US Army Corps of Engineers®
Portland District

WATER QUALITY REPORT

DWORSHAK RESERVOIR
COLUMBIA RIVER BASIN
CLEARWATER RIVER, IDAHO

Dworshak Reservoir

Water Quality Report
August 2020

EXECUTIVE SUMMARY

The Dworshak Dam and Reservoir are located in Central Idaho on the North Fork of the Clearwater River, 1.9 miles above its confluence with the Clearwater River. The dam is a U.S. Army Corps of Engineers (Corps) project; the lower portion of the project is within the Nez Perce Indian Reservation and the entire project is located in Clearwater County, Idaho.

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ACRONYMS

Acronym	Description
µg/L	Micrograms Per Liter
µS/cm	Microsiemens Per Centimeter
Corps	U.S. Army Corps of Engineers
DWQI	U.S. Army Corps of Engineers Monitoring Station In Dworshak Reservoir Tailwater
EC-4	Elk Creek Arm River Mile 4
EPA	U.S. Environmental Protection Agency
GOES	Geostationary Operational Environmental Satellite
HRT	Hydrologic Residence Times
IDEQ	Idaho Department of Environmental Quality
IDFG	Idaho Department of Fish and Game
LNF-1	Little North Fork Arm River Mile 1
$mgC/m^2/day$	Milligrams Carbon-12 Per Square Meter Per Day
mg/L	Milligrams Per Liter
mm^3/L	Cubic Millimeters Per Liter
msl	Mean Sea Level
MW	Megawatts
NFC-19	North Fork Clearwater River Mile 19
NFC-3	North Fork Clearwater River Mile 3
NFC-35	North Fork Clearwater River Mile 35
NFC-45	North Fork Clearwater River Mile 45
NPDES	National Pollutant Discharge Elimination System
NPTFD	Nez Perce Tribe Fishery Department
NTU	Nephelometric Turbidity Unit
NWD	U.S. Army Corps of Engineers Northwestern Division
PEKI	U.S. Geological Survey Peck, Idaho, Gaging Station
RM	River Mile
SiO_2	Silica
TDG	Total Dissolved Gas
TMT	Technical Management Team
TN:TP	Total Nitrogen to Total Phosphorus
TSI	Trophic State Index
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
WRC	State of Washington Water Research Center

SECTION 1 - INTRODUCTION

1.1 STUDY AREA

The Dworshak Dam and Reservoir are located in Central Idaho on the North Fork of the Clearwater River, 1.9 miles above its confluence with the Clearwater River. The dam is a U.S. Army Corps of Engineers (Corps) project; the lower portion of the project is within the Nez Perce Indian Reservation and the entire project is located in Clearwater County, Idaho (Figure 1-1).

The North Fork Clearwater River has a mountainous, densely timbered, 2,440-square-mile watershed. Approximately 90 percent of the land above the reservoir is managed by the U.S. Forest Service (USFS) while the remaining 10 percent consists of private lands. Ownership within the lower portion of the watershed is a primarily a mix of USFS, private, and state lands, with smaller portions owned by the Bureau of Indian Affairs, Bureau of Land Management, and the Corps. Timber production is the predominant land use in the basin, followed by cattle and sheep summer grazing, and recreation.

The drainage represents about 25 percent of the Clearwater Basin and 2 percent of the Snake River drainage area above Lower Granite Dam. The network of perennial streams within the watershed provides about a third of the average annual discharge measured at the U.S. Geological Survey (USGS) gaging station on the Clearwater River at Spalding (Idaho Water Resources Board 1996).

Basin runoff follows a pattern typical of regions highly influenced by snowmelt. Stream flows gradually increase in March and peak between April and June when about 60 percent of the runoff occurs. Flows progressively diminish to base flow conditions by the end of July and remain low for the rest of the summer and into the fall/winter period. Winter low flows can occasionally be interrupted by high peak flows as a result of rain-on-snow events.

The dam itself is the highest straight-axis dam in the Western Hemisphere and the third highest in the United States. It is a concrete gravity structure with a crest length of 3,287 feet and a total height of 717 feet (Figure 1-2). The spillway is located in the center face of the dam at a crest elevation of 1,545 feet above mean sea level (msl) and is controlled by two gates. Three outlet works for deep water spill are located beneath the spillway gates at an elevation of 1,362 feet above msl. Three generating units are incorporated into the project with a total generating capacity of 400 megawatts (MW). Space exists for the future installation of three additional units capable of generating 660 MW. Water to turn the turbines is removed through an intake structure equipped with selector gates (sill elevation is 1,395 feet above msl) for selective withdrawal to provide temperature control of released water; the maximum flow through the turbines is about 10.9 kcfs. The dam was not provided with fish passage facilities, effectively eliminating migration of anadromous fish up the North Fork of the Clearwater River.

Figure 1-1. Location of Dworshak Reservoir and the Water Quality Sampling Stations

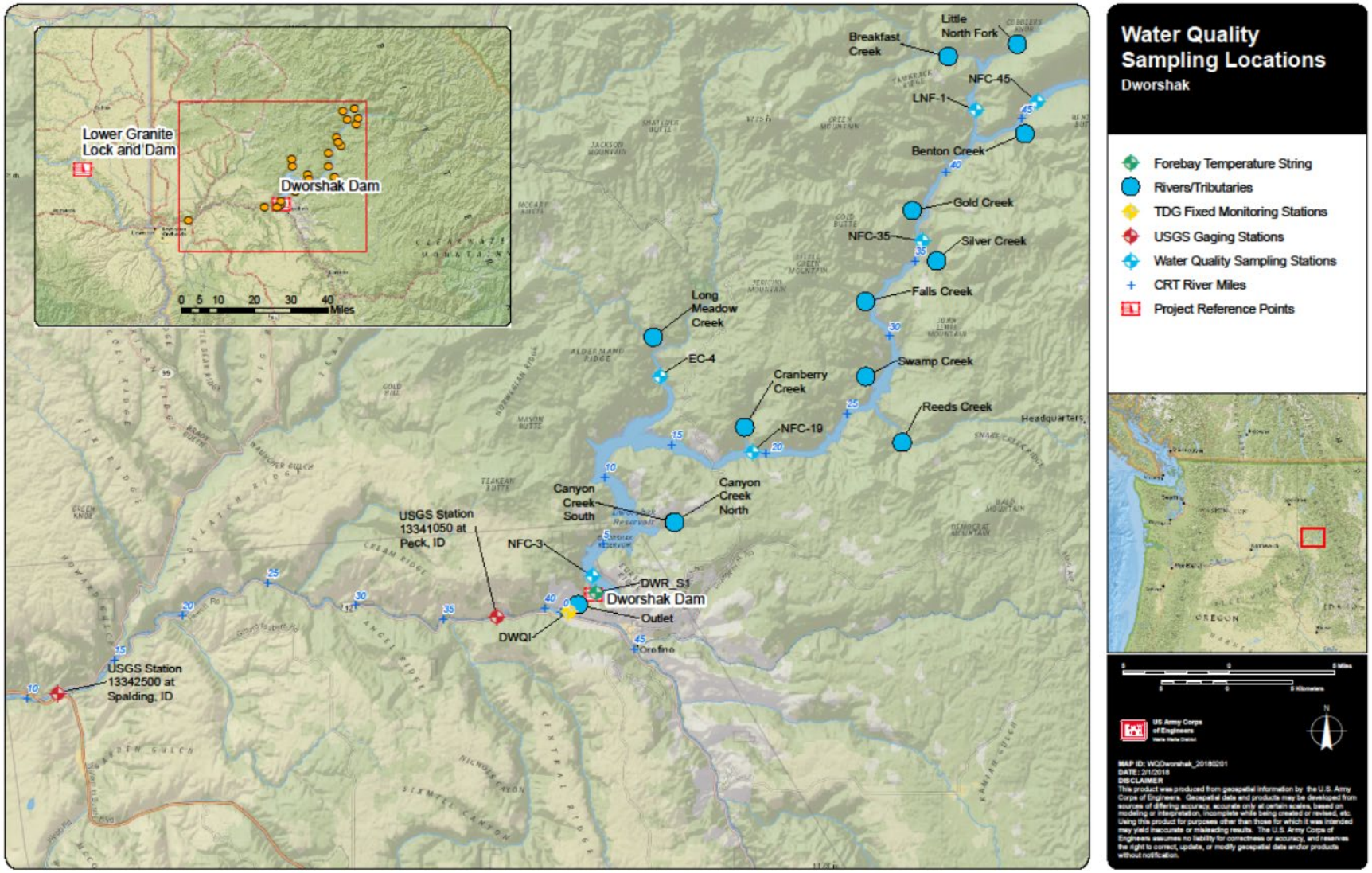
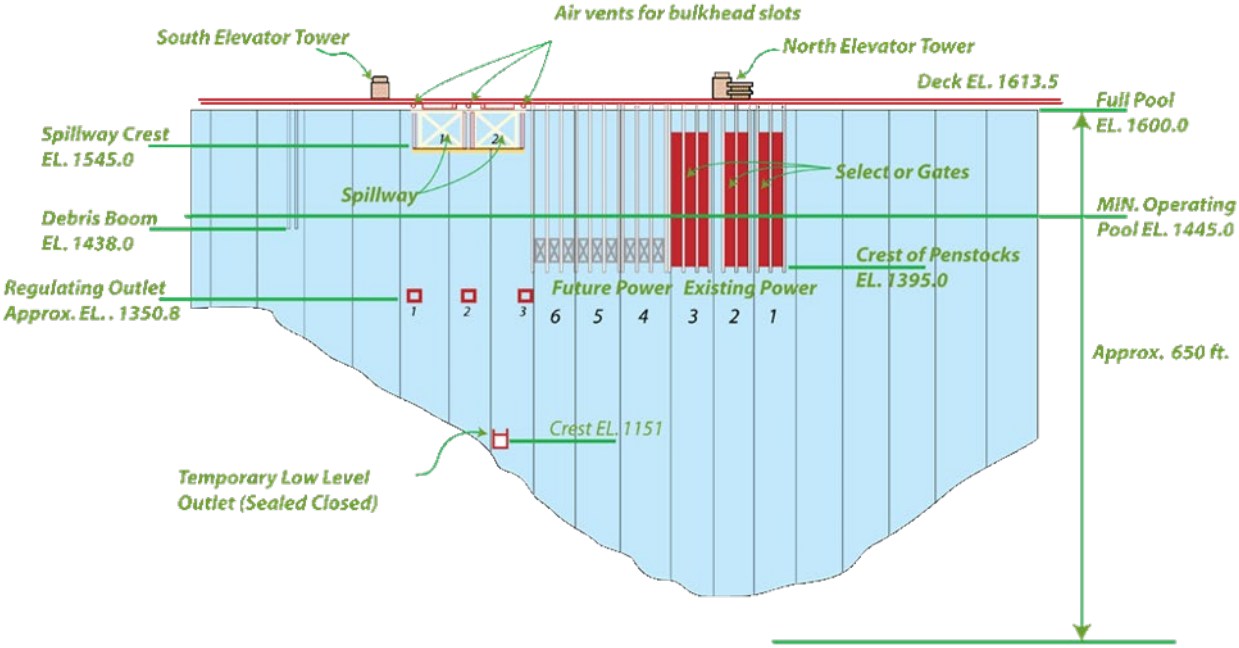


Figure 1-2. Cross Section of the Upstream Face of Dworshak Dam



Note: Not to scale.

At full pool, the reservoir is 53.6 miles long, has a surface area of 17,090 acres, maximum depth of about 650 feet in the forebay, maximum volume of 3,468,000 acre-feet, and shoreline length is 175 miles (Table 1-1).

Table 1-1. Selected Characteristics of Dworshak Reservoir

Parameter	Metric
Location	North Fork Clearwater River, River Mile 1.9
Year first completed	June 1972
Reservoir name	Dworshak Reservoir
Normal operating range	1,600 to 1,445 ft
Storage capacity, gross	3,468,000 af
Storage capacity, usable	2,016,000 af
Pool length at 1,600 ft above msl	53.6 miles
Surface area at 1,600 ft above msl	17,090 acres
Shoreline length	175 miles
Maximum depth	Approximately 650 ft

The Dworshak project is a multi-purpose water resource project with five congressionally authorized purposes: navigation, flood control, hydropower, fish and wildlife, and recreation.

1.2 PREVIOUS STUDIES

A variety of water quality investigations have been completed at Dworshak Reservoir. The intensity and objectives, however, have fluctuated throughout the years.

Falter, Skille, and Ringe (1973) and Falter et al. (1977) completed the first reservoir-wide limnological study between 1972 and 1974. This thorough investigation evaluated a suite of parameters ranging from standard field measurements, nutrients, ions, chlorophyll a, primary productivity, phytoplankton, and zooplankton, to log leachate and bacteriology.

Falter (1982) also completed a follow-up study in 1977 during a low-runoff year. This second investigation was less extensive than the original program and focused on the sampling stations at North Fork Clearwater River Mile (RM) 3 (NFC-3), NFC-19, and Elk Creek arm RM 4 (EC-4).

A period of 10 years elapsed before the next set of water quality data was reported. Maiolie, Statler, and Elam (1992) provide phosphorus, nitrogen, Secchi disk, and chlorophyll a data that was collected between late 1987 and 1990.

The early to mid-1990s saw a resurgence in efforts aimed at understanding the limnology of the reservoir. The Nez Perce Tribe Fishery Department (NPTFD) initiated collection of temperature, dissolved oxygen, light attenuation, and benthic invertebrate data in 1993. This occurred primarily at NFC-3, NFC-19, EC-4, and the outlet, although some data were also collected from other regions of the reservoir. NPTFD also collected zooplankton samples from the outlet between 1992 and 1997.

The State of Washington Water Research Center (WRC) performed additional limnological determinations between 1993 and 1996 (Juul and Funk, 1996). The 1993 objectives were to evaluate primary productivity at NFC-3, NFC-19, and EC-4 using the radiocarbon (^{14}C) method, plus complete nutrient, chlorophyll a, and algal analyses at the site nearest the dam. The outlet was also monitored for nutrients and occasionally phytoplankton. The NPTFD assisted with this fieldwork. This program continued into 1994 when an extensive summer drawdown provided the opportunity to increase the primary productivity stations to six (adding NFC-35, NFC-45, and Little North Fork arm RM 1 [LNF-1]), and collect water samples for nitrogen, phosphorus, ions, chlorophyll a, phytoplankton, and zooplankton analyses at all of the reservoir sites. Up to 13 inlets were also included and monitored for the field measurements, nutrients, ions, and suspended solids. This program continued through the 1995 growing season. The final year of the study was 1996 when the main modification to the program was the elimination of the primary productivity evaluations.

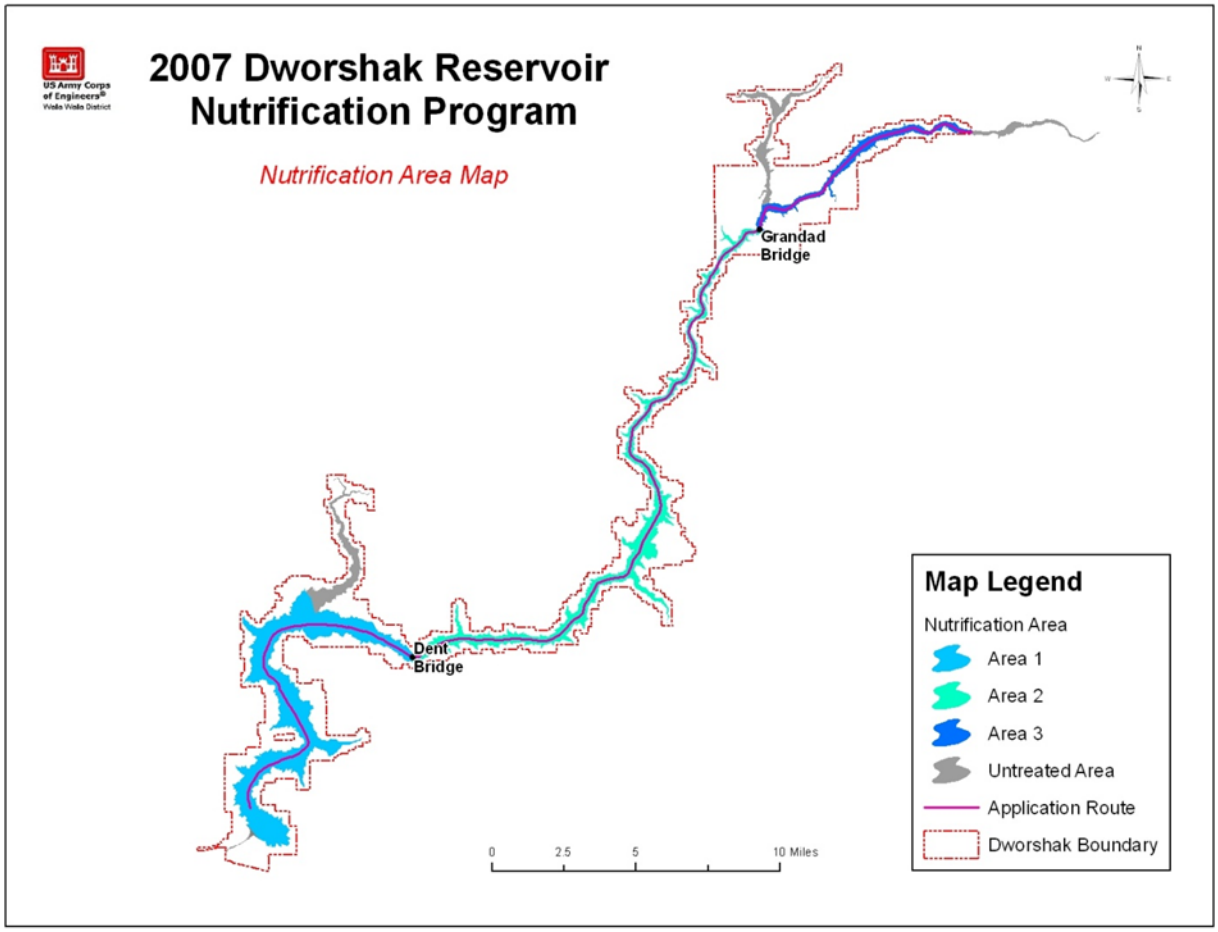
A series of in-reservoir and stream thermistors were installed in 1999 by the Corps. One vertical array was placed at each of the six reservoir sampling stations (NFC-3, EC-4, NFC-19, NFC-35, NFC-45, and LNF-1). Temperature loggers were also installed in the free-flowing reaches of eight inlets (North Fork Clearwater, Breakfast Creek, Little North Fork, Gold Creek, Silver Creek, Reeds Creek, Elk Creek, and Long Meadow Creek). These temperature recording devices were downloaded manually until the program ended in 2004. That same year a real-time thermistor string with 16 sensors was installed at the forebay log boom. This string measures hourly data that is transmitted via the Geostationary Operational Environmental Satellite (GOES) system to the Corps,

Northwestern Division's (NWD's) database (https://pweb.crohms.org/ftppub/water_quality/tempstrings/) throughout the year.

The Nez Perce Tribe funded an investigation for creating a rule-curve evaluation model for the reservoir in 2000. The model was a modification of the procedure developed for establishing operations rule curves for Hungry Horse and Libby Reservoirs in Montana. Substantial progress was made towards model completion, but there were unresolved issues that were largely due to insufficient data (Barber and Juul 2001).

Interest in implementing a nutrient augmentation program at the reservoir arose in the early 2000s. The objective of the project, jointly executed by the Corps and Idaho Department of Fish and Game (IDFG), was to increase productivity by changing the nitrogen to phosphorus ratios in the reservoir, thereby promoting the growth of desirable phytoplankton (i.e., edible by zooplankton). Increased primary production, if channeled through picoplankton and edible phytoplankton, was expected to lead to an increased abundance of zooplankton, therefore providing an improved forage base for fish. Baseline water quality data was collected in 2004 to 2006. In 2007 a 5-year pilot study consisted of application of a blended solution of 10-34-0 ammonium polyphosphate and 32-0-0 urea ammonium nitrate to three zones of the reservoir (Figure 1-3) (Stockner and Brandt 2006). After 2009 only 32-0-0 urea ammonium nitrate has been applied. Nutrient applications were suspended in late July of 2010 due to a legal challenge. At that time, the project was being conducted under the legal authority of a Consent Order issued by the Idaho Department of Environmental Quality (IDEQ). The U.S. Environmental Protection Agency (EPA) then made a determination that a National Pollutant Discharge Elimination System (NPDES) permit would be required for nutrient applications to continue (Corps 2017). An NPDES permit was not obtained until October 2011, which did not allow for nutrient applications in the final year of the pilot study. In order to fully assess the effects of the project on longer lived organisms (i.e., kokanee salmon [*Oncorhynchus nerka*]), it was determined that a full 5-year study was needed. Therefore, a second 5-year pilot project was initiated in 2012. The program has now progressed beyond the pilot stage and is funded annually (Wilson and Corsi 2016; Brandt 2017).

Figure 1-3. Dworshak Reservoir Nutrient Supplementation Application Zones



Source: Corps (2017)

1.3 WATER QUALITY DATA

Existing water quality conditions of Dworshak Reservoir were evaluated using the limnological data collected by IDFG between 2004 and 2016 (Wilson and Corsi 2016; Brandt 2017). The sampling locations and frequency of site visits was adapted over the years and are detailed in the report by Wilson and Corsi (2016). However, a comprehensive set of physicochemical and biological analyses were completed throughout the investigation.

The more recent data from IDFG was compared to limnological data collected by WRC between 1993 and 1996 to help evaluate long-term trends.

Extensive temperature and total dissolved gas (TDG) data is available for the project. The Corps operates a fixed-monitoring station (DWQI at North Fork Clearwater RM 0.5) in the Dworshak Reservoir tailwater where water temperature and TDG have been measured hourly throughout the year since 1995. A second temperature and TDG fixed-monitoring station is located downstream on the Clearwater River at the USGS Peck, Idaho, gaging station (Station 13341050, PEKI at RM 37.4). TDG and temperature data

has been recorded seasonally, April 1 to August 31, at that location since 1996. However, USGS has been measuring temperature there since 1964. Finally, the Corps installed a forebay temperature string in 2004 that measures water temperatures at 16 depths hourly during the entire year. All USGS and Corps data is transmitted real-time via the GOES system.

1.4 DATA ANALYSIS

The limnological data was evaluated using two approaches. First, the combined 2012 to 2016 May to September data from six reservoir stations are presented as box plots. The purpose of these charts is to provide a visual portrayal so the reader can see how the data from the six sampling locations compare for a given parameter. The nonparametric Kruskal-Wallis One-way Analysis of Variance test for differences between the six datasets was also completed as well as the non-parametric post hoc Conover-Inman test for pairwise comparisons. If the resulting p-value is less than or equal to 0.05 then there is strong evidence against the null hypothesis (i.e., the medians are equal) and it is rejected. Second, long-term (i.e., mid-1990s to 2016) trends were also evaluated for several of the limnological data sets. Excel bar charts of the median May to September data for each year were plotted (the analysis focused on this interval due to data availability), followed by the Mann-Kendall test to evaluate whether upward or downward trends were present (a p-value less than or equal to 0.05 again indicates that there is strong evidence that the null hypothesis, there is no trend, is rejected).

SECTION 2 - WATER QUALITY

1.1 GENERAL DESCRIPTION

Dworshak Reservoir, the North Fork Clearwater, and part of the Clearwater subbasin are subject to State of Idaho water quality standards. The surface water use designations for the reservoir, the downstream North Fork Clearwater, as well as the mainstem of the Clearwater River are cold water aquatic life, salmonid spawning, primary contact recreation, and domestic water supply. The reservoir is designated Category 3 (not assessed) and the North Fork Clearwater below the dam as well as the mainstem Clearwater River are designated Category 5 as a result of dissolved gas supersaturation.

2.1 EXISTING WATER QUALITY CONDITIONS

The following sections provide a synopsis of the relevant hydrologic, physical, chemical, and biological parameters that can be used to characterize water quality conditions within the area of interest.

2.1.1 Physical

2.1.1.1 *Hydrologic Characteristics*

The operation of Dworshak Dam has changed since it was initially completed in 1972. For about the first decade, the project was operated following a protocol whereby water was released through the powerhouse during the winter for power production and to lower the pool to acquire flood control capacity. Refill was completed by the end of June and the reservoir remained at about that level of the rest of the summer. Beginning in 1984, a Water Budget Allocation program was implemented that resulted in increased water releases in the spring to provide flow augmentation in the lower Snake River. The volume of the release was based on the runoff forecast and the amount of refill risk the operators were willing to take.

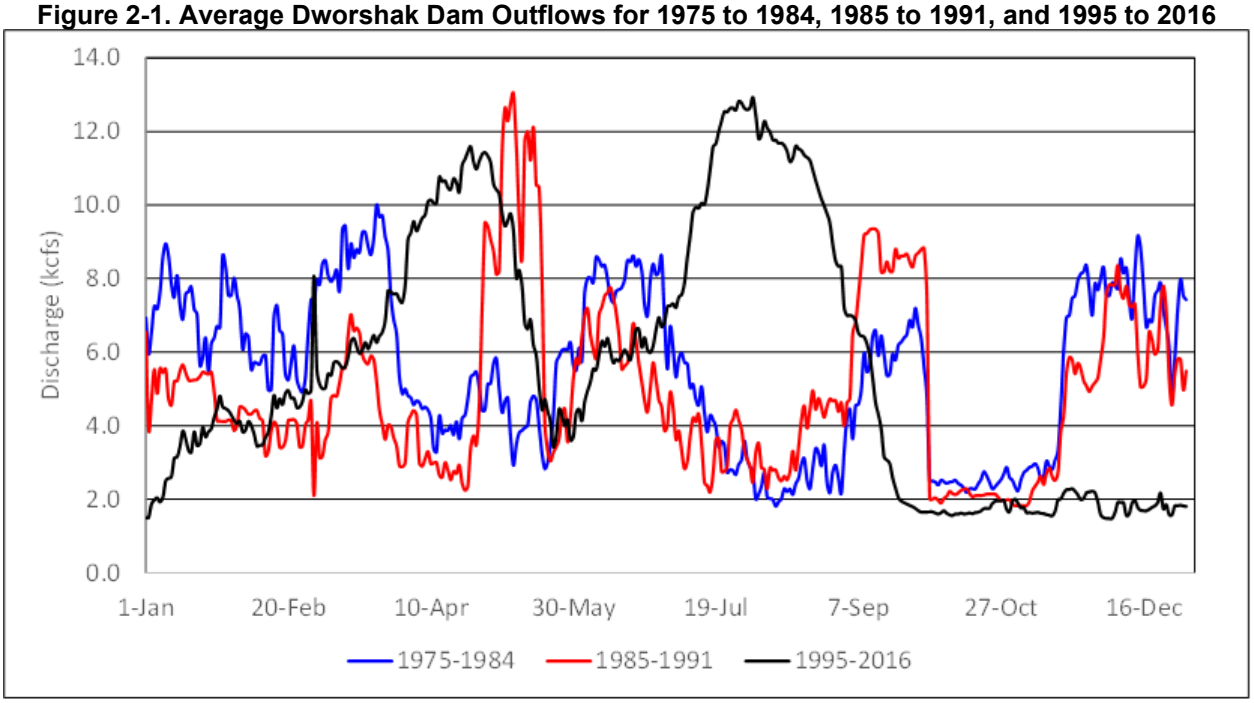
The occurrence of water temperatures greater than 68°F (20°C) in the lower Snake River has been documented since at least the 1950s (Peery, Bjornn, and Stuehrenberg 2003). Resource managers considered using cold water releases from the Dworshak project for many years as a means of moderating these conditions for the benefit of salmonids. To meet this goal, a summer flow augmentation program from the reservoir was implemented in 1992. Each year thereafter, the Dworshak augmentation flow procedure was adjusted and essentially standardized in 1995 for downstream flow and temperature control. The Corps currently releases 1.2 Maf of cold water from July to the end of August for downstream flow augmentation and temperature control. An additional 200,000 acre-feet is released during the first 2 weeks of September as part of the Snake River Basin Adjudication – Nez Perce Tribe Water Rights Settlement. Discharge during the summer release period can be as high as 14 kcfs without exceeding the State of Idaho's TDG standard. The actual amount released is determined by the Regional Technical Management Team (TMT) with input from Corps Walla Walla

District's CE-QUAL-W2 model results. The net effect is that during July and August Dworshak has released an average of 6.1 kcfs and 8.5 kcfs, respectively, more water during the 1995 to 2016 period than in the 1975 to 1984 period.

These shifts in reservoir operations can be seen in the following illustrations. Figure 2-1 shows the average discharge from Dworshak Dam for three intervals: 1975 to 1984, 1985 to 1991, and 1995 to 2016. During the early years of reservoir operation water was primarily released from December to March for power generation, so the monthly average release ranged from 6.1 to 8.3 kcfs, and during June for flood control, so an average of 7.9 kcfs was released.

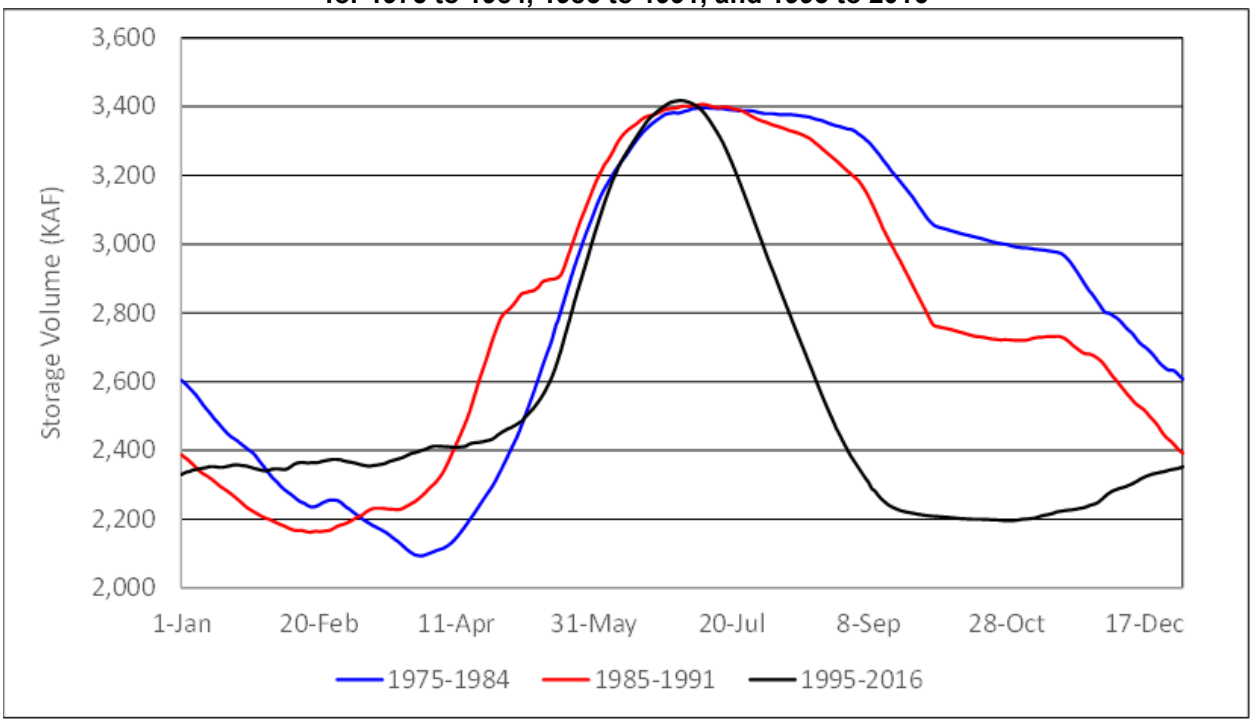
The plot of 1985 to 1991 releases shows the same general pattern, albeit with less discharge, with the exception of May when the average release increased from 4.6 to 8.1 kcfs due to the flow augmentation program. During the latest 12-year interval the major shifts include an increase in average April releases to 10.4 kcfs to provide storage capacity in the reservoir as well as downstream flow augmentation. Additionally, the average July and August 1995 to 2016 releases have increased to almost 11 kcfs and the average October to December releases were less than 2 kcfs.

Figure 2-1. Average Dworshak Dam Outflows for 1975 to 1984, 1985 to 1991, and 1995 to 2016



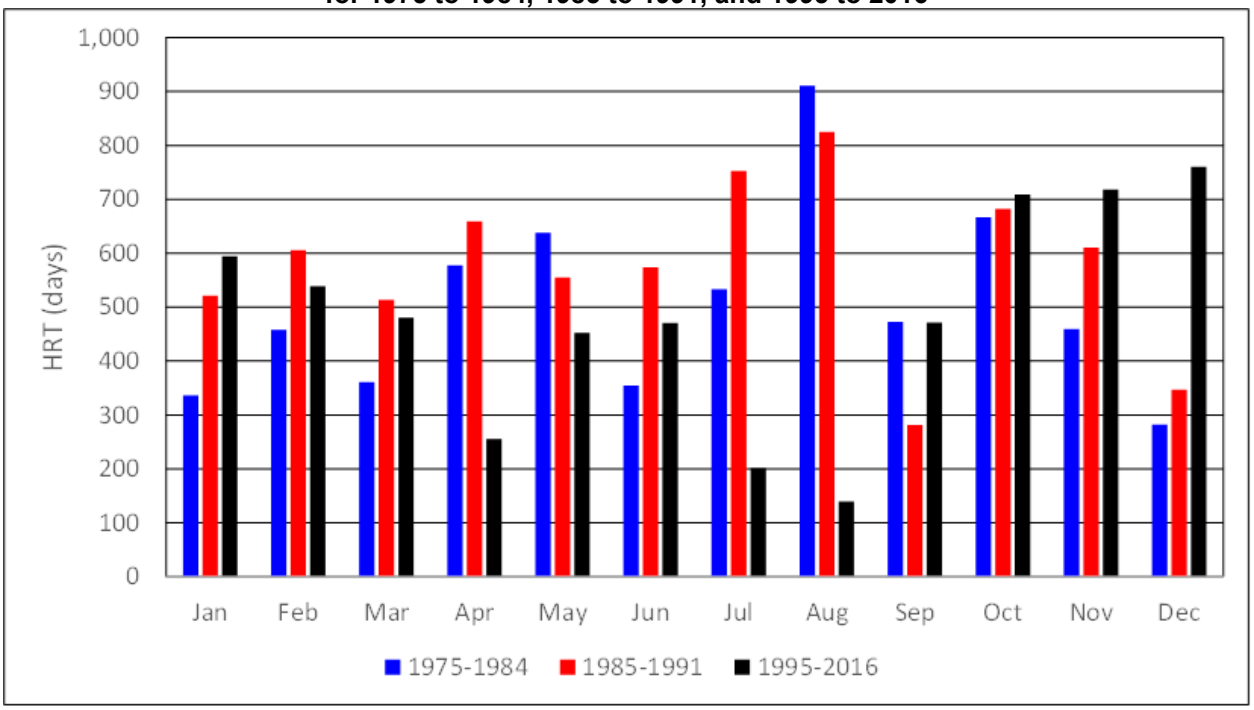
The project discharge changes over time are also apparent in the Storage Volume curves (Figure 2-2). For all three intervals the reservoir volume peaks at about 3,400 kaf, or 1,600 feet above msl, at the beginning of July. During the past 12 years the storage volume decreases rapidly during the late summer and reaches an average minimum of 2,200 kaf by mid-October. In contrast, the reservoir reached minimum pool of about 2,100 kaf by the end of March during the early years of operation. The 1985 to 1991 period is intermediate with an average minimum pool just under 2,200 kaf by mid-February.

Figure 2-2. Average Dworshak Reservoir Storage Volume Plots for 1975 to 1984, 1985 to 1991, and 1995 to 2016



The combination of changes to storage volume and outflow have also altered the hydrologic residence times (HRT), and for some months these shifts were significant (Figure 2-3). The largest change occurred for the month of August when the calculated average HRT decreased from 911 and 825 days for the 1975 to 1984 and 1985 to 1991 intervals, respectively, to 140 days for the 1995 to 2016 period. The calculated average July change was not as large, but still went from 533 days for the early period and 752 days for the 1985 to 1991 period, to 202 days during the latest 12-year period. Since these two summer months are a period of relatively high biological productivity, it is possible that the increased flushing rate influences those parameters.

Figure 2-3. Average Monthly Hydrologic Residence Times for 1975 to 1984, 1985 to 1991, and 1995 to 2016



2.1.1.2 *Water Temperature*

Temperature represents one of the most important characteristics of river water. It affects other physical properties, such as dissolved oxygen and TDG, and also influences the chemical and biological reactions that take place in aquatic systems.

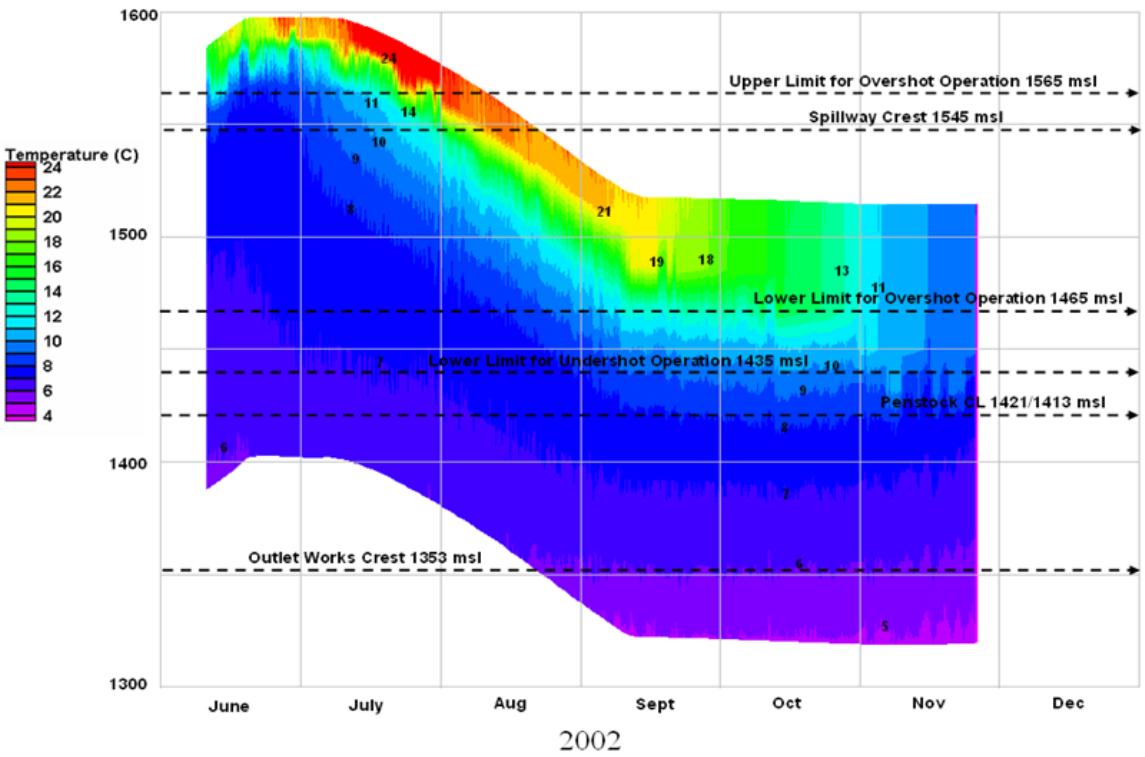
Water Temperatures in Dworshak Reservoir. Because Dworshak Dam is a high-head cold water storage project it has several features that provide flexibility for temperature control. First, it has three turbine units, and each of these units has a selector gate that can be moved vertically to control tailwater temperatures (see Figure 1-2). Total powerhouse capacity is about 10 kcfs and additional discharges can be released from the spillway and/or the regulating outlets that are located about 55 feet and 249 feet below full pool, respectively. Total discharge is normally limited to approximately 14 kcfs to avoid exceeding Idaho's TDG standard of 110 percent saturation. Second, because the forebay is about 650 feet deep, there is a considerable amount of cold water available during the summer, even though the thickness of the warmer surface layer increases as the season progresses (Figure 2-4). Depending on where the selector gates are positioned, water can be withdrawn in overshot mode (i.e., it enters over the top of the gate), undershot mode (i.e., it enters at the base of the gate) to tap into a specific thermal layer, or a combination of the two. Additional water can be released from the spillway at the beginning of the summer, or from the deep regulating outlets where the water is close to 33.8°F (4°C).

The reservoir typically starts to thermally stratify in April, but this process can be delayed until May or even June during colder years. Additionally, the water

temperatures in the upper reaches near NFC-45 and LNF-1 can remain cooler for a longer period of time in the spring due to ice and closer proximity to the major inlets. Peak summer temperatures and maximum stability of the thermocline occur during August at all sites. The deeper, lower 20 miles of the reservoir is monomictic with complete mixing occurring in January or February. The upper two-thirds of the reservoir is dimictic, with inverse stratification under ice cover during the winter. Ice typically does not form on the lower reservoir (Falter et al. 1977).

Even though Dworshak is classified as a cold water reservoir, surface temperatures are relatively warm during the summer (Figure 2-4). Mean summer surface temperatures can exceed 77°F (25°C) during the months of July and August and remain above 68°F (20°C) in the upper 20 to 26 feet (6 to 8 meters). The epilimnion averages 33 to 43 feet (10 to 13 meters) below the water surface and constitutes 20 to 22 percent of the total reservoir volume for the summer months. The hypolimnion makes up a majority (70 percent) of the water volume in the reservoir. Hypolimnetic temperatures during June, July, and August range from 48°F (9°C) around 66 feet (20 meters) below the water surface to 40°F (4.5°C) at depths greater than 197 feet (60 meters) (Stark and Stockner, 2006).

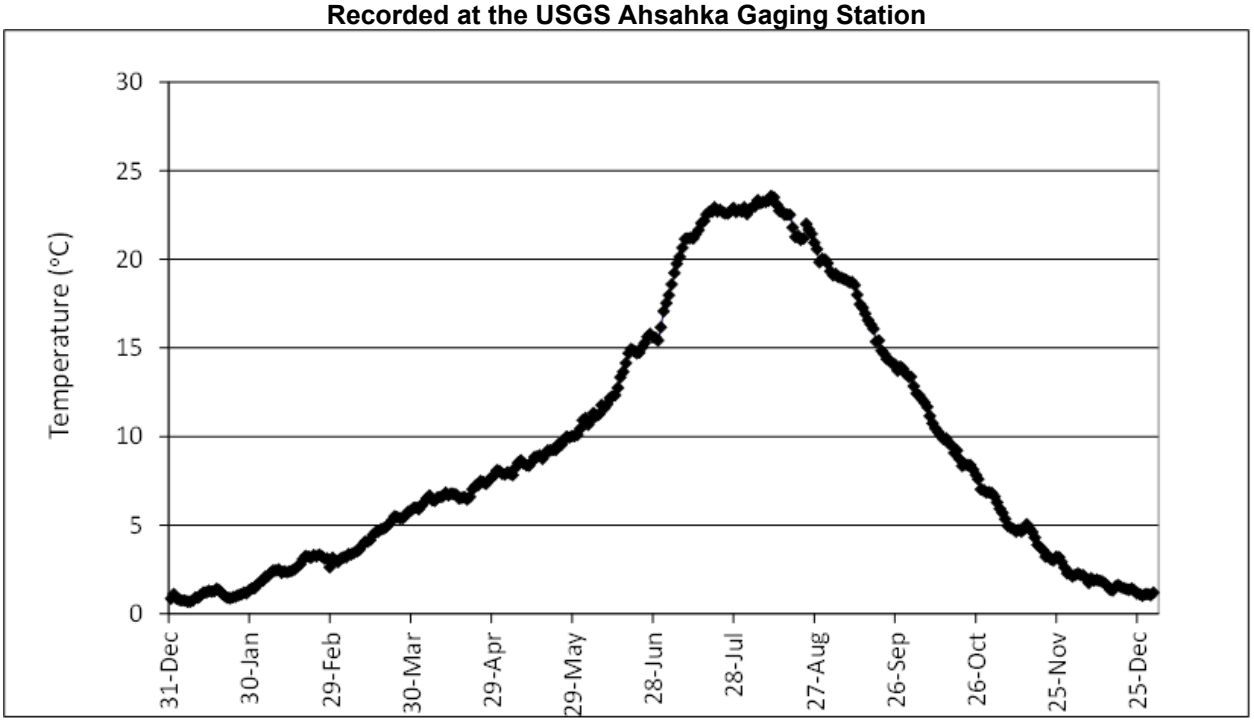
Figure 2-4. Dworshak Dam Forebay Cross Section Illustrating Typical Thermal Stratification



<u>Water Temperatures Downstream from Dworshak Dam.</u> Water temperatures were measured by USGS in the North Fork Clearwater River prior to completion of Dworshak Dam at the Ahsahka gaging station (Station 13341000). Daily minimum and maximum

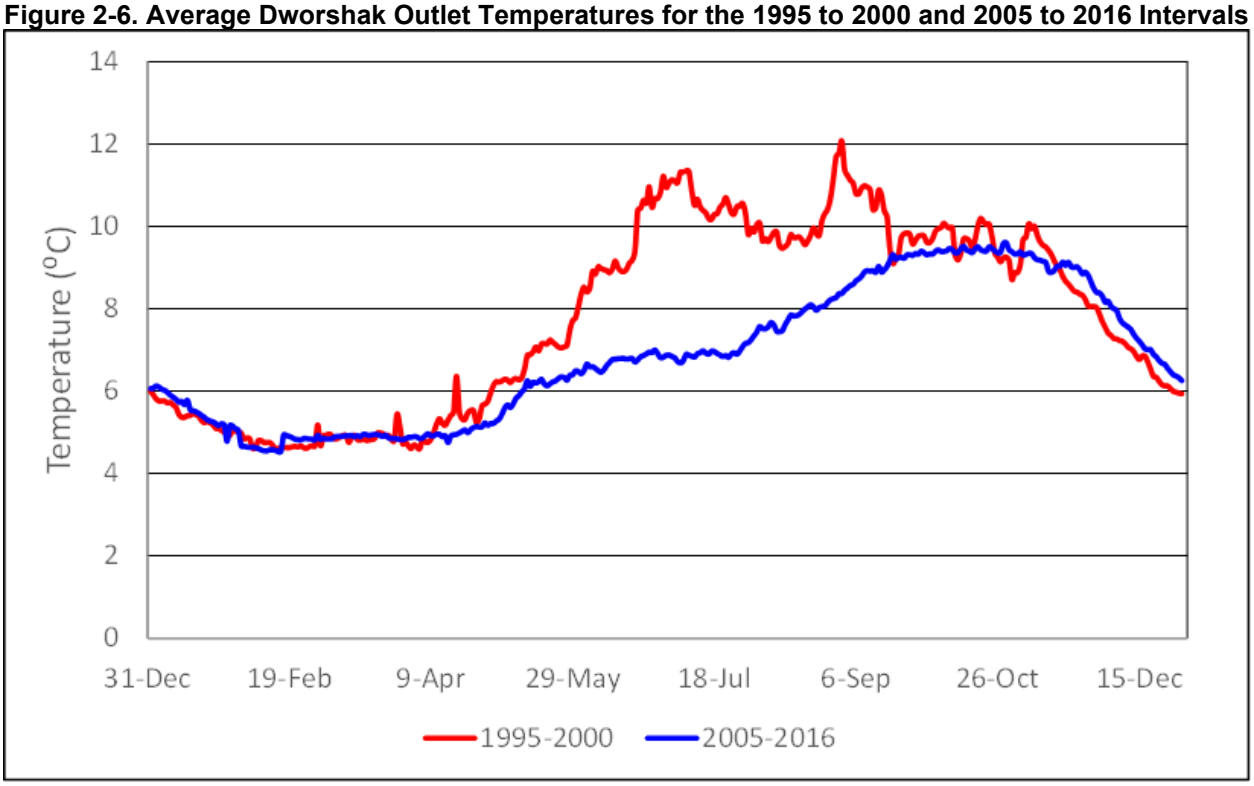
temperatures are available for most of the year for the period 1958 to 1970. The graph of the annual cycle for the average of the daily maximum temperatures (Figure 2-5) shows a pattern that is typical for regional streams. Water temperatures were minimal during the winter (the tributary sometimes froze over) with peak temperatures between 60 and 77°F (20 and 25°C) during the summer.

Figure 2-5. Annual Cycle for the Average Daily Maximum Temperatures Recorded at the USGS Ahsahka Gaging Station



Dworshak Dam tailwater water temperatures have been recorded at the Corps TDG and temperature fixed-monitoring station (DWQI) since 1993. The data from the first couple of years is questionable, but beginning in 1995 the April to December data appears reliable, and beginning with 1998 hourly data is available for the entire year. The annual temperature cycle at this location has changed since the mid-1990s, when the flow augmentation program began, until the present. Average winter temperatures during the 1995 to 2000 period and the 2005 to 2016 interval are similar (Figure 2-6), but a notable change occurred during the summer. Initially, the target was to keep summer and fall outflow temperatures between 48 to 54°F (9 to 12°C) to meet the needs of the Dworshak National Fish Hatchery. During the past decade there has been a greater emphasis on operating the selector gates in undershot mode to provide additional cooling water to the lower Snake River. Given this, summer water temperatures are typically between 43 to 46°F (6 to 8°C).

Figure 2-6. Average Dworshak Outlet Temperatures for the 1995 to 2000 and 2005 to 2016 Intervals



A comparison between the 1959 to 1971 USGS data from Ahsahka and the more recent daily maximum temperatures recorded at DWQI is shown in Figure 2-7. Prior to completion of the dam, water temperatures in the North Fork Clearwater were colder from mid-October to late March than they currently are. The differences between historic and recent average daily maximum values were greatest in the late November, early December timeframe when the mean difference was approximately 10.8°F (6°C). During April through September, water temperatures have been lower in the North Fork Clearwater since at least the mid-1990s when the Corps began recording temperatures at DWQI. The largest differences occur from mid-July to mid-August when the average maximum temperatures during the 2005 to 2016 interval are 27 to 29°F (15 to 16°C) less than they were before the dam was built, and 22 to 23°F (12 to 13 °C) cooler when the 1995 to 2000 interval is considered.

Because the discharge from Dworshak constitutes a large percentage of the flow in the Clearwater River during the summer, the thermal fingerprint of the Dworshak releases is evident. Since the completion of the dam, and through various operational changes, summer water temperatures in the mainstem of the Clearwater River have decreased (Figure 2-8). The average maximum water temperature during the recent 2005 to 2016 interval was 15.7°F (8.7°C) less than it was during the 1965 to 1971 period, with a peak difference of 22.7°F (12.6°C).

Figure 2-7. Comparison of Daily Maximum Temperatures in the North Fork Clearwater River Before and After Construction of Dworshak Dam

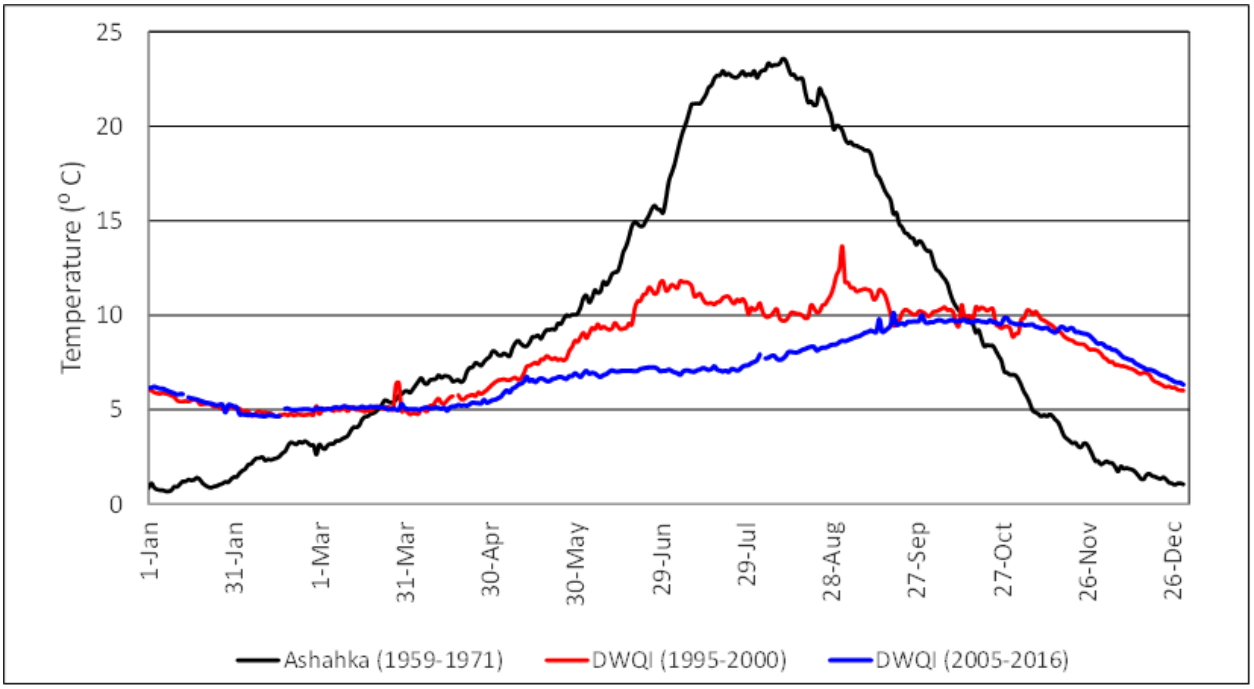
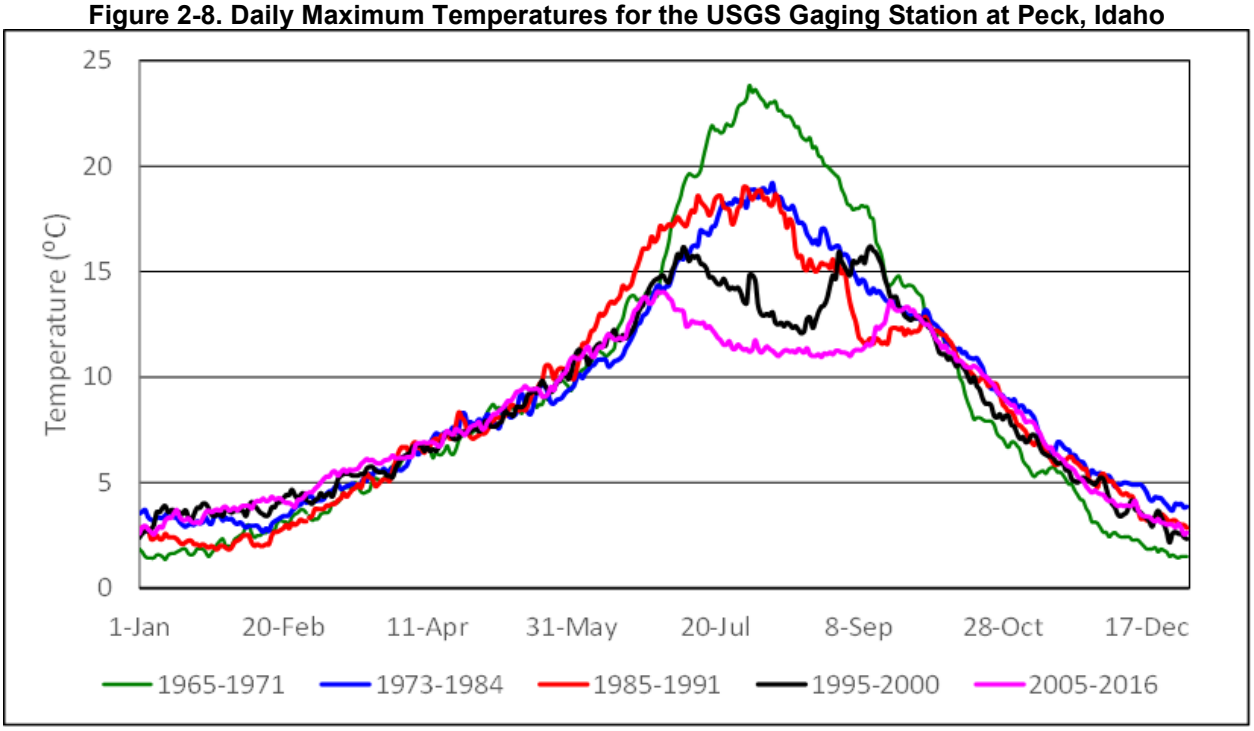


Figure 2-8. Daily Maximum Temperatures for the USGS Gaging Station at Peck, Idaho



2.1.1.3 *Dissolved Oxygen*

Dissolved oxygen is critical to the ecology of both riverine and reservoir systems. Foremost among the functions that it performs is the sustenance of most biological life. Nearly as important, oxygen is the key element in many chemical processes in water.

Through oxidation and reduction reactions, the concentration of oxygen has the ability to influence the concentration of many dissolved substances in water. These chemical processes include the decomposition of organic matter, the cycling of nutrients, and the transformation and transport of substances within the water column and between the sediments and the water column.

The biochemical processes of photosynthesis and respiration by living organisms provide a means by which the aquatic community can regulate the amount of oxygen in the aquatic environment, within limits. Most organisms cannot survive with too little oxygen, while the solubility of oxygen generally limits the maximum amount that can be dissolved in water under most conditions. Supersaturation of water with oxygen does occur during periods of intense photosynthetic activity (Bowie *et al.* 1985).

The water column profiles that were completed at the six reservoir stations between 1995 and 1996 showed oxygenated conditions at all depths. Percent saturation in the surface waters ranged from slightly below 100 to 120 percent; the highest values were recorded at EC-4. Anoxic conditions were not detected in the hypolimnion at any time and only two measurements were less than 5.0 milligrams per liter (mg/L). These measurements occurred near the sediments at NFC-45 during the September 1996 sampling event. Due to the riverine conditions at the time, previously deposited sediments were likely disturbed, creating an oxygen demand. Metalimnetic oxygen deficits did not occur frequently, or to a significant extent, and the lowest measured value was 5.1 mg/L at NFC-35.

Oxygen profiles were again completed at the same stations by IDFG between 2004 and 2016. This dataset does not exceed a depth of 60 meters, precluding comparisons to measurements from the deeper strata (up to 195 meters) taken during the previous investigation. Oxygen concentrations did remain near saturation for most of the season at all stations, but there were exceptions. Concentrations less than 5 mg/L were frequently observed in the metalimnion and hypolimnion late in the season for all years and may have been due to senescing phytoplankton settling in the water column (Wilson and Corsi 2016). The majority of the measurements less than 5 mg/L at NFC-45 and LNF-1 were from the bottom of the profiles and again associated with sediment oxygen demand. Metalimnetic and hypolimnetic oxygen deficits were most common at NFC-35 followed by EC-4. The metalimnetic deficits usually occurred during September and October, sometimes reaching values less than or equal to 2 mg/L. Hypolimnetic oxygen concentrations less than 5 mg/L were also more common at NFC-35 than at the two mainstem stations closer to the dam and typically occurred during October and November starting at depths greater than 45 to 50 meters. A notable exception occurred between March and May 2009 when measurements of 5 mg/L and less were recorded at depths as shallow as 38 meters and for the rest of the profile at NFC-35, NFC-19, and NFC-3 (Wilson and Corsi 2016).

2.1.1.4 *Total Dissolved Gas*

Nitrogen, oxygen, and argon compose about 78 percent, 21 percent, and 1 percent, respectively, of the elemental gases in dry air. When the pressure of every gas in the

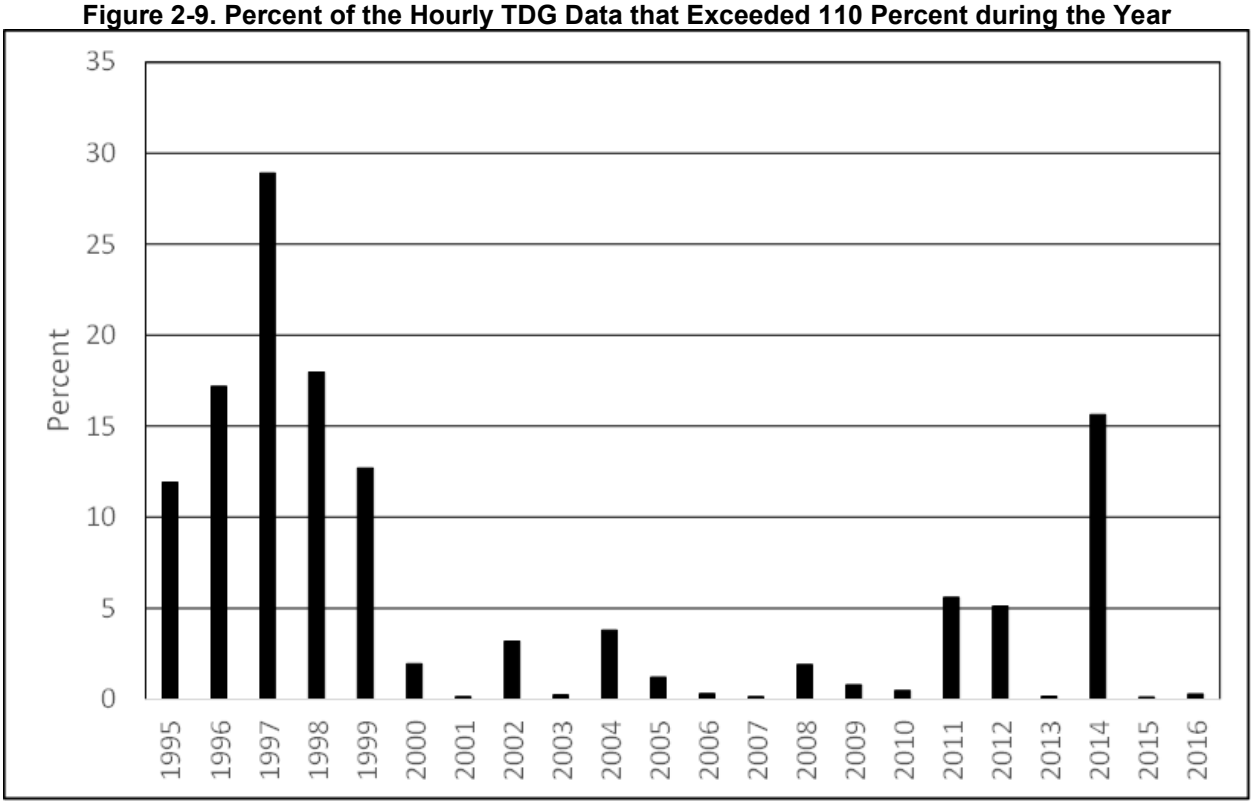
atmosphere reaches equilibrium with its dissolved form in water, the water is saturated. The pressures of gases in the air make up atmospheric pressure, and its counterpart in water is the TDG pressure. If the TDG pressure is greater than atmospheric pressure, the water is supersaturated.

The TDG standard for the outlet channel below Dworshak Dam is 110 percent. Compliance monitoring is accomplished by measuring TDG hourly throughout the year at the Corps fixed-monitoring station located along the left bank of the North Fork Clearwater at RM 0.5. All of the data is transmitted in near real-time via the GOES system and can be accessed at the Corps NWD's website (https://pweb.crohms.org/ftppub/water_quality/tdg/). Annual TDG and temperature reports are available at the NWD webpage (https://www.nwd.usace.army.mil/Missions/Water/ Columbia/Water-Quality/). These reports are comprehensive, and include information such as the fish operations plan for each year, quality assurance summaries from each district, and required court reports.

Gas saturation at Dworshak can originate from two sources: the powerhouse and spill. Powerhouse flows can contain TDG pressures that are higher than the forebay conditions when air is aspirated into the turbine hub and draft tube during low turbine flows. This occurs when the flow through one of the turbine units is less than about 1.6 kcfs and the vacuum breakers admit air to prevent cavitation. Spill from the spillway gates or the regulating outlets are the primary source of elevated gas pressures. Of the two spill routes, the spillway flow generates significantly lower TDG pressures when compared to regulating outlet flows.

The percentage of hourly TDG measurements recorded throughout the year that were greater than 110 percent are shown in Figure 2-9. From 1995 to 1999, 11.9 to 28.9 percent of the recorded values exceeded the TDG standard. This was primarily due to a combination of elevated releases for flood control and the early stages of the flow augmentation program when various discharge rates were tried. Since 2000 the median frequency of exceedances was 0.8 percent per year. Spring releases to provide flood control storage in the reservoir were the primary reason for the higher frequencies in years such as 2011, 2012, and 2014.

Figure 2-9. Percent of the Hourly TDG Data that Exceeded 110 Percent during the Year



2.1.1.5 *pH*

pH is a measure of the acidity or alkalinity of an aqueous solution. Solutions with a pH less than 7 units are considered acidic and solutions with a pH greater than 7 units are basic or alkaline.

The pH of the reservoir water was usually close to neutral, with epilimnial averages ranging from 7.2 to 7.4. At NFC-3 and EC-4, however, the pH did equal or exceed 8.3 at times, as a result of carbon uptake by the primary producers, and correspond with the elevated percent oxygen saturation data. At NFC-3, elevated pH measurements only occurred once during May of the mid-1990s investigation. At EC-4, however, the 8.3 mark was exceeded during July and August of 1993 and 1994 it reached highs of 8.7 and 8.8, respectively; this was also the site and times when algal primary productivity was greatest. These relatively high pH values were not attained in 1995.

2.1.1.6 *Specific Conductivity*

Specific conductivity is the reciprocal of resistance and is a measure of the water's ability to conduct an electric current. It varies both with the number and type of ions in solution.

Reservoir specific conductivity was measured in the 1970s and again in the mid-1990s. The overall reservoir average for the period between 1972 and 1974 was 28 microsiemens per centimeter (µS/cm). The mean decreased to about 26 µS/cm in 1977,

and in 1995 the water column averages ranged from about 27 to 31 µS/cm. This fluctuation could be partially due to times of data collection and instrumentation, but the general increase is consistent with the higher concentrations of ions found in 1995. A few other important items regarding specific conductivity should be mentioned. First, during the initial study by Falter et al. (1977) specific conductivity values as high as 95 µS/cm were recorded near the sediments, and attributed to decomposing organic matter. Such elevated specific conductivities were not detected in the 1990s. However, measured specific conductivities did increase by 1 to 5 µS/cm near the bottom of the profiles at NFC-3, NFC-19, and LNF-1 during part of the year. A second, and perhaps more interesting point is the decreased specific conductivity in the metalimnion that was observed at NFC-3, NFC-19, NFC-35, LNF-1, and to a lesser extent EC-4, during summer stratification. These depressions were possibly caused by inlet water entering as interflow. Subsequent increases towards the bottom of the water column were due to slight organic matter decomposition.

2.1.2 Chemical

2.1.2.1 *Major Ions, Alkalinity, and Hardness*

Since the conductivity of the water is dependent on ionic constituents, it is not surprising that the annual fluctuations in the concentrations of individual ions mimicked the ones set by conductivity.

The alkalinity of the water is comparatively low as a result of the geology of the drainage basin. Based on 1995 to 1996 data, the median water column values ranged from 10.0 mg $CaCO_3$/L at LNF-1 to 15.0 mg $CaCO_3$/L at NFC-3, and were relatively constant throughout the water column on any sample date. The trend of increasing alkalinity from the upper end of the reservoir to the lower is due to the net retention of ions as the water passes through the reservoir, and this trend was also identified in some of the concentrations of ions. Alkalinity values into the low 20 mg/L range did occur in the late summer and early fall, especially at the three upper sites, when the alkalinities of the inflowing streams increased during low flow periods. The alkalinity determined for the reservoir outlet station was essentially the same, with a calculated median of 14.0 mg $CaCO_3$/L.

The levels of the ions in the reservoir that were evaluated during the mid-1990s are relatively low (Table 2-1). Changes in concentrations appear to have occurred for some of the ions with time where previous data is available, while for others they are approximately the same. However, when the differences are slight they may represent a legitimate trend, but they may also be due to the sizes of datasets and inter-annual variability. Sulfate and magnesium are two ions that appear to have increased slightly between 1974 and 1995, although these changes are minor and may not be statistically significant. Calcium concentrations, however, appear to have doubled or tripled during the past 20 years, and this may be part of the reason that the alkalinity has also increased, though not as much, over the same time period. Silica (SiO2) is the ion that showed the greatest difference between 1972 and the mid-1990s. The average reservoir concentration was 0.6 mg/L in 1972 and doubled to 1.3 mg/L by 1974. In

1995, mean concentrations in the epilimnion ranged from 11.5 to 15.6 mg/L. This increase may be due to silica-bearing rocks weathering faster than rock types dominated by other minerals.

Table 2-1. Median Concentrations of Ions Analyzed Between 1994 and 1996

Parameter	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
Alkalinity	15.0	14.0	13.5	14.0	10.0	14.0
Hardness	14	13	11	13	9	12
Calcium	4.0	3.9	3.8	3.9	2.9	3.6
Chloride	0.3	0.2	0.2	0.2	0.2	0.2
Magnesium	0.9	0.8	0.8	0.8	0.6	0.9
Potassium	0.6	0.6	0.6	0.5	0.5	0.7
Silica	13.5	12.9	12.3	11.0	11.7	14.8
Sodium	1.7	1.6	1.6	1.7	1.6	1.8
Sulfate	1.2	1.4	1.3	1.3	1.3	1.5

2.1.2.2 *Other Inorganic Constituents*

Analytical results for other inorganic constituents that were determined in 1999 are presented in Table 2-2. Iron was the only parameter that was present in concentrations greater than the detection limit at five of the six sampling stations.

Table 2-2. Concentrations (mg/L) for Minor Inorganic Chemicals Determined for Dworshak Reservoir Water Samples Collected During Summer 1999

Parameter	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
Aluminum	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Antimony	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Barium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Beryllium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Chromium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cobalt	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Copper	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fluoride	<0.01	<0.01	<0.01	<0.01	<0.01	No data
Iron	<0.01	0.089	0.217	0.123	0.227	0.087
Lead	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Manganese	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Mercury	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Molybdenum	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nickel	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Vanadium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

2.1.2.3 *Turbidity and Total Suspended Solids*

Turbidity is the cloudiness or haziness of a fluid caused by individual particles (suspended solids) that are generally invisible to the naked eye, similar to smoke in air. Fluids can contain suspended solid matter consisting of particles of many different sizes. While some suspended material will be large enough and heavy enough to settle rapidly to the bottom of the container if a liquid sample is left to stand (the settable solids), very small particles will settle only very slowly or not at all if the sample is

regularly agitated or the particles are colloidal. These small solid particles cause the liquid to appear turbid.

Only a limited amount of turbidity data is available for the 1994 to 1995 period. Median values at all of the reservoir sampling stations were 1 Nephelometric Turbidity Unit (NTU) and seldom greater than 5 NTU.

Total suspended solids are solid materials, organic and inorganic, that are suspended in the water and can include silt, plankton, and urban wastes. The most recent reservoir suspended solids data was determined between 1994 and 1996. At that time, the median concentrations at five of the six reservoir sampling stations was less than 2 mg/L. The exception was the Elk Creek arm where the median concentration was 2.7 mg/L. Maximum concentrations determined during individual sampling events ranged from 8 to 27 mg/L, and were typically associated with samples collected at the bottom of the profile and may have included substrate material.

2.1.2.4 *Light Attenuation*

One of the traditional field methods for determining light attenuation in lakes and reservoirs is Secchi disk depth. Two of the most important factors related to measured depths are suspended solids concentrations, usually more influential during spring runoff, and chlorophyll a concentrations, typically more important during the summer. Other factors that affect Secchi disk depth readings during any sampling event include wind speed, time of day, and ambient light conditions. It has also been hypothesized that the Secchi disk depths determined for the reservoir are comparatively low due to the mineralogy of the water (e.g., very small mica particles that reflect ambient light).

The median Secchi disk depths determined for the six reservoir stations using the 2012 to 2016 May to September data ranged from 2.8 meters at EC-4 to 4.0 meters at NFC-3 (Figure 2-10). The non-parametric Kruskal-Wallis test resulted in a p-value of < 0.001, indicating that there is strong evidence all the medians are not equal. A subsequent evaluation using the non-parametric Conover-Inman test showed that the data from NFC-3 was significantly higher than analogous datasets from the other five sampling stations (Table 2-3). The data from EC-4 was also significantly lower than that from NFC-3, NFC-19, NFC-35, NFC-45, and LNF-1.

Figure 2-10. Box Plots of the May to September Secchi Disk Depths at the Six Reservoir Monitoring Stations from 2012 to 2016

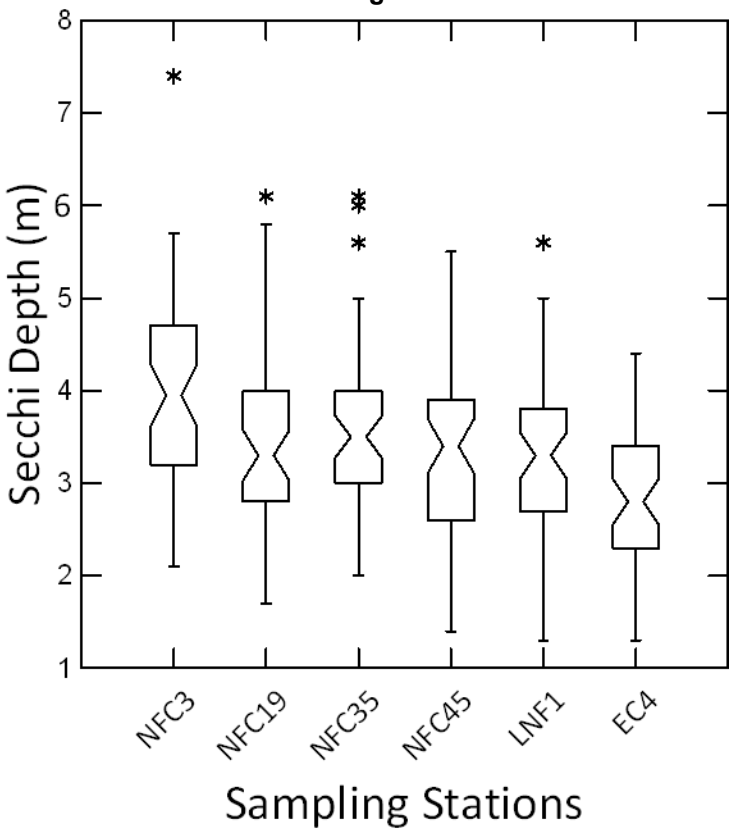
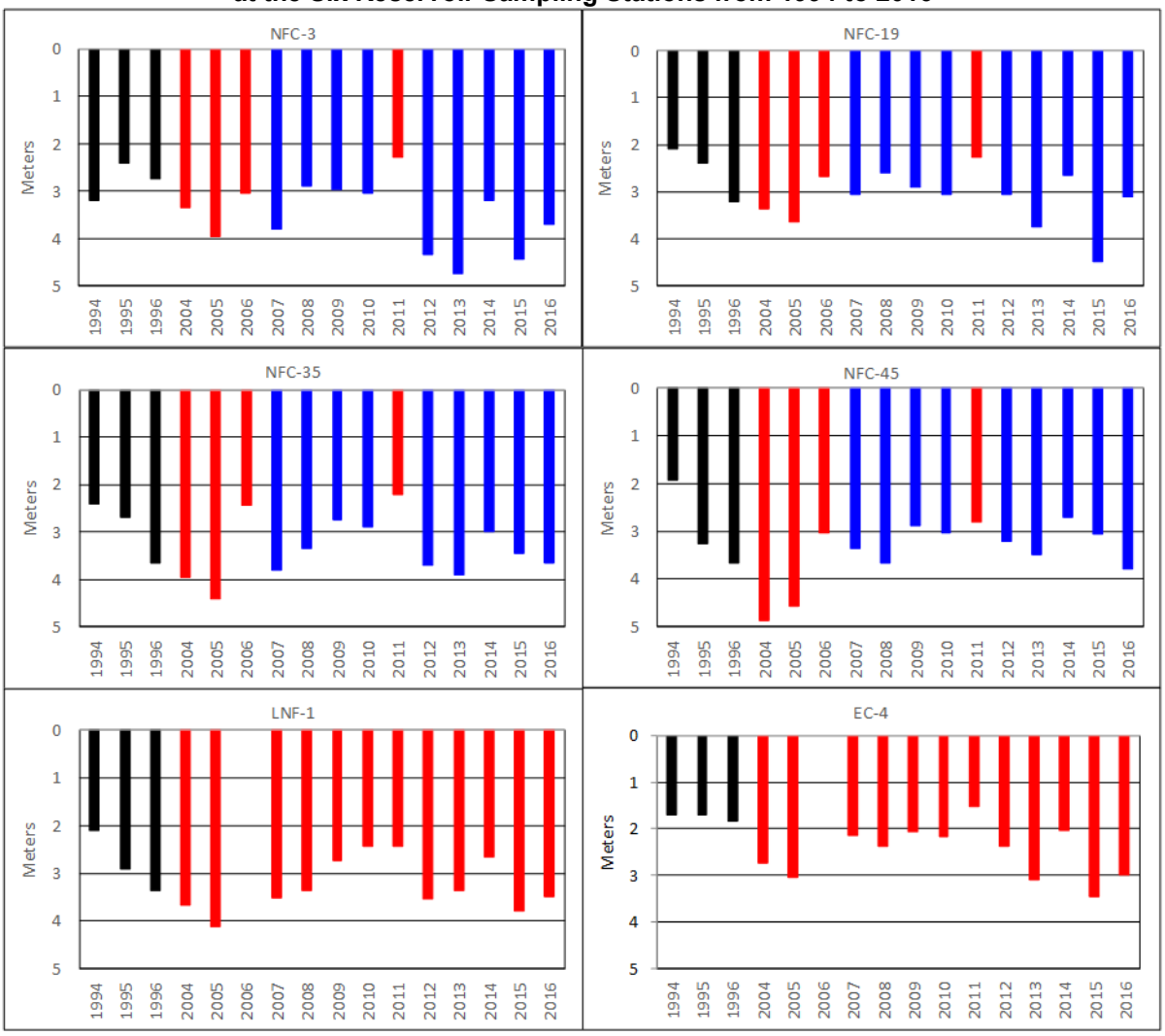


Table 2-3. Results of the Conover-Inman Pairwise Comparisons Test for the 2013 to 2016 May to September Secchi Disk Data at the Six Reservoir Stations

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
NFC-3	1.000	0.003	0.032	0.001	<0.001	<0.001
NFC-19		1.000	0.422	0.705	0.400	0.001
NFC-35			1.000	0.237	0.100	<0.001
NFC-45				1.000	0.643	0.003
LNF-1					1.000	0.011
EC-4						1.000

The available Secchi disk data was also evaluated for long-term trends. The median May to September values for each of the six reservoir stations are presented in Figure 2-11. There appears to be a trend of increasing depth for stations such as NFC-3 and NFC-19, but the presence of inter-annual variability can make it difficult to determine visually. Given this, the Mann-Kendall test was applied to each dataset and the resulting p-values are shown in Table 2-4. The results for EC-4 ($p = 0.047$) are not strong enough to indicate that there is or is not a trend. The p-values for the remaining five stations are all greater than 0.05, indicating that we cannot reject the null hypothesis that there is no trend.

Figure 2-11. Median May to September Secchi Disk Depths at the Six Reservoir Sampling Stations from 1994 to 2016



Note: Black bars represent 1990s data, red bars represent years when there was no reservoir nutrient augmentation program, and blue bars are years when nutrient augmentation occurred.

Table 2-4. Results of the Mann-Kendall Tests Used to Test for Upward Trends in the Secchi Disk Data

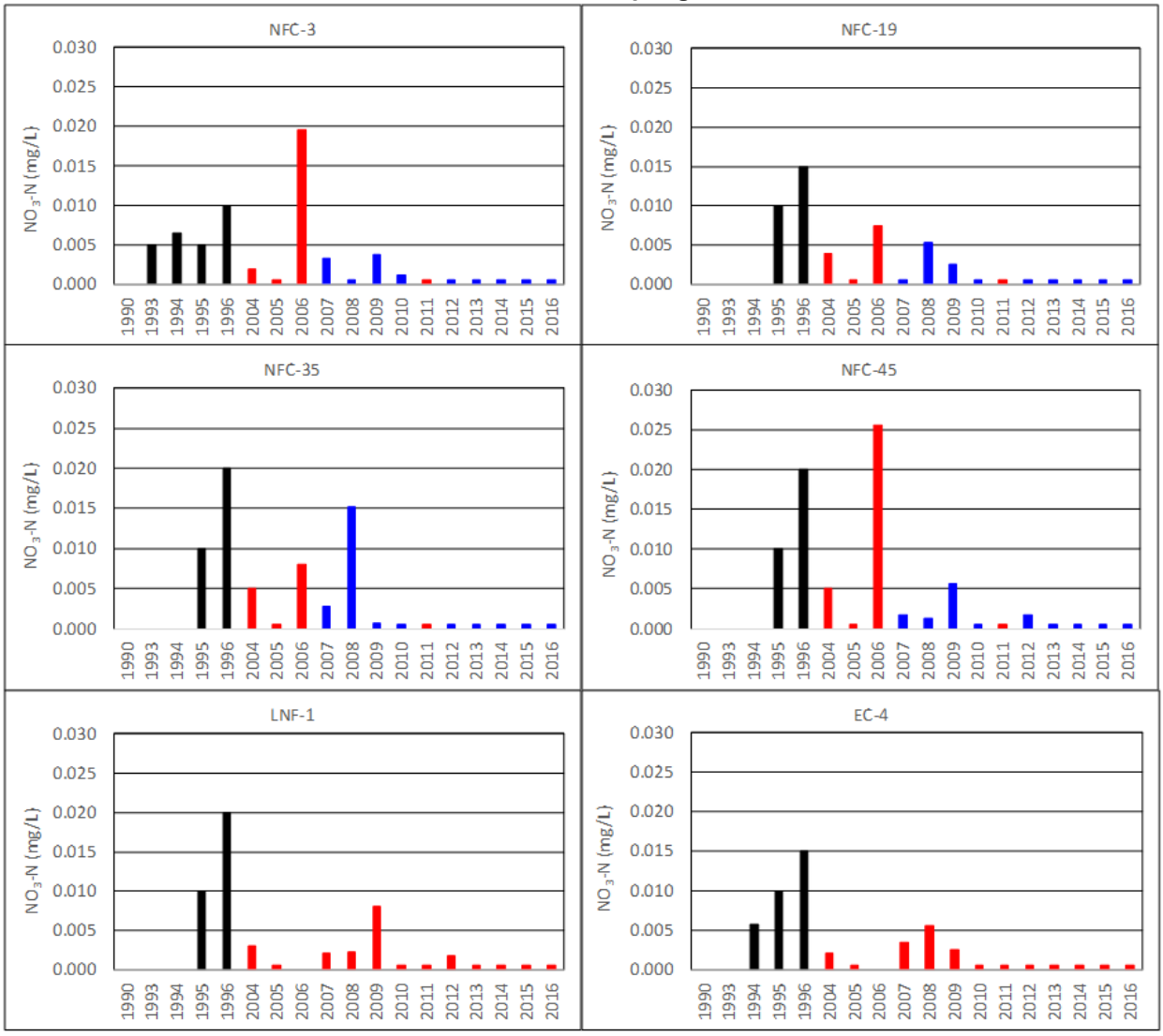
	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
p-value	0.057	0.088	0.325	0.658	0.446	0.047

2.1.2.5 *Nitrogen and Phosphorus*

Nitrogen. Nitrate+nitrite-N concentrations in the epilimnion have decreased over time. Median 1995 to 1996 May to September concentrations ranged from 0.007 mg/L at NFC-3 to 0.013 at NFC-35 (Figure 2-12). The calculated median at NFC-19 was 0.012 mg/L followed by 0.010 mg/L at the remaining three stations. For the 2012 to 2016

period, the median concentration at all of the reservoir stations was 0.001 mg/L (also the reported detection limit) for the same months.

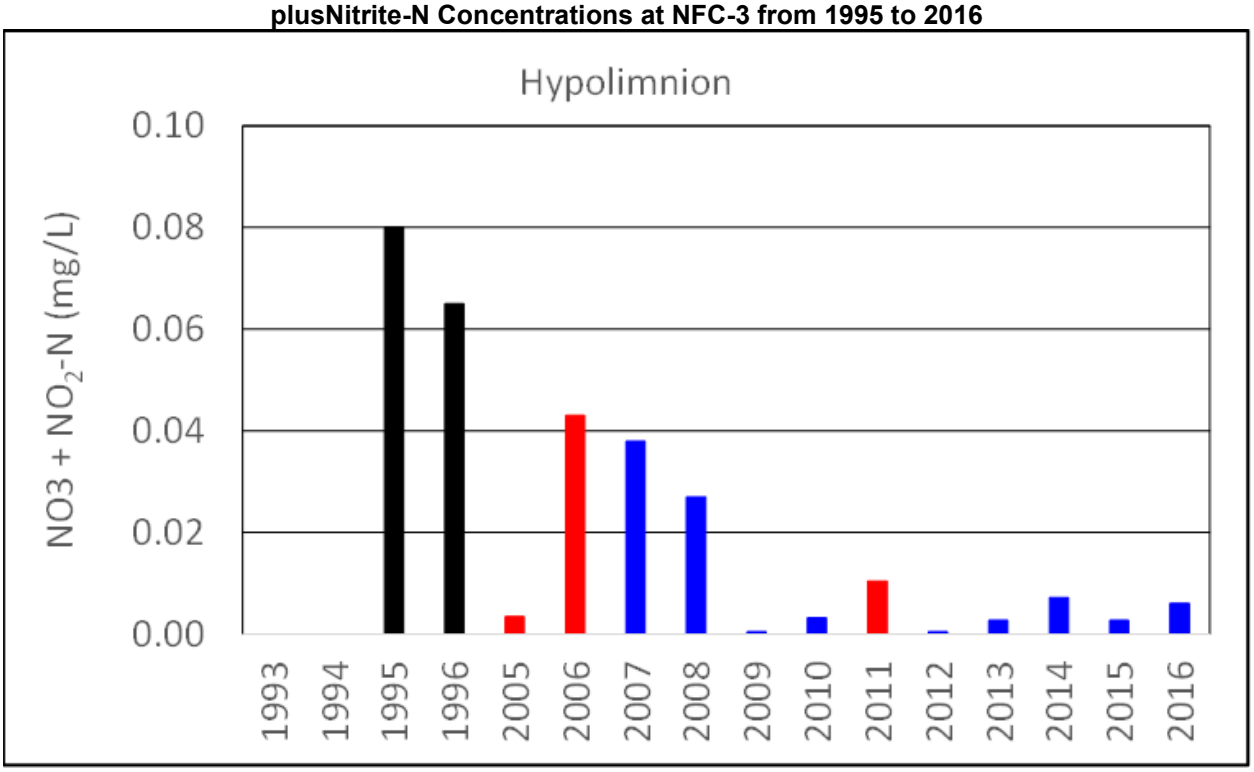
Figure 2-12. Median May to September Epilimnetic Nitrate+Nitrite-N Concentrations at the Six Reservoir Sampling Stations from 1993 to 2016



The strength of nitrate plusnitrite-N concentrations in the hypolimnion also appears to have decreased since the 1990s. The evaluation is limited since the deepest samples collected since 2005 were from a depth of 60 meters. Depending on the pool elevation, the water depth in the forebay approaches 200 meters. Given this, results from samples collected between 30 and 60 meters during 1995 and 1996 were used to compare with those identified as from the hypolimnion since 2005. The median May to September concentration was 0.080 mg/L in 1995 and decreased to 0.060 mg/L the following year at NFC-3 (Figure 2-13). With the exception of 2004 when the median concentration was 0.004 mg/L, concentrations appear to have continued downward through 2009. Since then, median concentrations have ranged from 0.001 mg/L in 2009 and 2012 to 0.011 mg/L in 2011. The combined median for the 2013 to 2016 period was 0.002 mg/L.

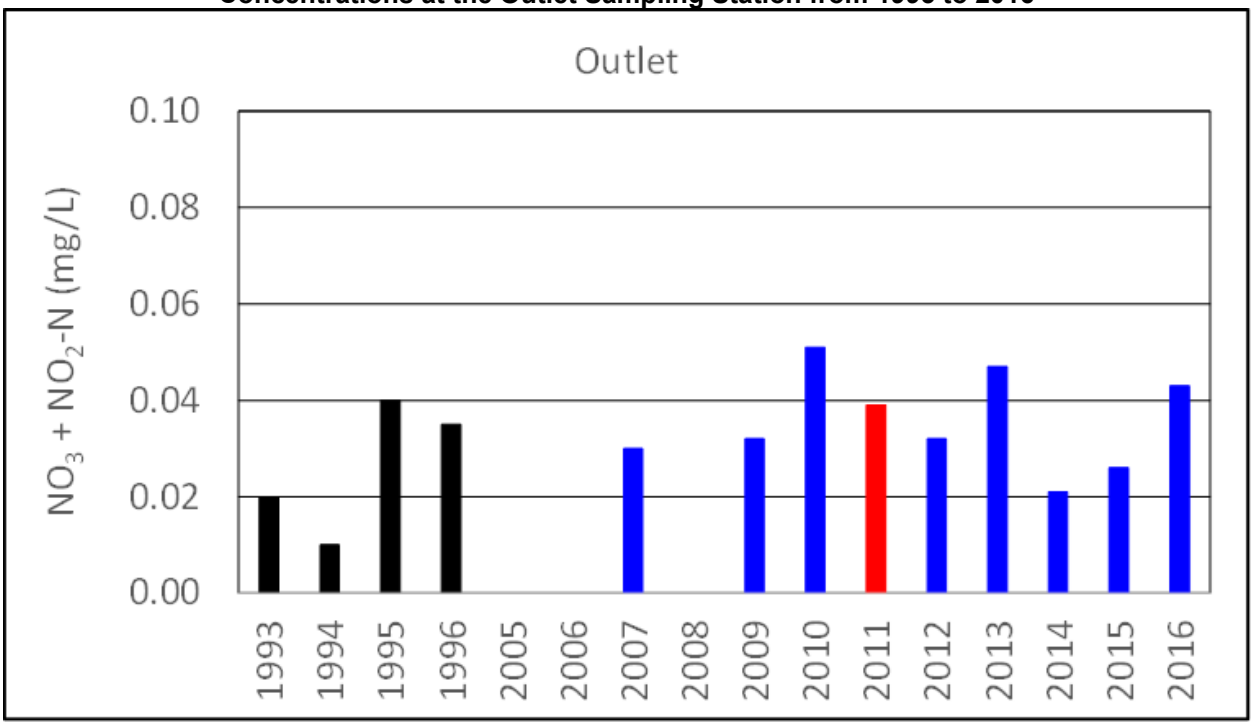
Water samples collected from deeper in the reservoir at NFC-3 during 1995 and 1996 had higher concentrations of nitrate plus nitrite-N. The median concentration for samples retrieved from depths greater than 60 meters was 0.100 mg/L and 0.095 mg/l in 1995 and 1996, respectively. Individual concentrations were as high as 0.130 mg/L for samples collected between depths of 160 and 183 meters.

Figure 2-13. Median May to September Hypolimnetic Nitrate plusNitrite-N Concentrations at NFC-3 from 1995 to 2016



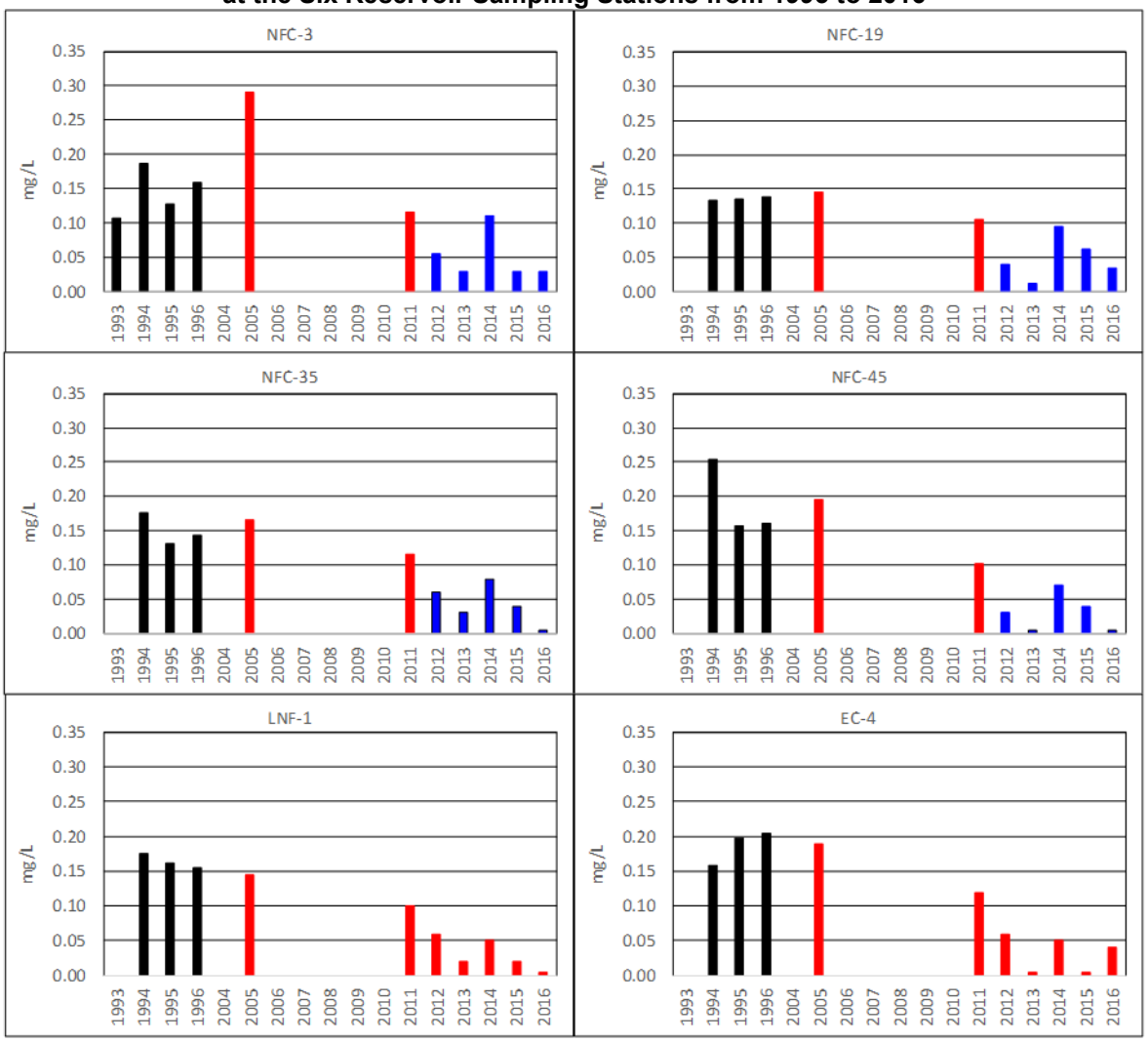
The concentrations of nitrate plus nitrite-N in the reservoir outlet depend on the elevation of the release point at the dam (i.e., the spillway, the deep regulating outlets, and whether the selector gates are in undershot or overshot mode) (see Figure 1-2). Despite these operational differences, concentrations have remained relatively stable over time (Figure 2-14). The median concentration for the 2013 to 2016 period was 0.039 mg/L, which is essentially the same as the 0.040 mg/L determined for the 1995 to 1996 dataset.

Figure 2-14. Median May to September Nitrate plus Nitrite-N Concentrations at the Outlet Sampling Station from 1993 to 2016



The epilimnetic total nitrogen data shows large differences between the information obtained from 1993 to 1996, as well as the 2005 data, when compared to the post-2011 data (Figure 2-15). The differences between the historical and recent data could be due to environmental conditions, but they could also be the result of different analytical methods. However, if only the 2012 to 2016 data is considered, then at most of the sampling locations the concentrations decreased from 2012 to 2013, increased in 2014, and decreased again towards 2016. The median concentration for the 2015 to 2016 May to September data was least at LNF-1 at 0.01 mg/L and highest at NFC-19 at 0.04 mg/L.

Figure 2-15. Median May to September Total Nitrogen Concentrations at the Six Reservoir Sampling Stations from 1993 to 2016



<u>Phosphorus.</u> Epilimnetic reservoir total phosphorus concentrations do differ with respect to sample location. The calculated medians for the 2012 to 2016 May to September data ranged from 0.004 mg/L at NFC-3 and NFC-19 to 0.007 mg/L at EC-4 (Figure 2-16). The results of the Conover-Inman test showed that the median concentrations at EC-4 could not be considered equal to the ones determined for NFC-3, NFC-19, NFC-35, and LNF-1 (Table 2-5). Similarly, the medians for LNF-1 and NFC-19 are not considered equal.

Figure 2-16. Box Plots of the May to September EpilimneticTotal Phosphorus Concentrations at the Six Reservoir Monitoring Stations from 2012 to 2016

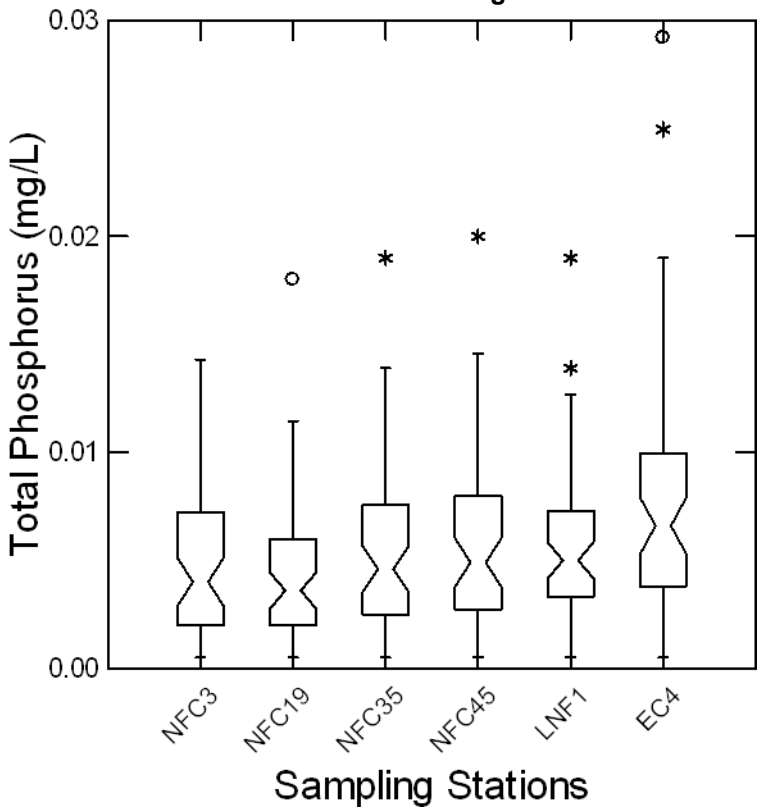


Table 2-5. Results of the Conover-Inman Pairwise Comparisons Test for the 2012 to 2016 May to September Total Phosphorus Data at the Six Reservoir Stations

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
NFC-3	1.000	0.402	0.576	0.207	0.339	0.002
NFC-19		1.000	0.163	0.036	0.073	<0.001
NFC-35			1.000	0.482	0.690	0.010
NFC-45				1.000	0.761	0.062
LNF-1					1.000	0.030
EC-4						1.000

Median total phosphorus concentrations in the epilimnion have decreased since the 1990s at all reservoir sampling locations (Figure 2-17). The downward trends were evaluated using the Mann-Kendall test and considered significant at each location, with p-values ranging from < 0.001 at NFC-19 to 0.004 at LNF-1 and EC-4 (Table 2-6). Maximum concentrations were determined in 2005 at five of the sampling stations where the calculated medians ranged from 0.019 mg/L at LNF-1 to 0.024 mg/L at NFC-3 and EC-4. The highest concentration at NFC-19 occurred in 2004 at 0.020 mg/L. A comparison of the 1995 to 1996 to the 2012 to 2016 data also displayed decreases over time. The station medians for the early set ranged from 0.009 mg/L at NFC-35 to 0.013 mg/L at EC-4. The calculated values for NFC-3, NFC-19, and NFC-45 were all 0.001 mg/L. For the most recent data, the median epilimnetic concentration at EC-4 was still the highest at 0.007 mg/L, and lowest at NFC-3 and NFC-19 at 0.004 mg/L. The three remaining stations all had median concentrations of 0.005 mg/L.

Figure 2-17. Median May to September Epilimnetic Total Phosphorus Concentrations at the Six Reservoir Sampling Stations from 1990 to 2016

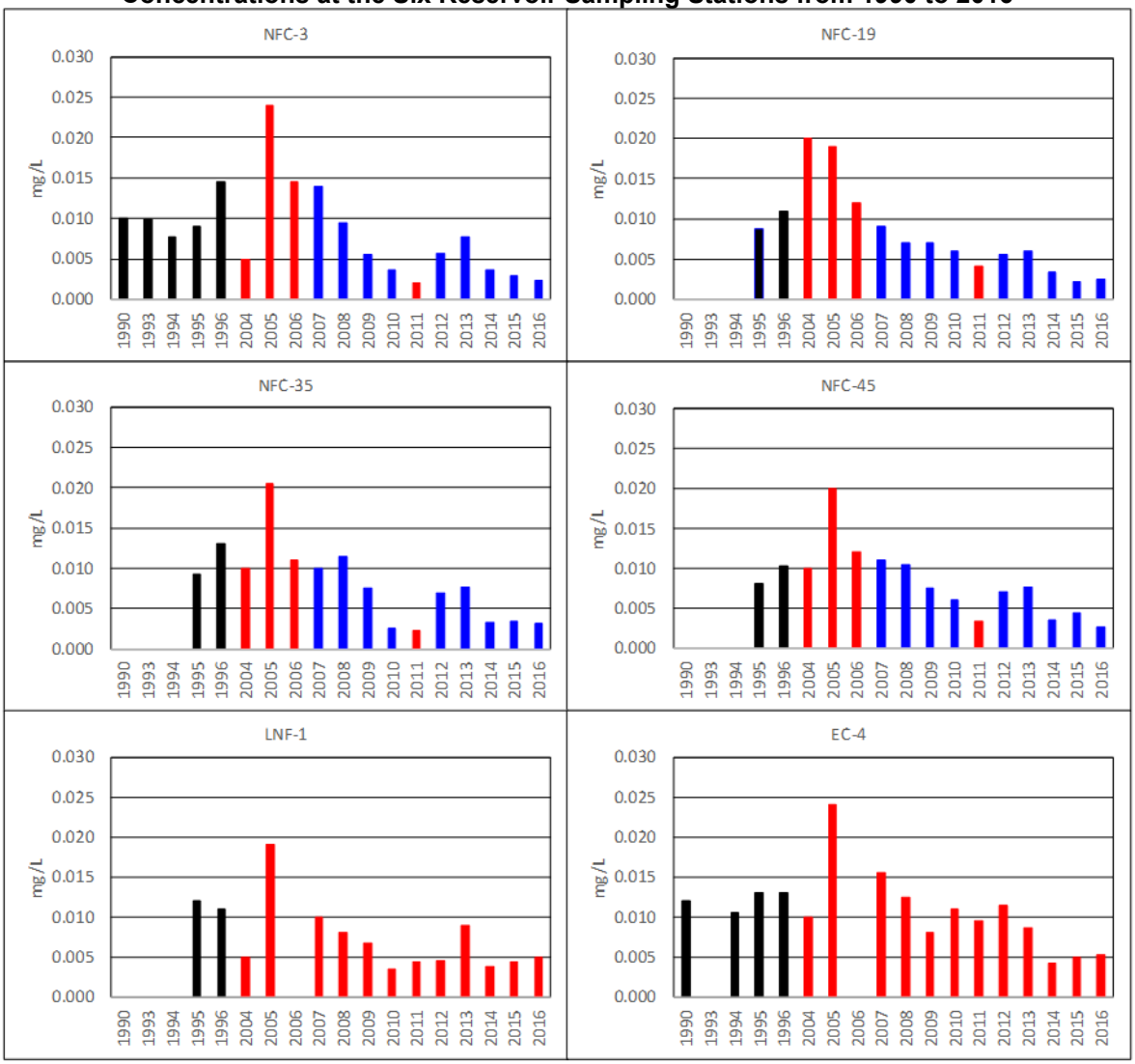
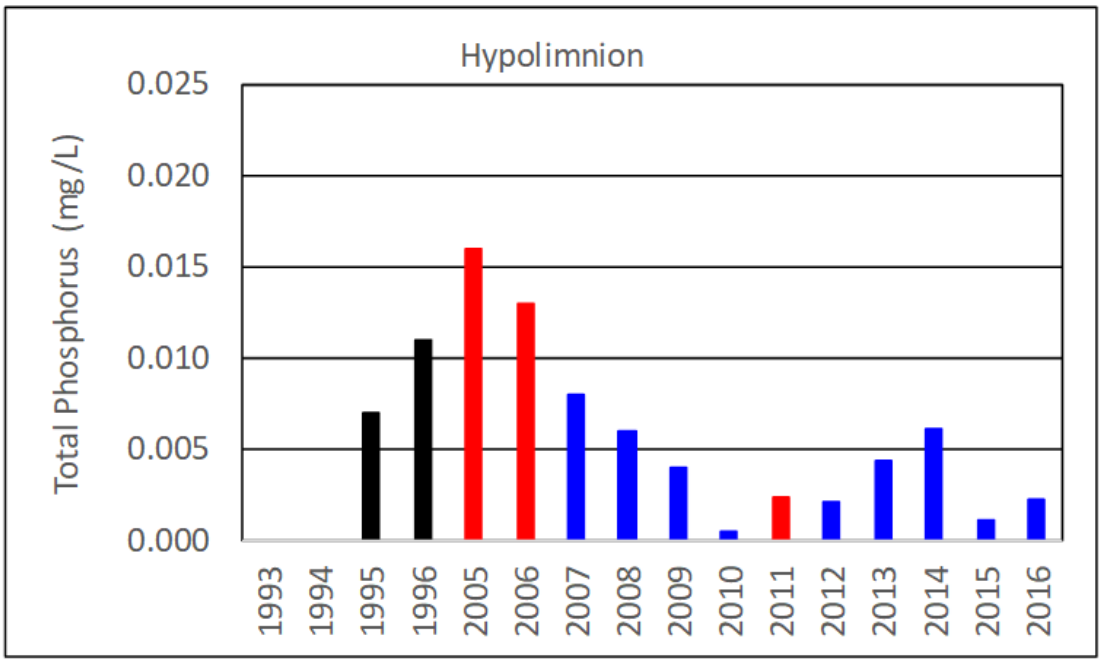


Table 2-6. Results of the Mann-Kendall Tests Used to Evaluate Trends in the Total Phosphorus Data

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
p-value	0.002	<0.001	0.002	0.003	0.004	0.004

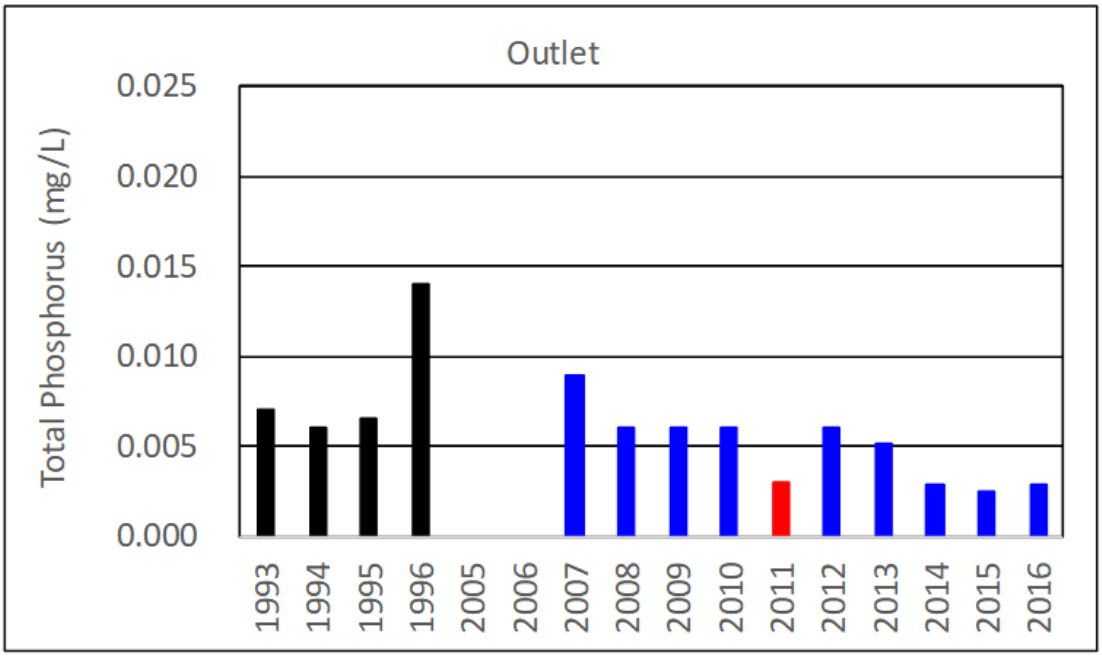
Hypolimnetic concentrations of total phosphorus have also decreased over time. At NFC-3, the pattern of seasonal median concentrations (Figure 2-18) is very similar to the one shown for the epilimnetic concentrations (see Figure 2-17). The data evaluation is again limited by the maximum sample depth of 60 meters during the 2005 to 2016 interval, but the median for the 1995 to 1996 data from depths of 30 to 60 meters was 0.007 mg/L compared to 0.002 mg/L for the 2012 to 2016 data set. The highest calculated median for the available data occurred in 2005 at 0.016 mg/L. The median values determined for the samples collected from depths ranging from 76 to 183 meters in 1995 and 1996 were 0.011 mg/L and 0.020 mg/L, respectively.

Figure 2-18. Median May to September Hypolimnetic Total Phosphorus Concentrations at NFC-3 from 1995 to 2016



Concentrations of total phosphorus in the outlet have also decreased over time (Figure 2-19). The calculated median for the 1993 to 1996 interval was 0.007 mg/L, reaching a peak of 0.014 mg/L in 1996. During the 2012 to 2016 interval, seasonal medians ranged from 0.006 mg/L in 2012 to 0.003 mg/L in 2014, 2015, and 2016.

Figure 2-19. Median May to September Total Phosphorus Concentrations at the Outlet Sampling Station from 1993 to 2016



Nitrogen to Phosphorus Ratios The total nitrogen to total phosphorus (TN:TP) ratios that were calculated using the 2012 to 2016 epilimnetic data varied within growing seasons and between sampling stations. In some instances, ratios determined for a given station could range from approximately 1 to 50, 60, or even over 100 during a 5-month period. The reason for these extremes is not known, and they may have been due to outliers. However, the calculated medians were less extreme, ranging from a low of 2.3 at NFC-45 to 9.2 at NFC-19 (Figure 2-20). The median values at the remainder of the sampling stations ranged from 4.6 at LNF-1 and EC-4, followed by 7.1 and 7.8 at NFC-35 and NFC-3, respectively. The Conover-Inman test for significant differences showed that the only differences where the median values could not be considered equal were between NFC-19, NFC-45, and EC-4 (Table 2-7).

Figure 2-20. Box Plots of the May to September Total Nitrogen to Total Phosphorus Ratios at the Six Reservoir Monitoring Stations from 2012 to 2016

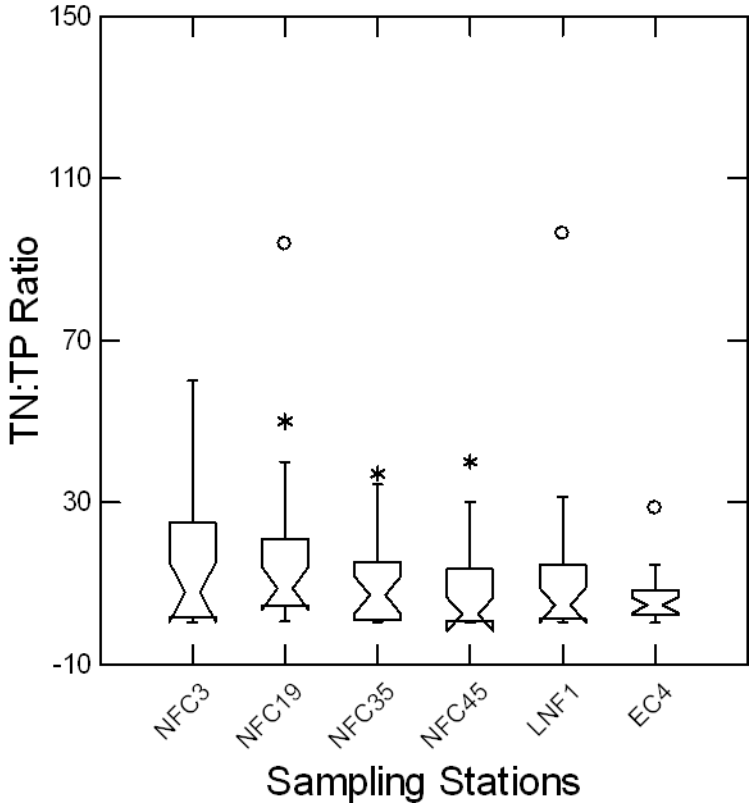


Table 2-7. Results of Conover-Inman Pairwise Comparisons Test for the 2012 to 2016 May to September Total Nitrogen to Total Phosphorus Ratios Calculated for the Six Reservoir Stations

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
NFC-3	1.000	0.383	0.297	0.097	0.288	0.088
NFC-19		1.000	0.058	0.012	0.055	0.010
NFC-35			1.000	0.539	0.985	0.514
NFC-45				1.000	0.551	0.974
LNF-1					1.000	0.526
EC-4						1.000

Long-term trend analyses for changes in TN:TP ratios at each sampling stations were not completed due to the lack of data for the period 2006 to 2010. Figure 2-21 shows that there were instances when the seasonal median for the 2012 to 2016 period was greater than analogous data from the 1990s (e.g., the 2011 data at NFC-3, NFC-35, and NFC-45, as well as the 2015 data from NFC-3 and NFC-19). When the 1995 to 1996 and 2012 to 2016 data are pooled there appears to be an overall decrease with time, ranging from 34 percent at NFC-19 to 86 percent at NFC-35 (Table 2-8). Since the reason for the differences between the total nitrogen concentrations is not known with a high level of certainty, the differences may not be "real." However, the median ratios that are less than 10 at each sampling location suggest nitrogen limitation.

Figure 2-21. Median May to September Total Nitrogen to Total Phosphorus Ratios at the Six Reservoir Sampling Stations from 1993 to 2016

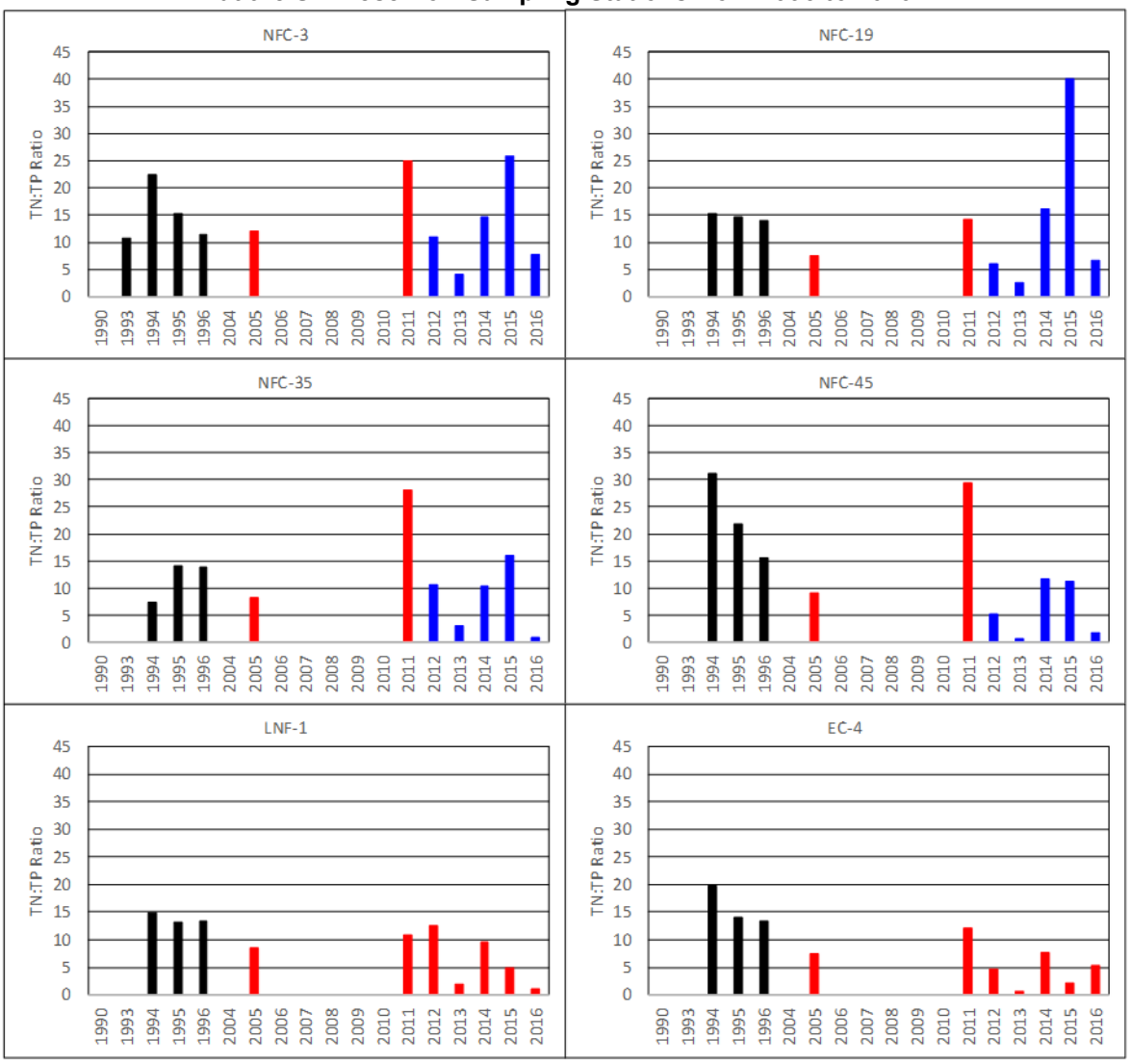


Table 2-8. Median Epilimnetic Total Nitrogen to Total Phosphorus Ratios Determined for the 1995 to 1996 and 2012 to 2016 May to September Data

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
1995–1996	12.7	14.0	14.0	16.4	13.3	13.7
2012–2016	7.8	9.2	7.1	2.3	4.6	4.6

2.1.2.6 *Organic Compounds*

Water samples from Dworshak Reservoir have not been routinely analyzed for organic compounds.

2.1.3 Biological

2.1.3.1 *Chlorophyll a*

Chlorophyll a is a specific form of chlorophyll used in oxygenic photosynthesis. It absorbs most of its energy from wavelengths of the violet to blue and orange to red light range. It is essential for photosynthesis in most algae and green plants and is often used as a trophic state indicator, and as an indirect measure of phytoplankton biomass.

Measured chlorophyll a values were moderately low. The median concentrations determined for the six reservoir stations using the 2012 to 2016 May to September data ranged from a low of 1.10 micrograms per liter (µg/L) at NFC-3 to a high of 1.46 µg/L at NFC-35 (Figure 2-22). The remaining stations ranged between 1.3 and 1.4 µg/L. The non-parametric Kruskal-Wallis test was used to determine whether the stations are equal and the resulting p-value was 0.125, indicating that there is weak evidence against the null hypothesis that all of the medians are equal and therefore it cannot be rejected. However, a subsequent evaluation using the nonparametric Conover-Inman test showed that the data from NFC-3 and NFC-35 were modestly different with a p-value of 0.024 (Table 2-9). A smaller p-value was determined for the comparison of the data from NFC-3 and LNF-1.

Figure 2-22. Box Plots of the May to September Chlorophyll a Concentrations at the Six Reservoir Monitoring Stations from 2012 to 2016

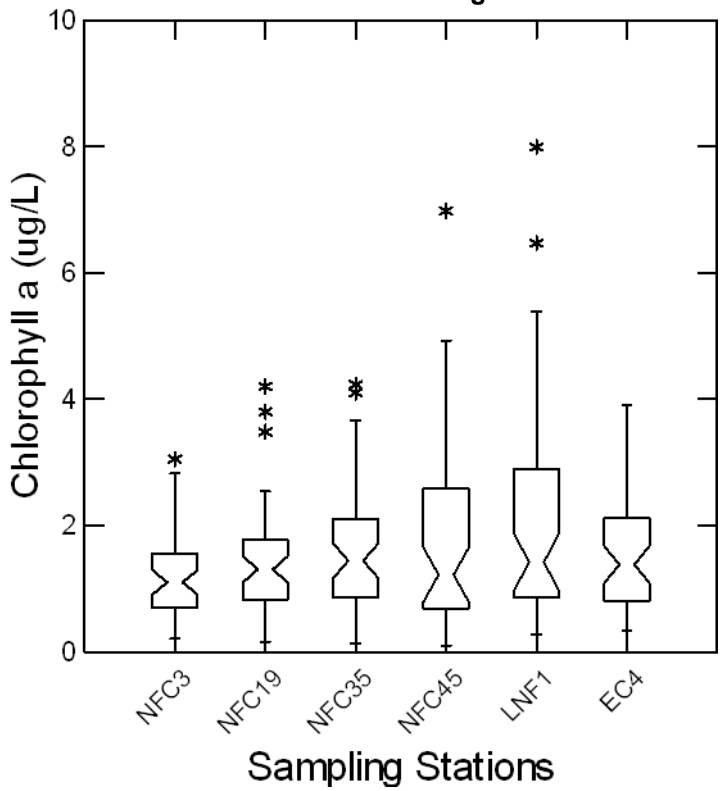


Table 2-9. Results of Conover-Inman Pairwise Comparisons Testfor the 2013 to 2016 May to September Chlorophyll a Concentrations at the Six Reservoir Stations

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
NFC-3	1.000	0.359	0.024	0.139	0.010	0.097
NFC-19		1.000	0.179	0.574	0.097	0.457
NFC-35			1.000	0.434	0.746	0.548
NFC-45				1.000	0.271	0.856
LNF-1					1.000	0.357
EC-4						1.000

The available chlorophyll a data were also evaluated for long-term trends. The median May to September values for each of the six reservoir stations are presented in Figure 2-23. At every station, the median values determined for the combined 1990s datasets were greater than 3 µg/L. The consistently highest values were determined for EC-4, where the median values ranged from 4.3 µg/L in 1994 to 8.7 µg/L in 1996. The concentrations appear to have decreased over time at each station. To verify, the Mann-Kendall test was applied to each dataset and the resulting p-values are shown in Table 2-10. The analysis shows that all of the p-values are less than 0.05, indicating that there is strong evidence against the null hypothesis that there are no trends. Additionally, the Sen's slope estimate for EC-4 had a larger magnitude (-0.242) than any of the other locations, indicating a steeper change.

Figure 2-23. Median May to September Chlorophyll a Concentrations at the Six Reservoir Sampling Stations from 1993 to 2016

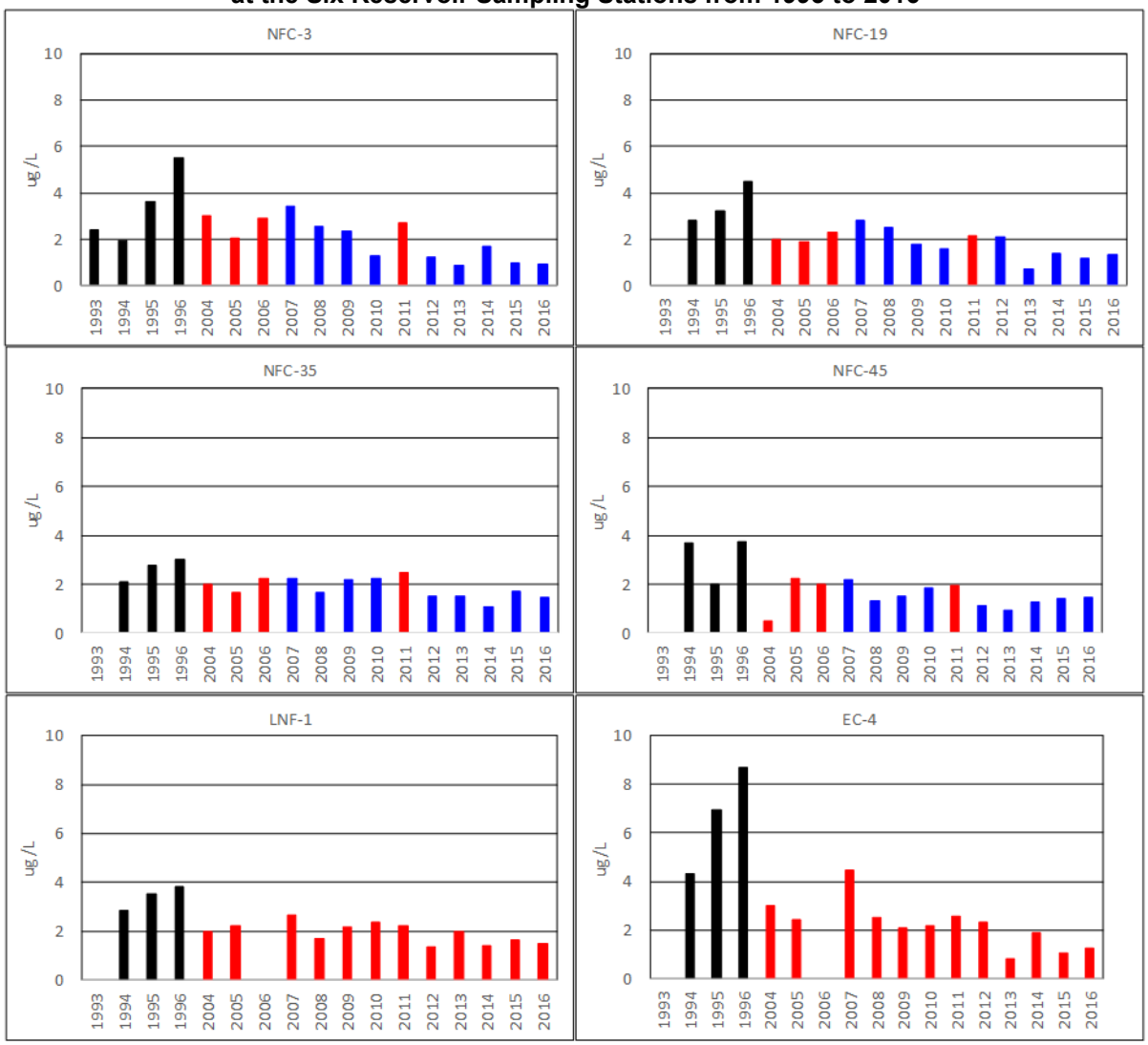


Table 2-10. Results of the Mann-Kendall Tests Used to Evaluate Trends in the Chlorophyll a Data

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
p-value	0.002	0.001	0.009	0.018	0.001	<0.001

2.1.3.2 *Phytoplankton*

Phytoplankton, also called algae, are small, photosynthetic organisms found floating in the water column. They lack any roots, stems, or leaves, thereby separating them from higher plants. Planktonic algae are found in unicellular, colonial, or filamentous forms, and range in size from 5 micrometers to over 100 micrometers in diameter. They are found in all lakes, slow-flowing rivers, estuaries, and oceans. Their role as primary producers makes them an important part of aquatic ecosystem. Algae use inorganic compounds to make complex organic molecules through the photosynthetic process, and are an essential link to higher trophic levels of the food web. As necessary as they are to the aquatic system, phytoplankton can also be a nuisance. If conditions in a body

of water shift to favor a particular species, algal blooms of 5 to 50 million cells per liter can occur. This sometimes results in lower water quality, specifically poor taste, odor, and color (Horne and Goldman 1994).

Phytoplankton grow best in low-velocity waters with warm temperatures and high nutrient availability, particularly phosphorus. Phytoplankton growth is generally limited in stream or riverine systems, which have much greater flow velocities. When evaluating phytoplankton data, a relative increase in species diversity or richness under similar habitat conditions is often considered a positive indication of improving ambient water quality conditions. In contrast, the dominance of certain robust species, such as some species of blue-green algae, can often be indicative of poor water quality conditions. To evaluate the importance of phytoplankton as a food source, the volume or quantity of algae available for consumption is often the most critical parameter to be considered. For this reason, phytoplankton data are typically expressed in terms of overall biovolume (*i.e.*, cubic millimeters per liter [mm^3/L]) as well as species composition.

An overview of the reservoir phytoplankton community shows that some shifts have occurred over time when the May to September data is compared from year to year (Figure 2-24). The percent of the total biovolume attributed to the bacilariophyta (diatoms) was generally higher in the 1990s, often ranging from 50 to 80 percent, and decreasing to less than 20 percent by the 2012 to 2016 period. Concurrently, the percentage due to the chlorophyta (green algae) increased at all stations. During the mid-1990s and mid-2000s green algae often comprised less than 10 percent of the total biovolume, yet during the 2014 to 2016 period their contribution was often over 30 percent. The percentage due to cyanophyta (blue-green algae) ranged from 0 to 30 percent during the mid-1990s, peaked at 60 to 70 percent between 2008 and 2010 depending on the location, and then decreased to 20 to 40 percent from 2012 to 2016.

Figure 2-24. Composition of the Phytoplankton Biovolume at the Six Reservoir Sampling Stations from 1993 to 2016

Seasonal total phytoplankton biovolume was not equal at the six reservoir stations (Figure 2-25). Based on the 2012 to 2016 data, the smallest median value of 0.21 mm^3/L was found at NFC-3. The calculated medians for the remaining five sampling stations ranged from 0.30 mm^3/L at NFC-19 to 0.35 mm^3/L at LNF-1. The results of the Conover-Inman test showed that the data from NFC-3 could not be considered equal to that from the other five locations (Table 2-11).

Figure 2-25. Box Plots of the May to September Total Phytoplankton Biovolume at the Six Reservoir Monitoring Stations from 2012 to 2016

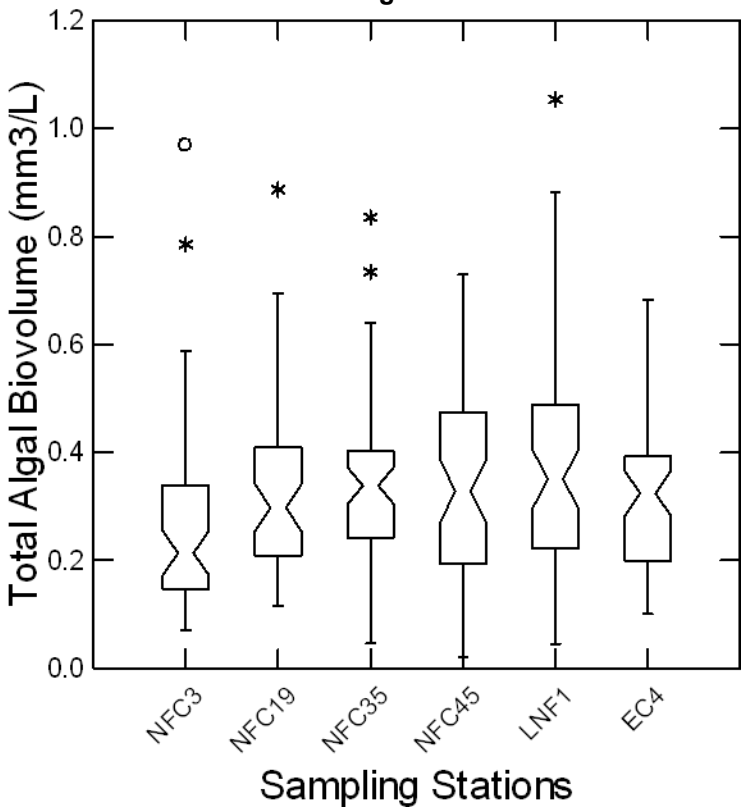


Table 2-11. Results of Conover-Inman Pairwise Comparisons Test for the 2012 to 2016 May to September Total Phytoplankton Biovolume at the Six Reservoir Stations

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
NFC-3	1.000	0.025	0.002	0.008	<0.001	0.024
NFC-19		1.000	0.420	0.687	0.131	0.981
NFC-35			1.000	0.682	0.486	0.436
NFC-45				1.000	0.264	0.705
LNF-1					1.000	0.139
EC-4						1.000

An evaluation of the long-term median May to September data shows that there are declining trends at each of the six sampling locations (Figure 2-26). The non-parametric Mann-Kendall test was used to evaluate these trends, and the results show that the declines at NFC-3, NFC-19, NFC-35, and EC-4 are considered significant at $p \leq 0.05$ (Table 2-12).

Figure 2-26. Median May to September Total Phytoplankton Biovolume at the Six Reservoir Sampling Stations from 1993 to 2016

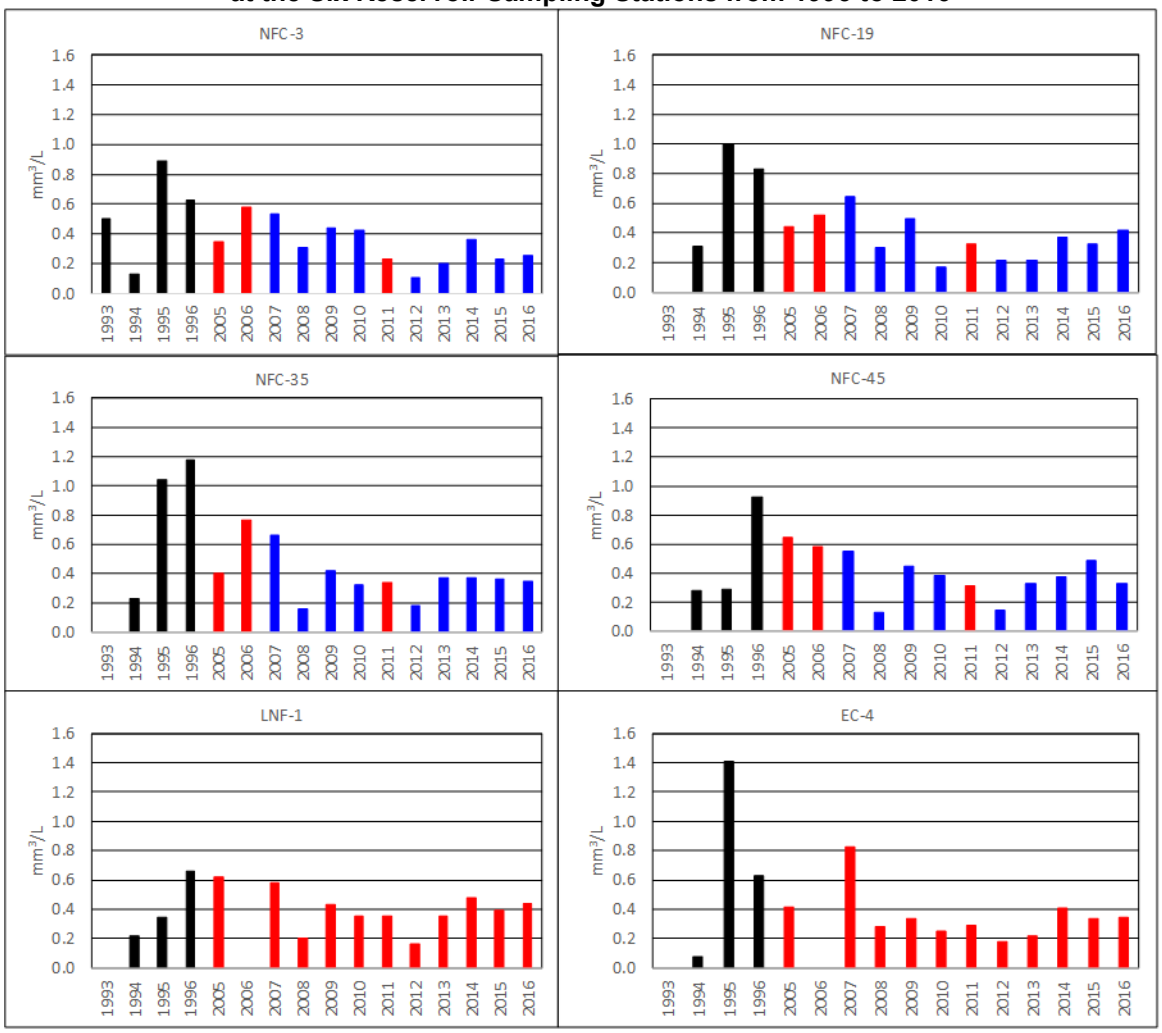


Table 2-12. Results of the Mann-Kendall Tests Used to Evaluate Trends in the Total Phytoplankton Biovolume Data

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
p-value	0.004	0.017	0.024	0.088	0.129	0.039

Bacillariophytes, or diatoms, are often considered to be the most important source of energy for the rest of the food chain. Their primary characteristic is the use of silica to construct their exterior cell wall. They often exhibit a “boom or bust” lifecycle, often during the spring when their competitive edge and rapid growth rate enable them to dominate the phytoplankton community.

The May to September 2012 to 2016 median diatom biovolume was 0.03 mm^3/L at NFC-19, NFC-35, NFC-45, and LNF-1 (Figure 2-27). The values determined for NFC-3 and EC-4 were less at 0.01 mm^3/L. The results of the Conover-Inman test (Table 2-13) confirmed that the null hypothesis for NFC-3 and EC-4 being equal could not be

rejected. Additionally, the test showed that the median for NFC-3 was not equal to the ones determined for NFC-19, NFC-35, NFC-45, and LNF-1.

Figure 2-27. Box Plots of the May to September Diatom Biovolume at the Six Reservoir Monitoring Stations from 2012 to 2016

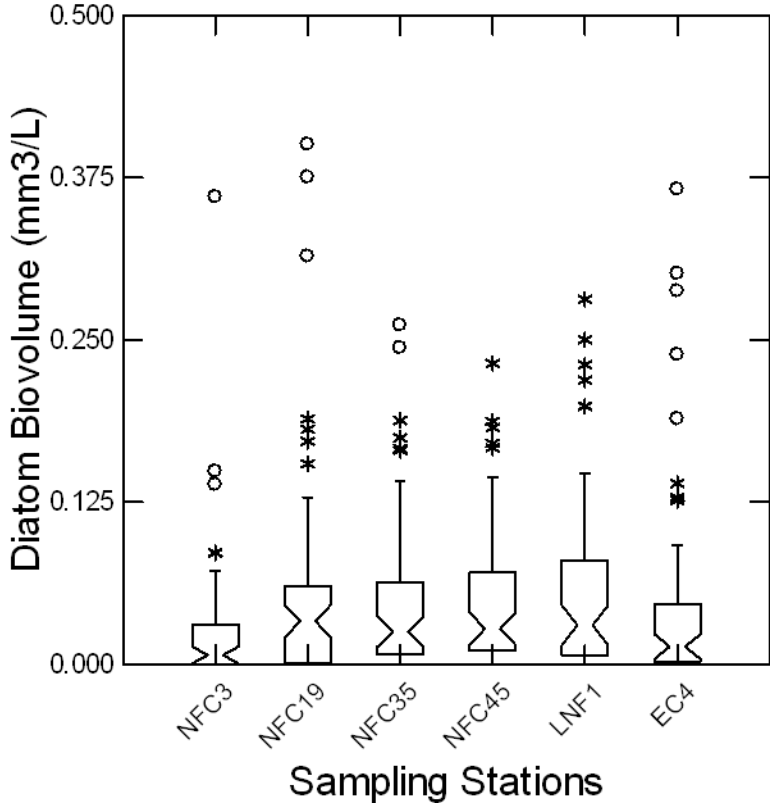


Table 2-13. Results of Conover-Inman Pairwise Comparisons Test for the 2012 to 2016 May to September Diatom Biovolume Determined for the Six Reservoir Stations

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
NFC-3	1.000	0.004	0.001	0.001	0.002	0.147
NFC-19		1.000	0.676	0.696	0.823	0.163
NFC-35			1.000	0.975	0.843	0.070
NFC-45				1.000	0.867	0.073
LNF-1					1.000	0.103
EC-4						1.000

Median growing season diatom biovolume showed decreasing trends over time (Figure 2-28; Table 2-14). At NFC-3, NFC-19, and EC-4 peak biovolume occurred in 1995 with median concentrations ranging from 0.31 mm^3/L to 0.66 mm^3/L. *Asterionella formoso*, *Fragilaria* spp., and *Tabellaria* spp. were the principal diatoms identified at that time, and *Tabellaria* spp. was often the primary contributor to the biovolume of this group. Interestingly, *Tabellaria* spp. was not identified in the samples collected since 2005. At the three remaining locations, seasonal median biovolume peaked between 2005 and 2007 with values ranging from 0.17 mm^3/L to 0.33 mm^3/L. *Asterionella* spp., *Fragilaria* spp., *Stephanodiscus* spp., and lesser contributions from *Aulicoseira* spp. and *Gomphonema* spp.

Figure 2-28. Median May to September Diatom Biovolume at the Six Reservoir Sampling Stations from 1993 to 2016

Table 2-14. Results of the Mann-Kendall Tests Used to Evaluate Trends in the Diatom Biovolume Data

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
p-value	0.005	0.013	0.005	0.035	0.026	0.006

Chlorophyta, or green algae, are the largest and most diverse group of algae. Most members of the group have chloroplasts that contain chlorophyll a and b, which gives them a bright green color. Some species are unicellular and live as single cells while others form colonies or long filaments.

The 2012 to 2016 growing season median biovolumes calculated for the green algae were two to five times greater than the ones calculated for the diatoms. Calculated values ranged from 0.04 mm^3/L at NFC-3, 0.05 m^3/L at NFC-35 and EC-4, to 0.06 mm^3/L at the remaining three stations (Figure 2-29). With the relatively small differences, the null hypothesis that the six datasets were equal could not be rejected (Table 2-15).

Figure 2-29. Box Plots of the May to September Chlorophyta Biovolume at the Six Reservoir Monitoring Stations from 2012 to 2016

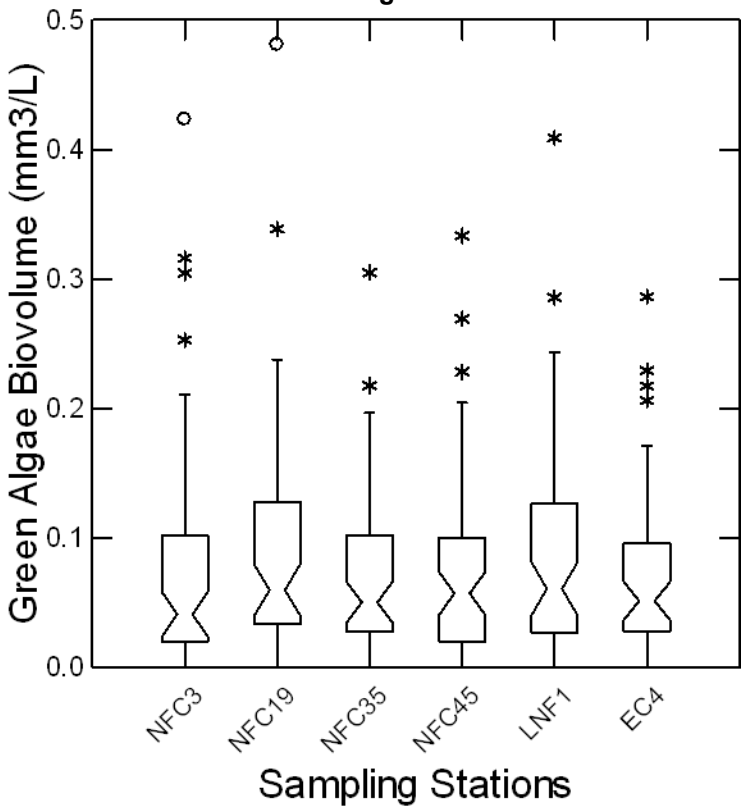


Table 2-15. Results of Conover-Inman Pairwise Comparisons Test for the 2013 to 2016 May to September Chlorophyta Biovolume at the Six Reservoir Stations

	NFC-3	NFC-19	NFC-35	NFC-45		LNF-1	EC-4
NFC-3	1.000	0.291	0.622	0.816		0.263	0.744
NFC-19		1.000	0.572	0.404		0.958	0.468
NFC-35			1.000	0.791		0.534	0.870
NFC-45				1.000		0.371	0.922
LNF-1						1.000	0.432
EC-4							1.000

Although there was inter-annual variability, the green algae biovolume at each station showed long-term increasing trends, especially during 2015 and 2016 (Figure 2-30). During the 1990s, the identified species included *Coelastrum* spp., *Cosmarium* spp., *Eudorina* spp., and *Sphaerocyctis* spp.. The relatively large 2009 increases were due to a larger presence of *Planctosphaeria* spp. which was first identified beginning with the 2005 samples. Additional species that were frequently abundant during the mid- to late 2000s included *Cosmarium* spp., *Sphaerocyctis* spp., and *Stichococcus minutissimus*. *Euglena* spp. was identified in some of the samples beginning in 2007, and by 2015 and 2016 was the species largely responsible for the increased biovolume. These algae can feed by autotrophy (i.e., producing their own complex organic compounds such as a plant does) and by heterotrophy (i.e., using plant or animal matter as a food source), and are often indicative of aquatic systems that have high concentrations of ammonia and dissolved organic matter (Wetzel 2001).

Figure 2-30. Median May to September Chlorophyta Biovolume at the Six Reservoir Sampling Stations from 1993 to 2016

Cyanophyta, also called cyanobacteria and blue-green algae, are ubiquitous to aquatic ecosystems. They are opportunistic, can crowd out other algae during a bloom, are not a food source for most zooplankton, and are able to inhabit systems that have higher temperatures and carbon dioxide concentrations than other algae. Additionally, some species are able to fix nitrogen and produce a variety of toxins.

The 2012 to 2016 growing season medians calculated for the blue-green algae were surprisingly higher than the ones calculated for the diatoms and green algae. Values ranged from 0.06 mm^3/L at NFC-3 to 0.09 mm^3/L at LNF-1 (Figure 2-31). The difference between NFC-3 and LNF-1 was also the only one considered significant, with a p-value of less than 0.05 (Table 2-16).

Figure 2-31. Box plots of the May to September Cyanophyta Biovolume at the Six Reservoir Monitoring Stations from 2012 to 2016

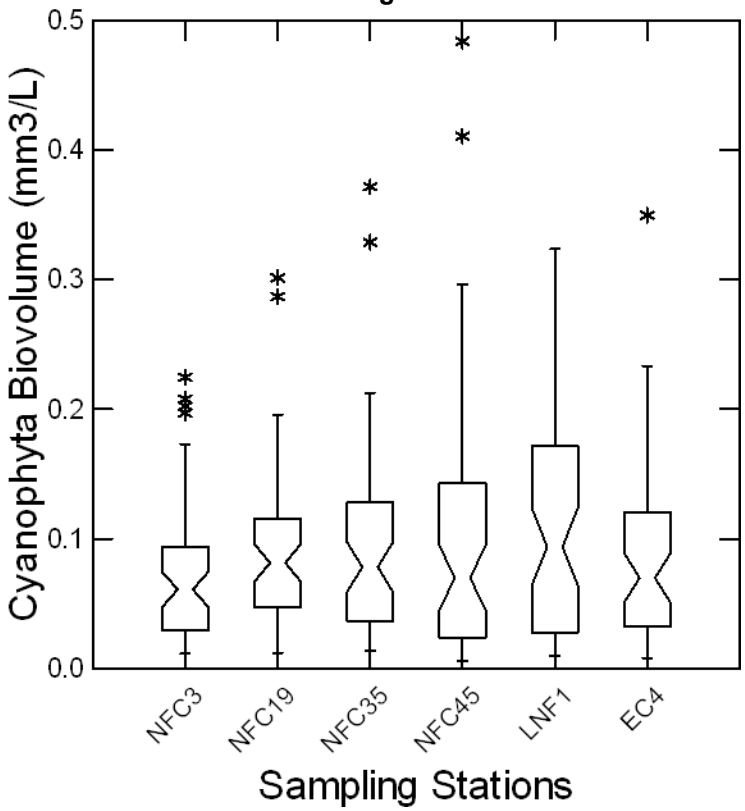


Table 2-16. Results of Conover-Inman Pairwise Comparisons Test for the 2013 to 2016 May to September Cyanophyta Biovolume at the Six Reservoir Stations

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
NFC-3	1.000	0.113	0.191	0.271	0.028	0.379
NFC-19		1.000	0.780	0.618	0.548	0.484
NFC-35			1.000	0.828	0.378	0.673
NFC-45				1.000	0.267	0.834
LNF-1					1.000	0.193
EC-4						1.000

The charts of the seasonal median cyanophyta biovolume over time at each sampling station display the same type of inter-annual variation noted for other parameters (Figure 2-32). For some stations, such as NFC-3, the biovolume appears to decrease over time. At other locations, such as LNF-1, there appears to be an increase. However, based on the results of the Mann-Kendall non-parametric test the only significant trend ($p \leq 0.05$) was the increase at LNF-1 (Table 2-17).

Figure 2-32. Median May to September Cyanophyta Biovolume at the Six Reservoir Sampling Stations from 1993 to 2016

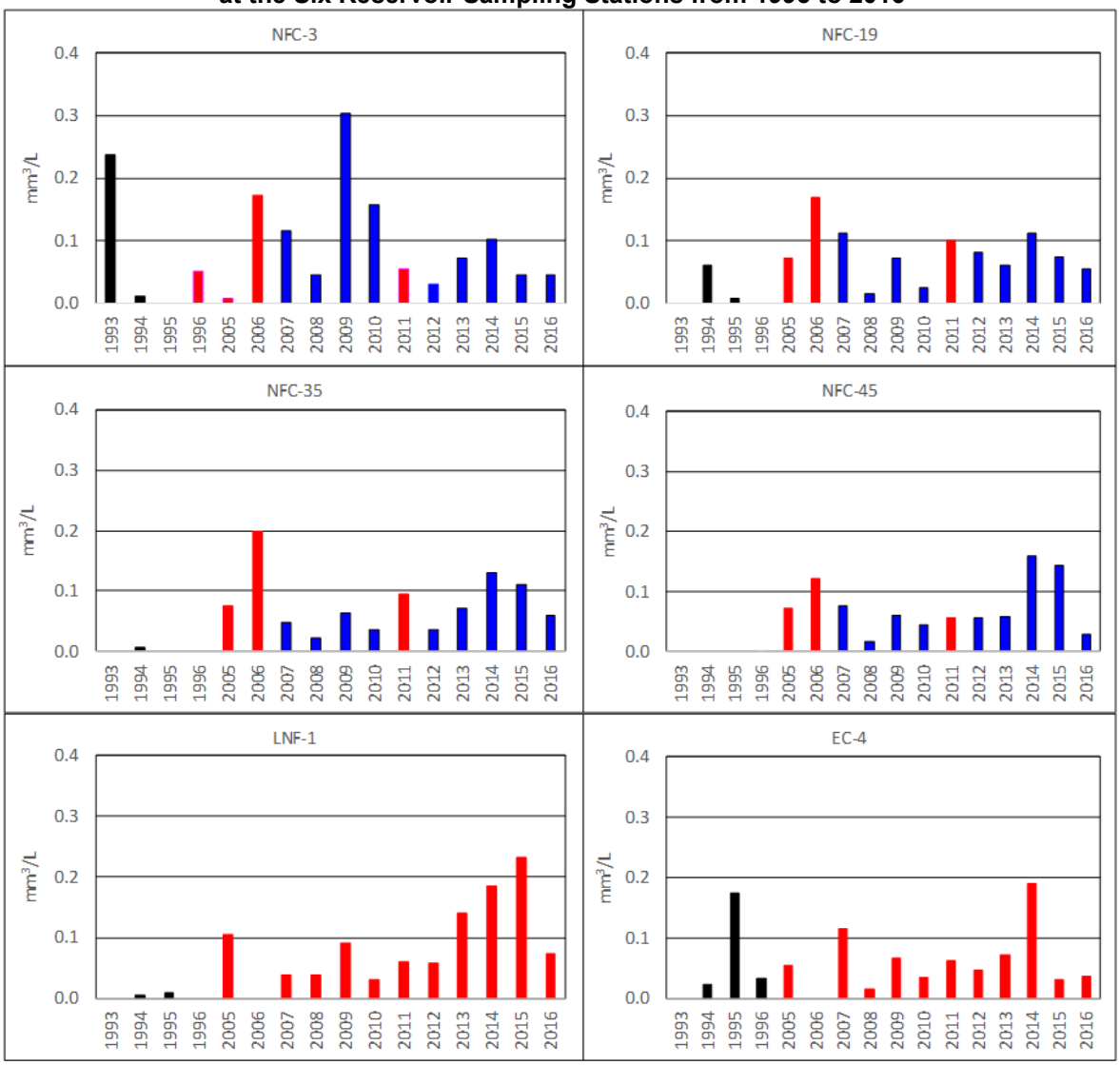


Table 2-17. Results of the Mann-Kendall Tests Used to Evaluate Trends in the Cyanophyta Biovolume Data

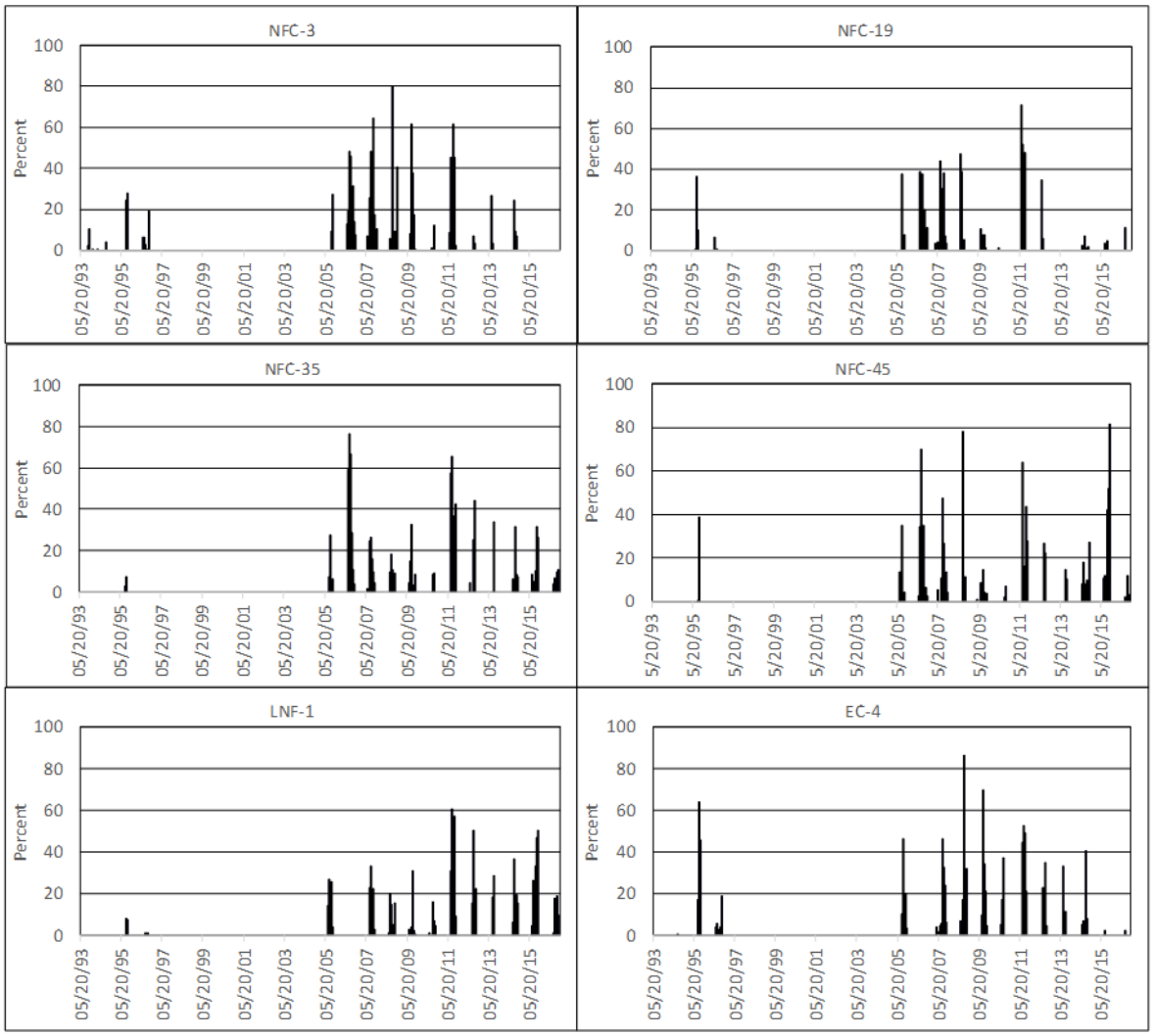
	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
p-value	0.309	0.518	0.172	0.137	0.035	0.310

Anabaena spp. is a blue-green algae that is very common in freshwater ecosystems and has the ability to fix nitrogen when the concentrations in solution are low, which gives it a competitive advantage. Because of this ability, it is of particular interest at the reservoir since one of the benefits of the nutrient supplementation program should be a decrease in the Anabaena spp. population. Seasonal median biovolumes peaked in 2006 at NFC-3, NFC-19, NFC-35, and NFC-45, with values ranging from 0.087 to 0.141 mm3/L. Maximum values occurred in different years and at lower levels: 0.096 mm3/L at LNF-1 in 2005 and 0.055 mm3/L in 2007 at EC-4. Since then, seasonal median concentrations have declined at NFC-3, NFC-19, NFC-35, and EC-4. Relatively few

Anabaena spp. were identified in the water samples collected at NFC-3, NFC-19, and EC-4 in 2015 and 2016. Median biovolumes ranging from 0.037 to 0.055 mm3/L were still determined at NFC-45 and LNF-1 during 2014 and 2015. Since 2005, there have been instances at all of the sampling locations when Anabaena spp. constituted 60 to 80 percent of the total phytoplankton biovolume (Figure 2-33). The occurrence of the elevated concentrations have decreased during the past 5 to 10 years at NFC-3, NFC-19, NFC-35, and EC-4. Periodic population increases similar to the ones that have occurred since 2005 have still been identified at NFC-45 and LNF-1 (Figure 2-33).

As the presence of Anabaena spp. has generally declined in the reservoir, other blue-green algae have become more prevalent. These include Aphanothecae spp., Chroococcus spp., and Synechococcus spp.

Figure 2-33. Percent of Total Algal Biovolume that was Attributed to Anabaena spp. at the Six Reservoir Monitoring Stations



2.1.3.3 *Picoplankton*

Picoplankton are a fraction of the plankton community that is composed of cells between 0.2 and 2 µm that can be either photosynthetic or heterotrophic. They are an important component of the ecosystem because they are able to produce and recycle dissolved matter very efficiently. This is due, in part, to their small size which leads to a greater surface to volume ratio that enables them to obtain nutrients at low concentrations. They are grazed upon by other algae, rotifers, and copepods, thereby provide energy to higher trophic levels.

Box plots of the 2012 to 2016 May to September biovolume data for the pico-cyanobacteria and heterotrophic bacteria are shown in Figure 2-34. The calculated medians for the pico-cyanobacteria at NFC-3 and NFC-19 were 0.80 mm3/L and 0.77 mm3/L, respectively. The data from these two locations is considered to be equal at p = 0.05. The median values for the remaining four stations ranged from 0.42 mm3/L at NFC-45 to 0.58 mm3/L at NFC-35, and they are considered to be equal as well. However, the median values from NFC-3 and NFC-19 are significantly greater than the ones for the other four stations (Table 2-18). The calculated median values for the heterotrophic bacteria ranged from 0.27 mm3/L at NFC-35 and LNF-1 to 0.31 mm3/L at NFC-3. The values for all six stations are considered to be equal (Table 2-19).

Figure 2-34. Box Plots of the May to September Pico-Cyanobacteria and Heterotrophic Bacteria Biovolumes at the Six Reservoir Monitoring Stations from 2012 to 2016

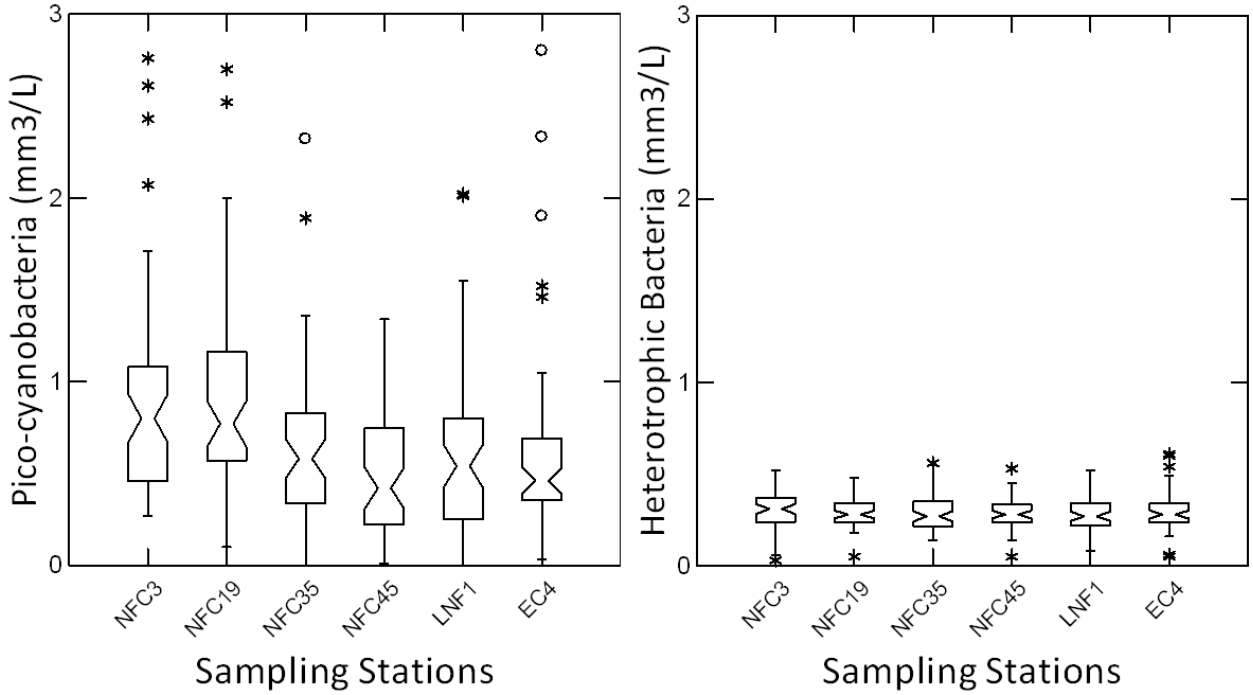


Table 2-18. Results of Conover-Inman Pairwise Comparisons Test for the 2012 to 2016 May to September Pico-Cyanobacteria Biovolume for the Six Reservoir Stations

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
NFC-3	1.000	0.530	0.005	<0.001	0.001	<0.001
NFC-19		1.000	0.001	<0.001	<0.001	<0.001
NFC-35			1.000	0.090	0.637	0.342
NFC-45				1.000	0.219	0.453
LNF-1					1.000	0.632
EC-4						1.000

Table 2-19. Results of Conover-Inman Pairwise Comparisons Test for the 2012 to 2016 May to September Heterotrophic Bacteria Biovolume for the Six Reservoir Stations

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
NFC-3	1.000	0.518	0.175	0.384	0.185	0.619
NFC-19		1.000	0.477	0.822	0.496	0.881
NFC-35			1.000	0.626	0.975	0.389
NFC-45				1.000	0.649	0.708
LNF-1					1.000	0.407
EC-4						1.000

Evaluations of the 2012 to 2016 biovolume data available for the pico-cyanobacteria and heterotrophic bacteria were also completed. The only sampling station where a significant upward trend was detected for the seasonal pico-cyanobacteria medians was at NFC-19 (Figure 2-35; Table 2-20). This result is likely influenced by the unusually low value of 0.24 mm3/L calculated for the 2008 data. Significant upward or downward trends were not present for the other datasets. Significant downward trends were determined for the analogous heterotrophic bacteria data (Figure 2-36; Table 2-21).

Figure 2-35. Median May to September Pico-Cyanobacterial Biovolume at the Six Reservoir Sampling Stations from 2007 to 2016

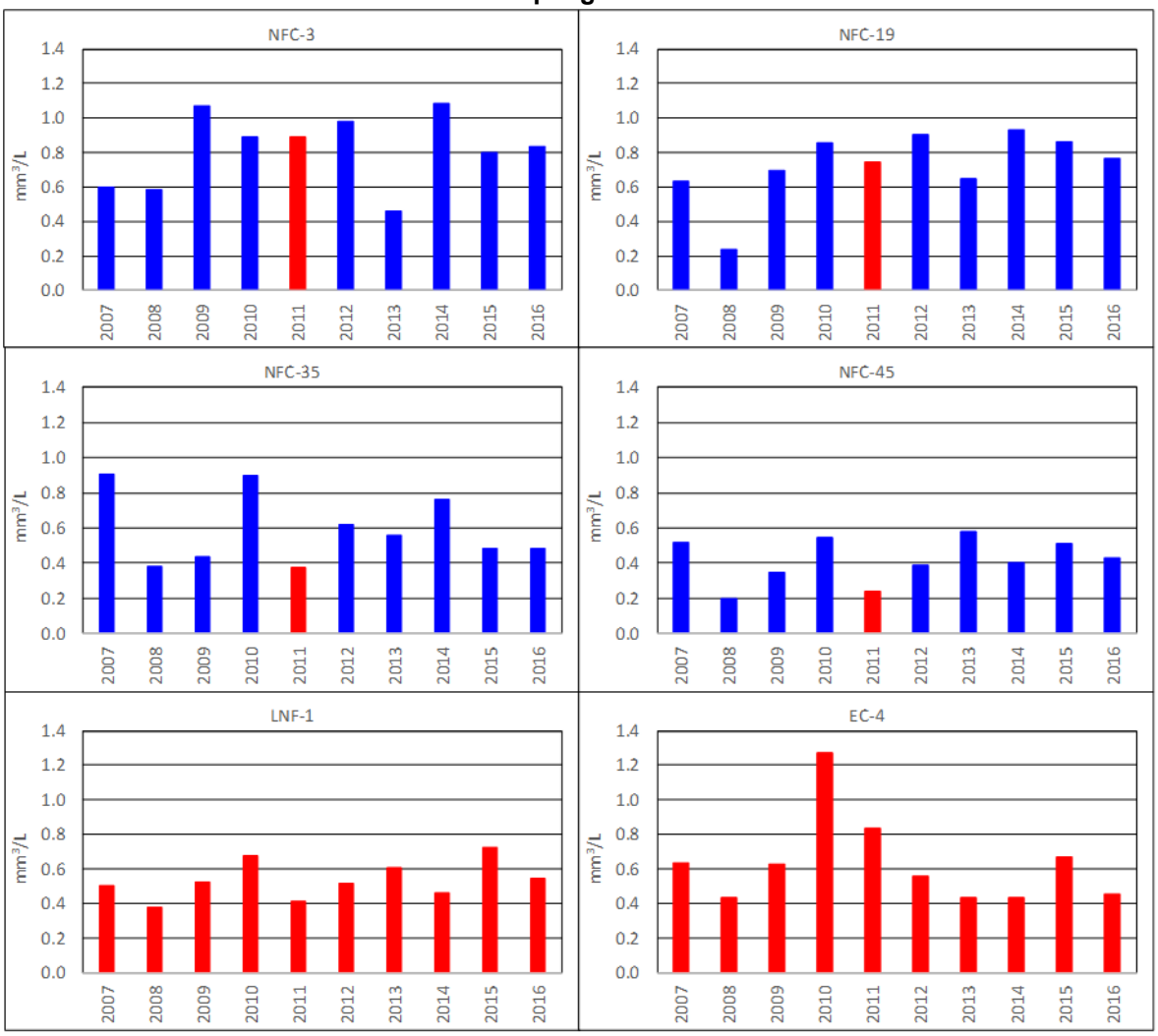


Table 2-20. Results of the Mann-Kendall Tests Used to Evaluate Trends in the Pico-Cyanophyta Biovolume Data

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
p-value	0.394	0.037	0.464	0.186	0.089	0.209

Figure 2-36. Median May to September Heterotrophic Bacteria Biovolume at the Six Reservoir Sampling Stations from 2007 to 2016

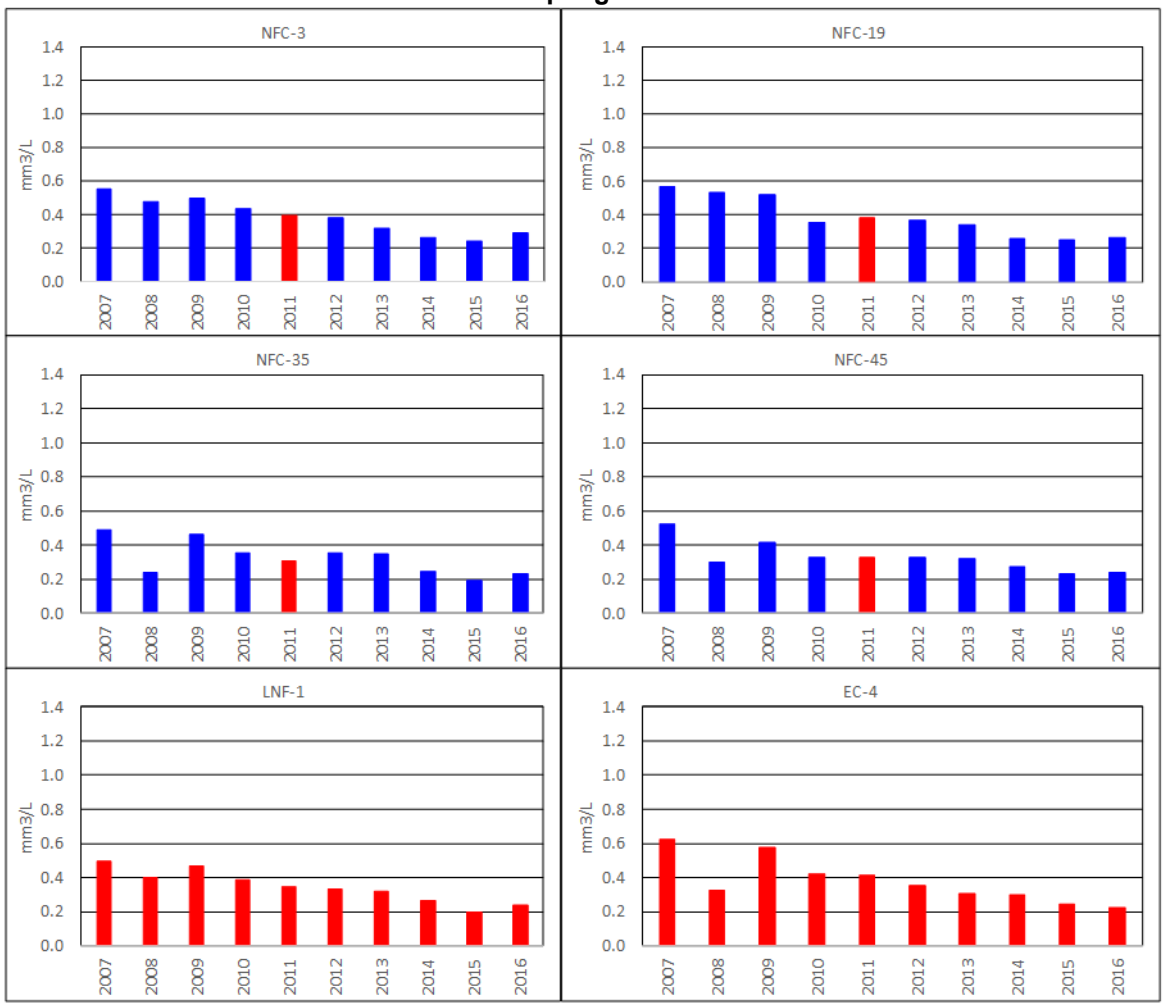


Table 2-21. Results of the Mann-Kendall Tests Used to Evaluate Trends in the Heterotrophic Bacteria Biovolume Data

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
p-value	<0.001	<0.001	0.018	0.004	<0.001	0.001

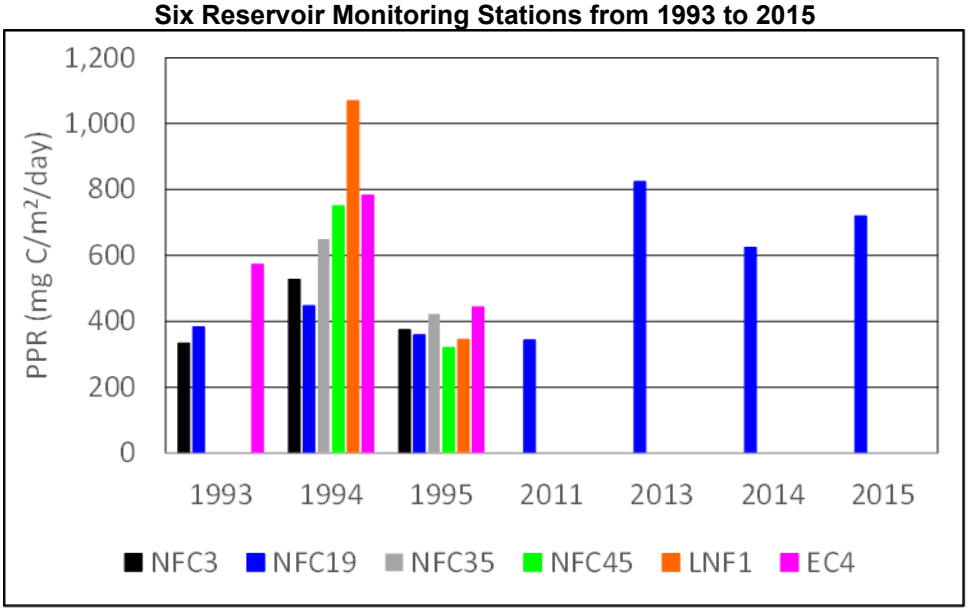
2.1.3.4 *Primary Productivity*

Primary productivity is a measure of the amount of carbon per unit time produced by all aquatic plants. As primary producers form the base of the food chain, the level of primary productivity ultimately dictates the productivity of the entire ecosystem.

Primary productivity is a measure of the rate of carbon uptake by phytoplankton. Assessments were completed at three reservoir stations (NFC-3, NFC-19, and EC-4) in 1993 (Figure 2-37). The growing season averages for NFC-3 and NFC-19 were similar at 334 milligrams carbon per square meter per day (mgC/m2/day) and 383 mgC/m2/day, respectively, and greatest was at EC-4 where the mean was 573 mgC/m2/day. Primary productivity evaluations were completed at all six reservoir

stations in 1994 and 1995. The 1994 growing season averages were the highest measured during the 1990s, reaching 1,070, 783, and 751 mgC/m2/day at LNF-1, EC-4, and NFC-45, respectively. Rates increased at the two sites by 15 to 37 percent. Primary productivity rates declined in 1995 with station averages ranging from 320 to 444 mgC/m2/day, and a reservoir average of 377 mgC/m2/day. Brandt (2017) began primary productivity assessments in 2011 at NFC-19, which has a computed seasonal average uptake rate of 343 mgC/m2/day. This value compares favorably with the 1994 and 1995 rates of 448 mgC/m2/day and 359 mgC/m2/day, respectively, determined for the same location. The average for the three subsequent years when nutrient supplementation occurred was 718 mgC/m2/day.

Figure 2-37. Median Daily Primary Productivity Rates at the Six Reservoir Monitoring Stations from 1993 to 2015



2.1.3.5 *Zooplankton*

The term zooplankton refers to invertebrate animals living in the water column of freshwater bodies. These planktonic animals are typically divided into three major groups based on taxonomy: the phylum Rotifera, and two orders of Crustacea, Cladocera and Copepoda (the Rotifera were included in the sample analyses completed in the 1990s but not in the ones completed since 2004). Zooplankton feed by filtering and/or grazing, and are primary consumers that feed on algae, organic detritus, and bacteria, with a few predaceous species that also prey on smaller crustaceans and rotifers (Pennak 1989). Zooplankton serve as a food base for larger crustaceans, aquatic insects, and planktivorous fish, and are therefore considered secondary producers (Kerfoot and Sih 1987; Pennak 1989). Zooplankton assemblages are expressed in terms of total biomass, population densities, or species composition. Species composition is usually determined first through enumeration and identification of the various organisms in a sample. Total biomass is then calculated through established length/width relationships for each species type.

Daphnia spp. are of interest since they are a primary food source for planktivorous fish in the reservoir. Based on the 2012 to 2016 May to September data, the median Daphnia spp. biomass at NFC-3 was 147 mm3/L (Figure 2-38), which was significantly greater than at the other five sampling locations (Table 2-22). The lowest median was determined for NFC-45 at 73 mm3/L followed closely by LNF-1 at 78 mm3/L.

Figure 2-38. Box Plots of the May to September *Daphnia* spp. Biomass at the Six Reservoir Monitoring Stations from 2012 to 2016

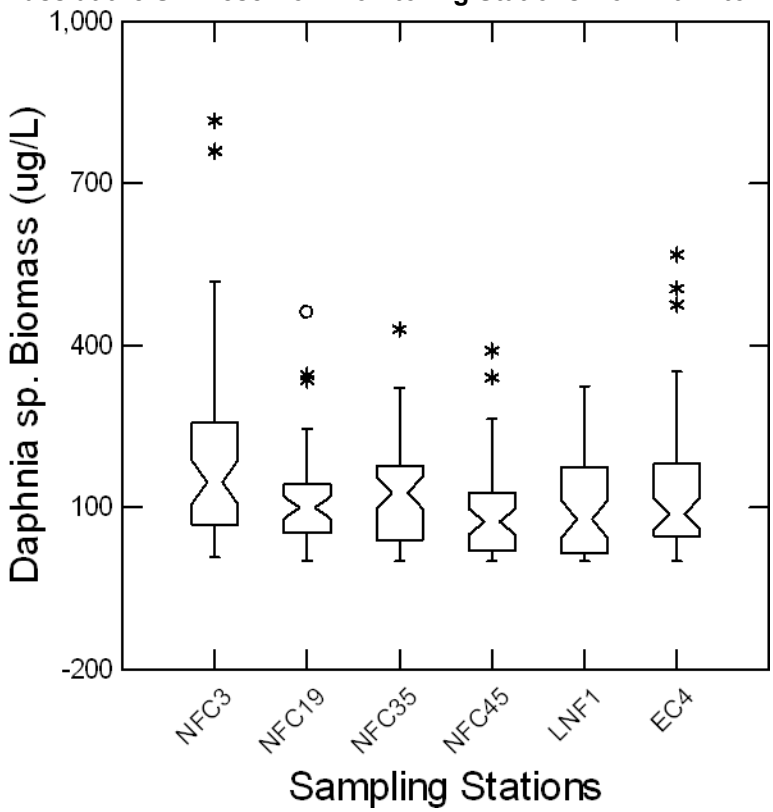


Table 2-22. Results of Conover-Inman Pairwise Comparisons Test for the 2012 to 2016 May to September *Daphnia* spp. Biomass at the Six Reservoir Stations

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
NFC-3	1.000	0.019	0.018	<0.001	<0.001	0.026
NFC-19		1.000	0.992	0.069	0.172	0.914
NFC-35			1.000	0.070	0.173	0.905
NFC-45				1.000	0.655	0.056
LNF-1					1.000	0.143
EC-4						1.000

The long-term trends for *Daphnia* spp. biomass show increases at NFC-3 and EC-4 (Figure 2-39; Table 2-23). When all of the data from LNF-1 is considered, a significant change over time is not present. However, if only the data from 2007 to 2016 is evaluated, then a decrease is apparent.

Figure 2-39. Median May to September *Daphnia* spp. biomass at the Six Reservoir Sampling Stations from 1993 to 2016

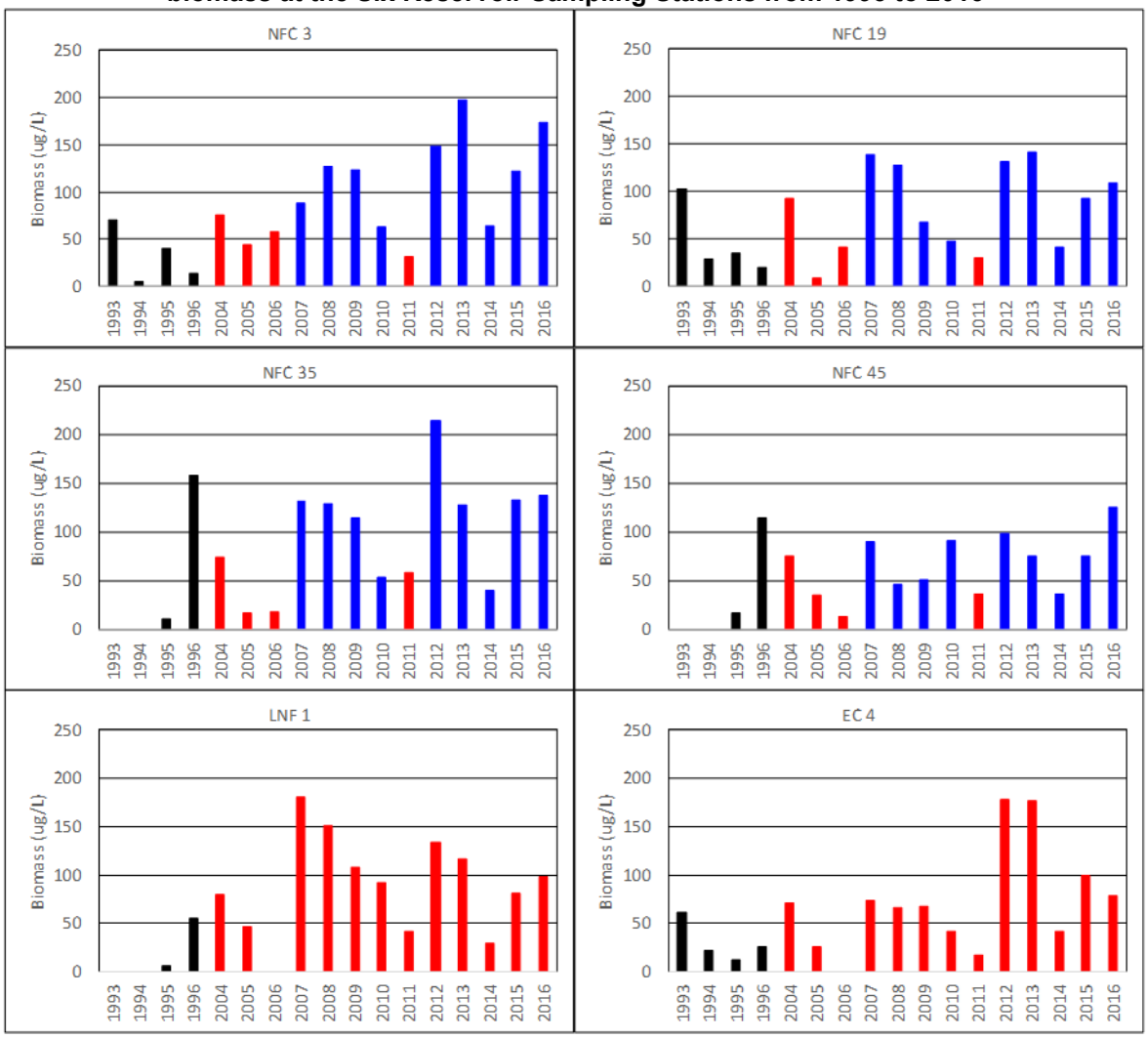


Table 2-23. Results of the Mann-Kendall Tests Used to Evaluate Trends in the *Daphnia* spp. Biomass Data

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
p-value	0.004	0.174	0.083	0.138	0.346	0.026

Copepoda biomass was not determined for the 2004 to 2016 data set, but density was and will be used as a comparison to Cladocera density. The median density of the Copepoda at each of the sampling stations was greater during the 2012 to 2016 period than it was for the Cladocera (Figure 2-40). For both groups, the lowest calculated medians occurred at NFC-45 and the highest were determined for EC-4, and the median values increased downstream from NFC-45 to NFC-3. The significant differences ($p \leq 0.05$) between stations were also quite similar (Table 2-24 and Table 2-25) with the exception of the NFC-19/EC-4 and NFC-45/LNF-1 comparisons for the Cladocera density (Table 2-26).

Figure 2-40. Box plots of the May to September Copepoda and Cladocera Density at the Six Reservoir Monitoring Stations from 2012 to 2016

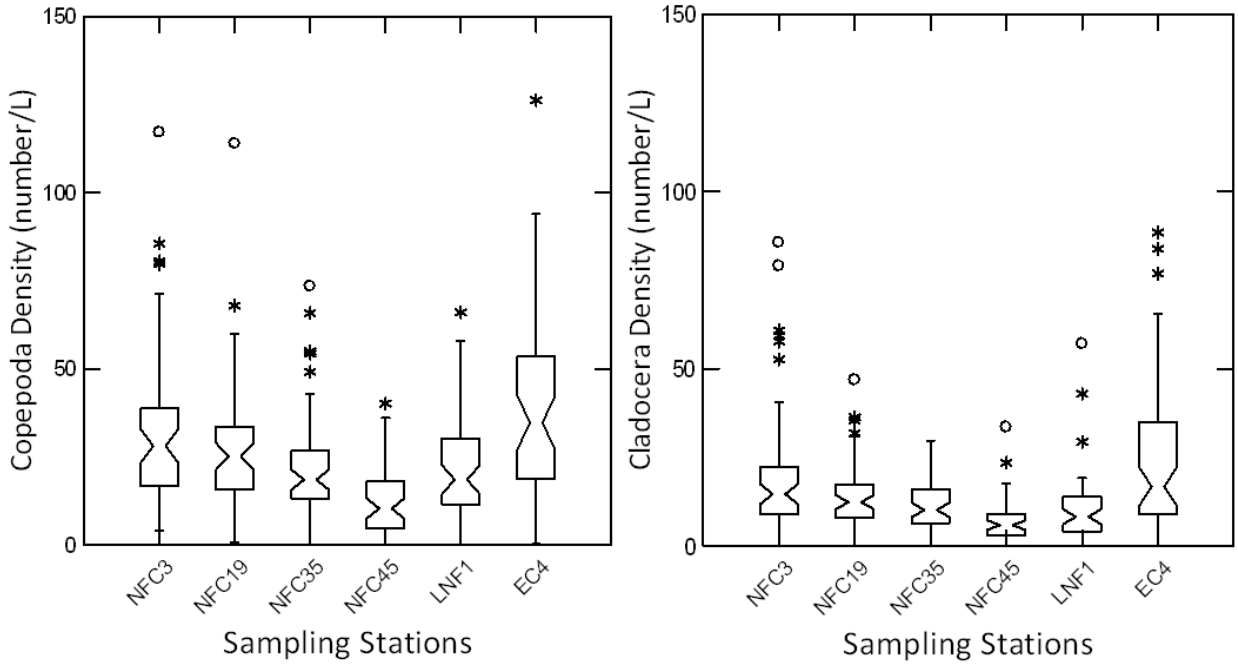


Table 2-24. Results of Conover-Inman Pairwise Comparisons Test for the 2012 to 2016 May to September Copepoda Density at the Six Reservoir Stations

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
NFC-3	1.000	0.149	0.001	0.000	0.000	0.312
NFC-19		1.000	0.046	0.000	0.015	0.014
NFC-35			1.000	0.001	0.639	0.000
NFC-45				1.000	0.003	0.000
LNF-1					1.000	0.000
EC-4						1.000

Table 2-25. Results of Conover-Inman Pairwise Comparisons Test for the 2012 to 2016 May to September Cladocera Density at the Six Reservoir Stations

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
NFC-3	1.000	0.313	0.016	0.000	0.000	0.387
NFC-19		1.000	0.158	0.000	0.004	0.062
NFC-35			1.000	0.001	0.145	0.001
NFC-45				1.000	0.065	0.000
LNF-1					1.000	0.000
EC-4						1.000

The long-term trends in the Copepoda and Cladocera data were evaluated using the approach used for the other parameters. The caveat to the analysis is that the 1996 densities reported for the Copepoda and Cladocera at NFC-35 and NFC-45, as well as the Copepoda density at LNF-1, appear abnormally high compared to the other data points (Figure 2-41 and Figure 2-42). Since it is difficult to verify data points that are over 20 years old and since no data was collected between 1996 and 2004, those data points were not included in the trend analysis.

The results of the Mann-Kendall tests showed that there are increasing trends for both the Copepoda and Cladocera at NFC-3, NFC-19, and NFC-35 (Table 2-26 and Table 2-27). The results for the two groups differed at the remaining sampling stations. The Copepoda density showed an increase at NFC-45 and LNF-1, but not at EC-4 (Table 2-26). The results for the Cladocera density were the opposite (Table 2-27).

Figure 2-41. Median May to September Copepoda Density at the Six Reservoir Sampling Stations from 1993 to 2016

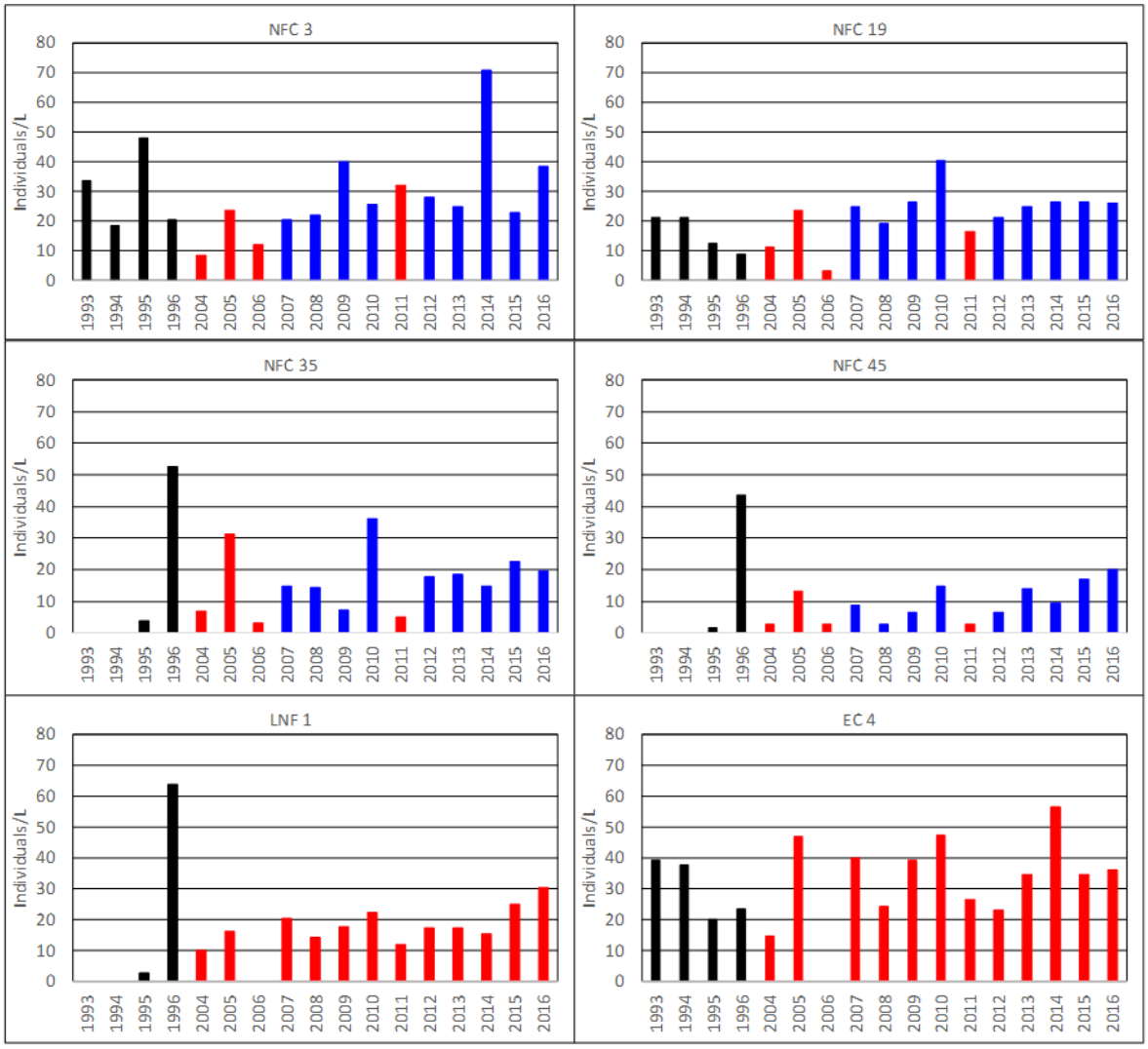


Table 2-26. Results of the Mann-Kendall Tests Used to Evaluate Trends in the Copepoda Density Data

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
p-value	0.075	0.015	0.024	0.001	0.007	0.268

Figure 2-42. Median May to September Cladocera Density at the Six Reservoir Sampling Stations from 1993 to 2016

Table 2-27. Results of the Mann-Kendall Tests Used to Evaluate Trends in the Cladocera Density Data

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
p-value	0.009	0.009	0.002	0.161	0.069	0.002

2.1.3.6 *Coliforms*

No fecal coliform data has been identified for Dworshak Reservoir, although it is possible that water samples from swim areas have been collected and analyzed that would help characterize current conditions.

2.1.4 Trophic State Classification

The trophic state of a lake or reservoir has been defined in various ways over the years. Three common classifications are oligotrophic, mesotrophic, and eutrophic. Oligotrophic conditions represent high-quality waters with good water clarity, low nutrient content,

and low algal production, while eutrophic conditions represent high nutrient levels, excessive algal growth, and poor water clarity (Welch 1992, Wetzel 2001). Mesotrophic conditions are somewhere in the middle and typically represent moderate levels of algal production, water clarity, and light transparency.

Several metrics have also been used to express the trophic state of a water body. These indices include nutrient loading, nutrient concentration, light penetration, chlorophyll a concentration, algal or zooplankton species and abundance, oxygen concentration, aquatic vegetation, and other limnological parameters used individually or combined. The Carlson Trophic State Index (TSI) is one of the more commonly used trophic indices and is the one used by the EPA. Three independent variables can be used to calculate the Carlson TSI: Secchi disk depth, chlorophyll a concentration, and total phosphorus concentrations. Calculated values of less than 40, 40 to 50, and 50 to 70 represent oligotrophic, mesotrophic, and eutrophic conditions, respectively (Chapra and Reckow 1983).

Box plots based on 2012 to 2016 May to September data from the six sampling stations for the three Carlson TSIs are presented in Figure 2-43. The spatial pattern for the Secchi disk TSI is the opposite of the Secchi disk depths presented earlier (see Figure 2-10) since the TSI is based on the assumption that trophic status increases with decreasing Secchi disk depth. The median values for the Secchi disk TSI are in the 40 to 50 range, which places the reservoir in the mesotrophic category (Figure 2-46). The TSI graphs for chlorophyll a and total phosphorus follow the same spatial patterns presented for the concentrations (see Figure 2-16 and Figure 2-22, respectively). The calculated median chlorophyll a and total phosphorus TSIs are both less than 40 at all of the sampling locations, which places the reservoir in the oligotrophic category (Figure 2-45).

The Conover-Inman test for each TSI produced mixed results. For the Secchi disk TSI, the median at NFC-3 is significantly lower than at the other locations, and that at EC-4 is higher than the other five. The only significant differences for the chlorophyll a TSI are between NFC-3, NFC-35, and LNF-1. Finally, the total phosphorus TSI for EC-4 is significantly higher than the ones for NFC-19, NFC-35, and LNF-1.

The primary productivity rate can also be used as a trophic state indicator. Welch (1992) provides information suggesting that rates from 30 to 100 $mgC/m^2/day$ represent oligotrophic conditions and rates ranging from 300 to 3,000 $mgC/m^2/day$ are indicative of eutrophic conditions. Mesotrophic waterbodies would be between 100 and 300 $mgC/m^2/day$. Based on this classification, the reservoir would be considered mesotrophic to eutrophic. However, as Welch (1992) also states, the use of areal productivity may be misleading since it depends as much on light availability as on nutrients.

Figure 2-43. Box Plots of the May to September Carlson Trophic State Indices for Secchi Disk Depth, Chlorophyll a Concentration, and Total Phosphorus Concentration for the Six Reservoir Monitoring Stations from 2012 to 2016

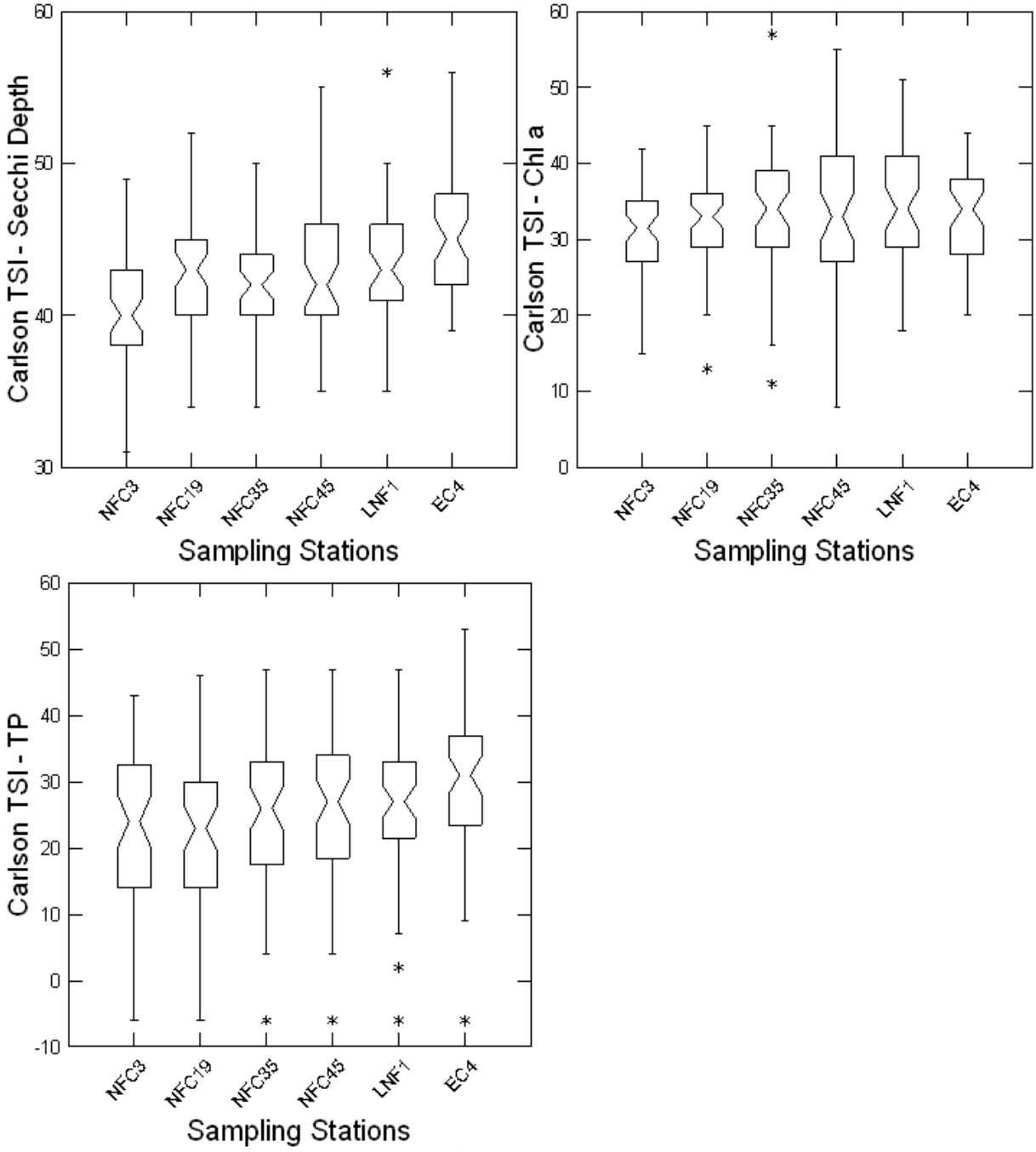


Table 2-28. Results of Conover-Inman Pairwise Comparisons Test for the 2012 to 2016 May to September Secchi Disk Carlson Trophic State Index for the Six Reservoir Stations

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
NFC-3	1.000	0.003	0.023	0.001	<0.001	<0.001
NFC-19		1.000	0.443	0.746	0.361	0.001
NFC-35			1.000	0.275	0.093	<0.001
NFC-45				1.000	0.556	0.002

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
LNF-1					1.000	0.013
EC-4						1.000

Table 2-29. Results of the Conover-Inman Pairwise Comparisons Test for the 2012 to 2016 May to September Chlorophyll a Carlson Trophic State Index for the Six Reservoir Stations

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
NFC-3	1.000	0.368	0.026	0.144	0.009	0.107
NFC-19		1.000	0.181	0.572	0.087	0.476
NFC-35			1.000	0.439	0.699	0.532
NFC-45				1.000	0.248	0.882
LNF-1					1.000	0.314
EC-4						1.000

Table 2-30. Results of the Conover-Inman Pairwise Comparisons Test for the 2012 to 2016 May to September Total Phosphorus Carlson Trophic State Index for the Six Reservoir Stations

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
NFC-3	1.000	0.379	0.601	0.222	0.349	0.002
NFC-19			0.162	0.036	0.070	<0.001
NFC-35				0.484	0.678	0.010
NFC-45					0.775	0.061
LNF-1						0.031
EC-4						1.000

Figure 2-44. Median May to September Secchi Disk Carlson Trophic State Indices at the Six Reservoir Sampling Stations from 1994 to 2016

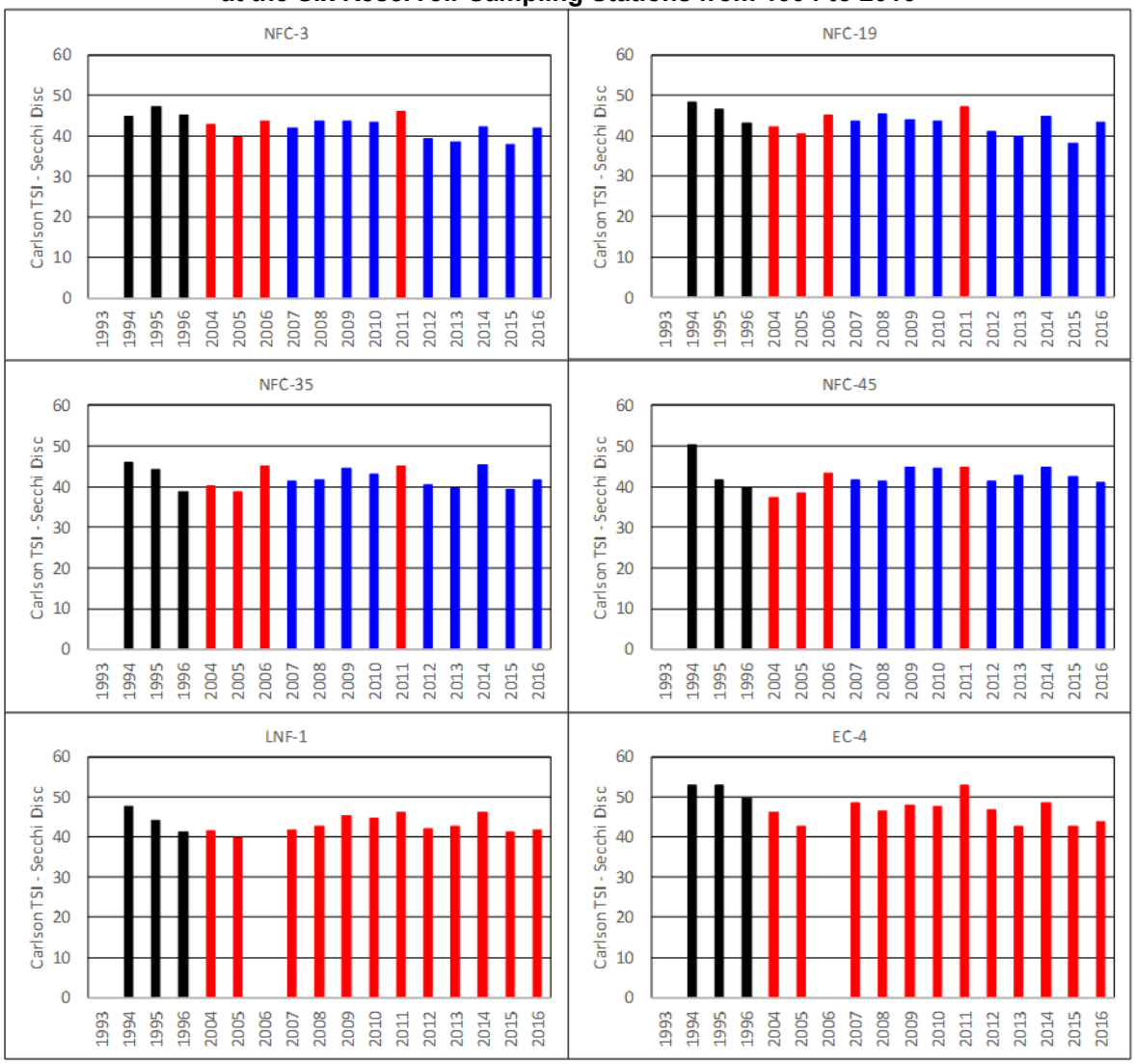


Table 2-31. Results of the Mann-Kendall Tests used to Evaluate Trends in the Secchi Disk Carlson Trophic State Index Data

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
p-value	0.007	0.051	0.410	0.247	0.625	0.066

Figure 2-45. Median May to September Chlorophyll a Carlson Trophic State Indices for the Six Reservoir Sampling Stations from 1993 to 2016

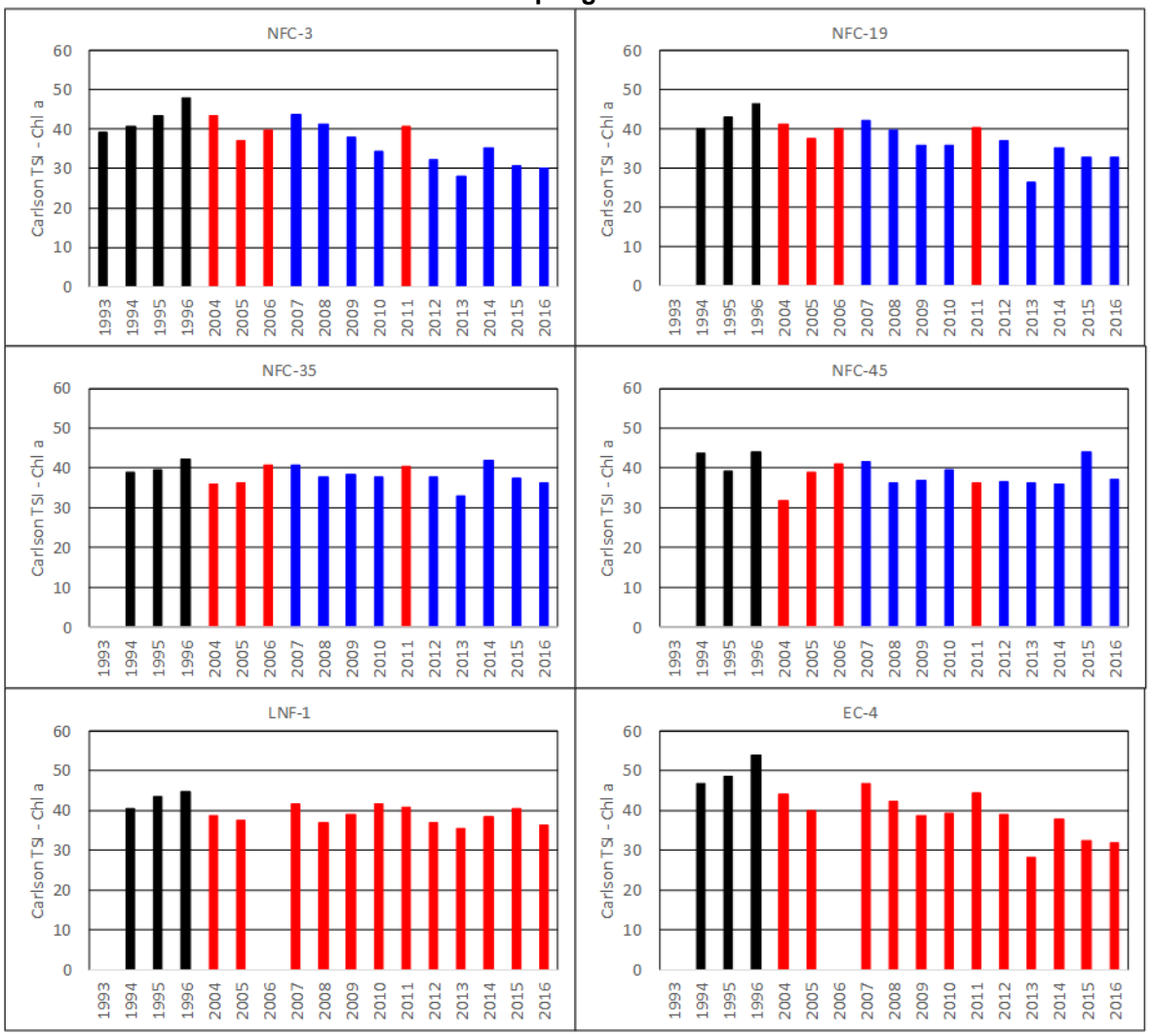


Table 2-32. Results of the Mann-Kendall Tests Used to Evaluate Trends in the Chlorophyll a Carlson Trophic State Index Data

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
p-value	0.002	<0.001	0.166	0.009	0.039	<0.001

Figure 2-46. Median May to September total phosphorus Carlson Trophic State Indices Determined for the Six Reservoir Sampling Stations from 1993 to 2016

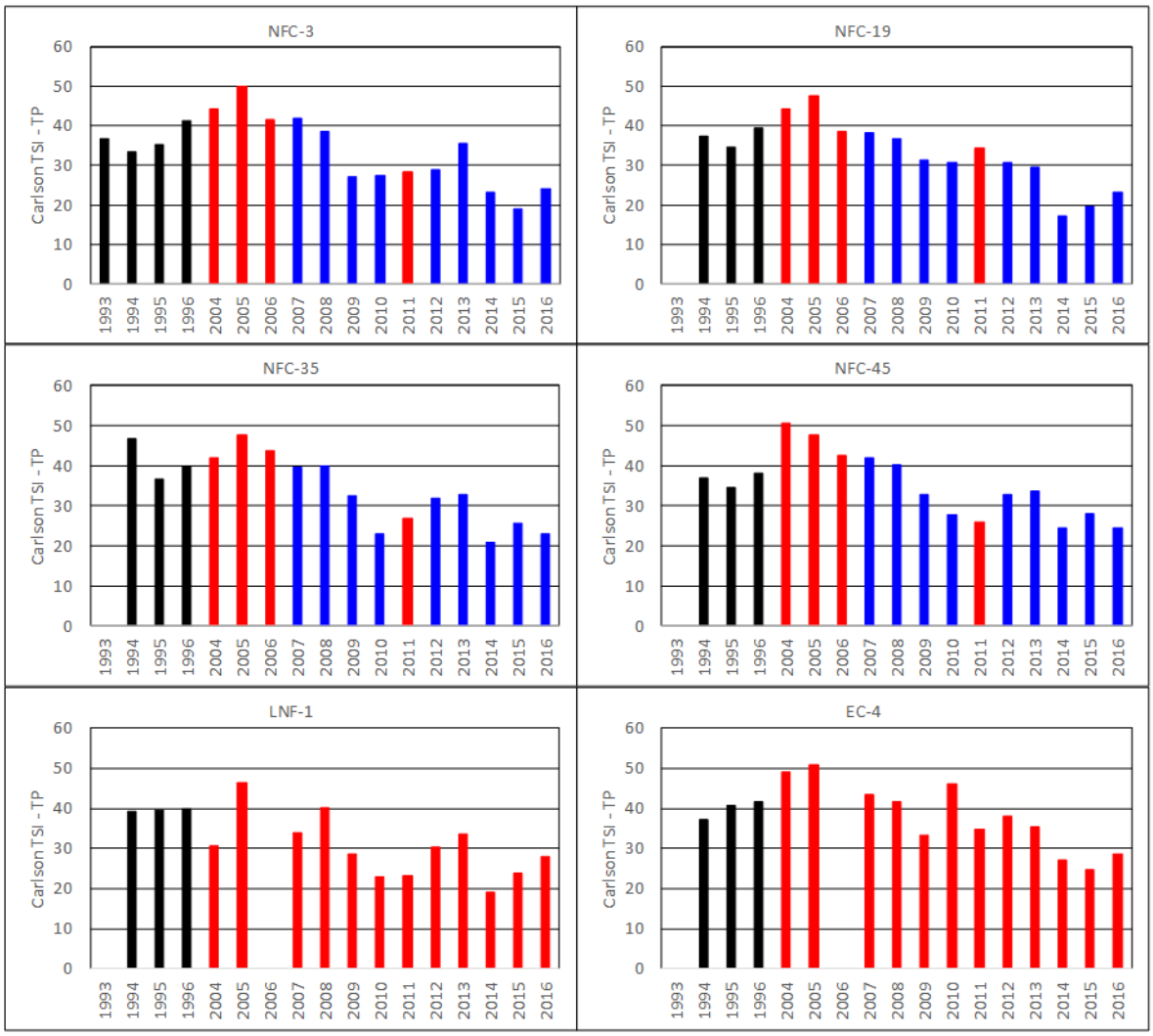


Table 2-33. Results of the Mann-Kendall Tests Used to Evaluate Trends in the total phosphorus Trophic State Index Carlson data

	NFC-3	NFC-19	NFC-35	NFC-45	LNF-1	EC-4
p-value	0.007	<0.001	0.001	0.002	0.004	0.007

SECTION 3 - SUMMARY

Dworshak is a cold, soft-water reservoir located on the North Fork Clearwater River in Idaho, which was completed in 1972. The reservoir is 54 miles long and has a surface area at full pool of 17,040 acres. Maximum storage volume is about 3.5 Maf while usable storage capacity is 2.0 Maf. Maximum depth in the forebay is almost 650 feet.

Authorized Dworshak project purposes include hydropower, flood control, fish and wildlife, recreation, and navigation. During the first 20 years of operation the reservoir was kept at full pool during the summer and drafted during the late fall and winter for power production. Since the mid-1990s, cold water releases during the summer for downstream temperature management have also become part of project operations and the reservoir elevation is lowered by approximately 80 feet between the beginning of July and mid-September.

This operational change has influenced outflow and hydrologic residence times. The average annual outflow from the project is about 5.3 kcfs, but this increases to 10 to 12 kcfs during July and August when summer flow augmentation occurs. The maximum project release from the powerhouse and spillbays or regulating outlets that can occur without exceeding the State of Idaho's TDG standard of 110 percent is about 14 kcfs. The average annual hydrologic residence time for the reservoir is about 475 days, but this decreases to less than 200 days during July and August when inflow is low and outflow relatively high.

The lower third of the reservoir is monomictic while the remaining upper two-thirds is dimictic. The epilimnion is 30 to 40 feet deep and temperatures exceed 68°F during the summer. The average temperature of the hypolimnion is about 39°F year round and is the source of water for downstream cooling. July and August outflow water temperatures average 45 to 46°F, which is considerably less than pre-dam temperatures that typically exceeded 68°F during the same time period. The effect of the cold water releases on the mainstem Clearwater River was evaluated by examining historic records from the USGS gaging station at Peck, which is about 5.5 miles downstream from the project. The analysis showed that current maximum July and August water temperatures average 52 to 54°F compared to the historic average of 69 to 71°F.

In 2007, the Corps started a 5-year pilot study in conjunction with the IDFG to assess the feasibility of increasing biological productivity in the reservoir by adding liquid inorganic fertilizer as mentioned in Section 1.2. The program progressed for 4 years, was halted in 2011, and resumed in 2012. The program is now funded annually.

The measured concentrations of nutrients in the reservoir have changed over time, but how much of these shifts can be attributed to the nutrification program, different analytical techniques, or reservoir nutrient loading from the watershed cannot be determined. However, the same pattern of changes have occurred throughout the reservoir regardless of whether a specific area was fertilized or not. Current May to September epilimnetic NO_2+NO_3-N concentrations at all of the sampling locations are <

0.001 mg/L, which is in many cases an order of magnitude less than they were in the mid-1990s and the 2004 to 2009 interval. Median concentrations in the outlet have not changed significantly over time and typically range between 0.02 and 0.04 mg/L. Median 2012 to 2016 total phosphorus concentrations in the epilimnion during the same months range from 0.004 to 0.007 mg/L. In comparison, median concentrations in the mid-1990s ranged from 0.008 mg/L to 0.015 mg/L. Concentrations in the outlet during 2014 to 2016 were 0.003 mg/L, whereas during prior years they were typically twice that amount.

The May to September data that represents the primary producers also displayed differences between sampling locations and over time regardless of whether the area was fertilized or not. Median 2012 to 2016 growing season chlorophyll a concentrations ranged from 1.10 µg/L at NFC-3 to 1.46 µg/L at NFC-35, and show a decreasing trend since the mid-1990s at all sampling locations. Diatom biovolume has also decreased over time throughout the reservoir and currently has calculated medians of 0.01 mm^3/L at NFC-3 and EC-4, and 0.03 mm^3/L at the remaining sampling stations. The primary contributors included *Asterionella* spp., *Fragilaria* spp., *Stephanodiscus* spp., and lesser amount of *Aulicoseira* spp. and *Gomphonema* spp. Green algae biovolume was not statistically different at the six reservoir stations, ranging from 0.04 mm^3/L at NFC-3 to 0.06 mm^3/L at NFC-19, NFC-45, and LNF-1. The notable trend in the chlorophyta community has been the strong emergence of *Euglena* spp. during the last few years that has led to a significant increase in green algae biovolume at all of the sampling locations. Cyanophyta biovolume was equal at five of the sampling locations with median values ranging from 0.06 to 0.08 mm^3/L at NFC-19 and NFC-35. The 0.09 mm^3/L determined for LNF-1 was considered significantly higher. The presence of *Anabaena* spp. blooms has always been ephemeral and there have been numerous occasions in the past when 60 to 80 percent of the phytoplankton biovolume has been attributed to this species. Their occurrence appears to have declined at four of the sampling locations, the two exceptions being LNF-1 and NFC-45 at the upper end of the reservoir. With the decline of *Anabaena* spp., other species such as *Aphanothecae* spp., *Chroococcus* spp., and *Synechococcus* spp. have become more prevalent.

Dissolved oxygen concentrations in the reservoir are, to some extent, influenced by the phytoplankton. Percent saturation in the epilimnion is usually close to 100 percent, and upwards to 120 percent at times, probably a result of algal photosynthesis. However, instances of low oxygen concentrations in the metalimnion appear to be increasing. These could be the result of phytoplankton that settle out of the epilimnion and into the metalimnion where the water density increases and decay, which uses oxygen.

Zooplankton are secondary producers and consist of Cladocera, Copepoda, and Rotifera. Rotifera were included in earlier datasets, but not in the more recent one that began in 2004. *Daphnia* sp., a Cladocera, are of interest since they are a primary food source for planktivorous fish. The median 2012 to 2016 May to September biomass determined for NFC-3 was 147 µg/L. This value was significantly higher than the calculated medians for the other locations, which ranged from 73 to 127 µg/L and were considered statistically equal. Trend analyses showed that *Daphnia* spp. biomass has increased at NFC-3 and EC-4, but remained the same at the other locations. One

caveat is at LNF-1, where a decrease has occurred if only the 2007 to 2016 period is considered. Median Copepoda density ranged from a low of 10 individuals/L at NFC-45 to 35 individuals/L at EC-4 and showed increasing trends at all of the samplings stations with the exception of EC-4.

The Carlson TSI is widely used as one indicator of a lake or reservoir's trophic state. The median Secchi disk TSIs were all between 40 and 45, which is considered the mesotrophic range. NFC-3 was significantly lower than the other sampling locations while EC-4 was higher. Since the Secchi disk TSI results are the inverse of the Secchi disk depth, it should be noted that the TSI assumes that Secchi disk depth is a function of the algae present. That is true to some extent at this reservoir, but Secchi disk depth measurements are also likely reduced by the presence of inorganic particulate matter in the water column. The median chlorophyll a and total phosphorus TSIs were between 20 and 30, which is considered oligotrophic.

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