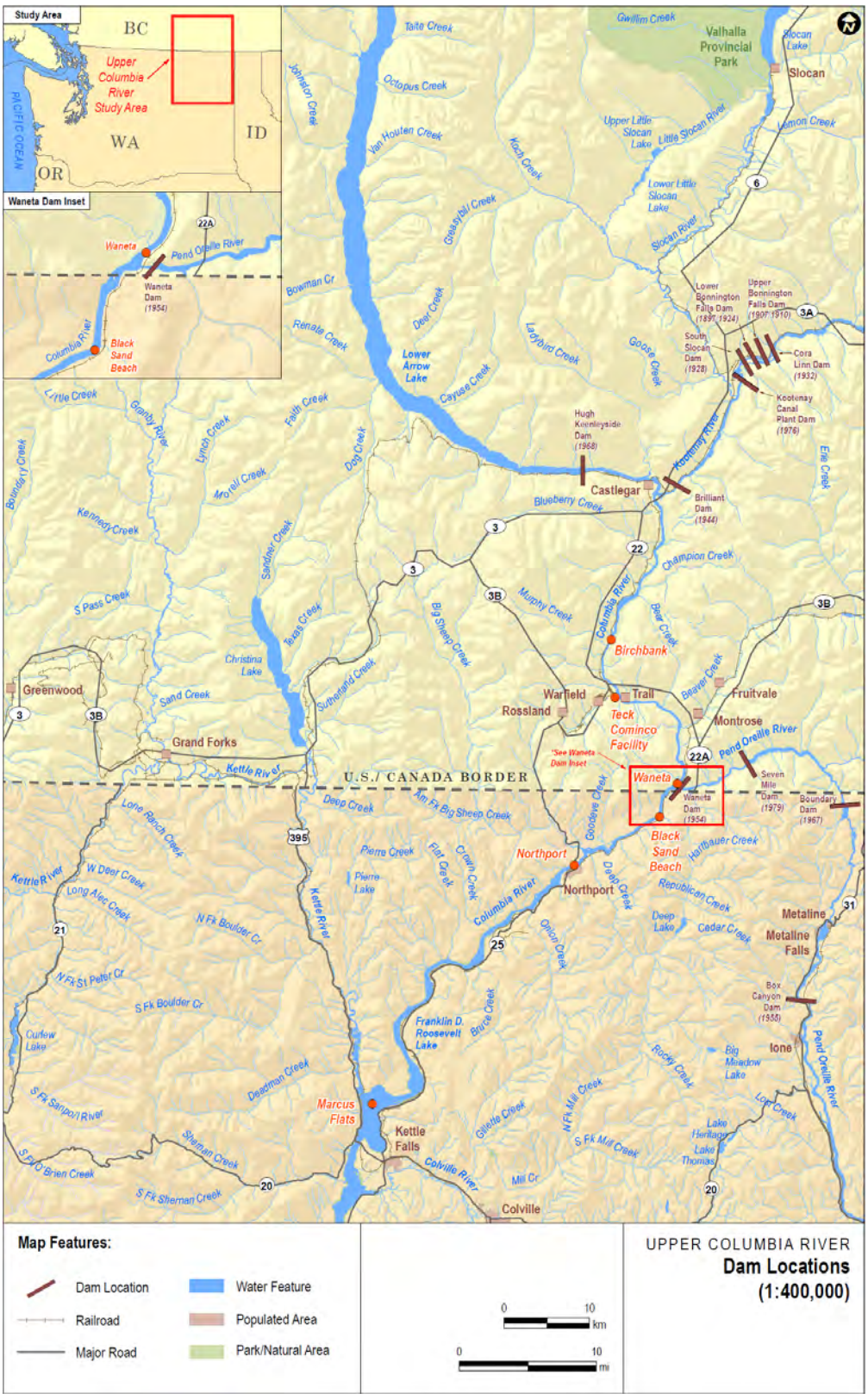


Figure 9. Map of Locations of Dams in the Upper Columbia River System in the Vicinity of the International Border

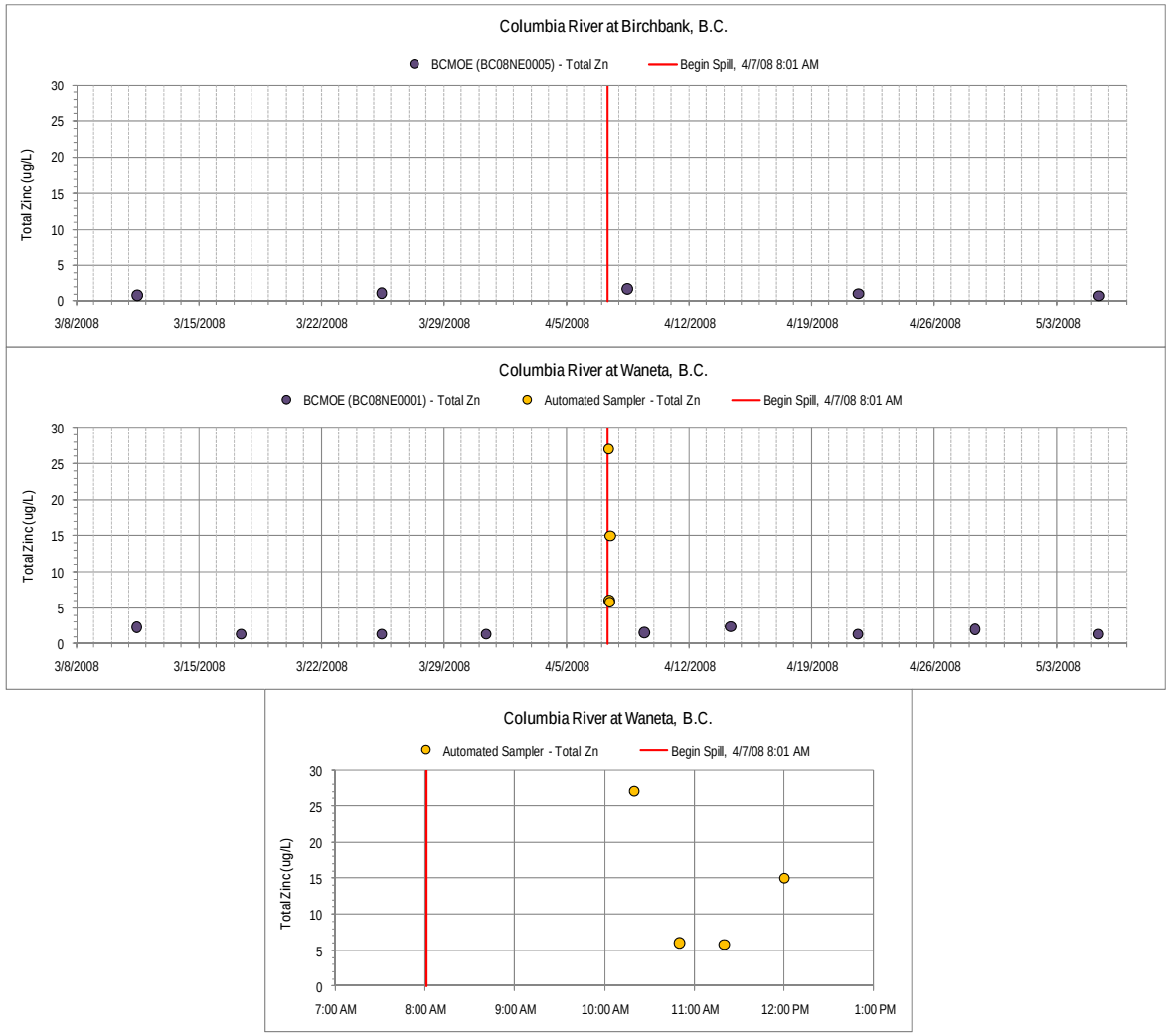


Figure 10. Water Column Total Zinc Concentrations Associated with Spill Event on April 7, 2008, at the Teck Cominco facility at Trail, British Columbia. Ambient Concentrations Upstream at Birchbank (top panel), Ambient and Spill Event Concentrations Downstream at Waneta (middle panel) and Spill Event Concentrations at Waneta on an Expanded Time Scale (bottom panel)

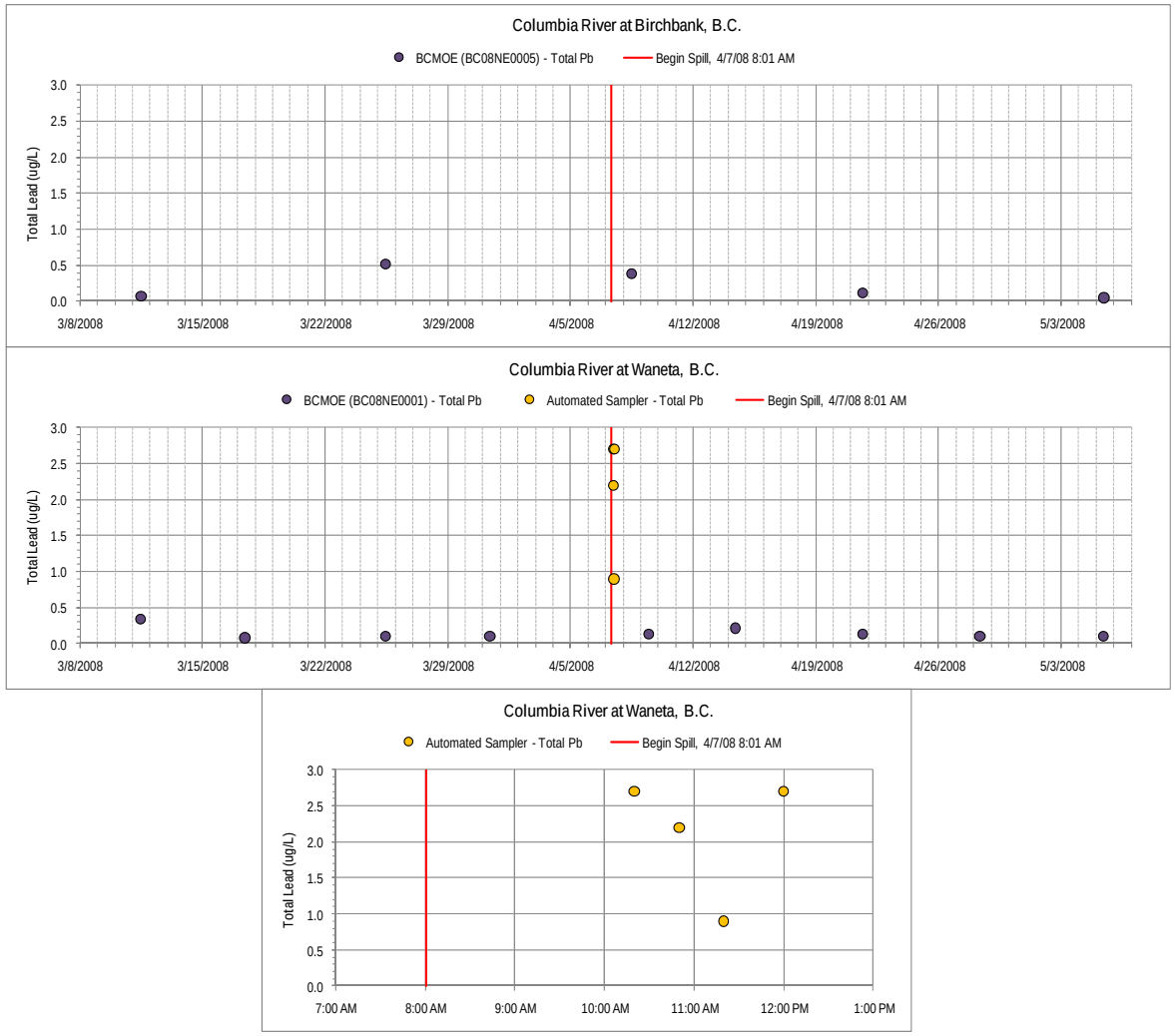
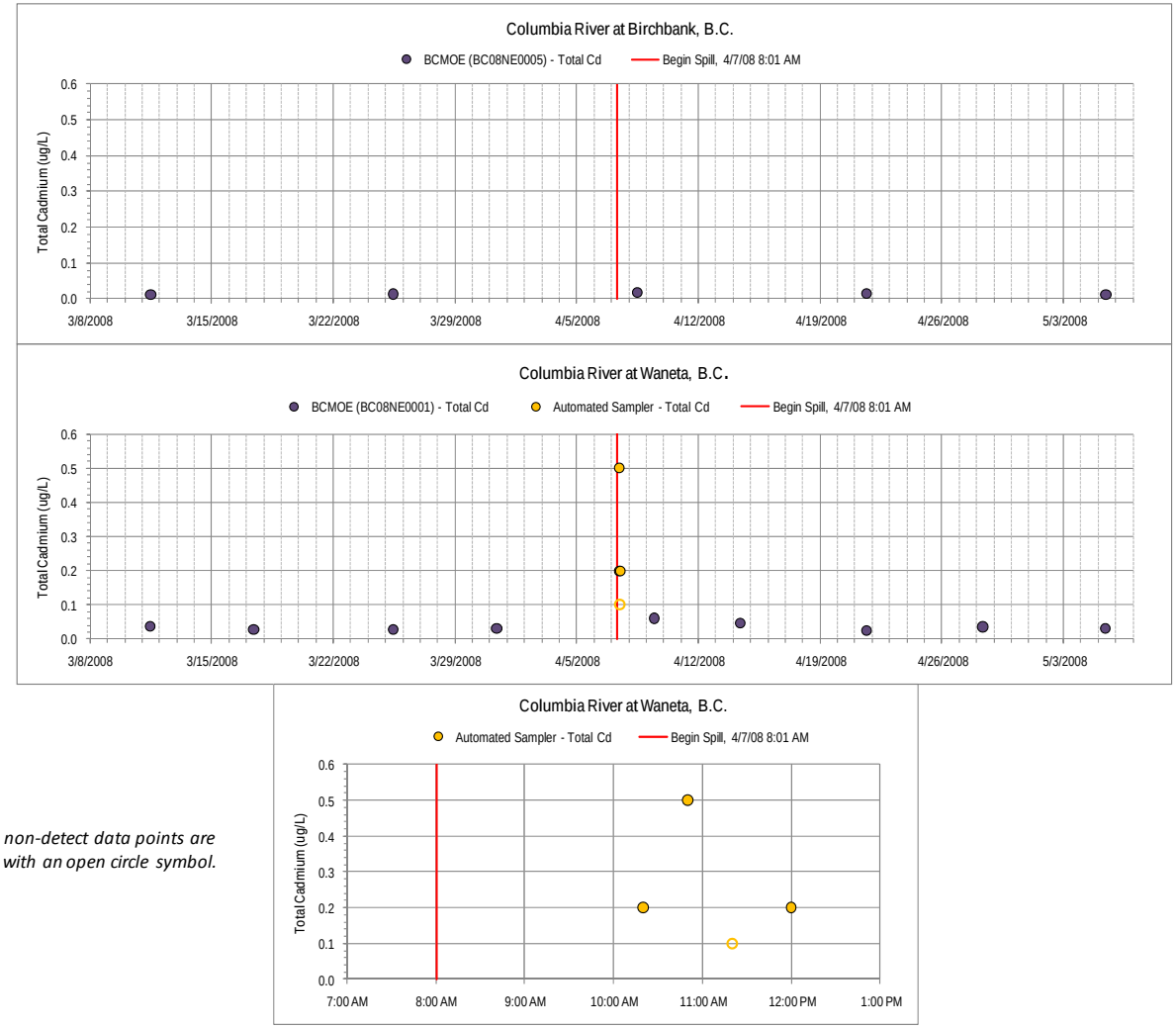


Figure 11. Water Column Total Lead Concentrations Associated with Spill Event on April 7, 2008, at the Teck Cominco facility at Trail, British Columbia. Ambient Concentrations Upstream at Birchbank (top panel), Ambient and Spill Event Concentrations Downstream at Waneta (middle panel) and Spill Event Concentrations at Waneta on an Expanded Time Scale (bottom panel)



Note that non-detect data points are displayed with an open circle symbol.

Figure 12. Water Column Total Cadmium Concentrations Associated with Spill Event on April 7, 2008, at the Teck Cominco facility at Trail, British Columbia. Ambient Concentrations Upstream at Birchbank (top panel), Ambient and Spill Event Concentrations Downstream at Waneta (middle panel) and Spill Event Concentrations at Waneta on an Expanded Time Scale (bottom panel)

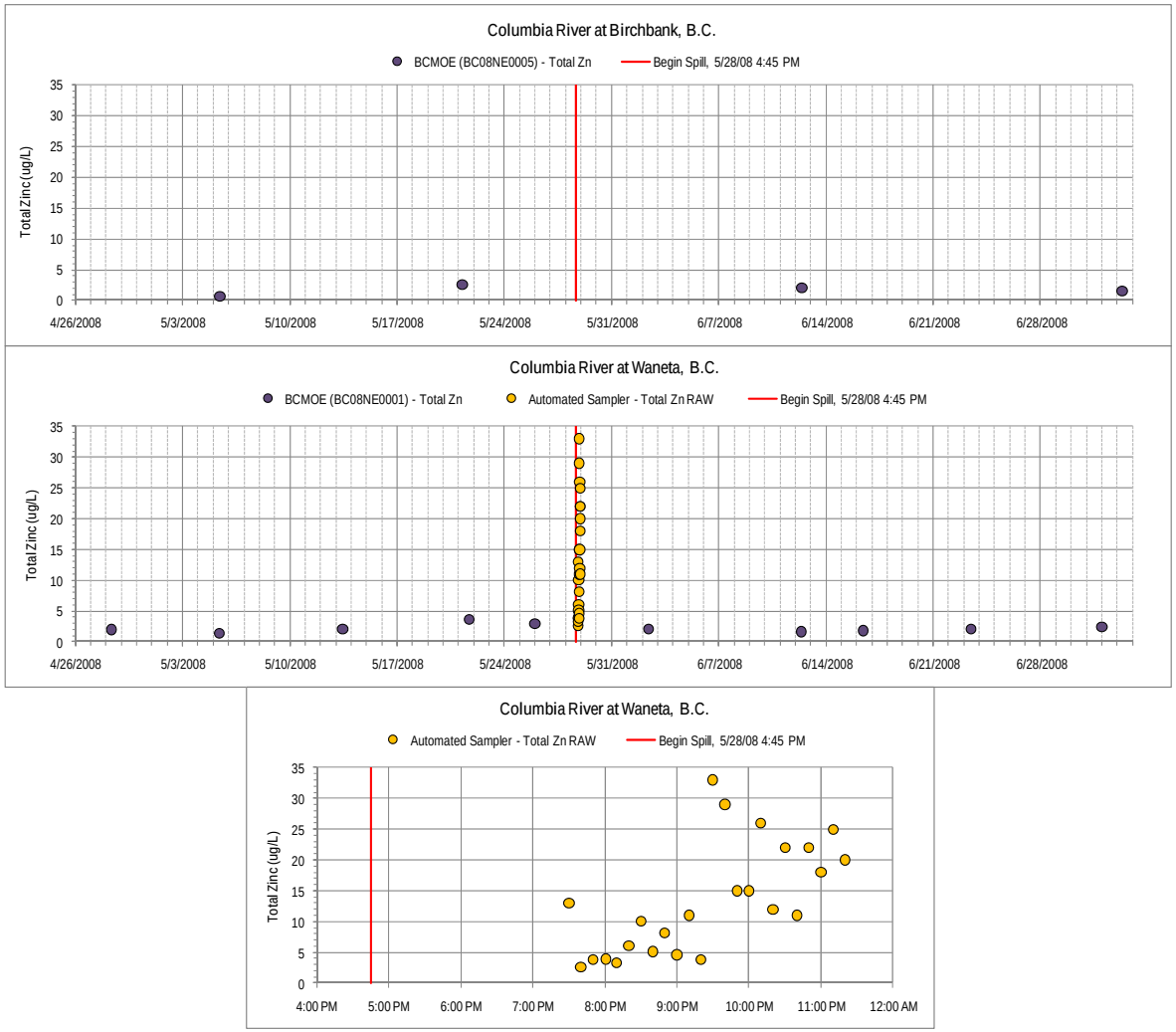


Figure 13. Water Column Total Zinc Concentrations Associated with Spill Event on May 28, 2008, at the Teck Cominco facility at Trail, British Columbia. Ambient Concentrations Upstream at Birchbank (top panel), Ambient and Spill Event Concentrations Downstream at Waneta (middle panel) and Spill Event Concentrations at Waneta on an Expanded Time Scale (bottom panel)

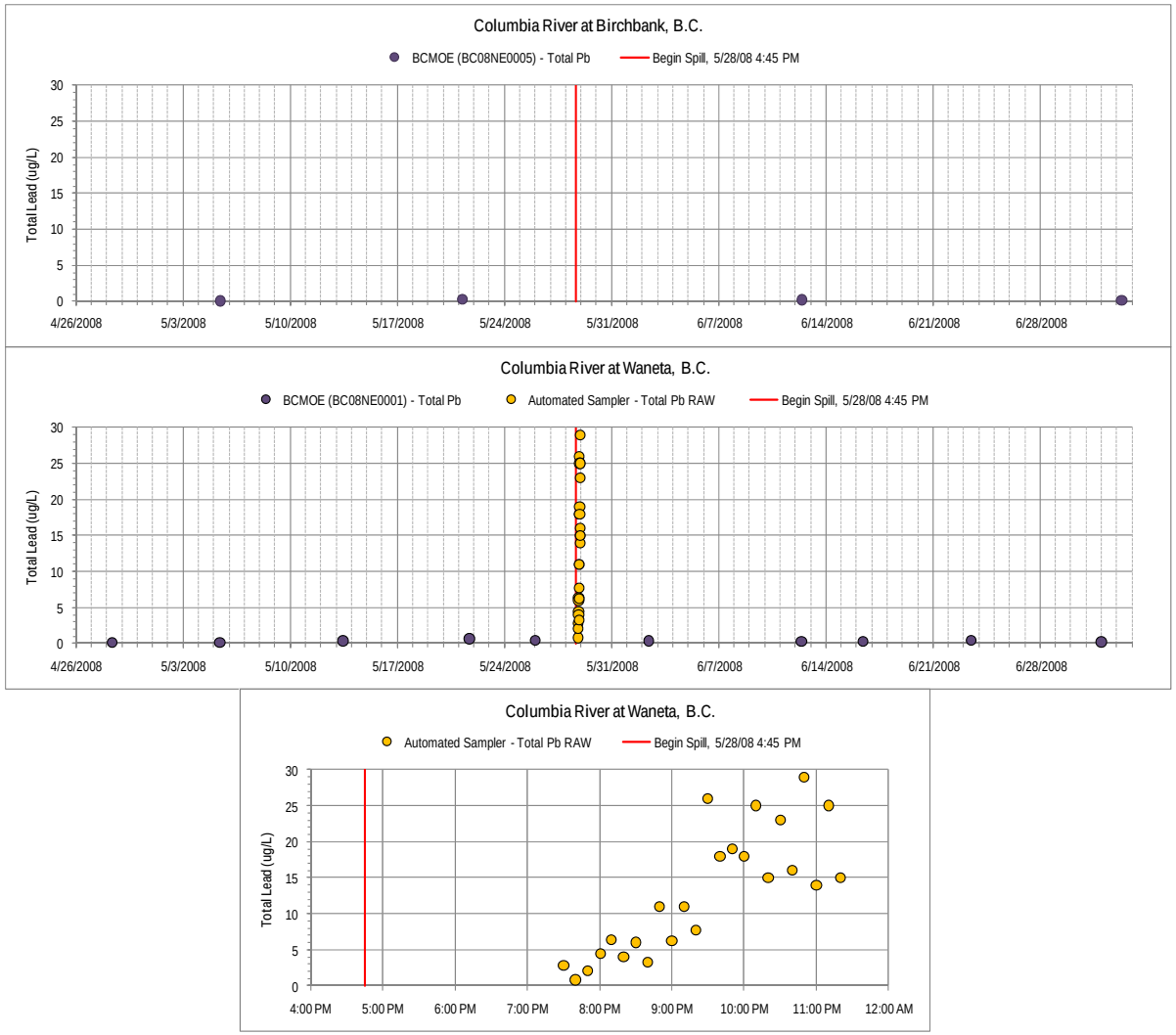
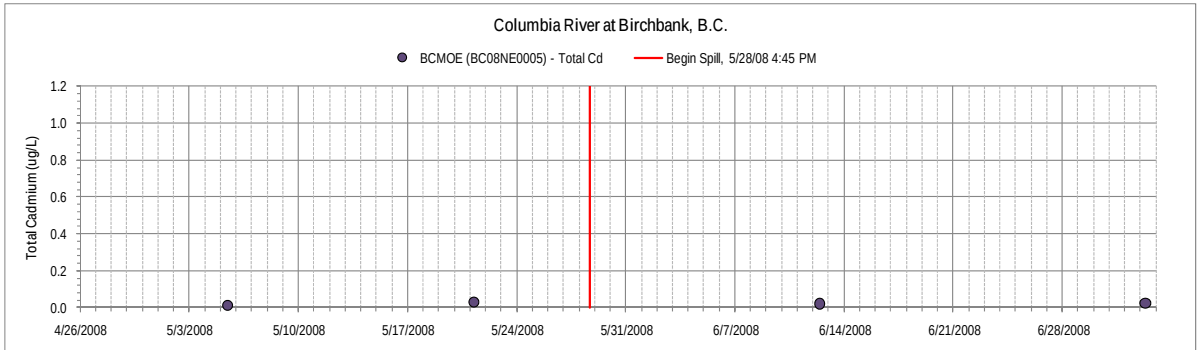
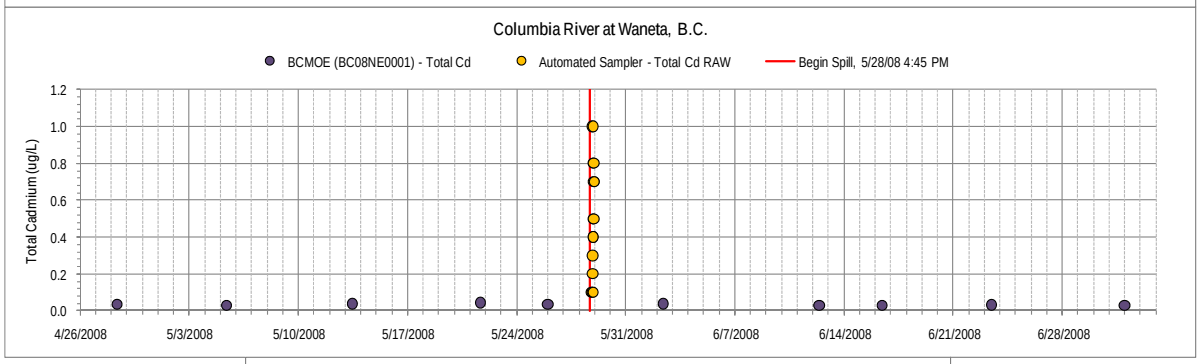
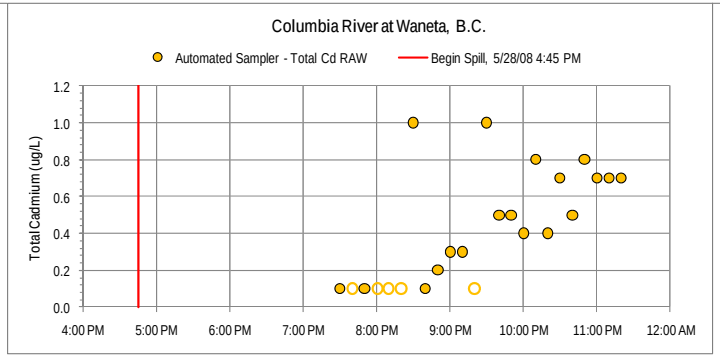


Figure 14. Water Column Total Lead Concentrations Associated with Spill Event on May 28, 2008, at the Teck Cominco facility at Trail, British Columbia. Ambient Concentrations Upstream at Birchbank (top panel), Ambient and Spill Event Concentrations Downstream at Waneta (middle panel) and Spill Event Concentrations at Waneta on an Expanded Time Scale (bottom panel)







Note that non-detect data points are displayed with an open circle symbol.

Figure 15. Water Column Total Cadmium Concentrations Associated with Spill Event on May 28, 2008, at the Teck Cominco facility at Trail, British Columbia. Ambient Concentrations Upstream at Birchbank (top panel), Ambient and Spill Event Concentrations Downstream at Waneta (middle panel) and Spill Event Concentrations at Waneta on an Expanded Time Scale (bottom panel)

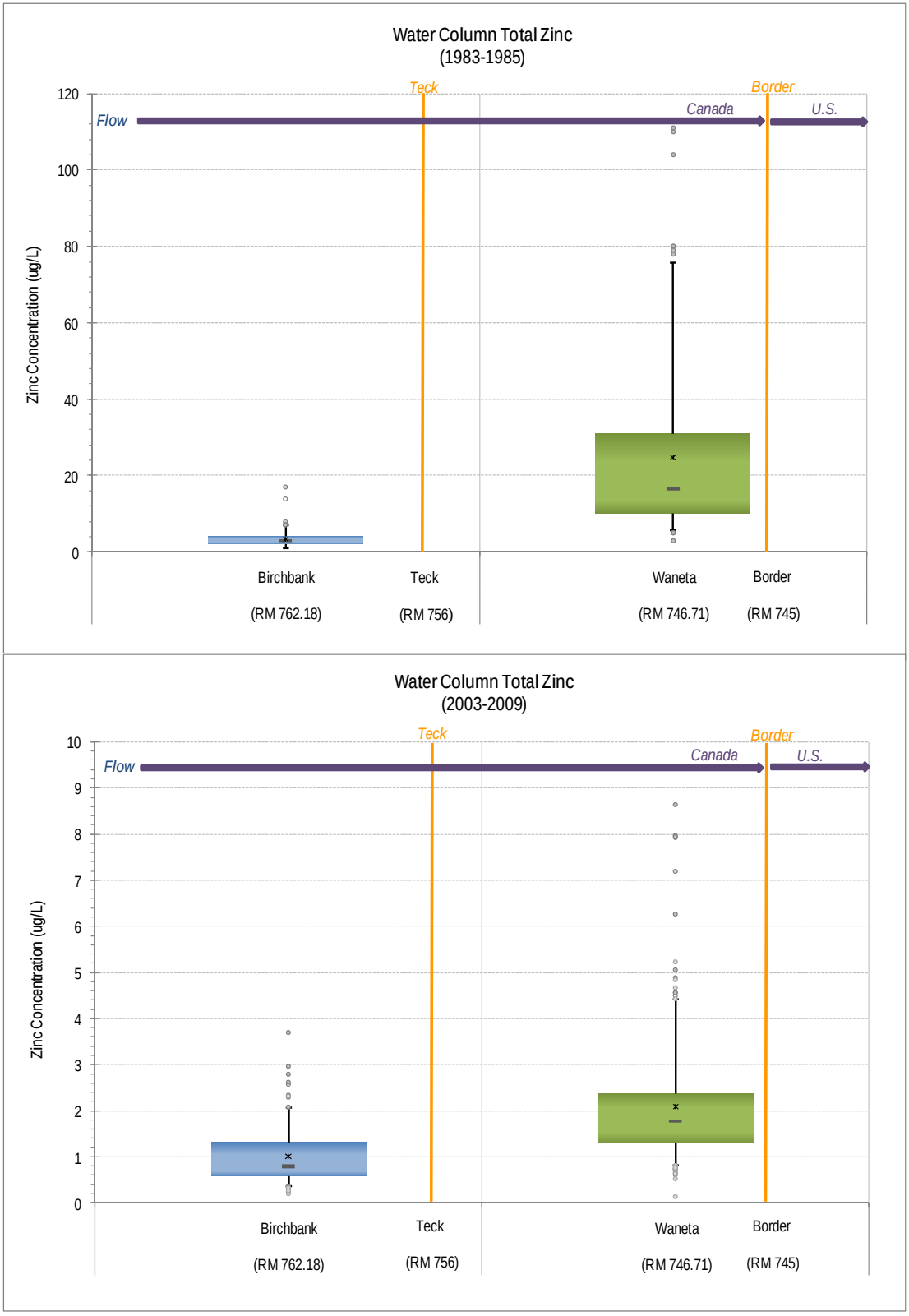


Figure 16. Water Column Total Zinc Concentrations at Birchbank and Waneta during 1983-1985 (top panel) and 2003-2009 (bottom panel)

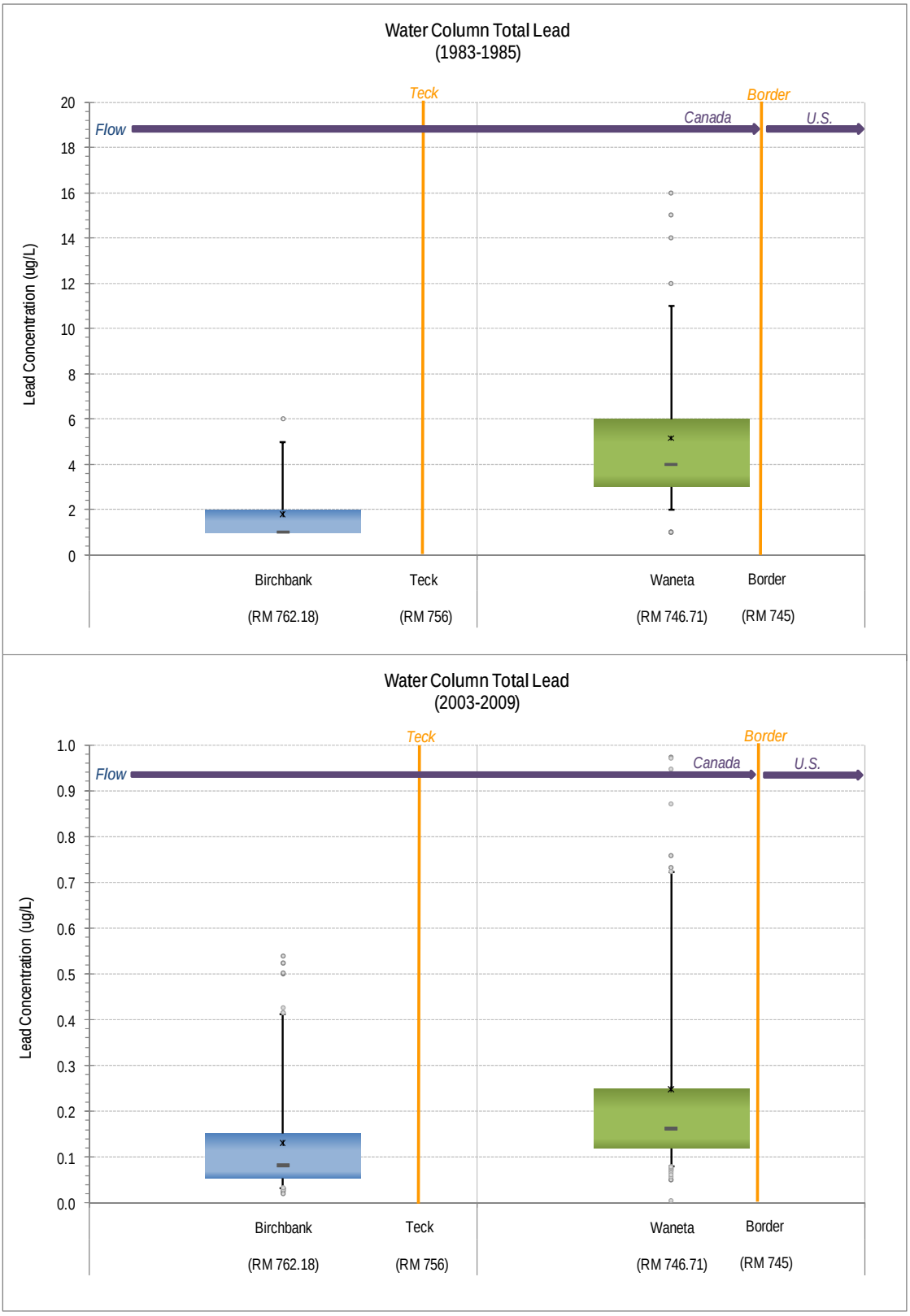


Figure 17. Water Column Total Lead Concentrations at Birchbank and Waneta during 1983-1985 (top panel) and 2003-2009 (bottom panel)

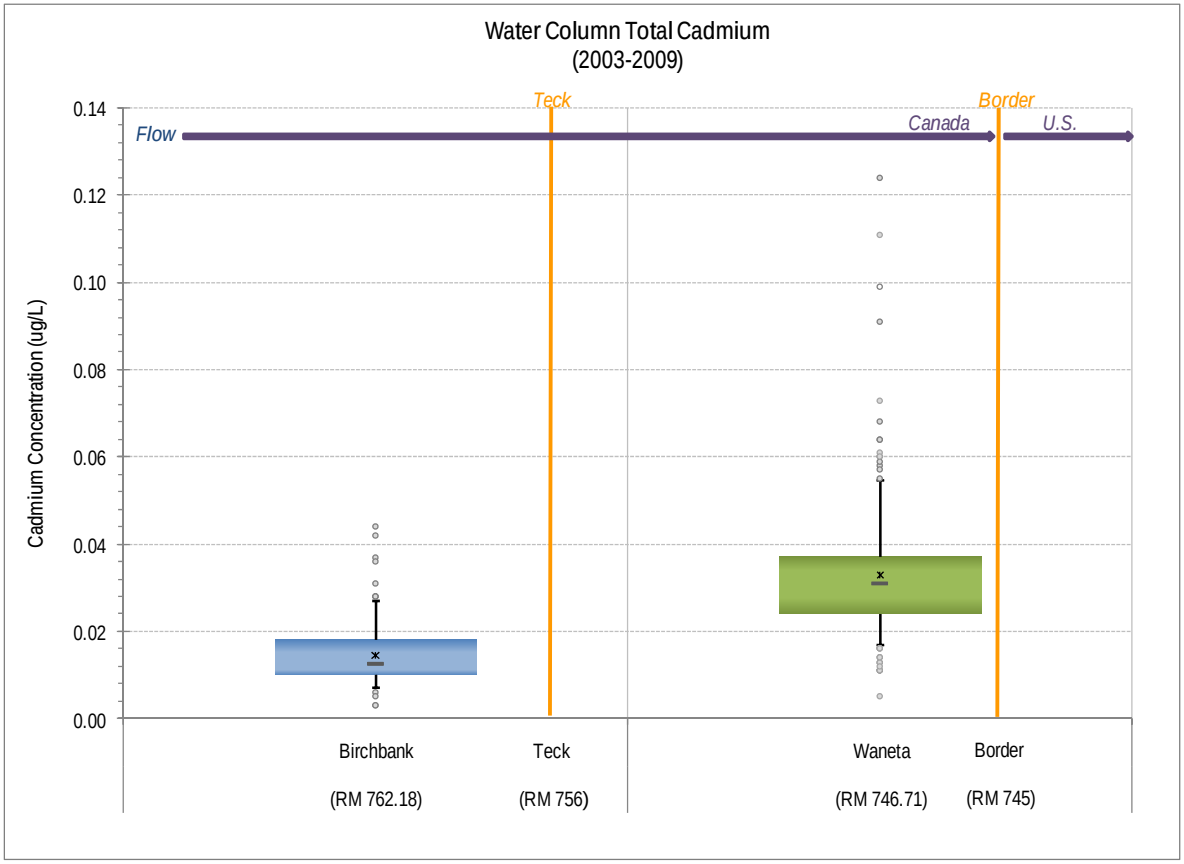


Figure 18. Water Column Total Cadmium Concentrations at Birchbank and Waneta during 2003-2009

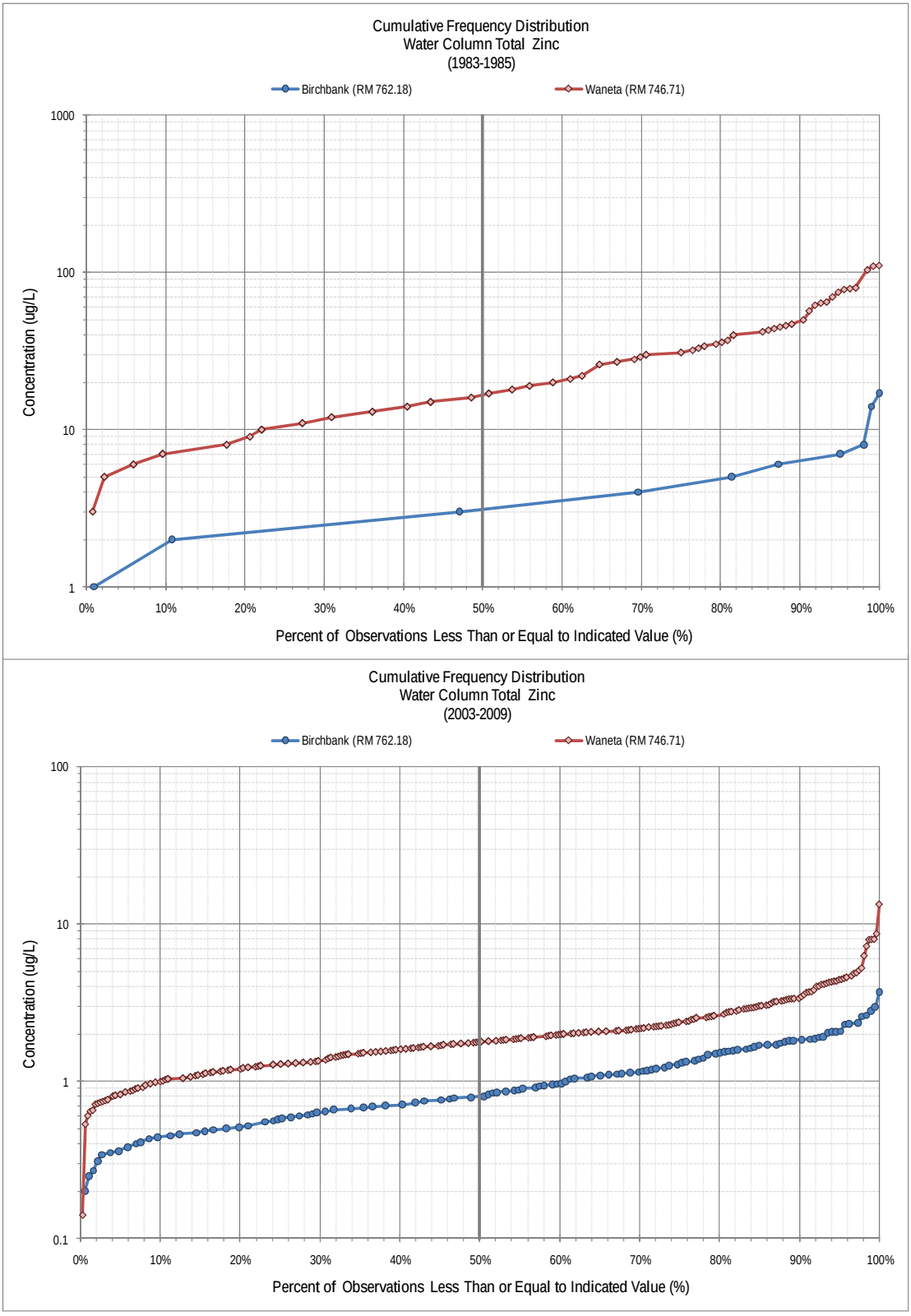


Figure 19. Cumulative Frequency Distributions for Water Column Total Zinc Concentrations at Birchbank and Waneta for 1983-1985 (top panel) and 2003-2009 (bottom panel)

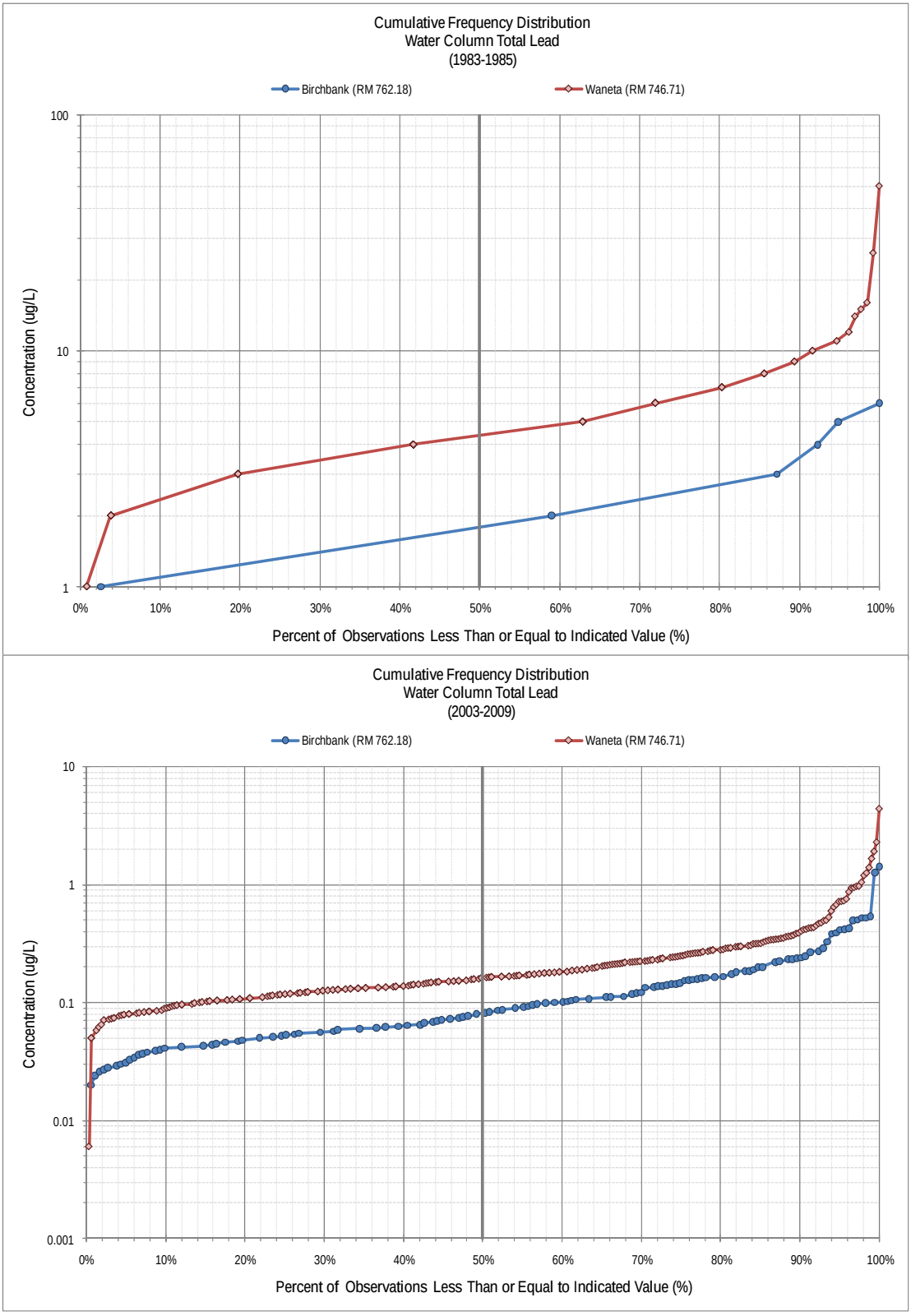


Figure 20. Cumulative Frequency Distributions for Water Column Total Lead Concentrations at Birchbank and Waneta for 1983-1985 (top panel) and 2003-2009 (bottom panel)

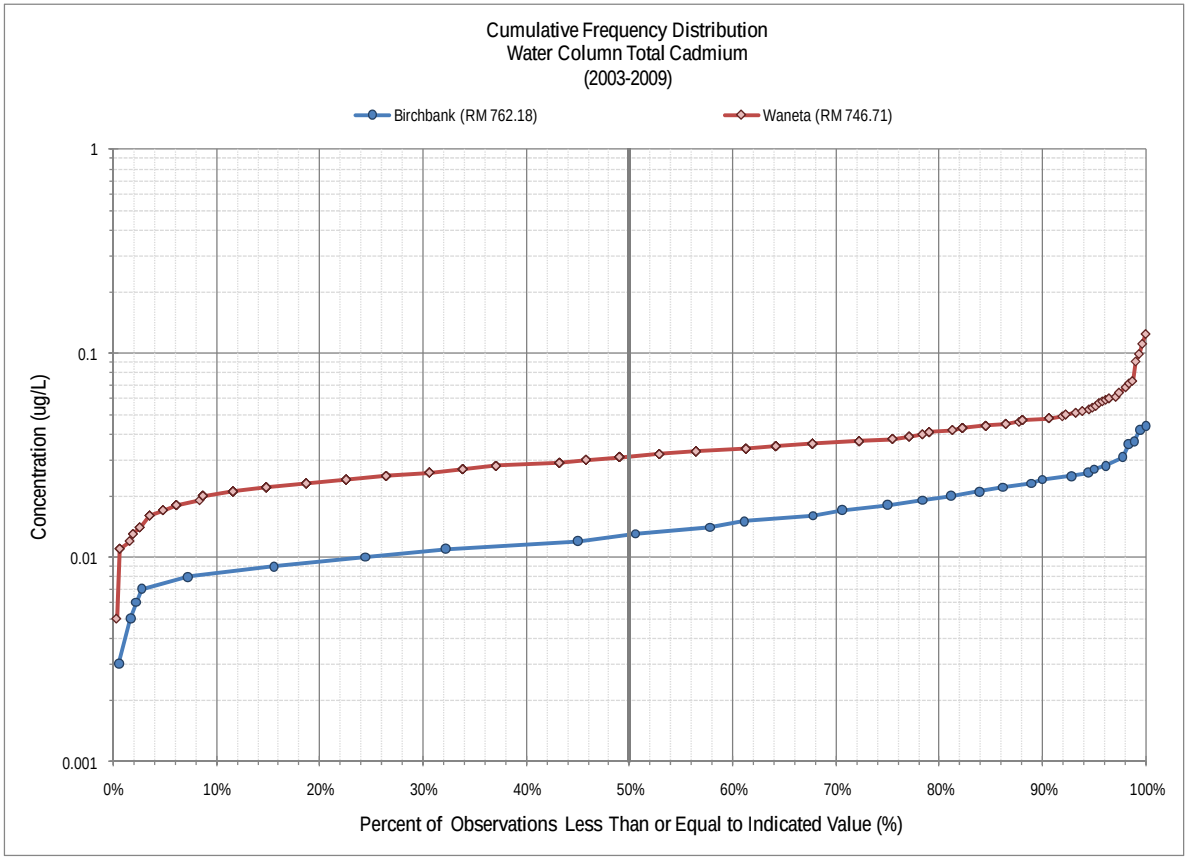


Figure 21. Cumulative Frequency Distributions for Water Column Total Cadmium Concentrations at Birchbank and Waneta for 2003-2009

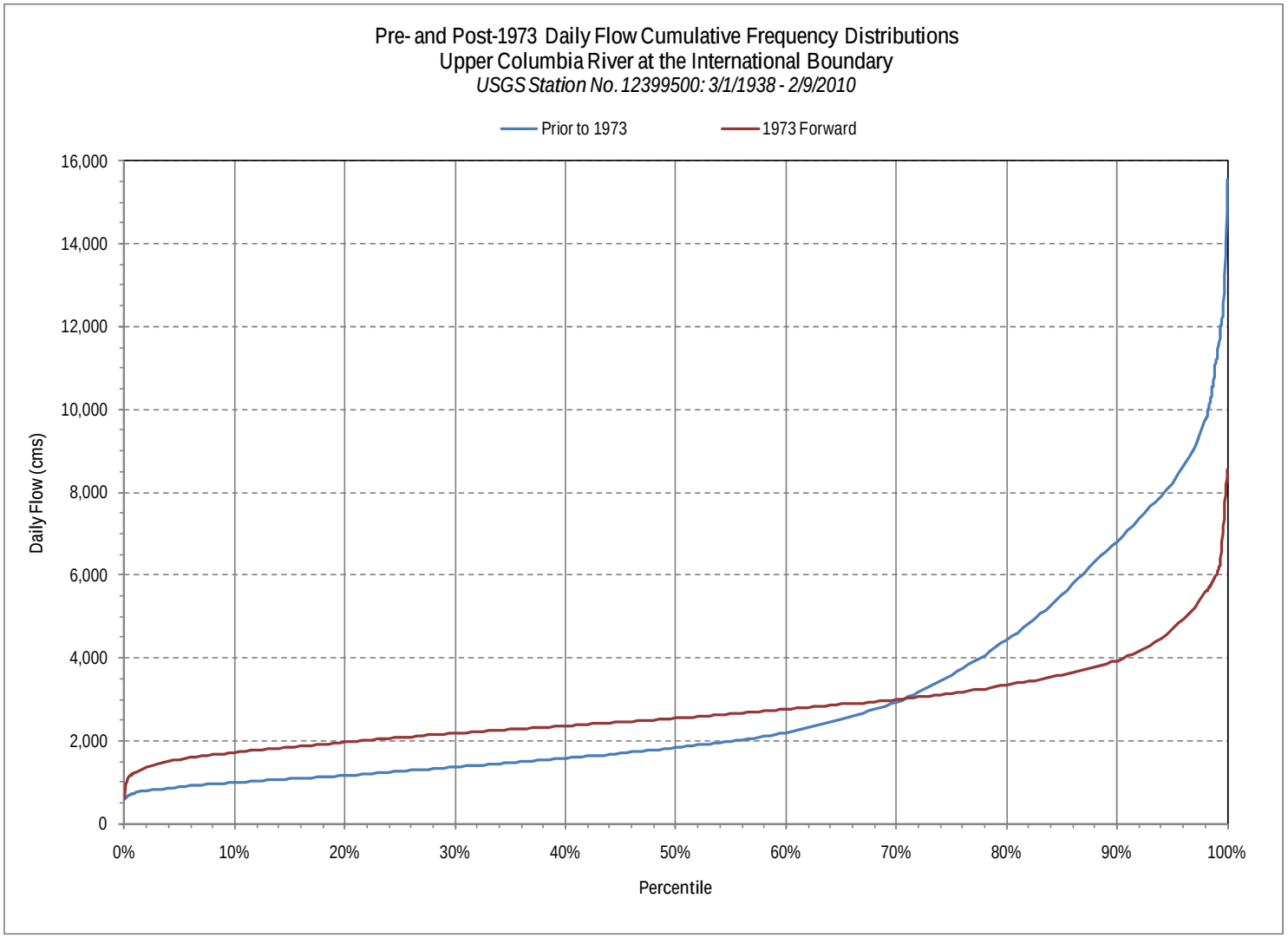


Figure 22. Pre- and Post-1973 Cumulative Frequency Distributions for Upper Columbia River Flows at the International Boundary for 1938-2010 Period of Record

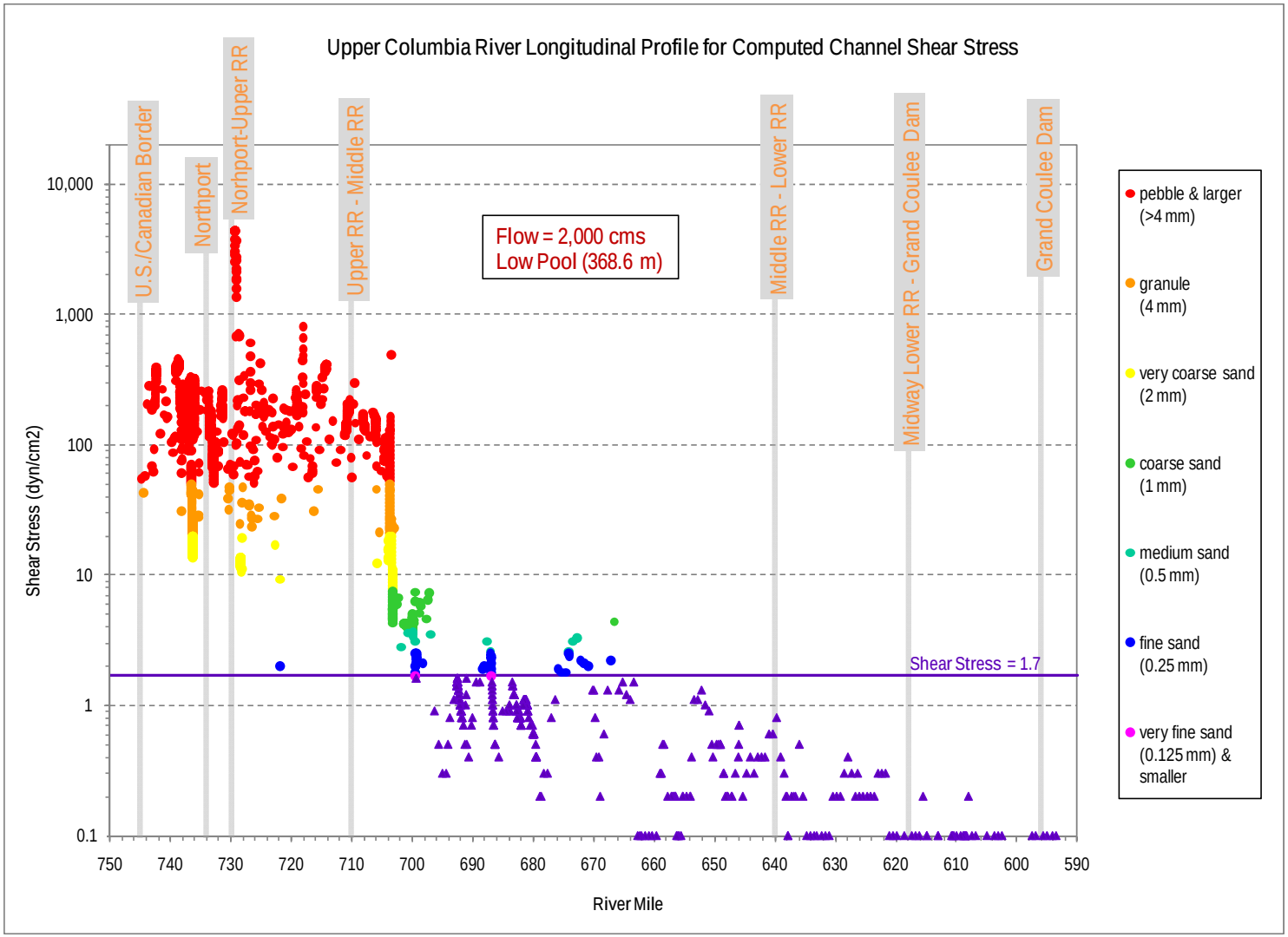


Figure 23. Shear Stresses Computed by the HydroQual HEC-RAS Hydraulic Model as a Function of River Mile for a Flow of 2,000 m^3/s at Low Pool (368.6 m). Colored Circles Indicate Largest Size of Movable Particles at each River Mile. Magenta Circles Indicate Non-Slag Particles. Purple Triangles Indicate Deposition of Non-Slag Particles.

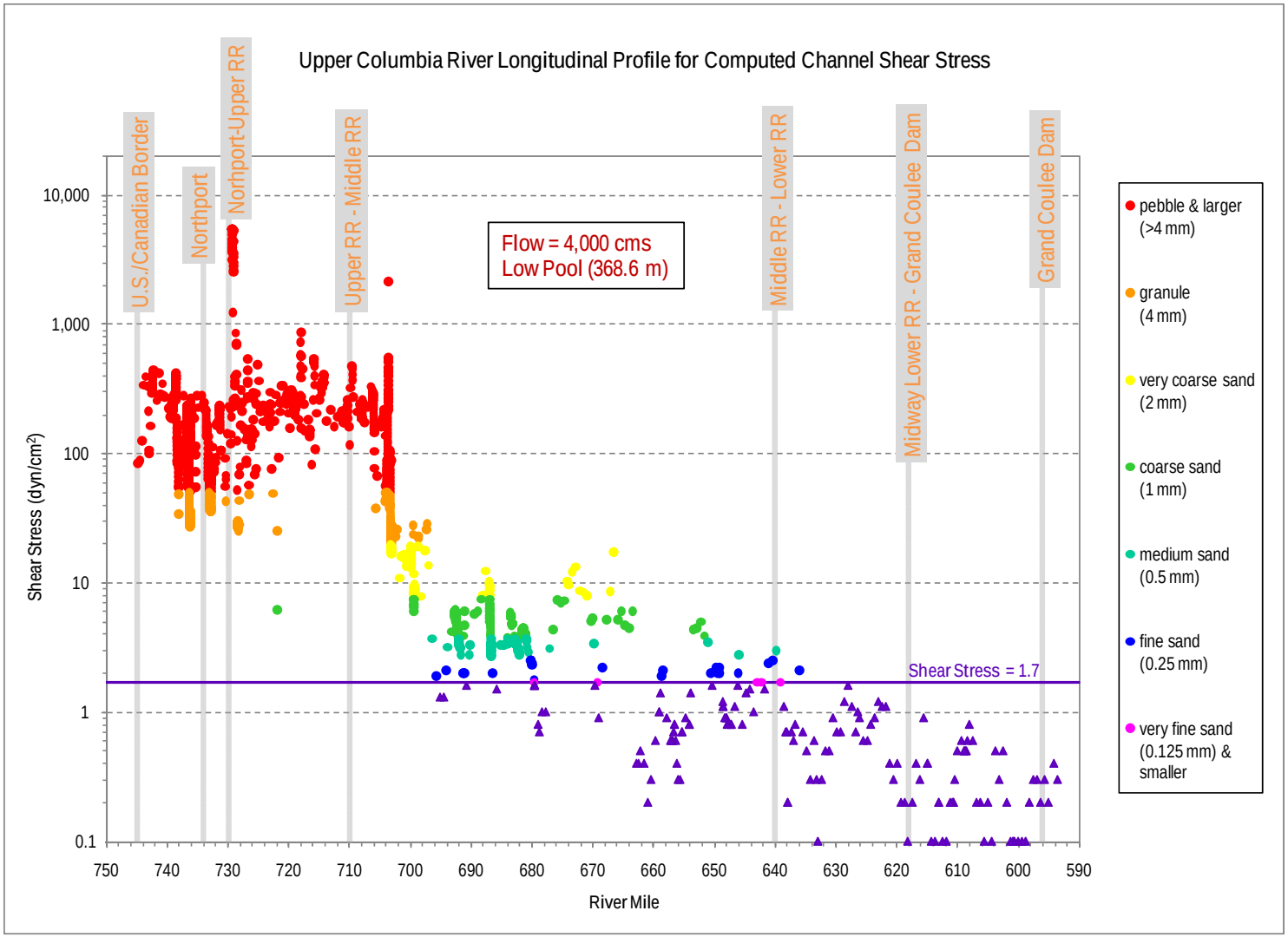


Figure 24. Shear Stresses Computed by the HydroQual HEC-RAS Hydraulic Model as a Function of River Mile for a Flow of 4,000 m^3/s at Low Pool (368.6 m). Colored Circles Indicate Largest Size of Movable Particles at each River Mile. Magenta Circles Indicate Non-Slag Particles. Purple Triangles Indicate Deposition of Non-Slag Particles.

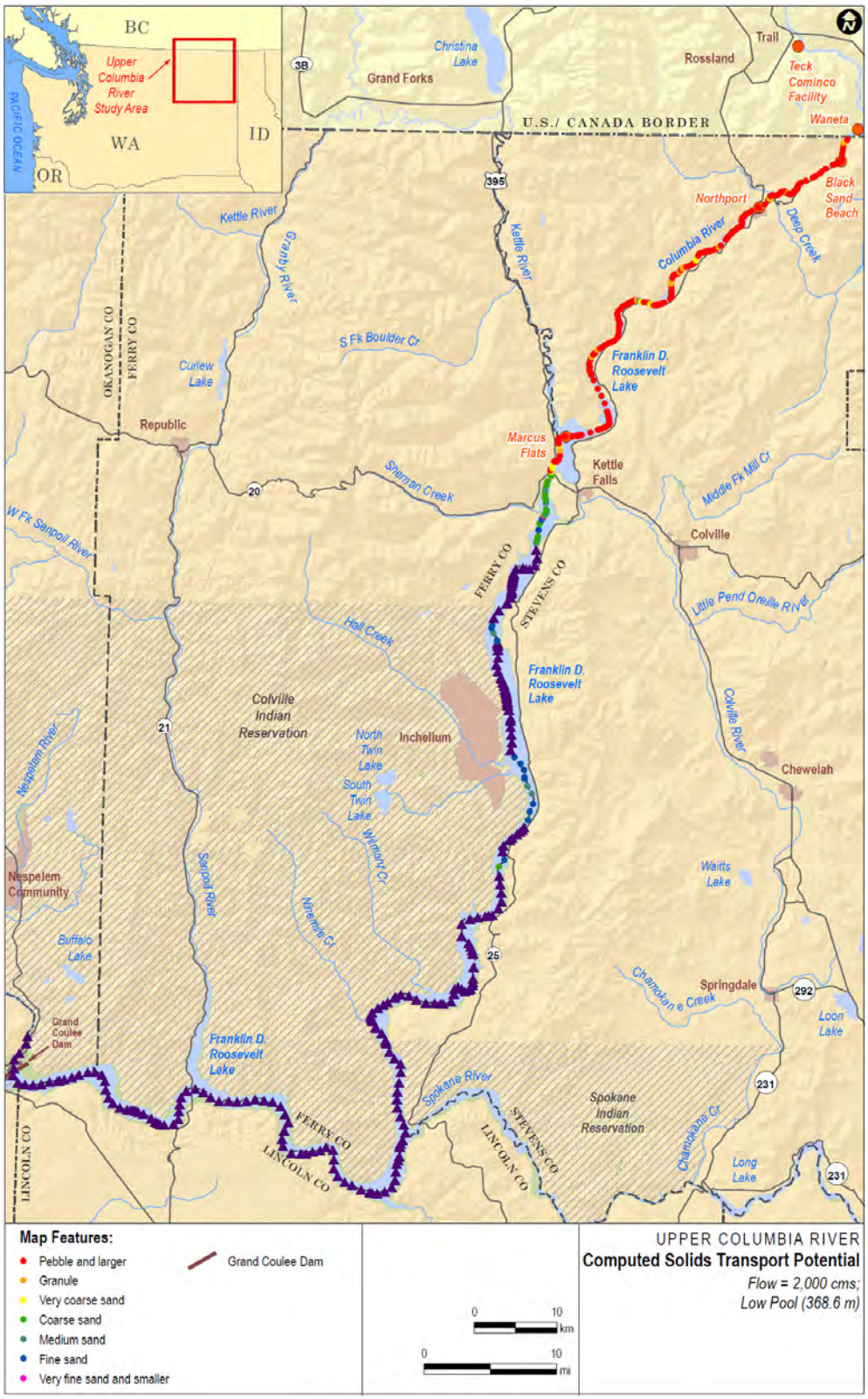


Figure 25. Map of Computed Solids Transport Potential for a Flow of 2,000 m^3/s at Low Pool (368.6 m). Map Features Correspond to the Legend in Figure 23. Purple Triangles Indicate Deposition of Non-Slag Particles.

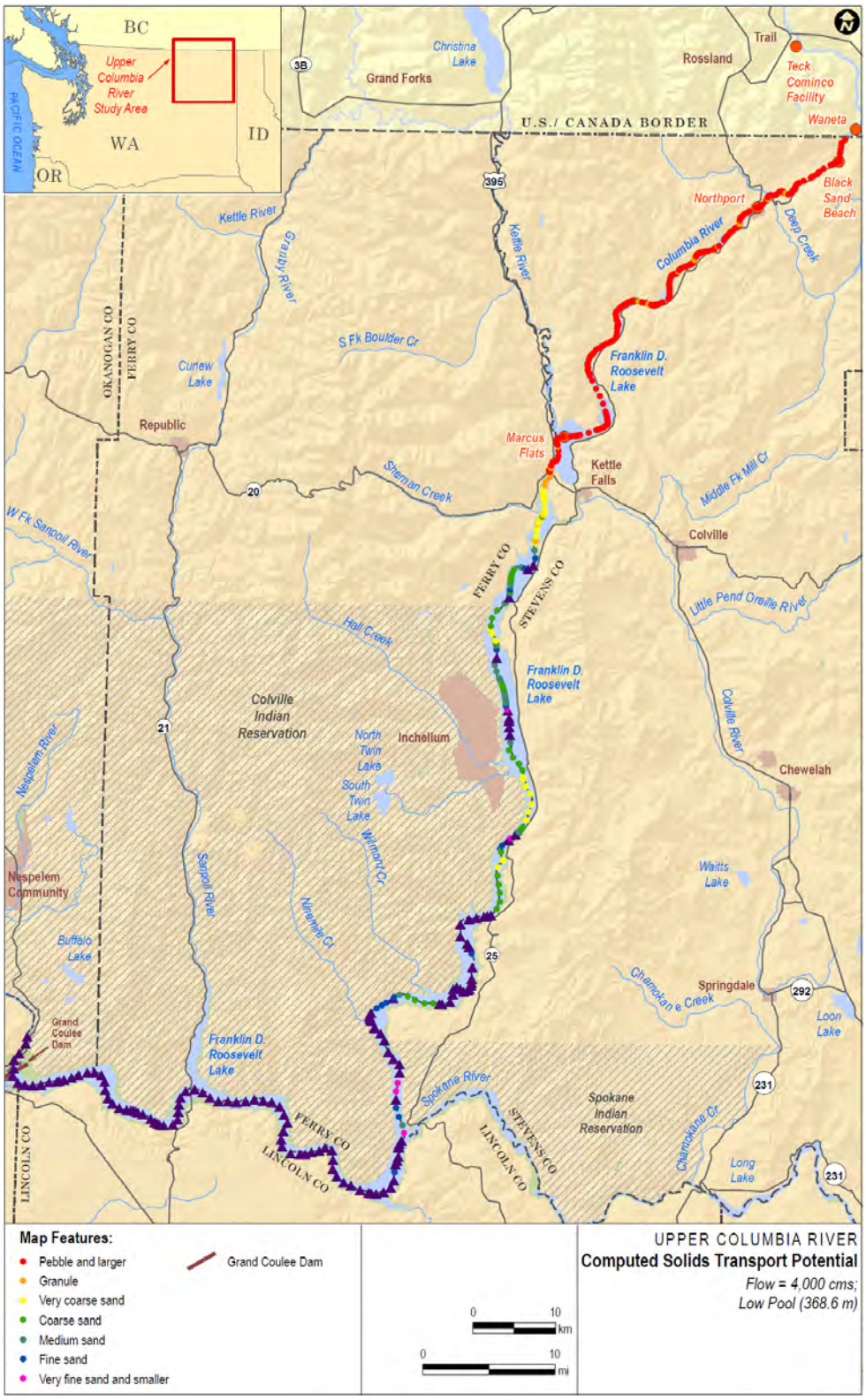


Figure 26. Map of Computed Solids Transport Potential for a Flow of 4,000 m^3/s at Low Pool (368.6 m). Map Features Correspond to the Legend in Figure 24. Purple Triangles Indicate Deposition of Non-Slag Particles.

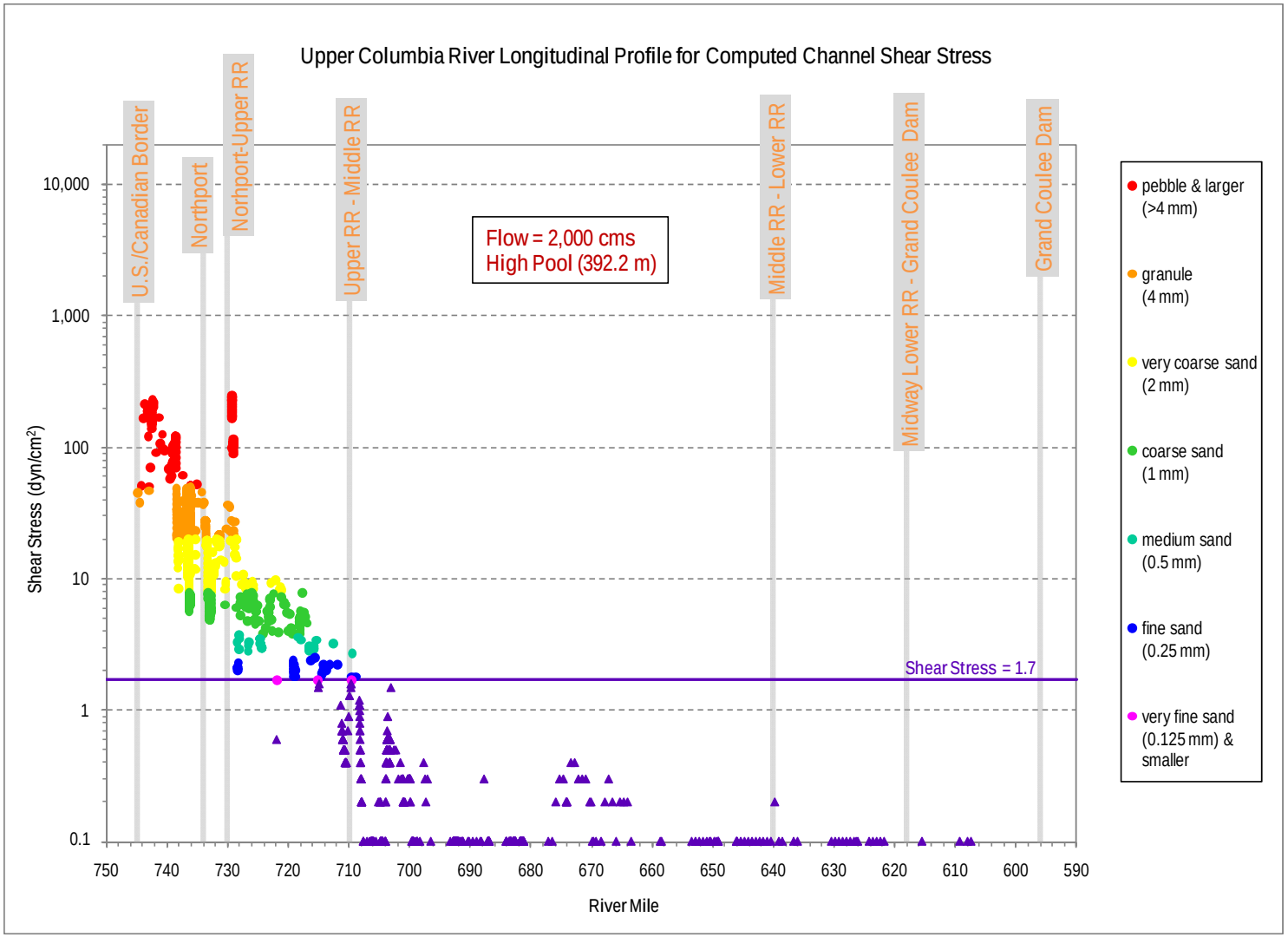


Figure 27. Shear Stresses Computed by the HydroQual HEC-RAS Hydraulic Model as a Function of River Mile for a Flow of 2,000 m^3/s at High Pool (392.2 m). Colored Circles Indicate Largest Size of Movable Particles at each River Mile. Magenta Circles Indicate Non-Slag Solids. Purple Triangles Indicate Deposition of Non-Slag Particles.

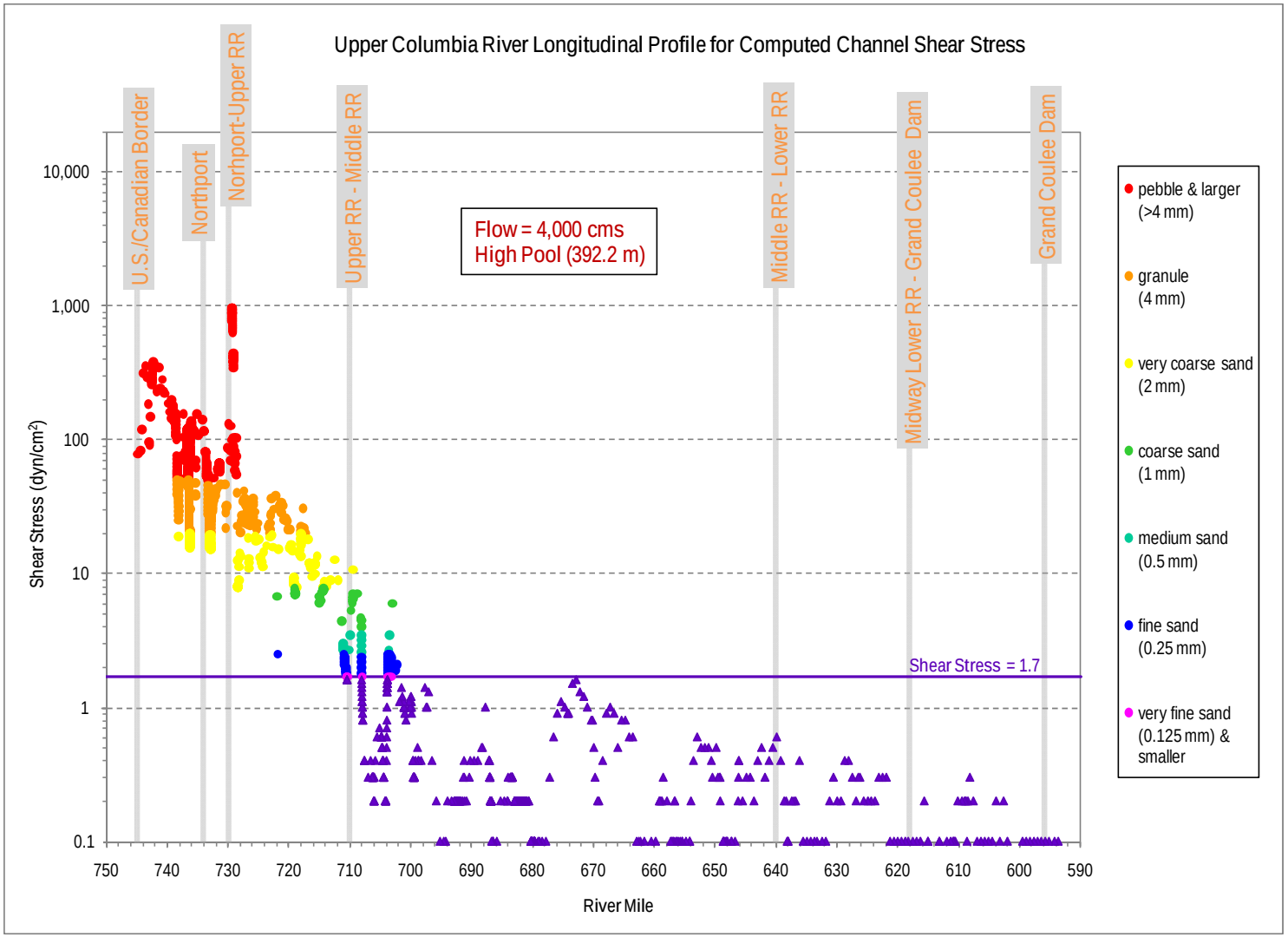


Figure 28. Shear Stresses Computed by the HydroQual HEC-RAS Hydraulic Model as a Function of River Mile for a Flow of 4,000 m^3/s at High Pool (392.2 m). Colored Circles Indicate Largest Size of Movable Particles at each River Mile. Magenta Circles Indicate Non-Slag Solids. Purple Triangles Indicate Deposition of Non-Slag Solids.

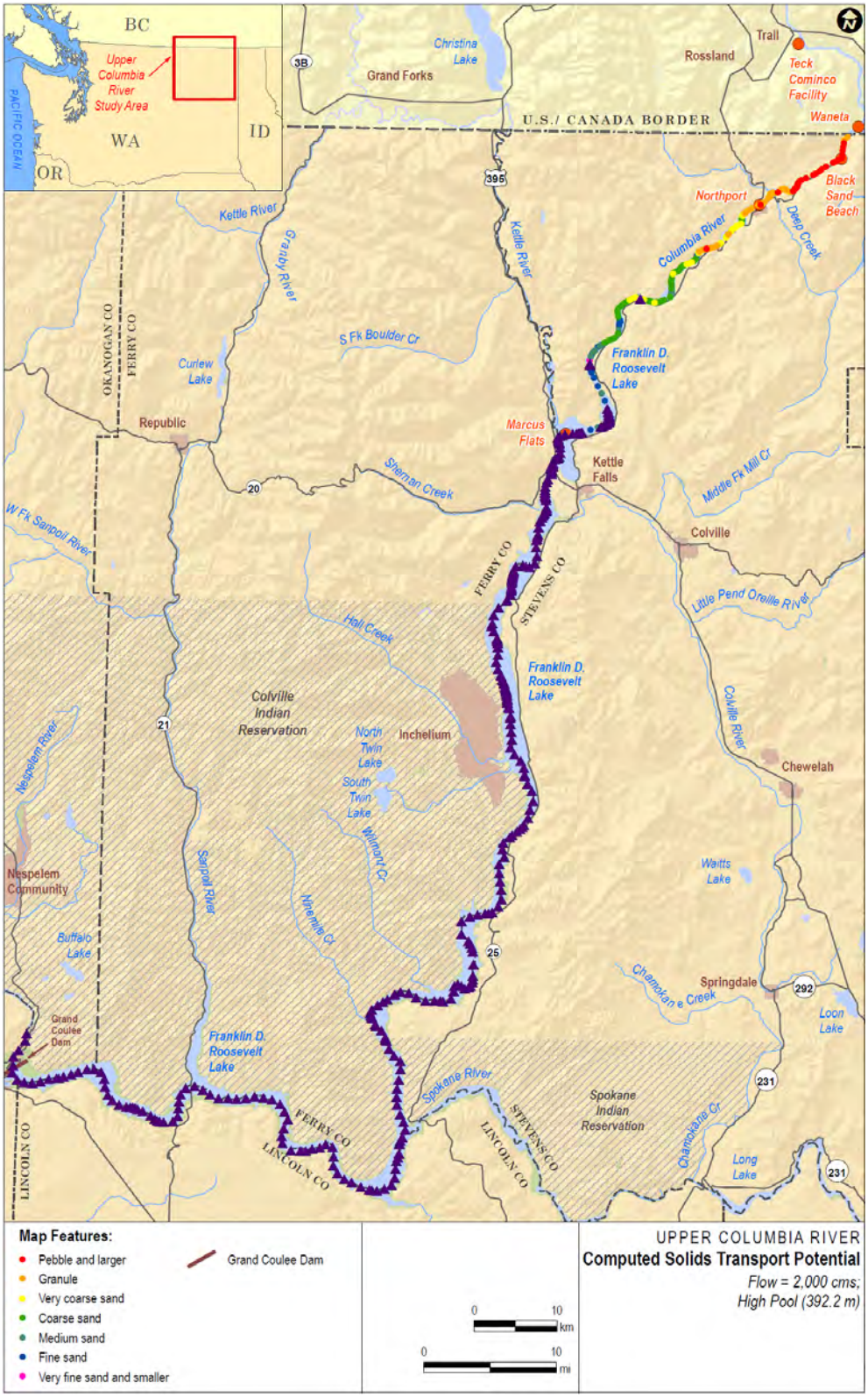


Figure 29. Map of Computed Solids Transport Potential for a Flow of 2,000 m^3/s at High Pool (392.2 m). Map Features Correspond to the Legend in Figure 27. Purple Triangles Indicate Deposition of Non-Slag Particles.

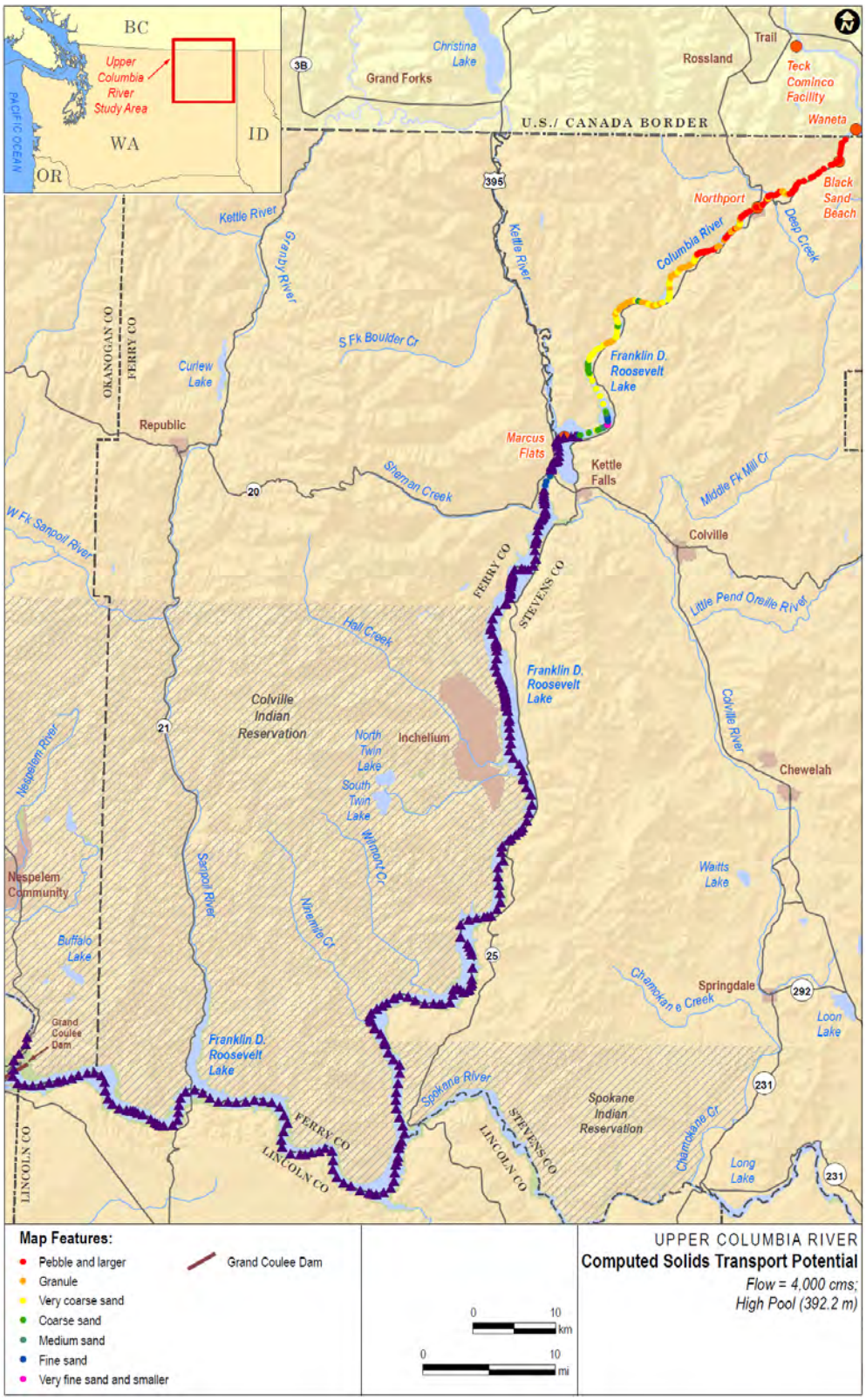


Figure 30. Map of Computed Solids Transport Potential for a Flow of 4,000 m^3/s at High Pool (392.2 m). Map Features Correspond to the Legend in Figure 28. Purple Triangles Indicate Deposition of Non-Slag Particles.

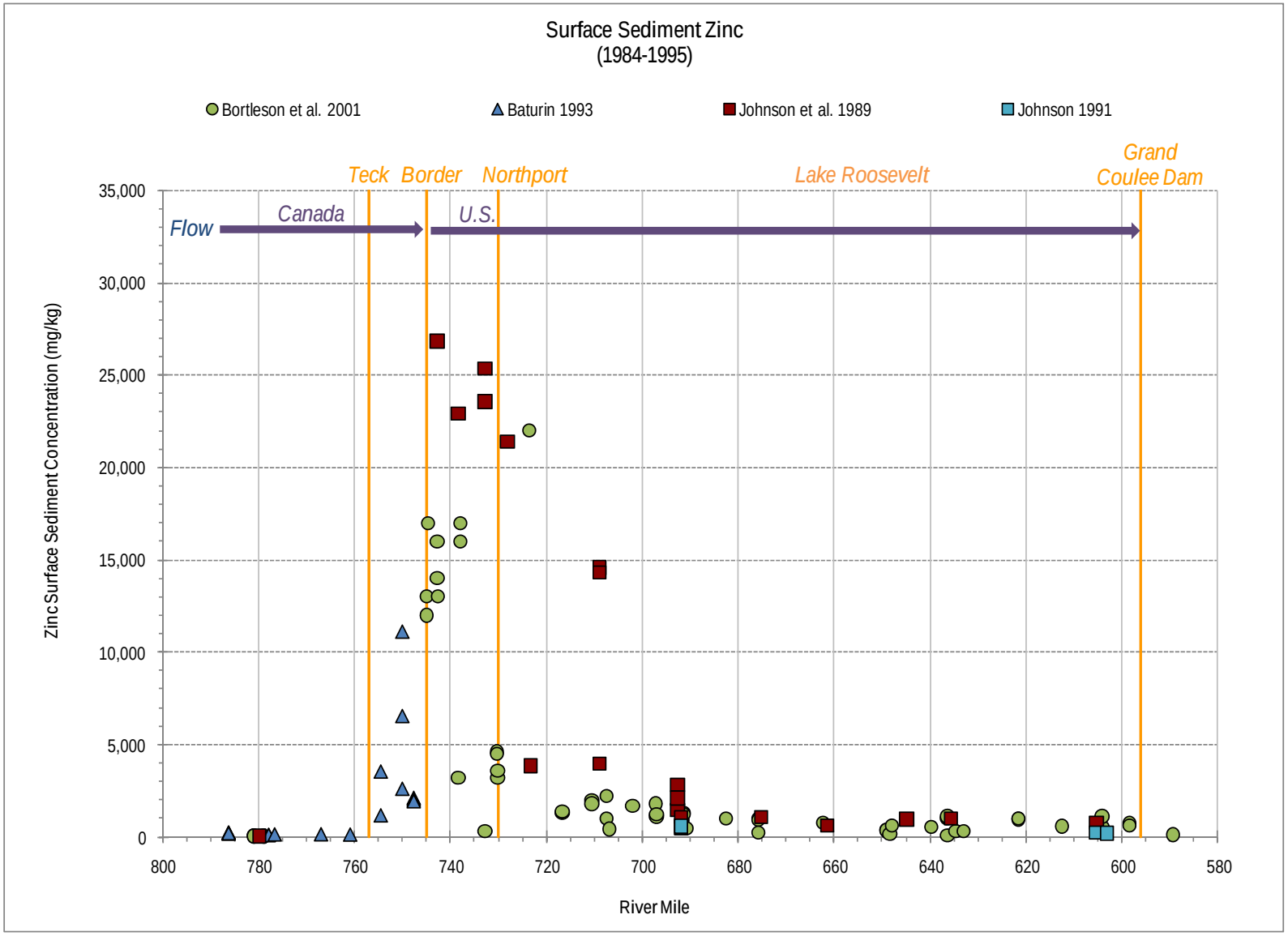


Figure 31. Surface Sediment Total Zinc Concentrations by River Mile for 1984-1995

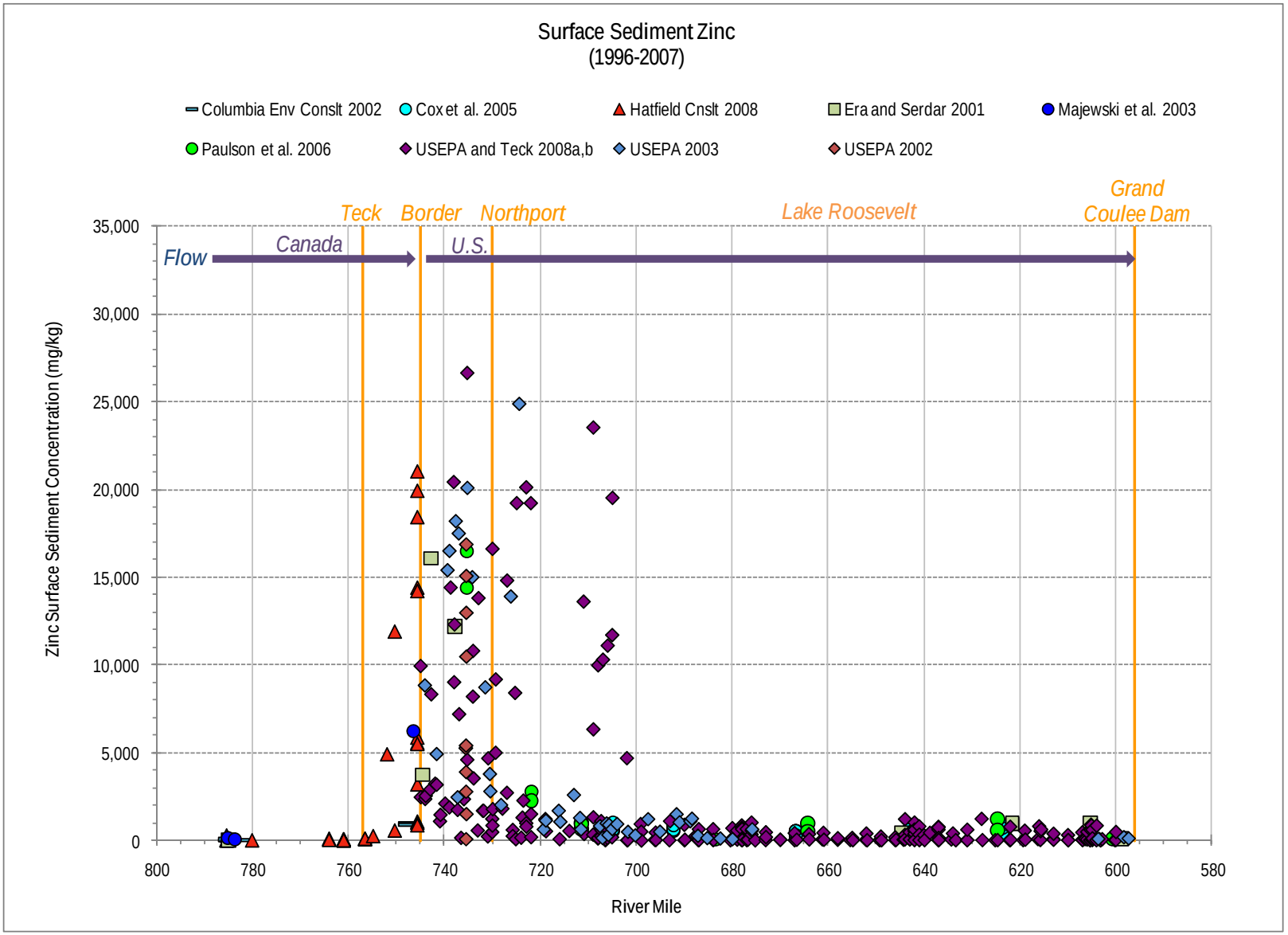


Figure 32. Surface Sediment Total Zinc Concentrations by River Mile for 1996-2007

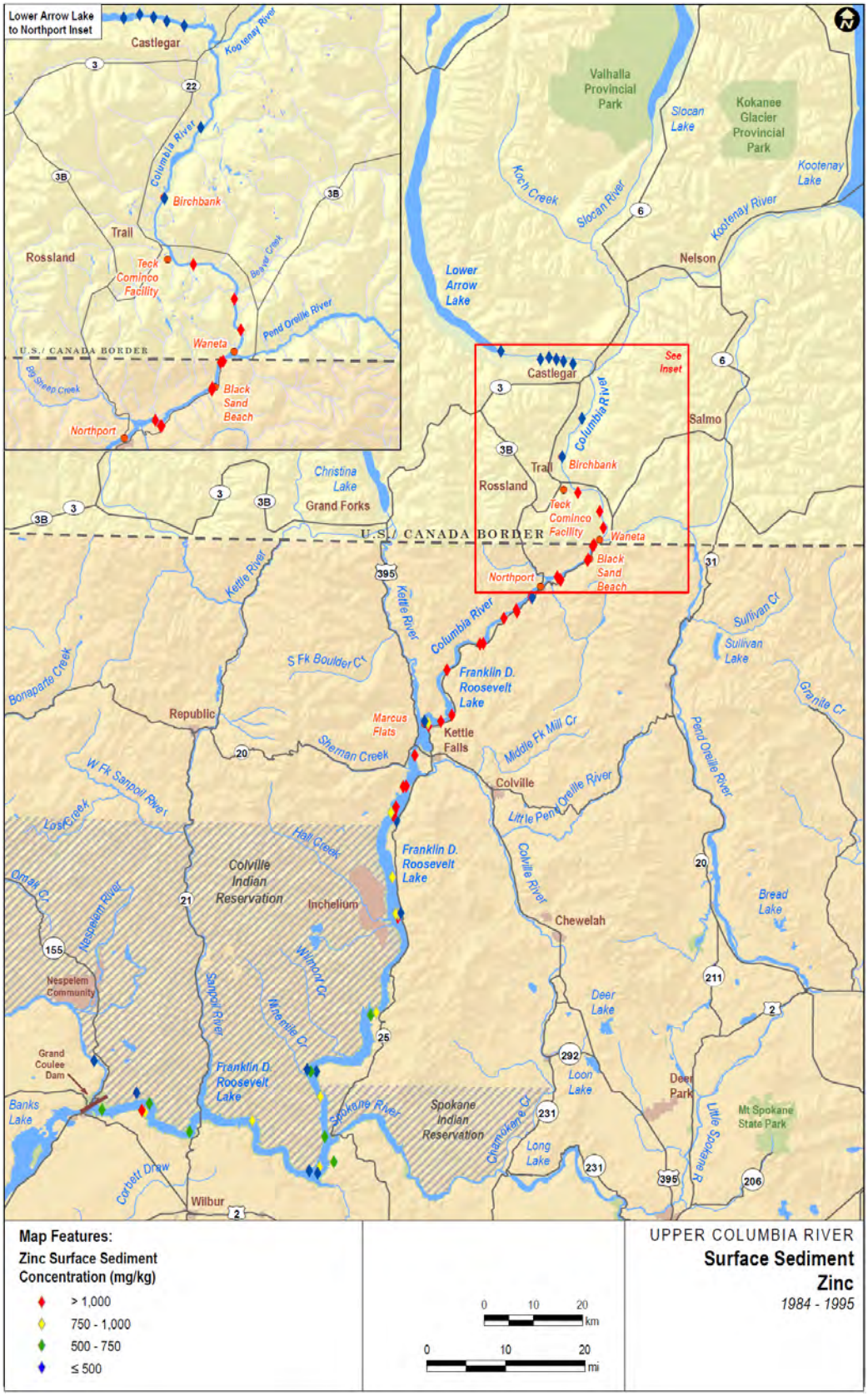


Figure 33. Map of Surface Sediment Total Zinc Concentrations for 1984-1995

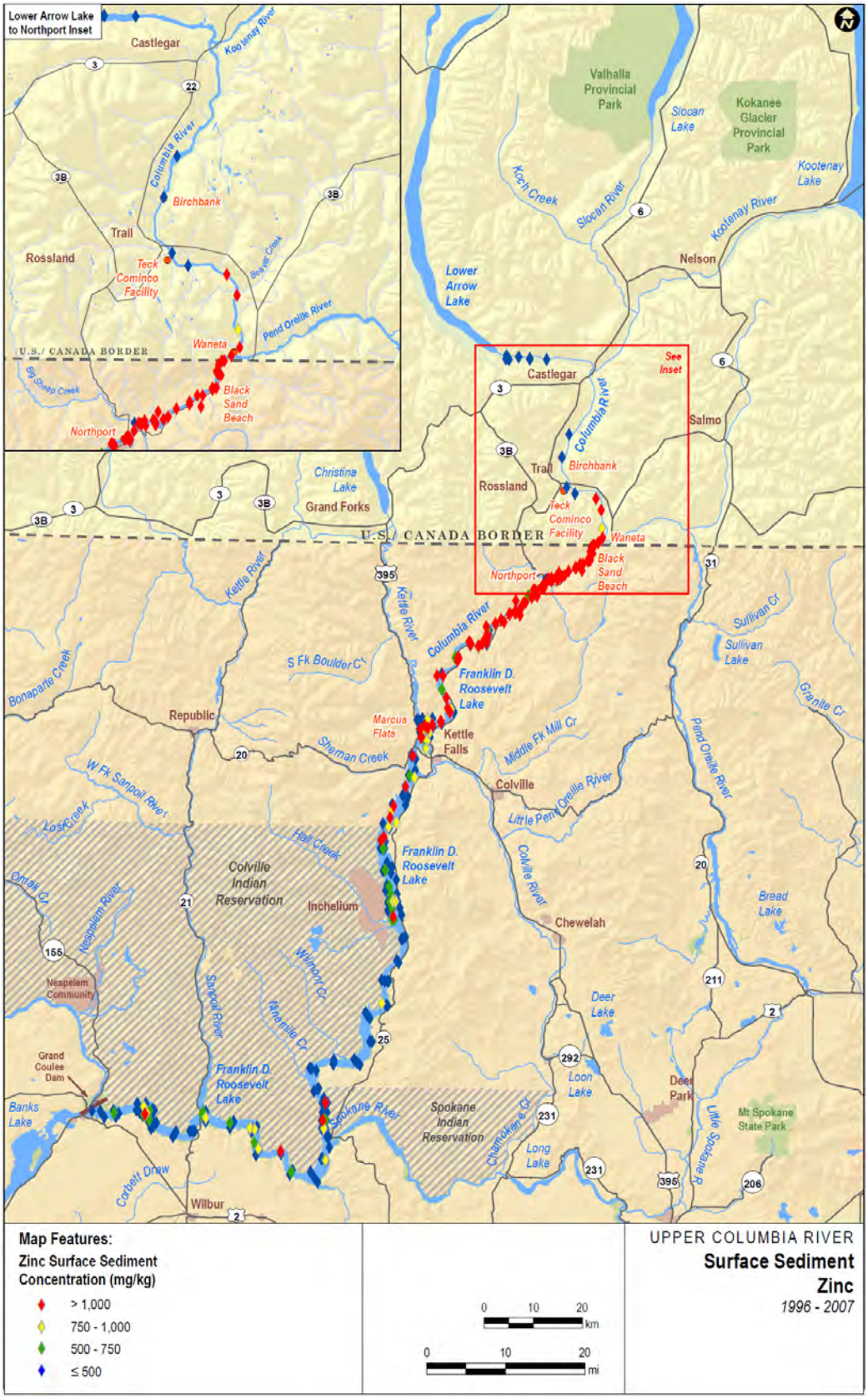


Figure 34. Map of Surface Sediment Total Zinc Concentrations for 1996-2007

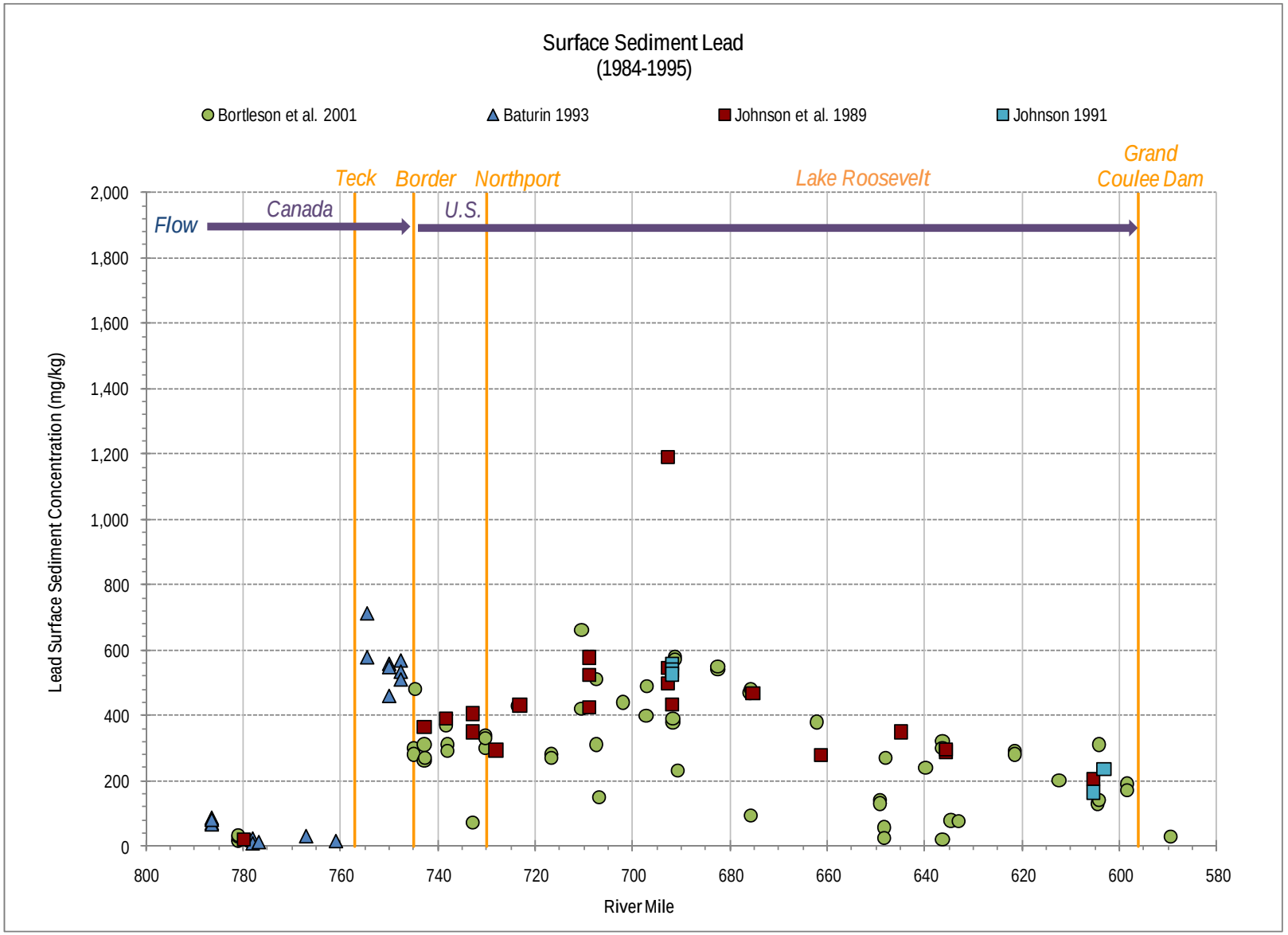


Figure 35. Surface Sediment Total Lead Concentrations by River Mile for 1984-1995

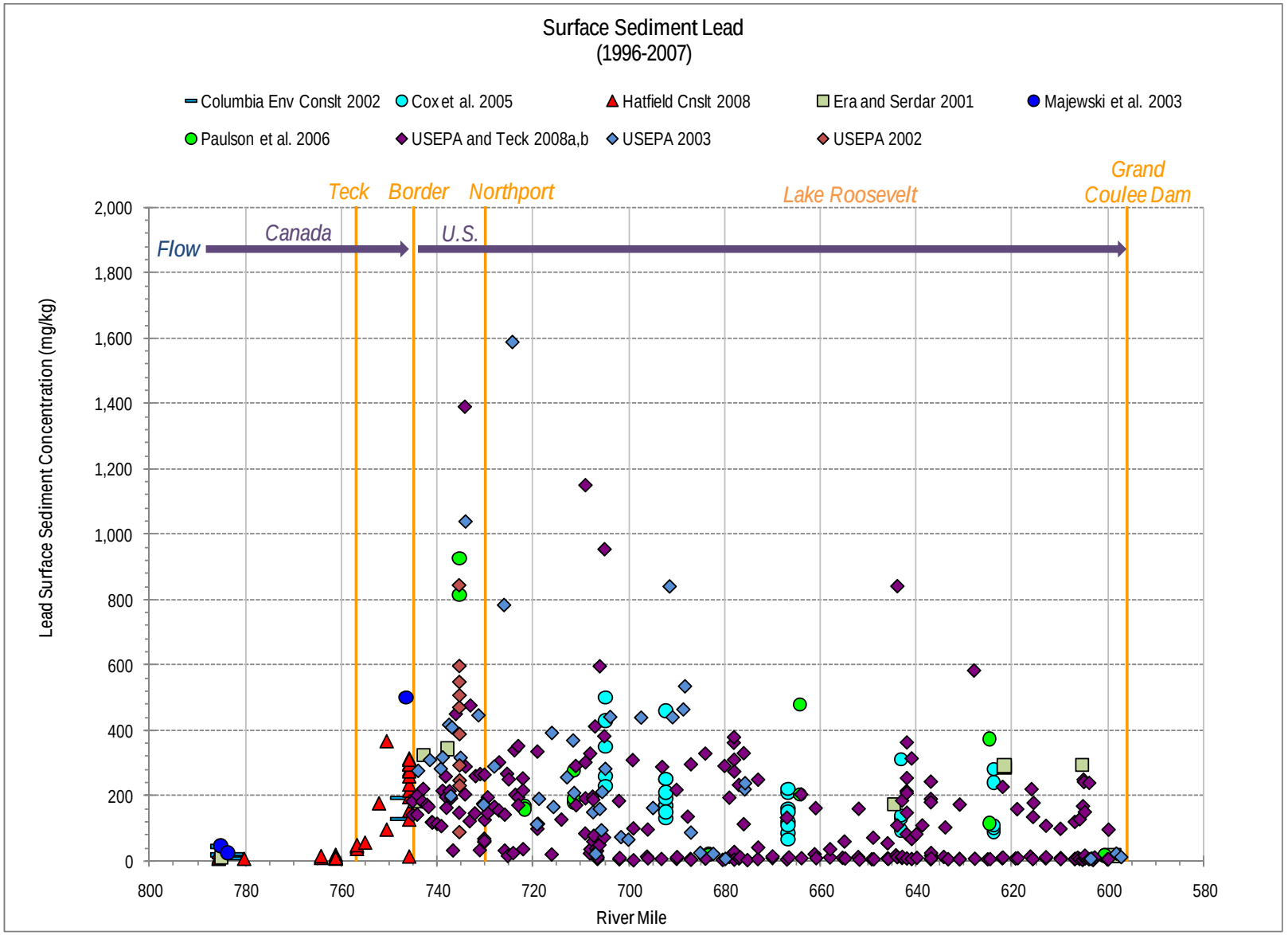


Figure 36. Surface Sediment Total Lead Concentrations by River Mile for 1996-2007

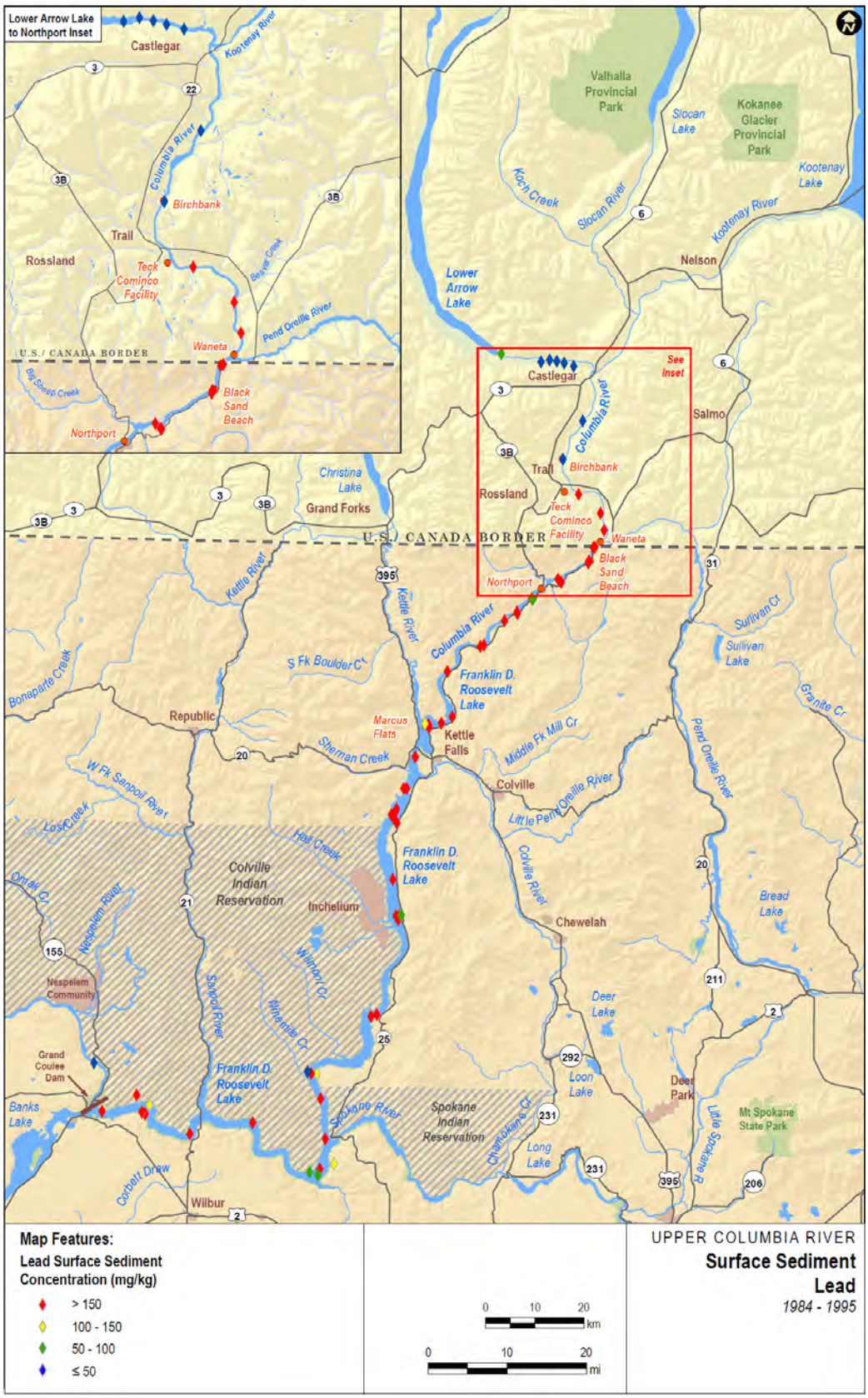


Figure 37. Map of Surface Sediment Total Lead Concentrations for 1984-1995

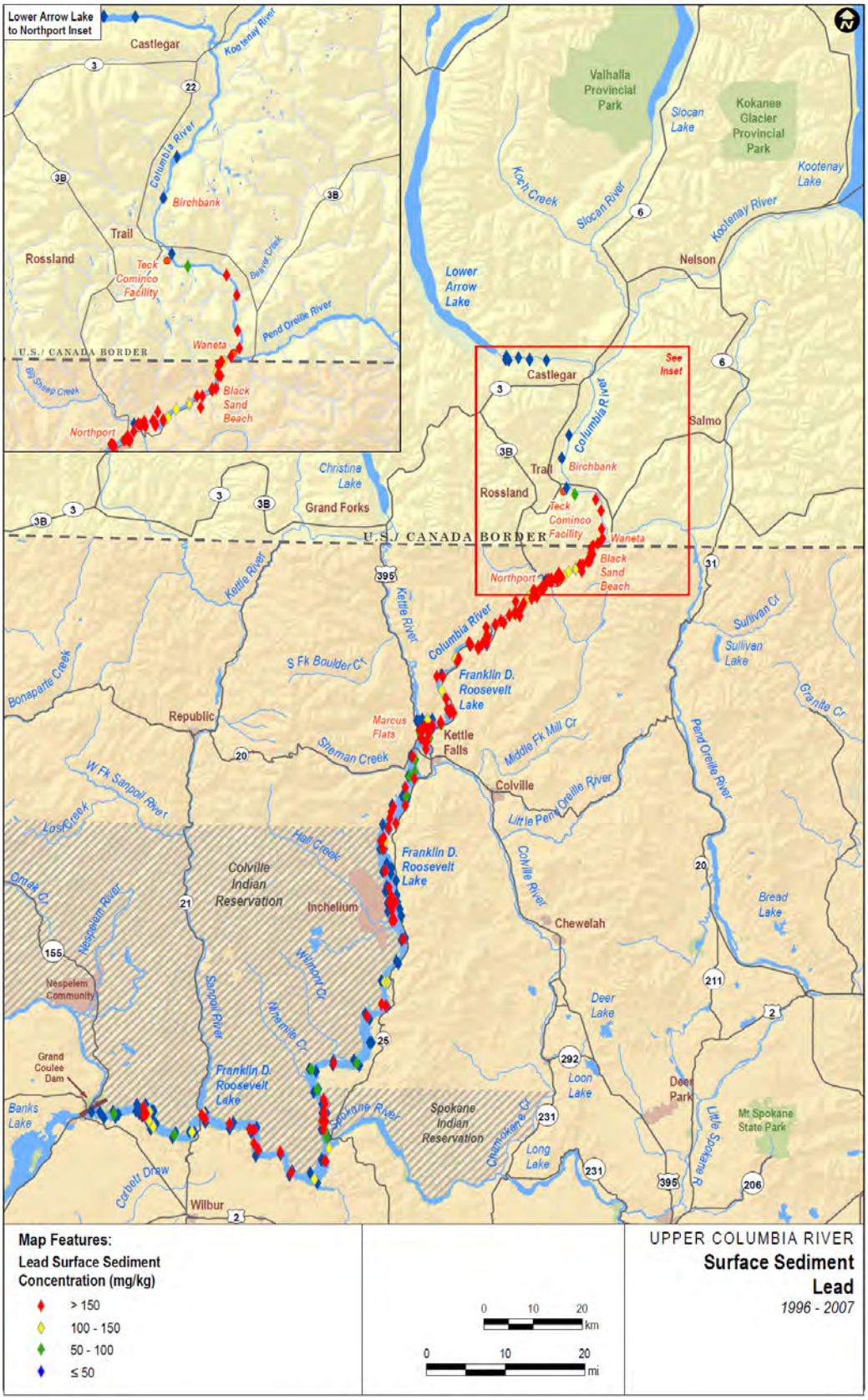


Figure 38. Map of Surface Sediment Total Lead Concentrations for 1996-2007

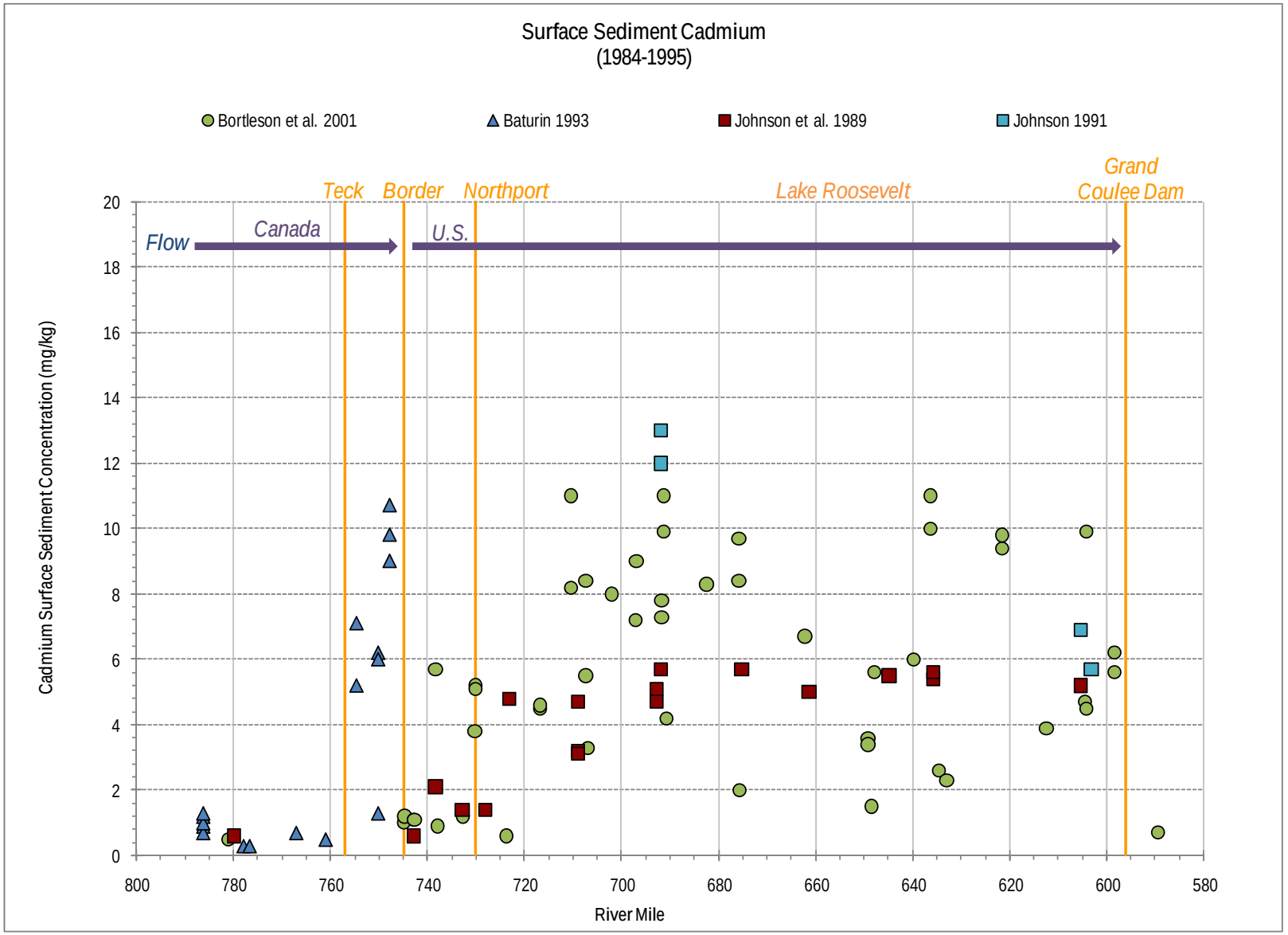


Figure 39. Surface Sediment Total Cadmium Concentrations by River Mile for 1984-1995

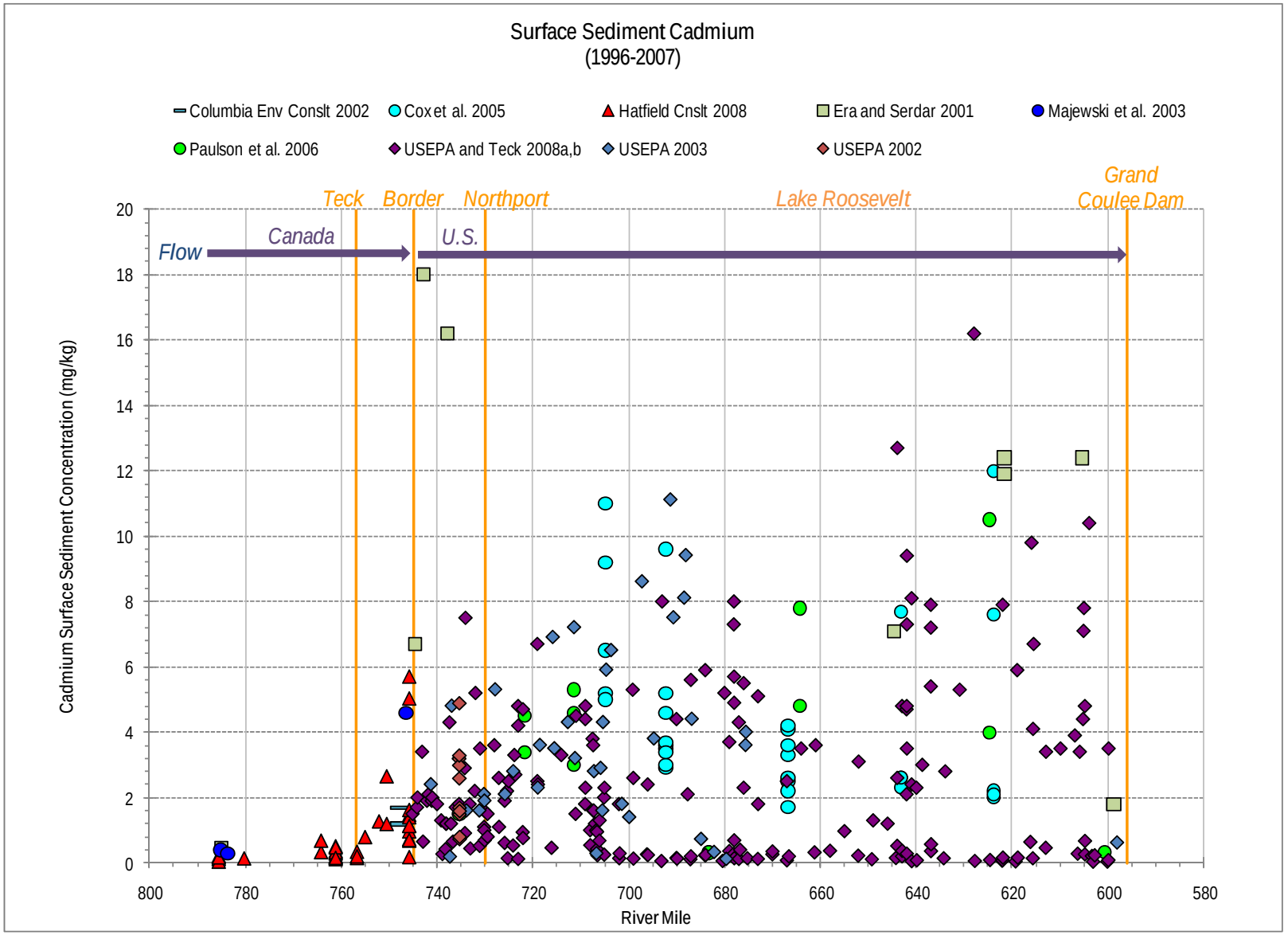


Figure 40. Surface Sediment Total Cadmium Concentrations by River Mile for 1996-2007

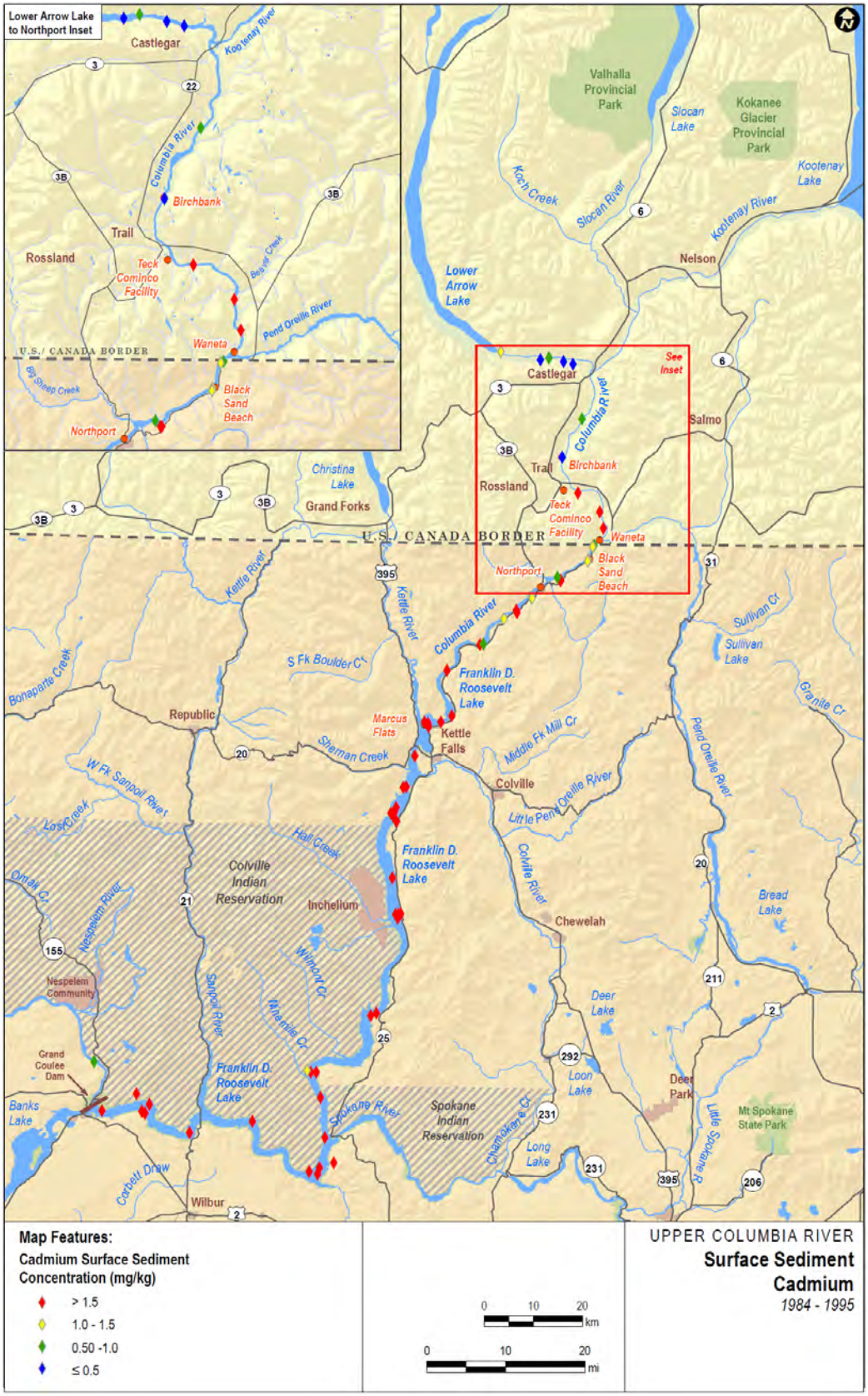


Figure 41. Map of Surface Sediment Total Cadmium Concentrations for 1984-1995

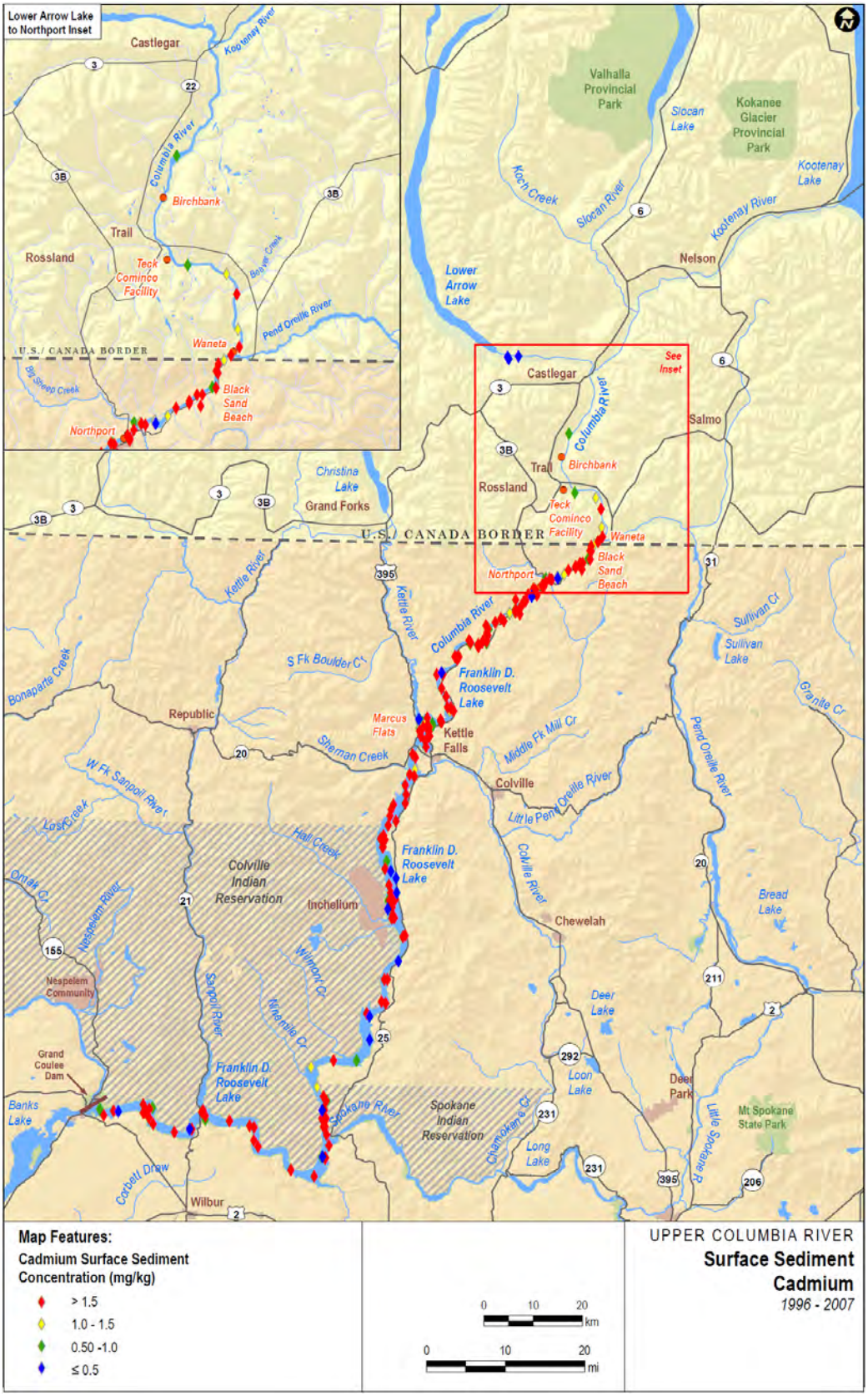


Figure 42. Map of Surface Sediment Total Cadmium Concentrations for 1996-2007

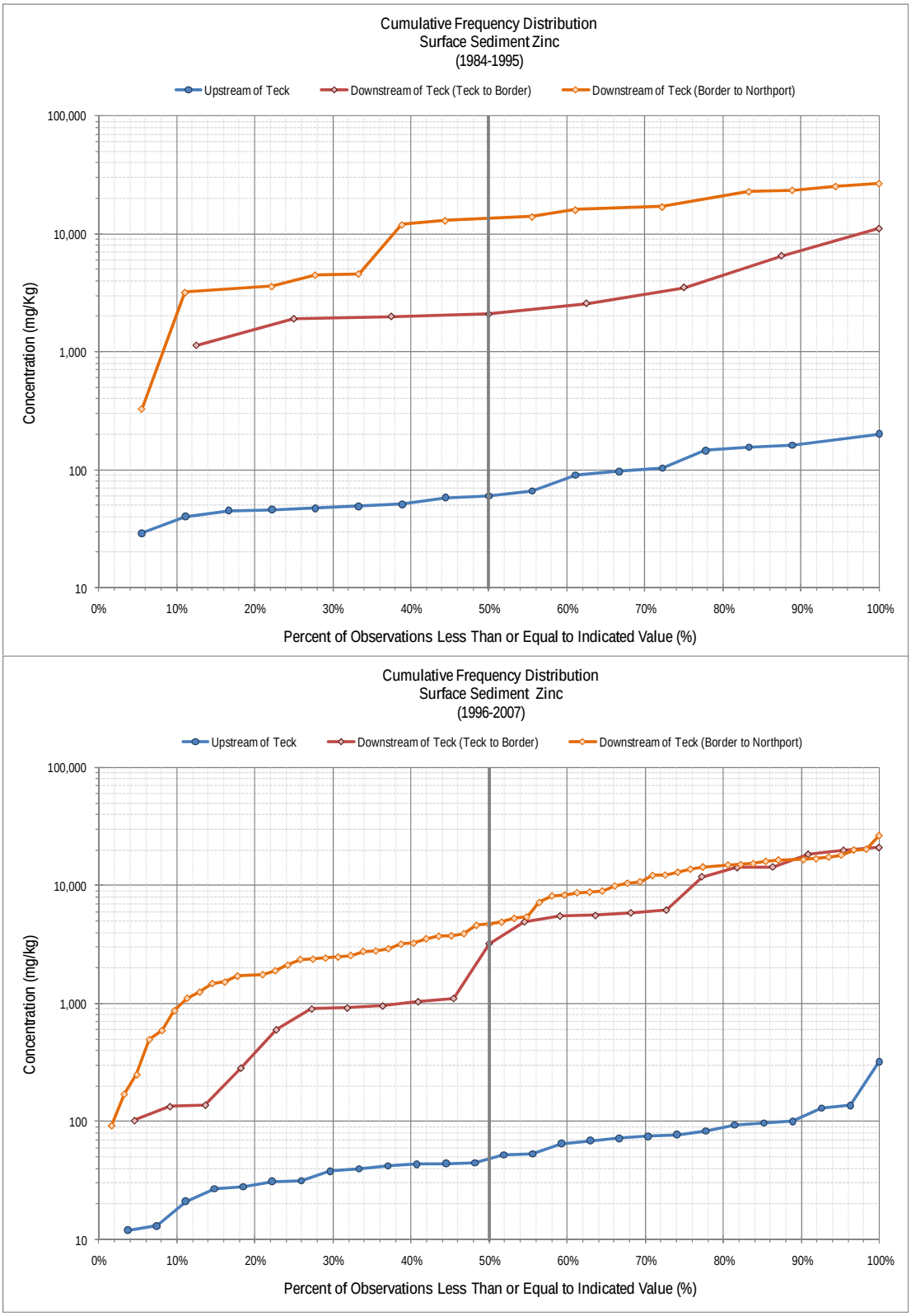


Figure 43. Cumulative Frequency Distributions for Surface Sediment Total Zinc Concentrations for 1984-1995 (top panel) and 1996-2007 (bottom panel)

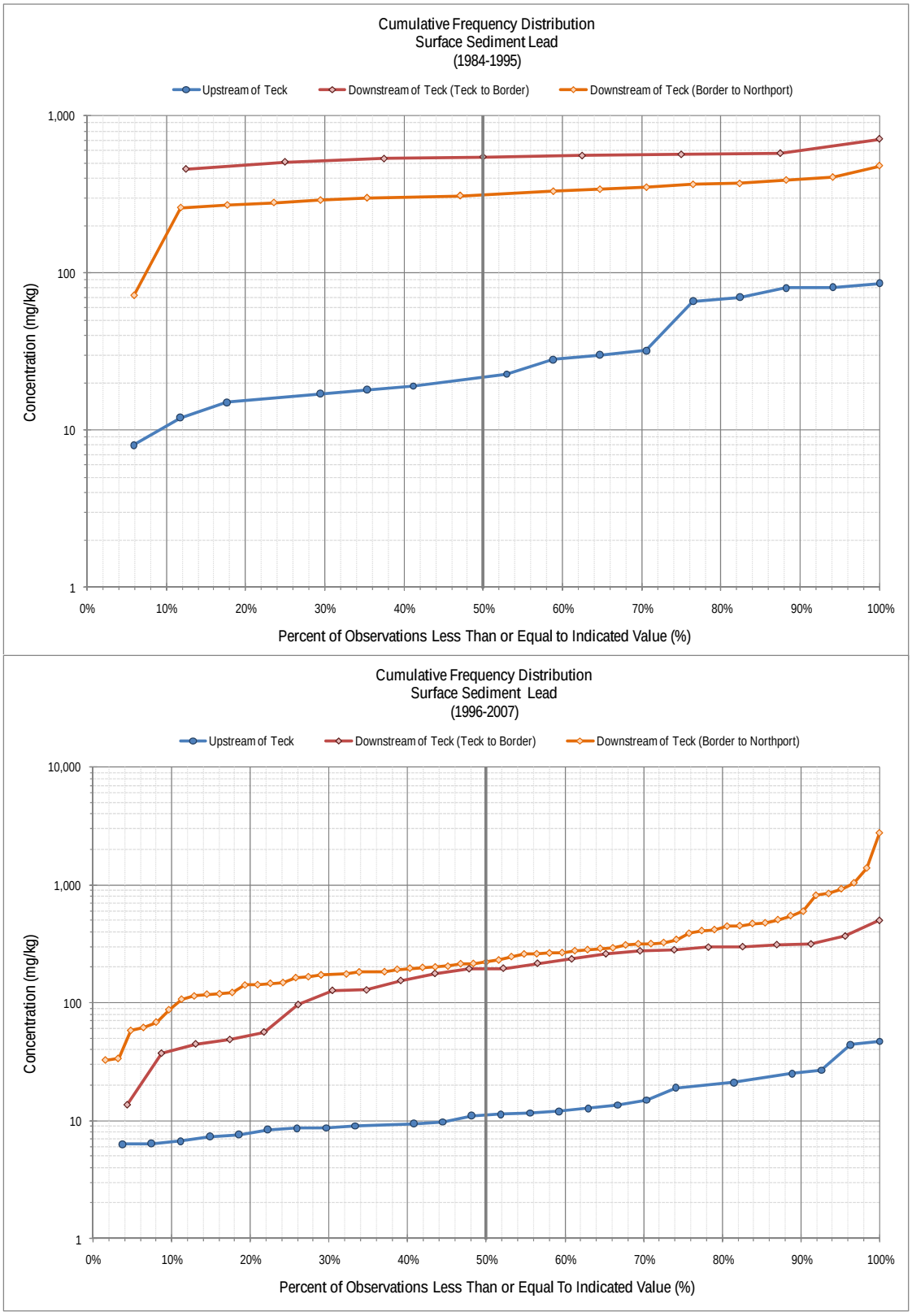


Figure 44. Cumulative Frequency Distributions for Surface Sediment Total Lead Concentrations for 1984-1995 (top panel) and 1996-2007 (bottom panel)

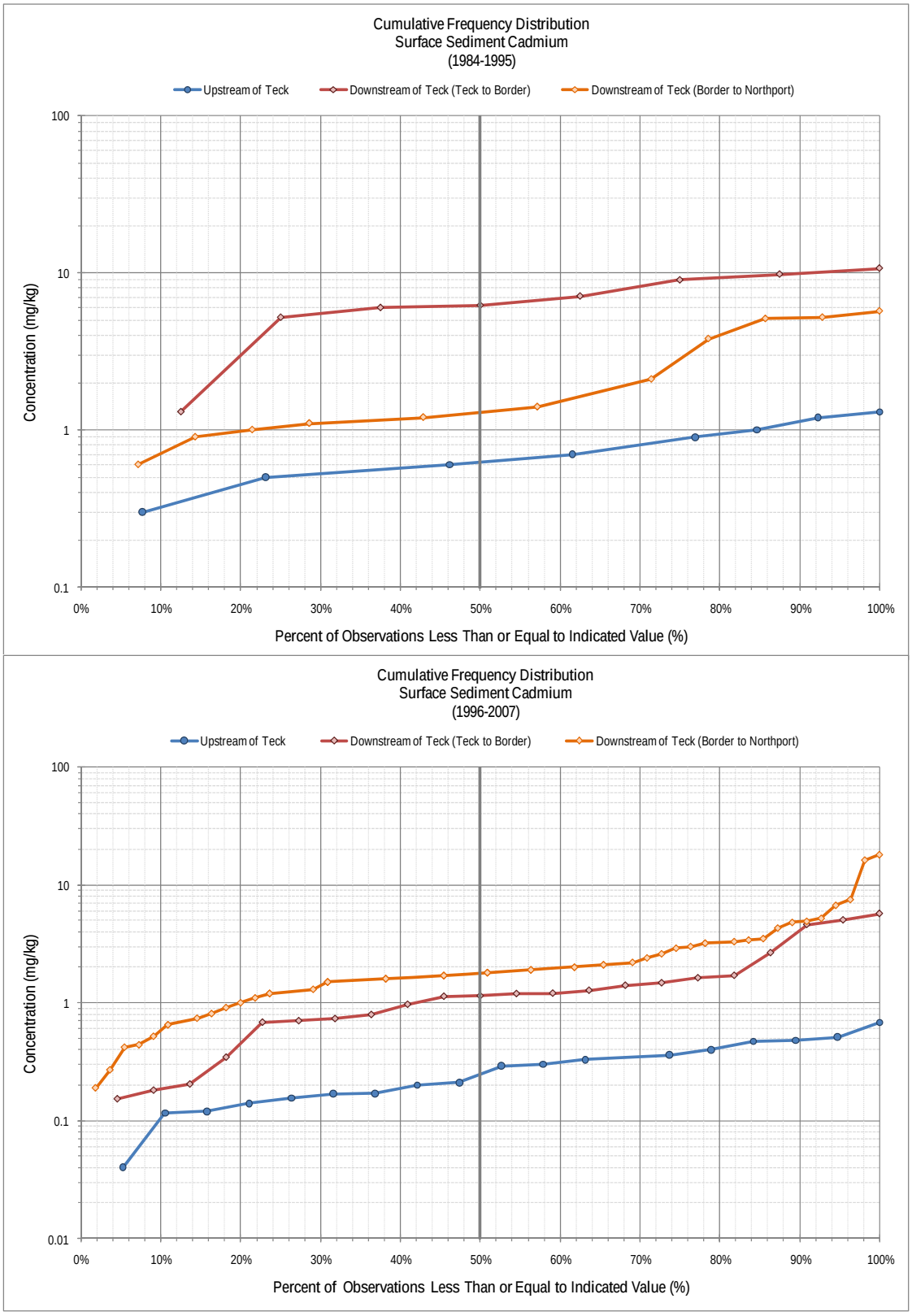


Figure 45. Cumulative Frequency Distributions for Surface Sediment Total Cadmium Concentrations for 1984-1995 (top panel) and 1996-2007 (bottom panel)

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APPENDIX A

CURRICULUM VITAE FOR VICTOR J. BIERMAN, JR.

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Victor J. Bierman, Jr., Ph.D., BCEEM

Senior Scientist
LimnoTech

Principal Expertise

- Water Quality Modeling
- Toxic Chemicals
- Eutrophication
- Ecosystems
- Environmental Assessment
- Regulatory Compliance

Education

Ph.D.	Environmental Engineering University of Notre Dame, Notre Dame, Indiana, 1974
M.S.	Physics University of Notre Dame, Notre Dame, Indiana, 1971
A.B.	Science Villanova University, Villanova, Pennsylvania, 1966

Professional Certifications

Board Certified Environmental Engineering Member (by Eminence), American Academy of Environmental Engineers

Experience Summary

Dr. Bierman is a Senior Scientist at LimnoTech, an environmental science and engineering consulting firm whose home office is located in Ann Arbor, Michigan. He has 37 years of experience in the development and application of water quality models for the transport and fate of toxic chemicals, and eutrophication, leading to his publication of over 100 technical papers and reports. He is a former U.S. Environmental Protection Agency National Expert in Environmental Exposure Assessment, and a former Associate Professor in the Department of Civil Engineering at the University of Notre Dame. He is also a Board Certified Environmental Engineering Member (by Eminence) of the American Academy of Environmental Engineers.

As a LimnoTech Senior Scientist, Dr. Bierman conducts research and development on projects for federal, state and regional government clients. He also provides scientific peer review, litigation support, and expert testimony on a variety of environmental issues for government agencies, and industrial, regulatory and private clients.

Dr. Bierman is a leading expert in toxic chemical transport, fate, partitioning and bioaccumulation. He has conducted assessment studies in major river systems, estuaries, and the Great Lakes, and remedial investigations at U.S. EPA Superfund sites. These studies have included organic chemicals, heavy metals, sediment processes, and mass balance modeling.

Dr. Bierman is also a leading expert in the assessment and solution of problems related to nutrients, nuisance algal blooms, nitrogen fixation, hypoxia, exotic species, and ecosystem processes. He has

conducted studies in watersheds, lakes, rivers, estuaries and coastal marine systems. This experience has included data synthesis, scientific review, and development and application of mass balance models.

Projects conducted by Dr. Bierman include eutrophication studies in the Great Lakes, Saginaw Bay, the Gulf of Mexico, Chesapeake Bay, the Potomac and Caloosahatchee River Estuaries, Lake Okeechobee, the Lower St. Johns River, and the Florida Everglades. They also include remedial investigations for contaminated sediments at Superfund sites in the Hudson, Fox and Kalamazoo Rivers, and toxic chemical transport and fate studies in the Great Lakes, Green Bay, Saginaw Bay, the Columbia River, and the Delaware and Potomac River Estuaries. Clients have included federal agencies such as the U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, and the National Oceanic and Atmospheric Administration; regional agencies such as the Metropolitan Washington Council of Governments, South Florida Water Management District, St. Johns River Water Management District, Delaware River Basin Commission, and the Port of Portland; and various other state and local government agencies. His clients have also included private sector industries and environmental organizations.

Key accomplishments by Dr. Bierman include synthesis of results from five different eutrophication models, including his own model of Saginaw Bay, to develop target phosphorus loadings to the Great Lakes as part of the 1978 Water Quality Agreement between the U.S. and Canada; modeling of hypoxia in the Gulf of Mexico to assess the influence of nutrient loadings from the Mississippi River Basin and produced water discharges from oil and gas drilling activities; transport and fate modeling of PCBs as part of the Hudson River Reassessment RI/FS; development of a coupled phytoplankton-exotic species-PCB model of Saginaw Bay, Lake Huron; development of models for PCB total maximum daily loads (TMDLs) for the Delaware and Potomac River Estuaries; modeling of eutrophication and sediment diagenesis in Lake Okeechobee; development of models for estuarine phosphorus dynamics and algal speciation in the Potomac River Estuary; modeling of phosphorus transport and fate in the Florida Everglades; development of a model to support a dioxin TMDL in the Columbia River Basin; and service on independent scientific peer review panels for the U.S. Environmental Protection Agency and U.S. Army Corps of Engineers.

Professional and Academic Appointments

Senior Scientist 2001-Present	LimnoTech Greensboro and Oak Ridge, North Carolina
Associate Vice President 1997-2001	LimnoTech Ann Arbor, Michigan
Senior Scientist 1992-1997	LimnoTech South Bend, Indiana
Senior Project Manager 1990-1992	LimnoTech South Bend, Indiana
Adjunct Associate Professor 1990-1992	Dept. of Civil Engineering & Geological Sciences University of Notre Dame, Notre Dame, Indiana
Associate Professor 1986-1990	Department of Civil Engineering University of Notre Dame, Notre Dame, Indiana
Environmental Scientist 1981-1986	Environmental Research Laboratory U.S. Environmental Protection Agency, Narragansett, Rhode Island EPA National Expert in Environmental Exposure Assessment

Adjunct Associate Professor 1985-1986	Department of Civil and Environmental Engineering University of Rhode Island, Kingston, Rhode Island
Environmental Scientist 1974-1981	Large Lakes Research Station U.S. Environmental Protection Agency, Grosse Ile, Michigan
Systems Ecologist 1974	Cranbrook Institute of Science Bloomfield Hills, Michigan
Graduate Student 1968-1973	Departments of Physics & Civil Engineering University of Notre Dame, Notre Dame, Indiana
Science Teacher 1966-1968	Northeast Catholic High School Philadelphia, Pennsylvania

Professional Affiliations

American Chemical Society

Water Environment Federation

Estuarine Research Federation

Society of Environmental Toxicology and Chemistry

North American Lake Management Society

American Society of Limnology and Oceanography

International Association for Great Lakes Research

Selected Professional Activities

Panel Member, Independent External Peer Review Panel, for U.S. Army Corps of Engineers St. Johns Bayou and New Madrid Floodway (MO) Consolidated National Environmental Policy Act (NEPA) Document (Phase I) and Project Work Plan (Phase II). 2009-Present.

Peer Reviewer, U.S. Environmental Protection Agency Science Advisory Board, Ecological Processes and Effects Committee, for EPA draft technical guidance on development of numeric nutrient criteria for the protection of aquatic life. 2009-2010.

Peer Reviewer, San Francisco Estuary Institute, for a dioxin issue paper for San Francisco Bay. 2008.

Scientific Facilitator, Independent Peer Review Panel, for South Florida Water Management District Everglades Landscape Model (ELM). 2006-2007.

Peer Reviewer, U.S. Environmental Protection Agency, for a Linked HSPF-AQUATOX Modeling System as an alternate approach for development of numeric nutrient water quality criteria. 2006.

Discussion Group Leader, Chesapeake Bay Program Scientific and Technical Advisory Committee Workshop, Modeling in the Chesapeake Bay Program: 2010 and Beyond, Annapolis, MD, January 17-18 2006.

Editorial Board, Aquatic Ecosystem Health & Management, Journal of the Aquatic Ecosystem Health and Management Society. 2003-2006.

Co-Chair, Session on Contaminant Fate and Transport, Third International Conference on the Remediation of Contaminated Sediments, New Orleans, Louisiana, January 24-27, 2005.

Member, Modeling Subcommittee of the Monitoring, Modeling and Research Committee, U.S. EPA Gulf of Mexico Program. 1999-2005. Provide expert assistance on design and implementation of a mathematical modeling program to address scientific and management questions related to hypoxia in the Gulf of Mexico.

Chair, Special Session on Total Maximum Daily Load (TMDL) for PCBs: Case Study of the Delaware River Estuary. Water Environment Federation, WEFTEC04, New Orleans, Louisiana, October 6, 2004.

Co-Chair, 5th International Symposium on Sediment Quality Assessment, Chicago, Illinois, October 16-18, 2002.

Invited Expert, Lake Michigan Mass Balance Sediment Modeling Workshop, U.S. EPA Great Lakes National Program Office. 2001. Provided expert review and technical guidance on alternate modeling approaches for sediment dynamics in the Lake Michigan Mass Balance Study.

Co-Chair, Task Group 4, Gulf of Mexico Hypoxia Assessment, White House Committee on Environment and Natural Resources. 1998-2000. Conducted a quantitative assessment of water quality responses in the Gulf of Mexico to potential changes in nutrient loadings from the Mississippi River Basin.

Invited Expert, Gulf Hypoxia Science Meeting, Gulf of Mexico Hypoxia Assessment. 1999. Provided expert advice on scientific questions related to causes of hypoxia in the Gulf of Mexico.

Member, Technical Advisory Committee, Nutrient Enhanced Coastal Ocean Productivity (NECOP) Program, NOAA. 1992-1995. Provide coordination and technical guidance for physical and water quality modeling activities in the NECOP Program.

White Paper Author, Workshop on Reducing Uncertainty in Mass Balance Models of Toxics in the Great Lakes: Lake Ontario Case Study. 1992. Invited to author a "white paper" on model formulations, spatial-temporal resolution and process aggregation for the purpose of guiding workshop discussions.

Associate Editor, Journal of Great Lakes Research. 1986-1991.

Discussion Leader, Mass Balance Workshop, International Joint Commission. 1990. Participated in development of management questions to define levels of mass balance modeling of toxic chemicals in the Great Lakes.

Member, Lake Huron Task Force, International Joint Commission. 1986-1990. Participate in development of surveillance plans, conduct data synthesis and prepare summary reports on water quality conditions in Lake Huron, pursuant to the Water Quality Agreements between the U.S. and Canada.

Task Group Leader, Workshop on Nutrient Cycling/Food Web Interactions for Lake Ontario. 1990. Invited to peer review a proposed Nutrient Cycling/Food Web Model for Lake Ontario.

Invited Expert, Workshop on Sediment and Food Web Effects on Bioaccumulation, U.S. EPA. 1990. Invited to review present understanding and future research approach to bioaccumulation of toxic chemicals.

Invited Expert, Workshop on Mississippi River Plume and Louisiana Shelf Interaction, NOAA. 1989. Invited to review a research plan to study nutrient fluxes, biological productivity and dissolved oxygen depletion as part of a new Coastal Ocean Program.

Member, Technical Advisory Committee, International Association for Great Lakes Research. 1986-1988. Assist the Board of Directors in identifying problems and opportunities in pursuit of long-term research programs to support environmental management in the Great Lakes.

Expert Reviewer, Workshop on Toxic Chemical Loadings in the Great Lakes, International Joint Commission. 1987. Invited to peer review results from three different mathematical models for toxic chemical concentrations in the Great Lakes.

Reviewer, National Sea Grant College Site Team, University of Rhode Island. 1987.

Member, Statistics and Modeling Group, Tributary Loading Workshop, International Joint Commission. 1987. Provided recommendations on monitoring plans and loading estimation techniques for tributaries to the Great Lakes.

Invited Expert, Surveillance Workshop, Great Lakes National Program Office, U.S. EPA. 1986. Invited to participate in a review of present activities and to make recommendations for future programs.

Chairman, Water Quality Working Group, Science and Technical Committee, U.S. EPA Narragansett Bay Project. 1985-1986. Provided technical coordination and program review for water quality-related projects.

Member, Science Advisory Committee, Marine Ecosystems Research Laboratory, Graduate School of Oceanography, University of Rhode Island. 1985-1986. Reviewed research accomplishments, current plans and future direction for the MERL, a Center of Excellence under a Cooperative Agreement between the U.S. EPA and the University of Rhode Island.

Member, Water Quality Group, Northeast Monitoring Program, NOAA. 1983-1985. Provided technical assistance on water quality assessments and mathematical modeling in the Middle Atlantic Bight.

Expert Reviewer, Environmental Program, National Marine Fisheries Service, NOAA. 1984. Served as an outside reviewer for the Environmental Assessment Program of the Northeast Fisheries Center.

Panelist, Eutrophication Symposium, New England Estuarine Research Society. 1984. Invited to participate in a discussion of alternative approaches to the study of eutrophication.

Member, Board of Directors, International Association for Great Lakes Research. 1981-1984. Elected for a three-year term.

Associate Editor, Journal of Great Lakes Research. 1979-1983.

Member, Steering Committee for Implementation of Ecosystem Approach Workshop, International Joint Commission. 1981-1982. Served as a technical consultant for ecosystem modeling related to management issues in the Great Lakes.

Member, Technical Advisory Committee, Chesapeake Bay Program, U.S. EPA. 1979-1982. Served as a technical consultant on eutrophication and water quality modeling.

Expert Witness, Public Hearings on Phosphorus Management Strategies for the Great Lakes. International Joint Commission, Windsor, Ontario. 1980.

Ad Hoc Member, Modeling Sub-Group, Phosphorus Management Strategies Task Force, International Joint Commission. 1979. Served as a technical consultant on the scientific basis for development of the target phosphorus loads for the Great Lakes as part of the 1978 Water Quality Agreement.

Member, Task Group III, A Technical Group to Review Phosphorus Loadings, U.S.-Canada Water Quality Agreement Re-Negotiation. 1978. Synthesized results from five different mathematical models and developed target phosphorus loading recommendations for the major basins in the Great Lakes.

Ad Hoc Member, Expert Committee on Ecosystems Aspects, International Joint Commission. 1977. Reviewed the Hydroscience water quality model of Lake Ontario.

Expert Witness, Conservation Committee Hearings, Michigan House of Representatives. 1977. Testified on House Bills 4015 and 4023 to ban phosphates in detergents.

Member, Inter-Agency Technical Advisory Group, U.S. Army Corps of Engineers Lake Erie Project. 1975-1977. Served as a technical consultant on projects related to eutrophication and water quality modeling of Lake Erie.

Participant in U.S.-U.S.S.R. Scientific Exchange Meetings. 1976. Moscow, Novosibirsk, Irkutsk, Baikal and Khabarovsk, U.S.S.R.

Selected Experience

Eutrophication Model for St. Johns River Estuary. 2010. Senior Scientist. Preparation and preliminary calibration of the combined Lower St. Johns River and Lake George eutrophication model to support the St. Johns River Water Management District Water Supply Impact Study.

Technical Assistance to U.S. EPA Region 2 on Upper Hudson River Dredging. 2010. Senior Scientist. Conducting an evaluation of an updated hydrodynamic, sediment transport and PCB transport and fate model developed by General Electric for use in informing the Phase 2 remediation and design decisions.

Litigation Support Pertaining to Metals Smelter on Upper Columbia River. 2009-Present. Expert Witness. Providing investigation, analysis and expert testimony on the transport and fate of slag and hazardous substances discharged by a large metals smelter on the Upper Columbia River.

Peer Review of U.S. Army Corps of Engineers Consolidated NEPA Document. 2009-Present. Senior Scientist. Serving on an Independent External Peer Review Panel for U.S. Army Corps of Engineers St. Johns Bayou and New Madrid Floodway (MO) Consolidated National Environmental Policy Act (NEPA) Document (Phase I) and Project Work Plan (Phase II).

Expert Assessment of Mercury Dynamics and Nutrients in Florida Waters. 2006-Present. Senior Scientist. Conducting scientific assessment and review of mercury and sulfur dynamics in the Florida Everglades, and nutrient TMDLs in the Everglades and tributaries to Lake Okeechobee.

Expert Assistance on Delaware River PCB Model for Total Maximum Daily Load (TMDL). 2002-Present. Senior Scientist. Providing expert technical assistance to Delaware River Basin Commission on model development, application and data needs to support a total maximum daily load (TMDL) for PCBs in the Delaware River Estuary.

Peer Review of EPA Technical Guidance on Numeric Nutrient Criteria. 2009-2010. Senior Scientist. Served as an expert consultant to the U.S. Environmental Protection Agency Science Advisory Board, Ecological Processes and Effects Committee, to provide scientific peer review of draft technical guidance on development of numeric nutrient criteria for the protection of aquatic life.

Litigation Support for a Food Processor in the Illinois River Watershed. 2006-2010. Expert Witness. Provided expert testimony pertaining to transport and fate of phosphorus from land application of poultry litter in the Illinois River Watershed, Arkansas. Prepared a written expert report, was deposed, and testified at trial in U.S. District Court for the Northern District of Oklahoma.

Chesapeake Bay Water Quality Model. 2004-2009. Senior Scientist. Developed new sub-models for estuarine phosphorus dynamics, pH-alkalinity, and algal speciation for the Potomac portion of the third-generation Chesapeake Bay Water Quality and Sediment Transport Model.

Expert Assistance on Water Quality Modeling for South Florida Water Management District. 2004-2009. Technical Director, LimnoTech/HydroQual Joint Venture. Provided task order consulting services for hydrologic, hydraulic and water quality modeling to support Comprehensive Everglades Restoration Programs (CERP) and other District programs.

Review of Dioxin Issue Paper for San Francisco Bay. 2008. Senior Scientist. Conducted a scientific peer review of a dioxin issue paper for San Francisco Bay under the auspices of the San Francisco Estuary Institute.

Review of Watershed and Water Quality Models for Nutrient TMDLs in the Caloosahatchee River Estuary. 2007-2008. Senior Scientist. Conducted a scientific review of a coupled HSPF-EFDC modeling

system for TMDLs for the Caloosahatchee River Estuary to ensure that nutrient levels are appropriate for restoration of water quality.

Assessment of EPA-Proposed TMDLs for Nutrients in Lake Okeechobee Tributaries. 2006-2007. Senior Scientist. Conducted forecast simulations with the Lake Okeechobee Water Quality Model (LOWQM) to investigate the impacts of the proposed nutrient TMDLs on nitrogen-fixing blue-green algae in the lake, and provided expert assistance to the Everglades Agricultural Area Environmental Protection District and South Florida Water Management District.

Peer Review of Everglades Landscape Model (ELM). 2006-2007. Scientific Facilitator. Conducted scientific facilitation of an independent peer review of the Everglades Landscape Model and its applicability to decision-making for management of nutrients and hydrology in the Florida Everglades.

Peer Review of a Linked HSPF-AQUATOX Modeling System. 2006. Senior Scientist. Conducted a scientific peer review for U.S. EPA on a demonstration application of a linked HSPF-AQUATOX modeling system as an alternate approach for development of numeric nutrient water quality criteria.

Model for PCB Total Maximum Daily Load (TMDL) in Potomac River Estuary. 2005-2007. Senior Scientist. Developed and calibrated a transport and fate model for PCBs in the Potomac River Estuary to support development of a TMDL by District of Columbia, Maryland and Virginia.

Assessment of Impacts of Produced Water Discharges on Gulf of Mexico Hypoxia. 2005-2007. Senior Scientist. Used existing models of Gulf of Mexico hypoxia to estimate incremental impacts of produced water discharges from oil and gas platforms.

Expert Assistance on Chesapeake Bay Water Quality Modeling. 2001-2007. Senior Scientist. Provided expert assistance to Metropolitan Washington Council of Governments by conducting a scientific assessment of the Chesapeake Bay Water Quality Model and its use for developing load allocations for nutrients and solids in the Potomac River and Estuary as part of the Chesapeake 2000 Agreement.

Characterization and Conceptual Site Model for Berry's Creek. 2004-2006. Senior Scientist. Conducted site investigation, data assessment and conceptual modeling to support remediation efforts at Universal Oil Products Superfund Site, Berry's Creek, East Rutherford, New Jersey.

Litigation Support for a Former Manufactured Gas Plant. 2004-2005. Expert Witness. Provided consulting and expert witness services pertaining to contaminant transport and fate at the site of a former manufactured gas plant.

Litigation Support for an Industrial Discharger on the Ohio River. 2004-2005. Expert Witness. Conducted an investigation of hydrodynamics, sediment transport and chemical transport and fate in the Ohio River. Prepared a written expert opinion report, was deposed, and provided technical review of opposing expert reports.

Litigation Support for Wastewater Treatment Plant Permit Challenge. 2004-2005. Expert Witness. Conducted investigations of constituent transport and fate in the Ohio River, and water quality standards applicable to the Ohio River in Kentucky and Ohio.

Water Quality Model to Support Biscayne Bay Feasibility Study. 2004-2005. Project Director. Developed a detailed scope of work for an integrated hydrodynamic, sediment transport and water quality model to support a Phase II Feasibility Study of Biscayne Bay, Florida.

Litigation Support for Hudson River Natural Resource Damage Assessment. 2003-2005. Consulting Expert. Investigated PCB transport and fate issues at the U.S. EPA Hudson River Superfund Site for the U.S. Department of Justice.

Expert Assistance on Offshore Siting Study for Relocation of Wastewater Treatment Plant Outfall. 2002-2005. Senior Scientist. Developed regional-scale nutrient loadings to the northeast continental shelf

of the U.S. to support a modeling assessment of the proposed relocation of a wastewater treatment plant outfall currently discharging to Jamaica Bay, New York.

Dynamics of Sediment-Water Nutrient Fluxes in the Lower St. Johns River. 2000-2005. Project Director. Conducted literature and field assessments of phosphorus, nitrogen, carbon and oxygen fluxes in the Lower St. Johns River to support a site-specific water quality model.

Expert Assistance on Modeling of Hypoxia in the Gulf of Mexico. 2004. Senior Scientist. Provided expert assistance to Offshore Operators Committee, EPA Region 6 and Minerals Management Service on use of existing models to estimate impacts of produced water discharges.

Expert Assistance on Urban Stream Total Maximum Daily Load (TMDL). 2002-2003. Member, Stakeholder Advisory Group. Provided expert technical assistance to City of Greensboro on development and review of an HSPF model for a fecal coliform TMDL on North Buffalo Creek.

Expert Assistance on Lower St. Johns River Water Quality Model for Nutrient Total Maximum Daily Load (TMDL). 2002-2003. Senior Scientist. Provided expert technical assistance to St. Johns River Water Management District and the U.S. Army Corps of Engineers on model development, calibration and incorporation of nitrogen fixation.

Effect of Zebra Mussels on Cycling and Potential Bioavailability of PCBs: Case Study of Saginaw Bay. 1998-2002. Senior Scientist. Developed a mass balance model to represent the influence of phytoplankton and zebra mussel dynamics on PCB transport, fate and bioavailability in Saginaw Bay, Lake Huron.

Water Quality Assessment for NPDES Permit, Cape Fear River. 2001. Project Director. Conducted data assessment and modeling analyses for dissolved oxygen to support NPDES permit re-issuance for an industrial discharge to the Middle Cape Fear River, North Carolina.

Modeling of PCB Fate and Transport for Hudson River Reassessment RI/FS. 1993-2001. Senior Scientist. Developed mass balance models for hydraulics, solids and PCBs to investigate the impacts of continued No Action and various remedial scenarios on water column and sediment PCB exposures in the Upper Hudson River. Results were used to support the EPA Record of Decision to remediate contaminated sediments in the Upper Hudson River.

Columbia River Channel Deepening Reconsultation Project. 2001. Project Director. Reviewed available data and modeling analyses for hydrodynamics, sediment transport and toxic chemicals to support development of a Biological Assessment for potential impacts on endangered species.

Ottawa River Environmental Hot Spot Delineation and Risk Assessment. 2000-2001. Project Director. Directed assessment of risks posed by existing conditions in the Ottawa River, Ohio, and identification of priority areas for remediation.

Modeling of PCB Fate and Transport in Kalamazoo River. 1999-2000. Senior Scientist. Provided expert advice on development of mass balance models for transport, fate and bioaccumulation of PCBs in the Kalamazoo River, Michigan.

Lake Michigan Ecosystem Model. 1998-2000. Senior Scientist. Developed an ecosystem mass balance model of the lower food web to support the Lake Michigan Mass Balance Study.

Fox River and Green Bay PCB Fate and Transport Model Evaluation. 1997-2000. Senior Scientist. Provided expert advice and consultation on evaluation of alternate PCB transport and fate models for the Fox River and Green Bay, as set forth in an agreement between the State of Wisconsin and several paper companies.

Gulf of Mexico Hypoxia Assessment, White House Committee on Environment and Natural Resources. 1997-1999. Co-Team Leader, Task Group 4. Developed and calibrated a water quality model for hydraulic transport, primary productivity and dissolved oxygen in the northern Gulf of Mexico to assess responses to potential changes in nutrient loadings from the Mississippi River Basin.

Mass Balance Modeling of Hypoxia on the Louisiana Inner Shelf. 1990-1999. Senior Scientist. Development and calibration of a water quality mass balance model for hydraulic transport, primary productivity and bottom water hypoxia in the Mississippi River Plume/Inner Gulf of Mexico Shelf Region.

Expert Assistance on James River Tributary Strategy. 1997-1999. Senior Scientist. Provided expert assistance in reviewing the revised Chesapeake Bay Water Quality Model to support development of a management strategy for the James River in response to a legislative mandate by the State of Virginia.

Litigation Support for U.S. Department of Justice in Case Involving Municipal Discharger. 1994-1995 and 1998-1999. Expert Witness. Conducted transport and fate analysis for solids and toxic chemicals discharged from the Hammond Sanitary District Plant. Prepared written expert opinion report, was deposed, and provided technical review of opposing expert reports.

Litigation Support and Expert Testimony for a Class Action Suit Involving Pesticide Contamination. 1996-1999. Expert Witness. Conducted an assessment of sources, environmental distribution and fate of Mirex at an EPA Superfund Site in Salem, Ohio. Prepared technical affidavit, was deposed, and provided technical review of opposing expert reports.

Sediment Diagenesis Model for Lake Okeechobee. 1997-1998. Senior Scientist. Developed a sediment diagenesis submodel of phosphorus for incorporation into an existing eutrophication mass balance model for Lake Okeechobee. Provided expert assistance to South Florida Water Management District in model application studies.

Caloosahatchee Estuary Hydrodynamic-Salinity Model. 1997. Senior Scientist. Developed and applied a one-dimensional, coupled, hydrodynamic-salinity model. Provided expert assistance to South Florida Water Management District in model calibration and predictive simulations.

Expert Assistance on Chesapeake Bay Water Quality Modeling. 1996-1997. Senior Scientist. Provided expert assistance to Metropolitan Washington Council of Governments in evaluating the rationale for nutrient reduction goals and in technical review of the Chesapeake Bay Watershed and Water Quality Models.

Application of a Coupled Primary Productivity-Exotic Species Model for Saginaw Bay, Lake Huron. 1996-1997. Senior Scientist. Developed and applied an ecosystem mass balance model to investigate water quality responses to changes in external nutrient loadings and zebra mussel dynamics.

Development of Everglades Water Quality Model. 1995-1997. Senior Scientist. Developed and applied a watershed mass balance model for hydraulics, chloride and total phosphorus for the overland areas and canal system in the Florida Everglades.

Litigation Support and Expert Testimony for a Major Chemical Company in Michigan Involving NPDES Permit Violations. 1996. Expert Witness. Conducted transport, fate and effects analysis for toxic chemicals and phosphorus discharged from an industrial outfall. Prepared expert opinion report, provided depositions for two separate cases, and testified at trial in State Circuit Court.

An Ecosystem Modeling Study of Saginaw Bay: Impacts of Long-Term Loading Reductions and Invasion by the Zebra Mussel. 1991-1994. Senior Scientist. Development and application of a mass balance model to assess relative water quality impacts of reductions in phosphorus loadings and potential impacts caused by zebra mussel invasion.

Expert Assistance on Lake Okeechobee Water Quality Modeling for Lake Management. 1993. Senior Scientist. Provided expert assistance in evaluating modeling results, technical guidance for additional modeling simulations, and co-authorship of two peer-reviewed manuscripts with South Florida Water Management District staff.

Development of Caloosahatchee Estuary Salinity Model. 1993. Senior Scientist. Developed and applied a one-dimensional salinity mass balance model, and determined steady-state salinity profiles in the Caloosahatchee Estuary for a suite of freshwater inflows from Lake Okeechobee.

Limnological Studies of Nitrogen Impacts on the Lake Okeechobee Ecosystem. 1993. Senior Scientist. Conducted literature review, data assessment and empirical modeling to understand and potentially control nitrogen impacts on Lake Okeechobee.

Testing the Use of Mass Balance Models for NPDES Permit Development to Protect Sediment Quality. 1992-1993. Senior Scientist. Development and test site applications of a mass balance modeling framework for implementing sediment quality criteria for hydrophobic organic chemicals and heavy metals.

St. Joseph River Combined Sewer Overflows Impact Assessment for the City of South Bend, Indiana in Support of the Development of Control Strategies. 1991-1993. Senior Scientist. Directed event-driven field sampling program for St. Joseph River and provided guidance on development and application of mass balance models for coliform bacteria and dissolved oxygen.

Evaluation of Potential Impacts of Nitrogen Removal on Eutrophication in the Potomac Estuary. 1991-1993. Senior Scientist. Conducted review of scientific literature, historical data and predictions of Potomac Eutrophication Model (PEM) to assess risk of proliferation of nitrogen-fixing blue-green algae under various point source nitrogen control strategies.

Lake Okeechobee Water Quality Modeling Evaluations. 1992. Senior Scientist. Provided expert assistance in development and application of a water quality model for eutrophication in Lake Okeechobee, Florida.

Peer Review of Everglades Water Quality Research Plan. 1992. Senior Scientist. Provided external peer review of planning components for best management practices (BMPs) and development of watershed mass balance modeling tools for multi-objective management of water resources.

Development and Validation of an Integrated Exposure Model for Toxic Chemicals in Green Bay, Lake Michigan. 1988-1992. Senior Scientist. Developed and applied a suite of individual models to describe hydraulics, eutrophication, particle dynamics and toxic chemicals in the bay.

Development of Phase II Screening Model for TCDD (Dioxin) in the Columbia River. 1991-1992. Senior Scientist. Application of a screening-level mass balance model to support development of a total maximum daily load (TMDL) for dioxin in the Upper and Lower Columbia, Snake and Willamette River Basins.

Evaluation of Potential Impacts on Juday Creek from Proposed Stormwater Detention Basins. 1991. Senior Scientist. Directed field monitoring, data synthesis and mass balance modeling of water and heat in the creek and proposed detention basins.

Expert Consulting and Review of Water Quality Modeling on Lake Mead, Nevada. 1990. Senior Scientist. Conducted peer review of water quality model for eutrophication in Lake Mead.

Toxics Modeling Workshops for Training EPA and State Regulatory Personnel. 1989. Principal lecturer on calibration of toxic chemical models at workshops in U.S. EPA Regions V (Chicago), IX (San Francisco), VIII (Boulder), IV (Atlanta) and X (Seattle), and for E.I. DuPont DeNemours and Company, Newark, Delaware.

Expert Consultant, U.S. Army Corps of Engineers. 1987. Provided expert assistance on selection of aquatic processes and state variables for a time-variable, three-dimensional water quality model of Chesapeake Bay.

Expert Consultant, Ontario Ministry of the Environment. 1987. Provided expert assistance on development of an aquatic food chain model to support the Ontario Municipal Industrial Strategy for Abatement.

Expert Consultant, Chesapeake Bay Program, U.S. EPA. 1984-1986. Provided technical assistance on planning and implementation of a water quality modeling program for nutrient enrichment and dissolved oxygen depletion in Chesapeake Bay.

Program Coordinator, Estuarine Research Program, Environmental Research Laboratory, Narragansett, U.S. EPA. 1984-1986. Conceived, planned and coordinated research in the areas of transport, fate and effects of contaminants and nutrients in estuarine and near-coastal environments.

Project Officer, U.S. Environmental Protection Agency. 1974-1986. Served as Project Officer on 12 research grants and cooperative agreements. Cumulative budgeted amount of this research was $4 million. Results included publication of over 60 scientific papers and reports.

Lead Scientist, Office of Research and Development, U.S. EPA. 1984. Prepared and presented technical briefings on ocean disposal and estuarine research for the Consolidated Water Research Committee as part of the EPA research planning for fiscal years 1985 and 1986.

Program Coordinator, Ocean Disposal Research Program, Environmental Research Laboratory, Narragansett, U.S. EPA. 1983-1984. Conceived, planned and coordinated ocean disposal research in the areas of transport, transformation and fate of ocean-dumped contaminants.

Expert Consultant, Region I, U.S. EPA. 1982-1984. Provided technical assistance on physical transport and food chain modeling for PCBs and heavy metals in support of the New Bedford Harbor (Massachusetts) Superfund Project.

Expert Consultant, Office of Water Regulations and Standards, U.S. EPA. 1982-1983. Developed a scientific protocol for ocean dumpsite designation, and conducted a workshop consisting of scientific and technical experts to peer review the protocol.

Program Manager, Waste Load Allocation Program, Large Lakes Research Station, U.S. EPA. 1980-1981. Initiated studies in the Flint River (Michigan) watershed on the development and field application of waste load allocation models for heavy metals.

Visiting Scientist, International Institute for Applied Systems Analysis, Laxenburg, Austria. 1980. Applied water quality models to Lake Balaton (Hungary) under terms of an International Agreement between the Institute and the Hungarian Academy of Science.

Expert Consultant, National Aeronautics and Space Administration. 1979. Provided technical assistance on the applications of remote sensing imagery to water quality problems in lakes.

Expert Consultant, British Broadcasting Corporation-The Open University Centre. 1979. Provided technical assistance on the use of the Great Lakes as an international case study on phosphorus enrichment, and appeared in a film production entitled, "Inorganic Chemistry Concepts and Case Studies."

Expert Consultant, World Health Organization. 1978. Provided technical assistance on a water quality modeling project for the Billings Reservoir, Sao Paulo, Brazil.

Collaboration, International Institute for Applied Systems Analysis, Laxenburg, Austria. 1978. Transferred a water quality database for Saginaw Bay, Lake Huron, to the Institute for use in mathematical model intercomparisons.

Research Assistant, Department of Civil Engineering, University of Notre Dame. 1971-1972. Provided field sampling and laboratory analytical support for an EPA-sponsored project on Stone Lake, Michigan. Provided technical support and data analysis for an advanced wastewater treatment project sponsored by Telecommunications Industries, Inc., Copiague, Long Island.

Teaching Assistant, Department of Civil Engineering, University of Notre Dame. 1971. Taught an undergraduate laboratory course in air pollution. Constructed a monodisperse aerosol generator and various air sampling devices.

Research Assistant, Department of Physics, University of Notre Dame. 1969. Constructed and tested electronic instrumentation and field-mapped a large bending magnet in support of an NSF-sponsored high-energy physics project at Argonne National Laboratory.

Teaching Assistant, Department of Physics, University of Notre Dame. 1968-1969. Taught undergraduate laboratory courses and tutorial classes.

Science Teacher, Northeast Catholic High School, Philadelphia, Pennsylvania. 1966-1968. Taught lecture and laboratory courses in Physics (11th Grade) and Introductory Physical Science (9th Grade).

Selected Publications

Journal Articles

Predicted Impacts from Offshore Produced Water Discharges on Hypoxia in the Gulf of Mexico. Bierman, V.J., Jr., S.C. Hinz, D. Justić, D. Scavia, J.A. Veil, K. Satterlee III, M.E. Parker and S. Wilson. Society of Petroleum Engineers Projects, Facilities & Construction. 3(2):1-10. 2008.

Forecasting Gulf's Hypoxia: The Next 50 Years? D. Justić, V.J. Bierman, Jr., D. Scavia and R. Hetland. Estuaries and Coasts. 30(5):791-801. 2007.

Hard Lessons, Simple Truths: Restoring Large Water Systems Requires the Willingness to Learn from Experience – and Time. Freedman, P.L., V.J. Bierman, Jr. and J.V. DePinto. Water Environment and Technology. 19(6):57-62. 2007.

The Lake Okeechobee Water Quality Model (LOWQM): Enhancements, Calibration, Validation and Analysis. R.T. James, V.J. Bierman, Jr., M.J. Erickson and S.C. Hinz. Lake and Reservoir Management. 21(3):231-260. 2005.

Modeling the Role of Zebra Mussels in the Proliferation of Blue-green Algae in Saginaw Bay, Lake Huron. V.J. Bierman, Jr., J. Kaur, J.V. DePinto, T.J. Feist and D.W. Dilks. Journal of Great Lakes Research. 31(1):32-55. 2005.

Reducing Hypoxia in the Gulf of Mexico: Advice from Three Models. D. Scavia, D. Justić and V.J. Bierman, Jr. Estuaries. 27(3):419-425. 2004.

The Bioturbation-Driven Chemical Release Process. L.J. Thibodeaux and V.J. Bierman, Jr. Environmental Science and Technology. 37(13):252A-258A. 2003.

Nutrient-Enhanced Productivity in the Northern Gulf of Mexico: Past, Present and Future. N.N. Rabalais, R.E. Turner, Q. Dortch, D. Justic, V.J. Bierman, Jr. and W.J. Wiseman, Jr. Hydrobiologia. 475(1):39-63. 2002.

Exploring the Dynamics and Fate of Total Phosphorus in the Florida Everglades Using a Calibrated Mass Balance Model. R. Raghunathan, T. Slawecki, T.D. Fontaine, Z. Chen, D.W. Dilks, V.J. Bierman, Jr. and S. Wade. Ecological Modelling. 142:247-259. 2001.

Equilibrium Partitioning of PCB Congeners in the Water Column: Field Measurements from the Hudson River. Butcher, J.B., E.A. Garvey and V.J. Bierman, Jr. Chemosphere. 36(15):3149-3166. 1998.

Calibration of a Hydraulic Transport Model for Green Bay, Lake Michigan. Martin, S.C., S.C. Hinz, P.W. Rodgers, V.J. Bierman, Jr., J.V. DePinto and T.C. Young. Journal of Great Lakes Research. 21(4):599-609. 1995.

A Preliminary Modeling Analysis of Water Quality in Lake Okeechobee, Florida: Calibration Results. James, R.T and V.J. Bierman, Jr. Water Research. 29(12):2755-2766. 1995.

A Preliminary Modeling Analysis of Water Quality in Lake Okeechobee, Florida: Diagnostic and Sensitivity Analyses. Bierman, V.J., Jr. and R.T. James. Water Research. 29(12):2767-2775. 1995.

Historical Trends in the Lake Okeechobee Ecosystem, IV. Nitrogen:Phosphorus Ratios, Cyanobacterial Dominance, and Nitrogen Fixation Potential. Smith, V.H., V.J. Bierman, Jr., B.L. Jones and K.E. Havens. Archiv fur Hydrobiologie/Supplement. 107:71-88. 1995.

Historical Trends in the Lake Okeechobee Ecosystem, VI, Synthesis. Havens, K.E., V.J. Bierman, Jr., E.G. Flaig, C. Hanlon, R.T. James, B.L. Jones and V.H. Smith. Archiv fur Hydrobiologie/Supplement. 107:101-111. 1995.

A Preliminary Mass Balance Model of Primary Productivity and Dissolved Oxygen in the Mississippi River Plume/Inner Gulf Shelf Region. Bierman, V.J., Jr., S.C. Hinz, D. Zhu, W.J. Wiseman, Jr., N.N. Rabalais and R.E. Turner. Estuaries. 17(4):886-899. 1994.

Analysis of Organic Carbon Sediment-Water Exchange in Green Bay, Lake Michigan, USA. DePinto, J.V., R. Raghunathan, V.J. Bierman, Jr., P.W. Rodgers, T.C. Young and S.C. Martin. Water Science Technology. 28(8-9):149-159. 1993.

Field Application of a Steady-State Mass Balance Model for Hydrophobic Organic Chemicals in an Estuarine System. Dilks, D.W., J.S. Helfand, V.J. Bierman, Jr. and L. Burkhard. Water Science Technology. 28(8-9):263-271. 1993.

Transport of Low-Level Radioactive Soil at Deep-Ocean Disposal Sites. Bonner, J.S., C.D. Hunt, J.F. Paul and V.J. Bierman, Jr. Journal of Environmental Engineering. 118(1):101-119. 1992.

Impact of Flow Variability on Error in the Estimation of Tributary Mass Loads. Preston, S.D., V.J. Bierman, Jr. and S.E. Silliman. Journal of Environmental Engineering. 118(3):402-419. 1992.

Equilibrium Partitioning and Biomagnification of Organic Chemicals in Benthic Animals. V.J. Bierman, Jr. Environmental Science and Technology. 24(9):1407-1412. 1990.

An Evaluation of Methods for the Estimation of Tributary Mass Loads. Preston, S.D., V.J. Bierman, Jr. and S.E. Silliman. Water Resources Research. 25(6):1379-1389. 1989.

Methods for Waste Load Allocation of Municipal Sewage Sludge at the 106-Mile Ocean Disposal Site. Walker, H.A., J.F. Paul and V.J. Bierman, Jr. Environmental Toxicology and Chemistry. 6(6):475-489. 1987.

Modeling of Phytoplankton in Saginaw Bay: I. Calibration Phase. Bierman, V.J., Jr. and D.M. Dolan. Journal of Environmental Engineering. 112(2):400-414. 1986.

Modeling of Phytoplankton in Saginaw Bay: II. Post-Audit Phase. Bierman, V.J., Jr. and D.M. Dolan. Journal of Environmental Engineering. 112(2):415-429. 1986.

A Strategy for Monitoring of Contaminant Distributions Resulting from Proposed Sewage Sludge Disposal at the 106-Mile Ocean Disposal Site. O'Connor, T.P., H.A. Walker, J.F. Paul and V.J. Bierman, Jr. Marine Environmental Research. 16:127-150. 1985.

Retrospective Analysis of the Response of Saginaw Bay, Lake Huron, to Reductions in Phosphorus Loadings. Bierman, V.J., Jr., D.M. Dolan, R. Kasprzyk and J.L. Clark. Environmental Science and Technology. 18(1):23-31. 1984.

Mass Balance Modeling of DDT Dynamics in Lakes Michigan and Superior. Bierman, V.J., Jr. and W.R. Swain. Environmental Science and Technology. 16(9):572-579. 1982.

Mass Balance Modeling of Heavy Metals in Saginaw Bay, Lake Huron. Dolan, D.M. and V.J. Bierman, Jr. Journal of Great Lakes Research. 8(4):676-694. 1982

Modeling of Phytoplankton-Nutrient Dynamics in Saginaw Bay, Lake Huron. Bierman, V.J., Jr. and D.M. Dolan. Journal of Great Lakes Research. 7(4):409-439. 1981.

Statistical Analysis of the Spatial and Temporal Variability of the Ratio Chlorophyll *a* to Phytoplankton Cell Volume in Saginaw Bay, Lake Huron. Dolan, D.M., V.J. Bierman, Jr., M.H. Dipert and R.D. Geist. Journal of Great Lakes Research. 4(1):75-83. 1978.

Refereed Book Chapters

Partitioning of Organic Chemicals in Sediments: Estimation of Interstitial Concentrations using Organism Body Burdens. V.J. Bierman, Jr. In: J.V. DePinto, W. Lick and J.F. Paul. (eds.), *Transport and Transformation of Contaminants Near the Sediment-Water Interface*. Lewis Publishers, Chelsea, Michigan. pp. 149-170. 1993.

A Convective-Dispersive Transport Model for Wastes Disposed at the 106-Mile Ocean Disposal Site. Walker, H.A., J.F. Paul and V.J. Bierman, Jr. In: D.J. Baumgartner and I.W. Duedall (eds.), *Oceanic Processes in Marine Pollution, Vol. 6 - Physical and Chemical Processes: Transport and Transformation*. Krieger, Malabar, Florida. pp. 53-61. 1990.

A Protocol for Designation of Ocean Disposal Sites. Reed, M. and V.J. Bierman, Jr. In: M.A. Champ and P.K. Park (eds.), *Oceanic Processes in Marine Pollution, Vol. 3 - Marine Waste Management: Science and Policy*. Krieger, Malabar, Florida. pp. 155-166. 1989.

A Hazard Assessment Research Strategy for Ocean Disposal. Gentile, J.H., V.J. Bierman, Jr., J.F. Paul, H.A. Walker and D.C. Miller. In: M.A. Champ and P.K. Park (eds.), *Oceanic Processes in Marine Pollution, Vol. 3 - Marine Waste Management: Science and Policy*. Krieger, Malabar, Florida. pp. 200-212. 1989.

Application of a Hazard Assessment Research Strategy for Waste Disposal at the 106-Mile Ocean Disposal Site. Paul, J.F., V.J. Bierman, Jr., H.A. Walker and J.H. Gentile. In: D.W. Hood, A. Schoener and P.K. Park (eds.), *Oceanic Processes in Marine Pollution, Vol. 4 - Scientific Monitoring Strategies for Ocean Waste Disposal*. Krieger, Malabar, Florida. pp. 149-160. 1989.

The Application of a Hazard Assessment Research Strategy to the Ocean Disposal of a Dredged Material: Exposure Assessment Component. Paul, J.F., V.J. Bierman, Jr., W.R. Davis, G.L. Hoffman, W.R. Munns, C.E. Pesch, P.F. Rogerson and S.C. Schimmel. In: D.A. Wolfe and T.P. O'Connor (eds.), *Oceanic Processes in Marine Pollution, Vol. 5 - Urban Wastes in Coastal Marine Environments*. Krieger, Malabar, Florida. pp. 123-135. 1988.

Research Strategy for Ocean Disposal: Conceptual Framework and Case Study. Bierman, V.J., Jr., J.H. Gentile, J.F. Paul, D.C. Miller and W.A. Brungs. In: H.L. Bergman, R.A. Kimerle and A.W. Maki (eds.), *Environmental Hazard Assessment of Effluents*. Pergamon Press, New York. pp. 313-329. 1986.

Seasonal Phytoplankton Succession as a Function of Phosphorus and Nitrogen Levels. DePinto, J.V., V.J. Bierman, Jr. and F.H. Verhoff. In: R.P. Canale (ed.), *Modeling Biochemical Processes in Aquatic Ecosystems*. Ann Arbor Science Publishers, Ann Arbor, Michigan. pp. 141-169. 1976.

Mathematical Model of the Selective Enhancement of Blue-Green Algae by Nutrient Enrichment. V.J. Bierman, Jr. In: R.P. Canale (ed.), *Modeling Biochemical Processes in Aquatic Ecosystems*. Ann Arbor Science Publishers, Ann Arbor, Michigan. pp. 1-31. 1976.

Published Reports

Forecasting Hypoxia in the Gulf of Mexico: Responses to Nutrient Loadings from the Mississippi River Basin. Bierman, V.J., Jr., S.C. Hinz, W.J. Wiseman, Jr., N.N. Rabalais and R. Eugene Turner. In: N.J. Valette-Silver and D. Scavia (eds.), Ecological Forecasting: New Tools for Coastal and Ecosystem Management. NOAA Technical Memorandum NOS NCCOS. pp. 111-115. 2003.

Modeling. Bierman, V.J., Jr., S.C. Hinz, K.A. Nelson, D.P. Podber, D. Zhu, W.J. Wiseman, Jr., N.N. Rabalais and R.E. Turner. In: Wiseman, W.J., Jr., N.N. Rabalais, M.J. Dagg and T.E. Whitledge (eds.), Nutrient Enhanced Coastal Ocean Productivity in the Northern Gulf of Mexico – Understanding the Effects of Nutrients on a Coastal Ecosystem. NOAA Coastal Ocean Program Decision Analysis Series No. 14. NOAA Coastal Ocean Program, Silver Spring, MD. Chapter 6, pp. 103-125. 1999.

Effects of Reducing Nutrient Loads to Surface Waters within the Mississippi River Basin and the Gulf of Mexico: Topic 4 Report for the Integrated Assessment on Hypoxia in the Gulf of Mexico. Brezonik, P.L., V.J. Bierman, Jr., R. Alexander, J. Anderson, J. Barko, M. Dortch, L. Hatch, G.L. Hitchcock, D. Keeney, D. Mulla, V. Smith, C. Walker, T. Whitledge and W.J. Wiseman, Jr. NOAA Coastal Ocean Program Decision Analysis Series No. 18. NOAA Coastal Ocean Program, Silver Spring, Maryland. 130 pp. 1999.

Evaluation of Methods for the Estimation of Tributary Mass Loading Rates. Preston, S.D., V.J. Bierman, Jr. and S.E. Silliman. U.S. Geological Survey, Water Resources Research Center, Purdue University, West Lafayette, Indiana. Technical Report No. 187. 50 p. 1989.

Development of Estimation Methods for Tributary Loading Rates of Toxic Chemicals. Bierman, V.J., Jr., S.D. Preston and S.E. Silliman. U.S. Geological Survey, Water Resources Research Center, Purdue University, West Lafayette, Indiana. Technical Report No. 183. 58 p. 1988.

User Manual for Two-Dimensional Multi-Class Phytoplankton Model with Internal Nutrient Pool Kinetics. Bierman, V.J., Jr. and L.M. McIlroy. U.S. Environmental Protection Agency, Environmental Research Laboratory, Duluth, Minnesota. EPA/600/3-86/061. 149 p. 1986.

Sampling the Oceans for Pollution: EPA Research Strategy for Marine Waste Disposal. Prager, J.C., V.J. Bierman, Jr., D.C. Miller and J.H. Gentile. Dangerous Properties of Industrial Materials Report. 4(5):2-8. 1984.

Probabilistic Approach for the Determination of the Potential Area of Influence for Waste Disposed at the 106-Mile Ocean Disposal Site. Paul, J.F., H.A. Walker and V.J. Bierman, Jr. In: J.B. Pearce and D.C. Miller (eds.), 106-Mile Waste Disposal Site Characterization Update Report, NOAA Technical Memorandum NMFS-F/NEC-26, National Marine Fisheries Service, Northeast Fisheries Center, Woods Hole, Massachusetts. 1983.

The Development and Calibration of a Spatially Simplified, Multi-Class Phytoplankton Model for Saginaw Bay, Lake Huron. Bierman, V.J., Jr., D.M. Dolan, E.F. Stoermer, J.E. Gannon and V.E. Smith. Great Lakes Environmental Planning Study, Contribution No. 33, Great Lakes Basin Commission. Ann Arbor, Michigan. 126 p. 1980.

Responses of Saginaw Bay, Lake Huron, to Reductions in Phosphorus Loadings from the Saginaw River. Bierman, V.J., Jr. and D.M. Dolan. Problem-Oriented Report, U.S. Environmental Protection Agency. EPA 600-380-099. 79 p. 1980.

Proceedings

Transport and Fate Model for PCB TMDLs in the Potomac River Estuary. Bierman, V.J., Jr., S.C. Hinz, D.K. Rucinski, C. Haywood, C. Buchanan and A. Nagel. In: Proceedings, TMDL 2009, Combining Science and Management to Restore Impaired Waters, Minneapolis, MN, August 9-12, 2009.

Large-Scale Hypoxia in the Gulf of Mexico: History, Nutrient Load Reduction Goals, and Significance of Produced Water Discharges. Bierman, V.J., Jr., D. Scavia, D. Justić and S.C. Hinz. In: Proceedings of Texas Water 2006, Austin, Texas, April 4-7, 2006.

Dynamics of PCBs in the Delaware River Estuary: Existing Conditions and Loading Reductions Required for Achievement of Water Quality Standards. Bierman, V.J., Jr., S.C. Hinz, N.S. Suk, S. Liao, J.R. Yagecic and T.J. Fikslin. In: Proceedings of TMDL 2005, Philadelphia, Pennsylvania, June 26-29, 2005.

Conceptual Modeling Framework for the PCB TMDL in the Delaware River Estuary. Bierman, V.J., Jr., S.C. Hinz, J.V. DePinto, S. Liao, N.S. Suk and T.J. Fikslin. In: Proceedings of WEFTEC 2004, New Orleans, Louisiana, October 2-6, 2004.

Use of a Staged Approach to Develop TMDLs for Classes of Chemicals from Multiple Source Categories: PCBs in the Delaware River Estuary. Fikslin, T.J., N.S. Suk and V.J. Bierman, Jr. In: Proceedings of WEFTEC 2004, New Orleans, Louisiana, October 2-6, 2004.

A Simplified Mass Balance Modeling Framework for Toxics TMDLs: Application to PCBs in the Delaware River Estuary. Bierman, V.J., Jr., S.C. Hinz, S. Liao, N. Suk, J.R. Yagecic, T.J. Fikslin and J.V. DePinto. In: Proceedings of Watershed 2004, Dearborn, Michigan, July 11-14, 2004.

Modeling Ecosystem Changes Caused by the Zebra Mussel Invasion in Saginaw Bay, Lake Huron. Kaur, J., J.V. DePinto, V.J. Bierman, Jr. and T.J. Feist. In: Proceedings of Watershed 2004, Dearborn, Michigan, July 11-14, 2004.

Forecasting Hypoxia in the Gulf of Mexico: Responses to Nutrient Loadings from the Mississippi River Basin. Bierman, V.J., Jr., S.C. Hinz, W.J. Wiseman, Jr., N.N. Rabalais and R.E. Turner. In: Proceedings of the 12th Biennial Coastal Zone Conference, Cleveland, Ohio, July 15-19, 2001.

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Awards

James R. Rumsey Award, Michigan Water Environment Association, 1995.
Monetary Awards for Special Achievement, U.S. Environmental Protection Agency, 1981; 1982; 1983; 1984.
Monetary Awards for Scientific and Technical Achievement, U.S. Environmental Protection Agency, 1981; 1982; 1983.
Bronze Medal, U.S. Environmental Protection Agency, 1978.
Quality-Step Merit Award, U.S. Environmental Protection Agency, 1976.
National Wildlife Federation Fellowship, 1972.
National Science Foundation Traineeship, 1969.

Specialized Training and Coursework

Institute on Mathematical Modeling of Water Quality, Manhattan College, New York, 1985.

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APPENDIX B

ANNOTATED BIBLIOGRAPHY OF

UPPER COLUMBIA RIVER DATASETS

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This appendix contains an annotated bibliography which describes each of the 16 datasets I considered in forming my opinions in this expert report. The primary sources of these datasets were the Columbia River Integrated Environmental Monitoring Program (CRIEMP), United States Geological Survey (USGS), Confederated Tribes of the Colville Reservation, Teck Cominco, Environment Canada, Washington State Department of Ecology (WADOE), and the United States Environmental Protection Agency (U.S. EPA). The media included in these datasets were surface water, sediment and porewater. The parameters included metals (antimony, arsenic, cadmium, chromium, copper, lead, manganese, mercury and zinc), solids, organic carbon and grain size. The descriptions of each dataset include the field and laboratory quality assurance and quality control (QA/QC) procedures used by the reporting agency.

Baturin, W.T. 1993

A joint government and industry committee known as the Columbia River Integrated Environmental Monitoring Program (CRIEMP) was formed in 1991 to oversee environmental monitoring in the Columbia River. Surface sediment samples were collected from 14 stations on the Columbia River between Lower Arrow Lake and Waneta in September, 1992. Surface water samples were collected from eight (8) stations between Lower Arrow Lake and Waneta at approximately monthly intervals from September 1991 to October 1992. A variety of metals, organics, and other physical parameters were analyzed.

Surface sediment samples were obtained with equipment cleaned with phosphate free detergent and river water. The equipment was then rinsed three times with acetone and three times with hexane. Composite samples were prepared by personnel wearing polypropylene gloves and stainless steel equipment. Glass jars were used for samples intended for metals analysis and placed on dry ice. Samples were analyzed using standard equipment (e.g., Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) for metals) and published methods (U.S. EPA 1989). Water quality samples were taken from a boat at all sites except for Birchbank and Waneta, which were sampled from shore. Water quality sample collection followed Environment Canada and British Columbia Environment, Lands and Parks procedures.

A quality assurance/quality control (QA/QC) program was in place which included measures for field collection, laboratory analysis, and data input (Baturin 1993). Side-by-side sediment samples were collected for QA/QC purposes by both Norecol Consultants and Environment Canada and comparison of results suggested no significant differences in concentrations of metals between the two collection teams (Norecol Environmental Consultants 1993). Laboratory QA/QC included analysis of blanks, duplicates and spiked samples. QA/QC results are provided in Appendix 2 of the Norecol Environmental Consultants report (Norecol Environmental Consultants 1993). Water quality metals analysis followed the methods described in *Environment Canada Water Quality Monitoring Protocols* (Environment Canada 1990).

Borteleson, G. C., S.E. Cox, M.D. Munn, R.J. Schumaker and E. K. Block. 2001

The sediment-quality assessment study was done by the USGS in cooperation with the U.S. EPA to assess the occurrence and distribution of trace elements in the bed sediments of Lake Roosevelt and the upstream Columbia River. Surface sediment samples were collected from 41 stations on the Columbia River between the international border and Grand Coulee Dam in September and October of 1992. Sampling sites were spaced at closer intervals in the upstream reach of Lake Roosevelt and the Columbia River and spaced at wider but uniform intervals in the downstream part of the reservoir. Samples were collected at sites in midstream or toward either bank. Additional sampling locations included one (1) site in Rufus Woods Lake, one (1) site in Lower Arrow Lake, one (1) site below the Hugh Keenleyside Dam, one (1) site in the Kootenay River, one (1) site in the Pend Oreille River, one (1) site in the Sanpoil River Arm, one (1) site in the Big Sheep Creek, one (1) site in the Sherman Creek, one (1) site in the Hawk Creek, two (2) sites in the Kettle River, two (2) sites in the Hall Creek, two (2) sites in the Kootenay River, three (3) sites in the Colville River, three (3) sites in the Spokane River Arm, and three (3) sites in the Sanpoil River. Analytes included metals, carbon, and particle sizes.

Sample collection and processing procedures were designed to eliminate or minimize contamination. The general strategies and equipment used to sample the Columbia River were similar to those discussed by Meade and Stevens (1990). Most bed-sediment samples were collected with a stainless steel van Veen sampler. Procedures for collecting and processing samples are outlined by Edwards and Glysson (1988) for bed and suspended sediment while

some of the analytical procedures are discussed by Fishman and Friedman (1989) for inorganic constituents. Collected sediment came into contact with only glass, plastic, or Teflon during handling. Homogenized samples were wet sieved through a 2 millimeter nylon screen. Samples were dried in their containers at 60 degrees Celsius for 3 to 5 days and then ground to a powder of approximately 0.04 millimeters.

Surface sediment samples were quality-controlled by submitting quality-control samples to analyzing laboratories to assess analytical accuracy and precision. The laboratory-determined concentrations were within the certified concentrations in 19 of 24 analyses and none of the concentrations for the six key elements were consistently outside of the certification ranges. Thirteen of 18 interlaboratory samples had a relative percent difference (RPD) of 25% or less, 22 of 24 lab duplicates had a RPD of 10% or less. According to Borteleson et al. (2001), data from QC samples indicated good overall data quality.

Columbia Environmental Consulting, Ltd. 2002

Columbia Environmental Consulting Ltd. completed sediment sampling for the Confederated Tribes of the Colville Reservation to develop an understanding of concentrations of metals in the Columbia River below Trail, British Columbia and comparative background areas. Surface sediment samples were collected from 16 locations including six (6) in Lower Arrow Lake, two (2) in the Columbia River, six (6) in the Kootenay River, and two (2) in the Pend Oreille River in January 2002. Analytes measured included metals and particle size as well as other analytes. Samples were collected with a petite ponar grab sampler, targeting finer silt-clay sediments in depositional areas. Sterile containers from the lab were used and samples were maintained according to applicable chain of custody procedures and stored appropriately during shipment. Samples were analyzed by ICP-MS for metals and Cold Vapor Atomic Fluorescence for mercury. Particle size distribution was measured using methods described in the *Manual on Soil Sampling and Methods of Analysis, 2nd edition, 1978* (Canadian Society of Soil Science, 1978). Surface sediment samples were collected and analyzed using the *EPA Contract Laboratory Program (CLP) Guidance for Field Samplers* (U.S. EPA 2000), Roy F. Weston's *Standard Operating Procedure for Sediment Sampling* (Weston 2001), and *Lake and Stream Bottom Sediment Sampling Manual* (RISC 1997) as references.

Cox, S. E., P.R. Bell, J.S. Lowther and P. C. VanMetre. 2005

This study was conducted by the USGS in cooperation with the Confederated Colville Tribes of the Colville Reservation to determine the vertical distributions of trace-element concentrations in the accumulated sediments of Lake Roosevelt. Subsurface sediment samples were collected from six (6) widely spaced locations in the Columbia River between USGS river miles 624 and 705 and one (1) location in the Spokane River in September 2002 and July 2003. Coring depths ranged from 38 to 164 cm. Analytes focused on metals and also included Cesium-137. Sediment cores were collected using a Benthos gravity core with a 6.5 cm diameter. Sediment cores were collected near the pre-reservoir river channel with efforts made to avoid large landslide impacted areas and submerged ancestral tribal areas. Subsurface sediment samples underwent concentrated-acid digestions using a mixture of hydrochloric-nitric-perchloric-hydrofluoric acids and were analyzed by ICP-MS or cold-vapor atomic-absorption spectrometry for mercury.

Sediment porewater samples were collected from three (3) locations in the Columbia River for dissolved metals analysis. A box corer was used to obtain the samples which were purged with nitrogen and filtered through a 0.45 micron filter before analysis. Sediments from these samples were also retained for analysis.

QA/QC procedures were incorporated into the study including dedicated core liners for each core, equipment washing between samples, and the use of laboratory blanks, replicates, and quality-control samples. Sediment porewater samples were purged with nitrogen and acidified with ultra-pure nitric acid (HNO_3). ICP-MS analysis was used for trace-element concentrations. Laboratory analyses were conducted using procedures described by USGS (1996). Standard reference materials were used for assessment of lab QA/QC.

Duncan, B. 2008a

Surface water data were collected by Teck Cominco as part of an environmental assessment of a spill incident. Surface water quality samples were extracted from the Columbia River at Waneta at 10 minute intervals on May 28, 2008. Sampling was initiated in response to an accidental

discharge of lead refinery electrolyte. Sample analysis was primarily focused on total and dissolved concentrations of metals in the water column.

Surface water sampling involved 28 Sigma emergency grab samples taken by an automated sampler at 10 minute intervals. Polyethylene sample bottles were cleaned by environmental technicians by rinsing in 5% HNO_3 followed by triple rinsing in distilled/de-ionized water. Samples were shipped unpreserved to TCML Analytical Services for analysis. Total and dissolved metals were digested in HNO_3 then determined by ICP-MS.

Samples were collected per British Columbia Ministry of Environment (BCMOE) protocols. Sample analyses were completed in accordance with the laboratory's Standard Operating Procedure (SOP) for total and dissolved metals, which is based on EPA's Method 200.8 (U.S. EPA 1983). The SOP includes QA/QC requirements though no QA/QC results were provided for the analysis of the samples from this spill.

Duncan, B. 2008b

Surface water data were collected by Teck Cominco as part of an environmental impact assessment of a spill incident. Surface water quality samples were extracted from the Columbia River at Waneta at 10 minute intervals on April 7, 2008. Sampling was initiated in response to an accidental discharge of the ZFL fume. Surface water sampling involved 24 Sigma emergency grab samples taken by an automated sampler at 10 minute intervals. Sample analysis, conducted on four of the samples extracted, was primarily focused on total and dissolved concentrations of metals in the water column.

Environment Canada. 2010

Surface water quality data are collected routinely by the BCMOE for Environment Canada at stations at Birchbank and Waneta on the Columbia River. A surface water quality station also exists at Waneta on the Pend Oreille River. Surface water data are available from 1979 to the present. Analytes have included metals, solids, carbon, and physical parameters. Dissolved phase metals analysis began in 2009, with only total phase concentrations analyzed prior to 2009. The Waneta station on the Columbia River is typically sampled weekly, the Birchbank station is

typically sampled every other week, and the Waneta station on the Pend Oreille River is typically sampled monthly.

Field sampling and laboratory analyses are conducted in accordance with BCMOE protocols (British Columbia Ministry, 2003). These protocols include QA/QC requirements. Surface water metals concentrations have been measured by an optical emission spectrometer (ICP-OES) method and ICP-MS. Samples collected using standard sampling protocols and analyzed using the ICP-MS method met federal-provincial data quality objectives relative to sample contamination and data precision (Ryan 2005).

Era, B. and D. Serdar. 2001

The Washington Department of Ecology conducted an assessment of the toxicity of Lake Roosevelt sediments. Surface sediment samples were collected from a total of 10 locations including seven (7) stations on the Columbia River, one (1) location in the Kettle River, one (1) location in the Sanpoil River, and one (1) location in Lower Arrow Lake. Sampling was conducted in May, 2001. Analytes included metals and particle size.
Columbia River sediments were collected using a van Veen grab and Kettle River and Sanpoil River samples were collected with a spoon. Surface sediment samples were composited from three grab samples and homogenized.

Sediment samples were placed in glass jars with Teflon lid liners and cleaned to U.S. EPA QA/QC specifications (U.S. EPA 1990). Puget Sound Estuary Protocols (PSEP) procedures for collection, preservation, transportation, and storage of the sediment samples were followed (U.S. EPA 1996). Samples were analyzed using SW-846 protocols (U.S. EPA 1989). The report notes that chemical data met laboratory quality control analysis and the Quality Assurance Project Plan (QAPP) (Era and Serdar 2001) requirements for field and laboratory duplicates, laboratory and matrix spikes and field and method blanks and presents QA/QC results in Appendix B of the report.

Hatfield Consultants. 2008

CRIEMP sponsored this study as part of an ongoing assessment of the ecological health of the Canadian portion of the Columbia River between the Hugh Keenleyside Dam and the Canada-United States border. Surface sediment samples were collected from nine (9) locations on the Columbia River between Lower Arrow Lake and the international border. Attempts were made to focus on areas that would have the highest contaminant concentrations. Water column samples were collected at six (6) locations. Sample collection occurred at various times between 1999 and 2007. Sediment samples were collected annually from some stations, and only once from others. Water quality samples were taken at least once per year during low-flow periods (October through May) on five different days during a 30-day period. A variety of metals and physical parameters were analyzed.

All sediment sampling was conducted by deploying a Ponar grab sampler from a boat. Surface sediment samples were analyzed by ICP and ICP-MS for total metals. Water column samples were collected by directly immersing sampling bottles into the river, according to protocols provided in the *B.C. Ministry of Environment Ambient Fresh Water and Effluent Sampling Manual* (RIC 1997).

Data quality was assessed through collection of field duplicates, field blanks, trip blanks, and equipment swipes. QA/QC results are summarized in Appendix A3 of the Hatfield Consultants (2008) report.

Johnson, A. 1991

During August 14-17, 1989, Washington Department of Ecology re-sampled six of the 1986 sediment sites (Johnson et al. 1989) to assess the potential for metals-induced toxicity. Surface sediment samples were collected at four (4) locations on the Columbia River between river miles 604 and 743, one (1) location on the Sanpoil River, and one (1) location on the Spokane River. Porewater and bottom water samples were also obtained in this survey. Analytes of interest included metals, carbon, grain size and inorganics.

Sediment samples were collected using a van Veen grab sampler. At each sampling site, the surface 2-cm layer from five separate grabs was composited for analysis of metals, carbon, and grain size. Samples of the 2-cm surface layer from a separate set of four grabs were removed for extraction of porewater. The exposure of the porewater samples to air was minimized by quickly filling the sample containers and leaving no headspace. Water samples were collected approximately one (1) meter off the bottom and transferred to containers previously cleaned with reagent grade HNO_3 and rinsed with deionized water.

The samples were analyzed using a variety of published methods, as described in Table 2 of the report. QA/QC included analysis of standard reference materials, duplicates and blanks. Surface sediment samples were evaluated for accuracy using standard reference materials, with results provided in Table 3. The author, Johnson (1991), indicates good agreement was found with certified values except for results obtained using strong acid digestions. Splits of composited samples and replicate grabs of water samples were used to assess precision, with results presented in Tables 4 and 5. Johnson (1991) also reports that most sediment analyses agreed within 20% and there was good agreement on water sample replicates except for mercury. Field blank contamination also occurred for mercury. Johnson (1991) reports that "in light of the QC problems", mercury results were reported as non-detects at a raised detection limit.

Johnson, A., D. Norton and B. Yake. 1989

The Washington Department of Ecology conducted surveys of metals concentrations in bottom sediments, water, and fish from the Upper Columbia River between the international border and Grand Coulee Dam. Surface sediment samples were collected in August and September 1986 at 17 locations including 12 locations in the Columbia River between river miles 604 and 743, one (1) location in Lower Arrow Lake, and four (4) locations in tributaries to the Columbia River. Sediments below China Bend were obtained near mid-channel while sediments at China Bend and above were collected in back eddies and embayments. A single subsurface sediment sample was collected near Frenchman Point Rocks on September 23, 1986. Analytes included metals and particle size. Water column samples were collected as single grabs in Lake Roosevelt from September 23 through 26 and in Lake Roosevelt tributaries during spring runoff (May 13

through 15) and summer low flow (August 25 through 29). Samples were analyzed for metals, carbon and grain size.

Sediment samples were collected using a van Veen grab sampler, an Emery pipe dredge, and an Ekman grab sampler. A two-inch gravity corer was used to collect sediments to a depth of 50 cm and 5 inch increments. Surface sediment samples were homogenized in a stainless steel beaker with a stainless steel spoon. Equipment was washed between samples with LiquiNox detergent, 10% HNO_3, and de-ionized water. The core sample was kept vertical and transported to the laboratory on ice where it was frozen and later cut into 5 cm increments. Surface water samples were collected by hand and stored in appropriate bottles containing HNO_3 preservative (for metals). Samples were also filtered in the field with a 0.45 micron filter for dissolved metals analysis. All components of the filtering system were washed with HNO_3 solution and deionized water before use.

Standard U.S. EPA methods (U.S. EPA 1983) were used to analyze metals. Accuracy and precision were assessed by analysis of standard reference materials, laboratory duplicates, field replicates and field blanks. QA/QC results are provided in Tables 3 and 4 of the report and were good, according to Johnson et al. (1989). The standard reference material results for iron and cadmium in sediment and lead in water indicated that the sediment and water data reported for these analytes may underestimate actual concentrations.

Majewski, M.S., S.C. Kahle, J.C. Ebbert and E.G. Josberger. 2003

The USGS conducted this study in cooperation with the Confederated Tribes of the Colville Reservation, Lake Roosevelt Water Quality Council, the Bureau of Reclamation, and the National Park Service to determine the concentrations and distribution of trace elements in the fine-grained (<63 um) fraction of exposed beach, bed and bank sediments along the Columbia River. Surface sediment samples were collected at 30 locations on the Columbia River between Lower Arrow Lake and the Grand Coulee Dam. Sampling took place in April and May of 2001. The top 2 to 3 cm of exposed beach and bed sediments were sampled using a plastic spoon. Analysis for metals was performed on particle sizes less than 63 microns.

All sampling equipment was cleaned between sites by sequentially rinsing with detergent, water, dilute solution of HNO_3 and deionized water, followed by air drying. Surface sediment samples were freeze-dried, sieved to less than 63 microns, digested with a published four-acid digestion process, and analyzed with ICP-MS, flame atomic absorption spectroscopy, and cold vapor atomic absorption spectroscopy for mercury analysis methods from Fishman and Friedman (1989) and Horowitz and others (1989 and 2001).

QA/QC samples were used to assess analytical variability, bias, and percent recovery. Duplicate samples were comprised approximately 15 percent of the total number of samples. Twenty percent of the analyzed samples were blanks. Standard reference material was used to assess accuracy. QA/QC results are provided in Appendix 1 of the report.

Paulson, A.J., R.J. Wagner, R.F. Sanzolone and S.E. Cox. 2006

The USGS conducted this sampling program to collect data about the elemental composition of sediments collected from Lake Roosevelt (in September 2004), to evaluate the release of elements from sediments after sequential selective extraction, and to determine the concentration of elements in filtered water after contact with the sediments. Several types of reservoir water (surface water, porewater) were also analyzed for elemental concentrations. Surface sediment samples were collected at eight (8) locations, including seven (7) Columbia River locations between Northport and the Grand Coulee Dam and one (1) location on the Sanpoil River. Locations were selected where water depths were greater than 12 m for at least the previous two (2) years. Sediment porewater samples were extracted from sediment samples taken from eight (8) locations.

Surface water samples were obtained from the grabs and the box corers at the same eight (8) locations as the sediment and porewater samples. All of the sampled media were analyzed for an extensive list of metallic elements. Total (whole water) and dissolved portions of the surface water samples were analyzed.

Surface sediment samples were collected with a box corer following the protocol for collection and processing described by the U.S. EPA (U.S. EPA 2001). Sediment samples were extracted

from the box corer using polypropylene core liners. All plasticware was cleaned with LiquiNox, rinsed with de-ionized water, soaked in 5% trace-metal grade hydrochorlic acid (HCl), and rinsed with de-ionized water. Plasticware that came in contact with water samples was soaked in 4 N trace-metal grade HNO_3, rinsed with de-ionized water, and dried in a laminar flow hood. Sediment porewater was obtained within 8 hours of collection by inserting a 4.4-cm diameter core liner into the middle of the box core to the bottom, centrifuging the top 2 cm of sediment, and filtering through a 0.22 micron filter. Surface water samples were obtained for comparison to porewater concentrations.

Samples were analyzed at the USGS Minerals Laboratory in Denver, Colorado using published methods (Briggs & Meier 2002). Laboratory QA/QC procedures included digestion of the standard reference material (SRM) MAG-1 (duplicate), National Institute of Science and Technology (NIST) 2704, and SCO-1 and analysis of the digestion solution. A duplicate of standard National Research Council of Canada (NRCC) PACS-2 and the standard International Atomic Energy Association (IAEA)-405 were submitted as field samples. Water sample QC included analysis of blanks, duplicates, and reference samples. QA/QC results are presented in Tables 3 (sediments), 6 (water), 7 (water), and 8 (water) of the Paulson et al. (2006) report.

U.S. Environmental Protection Agency and Teck Cominco. 2008a

U.S. EPA conducted a sediment sampling program as part of Phase 1 of a Comprehensive Environmental Response, Compensation and Liability Act Remedial Investigation/Feasibility Study for the Upper Columbia River site (U.S. EPA and Teck Cominco 2008a, U.S. EPA 2006). Surface sediment samples were collected from 74 transect and 15 beach locations on the Columbia River between the international border and the Grand Coulee Dam as well as several tributary and reference areas. Subsurface sediment samples were collected at nine (9) locations between river miles 708 and 605. Porewater was obtained from sediment samples collected at 56 locations to assist with interpreting the toxicity results. Sampling was conducted over a six-week period in April and May, 2005. Analytes included metals, carbon, and particle sizes.

All sample collection and processing was conducted in accordance with the Phase 1 Sediment QAPP (CH2M Hill 2005). Surface sediment samples were obtained with a van Veen sampler and

with spoons. The upper 10 to 15 centimeters were typically sampled. Subsurface sediment samples, collected at mid-channel and submerged side-bank locations, were cored with a 10-cm vibracore. Porewater was obtained from the sediment by centrifuging under oxic conditions and decanting until 200 ml of water was collected (U.S. EPA and Teck Cominco 2008a).

Samples were analyzed by laboratories in the Contract Laboratory Program (CLP) and at U.S. EPA's Manchester Laboratory that used CLP methods (U.S. EPA 2004) that include requirements for accuracy, precision, and completeness. Information about QA/QC samples is provided in Appendix B in the Sediment Sampling Data Evaluation Report (U.S. EPA 2006). Surface and subsurface sediment sampling data were evaluated independently of the laboratory by project chemists and reviewed for the QC specifications identified in the project QAPP and U.S. EPA CLP statements of work. The authors indicate data met and exceeded project quality goals (U.S. EPA 2006).

U.S. Environmental Protection Agency. 2003

U.S. EPA conducted an expanded site investigation of the upper Columbia River and its tributaries under the authority of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 and the Superfund Amendments and Reauthorization Act (SARA) of 1986. The investigation was intended to collected sufficient data to determine a site's potential for inclusion on the National Priorities List (NPL). Surface sediment samples were collected from 49 locations on the Columbia River between river mile 675 and the international border (RM 745) as well as over 100 additional locations including Columbia River tributaries. Sampling was conducted in May and June of 2001. Analytes of interest included metals, carbon and particle sizes.

Sampling was conducted following SOPs contained in Appendix A of the Sampling Quality Assurance Plan (SQAP) (Weston 2001) developed for the project and the Sample Plan Alteration Forms for field activities. Most sediment samples were collected from 0 to 8 inches below the sediment surface from most downstream locations to most upstream locations, although some locations were collected from depth intervals ranging from 18 to 24 inches below the sediment

surface. Sediment samples were collected using stainless steel sampling equipment, including a petit ponar dredge, hand auger, and/or bowls and spoons.

Surface sediment samples were analyzed according to the U.S. EPA CLP Statement of Work for Inorganics Analysis ILM04.1 for metals (U.S. EPA 2000) and U.S. EPA SW-846 method 9060 for TOC (U.S. EPA 1989). Duplicates, matrix spikes, matrix spike duplicates were submitted to the CLP laboratories for metals analysis at a rate of one per 20 samples. Data from the CLP laboratories were reviewed and validated by U.S. EPA and/or Environmental Services Assistance Team chemists. QA/QC results are presented in Appendix G of the Expanded Site Inspection Report (U.S. EPA 2003). U.S. EPA (2003) reports that data quality met data quality objectives as stated in the SQAP. Details on precision, accuracy, completeness and representativeness objectives are provided in Section 4 of the report (U.S. EPA 2003).

U.S. Environmental Protection Agency. 2002

U.S. EPA conducted preliminary assessments and site investigations under the authority of the CERCLA (1980) as amended by the SARA (1986) at 39 mine and mill sites throughout Stevens County including the LeRoi Smelter at Northport. Water samples were collected at 13 locations. Surface sediment samples at Northport were collected in June and September, 2001. Analytes of interest included metals, carbon and particle sizes.

Sampling was conducted following standard operating procedures contained in Appendix A of the SQAP (E&E 2001) developed for the project and the Sample Plan Alteration Forms for field activities. Sediment samples were collected from 0 to 8 inches below the sediment surface from most downstream locations to most upstream locations. Potential contamination was minimized by homogenizing surface sediment samples in dedicated plastic bowls prior to placement in sample jars using dedicated plastic spoons and scoops.

Surface sediment samples were analyzed according to the U.S. EPA CLP Statement of Work for Inorganics Analysis ILM04.1 for metals (U.S. EPA 2000) and U.S. EPA SW-846 for TOC (U.S. EPA 1989). Rinsate blank samples, matrix spikes, and matrix spike duplicates were submitted to the CLP laboratories for metals analysis. Data from the CLP laboratories were reviewed and

validated by U.S. EPA and/or Environmental Services Assistance Team chemists. The author indicates that data quality met data quality objectives as stated in the SQAP. Details on precision, accuracy, completeness and representativeness objectives are provided in Section 4 of the Preliminary Assessments and Site Inspections Report (U.S. EPA 2003).

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APPENDIX C

DATA REVIEW PROCESS

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This appendix describes the review process I used and the results of my data and GIS reviews of each of the 16 datasets I considered in forming my opinions in this expert report. I obtained most of these datasets in electronic form from the U.S. EPA's Upper Columbia River CERCLA RI/FS project database and the Washington Department of Ecology's internet-based Environmental Information Management (EIM) database. One dataset (Environment Canada 2010) was downloaded directly from the Agency's website. The spill-related datasets (Duncan 2008a,b) were digitized from data tables in the published reports.

Data from the U.S. EPA's Upper Columbia River CERCLA RI/FS project database has been previously evaluated based on established U.S. EPA criteria and guidelines for data quality according to the *Contract Laboratory Program National Functional Guidelines for Inorganic/Organic Data Review* (CH2M HILL 2005). Data from the Washington Department of Ecology's EIM database has been formatted to conform to specific requirements and the database portal has utilities built into it to check for valid values when users upload data into the system.

To help evaluate these datasets I used an application tool developed by LimnoTech called the Data Viewer. The Data Viewer is a Windows-based application developed in Visual Basic to manage, visualize and analyze environmental data. It is a "wrapper" that links GIS information with data stored in a local Microsoft Access database. Datasets can be mapped by selecting attributes describing media, parameter and/or date. Datasets can be visualized and analyzed by aggregating or filtering based on media, location, parameter, date, depth and sample type. Non-detects can be excluded or scaled to a value between zero and the reported detection limit.

Analyses that can be conducted with the Data Viewer include spatial and temporal scatter plots (concentration versus time or space), vertical profiles (concentration versus depth), spatial or temporal statistics (box-and-whisker plots or cumulative frequency distributions). The Data Viewer is a screening-level tool that allows the user to compare results across datasets and evaluate potential trends in space, time or depth. The Data Viewer includes a utility to export results to Microsoft Excel for more detailed analyses and for producing report quality graphics.

Before using any of the 16 datasets, I conducted my own review of the data themselves and their associated sample location information before finalizing the local Microsoft Access database and the GIS information for use in the Data Viewer. This review involved comparison of the reported data and GIS information in each dataset to at least one independent source, usually a published report containing the data in tabulated form. In addition to comparing the reported value of each result, tallies of the total number of locations, samples and results were all compared for consistency so that potential missing data or duplicated data could be investigated. The GIS information was compared to published coordinates and/or maps in one or more independent sources, usually published reports. Each sampling location was inspected against an independent data source and the location description to confirm that the mapped location was correct. The GIS information for all datasets was standardized in a consistent coordinate system, the North American Datum 1983 (NAD83).

Baturin, W.T. 1993

Data were obtained electronically in Lotus-123 files from Northwest Hydraulic Consultants (NHC) (personal communication, May 28, 2010). The sediment sample site "Gravel Pit (IV-3)" from the spreadsheet was assumed to be location IV-3A as described in Norecol's 1992 Biological Reconnaissance and Sediment Sampling Report (Norecol Environmental Consultants 1993). At least 10% of the data values were compared to the published report (Baturin 1993) and found to be consistent. Tables and maps in Norecol's report were used to map sampling locations in ArcGIS and to obtain estimated sampling coordinates.

Borteleson, G. C., S.E. Cox, M.D. Munn, R.J. Schumaker and E. K. Block. 2001

Data and sample location information were obtained from the "Bortleson et al. 2001" Study ID in the U.S. EPA's Upper Columbia River CERCLA RI/FS project database. This electronic data source inconsistently flagged the sediment analysis as particles less than 2 millimeters whereas the published report (Bortleson et al. 2001) indicated that all metals analysis was performed on particles less than 2 millimeters. The dataset uploaded to the Data Viewer database was input to reflect all sediment metals analyses as performed on particles less than 2 millimeters as per the published report. Recoverable metals data from the Canadian sampling locations and Onion Creek left bank recoverable cadmium results from the published report were missing from the

electronic dataset and added to the Data Viewer database manually. No published report comparison could be made for sediment sampling results for antimony, chromium, iron, manganese, or grain size data other than percent silt because these results were not in the published report. Approximately half of the data for percent silt were missing from the electronic dataset when compared to the published report and added to the Data Viewer database manually. Grain size results in the electronic dataset which were stored in units of "mm" or "unk" for unknown were loaded into the database with units changed to percent by weight. No suspended sediment metals data were found in the electronic data. Coordinates for several of the sampling locations did not align with USGS National Hydrography Dataset (NHD) waterbody data. A comparison to USGS National Water Information System (NWIS) Station Inventory coordinate data did not show significantly different sampling locations so the coordinates were not changed. Upon making the data revisions described, over 90% of the data results were then compared to the published report and found to be consistent.

Columbia Environmental Consulting, Ltd. 2002

Data and sample location information were obtained from the "Columbia Environmental Co" Study ID in the U.S. EPA's Upper Columbia River CERCLA RI/FS project database. No specific coordinate system was given for the sampling location information in the published report, so data were projected in NAD_1983_UTM_Zone_11N. Data comparisons between the electronic dataset and the published report (Columbia Environmental Consulting 2002) were consistent.

Cox, S. E., P.R. Bell, J.S. Lowther and P. C. VanMetre. 2005

Data and sample location information were obtained from the "USGS_Cox2005" Study ID in the U.S. EPA's Upper Columbia River CERCLA RI/FS project database. Samples which were denoted as receiving a 0.25 M hydroxylamine hydrochloric acid (NH_2OH HCl) treatment at 50ºC were not considered representative of instream conditions and were not loaded into the Data Viewer database. Units for metals data were reported in the published report (Cox et al. 2005) as ug/kg but were stored in the electronic dataset as mg/kg. A database note indicated that the database developer contacted the author to confirm that the units of mg/kg were the correct units so units were stored in the Data Viewer database as mg/kg. Inorganic carbon results in the

electronic dataset were consistent with carbonate results from the published report, so the results were changed to carbonate in the Data Viewer database. Two of the slag sampling locations identified in the published report were not present in the electronic dataset and were added to the database manually. Coordinates from the electronic dataset did not match those in the report but were not changed because they were consistent with GIS data from NHD and USGS. Coordinates in the CERCLA RI/FS database and published report for stations CSA-8 and RSS-724 were different from the map and station description in the published report so they were moved manually for consistency with the map in the published report. At least 10% of the data values were compared to the published report and found to be consistent.

Duncan, B. 2008a

Data were obtained by digitizing data in the published report (Duncan 2008a). The entire digitized dataset was checked against the published report for transcription errors and found to be consistent. Sample locations were mapped using information in the published report.

Duncan, B. 2008b

Data were obtained by digitizing data in the published report. The entire digitized dataset was checked against the published report (Duncan 2008b) for transcription errors and found to be consistent. Sample locations were mapped using information in the published report.

Environment Canada. 2010

Data were obtained through a direct download from Environment Canada's website. Data were reformatted for upload into the Data Viewer database, spot-checked for transcription errors, and found to be consistent with the data download. The GoogleEarth utility in Environment Canada's website was used to locate the sampling stations.

Era, B. and D. Serdar. 2001

Data and sample location information were obtained from the "DSER0008" Study ID in the Washington Department of Ecology's internet-based EIM database except for the Lower Arrow Lake sample data, which were obtained from the "WADOE. 2001" Study ID in the U.S. EPA's

Upper Columbia River CERCLA RI/FS project database. At least 10% of the data values were compared to the published report (Era and Serdar 2001) and found to be consistent.

Hatfield Consultants. 2008

Data and sample location information were obtained from the "CRIEMP05" Study ID in the U.S. EPA's Upper Columbia River CERCLA RI/FS project database. A detailed comparison to the published report (Hatfield Consultants 2008) could not be made because the raw data were not published in the report.

Johnson, A. 1991

Data and sample location information were obtained from the "LAKEROOS" Study ID in the Washington Department of Ecology's internet-based EIM database. The electronic dataset was an incomplete representation of the published report (Johnson 1991), but the available results were found to be consistent. The EIM database did not include the data from the Spokane River Arm and Little Dalles tributaries and did not include the porewater and water data. These data were considered for inclusion in the Data Viewer database. The porewater data were not added because the sample handling and filtering information indicated that the data were not representative of in-situ, dissolved concentrations. The water and tributary data were not added because the water column analyses in my report relied primarily on routine monitoring data more than data obtained from discrete grab samples, such as these water samples. These actions have been noted and will be revisited in future work if appropriate.

Johnson, A., D. Norton and B. Yake. 1989

Sediment data were obtained from the "Johnson et al. 1989" Study ID in the U.S. EPA's Upper Columbia River CERCLA RI/FS project database except for the Lower Arrow Lake sediment sample, which was entered into the Data Viewer database manually from the published report (Johnson et al. 1989). Water quality data were obtained from the "AJOH0038" Study ID in the Washington Department of Ecology's internet-based EIM database. The water quality sample ID 8317 was found to be misattributed as 8315 upon comparison to the published report and was input into the Data Viewer database accordingly. Sample depths for the water samples were

taken from the CERCLA RI/FS project database because the information was not available in the EIM database.

Station location coordinates were not available in the electronic dataset or in the published report, so station locations were placed manually using the map in the published report. All of the sediment data and at least 10% of the surface water data values were compared to the published report and found to be consistent.

Majewski, M.S., S.C. Kahle, J.C. Ebbert and E.G. Josberger. 2003

Data were obtained from the "Majewski et al. 2003" Study ID in the U.S. EPA's Upper Columbia River CERCLA RI/FS project database. Results for location "Slag_747" were available in the electronic dataset, but the location information was missing and thus obtained from the published report (Majewski et al. 2003). At least 10% of the data values were compared to the published report and found to be consistent.

Paulson, A.J., R.J. Wagner, R.F. Sanzolone and S.E. Cox. 2006

Data were obtained from the "USGS_04_LR" Study ID in the U.S. EPA's Upper Columbia River CERCLA RI/FS project database. Results which were noted as being part of a tumbling experiment were not considered representative of instream conditions and were not loaded into the Data Viewer database. Grain size data from sediment samples, pre-composite sediment metals data, and surface water sample depths were found to be omitted from the electronic dataset. These actions have been noted and will be revisited in the future as needed. At least 10% of the data values were compared to the published report (Paulson et al. 2006) and found to be consistent.

U.S. Environmental Protection Agency and Teck Cominco. 2008a

Data and sample location information were obtained from the "U.S. EPA 2005 Sediment" Study ID in the U.S. EPA's Upper Columbia River CERCLA RI/FS project database. The electronic dataset described the coordinate system for the sample locations to be WA State Plane North, NAD83, but the sampling locations did not map correctly in this coordinate system. Sampling locations were projected in the NAD_1983_UTM_Zone_11N coordinate system and were

consistent with the published report (U.S. EPA 2006). Approximately 10% of the sediment coring data values were slightly different than values in the published report. Because the published report is still labeled draft, it was not clear whether either the report or electronic dataset values correspond to final values. Therefore, the values in the electronic dataset were added to the Data Viewer database. Published raw data for surface sediment samples taken at beaches were spot-checked and found to be consistent for at least 90% of the data values checked. A detailed comparison of surface sediment data to the published report could not be made because most of the raw data were not published in the report.

U.S. Environmental Protection Agency. 2003

Data and sample location information were obtained from the "U.S. EPA_2001_ESI" Study ID in the U.S. EPA's Upper Columbia River CERCLA RI/FS project database. Several sampling locations were found to have been erroneously combined based on a comparison to the published report (U.S. EPA 2003), so locations were reattributed for consistency with the published report. Surface water sampling data were found to be omitted from the electronic dataset. Because the water column data analyses rely primarily on datasets from routine monitoring programs, these actions have been noted and will be revisited at a future date as appropriate. At least 10% of the data values were compared to the published report and found to be consistent.

U.S. Environmental Protection Agency. 2002

Data and sample location information were obtained from the "U.S. EPA2001Mines/Mills" Study ID in the U.S. EPA's Upper Columbia River CERCLA RI/FS project database. Only the LeRoi/Northport smelter samples were needed for the analysis work and at least 10% of these data values were compared to the published report (U.S. EPA 2002) and found to be consistent.

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APPENDIX D

CUMULATIVE FREQUENCY DISTRIBUTIONS FOR

WATER COLUMN METALS

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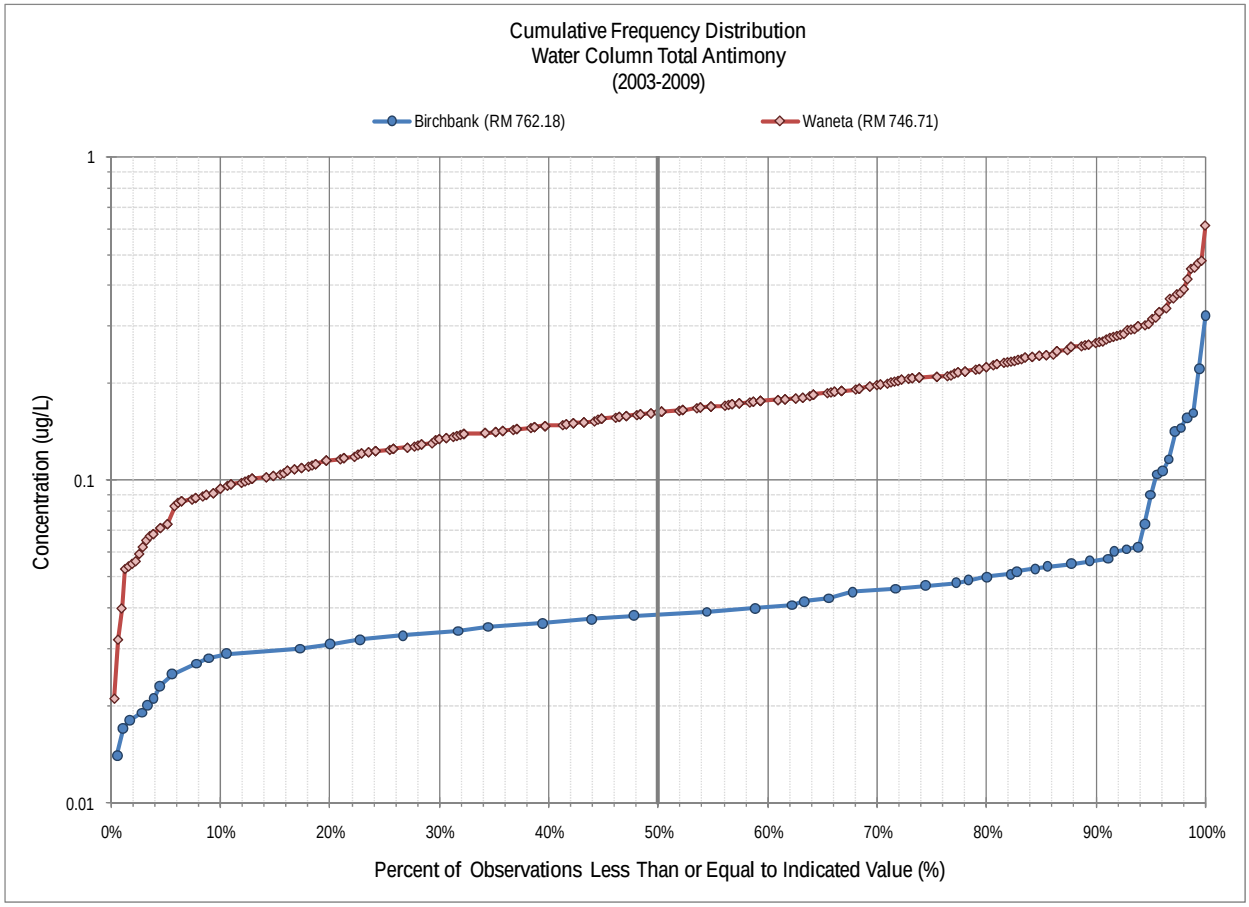

Figure D-1. Cumulative Frequency Distributions for Water Column Total Antimony Concentrations for 2003-2009

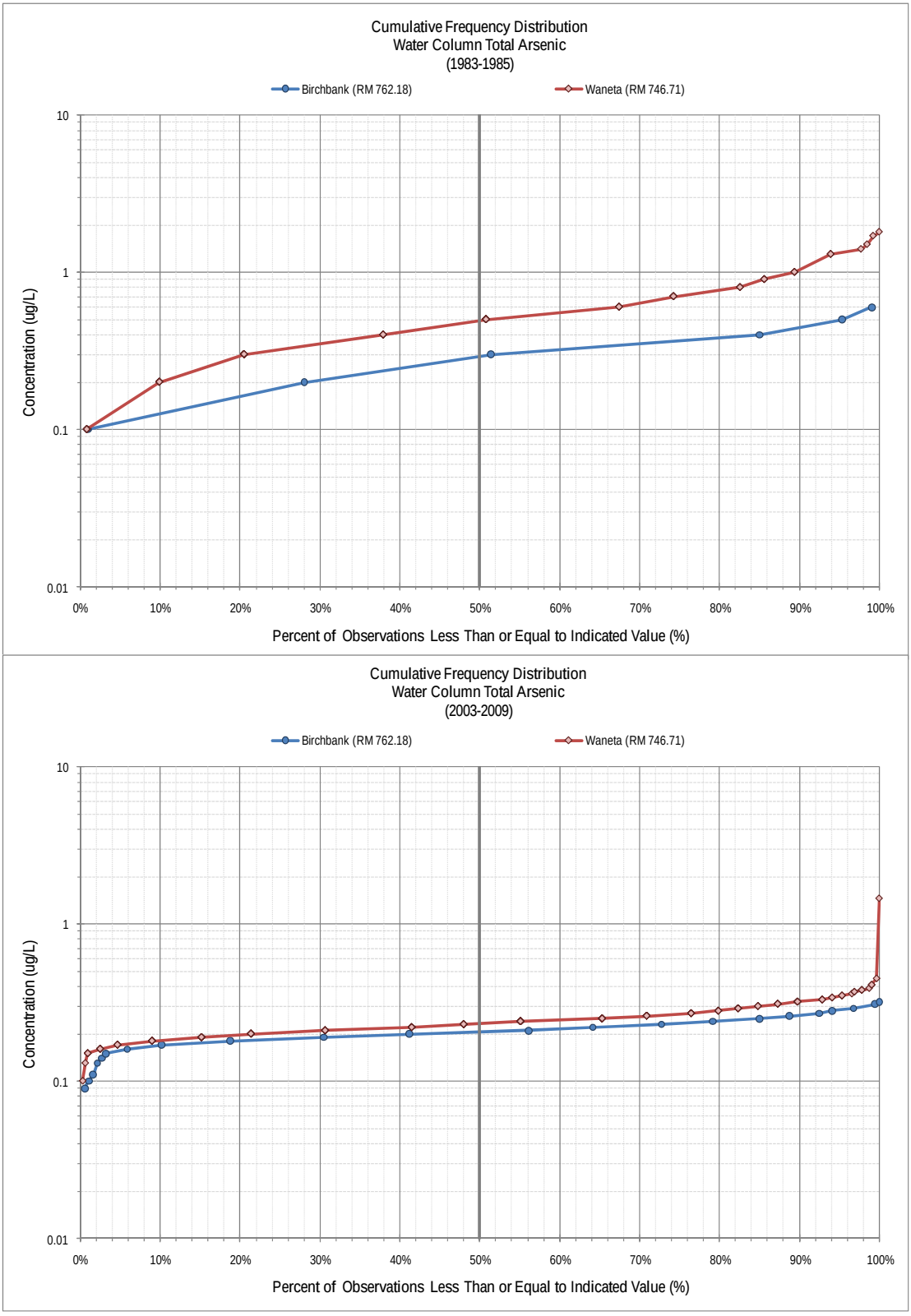

Figure D-2. Cumulative Frequency Distributions for Water Column Total Arsenic Concentrations for 1983-1985 (top panel) and 2003-2009 (bottom panel)

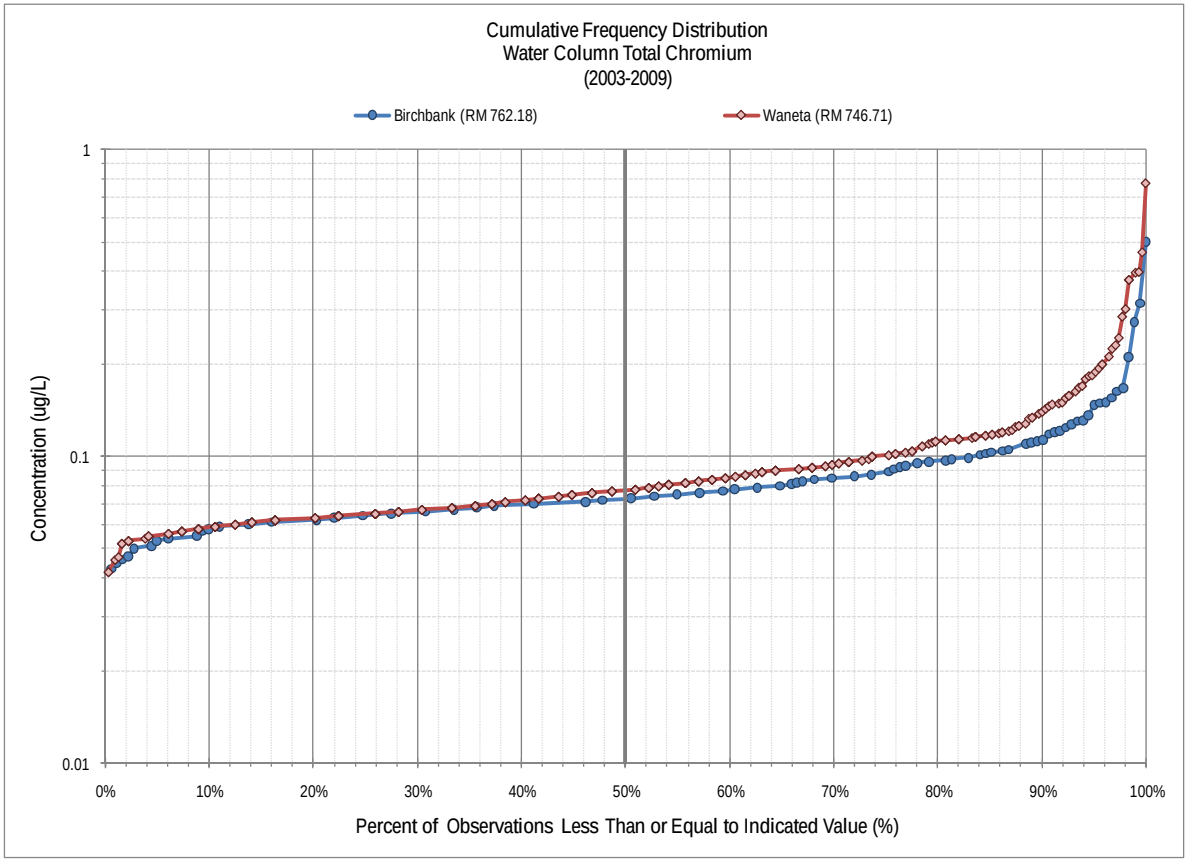

Figure D-3. Cumulative Frequency Distributions for Water Column Total Chromium Concentrations for 2003-2009

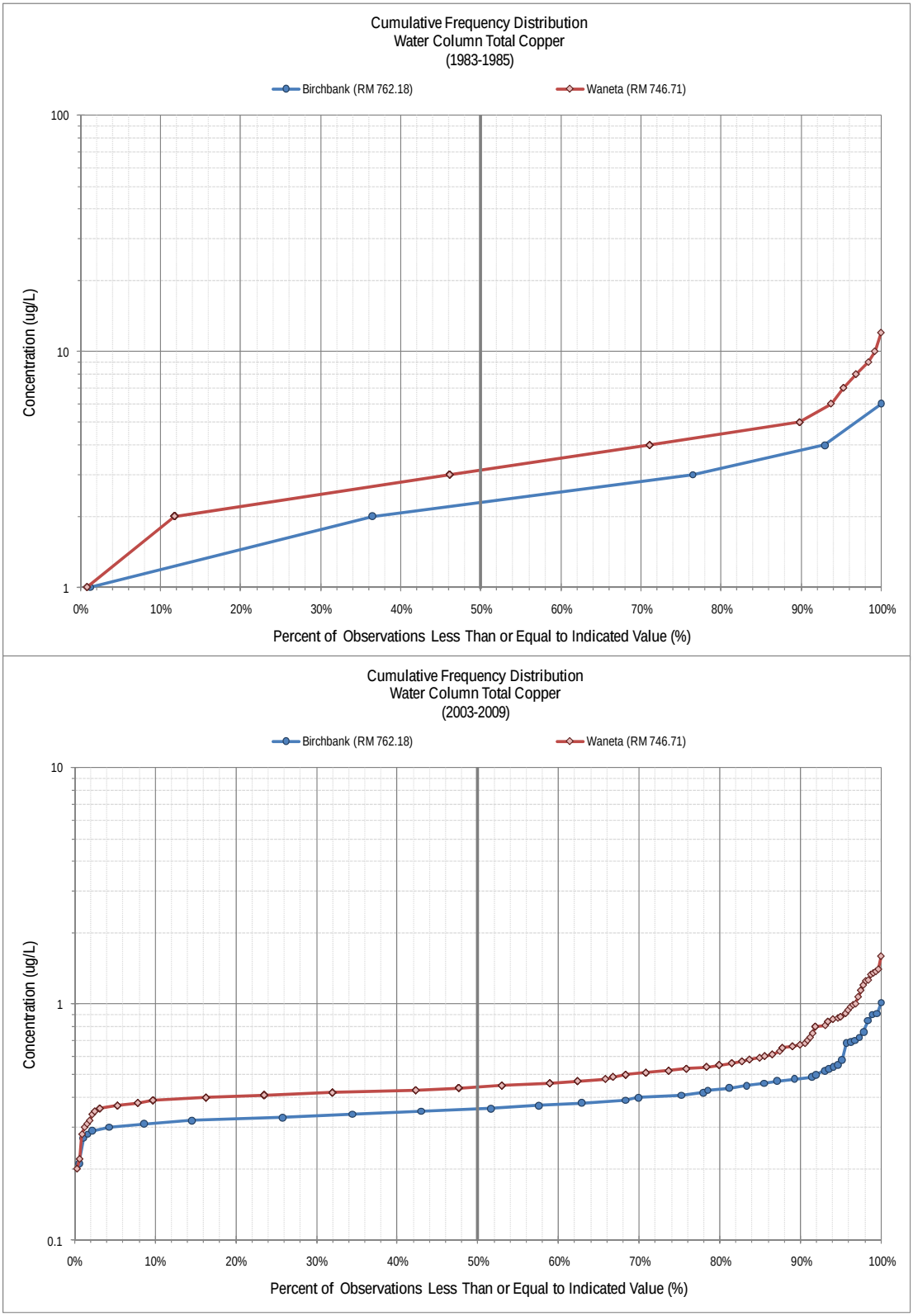

Figure D-4. Cumulative Frequency Distributions for Water Column Total Copper Concentrations for 1983-1985 (top panel) and 2003-2009 (bottom panel)

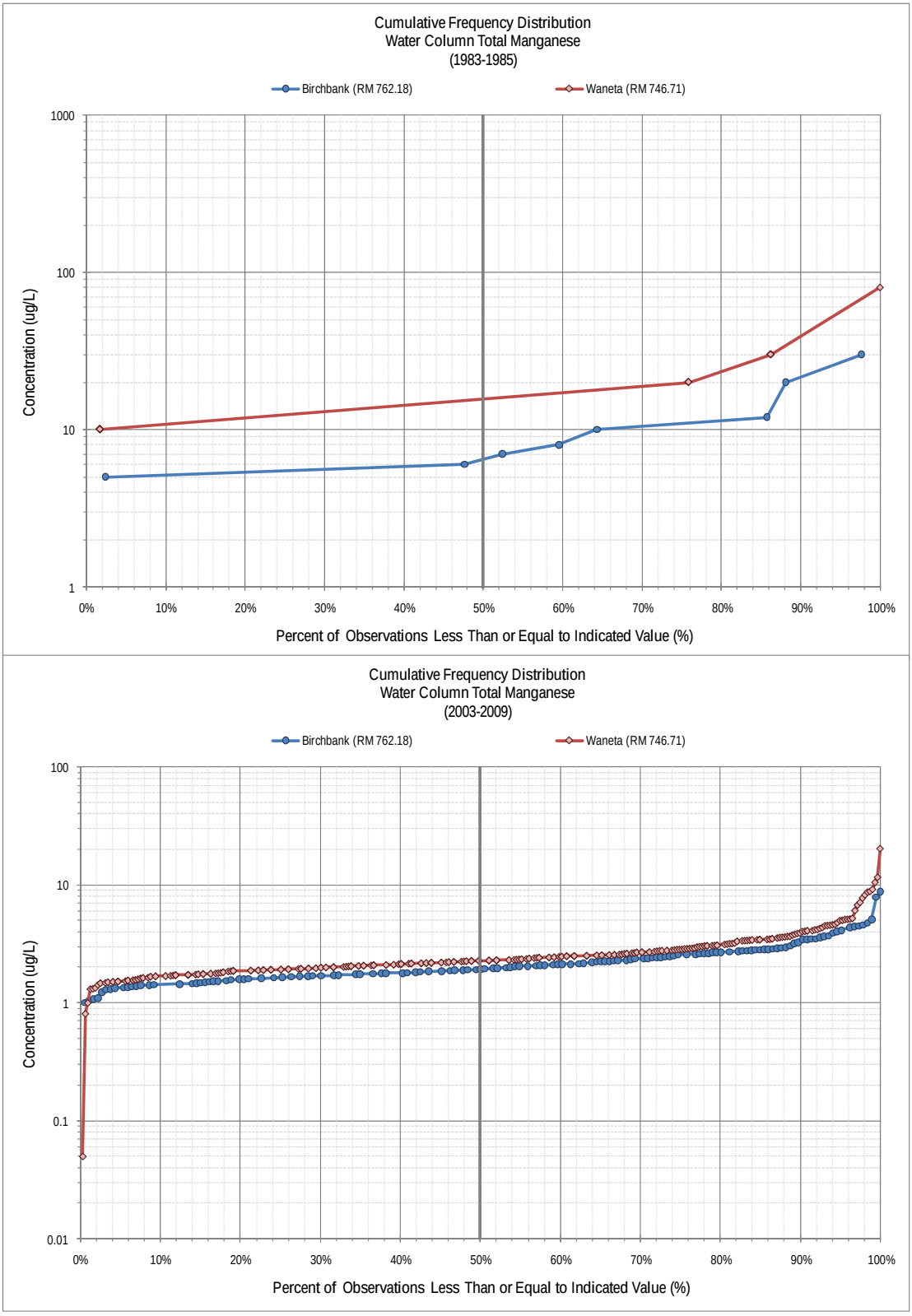

Figure D-5. Cumulative Frequency Distributions for Water Column Total Manganese Concentrations for 1983-1985 (top panel) and 2003-2009 (bottom panel)

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APPENDIX E

CUMULATIVE FREQUENCY DISTRIBUTIONS FOR

SURFACE SEDIMENT METALS

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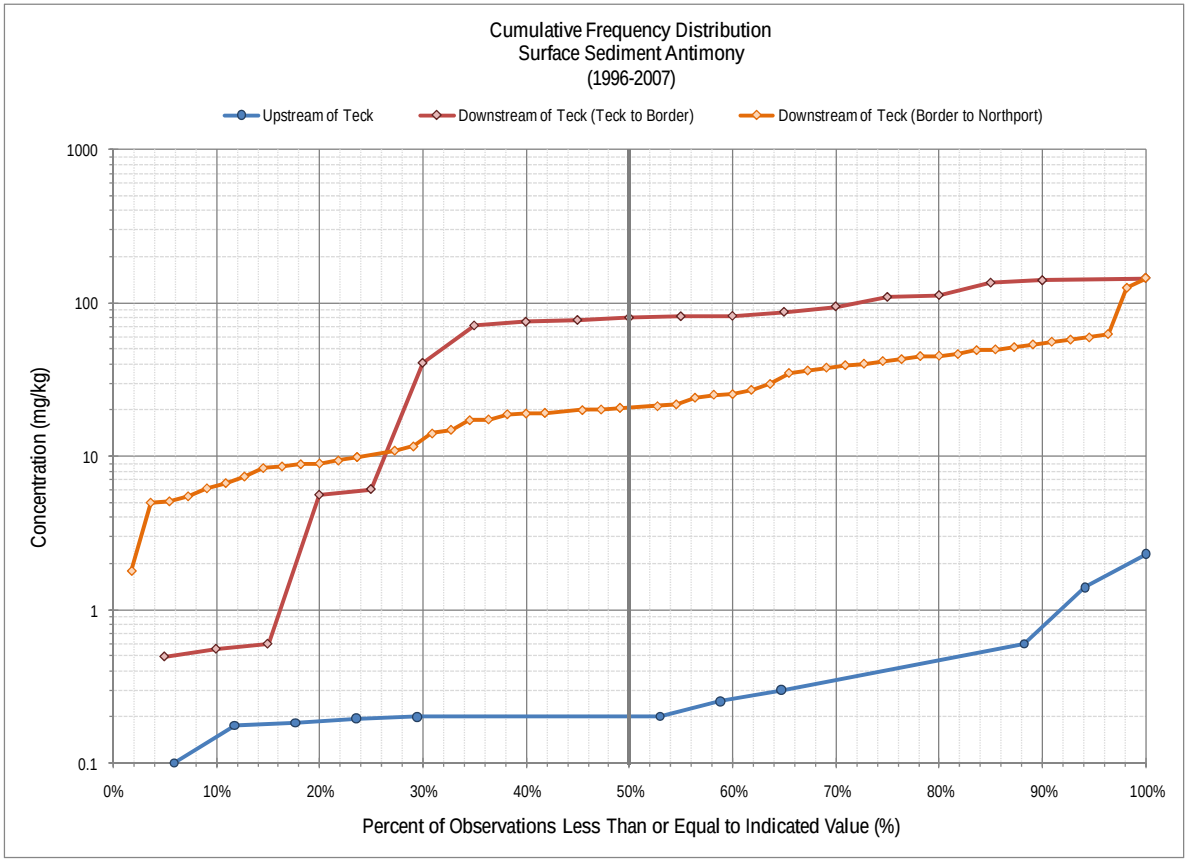


Figure E-1. Cumulative Frequency Distributions for Surface Sediment Total Antimony Concentrations for 1996-2007

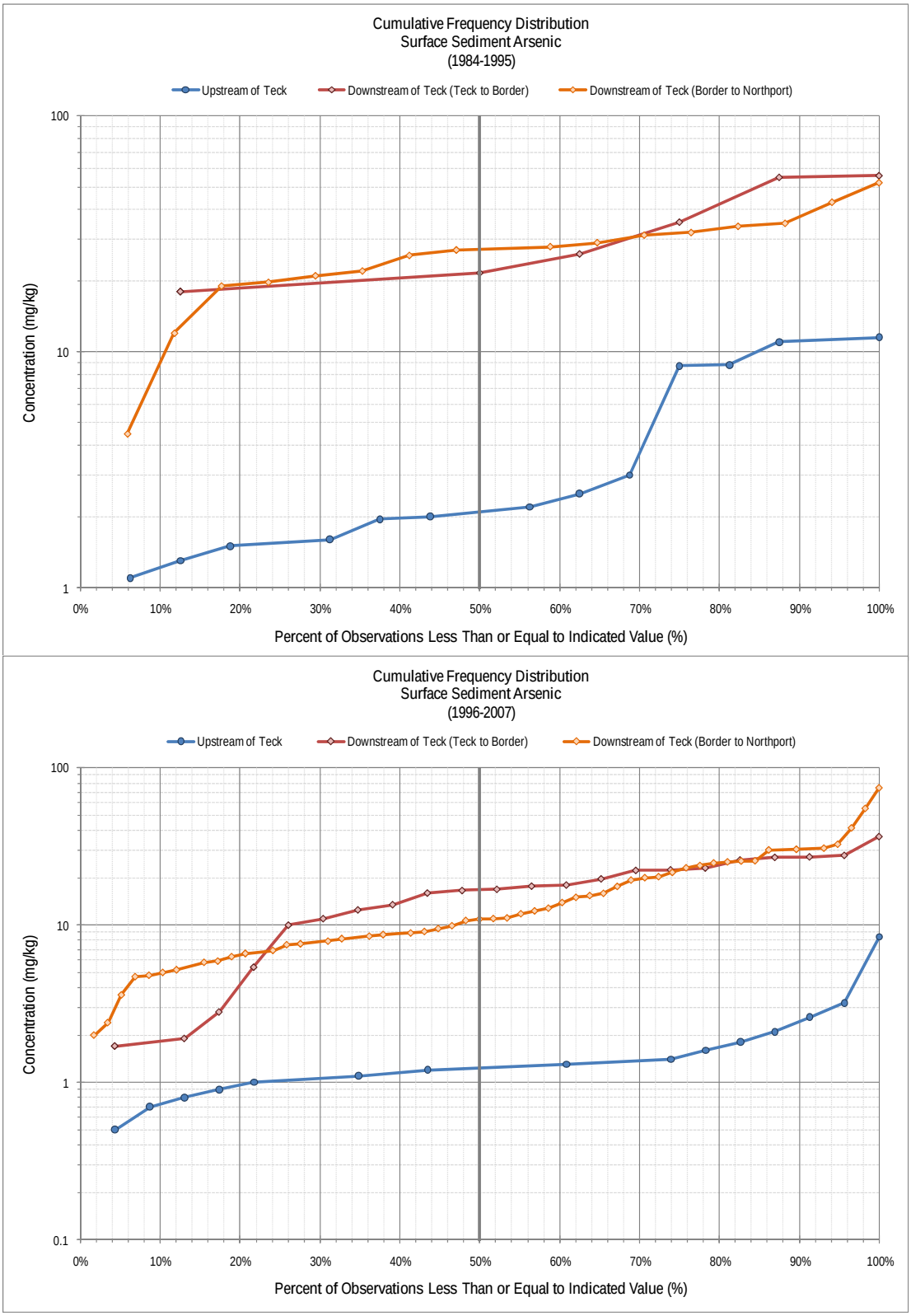
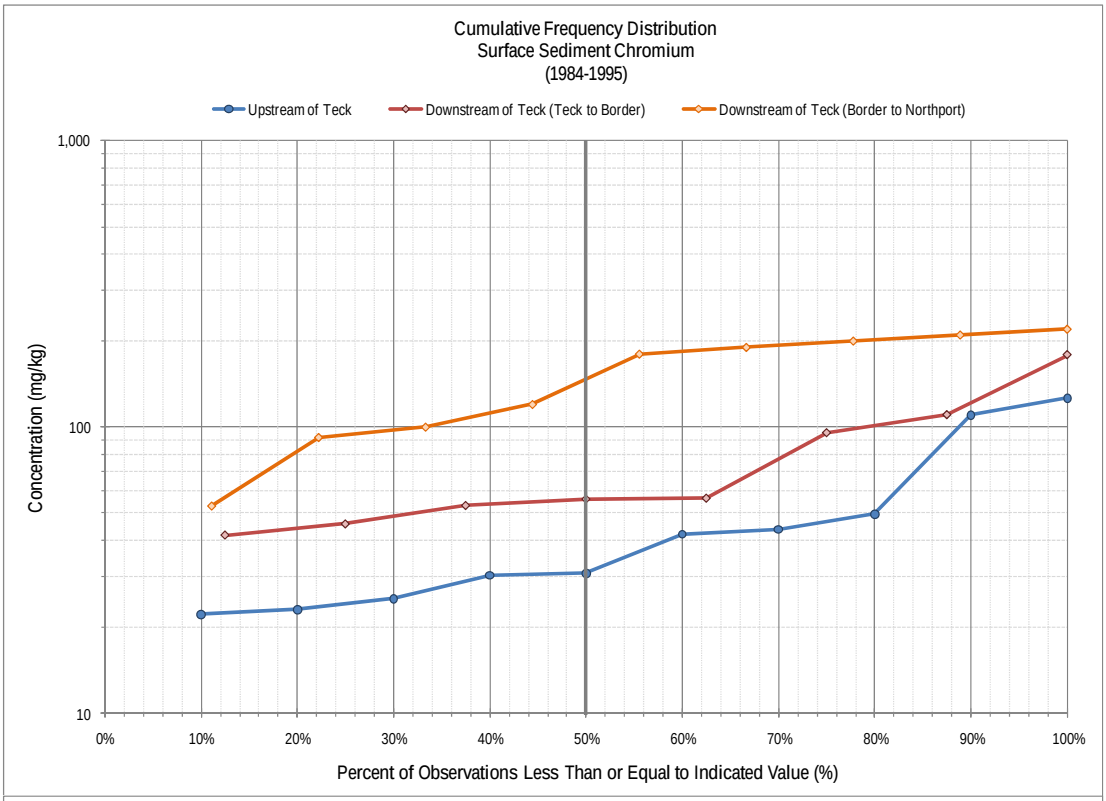


Figure E-2. Cumulative Frequency Distributions for Surface Sediment Total Arsenic Concentrations for 1984-1995 (top panel) and 1996-2007 (bottom panel)



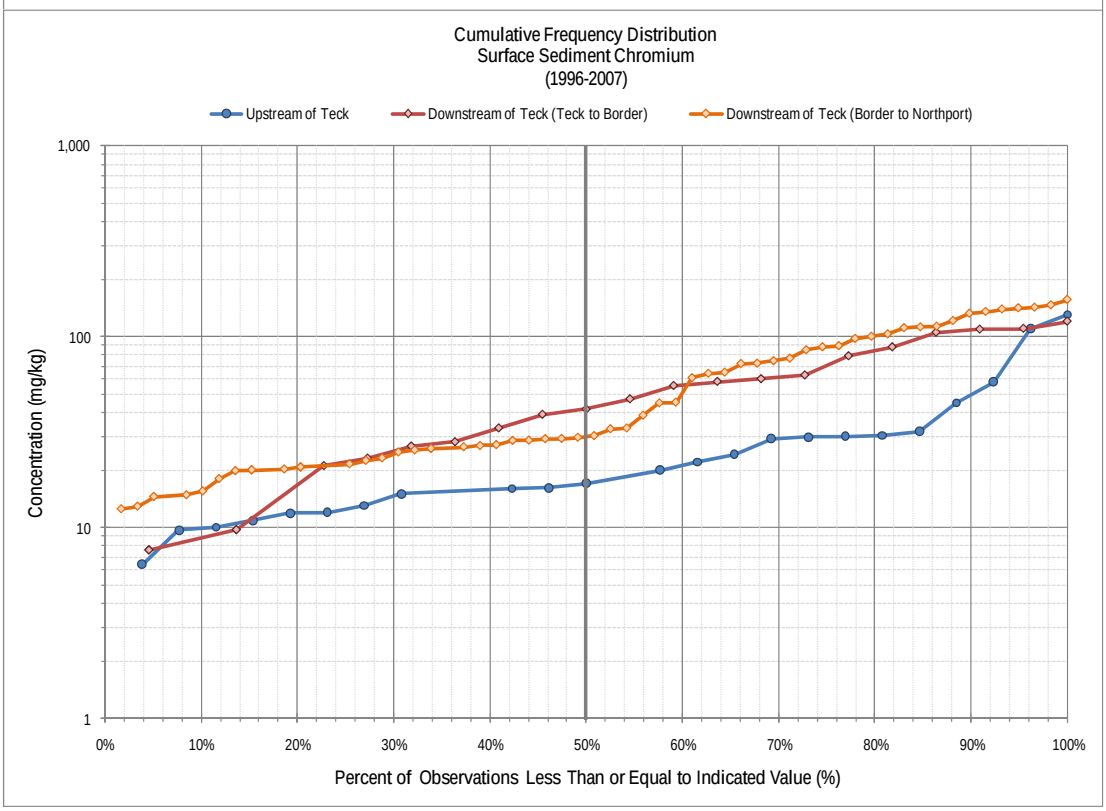


Figure E-3. Cumulative Frequency Distributions for Surface Sediment Total Chromium Concentrations for 1984-1995 (top panel) and 1996-2007 (bottom panel)

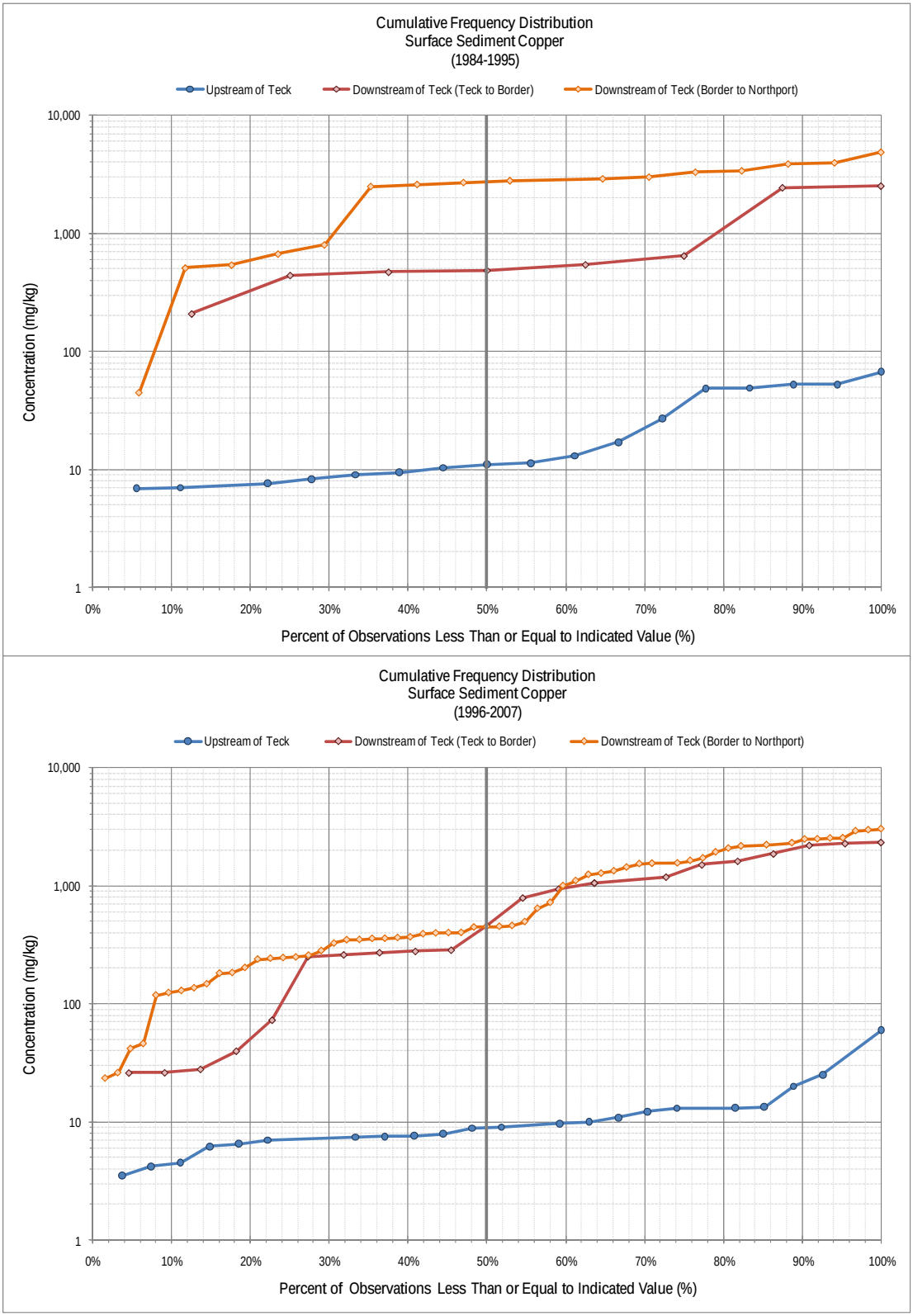
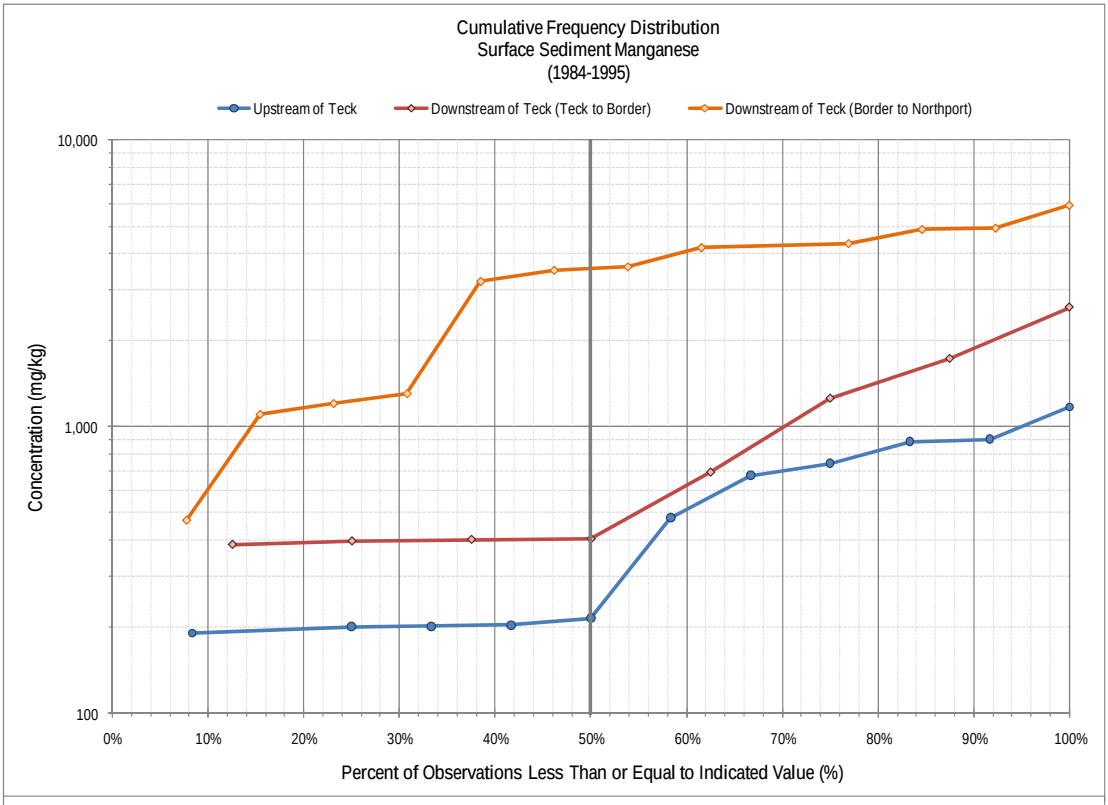


Figure E-4. Cumulative Frequency Distributions for Surface Sediment Total Copper Concentrations for 1984-1995 (top panel) and 1996-2007 (bottom panel)



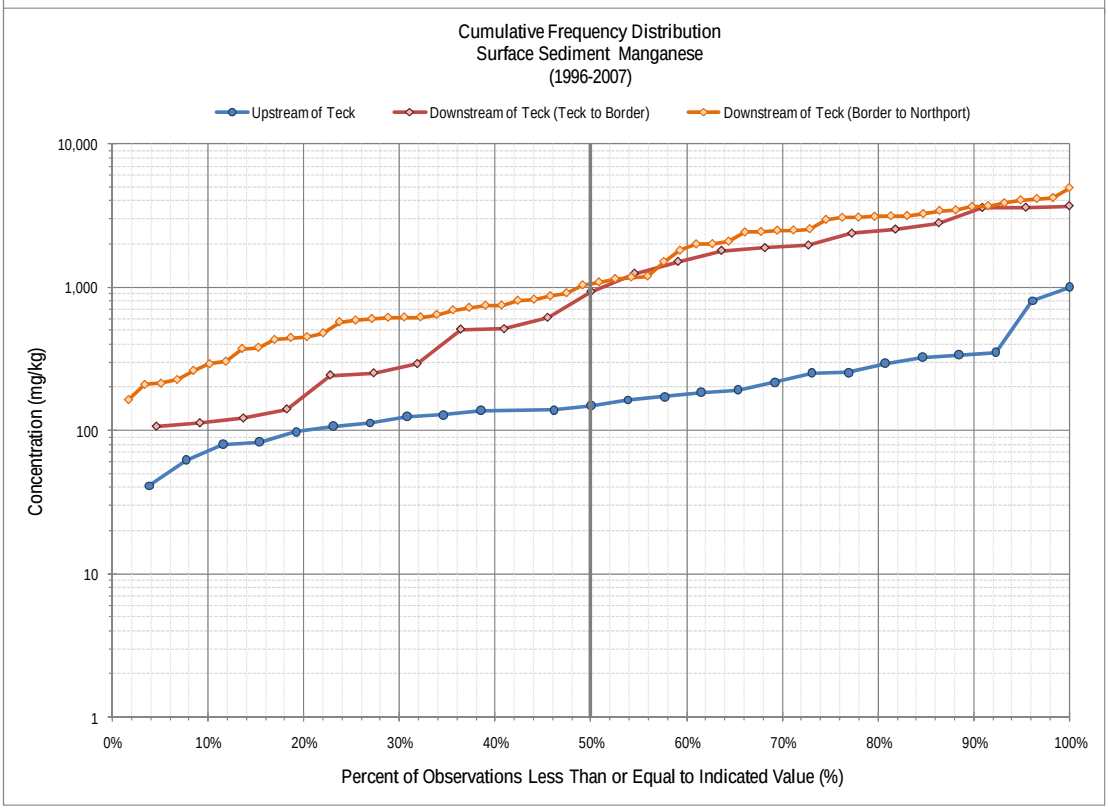
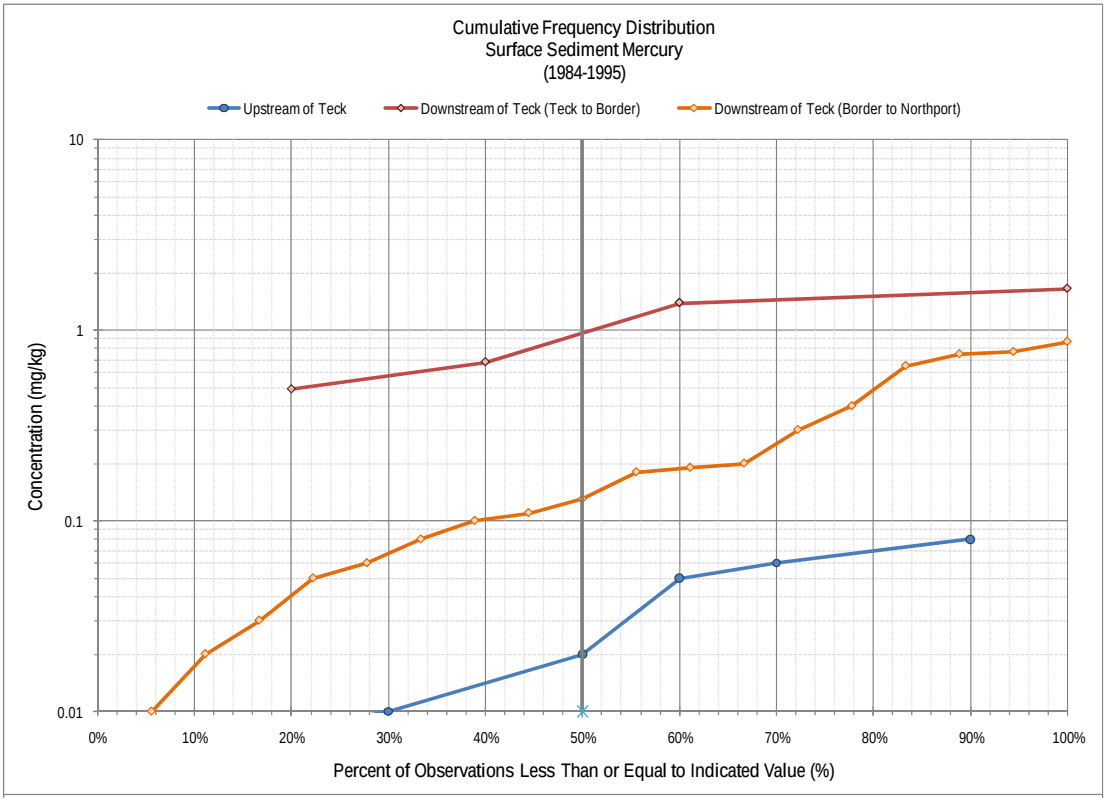


Figure E-5. Cumulative Frequency Distributions for Surface Sediment Total Manganese Concentrations for 1984-1995 (top panel) and 1996-2007 (bottom panel)



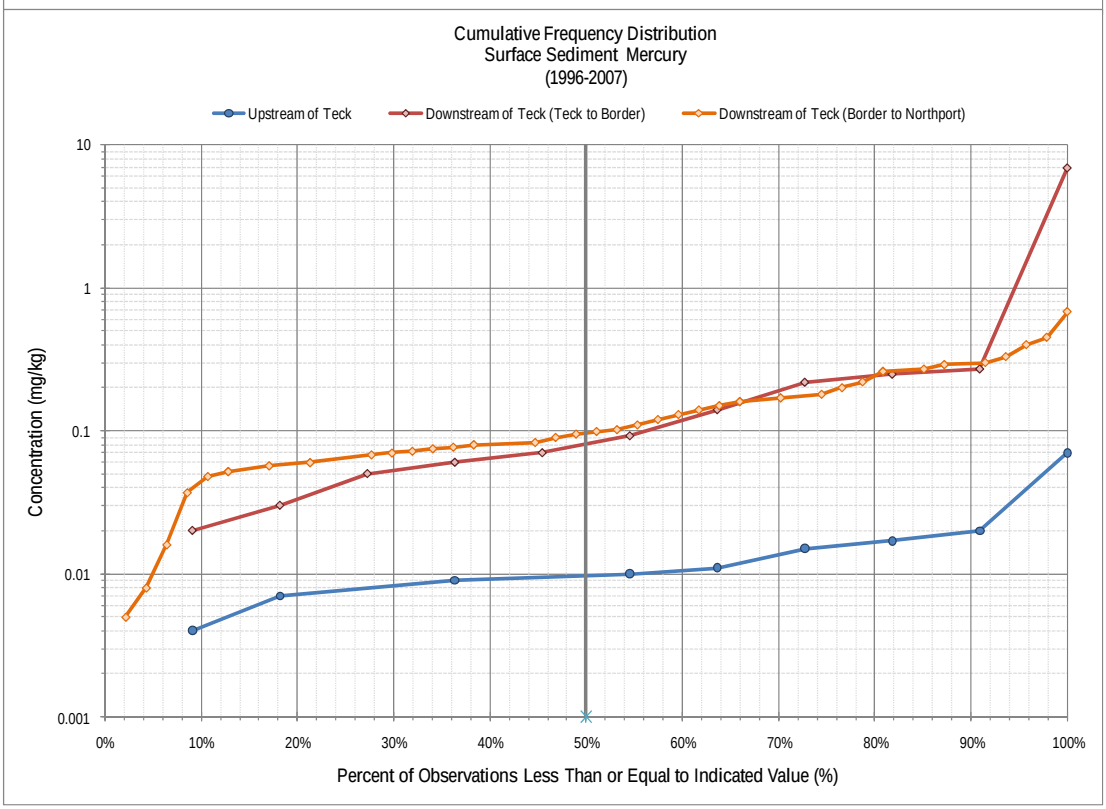


Figure E-6. Cumulative Frequency Distributions for Surface Sediment Total Mercury Concentrations for 1984-1995 (top panel) and 1996-2007 (bottom panel)