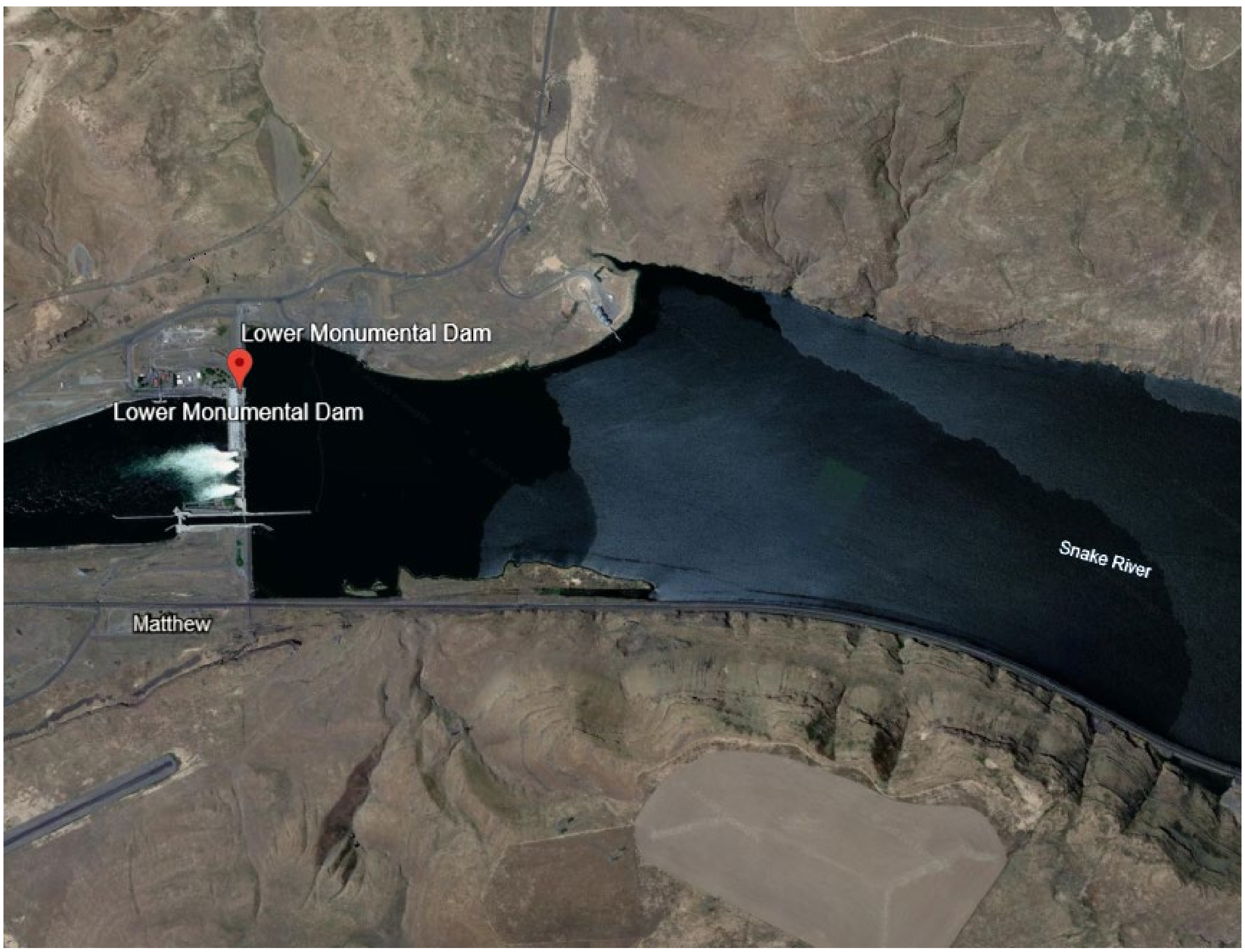
US Army Corps
of Engineers®
Portland District

WATER QUALITY REPORT

**LOWER MONUMENTAL RESERVOIR,
LAKE HERBERT G. WEST
COLUMBIA RIVER BASIN
SNAKE RIVER, WASHINGTON**

Lower Monumental Reservoir, Lake Herbert G. West



Water Quality Report
August 2020

EXECUTIVE SUMMARY

Lower Monumental Reservoir, also known as Lake Herbert G. West, is a run-of-river reservoir created by the Lower Monumental Dam located at Snake River Mile (RM) 41.6 (Figure 1-1). The reservoir extends 28.7 miles upstream to Little Goose Dam. Authorized purposes are power generation and inland navigation. Other uses include fishery and recreation. Table 1-1 summarizes some key elements of the Lower Monumental Dam project.

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ACRONYMS

Acronym	Description
µg/L	Micrograms Per Liter
$µm^3$/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-42	Lower Monumental pool sampling station at River Mile 42
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 Herbert G. West is a run-of-river reservoir created by the Lower Monumental Dam located at Snake River Mile (RM) 41.6 (Figure 1-1). The reservoir extends 28.7 miles upstream to Little Goose Dam. Authorized purposes are power generation and inland navigation. Other uses include fishery and recreation. Table 1-1 summarizes some key elements of the Lower Monumental Dam project.

Figure 1-1. Locations of the 2008 to 2010 Lake Herbert G. West Water Quality Sampling Stations

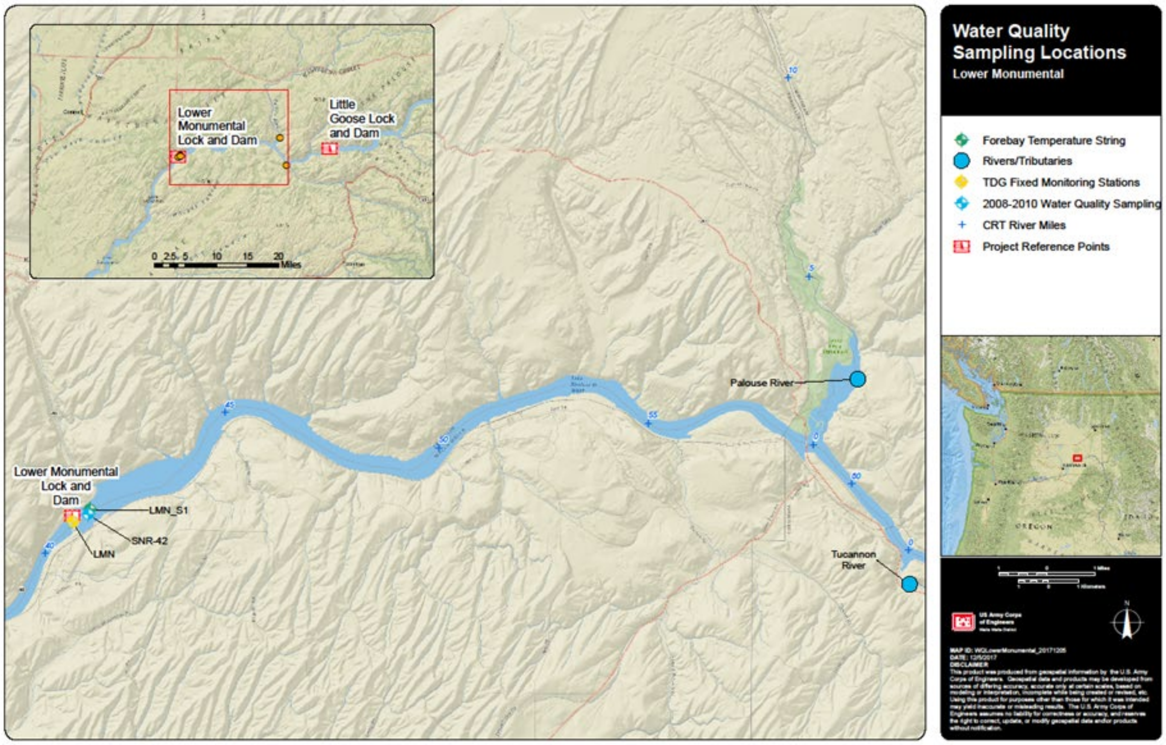


Table 1-1. Selected Characteristics of the Lower Monumental Dam Project

Parameter	Metric
Location	RM 41.6
Year first completed	1969
Reservoir name	Lake Herbert G. West
Normal operating range	537 to 540 feet mean sea level
Storage capacity below elevation 540 feet	376,171 acre-feet
Pool length	28.7 miles
Average reservoir width	0.4 mile
Maximum reservoir width	0.8 mile
Reservoir area at elevation 540 feet	6,590 acres
Maximum depth	125 feet
Mean depth	57.1 feet

1.2 PREVIOUS STUDIES

Water quality data collection began in Lake Herbert G. West shortly after Lower Monumental 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, specific 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).

1.3 WATER QUALITY DATA USED FOR THIS ANALYSIS

Extensive temperature data is available for Lake Herbert G. West. The Corps operates fixed-monitoring stations in the forebay and tailwater of the project where water temperature and total dissolved gas 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 Herbert G. West 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 Lower Monumental pool at RM 42 (SNR-42) (Figure 2-1Table 2-1) and was visited monthly. Field measurements included water column profiles for temperature, dissolved oxygen, pH, specific 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.

SECTION 2 - WATER QUALITY

2.1 GENERAL DESCRIPTION

The State of Washington use designation for Lake Herbert G. West includes salmonid spawning, rearing, and migration, 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) list Category 5 for temperature. 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 (TDG) (Washington State Department of Ecology [Ecology] 2003). A draft temperature TMDL was completed by the EPA in 2003 but never finalized. Dissolved oxygen and pH are listed as Category 2, which means that there is some evidence of a water-quality problem, but not enough to require an improvement project. 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

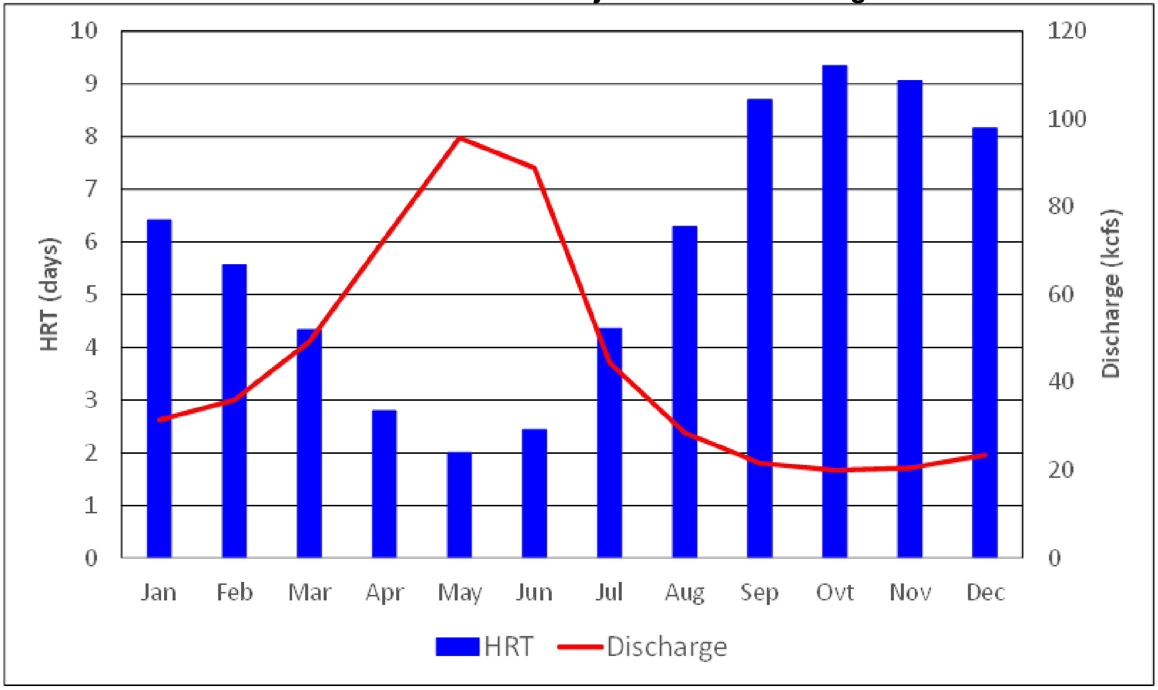
2.2.1.1 *Hydrologic Characteristics*

Since Lower Monumental is a run-of-river project, the long-term minimum, maximum, and average flows are similar to the ones determined for Lower Granite and Little Goose. Based on the project outflow data for the period of record, the minimum average monthly flow is 23.7 kcfs in October, the maximum average monthly flow is 104.0 kcfs, and the average annual flow is 50.3 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 Herbert G. West are the same as the ones determined for Lower Granite Lake: 214 kcfs as determined by the Ecology (2003) and 212 kcfs calculated by Walla Walla District.

Since the volume of Lake Herbert G. West is smaller than Lower Granite Lake and Lake Bryan, the calculated hydrologic residence times (HRTs) are also shorter. The long-term average, based on 1998 through 2016 project outflow data, is 5.8 days. However, the calculated values follow a cyclic pattern throughout the year (Figure 2-1). The shortest retention time occurs in May when the average is 2.0 days and is greatest in October at 9.3 days. The maximum 7-day moving average ranged from 9.1 days to 14.7 days and did not reach or exceed 20 days in any of the years considered.

Figure 2-1. Average Monthly Hydrologic Residence Time and Discharge for the Lower Monumental Project from 1998 through 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 and TDG, and also influences the chemical and biological reactions that take place in aquatic systems.

Recent and historical water temperature data were 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 Herbert G. West. Lake Herbert G. West 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 HRT in excess of 20 days before strong thermal stratification develops. The mean depth of the reservoir is greater than 33 feet, but the average annual residence time, based on 1998 to 2016 data, is 5.8 days. The calculated retention time can exceed 10 days during the summer and fall of low-flow years, but it still remains less than 20 days. Consequently, vertical temperature differences due to incoming solar radiation are minimal because wind- and flow-induced turbulent diffusion, along with convective mixing, prevents the formation of a thermal gradient most of the time.

A relatively small vertical thermal gradient does occur in Lake Herbert G. West as a consequence of the summer cold water releases from Dworshak Dam. However, because this reservoir is downstream of the Lower Granite and Little Goose Dam projects, the summer forebay thermal gradient is less apparent than in the upstream reservoirs. 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 2.3°F (1.3°C) in 2010 to 4.0°F (2.2°C) in 2005 and 2014. The average for the 12 year period was 3.1°F (1.7°C).

<u>Water Temperatures at Lower Monumental Dam Tailwater.</u> Summer tailwater temperatures at the Lower Monumental Dam tailwater station were higher than at the upstream Little Goose location (Figure 2-2). The 1995 through 2016 trace shows that the average of the daily maximum temperatures recorded at the Lower Monumental fixed monitoring system station were near or greater than 68°F (20°C) from mid-July through mid-September. The frequency distribution for the July 1 through September 15 daily maximum temperatures (Figure 2-3) shows that the 68°F (20°C) threshold was exceeded every year between 1995 and 2016. Annual values ranged from a low of 23 percent in 2008 to greater than 80 percent in 1998, 2013, and 2015.

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

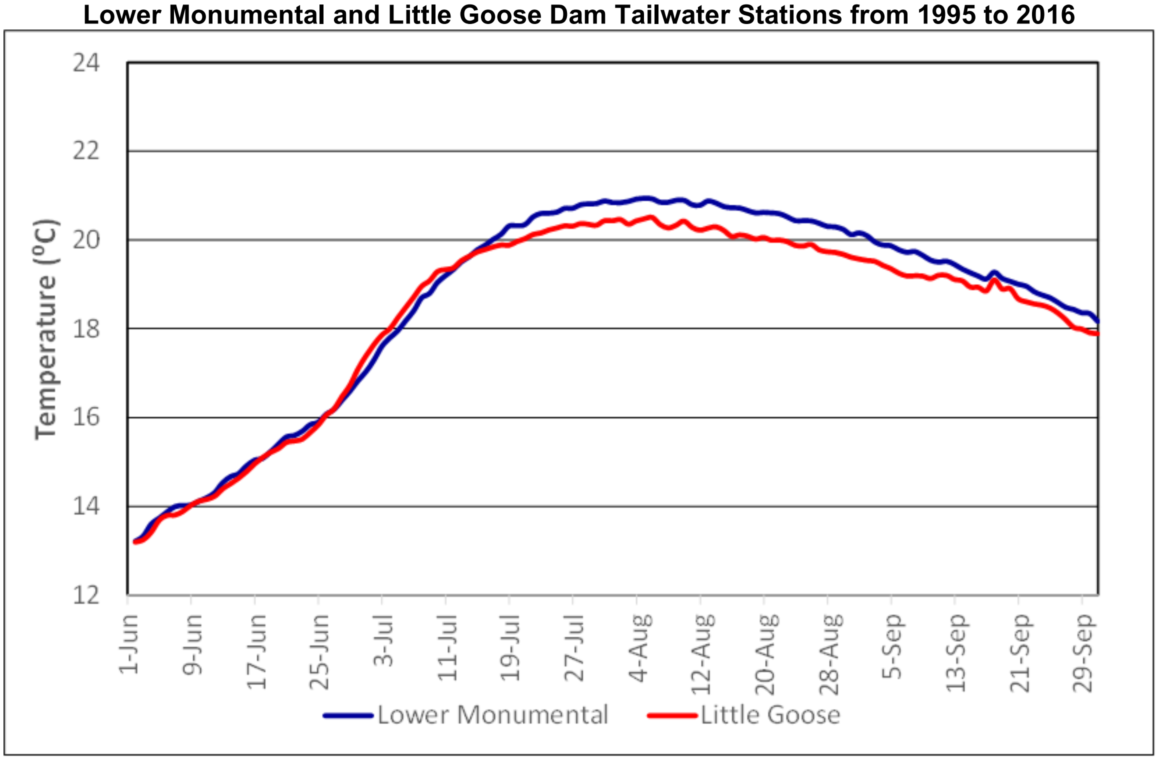
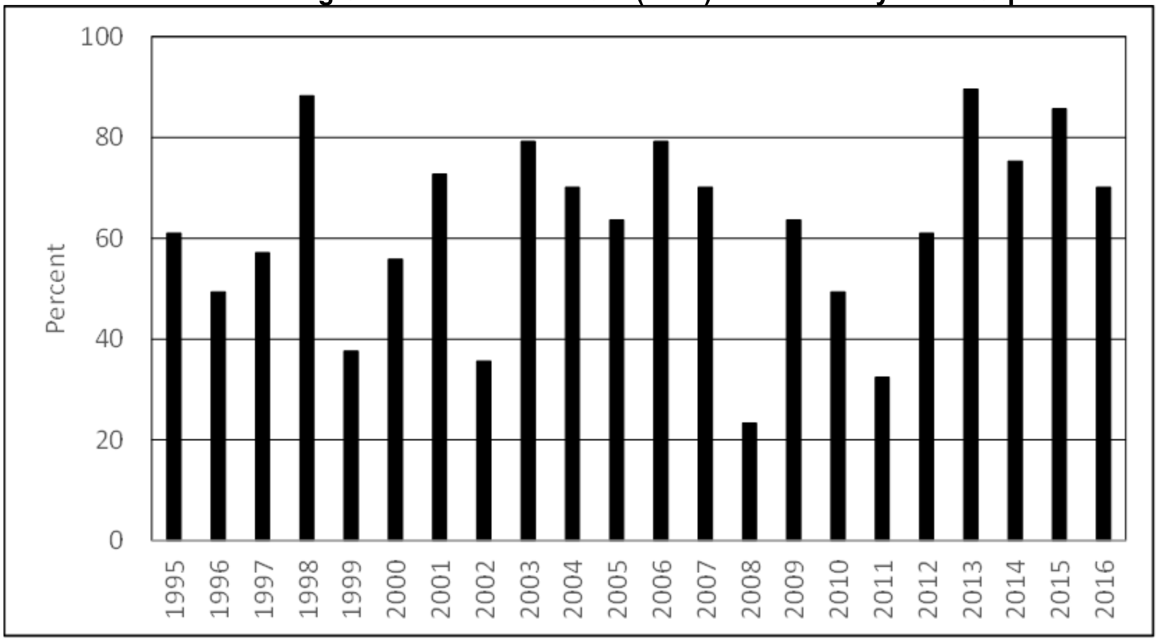


Figure 2-3. Percent of Days When the Daily Maximum Water Temperature at Lower Monumental Dam Tailwater Monitoring Station Exceeded 68°F (20°C) Between July 1 and September 15



2.2.1.3 *Dissolved Oxygen*

Dissolved oxygen is critical to the ecology of both riverine and reservoir systems and sustains most biological life. 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 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 Herbert G. West

Dissolved oxygen profiles were completed during each sampling event at SNR-42 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 12 milligrams per liter (mg/L). Calculated average water-column minimums occurred in October when they reached 7.6 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 exceeded 140 percent saturation during September 2009.

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 (*Oncorhynchus tshawytscha and O. nerka*) and steelhead (*O. mykiss*) 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 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 Lower Monumental Dam. Construction of the two end-bay deflectors were completed for the 2004 fish passage season. Other methodologies to reduce TDG loading below mainstem 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 Lower Monumental 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 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 in 2001 to 68 in 2011, with an 18-year average of 25. Exceedances at the tailwater station ranged from zero in 2001 to 62 in 2011, with a long-term average of 15.

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.

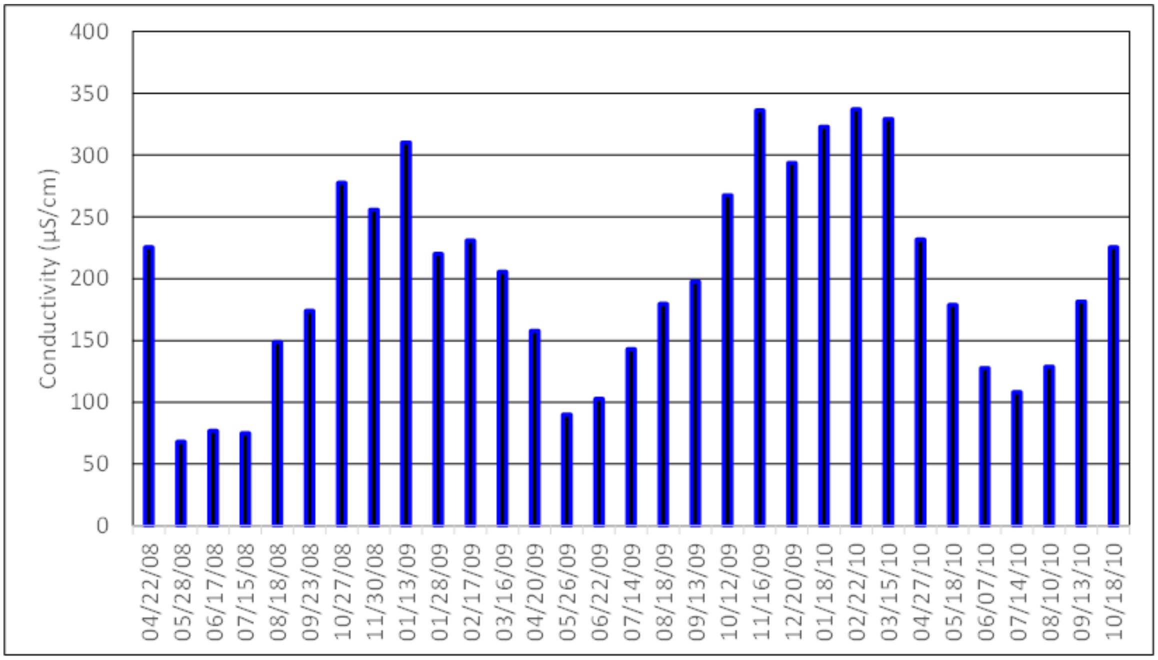
Hourly pH data was not recorded in Lake Herbert G. West during the 2008 through 2010 sampling period, but water column profile measurements were taken at SNR-42. Water column averages were typically lowest in the late fall, winter, and spring when they were often in the range of 7.4 to 7.6 units. The highest values were recorded during July, August, and September when they often exceeded 8.0 units, reaching water column means of 8.5 units in August 2008 and 8.6 units in September 2009. The overall average for the entire study period was 7.9 units.

2.2.1.6 *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.

The average water-column specific conductivity in Lake Herbert G. West, as measured at SNR-42 from 2008 through 2010, was 200 microsiemens per centimeter (µS/cm). Minimum values occurred during May, June, and July when water-column averages ranged from 68 to 128 µS/cm (Figure 2-4). Maximum specific conductivity was measured during the fall and winter months when it typically exceeded 300 µS/cm.

Figure 2-4. Annual Cycle for the Average Water-Column Specific Conductivity Determined for SNR-42 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 specific conductivity. The minimum, maximum, and median concentrations of the major ions, along with alkalinity and hardness, in the water at SNR-42 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 was 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-42

Parameter	Minimum	Maximum	Median
Alkalinity	23	100	68
Hardness	26	123	80
Calcium	7.2	31.0	21
Chloride	1.6	14.0	6.7
Iron	0.04	0.68	0.17
Magnesium	1.9	11.0	6.9
Potassium	1.0	3.4	2.4
Silicon	0.1	12.0	7.5
Sodium	5.2	24.0	15.0
Sulfate	4.9	35.0	18.5
Sulfur	1.6	21.0	6.6

2.2.2.2 *Other Inorganic Chemicals*

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-42 are lower.

Table 2-2. Minimum, Maximum, and Median Concentrations (mg/L) for Minor Inorganic Chemicals Determined for SNR-42 Water Samples Collected Between 2008 and 2010

Parameter	Detection Limit	Minimum	Maximum	Median
Aluminum	0.01	<0.01	0.69	0.16
Antimony	0.010	<0.010	0.010	0.010
Arsenic	0.010	<0.010	0.010	0.010
Barium	0.0005	0.009	0.031	0.018
Beryllium	0.0005	<0.0005	0.0005	0.0005
Boron	0.050	<0.050	0.050	0.050
Cadmium	0.0005	<0.0005	0.0007	0.0005
Chromium	0.001	<0.001	0.002	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	0.014	0.008
Manganese	0.0005	0.0008	0.019	0.013
Mercury	0.010	<0.010	0.010	0.010
Molybdenum	0.005	<0.005	0.008	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	0.049	0.181	0.120
Thallium	0.01	<0.01	0.01	0.01
Tin	0.005	<0.005	0.011	0.005
Titanium	0.001	<0.001	0.027	0.009
Vanadium	0.005	<0.005	0.008	0.005
Yttrium	0.0005	<0.0005	0.0010	0.0005
Zinc	0.001	0.001	0.012	0.002

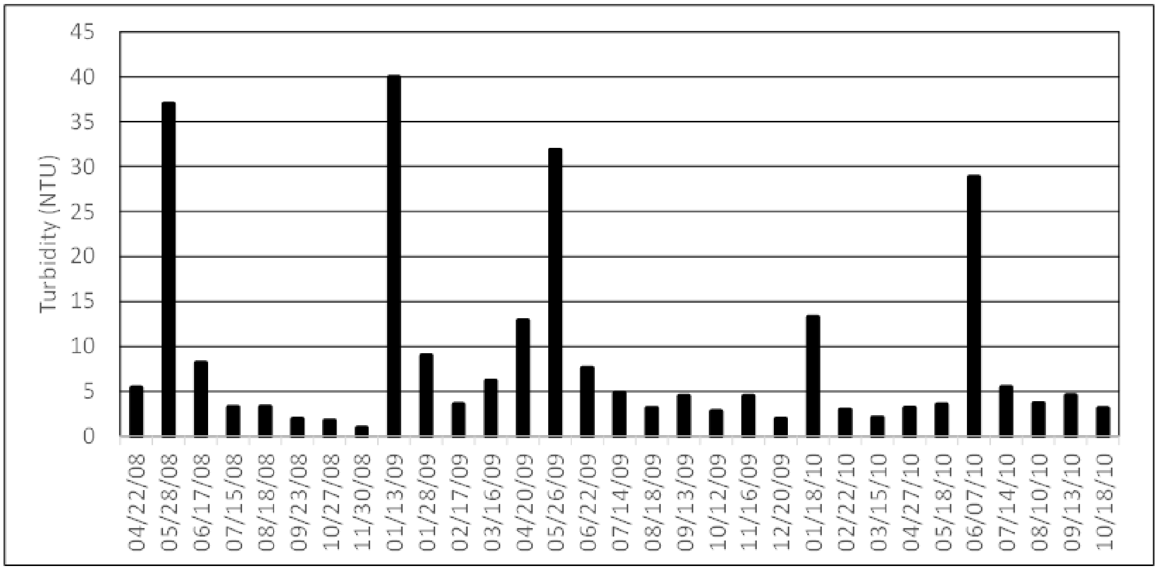
2.2.2.3 *Turbidity*

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). The water-column average for the entire 2008 through 2010 study period was 9

Nephelometric Turbidity Units (NTU). Season lows less than 5 NTU typically occurred in the late summer and fall. Values greater than 25 NTU were usually observed in May and June during the spring freshet, but the January 2009 value of 40 NTU was the highest for the study period.

Figure 2-5. Annual Cycle for Average Water-Column Turbidity Determined for SNR-42 between 2008 and 2010



2.2.2.4 *Total Suspended Solids*

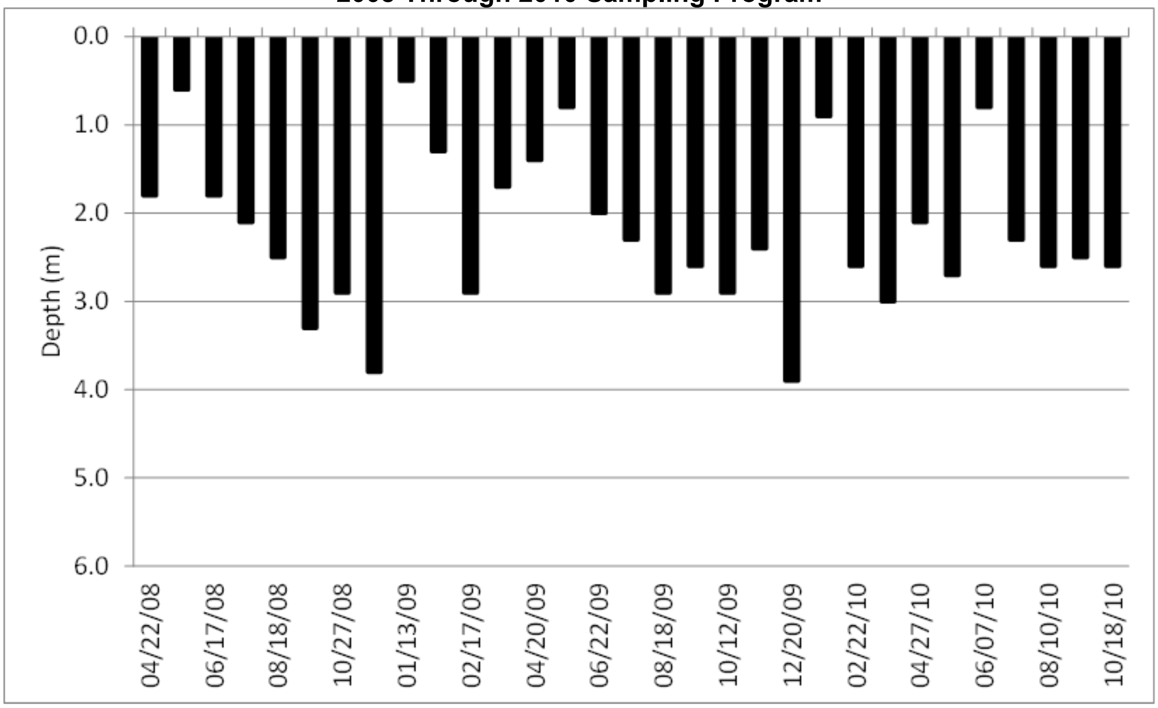
Total suspended solids are solid materials, organic and inorganic, that are suspended in the water and can include silt, plankton, and urban wastes. The larger particles transported by the upstream Clearwater and Snake Rivers settle out in Lower Granite Lake while the finer particles remain suspended and pass into Lake Herbert G. West. 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-42 was 4 mg/L. Calculated water-column averages between 10 and 30 NTU were typically associated with increased runoff events. The highest concentration of 30 NTU does not correspond to a discharge volume equivalent to a spring freshet, but rather to a smaller spike that may have been due to winter snowmelt from agricultural fields.

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-42 for the 2008 through 2010 data set was 2.4 meters. Minimum light transparency was usually associated with elevated runoff events, with individual measurements ranging from 0.5 to 0.6 meters in January 2009 and May 2008, respectively (Figure 2-6). Conversely, greatest water transparency typically occurred during late-fall and early winter with maximum values occurring in November 2008 and December 2009 at 3.8 and 3.9 meters, respectively.

Figure 2-6. Secchi Disk Depths Recorded at SNR-42 during the 2008 Through 2010 Sampling Program



2.2.2.6 *Nitrogen and Phosphorus*

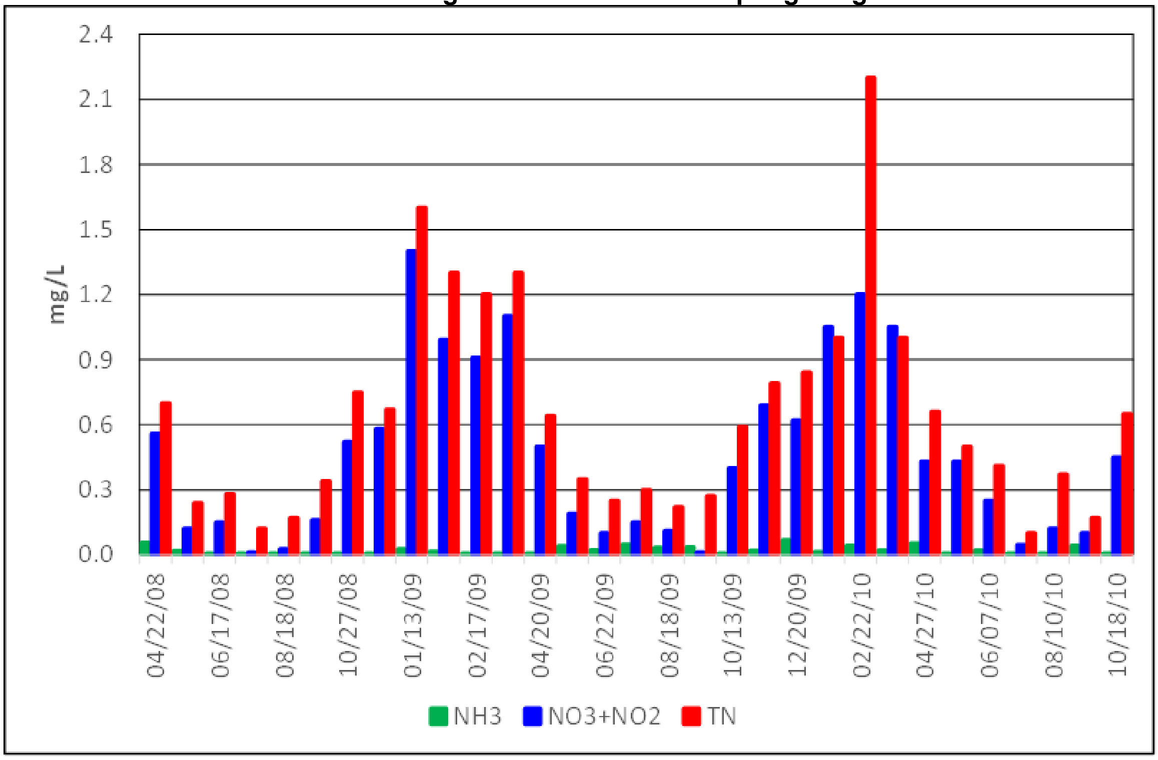
Nitrogen. Of the various soluble inorganic forms of nitrogen, nitrate plus nitrite nitrogen (NO_3+NO_2-N) (hereafter referred to as nitrate) was the principal component, comprising more than 90 percent of the soluble fraction at SNR-42. The calculated median water-column concentration for the entire sampling period was 0.43 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 0.15 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-42 was 0.01 mg/L. Forty-eight percent of the medians calculated for a given sampling event were less than or equal to 0.01 mg/L, and the highest values that ranged from 0.05 and 0.07 mg/L could occur during the winter, spring, or summer (Figure 2-7).

Total nitrogen (TN) includes inorganic and organic components. Total nitrogen concentrations in Lake Herbert G. West exhibited seasonal variability, similar to the one identified for NO_3+NO_2-N (Figure 2-7). Overall, NO_3+NO_2-N comprised 65 percent of the TN for the entire study period. Summer median water column TN concentrations were approximately 0.26 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-42 during the 2008 to 2010 Sampling Program

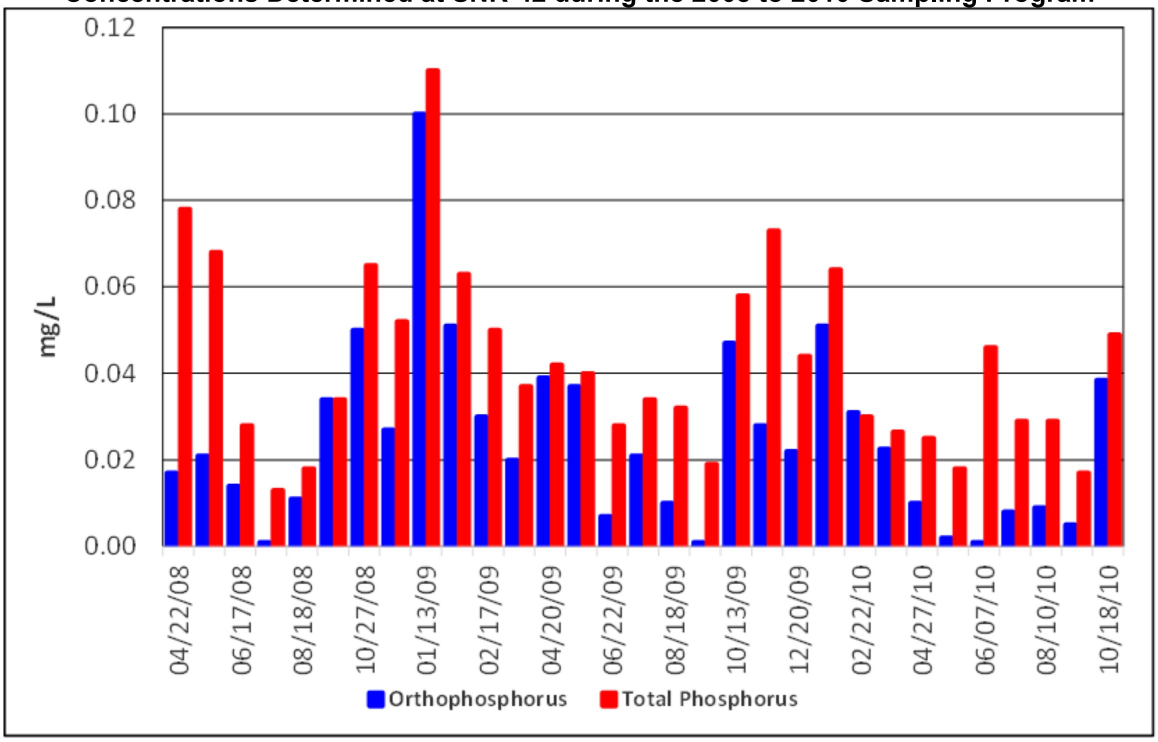


<u>Phosphorus.</u> Phosphorus is generally expressed in terms of total phosphorus (total-P) and orthophosphorus (ortho-P). Ortho-P represents the inorganic soluble fraction of the total phosphorus in water and is generally considered to be more readily available for biological uptake than total phosphorus. Total-P consists of both the soluble fraction and that portion adsorbed to sediments or tied up with biological materials in the water column. Because 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).

Orthophosphorus concentrations in Lake Herbert G. West tend to be highest in the fall and winter, with relatively low concentrations in the summer. The calculated summer water-column median values was 0.008 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 0.08 mg/L (Figure 2-8).

Total-P concentrations generally followed the temporal pattern set by ortho-P (Figure 2-8). The calculated median value for the percentage of total-P that was ortho-P was 56 percent. The median water-column total-P concentration for the 2008 to 2010 study period was 0.034 mg/L and 0.028 mg/L for the summer months. 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-42 during the 2008 to 2010 Sampling Program



2.2.2.7 *Organic Compounds*

Water samples from Lake Herbert G. West have not been routinely analyzed for organic compounds.

2.2.3 Biological

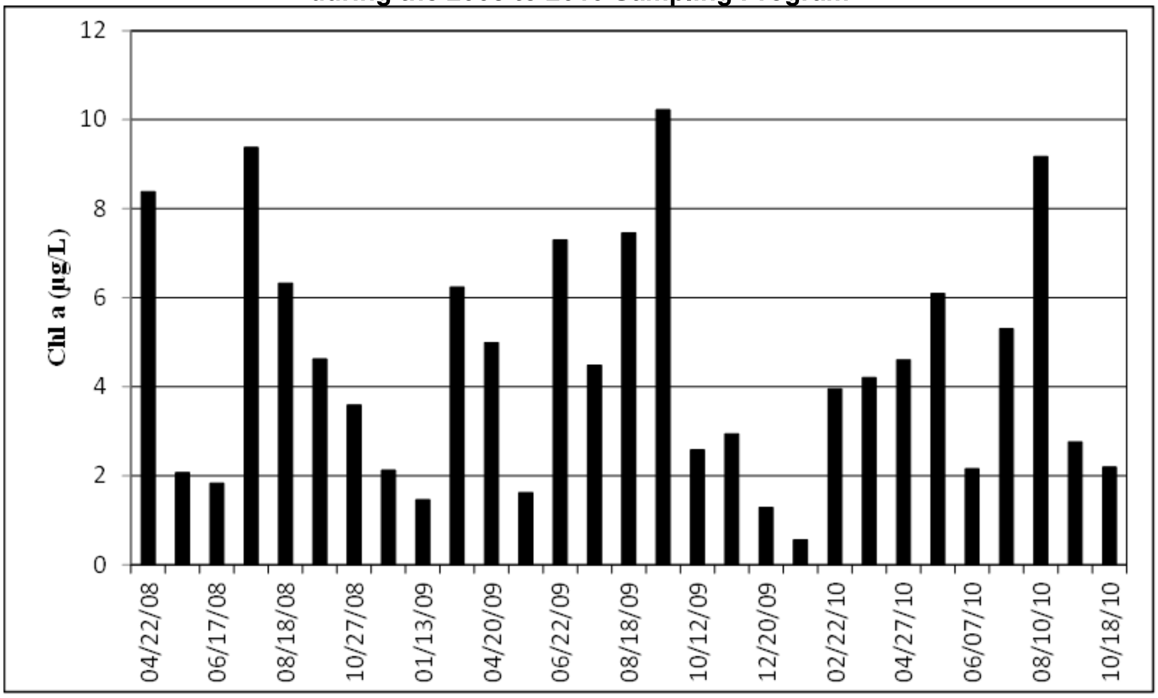
2.2.3.1 *Chlorophyll a*

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. Annual minimum values less than about 2 micrograms per liter (μg/L) occurred during the late fall and winter when the water is cold, and during peak runoff periods in May and June (Figure

2-9). Maximum concentrations greater than 6 μg/L usually occurred during the summer months but could also occur during early spring. The overall median for all of the 2008 through 2010 data was 4.2 μg/L, while June through September calculated medians ranged from 4.0 μg/L in 2010 to 7.3 μg/L in 2009.

Figure 2-9. Chlorophyll a Concentrations Determined for SNR-42 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, which 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 are 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 Herbert G. West was dominated by Bacillariophyta (diatoms) often accounting for greater than 90 percent of the total phytoplankton biovolume during any sampling event (Figure 2-10). *Aulascoseira* spp. (primarily *Aulascoseira granulata*) biovolume often exceeded the contribution from other individual diatom genera. Their largest biovolumes were determined during the months of August and September when they could account for greater than 90 percent of the diatom biovolume. The overall median for this genus during the study period was 1.65×10^9 $\mu m^3/L$ and reached a maximum of 3.30×10^{10} $\mu m^3/L$ during September 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-42. The median biovolume of this genus for the study period was 5.04×10^8 $\mu m^3/L$, but it did reach maximum values of 8.86×10^9 and 2.30×10^{10} $\mu m^3/L$ during July 2008 and August 2008, respectively. During these two events, they did account for more than 70 percent of the diatom biovolume. However, their presence was not consistent. During some months they would account for less than 5 percent of the total diatom biovolume but then rebound to 20 to 40 percent the next month. *Fragilaria* spp. biovolume (primarily *Fragilaria crotonensis)* had a calculated median biovolume of 1.53×10^8 $\mu m^3/L$, or 3.4 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-42. During the two-year study, their calculated median biovolume was 1.32×10^8 $\mu m^3/L$, or 2.9 percent.

The median Chlorophyte biovolume in Lake Herbert G. West 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 5.59×10^7 $\mu m^3/L$, or 62 percent of the total green algae biovolume (Figure 2-11). Other algae such as *Chlamydomonas* spp., *Oocystis lacustris*, *Pandorina morum*, *Pediastrum spp., Scenedesmus spp.,* and *Sphaerocystis schroeteri* would periodically be the dominant Chlorophyte during a sampling event and elevate the green algae to 10 percent of the total biovolume, but then not be identified in subsequent samples.

Cryptophyte biovolume in Lake Herbert G. West was very similar to the Chlorophytes. Median percent composition was 3.7 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 1.15×10^8 $\mu m^3/L$ and reached

1.03 x 10^9 µm^3/L during July 2010 when it constituted 20 percent of the total algal biovolume. However, during 40 percent of the sample trips, it constituted less than 2 percent of the total biovolume, and 84 percent of the time, it was less than 10 percent.

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 August 18, 2009, when it accounted for 8 percent of the total biovolume. The major species present on that date were *Anabaenopsis circularis* (3.91 x 10^8 µm^3/L) and *Cylindrospermopsis raciborskii* (2.41 x 10^8 µm^3/L) with lesser amounts of *Pseudanabaena* spp. (5.48 x 10^5 µm^3/L) and *Microcystis* spp. (3.93 x 10^5 µm^3/L). During two other 2009 sampling events, October 12 and July 14, the blue-green algae accounted for 4 percent and 2 percent of the total biovolume, respectively. The principal species in October was *Aphanizomenon* spp. (1.70 x 10^8 µm^3/L), while the July event consisted of *Anabaenopsis* spp. (1.19 x 10^8 µm^3/L), *Dactylococcopsis fascicularis* (5.04 x 10^6 µm^3/L), *Cylindrospermopsis raciborskii* (2.10 x 10^6 µm^3/L), and *Anabaena spp.* (3.34 x 10^5 µm^3/L). One other sample date when the blue-green algae comprised 2 percent of the total biovolume was June 17, 2008, when the only identified species was *Anabaena spp.* at 5.12 x 10^7 µm^3/L).

Figure 2-10. Percent Biovolume Composition of the Major Phytoplankton \Divisions at SNR-42 during the 2008 to 2010 Sampling Program

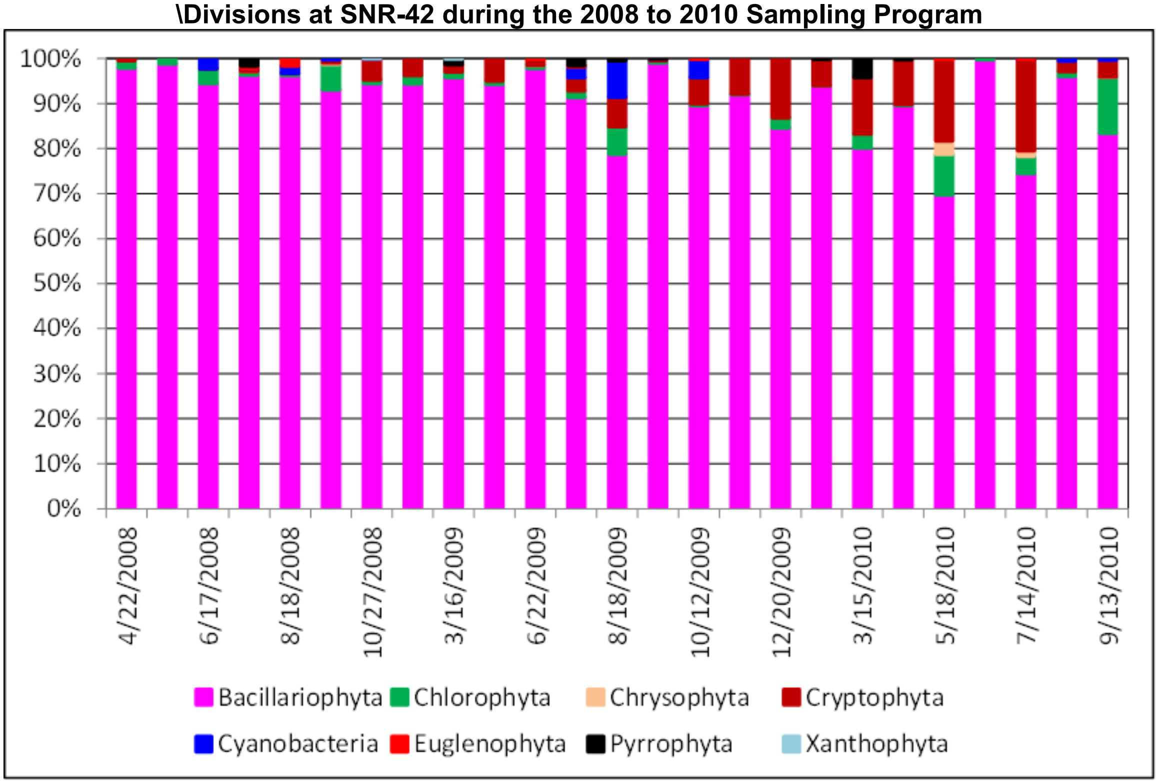
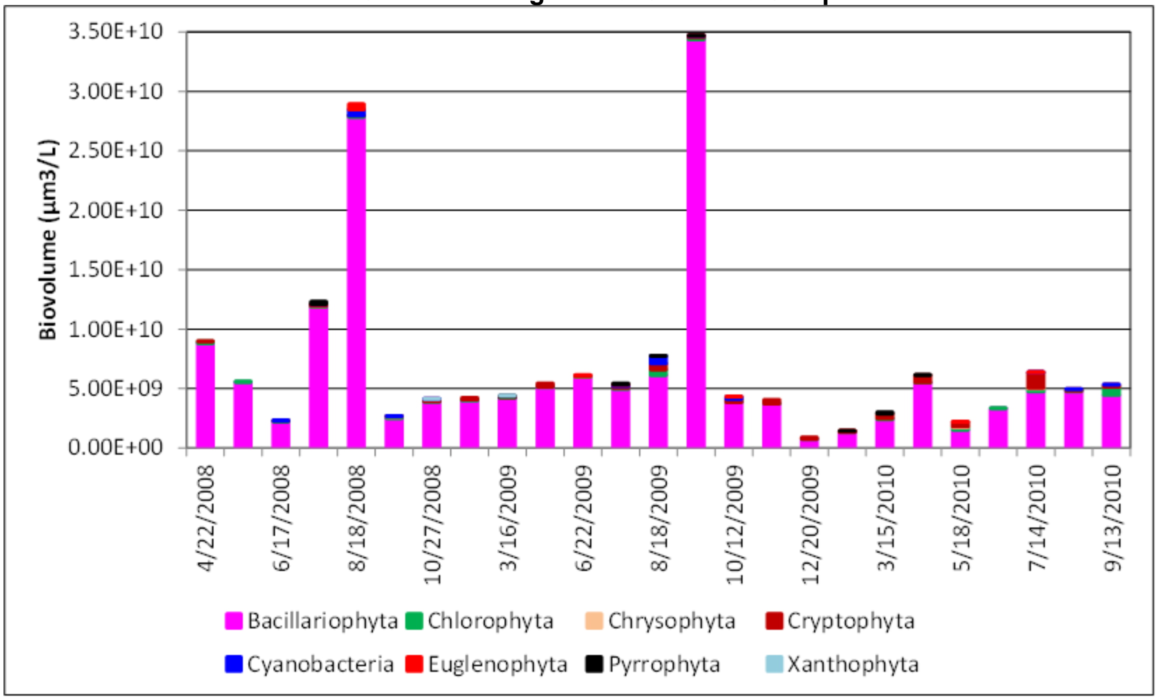


Figure 2-11. Biovolume Determined for the Major Phytoplankton Groups Identified at SNR-42 during the 2008 to 2010 Sample Events



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 June through October 1997 results as an example, the volume weighted hourly rate measured near SNR-50 ranged from 5.58 milligrams carbon-12 per cubic meter per hour (mg $^{12}C/m^3/hr$) in June to 27.68 mg $^{12}C/m^3/hr$ in July. The calculated median for the June through September growing season was 13.64 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 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 and Figure 2-13). *Daphnia retrocurva* was the primary species with an estimated biomass of 216 and 639 µg/L during the respective trips, which was equivalent to 95 and 74 percent of the total zooplankton biomass on those dates. Cladocerans were present during the remainder of the year, and for the 2008 through 2010 study, their median of the total zooplankton biomass was 12 percent. During some months they were not identified in the samples. Overall, the median Copepod biomass for the 2008 to 2010 sampling was greater than the Cladocerans: 1.7 versus 0.1 µg/L. For the same time period, their median proportion of the total biomass was 33 percent. *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 0.61 µg/L but did reach 18.3 and 30.8 µg/L during April 2009 and September 2009, respectively. Nauplii biomass peaked at a lower 3.2 and 4.9 µg/L during August 2008 and 2009, respectively. Their median biomass for the study period was 0.16 µg/L. Additionally, Copepods were more ephemeral, yet did have a biomass as high as 122.8 µg/L in September 2009, and included *Acanthocyclops robustus, Calanoid copepodid, Diacyclops thomasi, Leptodiaptomus* sicilis, and *Tropocyclops prasimus*. The median contribution of the Rotifers to the total zooplankton biomass was 41 percent. Their greatest presence could occur at any time of the year, and on three sample events (April 2008, February 2009, and July 2010), they comprised greater than 94 percent of the total biomass. Peak biomass occurred on April 20, 2009, at 122 µg/L, followed by approximately 27 µg/L on April 22, 2008. On February 22, 2010, their biomass was greater than 50 µg/L. These pulses typically would have tapered off to less than 1 µg/L during subsequent field trips. The primary representatives were *Brachionus calyciflorus, Polyarthra vulgaris*, and *Synchaeta pectinata*.

Figure 2-12. Zooplankton Biomass for the Three Major Divisions Determined at SNR-42 between 2008 and 2010

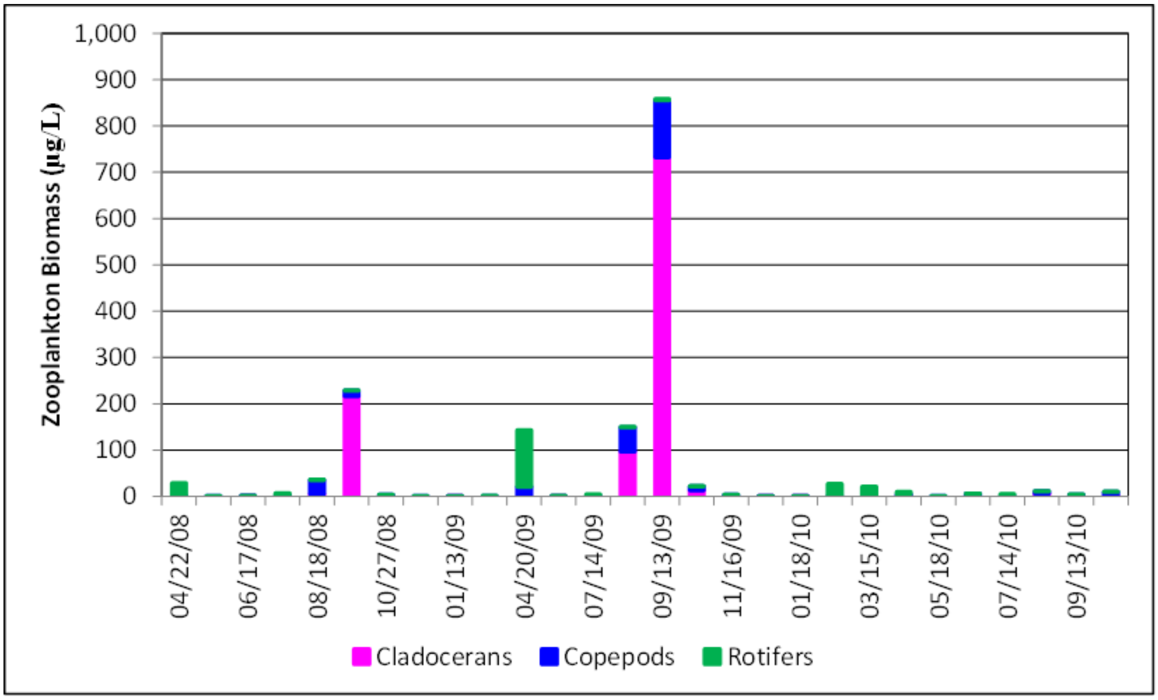
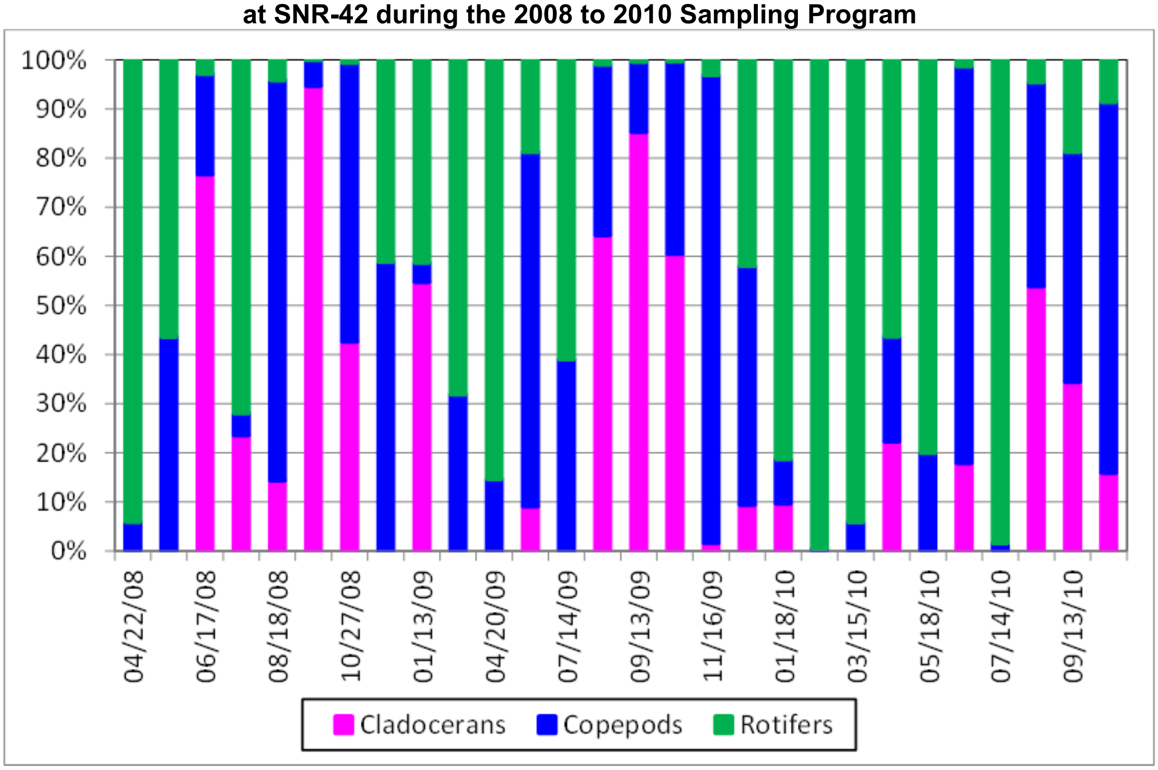


Figure 2-13. Median Zooplankton Assemblage Percent Composition at SNR-42 during the 2008 to 2010 Sampling Program



2.2.3.5 *Coliforms and Other Microbial Organisms*

Recent data for coliform or other bacteria is not available for Lake Herbert G. West.

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 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 Herbert G. West, using summer growing season measurements, was 47 in 2008 and 2009, and 50 in 2010. 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-42 and analyzed in a laboratory, range from 46 in 2010 to 50 in 2009 and are indicative of upper mesotrophic 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 50 in 2008 to 53 in 2009 and 2010. Based on this metric, Lake Herbert G. West 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 (0.42) and percent oxygen saturation (0.50) and negatively correlated with specific conductivity (-0.45) and Secchi disk depth (-0.49). Secchi disk depth was also negatively correlated with turbidity (-0.75). A coefficient of 0.59 was identified for pH and chlorophyll a, while the coefficient between chlorophyll a and phytoplankton biovolume was (0.54). pH was also positively correlated with phytoplankton biovolume (0.42) and zooplankton biomass (0.47). Zooplankton biomass was also positively correlated with chlorophyll a (0.43) and phytoplankton biovolume (0.40).

Table 2-3. Kendall's Tau-B Correlation Matrix for SNR-42

	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.	0.09	1.00															
% DO	**0.50**	0.29	1.00														
DO-mg/L	0.29	**-0.41**	**0.31**	1.00													
pH	-0.15	0.26	0.28	-0.03	1.00												
Sp. Cond.	**-0.45**	**-0.35**	**-0.43**	0.00	0.08	1.00											
Turb.	**0.42**	-0.19	0.25	**0.43**	-0.31	-0.24	1.00										
NH_3-N	0.18	-0.14	0.17	0.25	0.05	0.07	0.16	1.00									
NO_3+NO_2	-0.19	**-0.72**	**-0.37**	0.27	-0.21	**0.55**	0.04	0.06	1.00								
Total-N	**-0.30**	**-0.64**	**-0.38**	0.23	-0.11	**0.58**	0.00	0.07	**0.83**	1.00							
PO_4-P	-0.23	**-0.45**	**-0.51**	0.09	**-0.43**	0.35	0.07	-0.03	**0.54**	0.43	1.00						
Total-P	-0.13	**-0.42**	**-0.43**	0.08	-0.39	0.33	0.14	0.01	**0.47**	**0.41**	**0.60**	1.00					
TSS	**0.31**	-0.06	0.21	0.30	-0.15	-0.15	0.37	0.27	-0.02	-0.01	0.05	0.19	1.00				
Secchi	**-0.49**	0.18	-0.25	-0.39	0.33	0.29	**-0.75**	-0.23	-0.03	0.04	-0.10	-0.13	**-0.46**	1.00			
Chl a	0.01	**0.39**	**0.37**	-0.07	**0.59**	-0.20	-0.12	-0.10	-0.35	-0.24	**-0.49**	-0.38	0.00	0.09	1.00		
Phyto BV	0.17	**0.41**	**0.41**	0.03	**0.42**	-0.28	0.06	0.16	**-0.47**	**-0.41**	-0.35	-0.21	0.22	-0.16	**0.54**	1.00	
Zoop BM	-0.13	**0.38**	0.20	-0.14	**0.47**	-0.02	-0.19	-0.04	-0.27	-0.15	-0.17	-0.19	0.04	0.22	0.43	**0.40**	1.00

SECTION 3 - SUMMARY

Lake Herbert G. West is the next downstream reservoir from Lake Bryan. Because Lower Monumental 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 5.8 days but can range from less than 1 day to 19 days. June through September Secchi disk depths ranged from 0.6 to 3.3 meters, with a calculated median of 2.3 meters for that time period. The median 2008 to 2010 June through September chlorophyll a concentration was 5.0 µg/L with a range of 1.8 to 10.3 µg/L. The total algal biovolume was predominantly comprised of diatoms that accounted for calculated median of 94 percent. *Aulacoseira* spp. and *Stephanodiscus* spp. were the primary representatives. The copepods are consistently present in the reservoir and accounted for 35 percent of the zooplankton biomass during the 2008 to 2010 study. *Calanoid* spp., *Cyclopoid* spp., *Diacyclops* spp., *Leptodiaptomus* spp., and nauplii were the species that were consistently present. However, during individual sampling events, the cladocera, primarily *Daphnia retrocurva* and *Daphnia galeata*, could surpass the combined biomass of all other zooplankters during the summer months when biomass ranged from 200 to 700 µg/L. Carlson trophic state indices were calculated using summer chlorophyll a concentrations, Secchi disk depths, and total phosphorus concentrations. The resulting metrics placed the reservoir in the upper mesotrophic to lower eutrophic category.

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