US Army Corps of Engineers®
Portland District

WATER QUALITY REPORT

LIBBY RESERVOIR, LAKE KOOCANUSA
COLUMBIA RIVER BASIN
KOOTENAI RIVER, MONTANA

Libby Reservoir, Lake Koocanusa

Water Quality Report
May 2020

EXECUTIVE SUMMARY

The Kootenai River (spelled Kootenay in Canada) drains 49,987 square kilometers of the Pacific Northwest in the United States and Canada, of which 23,271 square kilometers are upstream of Libby Dam. The Kootenai system is the second largest tributary to the Columbia River after the Snake River and enters the Columbia River in British Columbia, Canada, just downstream of lower Arrow Lake, about 40 kilometers from the U.S.-Canada border. The construction of Libby Dam and the formation of Lake Koocanusa in 1972 altered the natural flow regime, river geometry, river velocity, water chemistry, and water residence time. The reservoir is 145 kilometers long, extends 68 kilometers into British Columbia, and has a mean depth of 38 meters, a maximum depth of 106 meters, and a mean water residence time of about 9 months.

From the 1950s through the late 1970s, contaminants were introduced to the river and reservoir from a variety of sources such as a phosphate fertilizer production plant, a kraft paper mill, municipal sewage outfalls, and mining operations (Woods 1982; Knudson 1994U.S. Fish and Wildlife Service). Prior to dam construction, Bonde and Bush (1975) predicted that Lake Koocanusa would become eutrophic or nutrient rich due to elevated loadings of phosphorus and nitrogen from industrial waste point sources located in British Columbia. Although blooms of cyanobacteria (commonly referred to as blue-green algae) indicative of eutrophic conditions occurred in 1974 and 1975, wastewater treatment reductions in nutrient loadings in the late 1970s and 1980s resulted in substantial reductions in phosphorus and nitrogen loadings to the reservoir and river. Consequently, marked reductions in reservoir and river phosphorus and nitrogen concentrations were measured by 1978, and the reservoir was classified as oligotrophic or nutrient poor, with little discharge of nutrients from the reservoir downstream to the river (Woods 1982; HydroQual Canada Limited 1990).

Although most sources of contamination were reduced or eliminated by the 1980s, contamination from coal mining operations in the Elk River watershed of British Columbia still exists (Jenni, Naftz, and Presser 2017). Indeed, coal production has expanded in the watershed with an estimated tenfold increase in waste spoils between 1997 and 2016 (Teck 2016). Hauer and Sexton (2013) reported elevated loadings of selenium, nitrate, and sulfate from the Elk River in British Columbia to Lake Koocanusa and the Kootenai River. Given this, the increased loadings of nitrate and selenium may be affecting the overall water quality state of Lake Koocanusa and the Kootenai River.

Water quality data collected in Lake Koocanusa and the Kootenai River is summarized to better understand the limnological functioning of this system. The majority of data discussed in this report is derived from two large-scale water quality monitoring studies conducted by the U.S. Geological Survey (USGS) and the U.S. Army Corps of Engineers (Corps), Seattle District during calendar years 1967 to 2004 and 2006 to 2016, respectively. The USGS 1967 to 2004 monitoring study was focused on chemical processes in the lake and river to determine pre–Libby Dam versus post–Libby Dam conditions. The Seattle District’s 2006 to 2016 limnological study was a more comprehensive study designed to investigate the interaction of physical, chemical, and

biological processes in the lake and river to better understand the possible water quality impacts of Libby Dam operations on Lake Koocanusa and the Kootenai River.

This existing conditions report will focus on summarizing the 2006 to 2016 data to gain an understanding of the current physical, chemical, and biological processes in the lake and river. The scope of this summary is extensive and will include (1) fate and transport of nutrients and trace metals in Lake Koocanusa and the Kootenai River immediately downstream of Libby Dam, (2) assessment of the temporal and spatial variability in key water quality parameters, (3) long-term trend analysis combining 1967 to 2004 USGS data with 2006 to 2016 Seattle District data, and (4) biological condition of Lake Koocanusa.

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ACRONYMS

Acronym	Description
#/100 mL	Number per 100 Milliliters
µg/L	Micrograms per Liter
µS/cm	Microsiemens per Centimeter
Ca	Calcium
Cl	Chloride
CO_3	Carbonate
EPA	U.S. Environmental Protection Agency
HAUL	Station Downstream of Libby Dam At An Old Haul Bridge Site
HCO_3	Bicarbonate
K	Potassium
L/min	Liters per Minute
LIBBOR	Libby Dam Border Station
LIBBOR-EPI	Libby Dam Border Station – Epilimnion
LIBBOR-HYPO	Libby Dam Border Station – Hypolimnion
LIBFB	Libby Dam Forebay Station
LIBFB-EPI	Libby Dam Forebay – Epilimnion
LIBFB-HYPO	Libby Dam Forebay Station – Hypolimnion
LIBTMC	Libby Dam Ten Mile Creek Station
LIBTW	Kootenai River Station in the Tailwater Of Libby Dam
MDEQ	Montana Department of Environmental Quality
Mg	Magnesium
mg $CaCO_3$/L	Milligrams Calcium Carbonate per Liter
mg/L	Milligrams Per Liter
Na	Sodium
NH_3	Ammonia
OECD	Organization for Economic Co-Operation and Development
organisms/L	Organisms Per Liter
Seattle District	U.S. Army Corps of Engineers, Seattle District
SO_4	Sulfate
TDG	Total Dissolved Gas
TMDL	Total Maximum Daily Load
TN:TP	Total Nitrogen to Total Phosphorus Ratio
TN-N	Total Nitrogen
TP	Total Phosphorus
TSI	Trophic State Index
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

SECTION 1 - INTRODUCTION

1.1 STUDY AREA

Libby Dam is located 29 kilometers northeast of Libby, Montana, at river kilometer 357.1 of the Kootenai River (Figure 1-1). The dam's reservoir, Lake Koocanusa, is 145 kilometers long, extending 68 kilometers into British Columbia. The dam is a concrete gravity structure rising about 130 meters above bedrock with a top length of about 880 m. The reservoir has a gross storage capacity of 7.24 million cubic kilometers, a mean depth of 38 m, a maximum depth of 106meters at the forebay, and a mean water residence time of about 9 months. Normal full pool and minimum regulated reservoir elevations are 749.5 and 697.1 meters, respectively. All elevations in this Appendix are referenced to NGVD29 datum.

The headwaters of the Kootenai River are in the Rocky Mountains of British Columbia in Kootenay National Park about 70 kilometers east of Golden, British Columbia. The river flows south for about 120 kilometers through a steep, forested canyon until reaching Canal Flats, British Columbia. From Canal Flats to about 15 kilometers south of the U.S.-Canada border in Montana near the mouth of the Tobacco River, the river and lake are situated in the Rocky Mountain Trench, a relatively wide (approximately 10 kilometers) and flat valley. From the Tobacco River to Libby Dam, Lake Koocanusa is located in a steep and narrow canyon with a general north-to-south aspect. Downstream of Libby Dam, the Kootenai River flows to the south for about 4.8 kilometers to the mouth of the Fisher River and then to the northwest for about 114 kilometers to Bonners Ferry, Idaho, through a steep, forested canyon with an average slope of about 1 meter per kilometer. At Bonners Ferry, the river valley widens and the river meanders to the north through a relatively flat section for about 75 kilometers to the U.S.-Canada border (Figure 2 1).

The Lake Koocanusa watershed is dominated by high, forested, northwest-trending mountain ranges separated by narrow river valleys. Elevations range from about 640 meters immediately downstream of Libby Dam to over 3,500 meters in the Rocky Mountains of British Columbia. The topography in the immediate Lake Koocanusa watershed is characterized by steep mountain slopes that plunge directly into the lake, as well as relatively flat terraces that lie at intervals between the lake and the mountain slopes. The mountains rise as much as 400 meters per kilometer from the lake, and vegetation is dominated by ponderosa pine (Pinus ponderosa), Douglas-fir (Pseudotsuga menziesii), western larch (Larix occidentalis), western red cedar (Thuja plicata), western hemlock (Tsuga hererophylla), and lodgepole pine (Pinus contorta) (U.S. Department of Agriculture [USDA], U.S. Forest Service [USFS], and Natural Resources Conservation Service [NRCS] 1995). The lake width ranges from about 0.9 kilometer at Libby Dam to about 4 kilometers near the U.S.-Canada border.

Figure 1-1. Location of Libby Dam in the Kootenai(y) River Basin Watershed

1.2 GEOLOGIC CHARACTERISTICS

The geology of the Kootenai River valley varies from rocks of Precambrian age to consolidated and unconsolidated alluvial and glacial deposits of Quaternary age (Harrison, Cressman, and Whipple 1992). Bedrock consists largely of metasedimentary rocks of the Middle Proterozoic Belt Supergroup and limited exposures of Paleozoic, Mesozoic, and Tertiary strata. Harrison, Cressman, and Whipple (1992) estimated the bedrock to be about 14,630 meters thick. Unconsolidated and consolidated valley deposits consist of Holocene alluvial deposits, as well as Pleistocene glacial and fluvioglacial deposits and Pleistocene lakebed deposits. The alluvial and glacial deposits compose the principal water bearing units in the Kootenai River Valley (Boettcher and Wilke 1978).

Fluvioglacial and glacial deposits overlie the Precambrian rocks. In general, the glacial deposits are composed primarily of broken and crushed Precambrian rocks that were deposited as till by the ice. The glacial deposits consist largely of poorly sorted boulders, gravel, sand, silt, and clay. Boettcher and Wilke (1978) estimated the thickness of these deposits to exceed 150 meters in the middle of the Libby Creek Valley. These authors noted that wells tapping these glacial deposits generally produce less than 115 liters per minute (L/min).

Lakebed deposits of clay, silt, and fine sand overlie the glacial deposit (Boettcher and Wilke 1978). Local deposits of gravel can be found at the top and base of these lakebed sediments. Lakebed deposits are known to yield little to no water because of their low permeability and because the formation has been drained due to downcutting of the Kootenai River. Estimated thickness of these deposits is more than 100 meters thick.

Alluvial deposits consist largely of relatively well-sorted and reworked silt, sand, gravel, and cobbles (Boettcher and Wilke 1978). Reworking separates the finer from the coarser materials, leading to coarser materials being deposited in the stream channels and the finer materials being deposited along the edge. The alluvium has been unevenly deposited on top of the glacial deposits, leading to wide ranges in the alluvium thickness and grain size in the valley. Boettcher and Wilke (1978) estimate the thickness of the alluvium in the vicinity of the town of Libby to be 30 meters locally, but the maximum thickness and shape of the alluvium in the Kootenai River Valley are unknown. Because of the coarse-grained texture of the alluvium, these deposits are more permeable than the glacial deposits, yielding from less than 400 L/min to more than 1,800 L/min. The variable yields are due to the variable thickness of the alluvial deposits.

1.3 HYDROLOGIC CHARACTERISTICS

The climate of the study area is influenced by easterly moving weather systems from the Pacific Ocean. Winters are generally cloudy, cool, and wet, with November through March being the wettest months. Most of the snowpack in the mountains falls between November and April. Summers are typically warm and dry, with little rainfall occurring from June through September. The mean annual precipitation near Libby Dam is about

490 millimeters, while annual precipitation in the Rocky Mountains near the headwaters can exceed 1,000 millimeters (USDA, USFS, and NRCS 1995). Annual snowfall amounts (cumulative depth) in the watershed varies from about 1,000 millimeters in the valleys to an estimated 7,600 millimeters in some mountain areas.

Much of the annual runoff in the Kootenai River Valley occurs in spring with the snowmelt. The impoundment of the Kootenai River by Libby Dam in 1972 for flood risk management and hydroelectric power production altered the seasonal flow patterns of the river (Bonde and Bush 1982). The annual pre-impoundment runoff conditions for the Kootenai River at the town of Libby showed high flows from April through June, with relatively low runoff the rest of the year, especially in the dry late-summer/fall period, and the cold winter period (Bonde and Bush 1982). Average pre-impoundment (1912 to 1971) flows in the Kootenai River ranged from about 1,850 cubic meters per second in late May and early June to about 110 cubic meters per second in January (USGS 2003). Post-impoundment conditions (1972 to 2016) have resulted in retaining water in Lake Koocanusa during historical high-flow periods and discharging water during historical low-flow periods. Since the early 1990s, the Corps has increased spring discharge levels from Lake Koocanusa to benefit downstream sturgeon survival. In general, the Kootenai River downstream of Lake Koocanusa experiences reduced flows for most of the year, with peak outflows of up to 750 cubic meters per second in late May through June for sturgeon survival, and again in December for power production.

The maximum discharge from Libby Dam through the powerhouse is about 740 cubic meters per second, considerably less than pre-impoundment Kootenai River peak flows. Consequently, Libby Dam must spill water to provide flows in excess of 740 cubic meters per second in the Kootenai River. Because of water quality concerns associated with spilling water at Libby Dam (i.e., high total dissolved gas [TDG]), outflows from the dam have only occasionally been greater than powerhouse flows. For example, a planned spill test in 2002 and high inflows in 2006 resulted in outflows of about 1,140 cubic meters per second and 1,560 cubic meters per second, respectively. However, the 2006 U.S. Fish and Wildlife Service (USFWS) Biological Opinion on the effects of the operation of Libby Dam on the endangered Kootenai River white sturgeon (*Acipenser transmontanus*) called for augmentation flows (powerhouse capacity plus up to 280 cubic meters per second spill) to aid in reproduction and recruitment of the white sturgeon. Consequently, Libby spilled in 2010 (220 cubic meters per second), 2012 (620 cubic meters per second), and 2013 (310 cubic meters per second). High inflows in 2012 and 2013 resulted in outflows exceeding the prescribed augmentation flows.

The primary source of inflow to Lake Koocanusa is the Kootenai River, where up to about 56 percent of the estimated inflow can be attributed to the gaged Kootenai River flows at Fort Steele, British Columbia. The second largest tributary is the Elk River in British Columbia, which accounts for about 22 percent of the inflow. The Bull River in British Columbia is estimated to contribute about 11 percent of the inflow to Lake Koocanusa. The only gaged tributary to Lake Koocanusa in Montana is the Tobacco River, which contributes only 2 percent of the inflow. The remaining ungaged inflow to Lake Koocanusa accounts for about 9 percent of the total annual inflow.

1.4 LAND USE

The Kootenai River watershed encompasses 49,987 square kilometers of southeastern British Columbia, northwestern Montana, and northern Idaho. The watershed is a sparsely populated mountainous area with a majority of the land in the basin being government owned or managed (Knudson 1994). In Montana, the Federal government owns approximately 72 percent of the land in the watershed, and in Idaho, the Federal government owns approximately 61 percent of the land in the watershed (Corps 2012). In British Columbia, the majority of land in the watershed is managed as Crown Land. In the British Columbia section of the watershed, populations centers such as Cranbrook and Kimberley are concentrated near the confluence of the St. Mary and Kootenay Rivers, and population centers such as Fernie, Sparwood, and Elkford are concentrated along the Elk River. In Montana and Idaho, population centers are concentrated along the Kootenai River Valley downstream of Libby Dam and include the towns of Libby and Troy in Montana, and Bonners Ferry in Idaho (Corps 2012).

The economy of the watershed relies heavily on forest products, mining, hydropower, recreation (tourism), technology, and agriculture. In the past, timber and mining were the main drivers of employment in the region; however, recently tourism and recreation have become more important, as has government employment. In addition, the technology and electronics industry is becoming economically important in several British Columbia cities, such as Cranbrook and Kimberley (Corps 2012). Agriculture, although present in the region, is not considered to be a major economic industry.

1.5 CONTAMINANT SOURCES

Historical and current point source discharges of contaminants that may impact Lake Koocanusa and the Kootenai River exist in the watershed. Mining has been active in the watershed since the 1800s. Pacific Watershed Institute (PWI) (1999) identified a variety of water and sediment quality impacts associated with historical mining activities including heavy metal loadings, increased suspended sediments and turbidity, elevated nitrate levels, and increased selenium loadings. Actions have been taken to reduce the loading of contaminants from historical and active mines in the watershed, including treatment and recycling of waste rock and tailings pile runoff, and restoration of abandoned mines. Nonetheless, coal mining operations continue in the watershed in British Columbia, and the impacts are discussed in greater detail in the following section.

Two major historical sources of contamination to the water and sediments were the Cominco Sullivan Mine and ammonium phosphate fertilizer plant near Kimberley, British Columbia, and the Crestbrook Forest Industries kraft pulp mill near Skookumchuck, British Columbia. The ammonia phosphate fertilizer plant began production in 1953 and discharged large quantities of phosphorus, fluoride, ammonia, and heavy metals into the St. Mary River, a major tributary to the Kootenay River in British Columbia. Levels of phosphorus and ammonia decreased in 1975 due to pollution abatement measures, and the plant closed in 1987. The Crestbrook pulp mill was one of the largest point sources of industrial wastewater to the river in the 1960s and 1970s. Pollution control

efforts in the 1980s substantially improved effluent water quality (Woods 1982; Knudson 1994; Tetra Tech 2004).

The communities of Cranbrook, Kimberley, Fernie, Sparwood, and Elkford in British Columbia; Libby, Troy, and Eureka in Montana; and Bonners Ferry in Idaho continue to discharge secondary treated water to the Kootenai River. In addition to these larger point sources, there are numerous small community wastewater systems and individual septic systems.

1.6 COAL MINING IMPACTS

The Elk River originates in southeastern British Columbia and is a major tributary to the Kootenai River and Lake Koocanusa (see Figure 1-1). Historical and current coal mining in the watershed has degraded the sediment and water quality in the Elk River entering Lake Koocanusa. Coal mining and the corresponding waste rock spoils it generates has increased in the watershed as mining operations have expanded. Estimates of the total amount of coal produced from mining operations along the Elk and Fording Rivers has increased from about 2,800 million tonnes in 1997 to more than 27,000 million tonnes in 2016, a tenfold increase (Teck 2016). Hauer and Sexton (2013) reported elevated loadings of selenium, nitrate, and sulfate from the Elk River in British Columbia to Lake Koocanusa and the Kootenai River. Jenni, Naftz, and Presser (2017) noted that selenium loading to Lake Koocanusa from the Elk River increased fivefold between 1992 and 2012.

The increased loads of these elements from the Elk River pose a serious ecological threat to fish and aquatic birds in Lake Koocanusa. In particular, increased selenium loading is of concern because selenium can bioaccumulate in the food web and is toxic to fish and aquatic birds (Skorupa 1998; Chapman et al. 2010). In addition, the increased loadings of nitrate to Lake Koocanusa are of concern because nitrate is an essential nutrient for plant growth. Although the vast majority of lake water quality problems are associated with increased phosphorus loadings, there is concern that increased nitrogen loadings may also negatively impact the water quality of Lake Koocanusa by increasing algal growth, changing the species composition of the algae, altering zooplankton size and abundance, and altering the trophic status of the lake (Elser, Marzolf, and Goldman 1990; Beaulieu, Pick, and Gregory-Eaves 2013; Hobbs et al. 2016).

1.7 EXISTING CLEAN WATER ACT 303(d) AND TOTAL MAXIMUM DAILY LOADS

The Montana Department of Environmental Quality (MDEQ), in its 2016 Integrated Report (MDEQ 2018), identified Lake Koocanusa as water quality impaired and not fully supporting aquatic life. Consequently, Lake Koocanusa was included in the 2016 MDEQ Clean Water Act 303(d) list Category 5 for flow alterations and selenium. The 303(d) list Category 5 is defined by the U.S. Environmental Protection Agency (EPA) as waters with one or more beneficial uses being impaired or threatened. A total maximum daily

load (TMDL) is required to address the impairment or threat. For Lake Koocanusa, a TMDL is needed for selenium but is not applicable for flow alteration.

The Kootenai River was identified by MDEQ as water quality impaired in the 2016 Integrated Report, and the river was included in the 303(d) Category 5 list for flow alterations and water temperature. A TMDL is being developed for water temperature. A TMDL is not applicable for flow alteration in the river.

1.8 PREVIOUS INVESTIGATIONS 1967 TO 2004

Water quality sampling of Lake Koocanusa and the Kootenai River was conducted by the USGS for the Seattle District from 1972 through 2004 and 1967 through 2004, respectively. A single sample collected in the Kootenai River in 1964 by the USGS was not considered part of the long term sampling program for the purpose of this report. The water quality program consisted of collecting monthly samples at three in-reservoir stations from May to October and at one downstream station from February to December. In-reservoir stations were located about 77 kilometers upstream of Libby Dam near the U.S.-Canada border (station LIBBOR [USGS No. 12300110]), 16 kilometers upstream of the dam near Ten Mile Creek (station LIBTMC [USGS No. 12302830]), and at the forebay (station LIBFB [USGS No. 12301919]),, while the downstream Kootenai River station was located in the tailwater of Libby Dam about 1 kilometer downstream of the dam at the site of the USGS gaging station (Station LIBTW [USGS No. 12301933]) (see Figure 1-1). Additional sampling stations were added and removed over time for special studies; however, the four core stations noted above remained the same during this time period.

The in-reservoir water quality program conducted by the USGS consisted of conducting vertical profiles of water quality at each station (temperature, conductivity, dissolved oxygen, and pH) and collecting monthly grab samples in the reservoir from May to October from about 3 meters above the reservoir bottom and 3 meters below the reservoir surface. These grab samples were analyzed for nutrients (monthly), major ions (twice per year), and trace metals (twice per year). Additionally, a photic zone composite sample was collected and analyzed for chlorophyll a (monthly). The river water quality program consisted of collecting monthly depth-integrated samples from February to December at the USGS tailwater gaging station. These depth-integrated samples were analyzed for nutrients (monthly), major ions (twice per year), and trace metals (twice per year).

Although water quality data was collected on the Kootenai River on Lake Koocanusa from 1967 to 2004, and considerable data analysis of pre-dam (1967 to 1971) versus post-dam (1972 to 1980) has been performed (Woods 1980; Bonde and Bush 1982; Storm et al. 1982; Whitfield and Woods 1984), little water quality analysis has been conducted on the post-1980s data. Bonde and Bush (1982) predicted that pre-impoundment loadings of nitrogen and phosphorus in the Kootenai River would lead to post-impoundment eutrophic conditions in Lake Koocanusa. However, beginning in 1976, phosphorus concentrations were substantially reduced because of improved wastewater treatment at a fertilizer plant upstream of the reservoir. Woods (1982)

concluded that even though the trophic state of Lake Koocanusa would be classified as eutrophic based on nutrient loadings, the water quality and primary productivity data classify the reservoir as oligotrophic. This discrepancy in predicted versus actual trophic state was a result of limnological processes in the reservoir that cause nutrients entering the reservoir to be largely unavailable to phytoplankton because these nutrients are carried beneath the euphotic zone and are settled out and removed from the water column due to the long residence time in the reservoir (Woods 1982).

1.9 CURRENT INVESTIGATION 2006 TO 2016

The Seattle District implemented a water quality monitoring study in 2006 to continue the long-term monitoring program on Lake Koocanusa and the Kootenai River that was started by the USGS in 1967. Water quality data presented in this summary was derived from both the current Seattle District program and the historical USGS program. The current Seattle District program consists of three permanent in-reservoir stations and one permanent downstream river station (located at the tailwater of Libby Dam) distributed throughout the Lake Koocanusa/Kootenai River system at the same locations sampled by the USGS between 1967 to 2004 (Figure 1-2).

The three in-reservoir stations consisted of one up-reservoir station located about 77 kilometers upstream of Libby Dam near the U.S.-Canada border (LIBBOR), one mid-reservoir station located about 16 kilometers upstream of Libby Dam near Ten Mile Creek (LIBTMC), and one forebay station located immediately upstream of the dam (LIBFB). The in-reservoir stations were collected from the reservoir thalweg, which represents the deepest point at each sampling location. The Kootenai River station (LIBTW) was located on the Kootenai River in the tailwater of Libby Dam about 0.5 kilometer downstream of the dam at the David Thompson Bridge and collected at mid-channel from the bridge. A temporary downstream station (HAUL) established in 2016 was located on the Kootenai River about 14 kilometers downstream of Libby Dam at the constriction of the river at an old haul bridge site and collected from the right bank. No other downstream river water quality stations were summarized for this report. Water quality sampling station locations used for this report are summarized in Table 2-1, with general sampling locations shown in Figure 2-2.

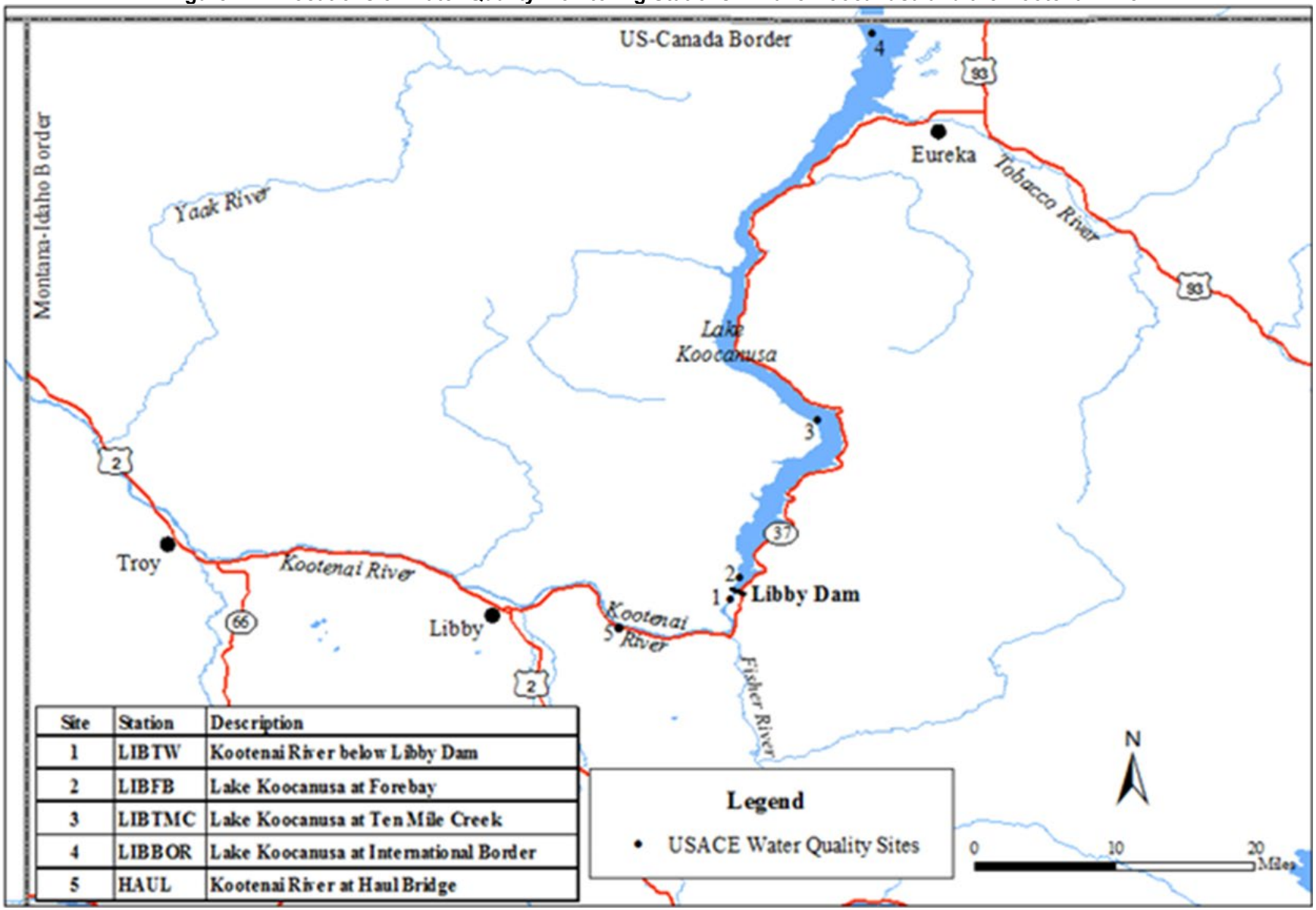
The Seattle District's in-reservoir water quality program consisted of conducting vertical profiles of water quality at each station (temperature, conductivity, dissolved oxygen, and pH) and collecting monthly grab samples in the reservoir from April through October. All water quality sampling was performed by two field technicians wearing new powder-free vinyl gloves. In-reservoir (LIBBOR, LIBTMC, and LIBFB) samples were collected by submerging a cleaned and decontaminated 3.0 liter (L) polycarbonate (Lexan) van-dorn style sampler with ultra-clean seals to depth and filling. From 2006 through 2013, samples were collected from up to four depths in the epilimnion and hypolimnion (as determined from vertical profiling) and equally composited in laboratory-cleaned, prelabled sample containers at the surface. From 2014 through 2016 samples were collected from a depth of 3 meters below the surface (representative of the epilimnion) and 3 meters above the bottom (representative of the hypolimnion). The downstream Kootenai River station (LIBTW) was collected from the

David Thompson Bridge about 0.5 km downstream of the dam in the tailwater of Libby Dam by submerging a cleaned and decontaminated van-dorn style sampler to depth and filling. At all stations, sample containers were rinsed three times prior to filling, capped with headspace for mixing or the addition of preservative, and immediately placed on ice in a cooler. Samples for chlorophyll a analysis were collected from up to five depths in the photic zone, and composited into a clean 22 L bucket at the surface. Measurements of field parameters (see Table 1-1) were performed in situ using a Hydrolab MiniSonde 5 multiprobe coupled with a Surveyor 4 surface display and recording unit. Equipment used for field measurements was calibrated prior to each sampling event.

Phytoplankton samples were collected from the photic zone following the procedures used for chlorophyll a sample collection. Zooplankton samples were collected by vertical tow from a depth of 10 meters to the surface using a 64 µm mesh net. Phytoplankton and zooplankton samples were immediately placed on ice in a cooler and preserved with either a 1-percent Lugols solution (phytoplankton) or 25-percent Isopropyl Alcohol solution (zooplankton) within 12 hours of sample collection.

Water quality parameters of concern, analytical methods, detection limits, and sampling details are presented in Table 1-2 and Table 1-3.

Figure 1-2. Locations of Water Quality Monitoring Stations in Lake Koocanusa and the Kootenai River



Site	Station	Description
1	LIBTW	Kootenai River below Libby Dam
2	LIBFB	Lake Koocanusa at Forebay
3	LIBTMC	Lake Koocanusa at Ten Mile Creek
4	LIBBOR	Lake Koocanusa at International Border
5	HAUL	Kootenai River at Haul Bridge

Table 1-1. Water Quality Sampling Locations in Lake Koocanusa and the Kootenai River for 2006 to 2016 and Historical U.S. Geological Survey 1967 to 2004

Station Name	Station Location	Water Body	Years Sampled	Historical USGS Station	Latitude (NAD 83)	Longitude (NAD 83)
LIBBOR	Lake Koocanusa at International Border	Lake Koocanusa	2006-2016	YES	48.995982	-115.182805
LIBTMC	Lake Koocanusa at Ten Mile Creek	Lake Koocanusa	2006-2016	YES	48.587128	-115.232889
LIBFB	Lake Koocanusa at Forebay	Lake Koocanusa	2006-2016	YES	48.411106	-115.312348
LIBTW	Kootenai River at Tailwater	Kootenai River	2006-2016	YES	48.406555	-115.317283
HAUL	Kootenai River at Hual Bridge Site	Kootenai River	2016	NO	48.371763	-115.428578

Table 1-2. Chemical Methods and Detection Limits for Lake Koocanusa Water Quality Analyses for the 2006 to 2016 Investigation

Type	Method Number 1/	Detection Limit	Container and Preservative 2/	Holding Time	Water Quality Stations Key 3/
Total phosphorus	SM18 4500PF	0.002 mg/L	P/G , 4°C, H2SO4 to pH<2	28 days	A
Soluble phosphorus	SM18 4500PF	0.001 mg/L	P/G, 4°C, filter immediately	48 hours	A
Total nitrogen	SM20 4500NC	0.050 mg/L	P/G, 4°C, H2SO4 to pH<2	28 days	A
Nitrate+nitrite	SM18 4500N03F	0.010 mg/L	P/G, 4°C, H2SO4 to pH<2	28 days	A
Ammonia	SM18 4500NH3H	0.005 mg/L	P/G, 4°C, H2SO4 to pH<2	28 days	A
Alkalinity	SM18 2320B	1.00 mg/L	P/G, 4°C	14 days	A
Hardness	SM18 2340B	0.700 mg/L	P/G, 4°C, HNO3 to pH<2	6 months	B
Calcium	EPA 200.7	0.100 mg/L	P/G, 4°C, HNO3 to pH<2	6 months	B
Magnesium	EPA 200.7	0.100 mg/L	P/G, 4°C, HNO3 to pH<2	6 months	B
Potassium	EPA 200.7	0.500 mg/L	P/G, 4°C, HNO3 to pH<2	6 months	B
Sodium	EPA 200.7	0.500 mg/L	P/G, 4°C, HNO3 to pH<2	6 months	B
Sulfate	SM18 4500SO4E	1.00 mg/L	P/G, 4°C	28 days	B
Chloride	SM18 4500CLC	0.50 mg/L	P/G, 4°C	28 days	B
Aluminum	EPA 200.8	0.003 mg/L	P/G, 4°C2/	6 months	B
Arsenic	EPA 200.8	0.003 mg/L	P/G, 4°C2/	6 months	B
Cadmium	EPA 200.8	0.0001 mg/L	P/G, 4°C2/	6 months	B
Chromium	EPA 200.8	0.0020 mg/L	P/G, 4°C2/	6 months	B
Copper	EPA 200.8	0.0010 mg/L	P/G, 4°C2/	6 months	B
Lead	EPA 200.8	0.0001 mg/L	P/G, 4°C2/	6 months	B
Selenium	EPA 200.8	0.0005 mg/L	P/G, 4°C2/	6 months	A
Selenium Speciation	EPA 1638DRC	0.00005 mg/L	P/G, 4°C2/	6 months	C
Zinc	EPA 200.8	0.005 mg/L	P/G, 4°C2/	6 months	B

Table 1-3. Biological Methods and Detection Limits for Lake Koocanusa Water Quality Analyses for the 2006 to 2016 Investigation

Type	Method Number 1/	Detection Limit	Container and Preservative 2/	Holding Time	Water Quality Stations Key 3/
Phytoplankton	–	–	P/G, 4°C, 1% Lugols	12 months	D
Zooplankton	–	–	G, 4°C, 25% Isopropyl Alcohol	12 months	D
Chlorophyll a	SM 1810200H	0.0001 mg/L	P, 4°C, filter, add MgCO3	28 days	D

Note: mg/L = milligrams per liter.
1/ SM method numbers are from Greenberg, Eaton, and Clesceri (2000); EPA method numbers are from EPA (1983, 1984, 1992).
2/ Samples for analysis of total trace metals should be preserved within 24 hours with HNO3 to pH < 2. Samples for dissolved trace metals should be preserved within 24 hours with HNO3 to pH < 2 after filtration.
3/ A = Stations LIBTW, LIBBOR, LIBTMC, LIBFB for all months (2006 to 2016); B = Stations LIBTW, LIBBOR, LIBTMC, LIBFB for May, July, and October samples (2006 to 2016); C = Stations LIBFB, LIBTW, HAUL for May, July, and September (2016); D = Stations LIBBOR, LIBTMC, LIBFB for all months (2006 to 2016).

1.10 WATER QUALITY CRITERIA

The MDEQ determines water quality criteria for the Kootenai River and Lake Koocanusa in Montana. The MDEQ has classified waters in the Kootenai River watershed as a Class B-1 water body, which is suitable for drinking after conventional treatment. It is also suitable for recreational use, growth and propagation of aquatic organisms (including salmonids), and agricultural and industrial uses. The State of Montana's numeric water quality standards are presented in Table 1-4. Criterion maximum concentrations (acute 1-hour average) and criterion chronic concentrations (chronic 4-day average) for metals sampled in Lake Koocanusa and the Kootenai River are presented in Table 1-4. Total ammonia concentrations shown in Table 1-5 are based on the combined ionized (NH4+-N – ammonium) and unionized (NH3-N – ammonia) forms. However, only the unionized form of ammonia (NH3-N) is toxic to freshwater life. Equations can be used to estimate the concentration of unionized ammonia fraction from measured values of the pH and temperature of the water. In general, the unionized form of ammonia (NH3) represents an extremely small percentage of the total ammonia nitrogen concentration (Greenberg, Eaton, and Clesceri 1992).

Table 1-4. Montana Department of Environmental General Water Quality Standards

Parameter/ Project	Regulator	Standard
Temperature		
Kootenai River	MDEQ	Class B-1: Shall not exceed 67°F due to human activities. A 1°F maximum increase above naturally occurring water temperature is allowed within the range of 32°F to 66°F; within the naturally occurring range of 66°F to 66.5°F, no discharge is allowed which will cause the water temperature to exceed 67°F; and where the naturally occurring water temperature is 66.5°F or greater, the maximum allowable increase in water temperature is 0.5°F. A 2°F per-hour maximum decrease below naturally occurring water temperature is allowed when the water temperature is above 55°F. A 2°F maximum decrease below naturally occurring water temperature is allowed within the range of 55°F to 32°F.When natural conditions exceed 16.0°C, no temperature increase will be allowed which will raise the receiving water by greater than 0.3°C.
pH		
Kootenai River	MDEQ	Class B-1: Shall be within the range of 6.5 to 8.5. Induced variation of hydrogen ion concentration (pH) within the range of 6.5 to 8.5 must be less than 0.5 pH unit. Natural pH outside this range must be maintained without change. Natural pH above 7.0 must be maintained above 7.0.
Dissolved Oxygen		
Kootenai River	MDEQ	Class B-1: For early life stages dissolved oxygen concentrations shall exceed a 1-day minimum of 8.0 (5.0) mg/L and shall exceed a 7-day mean of 9.5 (6.5) mg/L. For other life stages dissolved oxygen concentrations shall exceed a 1-day minimum of 4.0 mg/L and a 7-day mean minimum of 5.0 mg/L, and a 30-day mean of 6.5 mg/L. The dissolved oxygen concentrations presented are water column concentrations recommended to achieve the required inter-gravel dissolved oxygen concentrations shown in parentheses. For species that have early life stages exposed directly to the water column, the figures in parentheses apply.
Turbidity		
Kootenai River	MDEQ	Class B-1: The maximum allowable increase above naturally occurring turbidity is five nephelometric turbidity units except as permitted in 75-5-318, MCA.
Total Dissolved Gas		
Kootenai River	MDEQ	Class B-1: Shall not exceed 110 percent of saturation.

Table 1-5. Montana Department of Environmental Quality Metals and Ammonia Water Quality Standards

Category	Parameters	Acute Water Quality Criteria (µg/L) 1/	Chronic Water Quality Criteria (µg/L) 1/
Nutrients	Ammonia2	8110	2540
Dissolved Metals	Aluminum	750	87
Dissolved Metals	Arsenic	—	—
Dissolved Metals	Cadmium	—	—
Dissolved Metals	Chromium	—	—
Dissolved Metals	Copper	—	—
Dissolved Metals	Lead	—	—
Dissolved Metals	Zinc	—	—
Total Metals	Aluminum	—	—
Total Metals	Arsenic	360	190
Total Metals	Cadmium	3.9*	1.1*
Total Metals	Chromium	1737*	207*
Total Metals	Copper	17.7*	11.8*
Total Metals	Lead	81.6*	3.2*
Total Metals	Selenium	20	5
Total Metals	Zinc	117*	106*

Notes:
1/ MDEQ (2014)
2/ Total ammonia concentration. Based on salmonids present, pH value of 7.8 and temperature of 18C.
***** Hardness dependant. Value based on an average hardness in Lake Koocanusa of 100 mg/L as CaCO3.
— Not Available.

1.11 DATA ANALYSIS

Data analysis consisted of (1) trend analysis of long-term monitoring data in Lake Koocanusa and the Kootenai River, (2) graphing and visual inspection of timeseries data, and (3) determining what, if any, relationships exist between physical data, chemical data, and biological data. Water quality parameters used for these statistical analyses focused largely on nutrients and included total phosphorus, soluble reactive phosphorus, total nitrogen, nitrate + nitrite-nitrogen, ammonia-nitrogen, alkalinity, transparency, and chlorophyll a. Phytoplankton data used for these analyses focused on total phytoplankton density, total phytoplankton biovolume, and phytoplankton composition.

Trend analysis was performed on the long-term monitoring data from each station using a seasonal Kendall test (Hirsch, Slack, and Smith 1982). The seasonal Kendall test is a nonparametric test that is appropriate for data that is not normally distributed, such as water quality data. The test determines if a significant consistent trend exists and the magnitude of the trend. The magnitude of the trend is expressed as a slope, or a change per unit time (Hirsch, Slack, and Smith 1982). Seasonal Kendall tests were conducted on two sets of long-term monitoring data. First, data collected by the Seattle District from 2006 to 2016 was used to perform seasonal Kendall tests for the determination of trends over the past 11 years. Second, data collected by the USGS from 1993 to 2004 was combined with the 2006 to 2016 data to provide a more robust long-term data set spanning more than 20 years. Although the USGS data goes back to about 1972, analysis of this historical data set revealed that too many different analytical methods and reporting limits were used to allow the data set to be comparable to the

current data set. For this analysis, any data below the laboratory reporting limits was used in statistical tests and estimated at one-half the reporting limit.

Visual inspection of data and trends were examined using boxplots and graphs of moving means. Boxplots were used to summarize water quality data measured at each station during the study. Boxplots display essential characteristics of a data set (median, spread of data, outliers), and are useful when comparing copious amounts of data between multiple data sets. Graphical trend analyses were conducted using the 12-month moving mean method. This method takes the mean of consecutive 12-month time intervals (i.e., January to January, February to February, etc.) and plots each 12-month period in a continuous timeseries. The new month's numbers are added to the mean while the oldest month's numbers are dropped, resulting in the mean "moving" over time. Although such a method does not prove a trend, it tends to smooth the data over time, allowing for easier visual inspection of timeseries data to determine which parameters may have a trend that requires statistical trend analysis.

Relationships between physical, chemical, and biological data were conducted using the Kendall Tau rank correlation analysis (Zar 1984; Helsel and Hirsch 2002). The Kendall Tau correlation analysis is a nonparametric test used to identify relationships between variables. A statistical significance level of $p < 0.05$ was used to identify relationships between two variables. To create a more robust data set to compare, all data (April to October) from 2006 through 2016 was combined for all correlation tests.

SECTION 2 - WATER QUALITY

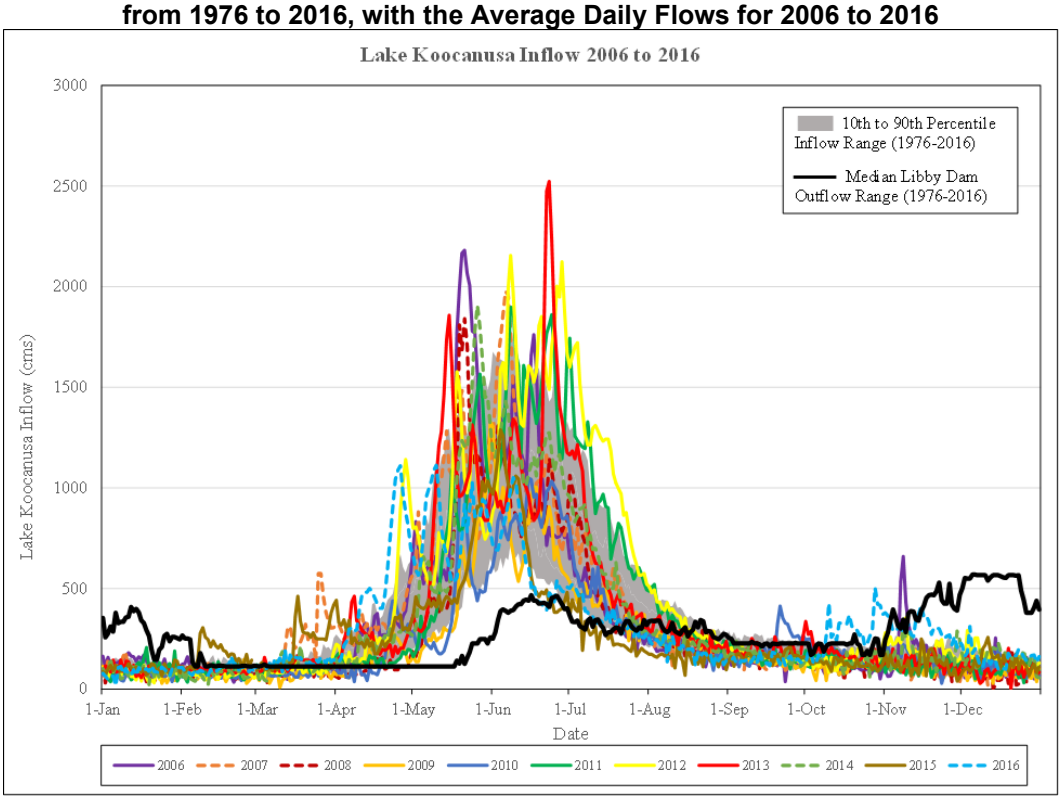
2.1 PHYSICAL CHARACTERISTICS

2.1.1 Hydrologic

2.1.1.1 *Inflow and Forebay Elevation*

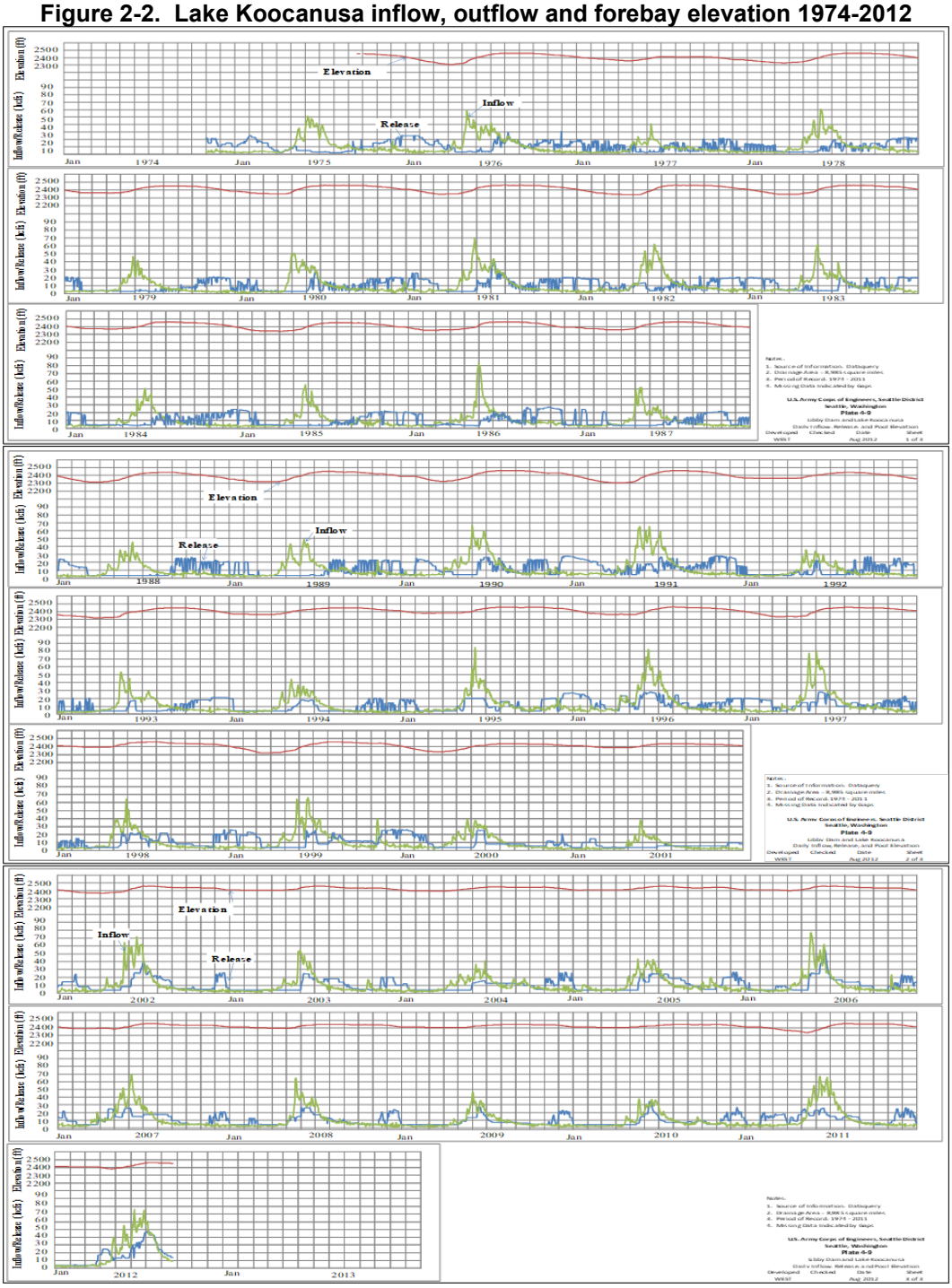
Hydrographs of average daily inflow for Lake Koocanusa during the 2006 through 2016 current investigation period, and for the post-dam period from 1976 to 2016, are presented in Figure 2-1. Post-dam period data shows that inflows generally peak during late May and June, with the 10th and 90th percentile maximum inflows ranging from about 735 to 1,780 cubic meters per second, respectively. Lake Koocanusa inflow volumes were high in 2006, 2012, and 2013 with peak May through July flows well above the 90th percentile of post-dam flows. Flows in 2007, 2008, 2011, and 2014 were moderate and slightly greater than the post-dam median levels. Similar or slightly lower than post-dam median inflows were experienced in 2009, 2010, 2015, and 2016. Peak flows during 2006 were about 2,150 cubic meters per second in late May; during 2012, they were about 2,100 cubic meters per second in mid-June; and in 2013, inflows peaked at about 2,500 cubic meters per second in late June. The lowest peak inflows during the study were measured in 2010 and 2016, with peak inflows of about 1,075 cubic meters per second, which is similar to or slightly lower than the post-dam median peak inflow.

Figure 2-1. Comparison of the Historical Daily Inflow to Lake Koocanusa from 1976 to 2016, with the Average Daily Flows for 2006 to 2016



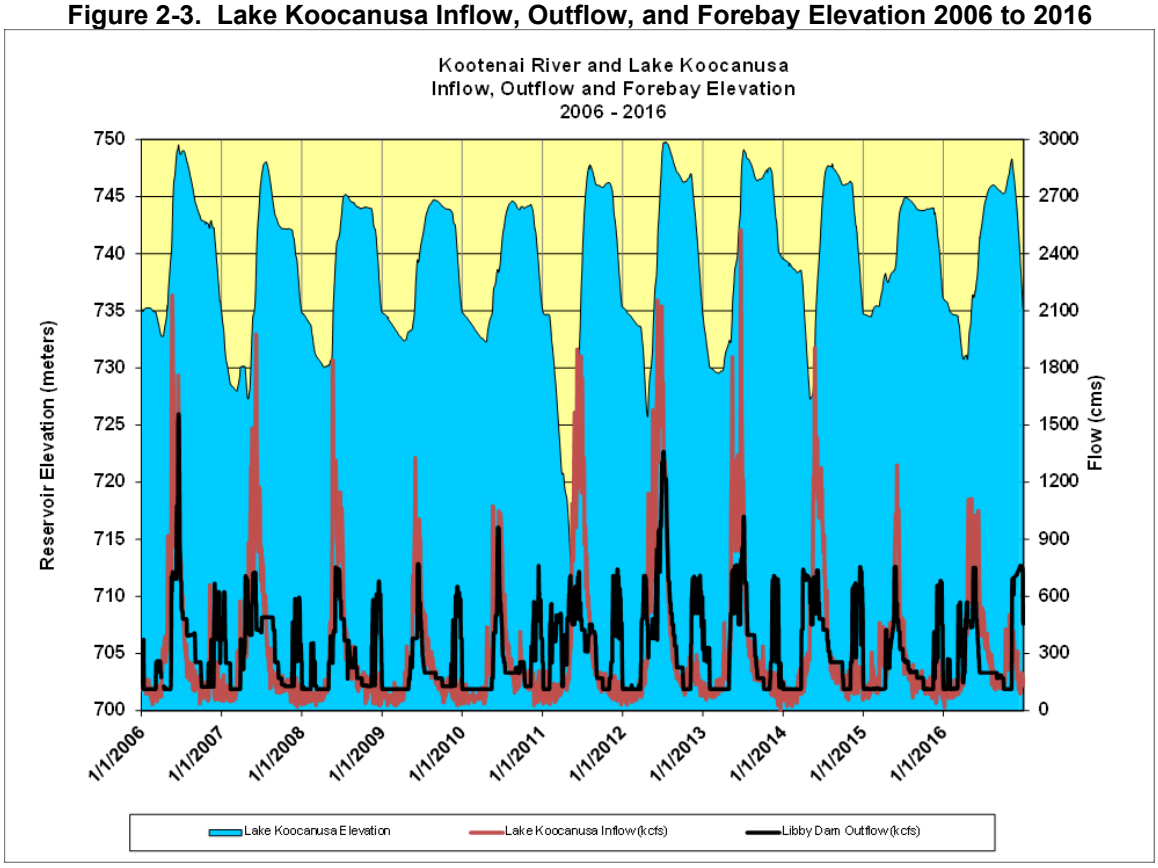
The operation of Libby Dam for flood risk management and power production has altered the hydrograph and reduced peak flows by greater than 50 percent in the Kootenai River downstream of the dam. This reduction in peak flows is shown in Figure 2-2 for the time period 1974-2012. In general, Lake Koocanusa is drawn down in the late fall and winter to a minimum forebay elevation in March or April for power production and to provide storage for the spring runoff.

Figure 2-2. Lake Koocanusa inflow, outflow and forebay elevation 1974-2012



High inflow volumes in the spring rapidly fill the reservoir with a maximum forebay elevation attained in July, August and September as shown in Figure 2-3 for the 2006 - 2016 study period. The minimum and maximum pool elevation for Lake Koocanusa is determined each year based on snowmelt runoff forecasts for the watershed. Consequently, the minimum winter pool elevation and maximum summer pool elevation varies from year to year due to weather and snowmelt variations.

Figure 2-3. Lake Koocanusa Inflow, Outflow, and Forebay Elevation 2006 to 2016



Minimum and maximum annual forebay elevations, corresponding reservoir volumes, and percent of maximum reservoir volume during 2006 to 2016 are shown in Table 2-1. The volume of the reservoir available to receive the spring runoff ranged from a low of 30.9 percent of capacity in 2011 to a high of 64.69 percent of capacity in 2015. Similarly, the volume of the reservoir at the maximum forebay elevation in the summer ranged from a low of 87 percent of capacity in 2010 to a high of 100.7 percent of capacity in 2012. Between 2006 and 2016, the reservoir minimum and maximum elevations and storage volumes changed from year to year with 2008, 2009, 2010, and 2015 being relatively low storage volume years while 2006, 2012, and 2013 were greater storage volume years.

Table 2-1. Lake Koocanusa Forebay Elevations and Reservoir Volumes from 2006 to 2016

	Minimum Forebay Elevation			Maximum Forebay Elevation		
Year	Minimum Forebay Elevation (m)	Volume (cubic km)	Percent of Maximum Volume	Maximum Forebay Elevation (m)	Volume (cubic km)	Percent of Maximum Volume
2006	732.7	4.47	61.71	749.5	7.24	100.00
2007	727.3	3.77	52.10	747.7	6.90	95.31
2008	730.0	4.11	56.71	744.9	6.41	88.48
2009	732.1	4.38	60.56	744.6	6.35	87.74
2010	732.1	4.38	60.56	744.3	6.30	87.00
2011	712.3	2.24	30.90	747.7	6.90	95.31
2012	725.4	3.56	49.17	749.8	7.30	100.79
2013	729.4	4.03	55.65	748.9	7.13	98.42
2014	727.3	3.77	52.10	747.7	6.90	95.31
2015	734.3	4.68	64.69	744.9	6.41	88.48
2016	730.6	4.18	57.78	745.8	6.57	90.73

2.1.1.2 *Lake Koocanusa Filling Rate and Retention Time*

Retention time, which is the inverse of the flushing rate, refers to the length of time water remains in a water body. Lake volume, inflow, and outflow are important factors in determining the overall retention time in a water body. One can calculate the retention time either by dividing the lake volume by the inflow (filling time) or by the outflow (residence time). In general, high flushing rates allow for the rapid exchange of chemical constituents through the lake. Longer retention times allow for the accumulation and transformations of chemical constituents in sediments and lake water, and their cycling through the ecosystem.

The theoretical retention time of Lake Koocanusa is about 9 months (0.75 year) based on historical average inflow volumes and a maximum reservoir volume of 7.24 cubic kilometers. During the study, the reservoir experienced a wide range of inflow, outflow, and reservoir volumes resulting in a large range in the annual retention time for Lake Koocanusa (Table 2-1 and Table 2-2). Annual lake-filling times ranged from a minimum of 0.526 year in 2012 to a maximum of 1.014 years in 2009. Annual lake-residence times were similar, ranging from 0.521 year in 2006 to 1.014 years in 2009. Years with the highest flushing rates were 2006, 2007, 2011, 2012, 2013, and 2014, while 2009, 2010, and 2015 had the lowest flushing rates. Although the annual lake-filling rate and lake-residence times were similar, the monthly filling rates and residence times were quite different, reflecting how the operation of Lake Koocanusa stores water during the high inflow spring runoff for flood risk management and releases water during the low inflow late-fall and early-winter periods for power production (Table 2-2). For example, in 2014, the lake filling rate ranged from 0.177 year in June to 2.599 years in February, while the residence time rate ranged from 0.246 year in December to 1.759 years in October. This difference in monthly filling rate and residence time stems from how the

reservoir is operated for flood risk management and power production. Inflow versus outflow hydrographs for the study period 2006 to 2016 are shown in Figure 2-3.

Table 2-2. Lake Koocanusa Monthly and Annual Lake-Filling Times and Residence Times

	Lake Filling Time in Years										
Year	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Jan	1.110	1.304	1.945	1.900	1.939	1.476	1.900	1.305	1.930	1.457	1.721
Feb	1.761	1.636	1.957	2.372	2.357	1.550	2.174	1.538	2.599	0.974	1.588
Mar	1.423	0.557	1.767	1.942	1.830	0.946	1.413	1.074	1.386	0.751	0.972
Apr	0.574	0.374	1.282	1.007	0.851	0.568	0.345	0.573	0.576	0.613	0.276
May	0.192	0.159	0.205	0.326	0.371	0.125	0.182	0.177	0.161	0.293	0.201
Jun	0.205	0.180	0.206	0.228	0.210	0.117	0.142	0.179	0.177	0.279	0.307
Jul	0.545	0.397	0.406	0.481	0.448	0.237	0.203	0.348	0.370	0.750	0.576
Aug	1.062	0.966	0.884	0.847	0.979	0.663	0.648	0.803	0.946	1.268	1.063
Sep	1.405	1.431	1.215	1.490	0.955	1.304	1.299	1.133	1.261	1.219	1.449
Oct	1.775	1.402	1.445	1.719	1.162	1.414	1.446	1.196	1.491	1.550	0.775
Nov	0.941	1.845	1.665	1.872	1.323	1.752	0.935	1.480	1.118	1.554	0.664
Dec	1.300	1.583	1.656	1.877	1.353	1.562	0.955	1.756	0.967	1.169	0.939
Annual	**0.697**	**0.676**	**0.831**	**1.014**	**0.928**	**0.623**	**0.526**	**0.646**	**0.683**	**0.910**	**0.738**

	Lake Residence Time in Years										
Year	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Jan	1.035	0.351	1.246	1.284	1.282	1.155	1.302	0.389	1.479	1.240	0.968
Feb	1.453	0.867	0.640	1.387	1.385	0.334	1.351	1.223	1.619	1.462	1.367
Mar	0.659	0.893	1.104	1.222	1.222	0.214	0.707	1.119	0.878	1.388	0.396
Apr	1.185	0.265	1.172	1.284	1.303	0.260	0.223	1.225	0.175	0.709	0.372
May	0.505	0.282	0.488	0.537	0.720	0.173	0.402	0.293	0.266	0.354	0.280
Jun	0.234	0.451	0.300	0.353	0.285	0.292	0.266	0.354	0.368	0.502	0.724
Jul	0.454	0.439	0.495	0.871	0.833	0.583	0.207	0.336	0.538	0.792	1.030
Aug	0.498	0.411	0.734	0.998	0.990	0.490	0.460	0.558	0.816	0.954	1.028
Sep	0.765	0.900	1.089	1.187	0.895	1.175	0.908	1.205	0.852	1.143	1.170
Oct	1.499	1.402	1.471	1.514	1.178	1.782	1.746	1.767	1.759	1.667	1.876
Nov	0.663	0.895	0.793	0.922	0.651	0.505	0.395	0.440	0.441	0.932	0.363
Dec	0.302	0.351	0.291	0.286	0.292	0.296	0.236	0.554	0.246	0.291	0.206
Annual	**0.683**	**0.677**	**0.832**	**1.014**	**0.933**	**0.623**	**0.521**	**0.692**	**0.638**	**0.930**	**0.722**

2.1.1.3 *Outflow and Spillway Flows*

TDG saturations in rivers are increased when dams release water through the spillways. Spilling water at a dam results in increased TDG levels in downstream waters by plunging the aerated spill water to depth where hydrostatic pressure increases the solubility of atmospheric gases. Elevated TDG saturations generated by spillway releases from dams are of concern because high saturations can promote the potential for gas bubble trauma in downstream aquatic biota (Weitkamp and Katz 1980; Weitkamp et al. 2002).

A detailed TDG study at Libby Dam was conducted in 2002 (Schneider 2003). Spillway flows ranged from 20 to 440 cubic meters per second with total river flows ranging from 665 to 1,132 cubic meters per second. This investigation determined the TDG exchange in spillway flows ranged from 104 to 134 percent saturation and were a direct function of the specific spillway discharge. The TDG saturation in spillway releases, as measured

immediately below the stilling basin, increased as an exponential function of the spillway discharge, and increased abruptly from 104 to 129 percent saturation as spill discharge increased from 20 to 110 cubic meters per second. A mild increase in TDG saturations from 129 to 134 percent was observed as spillway discharges increased from about 110 to 440 cubic meters per second. The passage of water through the powerhouse did not change the TDG saturations in the Kootenai River, and TDG pressures in powerhouse releases measured during the test ranged from 102 to 104 percent.

The TDG characteristics in the Kootenai River below Libby Dam are dominated by the development of a mixing zone between spillway and powerhouse releases and in-river processes such as degassing at the air/water interface, lateral mixing, and thermal heat exchange. The rapid development of a mixing zone and in-river processes result in decreasing TDG saturations in the Kootenai River downstream of the dam. A strong lateral TDG saturation gradient exists in the Kootenai River about 5.6 kilometers downstream at the Highway 37 Bridge immediately upstream of the Fisher River. However, TDG saturations in the Kootenai River are generally well mixed by about 14 kilometers downstream of the dam at the constriction of the river at an old haul bridge site (Schneider 2003).

Spillway flows from Libby Dam impact TDG saturations downstream in the Kootenai River. During the study, Libby Dam occasionally spilled water. High inflows in 2006 resulted in spillway flows up to about 880 cubic meters per second with corresponding downstream TDG saturations as high as 133 percent. Planned spillway operations were conducted in 2010 and 2012 to provide flows greater than the powerhouse capacity by up to 280 cubic meters per second, as required by the 2006 USFWS Biological Opinion to aid in reproduction and recruitment of the endangered Kootenai River white sturgeon. Libby Dam spillway flows were provided in 2010 (about 220 cubic meters per second) with a resulting maximum downstream TDG saturation of about 125. percent High inflows in 2012 resulted in spillway flows exceeding 620 cubic meters per second, with maximum TDG saturations of about 129. percent. Similarly, high inflows in 2013 resulted in spill flows exceeding 310 cubic meters per second, with maximum downstream TDG saturations of about 125 percent

2.1.2 Water Temperature

The temperature-related characteristics of water have a large effect on water quality and the ecology of lakes. As lake water warms in the spring and summer, it becomes less dense and floats on top of colder water. In the absence of sufficient energy (i.e., wind or high inflows) to mix the water and equilibrate the temperature, a lake will thermally stratify and form two separate temperature layers. Thermal stratification produces a warm water upper layer, called the epilimnion, and a cold water bottom layer, called the hypolimnion. The transition zone between these two layers is called the metalimnion or thermocline, and it is marked by rapid changes in water temperatures from top to bottom. Because of the temperature difference in a stratified lake, there is little mixing of water between the epilimnion and hypolimnion until the lake de-stratifies in the fall and winter, resulting in a uniform temperature throughout the water column.

The thermal structure in some lakes may be impacted by the temperature of the inflow water resulting in either underflow, when inflow temperatures are colder than the lake's epilimnion and plunge to the deeper layers, or overflow, when inflow temperatures are warmer than the lake's hypolimnion and therefore stay in the epilimnion (Wetzel 1975). Although inflow plume routing may be the dominant cause of thermal stratification in some lakes, it is typically more common that a combination of both inflow plume routing and solar heating of the lake surface results in the development of a thermocline. An inflow plume routing study was not conducted on Lake Koocanusa. However, the water quality study data collected from 2006 through 2016 showed numerous temperature, conductivity, pH, and dissolved oxygen profiles, as well as chemical constituents at the U.S.-Canada border, suggesting that underflow is the most common Kootenai River inflow water plume routing to Lake Koocanusa.

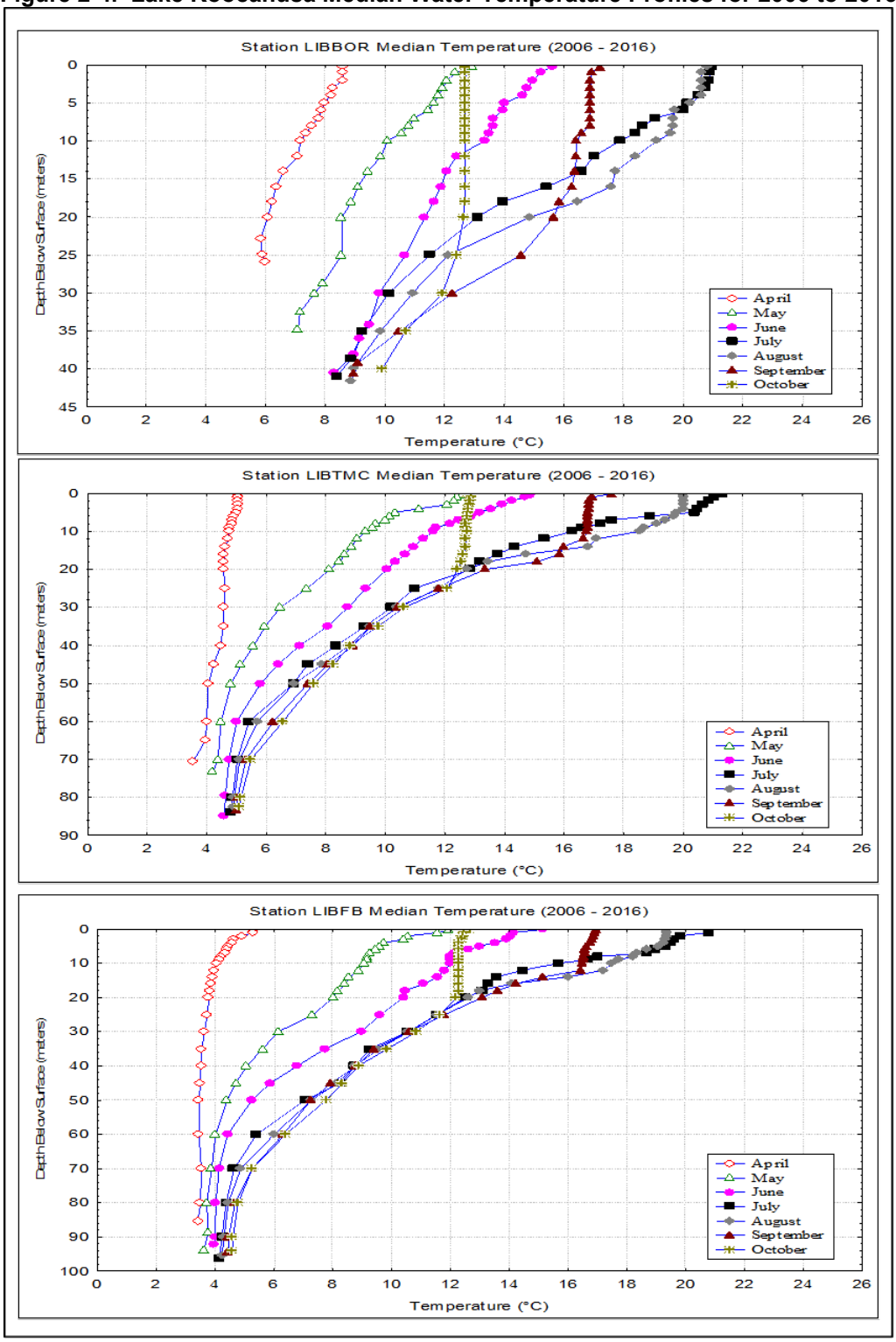
2.1.2.1 *Lake Koocanusa*

The thermal conditions in Lake Koocanusa at Libby Dam typically lag seasonal weather conditions by several months due to the long residence time and thermal inertia of the reservoir. The heat contained in the reservoir during the summer is carried over into the fall and winter months. The thermal conditions at Libby Dam typically reach minimum temperatures during late March or early April and are characterized by a uniform temperature near 4°C. Historical data suggests that the onset of thermal stratification typically begins at the shallower LIBBOR station during April and is generally not observed at the deeper LIBFB station until May. The initial stratification is weak and often short lived as weather systems disrupt the thermal structure. A warm front can rapidly add heat to the surface layer, strengthening the thermal stability in the water column. Wind events can result in vertical mixing of heat and initiate internal seiches that displace the temperature structure in the pool. Strong, prolonged winds out of the north can generate surface currents that transport surface temperatures to depth at Libby Dam and can influence release temperatures by several degrees over several days. The dissipation of a strong wind system will cause the restoration of a stable temperature structure in the reservoir. Turnover resulting in near-isothermal conditions generally begins at the shallow LIBBOR station in early November and at the deeper LIBFB station in late December.

Profiles representing the median monthly water temperature between 2006 and 2016 in Lake Koocanusa at stations LIBBOR, LIBTMC, and LIBFB are shown in Figure 2-4. Water temperature profiles at all three stations followed a similar pattern of warming from April through August and cooling in September and October. The onset of thermal stratification varies from year to year, likely due to many reasons such as inflow volumes, inflow temperatures, reservoir drawdown elevation, and weather conditions. In general, the thermal stratification in Lake Koocanusa is weak. Water temperatures tend to warm and stratify earlier in the year and more rapidly at the shallower LIBBOR station. However, temperatures also cool down quicker in September and October at LIBBOR, with near isothermal conditions periodically measured in October. Thermal stratification is most pronounced at the deeper (LIBTMC and LIBFB) reservoir stations with stratification continuing during October when the final temperature profiles are collected. Thermocline depths varied from year to year, but in general range from about

5 to 15 meters at LIBBOR and from about 10 to 25 meters at LIBTMC and LIBFB. Based on historical temperature string data collected at LIBFB, turnover resulting in near isothermal conditions occurs by the end of December at the LIBFB station.

Figure 2-4. Lake Koocanusa Median Water Temperature Profiles for 2006 to 2016



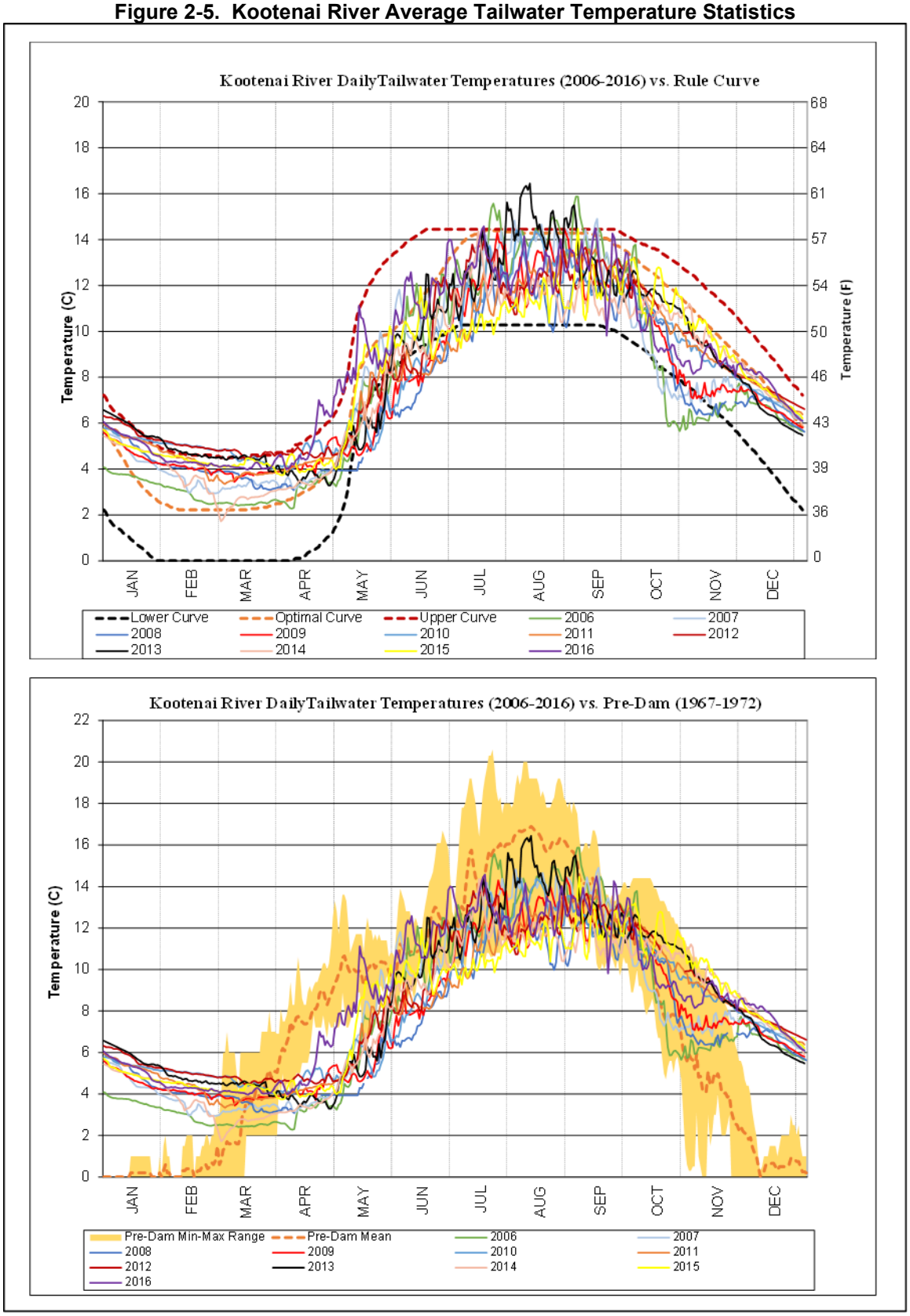
2.1.2.2 *Downstream Kootenai River*

Libby Dam was designed with a selective withdrawal system to manage release water temperatures downstream in the Kootenai River when thermal stratification develops in the reservoir. The system consists of a 14-bay concrete framework structure on the upstream face of the dam covering all powerhouse turbine intakes, 251 6-ton steel selector bulkheads, 69 7-ton pressure relief steel bulkheads, and a gantry crane to install and remove the bulkheads. Temperature control of the powerhouse outflow is accomplished by stacking or removing bulkheads to the desired depth of temperature as determined by a real-time temperature string on the face of the dam. The selective withdrawal system extends down approximately 75 meters below full pool (from elevation 749.5 to 674.5 meters).

The selective withdrawal system is operated to provide as close to a normative thermograph as possible downstream in the Kootenai River throughout the year. However, given the presence of a large, deep reservoir with stored latent heat as the source of water to the river, outflow temperatures can be cooler in the spring and warmer in the late fall compared to the natural pre-dam Kootenai River. Given this, the selective withdrawal system is operated to follow as best as possible a temperature rule curve developed by the Corps and Montana Fish, Wildlife & Parks. This rule curve, developed from pre-dam daily temperatures collected in the Kootenai River from 1967 to 1972, is presented together with a summary of release water temperatures from Libby Dam observed at the tailwater station (LIBTW) during the study from 2006 to 2016 (Figure 2-5). In general, Kootenai River tailwater temperatures are within the minimum and maximum rule curve temperature boundaries. However, average minimum temperatures released from Libby Dam are periodically cooler than the rule curve in the late spring (May and June) due to the difficulty in some years of accessing warmer water from the large reservoir.

Real-time Kootenai River tailwater temperatures from 2006 to 2016 were compared to pre-dam temperatures collected near the tailwater station from 1967 to 1972 (Figure 2-5). In general, post-dam downstream river temperatures during the fall and winter are several degrees warmer than pre-dam Kootenai River conditions, and during the spring and summer, water released from the dam is generally several degrees cooler than natural river conditions. Even though Libby Dam has a selective withdrawal system to access cooler/warmer waters, it has difficulty accessing warmer water in the early spring during the freshet and cooler water in the fall and winter due to the latent heat in the large reservoir. These shifts in the normal temperature pattern in the Kootenai River downstream of Libby Dam and the impacts on fish, including the endangered white sturgeon, were noted in the 2006 USFWS Biological Opinion.

Figure 2-5. Kootenai River Average Tailwater Temperature Statistics



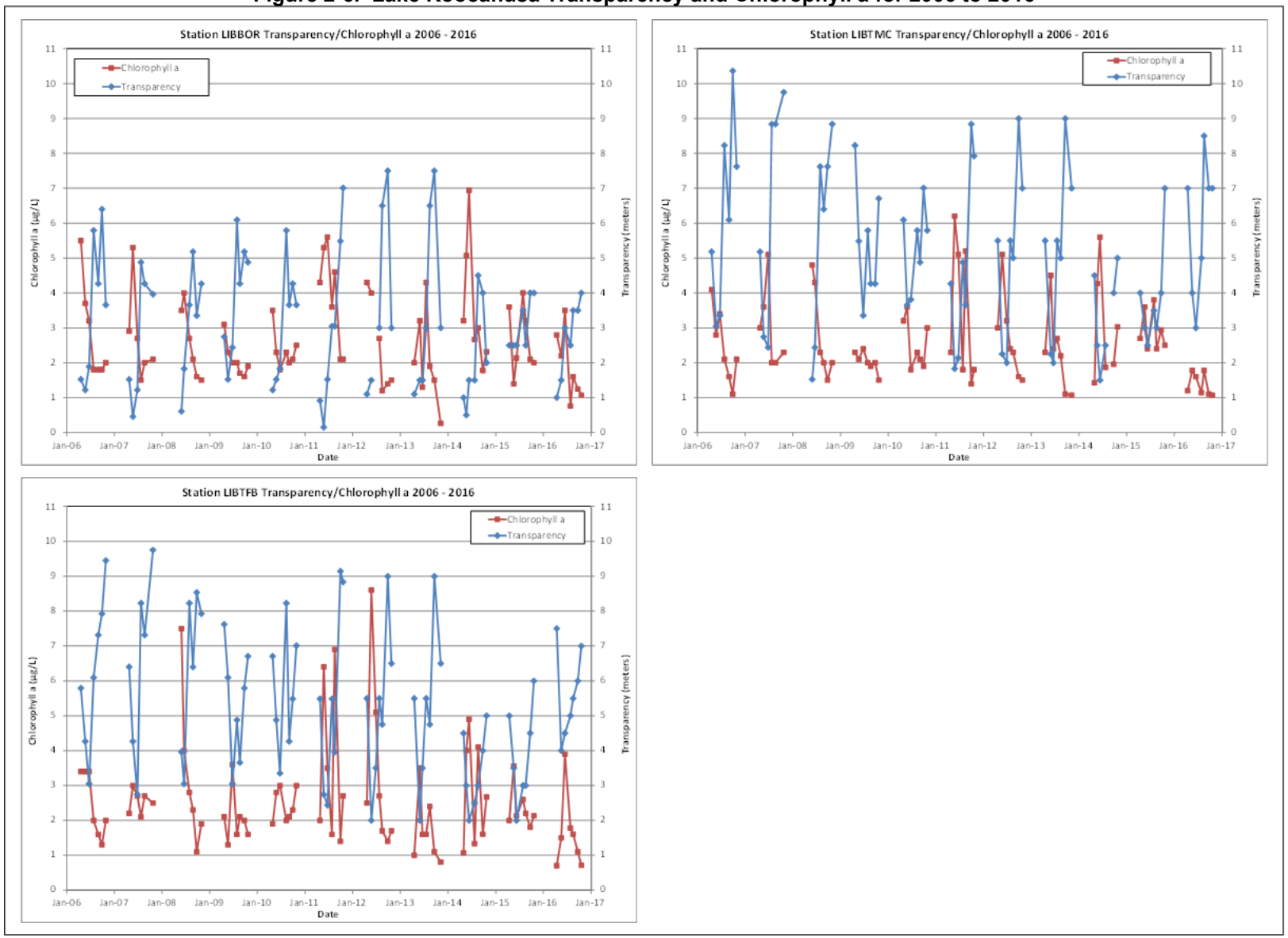
2.1.3 Water Transparency

Water transparency was measured in Lake Koocanusa using a Secchi disk, which is an 8-inch disk with alternating black and white quadrants. The depth at which the disk can no longer be seen in the water is called the Secchi disk depth. This depth is a relative measure of water transparency that can be used to look at changes in water clarity over time and between sampling stations. Water clarity is one of several parameters limnologists use to determine the trophic status of a lake because the number of phytoplankton suspended in the water column directly impacts transparency. However, transparency alone cannot be used to predict the trophic state because many other factors can affect transparency including suspended matter, soil particles, and natural water color.

Monthly variations in transparency at water quality stations in Lake Koocanusa for 2006 to 2016 are presented in Figure 2-6. Timeseries plots show that seasonal trends in transparency were similar at stations near the dam (LIBTMC and LIBFB) but different near the U.S.-Canada border (LIBBOR). Transparencies at LIBBOR were lowest from April through June (0.5 to 1.5 meters) showing the effect of high spring Kootenai River flows that generally reduce water clarity in the upper reservoir. The Kootenai River's watershed is heavily glaciated, resulting in highly turbid inflows to Lake Koocanusa. In particular, the transport of fine-grained glacial flour to Lake Koocanusa during the spring runoff results in highly turbid conditions and low water transparencies in the upper reservoir as measured at LIBBOR. Water transparencies increase during the summer months at LIBBOR with maximum water clarity (5 to 7 meters) generally in August or September.

The seasonal variation of water transparency near the dam at stations LIBTMC and LIBFB show a slightly different pattern than at LIBBOR. Transparencies are moderately high in April (4 to 5 meters), greatly reduced in May and June (1.5 to 2.5 meters), and then increasing during the summer to a maximum water clarity (7 to 9 meters) in August or September. The moderately high April transparencies near the dam indicate that any influence on water clarity from turbid spring inflows seen near the border at LIBBOR have not reached the dam due to the relatively long residence time of the reservoir. However, typically by the end of May, a reduction in water transparency can be measured near the forebay of the dam. The other main factor affecting the transparency of Lake Koocanusa is phytoplankton growth. Figure 2-6 plots transparency and chlorophyll a together as a timeseries. A moderately strong negative relationship between transparency and chlorophyll a is apparent at all stations, suggesting that in addition to inflow, the reduced water clarity measured at all stations for all years is also likely due in part to the amount of algae suspended in the water column (Figure 2-6).

Figure 2-6. Lake Koocanusa Transparency and Chlorophyll a for 2006 to 2016

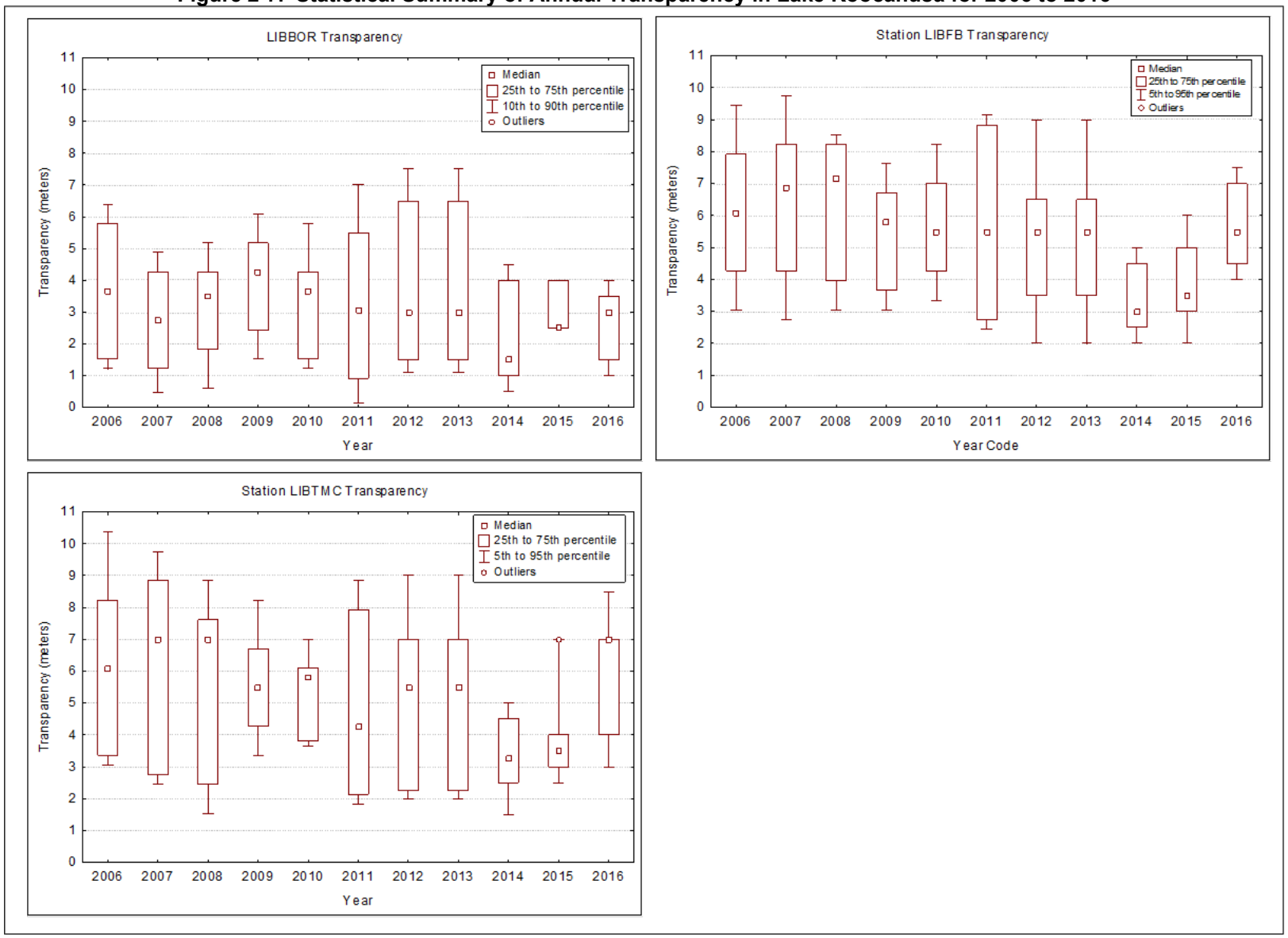


A summary of annual (April to October) water transparencies at each station from 2006 through 2016 is presented in Figure 2-7. This boxplot shows the median value, the 25th to 75th percentile range of data, the 10th to 90th percentile range of data, and outlier values. Annual transparency data exhibited both station-to-station and year-to-year variations. The median annual transparency was substantially lower at LIBBOR and ranged from 1.5 meters in 2014 to about 4 meters in 2009. Median annual transparencies were greater and similar at stations LIBTMC and LIBFB and ranged from about 3 meters in 2014 to more than 7 meters in 2008. The overall range of data was substantially less at all stations in 2014 and 2015 compared to other years largely due to the lower maximum transparencies measured those years. Transparencies during 2014 and 2015 were consistently low throughout Lake Koocanusa during the April to October sampling season.

2.1.4 Dissolved Oxygen

The concentration of dissolved oxygen in the water is important for determining the types of organisms that can survive and for regulating chemical processes, such as nutrients released from the sediments. For example, anoxic (no oxygen) conditions at the sediment water interface can result in the release of phosphorus from the sediments into the overlying water. Oxygen is supplied to the water from the atmosphere and from aquatic plants through photosynthesis. Oxygen can be removed from water by the respiration of aquatic organisms and plants, as well as the decomposition of organic matter in the water and sediments by bacteria.

Figure 2-7. Statistical Summary of Annual Transparency in Lake Koocanusa for 2006 to 2016

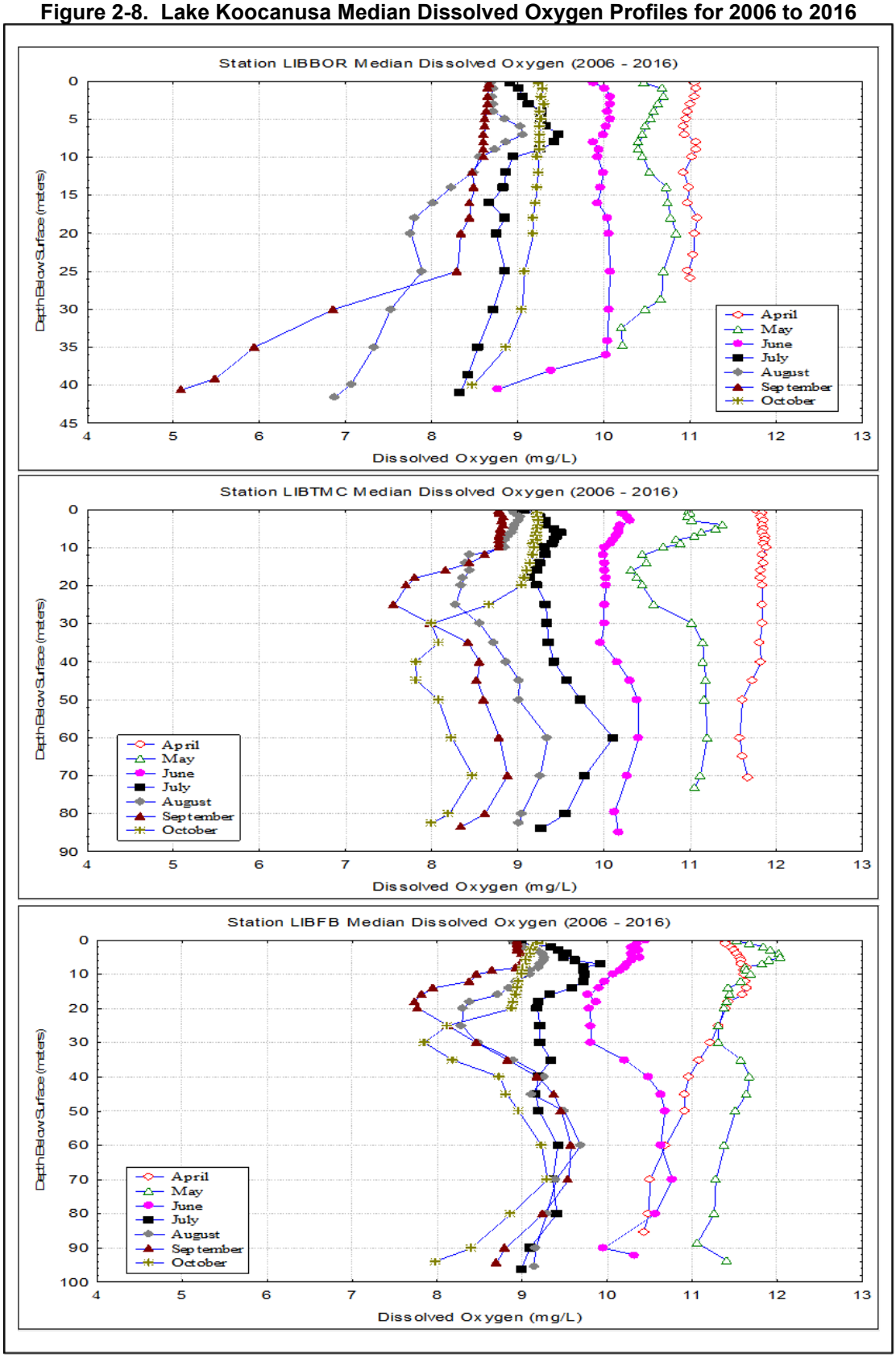


The solubility of oxygen in water is affected by temperature and air pressure. Oxygen solubility increases in cold water and with higher atmospheric partial pressure. The vertical pattern of dissolved oxygen concentration in a lake is controlled by a combination of physical and biological processes. In oligotrophic lakes (low nutrient input and biological productivity), oxygen is typically controlled by physical processes with an orthograde oxygen profile. Dissolved oxygen is at or near 100 percent saturation throughout the water column, and the concentration of oxygen is lower in the warmer epilimnion water and increases with depth in the cooler hypolimnion. A highly productive eutrophic lake is typically controlled by biological process and has an opposite dissolved oxygen profile called a clinograde profile, with oxygen concentrations highest in the near surface epilimnion and reduced oxygen with depth. Biological productivity results in oxygen production near the surface due to photosynthesis, and consumption at depth due to decomposition and respiration. When dissolved oxygen concentrations increase or decrease in the metalimnion, the profile is called a positive or negative heterograde, respectively. Increased metalimnetic oxygen (positive heterograde) can be the result of photosynthetic activity by phytoplankton that are adapted to the lower light levels and increased nutrient availability in the metalimnion. Or, if water transparency and nutrient conditions are sufficient, large population of metalimnetic algae may exist. Decreased metalimnetic oxygen (negative heterograde) is more unusual than increased metalimnetic oxygen and may result if there is excessive oxygen consumption in the metalimnion, such as from microbial or animal respiration. Typically, an oxygen minima in the metalimnion is possible if water transparency is not sufficient to allow photosynthesis in the stratified layer (Wetzel 1975).

2.1.4.1 *Lake Koocanusa*

Profiles representing the median monthly dissolved oxygen concentrations from 2006 through 2016 are presented in Figure 2-8. In general, dissolved oxygen concentrations measured near the surface in the epilimnion of all stations were similar and ranged from about 8 to 11 mg/L. The temporal pattern in dissolved oxygen concentrations measured in the epilimnion is related to the natural warming and cooling of water in Lake Koocanusa from spring through fall (see Figure 2-4). Dissolved oxygen concentrations measured near the bottom in the hypolimnion were lower at the LIBBOR station when compared to the LIBTMC and LIBFB stations. Hypolimnetic oxygen at LIBBOR ranged from about 9 to 11 mg/L in April and May to about 4 to 6 mg/L in August through October. Hypolimnetic oxygen at LIBTMC and LIBFB were similar and ranged from about 9 to 11 mg/L in April and May to about 7 to 9 mg/L in August through October. The lower dissolved oxygen near the bottom at the shallower LIBBOR station is likely due to both warmer hypolimnetic waters at LIBBOR compared to LIBTMC and LIBFB, as well as greater biological productivity near the border resulting in oxygen consumption from decomposition and respiration. However, the oxygen depletion exhibited is small compared to many other reservoirs and lakes, especially given the temperature stratification at the sites closer to the dam (see LIBFB in Figure 2-4), suggesting that processes causing eutrophication are relatively moderate in this large reservoir.

Figure 2-8. Lake Koocanusa Median Dissolved Oxygen Profiles for 2006 to 2016

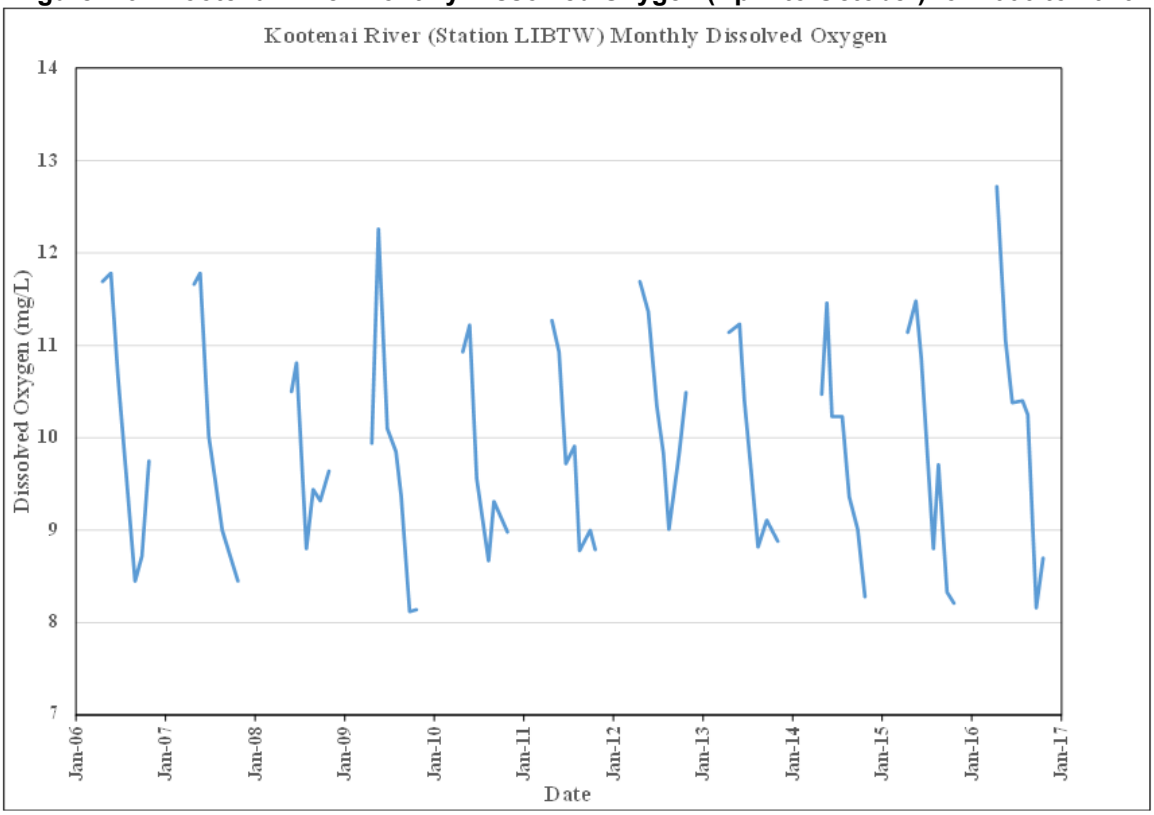


The vertical patterns of dissolved oxygen concentrations were similar between stations LIBTMC and LIBFB and slightly different at station LIBBOR. In general, vertical profiles at all stations in the spring followed an orthograde profile with relatively constant oxygen concentrations from surface to bottom. However, in the summer and fall, station LIBBOR's profile generally showed decreasing oxygen concentrations with depth, similar to a more biologically productive clinograde profile. In contrast, during the summer and fall, stations LIBTMC and LIBFB typically showed an oxygen profile with a metalimnetic decrease in oxygen and an increase in the hypolimnion, which is typical of a negative hetrograde profile.

2.1.4.2 *Downstream Kootenai River*

Monthly (April to October) downstream dissolved oxygen concentrations measured in the Kootenai River at station LIBTW are shown in Figure 2-9. Dissolved oxygen concentrations measured in the river were slightly greater than those measured at the forebay of Lake Koocanusa and ranged from about 8.5 to 12.5 mg/L. Oxygen concentrations were generally highest from April to June and lowest from July to September.

Figure 2-9. Kootenai River Monthly Dissolved Oxygen (April to October) for 2006 to 2016



2.1.5 Alkalinity, Hardness, and pH

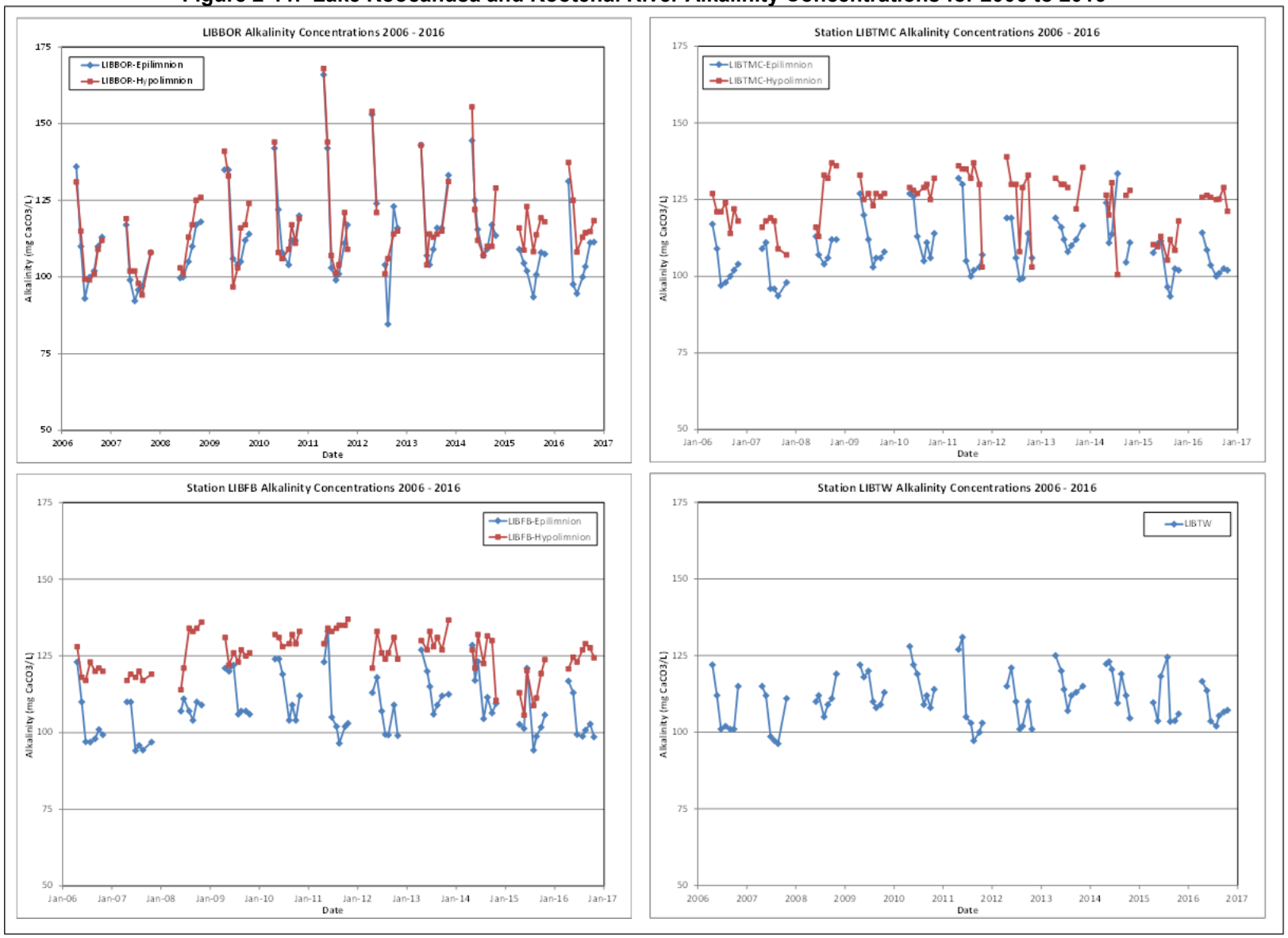
Alkalinity is a measure of the buffering capacity of the water to changes in pH. In many freshwater ecosystems, alkalinity is a function of the concentration of bicarbonates,

carbonates, and hydroxides (Wetzel 1975). It is likely that Lake Koocanusa's alkalinity is dominated by the carbonate system (HCO_3 and CO_3), as are most aquatic systems in the absence of other, more unique factors. Median annual alkalinity concentrations in the epilimnion ranged from about 100 to 120 milligrams calcium carbonate per liter (mg $CaCO_3$/L) at LIBBOR, and from about 100 to 110 mg $CaCO_3$/L at LIBTMC and LIBFB (Figure 2-10). Hypolimnetic median annual concentrations were slightly greater and ranged from about 110 to 120 mg $CaCO_3$/L at LIBBOR, and from about 120 to 135 mg $CaCO_3$/L at LIBTMC and LIBFB. Kootenai River concentrations measured at LIBTW were similar to LIBFB concentrations ranging from about 100 to 120 mg $CaCO_3$/L. Timeseries plots presented in Figure 2-11 show that concentrations were greatest in the spring, decreased during the summer, and increased slightly in the fall at most stations and depths. Based on this data, Lake Koocanusa would be classified as having moderate alkalinity with an average buffering capacity to pH changes.

Hardness is a measure of the amount of calcium and magnesium salts in water that are often combined with either bicarbonate or carbonate, or with anions such as sulfate or chloride (Wetzel 1975). Harder waters have greater concentrations of calcium and magnesium salts. In freshwater, hardness can be important in determining the toxicity of many metals, such as cadmium, chromium, copper, lead, and zinc. Toxicity decreases with an increase in hardness. Therefore, hardness measurements are necessary to calculate water quality criteria for various metals.

Figure 2-10. Statistical Summary of Annual Alkalinity in Lake Koocanusa and Kootenai River for 2006 to 2016

Figure 2-11. Lake Koocanusa and Kootenai River Alkalinity Concentrations for 2006 to 2016



For Lake Koocanusa, hardness concentrations followed a similar pattern as alkalinity with the greatest concentrations measured in the spring and fall. Hardness concentrations in the epilimnion ranged from about 90 to 150 mg CaCO3/L at LIBBOR, and from about 90 to 130 mg CaCO3/L at LIBTMC and LIBFB. Concentrations were slightly greater in the hypolimnion, ranging from about 100 to 160 mg CaCO3/L at LIBBOR and from about 100 to 145 mg CaCO3/L at LIBTMC and LIBFB. Hardness concentrations measured in the Kootenai River at LIBTW were similar to LIBFB epilimnion concentrations and ranged from about 90 to 130 mg CaCO3/L. These concentrations represent moderately hard to hard water that is typical of many freshwater ecosystems in northwestern Montana (USGS 1977).

The parameter pH is a measure of the hydrogen ion activity in the water and is measured on a base-10 logarithmic scale from 0 to 14 with values less than 7 being acidic, values greater than 7 being basic, and a value of 7 being neutral. MDEQ water quality standards for pH in Class B-1 waters are to be in the range of 6.5 to 8.5 (see Table 1-3). Monthly vertical pH profiles collected in the reservoir were generally similar between stations and years with a majority of pH readings ranging from about 8.6 near the surface to 7.4 near the bottom. In addition, pH values tended to be lowest during April and May with the greatest pH values measured in July, August, and September. Except for a few outliers, the higher pH values were largely associated with near surface waters in the summer and are likely due to photosynthetic activity of phytoplankton removing carbon dioxide from the water, thereby increasing pH. Conversely, the pH decrease in the hypolimnion may be partly because carbon dioxide and organic acids are released to the deeper waters by the respiration of bacteria and decomposition of organic matter. Periodically, epilimnetic pH values were between 8.5 and 9.0, most notably in 2014 and 2015. These high pH readings corresponded to phytoplankton blooms in Lake Koocanusa. Kootenai River pH values were slightly lower than Lake Koocanusa and ranged from about 7.0 to 8.4.

2.1.6 Specific Conductivity

Conductivity is a measurement of a solutions ability to conduct electricity and is often used as an indicator of the amount of dissolved ions present because conductivity increases with an increase in dissolved ions. Specific conductivity is the conductivity, normalized to a standard temperature (25°C), and is reported in microsiemens per centimeter (µS/cm). During the study, Lake Koocanusa specific conductivity was variable between stations, depths, and years and ranged from about 160 to 360 µS/cm. Monthly vertical profiles tend to show that specific conductivity increased with depth. In general, specific conductivity measured at all stations was greatest during April (stations LIBBOR, LIBTMC, LIBFB) and May (stations LIBTMC and LIBFB) with less vertical difference in conductivity during the spring. However, by May (LIBBOR), or June (LIBTMC and LIBFB), specific conductivity profiles begin to show a decrease in epilimnetic-specific conductivity levels and increasing levels in the hypolimnion. The decrease in epilimnetic-specific conductivity during the summer was most pronounced at stations LIBTMC and LIBFB, while the LIBBOR station had highly variable conductivities. The relatively consistent decrease in conductivities in the epilimnion and an increase in the hypolimnion at LIBTMC and LIBFB during the summer may be a

combination of the dilution effects of snowmelt and the possible underflow of the turbid higher conductivity Kootenai River inflow water moving down reservoir during the summer. Downstream Kootenai River-specific conductivity measured at station LIBTW ranged from about 180 to 280 µS/cm. In general, downstream-river-specific conductivity was greatest in the spring (April and May) and decreased slightly during the summer (June to September).

2.2 CHEMICAL CHARACTERISTICS

2.2.1 Nutrients

Phosphorus and nitrogen are the major nutrients required for the growth and productivity of phytoplankton and aquatic plants. The vast majority of lake water quality problems are associated with an overabundance of these nutrients resulting in excessive phytoplankton growth, causing nuisance blooms and resulting decay. The decay of large amounts of phytoplankton can reduce oxygen concentrations to levels that are harmful to many organisms. In freshwater ecosystems, phosphorus is generally the nutrient with the smallest supply-to-demand ratio for phytoplankton growth. Consequently, phosphorus is often the nutrient limiting productivity in freshwater ecosystems and also has relatively limited sources, so it is frequently the nutrient focused on for control of eutrophication. However, in some circumstances, nitrogen can be limiting instead of phosphorus, although nitrogen cycling and control of nitrogen sources is more complex. Increased phosphorus and nitrogen inputs to freshwater ecosystems from human activities can be attributed to numerous sources including the discharge of detergents, runoff containing fertilizers or manure, seepage from failing septic systems, urban runoff and sewage discharges, as well as from nitrogen-based explosives used in mining operations.

MDEQ has established ecoregional nutrient standards for total phosphorus and total nitrogen concentrations in wadeable streams (MDEQ 2014). However, MDEQ has not yet established nutrient standards for reservoirs, such as Lake Koocanusa, or many large rivers, such as the Kootenai River. Consequently, there are currently no MDEQ ecoregional nutrient standards for total phosphorus or total nitrogen in the Lake Koocanusa/Kootenai River watershed.

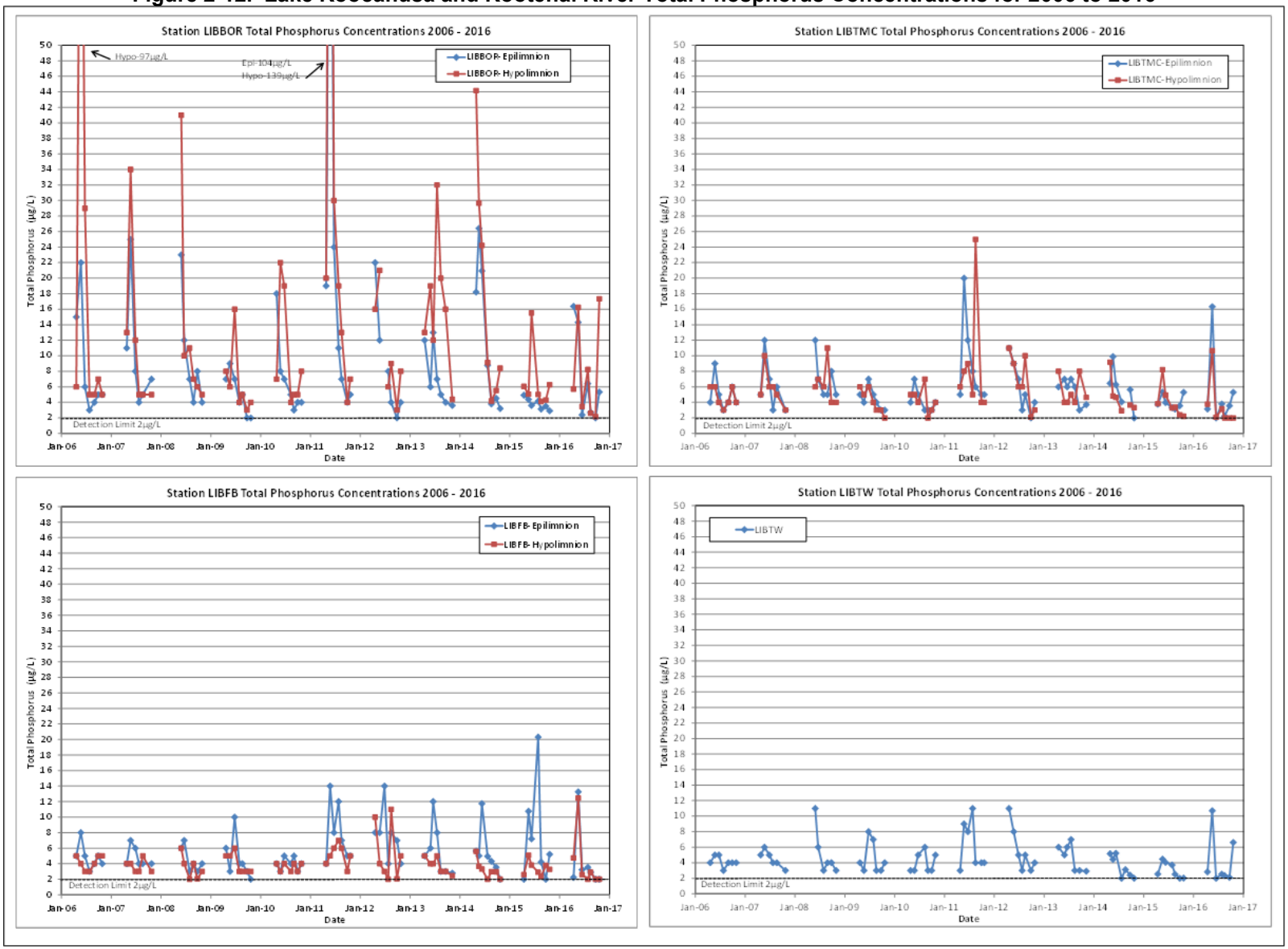
2.2.1.1 *Phosphorus*

Phosphorus concentrations in Lake Koocanusa were reported as total phosphorus (TP) and soluble reactive phosphorus. Total phosphorus represents all forms of phosphorus in water, both dissolved and particulate, including all organically combined phosphorus and all phosphate. Soluble reactive phosphorus represents the dissolved form of phosphorus that is readily available for aquatic plant uptake.

Monthly concentrations of total phosphorus in Lake Koocanusa for 2006 to 2016 are presented in Figure 2-12. Total phosphorus concentrations measured during the study ranged from less than the detection limit of 2 micrograms per liter (µg/L) measured periodically at all stations to 139 µg/L measured at LIBBOR. Total phosphorus followed

similar seasonal patterns at all stations with low concentrations in April, increasing concentrations during high runoff spring conditions in May and June, and decreasing concentrations during the summer and fall. Total phosphorus concentrations were substantially greater at the U.S.-Canada border (station LIBBOR) when compared to all other stations in Lake Koocanusa and the Kootenai River. Indeed, peak total phosphorus concentrations during high-flow spring runoff in May and June were typically two to five times greater at the border when compared to the LIBFB station. In general, total phosphorus concentrations were greatest at LIBBOR, greatly reduced 40 miles down-reservoir at LIBTMC, and lowest at LIBFB. This reduction in total phosphorus moving down-reservoir suggests that Lake Koocanusa is acting as a sink for total phosphorus during summers, with substantially lower total phosphorus concentrations exiting the reservoir at LIBTW compared to up reservoir measurements at LIBBOR. Annual total phosphorus data collected monthly in the Kootenai River at LIBTW by the USGS between 1980 and 2004 were consistently low (range from less than detection to 65 µg/L with a median concentration of 5 µg/L) support this conclusion. This data is in agreement with sediment phosphorus data collected by Iskandar and Shukla (1981), which suggested that Lake Koocanusa acts as a phosphorus sink.

Figure 2-12. Lake Koocanusa and Kootenai River Total Phosphorus Concentrations for 2006 to 2016

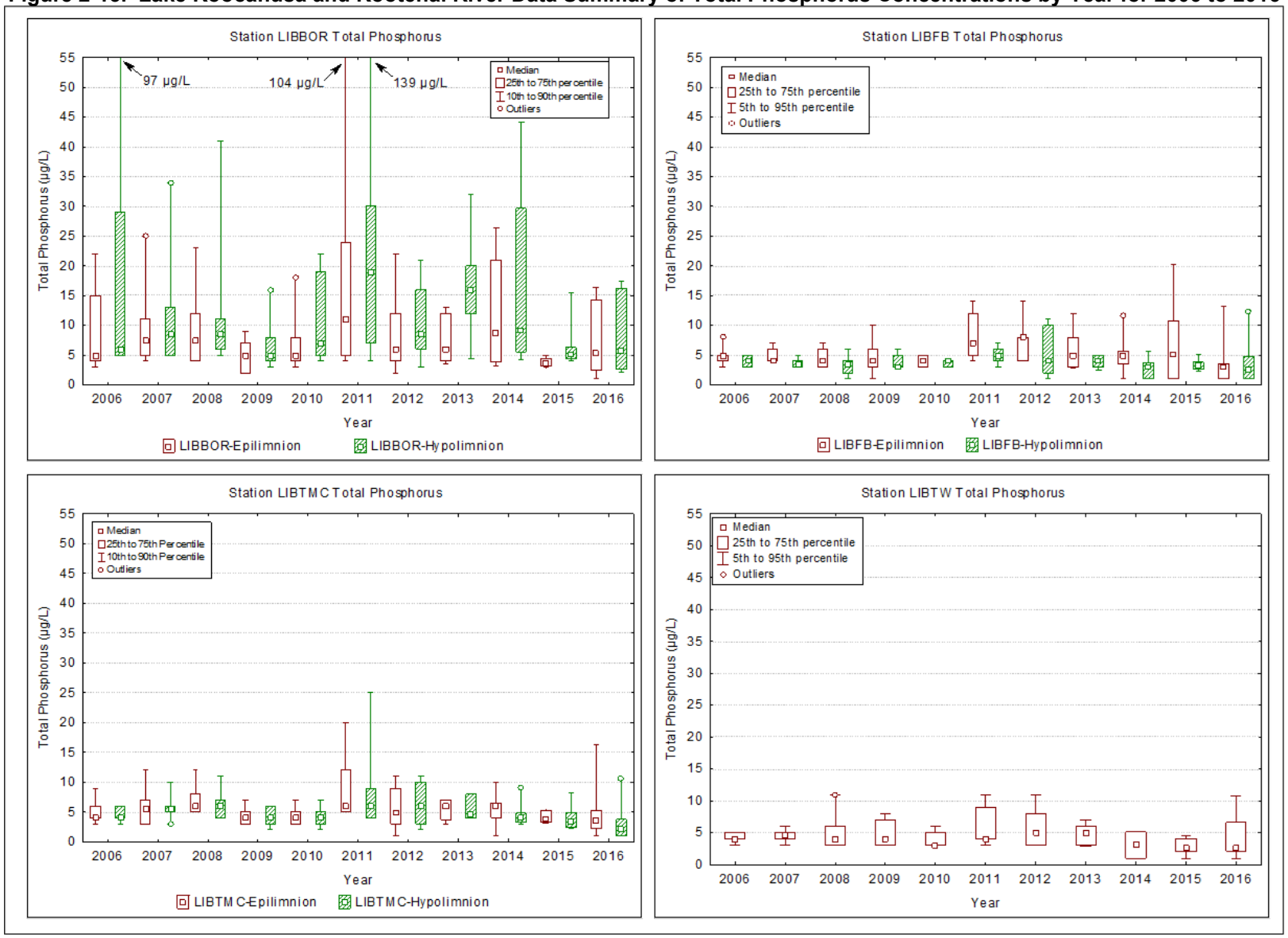


Total phosphorus concentrations in the epilimnion and hypolimnion were variable between stations in Lake Koocanusa. Up-reservoir LIBBOR phosphorus concentrations were substantially greater in the hypolimnion at all times of the year when compared to the epilimnion (Figure 2-12). However, at down-reservoir stations LIBTMC and LIBFB, concentrations of phosphorus were generally greater in the epilimnion. The elevated hypolimnetic total phosphorus concentrations measured consistently at LIBBOR suggests that inflow waters higher in total phosphorus concentrations are plunging to the bottom of Lake Koocanusa as underflow. Figure 2-12 shows that some of the total phosphorus loading from the inflow is mixed up through the epilimnion, but for many years, epilimnetic TP is quite small compared to the hypolimnetic concentrations. As the loading of phosphorus in the inflow waters moves down-reservoir largely as underflow, phosphorus continues to be settled out of the system with little phosphorus reaching the forebay of Libby Dam. Given this, it is likely that little of the inflow loading of phosphorus is available for phytoplankton and zooplankton beyond the border area.

It is likely that winter drawdown elevation and the corresponding reservoir volume, as well as spring runoff volume and the corresponding phosphorus concentrations, are all factors in determining how far down-reservoir total phosphorus reaches. Of interest is the high total phosphorus spike measured at LIBBOR in 2011, which was the year with the greatest reservoir drawdown and lowest reservoir volume during the 2006 to 2016 study with relatively high inflows (see Table 2-1 and Figure 2-1). Total phosphorus concentrations during the spring runoff were as high as 104 µg/L in the epilimnion and 139 µg/L in the hypolimnion at LIBBOR. These high total phosphorus concentrations appear to have reached down-reservoir as far as the LIBTMC station , resulting in the greatest total phosphorus concentrations measured at that site during the study (Figure 2-12). High total phosphorus concentrations in 2011 were not measured at LIBFB or downstream in the Kootenai River at LIBTW.

Boxplots of total phosphorus concentrations for each station for the 2006to 2016 study are shown in Figure 2-13. Median total phosphorus concentrations at LIBBOR ranged from about 4 µg/L in the epilimnion in 2014 to about 18 µg/L in the hypolimnion in 2011. Median concentrations at LIBTMC ranged from about 3 µg/L in the hypolimnion in 2014 to about 7 µg/L in the hypolimnion in 2012; at LIBFB, they ranged from about 2 µg/L in the hypolimnion in 2016 to about 6 µg/L in the epilimnion in 2011; and at LIBTW, they ranged from about 2 µg/L in 2015 to about 5 µg/L in 2012. The range of concentrations was substantially greater at LIBBOR, reflecting the high total phosphorus concentrations measured at this station during the spring runoff May and June time period. In general, median total phosphorus concentrations and the range of data were greater in the hypolimnion at LIBBOR, and greater in the epilimnion at LIBTMC and LIBFB. Kootenai River median total phosphorus concentrations measured at LIBTW were more similar to forebay hypolimnetic concentrations, likely reflecting the deeper outlet from the reservoir.

Figure 2-13. Lake Koocanusa and Kootenai River Data Summary of Total Phosphorus Concentrations by Year for 2006 to 2016



Soluble reactive phosphorus concentrations were low in Lake Koocanusa, ranging from less than the detection limit of 1 µg/L to a maximum concentration of 6 µg/L with several years having no detectable soluble phosphorus (Figure 2-14). In general, soluble phosphorus concentrations were greatest at LIBBOR and decreased down-reservoir at LIBTMC and LIBFB. Additionally, these soluble phosphorus concentrations were greatest in the hypolimnion at all stations. Similar to total phosphorus, soluble concentrations were greatest during the spring runoff May and June time period at all stations. Patterns in soluble reactive phosphorus can be deceptive because it is consumed by algae as it grows, thereby converting it to algal tissue and reducing apparent concentrations seasonally. The lack of soluble phosphorus moving downstream in the Kootenai River is clearly shown in the nearly consistent non-detected soluble phosphorus at the LIBTW station. Because soluble reactive phosphorus stimulates algal growth in freshwaters, it is often lowest during periods of algal uptake or growth. For Lake Koocanusa, the seasonal progression of soluble reactive phosphorus suggests that algal growth is largely occurring during the June through August time period with a decrease in algal growth during the fall.

Median soluble reactive phosphorus concentrations in Lake Koocanusa were low and less than the detection limit of 1 µg/L at most stations (Figure 2-15). Although the overall range in concentrations was greatest at LIBBOR, the range was small, and, in general, the 25th to 75th percentile data at all stations was between 1 and 2 µg/L. In addition, there were only small differences in soluble reactive phosphorus median concentrations measured between stations with slightly greater median concentrations measured at LIBBOR.

2.2.1.2 *Nitrogen*

Nitrogen, like phosphorus, is essential for the growth and production of phytoplankton in freshwaters. In freshwater ecosystems, nitrogen exists in many forms including dissolved molecular nitrogen, organic nitrogen, nitrite, nitrate, and ammonia. Sources of nitrogen to freshwaters are varied and include atmospheric inputs via precipitation, nitrogen fixation in the water and sediments, and via surface and groundwater inputs. Losses of nitrogen in the freshwater ecosystem include outflow from the system, reduction of nitrate to nitrogen via denitrification and the subsequent release of nitrogen from the water to the atmosphere, and sedimentation of inorganic and organic forms of nitrogen (Wetzel 1975). The most common forms of nitrogen used by freshwater plants for growth are the dissolved forms that include ammonia-nitrogen and nitrate-nitrogen.

Figure 2-14. Lake Koocanusa and Kootenai River Soluble Reactive Phosphorus Concentrations for 2006 to 2016

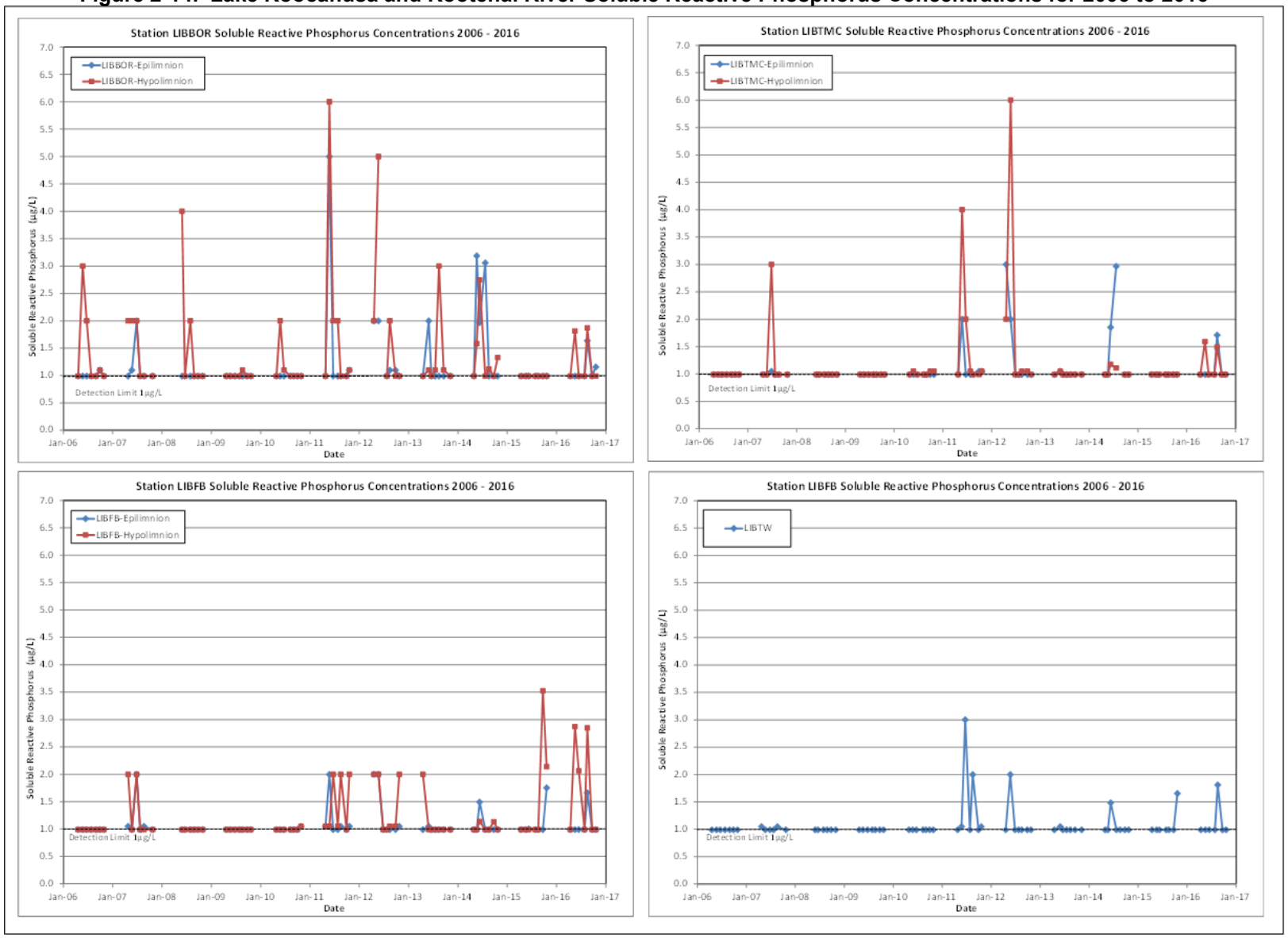
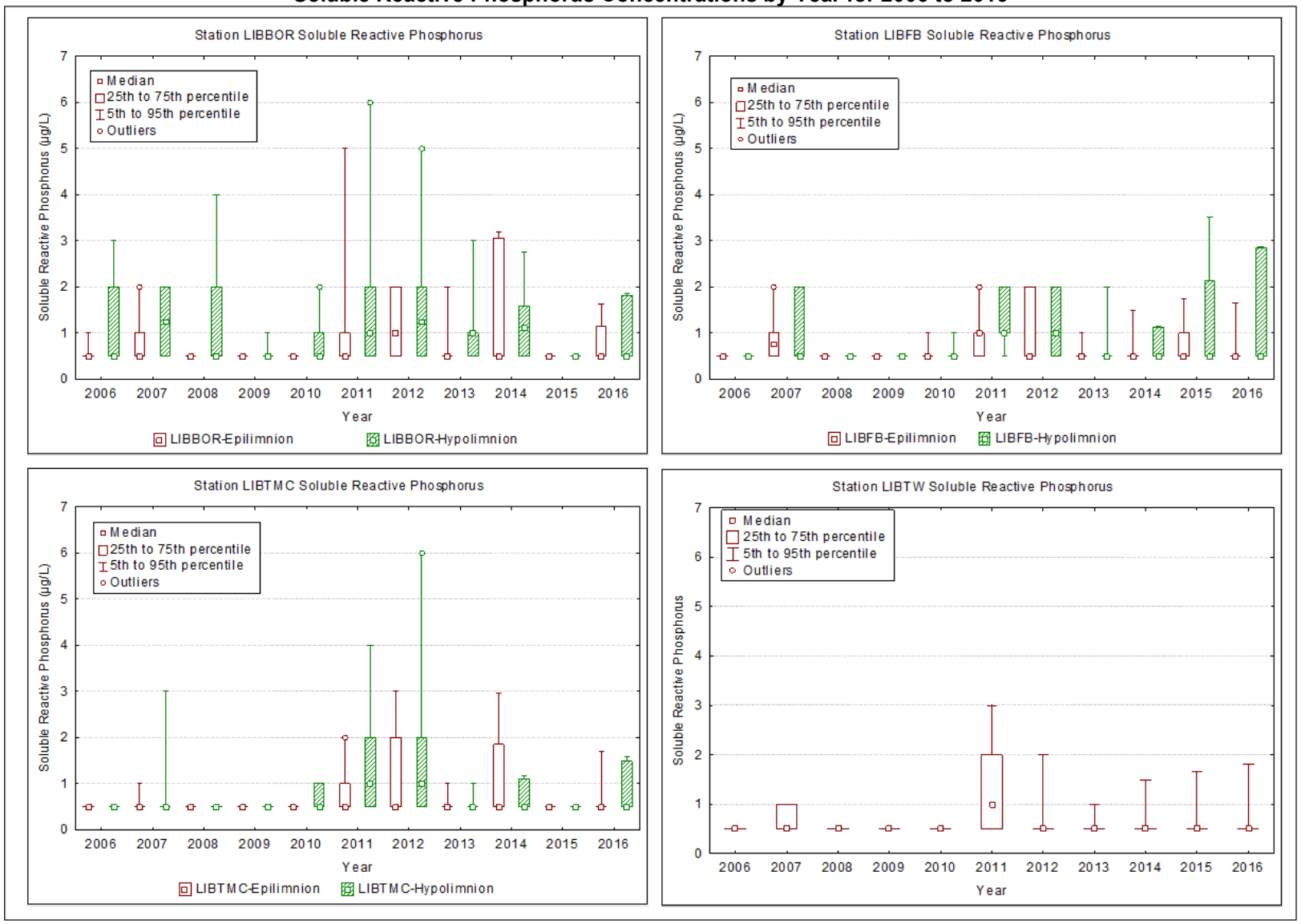


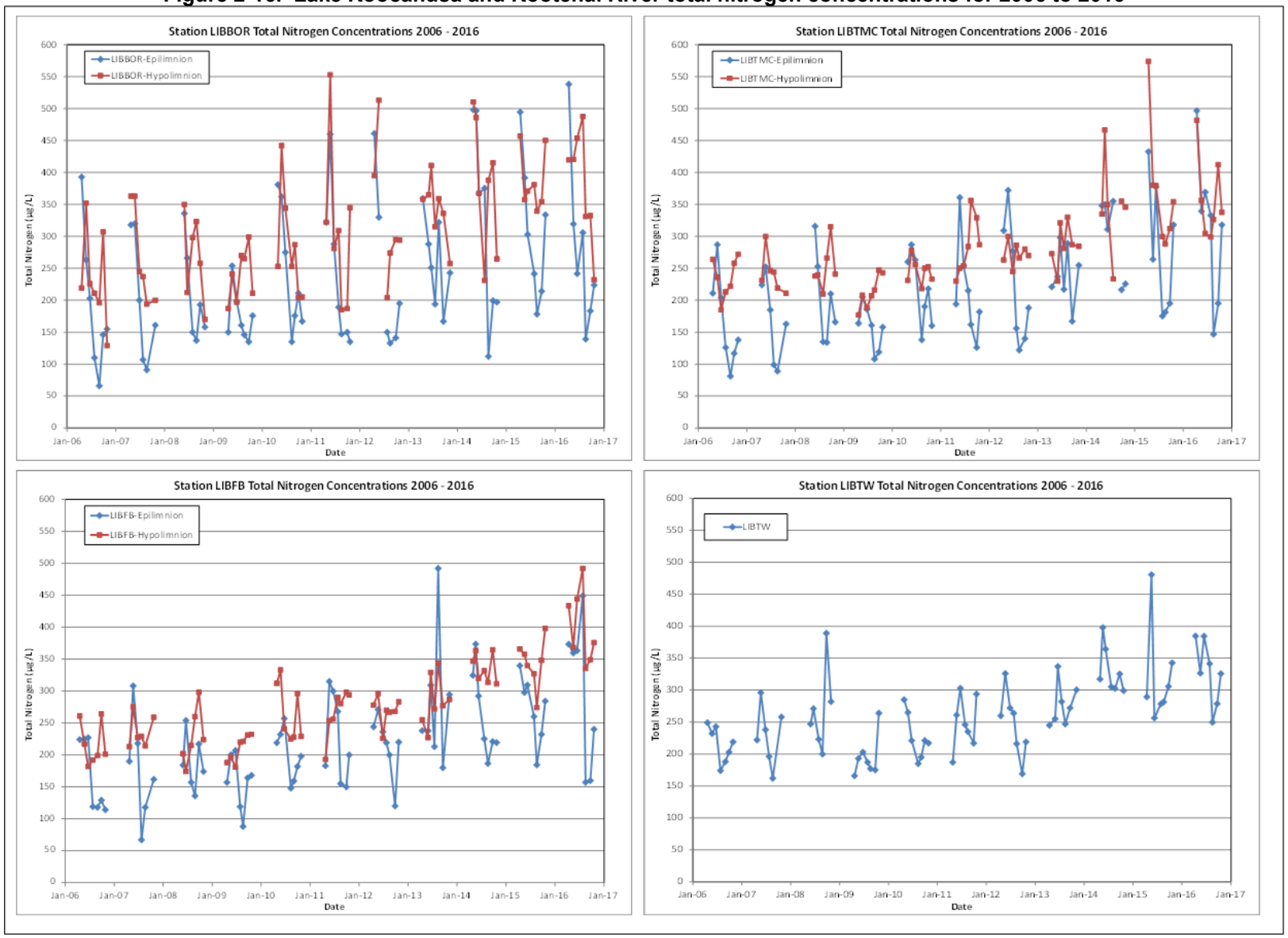
Figure 2-15. Lake Koocanusa and Kootenair River Data Summary of Soluble Reactive Phosphorus Concentrations by Year for 2006 to 2016



Three forms of nitrogen were measured, total nitrogen (TN-N), nitrate+nitrite-nitrogen (NO_3 + NO_2-N), and ammonia-nitrogen (NH_4^+-N + NH_3-N). The dissolved inorganic forms of nitrogen, ammonia and nitrate + nitrite are all readily available for phytoplankton growth. Total nitrogen was measured by the persulfate digestion method (see Table 1-2) and includes all inorganic plus organic forms of nitrogen, in both dissolved and particulate fractions. Nitrate + nitrite-nitrogen represents dissolved oxidized nitrogen, with nitrite being an intermediate state between ammonia and nitrate. Nitrate is an essential plant nutrient, while nitrite can be a plant nutrient but is generally unstable and is rapidly oxidized to ammonia in oxygenated waters. Ammonia-nitrogen is an essential plant nutrient that is often utilized before nitrate. Ammonia is formed in the natural environment through the fixation of nitrogen gas, excretion by animals, and the decomposition of organic material (plant and animal tissues). Ammonia is reported as the combined ionized (NH_4^+-N – ammonium) and unionized (NH_3-N – ammonia) forms of ammonia. The unionized form of ammonia (NH_3-N) is toxic to freshwater life and is most prevalent at high pH (greater than about 9.3 pH units). Equations can be used to estimate the concentration of unionized ammonia fraction from measured values of the pH and temperature of the water (see Table 1-3). In general, for pH and temperature values measured in Lake Koocanusa, the unionized form of ammonia (NH_3-N) represents an extremely small percentage of the total ammonia nitrogen concentration (Greenberg, Eaton, and Clesceri 1992).

Total nitrogen concentrations in Lake Koocanusa were greatest at LIBBOR and slightly less at down-reservoir stations LIBTMC and LIBFB, as well as in the Kootenai River at station LIBTW (Figure 2-16). Temporal plots show that total nitrogen concentrations have been increasing at all stations between 2006 and 2016. Total nitrogen concentrations were greatest in the hypolimnion at all stations and for all years, suggesting that considerable nitrogen loading from the inflow may be associated with underflow. In general, total nitrogen was greatest in both the epilimnion and hypolimnion during the April to June spring runoff time. During the summer, total nitrogen concentrations decrease in both the epilimnion and hypolimnion with a much greater decline in the epilimnion. An increase in total nitrogen is measured at all stations in the fall. During the summer, it is likely that the sharp decreases in total nitrogen measured at all stations in the epilimnion is due to the summer growth of algae utilizing ammonia-nitrogen and nitrate-nitrogen. Although total nitrogen concentrations were greater at the LIBBOR border station, concentrations measured down-reservoir at LIBTMC and LIBFB were only slightly less, suggesting that much of the nitrogen entering Lake Koocanusa at the border is passing down-reservoir. Given this, Lake Koocanusa does not appear to be a sink for nitrogen as it is for phosphorus, and increased nitrogen loadings to the system from the inflow will likely been seen at the forebay and down river.

Figure 2-16. Lake Koocanusa and Kootenai River total nitrogen concentrations for 2006 to 2016



Boxplots of total nitrogen concentrations for each station for the 2006 to 2016 study are shown in Figure 2-17. Median total nitrogen concentrations and the range of data in both the epilimnion and hypolimnion were greatest at LIBBOR and similar at LIBTMC and LIBFB. Additionally, the range of data was also greatest at LIBBOR likely reflecting the influence of the inflow on nitrogen concentrations entering Lake Koocanusa. At stations LIBTMC and LIBFB, the range of data in the hypolimnion was considerably less than in the epilimnion, likely due to the summer growth of algae utilizing epilimnetic nitrate. Median total nitrogen concentrations downstream in the Kootenai River at LIBTW were similar to hypolimnetic concentrations measured in the forebay.

Nitrate+nitrite-nitrogen concentrations measured in Lake Koocanusa were similar to or slightly less than total nitrogen concentrations, which indicates that nitrate is the dominant form of nitrogen in Lake Koocanusa. Nitrate concentrations at all stations followed similar seasonal patterns with the highest concentrations during the April to June spring runoff time, sharply lower concentrations during the July and August time, and slightly increased concentrations in September and October (Figure 2-18). The nitrate concentrations were greater in the hypolimnion, suggesting that nitrate in the epilimnion is being utilized by summer phytoplankton growth. Additionally, the greater hypolimnetic concentrations indicate that considerable loadings of nitrate from the inflow may be associated with underflow conditions. Similar to total nitrogen, nitrate concentrations measured down-reservoir at LIBTMC, LIBFB, and in the Kootenai River at LIBTW were only slightly less than at LIBBOR, suggesting that much of the nitrate entering Lake Koocanusa from the inflow is passing down-reservoir.

Boxplots of nitrate concentrations for each station for the 2006 to 2016 study are shown in Figure 2-19. Median nitrate concentrations and the range of data in both the epilimnion and hypolimnion were greatest at LIBBOR and similar at LIBTMC and LIBFB. In addition, the range of nitrate data was greatest at LIBBOR, which shows the influence of the inflow nitrogen concentrations entering Lake Koocanusa during highflow spring runoff conditions. At stations LIBTMC and LIBFB, the range of data in the hypolimnion was considerably less than the range of data in the epilimnion, likely due to the summer growth of algae utilizing epilimnetic nitrate resulting in drastically reduced nitrate concentrations in the summer. Median nitrate concentrations downstream in the Kootenai River at LIBTW were similar to hypolimnetic concentrations measured in the forebay.

Figure 2-17. Lake Koocanusa and Kootenai River Data Summary of Total Nitrogen Concentrations by Year for 2006 to 2016

Figure 2-18. Lake Koocanusa and Kootenai River Nitrate Concentrations for 2006 to 2016

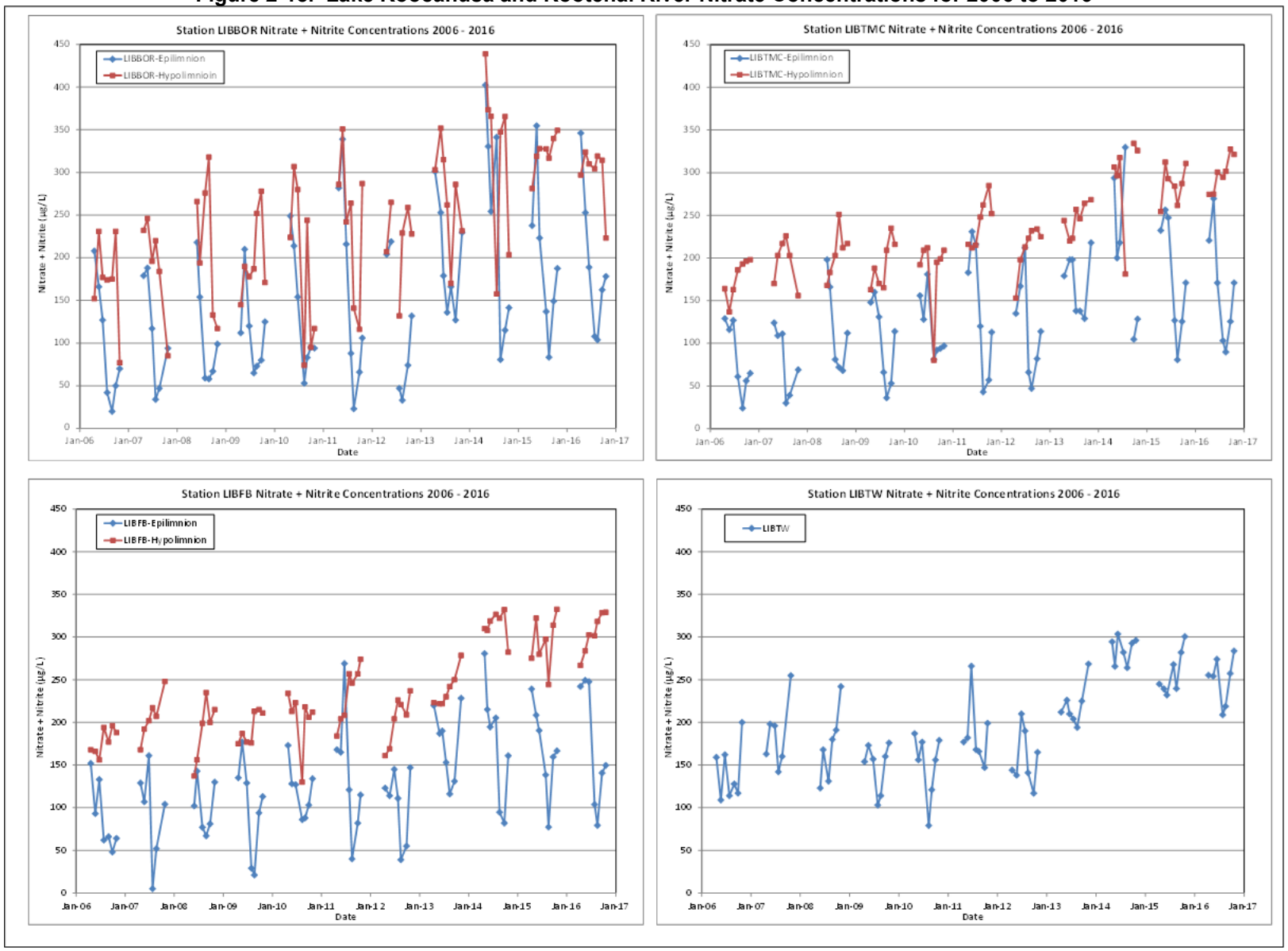


Figure 2-19. Lake Koocanusa and Kootenai River Data Summary of Nitrate+Nitrite Concentrations by Year for 2006 to 2016

During 2016, a Satlantic Submersible Ultraviolet Nitrate Analyzer was deployed at station LIBBOR from June 15 to October 18, maintained at a depth of about 3 to 5 meters off the bottom, and is representative of the hypolimnion (LIBBOR-HYPO). Hourly nitrate concentrations from the hypolimnion at LIBBOR are presented together with monthly grab sample nitrate concentrations from LIBBOR-EPI and LIBBOR-HYPO in Figure 2-20. Hourly data shows that nitrate concentrations at LIBBOR-HYPO consistently ranged from about 300 to 350 µg/L from mid-June to the end of September and matched up well with grab sample results. Nitrate concentrations sharply decreased in October prior to retrieval. Of interest is the periodic cycling of nitrate concentrations at LIBBOR-HYPO that is shown by the data during the entire deployment interval. This cycle is more clearly seen in an enlargement of the timeseries showing a one-month period from July 14 through August 25. Nitrate concentrations increase and decrease on a fairly consistent one-week period. This nitrate cycle may be due to an internal seiche in Lake Koocanusa that has a one-week period in the reservoir. As this internal wave moves back and forth in the reservoir, nitrate concentrations rise and fall with this movement of water. A similar 1-week cycling of temperature was also observed at the forebay during the same period. Further study is needed to investigate how this apparent seiching in Lake Koocanusa is impacting water quality measured in the reservoir.

Ammonia concentrations were low in general but varied between stations in Lake Koocanusa. The greatest concentrations were measured at LIBBOR, while stations down-reservoir (LIBTMC and LIBFB) and in the Kootenai River (LIBTW) generally had concentrations at or near the detection limit of 5 µg/L (Figure 2-21). Similar to nitrate, ammonia concentrations were greatest during the April-to-June spring runoff time, and sharply reduced in the summer. Hypolimnetic and epilimnetic ammonia concentrations were similar except during the high-flow spring-time period, which suggests that similar to nitrate, ammonia loadings from the inflow are likely associated with underflow conditions. Median ammonia concentrations were near the 5 µg/L detection limit for stations LIBTMC, LIBFB, and LIBTW (Figure 3-22). Even at LIBBOR, median ammonia concentrations were generally less than 10 µg/L in both the epilimnion and hypolimnion for all years studied. The greater range of data shown in the boxplots for station LIBBOR reflects the greater influence of inflow ammonia concentrations to the reservoir at this station.

Figure 2-20. Lake Satlantic Submersible Ultraviolet Nitrate Analyzer Nitrate Sensor Data, LIBBOR 2016

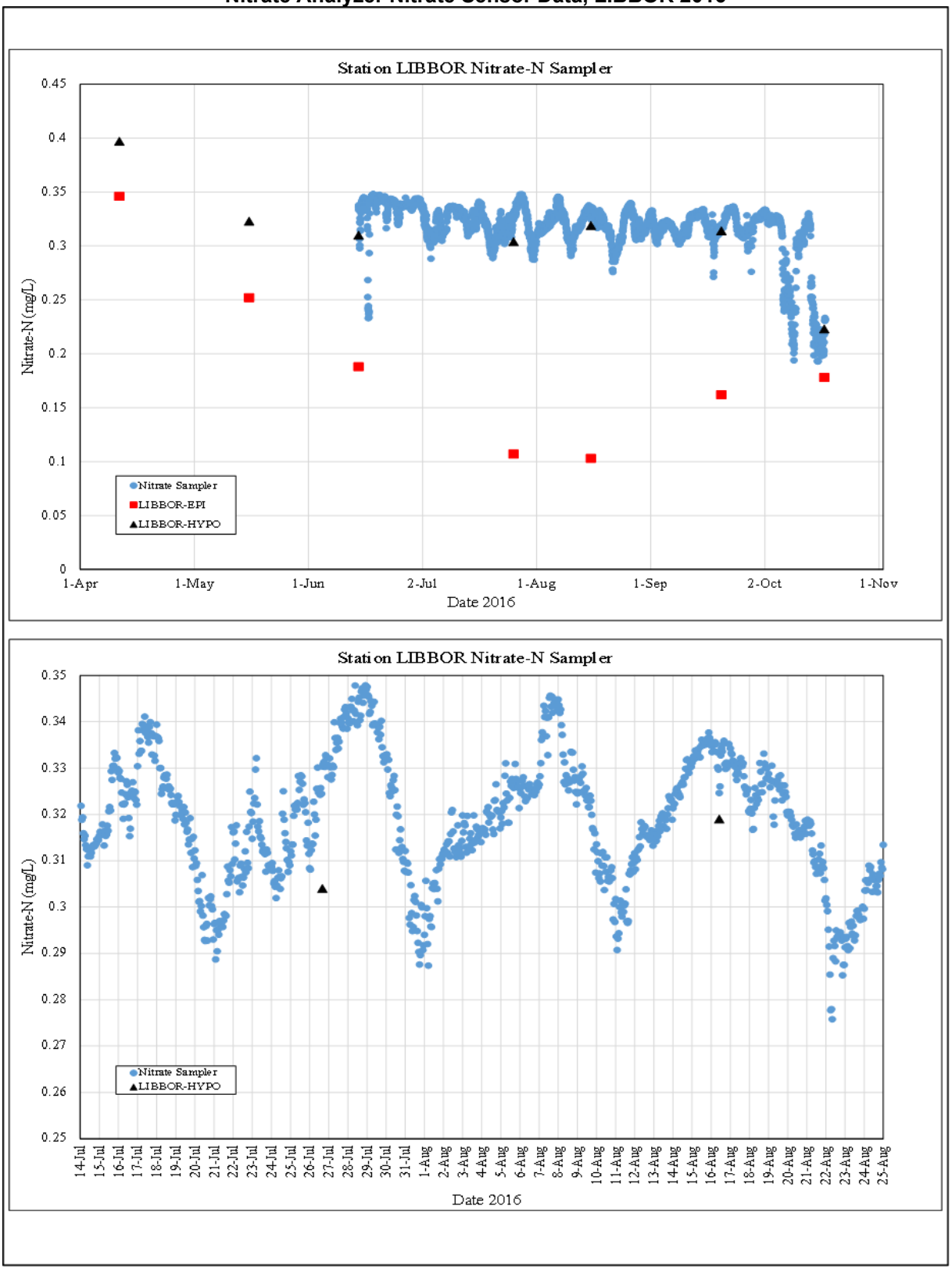


Figure 2-21. Lake Koocanusa and Kootenai River Ammonia Concentrations for 2006 to 2016

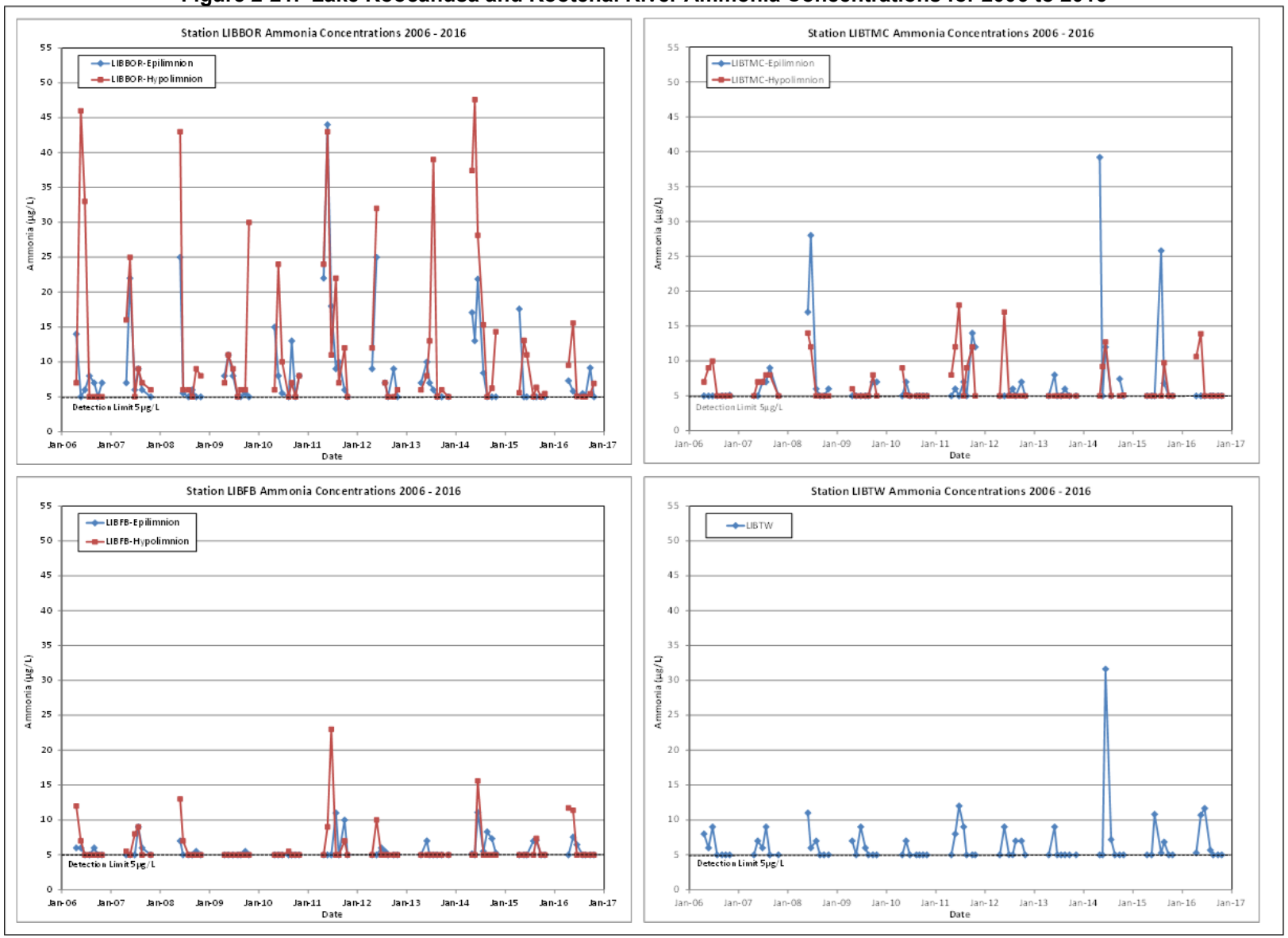
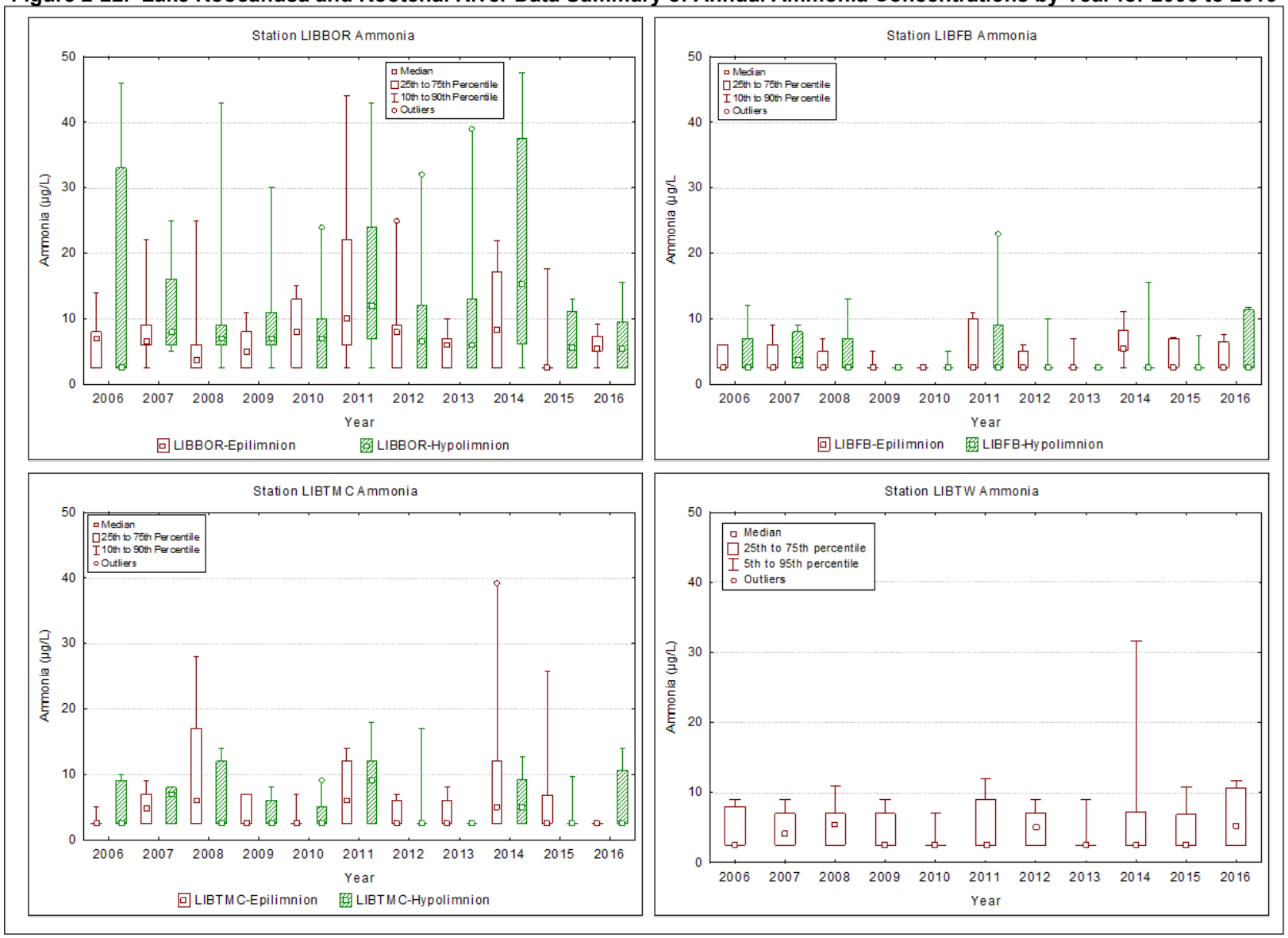


Figure 2-22. Lake Koocanusa and Kootenai River Data Summary of Annual Ammonia Concentrations by Year for 2006 to 2016



2.2.1.3 *Phosphorus and Nitrogen Moving Means*

Because of the important role phosphorus and nitrogen concentrations impart on the overall water quality of a lake, an initial investigation of possible trends in these parameters over time was conducted using the 12-month moving mean method. This method was used to smooth the data over time, allowing for easier visual inspection of timeseries data to determine which parameters may have a trend that requires statistical trend analysis. Data collected by the Seattle District from 2006 to 2016 was combined with data collected by the USGS from 1993 to 2004 to provide a robust, long-term dataset spanning more than 20 years. Because the moving mean is not a rigorous statistical test, changes in method detection limits that occurred over the 20-year period were not taken into consideration when plotting out the 12-month moving means. Figure 2-23 and Figure 2-24 show the moving means at LIBBOR and LIBFB for total phosphorus and nitrate. It is clear from this non-statistical test that an increasing trend in nitrate is likely while a trend in total phosphorus concentrations is remote. Based on this data, more rigorous statistical methods, which are described later in this report, were used to test for long-term trends in Lake Koocanusa.

2.2.1.4 *Nutrient Limitation*

Phosphorus and nitrogen are the two major essential nutrients that limit phytoplankton growth in freshwater ecosystems. The limiting nutrient concept maintains that the growth of a plant crop will be limited by the essential nutrient in shortest supply (Ryding and Rast 1989). Total nitrogen to total phosphorus ratios (TN:TP) are often used to determine whether nitrogen or phosphorus is most likely to limit phytoplankton growth. Typically, TN:TP ratios, by weight, greater than 17:1 suggest phosphorus limitation while ratios less than 10:1 suggest nitrogen limitation (Forsberg and Ryding 1980). Yearly variations in the TN:TP ratios in Lake Koocanusa and the Kootenai River are seen in Figure 2-25. The yearly progression of TN:TP suggests that phosphorus concentrations limited phytoplankton growth in Lake Koocanusa during the entire 2006 to 2016 study. Furthermore, there has been an increase in the TN:TP ratio at all stations during the study, with the most pronounced increase seen down-reservoir at LIBTMC, LIBFB, and LIBTW. Median annual ratios at these stations have increased from about 20 in 2006 to about 50 in 2016 at LIBBOR, from about 30 in 2006 to about 60 in 2016 at LIBTMC, and from about 30 in 2006 to more than 100 in 2016 at LIBFB. The TN:TP ratios at all stations clearly suggest that phosphorus is the limiting nutrient.

The lower nutrient ratios measured at LIBBOR are indicative of the greater loadings of phosphorus from the inflow resulting in ratios that are considerably lower than at LIBFB, where little phosphorus is measured. Because nitrogen moves through the reservoir while phosphorus is lost to the reservoir, the ratio of nitrogen to phosphorus becomes substantially greater toward the forebay. The increasing trend in the ratio since 2012 is likely due to increasing loadings of nitrogen to Lake Koocanusa, while phosphorus loadings have remained somewhat stable.

Figure 2-23. Lake Koocanusa 12-month Moving Mean for Nitrate in the Epilimnion and Hypolimnion 1993 to 2016

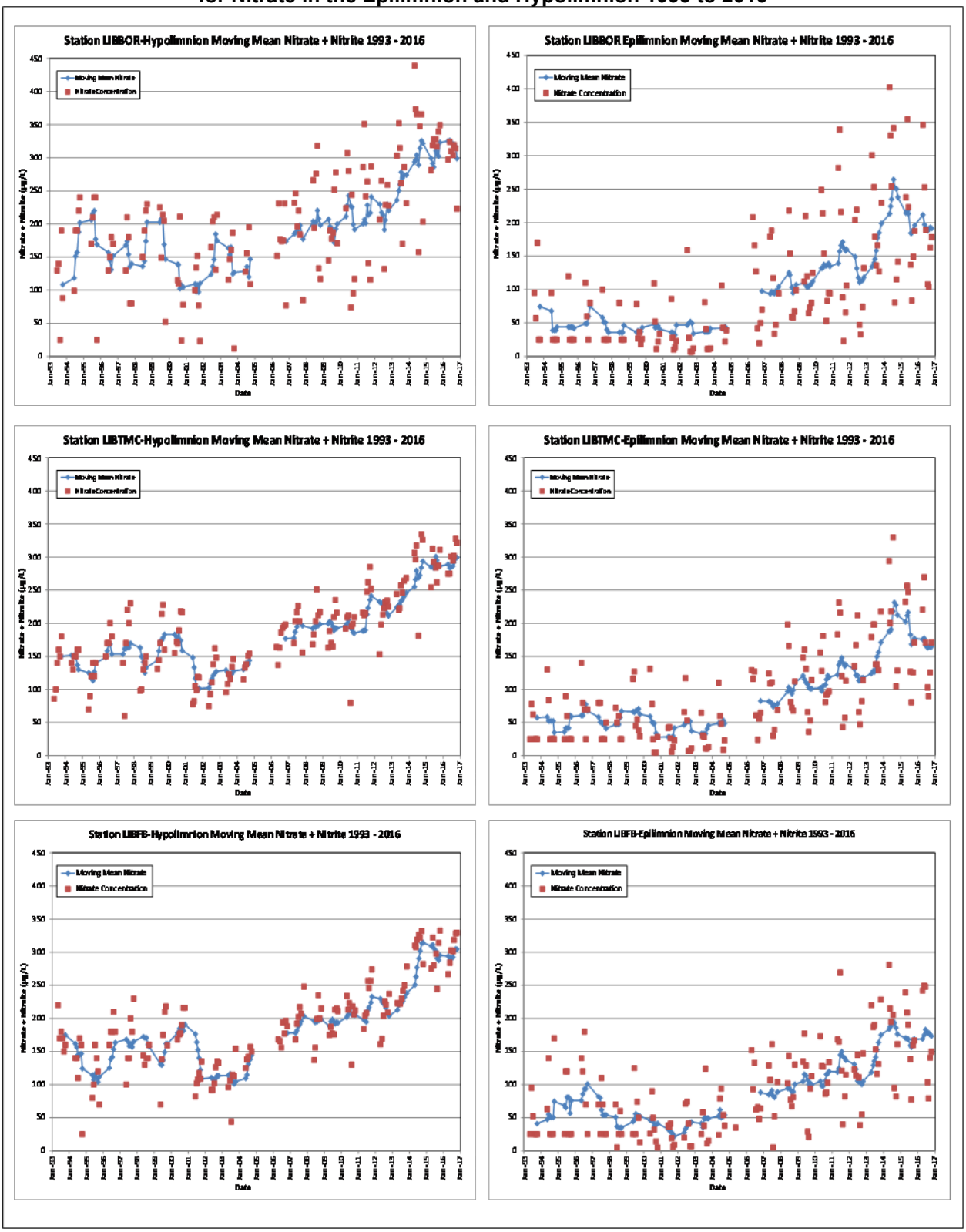


Figure 2-24. Lake Koocanusa 12-month Moving Mean for Total Phosphorus in the Epilimnion and Hypolimnion 1993 to 2016

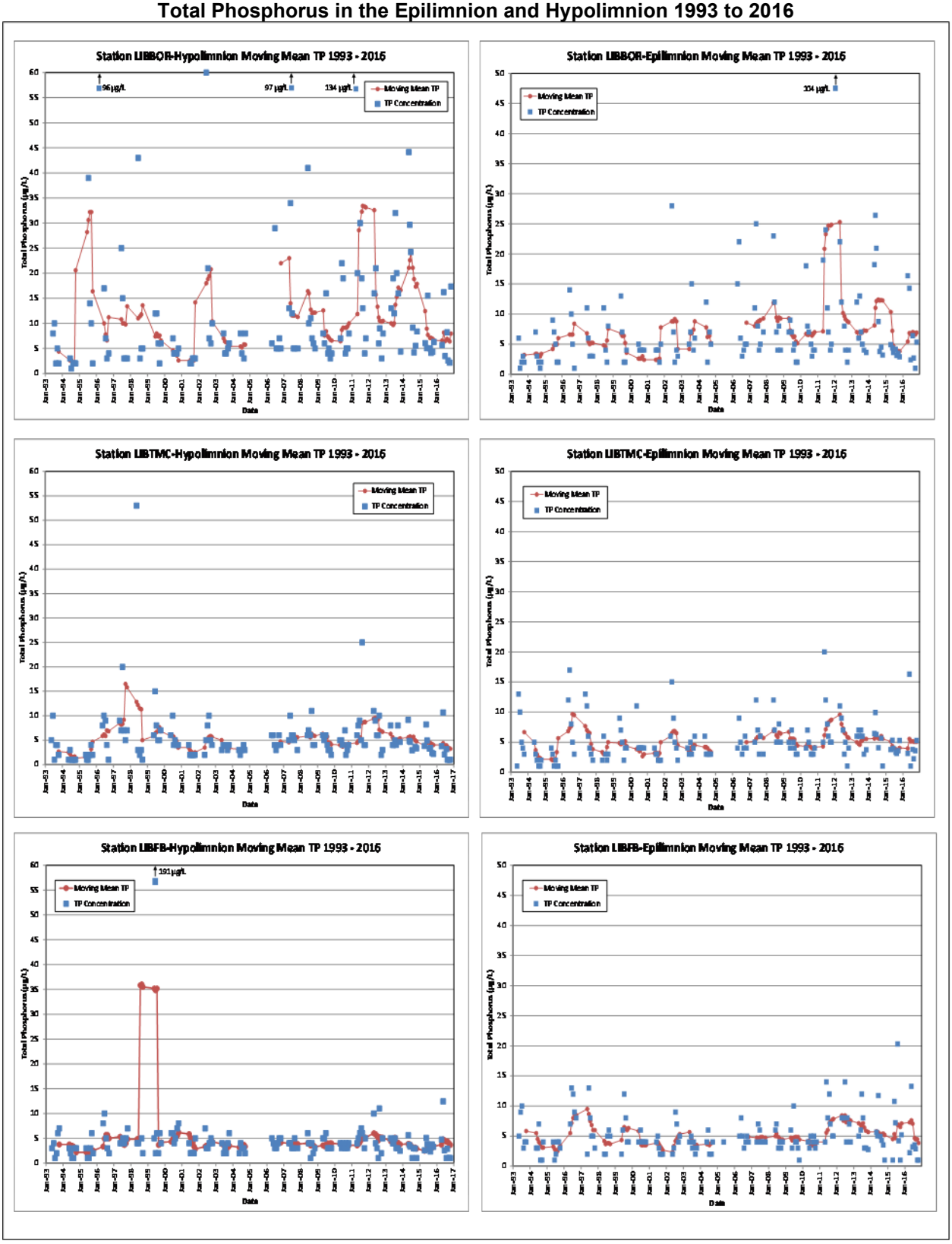
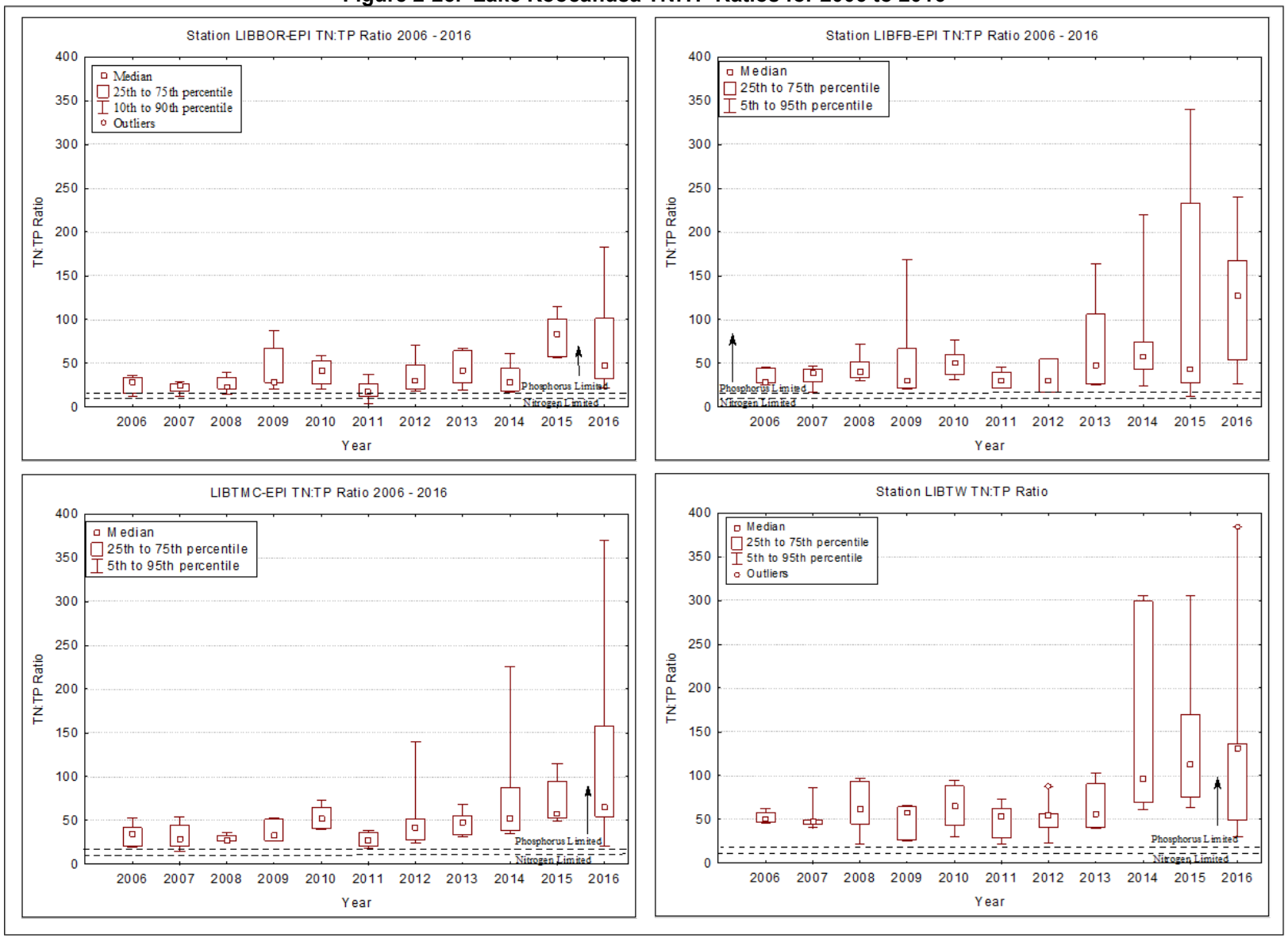


Figure 2-25. Lake Koocanusa TN:TP Ratios for 2006 to 2016



2.2.2 Major Anions and Cations

The chemical composition of the major ions of many freshwater lakes is largely derived from the weathering of soils and rocks in the drainage basin, atmospheric precipitation, and evaporation (Wetzel 1975). The ion balance of most fresh waters is dominated by the major cations calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K), and the major anions carbonate (CO_3), bicarbonate (HCO_3), sulfate (SO_4), and chloride (Cl). Other elements, such as phosphorus and nitrogen, are important biologically but are typically only a minor part of the overall chemical composition of freshwater ecosystems.

The major anions and cations were collected at quarterly intervals in May, July, and October at all stations. Over the course of the study, calcium and magnesium were the dominant cations in Lake Koocanusa and ranged from about 8 to 40 mg/L and 5 to 12 mg/L, respectively. Calcium and magnesium concentrations were greatest in the hypolimnion at all stations. Calcium concentrations were similar between stations while magnesium concentrations were greater at stations LIBTMC and LIBFB compared to LIBBOR. Sodium and potassium concentrations were less, ranging from about 1.5 to 4.5 mg/L and less than the detection limit of 0.5 to 0.9 mg/L, respectively. Sodium concentrations were greatest in the hypolimnion at all stations while potassium concentrations were relatively similar between the epilimnion and hypolimnion. Potassium concentrations were similar between stations while sodium concentrations were greater at stations LIBTMC and LIBFB compared to LIBBOR.

The importance and role of the carbonate system in Lake Koocanusa was previously described for alkalinity and hardness. After carbonate/bicarbonate, sulfate was the dominant anion with concentrations ranging from about 13 to 30 mg/L. Chloride concentrations were less and typically in the 1.5 to 4 mg/L range. Sulfate and chloride concentrations varied between stations, depths, and season. For the most part, sulfate and chloride concentrations in the epilimnion were greatest in May and lower in July and October. Hypolimnetic sulfate and chloride concentrations were relatively stable throughout the year with little seasonal variation. In general, sulfate and chloride concentrations were greatest in the hypolimnion of stations LIBTMC and LIBFB. Sulfate plays a role in influencing growth and population dynamics of freshwater biota. Given this, minor shifts in sulfate concentrations were seen between sampling dates and station locations. Conversely, chloride concentrations remained relatively stable in Lake Koocanusa, indicating the minor role this ion plays in freshwater ecosystems.

2.2.3 Trace Metals

Samples from the epilimnion and hypolimnion at all stations were analyzed for major trace metals including aluminum (Al), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), and zinc (Zn). The dissolved form of the metals was measured from 2006 through 2011, while the total recoverable form of the metals was measured from 2012 through 2016. Trace metals were collected quarterly in May, July, and October in conjunction with the quarterly anion/cation sampling. Starting in 2012,

total selenium was added to the trace metal sampling program and collected at all stations for all months. Selenium results will be discussed separately below.

Detection limits decreased for some metals during the 2006 through 2016 sampling period (Table 2-3). Most notable was a decrease in the detection limit for cadmium, lead, and selenium. From 2006 through 2015, the detection limits for cadmium and lead were 0.2 and 1.0 µg/L, respectively. In 2016, these detection limits were lowered to 0.04 and 0.005 µg/L, respectively. From 2012 through 2013, the detection limit for selenium was 1.0 µg/L. In 2014 and 2015, the detection limit was lowered to 0.1 µg/L, and in 2016, the detection limit was lowered to 0.01 µg/L.

From 2006 through 2015, concentrations of dissolved and total metals were near or below the laboratory detection limits except for aluminum and selenium, with periodic detections of copper and zinc (Table 2-3). Lower detection limits in 2016 allowed for a greater number of detections for cadmium, lead, and selenium. Dissolved and total aluminum concentrations were highest at the border station LIBBOR, with the greatest concentrations measured in the hypolimnion. Indeed, total aluminum concentrations measured at LIBBOR-HYPO were as high as 1,781 µg/L on May 20, 2014, and 1,960 µg/L on July 16, 2013. The increased aluminum concentrations measured in the hypolimnion at LIBBOR in May and July during periods of high spring runoff suggests that the major source of aluminum is likely suspended sediments from the watershed. Dissolved aluminum concentrations measured at all stations from 2006 through 2011 did not exceed MDEQ acute or chronic standards.

Table 2-3. Dissolved and Total Metal Detection Limits and Maximum Concentrations for Lake Koocanusa 2006 to 2016

Metal	Date Range	Detection	Detection Limit (µg/L)	Maximum Concentration (µg/L)
Dissolved Metals				
Al	2006-2011	95 out of 135	<3.0	41.7
As	2006-2011	0 out of 135	<3.0	<3.0
Cd	2006-2011	0 out of 135	<0.2	<0.2
Cr	2006-2011	0 out of 135	<2.0	<2.0
Cu	2006-2011	7 out of 135	<1.0	2.4
Pb	2006-2011	1 out of 135	<1.0	1.4
Ni	2006-2011	0 out of 135	<1.0	<1.0
Zn	2006-2011	25 out of 135	<5.0	23
Total Metals				
Al	2012-2016	73 out of 76	<3.0	1960
As	2016-2016	0 out of 76	<3.0	<3.0
Cd	2016-2015	0 out of 56	<0.2	<0.2
	2016	9 out of 35	<0.04	0.06
Cr	2012-2016	0 out of 76	<2.0	<2.0
Cu	2012-2016	4 out of 66	<1.0	8.1
Pb	2012-2015	1 out of 56	<1.0	2.2
	2016	32 out of 35	<0.005	0.154
Se	2012-2013	41 out of 96	<1.0	2.9
	2014-2015	89 out of 94	<0.1	1.87
	2016	48 out of 48	<0.01	1.502
Zn	2012-2016	7 out of 76	<5.0	40

Dissolved and total arsenic and chromium and dissolved nickel were consistently below the reported lab detection limits (see Table 3-5). Dissolved cadmium was consistently below the reported lab detection limits, while total concentrations were also consistently below the limits until 2016 when these detection limits were decreased by about a hundredfold. In 2016, low concentrations of cadmium were measured at all stations. These cadmium concentrations were below MDEQ acute and chronic criteria. Dissolved and total copper, lead, and zinc concentrations also tended to be below the laboratory detection limits except for an occasional sample. These periodic detections of copper, lead, and zinc were below the MDEQ acute and chronic criteria. Dissolved copper ranged from less than detection limit of 1 µg/L to 2.4 µg/L, while total copper ranged from less than detection of 1 µg/L to 8.1 µg/L. Dissolved lead was detected only one time above the detection limit of 1 µg/L (1.4 µg/L), while from 2012 through 2015, total lead was detected only one time above the detection limit of 1 µg/L (2.4 µg/L). However, in 2016 the lower total lead detection limit of 0.005 µg/L allowed lead to be detected

numerous times ranging from 0.005 to 0.248 µg/L. Dissolved zinc was detected periodically with concentrations ranging from less than 5 µg/L to 23 µg/L. Total zinc was also detected periodically with concentrations ranging from less than 5 µg/L to 40 µg/L. Detected copper, lead, and zinc concentrations did not exceed MDEQ chronic or acute standards (see Table 1-5).

2.2.4 Selenium

Total selenium was measured in Lake Koocanusa from 2012 through 2016. As noted in the Trace Metals section, from 2012 through 2013 the detection limit for selenium was 1.0 µg/L. In 2014 and 2015, the detection limit was lowered to 0.1 µg/L, and in 2016, the detection limit was lowered to 0.01 µg/L. Table 2-3 presents a general overview of detection limits and sample detection frequency.

Temporal variations in selenium in Lake Koocanusa are presented in Figure 2-26. In general, total selenium concentrations are greatest in the hypolimnion at all stations. There does not appear to be a substantial seasonal trend in the data, but concentrations were generally higher in the spring and fall and lower in the summer at all stations. Median selenium concentrations at station LIBBOR in the epilimnion and hypolimnion (1.0 and 1.1 µg/L, respectively) were similar to station LIBTMC (0.94 and 1.07 µg/L, respectively) and slightly greater than station LIBFB (0.8 and 1.03 µg/L, respectively).

A selenium speciation study was conducted in Lake Koocanusa and the Kootenai River in 2016. Water samples collected at LIBFB, LIBTW, and HAUL stations were analyzed for five selenium species: selenite (SeIV), selenate (SeVI), methylseleninic acid (MeSeIV), selenocyanate (SeCN), and selenomethionine (SeMet). Only selenite and selenate were detected with selenate accounting for 88 to 100 percent of the species (Figure 2-27). Selenate ranged from 0.66 to 1.2 µg/L, and selenite ranged from less than detection to 0.14 µg/L. Only small differences in speciation percentages and concentrations were noted between samples collected in the forebay at LIBFB, the tailwater station LIBTW, and 8 miles downstream of the dam. Additionally, only small differences in concentrations and percentages of selenate and selenite were noted between the forebay epilimnion and hypolimnion samples

Figure 2-26. Lake Koocanusa and Kootenai River Total Selenium Concentrations for 2012 to 2017

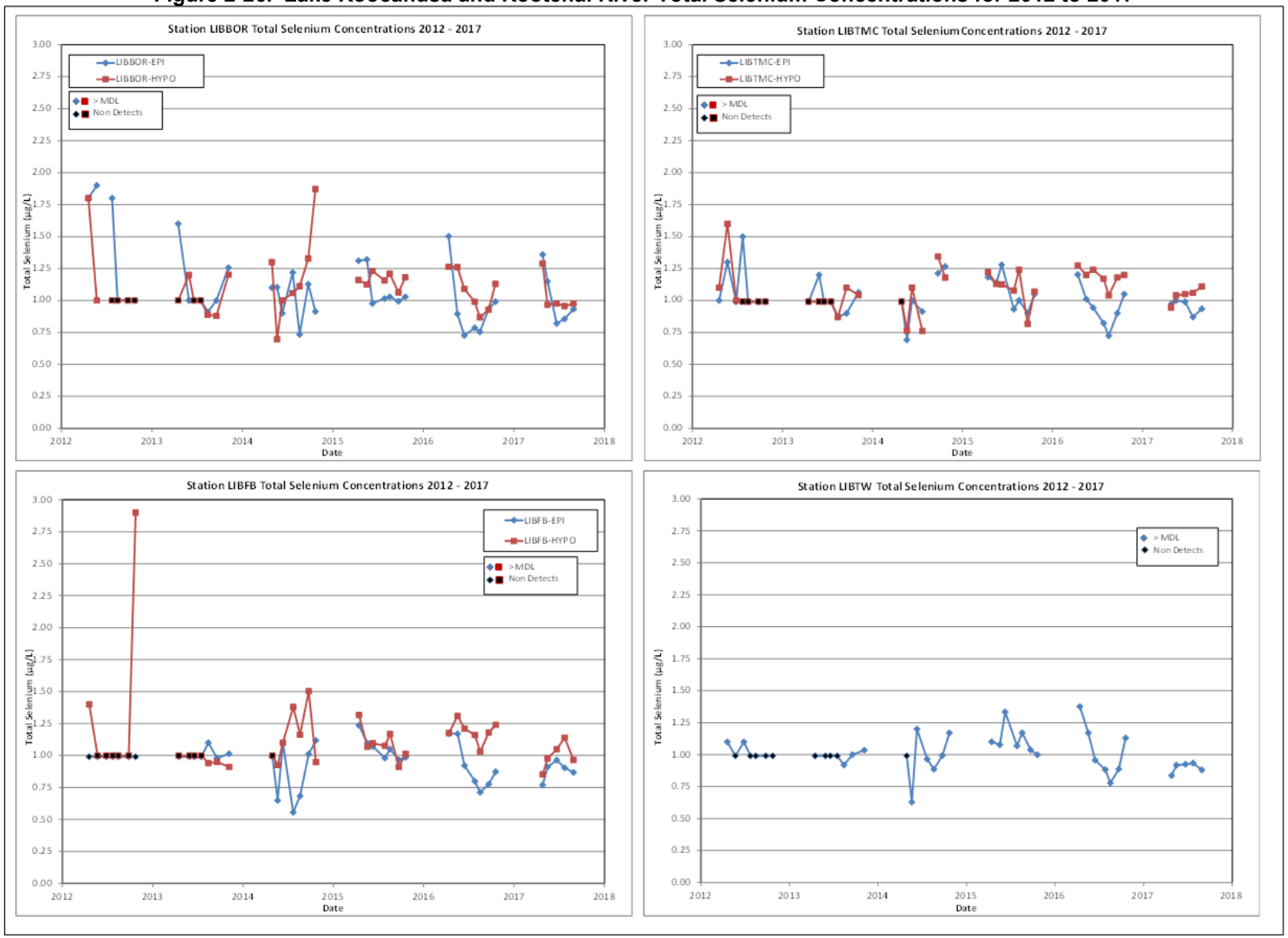
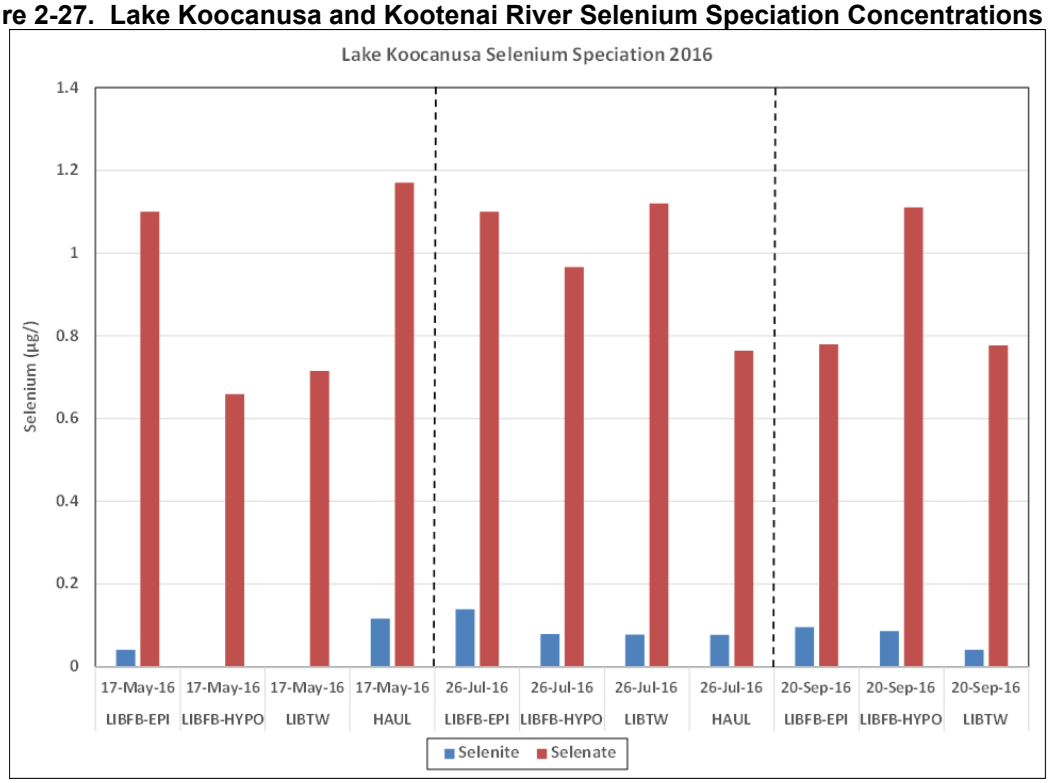


Figure 2-27. Lake Koocanusa and Kootenai River Selenium Speciation Concentrations 2016



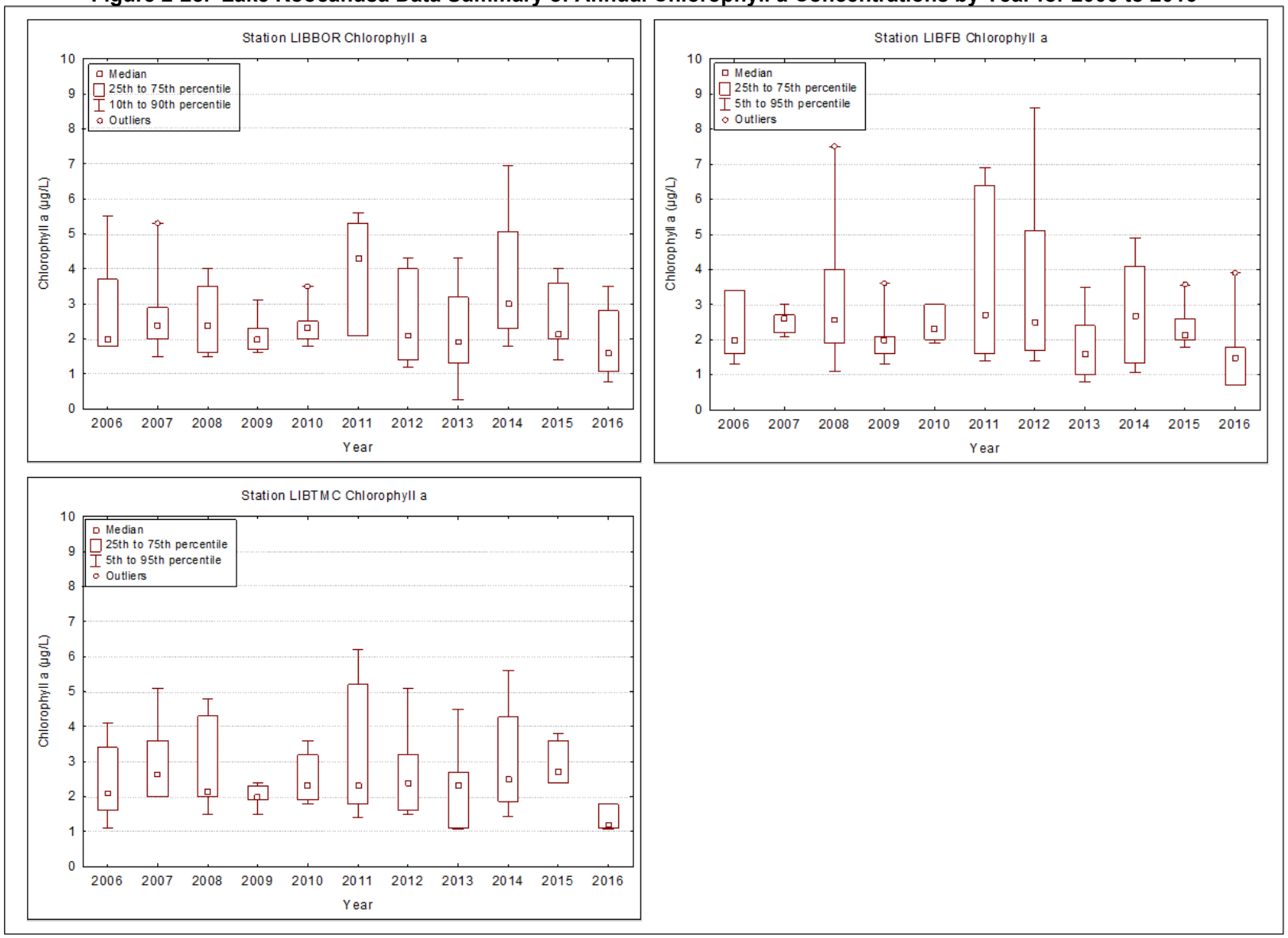
2.3 BIOLOGICAL CHARACTERISTICS

2.3.1 Chlorophyll a

Chlorophyll a is the primary photosynthetic pigment in all photosynthetic organisms requiring oxygen and is found in all freshwater phytoplankton species. Consequently, measurements of chlorophyll a in the water column are an indirect estimate of the amount of phytoplankton present. Although there are several different forms of chlorophyll present in plants, chlorophyll a is the dominant form and is generally considered an indicator of phytoplankton biomass in freshwater ecosystems (Wetzel 1975).

Temporal variations in chlorophyll a occurred at all stations during the study (see Figure 2-10). Chlorophyll a concentrations ranged from less than 1 µg/L to about 7 µg/L at LIBBOR; from about 1 µg/L to about 6 µg/L at LIBTMC; and from less than 1 µg/L to about 8.5 µg/L at LIBFB. In general, chlorophyll a concentrations varied seasonally, with peak concentrations in May and June and an occasional peak concentration in August and September. Concentrations did not vary much between stations with only small differences in peak chlorophyll a values measured between stations during the study. The negative relationship between transparency and chlorophyll a apparent at all stations during the study suggests that the reduced water clarity measured at all stations for all years is partly due to the amount of algae suspended in the water column (see Figure 2-10). Median chlorophyll a concentrations are presented in Figure 2-26. The overall range of data was similar between stations and was slightly less in 2009, 2010, 2015, and 2016 when compared to all other years.

Figure 2-28. Lake Koocanusa Data Summary of Annual Chlorophyll a Concentrations by Year for 2006 to 2016



2.3.2 Trophic State

The biological productivity, or trophic state, can be classified into three general categories: oligotrophic (low productivity), mesotrophic (moderate productivity), and eutrophic (high productivity). Lakes with low nutrient concentrations and low rates of phytoplankton productivity are classified as oligotrophic. Lakes with high nutrient concentrations and high rates of phytoplankton productivity are classified as eutrophic. Mesotrophic lakes have nutrient concentrations and phytoplankton productivity between eutrophic and oligotrophic lakes.

The water quality parameters most often used to assess the trophic state of a lake are total phosphorus, chlorophyll a, and transparency. These three variables have been used by Carlson (1977) and the Organization for Economic Co-Operation and Development (OECD 1982) to develop a trophic state classification system. The general relationship between these three variables and tropic state based on summer mean values and annual mean values is summarized in Table 2-4. Another useful way to group lakes by trophic classification is with the trophic state index (TSI), which is based on linear regression relationships developed for total phosphorus, chlorophyll a, and transparency in lakes (Carlson 1977). Trophic state indices were computed using equations developed by Carlson (1977). A lake with a TSI value less than 40 is classified as oligotrophic; a lake with a TSI value between 40 and 50 is classified as mesotrophic; and a lake with a TSI value greater than 50 is classified as eutrophic (Table 2-4). Carlson (1977) recommends using summer TSI values to classify lakes while the OECD (1982) recommends annual values for trophic classification. For this study, both summer TSI values and annual OECD values are presented for 2006 through 2016 to provide insight on the trophic state of Lake Koocanusa.

Lake Koocanusa would be classified as oligotrophic/mesotrophic on the basis of summer TSI values calculated at the border station LIBBOR, and oligotrophic on the basis of summer TSI values calculated at stations LIBTMC and LIBFB (Figure 2-29). Based on summer total phosphorus TSI values, Lake Koocanusa would be classified as oligotrophic at all stations. However, transparency and chlorophyll a TSI values calculated at station LIBBOR are in the mesotrophic range, while at stations LIBTMC and LIBFB, these two parameters are on the oligotrophic/mesotrophic boundary. Year-to-year fluctuations in the summer TSI value occurred at every station. For the most part, year to year summer total phosphorus concentrations are strongly in the oligotrophic range while chlorophyll a and especially transparency fluctuate between the oligotrophic and mesotrophic range at all stations. Using the OECD (1982) methodology, Lake Koocanusa would be classified as mesotrophic at the border station LIBBOR and oligotrophic/mesotrophic at the mid-reservoir station LIBTMC and the forebay station LIBFB (Table 2-5).

Table 2-4. Trophic Classification Values for Lake Koocanusa 2006 to 2016

Trophic State Classification	Total Phosphorus (µg/L)	Chlorophyll a (µg/L)	Transparency (meters)	Carlson Trophic State Index[3]
Oligotrophic				<40
Annual Mean Values Threshold[1]	<10	<2.6	>6	
Summer Mean Values Threshold[2]	<12	<2.6	>4	
Mesotrophic				40-50
Annual Mean Values Threshold[1]	10-35	2.6-8.0	3-6	
Summer Mean Values Threshold[2]	12-24	2.6-6.4	2-4	
Eutrophic				>50
Annual Mean Values Threshold[1]	>35	>8	<3	
Summer Mean Values Threshold[2]	>24	>6.4	<2	

Notes:
1. Based on OECD (1982)
2. Based on Carlson (1977)
3. Carlson (1977)
   Transparency TSI= 60-14.41*ln mean secchi disk (m)
   Chlorphyll a TSI= 9.81*ln mean chl a (µg/L)+30.6
   Total Phosphorus TSI= 14.42*ln mean TP + 4.15

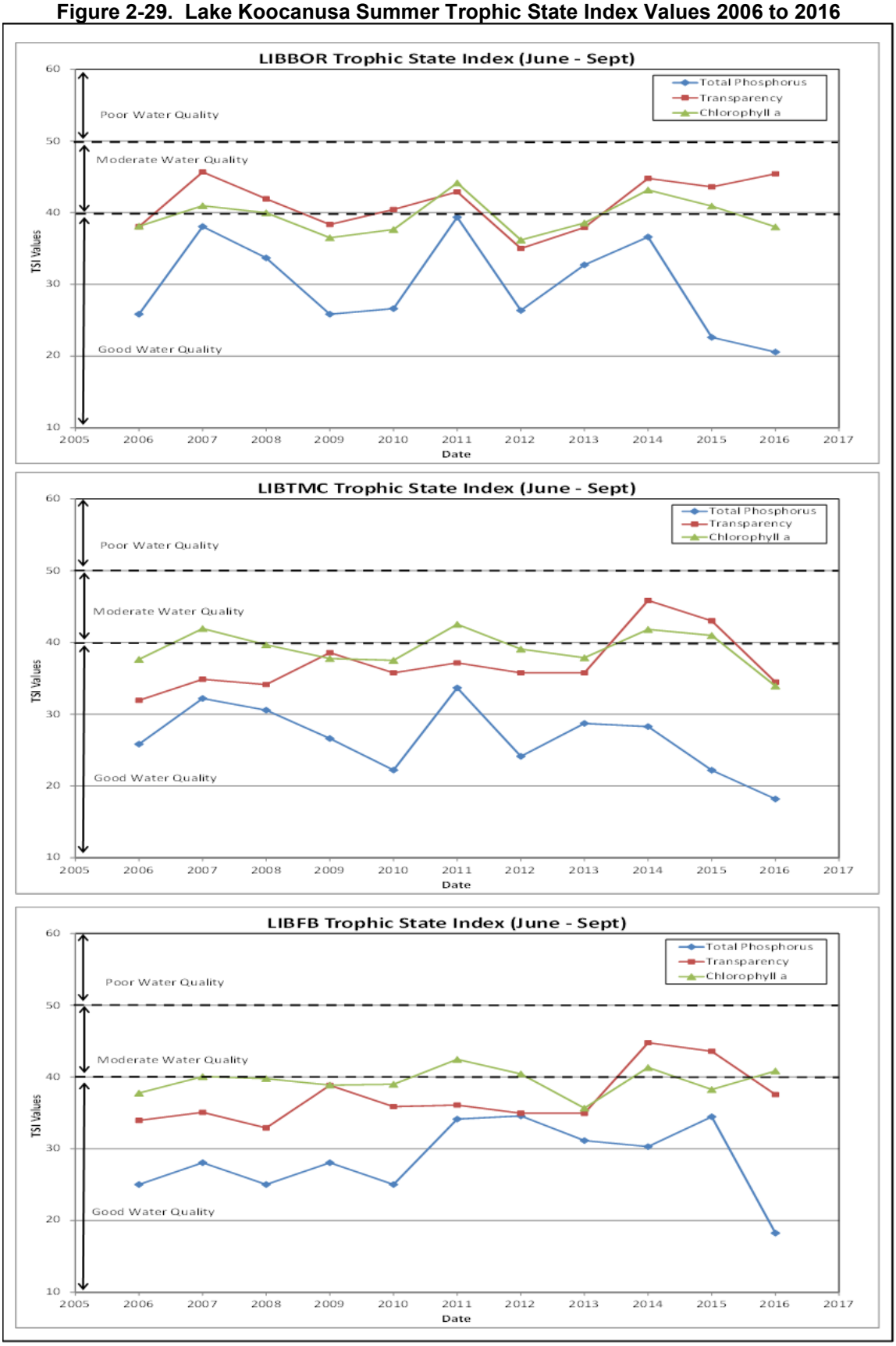
Table 2-5. OECD Trophic State Classification Total Phosphorus, Chlorophyll a, and Transparency Values for Lake Koocanusa 2006 to 2016

OECD (1982) Closed Boundary Annual Mean Values (µg/L)

	LIBBOR			LIBTMC			LIBFB		
Year	TP	Trans	Chl a	TP	Trans	Chl a	TP	Trans	Chl a
2006	8.6	3.5	2.8	5.0	6.3	2.5	4.9	6.3	2.4
2007	10.0	2.7	2.8	6.0	6.3	3.0	4.8	6.5	2.5
2008	9.7	3.1	2.6	7.0	5.7	2.8	4.5	6.4	3.3
2009	5.1	3.9	2.1	4.4	5.4	2.0	4.4	5.4	2.0
2010	7.0	3.1	2.4	4.1	5.3	2.6	4.0	5.7	2.4
2011	24.9	3.0	3.9	8.7	4.8	3.4	7.9	5.4	3.5
2012	8.7	3.8	2.5	5.3	5.8	2.6	7.6	5.3	3.4
2013	7.2	3.4	2.1	5.5	5.2	2.3	5.7	5.3	1.7
2014	12.3	2.1	3.6	5.6	3.3	3.0	5.2	3.4	2.8
2015	3.8	3.1	2.6	4.1	3.9	2.9	7.1	3.9	2.3
2016	6.9	2.7	1.9	5.0	5.9	1.4	3.9	5.6	1.6

	TP	Trans	Chl a
Oligotrophic	<10	>6	<2.5
Mesotrophic	10 - 35	3 - 6	2.5 - 8
Eutrophic	>35	<3	>8

Figure 2-29. Lake Koocanusa Summer Trophic State Index Values 2006 to 2016



2.3.3 Phytoplankton

Phytoplankton are photosynthetic microorganisms that live free-floating in water. Phytoplankton are plant-like but are not plants. In general, most freshwater phytoplankton can be placed in two classes, algae and cyanobacteria. Numerous types of phytoplankton co-exist in freshwater ecosystems, including free-swimming, free-floating, colonial, and unicellular. Phytoplankton provides the base of the food chain in aquatic environments and support crucial food-web dynamics up the trophic level to more familiar aquatic organisms, such as fish. Seasonal changes in water temperature and light, as well as nutrient availability play important roles in the natural temporal variation in phytoplankton species and abundance found in freshwaters. Additionally, human-caused impacts such as increased nutrient inputs from both point and non-point sources can greatly impact the natural phytoplankton species composition and abundance found in freshwaters. Increased nutrients can result in blooms that will produce high concentrations of phytoplankton in the water column and on the water surface. Wind and currents can cause phytoplankton blooms to accumulate in certain areas of lakes, resulting in surface scums, floating mats, and nuisance conditions. Consequently, the abundance, taxonomic diversity, and productivity of phytoplankton are indicators of the health and sustainability of an aquatic ecosystem (Reynolds 1984).

Phytoplankton productivity (biovolume and density) are typically highest in the spring and early summer because of warming water temperatures and the increased availability of nutrients. Phytoplankton levels often decline in the summer as nutrient supplies are depleted but can increase in early fall due to the breakdown of the thermocline making nutrients from the hypolimnion available to the epilimnion. Phytoplankton productivity levels and the dominant species composition are important when determining the general biological condition of a lake.

2.3.3.1 *Phytoplankton Characteristics*

Freshwater phytoplankton characteristics and traits are presented below by division.

Chlorophyta. Chlorophyta are also known as green algae and are a diverse group of algae commonly found in aquatic environments. Green algae are one of the most abundant algal groups in fresh water. Cells contain bright green pigments and can be either unicellular or filamentous. In general, most green algae species are considered part of a healthy aquatic ecosystem and a source of food for zooplankton. However, some filamentous green algae can create water quality problems by forming large slimy, stringy clouds of algae.

Cyanophyta. Cyanobacteria (commonly referred to as blue-green algae) are a bacteria, not algae. These unicellular, filamentous, motile, and colonial species are unique because they are a prokaryotic cell. Although they are prokaryotic, cyanobacteria have internal membranes that function in photosynthesis and contain chlorophyll a. Both filamentous and unicellular species occur in large colonies, all containing mucilaginous sheaths. Consequently, cyanobacteria are not a desirable food source for grazing zooplankton, can form nuisance algae blooms, and are generally

considered a less desirable and noxious phytoplankton species. In addition, some species of cyanobacteria can produce cyanotoxins that can be harmful to mammals.

Bacillariophyta. Dominated by diatoms, these are very abundant single-celled organisms that are major photosynthetic producers. Most species are non-motile and are diverse in form. Diatoms' primary characteristic is a silicified cell wall. Although there are species that can produce harmful toxins, diatoms are generally considered valuable to the food chain and functionality of an ecosystem and are considered to be ecologically beneficial. Diatoms are commonly abundant during the spring and again during late summer and early autumn.

Cryptophyta. Commonly known as cryptomonads, cryptophyta are unicellular algae that usually contain two flagellates of two unequal lengths. This group of algae is very small in size and little is understood about them. These algae are a desirable food source for zooplankton and are considered to be ecologically beneficial. When compared to other algae, cryptomonads can develop during colder periods with lower light intensities.

Chrysophyta. More commonly known as golden algae, this diverse algal group can be unicellular, colonial, and filamentous. Golden algae are characterized by their yellow-green coloration due to greater amounts of carotenoids versus chlorophylls in their cells. The majority of species possess two flagella.

Pyrrhophyta. Pyrrhophyta are known as dinoflagellates and are unicellular organisms with two flagella. Although most species are found in marine environments, there are a number of species found in freshwater systems. Dinoflagellates tend to bloom in temperate conditions toward the end of summer when stratification is stable and epilimnion nutrients are declining. In marine areas, some species can produce harmful toxins and are of particular concern to humans as they may cause red tides.

Euglenophyta. Commonly known as euglenoids, euglenophyta are a large and diverse group of phytoplankton commonly found in waters high in ammonia and organic matter (Wetzel 1975). Most euglenoids are unicellular, lack a cell wall, and have up to three flagella.

2.3.3.2 *Phytoplankton Abundance and Composition*

Phytoplankton samples were collected in Lake Koocanusa from 2008 through 2016. Collectively, 125 species of phytoplankton representing 7 genera were identified in Lake Koocanusa during the 2008 to 2016 study (Table 2-6). Of these 125 different species, there were 74 species of bacillariophyta (diatoms), 17 species of chlorophyta (green algae), 16 species of chrysophyta (golden algae), 5 species of cyanophyta (cyanobacteria), 5 species of cryptophyta (cryptomonads), 5 species of pyrrhophyta (dinoflagellates), and 3 species of euglenophyta (euglenoids). In general, Lake Koocanusa spring phytoplankton assemblages are a mixture of diatoms, cryptophytes, and chrysophytes, while summer and fall assemblages are dominated by diatoms.

Table 2-6. Phytoplankton Species List for Lake Koocanusa 2008 to 2016

Bacillariophytes

Achnanthes lanceolata
Achnanthes linearis
Achnanthes minutissima
Achnanthes recurvata
Amphora perpusilla
Amphora spp.
Anomoeoneis vitrea
Asterionella formosa
Caloneis ventricosa minuta
Cocconeis placentula
Cyclotella comta
Cyclotella distinguenda
Cyclotella kutzingiana
Cyclotella meneghiniana
Cyclotella ocellata
Cyclotella sp.
Cyclotella stelligera
Cymatopleura solea
Cymbella affinis
Cymbella cymbiformes
Cymbella microcephala
Cymbella minuta
Cymbella naviculiformis
Cymbella sinuata
Diatoma spp.
Diatoma tenue
Dinobryon divergens
Diploneis elliptica
Diploneis spp.
Epithemia turgida
Fragilaria construens venter
Fragilaria crotonensis
Fragilaria pinnata
Fragilaria sp.
Gomphonema angustatum
Gomphonema olivaceum
Gomphonema subclavatum
Gyrosigma spencerii
Melosira ambigua
Melosira granulata
Melosira granulata angustissima
Melosira varians
Meridion circulare
Navicula capitata

Bacillariophytes (continued)

Navicula cryptocephala
Navicula cryptocephala veneta
Navicula graciloides
Navicula gregaria
Navicula mutica
Navicula pupula
Navicula rhynchocephala
Navicula sp.
Navicula tripunctata
Navicula viridula
Nitzschia acicularis
Nitzschia capitellata
Nitzschia dissipata
Nitzschia frustulum
Nitzschia linearis
Nitzschia palea
Nitzschia paleacea
Nitzschia sigmoidea
Nitzschia spp.
Rhoicosphenia curvata
Stephanodiscus astraea minutula
Stephanodiscus hantzschii
Stephanodiscus niagarae
Surirella ovata
Synedra delicatissima
Synedra radians
Synedra rumpens
Synedra ulna
Tabellaria fenestrata
Tabellaria flocculosa

Cryptophytes

Cryptomonas erosa
Cryptomonas sp.
Cryptomonas spp.
Plagioselmis sp.
Rhodomonas minuta

Chlorophytes

Ankistrodesmus falcatus
Chlamydomonas sp.
Cosmarium sp.
Cosmarium spp.
Crucigenia quadrata
Desmidium sp.
Elakatothrix gelatinosa

Chlorophytes (continued)

Gloeocystis ampla
Kirchneriella spp.
Monoraphidium komarkovae
Monoraphidium tortile
Nephrocytium sp.
Oocystis lacustris
Oocystis pusilla
Pediastrum boryanum
Scenedesmus sp.
Sphaerocystis schroeteri

Chrysophytes

Chromulina sp.
Chrysococcus rufescens
Dinobryon bavaricum
Dinobryon divergens
Dinobryon sertularia
Dinobryon spp.
Kephyrion littorale
Kephyrion sp.
Kephyrion spirale
Lagynion sp.
Mallomonas sp.
Mallomonas spp.
Ochromonas spp.
Pseudokephyrion sp.
Rhizosolenia eriensis
Synura sp.

Cyanophytes

Chamaesiphon sp.
Chroococcus minimus
Chroococcus spp.
Planktolyngbya sp.
Snowella sp.

Euglenophytes

Trachelomonas crebea
Trachelomonas pulchella
Trachelomonas volvocina

Pyrrhophytes

Amphidinium spp.
Ceratium hirundinella
Glenodinium sp.
Peridinium cinctum
Peridinium sp.

Phytoplankton data are presented using both density and biovolume measurements. Phytoplankton density is a measure of the total number of organisms of each species

per milliliter in a sample. Phytoplankton biovolume is a measure of the total volume of organisms of each species in a sample. Because biovolume measurements incorporate both cell numbers and size, they can be very different from density measurements, depending on the size of the phytoplankton species. For example, cryptomonads are very small in size and may have large density numbers but small biovolume numbers. Conversely, diatoms which are generally large in size, may have low densities but high biovolumes.

The seasonal succession of species at all stations between 2008 and 2016 are presented in Figure 2-30 and Figure 2-31 for biovolume and density. In general, phytoplankton populations were a mixture of diatoms, cryptophytes and chrysophytes at all stations during the spring (April, May and June) with diatoms dominating during the summer and fall (July, August, September and October). A large increase in phytoplankton biovolume and densities were measured at all stations in Lake Koocanusa between 2008 and 2016. For the most part, low biovolumes were measured from 2008 to 2011, moderate biovolumes from 2012 to 2013, and a substantial increase in volumes measured from 2014 to 2016 (Figure 2-30). In general, biovolumes were greatest from June through September. Densities followed a similar trend. From 2008 to 2013, phytoplankton densities were low (2008 and 2010) to moderate (2009, 2011, 2012, 2013), with an increase in densities from 2014 to 2016 (Figure 2-31). Phytoplankton densities were generally lowest in April and October, and highest in May through September.

Lake Koocanusa water column phytoplankton populations were dominated by a mixture of diatoms, cryptophytes, and chrysophytes at all stations from 2008 to 2013 and by diatoms and chrysophytes from 2014 to 2016 (Figure 2-32 and Figure 2-33). In general, from 2008 to 2013, diatoms accounted for about 60 to 100 percent of phytoplankton composition by biovolume and about 40 to 100 percent by total density. Cryptomonads accounted for about 0 to 20 percent by biovolume and 0 to 50 percent by density, while crysophytes accounted for about 0 to 50 percent by biovolume and from about 0 to 20 percent by density. No cyanobacteria were measured at any station from 2008 to 2013. From 2014 to 2016, diatoms accounted for about 70 to 100 percent of phytoplankton composition by biovolume and total density. Cryptomonads accounted for about 0 to 20 percent by biovolume and 0 to 30 percent by density, while crysophytes accounted for about 0 to 15 percent by biovolume and for about 10 to 40 percent by density. In addition, cyanobacteria were detected for the first time in Lake Koocanusa in 2015 and 2016, accounting for about 0 to 5 percent by biovolume and about 0 to 15 percent by density.

Despite low to moderate biovolume and density numbers from 2008 through 2013, species diversity was moderate. From 2008 to 2013, the phytoplankton assemblage was dominated by a mixture of diatoms (*Asterionella*, *Cyclotella*, *Fragilaria*, *Synedra*, and *Tabellaria*), cryptophytes (*Cryptomonas,* and *Rhodomonas*.), and chrysophytes (*Dinobryon*). During peak blooms, phytoplankton biovolume and density was dominated by a mixture of diatoms (*Cyclotella*, *Fragilaria*, and *Synedra*).

Figure 2-30. Lake Koocanusa Temporal Variation in Phytoplankton Density for 2008 to 2016

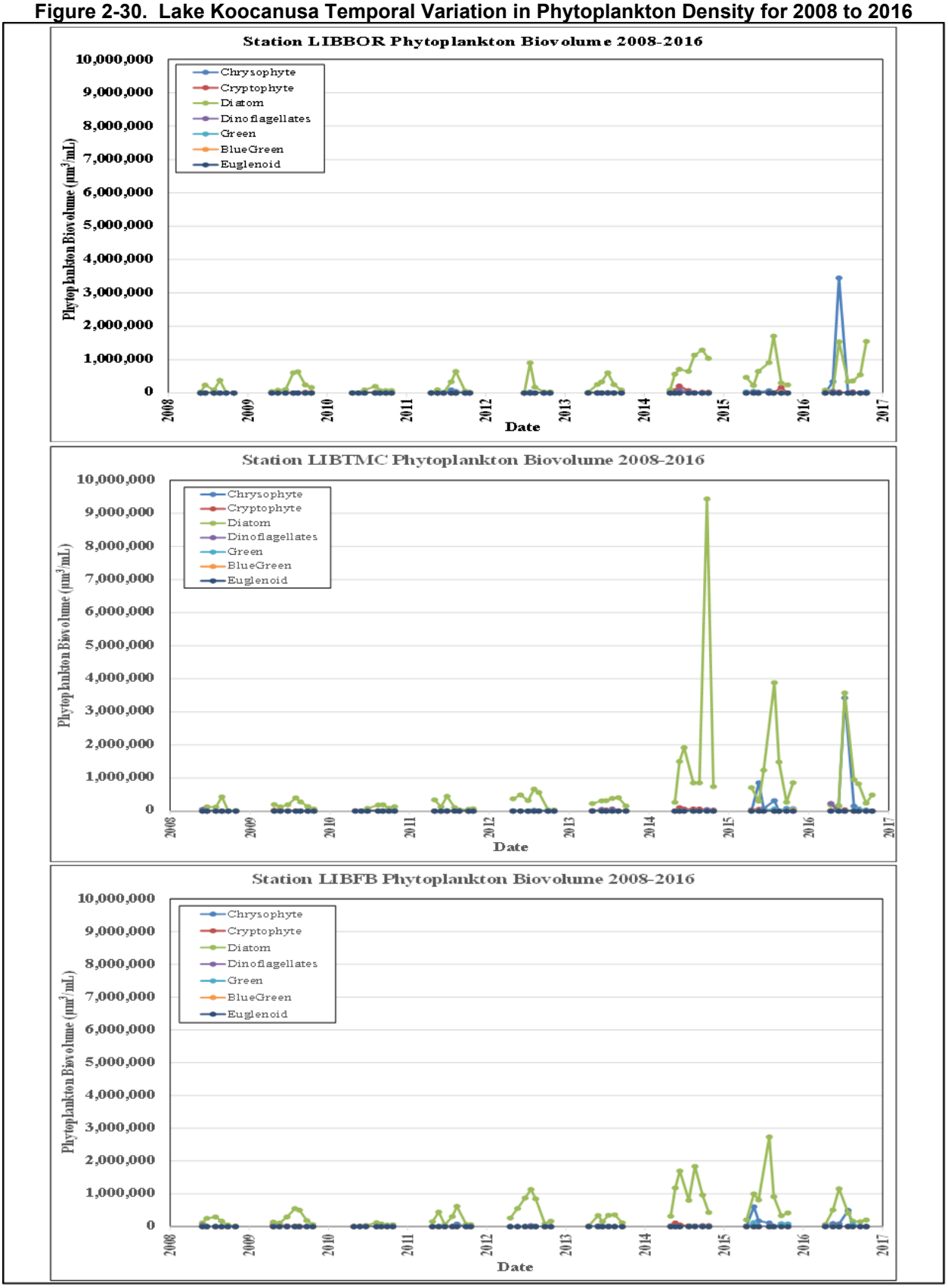


Figure 2-31. Lake Koocanusa Temporal Variation in Phytoplankton Biovolume for 2008 to 2016

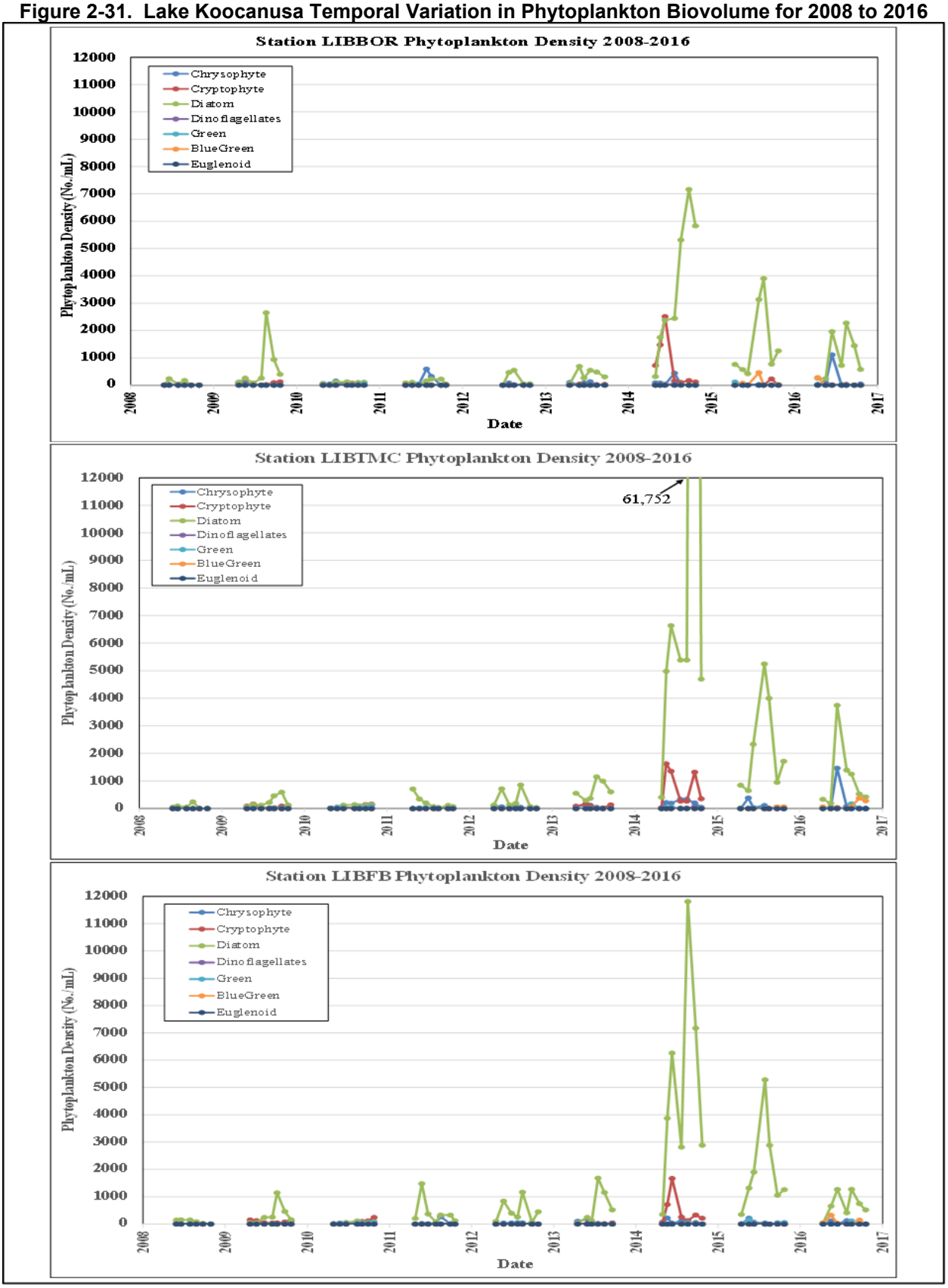


Figure 2-32. Lake Koocanusa 2008 to 2016 Average Yearly Phytoplankton Percent Composition by Biovolume

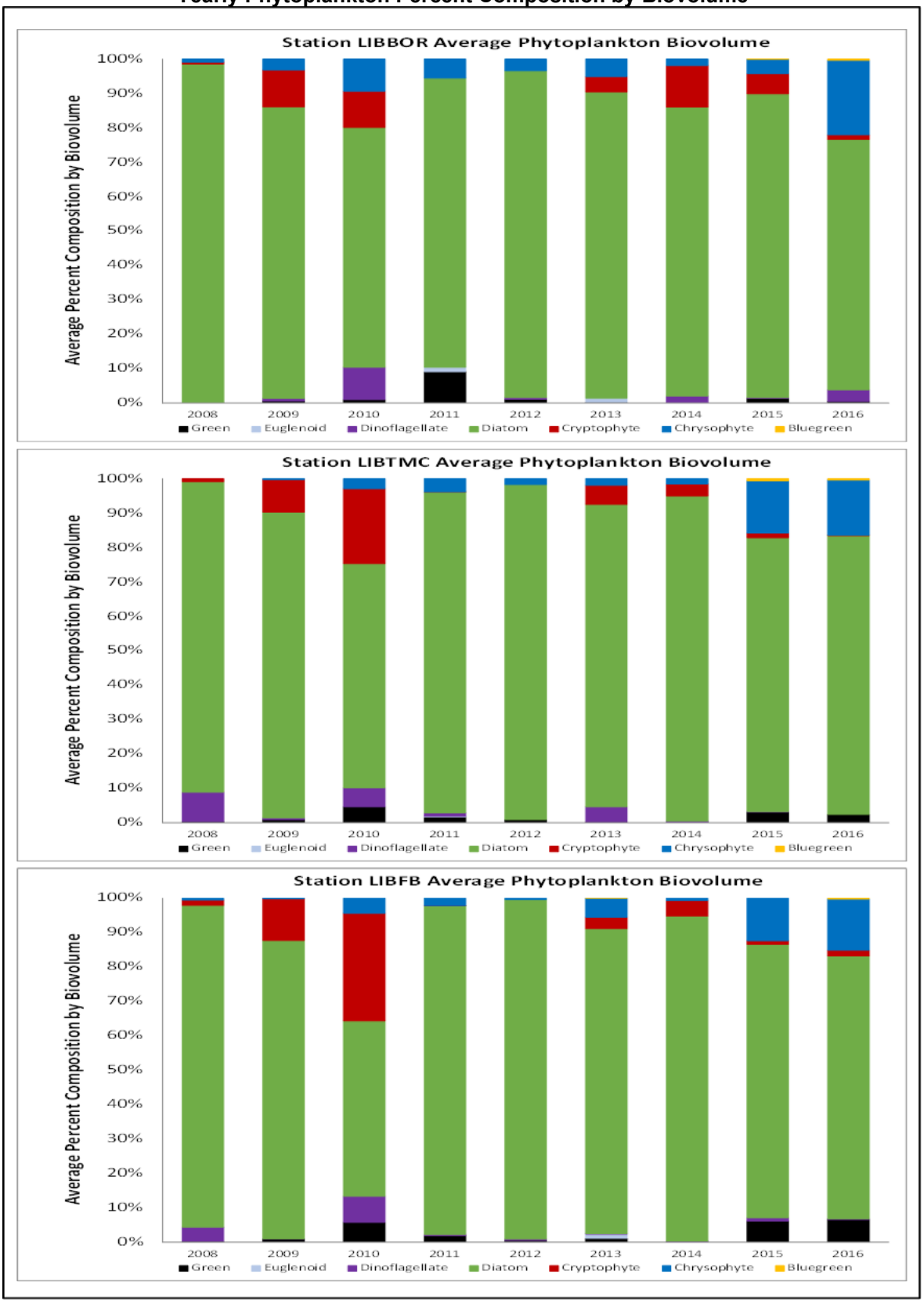
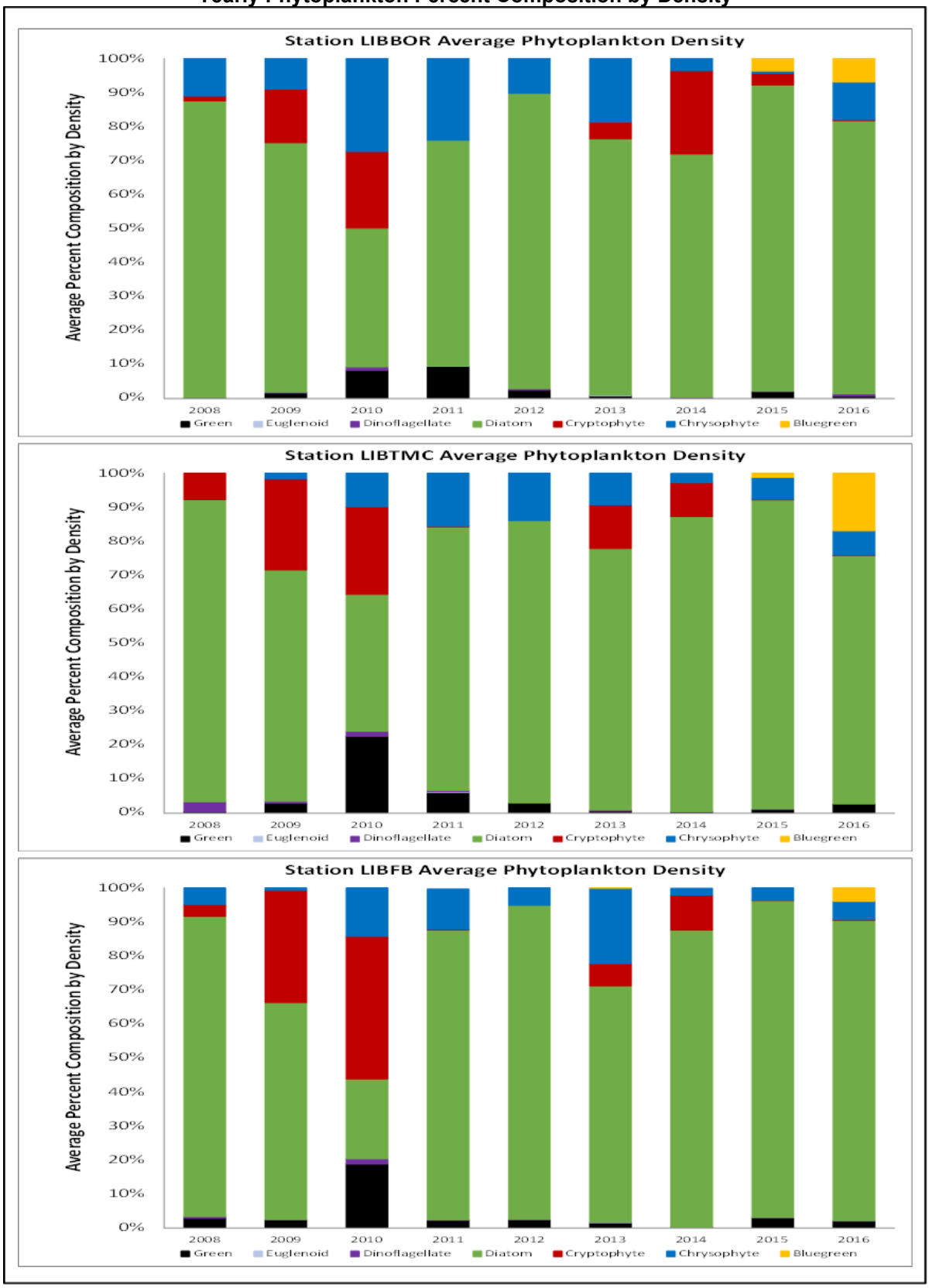


Figure 2-33. Lake Koocanusa 2008 to 2016 Average Yearly Phytoplankton Percent Composition by Density



A substantial increase in phytoplankton biovolume and density was measured at all stations between 2014 and 2016, with the greatest phytoplankton biovolume and density measured at stations LIBTMC and LIBFB (See Figure 2-30 and Figure 2-31). Although biovolumes were high from 2014 through 2016, species diversity was relatively low with often only one or two phytoplankton species dominating. From 2014 to 2016, the phytoplankton assemblage was largely dominated by a few diatoms (*Cyclotella*, *Fragilaria*, and *Synedra*) and the chrysophyte *Dinobryon*. Similarly, peak biovolumes had very little diversity and tended to be dominated by the diatom *Cyclotella* and the chrysophyte *Dinobryon*. Phytoplankton dominance by density calculations were similar with the exception that the chrysophyte *Dinobryon* tended to not dominate phytoplankton densities. In general, phytoplankton densities were dominated by the diatoms *Asterionella*, *Cyclotella*, *Fragilaria*, and *Synedra,* with peak densities often dominated solely by *Cyclotella*.

The large increase in phytoplankton biovolume and density from 2014 to 2016 may be partly due to the increased loadings of the nutrient nitrogen and the relatively stable loadings of phosphorus, resulting in extremely high nitrogen to phosphorus ratios (N:P). Traditionally, most research has shown a strong correlation between increased phosphorus loading and phytoplankton productivity in freshwaters, as long as the N:P ratio is high (Wetzel 1975; Schindler 1978; Anderson, Gilbert, and Burkholder 2002; Welch and Jacoby 2004). However, several recent studies on the impacts of increased nitrogen loadings to oligotrophic lakes have shown an increase in algal productivity due to increased nitrogen loadings (Bergström and Jansson 2006; Hobbs et al. 2016). Changes in species diversity and composition have also been attributed to increased nitrogen to phosphorus ratios. Studies by Lehman (1976) showed that *Dinobryon* were shown to outcompete other algal species when phosphorus concentrations are low and the corresponding nitrogen to phosphorus ratios are high because *Dinobryon* possess efficient mechanisms for uptake of nitrogen and low concentrations of phosphorus. Additionally, nitrate enrichment studies on Lake Huron concluded that the diatom *Cyclotella* increases in abundance due to an increased nitrogen to phosphorus ratio (Pappas and Stoermer 1995).

2.3.3.3 *Phytoplankton Correlation Analysis*

Correlation of water quality data and phytoplankton data was conducted using the Kendall Tau rank correlation analysis (see Table 2-8). To provide a more robust dataset, phytoplankton data from 2008 to 2016 was combined for all stations for the correlation analysis. A statistical significance level of $p < 0.05$ was used to identify relationships between two variables. The Kendall Tau correlation coefficient can range from -1 to 1, with negative values indicating a negative relationship between the two parameters and positive values indicating a positive relationship. The farther the coefficient values are from 0, the stronger the relationship.

Total phytoplankton density was moderately correlated to nitrate (0.153) and soluble reactive phosphorus (0.115), and strongly correlated to year (0.505). Total phytoplankton biomass was not correlated to any form of phosphorus or nitrogen but was strongly correlated to year (0.428).

2.3.4 Zooplankton

Zooplankton are microscopic animals found in the water column that are important to the trophic structure of an ecosystem because they feed on phytoplankton and, in turn, are consumed by fish. Zooplankton can be either herbivorous (feeds on phytoplankton), carnivorous (feeds on other zooplankton), or omnivorous (feeds on both phytoplankton and zooplankton). Water quality conditions can be assessed from the numbers and types of zooplankton species present in the water (Gannon and Stemberger 1978). For example, the presence of certain zooplankton species relative to other species may serve as an indicator of the biological productivity of a water body. However, this generalization may or may not be indicative of site-specific water quality conditions, such as those found in Lake Koocanusa. Consequently, zooplankton density and species information should be used in conjunction with phytoplankton data, physical data, and chemical data to determine the overall trophic condition of a lake.

Freshwater zooplankton are usually dominated by three main groups: the rotifers and two subclasses of the crustacea–cladocera and copepods. Zooplankton are classified by size, developmental stage, grazing techniques, reproductive characteristics, and/or morphology. The traits of these three main zooplankton are explained below.

2.3.4.1 *Cladocera*

Commonly known as water fleas, these organisms are filter feeders and generally range in size from 0.2 to 3.0 millimeters. These filter feeders are identifiable by the presence of a large eye and two-valved carapace. Cladocera are an important part of the freshwater ecosystem as they graze on phytoplankton and are a prime source of food for fish. Cladocera have the ability to migrate vertically in the water column on a daily basis. Herbivorous species dominate, although some carnivorous species of cladocera exist in fresh waters.

2.3.4.2 *Copepod*

Copepods are the second major group of crustacean zooplankton. Adult members grow slightly larger than cladocerans and range in size from 0.5 to 5.0 millimeters. These organisms are identifiable by their long teardrop-shaped body and antennae. No filtration mechanism exists for feeding, and food is seized by mouthparts and brought to the mouth. Both herbivorous and carnivorous species of copepods exist in fresh water. Some species of copepods have the ability to migrate vertically in the water column on a daily basis.

2.3.4.3 *Rotifers*

Rotifers, a large group of soft-bodied plankton, are among the smallest of the zooplankton, ranging in size from .002 to 0.2 millimeters in adult form. The majority of cotifers have an elongated body shape with distinguishable head, trunk, and foot regions. Characterized by the division of their body, rotifers are identified by their wheel-shaped corona. Herbivorous species dominate, although some carnivorous species of rotifers exist in fresh waters.

2.3.4.4 *Zooplankton Abundance and Composition*

Collectively, 74 species of zooplankton were identified in Lake Koocanusa during the 2006 to 2016 study (Table 2-7). Of these 74 species, there were 41 species of rotifers, 17 species of cladocera, and 16 species of copepods.

Table 2-7. Zooplankton Species List for Lake Koocanusa 2006 to 2016

Cladocera	**Rotifer (continued)**
Alona costata	*Asplanchna sp*
Bosmina longirostris	*Cephalodella sp.*
Ceriodaphnia sp.	*Collotheca sp*
Chydorus sphaericus	*Conochiloides sp.*
Daphnia galeata mendotae	*Conochilus sp*
Daphnia mendotae	*Euchlanis sp*
Daphnia retrocurva	*Filinia sp*
Daphnia sp.	*Gastropus sp*
Daphnia thorata	*Hexarthra sp*
Diaphanosoma birgei	*Kellicottia longispina*
Diaphanosoma brachyurum	*Keratella cochlearis*
Diaphanosoma sp.	*Keratella earlinae*
Eubosmina longispina	*Keratella hiemalis*
Holopedium gibberum	*Keratella irregulais*
Leptadora kindti	*Keratella quadrata*
Leptodora kindti	*Keratella sp*
Scapholeberis armata	*Lecane sp*
Copepod	*Monostyla lunaris*
Diacyclops sp	*Notholca acuminata*
Epischura nevadensis	*Notholca laurentiae*
Harpaticoida	*Notholca sp*
Leptodiaptomus minutus	*Platyias sp*
Nauplii	*Polyarthra major*
Calanoida - copepodites	*Polyarthra sp*
cyclopoid copepodites	*Polyarthra vulgaris*
Cyclopoida - copepodites	*Pompholyx sulcata*
Diacyclops thomasi	*Proales sp*
diaptomid copepodites	*Trichocerca porcellus*
Diaptomidae	*Trichocerca sp*
Epischurid copepodites	*Ascomorpha ovalis*
Leptodiaptomus ashlandi	*Kellicottia longispina*
Leptodiaptomus tyrrelli	*Keratella cochlearis*
Microcyclops varicans	*Keratella crassa*
Skistodiaptomus pallidus	*Keratella earlinae*
Rotifer	*Keratella quadrata*
Anuraeopsis sp	*Polyarthra sp.*
Ascomorpha escaudis	*Synchaeta sp.*
Ascomorpha sp	
Asplanchna priodonta	

Temporal variations in zooplankton density at all stations in Lake Koocanusa are presented in Figure 3-34. Zooplankton density was measured as the total number of organisms of each species per liter in a sample. Total zooplankton densities varied between years and stations. In general, zooplankton densities were greatest in May or June, depending on the year, at all stations and were greatly reduced during April and July through October. Annual peak zooplankton densities at all stations typically ranged from about 100 to 300 organisms/L, except for a peak of about 400 organisms/L at LIBBOR in 2009 and nearly 1,000 organisms/L at LIBTMC in 2011. Rotifers and copepods dominated density measurements at all stations during the study.

The composition of zooplankton was similar between stations; however, seasonal and annual differences were apparent (Figure 3-35). Zooplankton densities from 2006 through 2010 were dominated by copepods, which accounted for about 40 to 90 percent of the total density depending on the month. However, from 2011 through 2014, rotifers have dominated the Lake Koocanusa zooplankton population, accounting for about 40 to nearly 100 percent of the total density depending on the month. Cladocera densities were relatively low (0 to 30 percent) during the entire study. Seasonal differences were apparent at all stations with rotifers tending to dominate from about April through August, and copepods dominating in September and October. Cladocera densities were generally low during all months. In general, rotifers were dominated by *Keretella* spp., *Kellicottia longispina*, and *Polyarthra* sp.; copepods were dominated by *Nauplii*, and *Diacyclops* sp.; and cladocerans were dominated by *Daphnia* spp. and *Bosmina longirostris*.

Figure 2-34. Lake Koocanusa Zooplankton Density by Station for 2006 to 2014

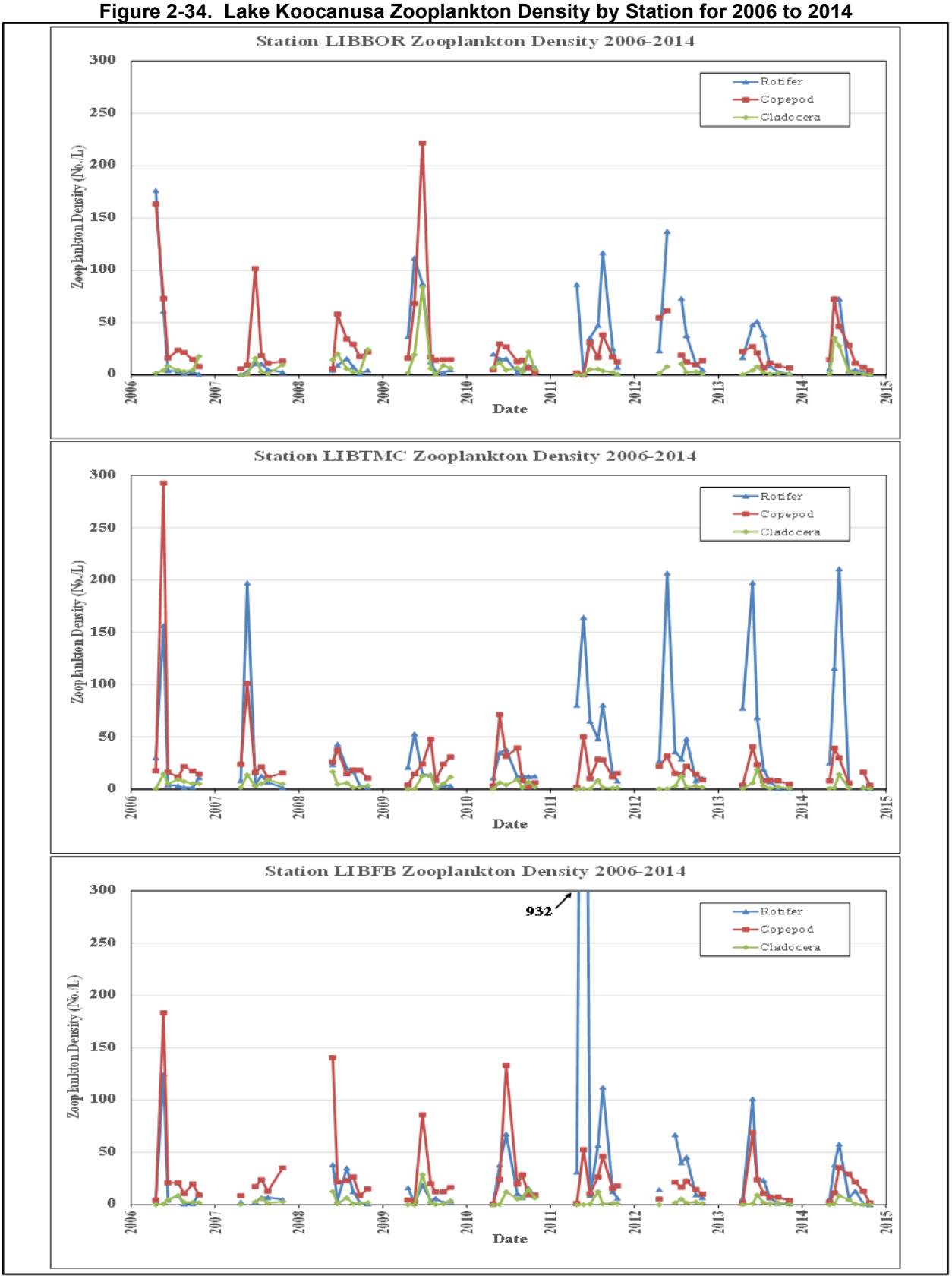
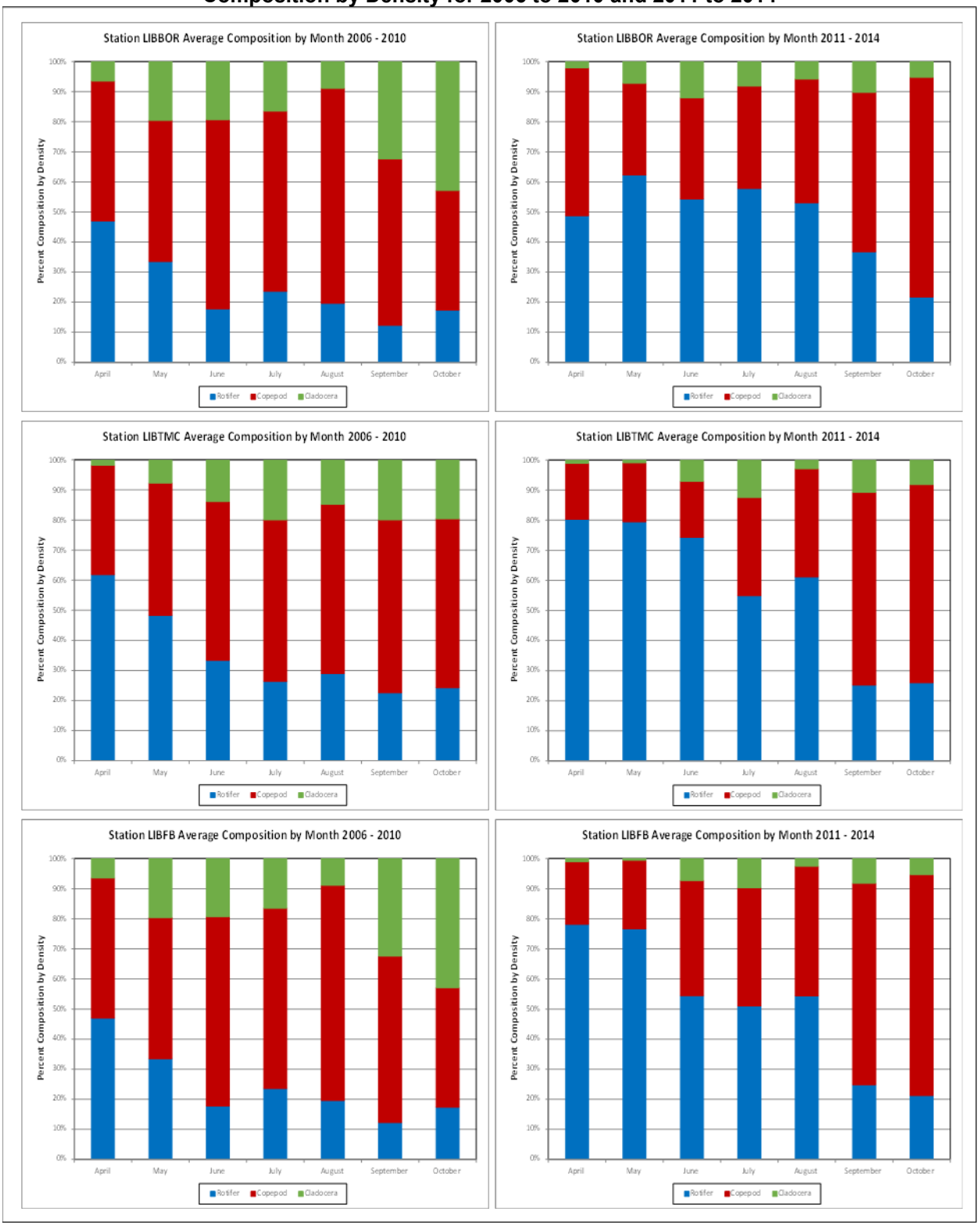


Figure 2-35. Lake Koocanusa Average Monthly Composition by Density for 2006 to 2010 and 2011 to 2014



The seasonal succession in zooplankton species seen in Lake Koocanusa is likely in response to food source availability, changes in temperature, and grazing by fish. Many zooplankton populations are low over the winter and begin to increase in the spring as food supplies (i.e., phytoplankton) increase and water temperatures rise. As phytoplankton species shift in dominance during spring, summer, and fall, the zooplankton populations will cycle in response to the quality and size of the food (with some phytoplankton species being more palatable than others), as well predation by other zooplankton species (Wetzel 1975). The annual succession in zooplankton species from dominance by larger copepods to dominance by smaller rotifers may be in part a response to the change in algal species and diversity that was measured in Lake Koocanusa or possibly due to grazing by Kookanee. Abrupt changes in zooplankton species dominance from larger Daphnia to smaller Bosmina were noted in the late 1980s and believed to have been the result of increased Kookanee grazing (Chisholm et al. 1989; Hamilton et al. 1990).

2.4 STATISTICAL ANALYSIS

2.4.1 Seasonal Kendall Trend Analysis

Trend analysis was performed on the long-term monitoring data from each station using a seasonal Kendall test (Hirsch, Slack, and Smith 1982). The seasonal Kendall test is a nonparametric test that accounts for seasonality by computing the Mann-Kendall test on each season (i.e., month) and then combining the results for each season. The seasonal Kendall test determines if a significant consistent trend exists and the magnitude of the trend as determined by a slope or change per unit time. A Sen-Theil slope test was used to measure the magnitude of the trend (Hirsch, Slack, and Smith 1982).

Seasonal Kendall tests were conducted on two sets of long-term monitoring data. First, data collected by the Seattle District for the current study from 2006 to 2016 was used to perform seasonal Kendall tests for the determination of trends over the past 11 years. Second, data collected by the USGS from 1993 to 2004 or 1999 to 2004 was combined with the 2006 to 2016 data to provide a more robust long-term data set spanning more than 20 years. Although the USGS data goes back to about 1972, analysis of this historical dataset revealed that too many different analytical methods and reporting limits were used to allow the dataset to be comparable to the current dataset. Consistent analytical methods and reporting limits for nutrients were not achieved until 1999, and therefore only nutrient data from 1999 to 2004 was combined with the 2006 to 2016 data for the trend analysis. However, consistent analytical methods and reporting limits for cations, anions, alkalinity, transparency, and chlorophyll a were achieved by 1993. Given this, for these parameters, data from 1993 to 2004 was included in statistical testing.

For a watershed as large as Lake Koocanusa, long-term trend analysis is the principal way to evaluate changes in water quality in relation to complex watershed changes. The major change in the Lake Koocanusa watershed during the past 20 years is an increase in coal mining operations in the Elk and Fording Rivers watershed. Estimates of the total

amount of waste spoils in the Elk and Fording Rivers mining operations has increased from about 2,800 million tonnes 1997 to more than 27,000 million tonnes in 2016, a tenfold increase (Teck 2016). Hauer and Sexton (2013) reported elevated loadings of selenium, nitrate, and sulfate from the Elk River in British Columbia to Lake Koocanusa and the Kootenai River. The USGS (2014) determined that selenium loading to Lake Koocanusa from the Elk River increased fivefold between 1992 and 2012. Because the expansion in mining operations happened over a period of many years, any change in Lake Koocanusa's water quality could likely only be detected using long-term trend analysis.

Long-term nutrient trend analysis was conducted on total phosphorus and nitrate-nitrogen. Soluble phosphorus and ammonia data had too many data points below the detection limit for a significant trend test. For Lake Koocanusa, total nitrogen and nitrate data are similar and given this only nitrate trend data is presented. The seasonal Kendall trend test for nutrients is presented in Table 2-6. Long-term 1999 to 2016 data shows a significant increasing trend for nitrate at all stations and all depths. The Mann-Kendall p-values were extremely low (range of 1.17E-11 to 1.47E-20), indicating a very significant trend. The Sen-Theil slope indicator was positive and large (range of 7.63 to 11.81), suggesting a significant increasing trend for nitrate between 1999 and 2016. A positive trend for total phosphorus was detected only at station LIBFB-HYPO. The overall phosphorus trend at LIBFB-HYPO was weak ($p = 0.02$) while the Sen-Theil slope indicator was zero, suggesting that no increase or decrease in total phosphorus could be detected at this station. Hence, although the Mann-Kendall p-value of 0.02 showed a trend, the Sen-Theil slope indicator could not determine the direction (increasing or decreasing) of the trend.

Table 2-8. Lake Koocanusa Seasonal Kendall Trend Analysis Test, 1999 to 2016

Station	Nitrate p value	Nitrate Sen Slope	Nitrate Trend	Total Phosphorus p Value	Total Phosphorous Sen Slope	Total Phosphorous Trend
LIBBOR-EPILIMNION	**5.11E-19**	7.63	Strong-Increasing	0.25	0.00	None
LIBBOR-HYPOLIMNION	**1.17E-11**	11.81	Strong-Increasing	0.69	0.00	None
LIBTMC-EPILIMNION	**1.47E-20**	8.17	Strong-Increasing	1.00	0.00	None
LIBTMC-HYPOLIMNION	**2.23E-18**	11.11	Strong-Increasing	0.10	0.00	None
LIBFB-EPILIMNION	**2.07E-18**	8.73	Strong-Increasing	0.20	0.00	None
LIBFB-HYPOLIMNION	**1.07E-18**	10.91	Strong-Increasing	**0.02**	0.00	Weak-Flat

Bold values indicate significant trend at p=0.05

2.4.2 Correlation Analysis

Correlation of water quality data and phytoplankton data was conducted using the Kendall Tau rank correlation analysis. April through October data from 2006 through 2016 was combined for all stations for the correlation analysis. A statistical significance level of $p < 0.05$ was used to identify relationships between two variables. The Kendall Tau correlation coefficient can range from -1 to 1, with negative values indicating a negative relationship between the two parameters and positive values indicating a

positive relationship. The farther the coefficient values are from 0, the stronger the relationship.

As would be expected, numerous significant relationships (both positive and negative) existed between several key water quality parameters (Table 2-7). Of particular interest was a moderate negative relationship between transparency and chlorophyll a (-0.383), and a moderate positive relationship between transparency and month (0.361). These results suggest that water clarity in Lake Koocanusa may be a factor of both phytoplankton growth and runoff. Additionally, chlorophyll a was correlated with many water quality parameters, with the strongest relationship with total phosphorus (0.341) and total nitrogen (0.201). Total phytoplankton density was not correlated to total phosphorus but had a moderate positive correlation to soluble phosphorus (0.115), and nitrate (0.153). This data suggests that phytoplankton growth was affected by both phosphorus and nitrogen concentrations in Lake Koocanusa.

Correlation of water quality parameters to location, month, and year was also investigated. The majority of water quality parameters was significantly correlated to month and year, affirming the importance of temporal variations in water quality at Lake Koocanusa. However, not all water quality parameters showed a significant correlation to station location, which suggests that spatial variations are not as important as temporal variations in determining water quality in Lake Koocanusa. The water quality parameters showing the greatest correlation to year were total algal density (0.505) and total algal biovolume (0.428). The parameters showing the greatest correlation to location were total phosphorus (-0.263) and transparency (0.298)

Table 2-9. Kendall Tau Correlation Coefficients Lake Koocanusa Water Quality Data for 2006 to 2016

Variable	Year Code	Location Code	Month Code	Total P	SRP	Ammonia	NO3+NO2	Total N	Alkalinity	Sulfate	Chloride	Chl a	Trans	Calcium	Magnesium	Potassium	Sodium	Hardness	Aluminum	Arsenic	Cadmium
Year Code	1	0	-0.002015	-0.09449	0.086782	-0.033741	0.344574	0.381715	0.03766	0.166838	-0.083869	-0.09196	-0.127733	0.225004	0.214994	-0.168497	-0.005233	0.258414	0.322623	-0.427264	-0.417804
Location Code	0.000000	1	0	-0.262658	-0.042447	-0.209447	0.077645	0.025183	0.082009	0.150285	0.16762	-0.05326	0.298275	0.033697	0.096579	0.023994	0.209968	0.032578	-0.118629	-0.006953	-0.012738
Month Code	-0.002015	0.000000	1	-0.310699	-0.084308	-0.234085	-0.124984	-0.21052	-0.159312	-0.171972	-0.145388	-0.328969	0.360808	-0.154984	-0.161965	-0.229957	-0.106871	-0.220954	-0.105446	-0.005352	-0.073667
Total P	-0.09449	-0.262658	-0.310699	1	0.216127	0.319876	0.04059	0.138938	0.035245	-0.01608	-0.061736	0.340984	-0.412081	0.050453	-0.011913	0.092179	-0.055898	0.055119	0.143632	-0.036744	0.106575
SRP	0.086782	-0.042447	-0.084308	0.216127	1	0.162298	0.160285	0.175184	0.094936	0.042748	-0.03239	0.172473	-0.127208	0.128955	0.005227	0.161387	-0.008527	0.049508	0.041233	0.027388	-0.068377
Ammonia	-0.033741	-0.209447	-0.234085	0.319876	0.162298	1	0.063362	0.095579	0.012896	-0.070425	-0.068015	0.184783	-0.292891	0.022978	-0.028051	0.218017	-0.139359	0.058933	0.042504	0.010189	0.033595
NO3+NO2	0.344574	0.077645	-0.124984	0.04059	0.160285	0.063362	1	0.655076	0.314001	0.30142	0.144336	0.158531	-0.360795	0.337282	0.314123	0.048257	0.194669	0.402756	0.249084	-0.16898	-0.208861
Total N	0.381715	0.025183	-0.21052	0.138938	0.175184	0.095579	0.655076	1	0.22883	0.250996	0.076662	0.200735	-0.401747	0.317228	0.242172	0.082018	0.116	0.354659	0.295457	-0.248124	-0.188902
Alkalinity	0.03766	0.082009	-0.159312	0.035245	0.094936	0.012896	0.314001	0.22883	1	0.520627	0.568556	0.06439	-0.144631	0.355067	0.433468	0.283329	0.527032	0.444533	-0.166462	0.022738	0.088568
Sulfate	0.166838	0.150285	-0.171972	-0.01608	0.042748	-0.070425	0.30142	0.250996	0.520627	1	0.574025	0.14612	-0.352642	0.364332	0.509159	0.187254	0.596926	0.449699	-0.060396	-0.145687	-0.024057
Chloride	-0.083869	0.16762	-0.145388	-0.061736	-0.03239	-0.068015	0.144336	0.076662	0.568556	0.574025	1	0.109	-0.224879	0.269677	0.477343	0.276675	0.62892	0.349423	-0.195352	-0.097648	-0.025286
Chl a	-0.09196	-0.05326	-0.328969	0.340984	0.172473	0.184783	0.158531	0.200735	0.06439	0.14612	0.109	1	-0.383369	0.164346	0.104298	0.164477	0.197004	0.128448	0.011266	0.305907	0.321013
Trans	-0.127733	0.298275	0.360808	-0.412081	-0.127208	-0.292891	-0.360795	-0.401747	-0.144631	-0.352642	-0.224879	-0.383369	1	-0.361095	-0.239116	-0.278595	-0.211651	-0.351333	-0.292835	0.039788	0.029495
Calcium	0.225004	0.033697	-0.154984	0.050453	0.128955	0.022978	0.337282	0.317228	0.355067	0.364332	0.269677	0.164346	-0.361095	1	0.405057	0.191288	0.40124	0.848743	0.127153	-0.078242	-0.165834
Magnesium	0.214994	0.096579	-0.161965	-0.011913	0.005227	-0.028051	0.314123	0.242172	0.433468	0.509159	0.477343	0.104298	-0.239116	0.405057	1	0.175987	0.564677	0.563043	-0.003373	-0.05639	-0.031341
Potassium	-0.168497	0.023994	-0.229957	0.092179	0.161387	0.218017	0.048257	0.082018	0.283329	0.187254	0.276675	0.164477	-0.278595	0.191288	0.175987	1	0.245726	0.217623	-0.053864	0.12445	0.041806
Sodium	-0.005233	0.209968	-0.106871	-0.055898	-0.008527	-0.139359	0.194669	0.116	0.527032	0.596926	0.62892	0.197004	-0.211651	0.40124	0.564677	0.245726	1	0.475412	-0.140188	0.030514	-0.009498
Hardness	0.258414	0.032578	-0.220954	0.055119	0.049508	0.058933	0.402756	0.354659	0.444533	0.449699	0.349423	0.128448	-0.351333	0.848743	0.563043	0.217623	0.475412	1	0.081961	-0.064755	-0.127798
Aluminum	0.322623	-0.118629	-0.105446	0.143632	0.041233	0.042504	0.249084	0.295457	-0.166462	-0.060396	-0.195352	0.011266	-0.292835	0.127153	-0.003373	-0.053864	-0.140188	0.081961	1	-0.205335	-0.358346
Arsenic	-0.427264	-0.006953	-0.005352	-0.036744	0.027388	0.010189	-0.16898	-0.248124	0.022738	-0.145687	-0.097648	0.305907	0.039788	-0.078242	-0.05639	0.12445	0.030514	-0.064755	-0.205335	1	0.712507
Cadmium	-0.417804	-0.012738	-0.073667	0.106575	-0.068377	0.033595	-0.208861	-0.188902	0.088568	-0.024057	-0.025286	0.321013	0.029495	-0.165834	-0.031341	0.041806	-0.009498	-0.127798	-0.358346	0.712507	1
Chromium	-0.03013	0.01514	0.092295	-0.001151	0.053856	0.009704	0.088406	0.036831	0.102167	-0.00067	0.046125	0.000000	0.000000	0.001786	0.018316	0.116601	0.028565	-0.005167	-0.049144	0.043511	-0.00155
Copper	0.037159	0.09018	0.062047	0.00215	-0.00788	0.089313	0.060611	0.050413	0.01825	-0.030276	0.120773	-0.109662	0.074553	0.055131	0.116263	-0.042433	-0.00903	0.066884	-0.066564	-0.314136	-0.300621
Lead	-0.47583	-0.041109	-0.117417	0.182174	-0.056093	0.091494	-0.157516	-0.169387	0.032838	-0.154036	-0.109512	0.347156	-0.017335	-0.065665	-0.055087	0.122325	0.00846	-0.054377	-0.173204	0.933742	0.774704
Zinc	-0.232939	0.001569	0.019417	-0.109418	-0.13514	-0.015745	-0.040577	-0.112321	-0.104597	-0.032244	0.009714	-0.017617	0.160527	-0.076459	-0.058587	-0.09743	0.029956	-0.080287	-0.03317	0.073599	-0.036272
Selenium	0.302778	-0.087608	-0.036887	-0.022059	0.02592	0.141614	0.257783	0.298401	0.121591	0.28054	0.122426	0.114633	-0.193471	0.211028	0.197752	0.004291	0.114265	0.215257	-0.035592	-0.173152	-0.05116
Total Density	0.505189	0.026685	0.016935	-0.033605	0.114508	-0.010343	0.134771	0.153471	-0.091242	0.224443	-0.091429	0.133154	-0.207493	0.286081	0.117858	0.022069	0.16359	0.176342	0.508349	0.000000	-0.215551
Total Biovolume	0.428254	0.069496	-0.047756	0.022078	0.079107	-0.028323	0.059671	0.103233	-0.202416	0.049193	-0.179242	0.204871	-0.203356	0.14868	-0.027671	0.060549	0.001538	0.064204	0.491614	0.000000	-0.291507
Density BG%	0.234416	-0.079134	0.113746	-0.118898	-0.0902	-0.145153	0.085179	0.093028	-0.132394	0.116457	-0.117394	-0.040765	0.037773	0.116517	0.107723	-0.231489	0.046619	0.03214	0.193145	0.000000	-0.104973
Density Chr%	0.033186	-0.069469	-0.25116	0.219537	0.059687	0.133621	0.137629	0.138562	0.070114	-0.016682	-0.005781	0.112703	-0.153983	-0.053723	0.010426	0.083475	0.028694	-0.002927	0.034584	0.000000	0.056388
Density Crp%	-0.154401	0.030361	-0.083107	-0.131457	-0.135413	-0.034357	0.067425	-0.032352	0.288888	0.242209	0.309378	-0.067384	0.044016	-0.0592	0.147095	0.038472	0.163257	0.012344	-0.098204	0.000000	0.39212
Density Dia%	0.162682	0.048286	0.162671	-0.069325	0.051335	-0.086136	-0.082192	-0.037564	-0.18226	-0.138355	-0.19164	-0.048532	0.017266	0.154832	-0.053292	-0.006225	-0.062051	0.037603	0.244761	0.000000	-0.424943
Density Dino%	-0.108998	0.019634	-0.060796	-0.099386	-0.043599	-0.049771	-0.037756	-0.020882	0.038758	0.048163	0.033838	0.057102	0.044891	-0.090534	0.037217	0.075751	-0.008764	-0.126456	-0.01862	0.000000	0.35374
Density Eug%	0.030903	-0.047912	-0.159919	0.130672	-0.073472	0.099543	0.135225	0.097375	0.113554	-0.155303	-0.142057	-0.063066	-0.071911	-0.172648	-0.172559	-0.114336	-0.172692	0.046939	0.029353	0.000000	-0.051848
Density Gr%	-0.189163	0.137626	0.016604	-0.141024	-0.08512	-0.109246	-0.089547	-0.116054	0.053579	0.037969	0.023512	-0.098708	0.255483	-0.33213	-0.14591	-0.182695	-0.021713	-0.204654	-0.393612	0.000000	0.491102
BioVol BG%	0.2338	-0.077015	0.114992	-0.116508	-0.0902	-0.145153	0.085179	0.093028	-0.132394	0.110634	-0.117394	-0.041938	0.040115	0.110691	0.107723	-0.231489	0.046619	0.029619	0.187202	0.000000	-0.104973
BioVol Chr%	0.243911	-0.071255	-0.229275	0.155086	0.047017	0.107437	0.229924	0.217694	0.016584	0.125115	-0.059382	0.109572	-0.189024	0.091276	0.118859	-0.048934	0.078779	0.110986	0.163343	0.000000	0.025062
BioVol Crp%	-0.094462	-0.009077	-0.14477	-0.135339	-0.143996	-0.05411	0.143577	0.049641	0.307532	0.321839	0.340594	-0.062534	-0.002508	-0.03043	0.199076	0.09954	0.203103	0.068709	-0.042894	0.000000	0.416489
BioVol Dia%	-0.058835	0.034845	0.161056	0.015667	0.065222	-0.0087	-0.221768	-0.144736	-0.153108	-0.347425	-0.142051	-0.072357	0.072084	-0.011279	-0.218294	0.063944	-0.235385	-0.075866	0.03138	0.000000	-0.309983
BioVol Dino%	-0.073533	0.022342	-0.061274	-0.08931	-0.019399	-0.029317	-0.004442	0.011996	0.035621	0.077353	0.04855	0.072389	0.015039	-0.05987	0.069326	0.098316	0.020449	-0.093212	0.01713	0.000000	0.306964
BioVol Eug%	0.030903	-0.047912	-0.159919	0.130672	-0.073472	0.099543	0.135225	0.097375	0.113554	-0.155303	-0.142057	-0.063066	-0.071911	-0.172648	-0.172559	-0.114336	-0.172692	0.046939	0.029353	0.000000	-0.051848
BioVol Gr%	-0.056457	0.137221	0.081589	-0.186891	-0.041483	-0.126366	-0.033777	-0.086999	0.017246	0.114993	-0.000547	-0.083923	0.235857	-0.200798	-0.060208	-0.258169	0.057541	-0.13293	-0.293963	0.000000	0.360721

Variable	Chromium	Copper	Lead	Zinc	Selenium	Total Density	Total Biovolume	Density BG%	Density Chr%	Density Crp%	Density Dia%	Density Dino%	Density Eug%	Density Gr%	BioVol BG%	BioVol Chr%	BioVol Crp%	BioVol Dia%	BioVol Dino%	BioVol Eug%	BioVol Gr%
Year Code	-0.03013	0.037159	-0.47583	-0.232939	0.302778	0.505189	0.428254	0.234416	0.033186	-0.154401	0.162682	-0.108998	0.030903	-0.189163	0.2338	0.243911	-0.094462	-0.058835	-0.073533	0.030903	-0.056457
Location Code	0.01514	0.09018	-0.041109	0.001569	-0.087608	0.026685	0.069496	-0.079134	-0.069469	0.030361	0.048286	0.019634	-0.047912	0.137626	-0.077015	-0.071255	-0.009077	0.034845	0.022342	-0.047912	0.137221
Month Code	0.092295	0.062047	-0.117417	0.019417	-0.036887	0.016935	-0.047756	0.113746	-0.25116	-0.083107	0.162671	-0.060796	-0.159919	0.016604	0.114992	-0.229275	-0.14477	0.161056	-0.061274	-0.159919	0.081589
Total P	-0.001151	0.00215	0.182174	-0.109418	-0.022059	-0.033605	0.022078	-0.118898	0.219537	-0.131457	-0.069325	-0.099386	0.130672	-0.141024	-0.116508	0.155086	-0.135339	0.015667	-0.08931	0.130672	-0.186891
SRP	0.053856	-0.00788	-0.056093	-0.13514	0.02592	0.114508	0.079107	-0.0902	0.059687	-0.135413	0.051335	-0.043599	-0.073472	-0.08512	-0.0902	0.047017	-0.143996	0.065222	-0.019399	-0.073472	-0.041483
Ammonia	0.009704	0.089313	0.091494	-0.015745	0.141614	-0.010343	-0.028323	-0.145153	0.133621	-0.034357	-0.086136	-0.049771	0.099543	-0.109246	-0.145153	0.107437	-0.05411	-0.0087	-0.029317	0.099543	-0.126366
NO3+NO2	0.088406	0.060611	-0.157516	-0.040577	0.257783	0.134771	0.059671	0.085179	0.137629	0.067425	-0.082192	-0.037756	0.135225	-0.089547	0.085179	0.229924	0.143577	-0.221768	-0.004442	0.135225	-0.033777
Total N	0.036831	0.050413	-0.169387	-0.112321	0.298401	0.153471	0.103233	0.093028	0.138562	-0.032352	-0.037564	-0.020882	0.097375	-0.116054	0.093028	0.217694	0.049641	-0.144736	0.011996	0.097375	-0.086999
Alkalinity	0.102167	0.01825	0.032838	-0.104597	0.121591	-0.091242	-0.202416	-0.132394	0.070114	0.288888	-0.18226	0.038758	0.113554	0.053579	-0.132394	0.016584	0.307532	-0.153108	0.035621	0.113554	0.017246
Sulfate	-0.00067	-0.030276	-0.154036	-0.032244	0.28054	0.224443	0.049193	0.116457	-0.016682	0.242209	-0.138355	0.048163	-0.155303	0.037969	0.110634	0.125115	0.321839	-0.347425	0.077353	-0.155303	0.114993
Chloride	0.046125	0.120773	-0.109512	0.009714	0.122426	-0.091429	-0.179242	-0.117394	-0.005781	0.309378	-0.19164	0.033838	-0.142057	0.023512	-0.117394	-0.059382	0.340594	-0.142051	0.04855	-0.142057	-0.000547
Chl a	0.000000	-0.109662	0.347156	-0.017617	0.114633	0.133154	0.204871	-0.040765	0.112703	-0.067384	-0.048532	0.057102	-0.063066	-0.098708	-0.041938	0.109572	-0.062534	-0.072357	0.072389	-0.063066	-0.083923
Trans	0.000000	0.074553	-0.017335	0.160527	-0.193471	-0.207493	-0.203356	0.037773	-0.153983	0.044016	0.017266	0.044891	-0.071911	0.255483	0.040115	-0.189024	-0.002508	0.072084	0.015039	-0.071911	0.235857
Calcium	0.001786	0.055131	-0.065665	-0.076459	0.211028	0.286081	0.14868	0.116517	-0.053723	-0.0592	0.154832	-0.090534	-0.172648	-0.33213	0.110691	0.091276	-0.03043	-0.011279	-0.05987	-0.172648	-0.200798
Magnesium	0.018316	0.116263	-0.055087	-0.058587	0.197752	0.117858	-0.027671	0.107723	0.010426	0.147095	-0.053292	0.037217	-0.172559	-0.14591	0.107723	0.118859	0.199076	-0.218294	0.069326	-0.172559	-0.060208
Potassium	0.116601	-0.042433	0.122325	-0.09743	0.004291	0.022069	0.060549	-0.231489	0.083475	0.038472	-0.006225	0.075751	-0.114336	-0.182695	-0.231489	-0.048934	0.09954	0.063944	0.098316	-0.114336	-0.258169
Sodium	0.028565	-0.00903	0.00846	0.029956	0.114265	0.16359	0.001538	0.046619	0.028694	0.163257	-0.062051	-0.008764	-0.172692	-0.021713	0.046619	0.078779	0.203103	-0.235385	0.020449	-0.172692	0.057541
Hardness	-0.005167	0.066884	-0.054377	-0.080287	0.215257	0.176342	0.064204	0.03214	-0.002927	0.012344	0.037603	-0.126456	0.046939	-0.204654	0.029619	0.110986	0.068709	-0.075866	-0.093212	0.046939	-0.13293
Aluminum	-0.049144	-0.066564	-0.173204	-0.03317	-0.035592	0.508349	0.491614	0.193145	0.034584	-0.098204	0.244761	-0.01862	0.029353	-0.393612	0.187202	0.163343	-0.042894	0.03138	0.01713	0.029353	-0.293963
Arsenic	0.043511	-0.314136	0.933742	0.073599	-0.173152	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Cadmium	-0.00155	-0.300621	0.774704	-0.036272	-0.05116	-0.215551	-0.291507	-0.104973	0.056388	0.39212	-0.424943	0.35374	-0.051848	0.491102	-0.104973	0.025062	0.416489	-0.309983	0.306964	-0.051848	0.360721
Chromium	1	0.278538	0.036565	-0.052431	-0.121373	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Copper	0.278538	1	-0.271016	0.010968	0.093548	-0.419452	-0.307463	-0.104119	-0.096324	-0.01648	0.036651	0.107289	0.354268	-0.1207	-0.104119	-0.210255	-0.108769	0.16493	0.09859	0.354268	-0.191826
Lead	0.036565	-0.271016	1	0.096174	-0.066734	-0.068971	-0.017243	-0.032656	-0.005847	0.130253	-0.080466	0.196441	-0.016129	0.127763	-0.032656	-0.070166	0.117848	-0.028738	0.130961	-0.016129	0.036504
Zinc	-0.052431	0.010968	0.096174	1	0.097935	-0.041818	0.008364	-0.057023	0.020421	0.00361	-0.025091	-0.009528	-0.028164	-0.076137	-0.057023	0	0.054154	-0.068582	-0.014293	-0.028164	-0.026559
Selenium	-0.121373	0.093548	-0.066734	0.097935	1	0.190079	0.170968	0.117457	-0.1126	-0.012157	-0.009557	0.045514	0.025944	-0.193447	0.117457	0.116044	0.061547	-0.141985	0.047656	0.025944	-0.121467
Total Density	0.000000	-0.419452	-0.068971	-0.041818	0.190079	1	0.649186	0.144391	-0.127213	-0.006666	0.219295	-0.092939	-0.133288	-0.331381	0.144391	0.038286	0.00188	0.011322	-0.045028	-0.133288	-0.158479
Total Biovolume	0.000000	-0.307463	-0.017243	0.008364	0.170968	0.649186	1	0.069736	-0.086895	-0.127843	0.255936	-0.078521	-0.160157	-0.326408	0.070894	0.008047	-0.135363	0.14986	-0.062107	-0.160157	-0.262585
Density BG%	0.000000	-0.104119	-0.032656	-0.057023	0.117457	0.144391	0.069736	1	-0.053551	-0.108507	0.057587	-0.060002	-0.031229	-0.024709	0.99148	0.119965	-0.101588	-0.069739	-0.051022	-0.031229	0.121107
Density Chr%	0.000000	-0.096324	-0.005847	0.020421	-0.1126	-0.127213	-0.086895	-0.053551	1	-0.011221	-0.465402	0.170849	0.179474	0.126743	-0.053551	0.710228	0.03808	-0.314672	0.183691	0.179474	0.040705
Density Crp%	0.000000	-0.01648	0.130253	0.00361	-0.012157	-0.006666	-0.127843	-0.108507	-0.011221	1	-0.465434	0.285695	-0.049956	0.117479	-0.108507	-0.053276	0.81906	-0.398244	0.267131	-0.049956	0.047208
Density Dia%	0.000000	0.036651	-0.080466	-0.025091	-0.009557	0.219295	0.255936	0.057587	-0.465402	-0.465434	1	-0.303019	-0.109255	-0.303057	0.058745	-0.355169	-0.460306	0.575349	-0.289266	-0.109255	-0.167942
Density Dino%	0.000000	0.107289	0.196441	-0.009528	0.045514	-0.092939	-0.078521	-0.060002	0.170849	0.285695	-0.303019	1	0.001496	0.170003	-0.060818	0.137367	0.312697	-0.362899	0.906133	0.001496	0.109438
Density Eug%	0.000000	0.354268	-0.016129	-0.028164	0.025944	-0.133288	-0.160157	-0.031229	0.179474	-0.049956	-0.109255	0.001496	1	0.05479	-0.031229	0.160466	0.008454	-0.128343	-0.006483	1.000000	0.024972
Density Gr%	0.000000	-0.1207	0.127763	-0.076137	-0.193447	-0.331381	-0.326408	-0.024709	0.126743	0.117479	-0.303057	0.170003	0.05479	1	-0.023489	0.068985	0.121804	-0.239552	0.127912	0.05479	0.715309
BioVol BG%	0.000000	-0.104119	-0.032656	-0.057023	0.117457	0.144391	0.070894	0.99148	-0.053551	-0.108507	0.058745	-0.060818	-0.031229	-0.023489	1	0.118769	-0.101588	-0.069739	-0.051839	-0.031229	0.122327
BioVol Chr%	0.000000	-0.210255	-0.070166	0.000000	0.116044	0.038286	0.008047	0.119965	0.710228	-0.053276	-0.355169	0.137367	0.160466	0.068985	0.118769	1	0.015108	-0.4236	0.172684	0.160466	0.086466
BioVol Crp%	0.000000	-0.108769	0.117848	0.054154	0.061547	0.00188	-0.135363	-0.101588	0.03808	0.81906	-0.460306	0.312697	0.008454	0.121804	-0.101588	0.015108	1	-0.509684	0.297026	0.008454	0.065947
BioVol Dia%	0.000000	0.16493	-0.028738	-0.068582	-0.141985	0.011322	0.14986	-0.069739	-0.314672	-0.398244	0.575349	-0.362899	-0.128343	-0.239552	-0.069739	-0.4236	-0.509684	1	-0.37887	-0.128343	-0.268895
BioVol Dino%	0.000000	0.09859	0.130961	-0.014293	0.047656	-0.045028	-0.062107	-0.051022	0.183691	0.267131	-0.289266	0.906133	-0.006483	0.127912	-0.051839	0.172684	0.297026	-0.37887	1	-0.006483	0.084651
BioVol Eug%	0.000000	0.354268	-0.016129	-0.028164	0.025944	-0.133288	-0.160157	-0.031229	0.179474	-0.049956	-0.109255	0.001496	1	0.05479	-0.031229	0.160466	0.008454	-0.128343	-0.006483	1	0.024972
BioVol Gr%	0.000000	-0.191826	0.036504	-0.026559	-0.121467	-0.158479	-0.262585	0.121107	0.040705	0.047208	-0.167942	0.109438	0.024972	0.715309	0.122327	0.086466	0.065947	-0.268895	0.084651	0.024972	1

SECTION 3 - CONCLUSIONS AND RECOMMENDATIONS

3.1 CONCLUSIONS

Lake Koocanusa is the 145-kilometer-long reservoir formed in 1972 when Libby Dam impounded the Kootenai River near Libby, Montana. The reservoir is long and narrow, extending 68 kilometers into British Columbia, Canada. Considerable water quality data exists in the United States portion of Lake Koocanusa and the Kootenai River from two large-scale sampling programs conducted from 1967 to 2004 by the USGS, and from 2006to 2016 by the Seattle District. Evaluation of the monitoring results yielded the following conclusions:

In general, the water quality of Lake Koocanusa is good. Lake Koocanusa would be classified as oligotrophic/mesotrophic on the basis of summer TSI values calculated at the border station, and oligotrophic on the basis of summer TSI values calculated at the forebay station. Using the annual OECD (1982) methodology, Lake Koocanusa would be classified as mesotrophic at the border station, and oligotrophic/mesotrophic at the forebay station.

Lake Koocanusa experiences weak thermal stratification during the summer. Minimum temperatures occur during late March or early April and are characterized by a uniform temperature near 4°C. The onset of thermal stratification typically begins at the shallower border station during April and is generally not observed at the deeper forebay station until May. The initial stratification is weak and often short lived as weather systems disrupt the thermal structure.

Lake Koocanusa is well oxygenated, with oxygen concentrations generally ranging from 8 to 11 mg/L. Lower dissolved oxygen concentrations (4 to 6 mg/L) periodically occur near the bottom at the shallower border station due to both warmer hypolimnetic waters at the border when compared to the deeper forebay, as well as greater biological productivity near the border resulting in oxygen consumption from decomposition and respiration.

Total phosphorus concentrations in Lake Koocanusa are low and follow a seasonal pattern of increasing during spring runoff and decreasing during the summer and fall. Total phosphorus concentrations are typically two to five times greater at the border station compared to the forebay station, suggesting that Lake Koocanusa acts as a phosphorus sink. Low annual total phosphorus concentrations downstream in the Kootenai River support this conclusion.

Concentrations of nitrate have been increasing at all stations in Lake Koocanusa since the early 2000s. Median nitrate concentrations in the epilimnion and hypolimnion experienced about a two to three times increase in nitrate concentration from 2006 to 2016. Concentrations are only slightly greater at the border station compared to the forebay station, suggesting that nitrate is moving through the reservoir.

Trend analysis on nitrate and phosphorus concentrations using a seasonal Kendall test show that only nitrate is experiencing a significant increase in Lake Koocanusa. This nitrate increase is strongly significant at all stations and for all depths. The major change in the Lake Koocanusa watershed during the past 20 years is an increase in coal mining operations in the Elk and Fording Rivers watershed, and a corresponding increase in nitrate loading from the waste spoils runoff. Estimates are that the total amount of waste spoils from coal mining operations increased tenfold from 1997 to 2016.

Despite rising nitrate concentrations in both hypolimnetic and epilimnetic waters, algal blooms (measured as chlorophyll a) appear to have been kept in check by strong phosphorus limitation, as indicated by low phosphorus concentrations and high TN:TP ratios at all stations in Lake Koocanusa. However, these conditions also indicate that the lake could be susceptible to increased algal blooms, including potential nuisance species, if phosphorus loading increases significantly in the future. Such increases could come from changes in upstream land uses that result in soil erosion or waste inputs beyond those that are already occurring.

The USGS has estimated that increased coal mining in the Elk and Fording Rivers has increased selenium loading to Lake Koocanusa fivefold during the past 20 years. However, there does not appear to be a substantial seasonal trend in water column selenium data, but concentrations were generally higher in the spring and fall and lower in the summer at all stations. Median selenium concentrations at station LIBBOR in the epilimnion and hypolimnion (1.0 and 1.1 µg/L, respectively) were similar to station LIBTMC (0.94 and 1.07 µg/L, respectively) and slightly greater than station LIBFB (0.8 and 1.03 µg/L, respectively).

Lake Koocanusa water column phytoplankton populations were dominated by a wide mixture of diatoms, cryptophytes, and chrysophytes at all stations from 2008 to 2013 and by select diatoms and chrysophytes from 2014 to 2016. A substantial increase in phytoplankton biovolume and density was measured at all stations between 2014 and 2016. Although biovolumes were high from 2014 through 2016, species diversity was relatively low with often only one or two phytoplankton species dominating. From 2014 to 2016, the phytoplankton assemblage was largely dominated by a few diatoms (*Cyclotella*, *Fragilaria*, and *Synedra*) and the chrysophyte *Dinobryon*.

The composition of zooplankton was similar between stations and years; however, seasonal differences were apparent. From March through July, rotifers were the dominant zooplankton group accounting for about 75 to 95 percent of the total density,copepods accounted for about 5 to 20 percent, and cladocerans accounted for about 0 to 5 percent. From August through October, copepods were the dominant zooplankton group, accounting for about 60 to 70 percent of the density, with rotifers accounting for about 20 to 35 percent, and cladocerans accounting for about 5 to 10 percent.

The composition of zooplankton was similar between stations in Lake Koocanusa; however, seasonal and annual differences were apparent. Zooplankton densities from

2006 through 2010 were dominated by copepods, which accounted for about 40 to 90 percent of the total density depending on the month. However, from 2011 through 2014, rotifers have dominated the Lake Koocanusa zooplankton population, accounting for about 40 to nearly 100 percent of the total density depending on the month. Cladocera densities were relatively low during the entire study.

3.2 RECOMMENDATIONS

Annual physical, chemical, and biological water quality sampling of Lake Koocanusa should continue at current sampling locations. Adding an additional water quality sampling depth (e.g., a metalimnion sample) at all stations would provide valuable information on the vertical distribution of nutrients and metals in Lake Koocanusa. Moreover, increasing the sampling frequency to every two weeks during the spring freshet would be valuable for future water quality modeling efforts.

Additional research should be conducted on increased nitrate loadings to Lake Koocanusa and the potential impacts to phytoplankton, periphyton, and zooplankton communities. Further study on the impact of increased nitrate concentrations on the trophic state of Lake Koocanusa is recommended. The Kootenai River downstream of Libby Dam should be investigated to better determine the possible impacts of increased nitrogen and selenium loadings.

SECTION 4 - REFERENCES

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