US Army Corps
of Engineers®
Portland District

WATER QUALITY REPORT

LITTLE GOOSE RESERVOIR, LAKE BRYAN
COLUMBIA RIVER BASIN
SNAKE RIVER, WASHINGTON

Little Goose Reservoir, Lake Bryan

Water Quality Report
August 2020

EXECUTIVE SUMMARY

Little Goose Reservoir, also known as Lake Bryan, is a run-of-river reservoir created by Little Goose Dam located at Snake River Mile (RM) 70.3 (Figure 1-1). The reservoir extends 37.2 miles upstream to Lower Granite Dam. Authorized purposes are power generation and inland navigation. Other uses include fishery and recreation. Table 1-1 summarizes some key elements of the Little Goose Dam project.

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ACRONYMS

Acronym	Description
µg/L	Micrograms Per Liter
$\mu m^3/L$	Cubic Micrometers Per Liter
µS/cm	Microsiemens per Centimeter
BiOp	Biological Opinion
Bonneville	Bonneville Power Administration
Corps	U.S. Army Corps of Engineers
EPA	U.S. Environmental Protection Agency
GOES	Geostationary Operational Environmental Satellite
HRT	Hydrologic Residence Time
$mg\ ^{12}C/m^3/hr$	Milligrams Carbon-12 Per Cubic Meter Per Hour
mg/L	Milligrams Per Liter
msl	Mean Sea Level
NOAA	National Oceanic and Atmospheric Administration
NTU	Nephelometric Turbidity Unit
RM	River Mile
SNR-82	Little Goose Pool at River Mile 82
TDG	Total Dissolved Gas
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TSI	Trophic State Index

SECTION 1 - INTRODUCTION

1.1 STUDY AREA

The Snake and Clearwater Rivers are the two primary sources of flow into Lower Granite Lake. The Snake River originates in western Wyoming at Yellowstone National Park and flows approximately 1,000 miles through the states of Idaho, Washington, and Oregon. The Clearwater River originates in the Bitterroot Mountains near the Montana border and flows west to where it joins the Snake River at Lewiston, Idaho. The two drainage basins have a combined area of approximately 93,884 square miles upstream of the confluence at Lewiston, Idaho, and Clarkston, Washington. The topography within the basin ranges from steep mountainous areas, mainly in the upper headwater areas, to extensive volcanic plateaus and plains that have been deeply incised by the river over geologic time. The Snake River flows through several different physiographic provinces including the Columbia Plateau/Basalt Plain, which extends east from the foothills of the Cascade Range in Washington and Oregon to western Idaho; the Snake River Plain, which extends from southeastern Oregon, across southern Idaho and northern Nevada and Utah; the Blue Mountains province, which extends from southeastern Washington to central Oregon; and the Northern Rocky Mountains province, which encompasses much of Idaho and Wyoming (Bonneville Power Administration [Bonneville] 1995). Elevations range from approximately 500 feet above mean sea level (msl) along the gorges of the lower Snake River in the Columbia Plateau physiographic province to more than 10,000 feet above msl in the mountains (Bonneville 1995). The geology primarily consists of basaltic and granitic rocks, and to a lesser extent, consolidated sedimentary rocks and alluvium. Soils within the drainage area of the Snake River generally consist of young alluvial materials along the lower terraces of the river and a fine wind-deposited loess in large areas of the uplands in the Columbia Plateau. In addition, areas of glacial outwash and lake-bed silts caused by past glacial activity can be found in the Columbia Plateau. Soils within the Rocky Mountain province include a variety of parent materials, including metamorphic rock, as well as deposits of glacial drift, outwash, and alluvium (Bonneville 1995). The basin is exposed to Pacific weather systems with precipitation ranging from 12 inches at Lewiston, Idaho, to more than 90 inches at the higher elevations, much of which falls as snow (Sustainable Communities Initiative 2010).

Lake Bryan is a run-of-river reservoir created by Little Goose Dam located at Snake River Mile (RM) 70.3 (Figure 1-1). The reservoir extends 37.2 miles upstream to Lower Granite Dam. Authorized purposes are power generation and inland navigation. Other uses include fishery and recreation. Table 1-1 summarizes some key elements of the Little Goose Dam project.

1.2 PREVIOUS STUDIES

Water quality data collection began in Lake Bryan shortly after Little Goose Dam was completed. A comprehensive sampling program that was funded by the U.S. Army Corps of Engineers (Corps) and completed by Washington State University and the

University of Idaho was completed between 1971 and 1977 (Falter et al.. 1973; Funk, Falter and Lingg 1979). In 1994, the Corps initiated an extensive sampling program throughout the lower Snake River basin with the assistance of research teams from Washington State University and the University of Idaho. The primary goal of this sampling program was to provide a more complete synopsis of the existing limnological and biological productivity conditions above, below, and throughout the lower Snake River reach and to assess the effects, if any, that the dams have on water quality. Sampling was conducted both in the impoundments and in the “free-flowing” reaches and major tributaries. Initially, in 1994 and 1995, data was collected on a monthly or biweekly basis (Juul 1998a). The sampling frequency was increased in 1997 to biweekly monitoring through the growing season. An extensive suite of parameters was sampled during these investigations, including many of the same conventional parameters used in the long-term monitoring studies such as pH, alkalinity, conductivity, dissolved oxygen, nutrients, total suspended solids, and turbidity. Various anions and cations were also monitored including chloride, silica, sulfate, calcium, magnesium, sodium, and potassium. In addition, biochemical oxygen demand was also measured at selected locations, as well as various biological parameters including chlorophyll a, phytoplankton, zooplankton, attached benthic algae, and other primary productivity indicators (Juul 1998b, 1999; NAI 1999; Corps 2002).

Table 1-1. Selected Characteristics of the Little Goose Dam Project

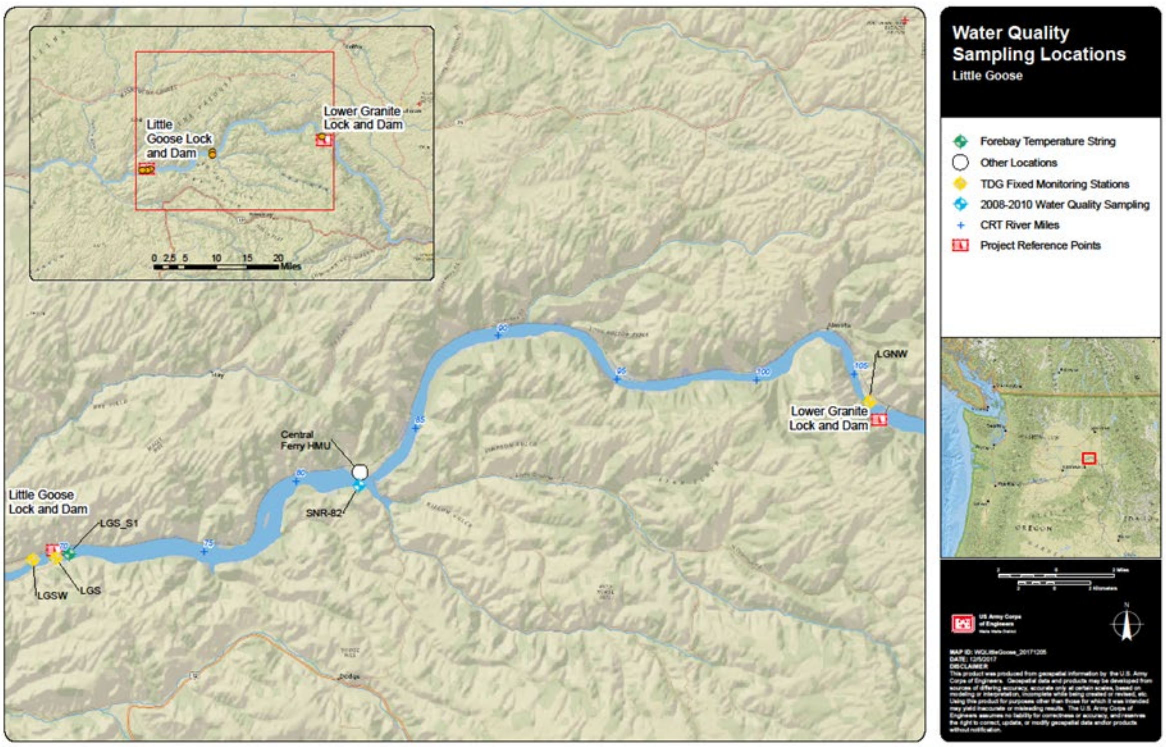
Parameter	Metric
Location	RM 70.3
Year first completed	1970
Reservoir name	Lake Bryan
Normal operating range	633 to 638 feet above mean sea level
Storage capacity below elevation 638 feet	565,200 acre-feet
Pool length	37.2 miles
Average reservoir width	0.4 mile
Maximum reservoir width	0.8 mile
Reservoir area at elevation 638 feet	10,025 acres
Maximum depth	135 feet
Mean depth	56.4 feet

1.3 WATER QUALITY DATA USED FOR THIS ANALYSIS

Extensive temperature data is available for Lake Bryan Lake. The Corps operates fixed-monitoring stations in the forebay and tailwater of the project where water temperature and total dissolved gas (TDG) are measured hourly. The tailwater station operates year-round, and the forebay station collects data from April 1 through August 31. The Corps also installed a forebay temperature string in 2004 that measures water temperatures at ten depths hourly during the entire year. All of the Corps data is transmitted real-time via the Geostationary Operational Environmental Satellite (GOES) system.

Existing water quality conditions in Lake Bryan were evaluated with data from a sampling program that began in April 2008 and ended in October 2010 (Corps 2014). One sampling station was located in Little Goose pool at RM 82 (SNR-82) (Figure 1-1) that was visited monthly. Field measurements included water column profiles for temperature, dissolved oxygen, pH, conductivity, and turbidity, as well as Secchi disk measurements. Water samples were collected at three depths for chemical analyses that included alkalinity, chloride, sulfate, inductively coupled plasma metals scan, nitrite plus nitrate nitrogen, ammonia nitrogen, total nitrogen, orthophosphate, total phosphorus, and total suspended solids. Chlorophyll a, phytoplankton, and zooplankton samples were also retrieved from the photic zone.

Figure 1-1. Locations of the 2008 to 2010 Lake Bryan Water Quality Sampling Stations



SECTION 2 - WATER QUALITY

2.1 GENERAL DESCRIPTION

The State of Washington use designation for Lake Bryan includes salmonid spawning, rearing, and migration, and primary contact recreation, as well as domestic, industrial, agricultural, and stock water uses. Various parts of the reach are on the State of Washington's Clean Water Act 303(d) Category 5 list for temperature and dissolved oxygen. There are two total maximum daily loads (TMDLs) in place, one for dioxin (U.S. Environmental Protection Agency [EPA] 1991) and one for total dissolved gas (Washington State Department of Ecology [Ecology] 2003). A draft temperature TMDL was completed by the EPA in 2003 but never finalized. Blue-green algal blooms also occur periodically in the reservoir, especially in the forebay and swim areas (NAI 1999), but have not been tested for toxins such as anatoxin, saxitoxin, and microcystin.

2.2 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.

2.2.1 Physical

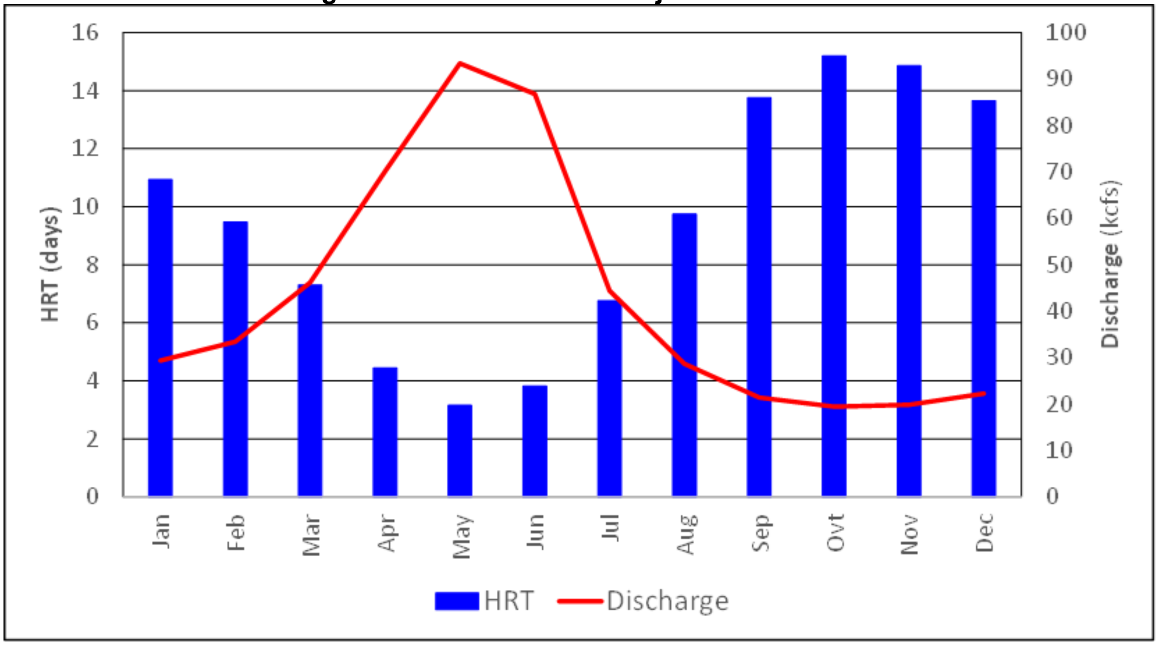
2.2.1.1 *Hydrologic Characteristics*

Because Little Goose is a run-of-river project, the long-term minimum, maximum, and average flows are similar to the ones determined for Lower Granite. Based on the project outflow data for the period of record, the minimum average monthly flow of 23.4 kcfs in October, the maximum average monthly flow is 102.7 kcfs, and the average annual flow is 49.2 kcfs.

The 7Q10 is the average peak annual flow for 7 consecutive days that has a recurrence interval of 10 years. The calculated values for Lake Bryan are the same as the ones determined for Lower Granite Lake: 214 kcfs as determined by the Washington State Department of Ecology (Ecology 2003) and 212 kcfs calculated by Walla Walla District.

Since the volume of Lake Bryan is larger than Lower Granite Lake, the calculated hydrologic residence times (HRT) are also longer. The long-term average, based on 1998 through 2016 project outflow data, is 9.4 days. However, the calculated values follow of cyclic pattern throughout the year (Figure 2-1). The shortest retention time occurs in May, when the average is 3.2 days, and is greatest in October at 15.2 days. The maximum 7-day moving average ranged from 14.5 days to 21.6 days and reached or exceeded 20 days for 5 of the 18 years considered.

Figure 2-1. Average Monthly Hydrologic Residence Time and Discharge for the Little Goose Project from 1998 to 2016



2.2.1.2 *Water Temperature*

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

Recent and historical water temperature data was evaluated to quantify water temperature conditions through the reservoir. The primary sources of information included the hourly data collected at the tailwater fixed monitoring station and the forebay temperature string.

Water Temperatures in Lake Bryan. Lake Bryan does not stratify thermally to the extent that Dworshak Reservoir and other deep lakes do. Significant temperature differences between the surface and bottom waters are generally rare in running waters. A frequently used rule-of-thumb is that a water body has to have a mean depth greater than 33 feet and a mean annual hydrologic residence time in excess of 20 days before strong thermal stratification develops. The mean depth of Lake Bryan is greater than 33 feet, but the average annual residence time, based on 1998 to 2016 data, is 9.4 days. The calculated retention time can approach 20 days during the summer and fall of low-flow years and facilitate the development of vertical temperature differences. However, wind- and flow-induced turbulent diffusion, along with convective mixing, prevents that from happening most of the time.

Vertical thermal gradients in Lake Bryan are more pronounced now than they were prior to implementation of summer cold water releases from Dworshak Dam. Because Lake Bryan is downstream of the Lower Granite Dam project, the summer forebay thermal gradient is less apparent than in the upstream reservoir. Based on hourly data recorded between July 15 through August 31 from 2005 to 2016 at the forebay temperature sting, the temperature difference between a depth of 3.3 feet (1 meter) and 98.4 feet (30 meters) ranged from 2.2°F (1.2°C) in 2011 to 4.5°F (2.5°C) in 2014 and 2016. The average for the 12-yr period was 3.8°F (2.1°C).

Water Temperatures at Little Goose Dam Tailwater. Summer tailwater temperatures at the Little Goose Dam tailwater station were higher than at the upstream Lower Granite Dam location (Figure 2-2). The 1995 through 2016 trace shows that the average of the daily maximum temperatures recorded at the Little Goose fixed monitoring system station were greater than 20°C (68°F) from mid-July through most of August. The frequency distribution for the 1 July through 15 September daily maximum temperatures (Figure 2-3) shows that the 20°C (68°F) threshold was exceeded every year between 1995 and 2016. Annual values ranged from 10 percent in 2008 to greater than 80 percent in 1998 and 2015.

Figure 2-2. Comparison of the Average Daily Maximum Temperatures at the Little Goose and Lower Granite Dam Tailwater Stations from 1995 to 2016

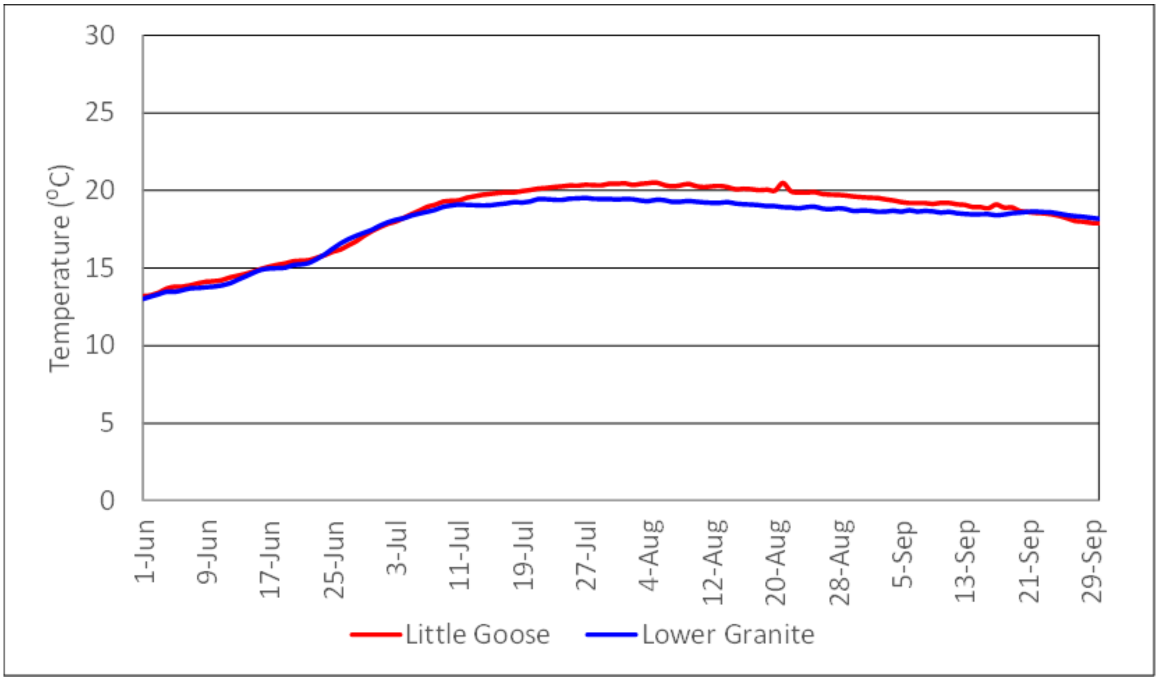
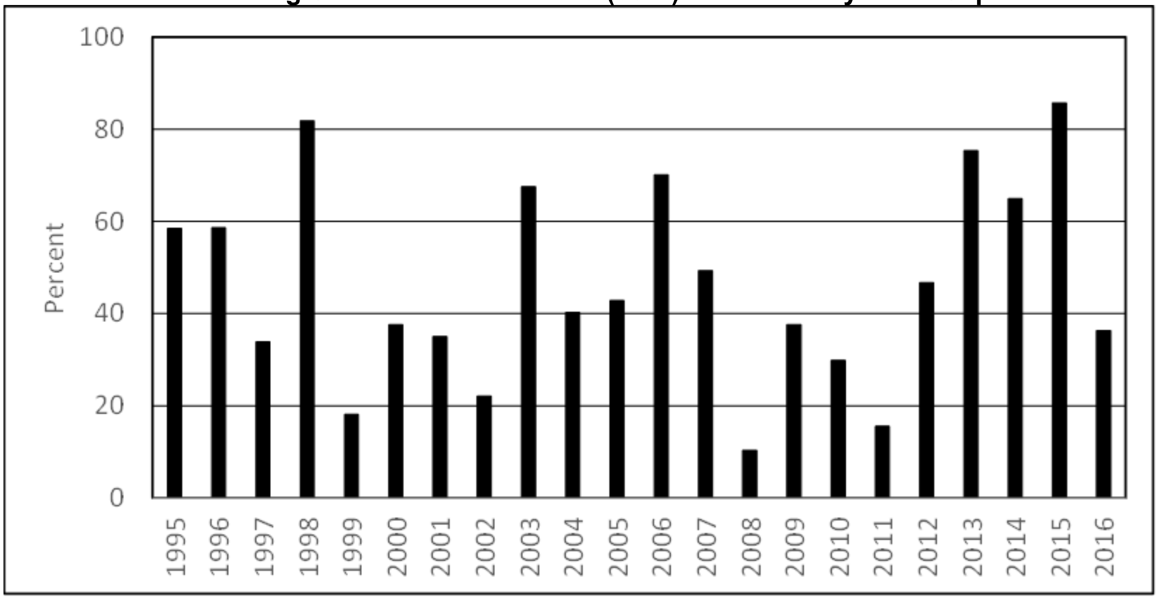


Figure 2-3. Percent of Days When the Daily Maximum Water Temperature at Little Goose Dam Tailwater Monitoring Station Exceeded 20°C (68°F) Between July 1 and September 15



2.2.1.3 *Dissolved Oxygen*

Dissolved oxygen is critical to the ecology of both riverine and reservoir systems and sustains 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 occurs during periods of intense photosynthetic activity and as a result of dissolution of oxygen under high hydrostatic pressure in the plunge pools of high head dams (Bowie et al. 1985). Both of these situations occur, at times, in Lake Bryan.

Dissolved oxygen profiles were completed during each sampling event at SNR-82 during the 2008 through 2010 sampling period. Water-column averages were higher during the winter months when water temperatures were at a minimum concentrations and typically exceeded 13 milligrams per liter (mg/L). Calculated average water-column minimums occurred in October when they reached 8.2 mg/L. Oxygen super-saturation within the water column was noted in the spring and increased as the season progressed toward August and September. Maximum concentrations occurred in the upper 4 meters of the water column, and at times exceeded 150 percent saturation.

2.2.1.4 *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 2008 National Oceanic and Atmospheric Administration (NOAA) Federal Columbia River Power System Biological Opinion (BiOp) relies on spill operations at Corps mainstem projects to benefit Endangered Species Act listed juvenile salmon and steelhead passage. Currently, the spill operations during the juvenile fish passage season (generally early April into August) at Corps dams are consistent with court-ordered operations and the adaptive management provisions in the 2008 NOAA BiOp as implemented through the Adaptive Management Implementation Plan. The intent of the spill operations is to help meet juvenile fish survival performance standards identified in the BiOp. These fish passage spills may result in the generation of TDG supersaturation in the lower Snake River at levels above current state and federal water quality standards. The State of Washington has authorized exceptions to these standards as long as the elevated TDG levels provide for improved fish passage through the spillway without causing more harm to fish populations than through other passage routes.

The general approach for TDG abatement activities focuses on limiting the entrainment of air into the water column, the water flow rate that encounters the bubble plume, and thirdly, the effective depth of the air that does become entrained. Spillway flow deflectors, commonly referred to as flip lips, redirect the spill jet from a plunging flow that transports air bubbles deep into the stilling basin to a horizontal jet that maintains entrained air much closer to the water surface. The influence of spillway flow deflectors is also to transport highly aerated flow conditions well downstream of the stilling basin into the tailrace channel, promoting the exchange of atmospheric gasses at shallow depths. The effectiveness of spillway flow deflectors in abating TDG production has been consistently demonstrated at Corps projects on the Columbia and Snake Rivers. Flow deflectors were installed on the six interior spillways during the original construction of Little Goose Dam. Construction of the two end-bay deflectors were completed for the 2009 fish passage season. Other methodologies to reduce TDG loading below main-stem dams involve minimizing the use of spillways for involuntary spill. Limiting the entrainment of powerhouse flows into the turbulence bubbly flow in the stilling basin can also be an effective method of TDG enhancement. A spill pattern that widely distributes spillway flows uniformly across the entire spillway has been found to lower TDG exchange rates.

The Little Goose project includes two TDG fixed-monitoring stations: one at the project forebay, and one downstream from the dam. The tailwater station records data on an hourly basis throughout the year while the forebay station is maintained throughout the fish passage season (April 1 through August 31). All of the data is transmitted in near real-time via the GOES system and can be accessed at the Corps Northwestern Division's (NWD's) website (https://pweb.crohms.org/ftppub/water_quality/tdg/).

Annual TDG and temperature reports are available at the Corps Northwestern Division's website (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 Corps district, and required court reports. The number of times when the TDG concentrations exceeded water quality standards in any of the years between 1999 and 2016 at the forebay station ranged from 0 to 51. Exceedances at the tailwater station ranged from 0 to 47 in any given year.

2.2.1.5 *pH*

pH is a measure of the acidity or basicity 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.

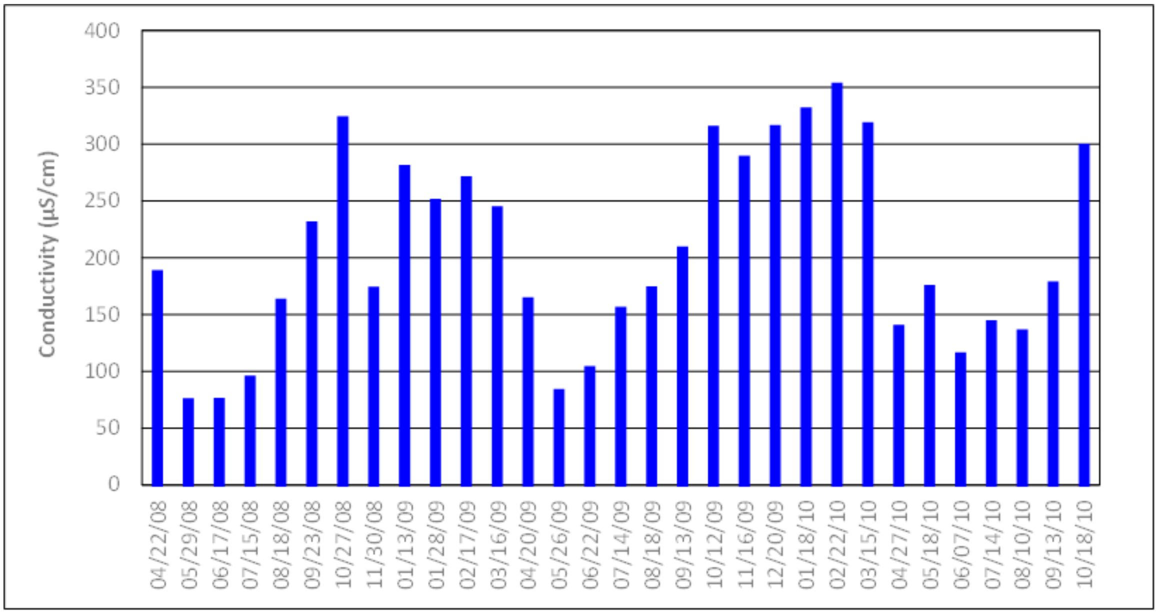
Hourly pH data was not recorded in Lake Bryan during the 2008 through 2010 sampling period, but water column profile measurements were taken at SNR-82. Water column averages ranged from 7.5 units in May 2009 to 8.8 units during August 2008.

2.2.1.6 *Specific Conductance*

Specific conductance, or 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.

The average water column conductivity in Lake Bryan, as measured at SNR-82 from 2008 through 2010, was 205 microsiemens per centimeter (μS/cm). Minimum values occurred during May and June of 2008 and 2009 when average concentrations were 75 and 83 μS/cm, respectively (Figure 2-4). Maximum conductivity was measured during the fall and winter months, exceeding 300 μS/cm during October 2008 and 2009, as well as from December through March 2009.

Figure 2-4. Annual Cycle for the Average Water-Column Specific Conductance Determined for SNR-82 between 2008 and 2010



2.2.2 Chemical

2.2.2.1 *Major Ions, Alkalinity, and Hardness*

Since the conductivity of the water is dependent on ionic constituents, the annual fluctuations in the concentrations of individual ions mimicked the one set by conductivity. The minimum, maximum, and median concentrations of the major ions, along with alkalinity and hardness, in the water at SNR-82 are presented in Table 2-1. Ionic concentrations, as well as hardness, are typically inversely related to river discharge. During high runoff events, the water hardness is considered slightly hard but increases to the lower end of the moderately hard classification during low-flow periods. The one exception to this trend is silicon, which is present in lower concentrations during the growing season, likely as a result of uptake by the Bacillariophyta (diatoms).

Table 2-1. Concentrations (mg/L) of the Major Ions, Alkalinity, and Hardness Analyzed Between 2008 and 2010 at SNR-82

Parameter	Minimum	Maximum	Median
Alkalinity	24	110	53
Hardness	32	123	55
Calcium	8.7	31.0	14.0
Chloride	2.4	13.0	6.0
Iron	0.03	0.52	0.22
Magnesium	2.5	11.0	4.9
Potassium	1.2	3.4	2.0
Silicon	5.2	11.0	7.9
Sodium	6.7	25.0	12.0
Sulfate	6.7	34.0	17.5
Sulfur	2.2	12.0	4.2

2.2.2.2 *Other Inorganic Constituents*

A suite of additional inorganic compounds that are typically present in smaller concentrations than the major ions were also analyzed quarterly during the 2008 through 2010 sampling period. All of the concentrations shown in Table 2-2 are low and often below instrument detection limits. Additionally, in the instances where there are EPA National Primary Drinking Water Regulations established to protect public health, the analytical results from SNR-82 are lower.

Table 2-2. Minimum, Maximum, and Median Concentrations (mg/L) for Minor Inorganic Chemicals Determined for SNR-82 Water Samples Collected Between 2008 and 2010

Parameter	Detection Limit	Minimum	Maximum	Median
Aluminum	0.01	<0.01	0.49	0.19
Antimony	0.010	<0.01	0.020	0.010
Arsenic	0.010	<0.01	0.010	0.010
Barium	0.001	0.010	0.032	0.018
Beryllium	0.001	<0.001	<0.001	<0.001
Boron	0.050	<0.050	0.080	0.050
Cadmium	0.001	<0.001	<0.001	<0.001
Chromium	0.001	<0.001	0.004	0.001
Cobalt	0.001	<0.001	0.012	0.001
Copper	0.001	<0.001	0.005	0.002
Lead	0.010	<0.010	0.010	0.010
Lithium	0.005	<0.005	0.017	0.006
Manganese	0.001	0.003	0.042	0.015
Mercury	0.010	<0.010	0.010	0.010
Molybdenum	0.005	<0.005	0.006	0.005
Nickel	0.005	<0.005	0.005	0.005
Selenium	0.010	<0.010	0.010	0.010
Silver	0.010	<0.010	0.010	0.010
Strontium	0.001	0.064	0.180	0.093
Thallium	0.01	<0.01	0.01	0.01
Tin	0.005	<0.005	0.010	0.005
Titanium	0.001	<0.001	0.028	0.009
Vanadium	0.005	<0.005	0.008	0.005
Yttrium	0.0005	0.00025	0.0013	0.0005
Zinc	0.001	0.0005	0.004	0.001

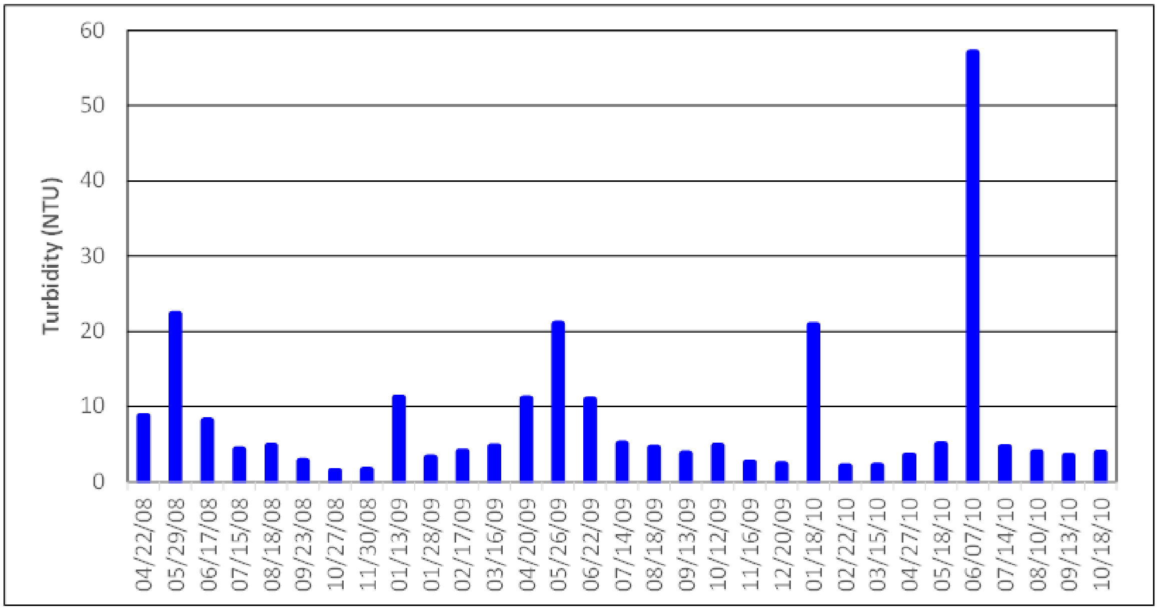
2.2.2.3 *Turbidity*

Turbidity is the cloudiness or haziness of a fluid caused by individual particles (suspended solids) that are often invisible to the naked eye. 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 river, very small particles will settle only very slowly or not at all if mixing occurs or the particles are colloidal. These small solid particles cause the liquid to appear turbid.

Turbidity values typically displayed a seasonal cycle with low values during late-fall or early-winter, followed by elevated concentrations during spring runoff (Figure 2-5). Winter water-column averages were typically less than 3 Nephelometric Turbidity Units

(NTU), although the 2008 and 2009 mid-January averages were higher at 11 and 21 NTU, respectively. The late-May and early-June averages were greater than 20 NTU during 2008 and 2009 and reached 57 NTU in early June 2010.

Figure 2-5. Annual Cycle for Average Water-Column Turbidity Determined for SNR-82 between 2008 and 2010



2.2.2.4 *Total Suspended Solids*

Total suspended solids are solid materials, organic and inorganic, that are suspended in the water and can include silt, plankton, and urban wastes. The larger particles transported by the upstream Clearwater and Snake Rivers settle out in Lower Granite Lake while the finer particles remain suspended and pass into Lake Bryan. The highest concentrations are generally observed at deeper sampling depths, but elevated concentrations occasionally occur near the surface in the reservoirs as a result of localized algal blooms, tributary inflows, and near-shore wave action.

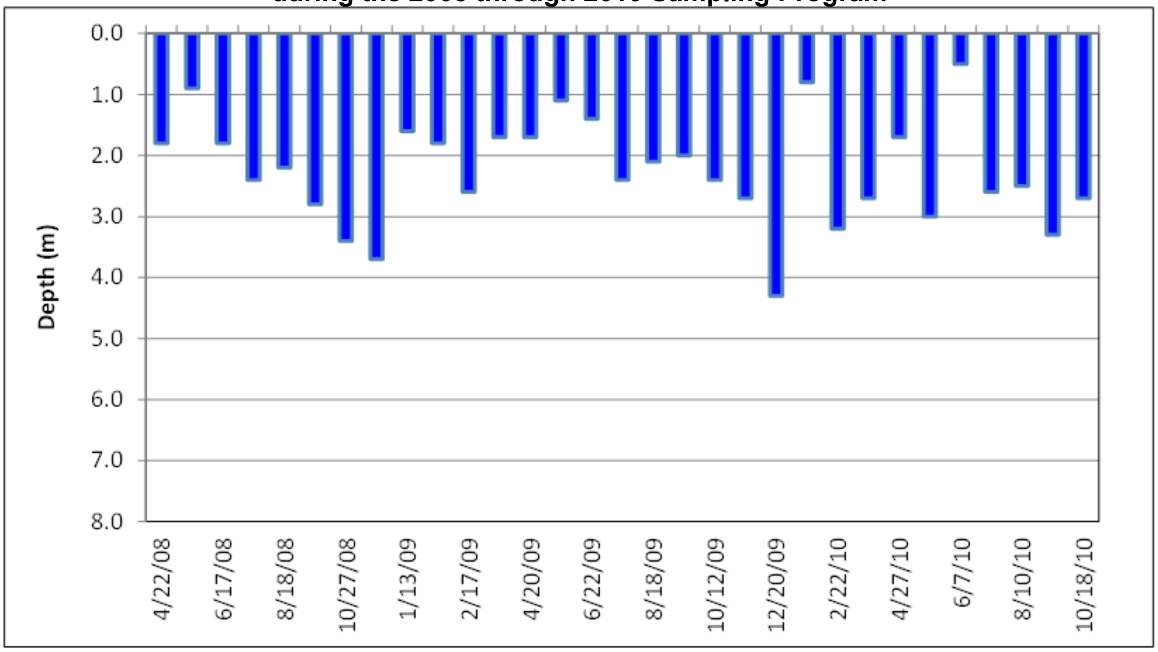
Total suspended solids concentrations displayed several similarities, and some differences, with the turbidity data. The median water-column concentration at SNR-82 was 5 mg/L. Calculated median values between 10 and 20 NTU were typically associated with increased runoff events, and the highest median value of 60 NTU corresponds to the period of peak runoff.

2.2.2.5 *Light Attenuation*

Light attenuation in the water column is dependent on the type and quantity of dissolved or suspended material. One of the traditional field methods for determining this parameter is Secchi disk depth. The median Secchi disk depths determined for SNR-82 for the 2008 through 2010 data set was 2.4 meters. Individual measurements ranged from 0.5 meter in June 2010 to 4.3 meters in December 2009 (Figure 2-6). Greatest water transparency typically occurred during late summer and through autumn.

Conversely, minimum light transparency was usually associated with higher runoff events during late spring and early summer, as well as from wind-induced surface roughness due to wind on the day of the sampling event.

Figure 2-6. Secchi Disk Depths Recorded at SNR-82 during the 2008 through 2010 Sampling Program



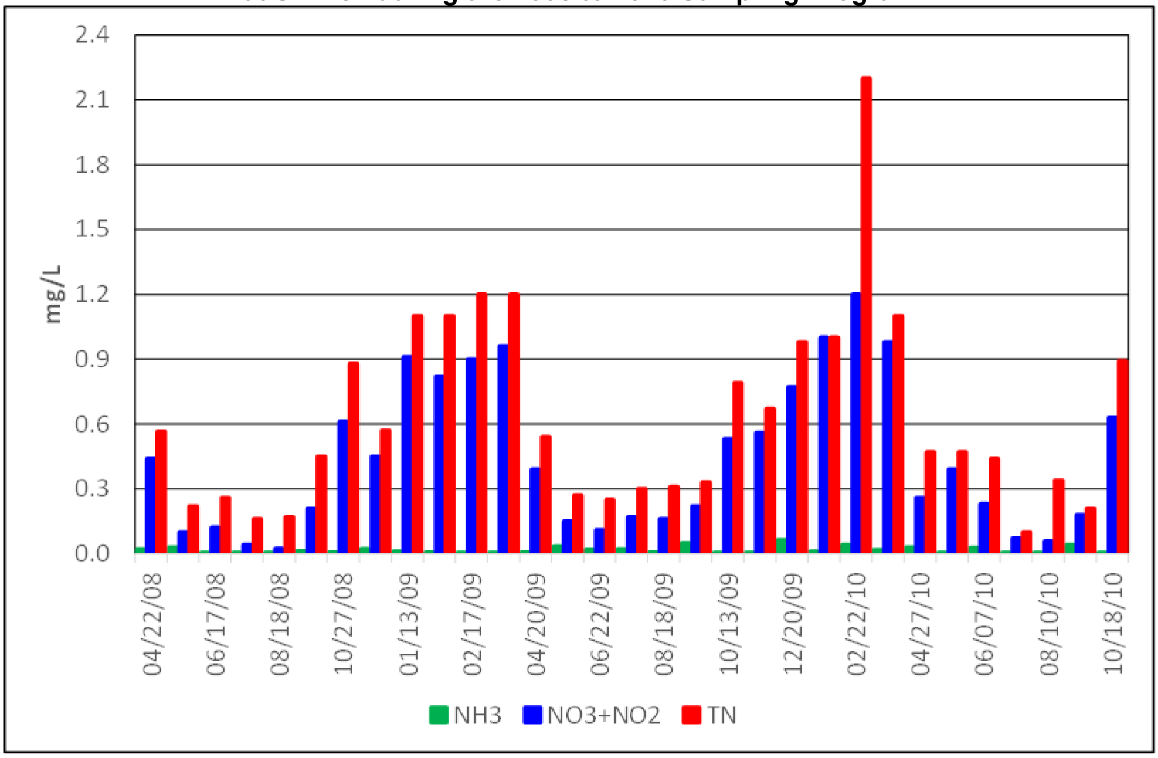
2.2.2.6 *Nitrogen and Phosphorus*

Nitrogen. Of the various soluble inorganic forms of nitrogen, nitrate plus nitrite nitrogen (NO_3+NO_2-N) (hereafter referred to as nitrate) was the principal component, comprising more than 90 percent of the soluble fraction at SNR-82. The calculated median water-column concentration for the entire sampling period was 0.39 mg/L. There was a pronounced seasonal distribution with the highest concentrations (greater than 0.80 mg/L) occurring during the winter and low concentrations (less than 0.10 mg/L) during the summer growing season (Figure 2-7).

Ammonia (NH_3-N) concentrations were consistently lower than nitrate values, often by an order of magnitude. The median water-column concentration at SNR-82 was 0.01 mg/L. Fifty-eight percent of the medians calculated for a given sampling event were less than 0.01 mg/L, and the two highest values of 0.05 and 0.07 mg/L occurred during late fall 2010 (Figure 2-7).

Total nitrogen (TN) includes inorganic and organic components. Total nitrogen concentrations in Lake Bryan exhibited seasonal variability, similar to the one identified for NO_3+NO_2-N (Figure 2-7). Overall, NO_3+NO_2-N comprised 61 percent of the TN for the entire study period. Summer median water column TN concentrations were approximately 0.30 mg/L. Concentrations increased considerably in the fall and winter. Winter water column median values were greater than 1.0 mg/L, but peaked in February 2010 at 2.2 mg/L. The late-season increases may have been due to a reduction in plant uptake associated with aquatic plant and algae senescing or going dormant, as well as agricultural practices in the watershed. Early fall rains after prolonged dry periods can also increase nutrient concentrations.

Figure 2-7. Seasonal Median Water-Column Concentrations of the Total Nitrogen, Ammonia Nitrogen, and Nitrate plus Nitrite Nitrogen Concentrations Determined at SNR-82 during the 2008 to 2010 Sampling Program

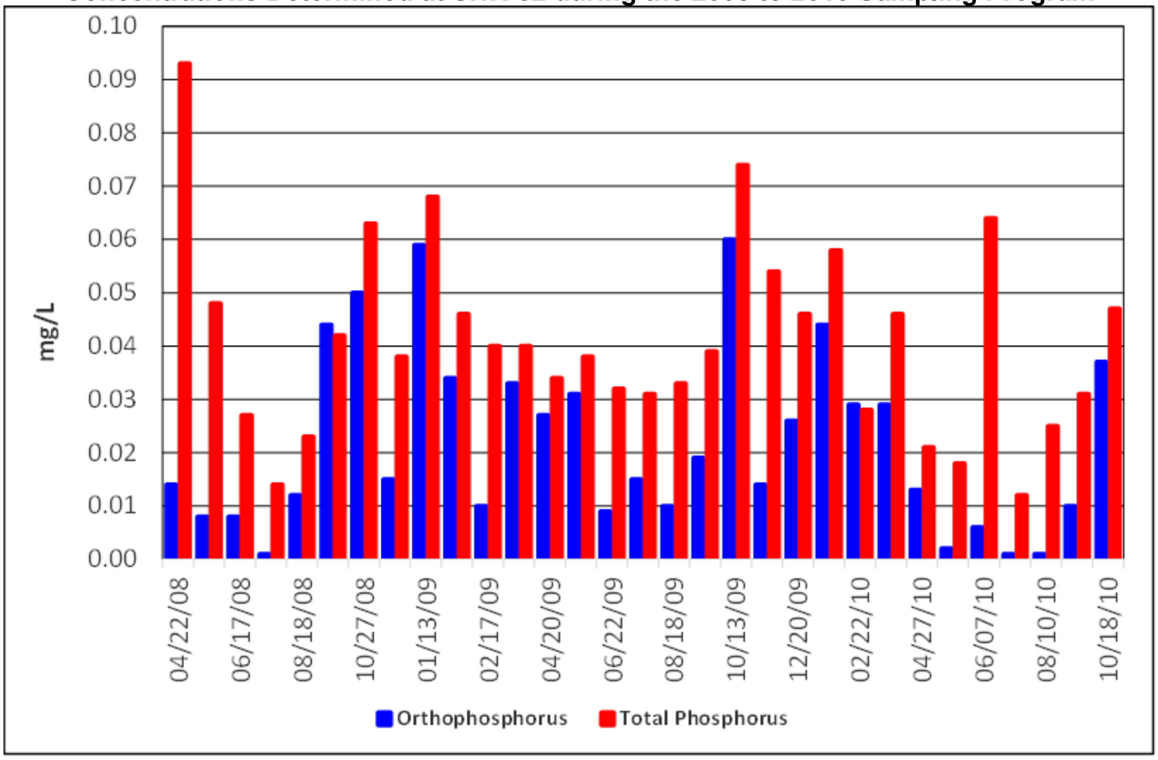


Phosphorus. Phosphorus is generally expressed in terms of total phosphorus (total-P) and orthophosphorus (ortho-P). Ortho-P represents the inorganic soluble fraction of the total phosphorus in water and is generally considered to be more readily available for biological uptake than is total phosphorus. Total-P consists of both the soluble fraction and that portion adsorbed to sediments or tied up with biological materials in the water column. Since phosphorus readily attaches to and travels with sediments, adsorbed or biological quantities usually represent the largest portion of total phosphorus. Phosphorus is often the limiting nutrient for plant growth in freshwater systems (Wetzel 2001).

Ortho-P concentrations in the Lake Bryan tend to be highest in the fall and winter, with relatively low concentrations in the summer (Figure 2-8). The calculated summer water-column median values was 0.009 mg/L and likely influenced by biological uptake by aquatic plants and algal growth. As plant growth diminished in the fall due to less uptake and biological senescence, the phosphorus water-column median values increased to between 0.03 and 0.06 mg/L.

Total-P concentrations generally followed the spatial pattern set by ortho-P (Figure 2-8). The calculated median value for the percentage of total-P that was ortho-P was 49 percent and ranged from 10 to almost 100 percent. The median water-column total-P concentration for the 2008 to 2010 study period was 0.038 mg/L. The highest total-P concentrations generally occurred during the fall and winter when the concentrations of most ions increased due to less dilution, and during runoff events when suspended solids concentrations increased.

Figure 2-8. Seasonal Median Water-Column Concentrations of the Ortho-P and Total-P Concentrations Determined at SNR-82 during the 2008 to 2010 Sampling Program



2.2.2.7 *Organic Compounds*

Water samples from Lake Bryan have not been routinely analyzed for organic compounds. Some elutriate samples have been analyzed for compounds such as organic pesticides and herbicides, polychlorinated biphenyls (PCBs), as well as other chemicals of concern. These results are discussed in Chapter 8-8.

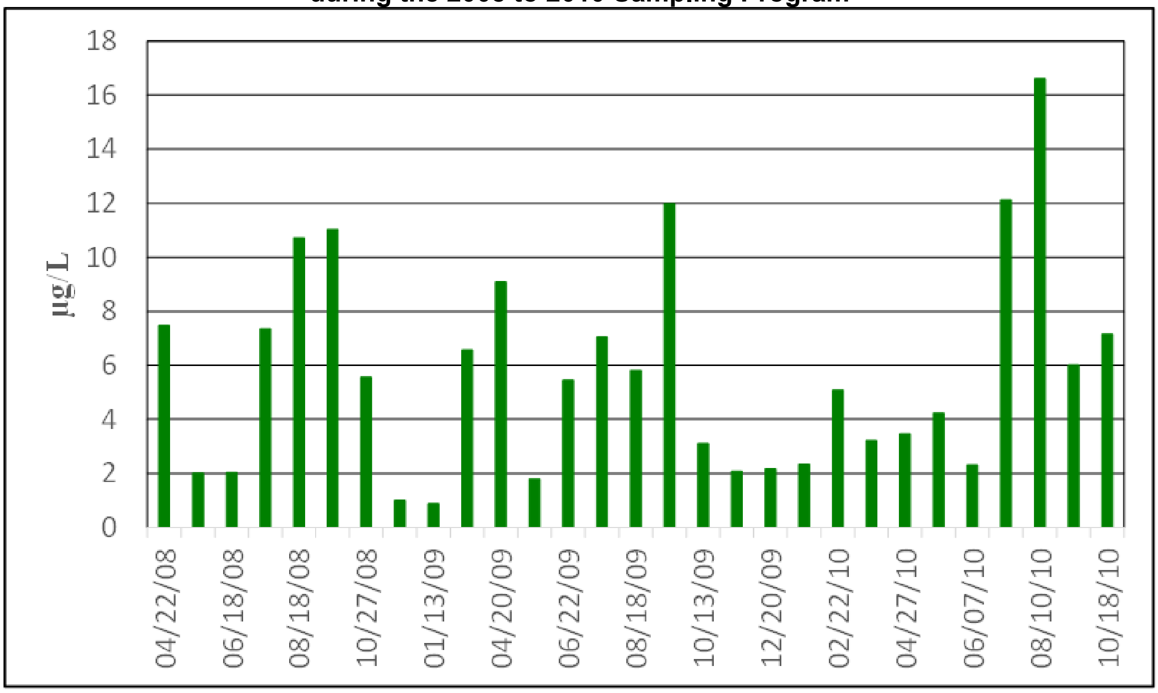
2.2.3 Biological

2.2.3.1 *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-blue and orange-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.

Seasonal variations were evident in the chlorophyll a concentrations, with minimum values in the November through January period followed by maximum values in the summer (Figure 2-9). The 2008–2009 November through January values were about 1 micrograms per liter (µg/L), and approximately twice that the following year. The single maximum concentration was 16.6 µg/L determined for the August 2010 sampling event. The calculated median for all July through September sampling events was 10.7 µg/L. This is higher than the calculated median for all data points, which was 5.5 µg/L.

Figure 2-9. Chlorophyll a Concentrations Determined for SNR-82 during the 2008 to 2010 Sampling Program



2.2.3.2 *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 across 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 5-50 million cells per liter can occur. This sometimes results in lower water quality, specifically, poor taste, odor, and color (Horne and Goldman 1994).

Phytoplankton are the most important primary producer in the lower Snake River. At the foundation of the food web, they transform light and nutrients into energy for herbivores such as zooplankton, which in turn support higher trophic levels. 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 that have much greater flow velocities. In 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 is typically expressed in terms of overall biovolume (i.e., cubic micrometers per liter [$\mu m^3/L$]), as well as species composition.

The phytoplankton composition in Lake Bryan was dominated by Bacillariophyta (diatoms) often accounting for greater than 90 percent of the total phytoplankton biovolume during any sampling event (Figure 2-10 and Figure 2-11). *Aulascoseira* spp. (primarily *Aulascoseira granulata*) biovolume generally exceeded the contribution from other individual diatom genera. Their largest biovolumes were determined during the months of August, September, and October when they accounted for 87 to 99 percent of the diatom biovolume. The overall median for this genus during the study period was 1.74×10^9 $\mu m^3/L$ and reached a maximum of 3.38×10^{10} $\mu m^3/L$ during August 2009. *Stephanodiscus* spp. (primarily *S. niagarae* and to a lesser extent *S. hantzschii* and *S. parvus*) biovolume was less than that of *Aulascoseira* spp. at SNR-82. The median biovolume of this genus for the study period was 6.19×10^8 $\mu m^3/L$, but it did reach maximum values of 4.69×10^9 and 7.43×10^9 $\mu m^3/L$ during July 2008 and June 2009, respectively. During these two events, they did account for more than 60 percent of the diatom biovolume, but for most months it was less than 10 percent. *Fragilaria* spp. biovolume (primarily *Fragilaria crotonensis)* had a calculated median biovolume of 3.26 $\times 10^8$ $\mu m^3/L$, or 7.6 percent of the total for the diatoms. As with the other genera, there were months when their contribution to the total was between 20 to 40 percent, but they generally accounted for less than 10 percent during any sampling event. *Synedra* spp. (primarily *Synedra ulna*) is the final genera that was present in significant volume at SNR-82. During the 2-year study, their calculated median biovolume was 2.36×10^8 $\mu m^3/L$, or 4.2 percent.

Figure 2-10. Percent Biovolume Composition of the Major Phytoplankton Divisions at SNR-82 during the 2008 to 2010 Sampling Program

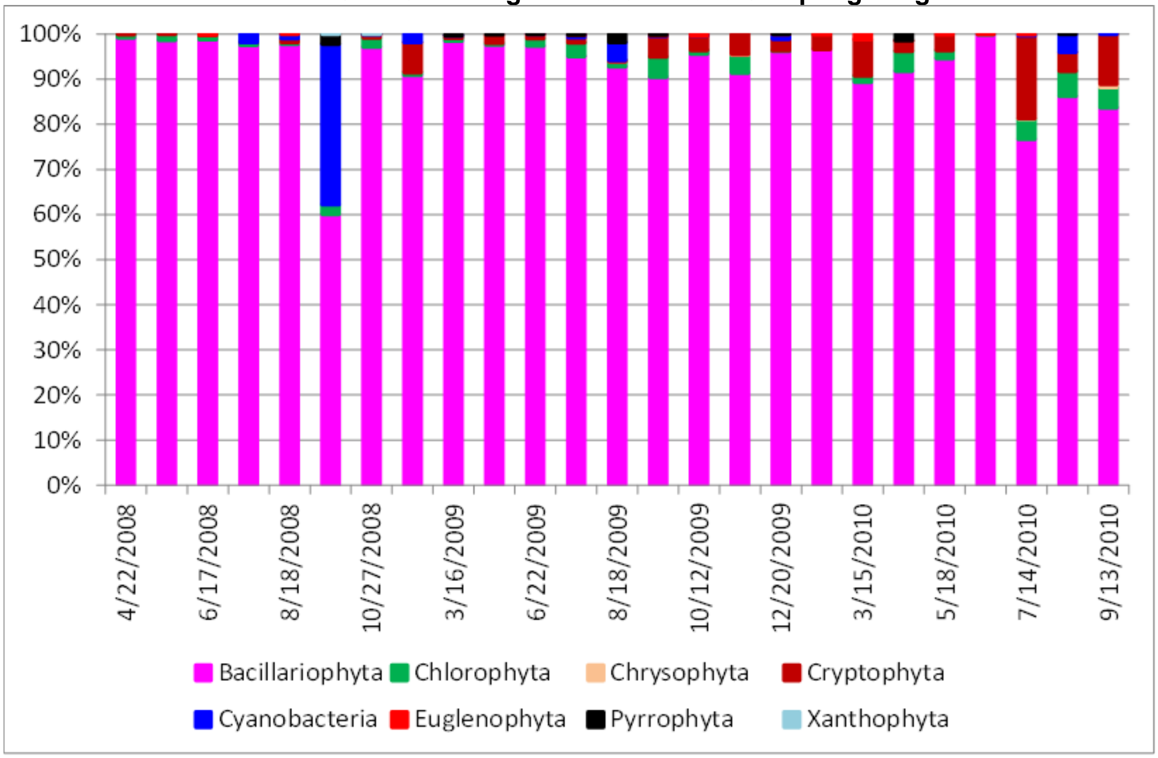
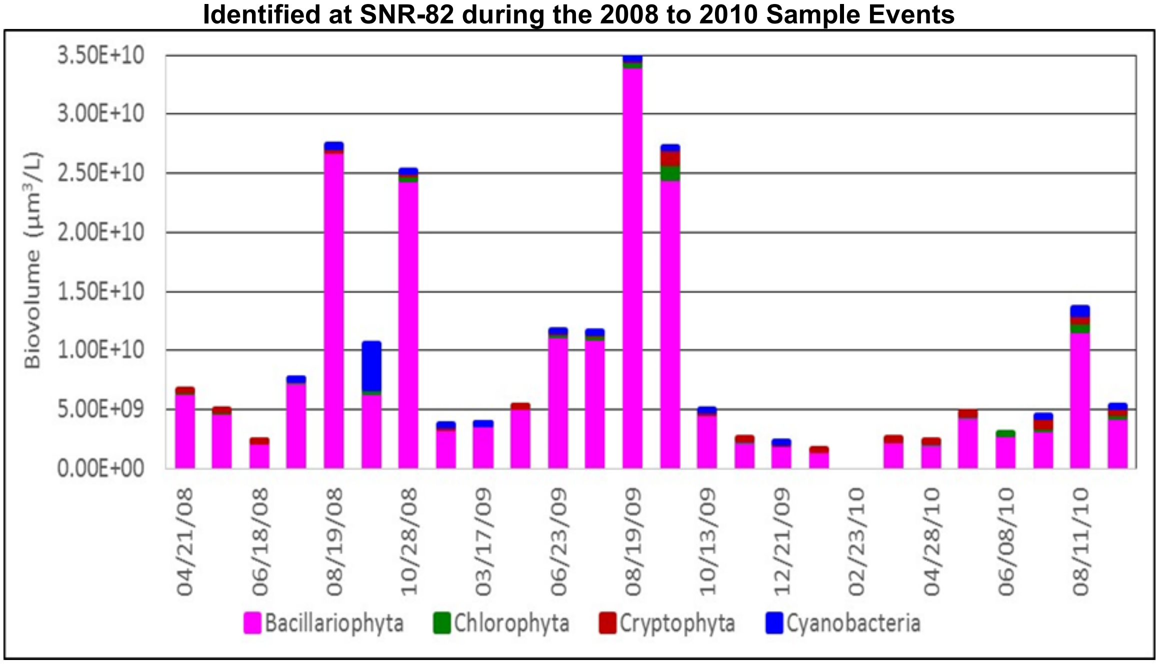


Figure 2-11. Biovolume Determined for the Major Phytoplankton Groups Identified at SNR-82 during the 2008 to 2010 Sample Events



The median Chlorophyte biovolume in Lake Bryan was less than 2 percent of the total algal biovolume during the 2008 through 2010 investigation. The green algae *Pyramimonas tetrarhynchus* was the one species that was consistently present during the sampling period, with a study median of 3.20 x 10^7 µm^3/L or 69 percent of the total green algae biovolume. Other algae such as *Chlamydomonas* spp., *Closteriopsis longissima*, *Pandorina morum*, *Pediastrum duplex, Sphaerocystis schroeteri*, and *Staurastrum* spp. would periodically be the dominant Chlorophyte during a sampling event and elevate the green algae to 4 percent of the total biovolume, but then not be identified in subsequent samples.

Cryptophyte biovolume in Lake Bryan was very similar to the Chlorophytes. Median percent composition was 1.9 percent and *Rhodomonas* spp. was the dominant species, typically accounting for 100 percent of the Cryptophyte population. The median *Rhodomonas* spp. biovolume for the study period was 1.06 x 10^8 $\mu m^3/L$ and did reach 8.02 x 10^8 $\mu m^3/L$ during July 2010 when they constituted 18 percent of the total algal biovolume. Additional periods when they constituted 4 to 11 percent of the total biovolume ranged from March through November with accompanying biovolumes spanning 1.16 to 6.65 x 10^8 $\mu m^3/L$.

The blue-green algae population was ephemeral with shifts in dominant species. Their overall median contribution to the total phytoplankton biovolume was less than 1 percent, but there were some exceptions during individual sampling events. Their largest presence was noted on 23 September 2008 when they accounted for almost 36 percent of the biovolume. The major species present on that date were *Cylindrospermopsis* spp. (3.84 x 10^9 $\mu m^3/L$), *Anabaenopsis circularis* (5.07 x 10^6 $\mu m^3/L$) and *Leptolyngbya* spp. (2.06 x 10^7 $\mu m^3/L$). During two other sampling events, 18 August 2009 and 10 August 2010, they accounted for 4 percent of the total biovolume. The principal species in 2009 were *Cylindrospermopsis raciborskii* (7.82 x 10^8 $\mu m^3/L$), *Anabaenopsis circularis* (2.82 x 10^8 $\mu m^3/L$), *Microcystis* spp. (3.90 x 10^8 $\mu m^3/L$), and *Pseudanabaena* spp. (2.85 x 10^6 $\mu m^3/L$). The 2010 blue-green pulse included *Anabaenopsis circularis* (5.07 x 10^8 $\mu m^3/L$), *Anabaena circinalis* (2.72 x 10^7 $\mu m^3/L$), *Aphanothece* spp. (8.06 x 10^6 $\mu m^3/L$), *Pseudanabaena* spp. (2.57 x 10^6 $\mu m^3/L$), and *Aphanocapsa planctonica* (6.39 x 10^6 $\mu m^3/L$).

2.2.3.3 *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 rates were not determined for this management plan, but were evaluated during previous investigations in 1994, 1995, and 1997 (Corps 2002). Using the most recent 1997 June through October results as an example, the volume weighted hourly rate measured near SNR-82 ranged from 7.81 milligrams carbon-12 per cubic meter per hour (mg $^{12}C/m^3/hr$) in June to 30.08 mg $^{12}C/m^3/hr$ in August. The calculated median for the June through September growing season was 21.24 mg $^{12}C/m^3/hr$.

2.2.3.4 *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 the Crustacea, the cladocera and copepoda. 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.

The biomass and composition of the zooplankton community also displays seasonal changes. The Cladocerans were notably present during the September 2008 and 2009 sampling events (Figure 2-12). *Daphnia retrocurva* was the primary species with an estimated biomass of 340 and 1,329 µg/L during the respective trips, which was equivalent to 85 and 96 percent of the total zooplankton biomass. Cladocerans were present during the remainder of the year, but typically comprised less than 40 percent of the total biomass, and during some winter months, they were not identified in the samples (Figure 2-13). Overall, the median Copepod biomass for the 2008 to 2010 sampling was greater than the Cladocerans; 0.63 versus 0.07 µg/L. *Cyclopoid copepodid* and nauplii were present during most of the year but exhibited greatest abundance during the summer and early fall. The median biomass for *Cyclopoid copepodid* was 0.11 µg/L, but they did reach 26.4 and 40.4 µg/L during August 2008 and September 2009, respectively. Nauplii biomass peaked at a lower 6.4 and 9.4 µg/L during August 2008 and August 2009, respectively, but their median biomass for the study period was greater, 0.17 µg/L. Additional Copepods that were more ephemeral, yet sometimes ranging between 45 and 112 µg/L, included *Acanthocyclops robustus, Calanoid copepodid, Diacyclops thomasi, Epischura nevadensis*, and *Leptodiaptomus* sicilis. The Rotifers typically had their greatest presence during the late-winter and early-spring, and there periods when they comprised greater than 95 percent of the total biomass. During peak periods of April 2009 and February 2010, their biomass was greater than 50 µg/L but rapidly tapered off to less than 1 µg/L. The median for the 2008 through 2010 sampling period was 0.32 µg/L. The primary representatives were *Brachionus calyciflorus, Polyarthra vulgaris*, and *Synchaeta pectinata*.

Figure 2-12. Zooplankton Biomass for the Three Major Divisions Determined Between 2008 and 2010

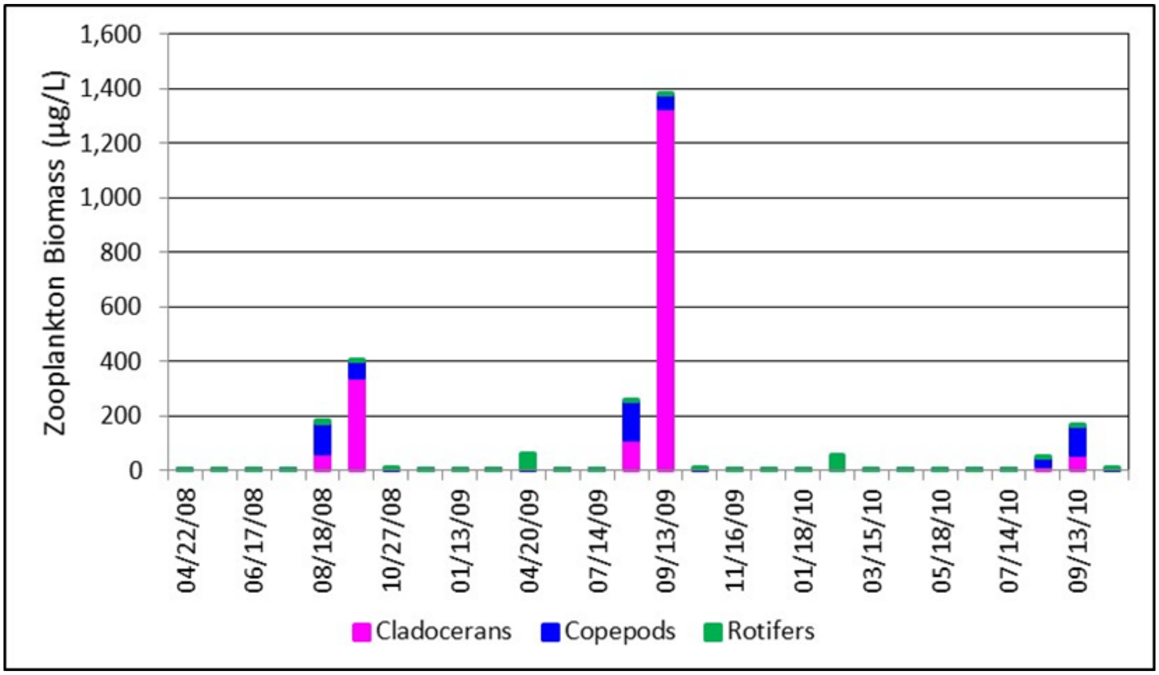
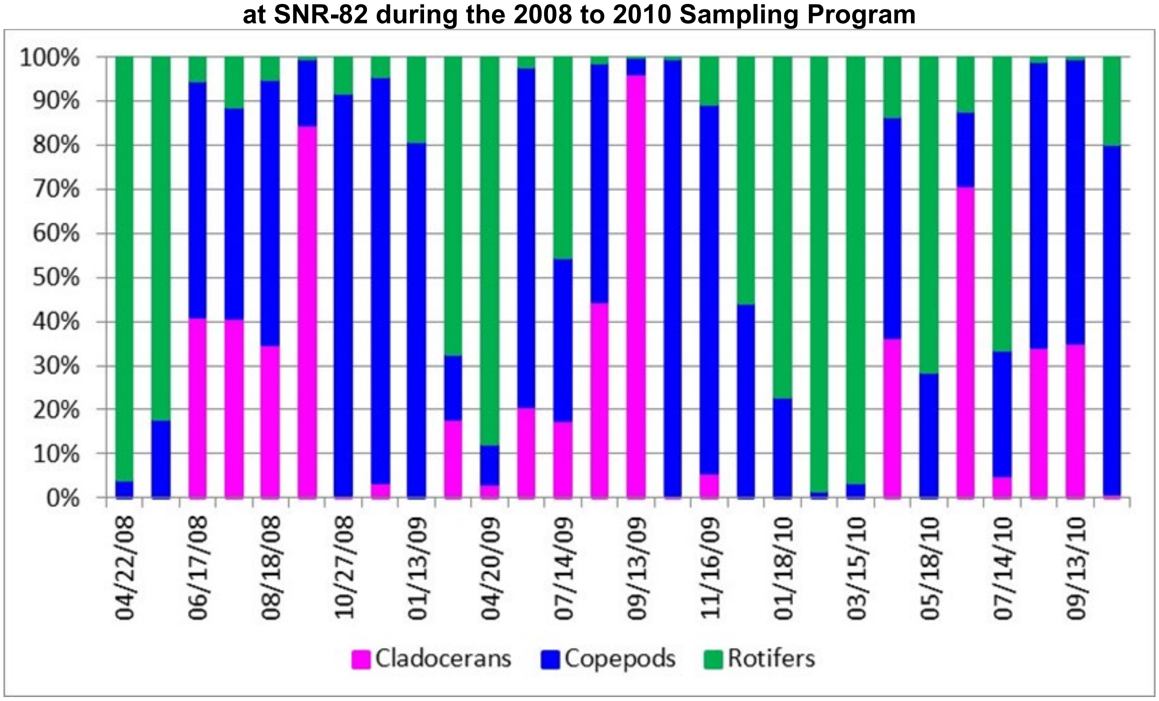


Figure 2-13. Median Zooplankton Assemblage Percent Composition at SNR-82 during the 2008 to 2010 Sampling Program



2.2.3.5 *Coliforms and Other Microbial Organisms*

Recent data for coliform or other bacteria is not available for Lake Bryan.

2.2.4 Trophic State Classification

The trophic state of a lake or reservoir has been defined in various ways over the years. Three common distinctions are oligotrophic, mesotrophic, and eutrophic classifications. 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. 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 Reckhow 1983).

The calculated Secchi disk TSI for Lake Bryan, using summer growing season measurements, was 48 in 2008 and 2010, and slightly higher at 50 in 2009. The value determined using the combined average for all three years was 49. Based on this method, the reservoir would be considered upper mesotrophic.

Chlorophyll a concentrations, as well as calculated Carlson TSIs, are measures of a lake or reservoirs trophic state. Published literature from some water bodies suggests that average chlorophyll a levels above 5.0 and 14.5 µg/L are indicative of mesotrophic and eutrophic conditions, respectively (Corps 2002). Wetzel (2001) provides broader ranges, stating that annual mean chlorophyll a levels between 3.0 and 11.0 µg/L indicate mesotrophic conditions, while a range of 3.0 to 78.0 µg/L represents eutrophic conditions. The calculated Carlson TSIs, based on integrated chlorophyll a samples collected at SNR-82 and analyzed in a laboratory, range from 50 in 2009 to 52 in 2010, which are indicative of lower eutrophic conditions.

Total phosphorus concentrations are often used as trophic state indicators. According to the State of Washington water quality standards for lakes in the Columbia Basin ecoregion, total phosphorus levels greater than 0.020 to 0.035 mg/L are considered indicative of upper mesotrophic conditions, and if the concentration exceeds 0.035 mg/L, a lake-specific study should be initiated. A Carlson TSI can also be calculated using total phosphorus concentrations. The results from using summer average water column concentrations provided TSIs that ranged from 51 in 2008 to 55 in 2010. Based on this metric, Lake Bryan would be classified as lower eutrophic.

2.2.5 Data Correlations

The non-parametric Kendall rank correlation coefficient (Kendall's tau) test was used to determine correlation coefficients between parameters. This type of analysis measures the strength and direction of a linear relationship between two variables (nonlinear relationships and those involving multiple variables are not considered). The Kendall's tau values range from -1 (a perfect downhill or negative relationship) to +1 (a perfect uphill or positive relationship), and the farther they are from zero, the stronger the relationship. It must be remembered that correlation does not imply causality, and it does not facilitate predicting a dependent variable from an independent variable. The Kendall's tau values were tested for significance at $\alpha = 0.05$ and are identified with bold font in Table 2-3.

The correlation coefficients are based on daily outflow from the project and average values determined for the upper 5 meters of the water column for the other parameters. Flow was positively correlated with turbidity (0.54) and negatively correlated with specific conductivity (-0.56) and Secchi disk depth (-0.52). Secchi disk depth was also negatively correlated with turbidity (-0.67). A coefficient of 0.62 was identified for pH and chlorophyll a, while the coefficient between chlorophyll a and phytoplankton biovolume was less (0.46). pH was also positively correlated with phytoplankton biovolume (0.57) and zooplankton biomass (0.56). Zooplankton biomass was also positively correlated with chlorophyll a (0.52) and phytoplankton biovolume (0.58).

Table 2-3. Kendall Tau-B Correlation Matrix for SNR-82

	Flow	Temp.	% DO	DO-mg/L	pH	Sp. Cond.	Turb.	NH_3-N	NO_3+NO_2	Total-N	PO_4-P	Total-P	TSS	Secchi	Chl a	Phyto BV	Zoop BM
Flow	1.00																
Temp.	0.11	1.00															
% DO	0.38	**0.44**	1.00														
DO-mg/L	0.19	-0.32	0.25	1.00													
pH	-0.21	0.36	0.34	-0.01	1.00												
Sp. Cond.	**-0.56**	-0.30	**-0.47**	-0.01	0.08	1.00											
Turb.	**0.54**	-0.03	0.24	0.30	-0.21	-0.31	1.00										
NH_3-N	0.00	-0.16	0.10	0.16	-0.02	0.11	-0.02	1.00									
NO_3+NO_2	-0.27	**-0.64**	**-0.53**	0.13	-0.23	**0.57**	-0.09	0.12	1.00								
Total-N	-0.35	**-0.59**	**-0.46**	0.17	-0.16	**0.59**	-0.13	0.08	**0.88**	1.00							
PO_4-P	-0.26	**-0.42**	**-0.52**	0.04	-0.27	**0.42**	-0.03	0.03	**0.58**	**0.53**	1.00						
Total-P	-0.24	-0.34	**-0.44**	0.03	-0.28	0.36	0.10	0.16	0.40	0.39	**0.54**	1.00					
TSS	0.26	0.05	0.19	0.16	-0.10	-0.12	0.40	0.28	-0.06	-0.06	0.12	0.22	1.00				
Secchi	**-0.52**	0.06	-0.18	-0.28	0.27	0.31	**-0.67**	-0.07	0.06	0.10	-0.01	-0.11	-0.39	1.00			
Chl a	-0.08	**0.47**	0.27	-0.16	**0.62**	-0.03	-0.08	-0.16	-0.31	-0.23	-0.23	-0.27	-0.09	0.11	1.00		
Phyto BV	-0.04	**0.56**	**0.42**	-0.09	**0.57**	-0.09	0.00	-0.03	**-0.44**	-0.35	-0.21	-0.12	0.24	0.03	**0.46**	1.00	
Zoop BM	-0.20	0.38	0.26	-0.08	**0.56**	0.07	-0.09	0.05	-0.21	-0.15	-0.06	-0.07	0.09	0.09	**0.52**	**0.58**	1.00

SECTION 3 - SUMMARY

Lake Bryan is the next downstream reservoir from Lower Granite Lake. Since Little Goose Dam is also a run-of-river project, many of the water quality characteristics are very similar to the other three lower Snake River projects. The average hydrologic residence time is 9.4 days, but that can range from less than 2 days to almost 30 days during any given year. The median June through September Secchi disk depth determined at SNR-83 was 2.3 meters with a range of 0.6 to 3.3 meters. The median chlorophyll a concentration for the same period was 6.5 µg/L and reached a maximum of 16.6 µg/L during August 2010. Greater than 90 percent of the algal biovolume was attributed to the diatoms. The greatest contribution was attributed to *Aulacoseira* spp., followed by *Stephanodiscus* spp., *Fragilaria* spp., and *Synedra* spp. The copepods were consistently present and usually accounted for the largest percentage of the biomass. The major representatives were *Calanoid copepodid, Cyclopoid copepodid, Diacyclops thomasi, Leptodiaptomas* spp., and nauplii. The cladocera, primarily *Daphnia retrocurva*, did surpass the combined biomass of all other zooplankters during some of the summer months. Carlson TSI was calculated using summer Secchi disk depth, chlorophyll a concentrations, and total phosphorus concentrations. The results indicated that the reservoir can be classified as upper mesotrophic to lower eutrophic.

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