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BUREAU OF RECLAMATION

WATER QUALITY REPORT

GRAND COULEE, LAKE ROOSEVELT
COLUMBIA RIVER BASIN
COLUMBIA RIVER, WASHINGTON

Grand Coulee, Lake Roosevelt

Water Quality Report
July 2020

EXECUTIVE SUMMARY

The reservoir formed by Grand Coulee Dam, Lake Roosevelt, stretches from near the U.S.-Canada border to the Grand Coulee Dam. The reservoir waters and surrounding lands are managed through a cooperative effort of five agencies: the Bureau of Reclamation (Reclamation), the National Park Service, the Bureau of Indian Affairs, the Confederated Tribes of the Colville Indian Reservation, and the Spokane Tribe of Indians. These five partners work closely with Bonneville Power Administration as well as state and county agencies to meet fishery, wildlife, emergency response, water quality and other needs. When water quality standards vary between managing partners, the most restrictive standard generally applies (U.S. Environmental Protection Agency [EPA] 2016).

The reservoir's total storage capacity is 9.4 Maf with an active (useable) capacity of 5.2 Maf. At full pool, the reservoir has a length of about 150 miles, covers an area of over 120 square miles, and has a shoreline of over 600 linear miles from Grand Coulee Dam to the U.S.-Canada border. Water retention time in the reservoir is relatively short and ranges from an average of 36 days in June, to an average of 76 days in September. The waterbody exhibits weak thermal stratification during the summer months with the largest temperature differences near Grand Coulee Dam and within 10 to 50 feet of the water surface (Reclamation 2018).

While the reservoir exhibits weak thermal stratification in summer months, surface water temperature also increases as the water approaches the dam (Reclamation 2018). High water temperature in summer is a concern for the entire Columbia River Basin; management of Grand Coulee waters to help cool downstream rivers has been investigated. However, nearly all the waters released during the summer months are from depths well below the epilimnion and are already the coldest waters the dam is able to pass downstream. Due to the higher summer reservoir temperature, weak thermal stratification, as well as operational and structural constraints, Grand Coulee Dam has very little potential to mitigate downstream temperatures (Reclamation 2018).

Total dissolved gas (TDG) has been identified as a primary concern throughout the Columbia River Basin. At Grand Coulee Dam, TDG is generally highest in the springtime during high flows from snowmelt. Sources of elevated TDG in Lake Roosevelt include water traveling across the U.S.-Canada border to the reservoir (Kain, Knudson, and Nichols 2018), and the Spokane River (Pickett, Rueda, and Herold 2004). At Grand Coulee Dam, water is released through various outlet pathways which help control the TDG impacts downstream, and through different combinations of powerhouse and outlet gates TDG levels can be somewhat controlled and balanced with power generation, flood control, and storage capacity needs (Reclamation 2018).

Lake Roosevelt's main channel is considered oligotrophic in general but has been observed to be slightly eutrophic, meaning that nutrient concentrations are relatively low, resulting in low primary productivity, generally defined by the total biomass in a waterbody. In general, the waters of Lake Roosevelt are phosphorous limited, and have become more so in recent years (Lee et al. 2006; Kain, Knudson, and Nichols 2018).

However, Lake Roosevelt is a large reservoir, and primary productivity varies considerably both spatially and temporally. The water characteristics change within the main channel where flowing waters predominate in the upper reaches towards the U.S.-Canada border, and transition to slack waters near Grand Coulee Dam.

The ecosystem of Lake Roosevelt is generally balanced in terms of primary productivity and fish populations. If issues do occur, they are normally correlated with primary productivity dieback in June and July. When the normal dieback in the system fails to occur, low nutrient availability can produce large-scale dieback. Lake Roosevelt does have a history of localized low oxygen conditions in bays with slow moving water, and in areas where excessive agriculture runoff has entered the reservoir. If low oxygen conditions from algal blooms do occur, they tend to be localized and not result in large scale fish die-offs (Kain, Knudson, and Nichols 2018), and these blooms have become less common as land management practices have evolved (Besser et al. 2007).

While the waters of Lake Roosevelt generally exhibit low levels of suspended and dissolved solids, contaminant issues do exist in the reservoir. In 1998, in response to deteriorating water quality conditions, Lake Roosevelt was listed as a Clean Water Act 303(d) impaired water for TDG, water temperature, dissolved oxygen, and mercury (Von Prause 2014). Conditions for these parameters have improved, but they remain a concern throughout the reservoir. TDG and temperature are especially a concern at Grand Coulee Dam.

The largest contaminant concern originates from the Teck Cominco Resources Limited of Canada (Teck) smelter, which has been operating in Trail, British Columbia, a few miles north of the international border, since the late 1800s. The Teck operations release liquid effluent into the Columbia River, and dumped between 10 to 14 million tons of slag directly into the Columbia River until that practice ceased in 1995 (EPA, 2009). Metals associated with slag and liquid effluents from Trail that have been introduced into the Columbia River impart distinctive geochemical signatures to the sediment deposits, such as slag-affected sediments having high iron, zinc, copper, and manganese, and sediments impacted by liquid effluents distinguishable from slag-affected sediments due to the relative enrichment in mercury, cadmium, and lead. Due to their grain size and density, most of the slag particles will settle out of the water quickly and are transported primarily along the river bed, as far downstream as Kettle Falls (river mile 700). Metals associated with the liquid effluent's finer suspended particles will be carried further downstream before being deposited (Vlassopoulos 2010).

Mercury contamination of the reservoir via Teck effluent and regional atmospheric deposition is difficult to control because of methylation cycles that are dependent on local conditions, and bioaccumulation of the metal can result in fish consumption advisories (EPA, 2009). Emerging contaminants such as pharmaceuticals from wastewater or polybrominated flame retardants have been found to be present elsewhere in the Columbia River System (Morace, 2012), but have not yet been documented in Lake Roosevelt.

The scope of this report is the water quality characteristics and concerns in Lake Roosevelt, and how Grand Coulee Dam management can impact any documented water quality concerns. This report is not developing new information, but summarizing the studies that have already been conducted on the waterbody. Some of the studies this report cites have more detailed data than can be covered here. Where applicable, trends have been discussed, and guidance to help a reader find the more detailed study have been provided. While this document does examine the sediments of Grand Coulee, a report located in a separate subsection takes a closer look at the characteristics of the sediment and geology of the reservoir.

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ACRONYMS

Acronym	Description
% w/w	Percent Weight by Weight
µg	Micrograms
µS/cm	Microsiemens Per Centimeter
CaCO3	Calcium Carbonate
Colville Tribes	Confederated Tribes of The Colville Indian Reservation
CV	Coefficient of Variation
DDT	Dichlorodiphenyltrichloroethane
DIN:DIP	Dissolved Inorganic Nitrogen to Dissolved Inorganic Phosphorus
DO	Dissolved Oxygen
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
FNU	Formazin Turbidity Unit
FRM	Flood Risk Management
kg	Kilogram
L	Liter
LRFEP	Lake Roosevelt Fisheries Evaluation Program
m2	Milligrams per Square Meter
m3	Milligrams per Cubic Meter
mg	Milligrams
mL	Millileter
mm	Millimeter
ng	Nanograms
NTU	Nephelometric Turbidity Unit
Ortho-P	Orthophosphorus
Reclamation	Bureau of Reclamation
RM	River Mile
SC	Specific Conductivity
SD	Standard Deviation
Spokane Tribe	Spokane Tribe of Indians
TDG	Total Dissolved Gas
TDS	Total Dissolved Solids
Teck	Teck Resources Limited
TN:TP	Total Nitrogen to Total Phosphorus
TSS	Total Suspended Solids
USGS	U.S. Geological Survey
WAC	Washington Administrative Code

SECTION 1 - INTRODUCTION

1.1 STUDY AREA

Grand Coulee Dam was completed in 1942, and construction of the dam resulted in the creation of a reservoir which is now called Lake Roosevelt. The reservoir has a total storage capacity of 9.4 Maf and active (useable) capacity of 5.2 Maf, covers an area of over 150 square miles, and has a shoreline of over 600 linear miles. It is the largest reservoir in terms of power generating capacity on the Columbia River (Magirl et al. 2014). Lake Roosevelt functions as a sediment sink for the majority of the incoming sediment load due to the slack water environment created by Grand Coulee Dam.

The reservoir provides multiple benefits to the communities within the Columbia River Basin. Federally defined uses of the dam and reservoir include: hydroelectric power generation, flood control, and irrigation. A map of Lake Roosevelt, the lands surrounding the reservoir, and other locations of interest mentioned in this report are displayed in Figure 1-1. Dam locations along waterways that feed into Lake Roosevelt, as well as dams immediately below Grand Coulee Dam, are displayed in Figure 1-2.

Figure 1-1. Map of Lake Roosevelt, Surrounding Lands, and Locations

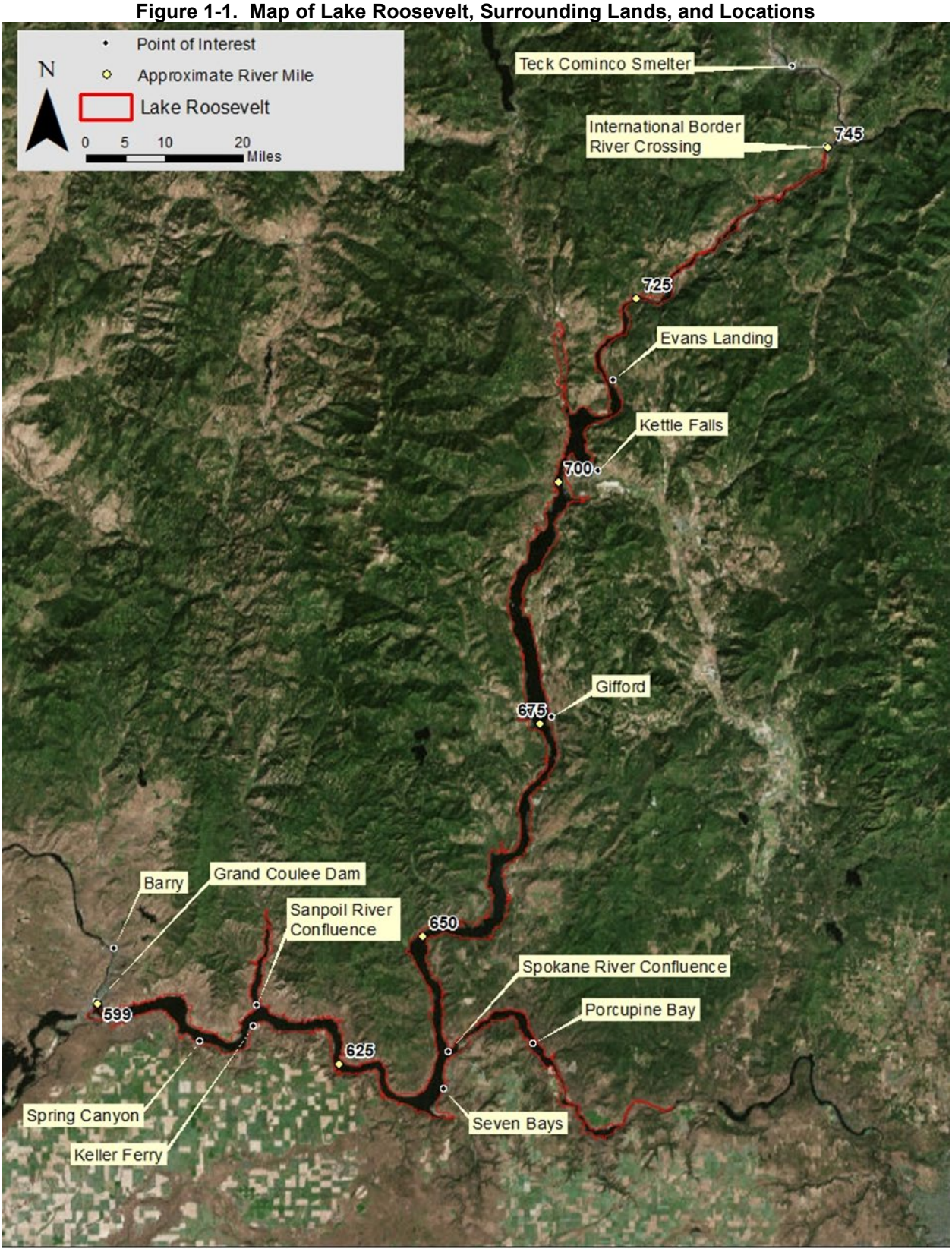
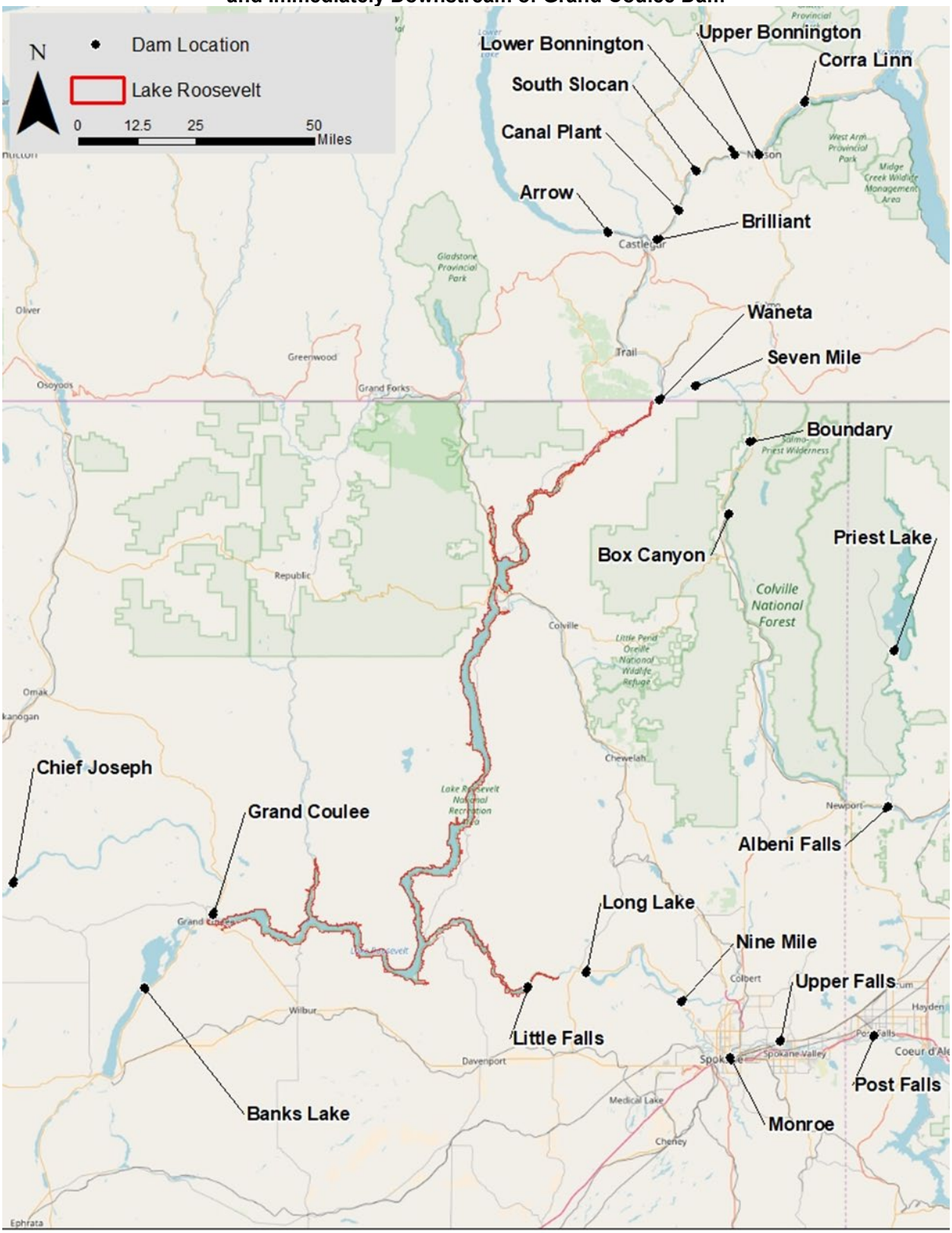


Figure 1-2. Location of Dams Along Waterways Feeding into Lake Roosevelt, and Immediately Downstream of Grand Coulee Dam



The lake and surrounding lands are managed through a cooperative effort of five agencies: the Bureau of Reclamation (Reclamation), the National Park Service, the Bureau of Indian Affairs, the Confederated Tribes of the Colville Indian Reservation (Colville Tribes), and the Spokane Tribe of Indians (Spokane Tribe). These five partners work closely with state and county agencies to meet fishery, wildlife, emergency response, and other needs.

Beginning in the late 1800's and continuing through the late 1900's, mining and smelting operations near the Columbia River upstream of Lake Roosevelt have had significant impacts on water quality in the watershed. Widespread mining activities throughout the basin (Figure 1) have all potentially contributed to the trace element contamination currently found in the reservoir, but the Trail Smelter, now owned by Teck, is reported as being the major contributor (Bortleson 2001). Today, this smelter is the only remaining operational smelter in the basin and is one of the world's largest lead-zinc smelting facilities (Barton 2000). These activities, occurring in both Canada and the United States, have historically discharged large volumes of trace metals into the Upper Columbia River in the form of fine-grained slag and liquid effluent. Primary metals of interest from these discharges are arsenic, cadmium, copper, lead, mercury, and zinc (Barton 2000).

Other industries have also been located along the Columbia River—each contributing its own form of pollution. Fertilizer plants have contributed phosphorous and nitrogen. Cedar pulp mills have contributed dioxin and furan. By the mid-twentieth century, many of the industrial discharges into the Columbia River and its tributaries had abated. Historically the reach of the Columbia River from the U.S.-Canada border to its confluence with the Snake River near Pasco, Washington, is considered impaired and multiple reaches, including Lake Roosevelt in 1998, have been specifically listed on Washington's Clean Water Act 303(d) impaired list due to total dissolved gas (TDG) in the lower reach of the reservoir, dissolved oxygen (DO) in the upper and lower reaches, mercury in the middle reach, and temperature in the upper and lower reaches. Sources of historical TDG impairment of the lake include dams on the Columbia, Kootenay, and Pend Oreille Rivers, both in the United States and Canada (Pickett, Rueda, and Herold 2004).

As a result of the numerous dams north of the U.S.-Canada border along the Columbia River and its tributaries, the TDG of water traveling across the border typically exceeds 100 percent for 5 to 6 months of the year (Pickett, Rueda, and Herold 2004). Another source of elevated TDG as a result of dam-generated turbulence in Lake Roosevelt is the Spokane River. Water exiting this tributary to the lake must pass six small dams before entering Lake Roosevelt. Both of these sources provide water with elevated TDG to the reservoir, and the TDG level is still elevated when the water is released from Lake Roosevelt at Grand Coulee dam.

TDG has been identified as a pollutant of concern in Lake Roosevelt and downstream of Grand Coulee Dam. Water routed through the dam follows one (or a combination) of three paths: (1) through turbines in the three powerplants that generate electricity at the dam, (2) the eleven spillway gates called drum gates on the top of the dam which are

only operational when the pool elevation is above 1266 feet, and (3) the 40 outlet works that allow spill through the dam. Outlet work discharges are an identified concern for elevated TDG, discharge through the outlet works plunge water into the river downstream of the dam. This results in supersaturated gases in the water that can have deleterious effects on fish, causing a disease known as gas bubble trauma. Based on the level of saturation and the length of exposure, this disease can be acute or chronic and may result in high mortality rates of fish in the system.

In addition, water temperature has been identified as a concern throughout the Columbia River Basin. As water slows behind the dam and its surface area increases (i.e., forms a lake), it is susceptible to additional solar insolation. Although the reservoir exhibits only a shallow and weak temperature stratification, surface water temperature increases as the water approaches the dam, particularly in late summer (Reclamation 2018). However, much of the water is taken at deep depths for power generation. This water is generally cooler than surface water at the dam.

Because of the difficulties of establishing environmental regulations across international borders, curtailing pollution into the river took over a decade. In 2004, Teck (current owners of Trail) agreed to comply with a 2003 U.S. Environmental Protection Agency (EPA) Unilateral Administrative Order under Superfund (Comprehensive Environmental Response, Compensation, and Liability Act) law (EPA 2011).

1.2 DATA USED FOR THIS ANALYSIS

The most recent sediment collection between Grand Coulee Dam and the US-Canada border (commonly known as the Upper Columbia River or UCR) were two studies completed by Teck and USGS to collect data regarding metal concentrations and whole sediment toxicity to benthic invertebrates. These studies built on the knowledge of over 30 years of study by the USEPA[1] and other agencies[2], and collected sediment from previously sampled areas in order to investigate dose-response relationships of sediment contamination and toxicity.

Data collected as part of the Lake Roosevelt Fisheries Evaluation Program (LRFEP) in 2004, 2014, 2015, and 2016 are utilized extensively in this chapter (Lee 2006) (Kain 2015) (Kain 2017) (Kain 2018). These data assist in defining the overall water quality of the reservoir and allow for some estimation of trends in the parameters addressed. When LRFEP sampled data throughout the reservoir normally sampling was at thalwag profiles, surface to bottom from near Grand Coulee Dam to areas north of Kettle Falls (Figure 3). Sample sites were selected based on stratified random design by dividing the river into 5 reaches, and randomly selecting river miles within each reach, and were

[1] https://www.epa.gov/columbiariver/upper-columbia-river-remedial-investigation-feasibility-study
[2] Washington State Department of Ecology: https://fortress.wa.gov/ecy/gsp/Sitepage.aspx?csid=12125; USGS does not maintain a single project site, but many relevant reports can be found here: https://www.usgs.gov/centers/wa-water/science/lake-roosevelt-upper-columbia-river and here: https://www.usgs.gov/science-explorer-results?es=lake+roosevelt+upper+columbia+river&classification=pub https://www.usbr.gov/pn/hydromet/gcl-profiles/index.html

normally collected at a selection of about 15 sites each year from May to October. From these reports we present the averages to explain the general limnological conditions within the lake, and when important highlight specific reaches. However, spatial variation of findings throughout the lake are large, and if investigating the detailed limnological conditions of a specific reach is desired the original reports should be referenced. These reports may be accessed by contacting the Spokane Tribal Fisheries manager at fisheriesdata@spokanetribe.com.

SECTION 2 - WATER QUALITY

2.1 GENERAL DESCRIPTION

The EPA, Washington Department of Ecology (Ecology), the Spokane Tribe, and the Confederated Tribes of the Colville Reservation (Colville Tribe) all have water quality criteria for various parameters within, above, and below Lake Roosevelt. For the purposes of this analysis EPA standards are presented in Table 2-1, but more restrictive standards may apply to specific areas of the waterbody. In general, when two water quality standards apply to the same area the most restrictive standard applies. These localized exceptions are discussed in the report and should be considered in future alternative analysis discussions depending on resolution of water quality model output data.

The Ecology and EPA water quality standard criteria for Total Dissolved Gas (TDG) states that on average 110% saturation must not be exceeded at any point sampled unless special exception applies (Pickett et al., 2004). The TDG criterion uses a rolling average of the highest 12 consecutive hourly readings in any one day, relative to atmospheric pressure. Physical water quality parameters that apply to Lake Roosevelt are listed in Table 2-1.

Table 2-1. EPA Water Quality Standards for the Upper Columbia Rive from the U.S.-Canada Border to a Few Miles Below Grand Coulee Dam

Parameter	Location (above or below FDR Lake)	Most Restrictive Washington State Use Designation(s)	Applicable Water Quality Standard(s)
DO	Below FDR Lake	Salmonid Spawning/Rearing	8.0 mg/L and >90% saturation
DO	FDR Lake to U.S.-Canada border	Core Summer Salmonid Habitat	9.5 mg/L or natural condition with human actions not decreasing DO more than 0.2 mg/L
Fecal Coliform	Below FDR Lake	Primary Contact Recreation (PCR)	100 colonies/100 mL (geometric mean) with no more than 10% of samples with greater than 200 colonies/100 mL (geometric mean)
Fecal Coliform	FDR Lake to U.S.-Canada border	Extraordinary PCR	50 colonies/100 mL (geometric mean) with no more than 10% of samples with greater than 100 colonies/100 mL (geometric mean)
pH	Below FDR Lake	Salmonid Spawning/Rearing	6.5–8.5, with human-caused variation less than 0.5 units
pH	FDR Lake to U.S.-Canada border	Core Summer Salmonid Habitat	6.5–8.5, with human-caused variation less than 0.2 units
TDG	Below FDR Lake	Salmonid Spawning/Rearing	Most restrictive is 110% at any point sampled or 120% (7-day average) where applicable; exemption during periods when river flows are above the seven-day, ten year frequency flow (7Q10) flood.
TDG	FDR Lake to U.S.-Canada border	Core Summer Salmonid Habitat	110% at any point sampled; exempt during periods of 7Q10 high flow.
Temperature	Below FDR Lake	Spawning/Rearing	18°C (1-day maximum)
Temperature	FDR Lake to U.S.-Canada border	Core Summer Salmonid Habitat	16°C (7-day maximum average) or 0.3 degrees Celsius above incoming (natural) water temperature
Turbidity	Below FDR Lake	Spawning/Rearing	5 NTU over background when background is less than 5 NTU or 10% increase when more than 50 NTU
Turbidity	FDR Lake to U.S.-Canada border	Core Summer Salmonid Habitat	5 NTU over background when background is less than 5 NTU or 10% increase when more than 50 NTU

Note: More restrictive standards may apply in the waterbody. FDR Lake = Franklin D. Roosevelt Lake, which terminates at Grand Coulee Dam. Extraordinary PCR = primary contact recreation areas which are anticipated to have heavy use by humans, or areas where humans are anticipated to come in direct contact with the environment for long periods of time. mg/L = milligrams per liter; NTU = Nephelometric Turbidity Units, 7Q10 = 7-day average flow that exceeds the 10-year reoccurrence interval.
Source: EPA (2016)

Teck has conducted surface water, sediment, fish tissue, and upland studies with EPA oversight as part of the Upper Columbia River Remedial Investigation and Feasibility Study (UCR RI/FS)[3]. The surface water sampling was conducted across several transects and depths, at three times of year, and analyzed samples for dioxins/furans, PCBs, PBDEs, organochlorine pesticides, PAHs, SVOCs, nutrients, and radionuclides in both filtered and unfiltered samples. The UCR RI/FS is ongoing at the time this report is being prepared, and future studies will likely refine the understanding of the impacts of smelting-related discharges on Lake Roosevelt and the Columbia River Basin.

Sediment and porewater samples were collected from the international border to Grand Coulee Dam between September 5 and October 25, 2013. The samples were analyzed for a variety of analytes, results are displayed in the Teck report as a set of approximately 250 graphs. Each graph displays the concentration of a given analyte organized by river mile (Teck Inc. 2017). In general, the studies both found that the concentration of toxic metals within the sediments and pore water adjacent to Lake Roosevelt were unnaturally high, and toxicity was observed (Besser et al. 2018). Studies to evaluate the nature and extent of contamination, as well as human health and ecological risk assessments, are ongoing.

2.2 PHYSICAL CHARACTERISTICS

2.2.1 Hydrologic

The average annual inflow to Lake Roosevelt is about 78 Maf (Reclamation 2017). Figure 2-1 displays the average discharge at Grand Coulee Dam from 1929 to 2016, which is lowest in the early fall with flows around 5 Maf per month, and highest in the early spring with flows around 13 Maf per month. Figure 2-1 also displays average inflow at the U.S.-Canada border from 1939 to 2016 to closely mirror the discharge curve at Grand Coulee Dam.

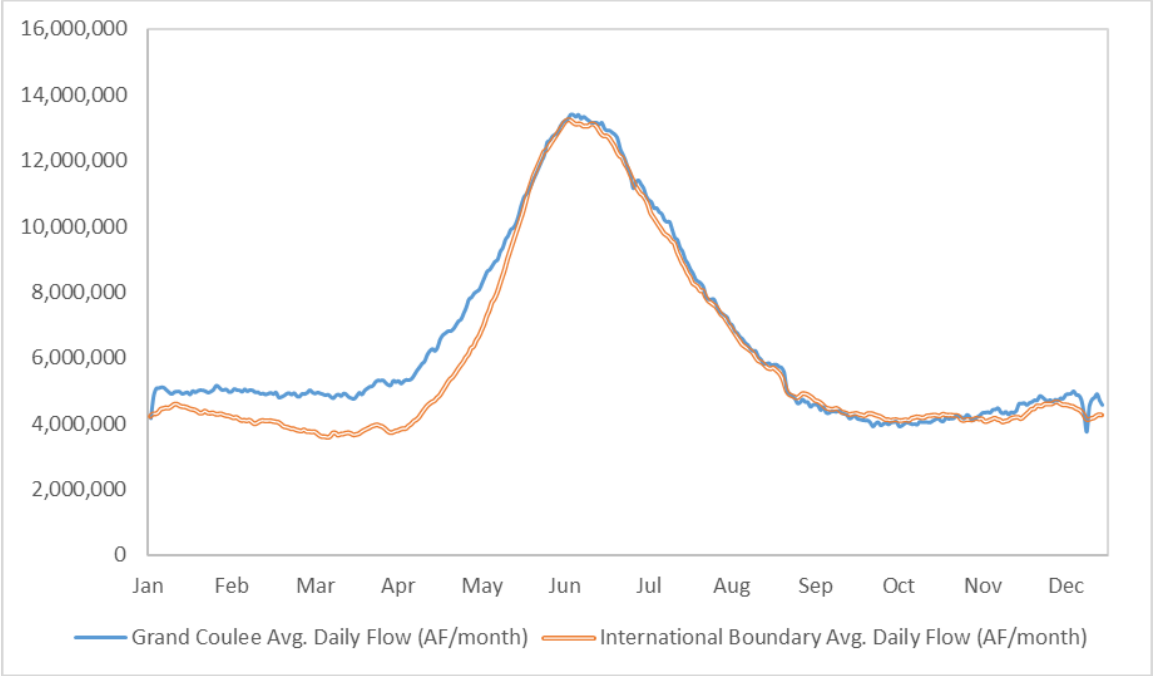
Figure 2-2 depicts the average monthly discharge each year at Grand Coulee Dam (1929 to 2016) and at upper Lake Roosevelt at the U.S.-Canada border (1939 to 2016). As anticipated, annual discharges at Grand Coulee Dam and the U.S.-Canada border are similar; this figure also shows the variation of flow volume can exceed several Maf from one year to the next, with an average flow volume of around 6 Maf from 1929 to 2016 (U.S. Geological Survey [USGS] 2017a).

The average monthly residence time for water in the reservoir, and the average monthly water surface elevation at Grand Coulee Dam are displayed in Figure 2-3 and Figure 2-4 respectively. Water retention within the nearly 150-mile-long reservoir is relatively short, averaging 36 days in June to 76 days in September with the largest variation of water retention in late winter though early spring. The water surface elevation varies from a maximum of about 1,285 feet above mean sea level to a minimum a little below 1,240 feet above mean sea level, the water surface elevation is relatively consistent in

[3] Teck study documents are available here: http://www.ucr-rifs.com/home/documents-plans

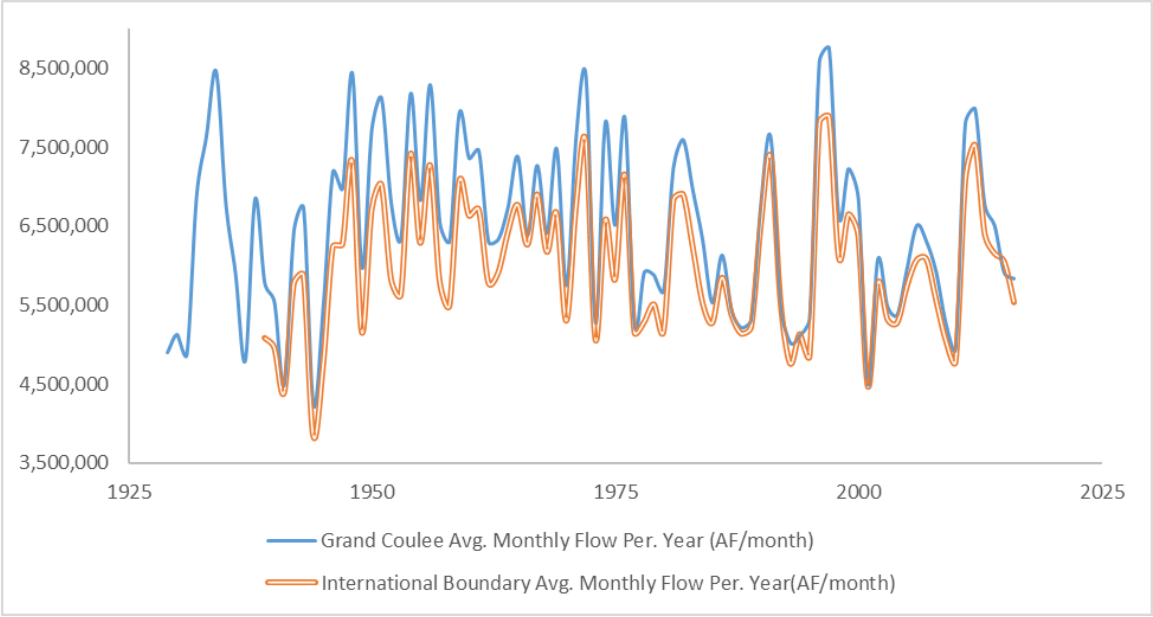
the summer through late winter and shows variation of about 50 feet throughout the spring (Reclamation 2018).

Figure 2-1. Average Daily Water Discharge (acre-feet per month) through Grand Coulee Dam and the U.S.-Canada Border



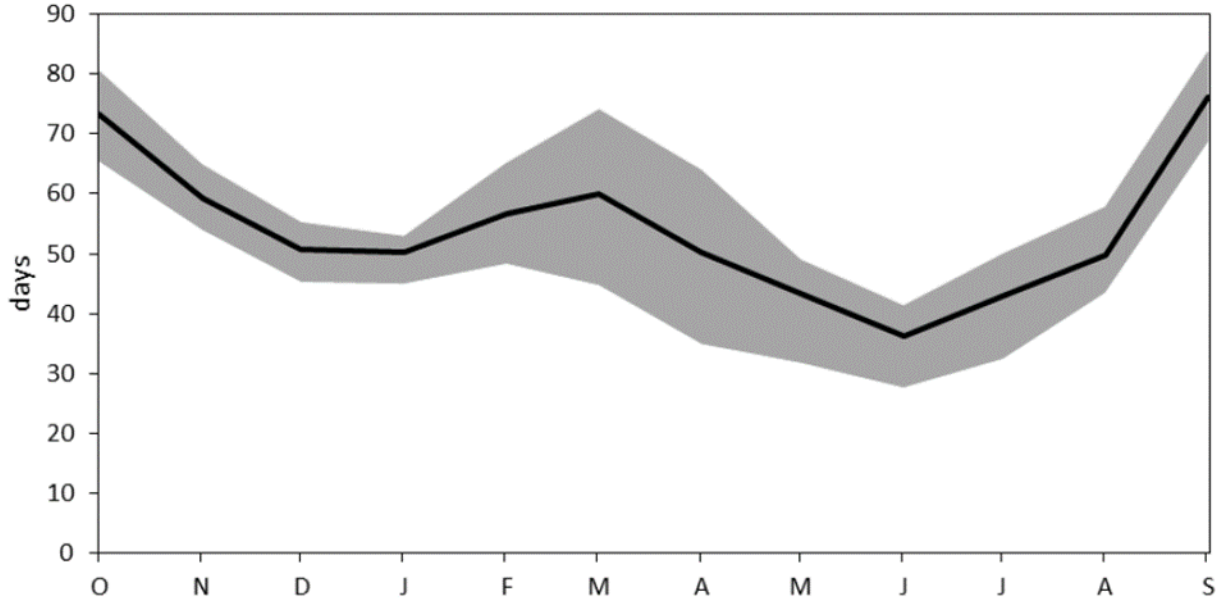
Note: From USGS Gage 12436500 (Grand Coulee Dam) and USGS Gage 12399500 (U.S.-Canada border).
Source: USGS (2017a)

Figure 2-2. Average Monthly Water Flow Each Year (acre-feet) at Grand Coulee Dam and the U.S.-Canada Border



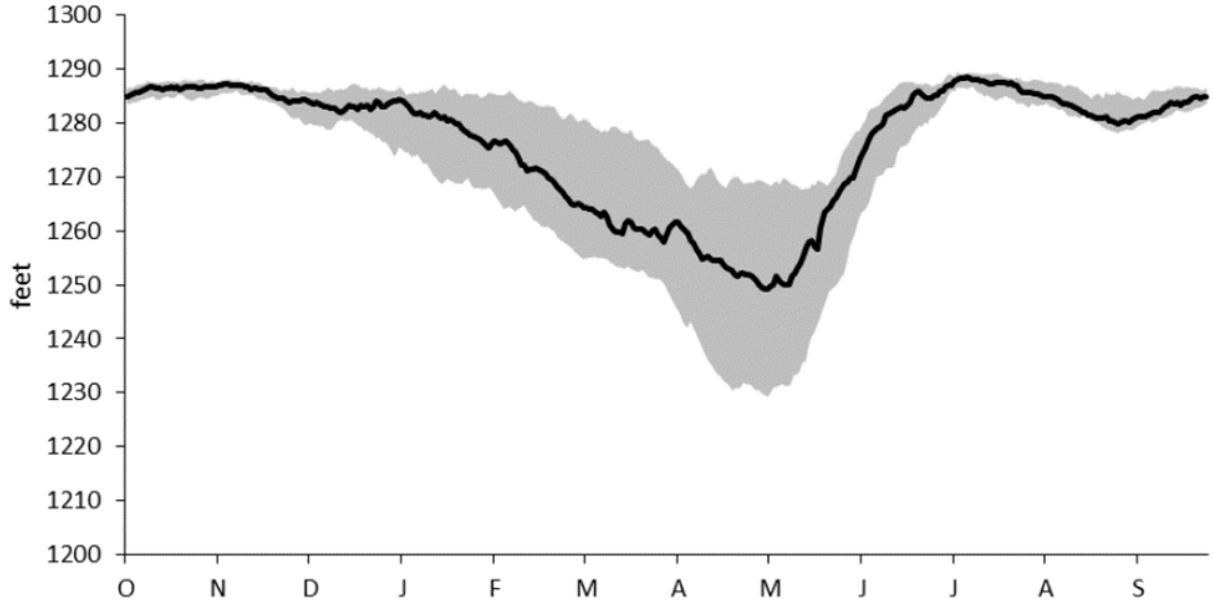
Note: From USGS Gage 12436500 (Grand Coulee Dam) and USGS Gage 12399500 (the U.S.-Canada border), from 1929 to 2016.
Source: USGS (2017a)

Figure 2-3. Average Monthly Residence Time and the 20th and 80th percentile of Water in Lake Roosevelt for the Water Years 2000 to 2015



Note: Determined by the ratio of storage volume and flow rate. Displayed by month, October to September.
Source: Reclamation (2018)

Figure 2-4. Water Surface Elevation Median, 20 Percent Exceedance, and 80 Percent Exceedance in Lake Roosevelt at Grand Coulee Dam for Water Years 1996 to 2016



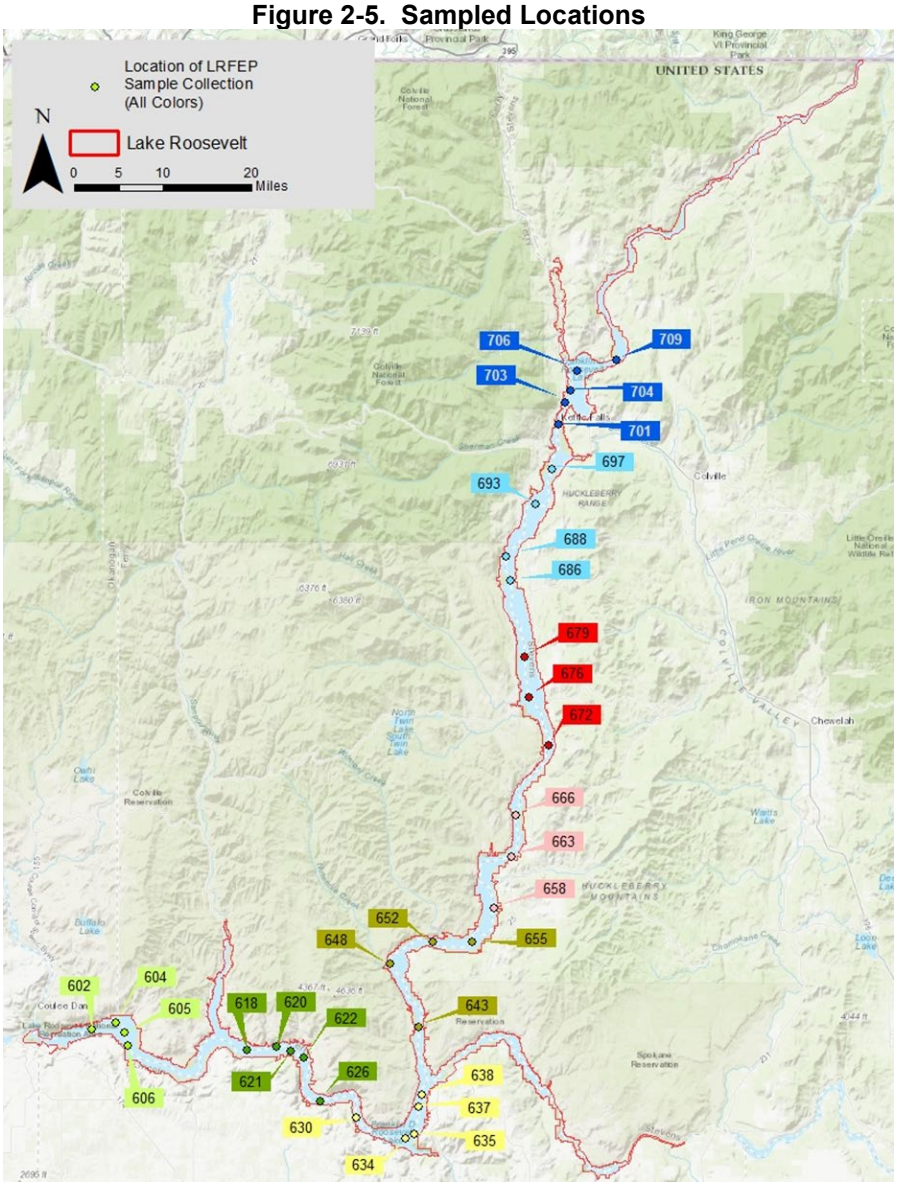
Note: Displayed by month, October to September.
Source: Reclamation (2018)

2.2.2 Temperature

Ecology, the Spokane Tribe, and Colville Tribes have set temperature criteria both above and below Grand Coulee Dam. Below the dam, Ecology set a standard of 17.5°C

which should not be exceeded for the 7-day average of the daily maximum, and the Colville Tribes water quality standard issued by the EPA is 18°C for the daily maximum. Above the dam to the U.S.-Canada border, Ecology water criteria state that temperature must stay below 16°C for the 7-day average of the daily maximum, or less than 0.3 degree Celsius above natural background temperature, and the Spokane Tribal Standard for River Mile (RM) 639 to 647 (near the Spokane arm, Figure 2-5 shows approximate location) is 16.5°C for the 7-day average of the daily maximum from June 1 to September 1. These standards are displayed in Table 2-1 (EPA 2018). In the summer these standards are often exceeded both upstream and downstream of the dam even though dam management is normally releasing the coldest water possible (Reclamation 2018).

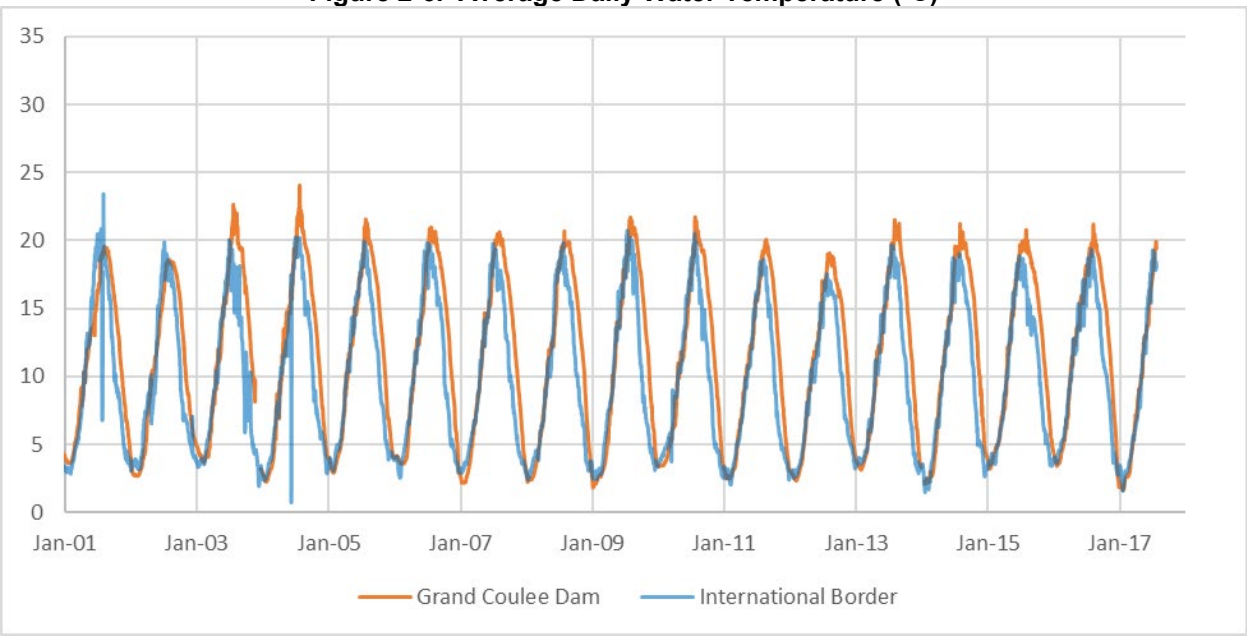
Figure 2-5. Sampled Locations



Note: Color groups correspond to the color of the associated figure headings of Figure 2-14 through Figure 2-21; numbers correspond to river miles.
Source: LRFEP (2018)

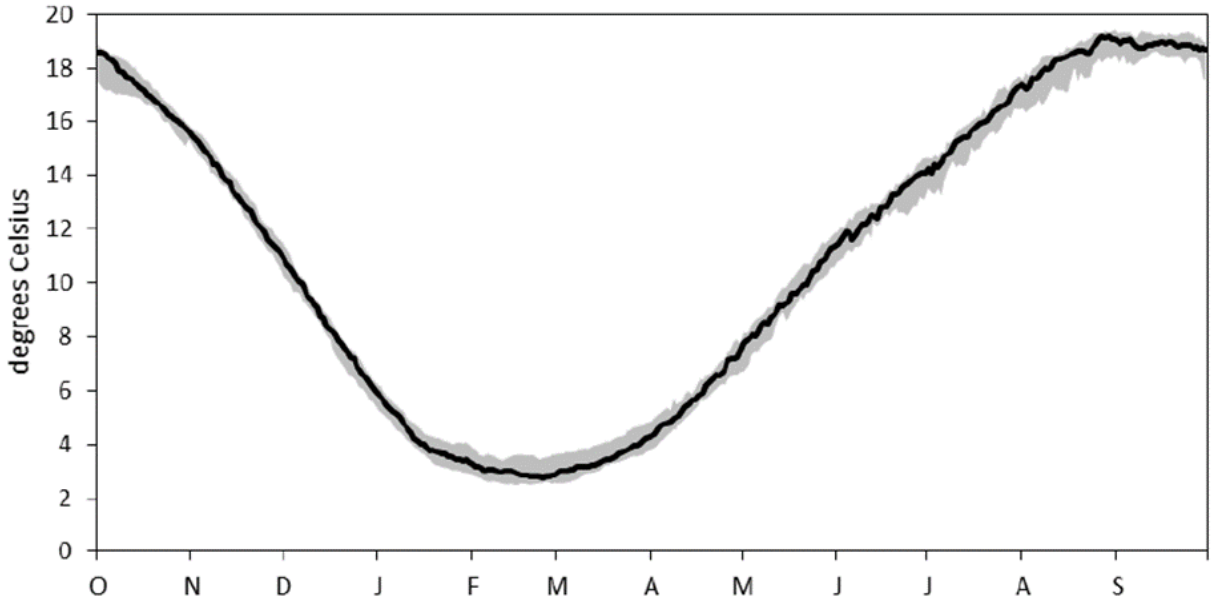
Reclamation has recorded water temperatures at automated gages below Grand Coulee Dam and at the U.S.-Canada border since 1995 and this data is displayed in Figure 2-6 and Figure 2-7. These figures display the daily average temperature at Grand Coulee Dam and at the U.S.-Canada border, as well as the average monthly temperature below Grand Coulee Dam. Water Temperatures in late June through mid-August the water temperature at the dam is generally lower than at the U.S.-Canada border, and this trend reverses in late August to September when the water released from the dam tends to be warmer. In early September, the temperatures in Lake Roosevelt are at their annual peak; however, cooler air temperatures during this time of year cause surface water temperatures start to cool. Median daily water temperature discharge from Grand Coulee Dam in October is approximately 17°C whereas the inflowing temperatures at the U.S.-Canada border are approximately 12°C (Reclamation 2018). By October, the weak thermal stratification in the reservoir normally dissipates (Reclamation 2018). In January, the median water temperature at Grand Coulee Dam (4°C) is nearly identical to the temperature at the U.S.-Canada border (3.5°C). Upstream and downstream of Grand Coulee Dam, water temperatures remain relatively uniform other from this time through the end of June. The relation of water temperature between Grand Coulee Dam and the U.S.-Canada border is displayed in Figure 2-8 (Reclamation 2018). Lee et al. (2006) report similar numbers for reservoir wide mean temperature. However, Kain, Knudson, and Nichols (2015, 2017, 2018) report higher mean temperatures near the dam of 16.61°C, 16.53°C, and 16.30°C in 2014, 2015, and 2016 respectively.

Figure 2-6. Average Daily Water Temperature (˚C)



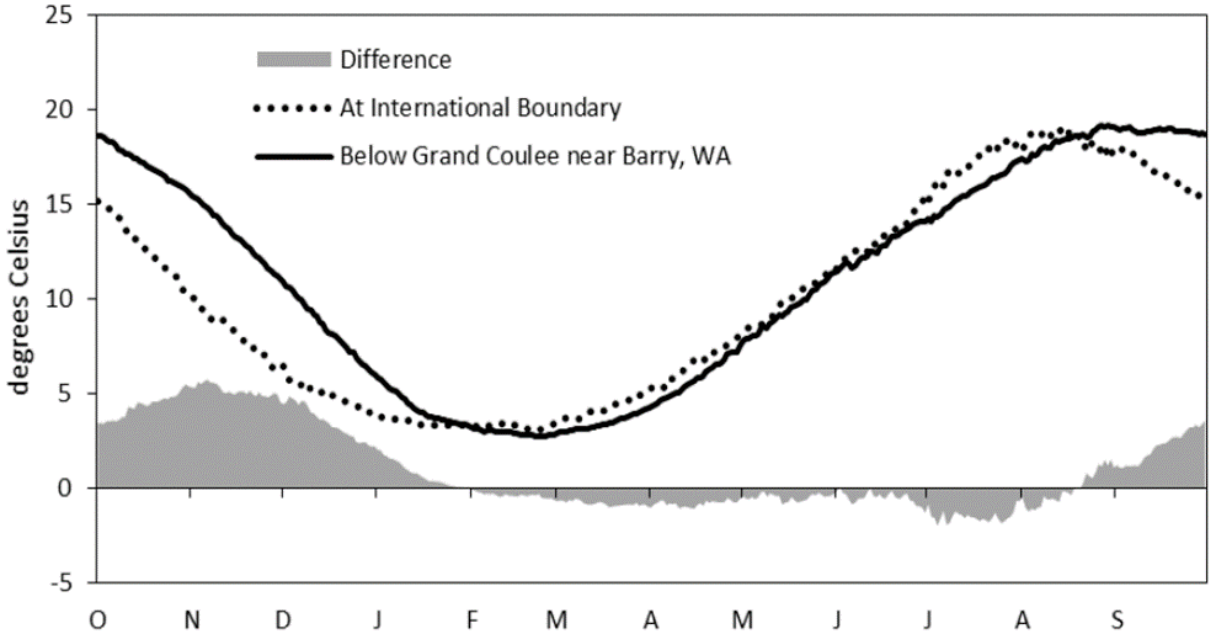
Note: Measured at the Reclamation Hydromet data collection station at the U.S.-Canada border and 0.5 mile downstream of Grand Coulee Dam. Some data gaps are present, and depth of water measurement is not specified, but the general location is listed as “surface.” The average water temperature over the entire sample time was 9.85°C.
Source: Reclamation (2017)

Figure 2-7. Mean, 20 Percent Exceedance, and 80 Percent Exceedance Water Temperatures for Water Years 2000 to 2015



Note: Measured at the Reclamation Hydromet station downstream of Grand Coulee Dam. Displayed by month, October to September.
Source: Reclamation (2018)

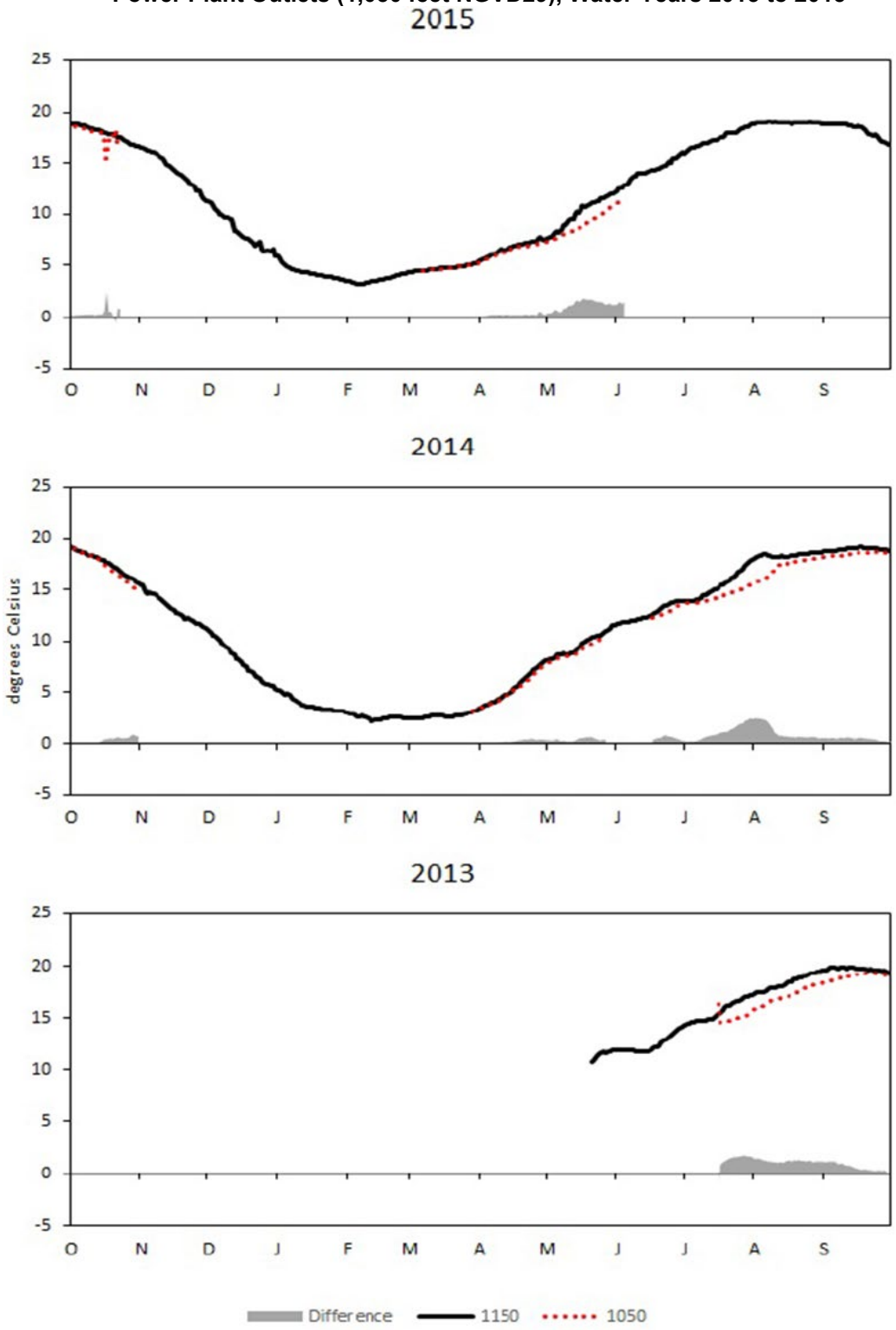
Figure 2-8. Water Temperatures Downstream of Grand Coulee Dam and at the U.S.-Canada border, Water Years 2000 to 2015



Note: The water temperature is generally warmer below the dam from late August through late January. Displayed by month, October to September.
Source: Reclamation (2018)

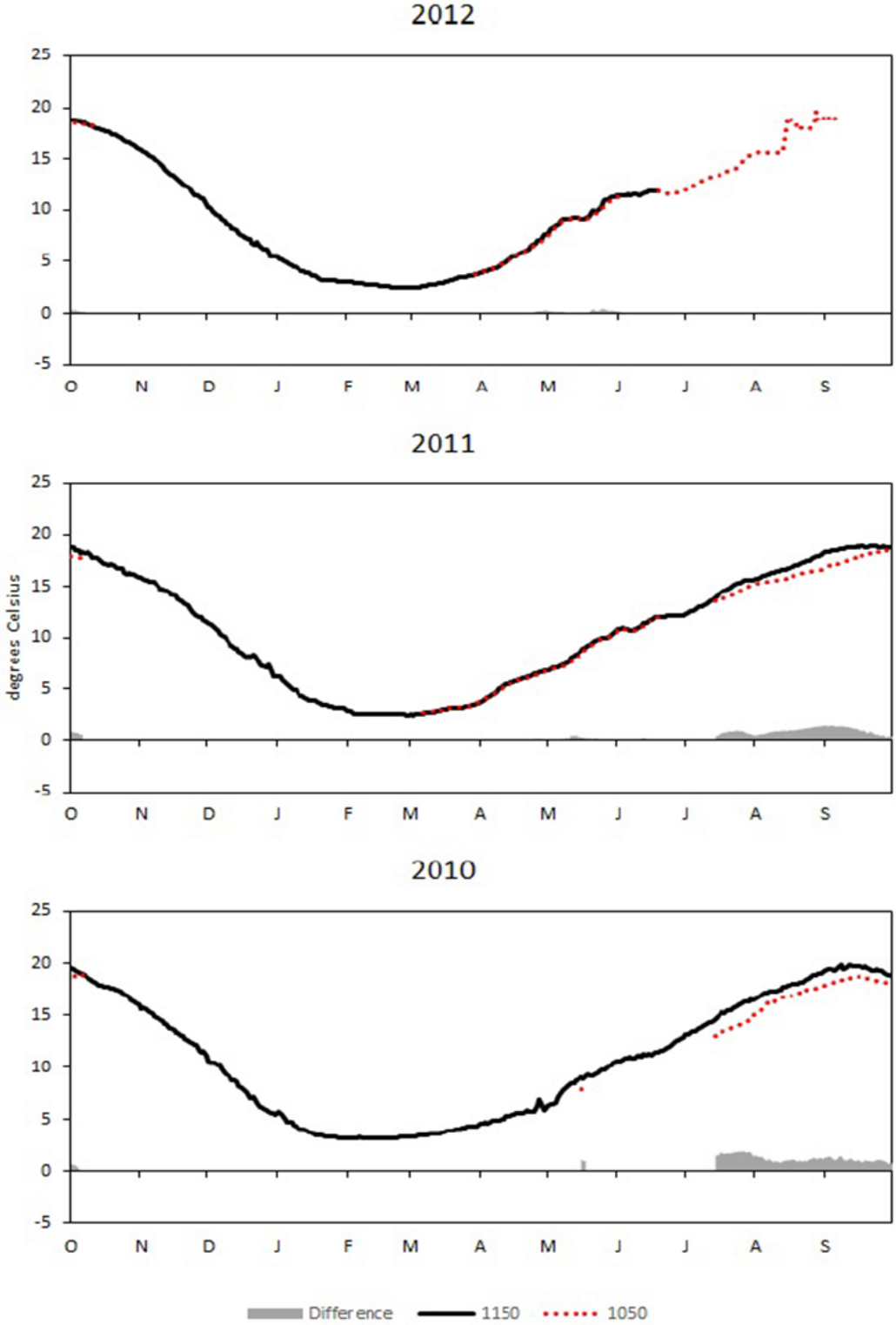
Reclamation has collected vertical temperature data at the dam forebay. Water column temperature data is collected from a string of temperature loggers attached to a log boom approximately 2,000 feet upstream of Grand Coulee Dam (Reclamation 2018). The water temperature at the dam's power plant outlets from 2001 to 2015 is displayed in Figure 2-9 through Figure 2-13. This data shows that water temperature at the outlets rarely goes above 20°C, and that the left and right power plant outlets are normally only a few degrees colder than the third power plant outlet at most (Reclamation 2018).

Figure 2-9. Water Temperature (°C) at Grand Coulee Dam at the Approximate Elevation of the Third Power Plant Intake (1,150 feet NGVD29) and the Left and Right Power Plant Outlets (1,050 feet NGVD29), Water Years 2013 to 2015



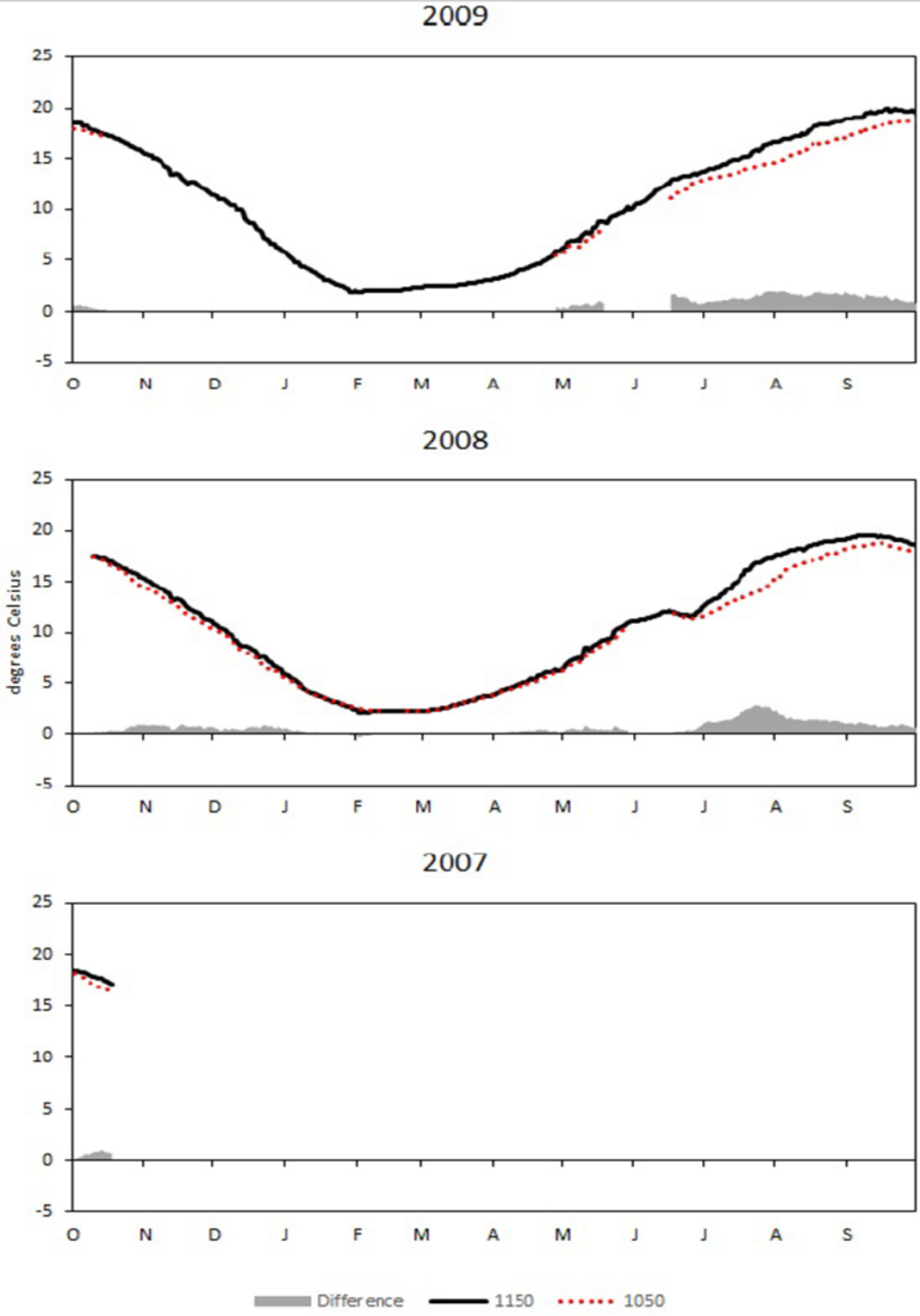
Note: Displayed by month, October to September.
Source: Reclamation (2018)

Figure 2-10. Water Temperature (°C) at Grand Coulee Dam at the Approximate Elevation of the Third Power Plant Intake (1,150 feet NGVD29) and the Left and Right Power Plant Outlets (1,050 feet NGVD29), Water Years 2010 to 2012



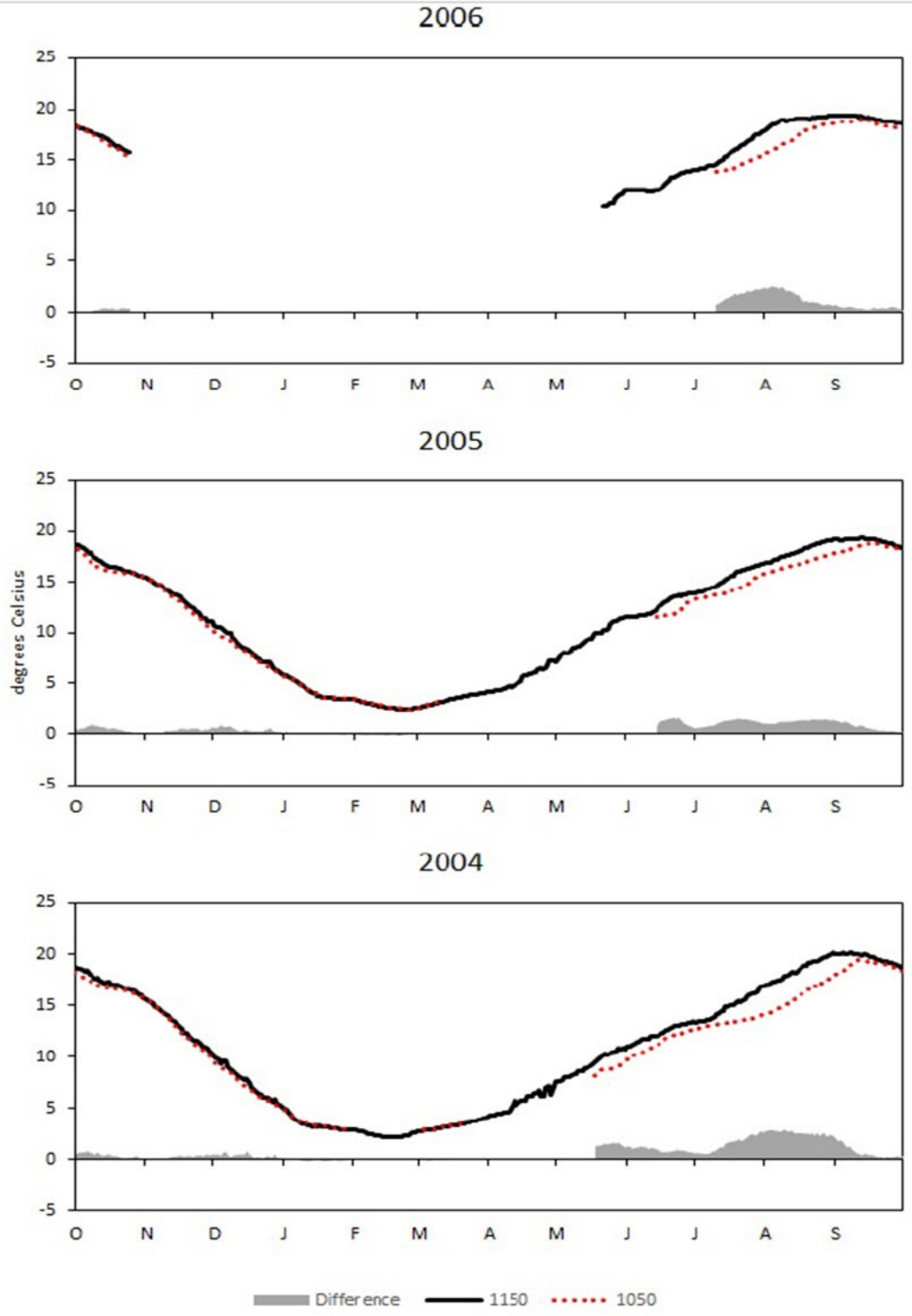
Note: Displayed by month, October to September.
Source: Reclamation (2018)

Figure 2-11. Water Temperature (°C) at Grand Coulee Dam at the Approximate Elevation of the Third Power Plant Intake (1,150 feet NGVD29) and the Left and Right Power Plant Outlets (1,050 feet NGVD29), Water Years 2007 to 2009



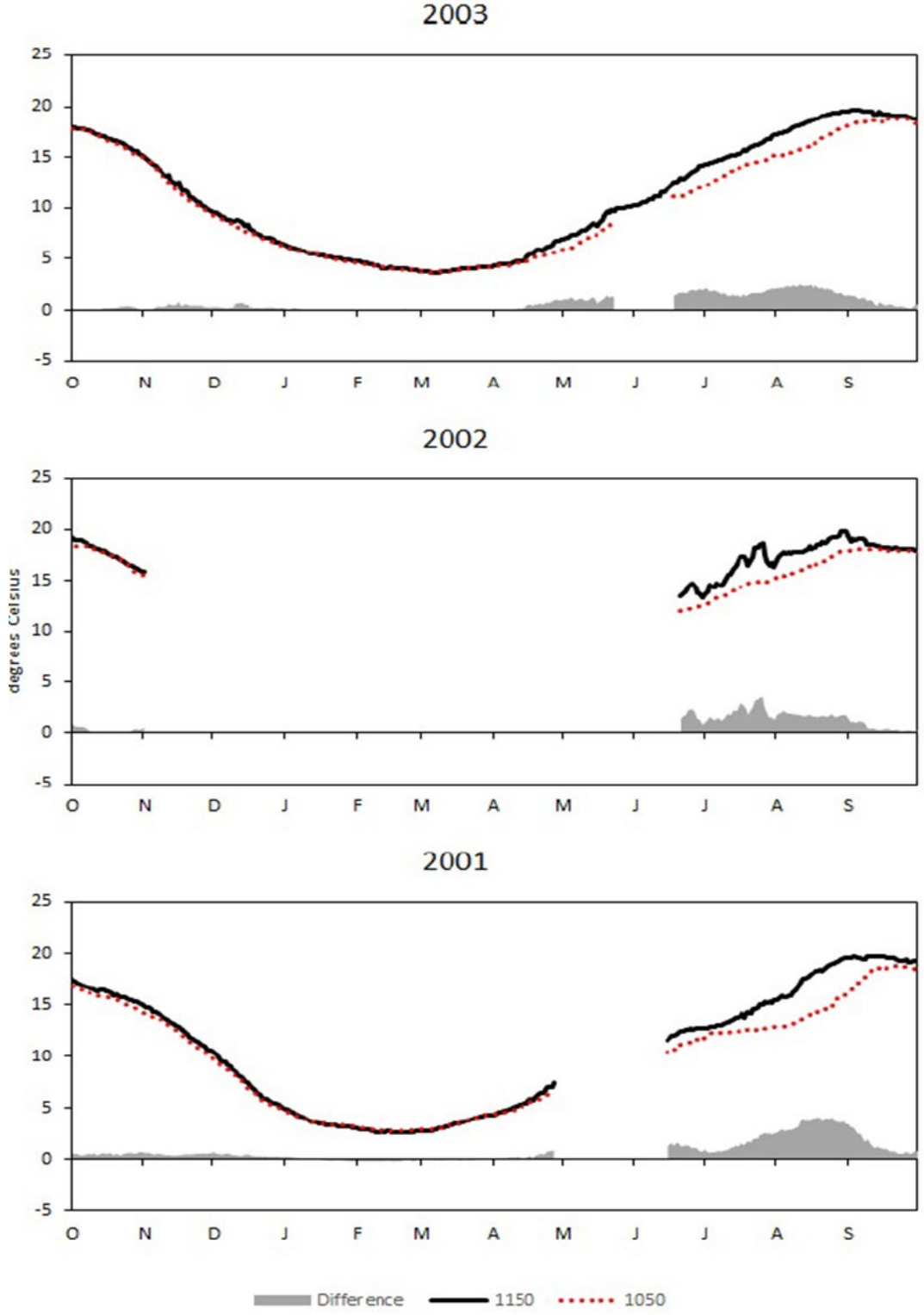
Note: Displayed by month, October to September.
Source: Reclamation (2018)

Figure 2-12. Water Temperature (°C) at Grand Coulee Dam at the Approximate Elevation of the Third Power Plant Intake (1,150 feet NGVD29) and the Left and Right Power Plant Outlets (1,050 feet NGVD29), Water Years 2004 to 2006



Note: Displayed by month, October to September.
Source: Reclamation (2018)

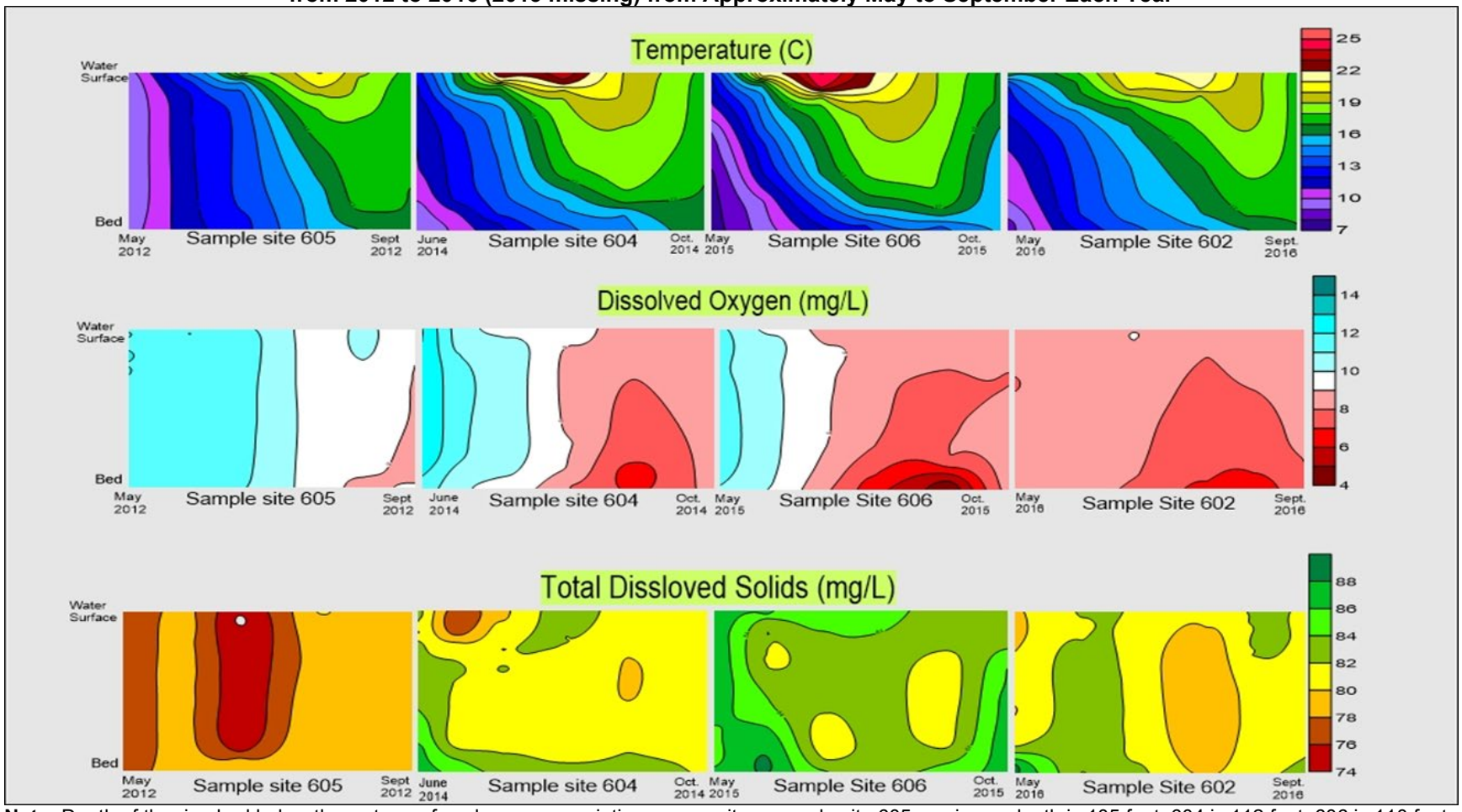
Figure 2-13. Water Temperature (°C) at Grand Coulee Dam at the Approximate Elevation of the Third Power Plant Intake (1,150 feet NGVD29) and the Left and Right Power Plant Outlets (1,050 feet NGVD29), Water Years 2001 to 2003



Note: Displayed by month, October to September.
Source: Reclamation (2018)

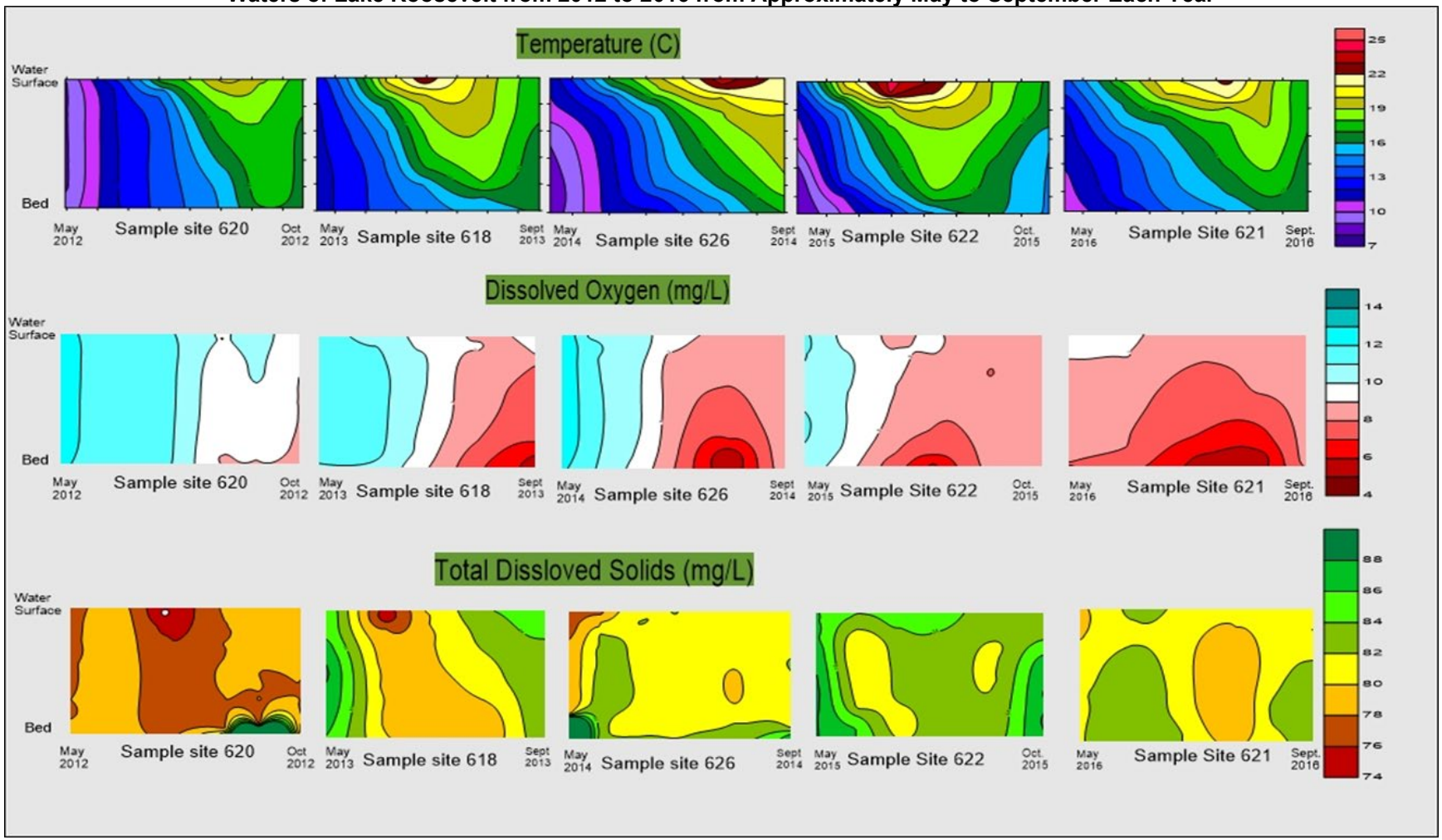
Additionally, the Spokane Tribe has collected vertical water temperature profiles at various locations throughout the reservoir as part of its Lake Roosevelt Fisheries Evaluation Program (LRFEP). The program found that mean annual temperature across all locations was reported as 14.1°C in 2016 (Kain, Knudson, and Nichols 2018). The data the Spokane Tribe collected from 2012 to 2016 is displayed in Figure 2-14 (closest to Grand Coulee Dam) through Figure 2-21 (closest to the U.S.-Canada border) (LRFEP 2018). Figure 2-5 displays the locations where these samples were collected. The data displayed in Figure 2-14 through Figure 2-21 clearly shows the shallow epilimnion that develops closer to the dam, and becomes less distinguishable north of where the Spokane River enters the reservoir (see Figure 2-17). In addition to weak stratification in the portion of the reservoir closer to the dam, a small temperature increase of a few degrees Celsius at all water depths is observed in July and early August, in relation to the upper portions of the reservoir (LRFEP 2018).

Figure 2-14. Temperature, Dissolved Oxygen, and Total Dissolved Solids in the Waters of Lake Roosevelt from 2012 to 2016 (2013 missing) from Approximately May to September Each Year



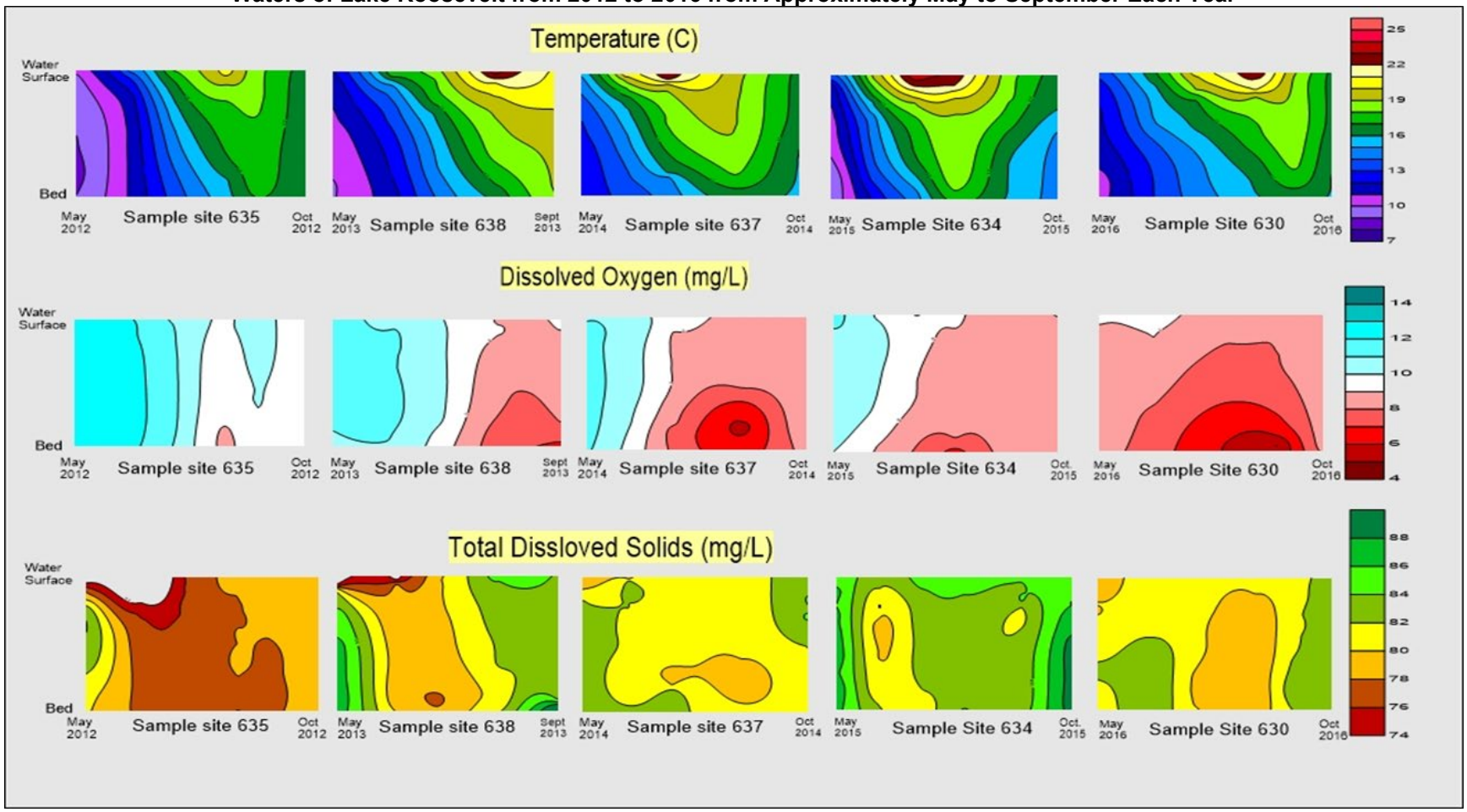
Note: Depth of the riverbed below the water surface has some variation among sites: sample site 605 maximum depth is 105 feet, 604 is 112 feet, 606 is 110 feet, and 602 is 99 feet.
Source: LRFEP (2018)

Figure 2-15. Temperature, Dissolved Oxygen, and Total Dissolved Solids in the Waters of Lake Roosevelt from 2012 to 2016 from Approximately May to September Each Year



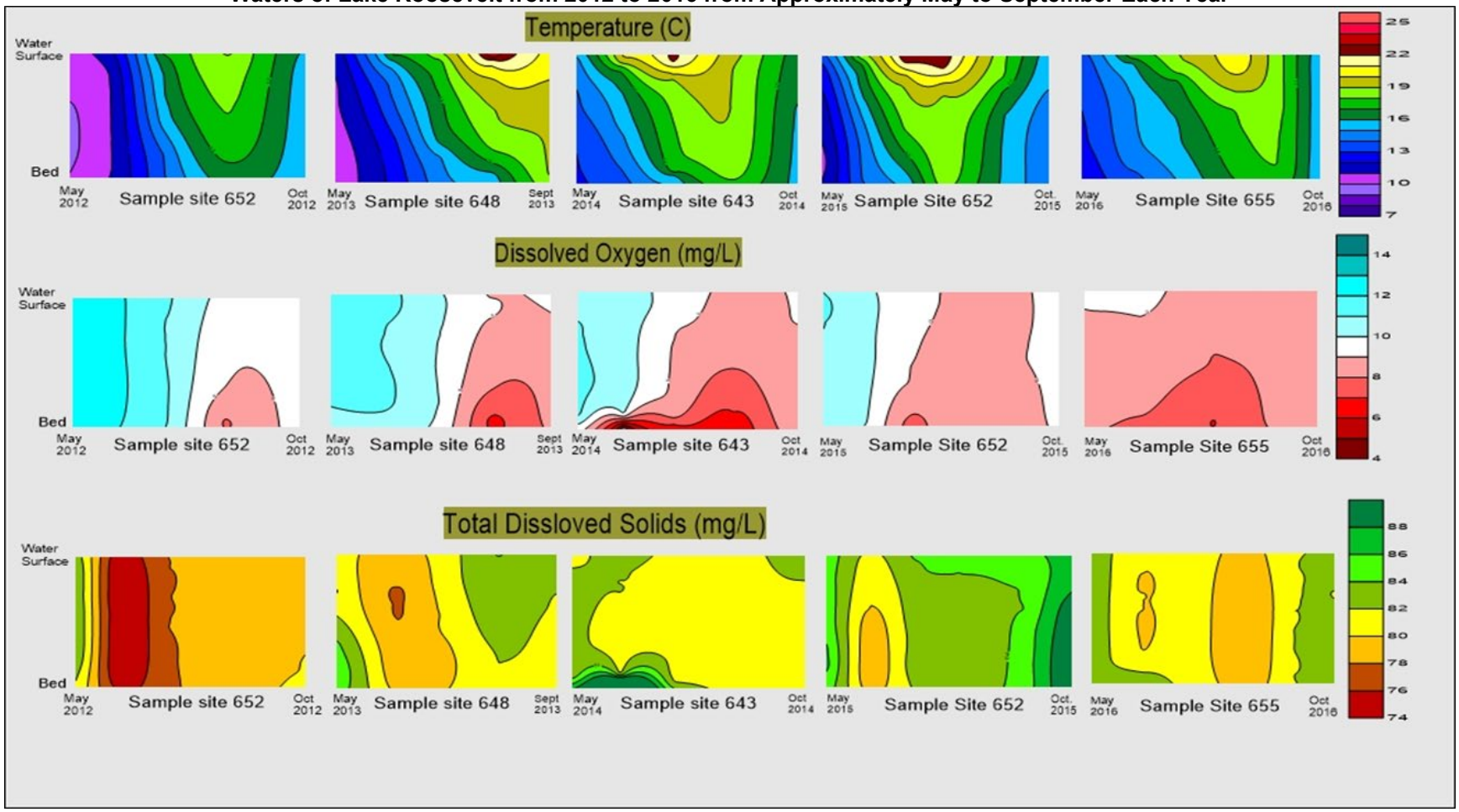
Note: Depth of the riverbed below the water surface has some variation among sites: sample site 620 maximum depth is 95 feet, 618 is 100 feet, 626 is 100 feet, 622 is 90 feet, and 621 is 95 feet.
Source: LRFEP (2018)

Figure 2-16. Temperature, Dissolved Oxygen, and Total Dissolved Solids in the Waters of Lake Roosevelt from 2012 to 2016 from Approximately May to September Each Year



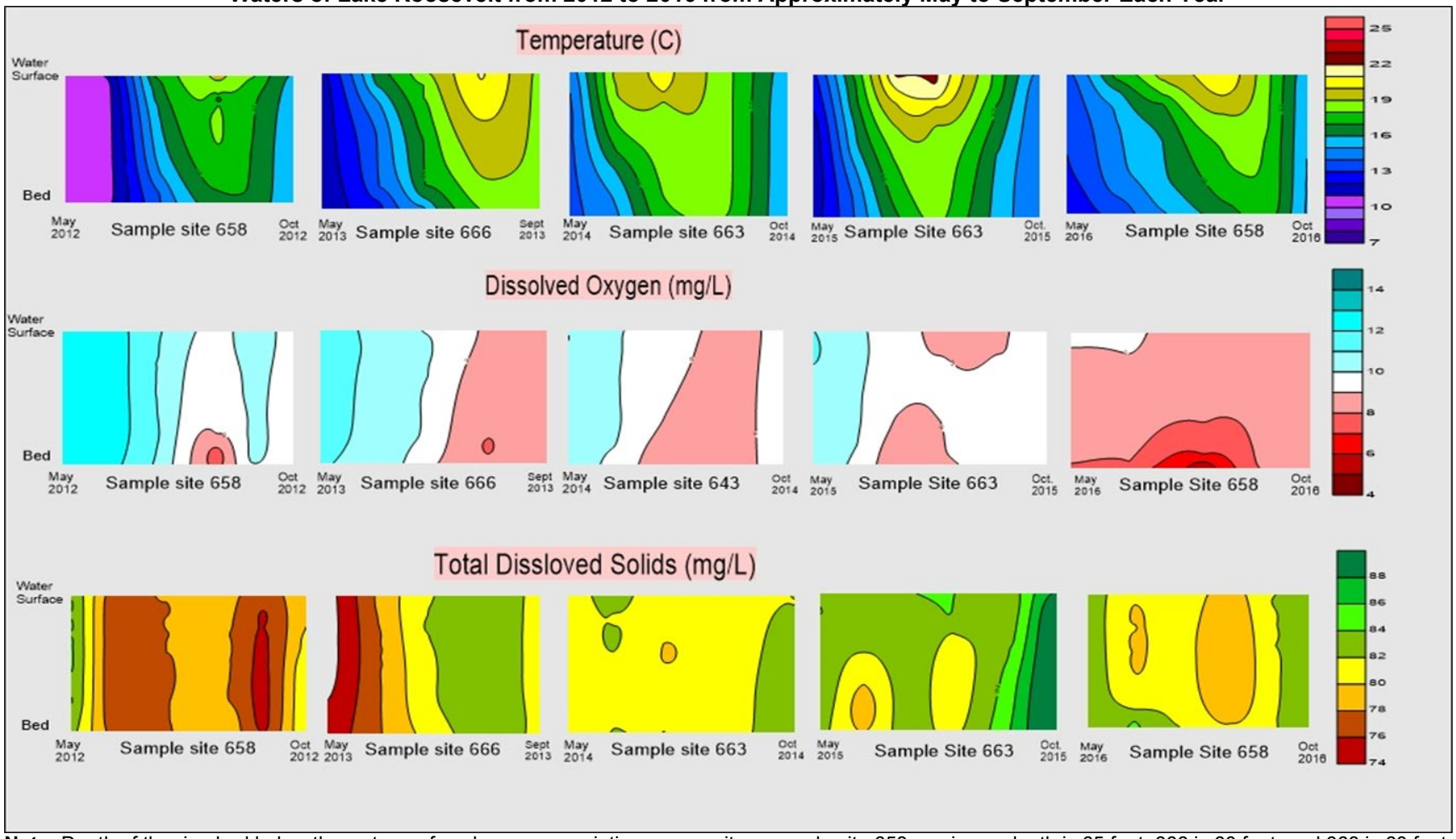
Note: Depth of the riverbed below the water surface has some variation among sites: sample site 635 maximum depth is 80 feet, 638 is 75 feet, 637 is 100 feet, 634 is 85 feet, and 630 is 95 feet.
Source: LRFEP (2018)

Figure 2-17. Temperature, Dissolved Oxygen, and Total Dissolved Solids in the Waters of Lake Roosevelt from 2012 to 2016 from Approximately May to September Each Year



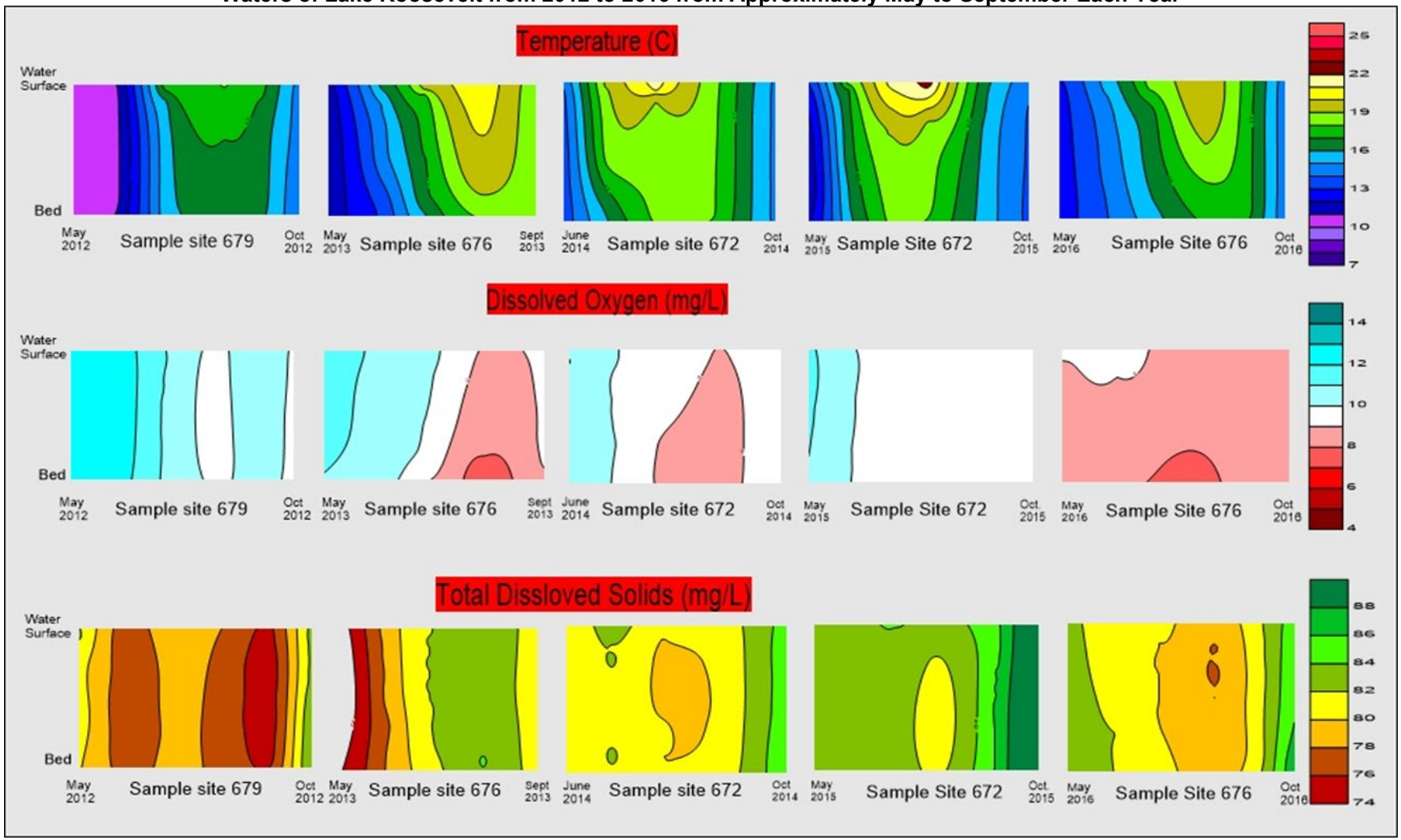
Note: Depth of the riverbed below the water surface has some variation among sites: sample site 652 maximum depth is 75 feet, 648 is 75 feet, 643 is 80 feet, and 655 is 70 feet.
Source: LRFEP (2018.

Figure 2-18. Temperature, Dissolved Oxygen, and Total Dissolved Solids in the Waters of Lake Roosevelt from 2012 to 2016 from Approximately May to September Each Year



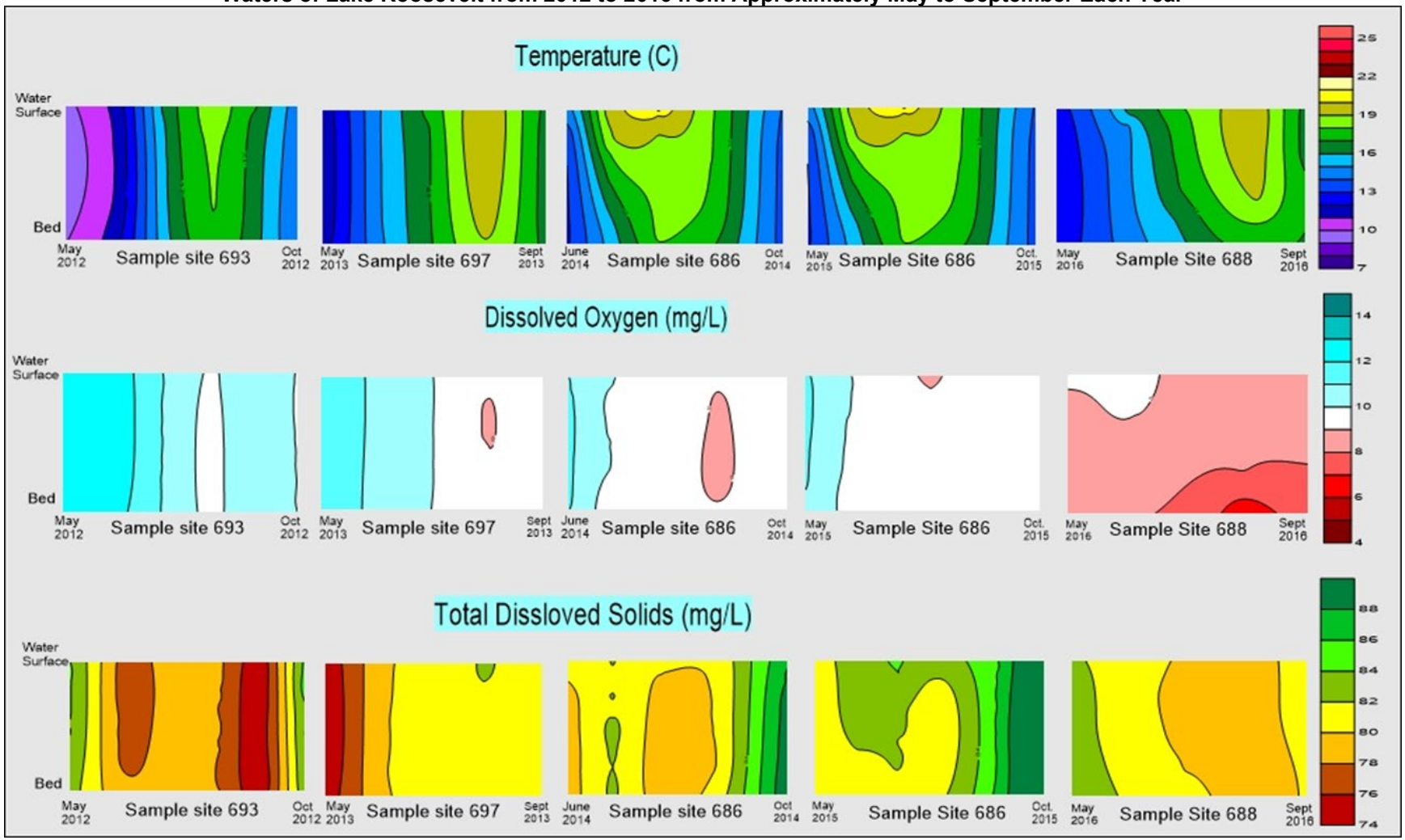
Note: Depth of the riverbed below the water surface has some variation among sites: sample site 658 maximum depth is 65 feet, 666 is 60 feet, and 663 is 60 feet.
Source: LRFEP (2018)

Figure 2-19. Temperature, Dissolved Oxygen, and Total Dissolved Solids in the Waters of Lake Roosevelt from 2012 to 2016 from Approximately May to September Each Year



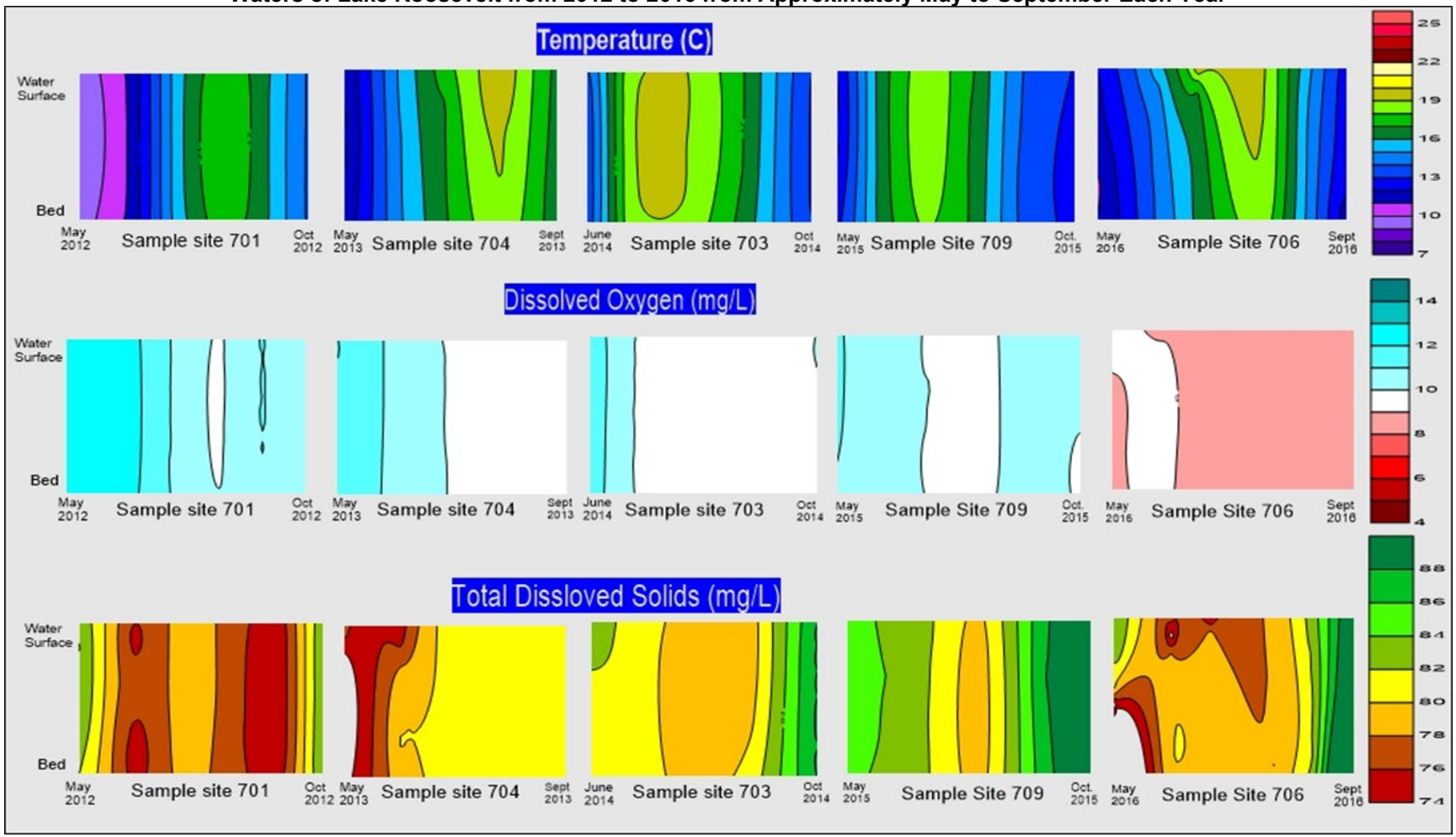
Note: Depth of the riverbed below the water surface has some variation among sites: sample site 679 maximum depth is 55 feet, 676 is 60 feel, and 672 is 55 feet.
Source: LRFEP (2018)

Figure 2-20. Temperature, Dissolved Oxygen, and Total Dissolved Solids in the Waters of Lake Roosevelt from 2012 to 2016 from Approximately May to September Each Year



Note: Depth of the riverbed below the water surface has some variation among sites: sample site 693 maximum depth is 45 feet, 697 is 40 feet, 686 is 55 feet, and 688 is 50 feet.
Source: LRFEP (2018)

Figure 2-21. Temperature, Dissolved Oxygen, and Total Dissolved Solids in the Waters of Lake Roosevelt from 2012 to 2016 from Approximately May to September Each Year



Note: Depth of the riverbed below the water surface has some variation among sites: sample site 693 maximum depth is 45 feet, 697 is 40 feet, 686 is 55 feet, and 688 is 50 feet.
Source: LRFEP (2018)

All the collected vertical temperature data indicates that Lake Roosevelt is properly classified as isothermal or a run-of-river reservoir, meaning that very little temperature stratification occurs in the waterbody. The short retention time described above and high spring flows limit thermal stratification, which results in the reservoir displaying only shallow and weak stratification during the summer (Reclamation 2018).

Often, during late spring and early summer, the reservoir warms near Grand Coulee Dam and weakly stratifies in the top 20 to 50 feet of the epilimnion. The main pathway for water passing the dam in this timeframe is through turbine penstocks. These penstocks are located well below the weakly stratified warmer surface of the epilimnion. In July and early August, water temperatures below Grand Coulee Dam are generally lower than inflowing temperatures: 15.5°C versus 17°C, respectively (Reclamation 2018).

Dam management has little ability to mitigate downstream temperatures due to a combination of higher summer reservoir temperatures, weak thermal stratification during summer, and operational constraints and because dam management already releases the coldest water possible from the reservoir during summer months without significant modification to the dam (Reclamation 2018).

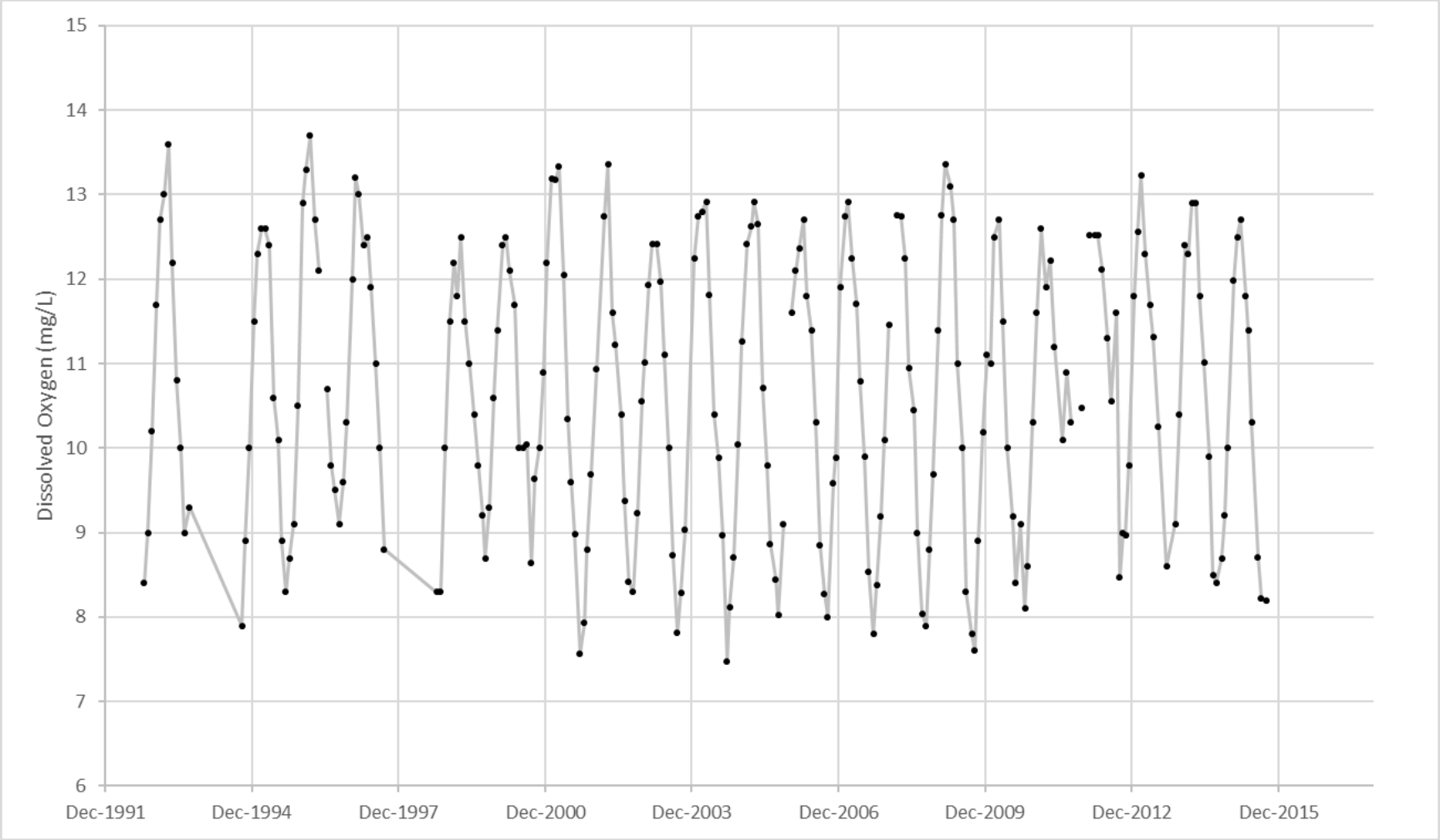
Reclamation has developed CE-QUAL-W2, a two-dimensional model, to assist in understanding existing and future dam operations and their impacts on downstream temperatures and TDG (http://www.ce.pdx.edu/w2/) (Reclamation 2018). This model was used to help determine that Grand Coulee Dam has little ability to pass cooler water downstream.

2.2.3 Dissolved Oxygen

DO is important for supporting biological life. Additionally, the amount of DO in a reservoir, or lack thereof, can influence mobilization of trace elements. Low DO levels that approach 0 mg/L often occur near the bottom of Lake Roosevelt towards Grand Coulee Dam and can affect the solubility of trace elements and other compounds. Figure 2-14 through Figure 2-21 display the DO in the reservoir at select locations from 2012 to 2016 during the summer months. These figures show that DO is decreasing from 2012 to 2016 and from the U.S.-Canada border to Grand Coulee Dam. When anoxic conditions exist, a pathway for elements and compounds otherwise trapped in sediment may develop and these compounds may enter the water column system. This potential pathway for leeching has not been studied in the reservoir enough to be able to confidently report the relation of leeching rates to DO values.

Ecology has set DO criteria at a minimum of 9.5 mg/L in Lake Roosevelt, and 8 mg/L downstream of Lake Roosevelt (see Table 2-1). Across the entire lake, mean monthly surface-level DO was highest in January (10.8 mg/L) and lowest in August (7.8 mg/L) (see Figure 2-22). DO was found to regularly be below the minimum criteria at some point in the summer, but anoxic conditions rarely occur in the Lake Roosevelt mainstream. However, water close to the reservoir bed near Grand Coulee Dam and the Spokane arm can experience anoxia in summer and early fall months (Figure 2-22) (Von Prause 2014).

Figure 2-22. Dissolved Oxygen (mg/L) Concentration Downstream from Grand Coulee Dam



Note: The dots indicate the time discrete samples were taken; lines only help to identify trends, and do not indicate continuous samples.
Source: Ecology (2017)

Lee et al. (2006) reports mean DO concentrations across all sampling locations throughout the reservoir to be 8.8 mg/L, with highest concentrations reported in January (10.8 mg/L), and lowest in August (7.8 mg/L). Additionally, DO concentration profiles were measured and reported by Lee et al. (2006) and found to average in the 5 mg/L range at depth in the Porcupine Bay, Keller Ferry, and Spring Canyon sites during the late summer and early fall months.

In 2014, mean annual DO concentrations in all reservoir reaches were above 9 mg/L, ranging widely between 0.91 and 13.07 mg/L (Kain, Knudson, and Nichols 2015). In 2015, DO concentrations measured in the reservoir ranged from 0 to 11.89 mg/L, with mean annual concentrations above 8 mg/L (Kain, Knudson, and Nichols 2017). Similar results were seen in 2016, with DO concentrations ranging from 0 to 9.42 mg/L, and annual mean DO above 8 mg/L (Kain, Knudson, and Nichols 2018). In all of these years, the Spokane arm suffered from low (less than 5 mg/L) DO concentrations during the summer and early fall months. Overall, using the data provided by the LRFEP, little change from the 2004 time period to more recent years is seen in DO levels.

2.2.4 Total Dissolved Gas

The TDG criterion is 110 percent within the reservoir and downstream of Grand Coulee Dam (see Table 2-1). The forebay standard is the average of the 12 highest consecutive hourly readings in one day. The 110 percent TDG standard applies when flows are below the seven-day, ten-year frequency flow (7Q10) (Pickett et al., 2004; EPA, 2016). USGS has determined that the 7Q10 flood flow on the Columbia River at the U.S.-Canada border is 227,000 cfs and the 7Q10 flood flow in the river below Grand Coulee Dam is 222,000 cfs (Pickett et al.,2004). During these flows TDG below Grand Coulee Dam often exceeds the 110 percent standard, and little can be done at Grand Coulee to correct for this exceedance (Reclamation 2018). However, management at other dam sites downstream of Grand Coulee is often adjusted, especially at Chief Joseph Dam, to help keep TDG as low as possible in the waterway while meeting other operation obligations such as power generation and flood risk management (FRM).

Across the entire reservoir from 2004 to 2005, the annual mean surficial TDG saturation was greatest at Seven Bays (106 percent) and lowest at Spring Canyon (104 percent). Annual mean TDG saturation at the U.S.-Canada border was 107 percent (standard deviation [SD] = 7; number of samples = 360). Annual mean TDG saturation at the Grand Coulee Dam forebay fixed monitoring station excluding the data from August 21 to 24 and November 11 to 12 (because of extreme outliers) was 103 percent (Lee et al. 2006). In addition, monthly average saturation levels exceeded 100 percent in May and July. The months of April through October produced maximum reported gas saturation levels above the 100 percent standard (Lee et al. 2006).

From January through December 2014, the total dissolved gas (TDG) levels across the reservoir averaged 107 percent (daily range: 94 to 130 percent). The EPA aquatic life maximum level of 100 percent was exceeded for approximately 17 weeks (April 14 to August 12) (Kain, Knudson, and Nichols 2015). During 2016, the TDG level exceeded the 110 percent level for 7 weeks (Kain, Knudson, and Nichols 2017). In 2017, TDG

averaged 103 percent across the entire reservoir, excluding the Spokane arm of the waterbody, with a daily range of 95 to 192 percent. The 100 percent maximum level was exceeded 45 days, primarily during the May and June period (Kain, Knudson, and Nichols 2018)

The Columbia River is particularly susceptible to high TDG in the springtime during snowmelt. Dam operators are often forced to spill large quantities of water over spillways or through outlet works (bypassing the turbines) either due to lack of demand or lack of unit capacity. For example, in April 1997, extreme TDG supersaturation occurred along the Columbia River due to large amounts of snowpack melting quickly. Operators in Canada and the United States were forced to open spill gates. TDG supersaturation exceeded 130 percent at the U.S.-Canada border and exceeded 140 percent just below Grand Coulee Dam for 3 weeks (Reclamation 2016).

Reclamation conducted TDG tests during the 1997 event. They varied releases from various outlet pathways in the dam to determine the effects on TDG downstream. Different combinations of powerhouses and outlet gates were open and closed to help determine the best combination that resulted in the lowest TDG increase in the river downstream (Pickett, Rueda, and Herold 2004). Pickett, Rueda, and Herold describe the tests and findings as:

- Five tests were conducted that explored combinations of upper and lower [mid-level] outlet works conduits and powerhouse discharges. Three tests were run with upper outlet conduits discharging at around 32 kcfs and power plant flows of 0, 31, and 66 kcfs. Two tests looked at outlet works discharges from the lower [mid-level] conduits alone, and combined upper and lower [mid-level] conduits, both with no powerhouse flows. TDG measurements were taken downstream of the dam at 2.3 miles, 6.6 miles (FMS site), and 15 miles (fish pens). Initial reconnaissance showed that powerhouse and spill flows were mixed by the 2.3-mile station (at flows of roughly 100 kcfs), but were not fully mixed at locations closer to the dam.
- Forebay TDG values were under 110 percent during the tests. TDG levels exceeded 140 percent saturation when either the upper or lower [mid-level] conduits were operated alone with no powerhouse flows. When the upper and lower [mid-level] conduits were operated together, TDG levels were relatively lower, but still exceeded 130 percent saturation. Increased powerhouse flows produced lower TDG levels, mostly through dilution. TDG levels were highest at 2.3 miles downstream and decreased with the downstream distance.
- Interpretation of results from these tests is limited due to the narrow range of flows under which they were conducted and the limited number of measurements and sample locations. However, the tests did demonstrate the high level of gas generated by use of the outlet works. The final report recommended operating paired high and low [mid-level] conduits if use of the outlet works was necessary.

2.2.5 Specific Conductivity

Specific conductivity (SC) is a measure of a solution's ability to conduct electricity. This physical characteristic is non-specific to any contaminant. A large change in SC may indicate the introduction of a wide range of pollutants (such as heavy metals) into a waterbody.

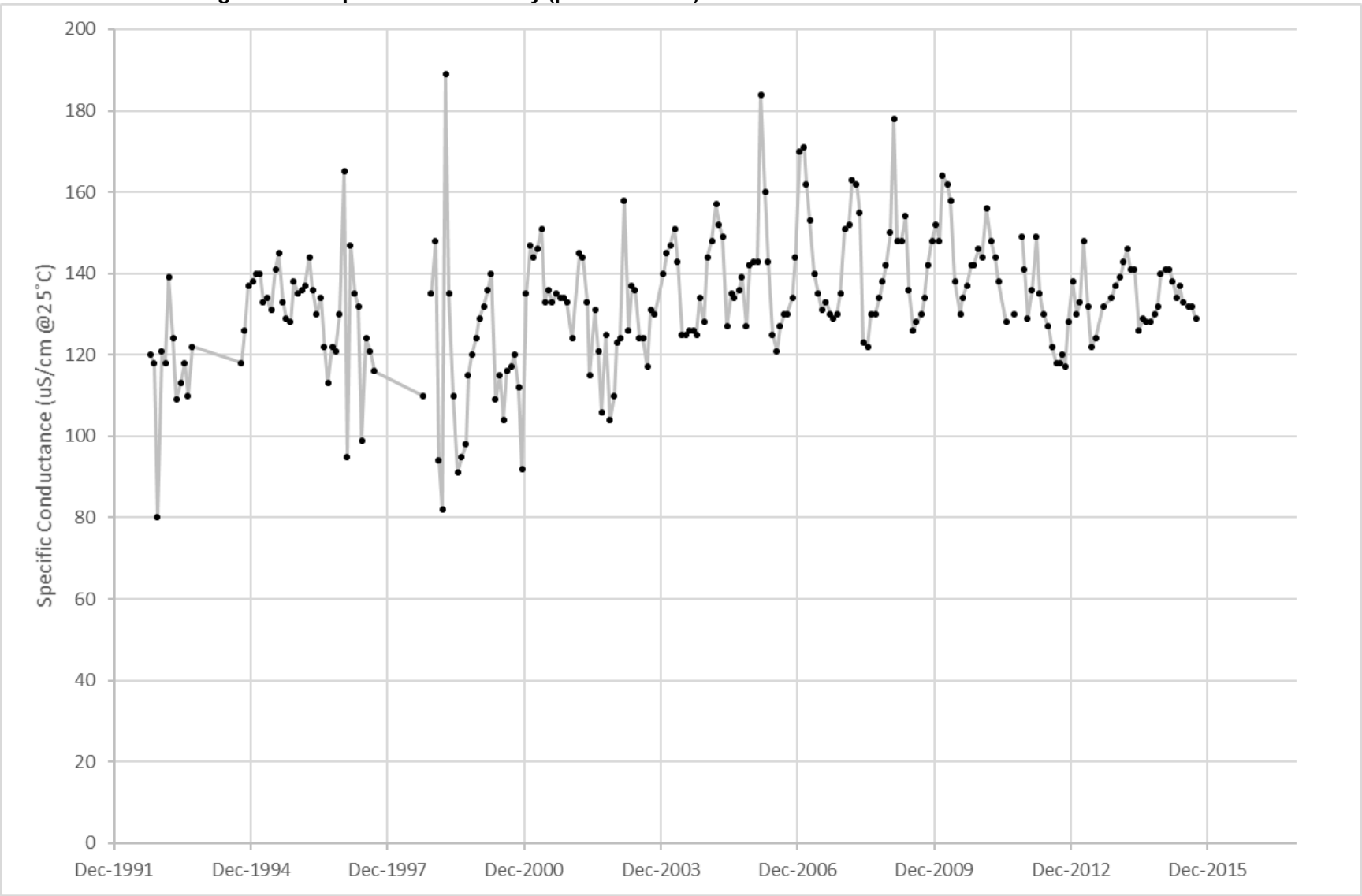
TDS and SC normally correspond as shown by the ratio TDS (mg/L)/SC (microsiemens per centimeter [µS/cm]) = 0.55 to 0.7. However, this is only a general correlation, which can be different if there is a large amount of non-ionic dissolved solids like sugar, or if there are any strong acids/bases which have a strong ionic signal, but are not dissolved solids. Windward LLC, in fieldwork for Teck (2017), reported the mean TDS downstream of the dam to be 80 mg/L in 2016 (see Table 2-8), and Ecology reported a mean SC from 1992 to 2015 of approximately 130 µS/cm (Figure 2-23), which gives a ratio of about 0.6, well within the anticipated range for the ratio. Understanding this correlation is helpful because SC tests are easier to conduct compared to TDS analysis, and given this SC data may be easier to acquire.

The correspondence of TDS and SC is further displayed by work conducted by Kain, Knudson, and Nichols (2018) displayed in Figure 2-24. Kain, Knudson, and Nichols (2018) recorded the TDS and SC throughout the reservoir and reported their findings for the upper, middle and lower reaches of the reservoir, as well as at the two major tributaries of the reservoir, the Spokane and Sanpoil Rivers. In their study they report SC and TDG have a general correlation of around 0.6 throughout the reservoir, and throughout the year.

Figure 2-23 depicts SC below the dam at 25˚C from 1991 to 2015. The mean annual SC downstream of the reservoir was 133.1 µS/cm (Ecology 2017).

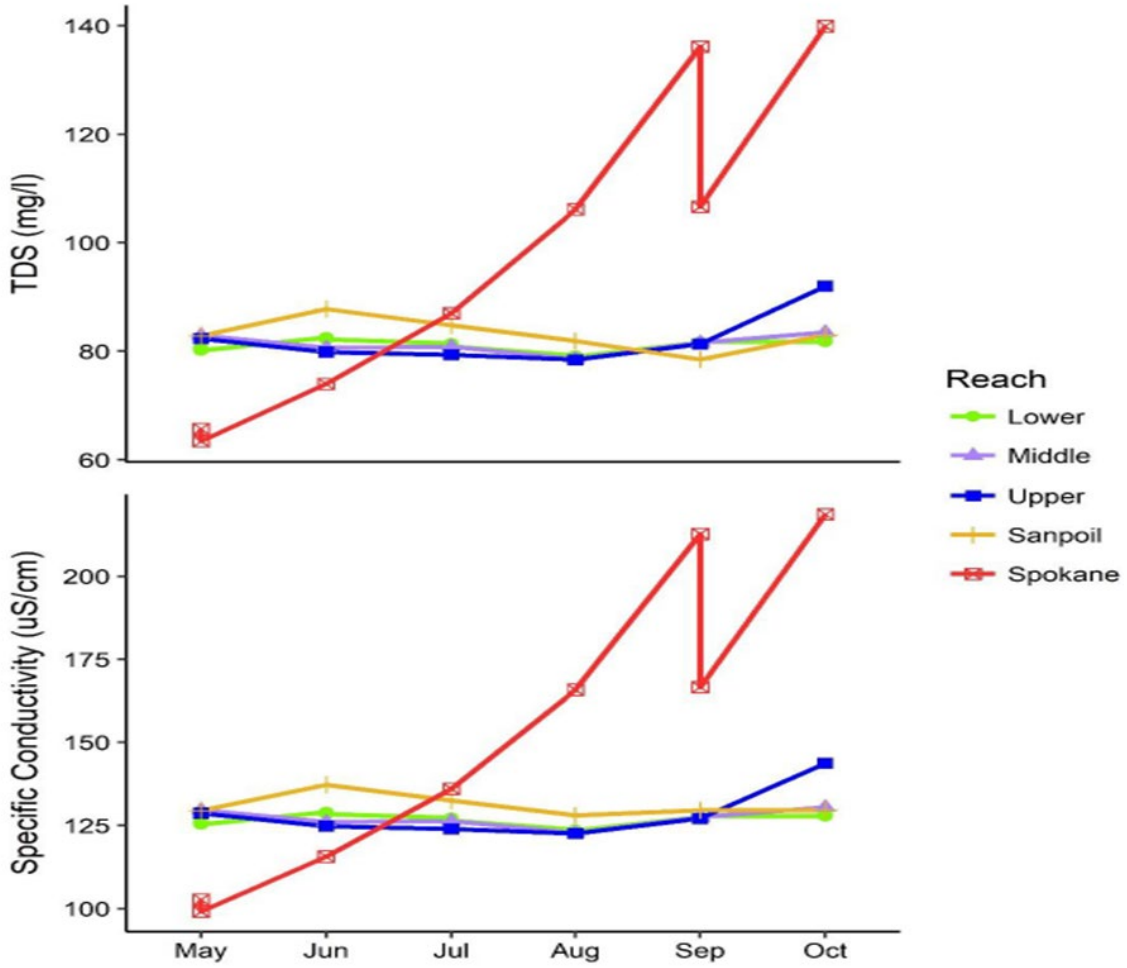
Lee et al. (2006) reports reservoir average SC as 126.8 µS/cm. Mean monthly SC was also measured, showing that the maximum SC occurred in September at 145.5 µS/cm, with the minimum at 105.7 µS/cm in June. These numbers corresponded with maximum and minimum TDS data of 93.1 and 67.6 mg/L in September and June respectively. In more recent years, mean, reservoir wide SC was measured as 127.6 µS/cm in 2014 (Kain, Knudson, and Nichols 2015), 132.3 µS/cm in 2015 (Kain, Knudson, and Nichols 2017), and a range of 99.7 to 218.6 µS/cm in 2016 (Kain, Knudson, and Nichols 2018).

Figure 2-23. Specific Conductivity (µS/cm at 25˚C) 0.5 mile Downstream from Grand Coulee Dam



Note: From Ecology Station 53A070. The dots indicate the time discrete samples were taken, lines only help to identify trends, and do not indicate continuous samples.
Source: Ecology (2017)

Figure 2-24. Monthly Mean Total Dissolved Solids and Specific Conductivity in Lake Roosevelt and its Major Tributaries During 2016



Note: The markers indicate the time discrete samples were taken, lines only help to identify trends, and do not indicate continuous samples.
Source: Kain, Knudson, and Nichols (2018)

2.2.6 Sediment Particle Size

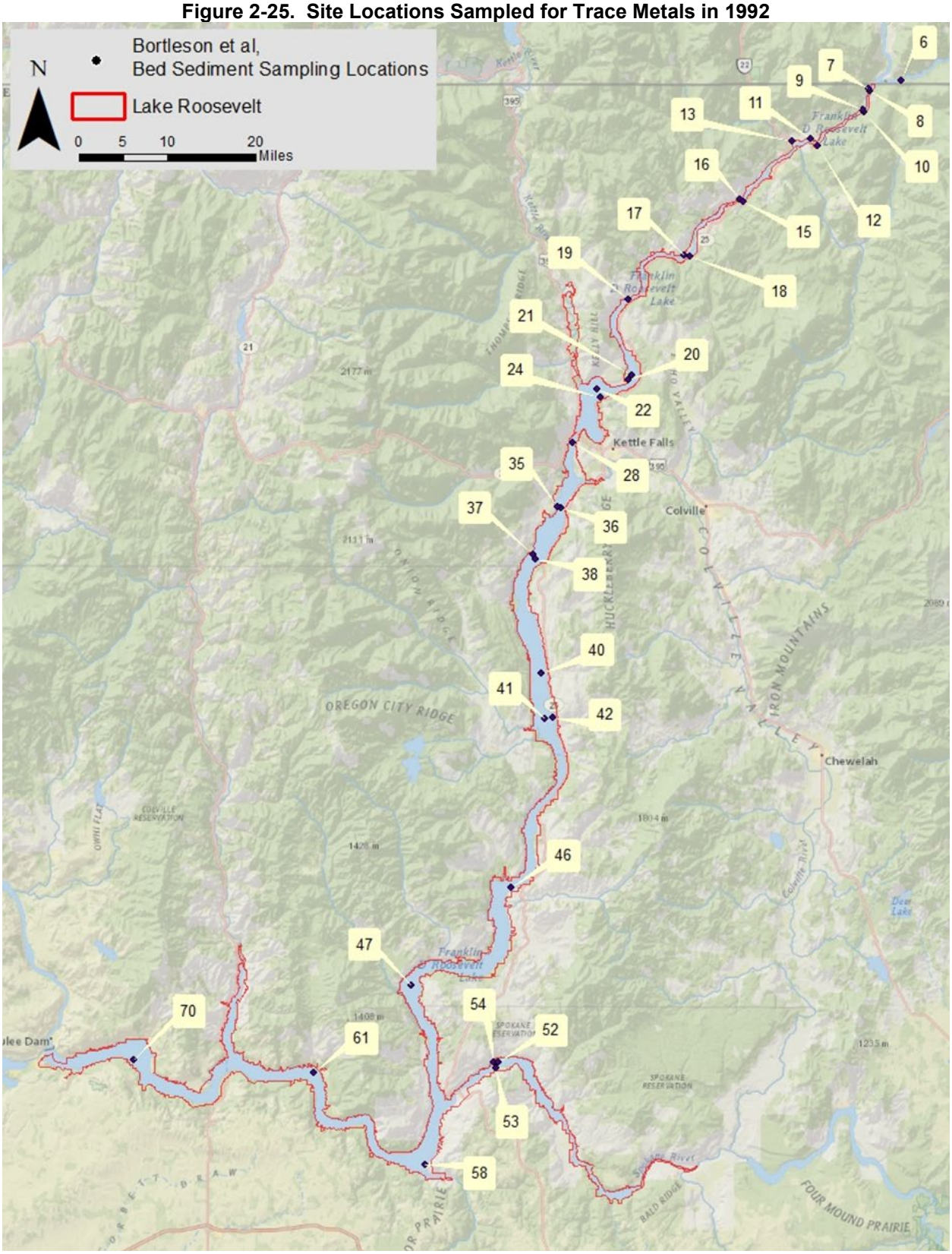
Lake sediment particle size can have an effect on the concentration and distribution of trace elements within Lake Roosevelt. Trace metals and organic matter often adhere to soil particles. Larger particles drop out quickly when water velocity drops; however, smaller particles can travel farther into the lake and potentially past the dam to the river reaches below the dam (Table 2-2).

Table 2-2. Total Trace Element Concentrations at Select Sites

Site number	Site name (see plate 1 for for complete name)	Site type	Concentrations of trace elements meeting or exceeding severe-effect level (in parentheses)					
			Arsenic (33 mg/kg)	Cadmium (10 mg/kg)	Copper (110 mg/kg)	Lead (250 mg/kg)	Mercury (2 mg/kg)	Zinc (820mg/kg)
6	Pend D'Oreille River LB	T	--	--	--	--	--	1,600
7	Boundary RB	C	52	--	**3,300**	480	--	**17,000**
8	Boundary LB	C	34	--	**2,700**	280	--	**13,000**
9	Auxiliary Gage RB	C	43	--	**2,600**	270	--	**13,000**
10	Auxiliary Gage LB	C	35	--	**3,000**	310	--	**16,000**
11	Goodeve Creek RB	C	--	--	**2,900**	310	--	**17,000**
12	Goodeve Creek LB	C	--	--	**670**	370	--	**3,200**
13	Big Sheep Creek RB	D	--	--	--	--	--	1,600
15	Onion Creek LB	C	--	--	**540**	340	--	**3,600**
16	Onion Creek RB	C	--	--	**800**	300	--	**4,600**
17	China Bend RB	R	--	--	**550**	480	--	**3,000**
18	China Bend MS	R	33	--	**3,000**	430	--	**22,000**
19	Bossborg RB	R	--	--	**230**	280	--	1,400
20	Summer Island RB1	R	--	11	**300**	**660**	2.7	**1,800**
21	Summer Island RB2	R	--	--	170	420	--	**2,000**
22	Marcus Island MS	R	--	--	170	310	--	1,000
24	Marcus Island LB	R	--	--	**410**	**510**	--	**2,200**
28	West Kettle Falls LB	R	--	--	**290**	440	--	**1,700**
35	Haag Cove RB	R	--	--	150	490	2.2	1,100
36	Haag Cove MS	R	--	--	**260**	400	--	**1,800**
37	French Point Rocks RB	R	--	--	--	390	--	930
38	French Point Rocks MS	R	--	--	**220**	**570**	2.3	1,300
40	Cheweka Creek LB	R	--	--	--	**550**	--	1,000
41	Gifford MS	R	--	--	110	470	2.8	1,000
42	Gifford LB	R	--	--	110	480	2.5	940
46	Hunters LB	R	--	--	--	380	--	--
47	Ninemile Creek MS	R	--	--	--	270	--	--
52	Spokane River MS	T	--	10	--	--	--	**1,800**
53	Spokane River LB	T	--	--	--	--	--	1,000
54	Spokane River RB	T	--	--	--	--	--	980
58	Seven Bays LB	R	--	10	--	320	--	1,100
61	Whitestone Creek MS	R	--	--	--	290	--	1,000
70	Swawilla Basin MS	R	--	--	--	310	--	1,100

Note: Lower number sites are closer to the U.S.-Canada border, higher number sites are closer to Grand Coulee Dam. Sites types detail the site location with "T" being tributaries, "C" Columbia River, "D" delta deposits, and "R" Lake Roosevelt. Name endings in LB, RB, or MS were collected near the left bank, right bank, or mid-channel respectively. Concentrations in the column header under the analyte name are trace element sediment quality guidelines for benthic organisms developed by the Ontario Ministry of Environment and Energy (Persaud, Jaagumagi, and Hayton 1991). All values displayed exceed these guidelines, all values in bold exceed these guidelines by at least 100 percent. Site location numbers correspond to those on the map in Figure 2-25 (Bortleson et al. 2001). mg/kg = milligrams per kilogram.

Figure 2-25. Site Locations Sampled for Trace Metals in 1992



Note: Trace metal concentrations from these sample locations are displayed in Table 2-2.
Source: Bortleson et al. (2001)

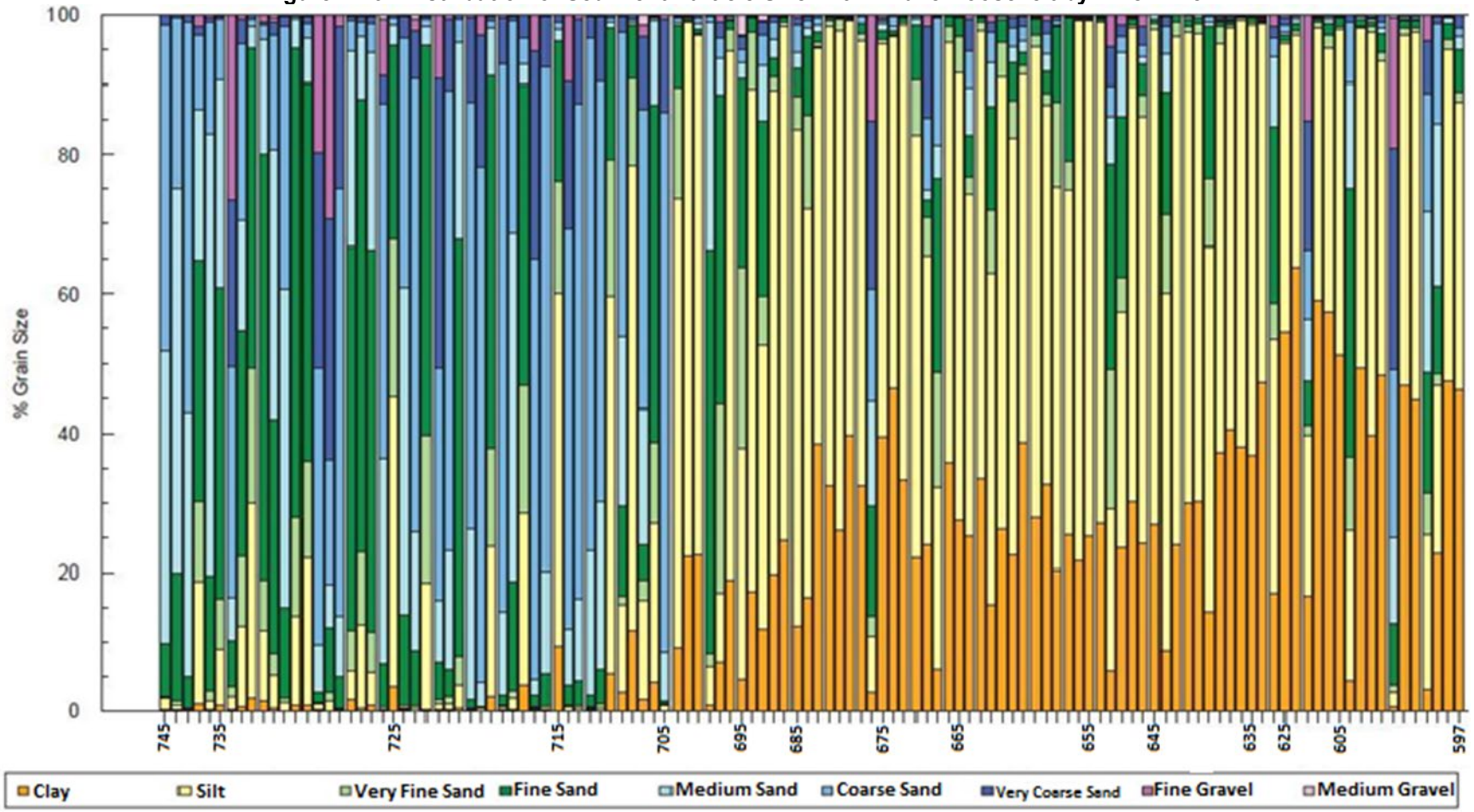
As previously mentioned, historical mining and smelting activities above Lake Roosevelt have resulted in over a century of trace metal waste deposition, from smelting slag and smelting effluent, into the watershed. These metals are associated with the sediments trapped in the lake since Grand Coulee Dam was completed in 1942, which created slack waters for the sediments to settle. Due to their grain size and density, most of the slag particles will settle out of the water quickly and are transported primarily along the river bed, as far downstream as Kettle Falls (river mile 700), resulting in high upstream concentrations of copper and zinc. Metals associated with the liquid effluent's finer suspended particles (lead, cadmium, and mercury) are carried further downstream before being deposited (Vlassopoulos 2010). (Teck Inc. 2017) Teck (2017) does not report high metal concentrations within approximately 70 river miles of Grand Coulee Dam (Table 2-2), although elevated concentrations of metals associated with smelting slag and effluent has been recorded near Grand Coulee Dam (Bortleson 2001) and (Hill 2012). Table 2-3 and Figure 2-26 display size class averages within the lake, and their distribution by river mile.

Table 2-3. Distribution of Sediment Particle Sizes by Grain Size (percent) Within Lake Roosevelt

Analyte	Number of Results	Minimum Value	Maximum Value	Mean Value
Clay	120	0	67.7	17.5
Silt	120	0.1	81.53	35.8
Very Fine	120	0.02	26.97	4.62
Fine Sand	120	0.18	63.4	13.2
Medium Sand	120	0.03	63	9.09
Coarse Sand	120	0	78.77	13.8
Very Coarse Sand	120	0	42.45	4.05
Fine Gravel	120	0	27.55	1.6
Medium Gravel	120	0	2.87	0.0569

Source: Teck (2017)

Figure 2-26. Distribution of Sediment Particle Size Within Lake Roosevelt by River Mile



Note: River miles are marked approximately every 10 miles for general location reference only. Spacing is uneven to reflect the number of samples gathered, which was variable for each river segment (to determine the exact location of a sample the original report should be referenced). RM 745 is near the U.S.-Canada border and RM 597 is near the Grand Coulee Dam.
Source: Teck (2017)

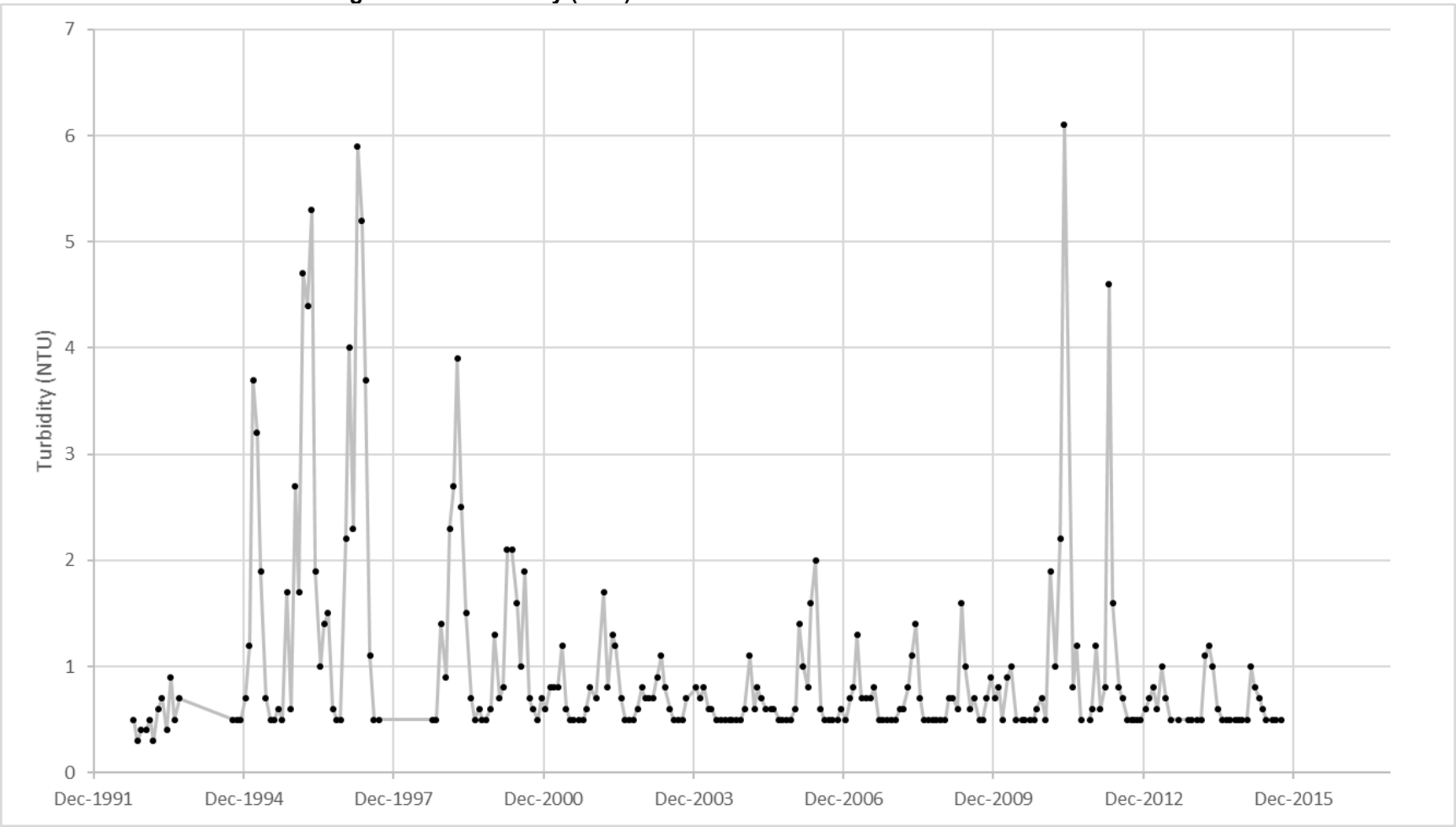
2.2.7 Turbidity and Light Attentuation

Turbidity is essentially a measurement of organic and inorganic particles in water and is reported in a variety of units depending on the instruments optical configuration including Nephelometric Turbidity Units (NTU) and Formazin Turbidity Units (FNU) (Anderson 2005). Water quality standards that apply to Lake Roosevelt are displayed in Table 2-1. In general Lake Roosevelt is well under these standards as the reservoir displays very low turbidity. Low turbidity indicates low levels of suspended sediment and, to some extent, microbial blooms in the reservoir. Figure 2-27 displays turbidity data taken half a mile downstream of the dam. In general, the trend displays very low turbidity in fall and winter, and higher turbidity in springs and summer during which time readings above 5 NTU are occasionally recorded (Lee et al. 2006).

In 2006, field turbidity across the reservoir, as measured via Hydrolab in FNU, was below the instrument's detection limit (0.5 FNU) (Lee et al. 2006). Based on laboratory samples measured in NTU, mean annual turbidity across the entire reservoir was 1.2 NTU, while mean monthly turbidity was highest in June at 3.6 NTU and lowest at 0.5 NTU in September (Lee et al. 2006).

In 2016 mean turbidity throughout the reservoir was 0.29 NTU, and the highest monthly mean turbidity was reported at the Spokane arm in May at 3.11 NTU. The highest turbidity value observed was 20.6 NTU in the middle reach of the reservoir and 9.2 NTU in the Spokane Arm in September (Kain, Knudson, and Nichols 2018).

Figure 2-27. Turbidity (NTU) 0.5 mile Downstream from Grand Coulee Dam

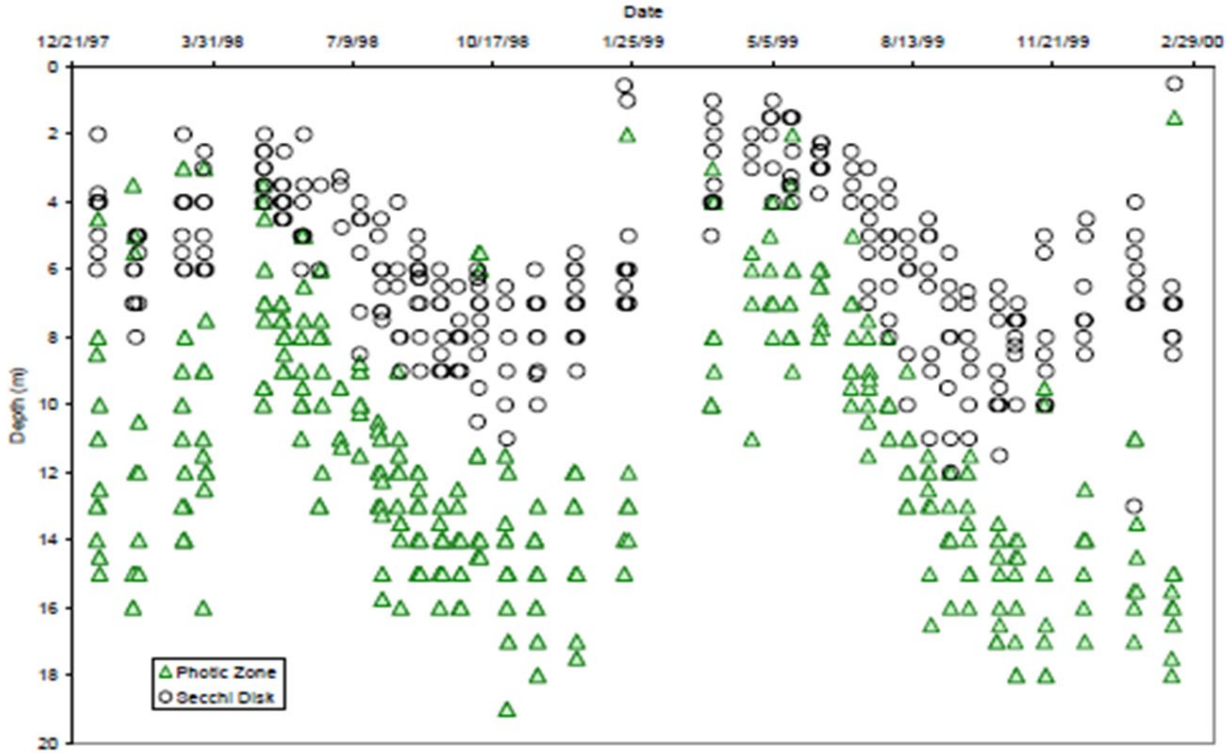


Note: From Ecology Station 53A070. The dots indicate the time discrete samples were taken, lines only help to identify trends, and do not indicate continuous samples.
Source: Ecology (2017)

Lake clarity displays distinct spatial and temporal variation. The clarity of lake water generally increases closer to Grand Coulee Dam, and decreases with spring runoff resulting in the highest clarity in October and lowest in April. This variation of lake clarity is likely due to increases in sediments from tributaries during spring runoff, and an increase in suspended sediment and nutrients within the reservoir with increased spring flows. As is normal, photic zone depth is strongly correlated with lake clarity, as displayed in Figure 2-28 (Scofield and Pavlik-Kunkel 2000).

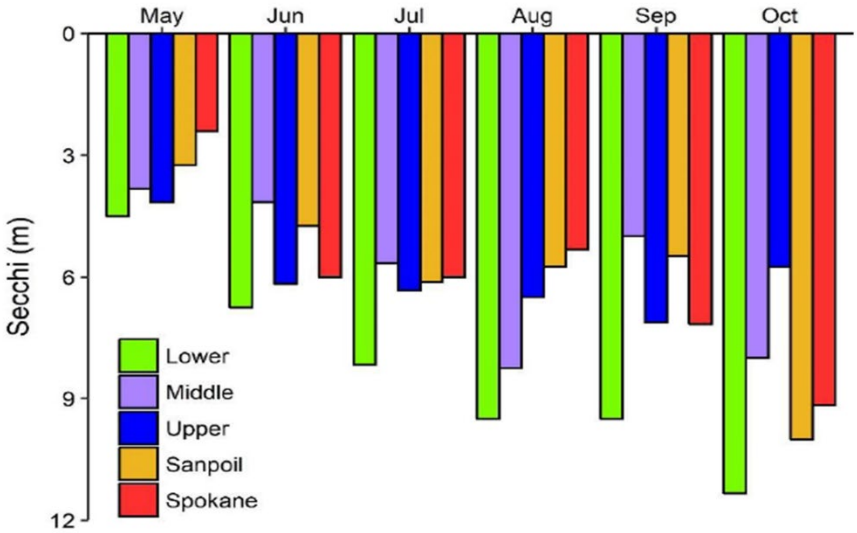
Secchi disk depth, a measure of water clarity that involves lowering a disk into the water until it is at a depth where it cannot be seen, was measured in the reservoir. The mean monthly Secchi disk depth in Lake Roosevelt ranged between a minimum of 4.5 meters (May) to a maximum of 10.0 meters in October, with an average of 7.4 meters (Lee et al. 2006). These depths are consistent with an oligotrophic system, one that is low in nutrient concentrations, and has a small algal population. More recent reports by Kain, Knudson, and Nichols (2015, 2017, 2018) list mean annual Secchi disk depths at 6.0 meters, 6.1 meters, and 6.4 meters in 2014, 2015, and 2016, indicating a slight reduction of reservoir water clarity in the past few years. The monthly mean Secchi disk depth from May to October 2016 in the reservoir is displayed in Figure 2-29. The figure shows the decrease in turbidity following the initial increase caused by higher tributary flows at this time of year, a pattern which is also visible in Table 2-4. The average annual Secchi disk depth by reservoir reach is displayed in Table 2-5 (Scofield and Pavlik-Kunkel 2000).

Figure 2-28. Photic Zone and Secchi Disk Depths in Lake Roosevelt near Grand Coulee Dam, Collected from 1997 to 2000



Source: Scofield and Pavlik-Kunkel (2000)

Figure 2-29. Monthly Mean Secchi Disk Depths in the Reaches of Lake Roosevelt and Major Tributaries in 2016



Source: Kain, Knudson, and Nichols (2018)

Table 2-4. Mean Secchi Disk Depth (meters), Standard Deviation, Sample Size, and Range from Lake Roosevelt by Month from 1997 to 2000

Month	Mean	SD	Sample Size	Minimum	Maximum
January	5.5	2.2	30	0.5	13
February	6.3	1.4	31	0.5	8.5
March	4.6	1.5	38	1	7
April	2.9	1.3	11	1.5	6
May	3	0.9	42	1	4.5
June	3.4	1	31	2	6
July	5.4	1.5	50	3	8.5
August	6.8	1.8	41	3.5	11.5
September	8.3	1.5	43	5.5	12.5
October	8.4	1.5	40	6	11.5
November	8.2	1.8	22	5	11
December	6.6	1.3	23	4	9
Overall	**5.8**	**1.5**	**402**	**0.5**	**13**

Table 2-5. Mean Secchi Disk Depth (meters), Standard Deviation, Sample Size, and Range from Lake Roosevelt by Sample Location from 1997 to 2000

Sample Location	Mean	SD	Sample Size	Minimum	Maximum
Evan's Landing	5.4	1.8	37	1.5	8.3
Kettle Falls	5.4	1.9	38	1.5	8
Gifford	5.8	2.6	39	0.5	13
Hunters	5.3	1.9	39	2	10
Spokane River Confluence	5.6	2	35	3	11
Seven Bays	6	2.1	36	2.5	9.5
Sanpoil River Confluence	6.8	2.6	37	2	12.5
Keller Ferry	6.7	2.6	36	1.5	11.5
Spring Canyon	7.1	2.3	37	3	12
Porcupine Bay	4.9	3.1	34	0.5	11
Sanpoil River	5.9	2.4	33	1	11
Overall	**5.9**	**2.3**	**401**	**0.5**	**13**

Source: Scofield and Pavlik-Kunkel (2000)

Mean annual photic zone depth across the reservoir was 12.8 meters. Mean monthly photic zone depth from all locations was highest in September at 15.1 meters and lowest in May at 7.8 meters (Lee et al. 2006). This trend, from 1997 to 2000, is displayed in the data presented in Figure 2-28 and Table 2-6. The average annual data separated by reservoir reach is presented in Table 2-7 (Scofield and Pavlik-Kunkel 2000).

Table 2-6. Mean Photic Zone Depth (meters), Standard Deviation, Sample Size, and Range from Lake Roosevelt by Month from 1997 to 2000

Month	Mean	SD	Sample Size	Minimum	Maximum
January	12.5	3.2	33	2	17
February	12.3	4.2	33	1.5	18
March	9.9	3.5	43	3	16
April	6.8	2	11	3	11
May	6.8	1.8	44	2	10
June	8.3	2.1	48	5	13
July	10.3	1.7	50	7.5	15.8
August	12.7	1.7	44	9	16.5
September	14	1.3	44	11.5	16
October	14.1	3.2	44	5.5	19
November	15.6	2.5	21	9.5	18.5
December	13.8	2.1	23	8.5	17.5
Overall	**11.4**	**2.4**	**438**	**1.5**	**19**

Source: Scofield and Pavlik-Kunkel (2000)

Table 2-7. Mean Photic Zone Depth (meters), Standard Deviation, Sample Size, and Range from Lake Roosevelt by Sample Location from 1997 to 2000

Sample Location	Mean	SD	Sample Size	Minimum	Maximum
Evan's Landing	11.2	3.5	39	4.5	18
Kettle Falls	10.9	3.6	39	2	17.5
Gifford	11.6	3.2	40	5	16
Hunters	11.2	3.1	40	5	17
Spokane River Confluence	11.2	3.2	39	5.5	18
Seven Bays	11.2	3.4	40	4	18.5
Sanpoil River Confluence	12.4	3.4	39	4	18
Keller Ferry	12	3.9	40	4	18
Spring Canyon	12.7	3.5	40	6	19
Porcupine Bay	9.3	4.7	41	1.5	14
Sanpoil River	11.3	3.7	40	3	16.5
Overall	**11.4**	**3.6**	**437**	**1.5**	**19**

Source: Scofield and Pavlik-Kunkel (2000)

2.2.8 Total Suspended and Dissolved Solids

Total suspended solids (TSS) is a measurement of the dry weight of particles in a water sample. It is used to determine the silt, plankton, animal waste, and any other matter suspended in the water. Elevated TSS levels may increase turbidity, thus reducing water clarity and limiting light penetration. This condition may lead to adverse effects on primary productivity within a large waterbody. Low turbidity rates in the reservoir, as previously stated, indicated that very little suspended solids are found within the water column. The data indicates that TSS in the lake is generally very low (Table 2-8. Total

Suspended and Dissolved Solids in Lake Roosevelt for all Locations Sampled; Figure 2-30) (Lee et al. 2006).

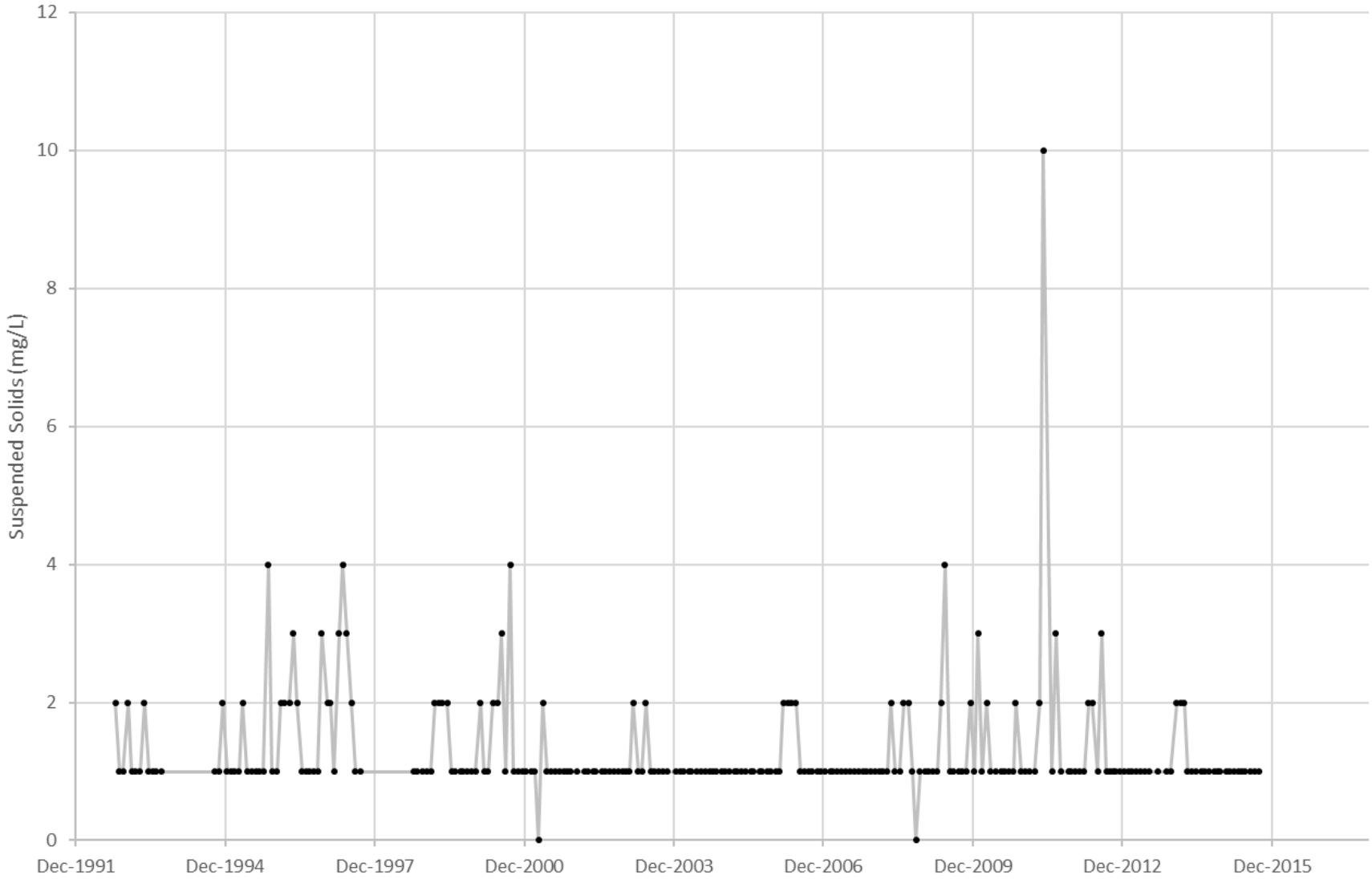
TDS are solids that can pass through a filter membrane with a pore size of 0.45 micrometers. TDS is a measurement of material dissolved in the water such as carbonate, sulfate, nitrate, phosphate, chloride, and other ions. Work completed by Kain, Knudson, and Nichols (2018) displayed in Figure 2-24 shows TDS in each of the three reservoir reaches, as well as at the two major tributaries entering the reservoir. More detailed analysis, both spatially and temporally, of TDS concentrations within the reservoir was reported by the Spokane Tribe (LRFEP 2018). This collected data was displayed in Figure 2-5 to Figure 2-21. These figures agree well with Figure 2-24, as well as the mean values reported for the entire reservoir in Table 2-8. TDS is higher than TSS in this reservoir, which is anticipated because lake clarity is high, but ionic content is normal for the region.

Table 2-8. Total Suspended and Dissolved Solids in Lake Roosevelt for all Locations Sampled

Analyte	Concentration Units	Measurement Basis	Number of Acceptable Analyses	Number of Detected Values	Minimum Value	Mean Value	Maximum Value
Total dissolved solids	mg/L	Total	101	99	50	80	1,070
Total suspended solids	mg/L	Total	101	0	–	–	–

Source: Exponent (2013)

Figure 2-30. Suspended Solids (mg/L) Measured 0.5 mile Downstream from Grand Coulee Dam



Note: From Ecology Station 53A070. The dots indicate the time discrete samples were taken; lines only help to identify trends, and do not indicate continuous samples.
Source: Ecology (2017)

2.3 CHEMICAL CHARACTERISTICS

2.3.1 pH

The pH in Lake Roosevelt is circum-neutral (nearly neutral, having a pH between 6.5 and 7.5), and slightly higher than that of the water which flows into the lake (Table 2-9. The water quality standards that apply to the reservoir for pH of 6.5 to 8.5 in the reservoir are listed in Table 2-1 (Ecology 2017).

The data reported by Teck (2017) (Table 2-9), by Exponent (2013) (Table 2-10), Ecology (2017) (Figure 2-31), and LRFEP yearly limnology reports (Kain, Knudson, and Nichols 2018) show that pH in the reservoir, and the water released from Grand Coulee Dam, range from around 7 to about 9, but are seldom found above 9 for a large area over an extended period of time. These values are typically not a cause for concern in terms of environmental health.

Table 2-9. pH Values Recorded in Lake Roosevelt and its Tributaries

Location	Number of Results	Minimum Detected Value	Maximum Detected Value	Mean Detected Value
Tributaries and Upstream of Lake Roosevelt	16	5.27	8.44	7.19
In Lake Roosevelt	120	6.37	9.37	7.36

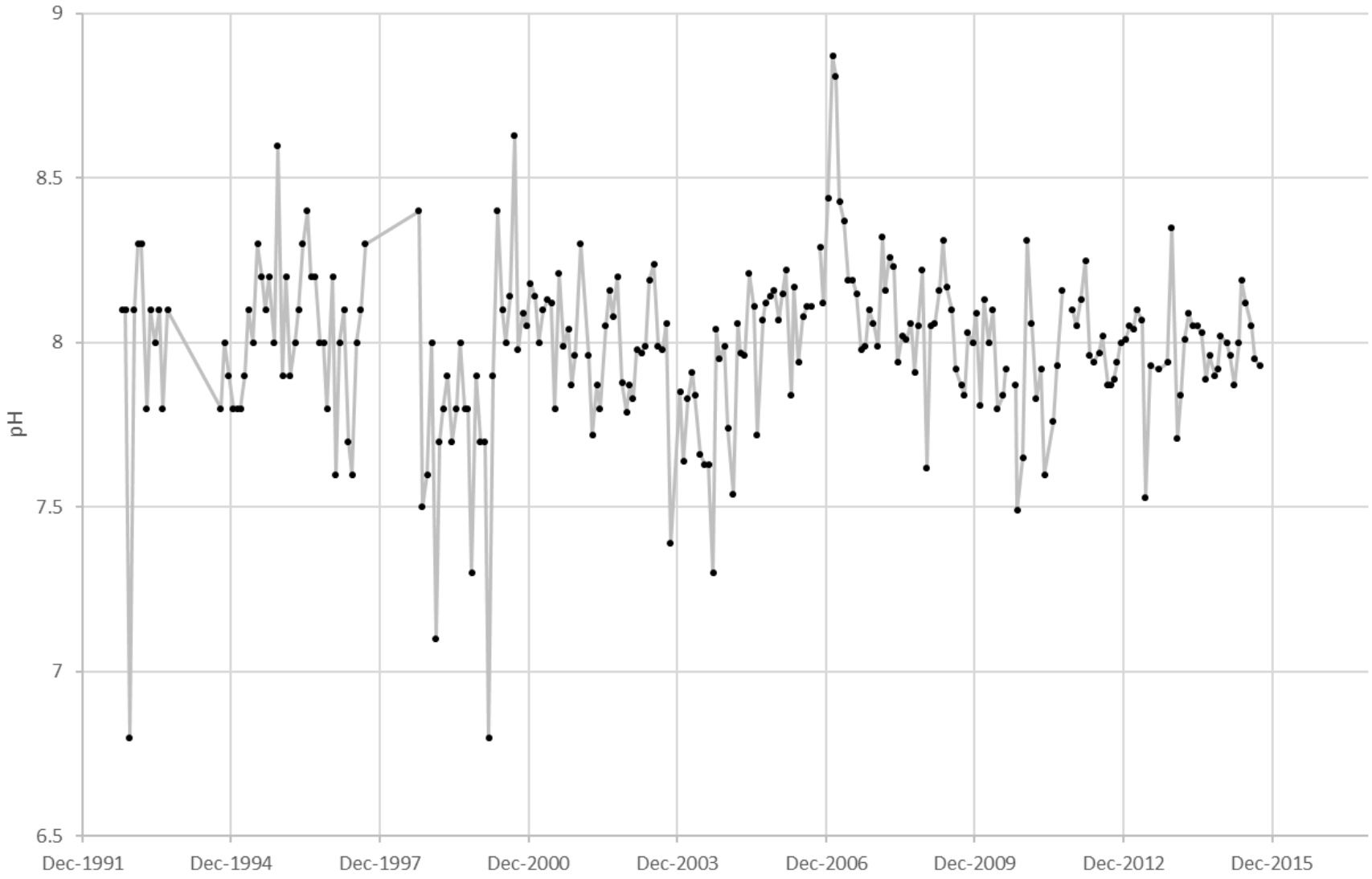
Source: Teck (2017)

Table 2-10. pH Values Recorded in Lake Roosevelt

Concentration Units	Measurement Basis	Number of Acceptable Analyses	Number of Detected Values	Minimum Value	Mean Value	Maximum Value
SU	Total	101	101	7.77	8.06	8.35

Source: Exponent (2013)

Figure 2-31. pH Measured 0.5 mile Downstream from Grand Coulee Dam



Note: From Ecology Station 53A070. The dots indicate the time discrete samples were taken; lines only help to identify trends, and do not indicate continuous samples.
Source: Ecology (2017)

When pH exceeds 8-9 it indicates significant primary production, often from an algal bloom. While algal blooms have been documented in the reservoir, they tend to be localized and do not cause widespread issues like fish die-offs (Ecology 2017). The mean annual pH across the entire reservoir from 2004 to 2005 was 7.8 (SD = 7.7; sample size = 582), however, the Spokane arm reported a maximum of 8.7 at the Little Falls Spillway. Mean monthly pH across the waterbody was highest in August at 8.2 and lowest in June at 7.6 (Lee et al. 2006). More recent pH measurements show a marked difference. In 2014, the pH in Lake Roosevelt averaged 7.88, with a range of 6.94 and a maximum of 9.08 (Kain, Knudson, and Nichols 2015). In 2015, the pH ranged from 6.48 to 9.14 with an average of 7.79 (Kain, Knudson, and Nichols 2017). In 2016, the average pH was 8.08 with a range of 6.62 to 9.39 (Kain, Knudson, and Nichols 2018).

2.3.2 Major Ions, Alkalinity, and Hardness

The balance of major ions and alkalinity of the waters in Lake Roosevelt are as anticipated given the environment of the lake. Lower calcium carbonate ($CaCO_3$) levels are observed due to the lowered amount of calcium carbonate geochemistry, such as calcite (a calcium carbonate mineral), in the basin. Since there is little calcium carbonate chemistry activity in the system, alkalinity behaves as a conservative constituent (EPA 2011). These results, as well as other major ion concentrations, are summarized in Table 2-11 and Table 2-12, and show Lake Roosevelt to be classified as soft to moderately hard water.

Table 2-11. Major Ions and Alkalinity in Lake Roosevelt

Analyte	Concentration Units	Measurement Basis	Number of Acceptable Analyses	Number of Detected Values	Minimum Value	Mean Value	Maximum Value
Alkalinity	mg/L	Total	101	101	51.2	59.6	74.8
Chloride	mg/L	Total	82	82	0.5	3.08	30.1
Fluoride	mg/L	Total	101	101	0.03	0.064	0.1
Hardness as CaCO3	mg/L	Total	94	94	54.5	63.4	70.6
Silica	mg/L	Total	101	95	1.14	2.99	5.81
Sulfate	mg/L	Total	101	101	6.46	9.2	10.6

Source: Exponent (2013)

Table 2-12. Organic Constituent Water Quality Parameters within Lake Roosevelt and Major Tributaries in 2016

Parameter	Lower	Middle	Upper	Sanpoil	Spokane
NO_3	0.059	0.0548	0.065	0.048	0.516
NO_2	0.005	0.005	0.005	0.005	0.007
NH_3	0.005	0.006	0.005	0.013	0.008
TKN	0.085	0.077	0.075	0.114	0.044
TN	0.1483	0.1367	0.1444	0.1675	0.5661
Ortho-P	0.0011	0.0008	0.0008	0.0057	0.0021
TP	0.0062	0.0062	0.0061	0.0140	0.0089
DIN:DIP	78.6	94.1	103.0	39.4	284.3
TN:TP	25.3	23.0	25.0	16.8	65.3
Alkalinity	56.0	56.2	56.9	60.1	69.3
TSS	1.2	1.3	1.1	1.4	1.4
Turbidity	0.64	1.21	0.99	1.23	1.18

Note: NO3 = Nitrate ; NO2 = Nitrite ; NH3 = Ammonia ; TKN = total Kjeldahl nitrogen; Ortho-P = orthophosphorus; TP = total phosphorus; DIN:DIP = dissolved inorganic nitrogen to dissolved inorganic phosphorus; TN:TP = total nitrogen to total phosphorus. All Samples in mg/L except turbidity (NTU).
Source: Kain, Knudson, and Nichols (2018)

2.3.3 Metals

Metal contamination present in Lake Roosevelt's bed sediments is a major concern. These metals, primarily originated from an estimated 10 to 14 million tons of slag dumped from 1896-1995 directly into the Columbia River north of the U.S.-Canada border by the smelter now owned by Teck, as well as historical and ongoing liquid effluent discharge from Teck's operation. The historic discharge of slag, liquid effluent, and spills from the Cominco Smelter complex is the single largest known and documented source of metals contamination in Lake Roosevelt. Other potential metal sources include mining and milling operations, smelting operations at the former Le Roi/Northport smelter, sewage treatment plants, and other industrial activities.

The primary source for data on the metal contamination in the reservoir is developed from studies by Teck, which are continuing at the time this report is written. These studies, while funded by Teck, were conducted by third party contractors, and carried out under EPA oversight. All documents, were signed off by the third-party contractors for accuracy, go through an EPA review process, and are approved by the EPA before being approved for public viewing. This report draws heavily on these Teck studies to define metal contamination location and concentration as it provides the most thorough and detailed study of slag related contaminants within the reservoir.

The data collected by Teck is too extensive to display completely here. Given this, instead of displaying all of the sampling results for all of the analytes, here trends in mean, minimum and maximum values are displayed and analyzed as well as other generalized characteristics to develop a summary of these extensive and ongoing studies. If more data is needed on a particular constituent, these documents and plans are maintained by the Upper Columbia River Project (https://www.ucr-rifs.com/home/documents-plans). These documents present, among many other items of interest, plots of the concentrations of almost all analytes by river mile which are presented in Table 2-13 and other tables in this section (Exponent 2013; Teck 2017).

Table 2-13. Mean, Median, Standard Deviation, Sample Size, Range, and Coefficients of Variation for Trace Metals (µg/L) in Lake Roosevelt surface water

Analyte	Mean	Median	SD	Sample Size	Minimum	Maximum	CV
Arsenic	44.7	57	33	15	1	98	74
Cadmium	5.9	5.5	1	8	5	7	17
Copper	9.1	8	6.2	14	4	28	68
Lead	5.6	4	11	402	1	182	188
Mercury	1.2	1.2	–	1	1.2	1.2	–
Zinc	22.5	14.5	16	92	5	84	72

Note: CV = coefficient of variation.
Source: Scofield and Pavlik-Kunkel (2000)

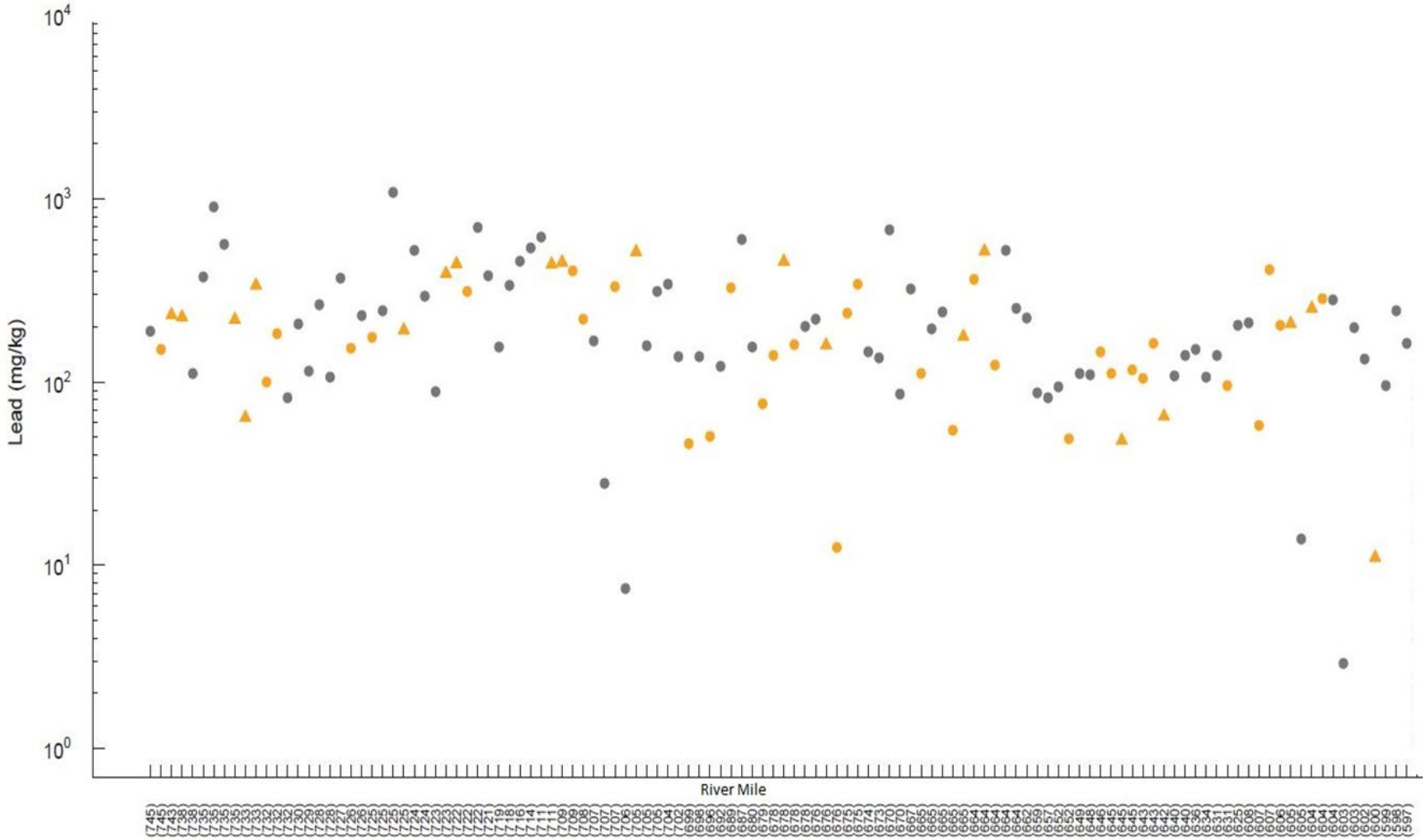
Today, slag deposits are primarily located in the upper portion of the reservoir and slag is not reported at high concentrations closer than 70 miles to Grand Coulee Dam, as displayed in Table 2-14 (Teck 2017). Additionally, in the areas of the reservoir where slag-related sediment deposits are reported, the river typically displays trends of decreasing contaminant concentration from the 1964 sediment horizon to the sediment-water surface (Cox et al. 2005). However, Bortleson et al. (2001) conducted a study in 1992 which reported elevated lead and zinc concentrations (two metals strongly associated with slag contamination from Teck [Cox et al. 2005]) within about 10 miles of Grand Coulee Dam. These concentrations are displayed in Table 2-2, and sample locations are shown in Figure 2-25. The elevated concentrations of zinc and lead reported by Bortleson et al. (2001) have also been observed in the Teck studies; some of these results are displayed in Figure 2-32 and Figure 2-33. Elevated metal concentrations closer to the dam are associated with finer particles in effluent that are carried further downstream before settling out (Vlassopolous 2010).

Table 2-14. The Percent of Total Slag Associated with Three Particle Size Classes as Analyzed by River Mile

River Mile	>4 mm	2–4 mm	<2 mm	River Mile	>4 mm	2–4 mm	<2 mm
(Border) 745	0.08	0.78	99.22	722	0	0	100
745	0	0	100	722	0	0	100
743	0	0	100	721	1.32	0	100
738	0	1.68	98.32	716	0.02	0.6	99.4
738	0	0	100	711	4.58	5.91	94.09
735	0.76	22.26	77.74	711	0.05	0.92	99.08
735	0.02	0	100	709	0.07	0.23	99.77
735	0	0	100	709	0.17	0	100
733	0.25	0	100	707	0	0	100
733	0.62	1.75	98.25	705	0.1	0	100
733	0	0	100	705	0	0	100
732	0	0	100	692	0.54	2.33	97.67
729	0.27	5.95	94.05	689	0.14	0	100
728	0	4.17	95.83	678	0	0	100
727	2.27	0	100	673	0	0	100
726	0	1.73	98.27	664	0	0	100
725	1.45	1.76	98.24	652	0	0	100
724	0	6.33	93.67	645	0	0	100
724	0	1.88	98.12	604	0	0	100
723	0	0.36	99.64	(Dam) 599	0.11	0	100
722	0	2.02	97.98				

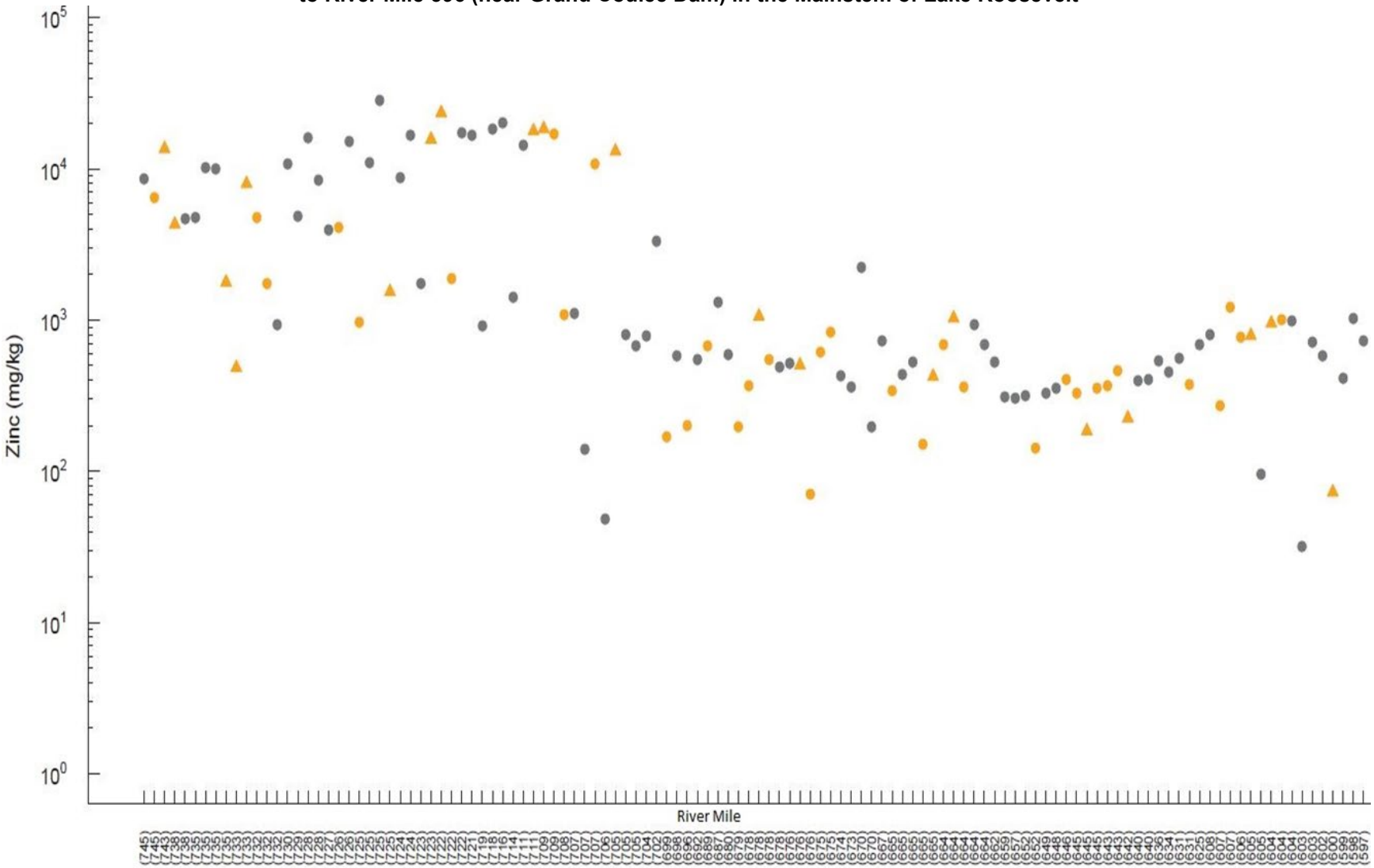
Note: RM 745 is near the U.S.-Canada border and RM 599 is near the Grand Coulee Dam. mm = millimeter.
Source: Teck (2017)

Figure 2-32. Lead Concentration by River Mile from River Mile 745 (near the U.S.-Canada border) to River Mile 596 (near Grand Coulee Dam) in the Mainstem of Lake Roosevelt



Source: Teck (2017)

Figure 2-33. Zinc Concentration by River Mile from River Mile 745 (near the U.S.-Canada border) to River Mile 596 (near Grand Coulee Dam) in the Mainstem of Lake Roosevelt



Source: Teck (2017)

A major concern due to the slag deposits in the reservoir's bed sediments is the rate these metals are leaching into the overlying water column, but this process has not been studied enough to be able to characterize in situ leaching rates. The rate of any leaching is likely increased in the summer time when, as displayed in Figure 2-14 through Figure 2-21, DO levels can approach 0 mg/L. This is because when oxygen is depleted, anaerobic microbes begin using metals as electron acceptors which tends to increase a metal's solubility, as well as the solubility of any constituents sorbed to it. Surface water samples were collected throughout the reservoir in September and October, about a month after DO levels are the lowest. Elevated metals in surface water samples indicate that some leaching of these heavy metals associated with slag contaminants into the overall water column is occurring, but likely not at very high levels (Exponent 2013). In addition to Teck's study, Scofield and Pavlik-Kunkel (2000) analyzed trace metals in the surface waters at various locations across Lake Roosevelt from January 1998 to March 2000 and reported their findings as total recoverable concentrations. All metals reported by Scofield and Pavlik-Kunkel (2000) displayed higher levels (Table 2-15) then reported in the Teck funded report by Exponent and Parametrix (Exponent 2013) for all metals except zinc. This may be because Teck dumped slag into the Columbia River until the mid-1990s and the younger slag is more biologically available than the older slag present when the surface waters were re-sampled in 2013, because the Exponent and Parametrix study collected data over a short time period, or because of some other environmental variability not discussed in either report.

Table 2-15. Metals in Undisturbed Surface Water Samples Collected from September to October 2009

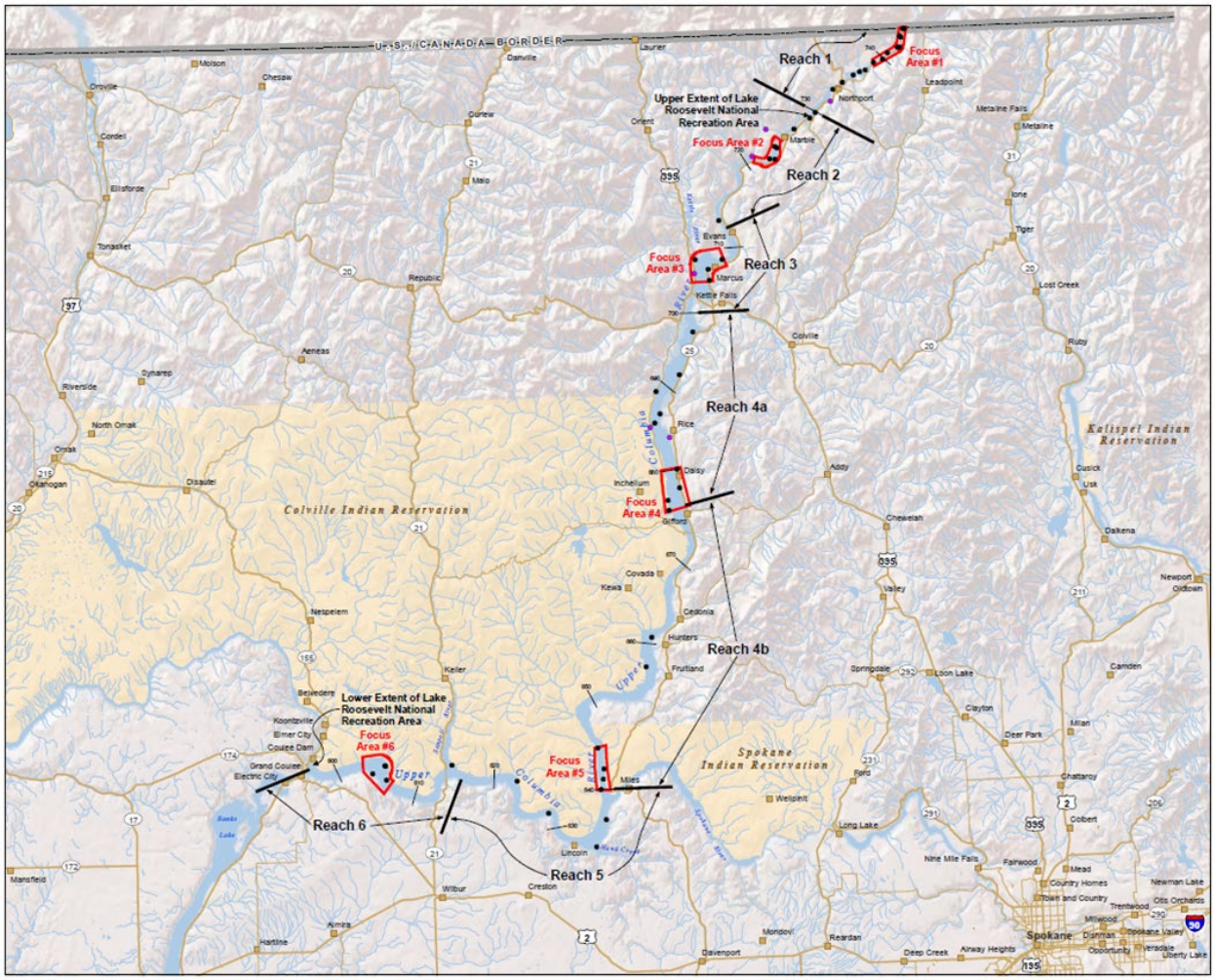
Analyte	Concentration Units	Measurement Basis	Number of Acceptable Analyses	Number of Detected Values	Minimum Value	Mean Value	Maximum Value
Aluminum	µg/L	Dissolved	101	4	5.8	12.5	18.9
Aluminum	µg/L	Total	101	46	11.3	22.3	75.9
Antimony	µg/L	Dissolved	99	46	0.114	0.177	0.229
Antimony	µg/L	Total	99	93	0.118	0.178	0.229
Arsenic	µg/L	Dissolved	101	24	0.2	0.494	0.7
Arsenic	µg/L	Total	101	0	–	–	–
Inorganic Arsenic	µg/L	Dissolved	101	101	0.046	0.365	0.749
Inorganic Arsenic	µg/L	Total	101	91	0.0557	0.388	0.923
Barium	µg/L	Dissolved	101	101	17.6	30.9	58.6
Barium	µg/L	Total	101	101	18	31.4	59.7
Beryllium	µg/L	Dissolved	101	0	–	–	–
Beryllium	µg/L	Total	101	2	0.007	0.0075	0.008
Boron	µg/L	Dissolved	74	0	–	–	–
Boron	µg/L	Total	74	1	1.47	1.47	1.47
Cadmium	µg/L	Dissolved	101	87	0.00367	0.0121	0.028
Cadmium	µg/L	Total	101	90	0.00617	0.0162	0.033
Chromium	µg/L	Dissolved	100	1	0.16	0.16	0.16
Chromium	µg/L	Total	101	0	–	–	–
Cobalt	µg/L	Dissolved	99	92	0.0208	0.0354	0.088
Cobalt	µg/L	Total	99	97	0.0287	0.0448	0.081
Copper	µg/L	Dissolved	101	2	0.64	0.775	0.91
Copper	µg/L	Total	101	82	0.45	0.65	1.59
Iron	µg/L	Dissolved	93	14	2.07	4.8	19.9

Iron	µg/L	Total	101	76	4	28	110
Lanthanum	µg/L	Dissolved	74	5	0.003	0.00318	0.008
Lanthanum	µg/L	Total	74	74	0.011	0.023	0.122
Lead	µg/L	Dissolved	101	0	0.0025	0.0076	0.0235
Lead	µg/L	Total	101	34	0.0125	0.09	0.352
Lithium	µg/L	Dissolved	74	13	1.47	2.23	2.9
Lithium	µg/L	Total	74	11	1.43	2.27	3.4
Manganese	µg/L	Dissolved	99	3	0.375	0.81	1.1
Manganese	µg/L	Total	99	99	1.58	3.2	13.2

Source: Exponent (2013)

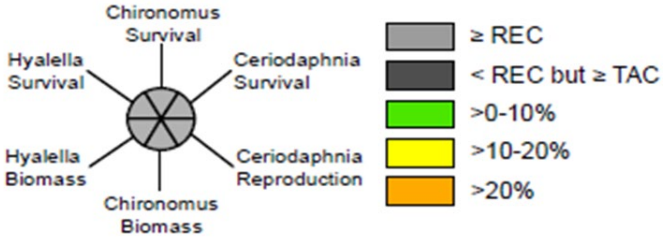
The toxicity of the metals in sediments gathered throughout the reservoir has been analyzed using three different macroinvertebrates, amphipods of the Hyalella genus, midges of the genus Chrionomus, and water fleas of the genus Ceriodaphnia. The survival, reproduction rate, and biomass accumulation (biological activity) of each of these macroinvertebrates was studied in samples of sediments of Lake Roosevelt and compared to an uncontaminated standard. The standard provided a “reference envelope” to compare the biological activity of the macroinvertebrates to. Those samples which displayed reduced biological activity were considered more toxic than samples which did not reduce the biological activity. Figure 2-34 and Figure 2-35 show the locations of samples collected and provide a key to interpret the results from this work, and then the results are displayed in Figure 2-36 through Figure 2-46. Almost all the samples which displayed toxicity were found north of Kettle Falls, which is where the majority of the slag deposits have been recorded.

Figure 2-34. Map of Sediment Toxicity Analysis Sample Locations Within Lake Roosevelt, from the U.S.-Canada Border to Grand Coulee Dam



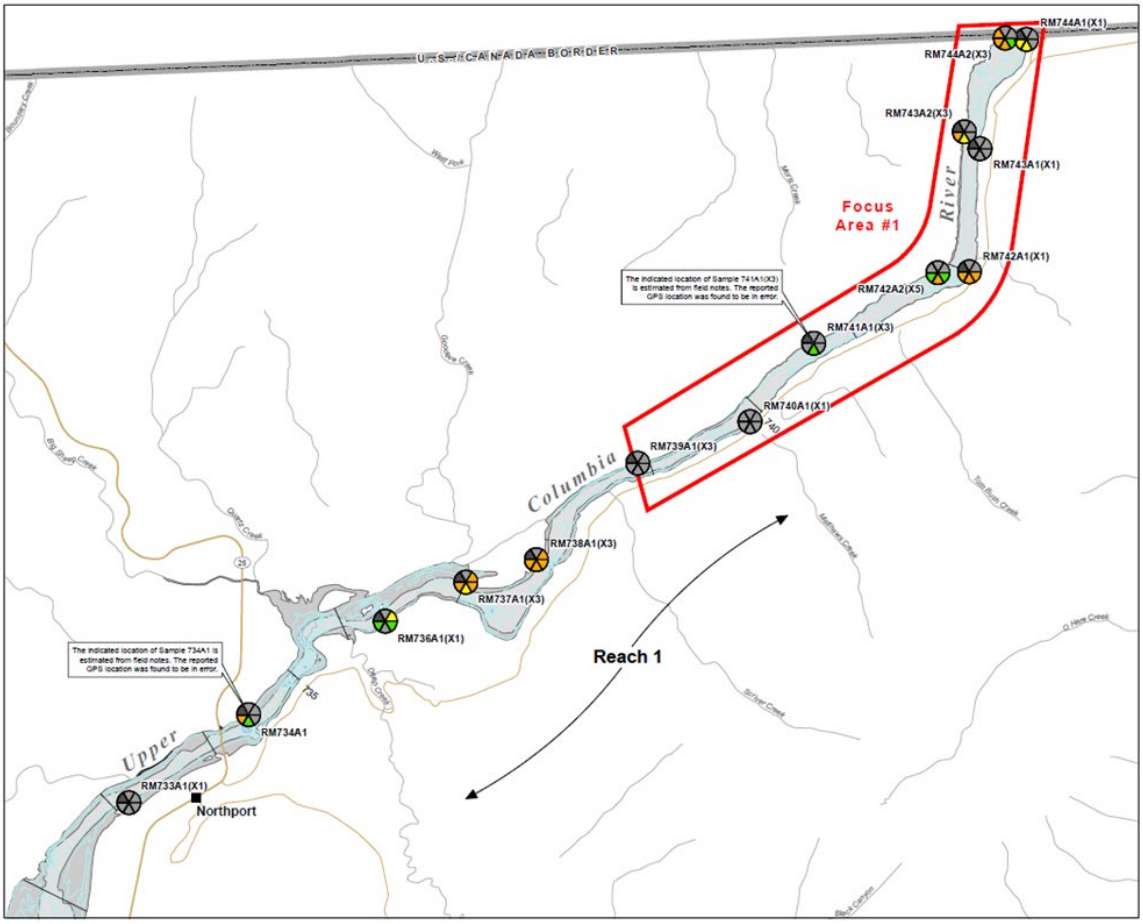
Source: CH2M Hill (2012)

Figure 2-35 Key to Shaded Pies Associated with the Sediment Toxicity Analysis Figures



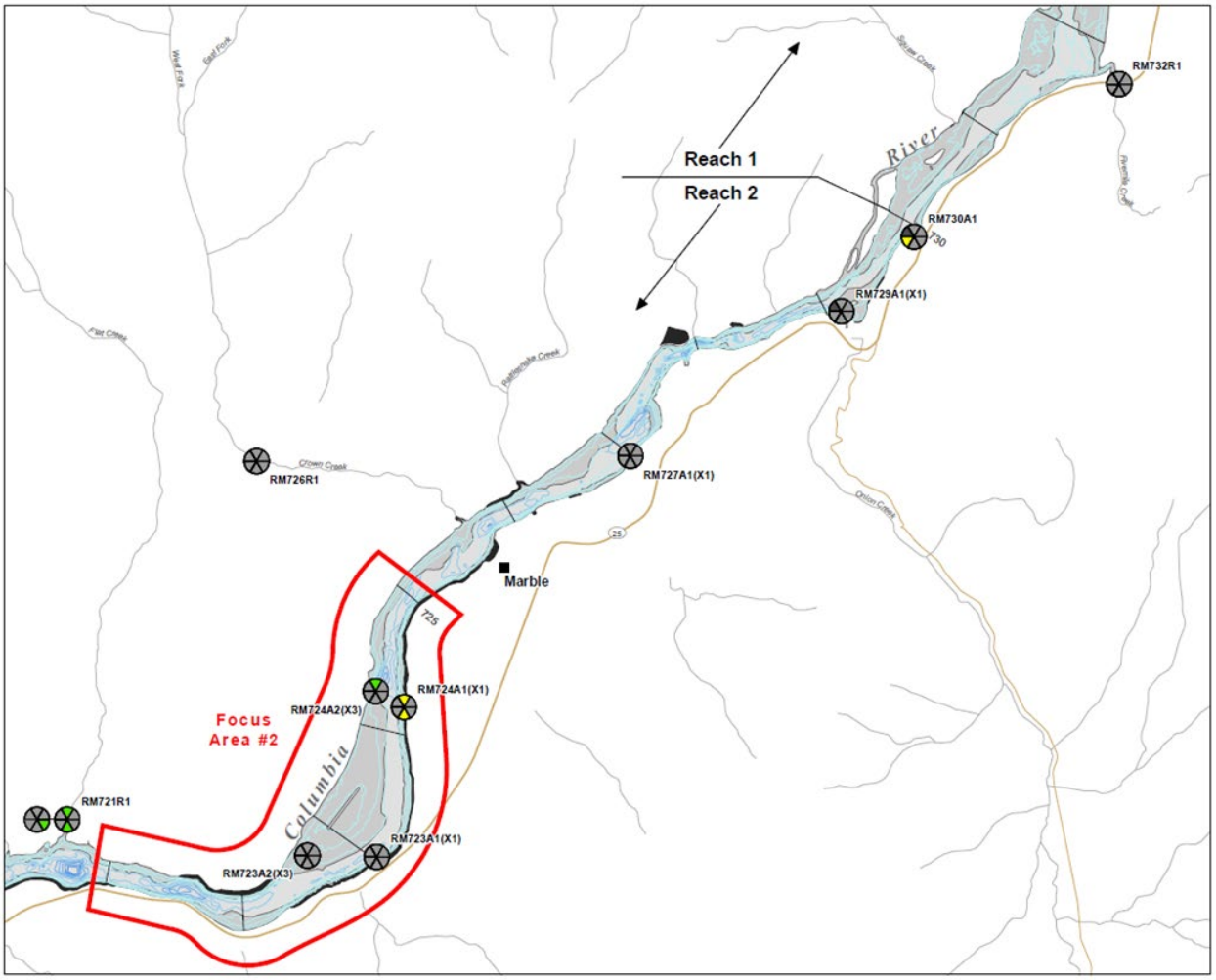
Note: Associated with Figure 2-36 through Figure 2-46. Each pie section is related to a specific macroinvertebrate and its survival, biomass, or reproduction (biological activity) rates. REC refers to a "reference envelope" or the biological activity rate of the same macroinvertebrate species in a similar, but uncontaminated sample. TAC is the test acceptability criterion in which the biological activity in a sample was below the reference envelope rate, but was close enough to be acceptable. The colors within a pie section indicate the given species biological activity rates within a soil sample in relation to a standard soil reference. Light and dark grey indicate a survival rate close to the reference, green indicates survival rates were 10 percent less than the reference envelope, yellow between 10 to 20 percent less than the reference envelope, and orange indicates a survival rate greater than 30 percent below the reference envelope survival rate. Samples which resulted in greater than 20 percent below the reference envelope survival rates tended to be collected from Reaches 1 through 3.
Source: CH2M Hill (2012)

Figure 2-36. Results of Sediment Toxicity Analysis Through Survival of Macroinvertebrates, Reach 1



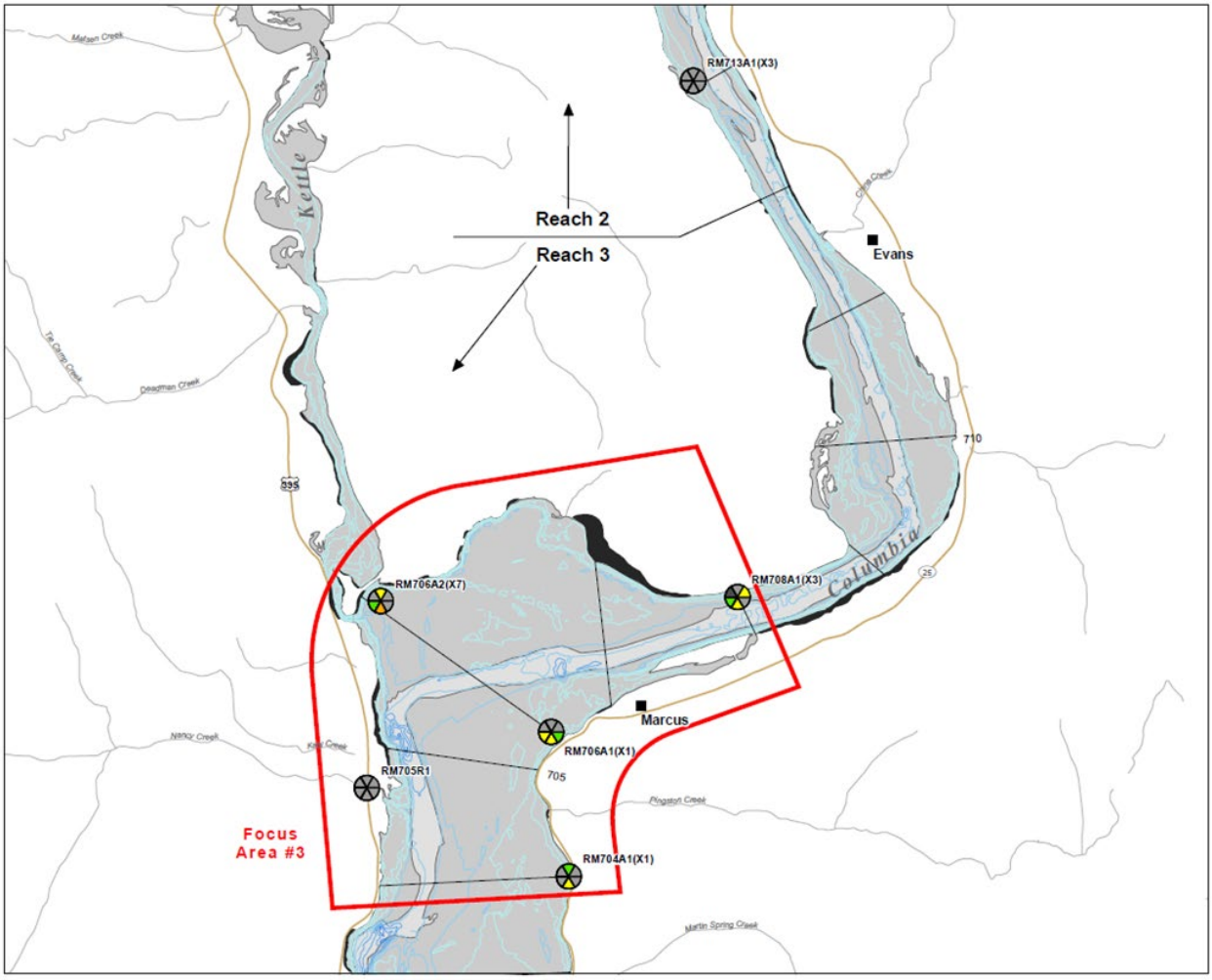
Note: See Figure 2-35 for key to pie sections.
Source: CH2M Hill (2012)

Figure 2-37. Results of Sediment Toxicity Analysis Through Survival of Macroinvertebrates, Reaches 1 and 2



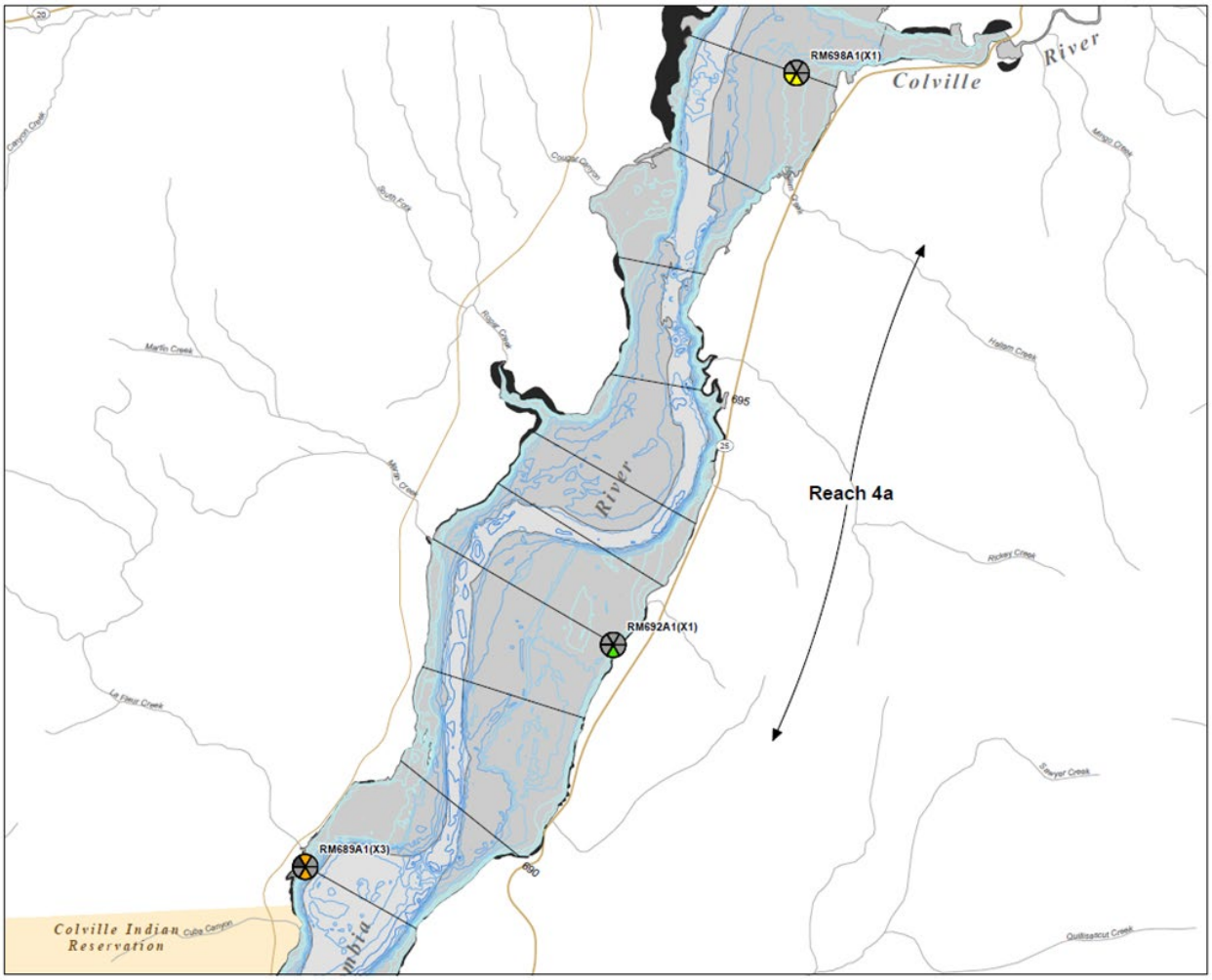
Note: See Figure 2-35 for key to pie sections.
Source: CH2M Hill (2012)

Figure 2-38. Results of Sediment Toxicity Analysis Through Survival of Macroinvertebrates, Reaches 2 and 3



Note: See Figure 2-35 for key to pie sections.
Source: CH2M Hill (2012)

Figure 2-39. Results of Sediment Toxicity Analysis Through Survival of Macroinvertebrates, Reach 4a



Note: See Figure 2 35 for key to pie sections.
Source: CH2M Hill (2012)

Figure 2-40. Results of Sediment Toxicity Analysis Through Survival of Macroinvertebrates, Reach 4a

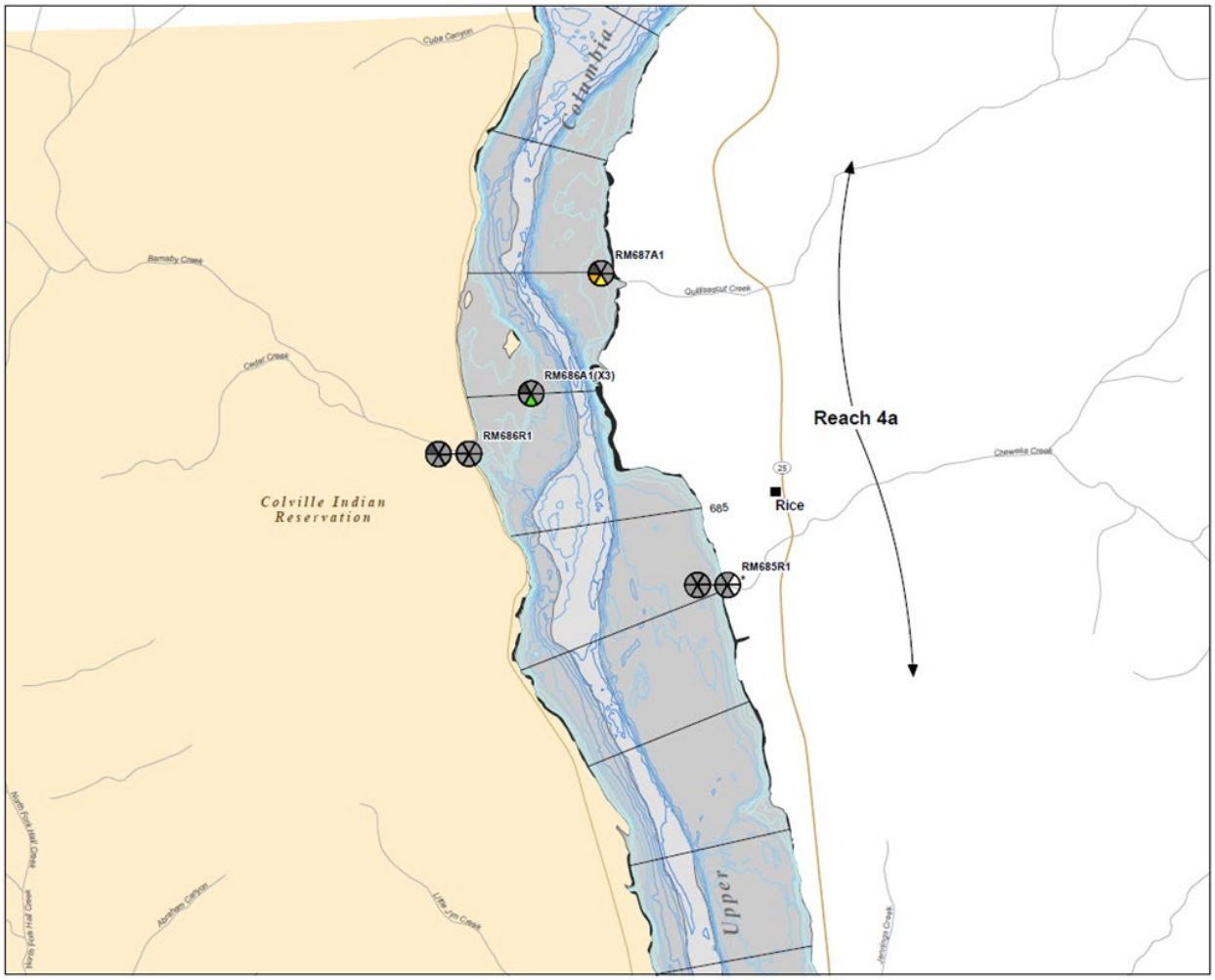
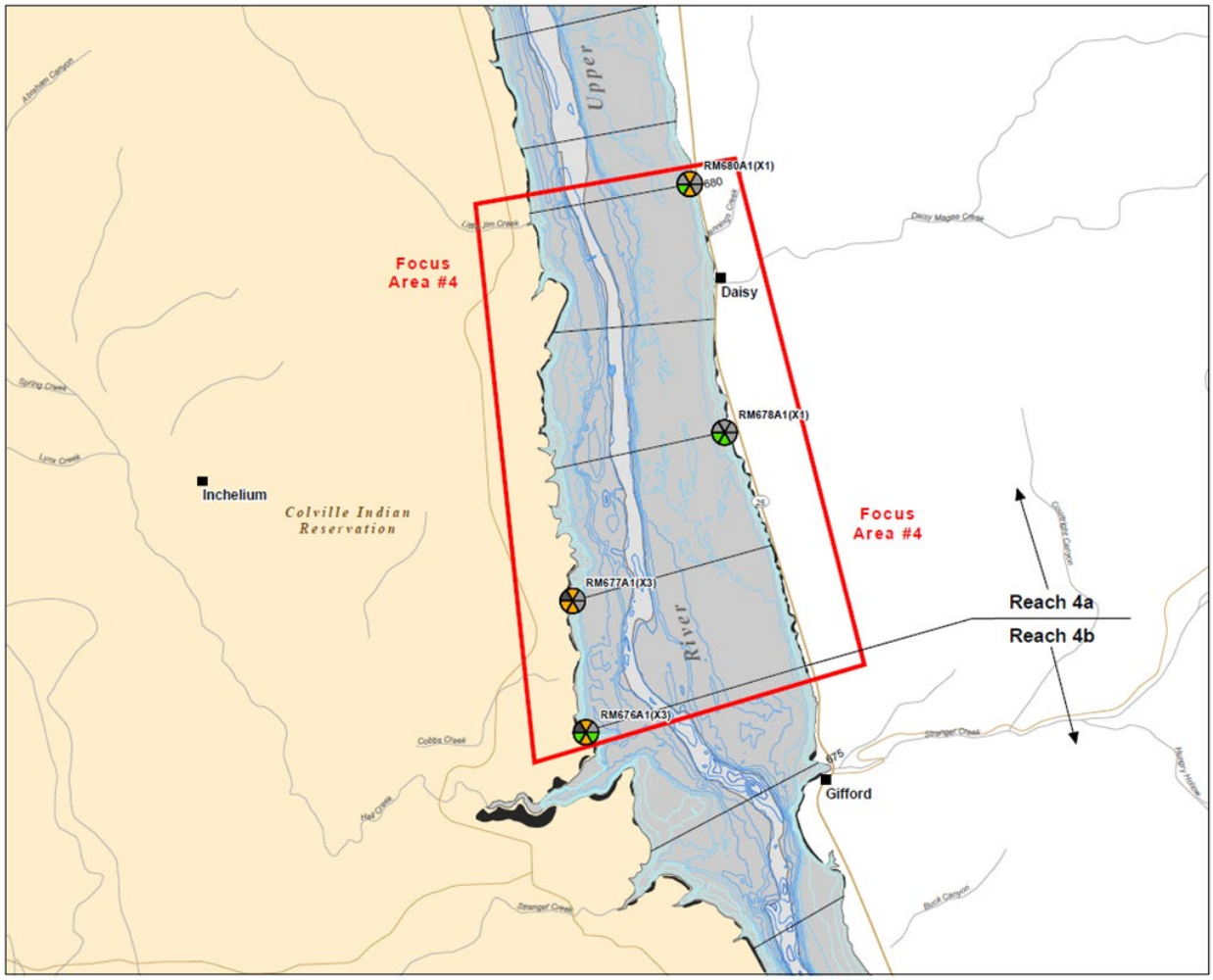
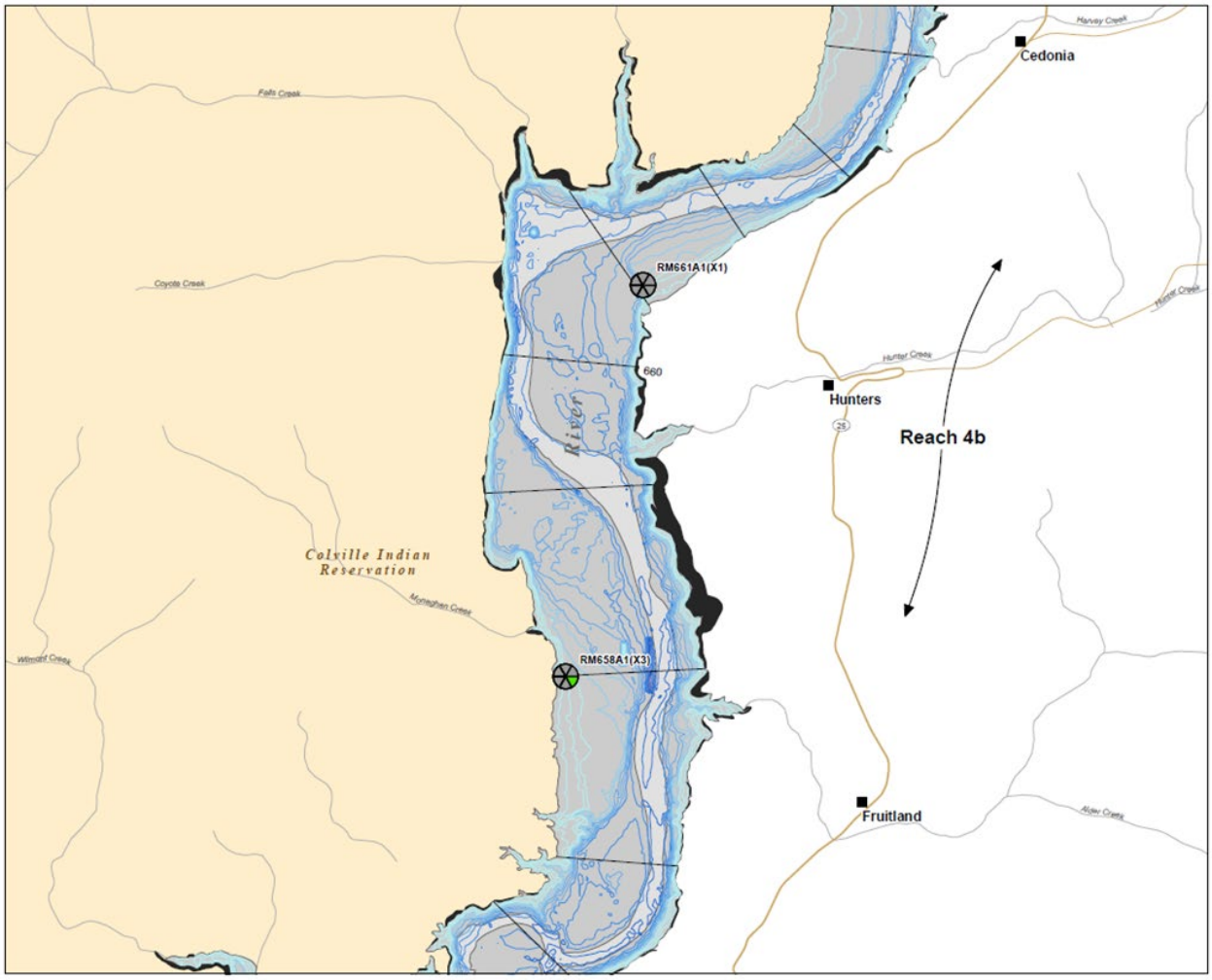


Figure 2-41. Results of Sediment Toxicity Analysis Through Survival of Macroinvertebrates, Reach 4a



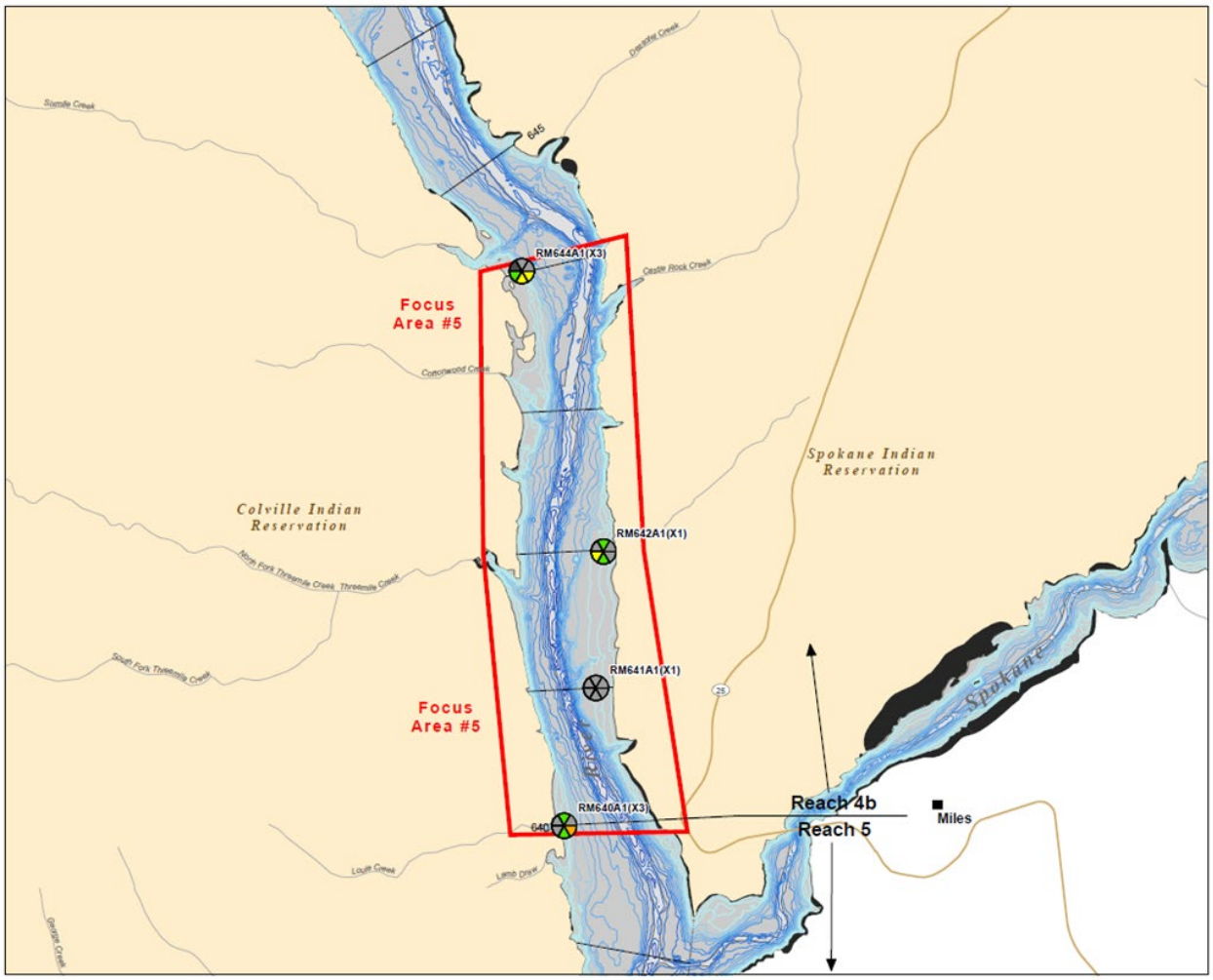
Note: See Figure 2-35 for key to pie sections.
Source: CH2M Hill (2012)

Figure 2-42. Results of Sediment Toxicity Analysis Through Survival of Macroinvertebrates, Reach 4b



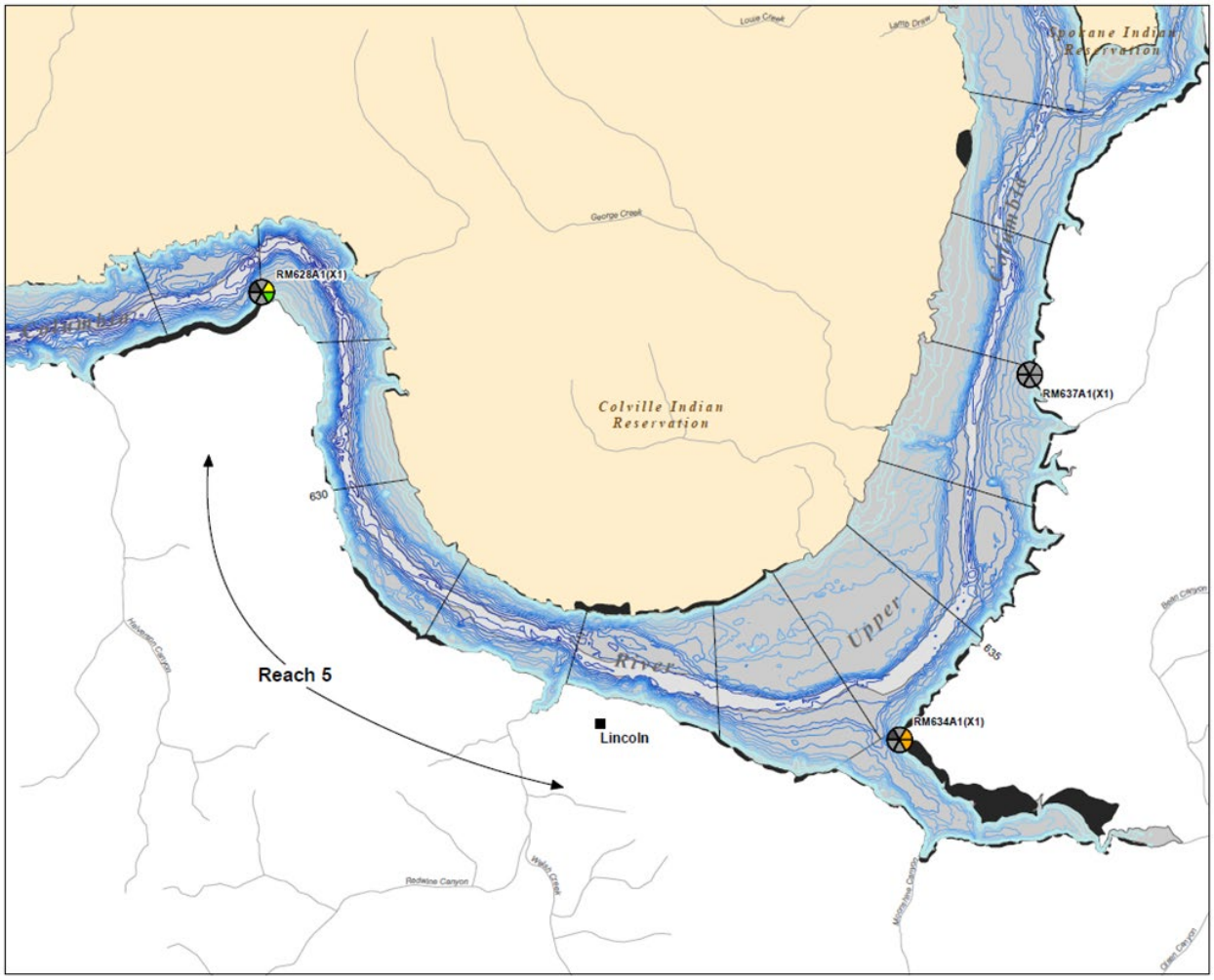
Note: See Figure 2-35 for key to pie sections.
Source: CH2M Hill (2012)

Figure 2-43. Results of Sediment Toxicity Analysis Through Survival of Macroinvertebrates, Reaches 4b and 5



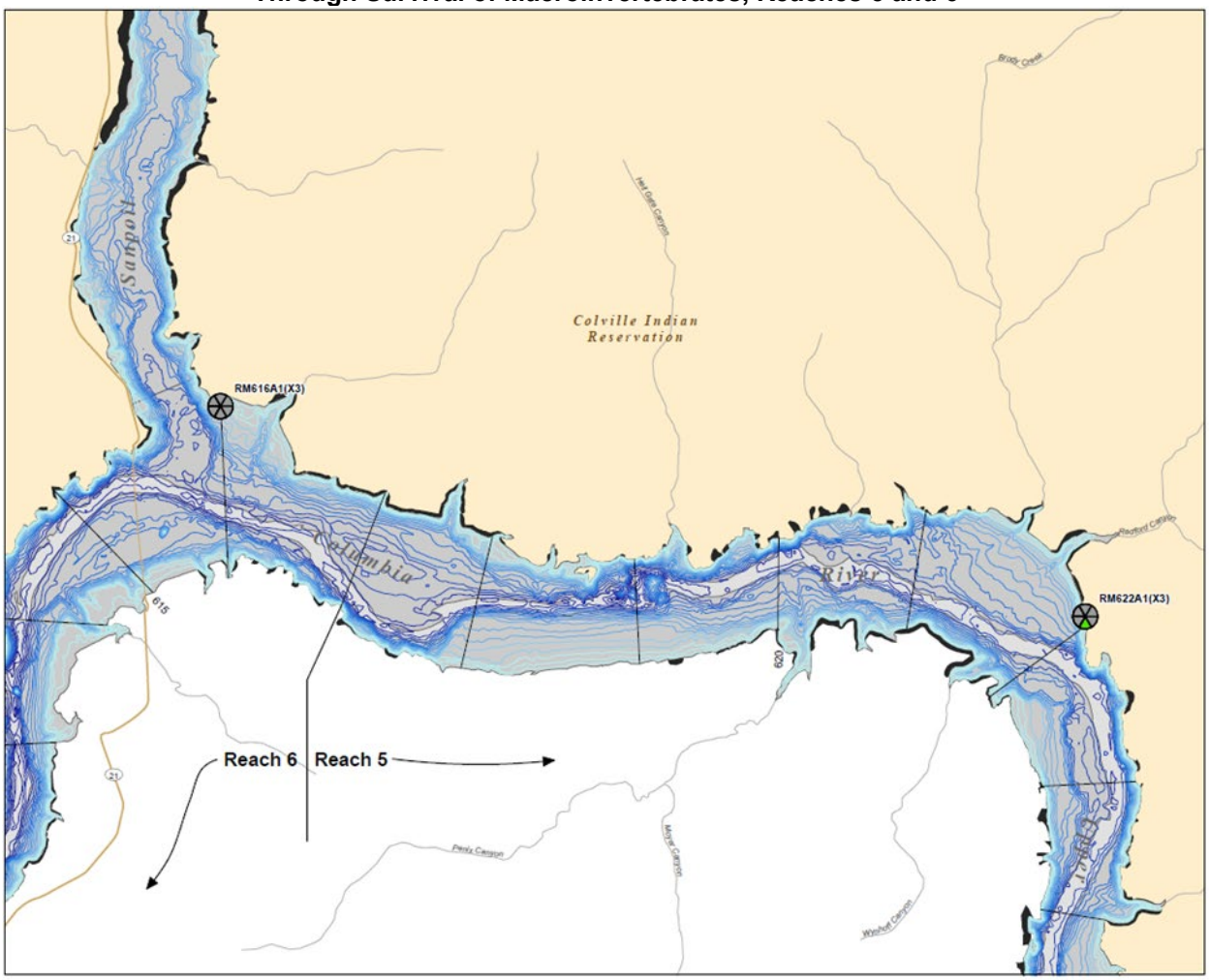
Note: See Figure 2-35 for key to pie sections.
Source: CH2M Hill (2012)

Figure 2-44. Results of Sediment Toxicity Analysis Through Survival of Macroinvertebrates, Reach 5



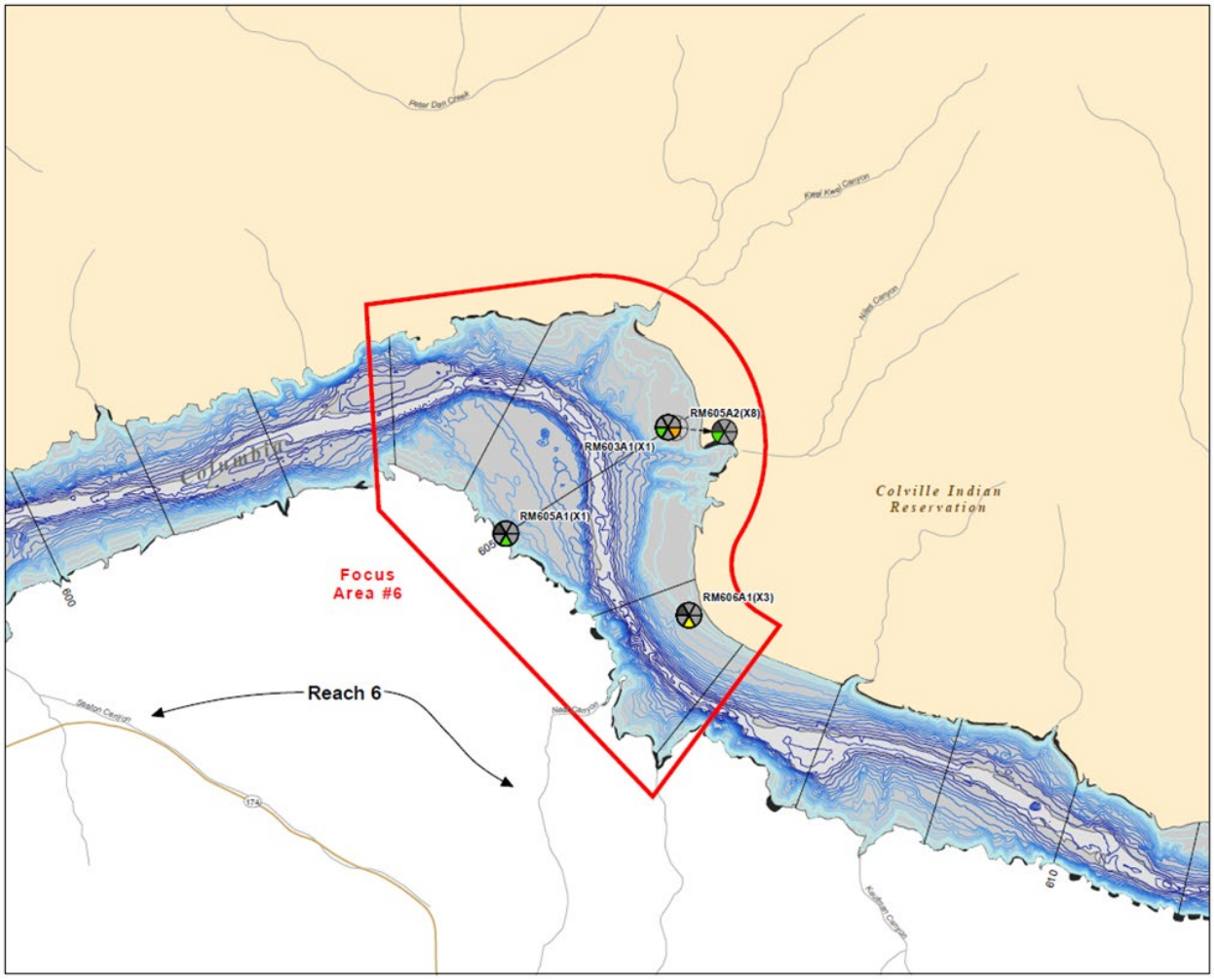
Note: See Figure 2-35 for key to pie sections.
Source: CH2M Hill (2012)

Figure 2-45. Results of Sediment Toxicity Analysis Through Survival of Macroinvertebrates, Reaches 5 and 6



Note: See Figure 2-35 for key to pie sections.
Source: CH2M Hill (2012)

Figure 2-46. Results of Sediment Toxicity Analysis Through Survival of Macroinvertebrates, Reach 6



Note: See Figure 2-35 for key to pie sections.
Source: CH2M Hill (2012)

In the upper portion of Lake Roosevelt higher metal concentrations in lake bed sediments are well documented. Given this, bottom feeding fish have been found to have higher metal concentrations in the upper portion of the reservoir, near the U.S.-Canada border, when compared with primary producers (e.g., plankton, aquatic plants, cyanobacteria) because the primary method for metals entering the food web in this upper region is likely through direct consumption of sediments (Munn, Cox, and Dean 1994). However, the lower portion of Lake Roosevelt near Grand Coulee Dam has much lower oxygen concentrations than the upper reach, and here higher amounts of metal bioaccumulation are observed throughout the food web, as is a reduction in midge growth (Munn, Cox, and Dean 1994; Besser et al. 2007). Additionally, seasonal changes in the pool level of the reservoir which change the redox interface depth can change the solubility of metals in water, producing further variation for the concentration and bioaccumulation of metals within Lake Roosevelt (Besser et al. 2007). However, while the concentrations of metals in Lake Roosevelt do fluctuate, in general there tends to be a low enough amount of bioaccumulation to allow human consumption of limited

amounts of fish to be within acceptable health risk parameters, although subsistence-level consumption is not advised (Munn 2000; Ecology 2017).

Mass movement of slag, and associated sediments, in the reservoir has not been characterized. Given this, it cannot be determined in this report at what rate, if at all, large quantities of slag-associated bed sediments are moving toward Grand Coulee Dam. In addition to water transport being a concern, air transport of contaminated sediments is also a concern. Majewski et al. (2001) reported that slag contaminants associated with fine-grained sediments could be components of airborne dust from exposure of bed sediments during drawdowns, but sufficient studies were not conducted in order to determine at what rate slag-associated sediments are transported through the air (Majewski et al. 2001).

One beach remediation project has been completed in an effort to reduce human exposure. Over 9,100 tons of sediment from Black Sand Beach north of the town of Northport was removed and replaced with clean fill (EPA 2011). In addition, Teck and EPA have sampled 43 beaches along the upper Columbia River for metal contamination. In addition to sampling beach soils for metals, Teck also studied the particle size of smelting byproducts typically associated with each river mile (Table 2-14), and the percent weight of slag in sediment samples (Table 2-16). The composition of the slag size found in sediment samples is displayed in Table 2-17. In addition, the average chemical composition of the slag is displayed in Table 2-17, Table 2-18 and Table 2-19 (Teck Inc. 2017).

Throughout its history, Teck has discharged over 220 tons of mercury to the Columbia River, although its operations today are far less polluting than they once were (Vlassopolous 2010). Additional mercury contamination of the Columbia River basin occurs from industrial and energy-related activities taking place both within and outside of the basin. Mercury is a special challenge because at least some of the mercury pollution being contributed today comes from global atmospheric sources. While the concentration of mercury tends to be low in the atmosphere, bioaccumulation of the metal can result in fish consumption advisories which have been issued throughout the Basin (EPA 2009). Additionally, it has been documented that water management can provide a method to reduce mercury bioaccumulation by keeping water levels raised, particularly during the spring and summer growing seasons from January to July (Willacker 2016).

Table 2-16. Percent Weight Composition of Slag in Sediment Samples by River Mile

River Mile	% w/w	River Mile	% w/w
(Border) 745	31.1	722	76
745	16.8	722	3.6
743	33	722	50.5
738	27	721	46.6
738	13.6	716	66.3
735	48.9	711	47
735	10.9	711	52.5
735	29	709	60.2
733	0.319	709	59.8
733	22.9	709	61.4

River Mile	% w/w	River Mile	% w/w
733	12.3	709	59.8
732	3	707	35.4
729	71.3	705	37.1
728	23.6	705	0.234
727	5.4	692	0.024
726	48.7	689	0.0005
725	72.4	678	0.003
724	26.4	673	0.013
724	60.4	664	0
724	66.7	652	0
723	44	645	0
723	62.7	604	0
723	52.9	(Dam) 599	0

Note: % w/w = percent weight by weight, i.e., X g of slag in 100 g of water. RM 745 is near the U.S.-Canada border and RM 599 is near the Grand Coulee Dam.
Source: Teck (2017)

Table 2-17. Metals in Undisturbed Surface Water Samples Collected from September to October 2009

Analyte	Concentration Units	Measurement Basis	Number of Acceptable Analyses	Number of Detected Values	Minimum Value	Mean Value	Maximum Value
Mercury	ng/L	Dissolved	101	0	–	–	–
Mercury	ng/L	Total	101	4	0.7	1.88	4.24
Molybdenum	µg/L	Dissolved	101	101	0.519	0.591	0.719
Molybdenum	µg/L	Total	101	101	0.49	0.582	0.712
Neodymium	µg/L	Dissolved	74	0	–	–	–
Neodymium	µg/L	Total	74	26	0.0133	0.029	0.11
Nickel	µg/L	Dissolved	100	82	0.162	0.41	0.96
Nickel	µg/L	Total	100	82	0.17	0.412	0.75
Scandium	µg/L	Dissolved	74	64	0.0977	0.253	0.359
Scandium	µg/L	Total	74	65	0.106	0.266	0.406
Selenium	µg/L	Dissolved	101	3	0.3	0.4	0.5
Selenium	µg/L	Total	101	1	0.3	0.3	0.3
Silicon	µg/L	Dissolved	74	74	764	1440	2760
Silicon	µg/L	Total	74	74	791	1470	2740
Strontium	µg/L	Dissolved	74	74	62.6	93	107
Strontium	µg/L	Total	74	74	63.5	94	109
Thallium	µg/L	Dissolved	101	10	0.026	0.0312	0.042
Thallium	µg/L	Total	101	12	0.0142	0.0305	0.04
Thorium	µg/L	Dissolved	74	3	0.006	0.0068	0.008
Thorium	µg/L	Total	74	17	0.005	0.0106	0.029
Tin	µg/L	Dissolved	73	0	–	–	–
Tin	µg/L	Total	73	1	0.03	0.03	0.03
Titanium	µg/L	Dissolved	74	0	–	–	–
Titanium	µg/L	Total	74	1	1.7	1.7	1.7
Tungsten	µg/L	Dissolved	74	0	–	–	–
Tungsten	µg/L	Total	74	0	–	–	–
Uranium	µg/L	Dissolved	101	101	0.404	0.481	0.573
Uranium	µg/L	Total	101	101	0.405	0.487	0.544
Vanadium	µg/L	Dissolved	101	62	0.1	0.159	0.23
Vanadium	µg/L	Total	101	3	0.193	0.271	0.31
Zinc	µg/L	Dissolved	101	0	–	–	–
Zinc	µg/L	Total	101	0	–	–	–

Note: ng/L = nanograms per liter.
Source: Exponent (2013)

Table 2-18. Organic Compounds in the Waters of Lake Roosevelt

Analyte	Concentration Units	Measurement Basis	Number of Acceptable Analyses	Number of Detected Values	Minimum Value	Mean Value	Maximum Value
Organic Carbon	mg/L	Dissolved	101	0	–	–	–
Organic Carbon	mg/L	Total	101	0	–	–	–
Trichlorobenzene	µg/L	Total	43	2	0.008	0.0107	0.065
Dichlorobenzene	µg/L	Total	43	2	0.011	0.0126	0.039
Trichlorophenol	µg/L	Total	43	1	0.029	0.0306	0.058
Dichlorophenol	µg/L	Total	43	0	–	–	–
Dimethylphenol	µg/L	Total	43	0	–	–	–
Chlorophenol	µg/L	Total	43	2	0.027	0.0294	0.063
Chloroaniline	µg/L	Total	43	0	–	–	–
Methylphenol	µg/L	Total	43	0	–	–	–
Nitroaniline	µg/L	Total	43	0	–	–	–
Nitrophenol	µg/L	Total	43	0	–	–	–
Acetophenone	µg/L	Total	43	0	–	–	–
Benzaldehyde	µg/L	Total	43	0	–	–	–
Benzoic Acid	µg/L	Total	43	1	0.55	0.77	1.6
Benzyl Alcohol	µg/L	Total	43	2	0.0365	0.04	0.079
Caprolactam	µg/L	Total	43	0	–	–	–
Carbazole	µg/L	Total	43	1	0.000195	0.00063	0.0075
Dibenzothiophene	ng/L	Total	43	0	–	–	–
Diethyl Phthalate	µg/L	Total	43	8	0.006	0.013	0.1
Dimethyl Phthalate	µg/L	Total	43	2	0.0105	0.0124	0.045
Hexachlorobenzene	ng/L	Total	43	0	–	–	–
Hexachloroethane	µg/L	Total	43	0	–	–	–
Isophorone	µg/L	Total	43	1	0.008	0.0089	0.033
Nitrobenzene	µg/L	Total	43	0	–	–	–
Pentachlorophenol	µg/L	Total	43	1	0.17	0.18	0.52
Phenol	µg/L	Total	43	1	0.0315	0.035	0.068
Biphenyl	µg/L	Total	43	0	–	–	–
Methylnaphthalene	ng/L	Total	43	0	–	–	–
Acenaphthene	ng/L	Total	43	0	–	–	–
Acenaphthylene	ng/L	Total	43	3	0.185	0.22	0.89
Anthracene	ng/L	Total	43	1	0.145	0.158	0.34
Benzo(e)pyrene	ng/L	Total	43	1	0.245	0.29	1.1
Chrysene	ng/L	Total	43	1	0.325	0.35	1.02
Dibenzofuran	µg/L	Total	43	2	0.009	0.0102	0.033
Fluoranthene	ng/L	Total	43	0	–	–	–
Fluorene	ng/L	Total	43	0	–	–	–
Naphthalene	ng/L	Total	43	1	1.05	9.8	28
Perylene	ng/L	Total	43	1	0.18	0.204	0.77
Phenanthrene	ng/L	Total	43	0	–	–	–
Pyrene	ng/L	Total	43	0	–	–	–

Source: Exponent (2013)

Table 2-19. Average Content of Metals in Sediments as Sampled from U.S.-Canada Border to Grand Coulee Dam

Analyte	Concentration Units	Number of Acceptable Analyses	Number of Detected Values	Minimum Value	Mean Value	Maximum Value
Aluminum	mg/kg	120	120	4,670	16,800	29,500
Antimony	mg/kg	120	119	0.0185	12.9	98
Arsenic	mg/kg	120	120	0.91	11.1	36.8
Barium	mg/kg	120	120	37.5	523	2390
Beryllium	mg/kg	120	120	0.133	0.605	1.2
Cadmium	mg/kg	120	120	0.07	3.4	13.1

Calcium	mg/kg	120	120	1,840	19,400	85,200
Chromium	mg/kg	120	120	2.28	42.7	146
Cobalt	mg/kg	120	120	2.74	17.8	70.4
Copper	mg/kg	120	120	3.88	445	3370
Iron	mg/kg	120	120	10,100	59,900	291,000
Lead	mg/kg	120	120	2.9	235	1080
Magnesium	mg/kg	120	120	1,940	9,320	23,300
Manganese	mg/kg	120	120	148	1,340	5,710
Mercury	mg/kg	120	119	0.001	0.399	1.9
Nickel	mg/kg	120	120	2.38	22.2	38.8
Potassium	mg/kg	120	120	861	2,620	5,090
Selenium	mg/kg	120	119	0.1	1.21	5
Silver	mg/kg	120	120	0.042	1.43	7.32
Sodium	mg/kg	120	118	23.3	591	2,740
Thallium	mg/kg	120	110	0.0215	0.441	1.23
Vanadium	mg/kg	120	120	14.9	39.4	57.1
Zinc	mg/kg	120	120	32.1	3,870	28,200

Source: Teck (2017)

In addition to slag from smelting, mercury contamination of the Columbia River Basin occurs from industrial and energy-related activities taking place both within and outside of the basin. Mercury is a special challenge because at least some of mercury pollution occurs from atmospheric deposition. The relative contribution of metals from aerial deposition and from slag contamination in the water is currently being studied. While the concentration of mercury tends to be low in the atmosphere, bioaccumulation of the metal can result in fish consumption advisories which continue to be issued throughout the Columbia River Basin (EPA 2009).

2.3.4 Organics

Organic compounds may be toxins, vitamins, or food sources. While there are many sources for organic compounds, both natural and anthropogenic, the concentrations reported by the Teck study in Table 2-20 and Table 2-21 are generally acceptable values and should not cause harm to the ecosystem (Teck 2017). As discussed below in more detail under the Nitrogen and Phosphorous section as well as the Pesticides section, organic compound concentrations are not currently a major concern. Organic carbon is very low in the reservoir with none detected at 101 sample locations in the lake reported by Exponent (2013), as displayed in Table 2-22. However, Polychlorinated Biphenyls (PCB) is a concern in the Spokane River, and have been documented in fish tissues at concentrations exceeding guidelines for human health in this river (Marget, 1999). Currently, it is unknown at what rate PCBs from the Spokane River are entering Lake Roosevelt.

Table 2-20. Nitrogen and Phosphorous Concentrations in Lake Roosevelt

Analyte	Concentration Units	Measurement Basis	Number of Acceptable Analyses	Number of Detected Values	Overall Minimum Value	Overall Mean Value	Overall Maximum Value
Ammonia	mg/L	total	101	44	0.0045	0.0132	0.0405
Nitrate + Nitrite	mg/L	total	101	2	0.0045	0.0144	0.0375
Phosphorus	mg/L	total	101	2	0.002	0.00383	0.009

Source: Teck (2017)

Table 2-21. Four Trophic State Indices in Lake Roosevelt and Major Tributaries During 2016

Reach	Chl-*a*	Secchi	TN	TP
Upper	33	35	26	30
Middle	33	36	26	30
Lower	30	30	27	30
Spokane	34	36	46	35
Sanpoil	31	36	28	39
Reservoir	**32**	**34**	**31**	**32**

Note: Chl-a = chlorophyll a, Secchi = Secchi disk depth, TN = total nitrogen, and TP = total phosphorous.
Source: Kain, Knudson, and Nichols (2018)

Table 2-22. Organic Carbon in Lake Roosevelt

Analyte	Concentration Units	Measurement Basis	Number of Acceptable Analyses	Number of Detected Values	Minimum Value	Mean Value	Maximum Value
Organic Carbon	mg/L	Dissolved	101	0	–	–	–
Organic Carbon	mg/L	Total	101	0	–	–	–

Source: Exponent (2013)

2.3.5 Nitrogen and Phosphorous

Biologically available phosphorous, like nitrogen, is an essential nutrient to life, and both often act as the limiting component for the proliferation of simple organisms, such as an algal bloom, in a waterbody. When there is an excess of both nutrients in biologically available form, biological life tends to flourish until it uses up the other components required for life, such as oxygen (at least for aerobic organisms). Given this, the total phosphate and nitrogen concentrations are noteworthy because high levels of bioavailable phosphorous and nitrogen can result in large algal blooms which may ultimately result in reduced oxygen levels below that required to sustain fish life, and result in massive fish die-offs.

The primary forms of inorganic nitrogen in the waters of Lake Roosevelt are nitrate, ammonia and nitrite. Nitrite is highly unstable and doesn't last long in the environment, but instead is converted to nitrate. Ammonia is usually present in concentrations higher than nitrite, though it can also be nitrified to nitrate. Ammonia is also more biologically available to plants and animals than nitrate, but less biologically available than nitrite, and at high concentrations both ammonium and nitrite are toxic to fish.

In 2004 to 2005 the mean annual total nitrogen and nitrate concentrations throughout the waterbody were 0.264 mg/L and 0.153 mg/L, respectively. Dissolved inorganic nitrogen was most often measured in the form of nitrate. Mean annual nitrate concentration at Porcupine Bay in the Spokane arm was reported at 0.433 mg/L, which was much greater than concentrations at Gifford (in the middle reach) (0.070 mg/L), Seven Bays (in the lower reach) (0.094 mg/L), Keller Ferry (near the Sanpoil River confluence) (0.088 mg/L), and Spring Canyon (in the lower reach) (0.082 mg/L). Nitrite

was measured twice at the report limit (0.01 mg/L) out of 30 total samples so the annual mean concentration was estimated at 0.005 mg/L. Annual mean ammonia concentration was estimated to be 0.026 mg/L, with 16 samples out of 30 having measurable amounts of ammonia. Mean annual total Kjeldahl nitrogen (TKN), nitrogen contained in organic nitrogen and ammonia, was 0.264 mg/L. Most nitrogen from sampling locations appears to be in the most oxidized form or associated with organic matter (Lee et al. 2006). This means most nitrogen is in a not very biologically available form.

This compares to more recent measurements collected in 2016 wherein total nitrogen and nitrate concentrations throughout the waterbody were 0.148 mg/L and 0.057 mg/L respectively. Mean annual nitrate concentration reported in the Spokane arm was 0.5661 mg/L, which was much higher than concentrations reported in the middle reach (0.1367 mg/L), the lower reach (0.1483 mg/L), the Sanpoil arm (0.1675 mg/L), or the upper reach at 0.1444 mg/L. The only nitrite concentrations measured above the reporting limit (0.01 mg/L) was observed in the Spokane arm during July at 0.014 mg/L. Annual mean ammonia concentration was reported as 0.007 mg/L. Mean annual TKN in the mainstream and the Sanpoil River arm was reported as 0.086 mg/L (Kain, Knudson, and Nichols 2018).

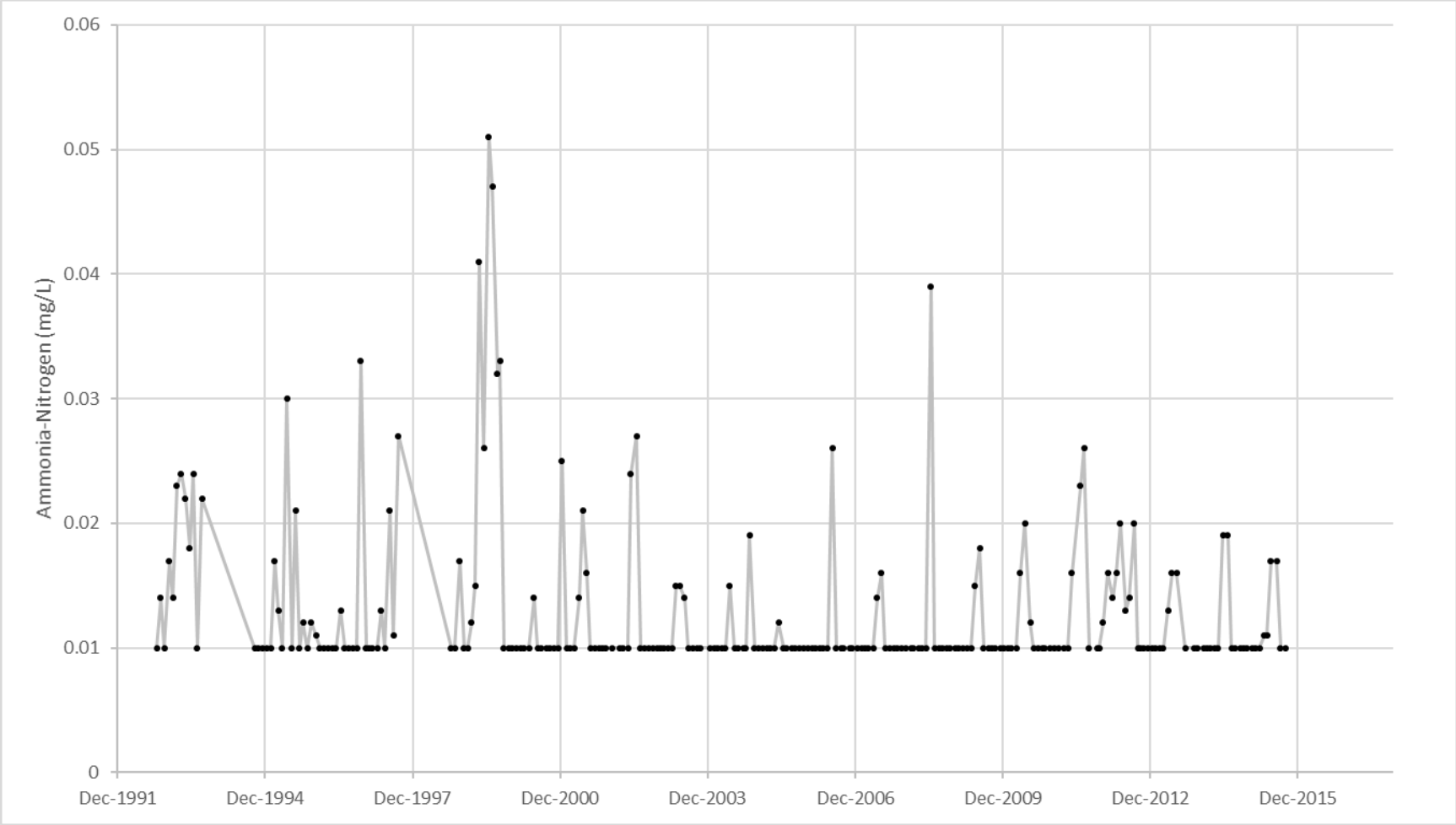
In 2006, mean annual dissolved inorganic nitrogen to dissolved inorganic phosphorus (DIN:DIP) ratio across the waterbody was 35:1 and total nitrogen to total phosphorous (TN:TP) 28:1, indicating potential phosphorus limitation. Annual mean DIN:DIP was greatest at Porcupine Bay in the Spokane arm (66:1) and lowest at Gifford in the middle reach of the reservoir (17:1). Annual mean TN:TP was also greatest at Porcupine Bay (44:1) and lowest at Gifford (16:1). Mean DIN:DIP across all locations was greatest in October (76:1) and lowest in July (18:1). Mean TN:TP across all locations was greatest in September (56:1) and least in June (13:1).

More recent measurements have found substantially different ratios. In 2016 Kain, Knudson, and Nichols (2018) reported that the mean TN:TP ratio decreased by 10 percent and the mean ratio of DIN:DIP increased by 240 percent compared to the 2006 to 2015 average. Annual mean DIN:DIP was highest in the Spokane arm (284:1) and lowest in the Sanpoil arm at 39:1 (for reference, the middle reach was reported at 94.1:1). Annual mean TN:TP was greatest in the Spokane arm at 65:1, and lowest in the Sanpoil arm at 17:1 (for reference, the middle reach was reported at 23:1) (Kain, Knudson, and Nichols 2018).

Annual mean total phosphorus concentration was 0.011 mg/L. Mean annual total phosphorus concentration at Porcupine Bay (0.019 mg/L) was notably greater than concentrations at Seven Bays (0.010 mg/L), Keller Ferry (0.008 mg/L), and Spring Canyon (0.008 mg/L). Annual mean orthophosphorus (ortho-P) concentration was 0.007 mg/L at all sites measured. Mean annual ortho-P at Porcupine Bay (0.012 mg/L) was higher than ortho-P at Spring Canyon (0.004 mg/L). Mean annual ortho-P across all other locations (Gifford, Seven Bays, and Keller Ferry) ranged from 0.005 to 0.006 mg/L (Lee et al. 2006).

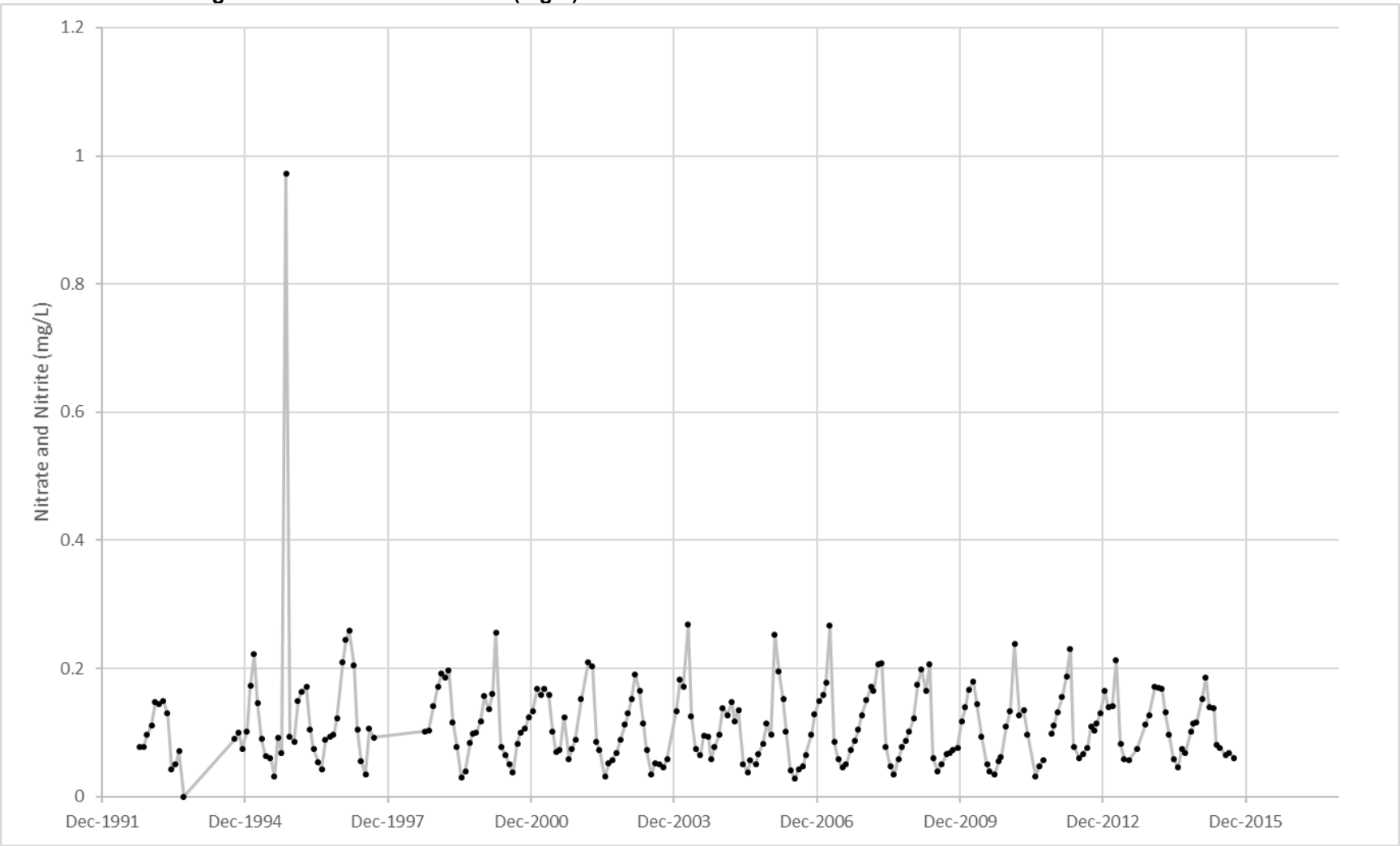
Generally, a phosphorous concentration below 0.025 mg/L is considered good in lakes and reservoirs, and a nitrate concentration at or below 0.6 mg/L is considered normal in this region (USGS 2017b). As was displayed in Table 2-20 and Table 2-21 and is displayed in Figure 2-47 through Figure 2-51, and the above discussion, nitrogen and phosphorous levels are generally reported at concentrations within regulatory limits.

Figure 2-47. Ammonia-Nitrogen (mg/L) Concentrations 0.5 mile downstream from Grand Coulee Dam



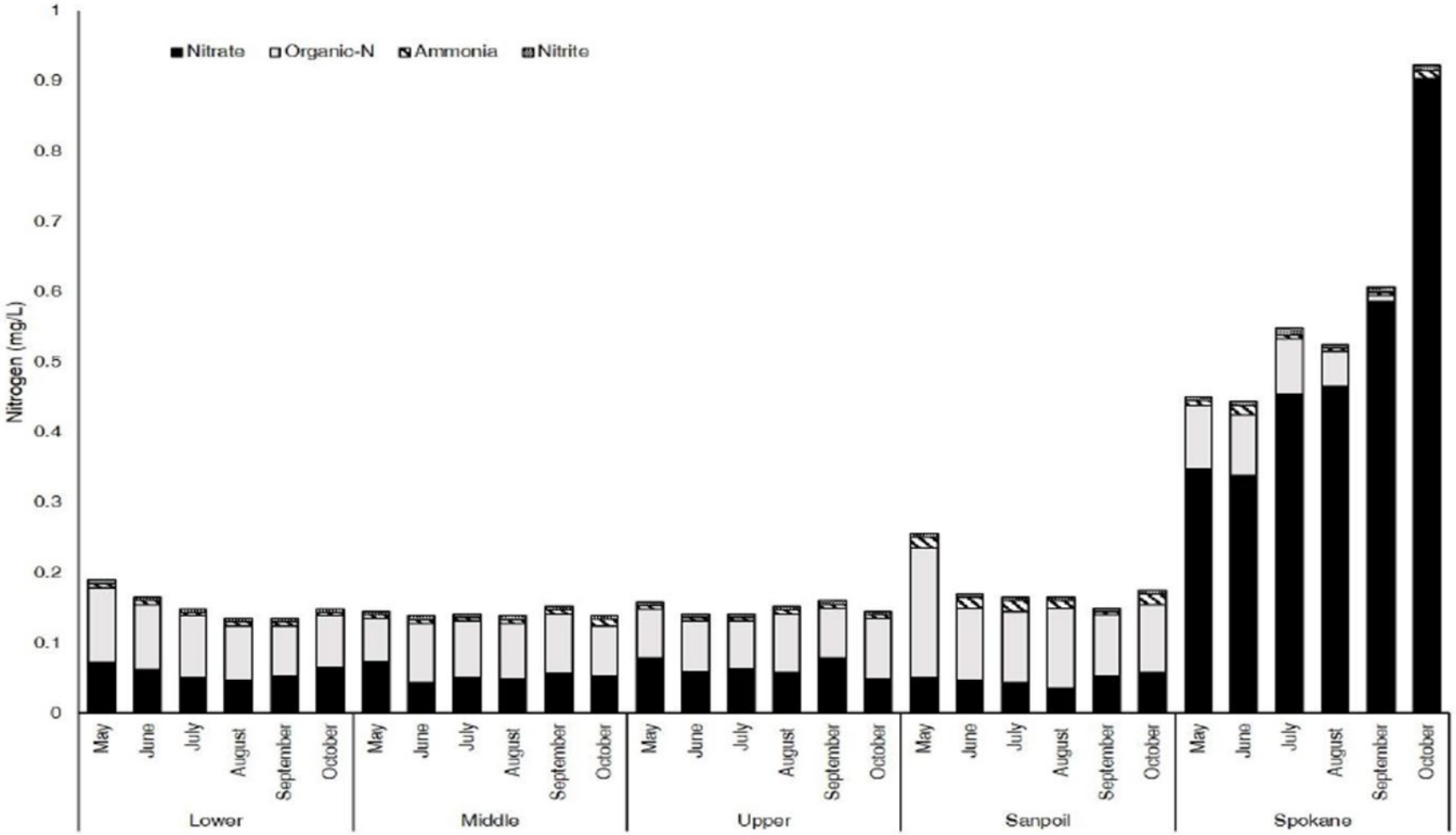
Note: From Ecology Station 53A070. The dots indicate the time discrete samples were taken; lines only help to identify trends, and do not indicate continuous samples.
Source: Ecology (2017)

Figure 2-48. Nitrate and Nitrite (mg/L) Concentration 0.5 mile Downstream from Grand Coulee Dam



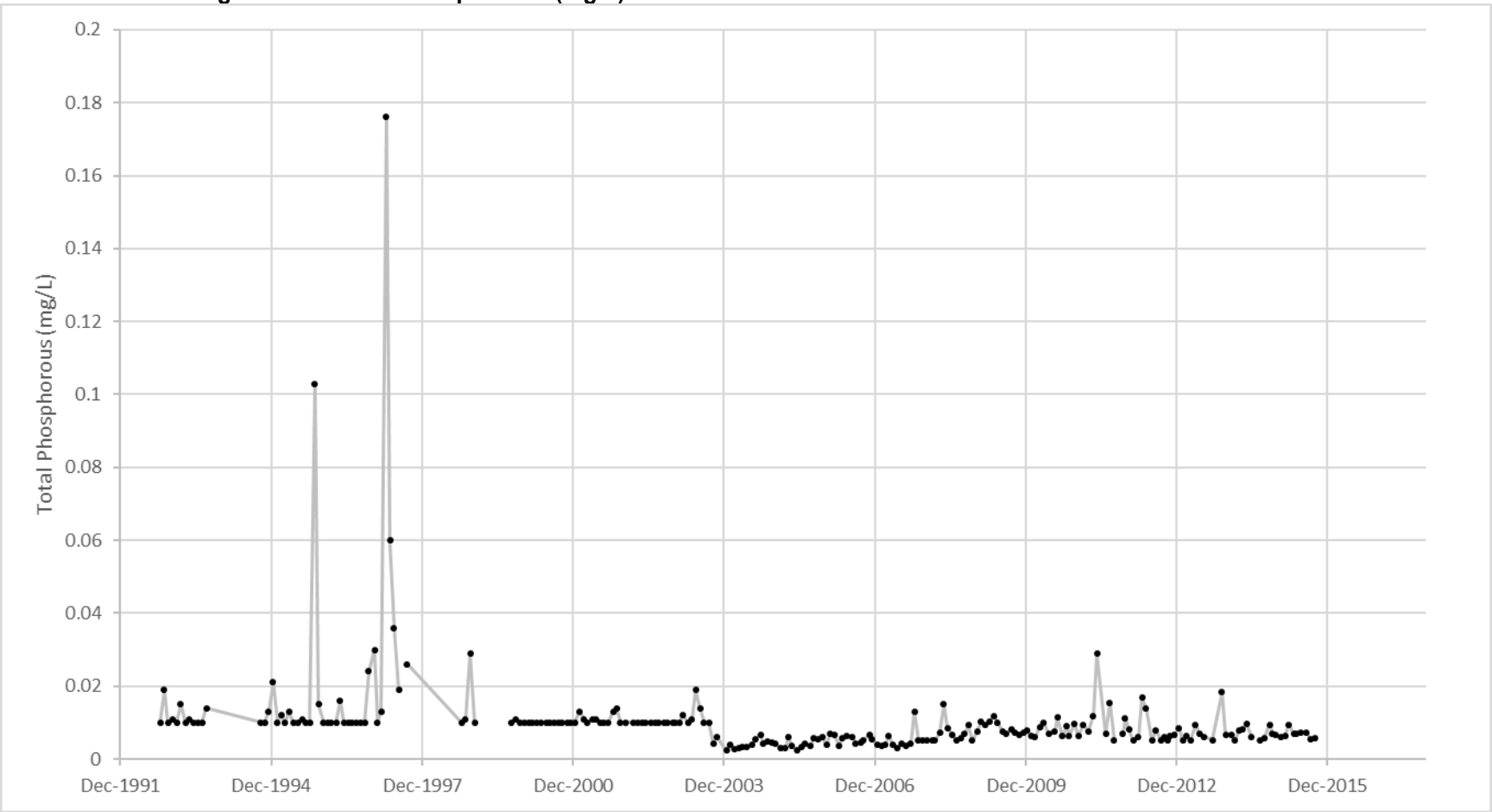
Note: From Ecology Station 53A070. The dots indicate the time discrete samples were taken; lines only help to identify trends, and do not indicate continuous samples.
Source: Ecology (2017)

Figure 2-49. Mean Total Nitrogen Concentration in Lake Roosevelt and Major Tributaries in 2016, Separated into Nitrate, Organic Nitrogen, Ammonia, and Nitrite



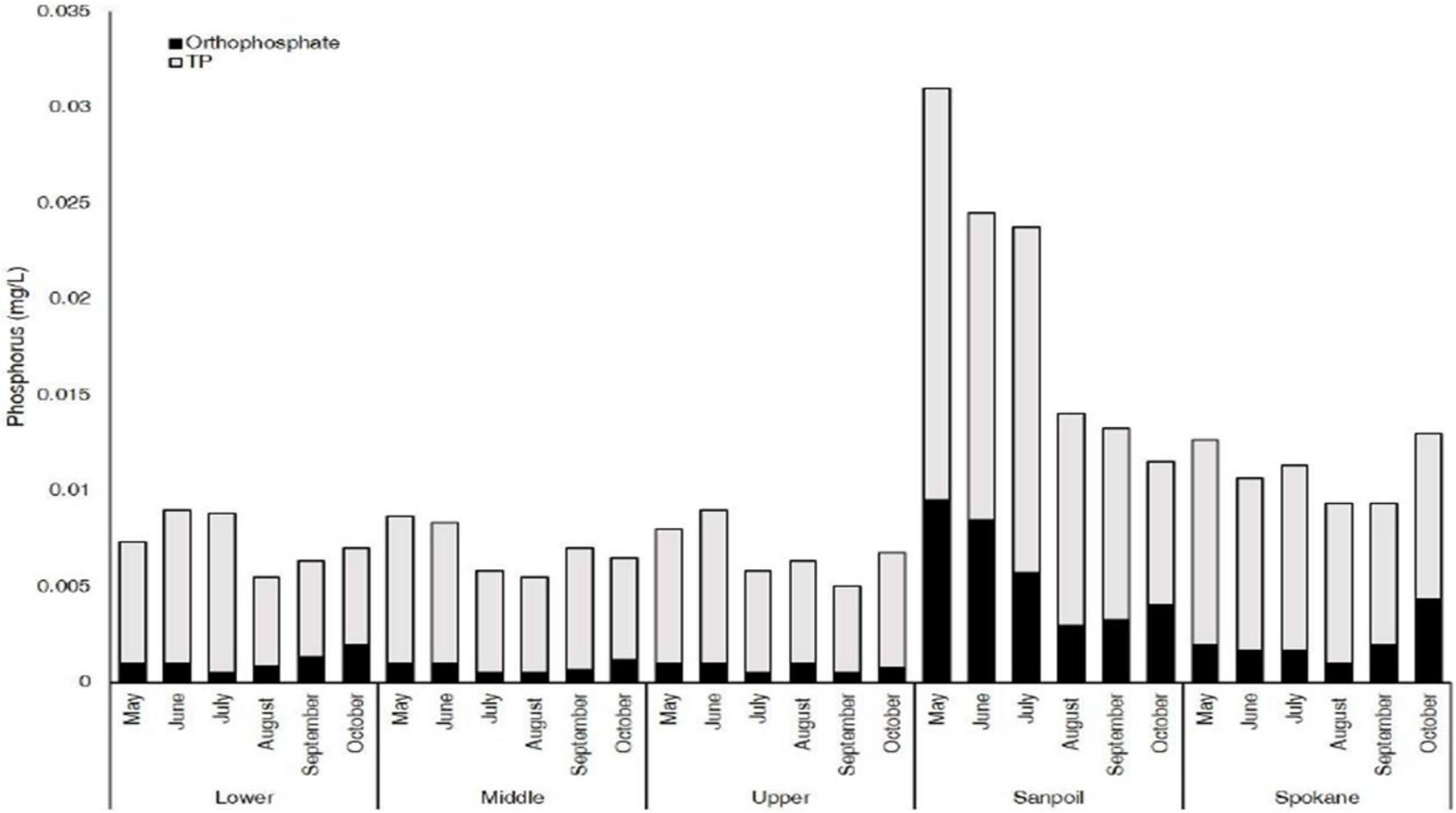
Source: Kain, Knudson, and Nichols (2018)

Figure 2-50. Total Phosphorous (mg/L) Concentration 0.5 mile Downstream from Grand Coulee Dam



Note: From Ecology Station 53A070. The dots indicate the time discrete samples were taken; lines only help to identify trends, and do not indicate continuous samples.
Source: Ecology (2017)

Figure 2-51. Mean Total Phosphorous Concentration in Lake Roosevelt and Major Tributaries in 2016, Including Orthophosphate Fraction



Source: Kain, Knudson, and Nichols (2018)

2.3.6 Pesticides

The pesticide dichlorodiphenyltrichloroethane (DDT) has been banned since 1972, and other reduction efforts have lowered its levels within the Columbia River Basin. However, this chemical still persists in the environment from a variety of sources, but primarily from agricultural soils slowly leeching the pesticides into the waterbody. However, reduction efforts since the 1970s have lowered its concentrations in the environment (EPA 2009).

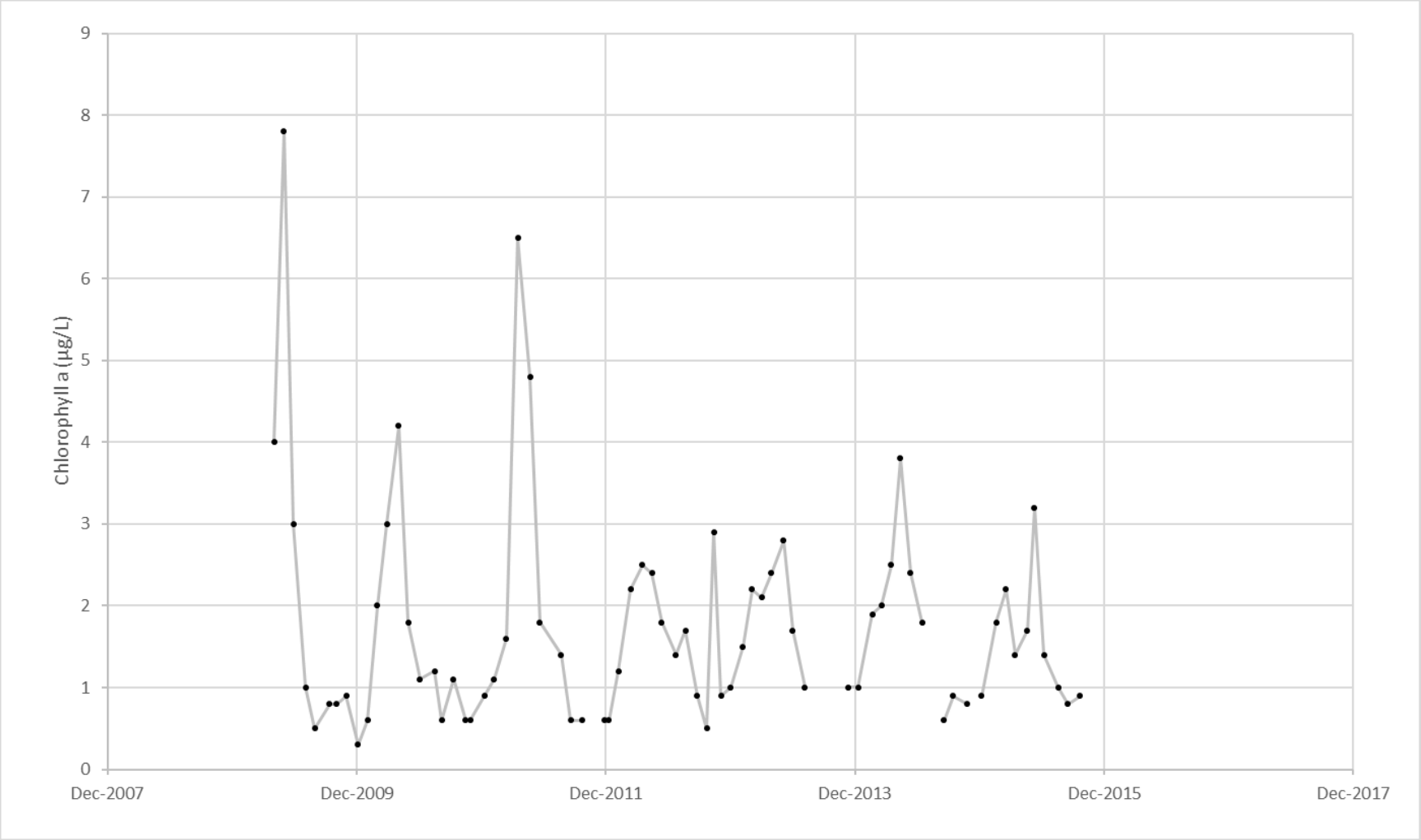
2.4 BIOLOGICAL CHARACTERISTICS

The pesticide dichlorodiphenyltrichloroethane (DDT) has been banned since 1972, and other reduction efforts have lowered its levels within the Columbia River Basin. However, this chemical still persists in the environment from a variety of sources, but primarily from agricultural soils slowly leeching the pesticides into the waterbody. However, reduction efforts since the 1970s have lowered its concentrations in the environment (EPA 2009).

2.4.1 Chlorophyll a

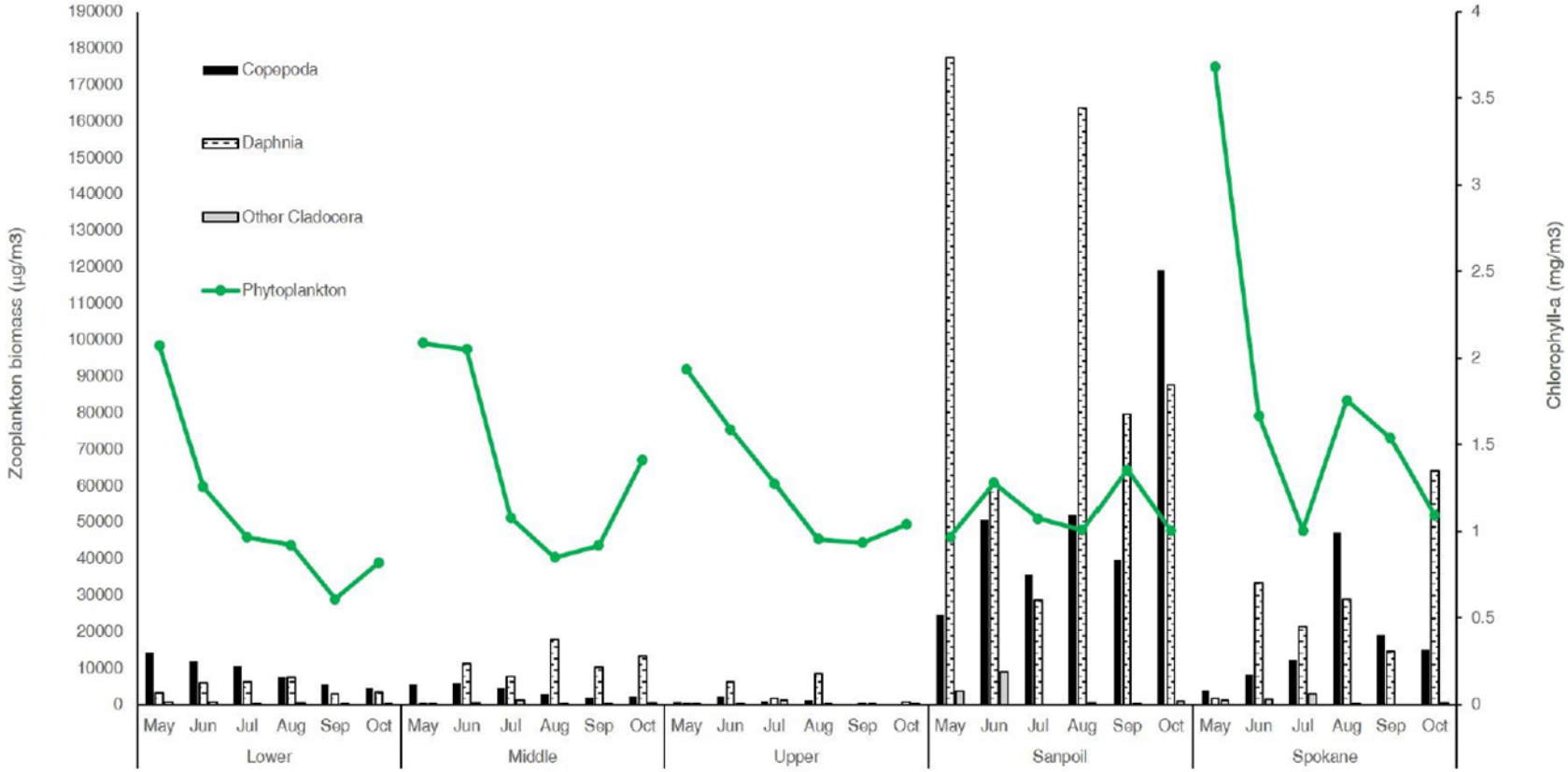
Chlorophyll a concentrations downstream of Grand Coulee Dam (Figure 2-52), and within Lake Roosevelt (Figure 2-53), display algal populations which tend to have moderate blooms in the summer (Lee et al. 2006). Mean annual phytoplankton chlorophyll a density was reported as 0.8 micrograms per liter (µg/L) throughout the reservoir in 2004 to 2005. Mean monthly phytoplankton chlorophyll a was highest in May at 1.9 µg/L and lowest in January at 0.3 µg/L (Lee et al. 2006). Mean annual periphyton chlorophyll a density across all locations was 8.7 µg/L with a mean annual production rate of 0.152 µg/L/day. Periphyton chlorophyll a was highest at Spring Canyon (14.3 µg/L) and lowest at Gifford (6.0 µg/L) (Lee et al. 2006). In more recent years, phytoplankton chlorophyll a concentrations showed a marked increase in 2014 and 2015, but a reduction in 2016. In 2014, reservoir wide concentrations ranged from 0.53 to 6.52 µg/L with a mean of 1.79 µg/L (Kain, Knudson, and Nichols 2015). In 2015, a similar increase was seen with concentrations ranging from 0.41 to 7.13 µg/L with a mean of 1.98 µg/L (Kain, Knudson, and Nichols 2017). A reduction in chlorophyll a concentrations was seen in 2016, with a mean of 1.37 µg/L (ranging from 0.37 to 4.61 µg/L) (Kain, Knudson, and Nichols 2018).

Figure 2-52. Chlorophyll a (µg/L) Concentration 0.5 mile Downstream from Grand Coulee Dam



Note: From Ecology Station 53A070. The dots indicate the time discrete samples were taken; lines only help to identify trends, and do not indicate continuous samples.
Source: Ecology (2017)

Figure 2-53. Mean Monthly chlorophyll a and Zooplankton Concentration in Lake Roosevelt and Major Tributaries in 2016

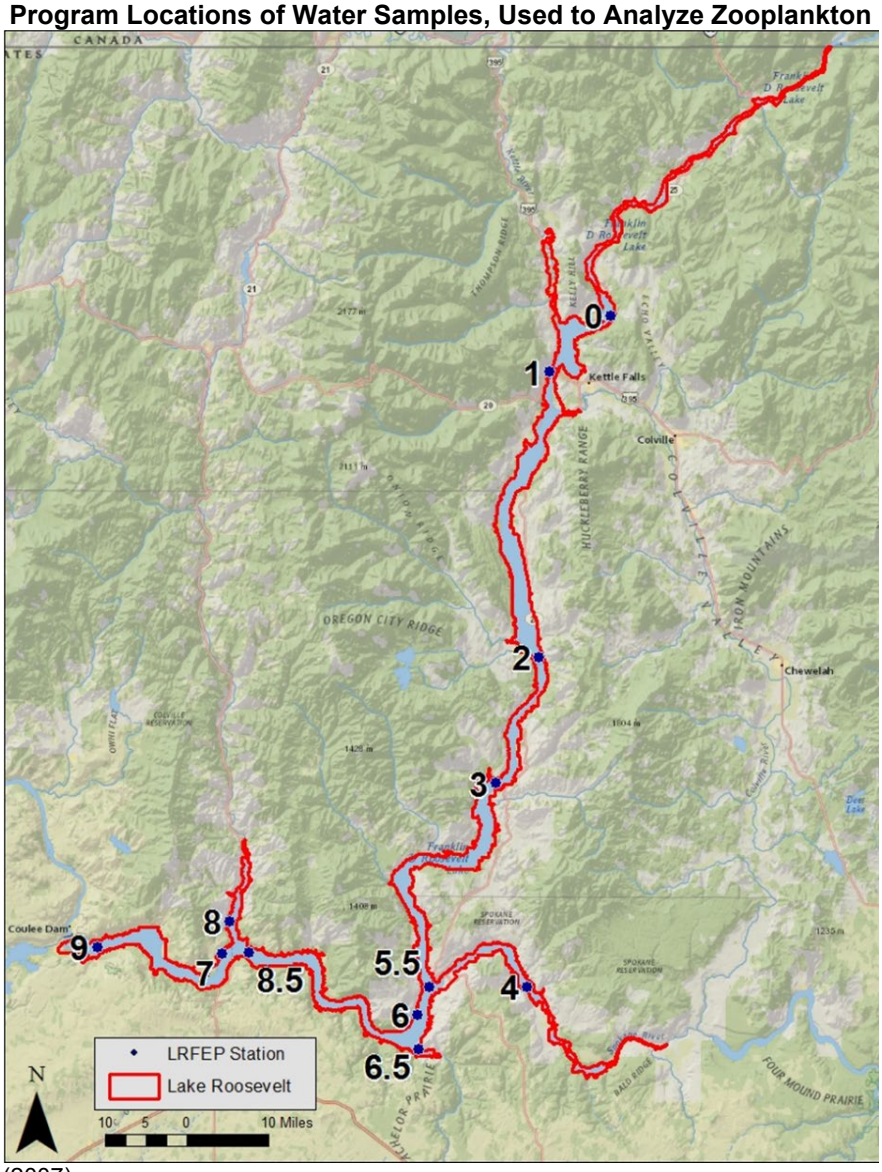


Source: Kain, Knudson, and Nichols (2018)

2.4.2 Zooplanktons

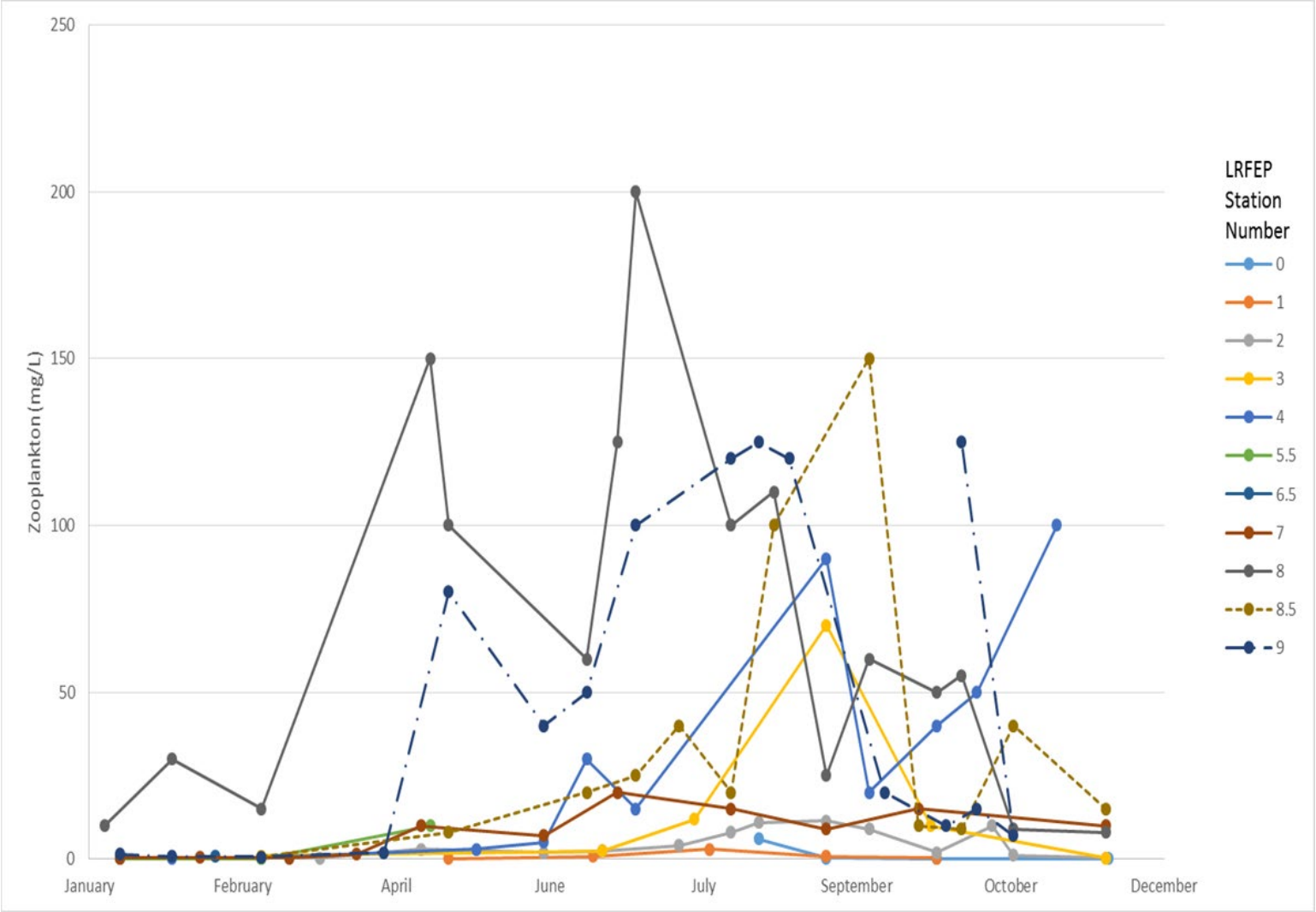
Zooplankton biomass (small animals and immature stages of larger animals which provide an important food source to larger organisms) in the reservoir is divided into three functional groups: herbivorous Copepod, omnivorous Copepod, and omnivorous Cladocera. Copepoda species are dominated in the water body by *Leptodiaptomus ashlandi* and *Diacyclops bicuspidatus thomasi*, with omnivorous Copepods comprising 10 percent of the biomass. The Cladocera species is dominated by the Daphnia subspecies, with about 50 percent of the species composed of *Daphnia pulex*. Diet studies show that Cladocera are the preferred prey for kokanee salmon (*Oncorhynchus nerka)* in the reservoir. Concentrations of zooplankton found in the reservoir and locations of zooplankton samples collected can be found in Figure 2-54 and Figure 2-55 (McKillip 2007).

Figure 2-54. Lake Roosevelt Fisheries Evaluation Program Locations of Water Samples, Used to Analyze Zooplankton



Source: McKillip (2007)

Figure 2-55. Zooplankton Concentration (mg/L) Sampled at Lake Roosevelt Fishery Evaluation Program Locations in 2006



Note: Location numbers correspond to Figure 2-54. The dots indicate the time discrete samples were taken; lines only help to identify trends, and do not indicate continuous samples.
Source: McKillip (2007)

In 2004 to 2005, mean annual zooplankton density across the reservoir was reported as 539 organisms/m^3. Copepoda (83 percent) contributed most to overall density followed by Daphnia (15 percent). Mean monthly density throughout the lake was greatest in May at 733 organisms/m^3 and least in January at 151 organisms/m^3. Mean annual density was greatest at Spring Canyon. Mean annual biomass across all locations was 1,995 µg/m^3. Daphnia (52 percent) accounted for the majority of overall zooplankton biomass followed by Copepoda (46 percent). Mean monthly biomass across the waterbody was greatest in July at 3,033 µg/m^3 and least in January at 389 µg/m^3. Mean annual biomass was highest at Porcupine Bay. Annual mean Daphnia biomass at index stations was 4,853 µg/m^3. Mean annual lengths throughout the reservoir for overall zooplankton, Daphnia, Copepoda, and other Cladocera were 0.7, 1.4, 0.6, and 0.6 mm, respectively. Mean annual zooplankton lengths were greatest at Keller Ferry and Spring Canyon (Lee et al. 2006).

By comparison, in 2014, mean annual zooplankton concentrations were 210 organisms/m^3. Additionally, the relative population concentrations remained the same as in 2004 to 2005 with Copepods most abundant (82 percent), followed by Daphnia at 15 percent (Kain, Knudson, and Nichols 2015). In 2015 and 2016, the zooplankton populations exploded. Kain, Knudson, and Nichols (2017, 2018) reported average reservoir wide zooplankton populations of 8,220 organisms/m^3 and 8,246 organisms/m^3 in 2015 and 2016 respectively. The relative family distribution remained largely the same, however, with Copepods being most abundant (83 percent in 2015, and 81 percent in 2016) followed by Daphnia (16 percent in both 2015 and 2016).

2.4.3 Primary Productivity

Production in the reservoir appears to be largely driven by pelagic photoautotrophy (i.e., photosynthetic organisms in open waters), and the majority of carbon contained by most organisms in Lake Roosevelt's food web was fixed by phytoplankton. The importance of pelagically derived production is also reflected in the diets of fish from Lake Roosevelt. Many fish, including those with typically benthic feeding habits, often contain considerable amounts of zooplankton (Black, Barlow, and Scholz 2003).

The major reservoir arms (Spokane and Sanpoil) appear to have more primary and secondary production than the mainstem (Pavlik-Kunkel et al. 2005; Lee et al. 2006). Littoral production is reduced because of the annual spring drawdown, which averages 15 meters (49 feet). Elevation is generally lowest in April and refill occurs by July. Drawdown has been shown to temporarily reduce littoral benthic production (Black, Barlow, and Scholz 2003).

2.4.4 Coliforms and Other Microbial Organisms

As a primary contact recreation area, Lake Roosevelt is allowed up to 200 coliforms/100 mL (Table 2-23). Historically Lake Roosevelt has had occasional problems with fecal coliform bacteria concentrations rising to levels in excess of 200 coliforms/100 mL (USGS 2017a). However, in recent years this has not been an issue with fecal coliform

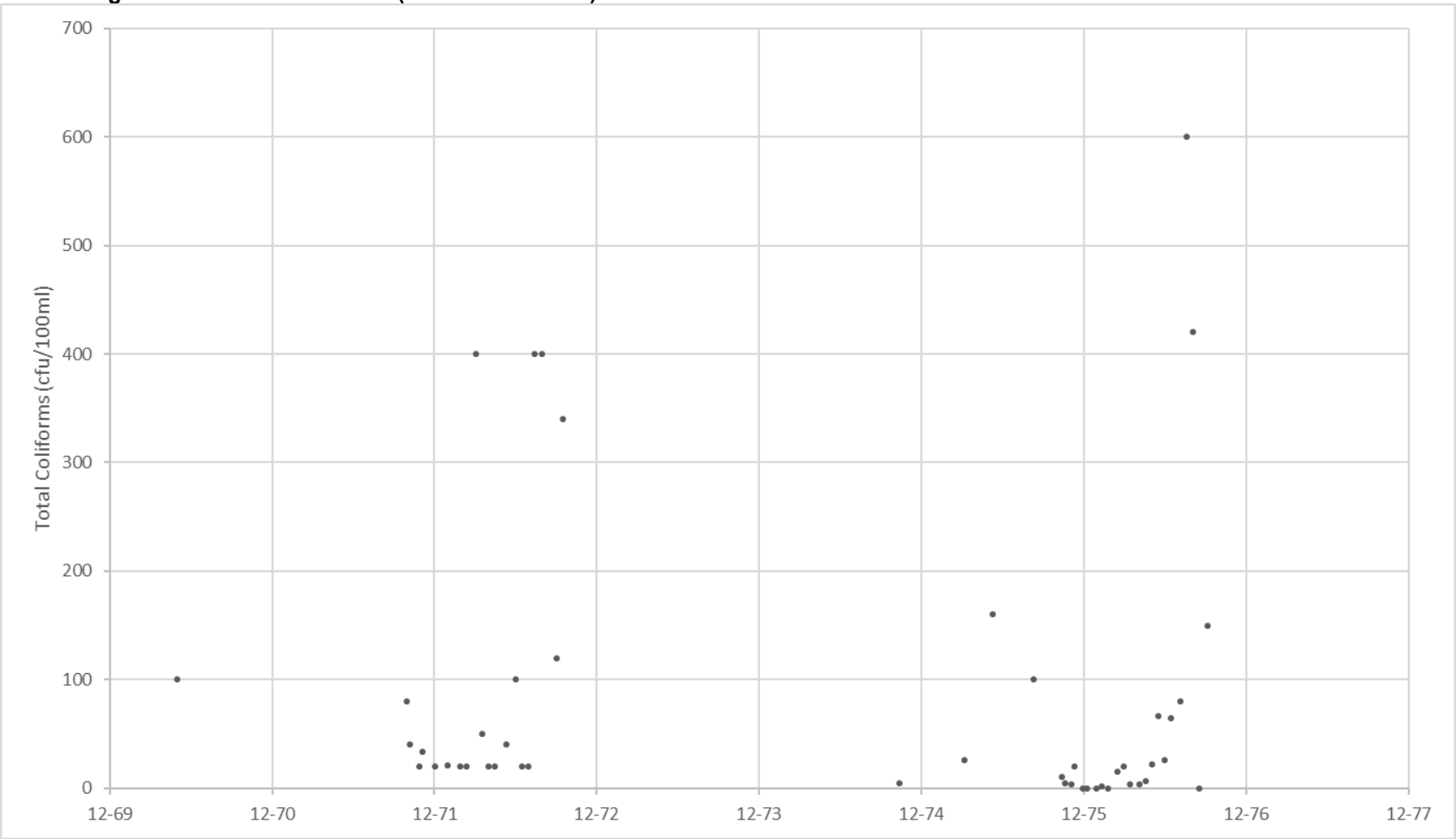
levels in excess of 20 coliforms/100 mL rarely being reported (Ecology 2017) (Figure 2-56 and Figure 2-57).

Table 2-23. Washington State Department of Ecology Water Quality Standards for Fecal Coliforms

Recreation Use	10%	Geometric Mean
Extraordinary primary contact recreation	< 100	< 50
Primary contact recreation	< 200	< 100
Secondary contact recreation	< 400	< 200

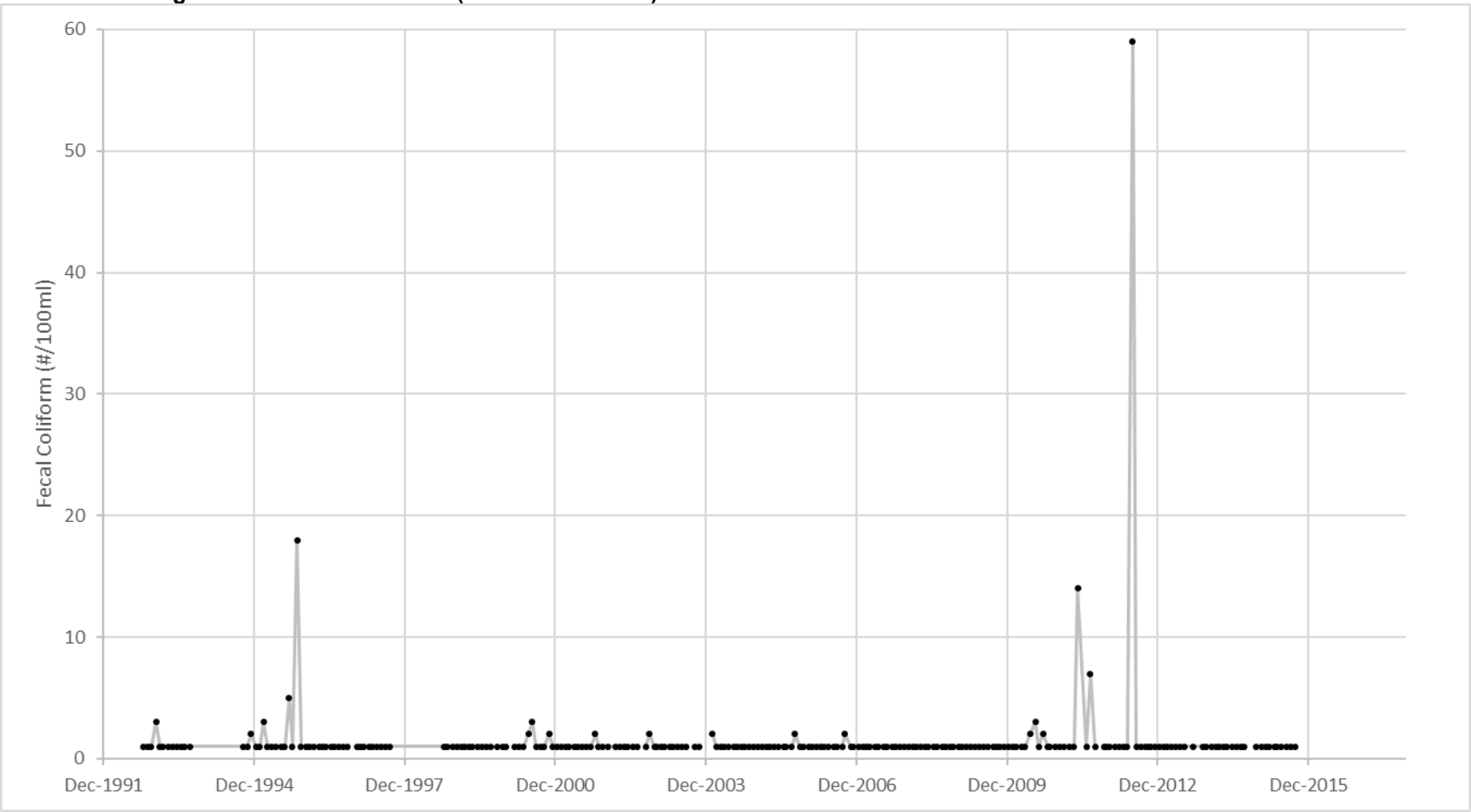
Note: Fecal Coliform Bacteria (coliforms/100 mL). Washington Administrative Code (WAC) 173-201A-602 identifies water quality standards' use designation for specific areas.
Source: (Ecology 2014)

Figure 2-56. Total Coliforms (coliforms/100 mL) Recorded at Grand Coulee Dam from December 1969 to December 1977



Note: From USGS Gage 12436500
Source: USGS (2017a)

Figure 2-57. Fecal Coliform (coliforms/100 mL) Concentration 0.5 mile Downstream from Grand Coulee Dam



Note: From Ecology Station 53A070. The dots indicate the time discrete samples were taken; lines only help to identify trends, and do not indicate continuous samples.
Source: Ecology (2017)

2.5 TROPHIC STATE

Lake Roosevelt's main channel is considered oligotrophic in general, meaning that primary productivity is generally low as defined by the total biomass in a waterbody. However, Lake Roosevelt is a large reservoir, and primary productivity varies both spatially and temporally as displayed in Table 2-24. The water *characteristics* even change within the main channel: lotic waters (i.e., flowing waters) predominate in the upper reaches, which transition to more lentic waters (i.e., pooling waters) towards Grand Coulee Dam. Additionally, while the mainstem of Lake Roosevelt is oligotrophic, the Spokane arm is mesotrophic as the Spokane River generally has a higher concentration of dissolved nutrients (Kain, Knudson, and Nichols 2018).

Table 2-24. Pesticides (ng/L) and Pesticide-Related Compounds in Lake Roosevelt

Analyte	Concentration Units	Measurement Basis	Number of Acceptable Analyses	Number of Detected Values	Minimum Value	Mean Value	Maximum Value
2,4'-DDD	ng/L	Total	43	1	0.107	0.107	0.107
2,4'-DDE	ng/L	Total	43	0	–	–	–
2,4'-DDT	ng/L	Total	43	1	0.147	0.147	0.147
4,4'-DDD	ng/L	Total	43	0	–	–	–
4,4'-DDE	ng/L	Total	43	2	0.19	0.21	0.23
4,4'-DDT	ng/L	Total	43	0	–	–	–
Aldrin	ng/L	Total	43	0	–	–	–
α-Benzenehexachloride	ng/L	Total	43	0	–	–	–
alpha-Chlordane	ng/L	Total	43	0	–	–	–
beta-BHC	ng/L	Total	43	0	–	–	–
Chlordane	ng/L	Total	43	0	–	–	–
cis-Nonachlor	ng/L	Total	43	0	–	–	–
delta-BHC	ng/L	Total	43	0	–	–	–
Endosulfan I	ng/L	Total	43	0	–	–	–
Endosulfan II	ng/L	Total	43	5	0.78	1	1.2
Endosulfan sulfate	ng/L	Total	43	0	–	–	–
Endrin	ng/L	Total	43	0	–	–	–
Endrin aldehyde	ng/L	Total	43	0	–	–	–
Endrin keytone	ng/L	Total	43	0	–	–	–
gamma-BHC	ng/L	Total	43	0	–	–	–
gamma-Chlordane	ng/L	Total	43	6	–	–	–
Heptachlor	ng/L	Total	43	0	–	–	–
Heptachlor epoxide	ng/L	Total	43	0	–	–	–
Methoxychlor	ng/L	Total	43	0	–	–	–
Oxychlordane	ng/L	Total	43	0	–	–	–
Toxaphene	ng/L	Total	43	0	–	–	–
trans-Nonachlor	ng/L	Total	43	5	0.18	0.234	0.327
DDD + DDE + DDT sum	ng/L	Total	43	3	0.61	0.88	1.15

Source: Exponent (2013)

SECTION 3 - CONCLUSIONS AND RECOMMENDATIONS

Over the past decade phosphorous has remained relatively consistent and nitrogen has decreased notably, but phytoplankton chlorophyll a and zooplankton density have both increased markedly (Lee 2006) (Kain 2015) (Kain 2017) (Kain 2018). This displays that while phosphorous and nitrogen often act as limiting constituents, other factors in the reservoir can regulate primary production.

The sediments of the upper Columbia River Basin are known to be contaminated in varying concentrations by a wide range of constituents associated with the long history of intense land use practices, including arsenic, cadmium, copper, dioxins, lead, mercury, zinc, pesticides, radionuclides, and industrial chemicals. Additional pollutants, natural or anthropogenic, also present challenges. Emerging contaminants such as pharmaceuticals from wastewater or polybrominated flame retardants have been found to be present elsewhere in the Columbia River system (Morace 2012) but have not yet been documented in Lake Roosevelt.

Methods to address and reduce contaminants in the Columbia Basin have been established and have displayed varying levels of success. Examples of these methods include reducing mining-related contaminants entering the waterbody, improved land management practices, and removal of some contaminated soils. Through the decades of work by organizations representing the interests of the roughly 5 million people living in the Columbia River Basin, the water quality within Lake Roosevelt and the rest of the Columbia River Basin has been improving since at least the 1990s.

Water temperatures are a concern throughout the Columbia River basin, including the inflowing and outflowing conditions of the Columbia River around Lake Roosevelt. In Lake Roosevelt, the short retention time and high spring flows limit thermal-stratification, which results in the reservoir displaying only shallow and weak surface stratification during the summer timeframe (Reclamation 2018). Nonetheless, Lake Roosevelt does have an effect of delaying downstream warming in the spring, generally warming downstream releases during the summer, and delating downstream cooling in the fall. While the effects are common among large reservoirs in the Pacific Northwest, the operational ability at Lake Roosevelt to minimize these effects are limited by available cold water and are anticipated to be cost prohibitive.

Additionally, TDG in Lake Roosevelt (as a result of inflowing waters) and downstream of Grand Coulee Dam are a concern. When spill is occurring upstream there is little that can be done at Grand Coulee Dam to reduce TDG. When spill operations are necessary through the regulating outlets using an over/under pattern has been found to reduce the generation of TDG below the project. Additionally, management at other projects to help keep TDG as low as possible while meeting other operational obligations, such as power and FRM, can reduce the amount of spill and TDG generation at Grand Coulee Dam. Operations at Chief Joseph Dam, this project has spill deflectors, can result in decreasing downstream TDG.

SECTION 4 - REFERENCES

Anderson, C. W. 2005. U.S. Geological Survey Techniques of Water Resources Investigations. Book 9, Chapter A6, Section 6.7. U.S. Geological Survey.

Besser, J. M., W. G. Brumbaugh, C. D. Ivey, C. G. Ingersoll, and P. W. Moran. 2007. “Biological and Chemical Characterization of Metal Bioavailability in Sediments from Lake Roosevelt, Columbia River, Washington, USA.” Archives of Environmental Contamination and Toxicology 54(40):557–570.

Black, A. R., G. W. Barlow, and A. T. Scholz. 2003. “Carbon and Nitrogen Stable Isotope Assessment of the Lake Roosevelt Aquatic Food Web.” Northwest Science 77(1):1–11.

Bortleson, G. C., S. E. Cox, M. D. Munn, R. J. Schumaker, and E. K. Block. 2001. Sediment-Quality Assessment of Franklin D. Roosevelt Lake and the Upstream Reach of the Columbia River, Washington, 1992. Water Supply Paper 2496. U.S. Geological Survey.

CH2M Hill. 2012. Summary and Evaluation of Phase 1 (2005) Sediment Toxicity Tests, Upper Columbia River Site. Prepared for U.S. Environmental Protection Agency, Region 10.

Cox, S. E., P. R. Bell, J. S. Lowther, and P. C. VanMetre. 2005. Vertical Distribution of Trace-Element Concentrations and Occurrence of Metallurgical Slag Particles in Accumulated Bed Sediments of Lake Roosevelt, Washington, September 2002. Scientific Investigations Report 2004-5090. U.S. Geological Survey.

Ecology (Washington State Department of Ecology). 2017. Statewide Water Quality Monitoring Network, Eastern Region, Site 53A070 - Columbia River at Grand Coulee. https://fortress.wa.gov/ecy/eap/riverwq/regions/state.asp.

EPA (U.S. Environmental Protection Agency). 2009. Columbia River Basin: State of the River Report for Toxics January 2009. EPA 910-R-08-004. Region 10.

EPA. 2011. Upper Columbia River Site Update 2011. Region 10 Superfund Records Center, Data Repository: Grand Coulee Library.

EPA. 2016. WAC 173-201A: Water Quality Standards for Surface Waters of the State of Washington.

EPA. 2018. Temperature Water Quality Standards for the Columbia, Lower Columbia and Lower Snake Rivers. Region 10.

Exponent. 2013. Upper Columbia River Surface Water Data Summary and Data Gap Report – Final. Prepared for Teck Resources Limited. Prepared in consultation with Parametrix. Accessed at: https://www.ucr-rifs.com/home/documents-plans/.

Kain, A., T. Knudson, and B. Nichols. 2015. Lake Roosevelt Fisheries Evaluation Program 2014 Limnological Assessment. Spokane Tribal Fisheries Project No. 1994-043-00, Bonneville Power Administration Contract No. 69860. Spokane Tribe of Indians Department of Natural Resources.

Kain, A., T. Knudson, and B. Nichols. 2017. Lake Roosevelt Fisheries Evaluation Program 2015 Annual Limnological Assessment. Spokane Tribal Fisheries Project No. 1994-043-00, Bonneville Power Administration Contract No. 69860. Spokane Tribe of Indians Department of Natural Resources.

Kain, A., T. Knudson, and B. Nichols. 2018. Lake Roosevelt Fisheries Evaluation Program 2016 Annual Limnological Assessment. Spokane Tribal Fisheries Project No. 1994-043-00, Bonneville Power Administration Contract No. 69860. Spokane Tribe of Indians Department of Natural Resources.

Lee, C., D. Pavlik-Kunkel, K. Fields, B. Scofield. 2006. Lake Roosevelt Fisheries Evaluation Program, Limnological and Fisheries Monitoring 2004-2005 Annual Report. Project No. 1994-043-00, Contract No. 00014804. Spokane Tribe of Indians Department of Natural Resources.

LRFEP (Lake Roosevelt Fisheries Evaluation Program). 2018. Direct Communication with Lake Roosevelt Fisheries Evaluation Program and Bureau of Reclamation, Spokane Tribe of Indians Department of Natural Resources, Spokane Tribal Fisheries.

Magirl, C. DS., R. S. Dinicola, S. E. Cox, M. C. Mastin, C. P. Konrad, and J. A. Czuba. 2014. Sediment Transport in the Upper Columbia River to Support Columbia River Treaty 2014/2024 Review. Administrative Report. U.S. Geological Survey.

Majewski, M. S., S. C. Kahle, J. C. Ebbert, and E. G. Josberger. 2001. Concentrations and Distribution of Slag-Related Trace Elements and Mercury in Fine-Grained Beach and Bed Sediments of Lake Roosevelt, Washington, April–May 2001. Water-Resources Investigations Report 03-4170, Version 1.10. U.S. Geological Survey, Confederated Tribes of the Coleville Reservation, Lake Roosevelt Water-Quality Council, U.S. Bureau of Reclamation, National Park Service.

McKillip, M. L. 2007. Lake Roosevelt Water Quality and Hydrodynamic Model Calibration with Fish Bioenergetics. Technical Report EWR-03-06. Civil and Environmental Engineering Faculty Publications and Presentations 3-2007. Portland State University.

Morace, J. L. 2012. Reconnaissance of Contaminants in Selected Wastwater Treatment Plant Effluent and Stormwater Runoff Entering the Columbia River, Columbia River Basin, Washington and Oregon, 2008–2010. Scientific Investigations Report 2012-5068. U.S. Geological Survey Scientific Investigations in Cooperation with the Columbia River Inter-Tribal Fish Commission and the Lower Columbia Estuary Partnership.

Munn, M. D. 2000. Contaminant Trends in Sport Fish from Lake Roosevelt and the Upper Columbia River, Washington, 1994–1998. Water Resources Investigation Report 2000-4024. U.S. Geological Survey.

Munn, M. D., S. E. Cox, and C. J. Dean. 1994. Concentrations of Mercury and Other Trace Elements in Walleye, Smallmouth Bass, and Rainbow Trout in Franklin D. Roosevelt Lake and the Upper Columbia River, Washington. Open-File Report 95-195. U.S. Geological Survey.

Pavlik-Kunkel, D., K. Fields, B. Scofield, and C. Lee. 2005. Lake Roosevelt Fisheries Evaluation Program Annual Report January 2003 - December 2003. Project No. 1994-043-00, Contract No. 00014804. Spokane Tribe of Indians, Department of Natural Resources.

Persaud, D., R. Jaagumagi, and A. Hayton. 1991. The Provincial Sediment-Quality Guidelines. Ontario Ministry of Environment and Energy, Water Resources Branch.

Pickett, P., H. Rueda, and M. Herold. 2004. Total Maximum Daily Load for Total Dissolved Gas in the Mid-Columbia River and Lake Roosevelt. Publication Number 04-03-002. U.S. Environmental Protection Agency and Washington State Department of Ecology, in cooperation with the Spokane Tribe of Indians.

Reclamation (U.S. Bureau of Reclamation). 2017. Pacific Northwest Region Hydromet. Accessed Sept, 1, 2017, https://www.usbr.gov/pn/hydromet/.

Reclamation. 2018. Thermal Regime of the Columbia River at Lake Roosevelt. In Peer Review, Peer Review Lead: Eric Rothwell.

Scofield, B., and D. Pavlik-Kunkel. 2000. Trace Metal Concentrations in Surface Water of Lake Roosevelt Supplemental Report, Janurary 1998 - March 2000. Lake Roosevelt Fisheries Evaluation Program, Spokane Tribe of Indians, Department of Natural Resources.

Teck (Teck Resources Limited). 2017. FINAL Phase 2 Sediment Study Data Summary and Data Gap Report. Prepared by Windward Environmental, Exponent, Parametrix, and HDR.

USGS (U.S. Geological Survey). 2017a. United States Geological Survey, National Water Information System: Web Interface. Accessed Sept, 1, 2017, https://waterdata.usgs.gov/nwis/inventory?search_criteria=search_site_no&submitted_form=introduction.

USGS. 2017b. United States Geological Survey Water Science School, Nitrogen and Water. https://water.usgs.gov/edu/nitrogen.html.

Von Prause, M. 2014. River and Stream Water Quality Monitoring Report 2013. Publication No. 14-03-047. Washington State Department of Ecology. Olympia, WA.