2005-2006 and 2006-2007 North Dakota Lake Water Quality Assessment Reports

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Prepared by:
Peter Wax, Environmental Scientist;
Andy McDonald, Environmental Scientist; and
Michael J. Ell, Environmental Administrator
North Dakota Department of Health
Division of Water Quality
Gold Seal Center, 4th Floor
918 East Divide Avenue
Bismarck, ND 58501-1947

North Dakota Department of Health
Division of Water Quality

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INTRODUCTION

Project Description and Purpose

The 2005-2006 and 2006-2007 Lake Water Quality Assessment Project was a cooperative effort between the North Dakota Game and Fish Department♣s Fisheries Division (NDGF) and the North Dakota Department of Health Division of Water Quality♣s Surface Water Quality Management Program (SWQMP). One of the primary goals of the SWQMP is to monitor the quality of the state's surface water resources, including lakes and reservoirs, and to assess and report on the quality of those waters. There are currently an estimated 246 lakes and reservoirs in the state that are managed for fishing and/or used for public recreation. With its limited resources, it is not possible for the SWQMP to adequately sample all of these lakes and reservoirs in a timely matter.

As part of its normal operation, the NDGF routinely visits many of the state's lakes and reservoirs. For example, NDG&F district fisheries staff conduct routine adult population test netting, fall reproduction sampling, and limited summer and winter water quality monitoring on many of the states lakes and reservoirs. In an effort to improve the state's lakes and reservoir water quality monitoring program, the NDGF and the SWQMP are cooperating in this project. Through this cooperative effort, the SWQMP has taken advantage of the NDGF's existing lake and reservoir sampling schedule by providing training, equipment, and water quality analysis for lake and reservoir samples collected by the NDGF Fisheries Division staff.

The purpose of this monitoring and assessment project is to: 1) monitor the chemical, physical and biological character of the state♣s lakes and reservoirs; 2) use chemical, physical and biological indicators to assess the current water quality condition and trophic status of monitored lakes and reservoirs; 3) determine spatial differences among lakes and reservoirs; and 4) determine temporal trends in lake water quality by comparing project data to Lake Water Quality Assessment data or other historic water quality data. Assessment information generated from this project will be used by both the North Dakota Game and Fish Department and the North Dakota Department of Health♣s Division of Water Quality to prioritize lakes, reservoirs and their watersheds for lake maintenance and improvement projects (i.e., Save Our Lakes, Total Maximum Daily Loads, Section 319 Non-point Source Management Program).

The result of these assessments are not intended to be in-depth evaluation of the individual lake or reservoir but rather a simple and functional assessment that characterizes the major water quality parameters, limiting nutrients, and current trophic status of the lake or reservoir. If sufficient historic data are available for a lake or reservoir, trends (improving, declining, or stable) in water quality are also assessed.

Lakes and Reservoirs Assessed in 2005-2006 and 2006-2007

Assessed lakes and reservoirs were selected by the North Dakota Game and Fish Department's six District Biologists. With the exception of Sather Dam, that was sampled 5 times between the Jan 2006 and Aug 2007, the lakes and reservoirs targeted for assessment were monitored a minimum of two times during the open water period and once during ice cover the following winter (i.e., twice during the summer of 2005 and once during the winter 2005/2006).

A total of sixty-seven (67) lakes and reservoirs were selected and monitored (Figure1, Table 1). Eleven (11) lakes and reservoirs are located in the southwest fisheries district, eight (8) in the south-central district, 13 in the southeast district, two (2) in the northwest district, 27 in the north-central district, and six (6) in the southeast district. Fifty-seven (57) lakes and reservoirs were sampled during the first year of the project, seven (7) during second year, and three (3) (Blumhardt Lake, Heinrich-Martin Dam, and Moon Lake) were sampled both years.

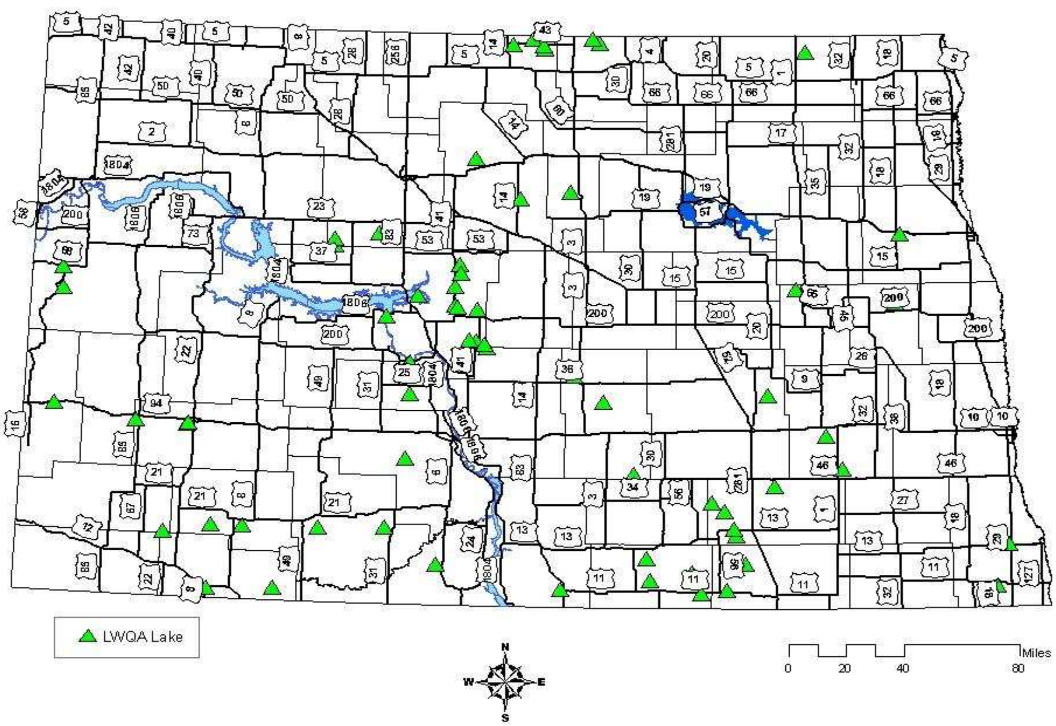


Figure 1. Location of 2005 and 2006 Lake Water Quality Assessment Lakes and Reservoirs in North Dakota.

Water Quality Variables

Water Quality data collected for each assessment included field measurements of Secchi disk transparency, a temperature and dissolved oxygen profile, and a sample collected for chemical and chlorophyll-a analysis (Table 2). Samples collected for chemical analysis were analyzed by the North Dakota Department of Health’s Division of Laboratory Services for general chemistry (i.e., major cations/anions hardness, alkalinity, pH and specific conductance), nutrients (i.e., total nitrogen, total Kjeldahl nitrogen, ammonia, nitrate/nitrite, and total phosphorus), and chlorophyll-a (Table 2).

Table 1. Summary of Lakes and Reservoirs Included in 2005-2006 and 2006-2007 Lake Water Quality Assessment Project (by county).

Lake Name	County	Lake Name	County
Mirror Lake	Adams	Leland Dam	McKenzie
North Lemmon Lake	Adams	Sather Dam	McKenzie
Clausen Springs	Barnes	Brush Lake	McLean
Moon Lake	Barnes	Crooked Lake	McLean
Lake Metigoshe	Bottineau	East Park Lake	McLean
Long Lake	Bottineau	Lake Audubon	McLean
Pelican Lake	Bottineau	Lake Brekken	McLean
Strawberry Lake	Bottineau	Lake Holmes	McLean
New Johns Lake	Burleigh	Long Lake	McLean
Mt. Carmel Dam	Cavalier	Riverdale Spillway Pond	McLean
Wilson Dam	Dickey	Strawberry Lake	McLean
Rice Lake	Emmons	West Park Lake	McLean
Camels Hump Dam	Golden Valley	Fish Creek Dam	Morton
Larimore Dam	Grand Forks	East Arroda Lake	Oliver
Raleigh Dam	Grant	Nelson Lake	Oliver
Sheep Creek Dam	Grant	West Arroda Lake	Oliver
Red Willow Lake	Griggs	Balta Dam	Pierce
Castle Rock Dam	Hettinger	Lake Elsie	Richland
Indian Creek Dam	Hettinger	Mooreton Pond	Richland
Alkaline Lake	Kidder	Dion Lake	Rolette
Horsehead Lake	Kidder	Lake Upsilon	Rolette
Lake Josephine	Kidder	Heckers Lake	Sheridan
Heinrich-Martin Dam	LaMoure	Froelich Dam	Sioux
Kalmbach Dam	LaMoure	Cedar Lake	Slope
Kulm-Edgeley Dam	LaMoure	Belfield Dam	Stark
Schlecht-Thom Dam	LaMoure	Dickinson Dike	Stark
Schlecht-Weixel Dam	LaMoure	Patterson Lake	Stark
Buffalo Lodge Lake	McHenry	South Golden Lake	Steele
Cottonwood Lake	McHenry	Spiritwood Lake	Stutsman
Lake George	McHenry	Hiddenwood Lake	Ward
Blumhardt Lake	McIntosh	Makoti Lake	Ward
Coldwater Lake	McIntosh	North Carlson Lake	Ward
Dry Lake	McIntosh	Rice Lake	Ward
Green Lake	McIntosh		

Table 2. Summary of Lake Water Quality Assessment Water Quality Variables.

Field Measurements	General	Nutrients	Biological
Secchi Disk Transparency	Sodium	Total Nitrogen	Chlorophyll-a
Dissolved Oxygen	Potassium	Total Phosphorus	
Temperature	Magnesium	Total Kjeldahl Nitrogen	
	Calcium	Nitrate + Nitrite	
	Iron	Total Ammonia	
	Hardness		
	Alkalinity		
	Bicarbonate		
	Carbonate		
	Hydroxide		
	Chloride		
	Sulfate		
	Conductivity		
	pH		

Sample Methods

All samples were collected from a single location on each lake or reservoir located over the deepest area. Each time the waterbody was visited a temperature and dissolved oxygen profile was recorded and a surface sample collected for chemical analysis. Summer, open water samples also consisted of a Secchi disk transparency measurement and sample for chlorophyll-a analysis. All water quality samples were collected using a 2-meter depth integrated water column tube sampler. For a detailed description of the sampling methods the reader is referred to the document entitled “Sampling and Analysis Plan for the North Dakota Game and Fish Department Fisheries Division District Lake Monitoring and Assessment Project 2005-2006 and 2006-2007” provided in Appendix A. At the end of each sampling trip, water quality samples were either mailed or hand delivered to the North Dakota Department of Health’s Division of Laboratory Services-Chemistry laboratory for analysis.

Sample Frequency

Sampling was conducted on each lake or reservoir two to four times per year and was coordinated with existing NDGF district lake sampling activities (e.g., standard adult fish population surveys, summer water quality sampling, fall reproduction sampling, winter water quality sampling). At a minimum, two samples were collected, one during the summer (June, July or August) and one during the winter under ice cover.

Historical Water Quality and Trends Analysis

Data collected from lakes and reservoirs for the project were compared with available historical water quality data in order to determine water quality trends. Historically, water quality samples collected for chemical analysis were collected at two or more discrete depths in the water column. Typically samples were collected at the surface (1-meter depth interval) and near the bottom. In deeper, stratified lakes or reservoirs, a mid-depth sample may also have been collected. While samples collected for chemical analysis were typically collected from discrete depth, chlorophyll-a samples were typically collected using the 2-meter depth integrated water column tube sampler. As stated previously, water samples collected for this project were collected from the top 2-mters in the water column using the depth integrated tube sampler. Therefore, in order to provide historical data for comparative purposes only historical data collected from the surface to 2 meters of depth were queried and used in this report.

Only historical water quality data collected by the SWQMP and stored in its Sample Identification Database (SID) were used for this report. Historical data stored in SID and used for this report are for the period 1991-2004.

Trends analysis were conducted for each lake or reservoir by summarizing and analyzing historical water quality data through several descriptive statistics (e.g., mean, minimum, maximum and standard deviation) and through graphical comparisons with 2005 and/or 2006.

Temperature and Dissolved Oxygen Profile Analysis

Temperature and dissolved oxygen (DO) play an important role in a lake or reservoir's over all health and ability to sustain appropriately diverse populations of aquatic life. In general, cooler water temperatures and the higher oxygen concentrations will result in increased diversity and populations of aquatic species.

During periods of summer stratification, the majority of the cool water in a lake or reservoir is in a region referred to as the hypolimnion. The hypolimnion is defined as the water below the thermocline. The thermocline is defined as the depth where a 1 degree shift in temperature occurs within a 1-meter change in depth. The thermocline results in two layers of water, a warmer upper layer, termed the epilimnion, and a cooler bottom layer, the hypolimnion. While the epilimnion is exposed to wind action and the photosynthetic activity of algae, the hypolimnion is isolated.

The water in the hypolimnion is typically an area of oxygen consumption, where accumulated organic matter (e.g., settling algae) is decomposed. These decomposition processes require oxygen which is obtained from the water column in the hypolimnion. The rate at which oxygen is consumed in the hypolimnion, termed the hypolimnetic oxygen depletion rate, is directly related to the amount of organic matter deposited in the hypolimnion which is directly related to the lake or reservoir's trophic status. This relationship makes the tracking of temperature and dissolved oxygen profiles an excellent measure of increasing or decreasing eutrophication.

Trophic Status Assessment

Trophic status is the primary indicator used to assess whether a lake or reservoir is meeting its intended uses (e.g., fishery class, recreation use). Trophic status is a measure of the productivity of a lake or reservoir and is directly related to the level of nutrients (i.e., phosphorus and nitrogen) entering the lake or reservoir from its watershed and/or from the internal recycling. Highly productive lakes, termed "hypereutrophic," contain excessive phosphorus and are characterized by large growths of weeds, blue-green algal blooms, low transparency, and low dissolved oxygen (DO) concentrations. These lakes experience frequent fish kills and are generally characterized as having excessive rough fish populations (carp, bullhead, and sucker) and poor sport fisheries. Due to the frequent algal blooms and excessive weed growth, these lakes are also undesirable for recreational uses such as swimming and boating.

Mesotrophic and eutrophic lakes, on the other hand, have lower phosphorus concentrations, low to moderate levels of algae and aquatic plant growth, high transparency, and adequate DO concentrations throughout the year. Mesotrophic lakes do not regularly experience algal blooms, while eutrophic lakes experience occasional algal blooms of moderate to short duration, typically a few days to a few weeks.

Due to the relationship between trophic status indicators and the aquatic community (as reflected by the fishery) or between trophic status indicators and the frequency of algal blooms, trophic status becomes an effective indicator of aquatic life and recreation use support in lakes and reservoirs. For purposes of this assessment methodology, it is assumed that hypereutrophic lakes do not fully support a sustainable sport fishery and are limited in recreational uses, whereas mesotrophic lakes fully support both aquatic life and recreation use. Eutrophic lakes may be assessed as fully supporting, fully supporting but threatened, or not supporting their uses for aquatic life or recreation.

Since trophic status indicators specific to North Dakota waters have not been developed, Carlson's trophic status index (TSI) (Carlson, 1977) has been chosen to assess the trophic status of lakes or reservoirs. To create a numerical TSI value, Carlson's TSI uses a mathematical relationship based on three indicators: 1) Secchi Disk Transparency in meters (m); 2) surface total phosphorus as P concentration expressed as µg/ L; and 3) chlorophyll-a concentration expressed as µg/L.

This numerical value, ranging from 0-100, corresponds to a trophic condition with increasing values indicating a more eutrophic (degraded) condition. Carlson's TSI estimates are calculated using the following equations and is also depicted graphically in Figure 2.

X Trophic status based on Secchi Disk Transparency (TSIS):
$TSIS = 60 - 14.41 \ln (SD)$
Where SD = Secchi disk transparency in meters.

X Trophic status based on total phosphorus (TSIP):
$TSIP = 14.20 \ln (TP) + 4.15$
Where TP = Total phosphorus concentration in $\mu g\ L^{-1}$.

X Trophic status based on chlorophyll-a (TSIC):
$TSIC = 9.81 \ln (TC) + 30.60$
Where TC = Chlorophyll-a concentrations in $\mu g\ L^{-1}$.

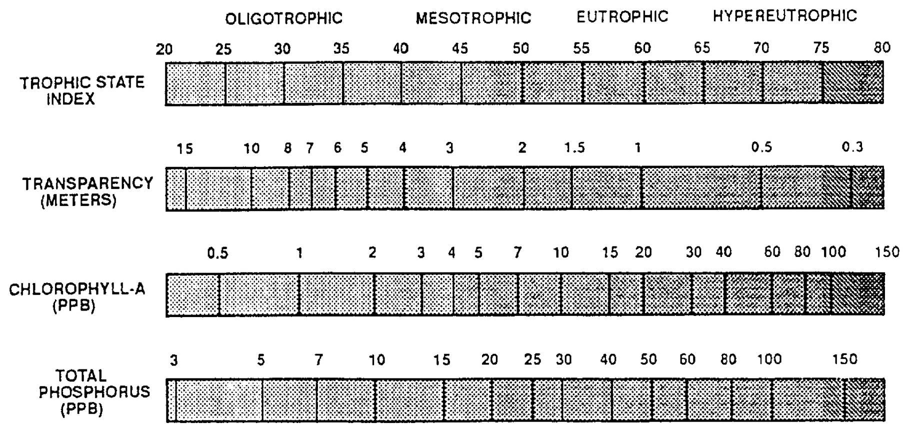


Figure 2. A Graphic Representation of Carlson's TSI

In general, of the three indicators it is believed that chlorophyll-a is the best indicator of trophic status, since it is a direct measure of lake productivity. Secchi disk transparency should be used next, followed by phosphorus concentration. In theory, for a given lake or reservoir, the measures of chlorophyll-a, Secchi disk transparency, and phosphorus concentration are all interrelated and should yield similar trophic status index values. This, however, is often not the case. Many lakes and reservoirs in the state are shallow and windswept causing non-algal turbidy to limit light pentration. This situation may result in a lake having a high phosphorus concentration, low Secchi disk transparency, and low chlorophyll-a concentration. In other instances, other micronutients may be limiting algal growth even though excessive phosphorus is present.

Regional Analysis

The question is often asked, "How does this lake or reservoir compare to other lakes or reservoirs in the state or region?" In order to place a lake or reservoir's water quality into the proper context, the 2005 and/or 2006 water quality data for a lake or reservoir were compared to that of all lakes or reservoirs of a similar type within a similar ecological region (i.e., ecoregion). For this analysis, current and historical water quality data were pooled and summarized statistically by waterbody type (i.e., natural lakes vs. reservoirs) and by ecoregion.

While additional lake types or classes could be defined (e.g., shallow vs. deep, large vs. small), for purposes of regional comparison, lakes and reservoirs were divided into two general types, natural lakes and manmade reservoirs. By comparison, natural lakes are older, have no control structure, and generally have longer residence times. Reservoirs by contrast are manmade with a control structure that controls the rate and volume of discharge and have shorter hydraulic residence times (less than one year). These factors can have a significant effect on the natural water quality of a lake or reservoir which should be considered when making regional comparisons.

Another factor which should be considered when making regional comparisons is landscape or climatic setting of the lake or reservoir. For example, lakes or reservoirs in the eastern part of the state will have naturally different water quality than lakes or reservoirs in the west based on the soils, natural vegetation, land use patterns, and precipitation patterns of the area. One way to group or classify broad regional area based factors is to use ecorgions that have similar land forms, geological history, soils and ecological function. There are four different Level III Ecoregions in North Dakota. From east to west they are the Lake Agassiz Plain (48), Northern Glaciated Plains (46), Northwestern Glaciated Plains (42), and the Northwestern Great Plains (43) (Figure 2).

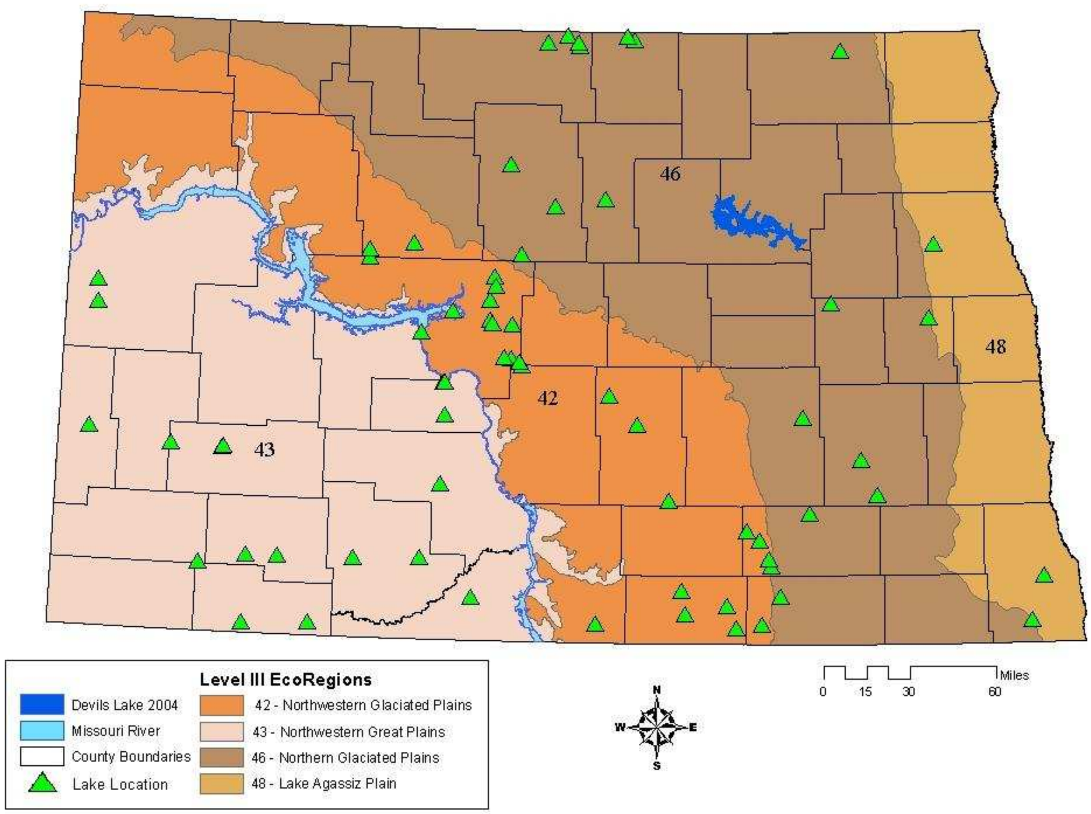


Figure 2. Level III Ecoregions and 2005 and 2006 Lake Water Quality Assessment Lakes and Reservoirs.

While it is most helpful to compare each lake or reservoir in relationship to as specific an ecological region as possible, it is also necessary to have an adequate sample size of lakes and reservoirs to compare. Therefore, to ensure an adequate sample size of lakes and reservoirs the four level III ecoregions in the state were combine into two broader ecoregions. The Lake Agassiz Plain (48) and Northern Glaciaed Plains (46) ecoregions were combined to form the Cultivated Plains region and the Northwestern Glaciated Plains (42) and Northwestern Great Plains (43) ecoregions were combined to form the Rangeland Plains region (Figure 3).

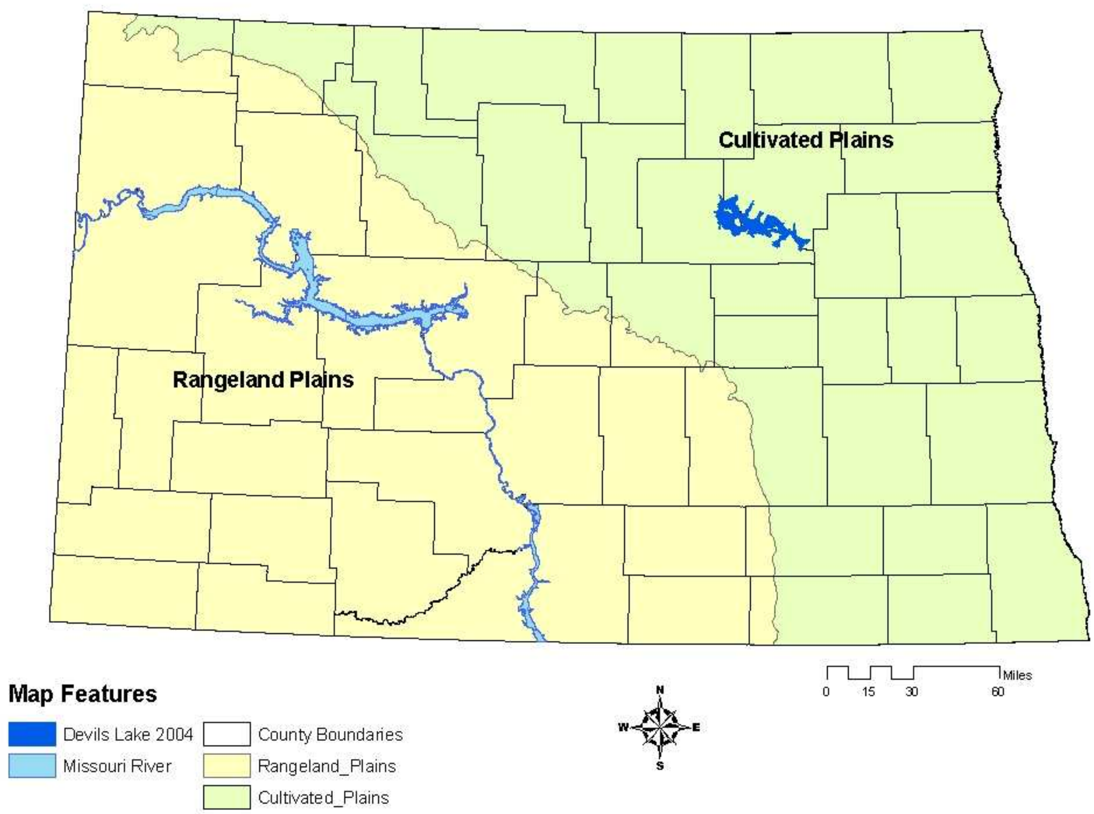


Figure 3. Cultivated Plains and Rangeland Plains Regions in North Dakota.

Mirror Lake, Adams County

BACKGROUND

Location: Mirror Lake is a small recreational impoundment on Flat Creek located on the southern edge of the town of Hettinger, North Dakota (Figure 1). The reservoir is managed by the town of Hettinger and the North Dakota Game and Fish Department.

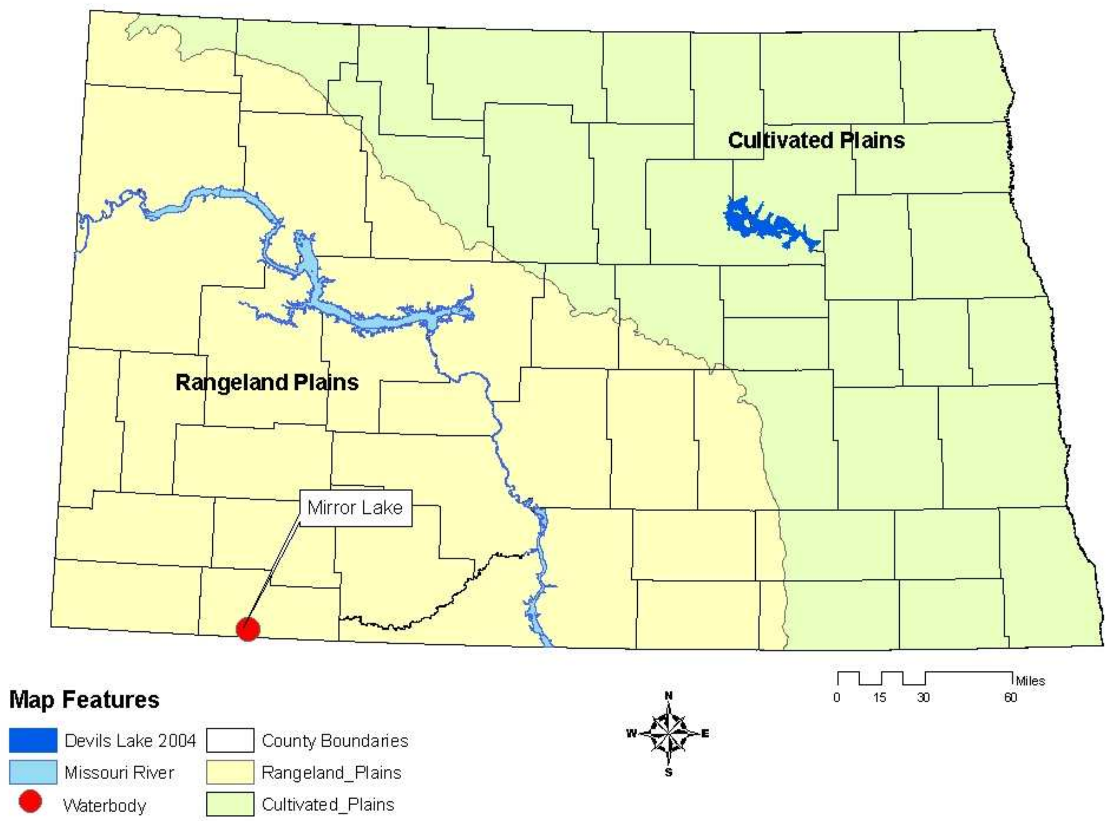


Figure 1. Location of Mirror Lake.

Physiographic/Ecological Setting: Mirror Lake has a surface area of 63.0 acres, a maximum depth of 14.3 ft and an average depth 5.5 ft (Figure 2). The reservoir's watershed is 45,600 acres in size and is located the Northwestern Great Plains (NWGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The Mirror Lake watershed landscape is rolling plains. Flood plain slopes and hillsides are usually native grasslands, while the uplands and flood plains themselves have mostly been converted to small grains and alfalfa.

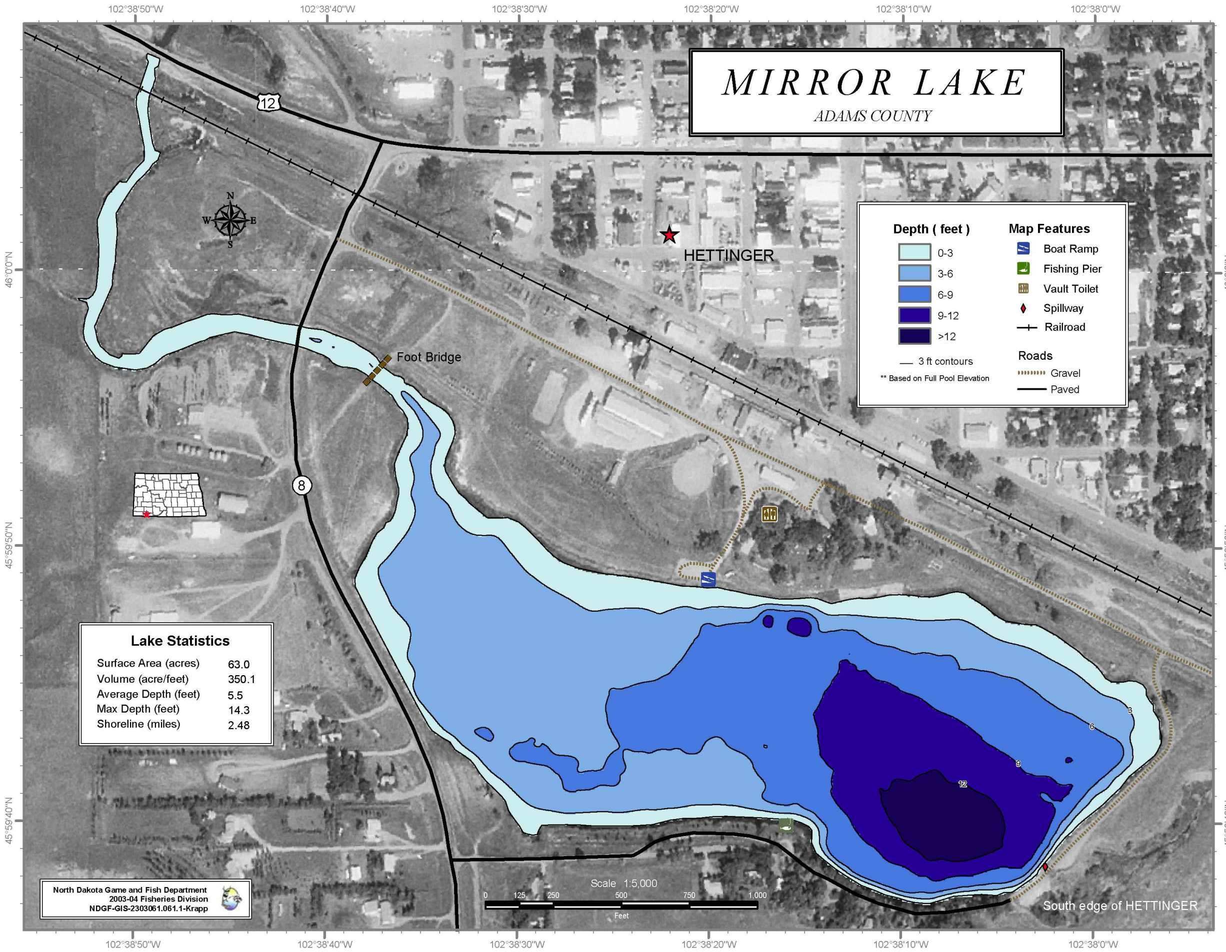


Figure 2. Contour Map of Mirror Lake (Map Courtesy of North Dakota Game and Fish Department).

Construction History: Mirror Lake was formed in 1907 when the Milwaukee, St. Paul, and Pacific Railroad dammed Flat Creek to provide a reliable water source for steam locomotion. The reservoir was renovated in 1983 and increased in surface acreage from 63 to 63.3 acres and in maximum depth from 9 to 18 ft. Since the 1983 renovation the lake has lost 0.3 acres of surface area and 3.7 ft of depth.

Recreational Facilities: Recreational facilities at Mirror Lake include a cement boat ramp, boat and vehicle parking, a city park, walk bridge, and fishing pier. The city park on the north side of the lake includes parking, restrooms, and a swimming beach.

Water Quality Standards Classification: Mirror Lake is classified in the state “Standards of Quality for Waters of the State” (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a “warm water fishery” or “waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present.”

Historical and Current Fishery: Mirror Lake's fishery over time has included nearly every fish stocked by the NDG&F. Currently, the fishery includes northern pike, perch, and bluegill. Boats are restricted to idle speeds to prevent undue erosion to the shoreline.

Historical Water Quality Sampling: Historical water quality data includes results from 45 samples collected from 1992 through 2002.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Mirror Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There were 24 temperature and dissolved oxygen profiles for Mirror Lake collected intermittently between 1992 and 2006. Temperature and oxygen profiles are presented for three time periods, 1992-1995 (Figures 3 and 4), 2001 (Figures 5 and 6), and 2005-2006 (Figures 7 and 8). The profile data shows that during thermal stratification Mirror Lake experiences rapid oxygen decay, but rarely drops below the state's water quality standard of 5 mg/L. Of the 25 profiles, only four collected on 6/1/1995, 7/23/1995, 7/20/2006 and 3/6/2006 dropped below the state standard of 5 mg/L. While the rapid loss of dissolved oxygen during these periods is concerning, there does appear to be enough dissolved oxygen to maintain aquatic life in the upper two meters of the water column.

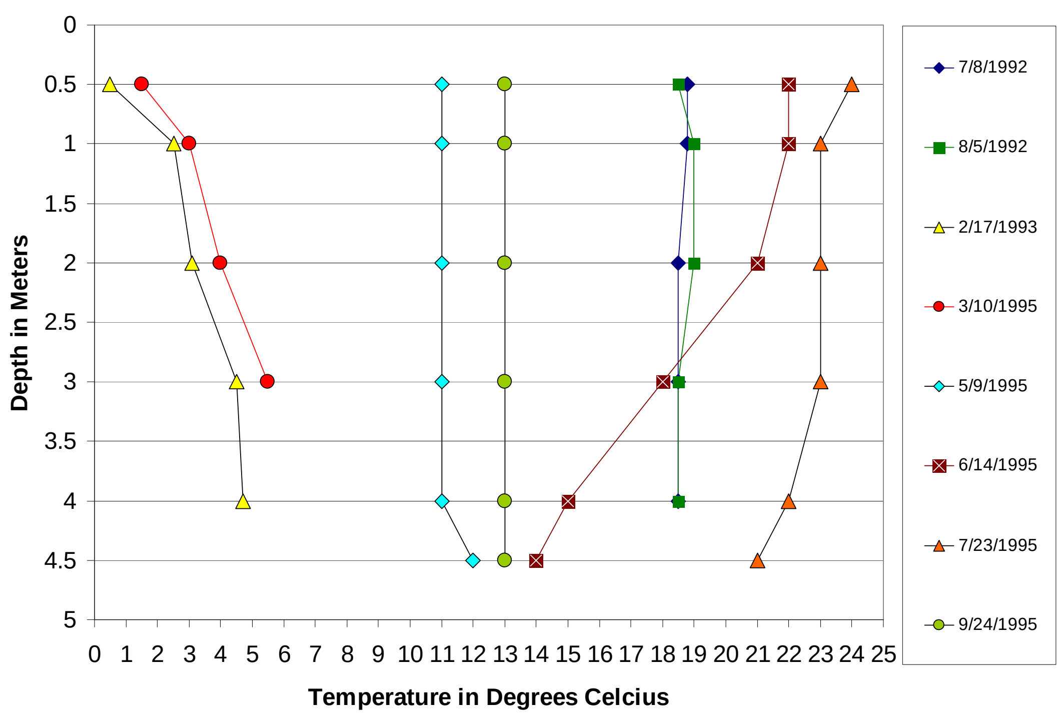


Figure 3. Temperature Profiles for Mirror Lake from 1992 to 1995.

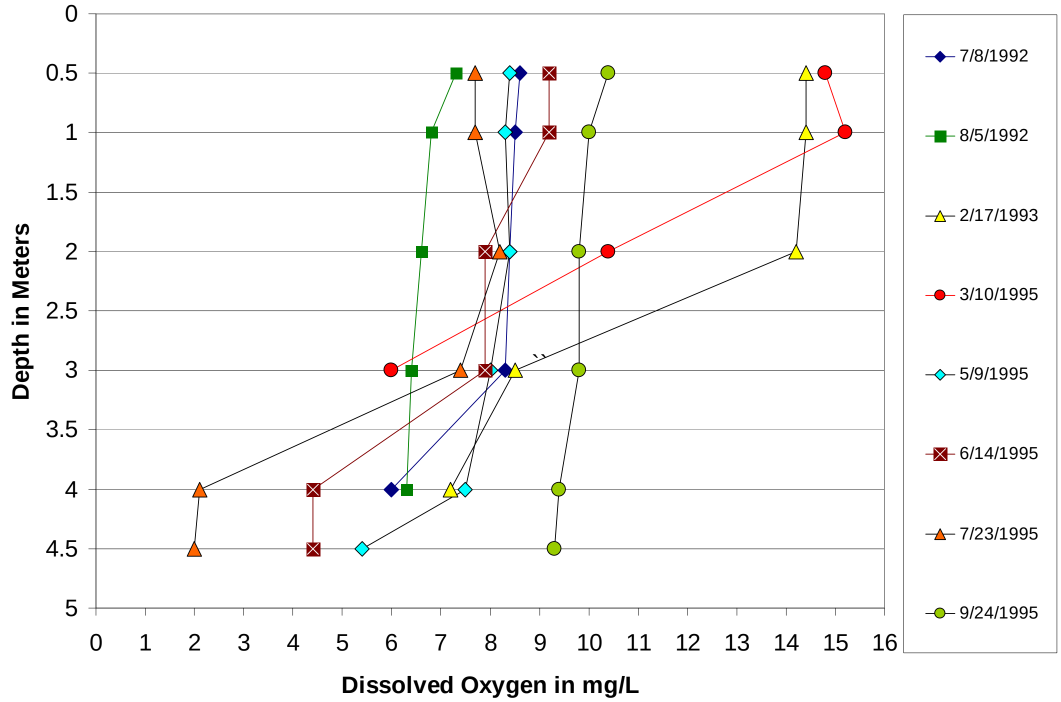


Figure 4. Dissolved Oxygen Profiles for Mirror Lake from 1992 to 1995.

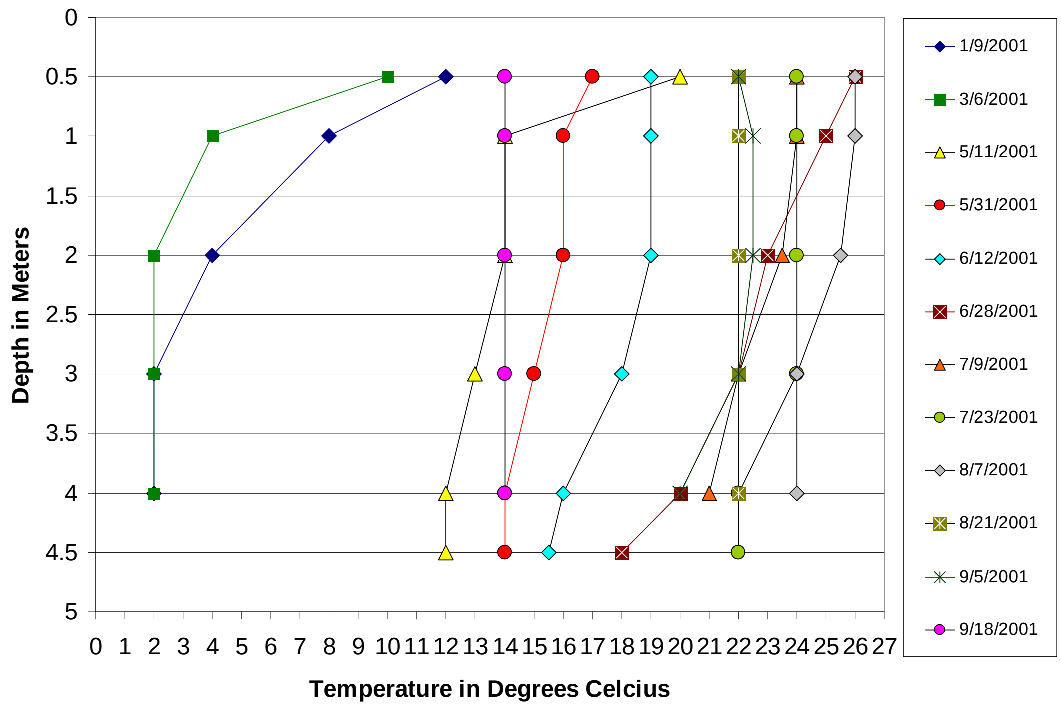


Figure 5. Temperature Profiles for Mirror Lake in 2001.

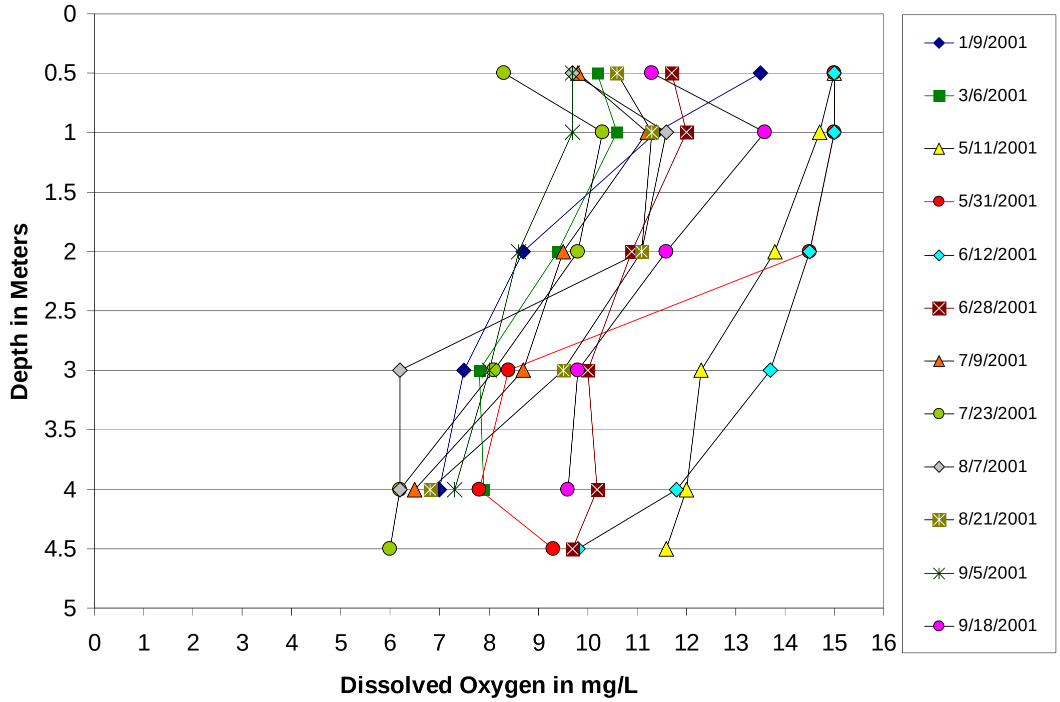


Figure 6. Dissolved Oxygen Profiles for Mirror Lake in 2001.

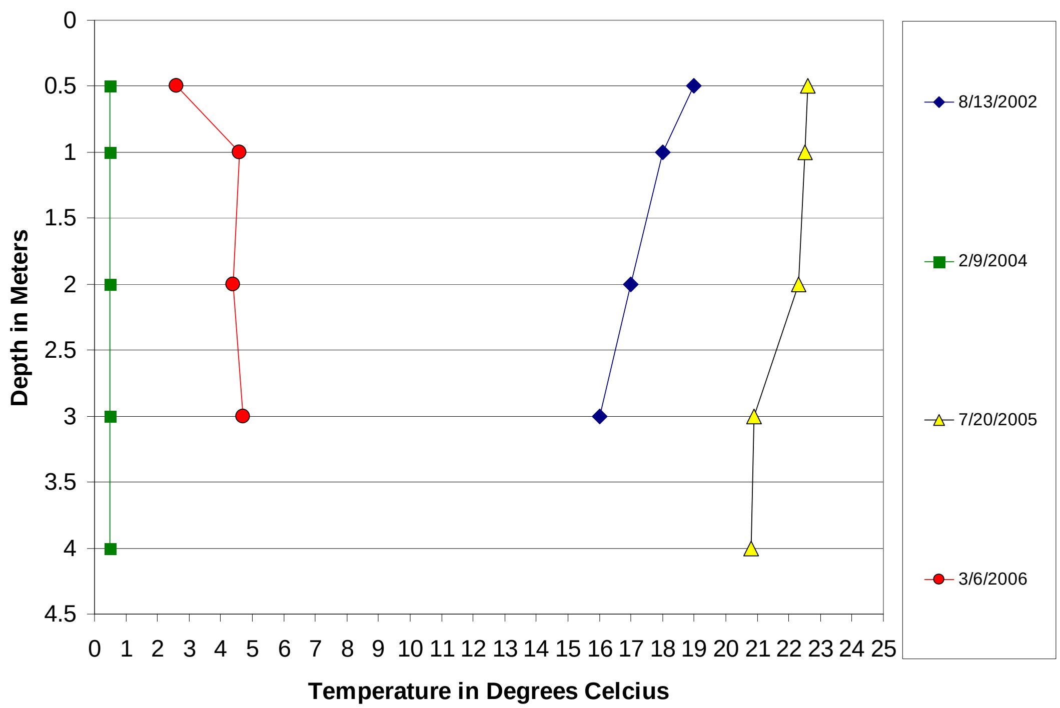


Figure 7. Temperature Profiles for Mirror Lake from 2002 to 2006.

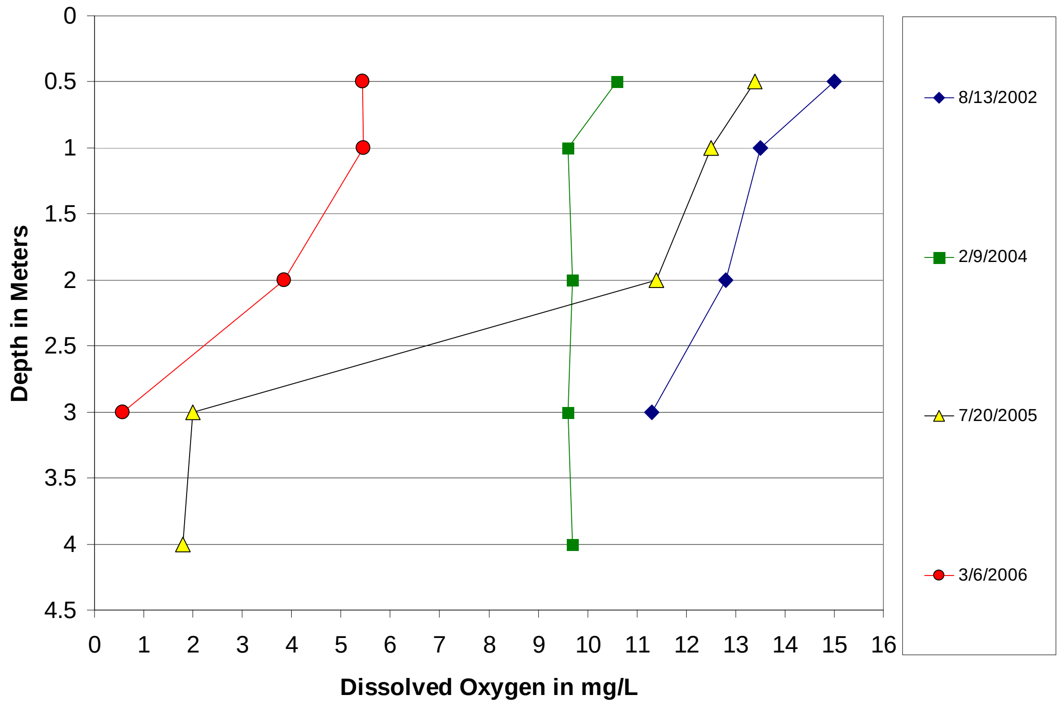


Figure 8. Dissolved Oxygen Profiles for Mirror Lake from 2002 to 2006.

General Water Quality: Data collected by the NDGF in 2005 and 2006 indicate Mirror Lake is well buffered with total alkalinity as $CaCO_3$ concentrations ranging from 296 to 369 mg/L (Table 1). Based on the 2005-2006 water quality data, Mirror Lake is sodium sulfate dominated with an average sodium concentration of 347 mg/L and an average sulfate concentration of 880 mg/L. The average total dissolved solids (TDS) concentration and specific conductance measurement for the 2005-2006 sampling period were 1623 mg/L and 2253 µmhos/cm respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.66 mg/L and 0.155 mg/L respectively.

When compared to historical water quality data for Mirror Lake, it appears that concentrations of most water quality constituents have increased. For example, the average sulfate and sodium concentrations for the period 1992-2002 were 578 mg/L and 190 mg/L respectively (Table 2), compared to average concentrations of 880 ml/L for sulfate and 347 mg/L for sodium recorded for the period 2005-2006 (Table 1). While not significant, average total nitrogen and phosphorus concentrations have also increased when compared to the historical data. Historical (1992-2002) average total nitrogen and total phosphorus concentrations were 1.487 mg/L and 0.122 mg/L respectively (Table 2), compared to average concentrations of 1.66 mg/L and 0.155 mg/L for total nitrogen and total phosphorus respectively (Table 1).

Table 1. Statistical Summary of Mirror Lake's 2005-2006 Water Quality Data.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	321	296	369	42
Total Ammonia as N	mg/L	3	0.025	0.010	0.047	0.019
Bicarbonate (HCO_3)	mg/L	3	226	154	369	124
Calcium (Ca)	mg/L	3	37.5	30.9	49.3	10.3
Carbonate (CO_3)	mg/L	3	81	40	103	36
Chloride (Cl)	mg/L	3	32	25	44	11
Chlorophyll-a	µg/L	1	98.5	98.5	98.5	
Specific Conductance	µmhos	3	2253	2030	2700	387
Total Dissolved Solids	mg/L	3	1623	1420	2010	335
Total Hardness as ($CaCO_3$)	mg/L	3	527	450	662	117
Hydroxide (OH)	mg/L	3	1	1	1	0
Iron (Fe)	mg/L	3	0.189	0.169	0.207	0.019
Magnesium (Mg)	mg/L	3	105.4	90.7	131.0	22.2
Nitrate + Nitrite as N	mg/L	3	0.030	0.020	0.050	0.017
Total Kjeldahl Nitrogen as N	mg/L	3	1.630	1.490	1.880	0.217
Total Nitrogen as N	mg/L	3	1.660	1.510	1.930	0.234
pH		3	9.33	8.74	9.64	0.51
Total Phosphorus as P	mg/L	3	0.155	0.149	0.160	0.006
Potassium (K)	mg/L	3	29.6	27.7	32.1	2.3
Sodium (Na)	mg/L	3	347	294	439	80
Sulfate (SO4)	mg/L	3	880	775	1090	182

[1]Equal to minimum reporting limit

When compared to regional average concentrations, it appears Mirror Lake is slightly higher than that reported for all reservoirs in the Rangeland Plains region (Table 3). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1176 mg/L, 1.472 mg/L, and 0.135 mg/L respectively, compared to Mirror Lake's average TDS, total nitrogen, and total phosphorus concentrations of 1623 mg/L, 1.66 mg/L and 0.155 mg/L respectively, for the period 2005-2006.

Limiting Nutrients: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Mirror Lake and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight in algae, is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were 45 water quality sample results for Mirror Lake collected between July 1992 and March 2007 where the N:P ration could be calculated. The results from this analysis indicate that while Mirror Lake is most often nitrogen limited, the N:P relationships in Mirror Lake are dynamic, and variable based on the time of the year and the natural processes occurring at the time of sampling (Figure 9).

Table 2. Statistical Summary of Mirror Lake's Historical Water Quality Data Collected Between 1992 and 2002.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	13	261	221	323	36
Total Ammonia as N	mg/L	46	0.037	0.001	0.397	0.071
Bicarbonate (HCO_3)	mg/L	13	288	232	368	43
Calcium (Ca)	mg/L	13	55	38	76	13
Carbonate (CO_3)	mg/L	13	16	1	38	11
Chloride (Cl)	mg/L	13	13.7	9.8	26.0	4.8
Chlorophyll-a	µg/L	30	21.3	3.0	69.0	18.5
Specific Conductance	µmhos	13	1593	1031	2740	570
Total Dissolved Solids	mg/L	13	1076	649	1970	433
Total Hardness as ($CaCO_3$)	mg/L	13	421	274	624	125
Hydroxide (OH)	mg/L	8	1	1	1	0
Iron (Fe)	mg/L	13	0.169	0.021	0.432	0.126
Magnesium (Mg)	mg/L	13	69.2	42.8	111.0	23.3
Nitrate + Nitrite as N	mg/L	40	0.033	0.014	0.520	0.079
Total Kjeldahl Nitrogen as N	mg/L	36	1.409	0.871	2.820	0.457
Total Nitrogen as N	mg/L	32	1.487	0.891	3.340	0.521
pH		13	8.59	8.13	8.86	0.25
Total Phosphorus as P	mg/L	47	0.122	0.018	0.592	0.097
Potassium (K)	mg/L	13	17.9	14.2	24.0	3.0
Sodium (Na)	mg/L	13	190	99	342	78
Sulfate (SO4)	mg/L	12	578	291	1230	321

[1]Equal to minimum reporting limit

N:P ratios for Mirror Lake ranged from a low of 3 to a high of 57 with an average of 16. Of the 45 samples collected on Mirror Lake, 29 were below an N:P ratio of 15 indicating nitrogen limitation and 16 were above 15 indicating phosphorus limitation.

Trophic Status Assessment: Based on limited chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005-2006, Mirror Lake's current trophic status is eutrophic to hypereutrophic. TSI scores ranged from a low of 63 based on Secchi disk transparency to a high of 76 based on chlorophyll-a. The trophic status score based on total phosphorus was similar to that estimated based on chlorophyll-a, at 77 (Figure 10).

A total of 45 total phosphorus samples, 29 chlorophyll-a samples, and 10 Secchi disk transparency measurements collected between 1992 and 2006 were used to evaluate trends in the trophic status of Mirror Lake. Based on a visual assessment, Mirror Lake's trophic status is stable to increasing (Figure 6).

Table 3. Statistical Summary of Water Quality Data[1] Collected from Reservoirs in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	408	309	101	982	130
Total Ammonia as N	mg/L	469	0.097	0.001	2.440	0.200
Bicarbonate (HCO_3)	mg/L	408	318	14	1040	150
Calcium (Ca)	mg/L	408	50	5	160	26
Carbonate (CO_3)	mg/L	402	30	1	197	30
Chloride (Cl)	mg/L	408	13.3	0.3	74.5	8.8
Chlorophyll-a	µg/L	321	21.2	1.5	218.0	27.9
Specific Conductance	µmhos	428	1733	262	5880	959
Total Dissolved Solids	mg/L	409	1176	147	5110	750
Total Hardness as ($CaCO_3$)	mg/L	408	397	45	1850	260
Hydroxide (OH)	mg/L	337	1	1	1	0
Iron (Fe)	mg/L	409	0.179	0.007	4.110	0.334
Magnesium (Mg)	mg/L	408	66.0	5.6	353.0	49.6
Nitrate + Nitrite as N	mg/L	395	0.048	0.001	0.790	0.092
Total Kjeldahl Nitrogen as N	mg/L	359	1.556	0.365	7.720	0.779
Total Nitrogen as N	mg/L	302	1.472	0.405	4.840	0.562
pH		428	8.61	6.73	9.87	0.56
Total Phosphorus as P	mg/L	475	0.135	0.004	3.160	0.205
Potassium (K)	mg/L	408	14.6	4.2	39.2	6.3
Sodium (Na)	mg/L	408	239	3	932	171
Sulfate (SO4)	mg/L	406	604	1	3210	501

[1] Data Collected from 69 Natural Lakes between 1991 and 2007

[2] Equal to minimum reporting limit

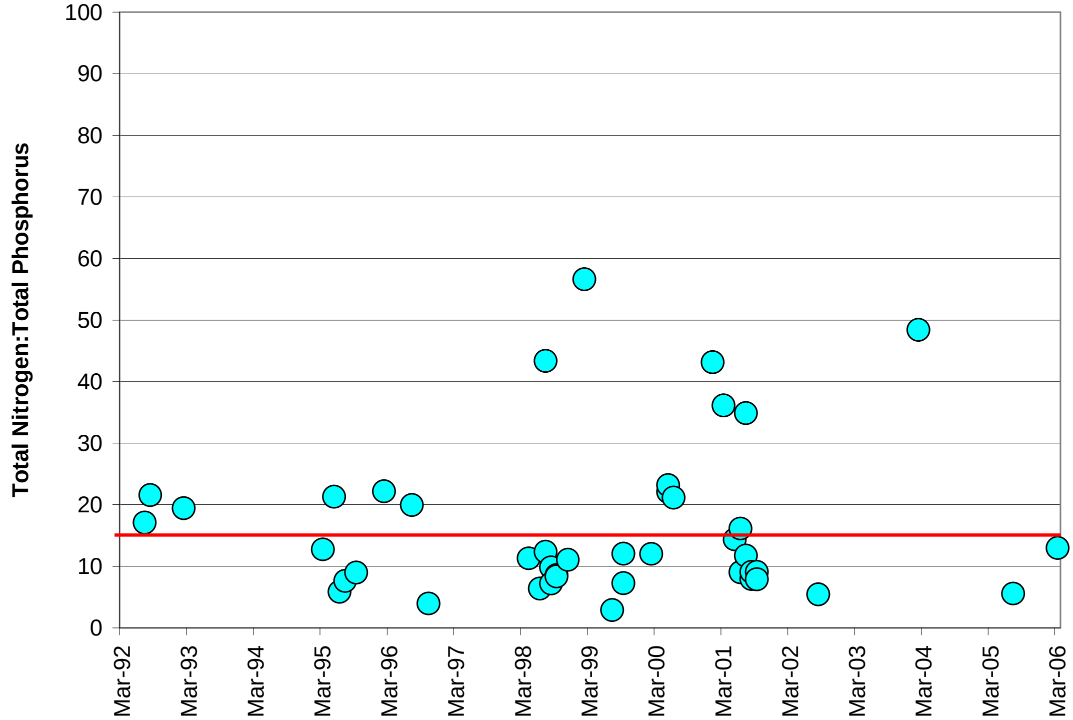


Figure 9. Total Nitrogen to Total Phosphorus Ratios in Mirror Lake (1992-2006).

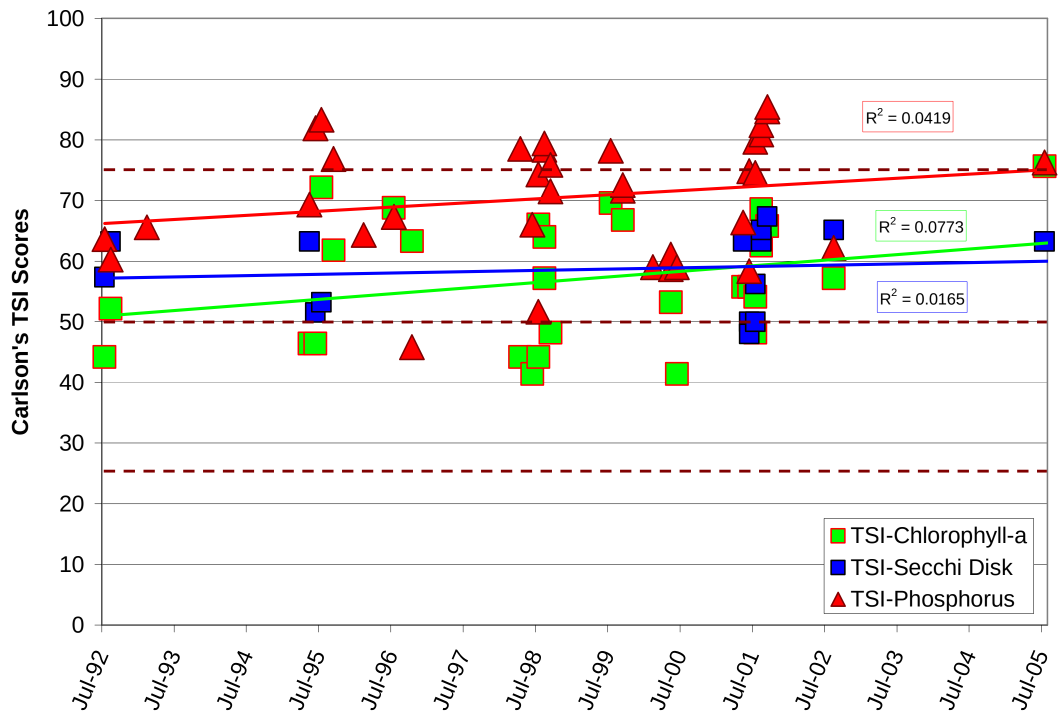


Figure 10. TSI Scores and Temporal Trends for Mirror Lake from 1992 to 2006.

North Lemmon Lake, Adams County

BACKGROUND

Location: North Lemmon Lake is on the very southern edge of North Dakota approximately half way between the Missouri River and the Montana border. Directions to North Lemmon Lake are 5 miles north of Lemmon, South Dakota or 25 miles east and 5 miles north of Hettinger, North Dakota (Figure 1).

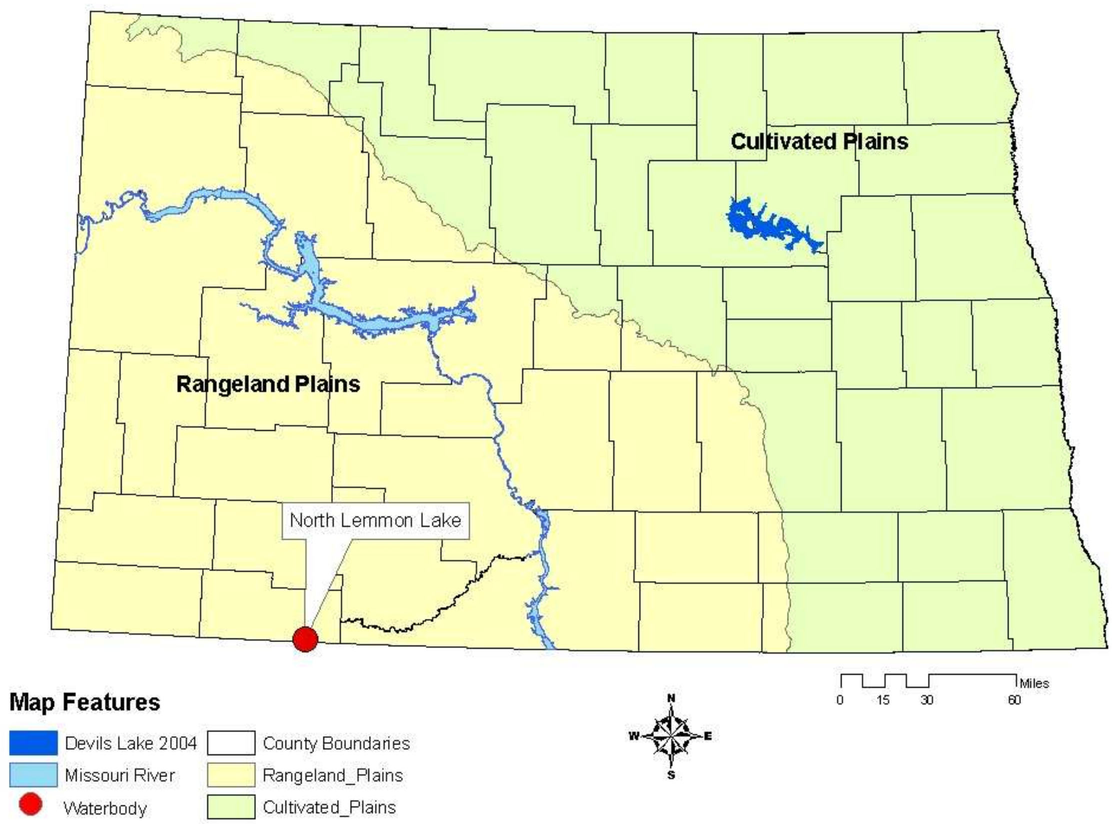


Figure 1. Location of North Lemmon Lake.

Physiographic/Ecological Setting: North Lemmon Lake is located in the Northwestern Great Plains (NWGP) Level III Ecoregion (Figure 2). The NWGP is the Missouri Plateau of the Great Plains (USEPA 1994). The watershed landscape is rolling plains. Flood plain slopes and hillsides are usually native grass, while the uplands and flood plains themselves have mostly been converted to small grains and alfalfa.

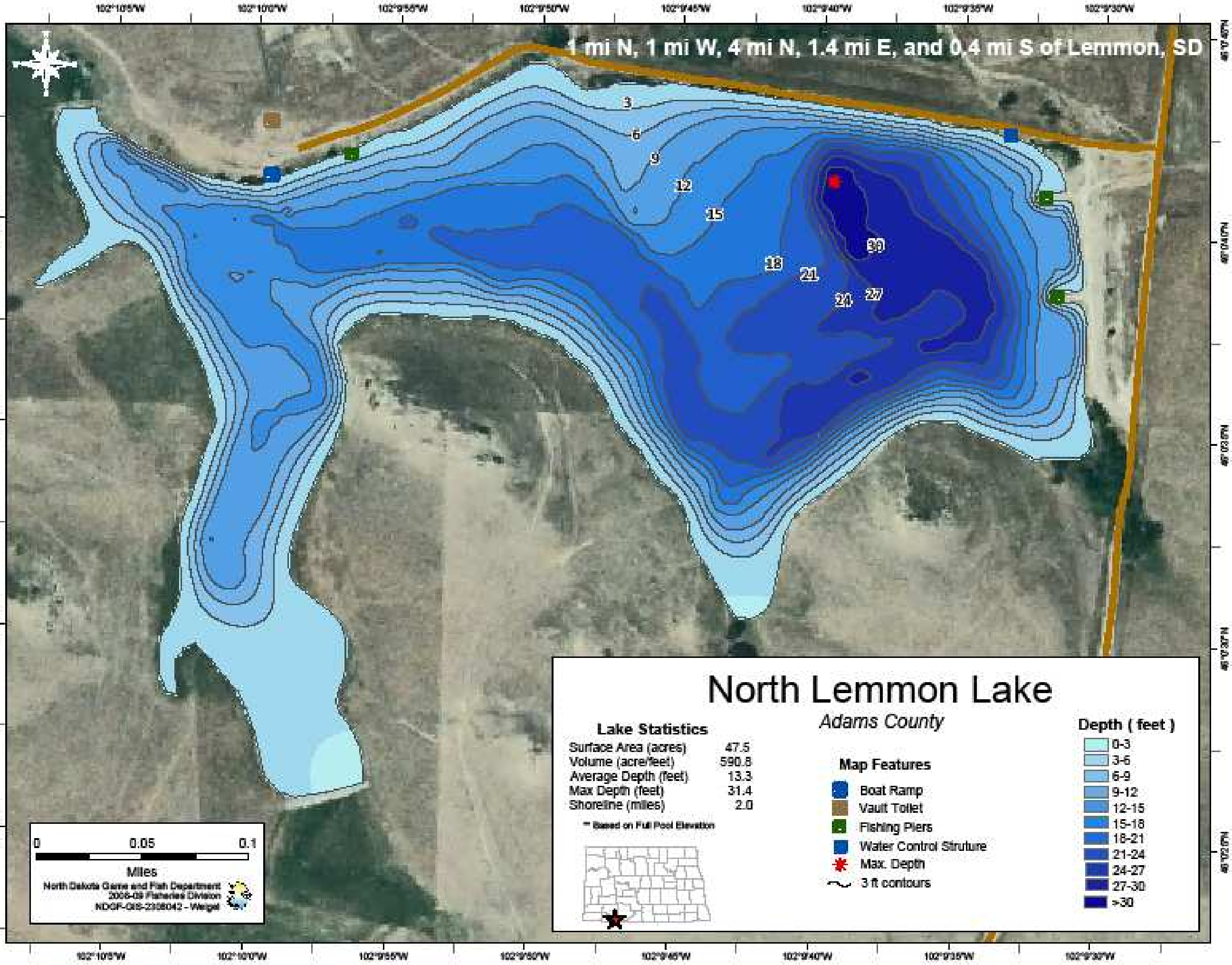


Figure 2. Contour Map of North Lemmon Lake (Map Courtesy of North Dakota Game and Fish Department).

Construction History: North Lemmon Lake is a 55 acre impoundment on a tributary to Cedar Creek. The reservoir has a maximum depth of 33 feet and an average depth of 13.2 feet (Figure 2). Since construction the reservoir has lost depth. Samples collected in 2005 and 2006 indicate a maximum depth of 21 feet.

Recreational Facilities: North Lemmon Lake and the immediate area surrounding the shoreline is owned and managed by the North Dakota Game and Fish Department. Recreational facilities at North Lemmon Lake include a boat ramp and associated parking, fishing pier, and picnic area.

Water Quality Standards Classification: North Lemmon Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 1 lake or reservoir. Class 1 lakes or reservoirs are defined as a "cold water fishery" or "waters capable of supporting growth of cold water fish species (e.g., salmonids) and associated aquatic biota."

Historical and Current Fishery: North Lemmon Lake's fishery is managed by the North Dakota Game and Fish Department. Historical and current fishery is trout, bluegill, and largemouth bass. No live bait fish are allowed.

Historical Water Quality Sampling: Historical water quality data includes results from three samples collected from 1991 and 1993.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for North Lemmon Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There were five temperature and dissolved oxygen profiles for North Lemmon Lake collected intermittently between 1991 and 2006. Temperature and oxygen profiles are presented for two time periods, 1991-1993 and 2005-2006 (Figures 3 and 4).

The profile data shows that during thermal stratification North Lemmon Lake experiences rapid oxygen decay, but rarely drops below the state's water quality standard of 5 mg/L. Of the five profiles, only two collected on 2/16/1993 and 7/20/2005 dropped below the state standard of 5 mg/L. While the dissolved oxygen loss did twice drop below the state standard, during these periods the largest percentage of the water column and lake volume was adequately oxygenated to support cold water species.

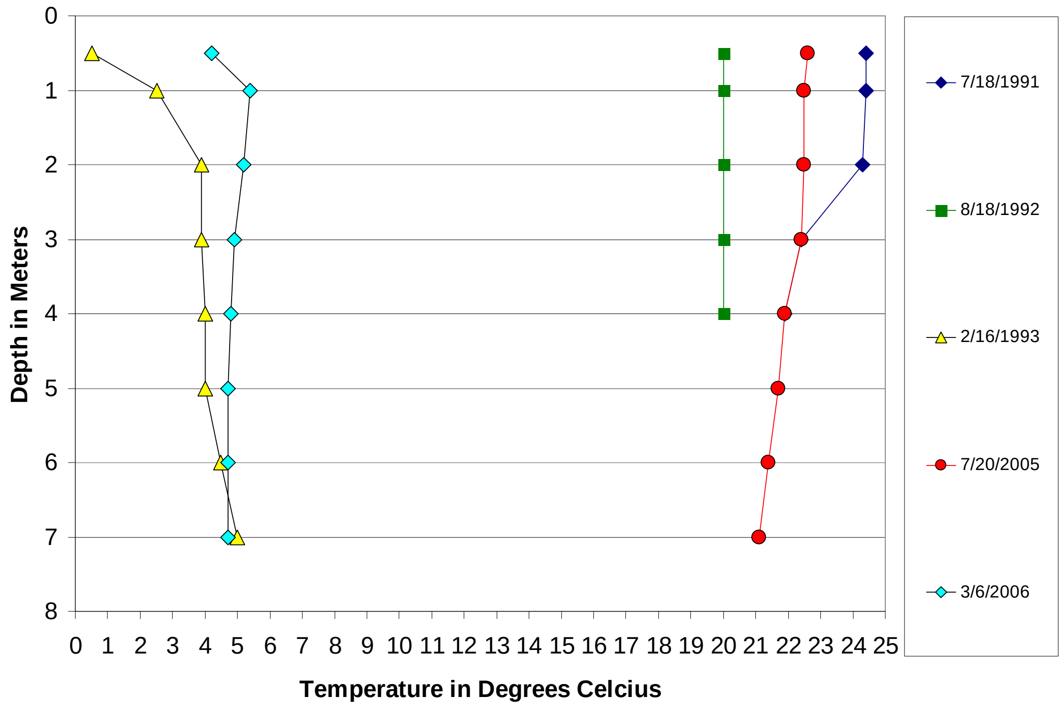


Figure 3. Temperature Profiles for North Lemmon Lake from 1991 to 2006.

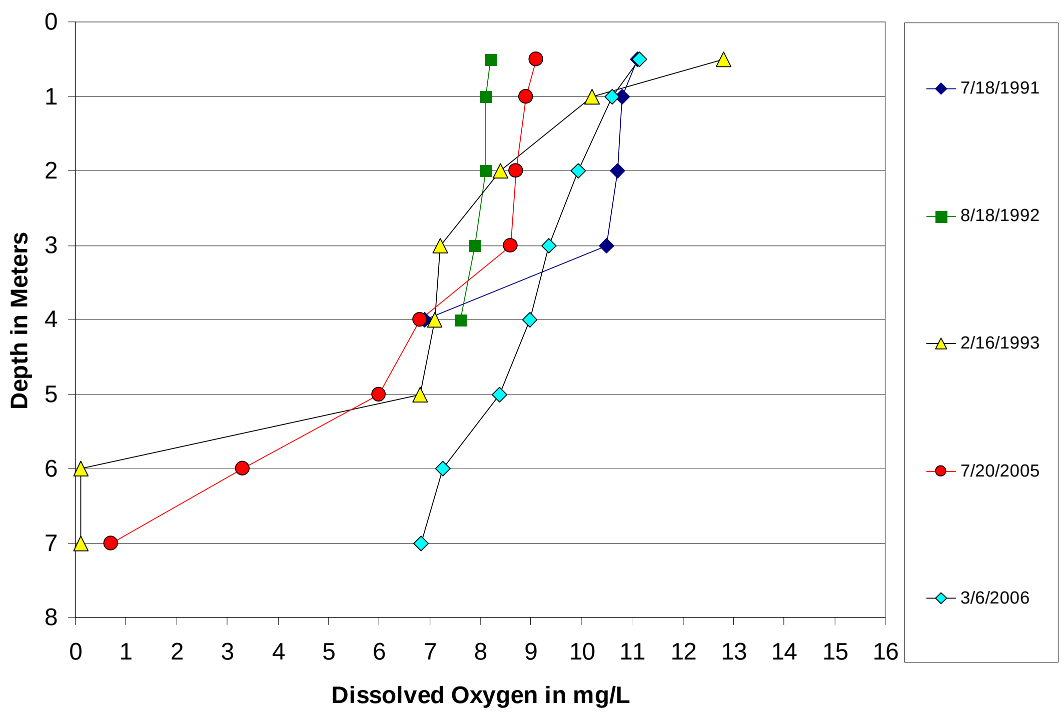


Figure 4. Dissolved Oxygen Profiles for North Lemmon Lake from 1991 to 2006.

General Water Quality: Data collected by the NDGF in 2005 and 2006 indicate North Lemmon Lake is well buffered with total alkalinity as $CaCO_3$ concentrations ranging from 329 to 407 mg/L (Table 1). Based on the 2005-2006 water quality data, North Lemmon Lake is sodium bicarbonate dominated with an average sodium concentration of 52 mg/L and an average bicarbonate concentration of 354 mg/L. The average total dissolved solids (TDS) concentration and specific conductance measurement for the 2005-2006 sampling period were 433 mg/L and 735 µmhos/cm respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.200 mg/L and 0.025 mg/L respectively.

Table 1. Statistical Summary of North Lemmon Lake's 2005-2006 Water Quality Data.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	2	368	329	407	55
Total Ammonia as N	mg/L	2	0.048	0.011	0.084	0.052
Bicarbonate (HCO_3)	mg/L	2	354	240	467	161
Calcium (Ca)	mg/L	2	18.9	13.8	23.9	7.1
Carbonate (CO_3)	mg/L	2	47	14	79	46
Chloride (Cl)	mg/L	2	8	7	10	2
Chlorophyll-a	µg/L	1	6.1	6.1	6.1	
Specific Conductance	µmhos	2	735	633	836	144
Total Dissolved Solids	mg/L	2	433	386	479	66
Total Hardness as ($CaCO_3$)	mg/L	2	334	292	375	59
Hydroxide (OH)	mg/L	2	1	1	1	0
Iron (Fe)	mg/L	2	0.141	0.104	0.178	0.052
Magnesium (Mg)	mg/L	2	69.7	62.6	76.7	10.0
Nitrate + Nitrite as N	mg/L	2	0.040	0.020	0.060	0.028
Total Kjeldahl Nitrogen as N	mg/L	2	1.160	1.020	1.300	0.198
Total Nitrogen as N	mg/L	2	1.200	1.040	1.360	0.226
pH		2	8.96	8.50	9.41	0.64
Total Phosphorus as P	mg/L	2	0.025	0.019	0.031	0.008
Potassium (K)	mg/L	2	11.9	10.6	13.2	1.8
Sodium (Na)	mg/L	2	52	46	58	8
Sulfate (SO4)	mg/L	2	50	47	53	4

[1]Equal to minimum reporting limit

When compared to historical water quality data for North Lemmon Lake, it appears that concentrations of most water quality constituents have increased. For example, the historical average sulfate and sodium concentrations were 15 mg/L and 43 mg/L respectively (Table 2), compared to average concentrations of 50 ml/L for sulfate and 52 mg/L for sodium recorded for the period 2005-2006 (Table 1).

Unlike the dissolved solids the average total nitrogen and phosphorus concentrations have decreased when compared to the historical data. The historical average for total nitrogen and total phosphorus concentrations were 1.560 mg/L and 0.048 mg/L respectively (Table 2), compared to average concentrations of 1.200 mg/L and 0.0.25 mg/L for total nitrogen and total phosphorus respectively.

Table 2. Statistical Summary of North Lemmon Lake's Historical Water Quality Data Collected Between 1991 and 1993.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	323	294	379	49
Total Ammonia as N	mg/L	3	0.112	0.028	0.272	0.139
Bicarbonate (HCO_3)	mg/L	3	271	199	414	124
Calcium (Ca)	mg/L	3	17	14	21	4
Carbonate (CO_3)	mg/L	3	60	24	79	31
Chloride (Cl)	mg/L	3	7.8	7.2	9.0	1.0
Chlorophyll-a	µg/L	1	12.0	12.0	12.0	0
Specific Conductance	µmhos	3	559	500	675	100
Total Dissolved Solids	mg/L	3	345	320	393	42
Total Hardness as ($CaCO_3$)	mg/L	3	272	256	304	28
Hydroxide (OH)	mg/L	1	0	0	0	0
Iron (Fe)	mg/L	3	0.049	0.019	0.093	0.039
Magnesium (Mg)	mg/L	3	56.1	53.3	61.2	4.4
Nitrate + Nitrite as N	mg/L	1	0.002	0.002	0.002	0
Total Kjeldahl Nitrogen as N	mg/L	2	1.360	1.260	1.460	0.141
Total Nitrogen as N	mg/L	2	1.560	1.488	1.56	.095
pH		3	9.32	8.75	9.60	0.49
Total Phosphorus as P	mg/L	3	0.048	0.014	0.104	0.049
Potassium (K)	mg/L	3	12.9	12.1	14.2	1.1
Sodium (Na)	mg/L	3	43	40	48	4
Sulfate (SO4)	mg/L	3	15	12	17	3

[1]Equal to minimum reporting limit

When compared to the Rangeland Plains regional averages North Lemmon Lake is fresher and less eutrophic than that reported for most reservoirs (Table 3). For example, the regional average for TDS, total nitrogen, and total phosphorus concentrations are 1176 mg/L, 1.472 mg/L, and 0.135 mg/L respectively, compared to North Lemmon Lake's average TDS, total nitrogen, and total phosphorus concentrations of 433 mg/L, 1.200 mg/L and 0.025 mg/L, respectively, for the period 2005-2006.

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in North Lemmon Lake and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight in algae, is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There are three water quality sample sets for North Lemmon Lake between August 1992 and July 2005. The three samples used in this interpretation indicate that North Lemmon Lake is phosphorus limited (Figure 5). The nitrogen to phosphorus ratio for North Lemmon Lake ranged from a low of 16 to a high of 106.

Table 3. Statistical Summary of Water Quality Data[1] Collected from Reservoirs in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	408	309	101	982	130
Total Ammonia as N	mg/L	469	0.097	0.001	2.440	0.200
Bicarbonate (HCO_3)	mg/L	408	318	14	1040	150
Calcium (Ca)	mg/L	408	50	5	160	26
Carbonate (CO_3)	mg/L	402	30	1	197	30
Chloride (Cl)	mg/L	408	13.3	0.3	74.5	8.8
Chlorophyll-a	µg/L	321	21.2	1.5	218.0	27.9
Specific Conductance	µmhos	428	1733	262	5880	959
Total Dissolved Solids	mg/L	409	1176	147	5110	750
Total Hardness as ($CaCO_3$)	mg/L	408	397	45	1850	260
Hydroxide (OH)	mg/L	337	1	1	1	0
Iron (Fe)	mg/L	409	0.179	0.007	4.110	0.334
Magnesium (Mg)	mg/L	408	66.0	5.6	353.0	49.6
Nitrate + Nitrite as N	mg/L	395	0.048	0.001	0.790	0.092
Total Kjeldahl Nitrogen as N	mg/L	359	1.556	0.365	7.720	0.779
Total Nitrogen as N	mg/L	302	1.472	0.405	4.840	0.562
pH		428	8.61	6.73	9.87	0.56
Total Phosphorus as P	mg/L	475	0.135	0.004	3.160	0.205
Potassium (K)	mg/L	408	14.6	4.2	39.2	6.3
Sodium (Na)	mg/L	408	239	3	932	171
Sulfate (SO4)	mg/L	406	604	1	3210	501

[1] Data Collected from 69 Natural Lakes between 1991 and 2007
[2] Equal to minimum reporting limit

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected in 2005, North Lemmon Lake's trophic status is mesotrophic (Figure 6). TSI scores ranged from a low of 41 based on Secchi disk transparency to a high of 48 based on chlorophyll-a. The trophic status score based on total phosphorus was similar to that estimated based on chlorophyll-a, at 47 (Figure 6).

A total of two phosphorus and chlorophyll-a samples, and two secchi disk measurements collected between 1991 and 2005 were used to evaluate trends in the trophic status of North Lemmon Lake. Based on a visual assessment, North Lemmon Lake's trophic status is stable to improving (Figure 6).

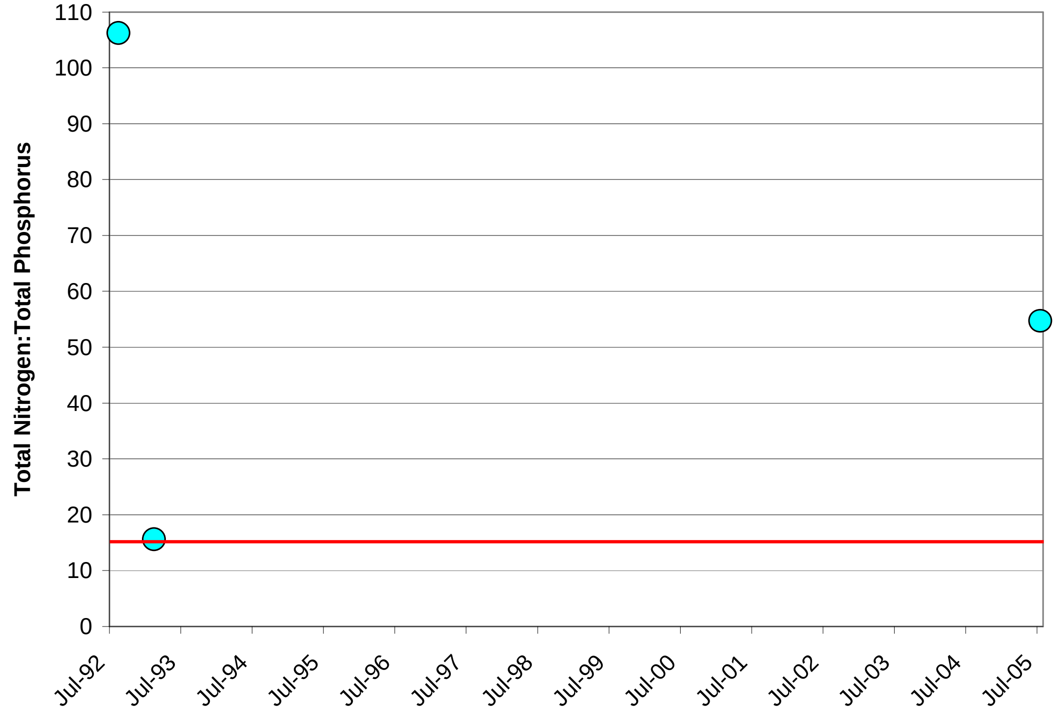


Figure 5. Total Nitrogen to Total Phosphorus Ratios in North Lemmon Lake (1992-2005).

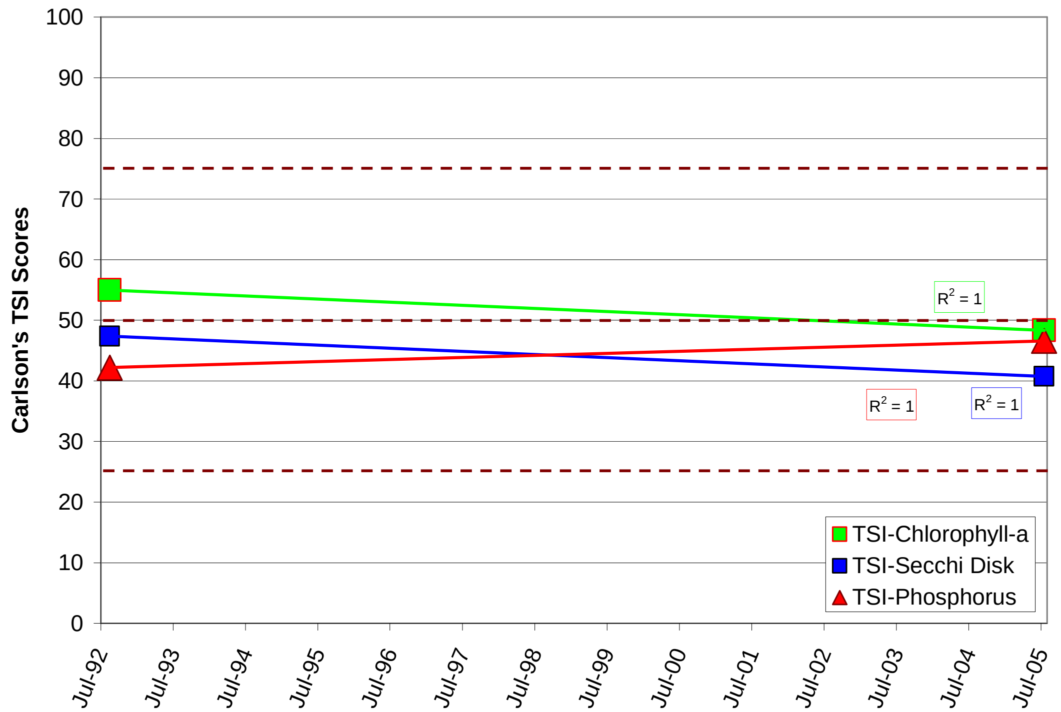


Figure 6. TSI Scores and Temporal Trends for North Lemmon Lake from 1992 to 2006.

Clausen Springs, Barnes County

BACKGROUND

Location: Clausen Springs is a reservoir in southeastern North Dakota, on a tributary to the Sheyenne River (Figure 1). Directions to Clausen Springs from the junction of U.S Highways 46 and 1 are: Three miles north, then 1 mile east, then ½ mile north. Clausen Springs is managed by the North Dakota Game and Fish Department and the Barnes County Park Board.

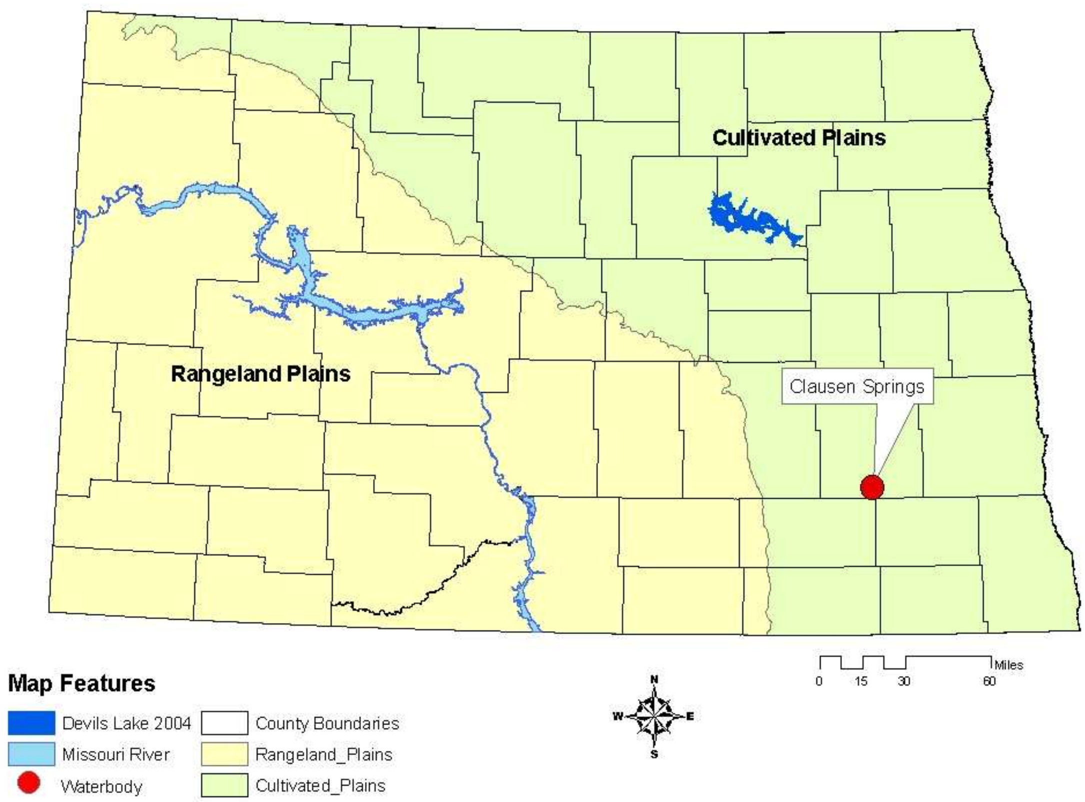


Figure 1. Location of Clausen Springs.

Physiographic/Ecological Setting: Clausen Springs is located in the Northern Glaciated Plains (NGP) Level III Ecoregion, part of the broader Cultivated Plains region (Figure 1). The NGP is characterized by flat to rolling landscape composed of glacial drift (USEPA 1994). This region is the transitional zone between tall and mixed grass prairie. The region has numerous wetlands essential for spring and fall migrations of wetland dependent birds. Flood plain slopes and hillsides are usually native grass while the uplands and flood plains proper have mostly been converted to small grains, row crops and alfalfa.

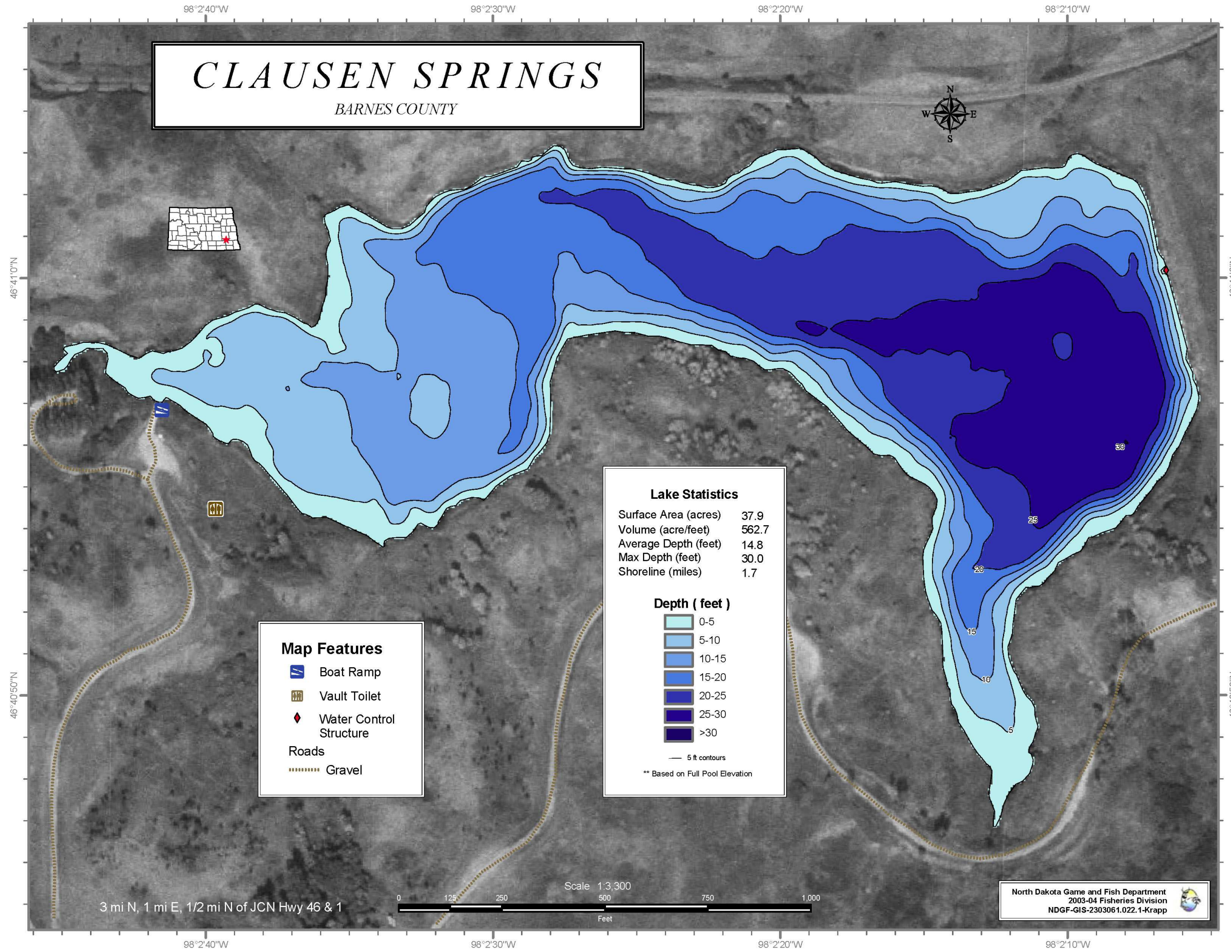


Figure 2. Contour Map of Clausen Springs (Map Courtesy of the North Dakota Game and Fish Department).

Construction History: Clausen Springs was formed in 1967 by damming Spring Creek. The dam backed up 38 acres of water with a maximum depth of 33 feet. In 2004 when resurveyed by the NDG&F Clausen Springs' maximum depth was 30 feet with an average depth of 14.8 feet (Figure 2).

Recreational Facilities: Clausen Springs and the immediate area surrounding the reservoir are owned by the North Dakota Game and Fish Department. Recreational facilities include a boat ramp, parking, campgrounds, day use areas, and a fishing pier. Recreational facilities are in part provided by and managed by the Barnes County Park Board.

Water Quality Standards Classification: Clausen Springs is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a "warm water fishery" or "waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present."

Historical and Current Fishery: In 1968 Clausen Springs was stocked with rainbow trout. In 1976 Clausen Springs was chemically eradicated. In the years following eradication, the current fishery of perch, largemouth bass, and walleye was established.

Historical Water Quality Sampling: Historical water quality data includes results from three samples collected from 1991 through 1992.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessment for Clausen Springs have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Cultivated Plains region.

Temperature and Dissolved Oxygen Profile Results: There are seven temperature and dissolved oxygen profiles for Clausen Springs collected in two clusters between 1991-1992 and 2005-2006 (Figures 3 and 4). The profile data shows that Clausen Springs experiences moderate oxygen decay during thermal stratification, but maintains concentrations above the State's Standard of 5 mg/L above 4 meters of depth and during periods lacking stratification.

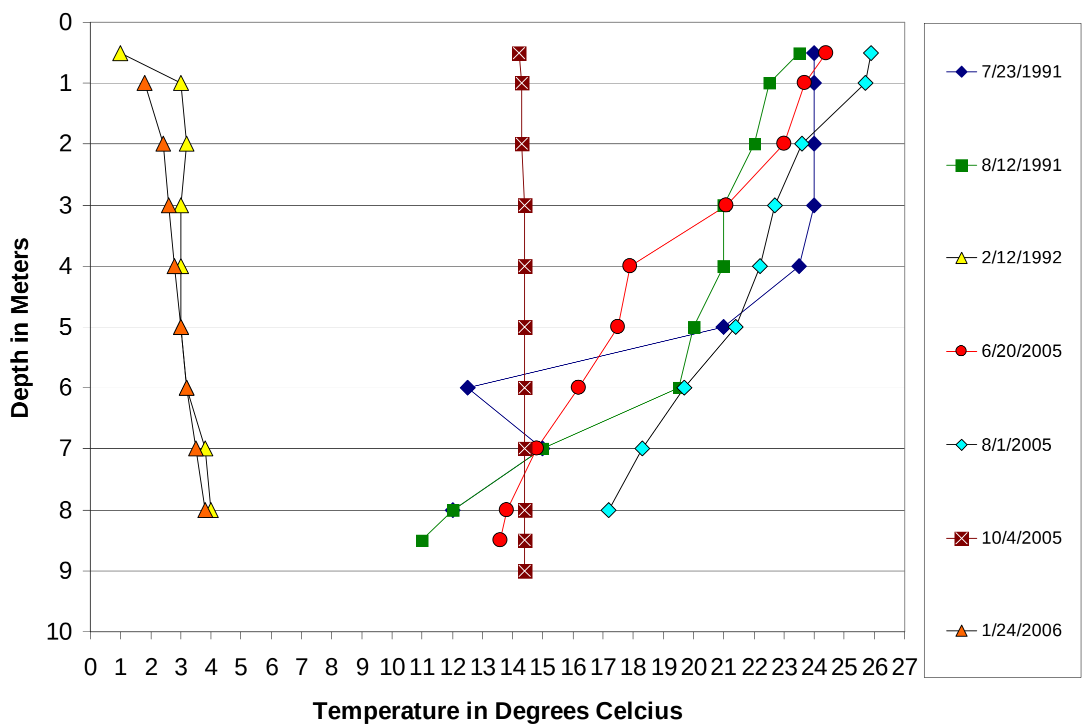


Figure 3. Clausen Springs' Temperature Profiles from 1991 to 2006.

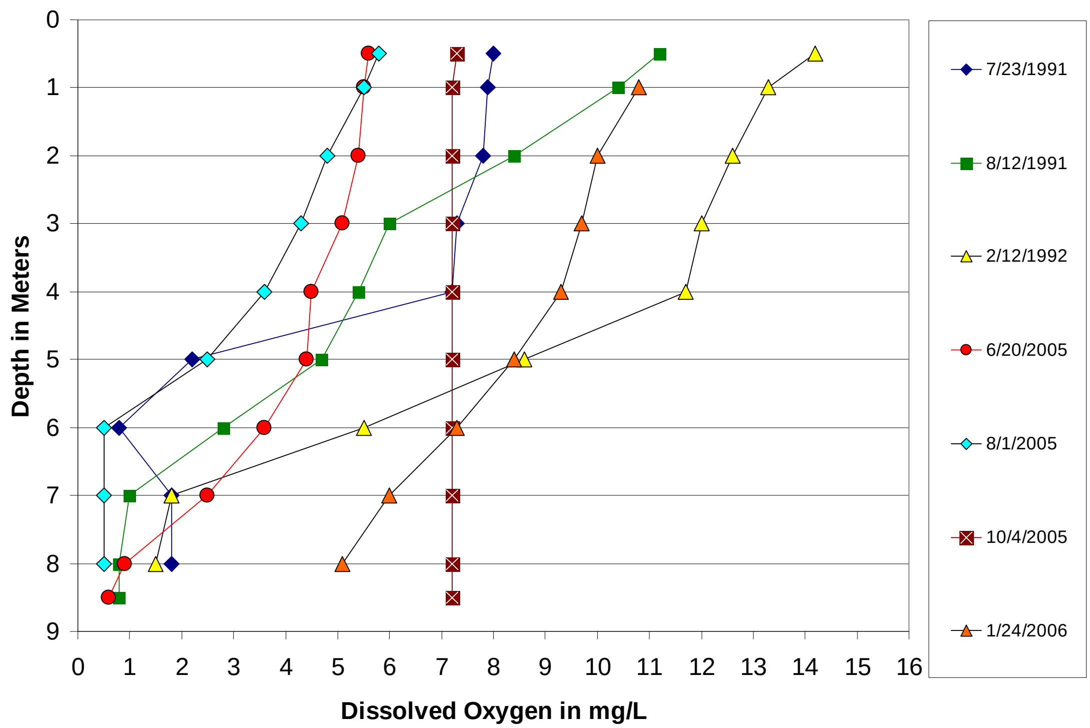


Figure 4. Clausen Springs' Dissolved Oxygen Profiles From 1991 to 2006.

General Water Quality: Data collected by the NDGF between 2005 and 2006, indicate Clausen Springs is a well buffered water body with alkalinity as $CaCO_3$ concentrations ranging from 371 mg/L to 413 mg/L (Table 1). Clausen Springs is sodium bicarbonate dominated, with average bicarbonate concentrations of 450 mg/L and average sodium concentrations of 132 mg/L, respectively (Table 1). The Average TDS concentrations and specific conductance measurements for the 2005-2006 sampling period were 770 mg/L and 1243 µmhos/cm, respectively. The average total nitrogen and total phosphorus concentrations were 1.530 mg/L and 0.371 mg/L, respectively.

When compared to historical water quality data for Clausen Springs, it appears that concentrations of most water quality constituents have increased. For example, the average bicarbonate and sodium concentrations for the period 1991-1992 were 322 mg/L and 86.4 mg/L, respectively (Table 2), compared to average concentrations of 450 mg/L for bicarbonate and 132 mg/L for sodium, recorded for the period 2005-2006 (Table 1). While not significant, average total nitrogen and total phosphorus concentrations have also increased when compared to the historical data. Historical average total nitrogen and total phosphorus concentrations were 1.332 mg/L and 0.140 mg/L, respectively (Table 2), compared to average concentrations of 1.530 mg/L for total nitrogen and 0.371 mg/L for total phosphorus, respectively.

Table 1. Statistical Summary of Clausen Springs' 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	386	371	413	19
Total Ammonia as N	mg/L	4	0.083	0.010[1]	0.144	0.056
Bicarbonate (HCO_3)	mg/L	4	450	427	467	16.7
Calcium (Ca)	mg/L	4	72	63	82	8
Carbonate (CO_3)	mg/L	4	11	1[1]	18	7
Chloride (Cl)	mg/L	4	57.4	44.6	73.8	13.2
Chlorophyll-a	µg/L	4	1.7	1.5[1]	2.4	0.45
Specific Conductance	µmhos	4	1242	1160	1360	88.8
Total Dissolved Solids	mg/L	4	769	707	870	71.8
Total Hardness as ($CaCO_3$)	mg/L	4	390	353	430	35.8
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.099	0.042	0.142	0.042
Magnesium (Mg)	mg/L	4	51.1	47.3	59.8	5.9
Nitrate + Nitrite as N	mg/L	4	0.100	0.040	0.230	0.088
Total Kjeldahl Nitrogen as N	mg/L	4	1.430	1.030	1.810	0.348
Total Nitrogen as N	mg/L	4	1.530	1.260	1.850	0.277
pH		4	8.40	8.26	8.49	0.10
Total Phosphorus as P	mg/L	4	0.371	0.262	0.501	0.099
Potassium (K)	mg/L	4	8.8	7.8	10.5	1.17
Sodium (Na)	mg/L	4	132	109	170	28.5
Sulfate (SO4)	mg/L	4	214	197	248	23.3

[1]Equal to Minimum Reporting Limit

When compared to the Cultivated Plains regional average Clausen Springs is slightly higher in dissolved solids and nutrients than reported for most reservoirs (Table 3). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 667 mg/L, 1.488 mg/L, and 0.322 mg/L, respectively, compared to Clausen Springs' average TDS, total nitrogen, and total phosphorus concentrations of 769 mg/L, 1.530 mg/L and 0.371 mg/L, respectively, for the period 2005-2006.

Limiting Nutrient: The limiting nutrient assessment is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Clausen Springs and that the weight ratio of total nitrogen to total phosphorus (N:P) in the lake's algae is approximately 15 to 1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There are seven water quality sample sets for Clausen Springs between August 1991 and March 2006. The seven samples used in this interpretation indicate that Clausen Springs is nitrogen limited (Figure 5). The N:P ratios for Clausen Springs ranged from a low of 3 to a high of 14 with an average of 6. All seven samples collected were below an N:P ratio of 15 indicating nitrogen limitation.

Table 2. Statistical Summary of Clausen Springs' Historical Water Quality Data Collected Between 1991 and 1992.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	283	278	292	7.8
Total Ammonia as N	mg/L	3	0.041	0.006[1]	0.080	0.037
Bicarbonate (HCO_3)	mg/L	3	322	300	357	31
Calcium (Ca)	mg/L	3	64	54	73	10
Carbonate (CO_3)	mg/L	2	17	15	20	4
Chloride (Cl)	mg/L	3	50.4	38.2	57.6	10.6
Chlorophyll-a	µg/L	2	3.0[1]	3.0[1]	3.0[1]	0.0
Specific Conductance	µmhos	3	941	917	957	21
Total Dissolved Solids	mg/L	3	558	533	586	27
Total Hardness as ($CaCO_3$)	mg/L	3	290	250	317	35
Hydroxide (OH)	mg/L		NC[2]	NC[2]	NC[2]	0
Iron (Fe)	mg/L	3	0.068	0.024	0.127	0.053
Magnesium (Mg)	mg/L	3	31.2	27.8	33.5	3.0
Nitrate + Nitrite as N	mg/L	3	0.099	0.004[1]	0.281	0.157
Total Kjeldahl Nitrogen as N	mg/L	3	1.233	1.010	1.570	0.297
Total Nitrogen as N	mg/L	3	1.332	1.014	1.851	0.208
pH		3	8.40	8.20	8.60	0.20
Total Phosphorus as P	mg/L	3	0.140	0.074	0.173	0.057
Potassium (K)	mg/L	3	7.9	7.5	8.3	0.4
Sodium (Na)	mg/L	3	86	79	97	9
Sulfate (SO4)	mg/L	3	147	136	156	10

[1]Equal to Minimum Reporting Limit
[2]Data not collected

Trophic Status Assessment: Based on chlorophyll-a, and Secchi disk transparency data collected during 2005, Clausen Springs' current trophic status is mesotrophic. Total phosphorus scores are not indicative to the trophic status of Clausen Springs, because the lake is nitrogen limited. TSI scores ranged from a low of 35 based on chlorophyll-a, to a high of 94 based on total phosphorus. The trophic status score based on Secchi disk transparency was similar to that of chlorophyll-a, at 40 (Figure 6).

A total of seven total phosphorus samples, six chlorophyll-a samples and six Secchi disk transparency measurements collected from 1991-2006 were used to evaluate trends in the trophic status of Clausen Springs. Based on a visual assessment of the data, Clausen Springs trophic status is stable (Figure 6).

Table 3. Statistical Summary of Water Quality Data[2] Collected from Reservoir's in the Cultivated Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	352	263	88	891	103
Total Ammonia as N	mg/L	463	0.131	0.001[1]	2.070	0.203
Bicarbonate (HCO_3)	mg/L	352	296	91	951	114
Calcium (Ca)	mg/L	352	65	19	169	22
Carbonate (CO_3)	mg/L	324	14	1[1]	93	16
Chloride (Cl)	mg/L	351	21	1[1]	113	18
Chlorophyll-a	µg/L	373	20	2[1]	388	31
Specific Conductance	µmhos	352	1021	217	3140	516
Total Dissolved Solids	mg/L	344	667	127	2300	387
Total Hardness as ($CaCO_3$)	mg/L	352	334	95	1090	121
Hydroxide (OH)	mg/L	280	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	350	0.137	0.007	3.190	0.216
Magnesium (Mg)	mg/L	352	42	11	161	20
Nitrate + Nitrite as N	mg/L	411	0.097	0.003	2.060	0.191
Total Kjeldahl Nitrogen as N	mg/L	376	1.476	0.207	4.410	0.642
Total Nitrogen as N	mg/L	315	1.488	0.418	3.220	0.587
pH		352	8.36	6.89	9.40	0.43
Total Phosphorus as P	mg/L	464	0.322	0.004[1]	1.380	0.267
Potassium (K)	mg/L	352	12	3	35	5
Sodium (Na)	mg/L	352	97	2	582	107
Sulfate (SO4)	mg/L	351	269	8	1350	217

[1]Equal to lower detection limit
[2]Data Collected from 40 Reservoirs between 1991 and 2007

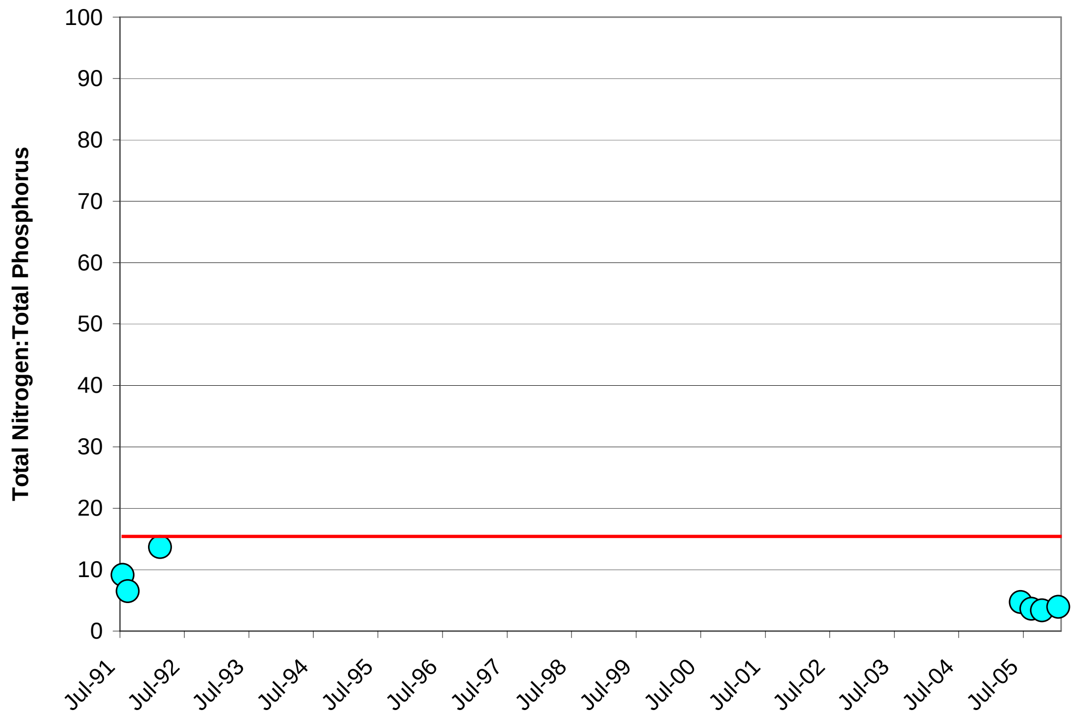


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Clausen Springs (1991-2006).

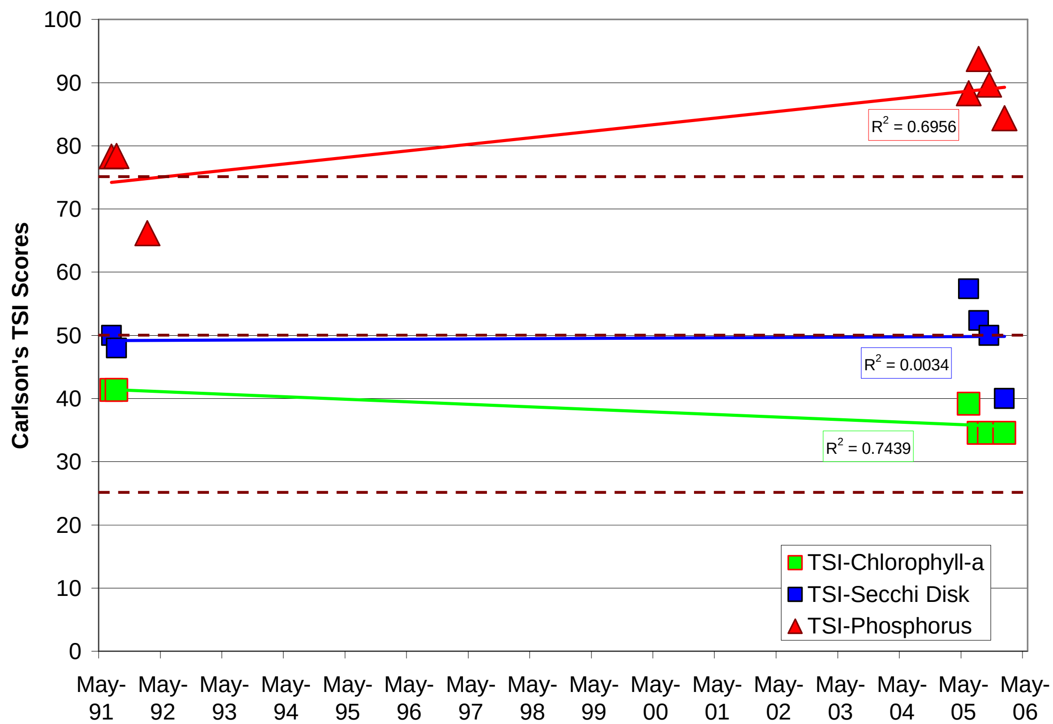


Figure 6. TSI Scores and Temporal Trends for Clausen Springs from 1991 to 2006.

Moon Lake, Barnes County

BACKGROUND

Location: Moon Lake is an enhanced natural lake located 6 miles west and 3 and one half miles south of Valley City (Figure 1). Moon Lake is managed by the North Dakota Game and Fish Department.

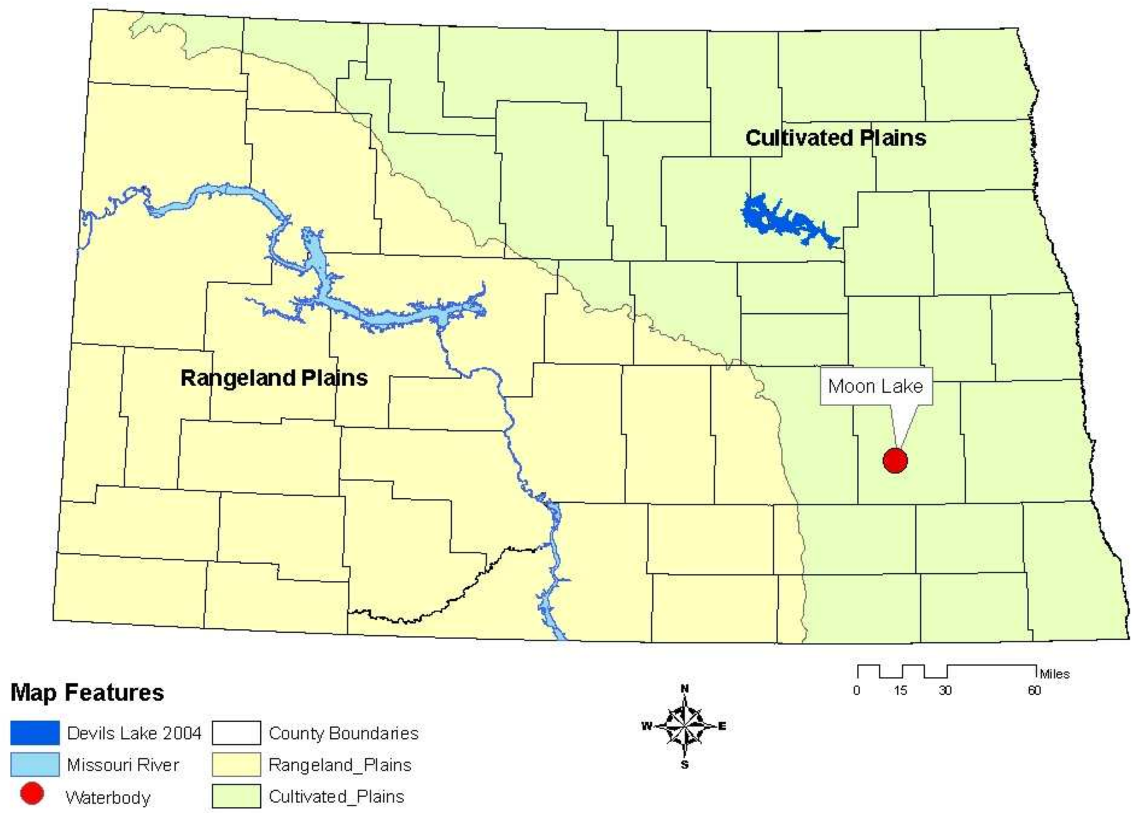


Figure 1. Location of Moon Lake.

Physiographic/Ecological Setting: Moon Lake is a 106.1 acre teardrop shaped lake, with a surprising maximum depth of 51 feet and a mean depth of 22 feet (Figure 2). Moon Lake has a limited watershed resulting in some variations in water levels due to amount of recent precipitation. Moon Lake resides in the Northern Glaciated Plains Level III Ecoregion within the Cultivated Plains region of central North Dakota. The Northern Glaciated Plains is characterized by flat to rolling landscape composed of glacial drift (USEPA 1994). This region is the transitional zone between tall and mixed grass prairie. The region has numerous wetlands essential for spring and fall migrations of wetland dependent birds. Flood plain slopes and hillsides are usually native grass while the uplands and flood plains proper have mostly been converted to small grains, row crops and alfalfa.

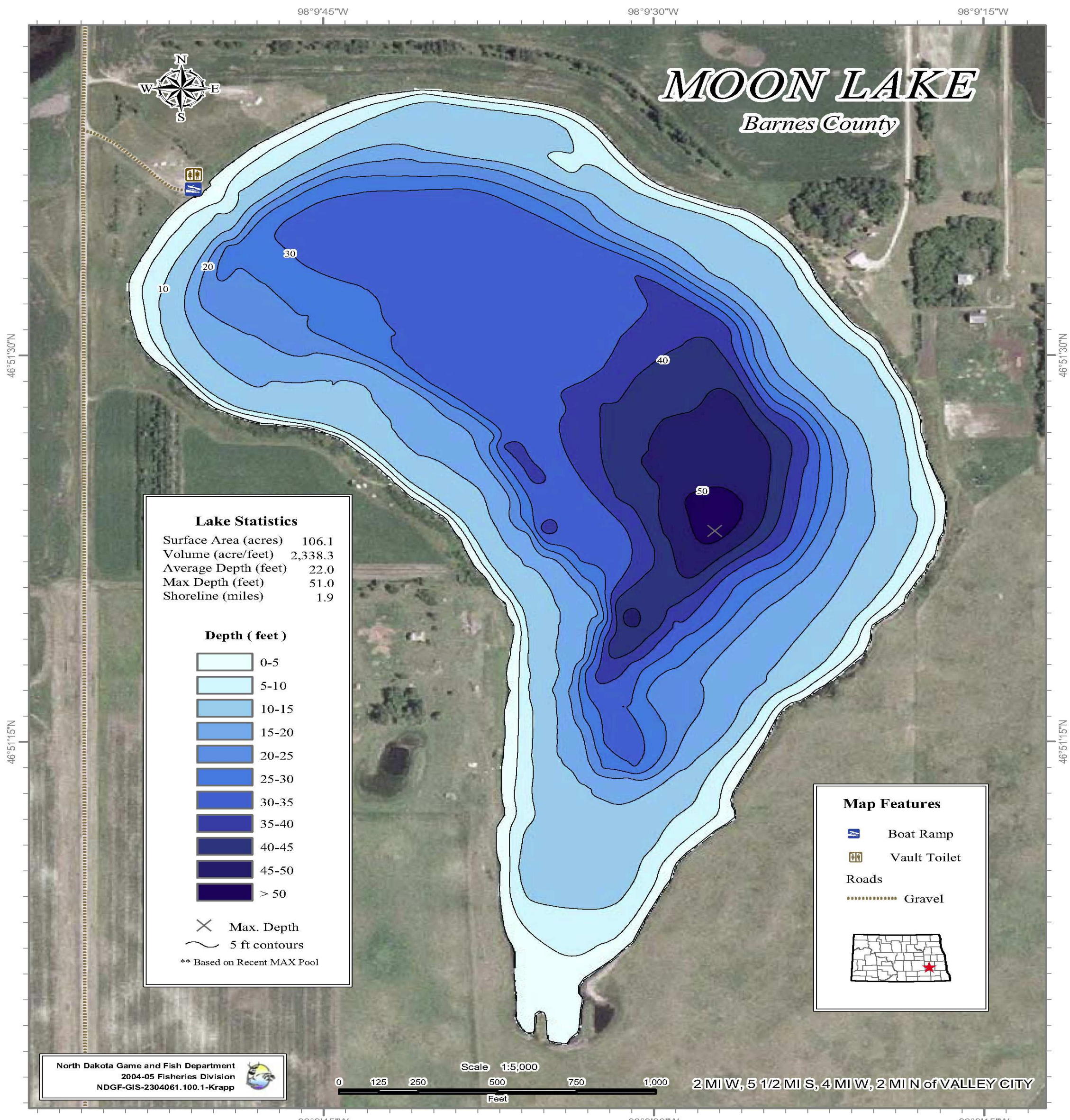


Figure 2. Contour Map of Moon Lake (Map Courtesy of North Dakota Game and Fish Department).

Recreational Facilities: Recreational facilities at Moon Lake include a boat ramp along with boat and vehicle parking. Public access to the lake is on the northwest side, and it includes the boat ramp and a vaulted toilet.

Water Quality Standards Classification: Moon Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2007) as a class 2 lake. Class 2 Lakes and reservoirs are defined as "Cool Water Fisheries" or "waters capable of supporting natural reproduction and growth of cool water fishes (e. g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: Moon Lake's fishery is smallmouth bass, walleye, and yellow perch. The lakes historical fishery includes smallmouth bass, largemouth bass, and trout.

Historical Water Quality Sampling: Historical water quality data includes results from a single temperature and oxygen profile collected in 1994.

WATER QUALITY MONITORINGRESULTS

The water quality analysis and trend assessments for Moon Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural and enhanced lakes in the Cultivated Plains region.

Temperature and Dissolved Oxygen Profile Results: There were 11 temperature and dissolved oxygen profiles for Moon Lake collected in 1994 and between 2005 and 2007 (Figures 3 and 4). The profile data shows that while Moon Lake has adequate dissolved oxygen throughout the water column and above the metalimnion during thermal stratification (Figure 4). Of the 11 profiles collected, five collected on 6/20/2005, 8/1/2005, 5/4/2006, 7/19/2006, and 8/1/2007, had dissolved oxygen concentrations that declined below the state water quality standard of 5 mg/L below the metalimnion. The depth of thermal stratification ranged from 6 to 11 meters of depth leaving a significant amount of the lake's water column still adequately oxygenated (Figures 3 and 4).

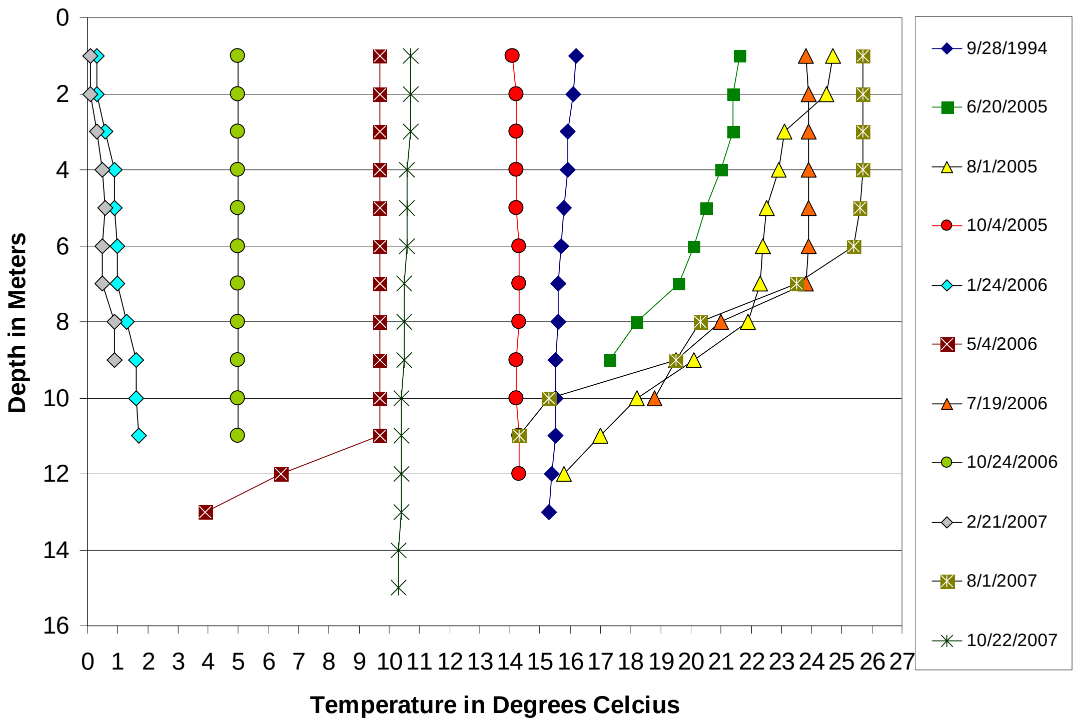


Figure 3. Temperature Profiles for Moon Lake from 1994 to 2007.

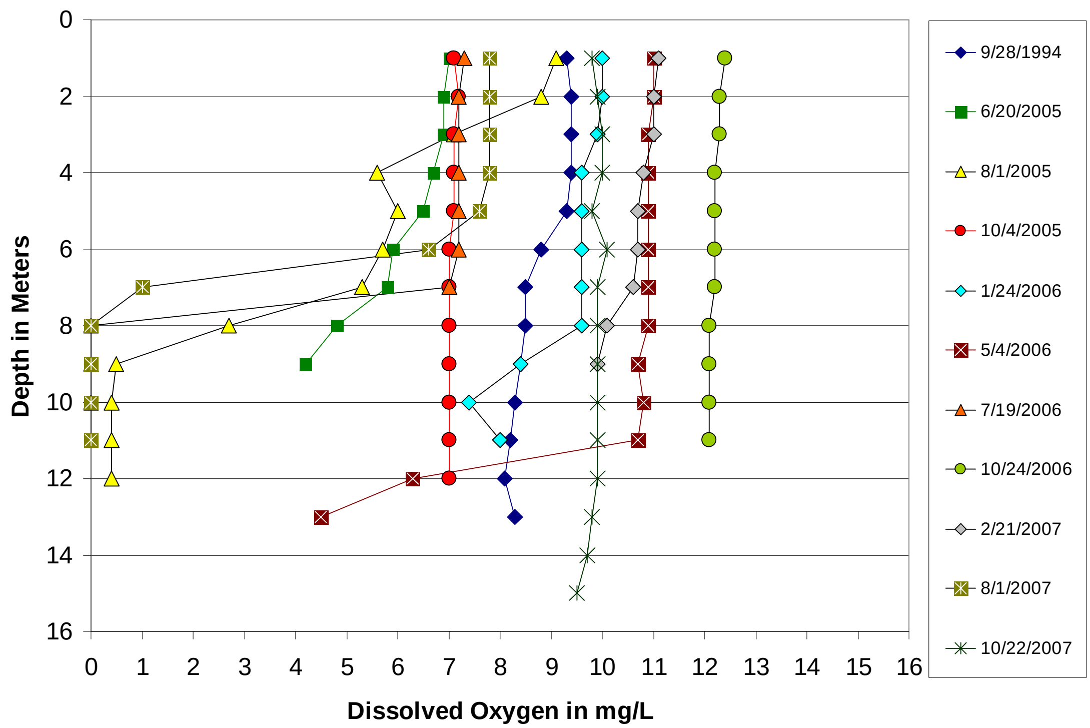


Figure 4. Dissolved Oxygen Profiles for Moon Lake from 1994 to 2007.

General Water Quality: Data collected by the NDG&F in 2005 through 2007 indicate Moon Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 637 to 788 mg/L (Table 1). Moon Lake is sodium sulfate dominated with an average sulfate concentration of 1917 mg/L, and an average sodium concentration of 918 mg/L. The average TDS concentration and specific conductance measurements for the 2005-2007 sampling period were 3999 mg/L and 5387 µmhos/cm, respectively. Average total nitrogen and total phosphorus concentrations were 2.144 mg/L and 0.130 mg/L, respectively (Table 1).

When compared to the Cultivated Plains regional average for natural and enhanced lakes Moon Lake has higher reported concentrations of dissolved solids and nutrients (Table 2). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1376 mg/L, 1.440 mg/L, and 0.068 mg/L, respectively, compared to Moon Lake's average TDS, total nitrogen, and total phosphorus concentrations of 3999 mg/L, 2.144 mg/L, and 0.130 mg/L, respectively.

Table 1. Statistical Summary of Moon Lake's 2005-2007 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	9	702	637	788	41.1
Total Ammonia as N	mg/L	9	0.095	0.010[1]	0.271	0.096
Bicarbonate (HCO_3)	mg/L	9	646	533	747	64.5
Calcium (Ca)	mg/L	9	27	20	34	3.7
Carbonate (CO_3)	mg/L	9	103	77	126	19.4
Chloride (Cl)	mg/L	9	346	325	375	16.5
Chlorophyll-a	µg/L	9	9.1	1.5[1]	26.3	9.9
Specific Conductance	µmhos	9	5387	5110	5900	244.9
Total Dissolved Solids	mg/L	9	3999	3820	4240	151.8
Total Hardness as ($CaCO_3$)	mg/L	9	919	837	1020	54.5
Hydroxide (OH)	mg/L	9	1.0[1]	1.0[1]	1.0[1]	0.0
Iron (Fe)	mg/L	9	0.23	0.05	1.01	0.30
Magnesium (Mg)	mg/L	9	207	187	228	11.9
Nitrate + Nitrite as N	mg/L	9	0.143	0.020[1]	0.300	0.119
Total Kjeldahl Nitrogen as N	mg/L	9	2.001	1.660	2.450	0.235
Total Nitrogen as N	mg/L	9	2.144	1.700	2.690	0.284
pH		9	8.9	8.7	9.0	0.12
Total Phosphorus as P	mg/L	9	0.130	0.020	0.194	0.068
Potassium (K)	mg/L	9	159	115	179	17.8
Sodium (Na)	mg/L	9	918	818	1030	77.7
Sulfate (SO4)	mg/L	9	1917	1820	2020	69.1

[1]Equal to Minimum Reporting Limit

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Moon Lake, and that the ratio of total nitrogen to total phosphorus (N:P) in algae by weight is approximately 15 to 1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There are nine water quality sample results for Moon Lake collected between June 2005 and August 2007. The nine samples used in this interpretation indicate that Moon Lake's nutrient relationship is dynamic and variable depending on the season and the natural processes occurring at the time of sampling. Moon Lake is most often phosphorus limited, however there are times during peak production that it is nitrogen limited (Figure 5).

The nitrogen to phosphorus ratio for Moon Lake ranged from a low of 11 to a high of 85 with an average of 26. Of the nine samples collected on Moon Lake, five were above 15 indicating that phosphorus was limiting primary production and four were below 15, indicating nitrogen was limiting primary production.

Table 2. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lakes in the Cultivated Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	142	346	175	1120	180
Total Ammonia as N	mg/L	230	0.098	0.001[1]	1.620	0.208
Bicarbonate (HCO_3)	mg/L	142	363	171	1040	158
Calcium (Ca)	mg/L	142	45	16	108	23
Carbonate (CO_3)	mg/L	136	31	1[1]	181	39
Chloride (Cl)	mg/L	142	105	3[1]	1260	233
Chlorophyll-a	µg/L	185	10	2[1]	167	17
Specific Conductance	µmhos	161	1819	361	11500	2071
Total Dissolved Solids	mg/L	143	1376	191	9880	1786
Total Hardness as ($CaCO_3$)	mg/L	142	507	173	1820	284
Hydroxide (OH)	mg/L	111	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	138	0.095[1]	0.007	1.010	0.123
Magnesium (Mg)	mg/L	142	95.7	28.4	413.0	68.0
Nitrate + Nitrite as N	mg/L	175	0.047	0.001	0.540	0.078
Total Kjeldahl Nitrogen as N	mg/L	128	1.504	0.080	4.110	0.609
Total Nitrogen as N	mg/L	103	1.440	0.609	2.740	0.466
pH		142	8.55	7.75	9.33	0.36
Total Phosphorus as P	mg/L	230	0.068	0.004[1]	1.460	0.118
Potassium (K)	mg/L	142	30	8	179	37
Sodium (Na)	mg/L	142	255	5	2570	498
Sulfate (SO4)	mg/L	142	591	7	3880	807

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 49 Natural Lakes Between1991 and 2007

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected from 2005 to 2007, Moon Lake's current trophic status is eutrophic bordering on mesotrophic (Figure 6). TSI scores ranged from a low of 33 based on chlorophyll-a, to a high of 79 based on total phosphorus. The trophic status score based on Secchi disk transparency was similar to that of chlorophyll-a, at 48 (Figure 6).

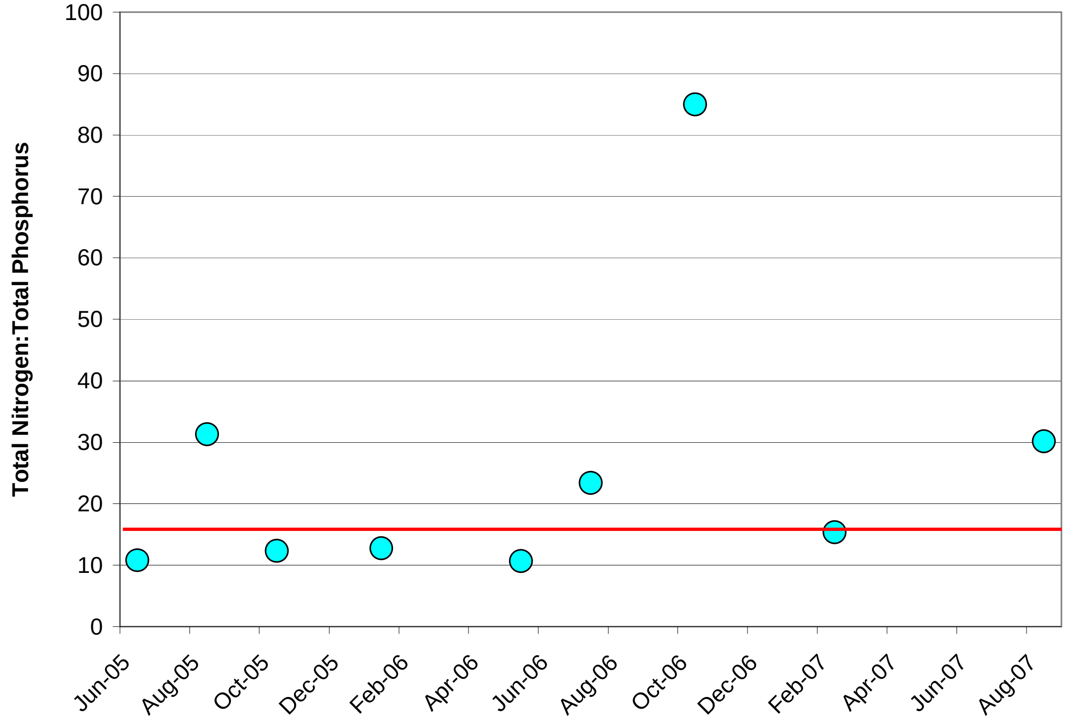


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Moon Lake (2005-2007).

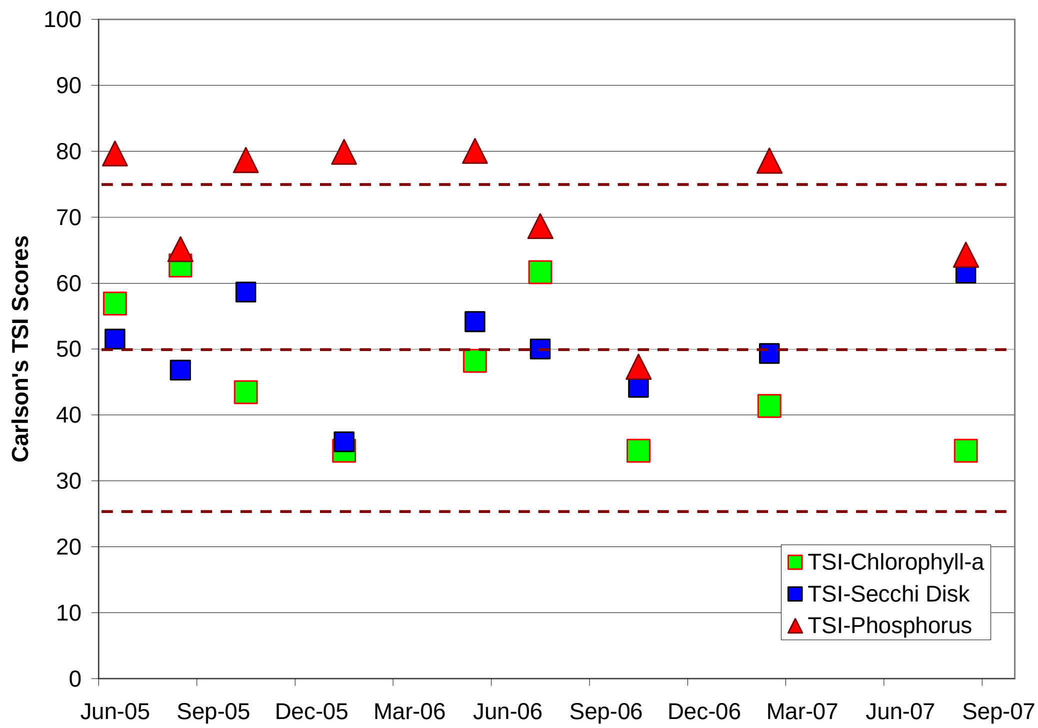


Figure 6. TSI Scores for Moon Lake from 2005 to 2007.

Lake Metigoshe, Bottineau County

BACKGROUND

Location: Lake Metigoshe is a natural lake located in the Turtle Mountains in northern Bottineau County, North Dakota. The lake is 13 miles north and 2 miles east of the town of Bottineau (Figure 1). Lake Metigoshe is managed by the NDG&F.

Figure 1. Location of Lake Metigoshe.

Physiographic/Ecological Setting: Lake Metigoshe is a 1,544.1 acre lake with a maximum depth of 24.3 feet and a mean depth of 11.3 feet (Figure 2). Lake Metigoshe has a large watershed that extends into the province of Manitoba, Canada. Lake Metigoshe is in the Turtle Mountains and the Northern Glaciated Plains Level III Ecoregion, part of the broader Cultivated Plains region (Figure 1). This region is the transitional zone between tall and mixed grass prairie. The region has numerous wetlands essential for spring and fall migrations of wetland dependent birds. Flood plain slopes and hillsides are usually native grass while the uplands and flood plains proper have mostly been converted to small grains, row crops and alfalfa.

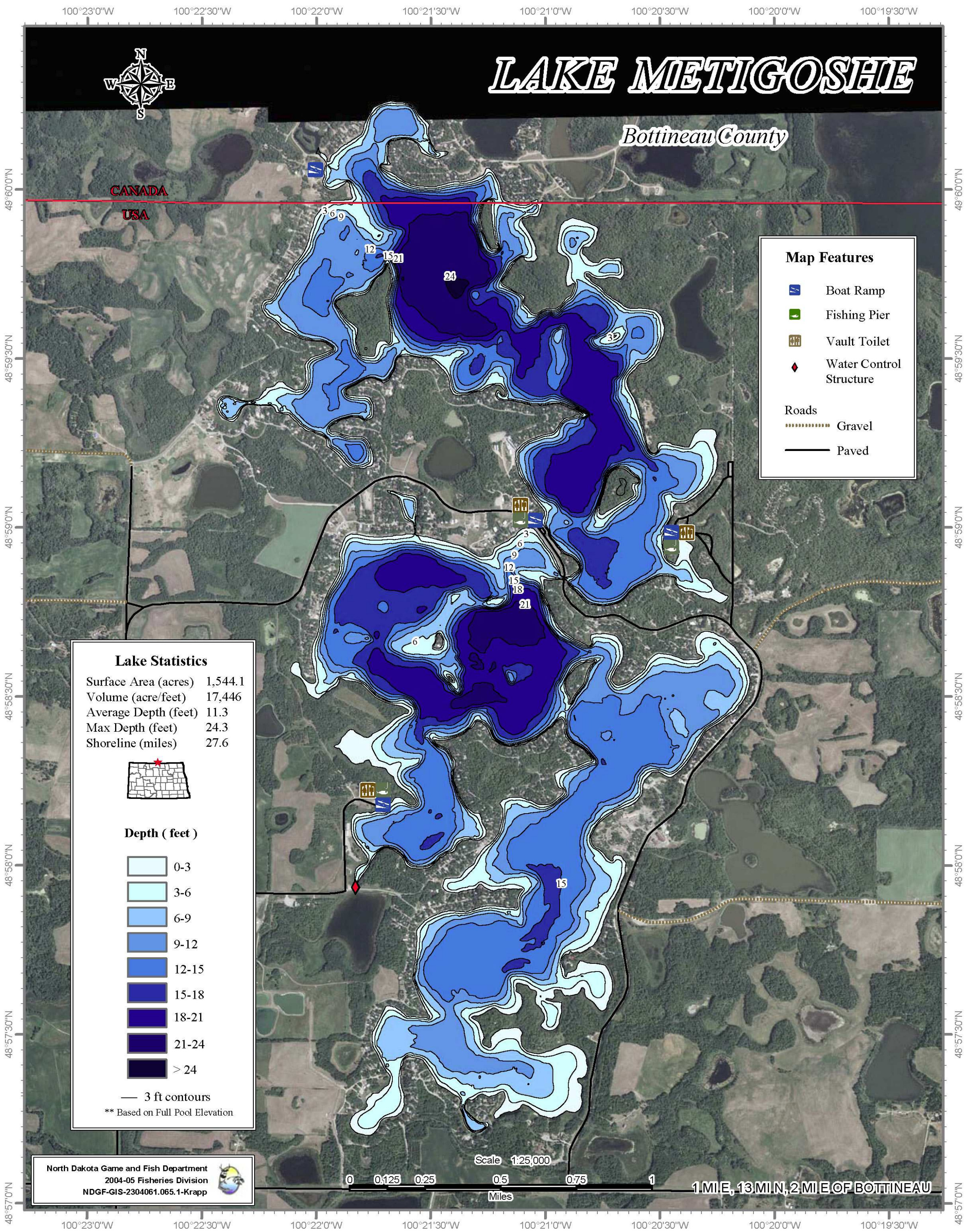


Figure 2. Contour Map of Lake Metigoshe (Map Courtesy of North Dakota Game and Fish Department).

Recreational Facilities: Lake Metigoshe is a popular recreation destination. There are three points of public access to the lake which include boat ramps, fishing piers, and vaulted toilets. There are approximately 1,000 recreational homes, two resorts, and a state park in the immediate area of Lake Metigoshe.

Water Quality Standards Classification: Lake Metigoshe is classified in the state “Standards of Quality for Waters of the State” (NDDoH, 2007) as a class 2 lake. Class 2 Lakes and reservoirs are defined as “Cool Water Fisheries” or “waters capable of supporting natural reproduction and growth of cool water fishes (e. g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota.”

Historical and Current Fishery: Lake Metigoshe’s fishery is northern pike, walleye, and yellow perch. The lake’s historical fishery includes smallmouth bass, largemouth bass, muskellunge, and bullhead.

Historical Water Quality Samples: Lake Metigoshe has up to 22 historical water quality sample results collected from 1990 to 2000.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Lake Metigoshe have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural and enhanced lakes in the Cultivated Plains region.

Temperature and Dissolved Oxygen Profile Results: There are nine temperature and dissolved oxygen profiles for Lake Metigoshe collected intermittently between 1990 and 2006. Temperature and dissolved oxygen profiles are represented for two time periods, 1990-1993 and 2005-2006 (Figures 3 through 4). The profile data indicates that Lake Metigoshe rarely thermally stratifies but the lake still experiences oxygen decay below 3 meters of depth. Of the nine profiles sampled, five collected on 2/13/1991, 8/18/1992, 3/4/1993, 7/21/2005, and 1/24/2006, fell below the State standard of 5 mg/L. At all other times and at all depths dissolved oxygen concentrations were adequate to maintain all species of native fishes.

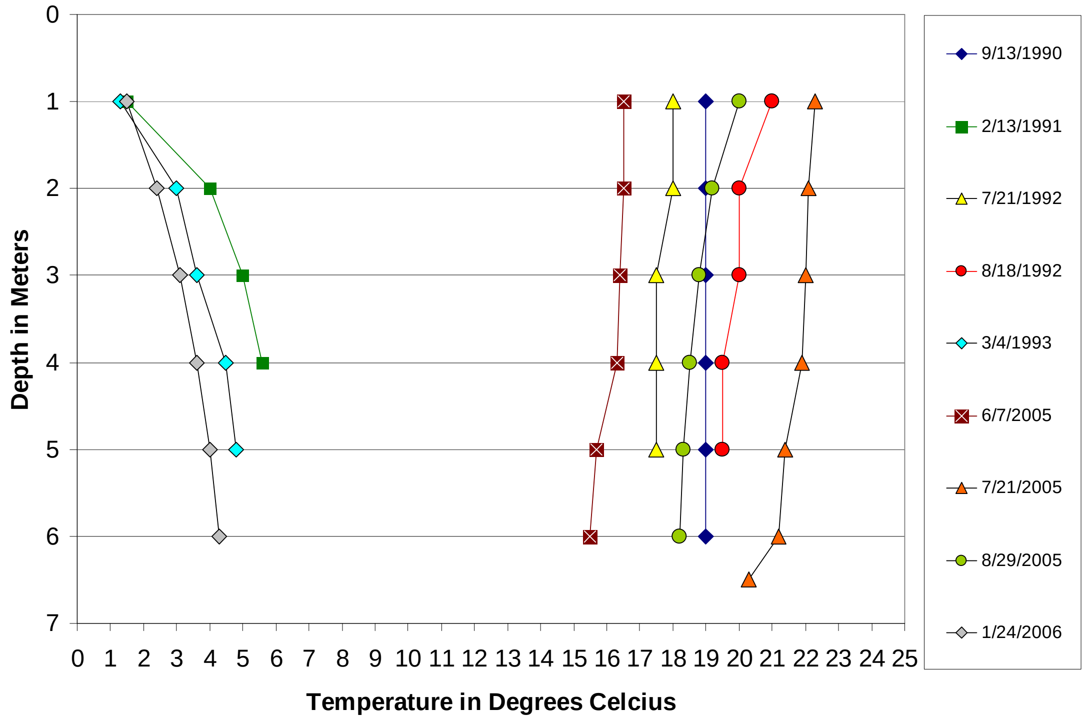


Figure 3. Lake Metigoshe's Temperature Profiles From 1990 to 2006.

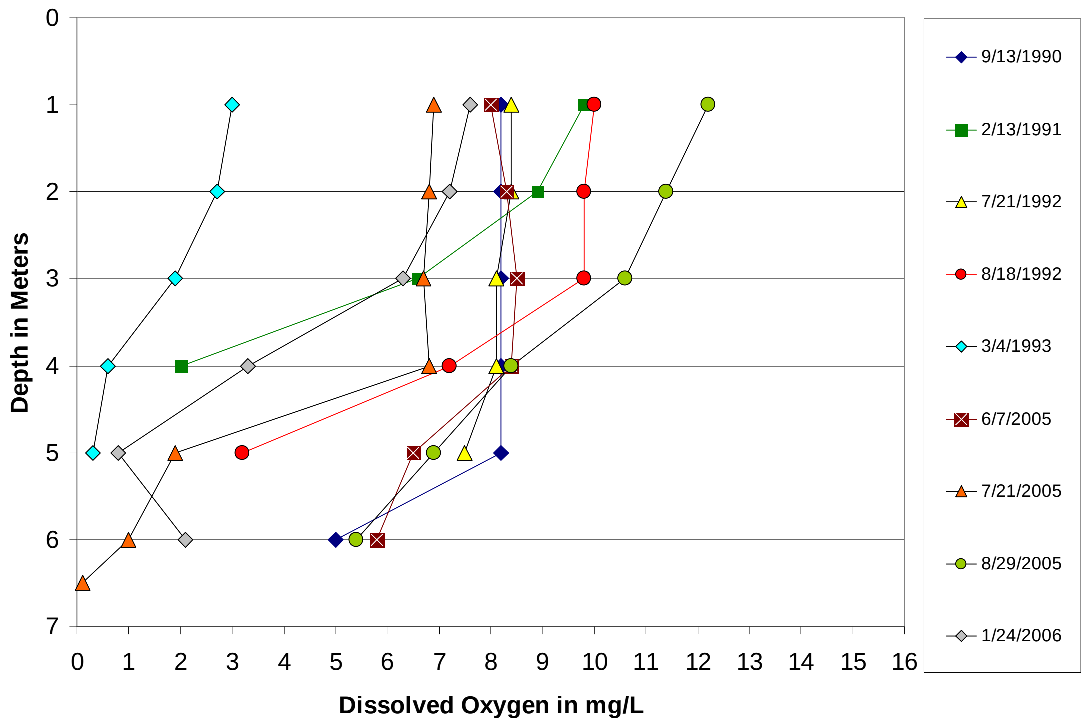


Figure 6. Lake Metigoshe's Dissolved Oxygen Profiles From 1990 to 2006.

General Water Quality: Data collected by the NDG&F in 2005 and 2006 indicate Lake Metigoshe is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 248 mg/L to 280 mg/L (Table 1). Based on the 2005-2006 water quality data, Lake Metigoshe is sodium bicarbonate dominated with an average sodium concentration of 7 mg/L and an average bicarbonate concentration of 296 mg/L. The average TDS concentration and specific conductance measurements for the 2005-2006 sampling period were 302 mg/L, and 549 µmhos/cm, respectively. Average total phosphorus and total nitrogen concentrations were 0.020 mg/L and 1.523 mg/L, respectively.

When compared to historical water quality data for Lake Metigoshe, it appears that concentrations of most water quality constituents have decreased. For example, the historical average bicarbonate and sodium concentrations were 337 mg/L and 10 mg/L, respectively (Table 2), compared to average concentrations of 296 mg/L for bicarbonate and 7 mg/L for sodium recorded for the period 2005-2006 (Table 1). While probably not significant, average total nitrogen and total phosphorus concentrations have slightly fluctuated when compared to the historical data. Historical average total nitrogen and total phosphorus concentrations were 1.371 mg/L and 0.112 mg/L, respectively (Table 2), compared to average concentrations of 1.523 mg/L for total nitrogen, and 0.020 mg/L for total phosphorus, respectively.

Table 1. Statistical Summary of Lake Metigoshe's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	263	248	280	14
Total Ammonia as N	mg/L	4	0.119	0.010[1]	0.435	0.211
Bicarbonate (HCO_3)	mg/L	4	297	254	341	36
Calcium (Ca)	mg/L	4	36.8	28.5	44.0	6.6
Carbonate (CO_3)	mg/L	4	12	1[1]	28	13
Chloride (Cl)	mg/L	4	5	4	6	1
Chlorophyll-a	µg/L	3	10.5	9.1	11.8	1.4
Specific Conductance	µmhos	4	549	517	608	42
Total Dissolved Solids	mg/L	4	302	285	324	18
Total Hardness as ($CaCO_3$)	mg/L	4	276	265	295	13
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.074	0.047	0.109	0.032
Magnesium (Mg)	mg/L	4	44.7	41.3	49.5	3.5
Nitrate + Nitrite as N	mg/L	4	0.038	0.020	0.090	0.035
Total Kjeldahl Nitrogen as N	mg/L	4	1.485	1.220	1.930	0.314
Total Nitrogen as N	mg/L	4	1.523	1.240	2.020	0.347
pH		4	8.41	7.98	8.68	0.33
Total Phosphorus as P	mg/L	4	0.020	0.011	0.024	0.006
Potassium (K)	mg/L	4	10.9	9.5	12.4	1.2
Sodium (Na)	mg/L	4	7	6	8	1
Sulfate (SO4)	mg/L	4	38	34	43	5

[1]Equal to Minimum Reporting Limit

Table 2. Statistical Summary of Lake Metigoshe's Historical Water Quality Data Collected Between 1990 and 2000.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	2	323	293	354	43.1
Total Ammonia as N	mg/L	22	0.031	0.010[1]	0.150	0.037
Bicarbonate (HCO_3)	mg/L	2	337	282	393	78.4
Calcium (Ca)	mg/L	2	24	23	26	1.8
Carbonate (CO_3)	mg/L	2	28	19	37	13
Chloride (Cl)	mg/L	2	7.2	5.8	8.7	2.0
Chlorophyll-a	µg/L	22	4.6	3.0[1]	16.0	3.3
Specific Conductance	µmhos	2	639	575	703	90.5
Total Dissolved Solids	mg/L	2	360	324	396	50.9
Total Hardness as ($CaCO_3$)	mg/L	2	326	305	348	30.4
Hydroxide (OH)	mg/L	1	0	0	0	0
Iron (Fe)	mg/L	2	0.025	0.018	0.031	0.009
Magnesium (Mg)	mg/L	2	64.3	59.8	68.8	6.3
Nitrate + Nitrite as N	mg/L	16	0.023	0.020[1]	0.040	0.007
Total Kjeldahl Nitrogen as N	mg/L	8	1.380	1.160	1.770	0.213
Total Nitrogen as N	mg/L	7	1.371	1.180	1.790	0.208
pH		2	8.8	8.6	9.0	0.2
Total Phosphorus as P	mg/L	22	0.112	0.018	1.460	0.304
Potassium (K)	mg/L	2	14.8	14.2	15.4	0.85
Sodium (Na)	mg/L	2	9.9	9.2	10.6	0.99
Sulfate (SO4)	mg/L	2	45	36	54	12.7

[1]Equal to Minimum Reporting Limit

When compared to the Cultivated Plains regional average Lake Metigoshe is lower in dissolved solids than reported for most natural and enhanced lakes in the region (Table 3). Lake Metigoshe's nutrient concentrations also varied from the regional average. For example the regional average TDS, total nitrogen, and total phosphorus concentrations are 1376 mg/L, 1.440 mg/L, and 0.068 mg/L, respectively, compared to Lake Metigoshe's average TDS, total nitrogen, and total phosphorus concentrations of 302 mg/L, 1.523 mg/L, and 0.020 mg/L, respectively (Table 2), for the 2005-2006 period (Table 1).

Table 3. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lake's in the Cultivated Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	142	346	175	1120	180
Total Ammonia as N	mg/L	230	0.098	0.001[1]	1.620	0.208
Bicarbonate (HCO_3)	mg/L	142	363	171	1040	158
Calcium (Ca)	mg/L	142	45	16	108	23
Carbonate (CO_3)	mg/L	136	31	1[1]	181	39
Chloride (Cl)	mg/L	142	105	3[1]	1260	233
Chlorophyll-a	µg/L	185	10	2[1]	167	17
Specific Conductance	µmhos	161	1819	361	11500	2071
Total Dissolved Solids	mg/L	143	1376	191	9880	1786
Total Hardness as ($CaCO_3$)	mg/L	142	507	173	1820	284
Hydroxide (OH)	mg/L	111	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	138	0.095[1]	0.007	1.010	0.123
Magnesium (Mg)	mg/L	142	95.7	28.4	413.0	68.0
Nitrate + Nitrite as N	mg/L	175	0.047	0.001	0.540	0.078
Total Kjeldahl Nitrogen as N	mg/L	128	1.504	0.080	4.110	0.609
Total Nitrogen as N	mg/L	103	1.440	0.609	2.740	0.466
pH		142	8.55	7.75	9.33	0.36
Total Phosphorus as P	mg/L	230	0.068	0.004[1]	1.460	0.118
Potassium (K)	mg/L	142	30	8	179	37
Sodium (Na)	mg/L	142	255	5	2570	498
Sulfate (SO4)	mg/L	142	591	7	3880	807

[1]Equal to lower detection limit
[2]Data Collected from 49 Natural Lakes between 1991 and 2007

Limiting Nutrient: The limiting nutrient analysis is assessed based on the assumption that either nitrogen or phosphorus is limiting algal growth in Lake Metigoshe, and that the ratio of total nitrogen to total phosphorus (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were 26 water quality sample results for Lake Metigoshe collected between June 1992 and January 2006, where the N:P ratio could be calculated. The 26 samples used in this interpretation indicate that Lake Metigoshe is most often phosphorus limited, and that the nutrient relationships are dynamic and variable depending on the time of the year and the natural processes occurring at the time of sampling (Figure 5).

The nitrogen to phosphorus ratio for Lake Metigoshe ranged from a low of 1 to a high of 124 with an average of 57. Of the 26 samples collected all but three were above an N:P ratio of 15 indicating phosphorus is limiting primary production.

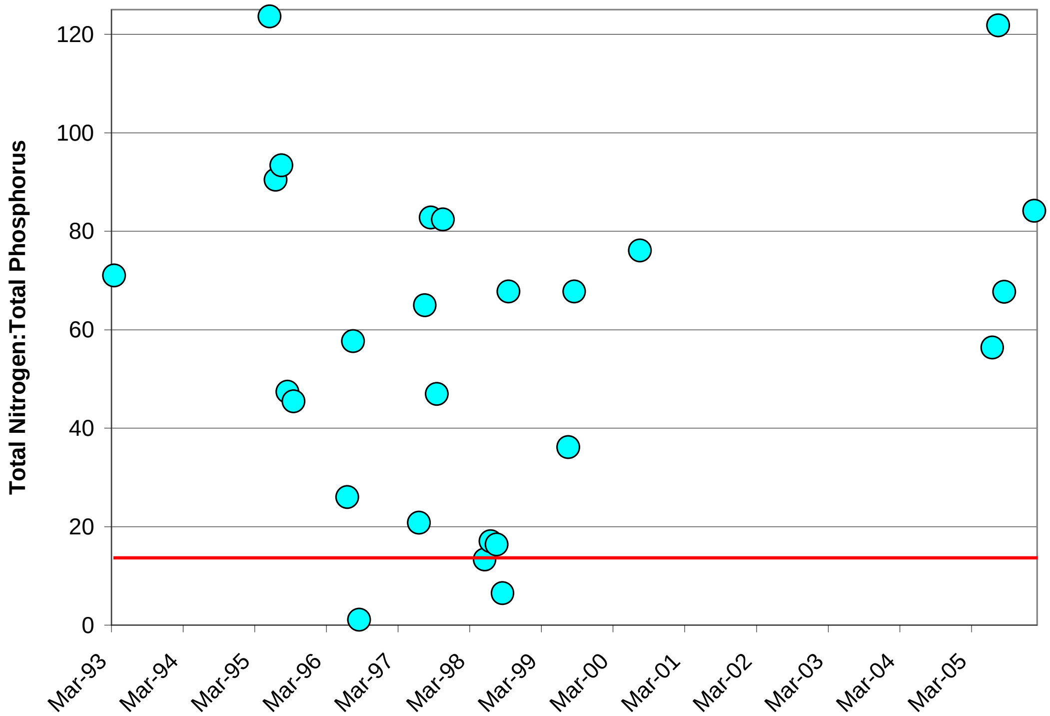


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Lake Metigoshe (1993-2006).

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus measurements collected during 2005, Lake Metigoshe's current trophic status is mesotrophic bordering on eutrpohic. TSI scores ranged from a low of 39 based on total phosphorus, to a high of 59 based on Secchi disk transparency. The trophic status score based on chlorophyll-a, was similar to that estimated by Secchi disk transparency, at 55 (Figure 6).

A total of 25 phosphorus samples, 25 cholorphyll-a samples and five Secchi disk measurements collected from 1992 to 2005 were used to evaluate trends in the trophic status of Lake Metigoshe. Since Lake Metigoshe is phosphorus limited all three indicators chlorophyll-a, Secchi disk, and total phosphorus are possibly good indicators of trophic status, but since chlorophyll-a is the only direct measurement of primary production it was given greater consideration when making this assessment. Based on a visual assessment, Lake Metigoshe's trophic status trend is stable (Figure 6).

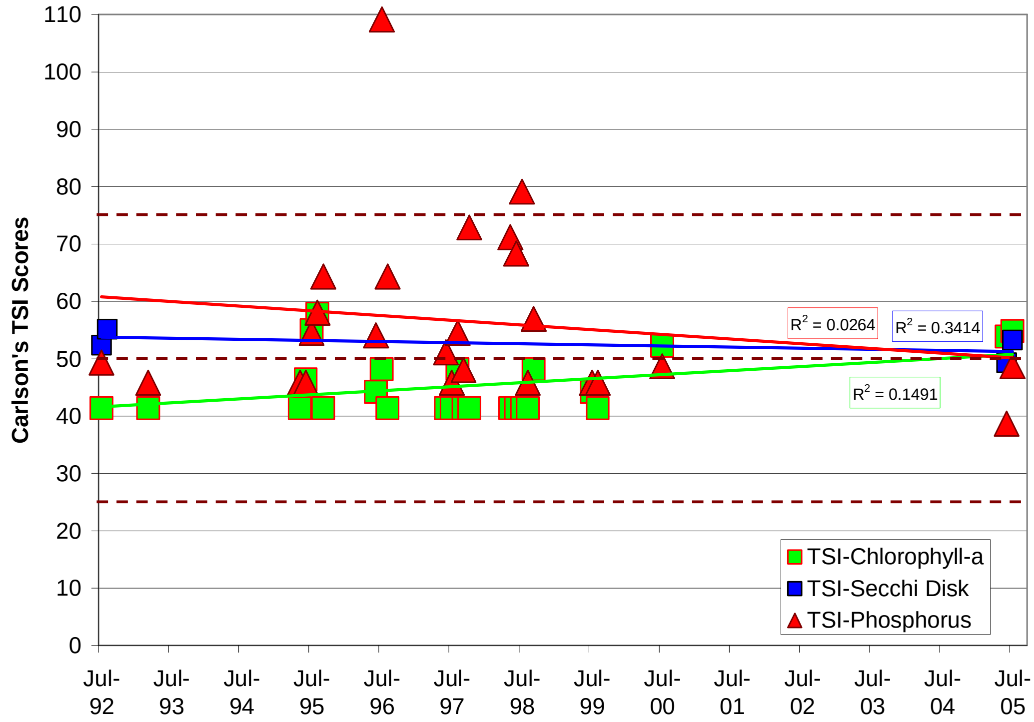


Figure 6. TSI Scores and Temporal Trends for Lake Metigoshe from 1992 to 2005.

Long Lake, Bottineau County

BACKGROUND

Location: Long Lake is located in the Turtle Mountains near the United States - Canada border in Bottineau County. Directions to Long Lake from the town of Bottineau are; one mile east, 11 miles north, 4 miles east, 1 mile south, 3 miles east, 1 mile south, and 1 mile west (Figure 1). Long Lake is managed by the North Dakota Game and Fish Department.

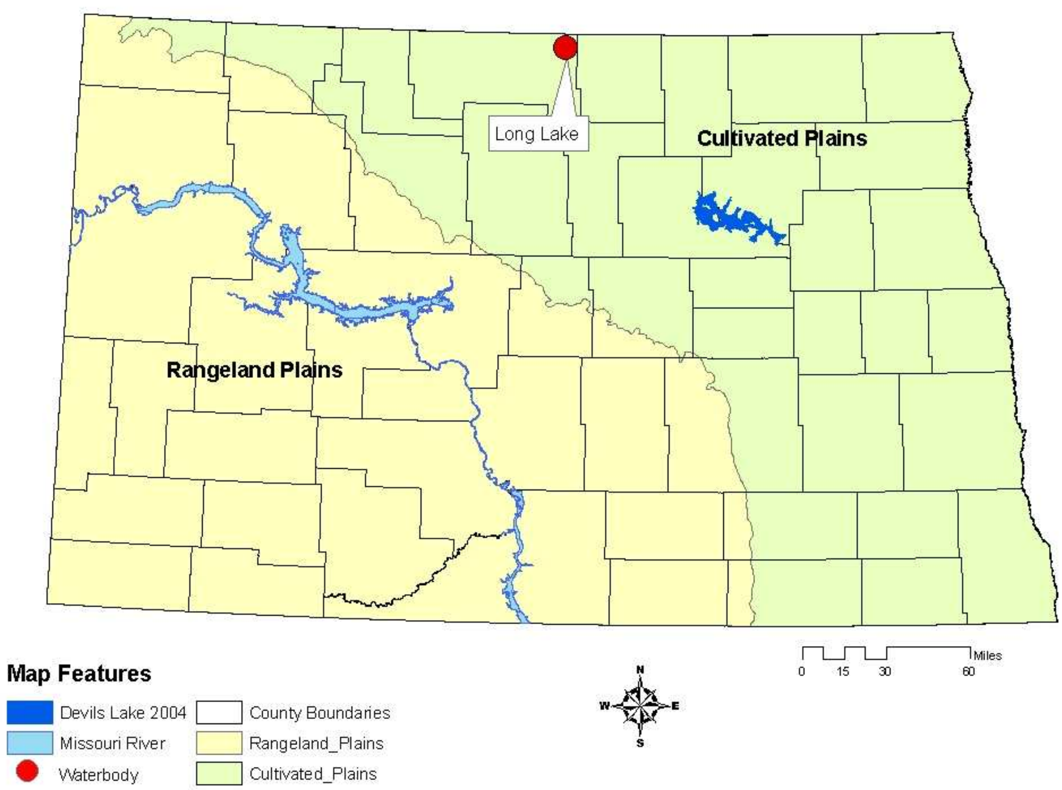


Figure 1. Location of Long Lake.

Physiographic/Ecological Setting: Long Lake is a 287 acre lake with a maximum depth of 26 feet and a mean depth of 8.2 feet (Figure 2). Long Lake lies in the Turtle Mountains and the Northern Glaciated Plains Level III Ecoregion part of the broader Cultivated Plains Region (Figure 1). The Turtle Mountains are a tree covered hilly area which rapidly rise above the prairie with relief ranging from 300 to 500 feet. The Northern Glaciated Plains Ecological region is characterized by flat to rolling landscape composed of glacial drift (USEPA 1994). This region is the transitional zone between tall and mixed grass prairie. The region has numerous wetlands essential for spring and fall migrations of wetland dependent birds. Flood plain slopes and hillsides are usually native grass while the uplands and flood plains proper have mostly been converted to small grains, row crops and alfalfa.

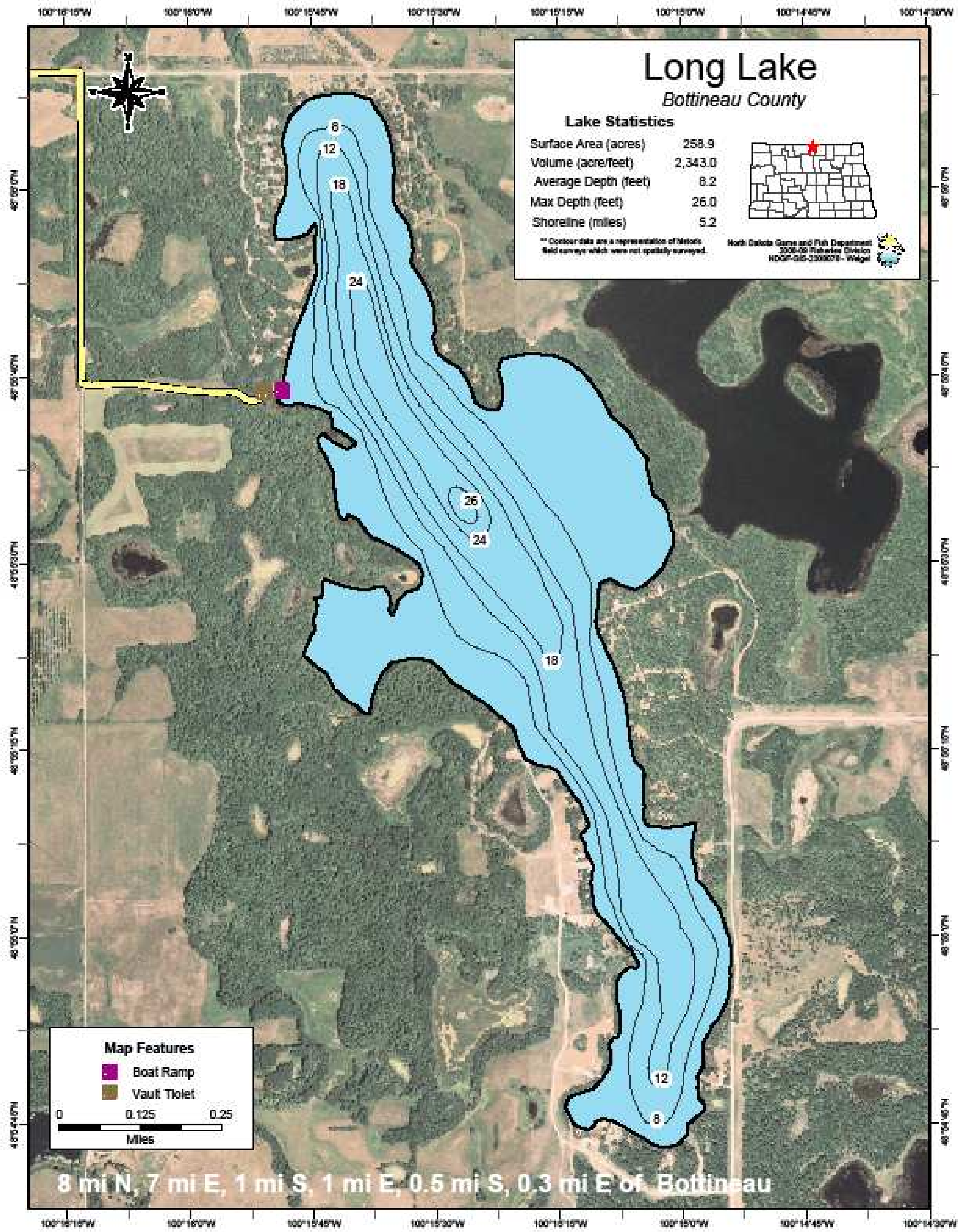


Figure 2. Contour Map of Long Lake (Map Courtesy of North Dakota Game and Fish Department).

Recreational Facilities: Long Lake enjoys four seasons of recreation. Public access is on the north and southeast shores with a boat ramp, parking, vault toilet, and a limited picnic area. There are approximately 25 recreational homes within a 20 acre area on the north end of the lake, with a small beach area for swimming.

Water Quality Standards Classification: Long Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2007) as a class 2 lake. Class 2 lakes and reservoirs are defined as "Cool Water Fisheries" or "waters capable of supporting natural reproduction and growth of cool water fishes (e. g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: Long Lake's current fishery is northern pike, walleye, and yellow perch. The historical fishery also included largemouth bass, rainbow trout, crappie and bluegill. Long Lake is aerated during the winter months.

Historical Water Quality Sampling: Historical water quality data include three sample results collected in 1995-1996.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Long Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural and enhanced lakes in the Cultivated Plains region.

Temperature and Dissolved Oxygen Profile Results: There were six temperature and dissolved oxygen profiles for Long Lake collected in two clusters between 1995-1996 and 2005-2006 (Figures 3 through 4).

The profile data indicates that Long Lake is usually not stratified, but still experiences oxygen decay below 5 meters of depth. Of the six profiles collected, four dipped below the state standard of 5 mg/L, but only one collected on February 18, 1995 was consistently below the state standard. At all other times there was adequate dissolved oxygen to support all species of fishes.

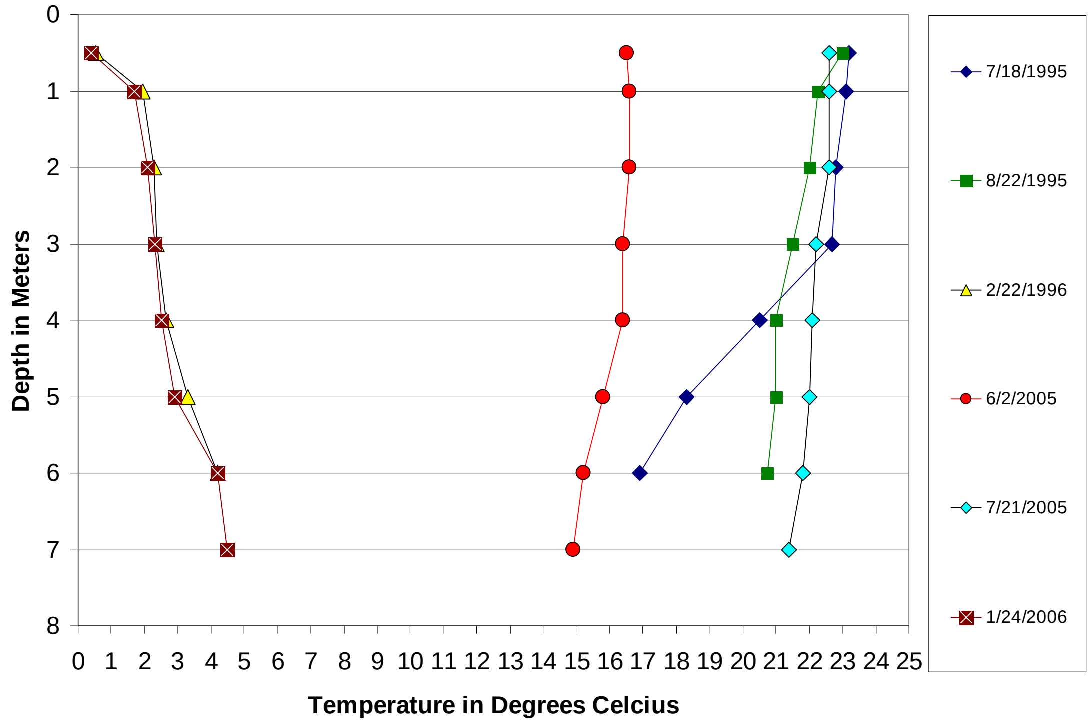


Figure 3. Long Lake's Temperature Profiles From 1995 to 2006.

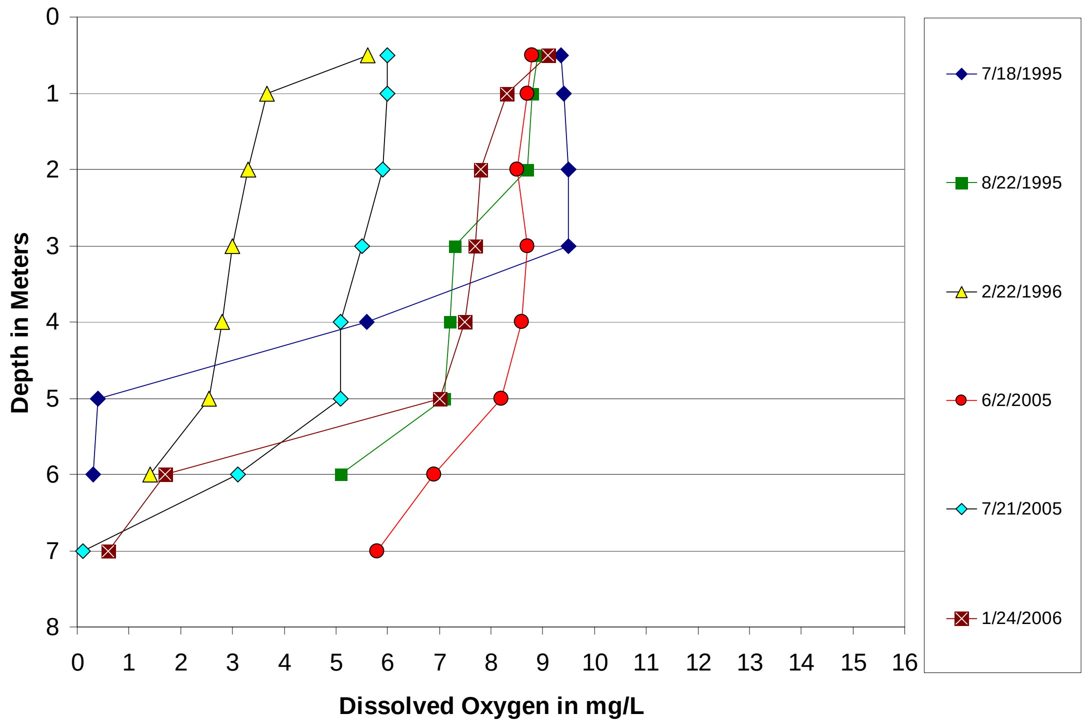


Figure 4. Long Lake's Dissolved Oxygen Profiles From 1995 to 2006.

General Water Quality: Data collected by the NDG&F in 2005 and 2006 indicates that Long Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 275 to 322 mg/L (Table 2). Long Lake is sodium bicarbonate dominated with an average bicarbonate concentration of 330 mg/L and an average sodium concentration of 9.4 mg/L. The average TDS and specific conductivity measurements for the 2005-2006 sampling period were 390 mg/L and 688 µmhos/cm, respectively. Average total phosphorus and total nitrogen concentrations were 0.021 mg/L and 1.583 mg/L, respectively.

When compared to historical water quality data for Long Lake it appears that concentrations of most water quality constituents have decreased. For example, the historical average concentration for bicarbonate and sodium were 357 mg/L and 9.8 mg/L, respectively (Table 2), compared to the current bicarbonate and sodium concentrations of 330 mg/L and 9.4 mg/L , respectively (Table 1). The average total nitrogen and total phosphorus concentrations have also decreased when compared to the historical data. Historical average total nitrogen and total phosphorus concentrations were 2.301 mg/L and 0.036 mg/L, respectively (Table 2), compared to average concentrations of 1.583 mg/L and 0.021 mg/L for total nitrogen and total phosphorus, respectively (Table 1).

Table 1. Statistical Summary of Long Lake's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	293	275	322	21.1
Total Ammonia as N	mg/L	4	0.059	0.010[1]	0.190	0.088
Bicarbonate (HCO_3)	mg/L	4	330	290	392	44.2
Calcium (Ca)	mg/L	4	34.1	29.4	39.1	4.4
Carbonate (CO_3)	mg/L	4	14	1[1]	32	14
Chloride (Cl)	mg/L	4	6	6	7	0.4
Chlorophyll-a	µg/L	3	7.5	2.8	12.5	4.9
Specific Conductance	µmhos	4	688	650	753	45.3
Total Dissolved Solids	mg/L	4	390	368	426	24.9
Total Hardness as ($CaCO_3$)	mg/L	4	343	324	373	20.9
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0.0
Iron (Fe)	mg/L	4	0.074	0.038	0.124	0.040
Magnesium (Mg)	mg/L	4	62.7	58.9	66.9	3.4
Nitrate + Nitrite as N	mg/L	4	0.043	0.020	0.110	0.045
Total Kjeldahl Nitrogen as N	mg/L	4	1.540	1.430	1.690	0.113
Total Nitrogen as N	mg/L	4	1.583	1.450	1.800	0.155
pH		4	8.5	8.2	8.7	0.24
Total Phosphorus as P	mg/L	4	0.021	0.016	0.028	0.006
Potassium (K)	mg/L	4	17	16	19	1.4
Sodium (Na)	mg/L	4	9.4	9.0	10.1	0.49
Sulfate (SO4)	mg/L	4	83	78	89	5.6

[1]Equal to Minimum Reportable Limit

Table 2. Statistical Summary of Long Lake's Historical Water Quality Data Collected Between 1995 and 1996.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	319	295	359	34.6
Total Ammonia as N	mg/L	3	0.211	0.011	0.563	0.306
Bicarbonate (HCO_3)	mg/L	3	357	301	438	71.7
Calcium (Ca)	mg/L	3	34.9	31.9	38.9	3.6
Carbonate (CO_3)	mg/L	3	16	1[1]	29	14.2
Chloride (Cl)	mg/L	3	6.7	5.8	8.3	1.3
Chlorophyll-a	µg/L	2	6	4	9	3.5
Specific Conductance	µmhos	3	758	694	847	79.2
Total Dissolved Solids	mg/L	3	432	400	488	48.7
Total Hardness as ($CaCO_3$)	mg/L	3	375	343	415	36. 6
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0.0
Iron (Fe)	mg/L	3	0.015	0.010[1]	0.022	0.006
Magnesium (Mg)	mg/L	3	70.0	63.9	77.3	6.8
Nitrate + Nitrite as N	mg/L	1	0.040	0.040	0.040	0.0
Total Kjeldahl Nitrogen as N	mg/L	3	2.090	1.430	2.440	0.315
Total Nitrogen as N	mg/L	3	2.301	1.845	3003	0.617
pH		3	8.473	7.980	8.830	0.441
Total Phosphorus as P	mg/L	3	0.036	0.018	0.064	0.024
Potassium (K)	mg/L	3	19.5	18.1	21.4	1.7
Sodium (Na)	mg/L	3	9.8	8.7	11.1	1.2
Sulfate (SO4)	mg/L	3	98	85	113	14..2

[1]Equal to Minimum Reportable Limit

When compared to the Cultivated Plains regional average, Long Lake is lower in dissolved solids than reported for most natural and enhanced lakes in the region (Table 3). Concentrations of total phosphorus in Long Lake are also lower than the Cultivated Plains average, while the total nitrogen concentrations are about on par. For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1376 mg/L, 1.440 mg/L, and 0.068 mg/L, respectively, compared to Long Lake's average TDS, total nitrogen, and total phosphorus concentrations of 390 mg/L, 1.583 mg/L and 0.021 mg/L, respectively, for the period 2005-2006.

Table 3. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lakes in the Cultivated Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	142	346	175	1120	180
Total Ammonia as N	mg/L	230	0.098	0.001[1]	1.620	0.208
Bicarbonate (HCO_3)	mg/L	142	363	171	1040	158
Calcium (Ca)	mg/L	142	45	16	108	23
Carbonate (CO_3)	mg/L	136	31	1[1]	181	39
Chloride (Cl)	mg/L	142	105	3[1]	1260	233
Chlorophyll-a	µg/L	185	10	2[1]	167	17
Specific Conductance	µmhos	161	1819	361	11500	2071
Total Dissolved Solids	mg/L	143	1376	191	9880	1786
Total Hardness as ($CaCO_3$)	mg/L	142	507	173	1820	284
Hydroxide (OH)	mg/L	111	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	138	0.095[1]	0.007	1.010	0.123
Magnesium (Mg)	mg/L	142	95.7	28.4	413.0	68.0
Nitrate + Nitrite as N	mg/L	175	0.047	0.001	0.540	0.078
Total Kjeldahl Nitrogen as N	mg/L	128	1.504	0.080	4.110	0.609
Total Nitrogen as N	mg/L	103	1.440	0.609	2.740	0.466
pH		142	8.55	7.75	9.33	0.36
Total Phosphorus as P	mg/L	230	0.068	0.004[1]	1.460	0.118
Potassium (K)	mg/L	142	30	8	179	37
Sodium (Na)	mg/L	142	255	5	2570	498
Sulfate (SO4)	mg/L	142	591	7	3880	807

[1]Equal to lower detection limit
[2]Data Collected from 49 Natural Lakes between 1991 and 2007

Limiting Nutrient: The limiting nutrient assessment is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Long Lake, and that the ratio of total nitrogen to total phosphorus (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were seven water quality sample results for Long Lake collected between June 1995 and January 2006, for which the N:P ratio could be calculated. The results from this analysis indicate that Long Lake is phosphorus limited, and that the nutrient relationships are dynamic and variable depending on the time of the year and the natural processes occurring at the time of sampling (Figure 5).

N:P ratios for Long Lake ranged from a low of 29 to a high of 167, with an average of 84. All of the samples collected from Long Lake were above an N:P ratio of 15, indicating phosphorus is limiting primary production in the lake.

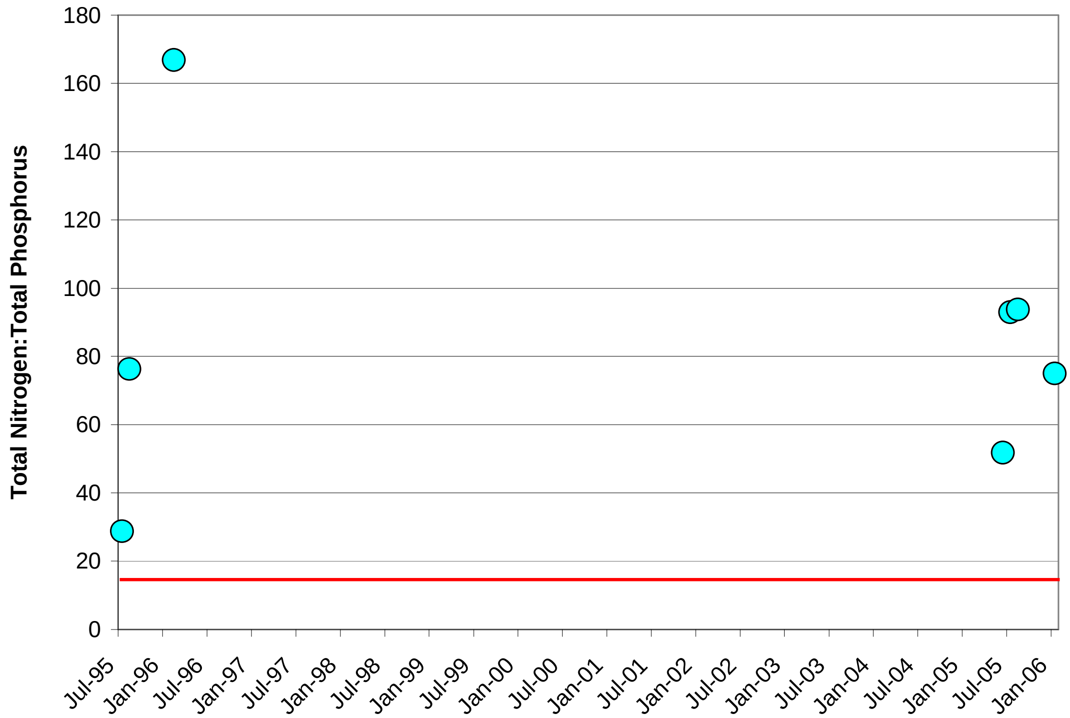


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Long Lake (1995-2006).

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected from 2005 to 2006, Long Lake's current trophic status is mesotrophic (Figure 6). TSI scores ranged from a low of 41, to a high of 55 based on chlorophyll-a measurements. The trophic status scores based on Secchi disk transparency and total phosphorus, were similar to chlorophyll-a, at 54 for Secchi disk transparency and 52 for total phosphorus, respectively (Figure 6).

A total of seven phosphorus samples, five chlorophyll-a samples, and five Secchi disk measurements collected from 1995 to 2006 were used to evaluate trends in the trophic status of Long Lake. Since Long Lake is phosphorus limited all three indicators, chlorophyll-a, Secchi disk transparency, and total phosphorus, are possibly good indicators of trophic status. Based on a visual assessment Long Lake's trophic status trend is stable (Figure 6).

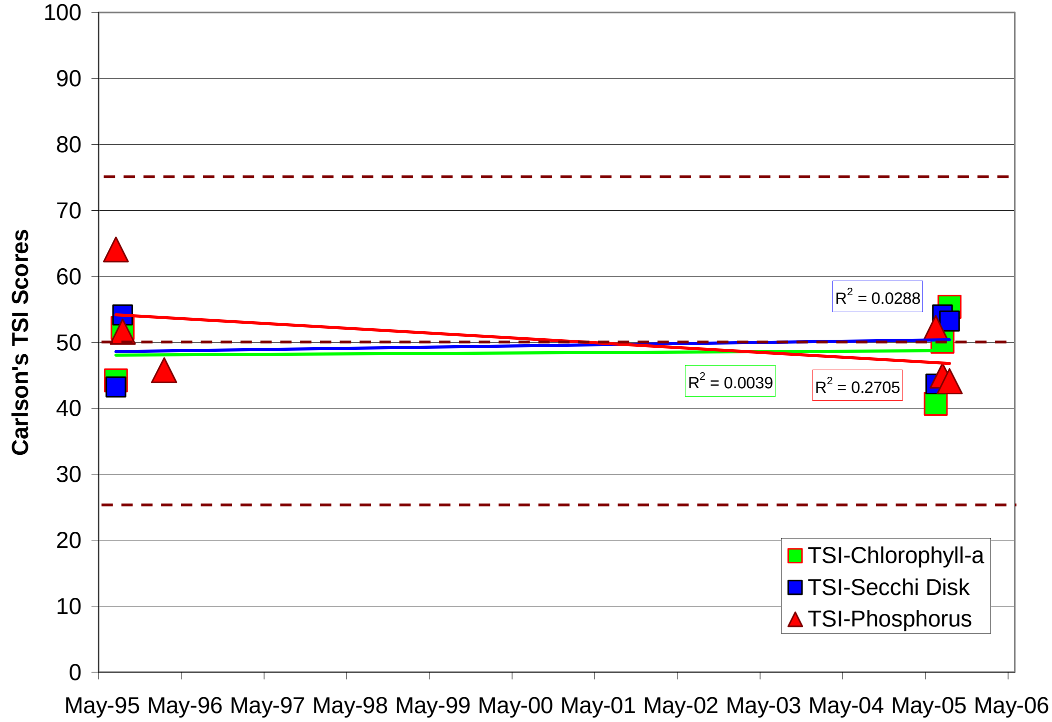


Figure 6. TSI Scores and Temporal Trends for Long Lake 1995 to 2006.

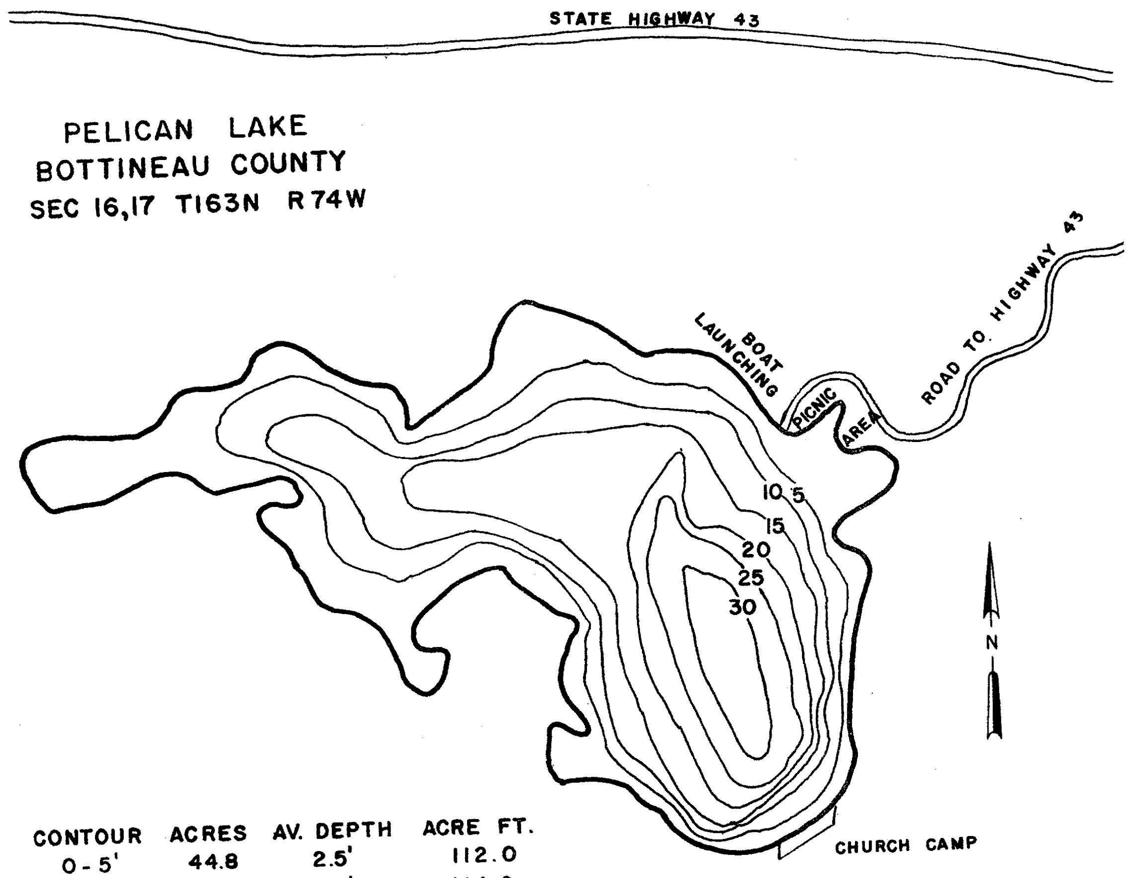
Pelican Lake, Bottineau County

BACKGROUND

Location: Pelican Lake is in the Turtle Mountains near the United States - Canada border. Pelican Lake is 1 miles east, by 11 miles north, by 6 miles east, by 1 mile southwest of the town of Bottineau (Figure 1).

Figure 1. Location of Pelican Lake.

Physiographic/Ecological Setting: Pelican Lake is a 114.5 acre natural lake with a maximum depth of 30 feet and a mean depth of 11 feet (Figure 2). Pelican Lake lies in the Turtle Mountains and the Northern Glaciated Plains Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The Turtle Mountains are a tree covered hilly area which rise above the prairie to a relief of 300 to 500 feet. The Northern Glaciated Plains Ecological region is characterized by flat to rolling landscape composed of glacial drift (USEPA 1994). This region is the transitional zone between tall and mixed grass prairie. The region has numerous wetlands essential for spring and fall migrations of wetland dependent birds. Flood plain slopes and hillsides are usually native grass while the uplands and flood plains proper have mostly been converted to small grains, row crops and alfalfa.



CONTOUR	ACRES	AV. DEPTH	ACRE FT.
0 - 5'	44.8	2.5'	112.0
5 - 10'	15.2	7.5'	114.0
10 - 15'	17.7	12.5'	221.3
15 - 20'	18.0	17.5'	315.0
20 - 25'	8.3	22.5'	186.7
30'	10.5	30.0'	315.0
	114.5	11.0'	1264.0

Figure 2. Contour Map of Pelican Lake (Map Courtesy of North Dakota Game and Fish Department).

Recreational Facilities: Pelican Lake enjoys four-seasons of recreation. Public access is on the north shore with a boat ramp, parking, vault toilet, camping, and a picnic area. There is a small church camp on the south shore with a small beach area for swimming. Boats are restricted to idle speeds on Pelican Lake.

Water Quality Standards Classification: Pelican Lake is classified in the "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a "warm water fishery" or "waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present."

Historical and Current Fishery: Pelican Lake's current and historical fishery is northern pike, walleye, and yellow perch. The historical fishery also includes largemouth bass and bluegill.

Historical Water Quality Sampling: Historical water quality data includes results from 3 sample sets collected in 1995-1996.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Pelican Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural and enhanced lakes in the Cultivated Plains region.

Temperature and Dissolved Oxygen Profile Results: There are seven temperature and dissolved oxygen profiles for Pelican Lake collected in two clusters between 1995-1996 and 2005-2006 (Figures 3 and 4). The temperature and oxygen profiles, indicates that Pelican Lake is often oxygen deficient below summer thermal stratification, and during ice cover.

All seven of the dissolved oxygen profiles collected dipped below the state standard of 5 mg/L of dissolved oxygen either below the thermal-cline, when approaching the sediment-water interface, or during ice cover. However on all dates, with the exception of February 22, 1996, there was enough oxygenated volume to support aquatic life.

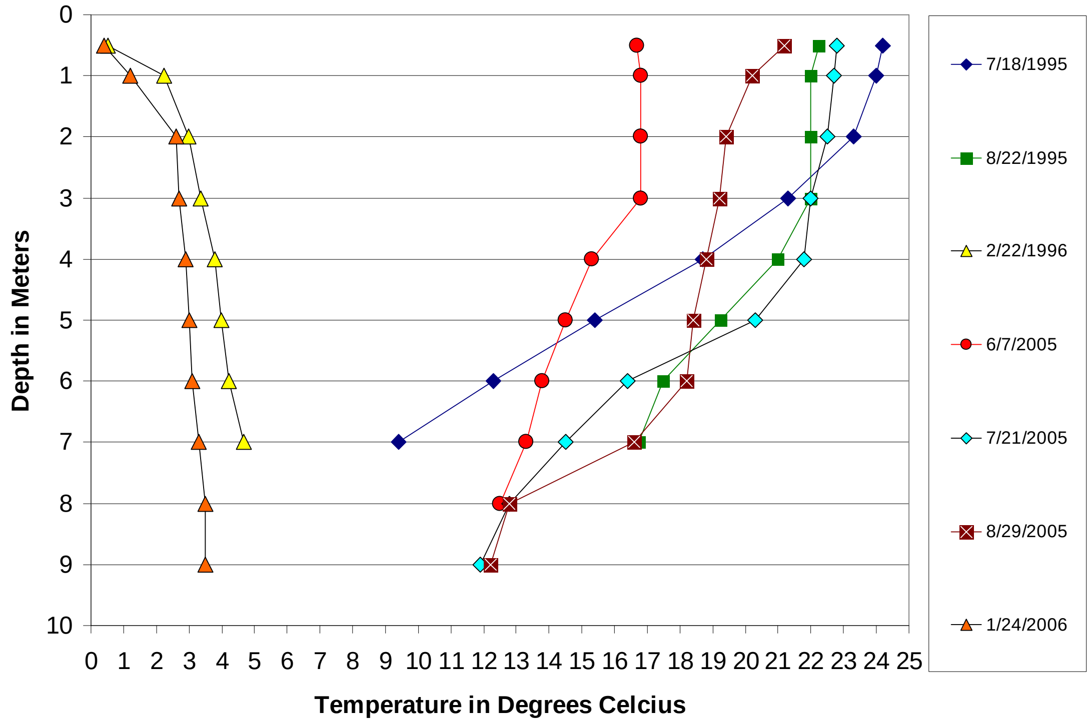


Figure 3. Temperature Profiles for Pelican Lake from 1995 to 2006.

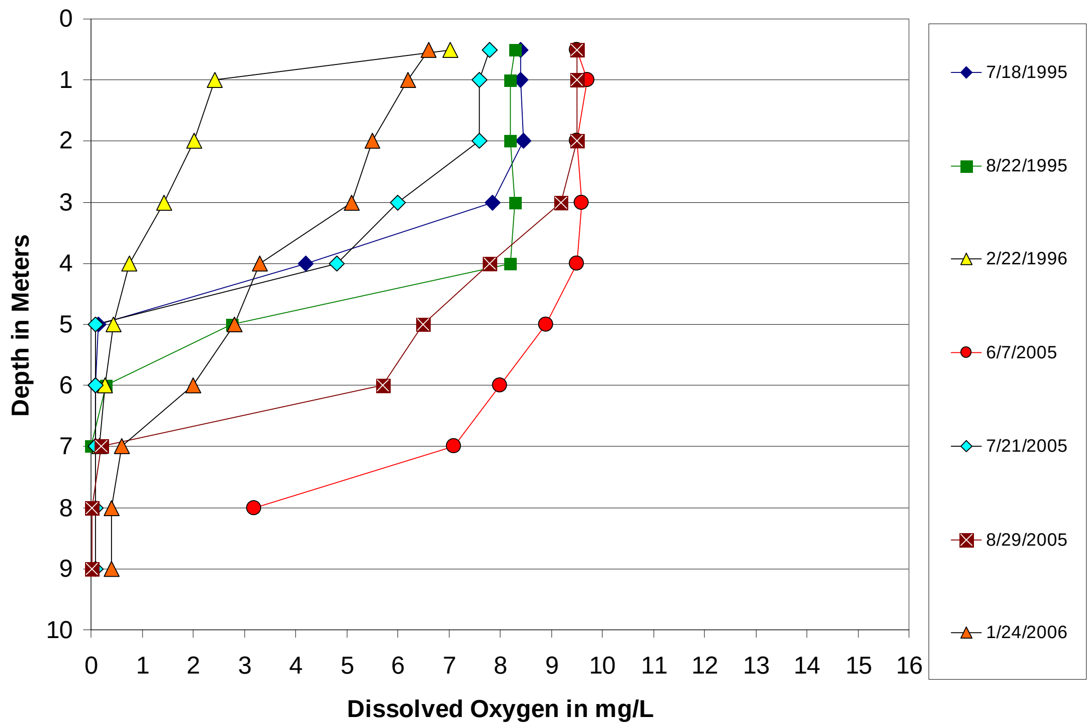


Figure 4. Dissolved Oxygen Profiles for Pelican Lake From 1995 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006 indicate Pelican Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 255 to 301 mg/L (Table 1). Pelican Lake is sodium bicarbonate dominated with an average sodium concentration of 7.4 mg/L and an average bicarbonate concentration of 319 mg/L. The average TDS and specific conductivity measurements were 327 mg/L and 590 µmhos/cm, respectively. Average total phosphorus and total nitrogen concentrations were 0.017 mg/L and 1.575 mg/L, respectively.

Table 1. Statistical Summary of Pelican Lake's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	276	255	301	18.9
Total Ammonia as N	mg/L	4	0.066	0.010[1]	0.226	0.107
Bicarbonate (HCO_3)	mg/L	4	319	295	368	33.1
Calcium (Ca)	mg/L	4	31.1	27.9	36.6	3.9
Carbonate (CO_3)	mg/L	4	9	1[1]	15	5.9
Chloride (Cl)	mg/L	4	4.5	4.0[1]	5.3	0.5
Chlorophyll-a	µg/L	3	5.9	3.7	8.0	2.2
Specific Conductance	µmhos	4	590	549	651	43
Total Dissolved Solids	mg/L	4	327	306	358	22
Total Hardness as ($CaCO_3$)	mg/L	4	292	276	323	21
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0.0
Iron (Fe)	mg/L	4	0.062	0.022	0.111	0.041
Magnesium (Mg)	mg/L	4	51.9	49.7	56.2	2.9
Nitrate + Nitrite as N	mg/L	4	0.043	0.020	0.110	0.045
Total Kjeldahl Nitrogen as N	mg/L	4	1.533	1.350	1.830	0.207
Total Nitrogen as N	mg/L	4	1.575	1.370	1.940	0.251
pH		4	8.4	8.0	8.7	0.27
Total Phosphorus as P	mg/L	4	0.017	0.010[1]	0.030	0.009
Potassium (K)	mg/L	4	16	14	17	1.4
Sodium (Na)	mg/L	4	7.4	6.8	8.2	0.6
Sulfate (SO4)	mg/L	4	49	47	51	1.8

[1]Equal to Minimum Reportable Limit

While not conclusive, there does appear to be an improving trend in Pelican Lake's water quality. Total phosphorus concentrations have declined over the historical average by 61 percent and dissolved solids between two and 23 percent (Table 2).

Water quality data collected in 2005 was compared to the state's long term data set for natural and enhanced lakes in cultivated plains ecological region. When compared to other lakes in the same ecological region, Pelican Lake has fewer nutrients and dissolved solids then the average (Tables 3).

Table 2. Statistical Summary of Pelican Lake's Historical Water Quality Data Collected Between 1995 and 1996.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	293	268	330	32.6
Total Ammonia as N	mg/L	3	0.136	0.015	0.364	0.197
Bicarbonate (HCO_3)	mg/L	3	337	295	403	58
Calcium (Ca)	mg/L	3	32	29.6	35.7	3.07
Carbonate (CO_3)	mg/L	3	11	1[1]	16	8.3
Chloride (Cl)	mg/L	3	4.5	3.8	6.0	1.27
Chlorophyll-a	µg/L	1	3[1]	3[1]	3[1]	0.0
Specific Conductance	µmhos	3	655	602	731	67.7
Total Dissolved Solids	mg/L	3	359	335	405	39.8
Total Hardness as ($CaCO_3$)	mg/L	3	321	297	344	23.5
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0.0
Iron (Fe)	mg/L	3	0.032	0.016	0.052	0.018
Magnesium (Mg)	mg/L	3	58.2	54.2	61.8	3.8
Nitrate + Nitrite as N	mg/L	1	0.210	0.210	0.210	0.0
Total Kjeldahl Nitrogen as N	mg/L	3	1.940	1.720	2.270	0.291
Total Nitrogen as N	mg/L	3	2.072	1.735	2.634	0.487
pH		3	8.4	8.0	8.6	0.33
Total Phosphorus as P	mg/L	3	0.051	0.034	0.071	0.019
Potassium (K)	mg/L	3	16.6	15.2	18.1	1.4
Sodium (Na)	mg/L	3	7.1	6.5	7.9	0.7
Sulfate (SO4)	mg/L	3	62	55	74	10

[1]Equal to Minimum Reportable Limit

Pelican Lake's average total phosphorus concentration of 0.017 mg/L is less then a quarter of the average concentration of lakes in the cultivated plains ecological region while the average concentration of total nitrogen is approximately equal. Dissolved solids were lower in Pelican Lake then the state's long term average for natural lakes in the Cultivated Plains ecological region with the total dissolved solids concentration being more then three fold less then the ecoregion's average.

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Pelican Lake and that the ratio of total nitrogen to total phosphorus (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There are seven water quality sample sets for Pelican Lake collected between June 1995 and January 2006, where the N:P ratio could be calculated. The seven samples used in this interpretation indicate that Pelican Lake is phosphorus limited, and that the nutrient relationships are dynamic and variable depending on the time of the year and the natural processes occurring at the time of sampling (Figure 5).

Table 3. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lake's in the Cultivated Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	142	346	175	1120	180
Total Ammonia as N	mg/L	230	0.098	0.001[1]	1.620	0.208
Bicarbonate (HCO_3)	mg/L	142	363	171	1040	158
Calcium (Ca)	mg/L	142	45	16	108	23
Carbonate (CO_3)	mg/L	136	31	1[1]	181	39
Chloride (Cl)	mg/L	142	105	3[1]	1260	233
Chlorophyll-a	µg/L	185	10	2[1]	167	17
Specific Conductance	µmhos	161	1819	361	11500	2071
Total Dissolved Solids	mg/L	143	1376	191	9880	1786
Total Hardness as ($CaCO_3$)	mg/L	142	507	173	1820	284
Hydroxide (OH)	mg/L	111	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	138	0.095[1]	0.007	1.010	0.123
Magnesium (Mg)	mg/L	142	95.7	28.4	413.0	68.0
Nitrate + Nitrite as N	mg/L	175	0.047	0.001	0.540	0.078
Total Kjeldahl Nitrogen as N	mg/L	128	1.504	0.080	4.110	0.609
Total Nitrogen as N	mg/L	103	1.440	0.609	2.740	0.466
pH		142	8.55	7.75	9.33	0.36
Total Phosphorus as P	mg/L	230	0.068	0.004[1]	1.460	0.118
Potassium (K)	mg/L	142	30	8	179	37
Sodium (Na)	mg/L	142	255	5	2570	498
Sulfate (SO4)	mg/L	142	591	7	3880	807

[1]Equal to lower detection limit
[2]Data Collected from 49 Natural Lakes between 1991 and 2007

The nitrogen to phosphorus ratio for Pelican Lake ranged from a low of 26 to a high of 151 with an average of 80. All seven samples collected were above an N:P ratio of 15 indicating phosphorus is limiting primary production.

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected from 2005 to 2006, Pelican Lake's current trophic status is mesotrophic (Figure 6). TSI scores ranged from a low of 37 to a high of 52 based on total phosphorus measurements. The trophic status scores based on chlorophyll-a and Secchi disk transparency were similar to that estimated by total phosphorus, at 51 for chlorophyll-a and 48 for Secchi disk transparency, respectively (Figure 6).

A total of seven total phosphorus samples, four chlorophyll-a samples, and five Secchi disk measurements were used in this interpretation. Since Pelican Lake is phosphorus limited all three indicators chlorophyll-a, Secchi disk transparency, and total phosphorus are possibly good indicators of trophic status. Based on a visual assessment, Pelican Lake's trophic status is stable (Figure 6).

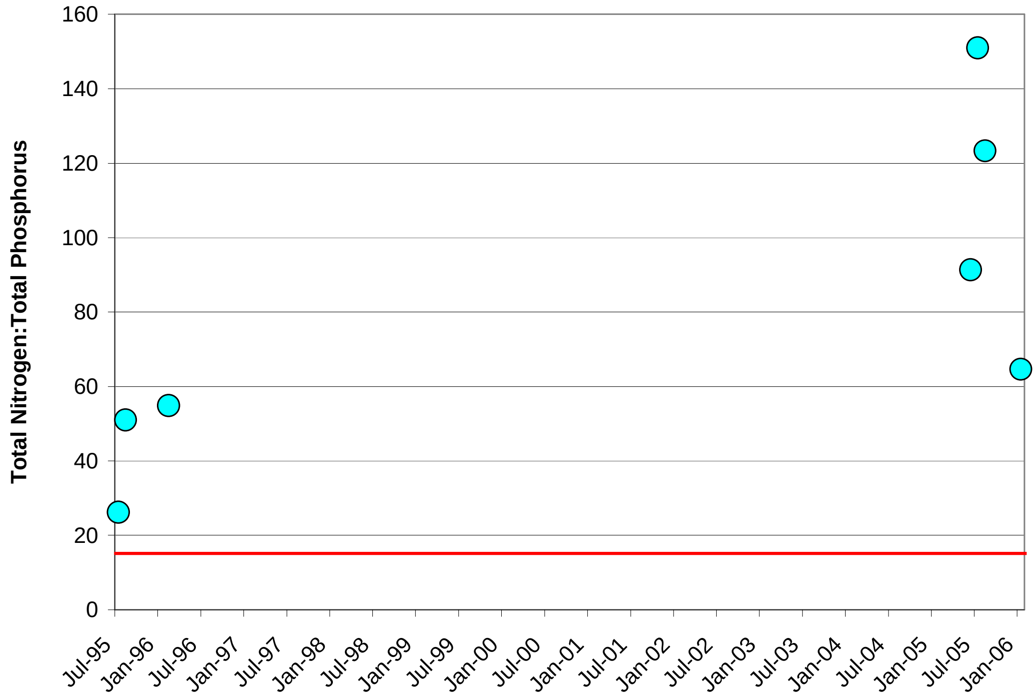


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Pelican Lake (1995-2006).

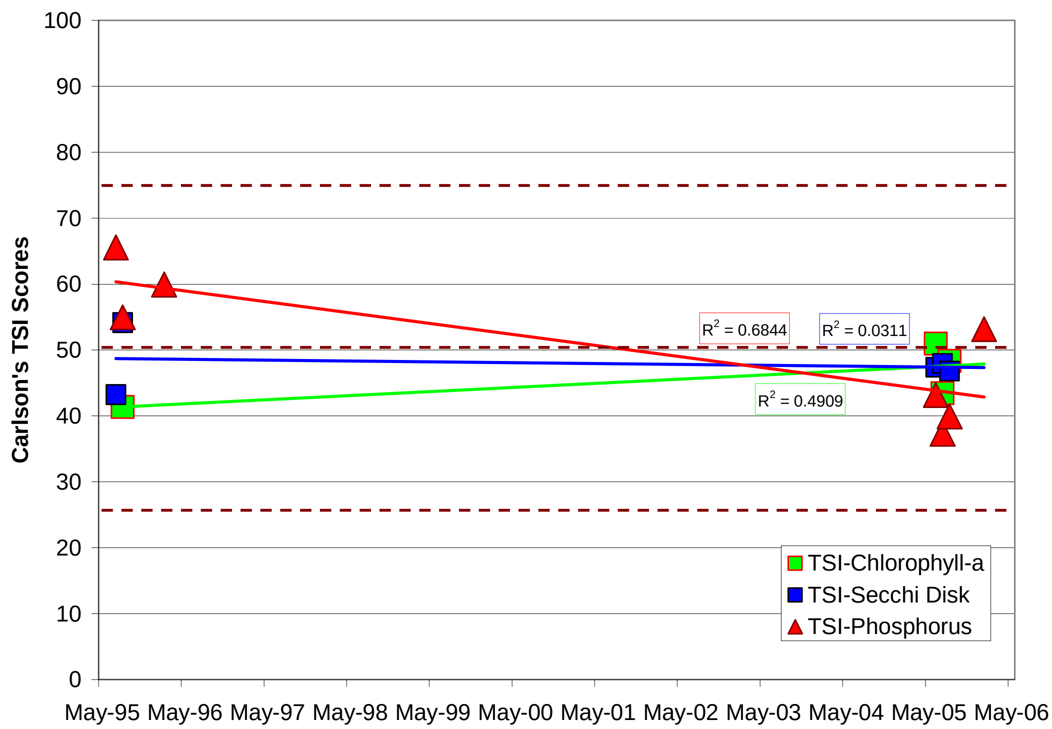


Figure 6. TSI Scores and Temporal Trends for Pelican Lake from 1995-2006.

Strawberry Lake, Bottineau County

BACKGROUND

Location: Strawberry Lake is on the western edge of the Turtle Mountains near the United States - Canada border in Bottineau County, North Dakota. Directions to Strawberry Lake from the town of Carbury, North Dakota are 4 miles north, 2 and 1 half miles east, and a ½ of a mile south (Figure 1).

Figure 1. Location of Strawberry Lake.

Physiographic/Ecological Setting: Strawberry Lake is a 31.8 acre natural lake with a maximum depth of 16 feet and a mean depth of 8.1 feet (Figure 2). Strawberry Lake lies in the Turtle Mountains and the Northern Glaciated Plains Level III Ecoregion, part of the broader Cultivated Plains region (Figure 1). The Turtle Mountains are a tree covered hilly area that rises rapidly above the plains in reliefs of 300 to 500 feet. The Northern Glaciated Plains Ecological region is characterized by flat to rolling landscape composed of glacial drift (USEPA 1994). This region is the transitional zone between tall and mixed grass prairie. The region has numerous wetlands essential for spring and fall migrations of wetland dependent birds. Flood plain slopes and hillsides are usually native grass while the uplands and flood plains proper have mostly been converted to small grains, row crops and alfalfa.

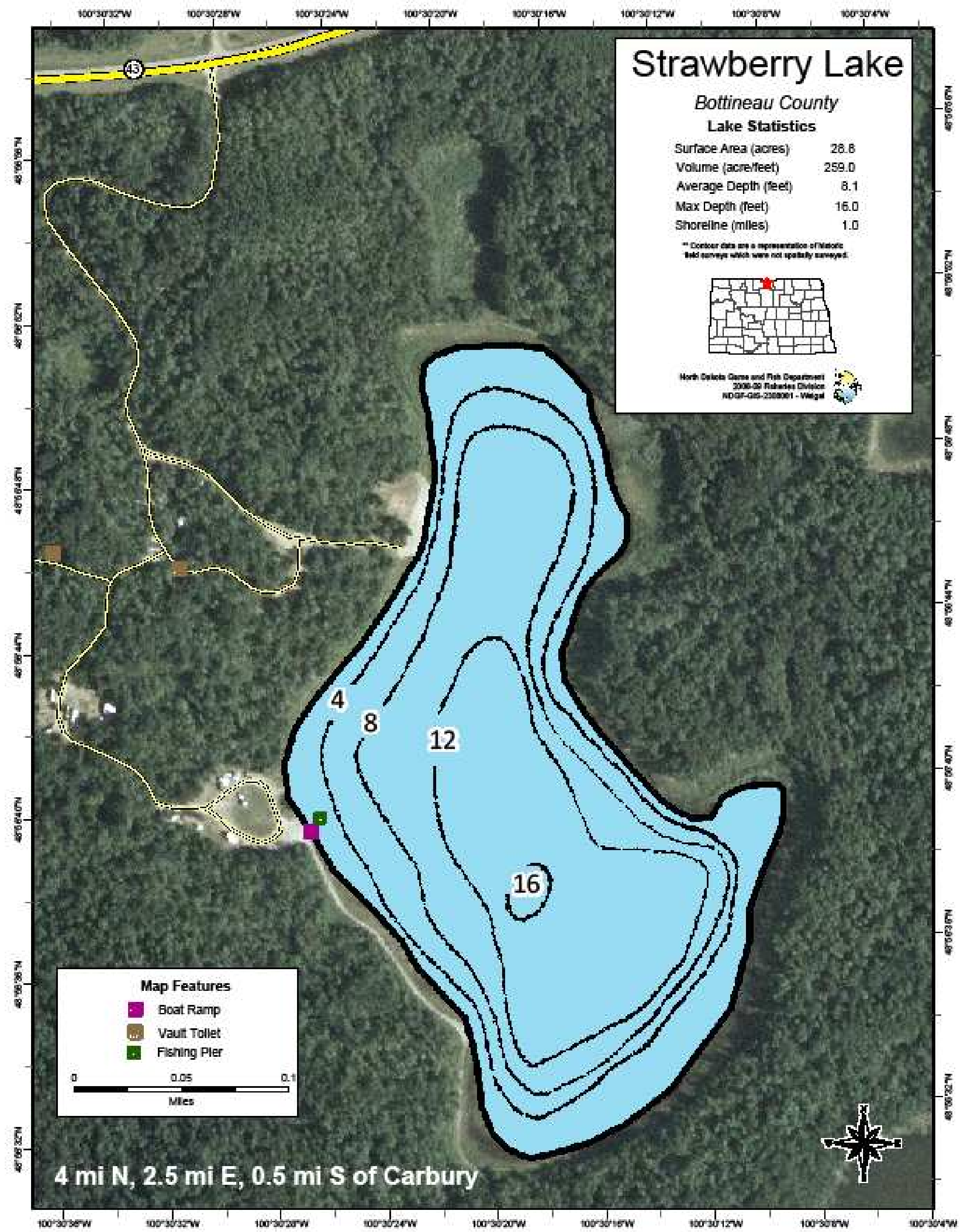


Figure 2. Contour Map of Strawberry Lake (Map Courtesy of North Dakota Game and Fish Department).

Recreational Facilities: Strawberry Lake enjoys four-seasons of recreation. Public access is on the northwest shore with a boat ramp, parking, vault toilet, swimming beach, fishing pier, camping, equestrian, and a picnic area. Boats are restricted to electric motors only.

Water Quality Standards Classification: Strawberry Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2007) as a class 2 lake. Class 2 Lakes and reservoirs are defined as "Cool Water Fisheries" or "waters capable of supporting natural reproduction and growth of cool water fishes (e. g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: Strawberry Lake's current and historical fishery is rainbow trout.

Historical Water Quality Sampling: Strawberry Lake has three historical water quality sample results collected in 1995-1996.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Strawberry Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural and enhanced lakes in the Cultivated Plains region.

Temperature and Dissolved Oxygen Profile Results: There were five temperature and dissolved oxygen profiles for Strawberry Lake collected in two clusters between 1995-1996 and 2005-2006 (Figures 3 and 4). The profile data indicates that Strawberry Lake loses depth during droughts and is often thermally stratified during the summer months. The profile data also indicates that Strawberry Lake experiences dissolved oxygen decay during periods of thermal stratification and under ice cover condition. Of the five profiles collected, three dipped below the state standard of 5 mg/L when approaching the sediment-water interface, and one collected on February 20, 1996 was consistently below.

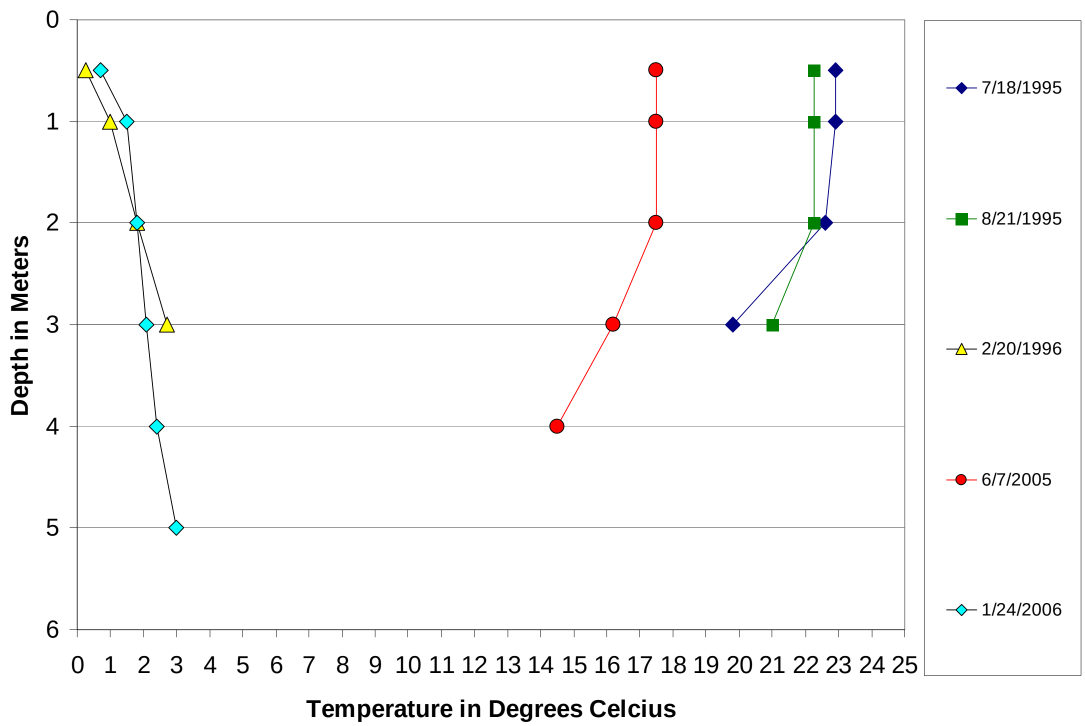


Figure 3. Strawberry Lake's Temperature Profiles From 1995 to 2006.

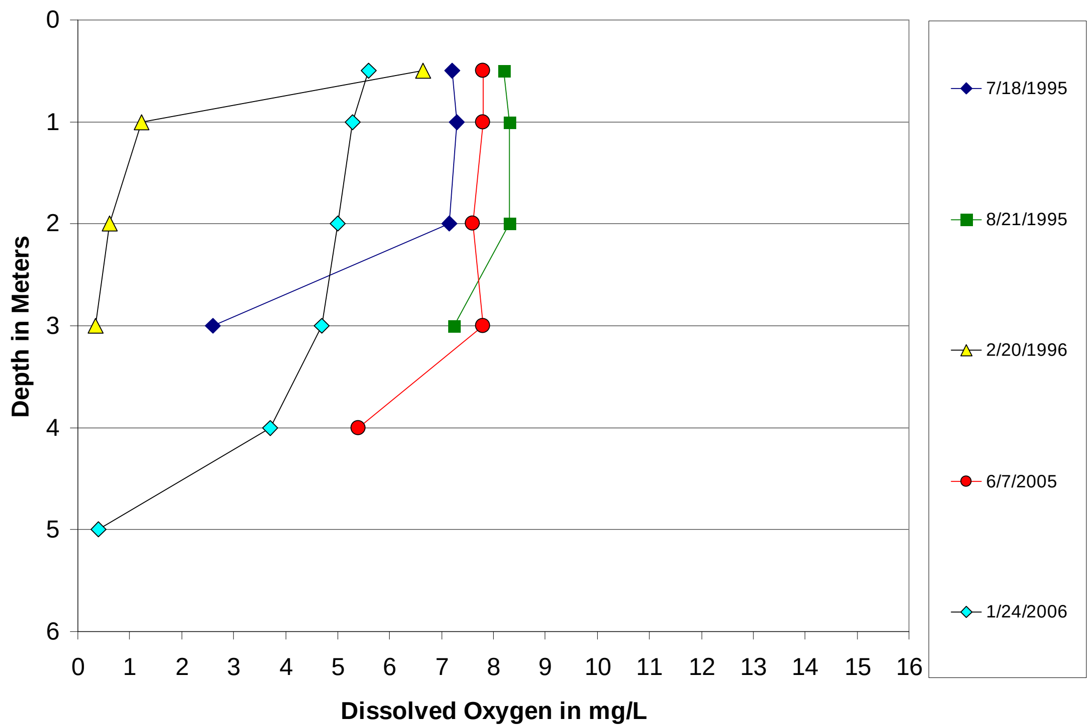


Figure 4. Strawberry Lake's Dissolved Oxygen Profiles From 1995 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005 and 2006 indicates Strawberry Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 422 to 461 mg/L (Table 1). Strawberry Lake is sodium sulfate dominated with an average sulfate concentration of 708 mg/L and an average sodium concentration of 33.8 mg/L. The average TDS and specific conductivity measurements were 1075 mg/L and 1850 µmhos/cm, respectively. Average total phosphorus and total nitrogen concentrations were 0.024 mg/L and 2.250 mg/L, respectively.

Table 1. Statistical Summary of Strawberry Lake's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	2	441	422	461	27.6
Total Ammonia as N	mg/L	2	0.472	0.010[1]	0.933	0.653
Bicarbonate (HCO_3)	mg/L	2	491	421	562	99.7
Calcium (Ca)	mg/L	2	48.0	38.8	57.2	13.0
Carbonate (CO_3)	mg/L	2	23	1[1]	46	31.8
Chloride (Cl)	mg/L	2	13.8	13.0	14.7	1.2
Chlorophyll-a	µg/L	1	2[1]	2[1]	2[1]	0.0
Specific Conductance	µmhos	2	1850	1780	1920	99
Total Dissolved Solids	mg/L	2	1335	1250	1420	120.2
Total Hardness as ($CaCO_3$)	mg/L	2	1075	1020	1130	77.8
Hydroxide (OH)	mg/L	2	1[1]	1[1]	1[1]	0.0
Iron (Fe)	mg/L	2	0.112	0.110	0.113	0.002
Magnesium (Mg)	mg/L	2	233	214	252	26.8
Nitrate + Nitrite as N	mg/L	2	0.020	0.020	0.020	0.000
Total Kjeldahl Nitrogen as N	mg/L	2	2.230	1.740	2.720	0.693
Total Nitrogen as N	mg/L	2	2.250	1.760	2.740	0.693
pH		2	8.430	8.060	8.800	0.523
Total Phosphorus as P	mg/L	2	0.024	0.022	0.025	0.002
Potassium (K)	mg/L	2	32.9	30.4	35.4	3.5
Sodium (Na)	mg/L	2	33.8	31.7	35.9	2.97
Sulfate (SO4)	mg/L	2	708	628	789	113.8

[1]Equal to Minimum Reporting Limit

While not conclusive, there does appear to be an improving trend in Strawberry Lake's water quality. Total phosphorus concentrations have declined over the historical average by 2.5 fold and dissolved solids between 14 and 40 percent (Tables 1 and 2).

Water quality data collected in 2005 was compared to the state's long term data set for natural and enhanced lakes in cultivated plains ecological region. When compared to other lakes in the same ecological region Strawberry Lake's dissolved solids were similar to but slightly elevated over the average, but lower in the crucial nutrient total phosphorus.

Table 2. Statistical Summary of Strawberry Lake's Historical Water Quality Data Collected Between 1995 and 1996.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	521	466	605	73.7
Total Ammonia as N	mg/L	3	0.245	0.010[1]	0.706	0.399
Bicarbonate (HCO_3)	mg/L	3	569	483	704	118.2
Calcium (Ca)	mg/L	3	44.6	43.3	47.2	2.2
Carbonate (CO_3)	mg/L	3	33	17	42	13.892
Chloride (Cl)	mg/L	3	19.0	15.7	23.7	4.1
Chlorophyll-a	µg/L	2	6	4	9	3.5
Specific Conductance	µmhos	3	2580	2360	2880	269.1
Total Dissolved Solids	mg/L	3	2113	1770	2460	345.0
Total Hardness as ($CaCO_3$)	mg/L	3	1606	1460	1820	189
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0.0
Iron (Fe)	mg/L	3	0.021	0.007	0.043	0.019
Magnesium (Mg)	mg/L	3	363	329	413	43.8
Nitrate + Nitrite as N	mg/L	1	0.020	0.020	0.020	0.0
Total Kjeldahl Nitrogen as N	mg/L	3	2.883	2.610	3.380	0.431
Total Nitrogen as N	mg/L	3	3.129	2.630	4.086	0.829
pH		3	8.5	8.3	8.6	0.14
Total Phosphorus as P	mg/L	3	0.060	0.018	0.126	0.058
Potassium (K)	mg/L	3	48.2	44.1	54.2	5.31
Sodium (Na)	mg/L	3	51.3	47.3	57.4	5.3
Sulfate (SO4)	mg/L	3	1273	1010	1500	247.0

[1]Equal to Minimum Reporting Limit

Strawberry Lake's average total phosphorus concentration of 0.024 mg/L is approximately 2½ fold less then the average concentration of lakes in the Cultivated Plains ecological region. Dissolved solids in Strawberry Lake were equal to the state's long term average for natural lakes in the Cultivated Plains ecological region with a total dissolved solid concentration of 1335 mg/L compared to the state's average of 1385 mg/L (Table 3).

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Strawberry Lake, and that the ratio of total nitrogen to total phosphorus (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were five water quality sample sets for Strawberry Lake between June 1995 and January 2006. The five samples used in this interpretation indicate that Strawberry Lake is phosphorus limited, and that the nutrient relationships are dynamic and variable depending on the time of the year and the natural processes occurring at the time of sampling (Figure 5).

Table 3. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lake's in the Cultivated Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	142	346	175	1120	180
Total Ammonia as N	mg/L	230	0.098	0.001[1]	1.620	0.208
Bicarbonate (HCO_3)	mg/L	142	363	171	1040	158
Calcium (Ca)	mg/L	142	45	16	108	23
Carbonate (CO_3)	mg/L	136	31	1[1]	181	39
Chloride (Cl)	mg/L	142	105	3[1]	1260	233
Chlorophyll-a	µg/L	185	10	2[1]	167	17
Specific Conductance	µmhos	161	1819	361	11500	2071
Total Dissolved Solids	mg/L	143	1376	191	9880	1786
Total Hardness as ($CaCO_3$)	mg/L	142	507	173	1820	284
Hydroxide (OH)	mg/L	111	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	138	0.095[1]	0.007	1.010	0.123
Magnesium (Mg)	mg/L	142	95.7	28.4	413.0	68.0
Nitrate + Nitrite as N	mg/L	175	0.047	0.001	0.540	0.078
Total Kjeldahl Nitrogen as N	mg/L	128	1.504	0.080	4.110	0.609
Total Nitrogen as N	mg/L	103	1.440	0.609	2.740	0.466
pH		142	8.55	7.75	9.33	0.36
Total Phosphorus as P	mg/L	230	0.068	0.004[1]	1.460	0.118
Potassium (K)	mg/L	142	30	8	179	37
Sodium (Na)	mg/L	142	255	5	2570	498
Sulfate (SO4)	mg/L	142	591	7	3880	807

[1]Equal to lower detection limit
[2]Data Collected from 49 Natural Lakes between 1991 and 2007

The nitrogen to phosphorus ratio for Strawberry Lake ranged from a low of 21 to a high of 227 with an average of 103. All five samples collected were above a ratio of 15 indicating phosphorus is limiting primary production.

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected in 2005-2006, Strawberry Lake's current trophic status is mesotrophic. TSI scores ranged from a low of 38 based on chlorophyll-a, to a high of 52 based on Secchi disk transparency. The trophic status score based on total phosphorus was similar to that estimated by Secchi disk transparency, at 49 (Figure 6).

A total of five phosphorus samples, three chlorophyll-a samples and three Secchi disk measurements collected between 1995 and 2006 were used to evaluate trends in the trophic status of Strawberry Lake. Since Strawberry Lake is phosphorus limited all three indicators chlorophyll-a, Secchi disk transparency, and total phosphorus are possibly good indicators of trophic status. Based on a visual assessment, Strawberry Lake's trophic status trend is stable or improving (Figure 6).

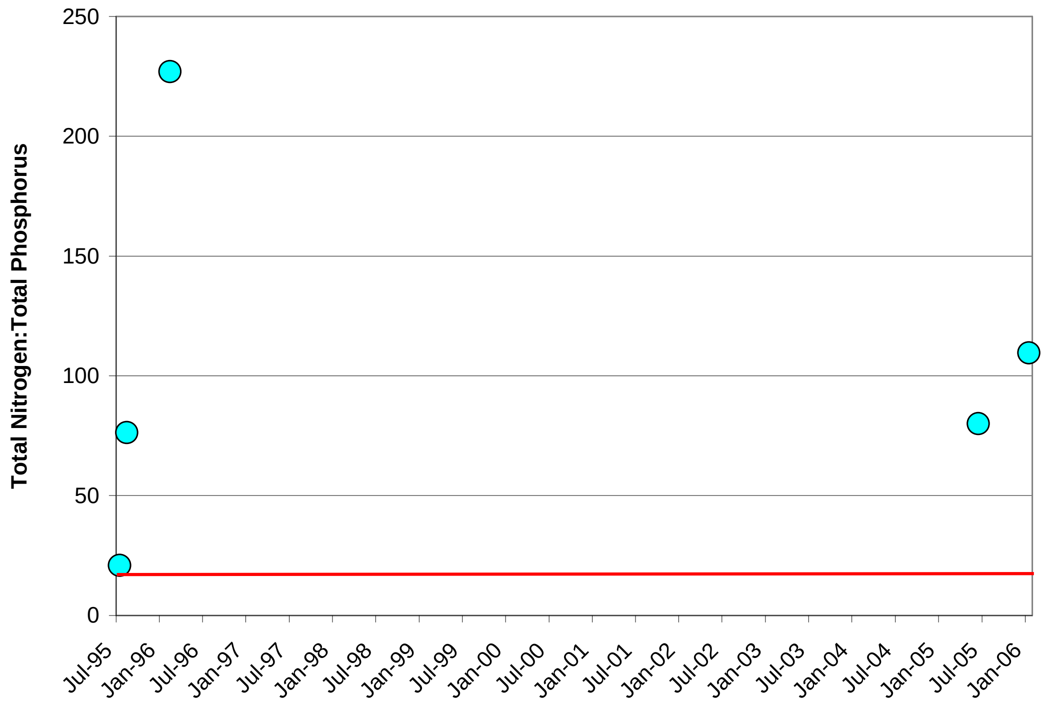


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Strawberry Lake (1995-2006).

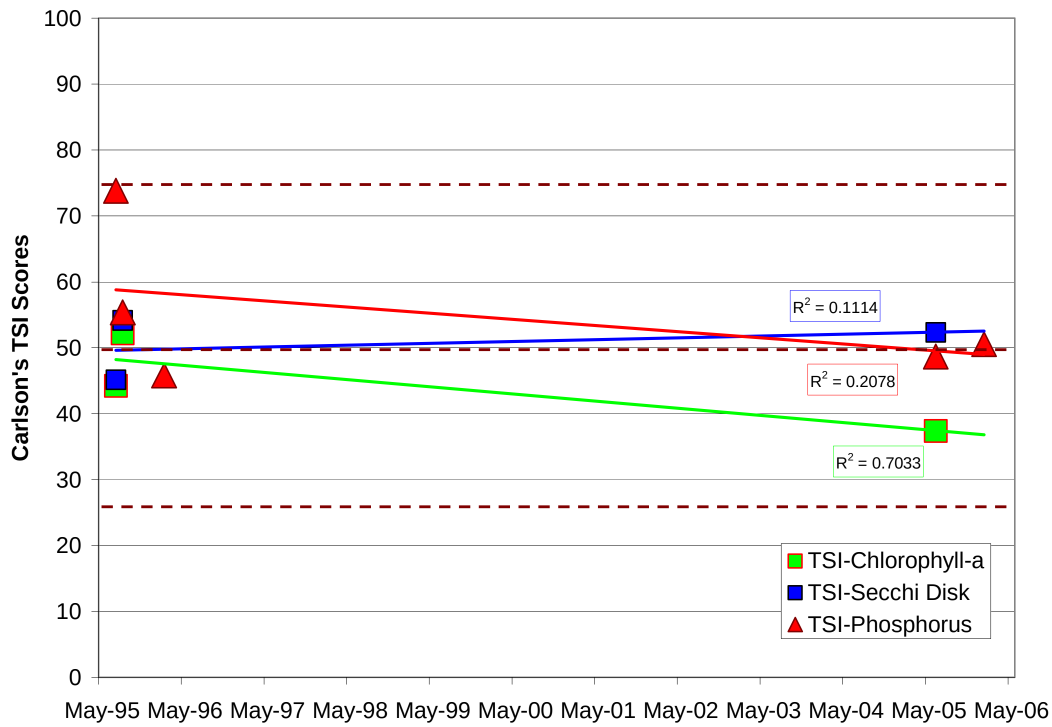


Figure 6. TSI Scores and Temporal Trends for Strawberry Lake 1995 to 2006.

New Johns Lake, Burleigh County

BACKGROUND

Location: New Johns Lake is located in the northeastern corner of Burleigh County, North Dakota. Directions to New Johns Lake from the town of Wilton, North Dakota are: Two miles east, then 11 miles north, and 3 miles east (Figure 1). New Johns Lake is managed by the North Dakota Game and Fish Department and the Bureau of Reclamation.

Figure 1. Location of New Johns Lake.

Physiographic/Ecological Setting: New Johns Lake is a 676 acre enhanced natural lake with a maximum depth of 31 feet and a mean depth of 20 feet (Figure 2). The lake was deepened and kept relatively stable by inflows from the McClusky channel (an irrigation channel) New Johns Lake lies in the Northwestern Great Plains Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The Northwestern Great Plains Ecological region is composed of the Missouri Coteau section of the Great Plains. It is a semiarid hilly region formed by the terminal advance of the last Wisconsin Ice age. The area is characterized by rises of 100 to 350 feet with many glacial lakes, ponds and wetlands at the feet of the rises to form a mosaic of the finest waterfowl resting and rearing area in the world (USEPA 1994).

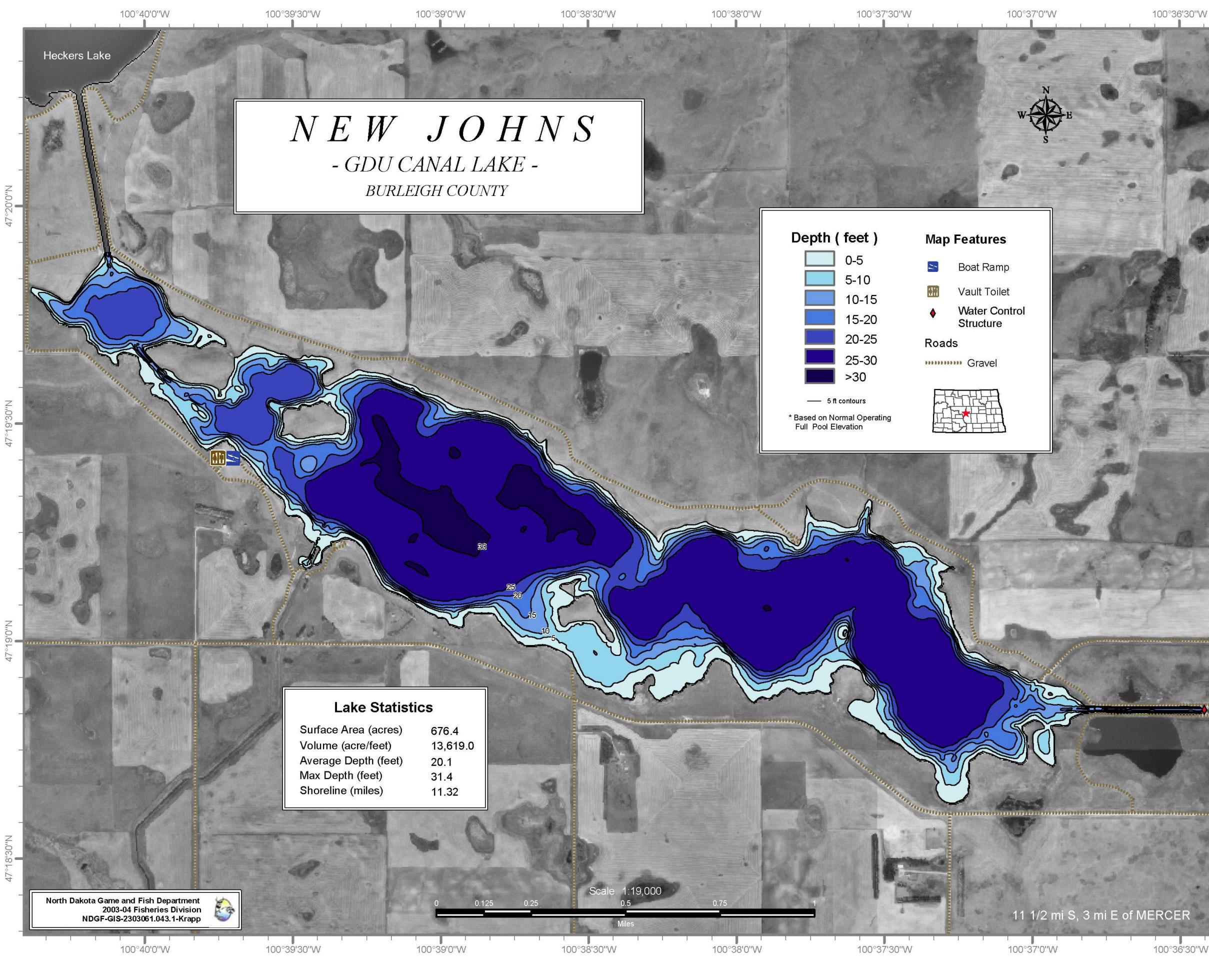


Figure 2. Contour Map of New Johns Lake (Map Courtesy of North Dakota Game and Fish Department).

Construction History: New Johns Lake was formed by enhancing the depth of natural depressions along the McClusky Canal irrigation right of way. Construction was competed in 1984 and since then the lake has been used solely for recreational purposes.

Recreational Facilities: New Johns Lake enjoys four-seasons of recreation. Public access is on the south shore with a boat ramp, parking, vault toilet, picnic area, primitive camping zones, and a fishing pier.

Water Quality Standards Classification: New Johns Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2007) as a class 2 lake. Class 2 Lakes and reservoirs are defined as "Cool Water Fisheries" or "waters capable of supporting natural reproduction and growth of cool water fishes (e. g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: New Johns Lake's has a very diverse fishery with the potential for nearly every species of warm water species present in the state being found in it's waters. An incomplete list of possible fish species are walleye, northern pike, muskellunge tiger muskellunge, small and large mouth bass, crappie, yellow perch bluegill and rainbow trout. Historically fish stocked into New Johns Lake include those listed plus any species already occurring in the Missouri River drainage.

Historical Water Quality Samples: Historical water quality data includes results from three sample sets collected in 1992-1993.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for New Johns Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural and enhanced lakes in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There are seven temperature and dissolved oxygen profiles for New Johns Lake collected in two clusters between 1992-1993 and 2005-2006 (Figures 3 - 4). The profile data indicates that New Johns Lake occasionally thermally stratifies but still maintains consistently high dissolved oxygen concentrations. Of the seven oxygen profiles collected all maintain dissolved oxygen concentrations above the State standard of 5 mg/L with minimal oxygen decay below the metalimnion or ice cover.

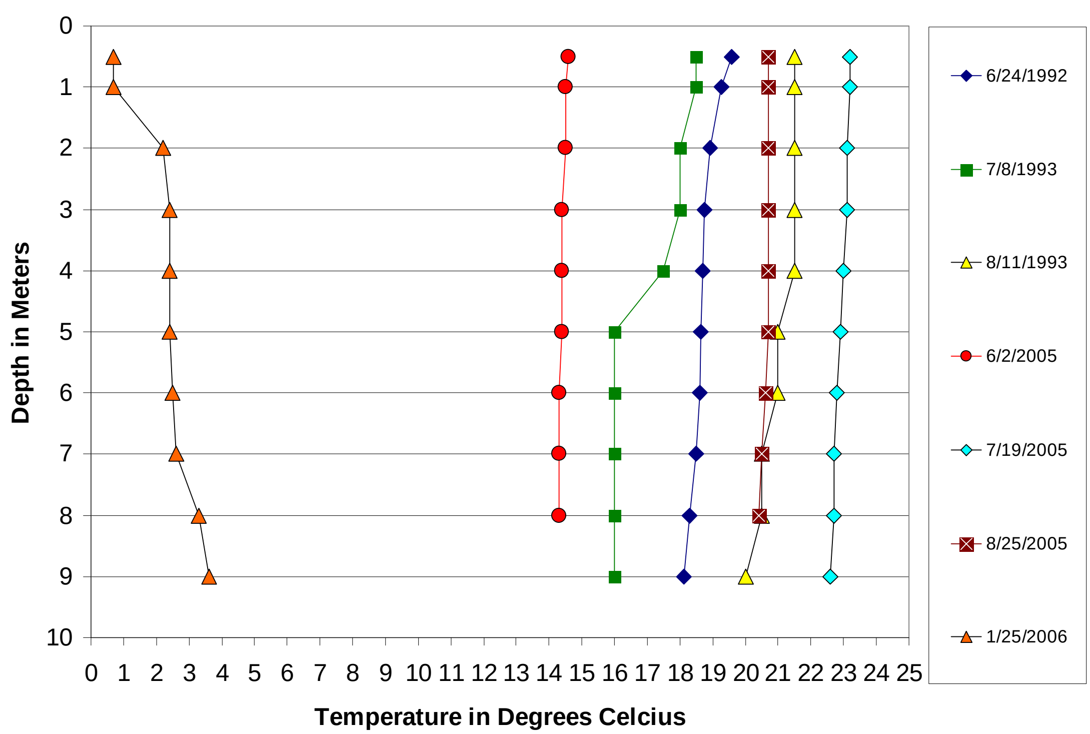


Figure 3. Temperature Profiles for New Johns Lake from 1992 to 2006.

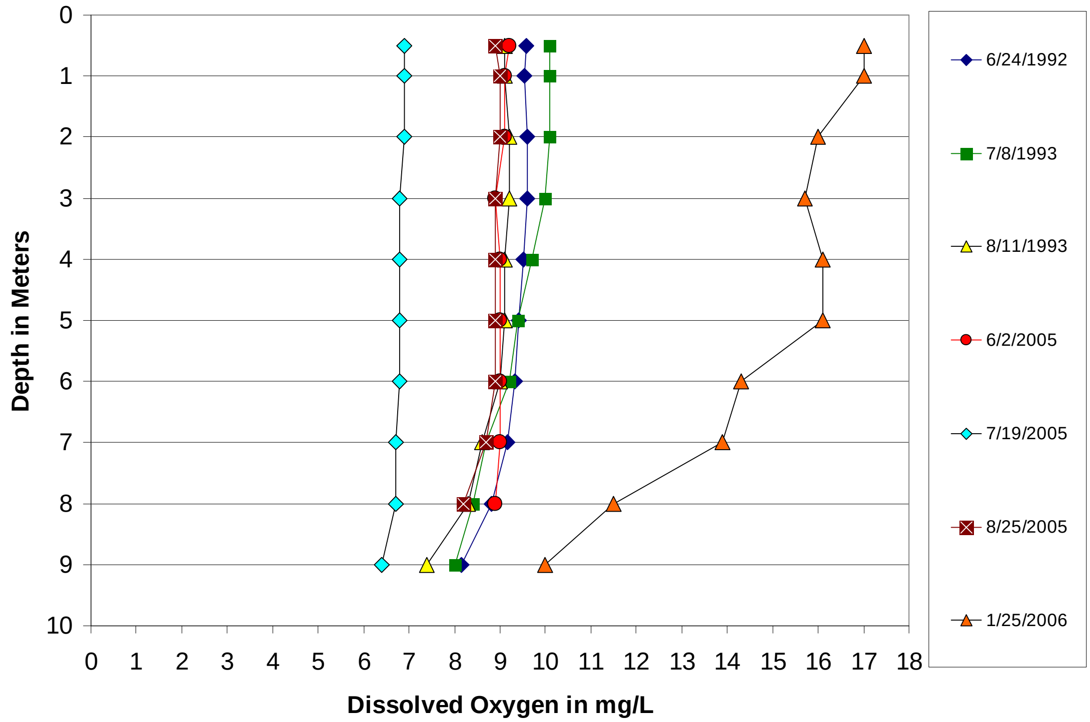


Figure 4. Dissolved Oxygen Profiles for New Johns Lake from 1992 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006, indicates New Johns Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 230 mg/L to 280 mg/L (Table 1). New Johns Lake is sodium sulfate dominated with an average sodium concentration of 174 mg/L and an average sulfate concentration of 718 mg/L.

The average TDS concentration and specific conductance measurements for the 2005-2006 sampling period were 1263 mg/L, and 1760 µmhos/cm, respectively. Average total phosphorus and total nitrogen concentrations were 0.017 mg/L and 0.725 mg/L respectively. Comparing 1992-1993 water quality results with the 2005-2006 show no recognizable trend (Table 2).

Table 1. Statistical Summary of New Johns Lake's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	252	230	280	21
Total Ammonia as N	mg/L	4	0.029	0.010[1]	0.071	0.029
Bicarbonate (HCO_3)	mg/L	4	286	263	325	27
Calcium (Ca)	mg/L	4	81.4	73.4	91.0	7.9
Carbonate (CO_3)	mg/L	4	11	8	13	2
Chloride (Cl)	mg/L	4	18	17	20	1
Chlorophyll-a	µg/L	3	4.0	1.5	8.1	3.6
Specific Conductance	µmhos	4	1760	1660	1890	109
Total Dissolved Solids	mg/L	4	1263	1190	1350	72
Total Hardness as ($CaCO_3$)	mg/L	4	608	565	660	42
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.151	0.055	0.254	0.089
Magnesium (Mg)	mg/L	4	98.2	92.6	105.0	5.3
Nitrate + Nitrite as N	mg/L	4	0.033	0.020	0.070	0.025
Total Kjeldahl Nitrogen as N	mg/L	4	0.692	0.602	0.794	0.082
Total Nitrogen as N	mg/L	4	0.725	0.622	0.864	0.104
pH		4	8.48	8.38	8.53	0.07
Total Phosphorus as P	mg/L	4	0.017	0.009[1]	0.023	0.006
Potassium (K)	mg/L	4	18.8	18.0	19.8	0.7
Sodium (Na)	mg/L	4	174	166	186	9
Sulfate (SO4)	mg/L	4	718	680	760	41

[1]Equal to Minimum Reporting Limit

Water quality data collected in 2005-2006 was compared to the state's long term data set for natural and enhanced lakes in the Rangeland Plains ecological region. When compared to other lakes in the same ecological region New Johns Lake is slightly fresher then average with lower then average nutrient concentrations (Tables 1 and 3).

New Johns Lake's historical average total phosphorus concentrations of 0.024 mg/L is less than one-half of the average lake in the cultivated plains ecological region while the average concentration of total nitrogen concentration of 1.148 mg/L is about 30% less. At 1236 mg/L total dissolved solids were close to the Rangeland Plains regional average of 1819 mg/L but like most of the dissolved solids and icp metals it is 10 to 20 percent less.

Table 2. Statistical Summary of New Johns Lake's Historical Water Quality Data Collected Between 1992 and 1993.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	245	223	276	27.6
Total Ammonia as N	mg/L	3	0.058	0.013	0.142	0.073
Bicarbonate (HCO_3)	mg/L	3	278	236	337	52.4
Calcium (Ca)	mg/L	3	55.6	48.9	63.6	7.8
Carbonate (CO_3)	mg/L	3	10.6	1[1]	18	8.7
Chloride (Cl)	mg/L	3	17.8	17.2	19.2	1.2
Chlorophyll-a	µg/L	2	3.5	3.0[1]	4.0	0.71
Specific Conductance	µmhos	3	1237	1140.	1350	105.9
Total Dissolved Solids	mg/L	3	794	754	870	65.8
Total Hardness as ($CaCO_3$)	mg/L	3	360	335	391	28.5
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0.0
Iron (Fe)	mg/L	3	0.058	0.045	0.072	0.014
Magnesium (Mg)	mg/L	3	54.3	51.8	56.5	2.3
Nitrate + Nitrite as N	mg/L	3	0.013	0.005[1]	0.021	0.008
Total Kjeldahl Nitrogen as N	mg/L	3	1.090	0.676	1.870	0.676
Total Nitrogen as N	mg/L	3	1.148	0.691	2.012	0.749
pH		3	8.4	8.1	8.6	0.25
Total Phosphorus as P	mg/L	3	0.024	0.004[1]	0.039	0.018
Potassium (K)	mg/L	3	9.4	9.2	9.7	0.25
Sodium (Na)	mg/L	3	125	125	127	1.15
Sulfate (SO4)	mg/L	3	383	351	428	40.1

[1]Equal to Minimum Reporting Limit

Limiting Nutrient: The limiting nutrient is assessed based on the assumption that either nitrogen or phosphorus is limiting algal growth in New Johns Lake, and that the ratio of total nitrogen to total phosphorus (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There are seven water quality sample sets for New Johns Lake between July 1993 and January 2006. The seven samples used in this interpretation indicate that New Johns Lake is phosphorus limited (Figure 5).

The nitrogen to phosphorus ratio for New Johns Lake ranged from a low of 19 to a high of 174 with an average of 65. All seven samples collected were above a ratio of 15 indicating phosphorus is limiting primary production.

Table 3. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lake's in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	272	544	119	4770	130
Total Ammonia as N	mg/L	371	0.107	0.001[1]	2.230	0.200
Bicarbonate (HCO_3)	mg/L	272	489	145	2990	150
Calcium (Ca)	mg/L	272	44	1[1]	282	26
Carbonate (CO_3)	mg/L	262	89	1[1]	1420	30
Chloride (Cl)	mg/L	272	51	4[1]	1070	9
Chlorophyll-a	µg/L	250	22	2[1]	292	28
Specific Conductance	µmhos	272	2168	448	20100	959
Total Dissolved Solids	mg/L	272	1588	227	18200	750
Total Hardness as ($CaCO_3$)	mg/L	272	538	170	2370	260
Hydroxide (OH)	mg/L	200	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	273	0.193	0.001[1]	2.260	0.334
Magnesium (Mg)	mg/L	272	104	20	567	50
Nitrate + Nitrite as N	mg/L	332	0.036	0.002[1]	0.338	0.092
Total Kjeldahl Nitrogen as N	mg/L	340	1.950	0.080	8.500	0.779
Total Nitrogen as N	mg/L	278	1.826	0.269	5.520	0.562
pH		272	8.80	7.40	9.87	0.56
Total Phosphorus as P	mg/L	377	0.244	0.004[1]	1.940	0.205
Potassium (K)	mg/L	272	38	3[1]	356	6
Sodium (Na)	mg/L	272	331	17	4680	171
Sulfate (SO4)	mg/L	272	680	34	10500	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 48 Natural and Enhanced Lakes Between 1991 and 2007

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005-2006, New Johns Lake's current trophic status is mesotrophic. TSI scores ranged from a low of 35 based on chlorophyll-a, to a high of 55 based on Secchi disk transparency. The trophic score based on total phosphorus was similar to that estimated by Secchi disk transparency, at 49 (Figure 6).

A total of seven phosphorus samples, five cholorphyll-a samples and five Secchi disk measurements were used in this interpretation. Since New Johns Lake is phosphorus limited all three indicators chlorophyll-a, Secchi disk, and total phosphorus are possibly good indicators of trophic status. Based on a visual assessment, the trophic status of New Johns Lake is stable (Figure 6).

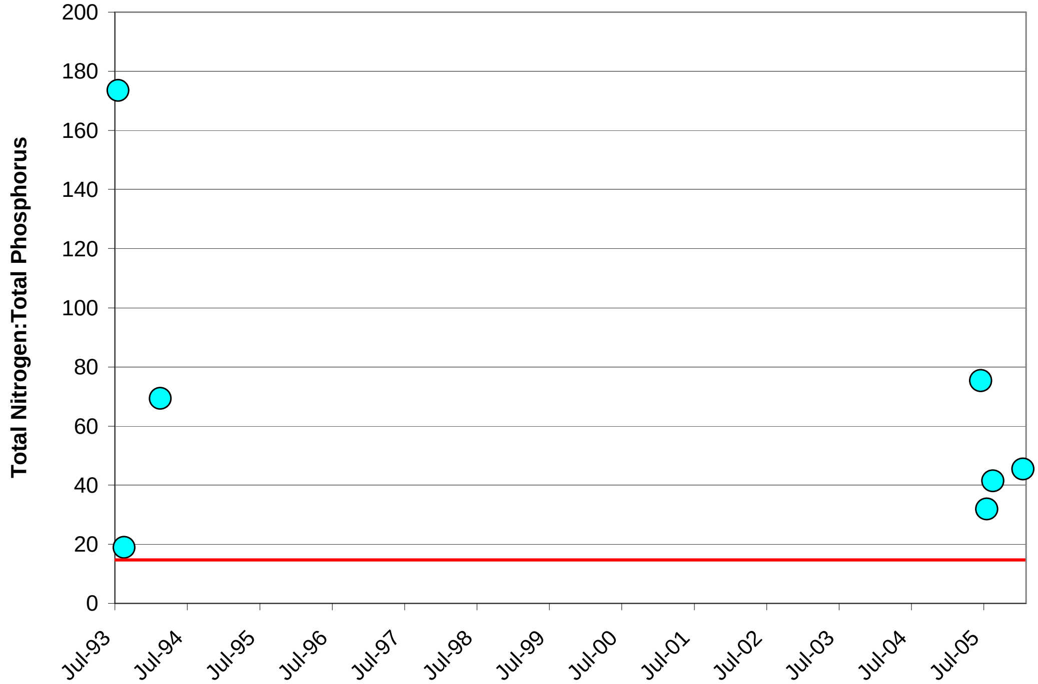


Figure 5. Total Nitrogen to Total Phosphorus Ratios in New Johns Lake (1993-2006).

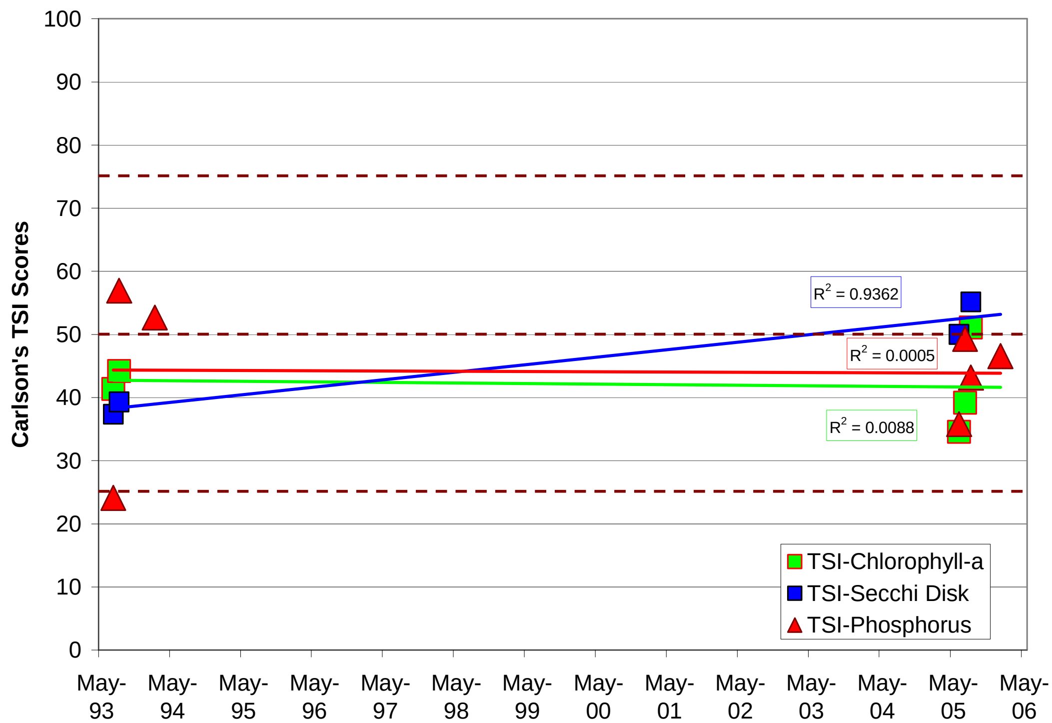


Figure 6. TSI Scores and Temporal Trends for New Johns Lake from 1993-2006.

Mount Carmel Dam, Cavalier County

BACKGROUND

Location: Mt. Carmel Dam is located in the very northeastern corner of North Dakota in Cavalier County. Directions to Mt. Carmel Dam from the town of Langdon, North Dakota are: Nine miles north, then 2 miles east, and 2 miles north (Figure 1). Mt. Carmel Dam is managed by the North Dakota Game and Fish Department.

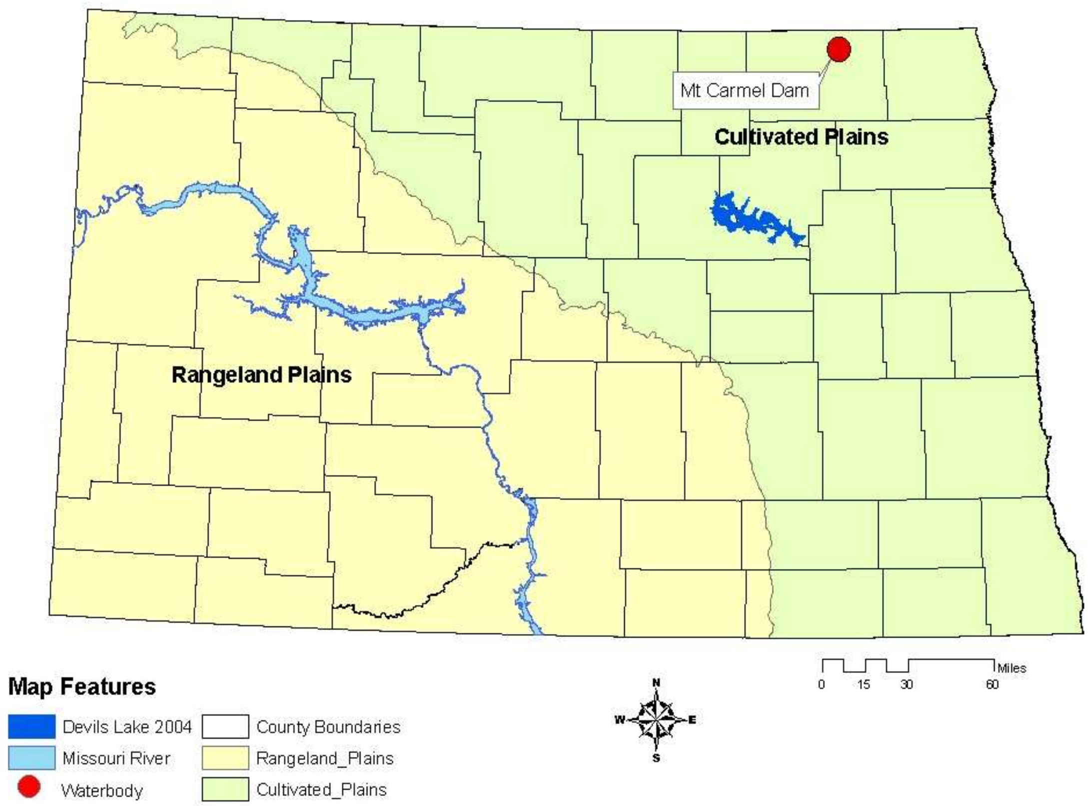


Figure 1. Location of Mt. Carmel Dam.

Physiographic/Ecological Setting: Mt. Carmel Dam is a 342.1 acre reservoir with a maximum depth of 32.6 feet and a mean depth of 14.1 feet (Figure 2). Mt. Carmel Dam lies in the Northern Glaciated Plains Level III Ecoregion, part of the broader Cultivated Plains region (Figure 1). The Northern Glaciated Plains Ecological region is characterized by flat to rolling landscape composed of glacial drift (USEPA 1994). This region is the transitional zone between tall and mixed grass prairie. The region has numerous wetlands essential for spring and fall migrations of wetland dependent birds. Flood plain slopes and hillsides are usually native grass, while the uplands and flood plains proper have mostly been converted to small grains, row crops, and alfalfa.

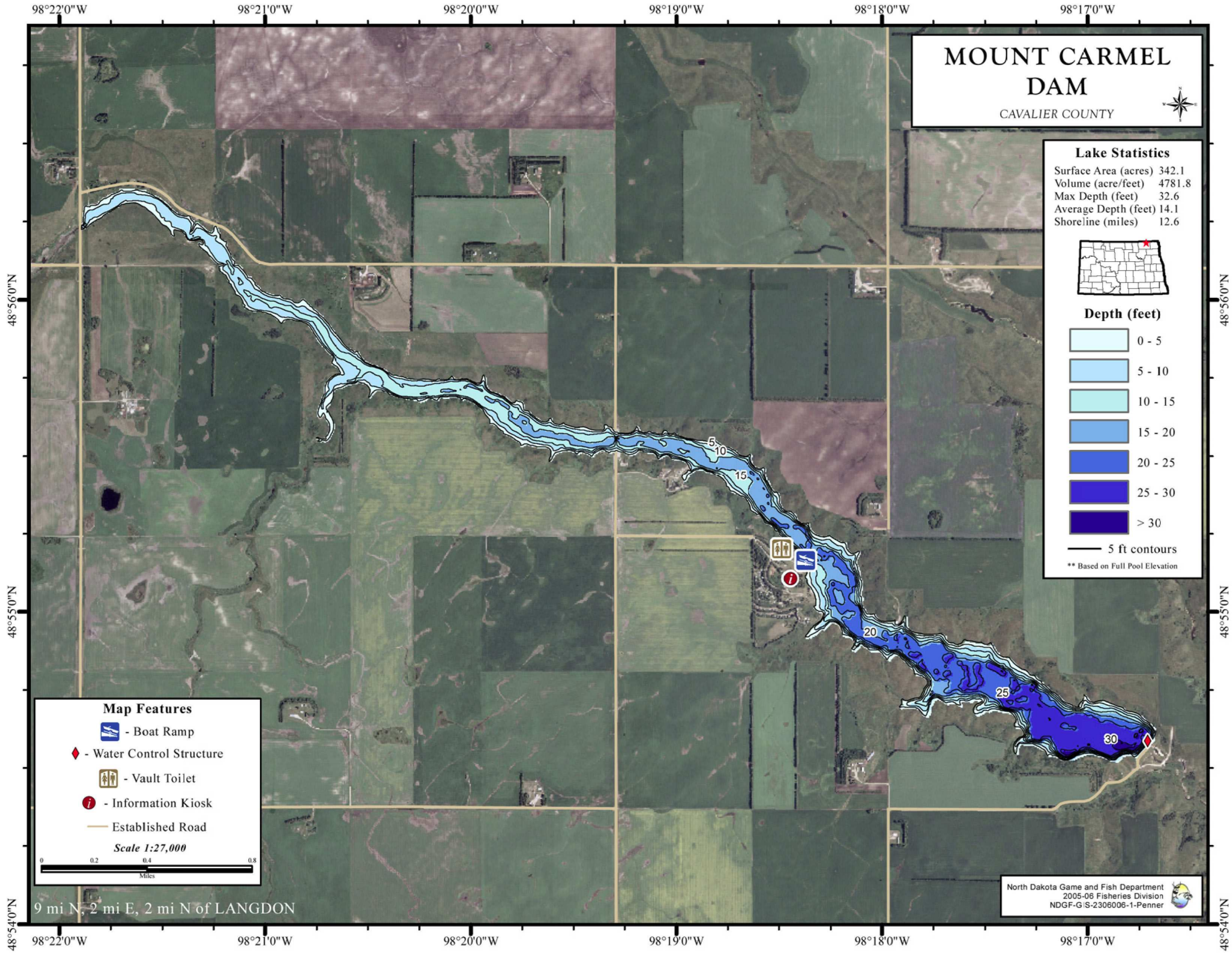


Figure 2. Contour Map of Mt. Carmel Dam (Map Courtesy of North Dakota Game and Fish Department).

Construction History: Mt. Carmel Dam is a rolled earth structure completed in 1971 that blocks a stream bed that has cut through the glacial till to the underlying shale. The reservoir was constructed for flood control, the city of Langdon water supply, recreational use and wild life propagation.

Recreational Facilities: Mt. Carmel Dam enjoys four-seasons of recreation. Public access is on the south shore with a boat ramp, parking, vault toilet, a picnic area, primitive camping zones, and a fishing pier.

Water Quality Standards Classification: Mt Carmel Dam is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2007) as a class 2 lake. Class 2 Lakes and reservoirs are defined as "Cool Water Fisheries" or "waters capable of supporting natural reproduction and growth of cool water fishes (e. g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: Mt. Carmel Dam Lake's fishery is northern pike, walleye, and yellow perch with seasonal restrictions. Historical fish stocked into Mt. Carmel Dam include northern pike, walleye, yellow perch, rainbow trout, bluegill, and crappie.

Historical Water Quality Sampling: Historical water quality data includes results from five historical water quality sample results collected between 1991 and 1997.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Mt. Carmel Dam have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Cultivated Plains ecological region.

Temperature and Dissolved Oxygen Profile Results: There are eight temperature and dissolved oxygen profiles collected on Mt. Carmel Dam in three clusters of 1991 and between 1996-1997 and 2005-2006 (Figures 3 through 4). The profile data indicates that Mt. Carmel Dam is usually not thermally stratified during the summer months but does thermally stratifies in late winter. Of the eight profiles, four, collected on 3/27/1991, 7/16/1996, 3/11/1997, and 1/31/2006, dropped below the state standard of 5 mg/L. When Mt. Carmel Dam is not stratified it maintains concentrations of dissolved oxygen concentrations above the state standard of 5 mg/L, but when stratified experiences moderate dissolved oxygen decay below the metalimnion.

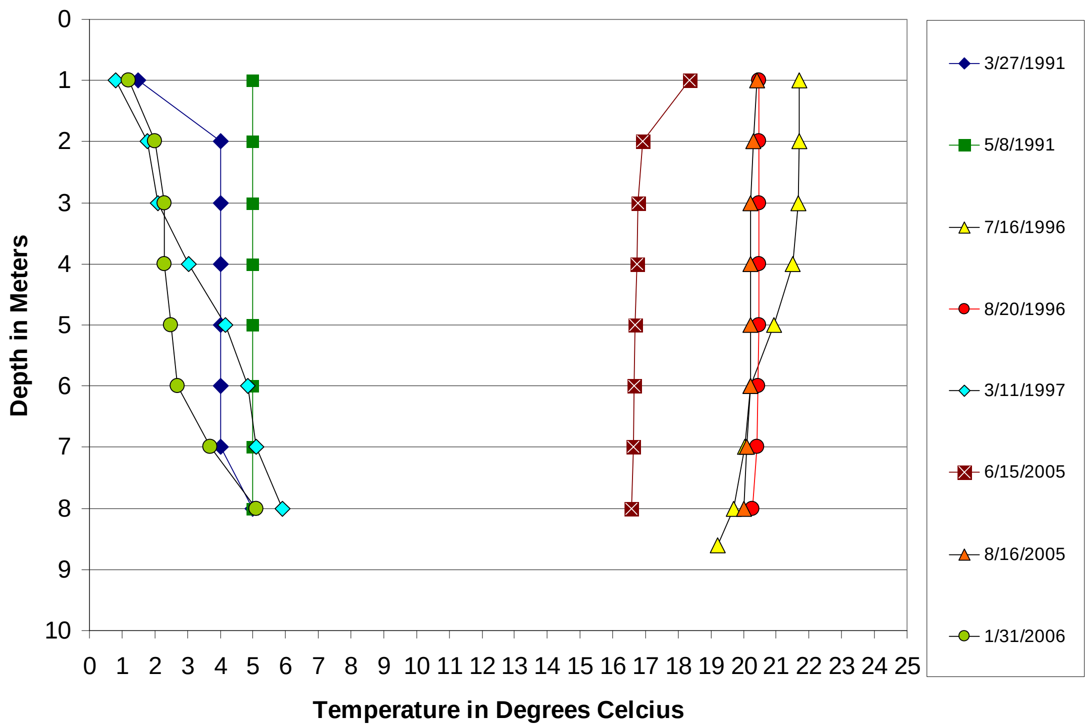


Figure 3. Temperature Profiles for Mt. Carmel Dam from 1991 to 2006.

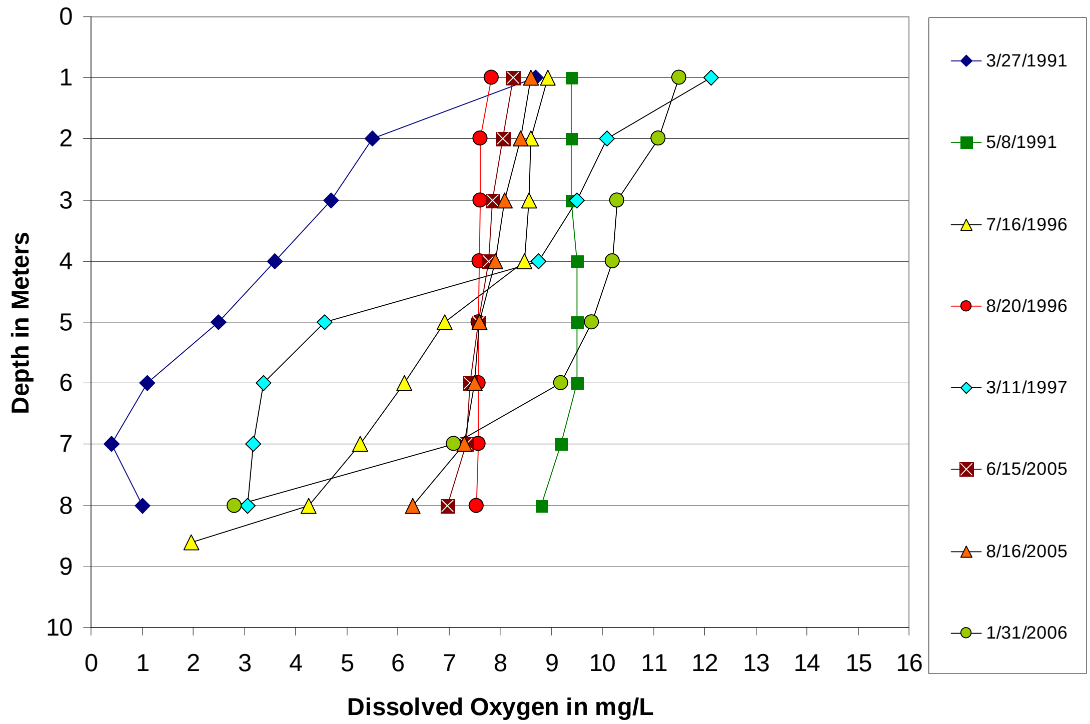


Figure 4. Dissolved Oxygen Profiles for Mt. Carmel Dam from 1991 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005 and 2006 indicate Mt. Carmel Dam is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 170 to 208 mg/L (Table 1). Mt. Carmel Dam is sodium bicarbonate dominated with an average sodium concentration of 65 mg/L and an average bicarbonate concentration of 224 mg/L.

The average TDS concentration and specific conductance measurements for the 2005-2006 sampling period were 506 mg/L, and 806 µmhos/cm, respectively. Average total phosphorus and total nitrogen concentrations were 0.753 mg/L and 2.206 mg/L, respectively. Additionally, there does appear to be a trend towards lower concentrations of dissolved solids in Mt. Carmel Dam (Tables 1 and 2).

Water quality data collected in 2005 and 2006 was compared to the state's long term data set for reservoirs in the Cultivated Plains region. In comparison Mt. Carmel Dam's current average concentration for total phosphorus of 0.753 mg/L is about double the average for lakes in the Cultivated Plains ecological region while the average concentration of total nitrogen of 2.207 is only about 50 percent greater. Dissolved solids were below the average at 506 mg/L compared to the regional averages for similar reservoirs of 667 mg/L (Tables 1 and 3).

Table 1. Statistical Summary of Mt. Carmel Dam's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	184	170	208	20.8
Total Ammonia as N	mg/L	3	0.198	0.070	0.275	0.112
Bicarbonate (HCO_3)	mg/L	3	224	207	254	25.5
Calcium (Ca)	mg/L	3	65.	54.4	72.6	10.05
Carbonate (CO_3)	mg/L	3	1[1]	1[1]	1[1]	0.0
Chloride (Cl)	mg/L	3	13.5	9.6	16.5	3.520
Chlorophyll-a	µg/L	2	4.1	1.5[1]	6.7	3.6
Specific Conductance	µmhos	3	806	668	914	125.9
Total Dissolved Solids	mg/L	3	506	421	569	76.7
Total Hardness as ($CaCO_3$)	mg/L	3	264	220	291	38.8
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0.0
Iron (Fe)	mg/L	3	0.111	0.035	0.199	0.083
Magnesium (Mg)	mg/L	3	24.2	20.4	26.6	3.3
Nitrate + Nitrite as N	mg/L	3	0.867	0.340	1.510	0.594
Total Kjeldahl Nitrogen as N	mg/L	3	1.340	1.170	1.550	0.193
Total Nitrogen as N	mg/L	3	2.207	1.640	3.060	0.752
pH		3	8.1	7.9	8.2	0.11
Total Phosphorus as P	mg/L	3	0.753	0.641	0.828	0.099
Potassium (K)	mg/L	3	11.7	9.7	14.1	2.2
Sodium (Na)	mg/L	3	65	54	74	10.3
Sulfate (SO4)	mg/L	3	209	164	240	39.8

[1]Equal to Minimum Reportable Limit

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen, or phosphorus is limiting algal growth in Mt. Carmel Dam, and that the ratio of total nitrogen to total phosphorus (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There are six water quality sample sets for Mt. Carmel Dam between July 1996 and January 2006. The six samples used in this interpretation indicate that Mt. Carmel Dam is nitrogen limited (Figure 5).

The nitrogen to phosphorus ratio for Mt. Carmel Dam ranged from a low of 0.4 to a high of 8 with an average of 4. All six samples collected were below a ratio of 15 indicating nitrogen is limiting primary production.

Table 2. Statistical Summary of Mt. Carmel Dam's Historical Water Quality Data Collected Between 1991 and 1997.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	221	163	311	68.5
Total Ammonia as N	mg/L	4	0.061	0.010[1]	0.197	0.091
Bicarbonate (HCO_3)	mg/L	4	270	199	380	83.875
Calcium (Ca)	mg/L	4	83.9	72.2	90.3	8.05
Carbonate (CO_3)	mg/L	4	1[1]	1[1]	1[1]	0.0
Chloride (Cl)	mg/L	4	13.5	9.6	19.2	4.1
Chlorophyll-a	µg/L	4	9	3[1]	21	8.5
Specific Conductance	µmhos	4	894	725	1100	154.7
Total Dissolved Solids	mg/L	4	551	384	699	129.2
Total Hardness as ($CaCO_3$)	mg/L	4	328	294	361	30.8
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0.0
Iron (Fe)	mg/L	4	0.065	0.007	0.119	0.052
Magnesium (Mg)	mg/L	4	28.8	22.8	32.9	4.6
Nitrate + Nitrite as N	mg/L	4	1.095	0.740	2.060	0.644
Total Kjeldahl Nitrogen as N	mg/L	4	1.340	1.170	1.550	0.193
Total Nitrogen as N	mg/L	4	2.206	1.640	3.060	0.752
pH		4	7.7	7.3	8.2	0.47
Total Phosphorus as P	mg/L	4	0.310	0.138	0.383	0.116
Potassium (K)	mg/L	4	8.9	5.7	10.4	2.2
Sodium (Na)	mg/L	4	59.2	21.6	80.7	26.7
Sulfate (SO4)	mg/L	4	217	44	316	119

[1]Equal to Minimum Reportable Limit

Trophic Status: Based on chlorophyll-a measurements and Secchi disk transparency collected in 2005-2006, Mt. Carmel Dam's current trophic status is mesotrophic (Figure 6). TSI scores ranged from a low of 35 based on chlorophyll-a, to a high of 101 based on total phosphorus. The trophic status score for Secchi disk transparency was similar to that estimated by chlorophyll-a, at 44 (Figure 6).

A total of six total phosphorus samples, four chlorophyll-a samples, and four Secchi disk measurements collected between 1996 and 2006 were used to evaluate trends in the trophic status of Mt. Carmel Dam. However, since Mt. Carmel Dam is nitrogen limited, only chlorophyll-a, and Secchi disk transparency are viable indicators of trophic status. Based on a visual assessment, the trophic status of Mt. Carmel Dam is improving (Table 6).

Table 3. Statistical Summary of Water Quality Data[2] Collected from Reservoir's in the Cultivated Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	352	263	88	891	103
Total Ammonia as N	mg/L	463	0.131	0.001[1]	2.070	0.203
Bicarbonate (HCO_3)	mg/L	352	296	91	951	114
Calcium (Ca)	mg/L	352	65	19	169	22
Carbonate (CO_3)	mg/L	324	14	1[1]	93	16
Chloride (Cl)	mg/L	351	21	1[1]	113	18
Chlorophyll-a	µg/L	373	20	2[1]	388	31
Specific Conductance	µmhos	352	1021	217	3140	516
Total Dissolved Solids	mg/L	344	667	127	2300	387
Total Hardness as ($CaCO_3$)	mg/L	352	334	95	1090	121
Hydroxide (OH)	mg/L	280	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	350	0.137	0.007	3.190	0.216
Magnesium (Mg)	mg/L	352	42	11	161	20
Nitrate + Nitrite as N	mg/L	411	0.097	0.003	2.060	0.191
Total Kjeldahl Nitrogen as N	mg/L	376	1.476	0.207	4.410	0.642
Total Nitrogen as N	mg/L	315	1.488	0.418	3.220	0.587
pH		352	8.36	6.89	9.40	0.43
Total Phosphorus as P	mg/L	464	0.322	0.004[1]	1.380	0.267
Potassium (K)	mg/L	352	12	3[1]	35	5
Sodium (Na)	mg/L	352	97	2[1]	582	107
Sulfate (SO4)	mg/L	351	269	8	1350	217

[1]Equal to lower detection limit
[2]Data Collected from 40 Reservoirs between 1991 and 2007

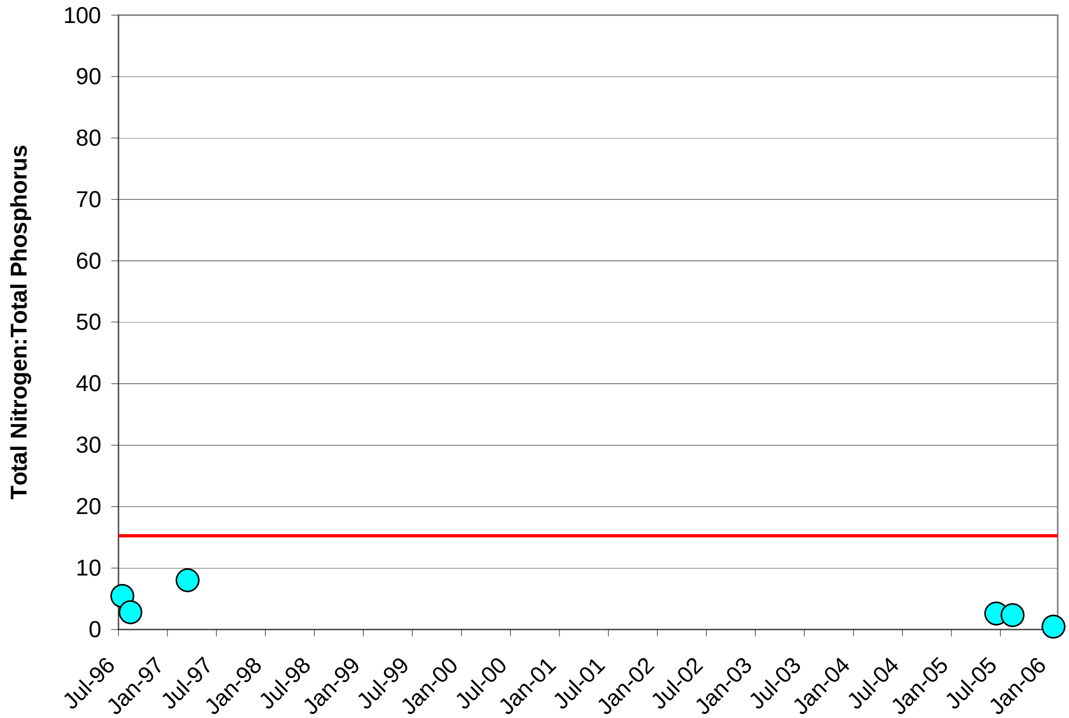


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Mt. Carmel Dam (1996-2006).

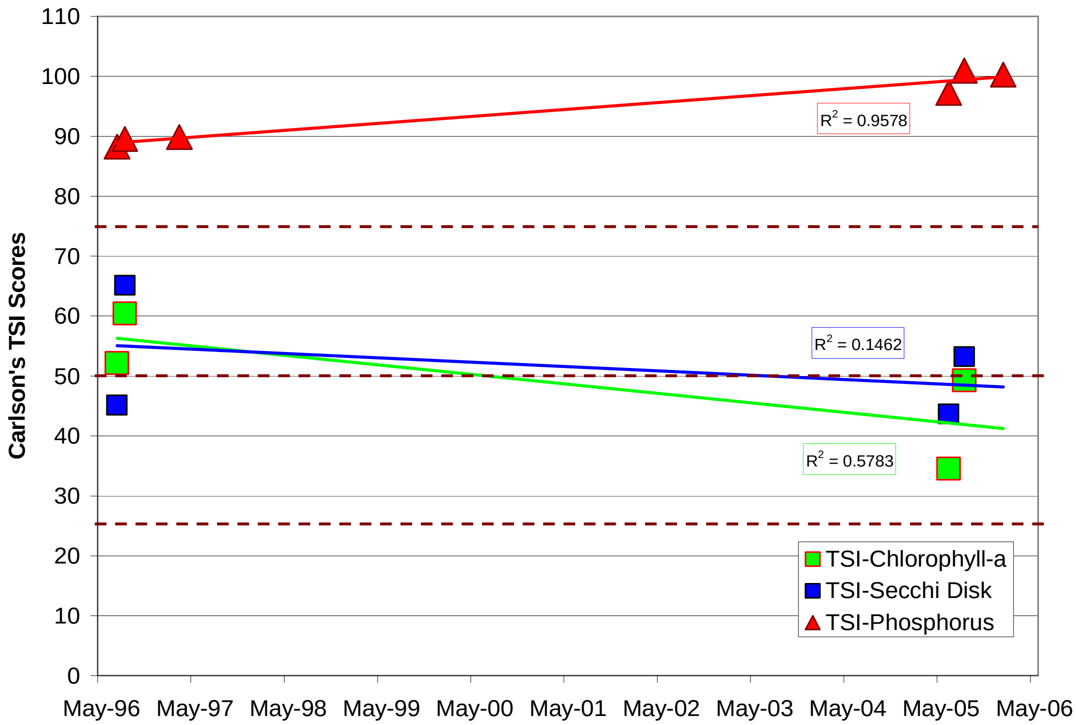


Figure 6. TSI Scores and Temporal Trends for Mt. Carmel Dam from 1996 to 2006.

Wilson Dam, Dickey County

BACKGROUND

Location: Wilson Dam is a small impoundment on an unnamed tributary to the south fork of the Maple River in Dickey County, North Dakota (Figures 1). The lake is located 7 miles west of Monango, North Dakota. Wilson Dam is managed by the North Dakota Game & Fish Department.

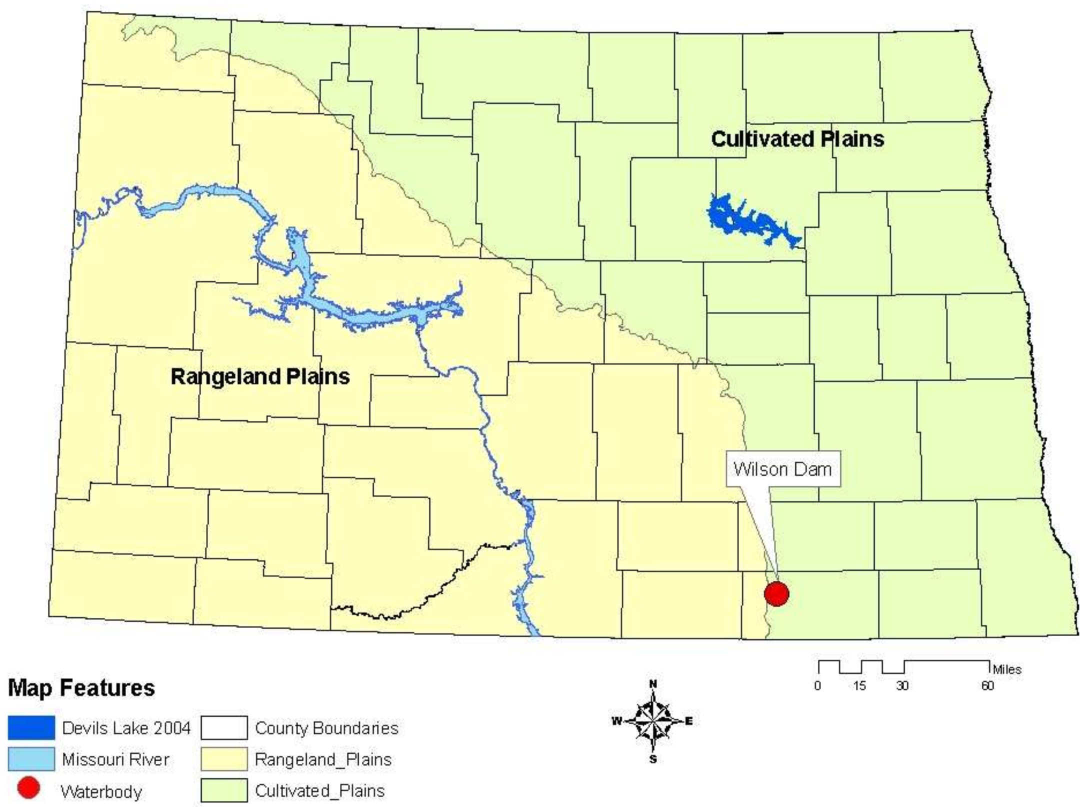


Figure 1. Location of Wilson Dam.

Physiographic/Ecological Setting: Wilson Dam is a 36.6 acre teardrop shaped reservoir with a maximum depth of 21.4 feet and a mean depth of 8.0 feet (Figure 2). The reservoir's watershed is 4,260-acres in size and located in the Northern Glaciated Plains (NGP) Level III Ecoregion, part of a broader Cultivated Plains region (Figure 1). The watershed is characterized by flat to rolling landscape composed of glacial drift in the transitional zone between tall and mixed grass prairie. The region has numerous wetlands essential for spring and fall migrations of wetland dependent birds. Flood plain slopes and hillsides are usually native grass while the uplands and flood plains proper have mostly been converted to small grains, row crops and alfalfa.

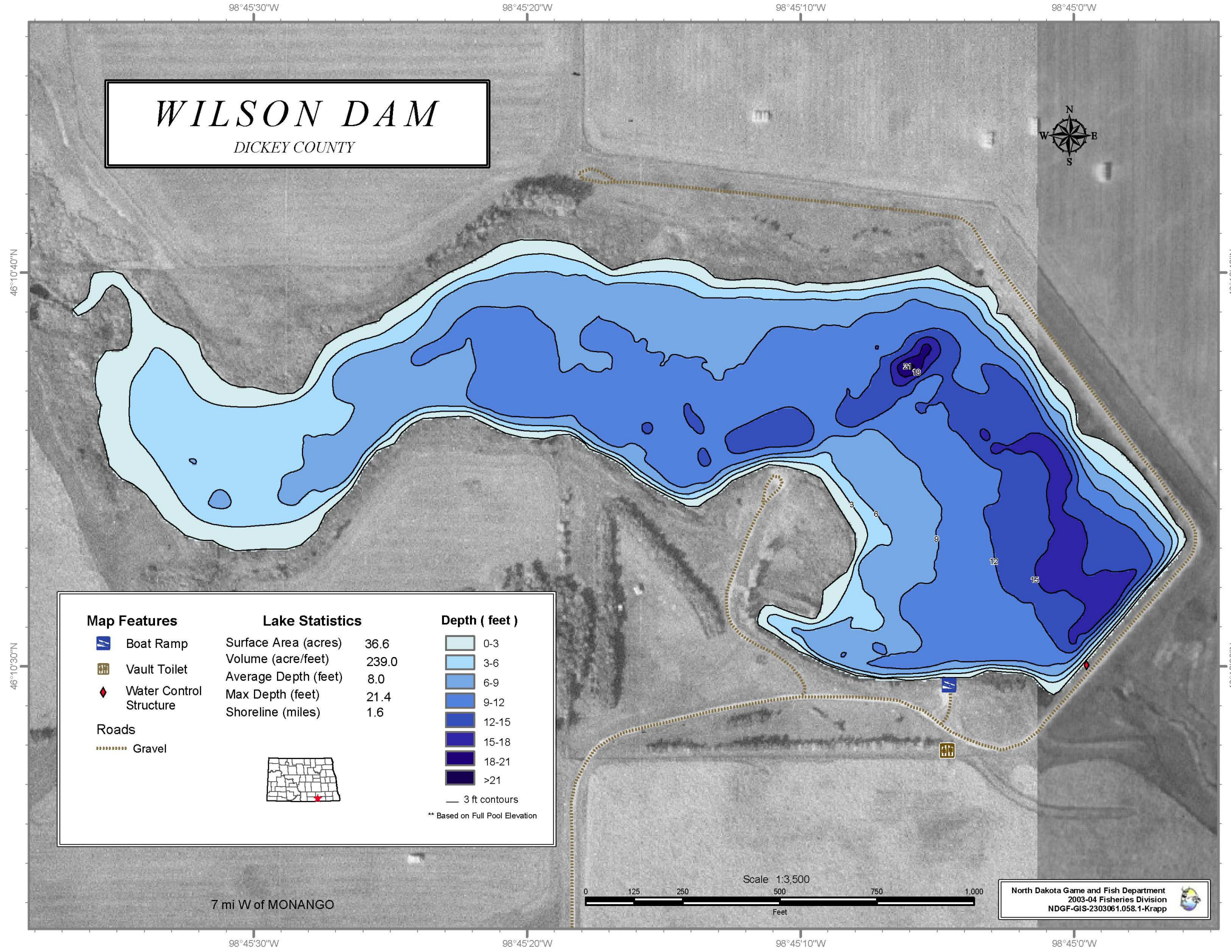


Figure 2. Contour Map of Wilson Dam (Map Courtesy of North Dakota Game and Fish Department).

Construction History: Wilson Dam is a rolled earthen structure built through the combined efforts of the Dickey County Water Resource District, the State Water Commission Board, and the North Dakota Game and Fish Department. Completed in 1968, Wilson Dam's primary function was for water based recreation.

Recreational Facilities: Recreational facilities at Wilson Dam are limited to one boat dock and a fishing pier on the south side of the lake, and walking access around the lake. There is also a vault toilet located south of the boat ramp.

Water Quality Standards Classification: Wilson Dam is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a "warm water fishery" or "waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present."

Historical and Current Fishery: Wilson Dam's fishery is largemouth bass, northern pike, and yellow perch. The historical fishery includes those mentioned plus the additional species of smallmouth bass, and channel catfish.

Historical Water Quality Samples: Historical water quality data includes results from three sample sets collected in 1993-1994.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Wilson Dam have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Cultivated Plains region.

Temperature and Dissolved Oxygen Profile Results: There are seven temperature and dissolved oxygen profiles for Wilson Dam collected in two clusters between 1993-1994 and 2005-2006 (Figures 3 and 4). The profile data shows that Wilson Dam usually has adequate or near adequate dissolved oxygen above the metalimnion, but experiences rapid oxygen depletion below (Figure 4). Of the seven profiles collected, six had dissolved oxygen concentrations that declined below the state standard of 5 mg/L. Three profiles collected on 7-23-1993, 6-21-2005, and 8-2-2005, begin at or below the state standard of 5 mg/L. The depth of thermal stratification ranged from 1 to 2 meters of depth at times leaving very little of the lake volume adequately oxygenated.

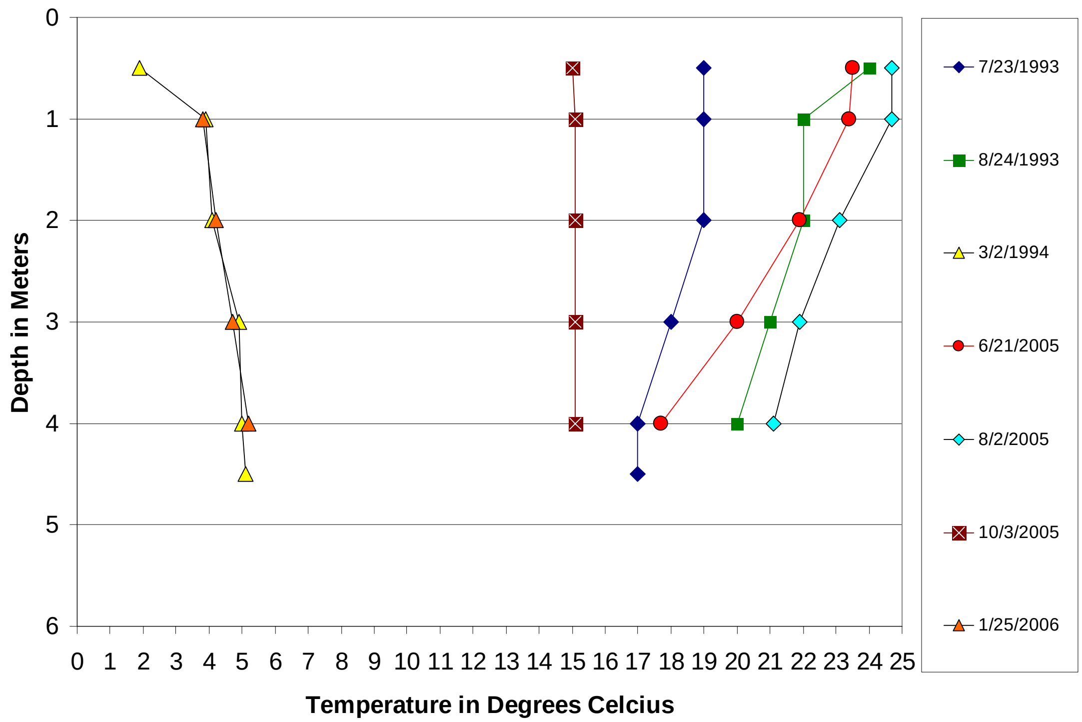


Figure 3. Temperature Profiles for Wilson Dam from 1993 to 2005.

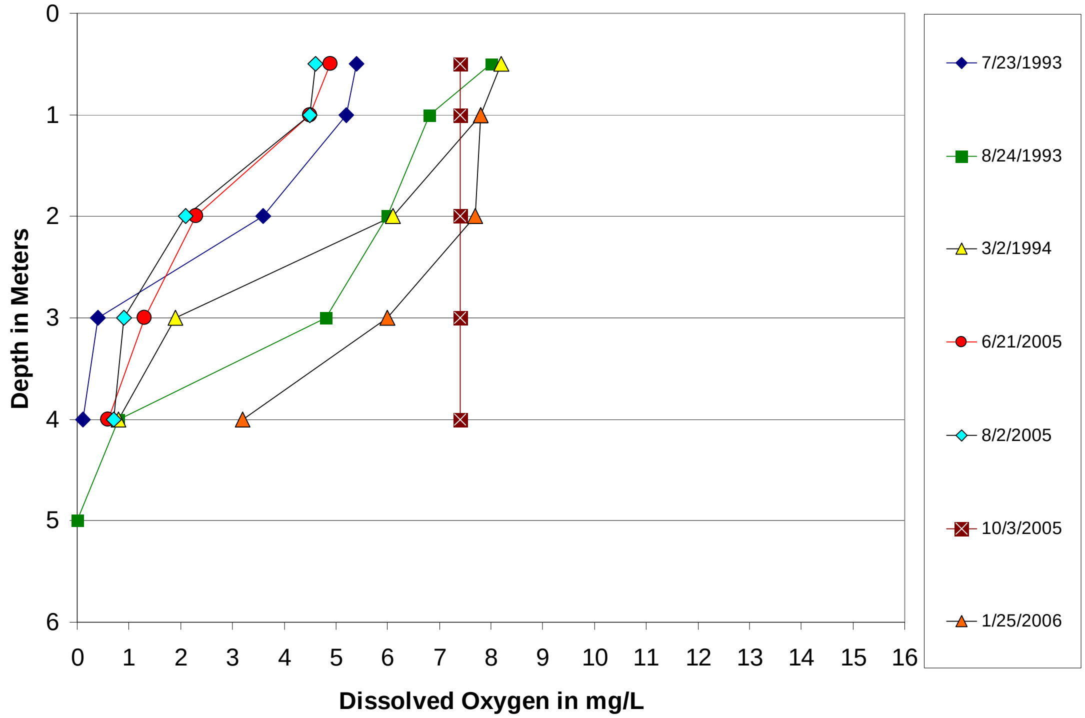


Figure 4. Dissolved Oxygen Profiles for Wilson Dam from 1993 to 2005.

General Water Quality: Data collected by the NDG&F in 2005 through 2006 indicates Wilson Dam is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 154 to 280 mg/L (Table 1). Wilson Dam is sodium sulfate dominated with an average sodium concentration of 92 mg/L and an average sulfate concentration of 319 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period was 752 mg/L and 1198 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.598 mg/L and 0.720 mg/L, respectively.

While there is a slight increase in major cations, anions, and icp metals between the historical data set and the current data, it is within the standard deviation and most likely can be attributed to fluctuations in lake levels (Tables 1 and 2).

Water quality data collected in 2005-2006 compared to the state's long term data set for reservoirs in the Cultivated Plains ecological region indicates that Wilson Dam has average concentrations of dissolved solids and nutrients with the exception of phosphorus (Tables 1 and 3). Wilson Dam's average total phosphorus concentrations of 0.720 mg/L is two fold higher than the region's average for reservoirs, of 0.322 mg/L (Table 3).

Table 1. Statistical Summary of Wilson Dam's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	214	154	280	52.0
Total Ammonia as N	mg/L	4	0.207	0.116	0.397	0.131
Bicarbonate (HCO_3)	mg/L	4	261	188	342	63.6
Calcium (Ca)	mg/L	4	69.9	57.1	88.40	13.7
Carbonate (CO_3)	mg/L	4	1[1]	1[1]	1[1]	0.0
Chloride (Cl)	mg/L	4	68.5	41.6	97.2	24.5
Chlorophyll-a	µg/L	4	6.5	2.0	15.6	6.2
Specific Conductance	µmhos	4	1198	911	1520	260
Total Dissolved Solids	mg/L	4	752	577	971	168.1
Total Hardness as ($CaCO_3$)	mg/L	4	417	337	529	83.5
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0.0
Iron (Fe)	mg/L	4	0.183	0.043	0.351	0.129
Magnesium (Mg)	mg/L	4	58.8	47.3	74.9	11.9
Nitrate + Nitrite as N	mg/L	4	0.175	0.070	0.310	0.101
Total Kjeldahl Nitrogen as N	mg/L	4	1.423	1.180	1.930	0.346
Total Nitrogen as N	mg/L	4	1.598	1.370	2.000	0.277
pH		4	8.0	8.0	8.2	0.09
Total Phosphorus as P	mg/L	4	0.720	0.507	1.050	0.264
Potassium (K)	mg/L	4	11.0	9.1	13.6	2.0
Sodium (Na)	mg/L	4	92.0	70.7	121.0	21.6
Sulfate (SO4)	mg/L	4	319	255	405	64.1

[1]Equal to Minimum Reportable Limit

Limiting Nutrient: The limiting nutrient assessment is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Wilson Dam, and that the ratio of total nitrogen to total phosphorus (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

Seven water quality sample sets for Wilson Dam between June 1993 and January 2006, indicate that Wilson Dam's nutrient relationship is not very dynamic and that Wilson Dam is strongly nitrogen limited (Figure 5).

The nitrogen to phosphorus ratio for Wilson Dam ranged from 2 to 4 with an average of about 3. Of the seven samples collected on Wilson Dam all were below 15 indicating that nitrogen is limiting primary production.

Table 2. Statistical Summary of Wilson Dam's Historical Water Quality Data Collected Between 1993 and 1994.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	221	160	301	72.3
Total Ammonia as N	mg/L	3	0.164	0.010[1]	0.284	0.140
Bicarbonate (HCO_3)	mg/L	3	270	195	368	88.7
Calcium (Ca)	mg/L	3	67.9	49.4	87.7	19.2
Carbonate (CO_3)	mg/L	3	1[1]	1[1]	1[1]	0.0
Chloride (Cl)	mg/L	3	48.9	31.9	67.8	18.0
Chlorophyll-a	µg/L	2	5.5	3[1]	8.000	3.5
Specific Conductance	µmhos	3	988	684	1340	330.5
Total Dissolved Solids	mg/L	3	618	421	833	206.5
Total Hardness as ($CaCO_3$)	mg/L	3	358	255	457	101.1
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0.0
Iron (Fe)	mg/L	3	0.218	0.167	0.251	0.045
Magnesium (Mg)	mg/L	3	45.9	31.9	57.8	13.1
Nitrate + Nitrite as N	mg/L	3	0311	0.010[1]	0.875	0.489
Total Kjeldahl Nitrogen as N	mg/L	3	0.844	0.704	0.970	0.134
Total Nitrogen as N	mg/L	3	0.890	0.724	1.070	0.173
pH		3	7.6	7.5	7.7	0.09
Total Phosphorus as P	mg/L	3	0.788	0.530	1.200	0.360
Potassium (K)	mg/L	3	15.9	13.9	19.2	2.8
Sodium (Na)	mg/L	3	71.8	51.6	90.6	19.5
Sulfate (SO4)	mg/L	3	233	143	327	92.1

[1]Equal to Minimum Reportable Limit

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected from 2005 to 2006, Wilson Dam's trophic status is mesotrophic bordering on eutrophic (Figure 6). TSI scores ranged from a low of 41 based on chlorophyll-a, to a high of 104 based on total phosphorus. The trophic status score based on Secchi disk transparency was similar to that estimated by chlorophyll-a, at 50 (Figure 6).

A total of seven total phosphorus samples, five chlorophyll-a samples, and five Secchi disk transparency measurements collected between 1993 and 2006 were used to evaluate trends in the trophic status of Wilson Dam. Since Wilson Dam is strongly nitrogen limited total phosphorus is a poor indicator of trophic status and at best can be used as an indicator of potential trophic status. Based on a visual assessment, and excluding the scores based on total phosphorus, Wilson Dam's trophic status is stable (Table 6).

Table 3. Statistical Summary of Water Quality Data[2] Collected from Reservoirs in the Cultivated Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	352	263	88	891	103
Total Ammonia as N	mg/L	463	0.131	0.001[1]	2.070	0.203
Bicarbonate (HCO_3)	mg/L	352	296	91	951	114
Calcium (Ca)	mg/L	352	65	19	169	22
Carbonate (CO_3)	mg/L	324	14	1[1]	93	16
Chloride (Cl)	mg/L	351	21	1[1]	113	18
Chlorophyll-a	µg/L	373	20	2[1]	388	31
Specific Conductance	µmhos	352	1021	217	3140	516
Total Dissolved Solids	mg/L	344	667	127	2300	387
Total Hardness as ($CaCO_3$)	mg/L	352	334	95	1090	121
Hydroxide (OH)	mg/L	280	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	350	0.137	0.007	3.190	0.216
Magnesium (Mg)	mg/L	352	42	11	161	20
Nitrate + Nitrite as N	mg/L	411	0.097	0.003	2.060	0.191
Total Kjeldahl Nitrogen as N	mg/L	376	1.476	0.207	4.410	0.642
Total Nitrogen as N	mg/L	315	1.488	0.418	3.220	0.587
pH		352	8.36	6.89	9.40	0.43
Total Phosphorus as P	mg/L	464	0.322	0.004[1]	1.380	0.267
Potassium (K)	mg/L	352	12	3[1]	35	5
Sodium (Na)	mg/L	352	97	2[1]	582	107
Sulfate (SO4)	mg/L	351	269	8	1350	217

[1]Equal to lower detection limit
[2]Data Collected from 40 Reservoirs between 1991 and 2007

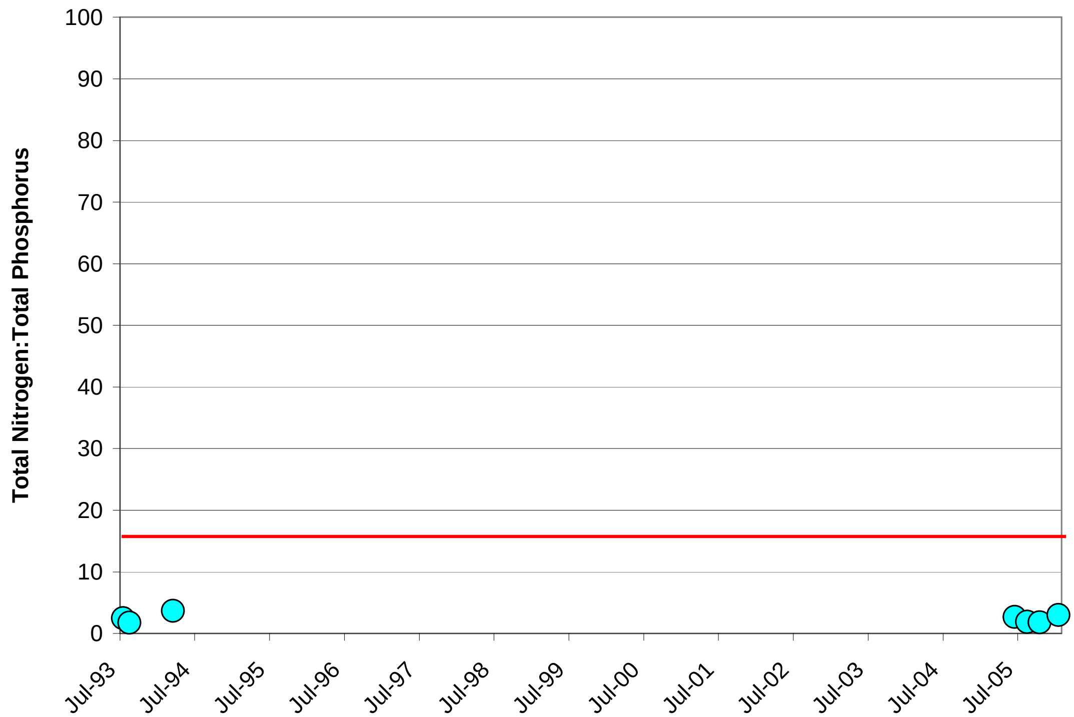


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Wilson Dam (1993-2006).

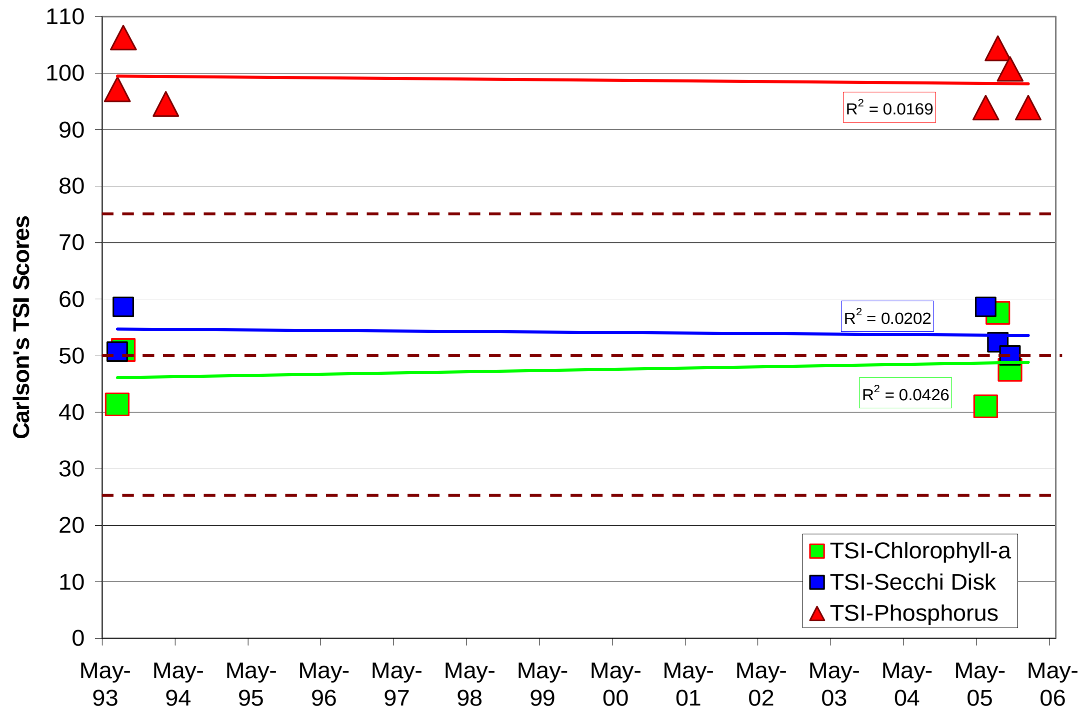


Figure 6. TSI Scores and Temporal Trends for Wilson Dam from 1993-2006.

Rice Lake, Emmons County

BACKGROUND

Location: Rice Lake is near the South Dakota-North Dakota border in Emmons County, North Dakota. The lake is located 8 miles south of Strasburg, North Dakota and managed by the North Dakota Game and Fish Department (Figure 1).

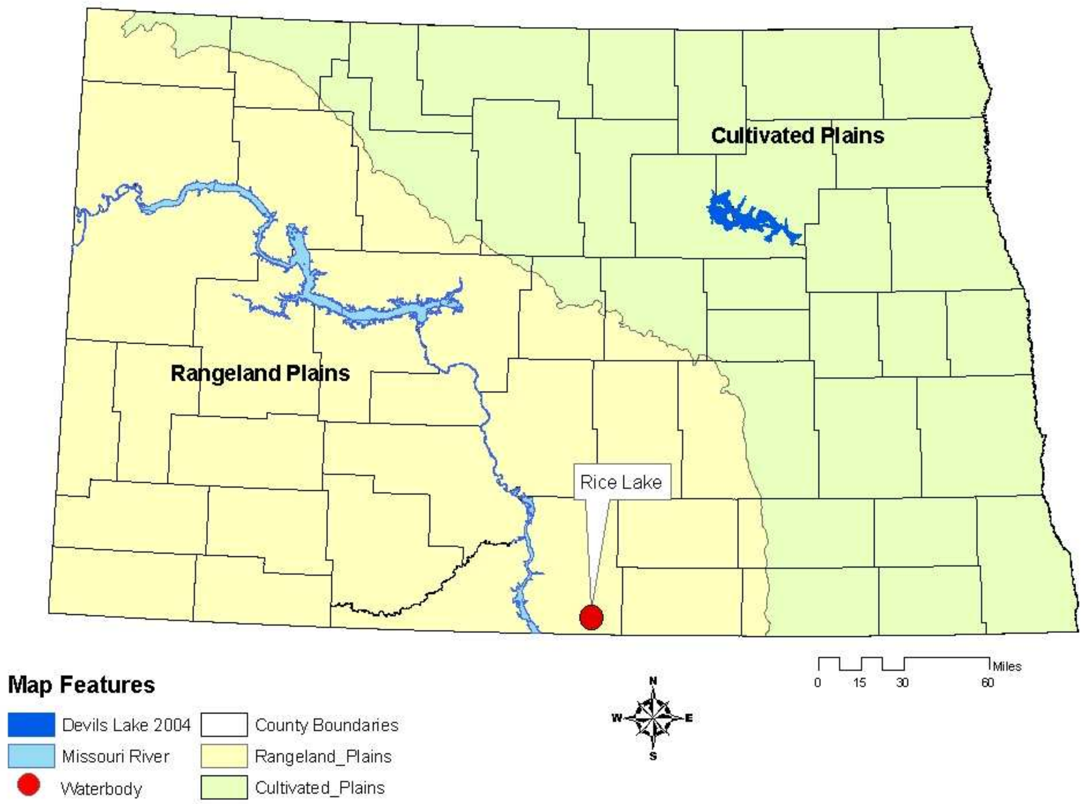


Figure 1. Location of Rice Lake.

Physiographic/Ecological Setting: Rice Lake is a 1,237 acre natural lake with a maximum depth of 22.3 feet and a mean depth of 16.7 feet (Figure 2). Rice Lake lies in the Northwestern Great Plains Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The Northwestern Great Plains Ecological region is composed of the Missouri Coteau section of the Great Plains. It is a semiarid hilly region formed by the terminal advance of the last Wisconsin Ice age. The area is characterized by rises of 100 to 350 feet with many glacial lakes, ponds, and wetlands at the feet of the rises to form a mosaic of the finest waterfowl resting and rearing area in the world.

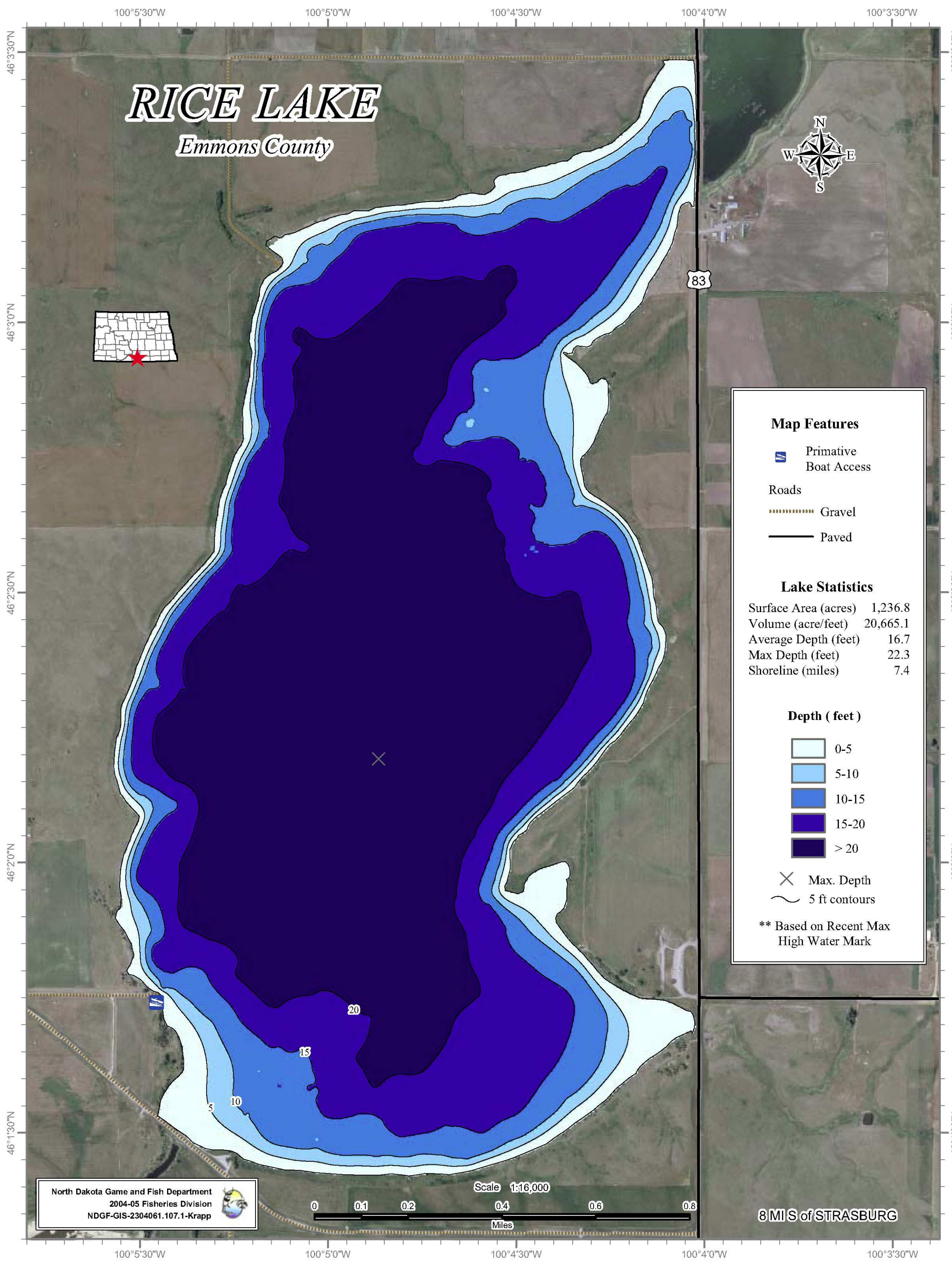


Figure 2. Contour Map of Rice Lake (Map Courtesy of North Dakota Game and Fish Department).

Recreational Facilities: Rice Lake enjoys four-seasons of recreation. Public access is on the south shore with a boat ramp, parking, a vault toilet, a picnic area, primitive camping zones, and a fishing pier.

Water Quality Standards Classification: Rice Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a "warm water fishery" or "waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present."

Historical and Current Fishery: Rice Lake's current and historical fishery includes northern pike, yellow perch, and walleye. Dark house spear-fishing is permitted on Rice Lake.

Historical Water Quality Sampling: There is no historical water quality data for Rice Lake.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trend assessments for Rice Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural and enhanced lakes in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There were four temperature and three dissolved oxygen profiles for Rice Lake collected in 2006-2007 (Figures 3 and 4). The profile data indicates that during thermal stratification, Rice Lake experiences rapid dissolved oxygen loss, and occasionally drops below the state standard of 5 mg/L. One of the profiles, collected on 2/14/2007, dropped below the state standard of 5 mg/L. While the rapid loss of dissolved oxygen during this period is concerning, there does appear to be enough dissolved oxygen to maintain aquatic life in the upper two and one half meters of the water column.

General Water Quality: Water quality data collected by the NDG&F in 2006 and 2007 indicate Rice Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 454 to 567 mg/L (Table 1). Rice Lake is sodium bicarbonate dominated with an average sodium concentration of 127 mg/L and an average bicarbonate concentration of 454 mg/L. The average TDS concentration and specific conductance measurement for the 2006-2007 sampling period were 841 mg/L and 1318 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 2.685 mg/L and 1.388 mg/L, respectively.

Water quality data collected in 2006 and 2007 was compared to the state's long term data set for natural and enhanced lakes in the Rangeland Plains ecological region. When compared to other lakes in the same ecological region Rice Lake is fresher than the average lake, with higher than average nutrient concentrations (Tables 1 and 2).

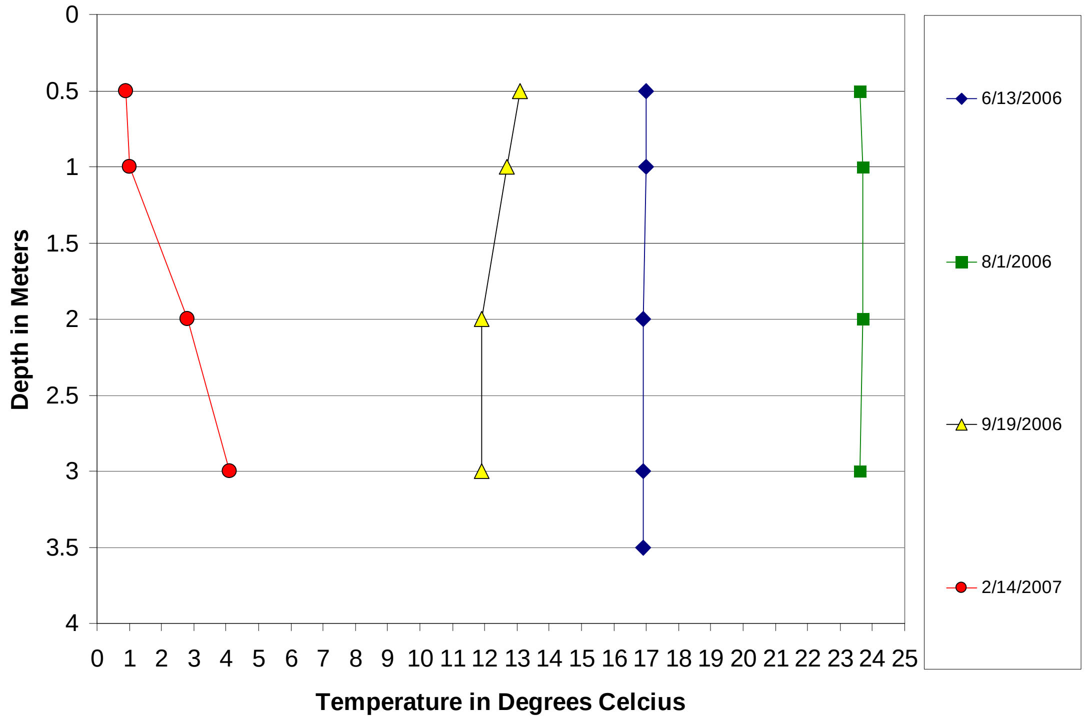


Figure 3. Temperature Profiles for Rice Lake from 2006 to 2007.

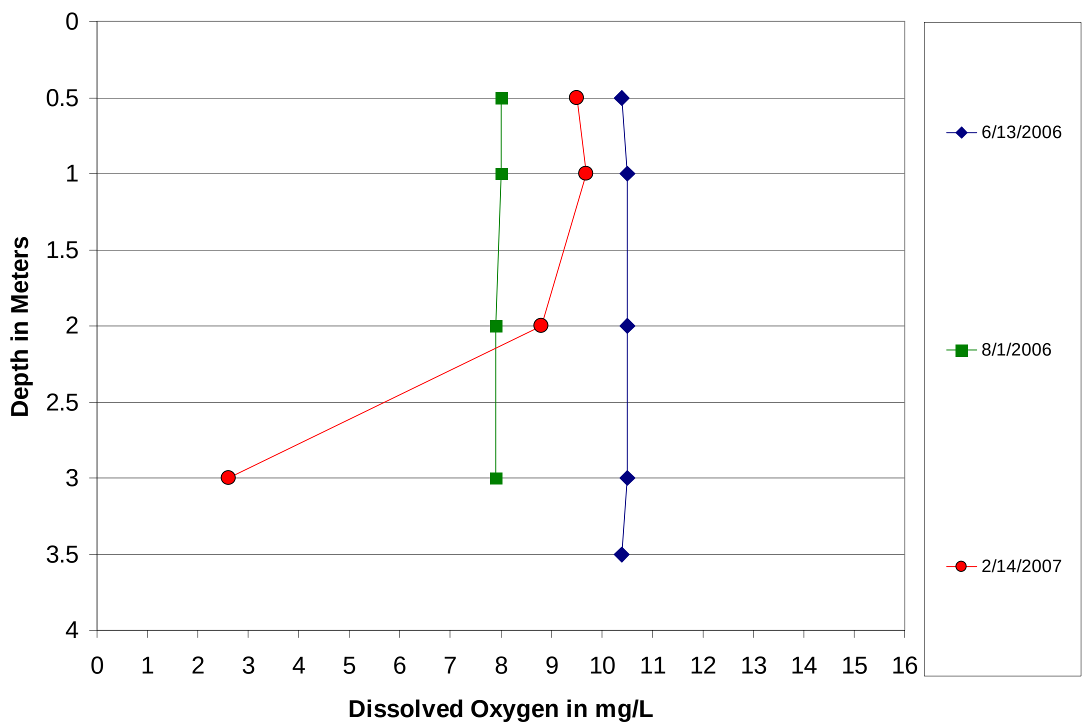


Figure 4. Dissolved Oxygen Profiles for Rice Lake from 2006 to 2007.

Table 1. Statistical Summary of Rice Lake's 2006-2007 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	506	454	567	50
Total Ammonia as N	mg/L	4	0.170	0.010[1]	0.623	0.302
Bicarbonate (HCO_3)	mg/L	4	454	377	532	63.8
Calcium (Ca)	mg/L	4	47.9	32.4	61.8	14.7
Carbonate (CO_3)	mg/L	4	81	59	99	16.8
Chloride (Cl)	mg/L	4	37	29	47	8
Chlorophyll-a	µg/L	4	62.4	10.7	119.0	55.9
Specific Conductance	µmhos	4	1318	1230	1520	138
Total Dissolved Solids	mg/L	4	841	749	963	90.1
Total Hardness as ($CaCO_3$)	mg/L	4	381	339	414	36
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0.0
Iron (Fe)	mg/L	4	0.144	0.050	0.211	0.069
Magnesium (Mg)	mg/L	4	63.3	52.3	77.1	10.2
Nitrate + Nitrite as N	mg/L	4	0.028	0.020	0.040	0.010
Total Kjeldahl Nitrogen as N	mg/L	4	2.658	1.660	3.640	0.811
Total Nitrogen as N	mg/L	4	2.685	1.700	3.670	0.807
pH		4	9.03	8.82	9.24	0.19
Total Phosphorus as P	mg/L	4	1.388	1.000	1.940	0.395
Potassium (K)	mg/L	4	87.1	70.6	101.0	13.1
Sodium (Na)	mg/L	4	127.4	91.6	153.0	27.4
Sulfate (SO4)	mg/L	4	173	158	204	20.9

[1]Equal to Minimum Reportable Limit

Rice Lake's average total phosphorus concentrations of 1.388 mg/L is ten fold greater than the regional average and the total nitrogen concentration of 2.685 mg/L is about 33 percent higher. Dissolved solids in Rice Lake were 841 mg/L compared to the regional average of 1,588 mg/L and hardness was 381 mg/L compared to 538 mg/L. Most of the major cations, anions, and icp metals were well within the standard deviation for the regions with the exception of potassium with a concentration of 87 mg/L compared to the regional average of 37 mg/L and a standard deviation of 13.

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Rice Lake, and that the ratio of total nitrogen to total phosphorus (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There are four water quality sample sets for Rice Lake between June 2006 and February 2007. The four samples used in this interpretation indicate that Rice Lake is nitrogen limited (Figure 5).

The nitrogen to phosphorus ratio for Rice Lake ranged from a low of 1 to a high of 3 with an average of 2. All four samples collected were below a ratio of 15 indicating nitrogen is limiting primary production.

Table 2. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lake's in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	272	544	119	4770	130
Total Ammonia as N	mg/L	371	0.107	0.001[1]	2.230	0.200
Bicarbonate (HCO_3)	mg/L	272	489	145	2990	150
Calcium (Ca)	mg/L	272	44	1[1]	282	26
Carbonate (CO_3)	mg/L	262	89	1[1]	1420	30
Chloride (Cl)	mg/L	272	51	4[1]	1070	9
Chlorophyll-a	µg/L	250	22	2[1]	292	28
Specific Conductance	µmhos	272	2168	448	20100	959
Total Dissolved Solids	mg/L	272	1588	227	18200	750
Total Hardness as ($CaCO_3$)	mg/L	272	538	170	2370	260
Hydroxide (OH)	mg/L	200	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	273	0.193	0.001[1]	2.260	0.334
Magnesium (Mg)	mg/L	272	104	20	567	50
Nitrate + Nitrite as N	mg/L	332	0.036	0.002[1]	0.338	0.092
Total Kjeldahl Nitrogen as N	mg/L	340	1.950	0.080	8.500	0.779
Total Nitrogen as N	mg/L	278	1.826	0.269	5.520	0.562
pH		272	8.80	7.40	9.87	0.57
Total Phosphorus as P	mg/L	377	0.244	0.004[1]	1.940	0.205
Potassium (K)	mg/L	272	38	3[1]	356	6
Sodium (Na)	mg/L	272	331	17	4680	171
Sulfate (SO4)	mg/L	272	680	34	10500	501

[1]Equal to Minimum Reporting Limit.
[2]Data Collected from 48 Natural and Enhanced Lakes Between 1991 and 2007

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected from 2006 to 2007, Rice Lake's current trophic status is eutrophic to hypereutrophic (Figure 6). TSI scores ranged from a low of 54 based on Secchi disk transparency, to a high of 113 based on total phosphorus data. The trophic status score based on chlorophyll-a was similar to that estimated by Secchi disk transparency, at 59 (Figure 6).

A total of four total phosphorus samples, four chlorophyll-a samples, and four Secchi disk measurements collected during the open water periods from 2006-2007 were used to evaluate trends in the trophic status of Rice Lake. Since Rice Lake is nitrogen limited only chlorophyll-a, and Secchi disk are good indicators of trophic status.

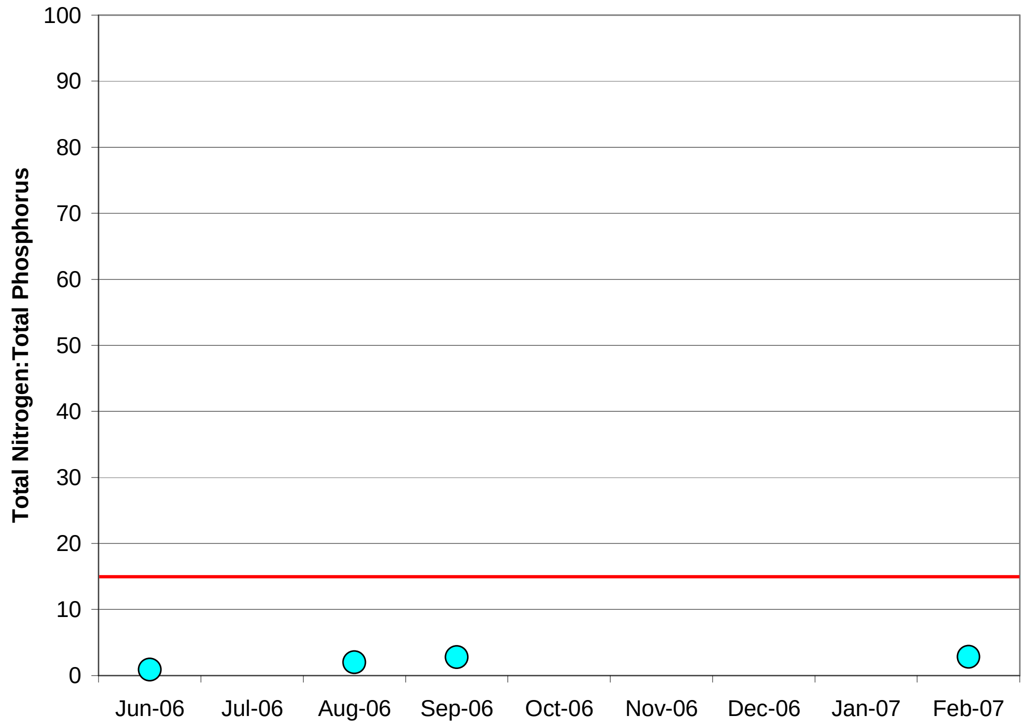


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Rice Lake (2006-2007).

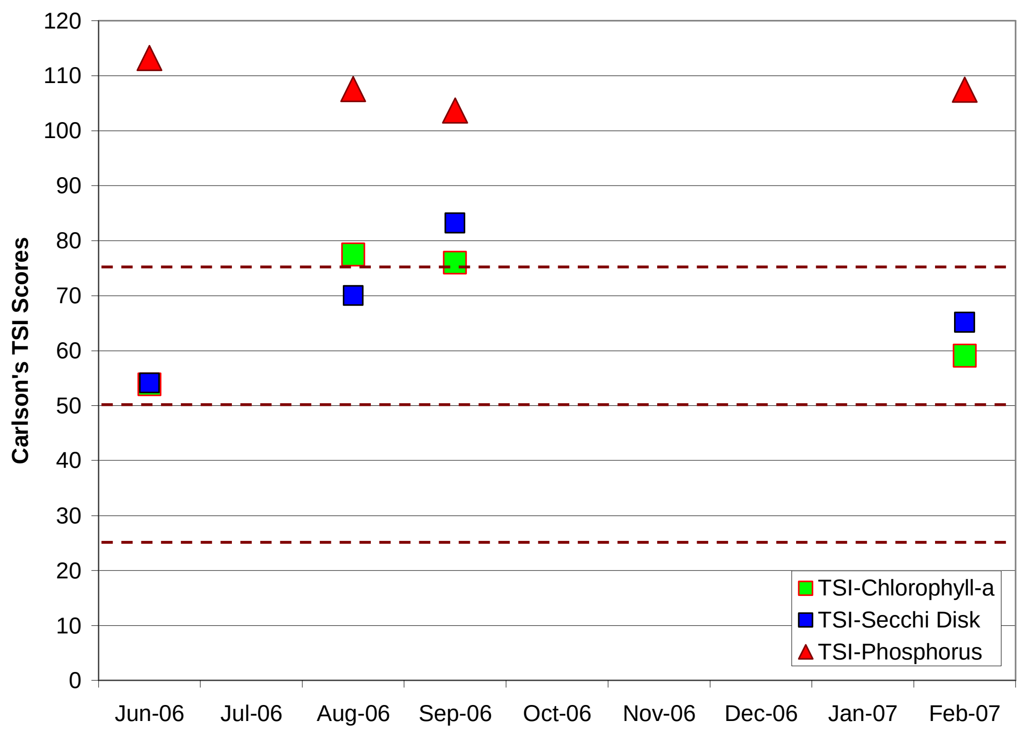


Figure 6. TSI Scores for Rice Lake from 2006 to 2007.

Camel Hump Dam, Golden Valley County

BACKGROUND

Location: Camel Hump Dam is a small reservoir on Andrew Creek near the western edge of North Dakota, approximately half way between the Missouri River and the South Dakota border. Camel Hump Dam is managed by the North Dakota Game and Fish Department and is located just off Interstate Highway 94, northeast of the Sentinel Butte, exit 10 (Figure 1).

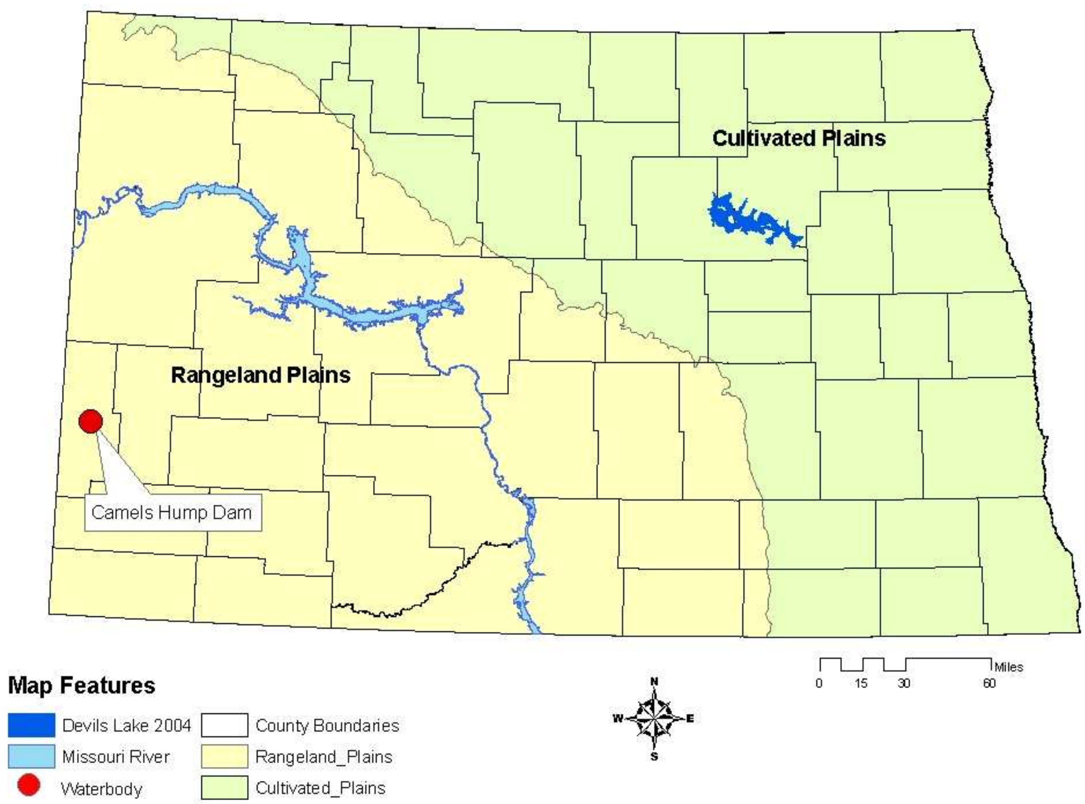


Figure 1. Location of Camel Hump Dam.

Physiographic/Ecological Setting: Camel Hump Dam is a 44.4 acre impoundment with a maximum depth of 35.8 feet and an average depth of 14.5 feet (Figure 2). Camel Hump Dam is located in the Northwestern Great Plains (NWGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The NWGP is the Missouri Plateau of the Great Plains (USEPA 1994). The watershed landscape is rolling plains. Flood plain slopes and hillsides are usually native grass while the uplands and flood plains themselves have mostly been converted to small grains and alfalfa.

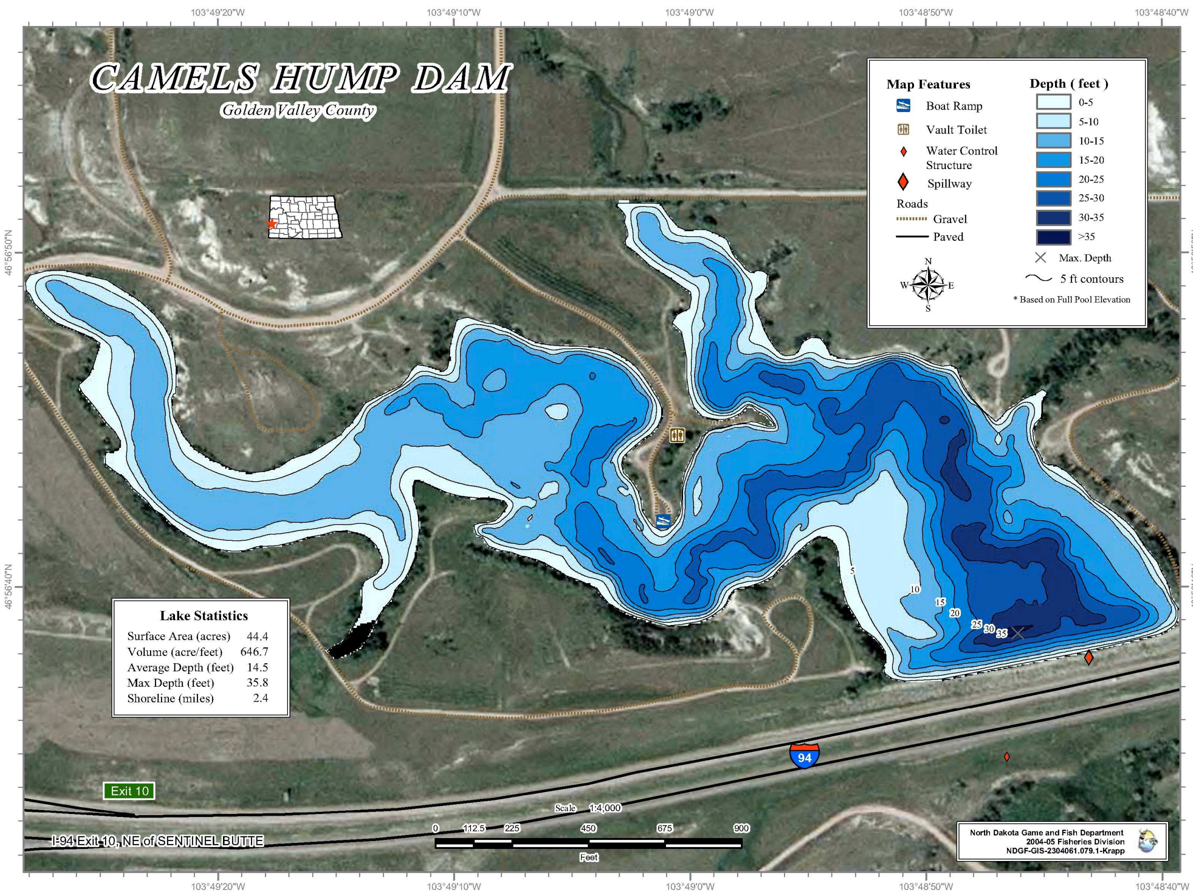


Figure 2. Contour Map of Camel Hump Dam (Map Courtesy of the North Dakota Game and Fish Department).

Construction History: Camel Hump Dam was constructed in 1968 through the efforts of local, state, and federal agencies. The reservoir was renovated by the North Dakota Game and Fish Department in 2001.

Recreational Facilities: Camel Hump Dam and the immediate area surrounding the shoreline are owned and managed by the North Dakota Game and Fish Department. Recreational facilities at Camel Hump Dam include a boat ramp, associated parking, a vault toilet, fishing piers, and picnic areas.

Water Quality Standards Classification: Camel Hump Dam is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 1 lake or reservoir. Class 1 lakes or reservoirs are defined as a "cold water fishery" or "waters capable of supporting growth of cold water fish species (e.g., salmonids) and associated aquatic biota."

Historical and Current Fishery: Camel Hump Dam's fishery is managed by the North Dakota Game and Fish Department. The historical and current fisheries for Camel Hump Dam include trout, bluegill, and largemouth bass. Boats are restricted to idle speeds and no live bait fish are allowed.

Historical Water Quality Sampling: There is no historical water quality data for Camel Hump Dam.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trend assessments for Camel Hump Dam have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There are three temperature and dissolved oxygen profiles for Camel Hump Dam collected in 1990, 2005, and 2006 (Figures 3 and 4). The profile data shows that Camel Hump is usually thermally stratified and during thermal stratification it experiences rapid dissolved oxygen depletion below 2 meters of depth.

All of the profiles, collected on 12/27/1990, 7/22/2005, and 2/23/2006 dropped below the state's water quality standard of 5 mg/L (Figure 4). While the rapid loss of dissolved oxygen during these periods is concerning, there appears to be adequate concentrations of dissolved oxygen in the upper four to five meters of the water column to sustain aquatic life.

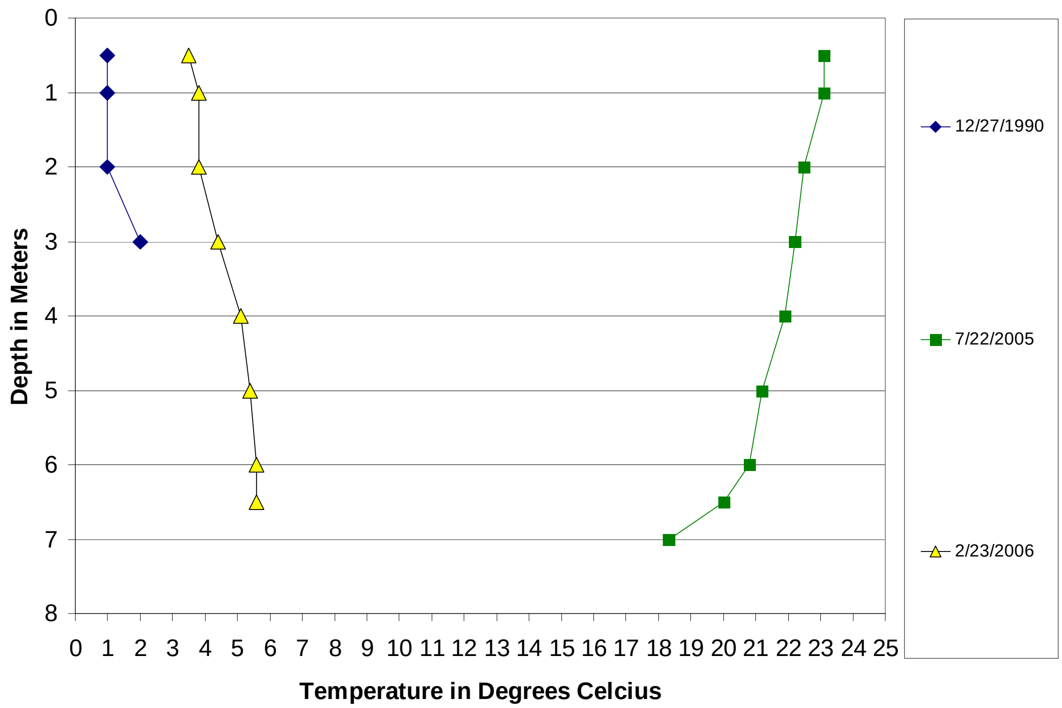


Figure 3. Temperature Profiles for Camel Hump Dam from 1990 to 2006.

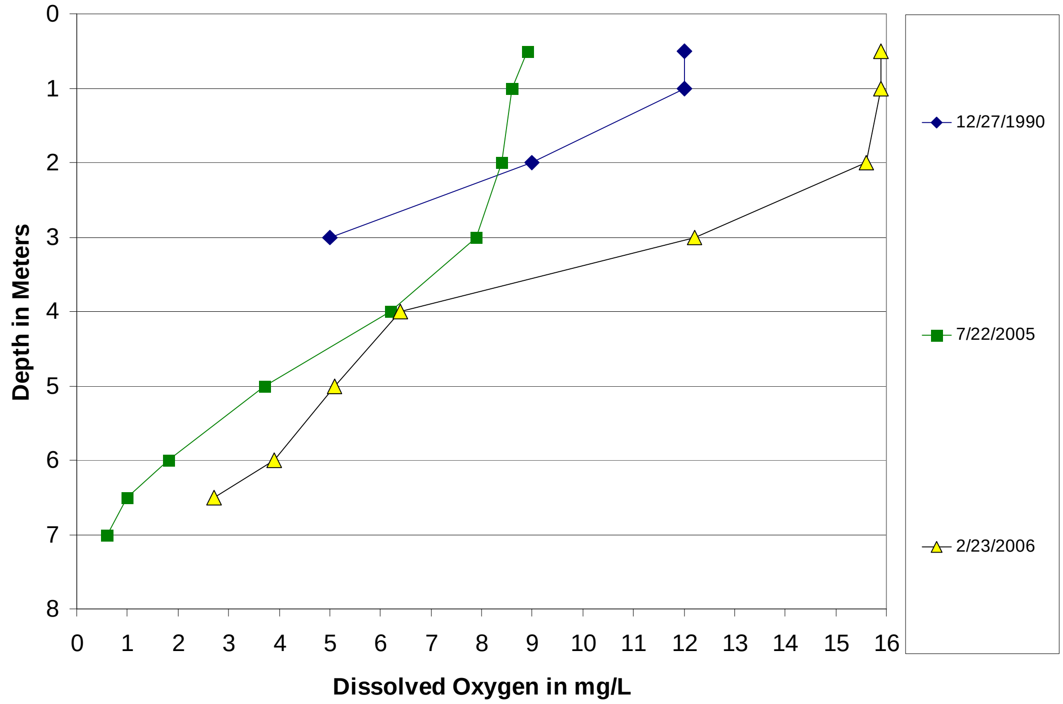


Figure 4. Dissolved Oxygen Profiles for Camel Hump Dam from 1990 to 2006.

General Water Quality: Current water quality data indicates Camel Hump Dam is well buffered with total alkalinity as $CaCO_3$ concentrations ranging from 202 to 208 mg/L (Table 1). Camel Hump Dam is sodium sulfate dominated with an average sodium concentration of 306 mg/L and an average sulfate concentration of 844 mg/L. The average total dissolved solids (TDS) concentration and specific conductance measurement for the 2005-2006 sampling period were 1405 mg/L and 1995 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 0.935 mg/L and 0.011 mg/L respectively.

Camel Hump Dam's general chemistry is similar to the long term state average for reservoir lakes in the Rangeland Plains region. Current total dissolved solids concentrations ranged from 1300 mg/L to 1510 mg/L (Table 1), while the long term average is 1176 mg/L (Table 2). Total phosphorus concentrations in Camel Hump Dam are below the state long term average for reservoirs in the Rangeland Plains region. Total phosphorus concentrations ranged from 0.010 mg/L to 0.012 mg/L (Table 1), while the long term average is 0.135 mg/L (Table 2).

Table 1. Statistical Summary of Camel Hump Dam's 2005-2006 Water Quality Data.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	2	205	202	208	4
Total Ammonia as N	mg/L	2	0.014	0.010	0.017	0.005
Bicarbonate (HCO_3)	mg/L	2	183	164	201	26
Calcium (Ca)	mg/L	2	44.8	39.3	50.3	7.8
Carbonate (CO_3)	mg/L	2	34	26	41	11
Chloride (Cl)	mg/L	2	7	7	8	1
Chlorophyll-a	µg/L	1	3.0	3.0	3.0	
Specific Conductance	µmhos	2	1995	1860	2130	191
Total Dissolved Solids	mg/L	2	1405	1300	1510	148
Total Hardness as ($CaCO_3$)	mg/L	2	381	373	389	11
Hydroxide (OH)	mg/L	2	1	1	1	0
Iron (Fe)	mg/L	2	0.116	0.082	0.150	0.048
Magnesium (Mg)	mg/L	2	65.5	60.2	70.7	7.4
Nitrate + Nitrite as N	mg/L	2	0.040	0.020	0.060	0.028
Total Kjeldahl Nitrogen as N	mg/L	2	0.895	0.853	0.937	0.059
Total Nitrogen as N	mg/L	2	0.935	0.913	0.957	0.031
pH		2	9.04	8.88	9.20	0.23
Total Phosphorus as P	mg/L	2	0.011	0.010	0.012	0.001
Potassium (K)	mg/L	2	14.3	12.8	15.7	2.1
Sodium (Na)	mg/L	2	306	274	338	45
Sulfate (SO4)	mg/L	2	844	771	917	103

[1]Equal to Minimum Reporting Limit

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Camel Hump Dam, and that the ratio of total nitrogen to total phosphorus (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There are two water quality sample results for Camel Hump Dam collected in July 2005 and February 2006, where the N:P ratio could be calculated. The nitrogen to phosphorus ratios for Camel Hump Dam were 76 and 96, for an average of 86. Both samples used in this interpretation indicate that Camel Hump Dam is phosphorus limited (Figure 5).

Table 2. Statistical Summary of Water Quality Data[2] Collected from Reservoirs in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	408	309	101	982	130
Total Ammonia as N	mg/L	469	0.097	0.001[1]	2.440	0.200
Bicarbonate (HCO_3)	mg/L	408	318	14	1040	150
Calcium (Ca)	mg/L	408	50	5	160	26
Carbonate (CO_3)	mg/L	402	30	1[1]	197	30
Chloride (Cl)	mg/L	408	13.3	0.3	74.5	8.8
Chlorophyll-a	µg/L	321	21.2	1.5	218.0	27.9
Specific Conductance	µmhos	428	1733	262	5880	959
Total Dissolved Solids	mg/L	409	1176	147	5110	750
Total Hardness as ($CaCO_3$)	mg/L	408	397	45	1850	260
Hydroxide (OH)	mg/L	337	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	409	0.179	0.007	4.110	0.334
Magnesium (Mg)	mg/L	408	66.0	5.6	353.0	49.6
Nitrate + Nitrite as N	mg/L	395	0.048	0.001[1]	0.790	0.092
Total Kjeldahl Nitrogen as N	mg/L	359	1.556	0.365	7.720	0.779
Total Nitrogen as N	mg/L	302	1.472	0.405	4.840	0.562
pH		428	8.61	6.73	9.87	0.56
Total Phosphorus as P	mg/L	475	0.135	0.004	3.160	0.205
Potassium (K)	mg/L	408	14.6	4.2	39.2	6.3
Sodium (Na)	mg/L	408	239	3[1]	932	171
Sulfate (SO4)	mg/L	406	604	1[1]	3210	501

[1]Equal to Minimum Reporting Limit.
[2]Data Collected from 69 Reservoirs between 1991 and 2007

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected from 2005 to 2006, Camel Hump Dam's trophic status is mesotrophic (Figure 6). TSI scores ranged from a low of 38 based on total phosphorus, to a high of 41 based on Secchi disk transparency and chlorophyll-a measurements.

A total of two total phosphorus samples, one chlorophyll-a sample, and one Secchi disk transparency measurement collected during the open water periods from 2005-2006 were used to evaluate trends in the trophic status of Camel Hump Dam. Since Camel Hump Dam is phosphorus limited, all three parameters are probably good indicators of the current or potential trophic status of Camel Hump Dam.

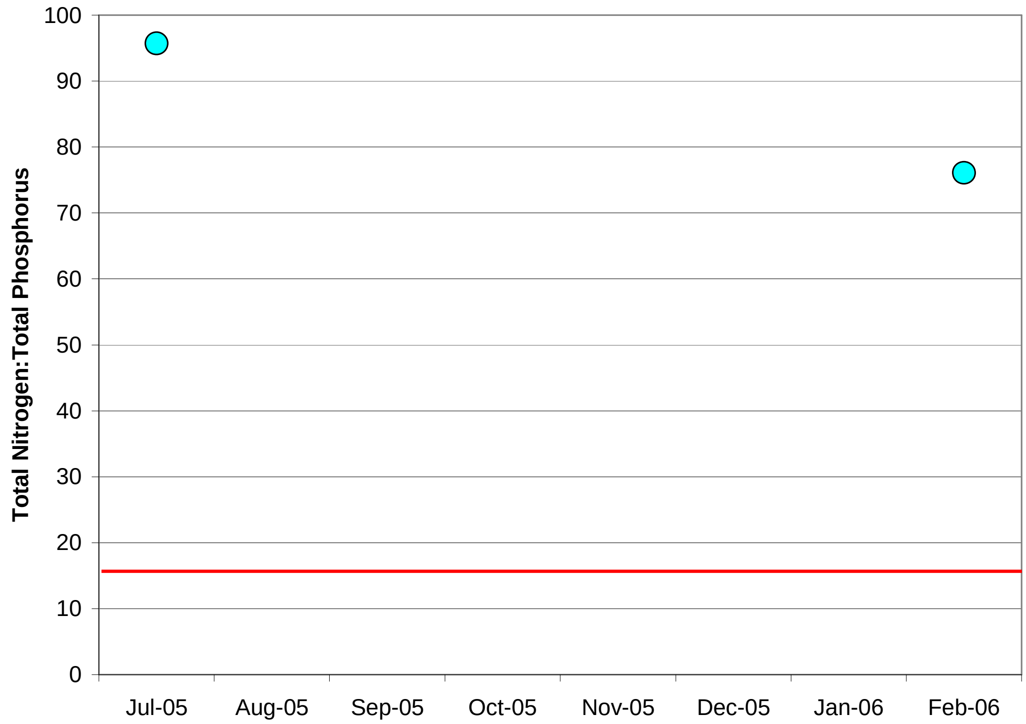


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Camel Hump Dam (2005-2006).

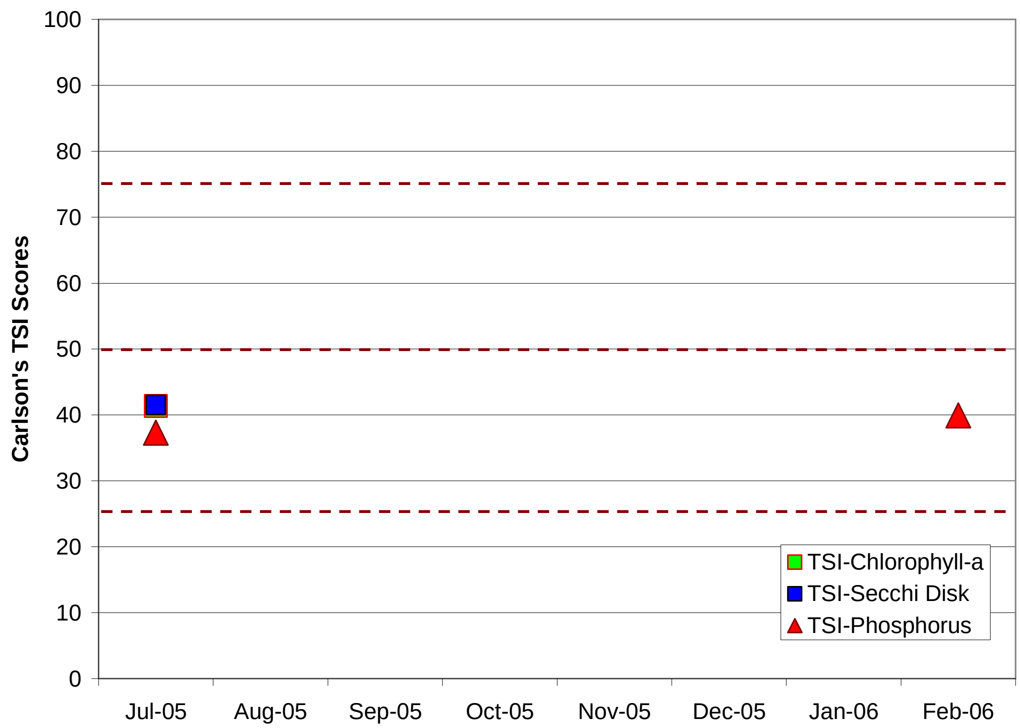


Figure 6. TSI Scores for Camel Hump Dam from 2005 to 2006.

Larimore Dam, Grand Forks County

BACKGROUND

Location: Larimore Dam on the Turtle River in Grand Forks County, North Dakota. To access the lake travel either 2 miles north of the town of Larimore or 25 miles west and 1mile south of the city of Grand Forks (Figure 1). Larimore Dam is managed by the North Dakota Game and Fish Department and the Larimore Park Board.

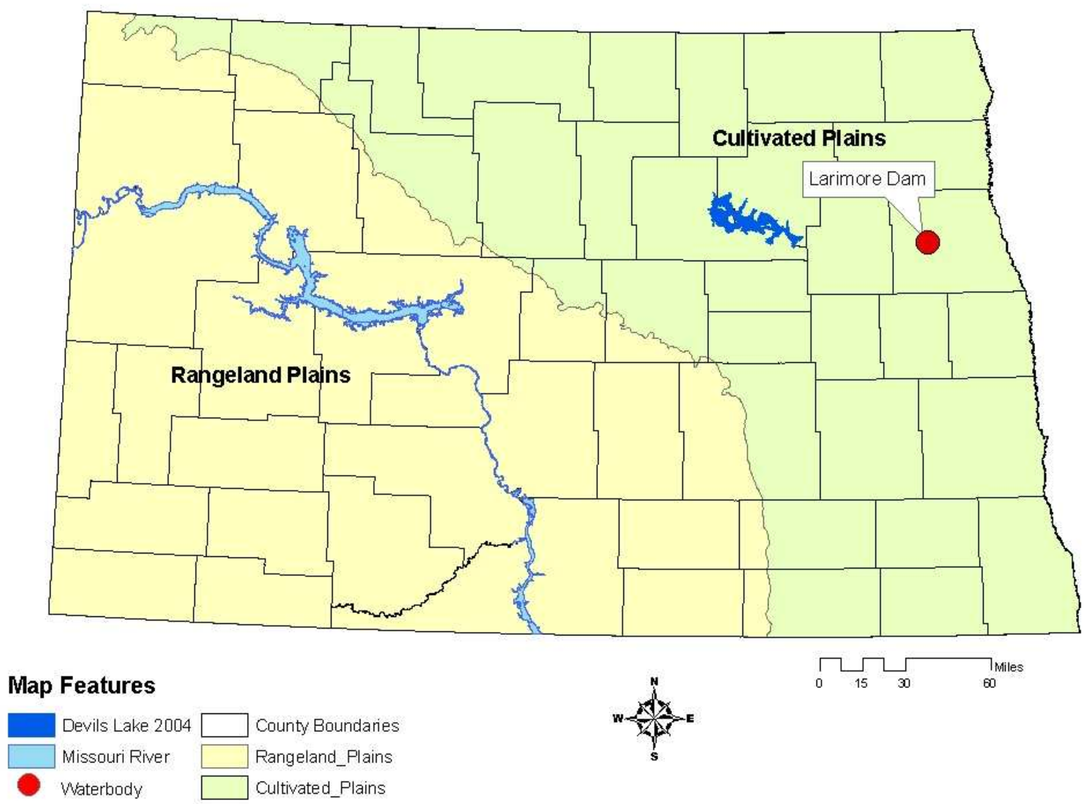


Figure 1. Location of Larimore Dam.

Physiographic/Ecological Setting: Larimore Dam is a 66.7 acre impoundment on the Turtle River in western Grand Forks County, North Dakota. It has an average depth of 11.1 feet and a maximum depth of 28.1 feet (Figure 2). Larimore Dam lies on the western edge of the Lake Agassiz Plains Level III Ecoregion with most of its contributing watershed located in the Northern Glaciated Plains Level III Ecoregion. The Lake Agassiz Plains and Northern Glaciated Plains combined form the broader Cultivated Plains region (Figure 1). The Lake Agassiz Plain Ecoregion was formed by the glacial Lake Agassiz during the last of the Wisconsin era ice ages. It is characterized by a flat landscape and contains some of the most fertile soils in North America. The Northern Glaciated Plains Ecological region is characterized by flat to rolling landscape composed of glacial drift (USEPA 1994).

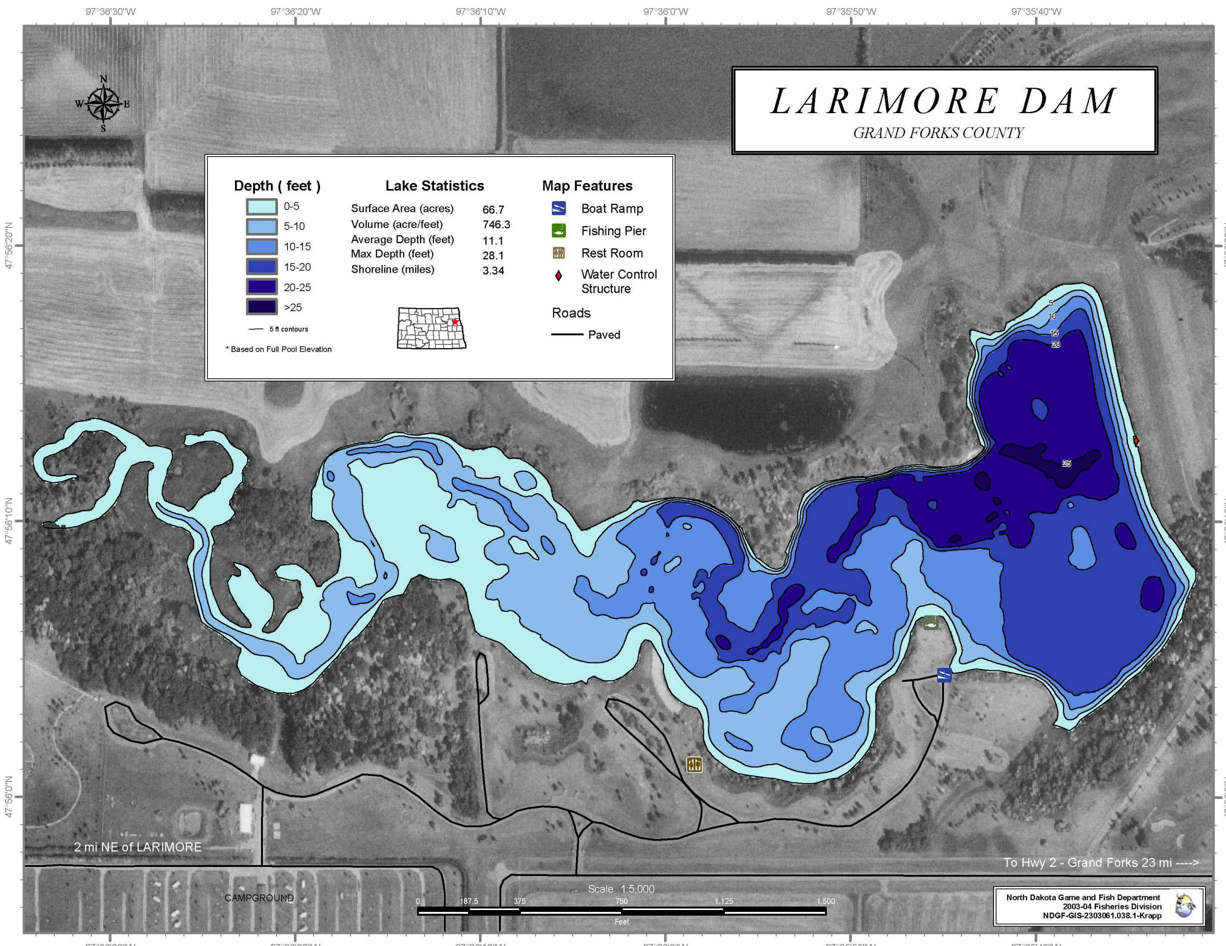


Figure 2. Contour Map of Larimore Dam (Map Courtesy of North Dakota Game and Fish Department).

This region is the transitional zone between tall and mixed grass prairie. The region has numerous wetlands essential for spring and fall migrations of wetland dependent birds. Flood plain slopes and hillsides are usually native grass while the uplands and flood plains proper have mostly been converted to small grains, row crops and alfalfa.

Construction History: Larimore Dam was built in 1978. It is one of seven flood control structures in the upper Turtle River watershed.

Recreational Facilities: Larimore Dam is a popular recreation area with the residents of Grand Forks and Grand Forks Air Force Base. There is a nice park on Larimore Dam's south shore maintained by the Larimore Park Board. Facilities include a boat ramp and associated parking, camping and picnic areas with toilets, and garbage pickup.

Water Quality Standards Classification: Larimore Dam is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2007) as a class 2 lake. Class 2 lakes and reservoirs are defined as "Cool Water Fisheries" or "waters capable of supporting natural reproduction and growth of cool water fishes (e. g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: Larimore Dam's fishery includes northern pike, bluegill, and yellow perch. The reservoir's historical fishery includes smallmouth bass, largemouth bass, trout, and crappie.

Historical Water Quality Sampling: Historical water quality data includes results from three sample sets collected in 1992-1993.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Larimore Dam have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Cultivated Plains region.

Temperature and Dissolved Oxygen Profile Results: There are 36 temperature and dissolved oxygen profiles for Larimore Dam collected in two clusters between 1992 and 1993, and between 2005 and 2007 (Figures 3 through 8). The profile data indicates that during thermal stratification Larimore Dam experiences rapid oxygen decay resulting in large portions of the water column with dissolved oxygen concentrations below the state standard of 5 mg/L. However the portions of the water column above the thermal stratification remain well oxygenated.

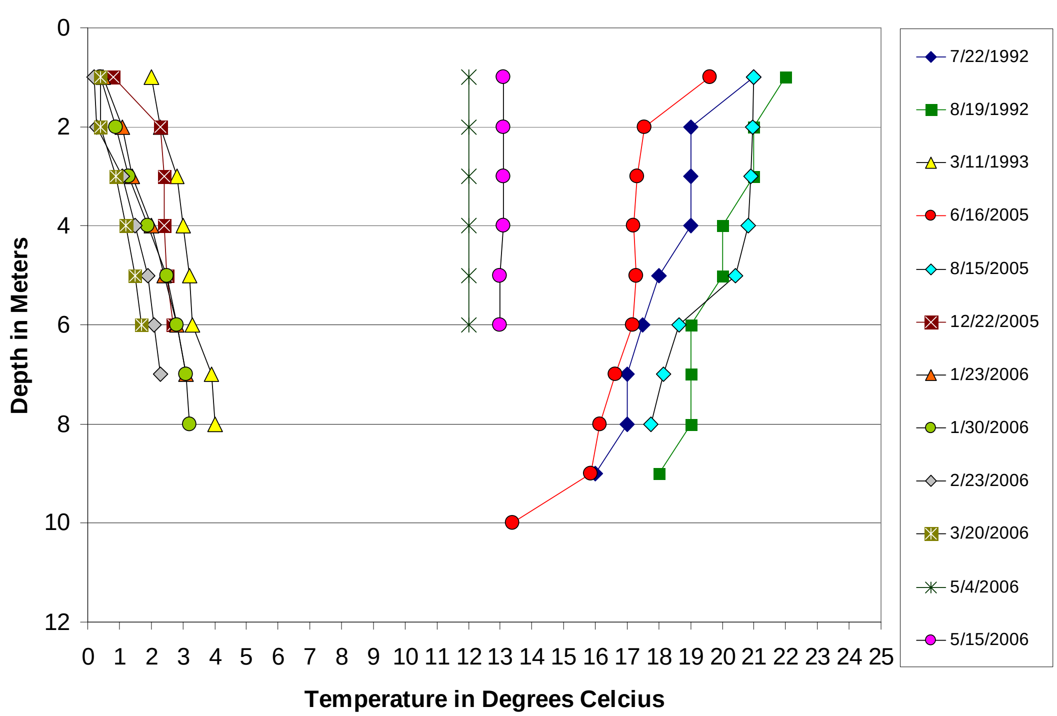


Figure 3. Temperature Profiles for Larimore Dam from 1992 to 2006.

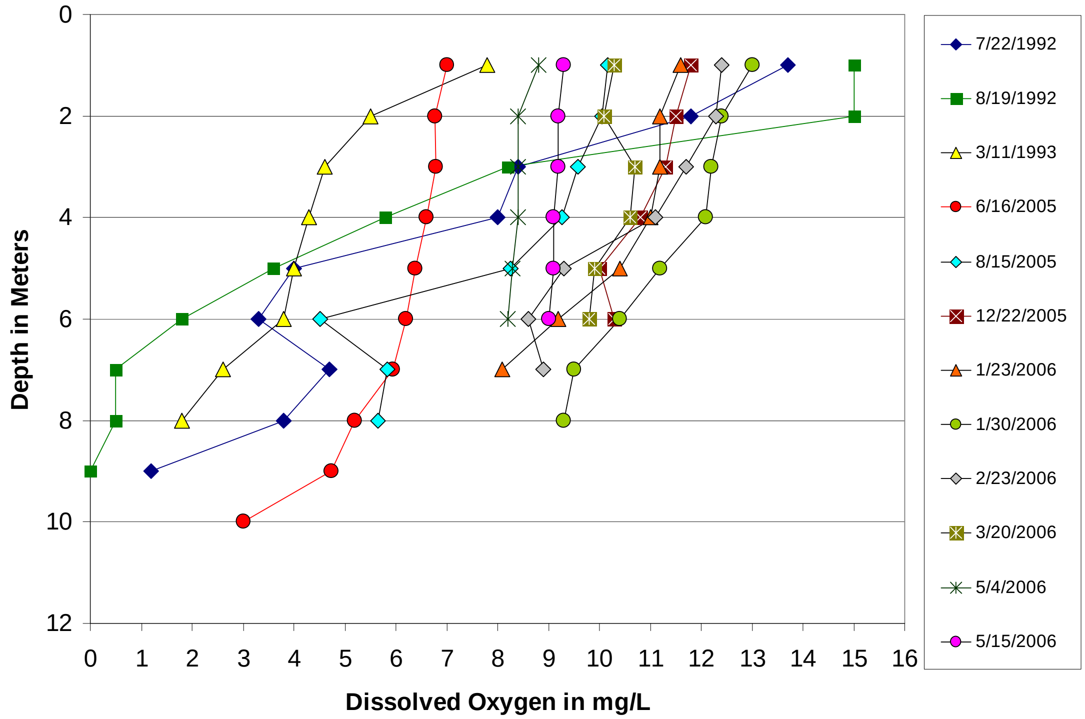


Figure 4. Dissolved Oxygen Profiles for Larimore Dam from 1992 to 2006.

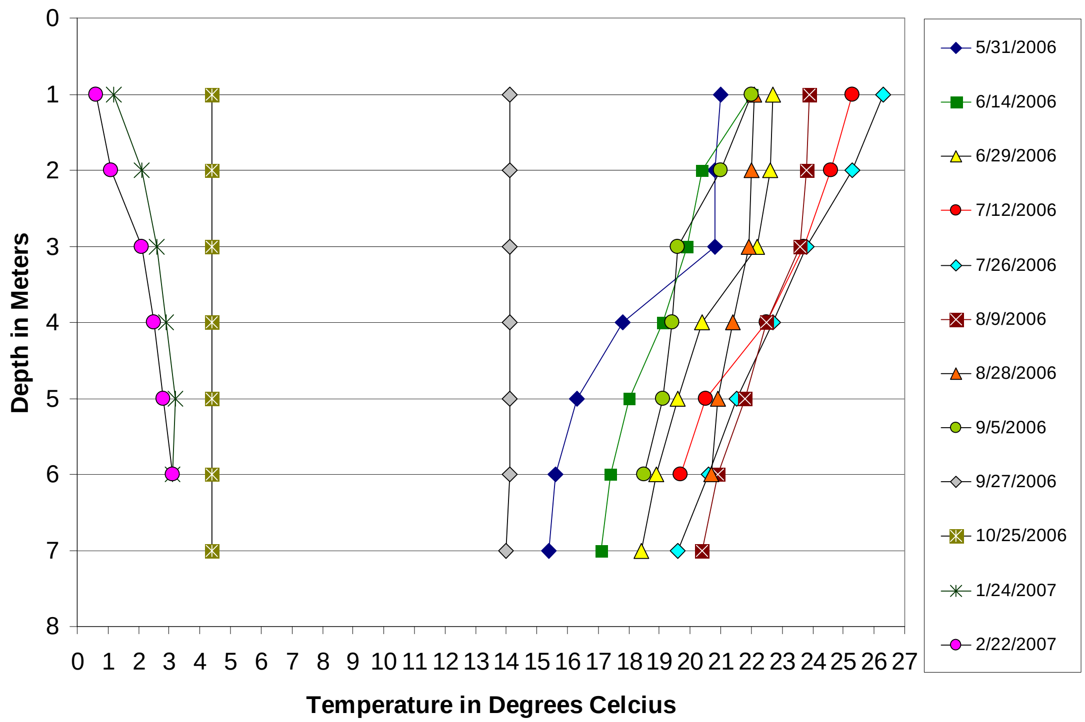


Figure 5. Temperature Profiles for Larimore Dam from 2006 to 2007.

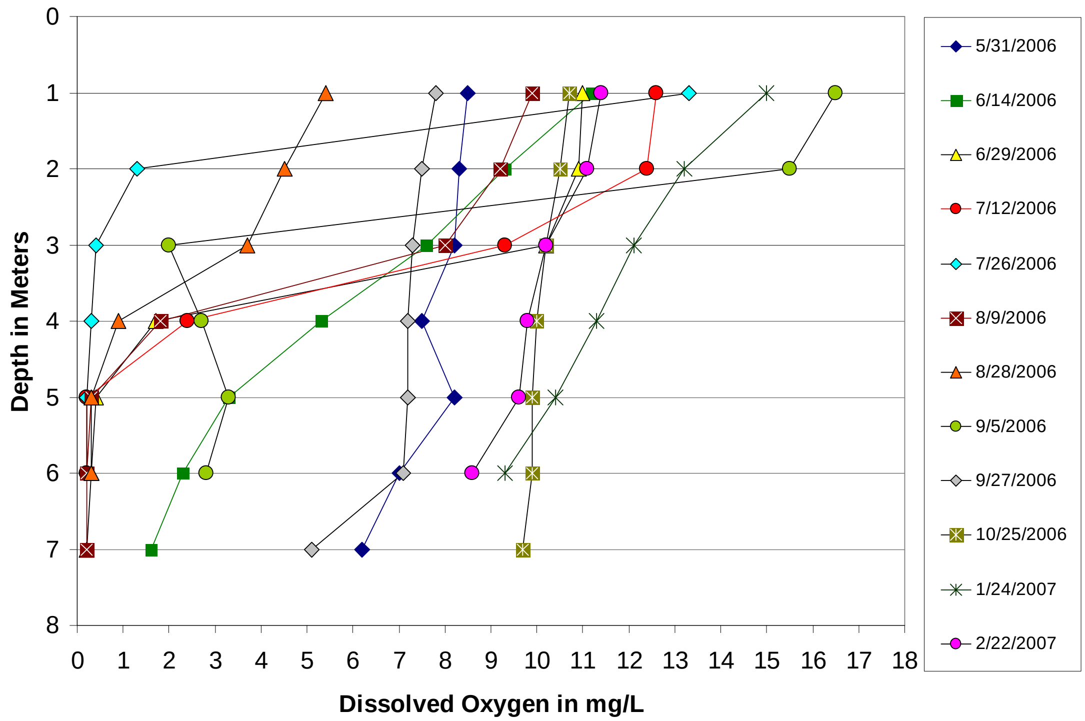


Figure 6. Dissolved Oxygen Profiles for Larimore Dam from 2006 to 2007.

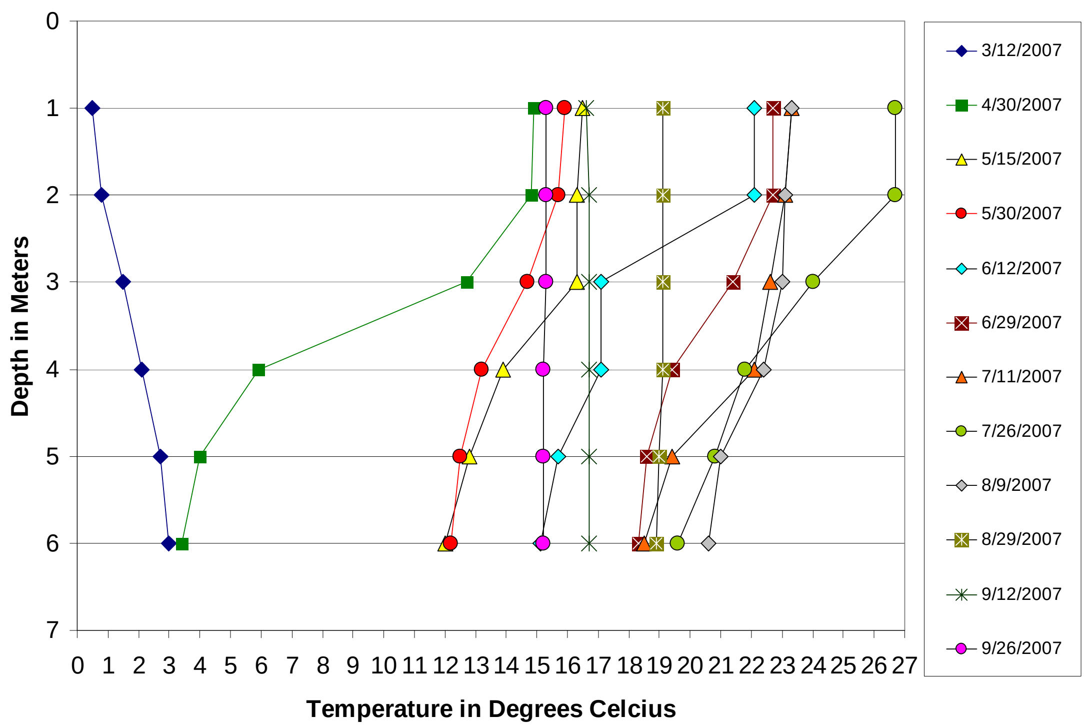


Figure 7. Temperature Profiles for Larimore Dam from 2007.

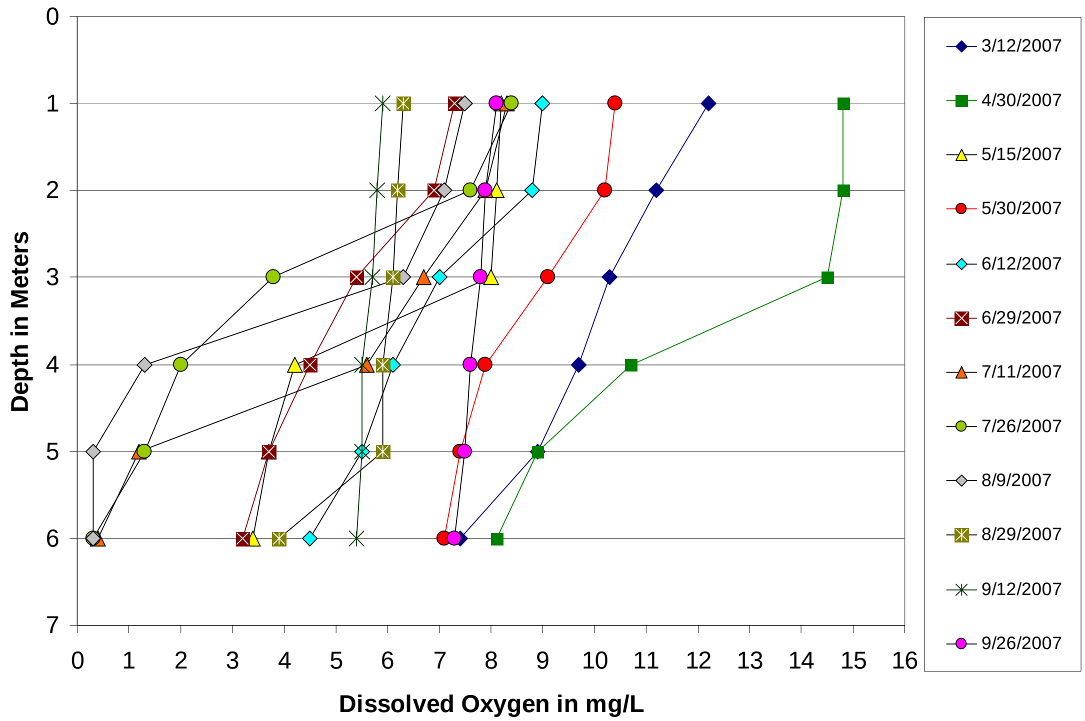


Figure 8. Dissolved Oxygen Profiles for Larimore Dam from 2007.

General Water Quality: Data collected by the NDG&F and GFCSCD in 2005–2007 indicate Larimore Dam is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 106 mg/L to 314 mg/L (Table 1). Larimore Dam is sodium bicarbonate dominated with an average sodium concentration of 55 mg/L, and an average bicarbonate concentration of 260 mg/L. The average TDS and specific conductivity measurements were 596 mg/L and 944 µmhos/cm, respectively. Average total phosphorus and total nitrogen concentrations were 0.076 mg/L and 0.803 mg/L, respectively.

There does appear to be an increasing trend in total nitrogen and dissolved solid concentrations in Larimore Dam from 1992-2007. While the trend is probably not significant, as the variation falls within the standard deviation and certain important parameters like total phosphorus have remained stable, it is a concern (Tables 1 and 2).

Water quality data collected in 2005 through 2007 was compared to the state's long term data set for reservoirs in the Cultivated Plains ecological region. When compared to other reservoirs in the same ecological region, Larimore Dam has similar levels of dissolved solids but slightly lower nutrient concentrations (Tables 1 and 3). Larimore Dam's average total phosphorus concentrations of 0.076 mg/L is approximately three fold less then the long term average for reservoirs in the Cultivated Plains region, while the average total nitrogen concentration of 0.803 mg/L is approximately one-half of the regional average. Dissolved solids were similar but consistently lower then the state's long term average for reservoirs in the Cultivated Plains region.

Table 1. Statistical Summary of Larimore Dam's 2005-2007 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	34	225	106	314	53.8
Total Ammonia as N	mg/L	34	0.073	0.010[1]	0.435	0.094
Bicarbonate (HCO_3)	mg/L	34	260	91	383	74.8
Calcium (Ca)	mg/L	34	94	45	126	19.89
Carbonate (CO_3)	mg/L	34	7.2	1[1]	28	7.4
Chloride (Cl)	mg/L	34	32.4	18.1	52.8	7.2
Chlorophyll-a	µg/L	22	43.8	1.5[1]	388	83.0
Specific Conductance	µmhos	34	944	700	1400	171.3
Total Dissolved Solids	mg/L	34	596	401	930	127.9
Total Hardness as ($CaCO_3$)	mg/L	34	382	268	500	59.4
Hydroxide (OH)	mg/L	34	1[1]	1[1]	1[1]	0.0
Iron (Fe)	mg/L	34	0.124	0.010	0.918	0.164
Magnesium (Mg)	mg/L	34	35.7	20.0	52.6	6.8
Nitrate + Nitrite as N	mg/L	34	0.119	0.020	0.680	0.155
Total Kjeldahl Nitrogen as N	mg/L	34	0.684	0.207	1.230	0.299
Total Nitrogen as N	mg/L	34	0.803	0.418	1.910	0.312
pH		34	8.31	7.481	8.921	0.341
Total Phosphorus as P	mg/L	34	0.076	0.016	0.410	0.073
Potassium (K)	mg/L	34	5.468	2.700	10.100	1.429
Sodium (Na)	mg/L	34	55.41	10.5	133.0	27.3
Sulfate (SO4)	mg/L	34	235	101	438	86.9

[1]Equal to Minimum Reportable Limit

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Larimore Dam, and that the ratio of total nitrogen to total phosphorus (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There are 35 nutrient sample sets for Larimore Dam between June 1992 and November 2007. The 35 samples used in this interpretation indicate that Larimore Dam's nutrient relationships are dynamic as both nitrogen and phosphorus are limiting productivity at different times of the year (Figure 9). The nitrogen to phosphorus ratio for Larimore Dam ranged from a low of 5 to a high of 52 with an average of 16. Of the 35 samples collected, 11 were above a ratio of 15, and 24 were at or below a ratio 15, indicating that nitrogen is most often limiting primary production.

Table 2. Statistical Summary of Larimore Dam's Historical Water Quality Data Collected Between 1992 through 1993.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	236	151	318	83.5
Total Ammonia as N	mg/L	3	0.135	0.012	0.295	0.145
Bicarbonate (HCO_3)	mg/L	3	254	180	292	64.0
Calcium (Ca)	mg/L	3	80.4	58.1	99.5	20.9
Carbonate (CO_3)	mg/L	2	25	2[1]	48	32.5
Chloride (Cl)	mg/L	3	25.6	20.1	28.4	4.7
Chlorophyll-a	µg/L	2	26	12	39	19
Specific Conductance	µmhos	3	667.3	625.3	728.7	54.3
Total Dissolved Solids	mg/L	3	428	373	512	74.1
Total Hardness as ($CaCO_3$)	mg/L	3	318	263	354	48.5
Hydroxide (OH)	mg/L		NC[2]	NC[2]	NC[2]	
Iron (Fe)	mg/L	3	0.081	0.035	0.169	0.076
Magnesium (Mg)	mg/L	3	28.5	25.6	31.2	2.8
Nitrate + Nitrite as N	mg/L	1	0.006[1]	0.006[1]	0.006[1]	0.0
Total Kjeldahl Nitrogen as N	mg/L	2	1.000	0.680	1.320	0.453
Total Nitrogen as N	mg/L	2	1.006	0.686	1.326	0.455
pH		3	8.290	7.800	8.610	0.431
Total Phosphorus as P	mg/L	3	0.074	0.046	0.113	0.035
Potassium (K)	mg/L	3	4.11	3.23	4.73	0.78
Sodium (Na)	mg/L	3	27	15	34	10.9
Sulfate (SO4)	mg/L	3	120	91	139	25.5

[1]Equal to Minimum Reportable Limit
[2]No data collected

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected from 1992 to 2007, Larimore Dam's trophic status is eutrophic (Figure 10). TSI scores ranged from a low of 35 based on chlorophyll-a, to a high of 91 based on total phosphorus data. The average trophic status score based on Secchi disk transparency was similar to that estimated by chlorophyll-a, at 50 (Figure 10).

A total of 35 total phosphorus samples, 23 chlorophyll-a samples, and 5 Secchi disk transparency measurements collected during the open water periods from 1992 to 2007, were used to evaluate trends in the trophic status of Larimore Dam. Since Larimore Dam is most often nitrogen limited, chlorophyll-a and Secchi disk transparency are probably better indicators of trophic status then total phosphorus. Based on a visual assessment of the data, Larimore Dam's trophic status is stable (Figure 6).

Table 3. Statistical Summary of Water Quality Data[2] Collected from Reservoirs in the Cultivated Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	352	263	88	891	103
Total Ammonia as N	mg/L	463	0.131	0.001[1]	2.070	0.203
Bicarbonate (HCO_3)	mg/L	352	296	91	951	114
Calcium (Ca)	mg/L	352	65	19	169	22
Carbonate (CO_3)	mg/L	324	14	1[1]	93	16
Chloride (Cl)	mg/L	351	21	1[1]	113	18
Chlorophyll-a	µg/L	373	20	2[1]	388	31
Specific Conductance	µmhos	352	1021	217	3140	516
Total Dissolved Solids	mg/L	344	667	127	2300	387
Total Hardness as ($CaCO_3$)	mg/L	352	334	95	1090	121
Hydroxide (OH)	mg/L	280	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	350	0.137	0.007	3.190	0.216
Magnesium (Mg)	mg/L	352	42	11	161	20
Nitrate + Nitrite as N	mg/L	411	0.097	0.003	2.060	0.191
Total Kjeldahl Nitrogen as N	mg/L	376	1.476	0.207	4.410	0.642
Total Nitrogen as N	mg/L	315	1.488	0.418	3.220	0.587
pH		352	8.36	6.89	9.40	0.43
Total Phosphorus as P	mg/L	464	0.322	0.004[1]	1.380	0.267
Potassium (K)	mg/L	352	12	3[1]	35	5
Sodium (Na)	mg/L	352	97	2[1]	582	107
Sulfate (SO4)	mg/L	351	269	8	1350	217

[1]Equal to lower detection limit
[2]Data Collected from 40 Reservoirs between 1991 and 2007

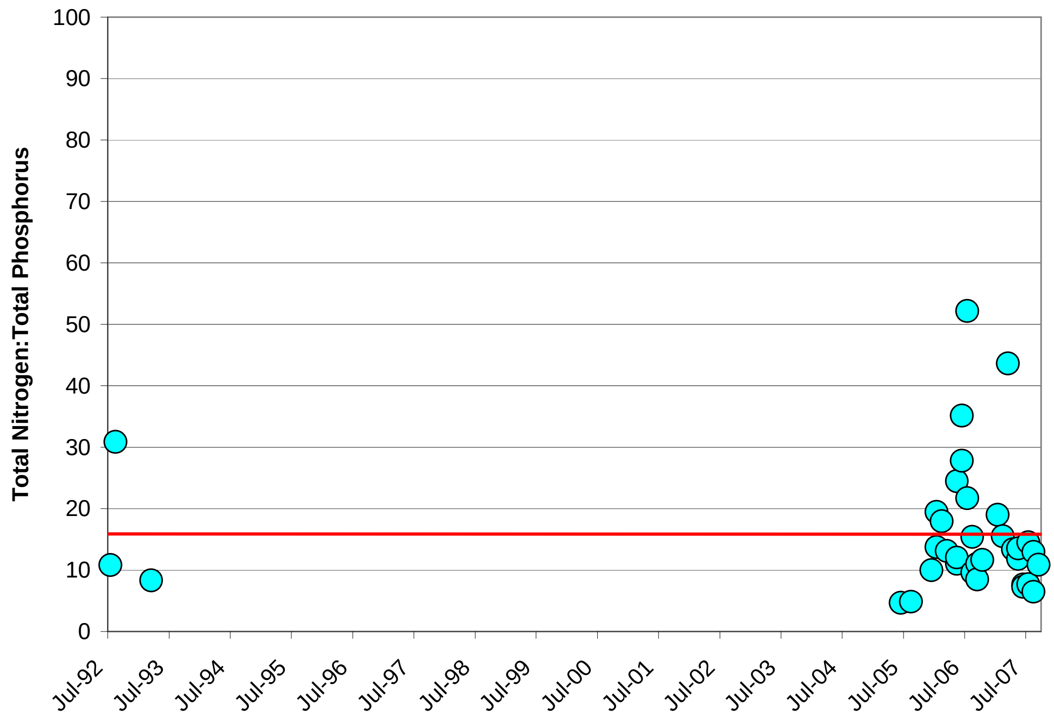


Figure 9. Total Nitrogen to Total Phosphorus Ratios in Larimore Dam (1992-2007).

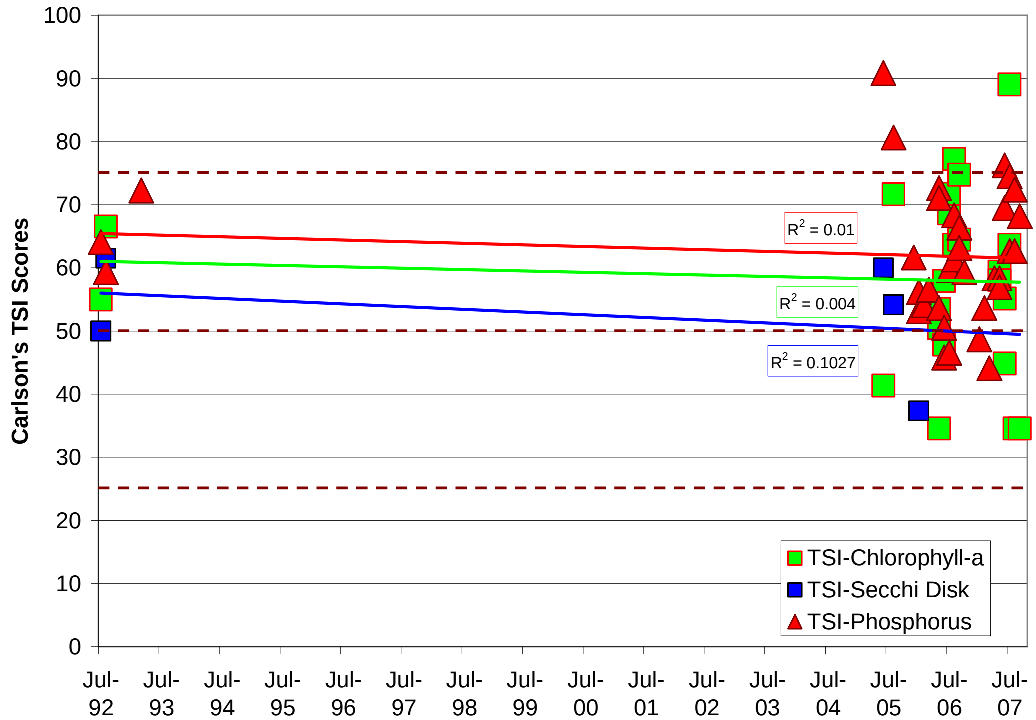


Figure 10. TSI Scores and Temporal Trends for Larimore Dam from 1992 to 2007.

Raleigh Reservoir, Grant County

BACKGROUND

Location: Raleigh Reservoir is located approximately 30 miles west of the Missouri River and 30 miles north of the South Dakota border. Directions to Raleigh Reservoir are 3.5 miles west of Raleigh and then 1 half mile south (Figure 1). Raleigh Reservoir is managed by the North Dakota Game and Fish Department.

Figure 1. Location of Raleigh Reservoir.

Physiographic/Ecological Setting: Raleigh Reservoir is a 59.2 acre reservoir with a maximum depth of 33.6 feet and an average depth of 13.3 feet (Figure 2). Raleigh Reservoir and its contributing watershed are located in the Northwestern Great Plains (NWGP) Level III Ecoregion. The NWGP is part of the broader Rangeland Plains located in the Missouri Plateau of the Great Plains (Figure1). The watershed landscape is rolling plains. Flood plain slopes and hillsides are usually native grass, while the uplands and flood plains themselves have mostly been converted to small grains and alfalfa.

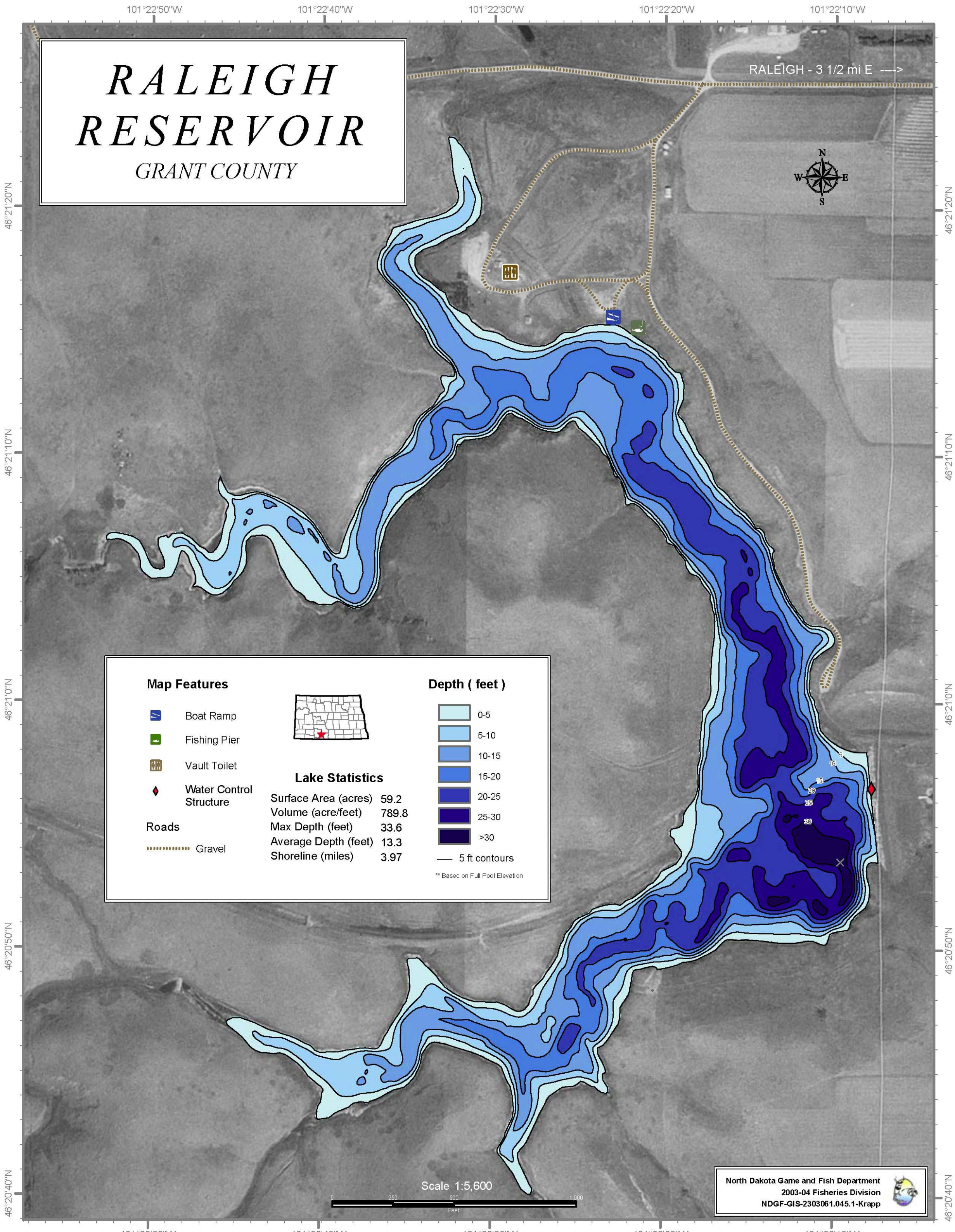


Figure 2. Contour Map of Raleigh Reservoir (Map Courtesy of the North Dakota Game and Fish Department).

Construction History: Raleigh Reservoir is an impoundment on a tributary to the Cannonball River. The reservoir was renovated in 1988 through the combined efforts of the State Water Commission, the North Dakota Game and Fish Department, and the Grant County Water Resources Board. After renovations, Raleigh Reservoir has a surface area of 59 acres, a maximum depth of 34 feet and an average depth of 13 feet (Figure 2).

Recreational Facilities: Raleigh Reservoir and the immediate area surrounding the shoreline is owned and managed by the North Dakota Game and Fish Department. Recreational facilities at the reservoir include a boat ramp, associated parking, a fishing pier, and a picnic area.

Water Quality Standards Classification: Raleigh Reservoir is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2007) as a class 2 lake. Class 2 lakes and reservoirs are defined as "Cool Water Fisheries" or "waters capable of supporting natural reproduction and growth of cool water fishes (e. g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: Raleigh Reservoir's fishery is managed by the North Dakota Game and Fish Department. Historical and current fisheries include trout, bluegill, and largemouth bass. Boats are restricted to idle speeds only and no live bait fish are allowed.

Historical Water Quality Samples: There is no historical data available for Raleigh Reservoir.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trend assessments for Raleigh Reservoir have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There are two temperature and dissolved oxygen profiles for Raleigh Reservoir collected in 2005 and 2006 (Figures 3 and 4). The limited profile data shows Raleigh Reservoir was weakly thermally stratified in July 19, 2005 but lacked stratification on March 7, 2006.

Dissolved oxygen concentrations remained above the state's water quality standard of 5 mg/L for nearly the entire water column in March of 2006 but rapidly decayed in July of 2005 below 5 meters of depth. While the rapid loss of dissolved oxygen in July is concerning, there does appear to be enough dissolved oxygen to maintain aquatic life throughout the majority of the lake volume on both dates.

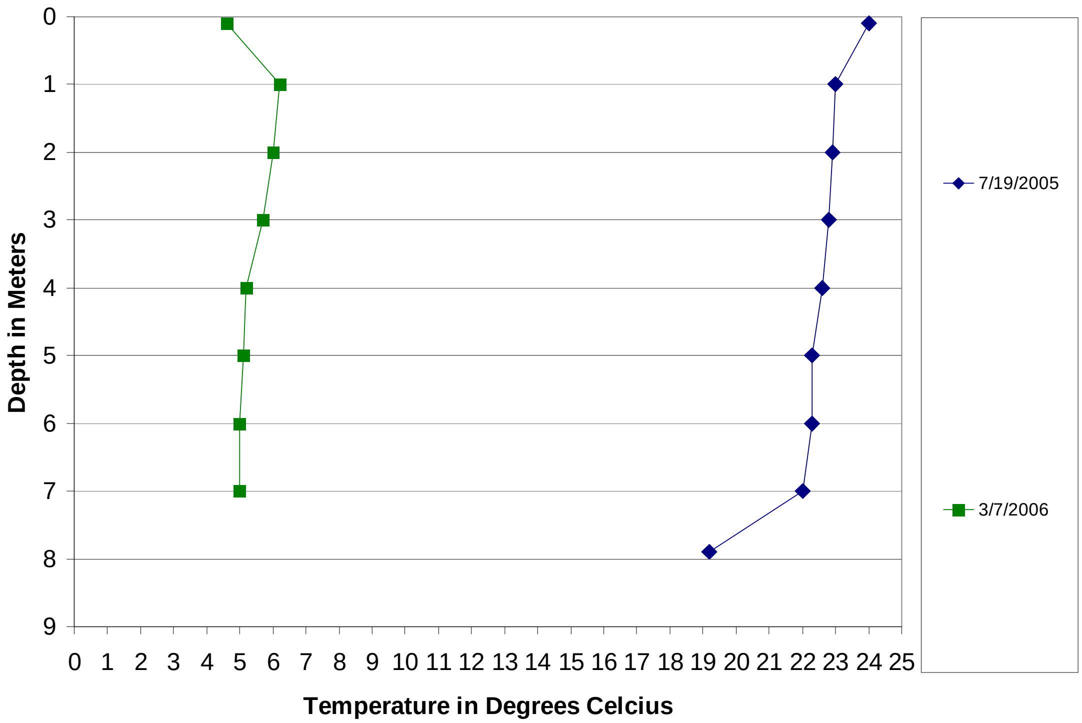


Figure 3. Temperature Profiles for Raleigh Reservoir from 2005 to 2006.

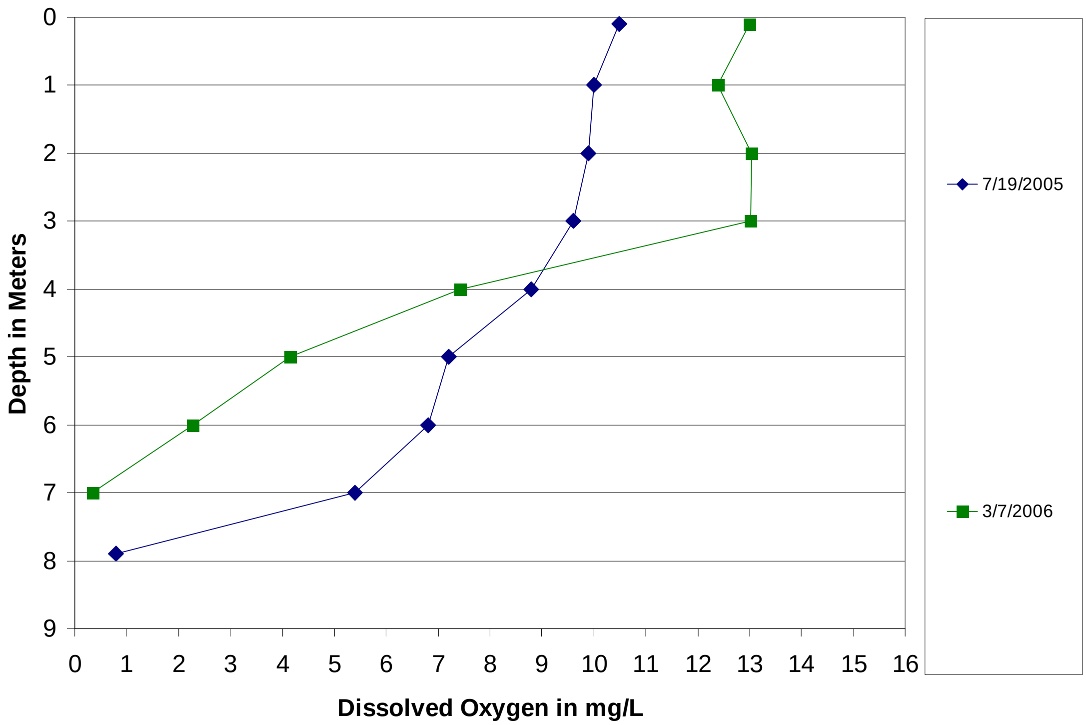


Figure 4. Dissolved Oxygen Profiles for Raleigh Reservoir from 2005 to 2006.

General Water Quality: Current water quality data collected by the NDGFD indicates Raleigh Reservoir is well buffered with total alkalinity as $CaCO_3$ concentrations ranging from 203 mg/L to 224 mg/L (Table 1). Raleigh Reservoir is sodium sulfate dominated with an average sodium concentration of 86 mg/L and an average sulfate concentration of 751 mg/L. The average total dissolved solids (TDS) concentration and specific conductance measurements for the 2005-2006 sampling period were 1245 mg/L and 1655 µmhos/cm respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.420 mg/L and 0.075 mg/L respectively.

An average total phosphorus concentration of 0.075 mg/L is approximately half the Rangeland Plains region average for reservoirs of 0.135 mg/L (Table 2). Total nitrogen concentrations on Raleigh Reservoir were nearly identical to the long term average for reservoirs in the Rangeland Plains ecological region (Tables 1 and 2).

Table 1. Statistical Summary of Raleigh Reservoir's 2005-2006 Water Quality Data.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	2	2147	203	224	15
Total Ammonia as N	mg/L	2	0.017	0.016	0.017	0.001
Bicarbonate (HCO_3)	mg/L	2	228	194	262	48.1
Calcium (Ca)	mg/L	2	95.4	87.7	103.0	10.8
Carbonate (CO_3)	mg/L	2	15	5	26	15
Chloride (Cl)	mg/L	2	20	18	23	3
Chlorophyll-a	µg/L	1	17.6	17.6	17.6	0
Specific Conductance	µmhos	2	1655	1530	1780	177
Total Dissolved Solids	mg/L	2	1245	1140	1350	149
Total Hardness as ($CaCO_3$)	mg/L	2	833	742	924	129
Hydroxide (OH)	mg/L	2	1[1]	1[1]	1[1]	0.0
Iron (Fe)	mg/L	2	0.181	0.147	0.215	0.048
Magnesium (Mg)	mg/L	2	144	127	162	24.7
Nitrate + Nitrite as N	mg/L	2	0.020	0.020	0.020	0
Total Kjeldahl Nitrogen as N	mg/L	2	1.40	1.38	1.42	0.03
Total Nitrogen as N	mg/L	2	1.420	1.400	1.440	0.028
pH		2	8.610	8.370	8.850	0.339
Total Phosphorus as P	mg/L	2	0.075	0.045	0.105	0.042
Potassium (K)	mg/L	2	18.1	17.0	19.1	1.5
Sodium (Na)	mg/L	2	86	78	95	12
Sulfate (SO4)	mg/L	2	751	686	816	92

[1]Equal to Minimum Reportable Limit

Table 2. Statistical Summary of Water Quality Data[2] Collected from Reservoirs in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	408	309	101	982	130
Total Ammonia as N	mg/L	469	0.097	0.001[1]	2.440	0.200
Bicarbonate (HCO_3)	mg/L	408	318	14	1040	150
Calcium (Ca)	mg/L	408	50	5	160	26
Carbonate (CO_3)	mg/L	402	30	1[1]	197	30
Chloride (Cl)	mg/L	408	13.3	0.3	74.5	8.8
Chlorophyll-a	µg/L	321	21.2	1.5	218.0	27.9
Specific Conductance	µmhos	428	1733	262	5880	959
Total Dissolved Solids	mg/L	409	1176	147	5110	750
Total Hardness as ($CaCO_3$)	mg/L	408	397	45	1850	260
Hydroxide (OH)	mg/L	337	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	409	0.179	0.007	4.110	0.334
Magnesium (Mg)	mg/L	408	66.0	5.6	353.0	49.6
Nitrate + Nitrite as N	mg/L	395	0.048	0.001[1]	0.790	0.092
Total Kjeldahl Nitrogen as N	mg/L	359	1.556	0.365	7.720	0.779
Total Nitrogen as N	mg/L	302	1.472	0.405	4.840	0.562
pH		428	8.61	6.73	9.87	0.56
Total Phosphorus as P	mg/L	475	0.135	0.004	3.160	0.205
Potassium (K)	mg/L	408	14.6	4.2	39.2	6.3
Sodium (Na)	mg/L	408	239	3[1]	932	171
Sulfate (SO4)	mg/L	406	604	1[1]	3210	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 69 Reservoirs between 1991 and 2007

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Raleigh Reservoir and that the ratio of total nitrogen to total phosphorus (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were two water quality sample results for Raleigh Reservoir, one in July of 2005 and one in May of 2006. The two samples used in this interpretation indicate that the N:P relationships in Raleigh Reservoir are dynamic and variable, based on the time of the year and the natural processes occurring at the time of sampling (Figure 5).

Trophic Status Assessment: Based on a single chlorophyll-a, Secchi disk transparency, and total phosphorus sample collected during the summer of 2005, Raleigh Reservoir's trophic status is eutrophic (Figure 6). TSI scores ranged from a low of 55 based on Secchi disk transparency, to a high of 71 based on total phosphorus. The trophic status score based on chlorophyll-a was 59 (Figure 6).

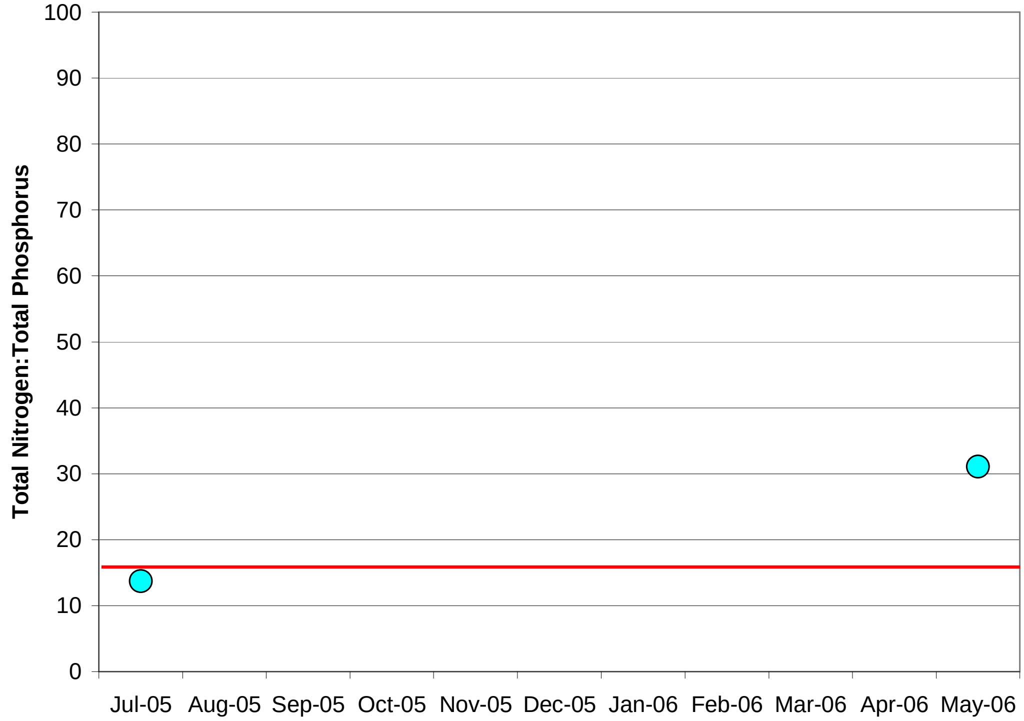


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Raleigh Reservoir (2005-2006).

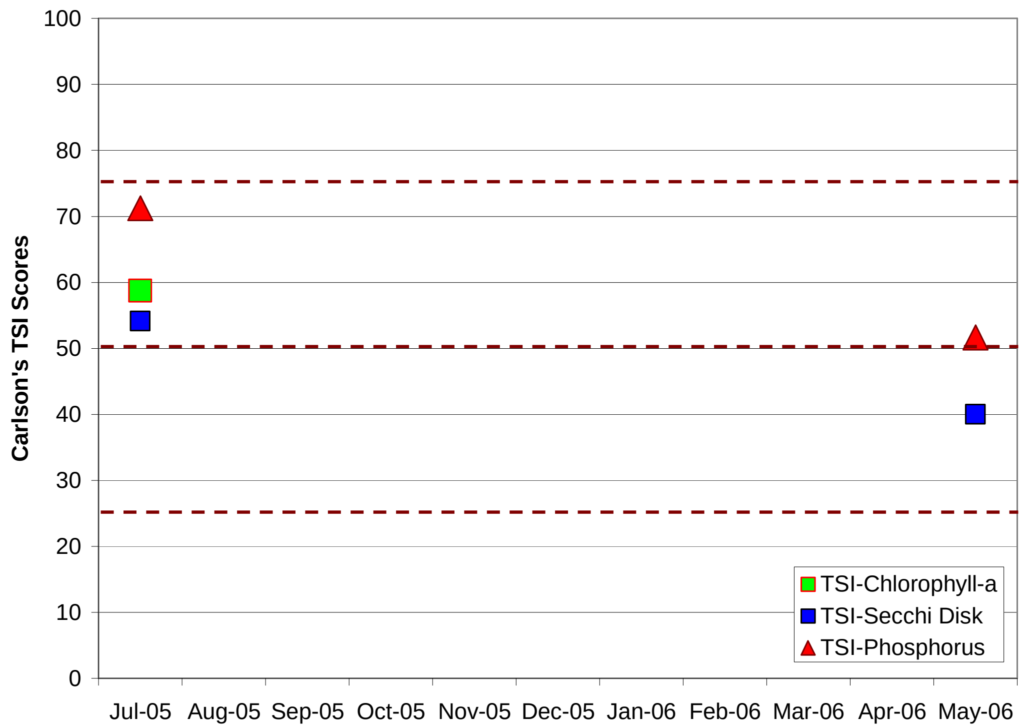


Figure 6. TSI Scores for Raleigh Reservoir from 2005-2006.

Sheep Creek Dam, Grant County

BACKGROUND

Location: Sheep Creek Dam is a small recreational impoundment located on a tributary to the Cannonball River. Directions to Sheep Creek Dam from Elgin are 4 miles south and ½ mile west (Figure 1). The reservoir is managed by the North Dakota Game and Fish Department.

Figure 1. Location of Sheep Creek Dam.

Physiographic/Ecological Setting: Sheep Creek Dam has a surface area of 83.4 acres, a maximum depth of 34.4 feet, and an average depth of 13.8 feet (Figure 2). Sheep Creek Dam is located in the Northwestern Great Plains (NWGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The watershed landscape is rolling plains. Flood plain slopes and hillsides are usually native grass, while the uplands and flood plains themselves have mostly been converted to small grains and alfalfa.

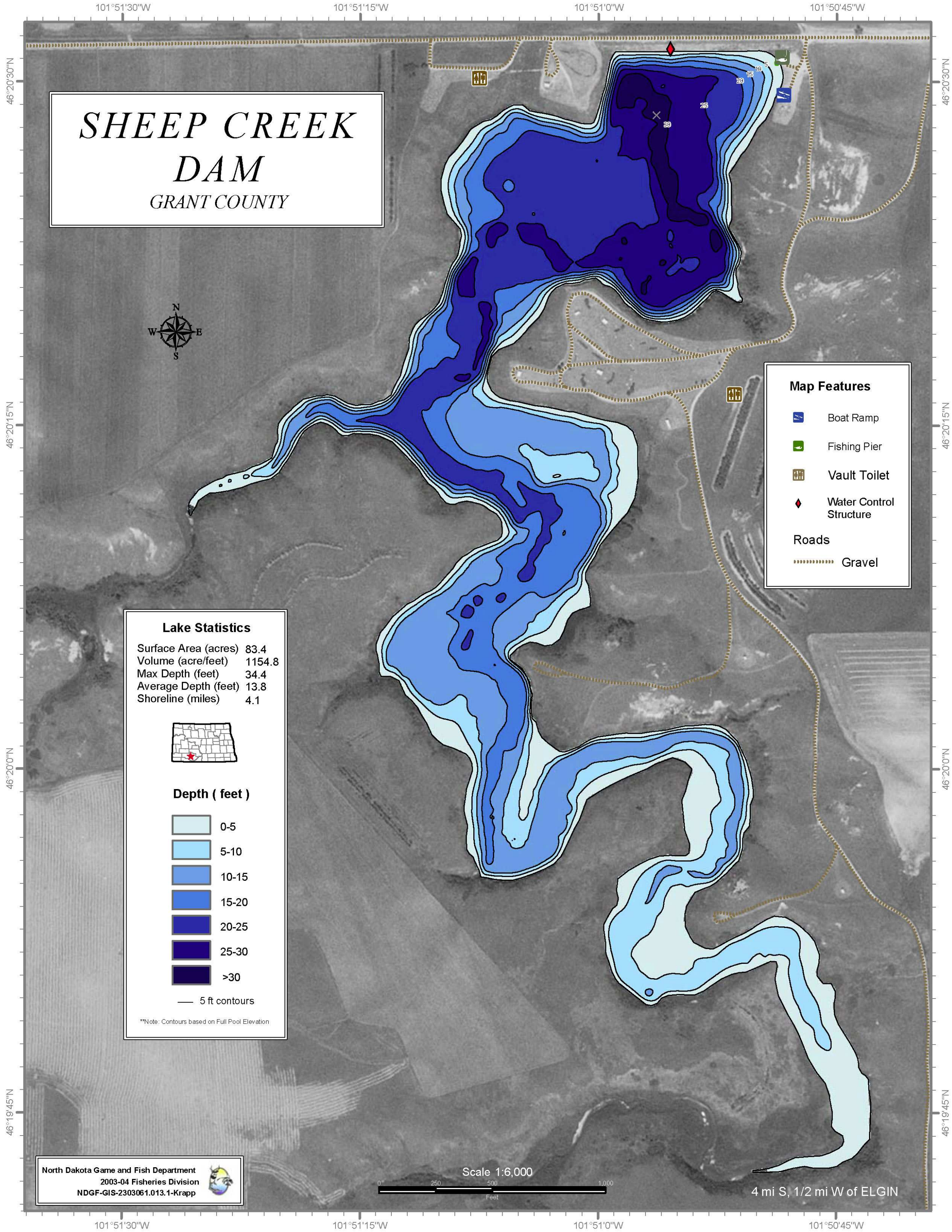


Figure 2. Contour Map of Sheep Creek Dam (Map Courtesy of the North Dakota Game and Fish Department).

Construction History: Sheep Creek Dam was built by the Bureau of Outdoor Recreations, the North Dakota Game and Fish Department, the Soil Conservation Service, and Grant County in the 1970's.

Recreational Facilities: Sheep Creek Dam and the immediate area surrounding the shoreline are publicly owned. The well maintained facilities include a boat ramp and two picnic areas with shelters and garbage pickup. Boats are restricted to idle speeds at Sheep Creek Dam.

Water Quality Standards Classification: Sheep Creek Dam is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2007) as a class 2 lake. Class 2 lakes and reservoirs are defined as "Cool Water Fisheries" or "waters capable of supporting natural reproduction and growth of cool water fishes (e.g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: The historical fishery for Sheep Creek Dam includes rainbow trout, northern pike, and smallmouth bass. The current fishery at the reservoir is bluegill, walleye, and largemouth bass. The No live bait fish are allowed.

Historical Water Quality Samples: Historical water quality data includes 13 sample sets collected in 1992-2004.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trend assessments for Sheep Creek Dam have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There are five temperature and dissolved oxygen profiles for Sheep Creek Dam collected between 1992-1993 and 2005-2006. The profile data shows that during thermal stratification Sheep Creek Dam experiences rapid oxygen decay below the thermal cline (Figures 3 and 4). All six samples collected fell below the state water quality standard of 5 mg/L and on February 16, 1993, dissolved oxygen concentrations were below the state standard for the entire water column (Figure 4).

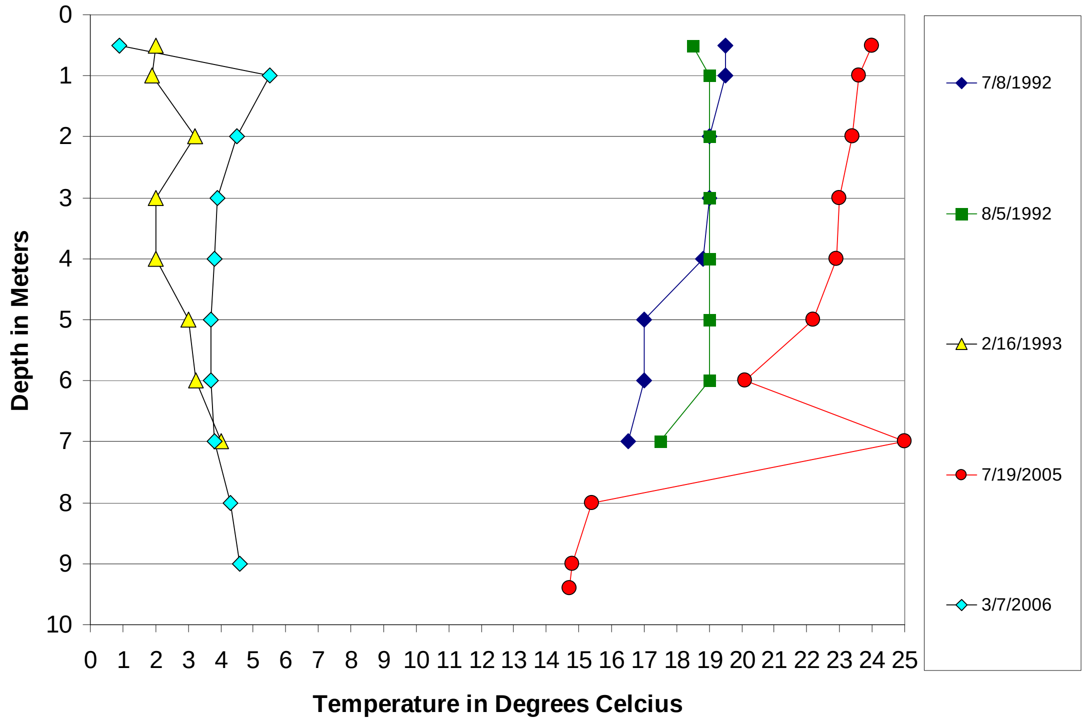


Figure 3. Temperature Profiles for Sheep Creek Dam from 1992 to 2006.

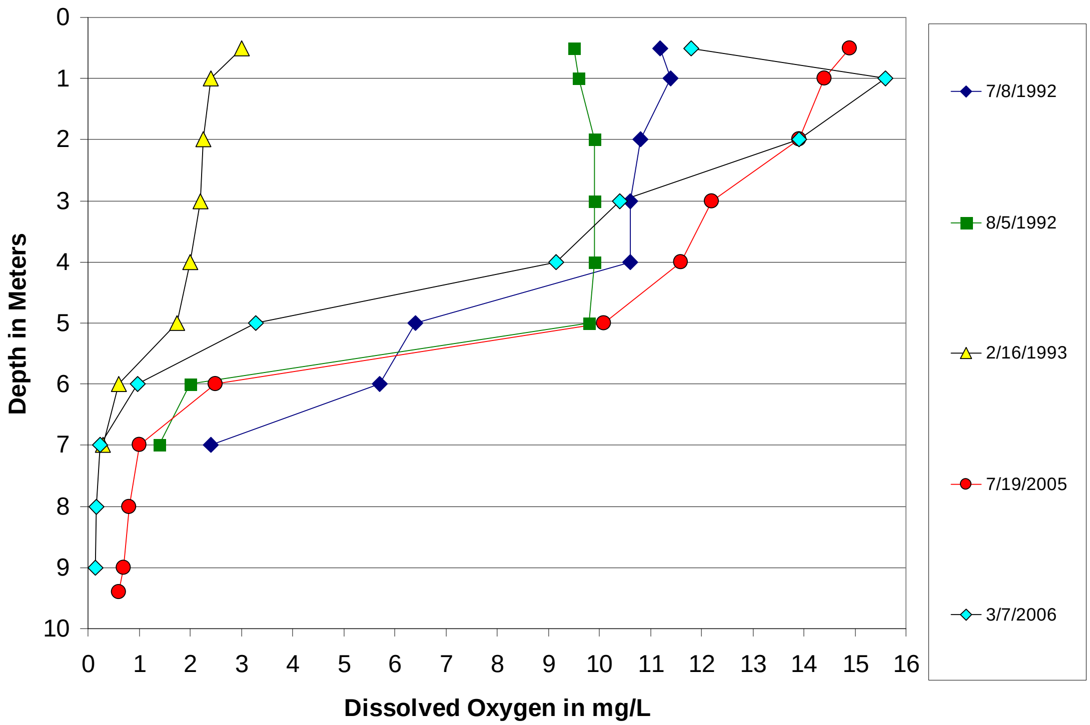


Figure 4. Dissolved Oxygen Profiles for Sheep Creek Dam from 1992 to 2006.

General Water Quality: Data collected by the NDGF in 2005 and 2006 indicate Sheep Creek Dam is well buffered with total alkalinity as $CaCO_3$ concentrations ranging from 322 mg/L to 377 mg/L (Table 1). Sheep Creek Dam is sodium sulfate dominated with an average sodium concentration of 300 mg/L and an average sulfate concentration of 671 mg/L. The average total dissolved solids (TDS) concentration and specific conductance measurements for the 2005-2006 sampling period were 1330 mg/L and 1915 µmhos/cm respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.380 mg/L and 0.118 mg/L respectively.

Table 1. Statistical Summary of Sheep Creek Dam's 2005-2006 Water Quality Data.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	2	350	322	377	38.9
Total Ammonia as N	mg/L	2	0.026	0.015	0.037	0.016
Bicarbonate (HCO_3)	mg/L	2	356	277	434	111
Calcium (Ca)	mg/L	2	52.6	46.8	58.5	8.2
Carbonate (CO_3)	mg/L	2	35	13	57	31.1
Chloride (Cl)	mg/L	2	7.78	7.51	8.05	0.38
Chlorophyll-a	µg/L	1	27.2	27.2	27.2	0.0
Specific Conductance	µmhos	2	1915	1790	2040	176
Total Dissolved Solids	mg/L	2	1330	1250	1410	113
Total Hardness as ($CaCO_3$)	mg/L	2	407	369	446	54
Hydroxide (OH)	mg/L	2	1[1]	1[1]	1[1]	0.0
Iron (Fe)	mg/L	2	0.139	0.078	0.200	0.086
Magnesium (Mg)	mg/L	2	67.1	61.3	72.9	8.2
Nitrate + Nitrite as N	mg/L	2	0.030	0.020	0.040	0.014
Total Kjeldahl Nitrogen as N	mg/L	2	1.350	1.320	1.380	0.042
Total Nitrogen as N	mg/L	2	1.380	1.360	1.400	0.028
pH		2	8.78	8.45	9.12	0.47
Total Phosphorus as P	mg/L	2	0.118	0.059	0.176	0.083
Potassium (K)	mg/L	2	17.8	17.5	18.0	0.3
Sodium (Na)	mg/L	2	300	282	318	25
Sulfate (SO4)	mg/L	2	671	639	703	45

[1]Equal to Minimum Reportable Limit

There appears to be a trend towards lower nutrient concentration between the historical data set and the current data set. The current average total nitrogen and total phosphorus concentrations are 1.380 and 0.118 mg/L respectively, compared to the historical averages of 1.431 mg/L and 0.209 mg/L respectively (Table 2).

Sheep Creek Dam's chemical makeup, while similar to the Rangeland Plains region's long term average, is slightly more saline and harder. Total dissolved solids concentrations averaged 1330 mg/L, while the long term average is 1176 mg/L. Total hardness averaged 407 mg/L, while the long term average is 397 mg/L (Tables 1 and 3).

Unlike the dissolved solids, the concentrations of nitrogen and phosphorus were below the long term average for reservoirs in the Rangeland Plains ecological region. Total nitrogen concentrations averaged 1.380 mg/L, while the long term average is 1.472 mg/L. Total phosphorus averaged 0.118 mg/L, while the long term average is 0.135 mg/L (Tables 1 and 3).

Table 2. Statistical Summary of Sheep Creek Dam's Historical Water Quality Data Collected Between 1992 and 2004.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	13	317	237	422	59.1
Total Ammonia as N	mg/L	12	0.171	0.010[1]	1.500	0.423
Bicarbonate (HCO_3)	mg/L	13	321	218	515	88
Calcium (Ca)	mg/L	13	48	36	63	7
Carbonate (CO_3)	mg/L	12	35	7	61	17
Chloride (Cl)	mg/L	13	8.6	7.2	12.6	1.7
Chlorophyll-a	µg/L	8	31.5	1.5[1]	91.0	31.8
Specific Conductance	µmhos	13	1913	1610	2750	371
Total Dissolved Solids	mg/L	13	1342	1110	2010	302
Total Hardness as ($CaCO_3$)	mg/L	13	396	315	573	74
Hydroxide (OH)	mg/L	10	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	13	0.064	0.033	0.114	0.020
Magnesium (Mg)	mg/L	13	67.0	54.7	101.0	14.1
Nitrate + Nitrite as N	mg/L	11	0.144	0.020	0.790	0.242
Total Kjeldahl Nitrogen as N	mg/L	12	1.440	0.980	2.300	0.342
Total Nitrogen as N	mg/L	10	1.431	1.130	1.680	0.185
pH		13	8.82	8.17	9.35	0.35
Total Phosphorus as P	mg/L	13	0.209	0.086	0.384	0.101
Potassium (K)	mg/L	13	15.4	13.7	18.0	1.1
Sodium (Na)	mg/L	13	291	226	430	61
Sulfate (SO4)	mg/L	13	719	528	1170	201

[1]Equal to Minimum Reportable Limit

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Sheep Creek Dam, and that the ratio of total nitrogen to total phosphorus (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There are 15 water quality sample sets for Sheep Creek Dam between August 1992 and March 2006. The 15 samples used in this interpretation indicate that while Sheep Creek Dam's nitrogen to phosphorus ratio is variable, nitrogen is most often the limiting nutrient (Figure 5). The nitrogen to phosphorus ratio for Sheep Creek Dam ranged from a low of 4 to a high of 23 with an average of 11.

Table 3. Statistical Summary of Water Quality Data[2] Collected from Reservoirs in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	408	309	101	982	130
Total Ammonia as N	mg/L	469	0.097	0.001[1]	2.440	0.200
Bicarbonate (HCO_3)	mg/L	408	318	14	1040	150
Calcium (Ca)	mg/L	408	50	5	160	26
Carbonate (CO_3)	mg/L	402	30	1[1]	197	30
Chloride (Cl)	mg/L	408	13.3	0.3	74.5	8.8
Chlorophyll-a	µg/L	321	21.2	1.5	218.0	27.9
Specific Conductance	µmhos	428	1733	262	5880	959
Total Dissolved Solids	mg/L	409	1176	147	5110	750
Total Hardness as ($CaCO_3$)	mg/L	408	397	45	1850	260
Hydroxide (OH)	mg/L	337	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	409	0.179	0.007	4.110	0.334
Magnesium (Mg)	mg/L	408	66.0	5.6	353.0	49.6
Nitrate + Nitrite as N	mg/L	395	0.048	0.001[1]	0.790	0.092
Total Kjeldahl Nitrogen as N	mg/L	359	1.556	0.365	7.720	0.779
Total Nitrogen as N	mg/L	302	1.472	0.405	4.840	0.562
pH		428	8.61	6.73	9.87	0.56
Total Phosphorus as P	mg/L	475	0.135	0.004	3.160	0.205
Potassium (K)	mg/L	408	14.6	4.2	39.2	6.3
Sodium (Na)	mg/L	408	239	3[1]	932	171
Sulfate (SO4)	mg/L	406	604	1[1]	3210	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 69 Reservoirs between 1991 and 2007

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected in 2004-2006, Sheep Creek Dam's trophic status is eutrophic (Figure 6). TSI scores ranged from a low of 35 based on chlorophyll-a, to a high of 90 based on total phosphorus. The average trophic status score of 58 based on Secchi disk transparency was similar to the average score estimated by chlorophyll-a, at 56 (Figure 6).

A total of 15 phosphorus samples, nine chlorophyll-a samples, and four Secchi disk measurements collected from 1992 to 2006, were used to evaluate trends in the trophic status of Sheep Creek Dam. Since Sheep Creek Dam is nitrogen limited, only chlorophyll-a concentrations and Secchi disk transparency measurements were used to estimate the trophic status of Sheep Creek Dam. Based on a visual assessment Sheep Creek dam's trophic status is improving (Figure 6).

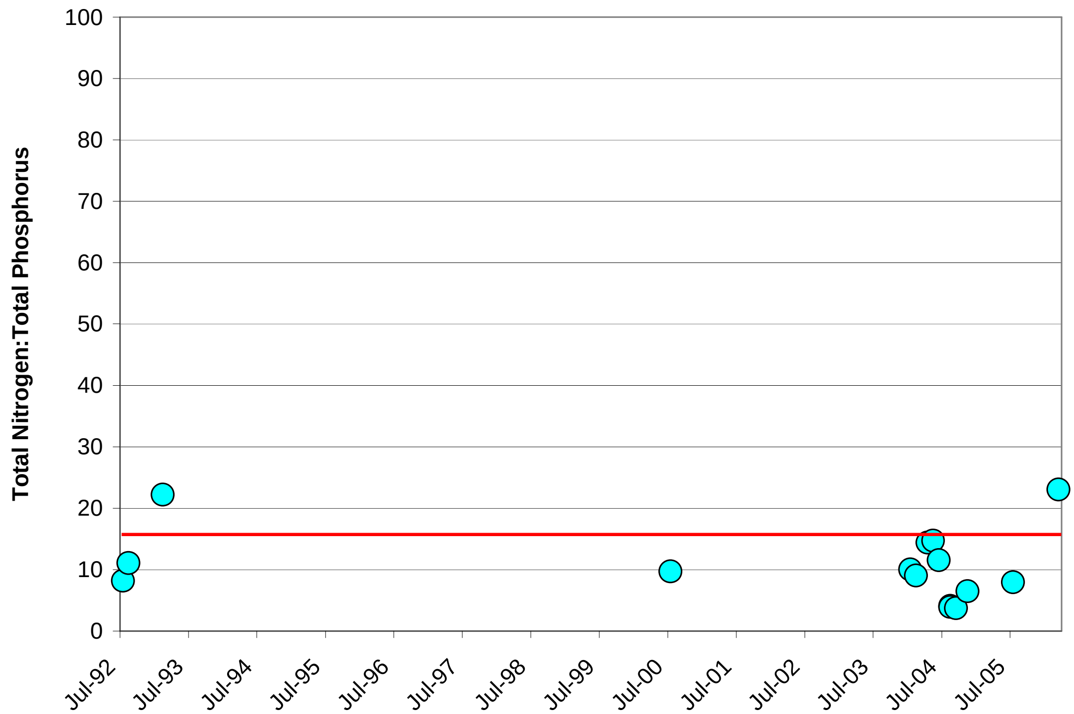


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Sheep Creek Dam (1992-2006).

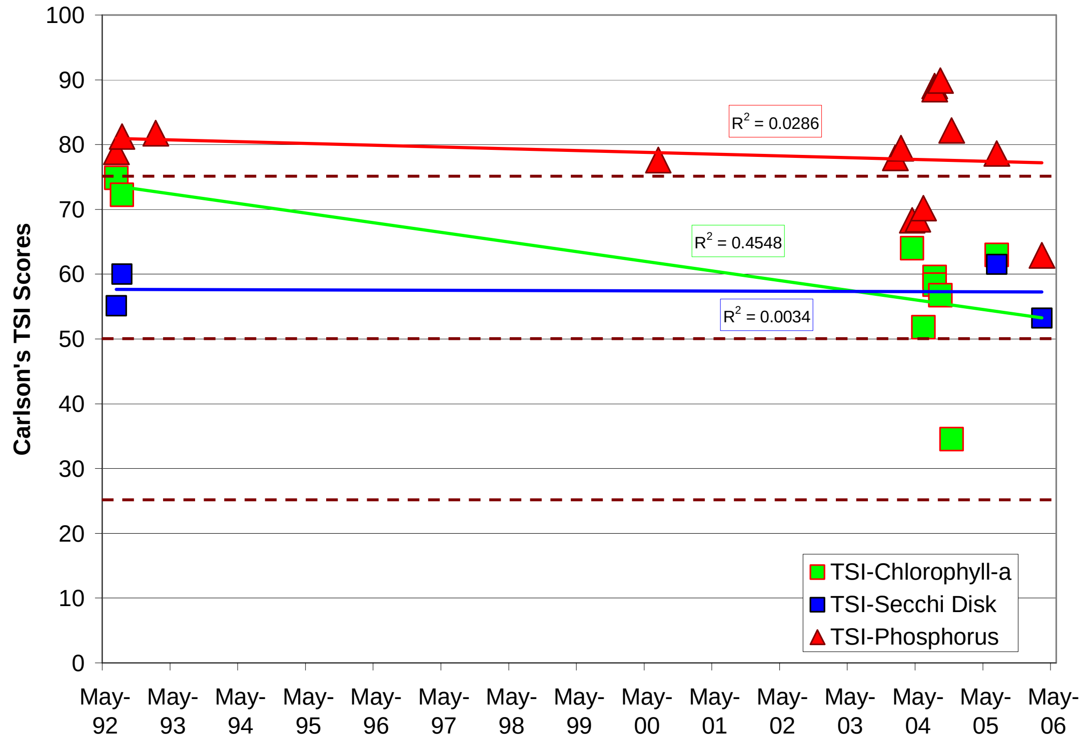


Figure 6. TSI Scores and Temporal Trends for Sheep Creek Dam from 1992 to 2006.

Red Willow Lake, Griggs County

BACKGROUND

Location: Red Willow Lake is a natural lake located 6 miles north and 2 miles west of Binford, North Dakota (Figure 1). The lake is managed by the North Dakota Game and Fish Department.

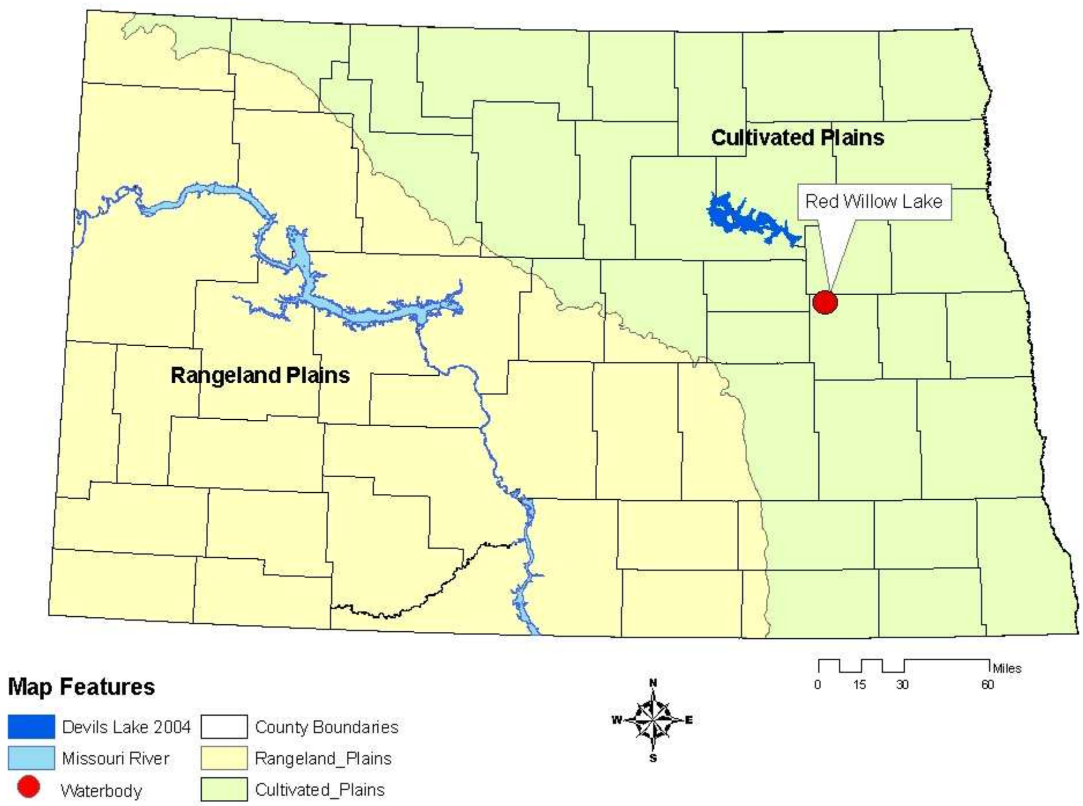


Figure 1. Location of Red Willow Lake.

Physiographic/Ecological Setting: Red Willow Lake has a surface area of 149 acres, a maximum depth of 25.2 feet, and a mean depth of 11.1 feet (Figure 2). Red Willow Lake lies in the Northern Glaciated Plains Level III Ecoregion, part of the broader Cultivated Plains region (Figure 1). The Northern Glaciated Plains Ecological region is characterized by flat to rolling landscape composed of glacial drift (USEPA 1994). This region is the transitional zone between tall and mixed grass prairie. The region has numerous wetlands essential for spring and fall migrations of wetland dependent birds. Flood plain slopes and hillsides are usually native grass while the uplands and flood plains proper have mostly been converted to small grains, row crops and alfalfa.

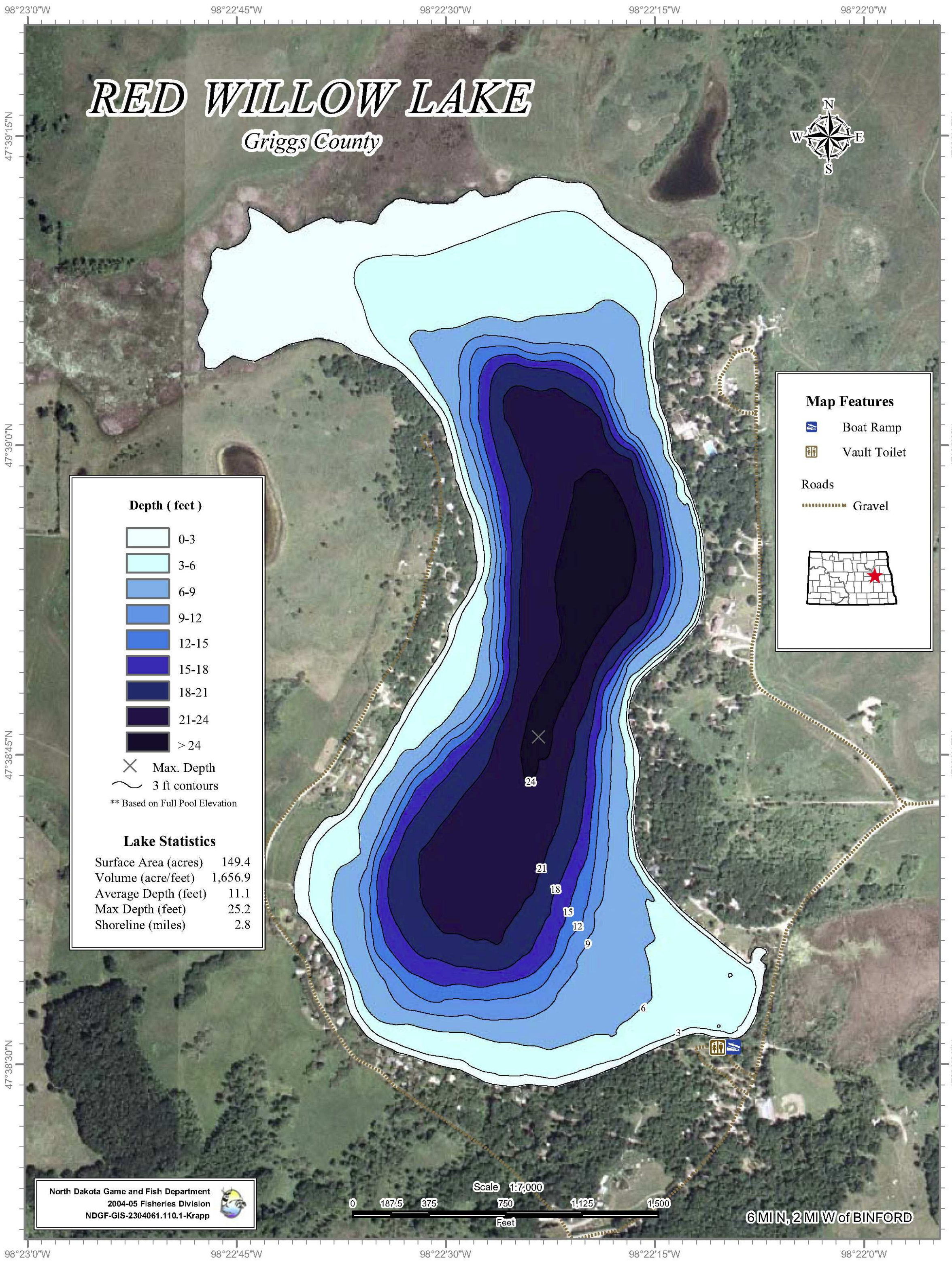


Figure 2. Contour Map of Red Willow Lake (Map Courtesy of North Dakota Game and Fish Department).

Recreational Facilities: Red Willow Lake's shoreline is nearly 100 percent privately owned and nearly 100 percent development. Recreational facilities include a boat ramp, parking, and a vault toilet on the south side of the lake.

Water Quality Standards Classification: Red Willow Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2007) as a class 2 lake. Class 2 lakes and reservoirs are defined as "Cool Water Fisheries" or "waters capable of supporting natural reproduction and growth of cool water fishes (e. g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: Red Willow Lake's historical fishery included walleye, yellow perch, largemouth bass, rainbow trout, and muskellunge. The current fishery consists of northern pike, walleye, and bluegill.

Historical Water Quality Samples: Historical water quality data from Red Willow Lake consists of eight sample results collected in 1992-2004.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trend assessments for Red Willow Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural and enhanced lakes in the Cultivated Plains region.

Temperature and Dissolved Oxygen Profile Results: There are six temperature and dissolved oxygen profiles for Red Willow Lake collected in two clusters between 1992-1993 and 2005-2006 (Figures 3 through 4). The profile data indicates that Red Willow Lake is often thermally stratified between 3 and 4 meters of depth and that dissolved oxygen concentrations decay rapidly under the thermal cline and as well as under ice conditions. Of the six profiles collected, three dipped below the state standard of 5 mg/L when approaching the sediment-water interface and 1 collected on March 10, 1993, was consistently below the state standard of 5 mg/L. At all other depths and times there was adequate dissolved oxygen to support aquatic life throughout the water column.

General Water Quality: Water quality data collected by the NDG&F in 2005 and 2006 indicate Red Willow Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 236 mg/L to 272 mg/L (Table 2). Red Willow Lake is sodium bicarbonate dominated with an average sodium concentration of 13 mg/L, and an average bicarbonate concentration of 300 mg/L. The average TDS concentration and specific conductance measurements for 2005-2006 sampling period were 321 mg/L and 561 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 0.891 mg/L and 0.036 mg/L, respectively.

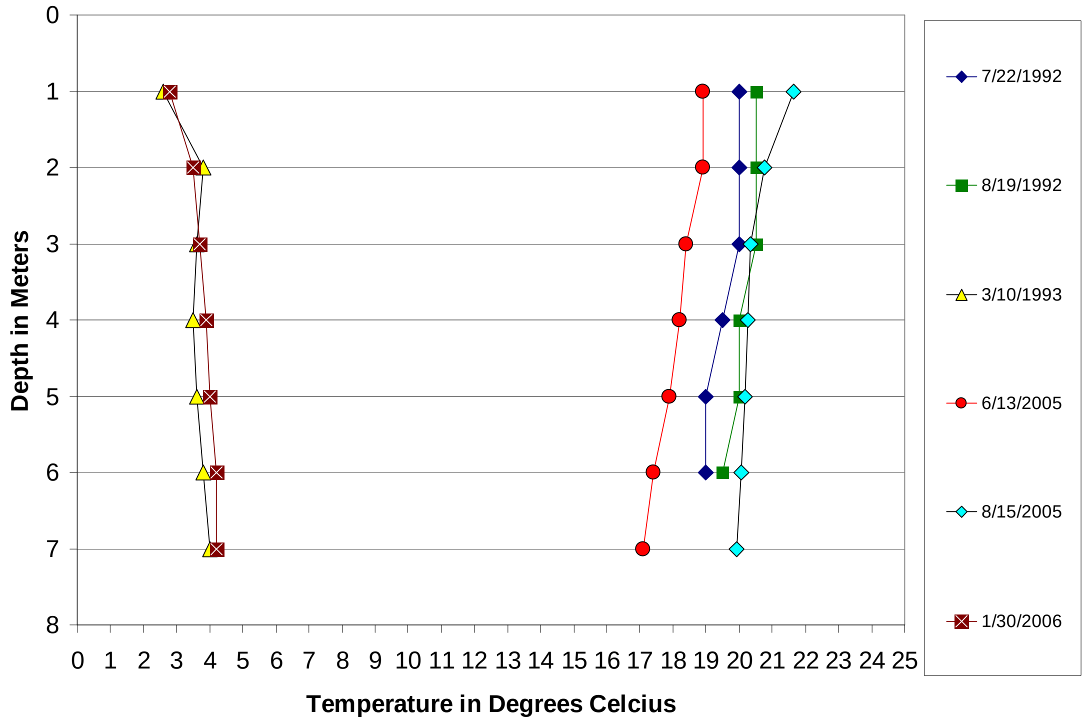


Figure 3. Temperature Profiles for Red Willow Lake from 1992 to 2006.

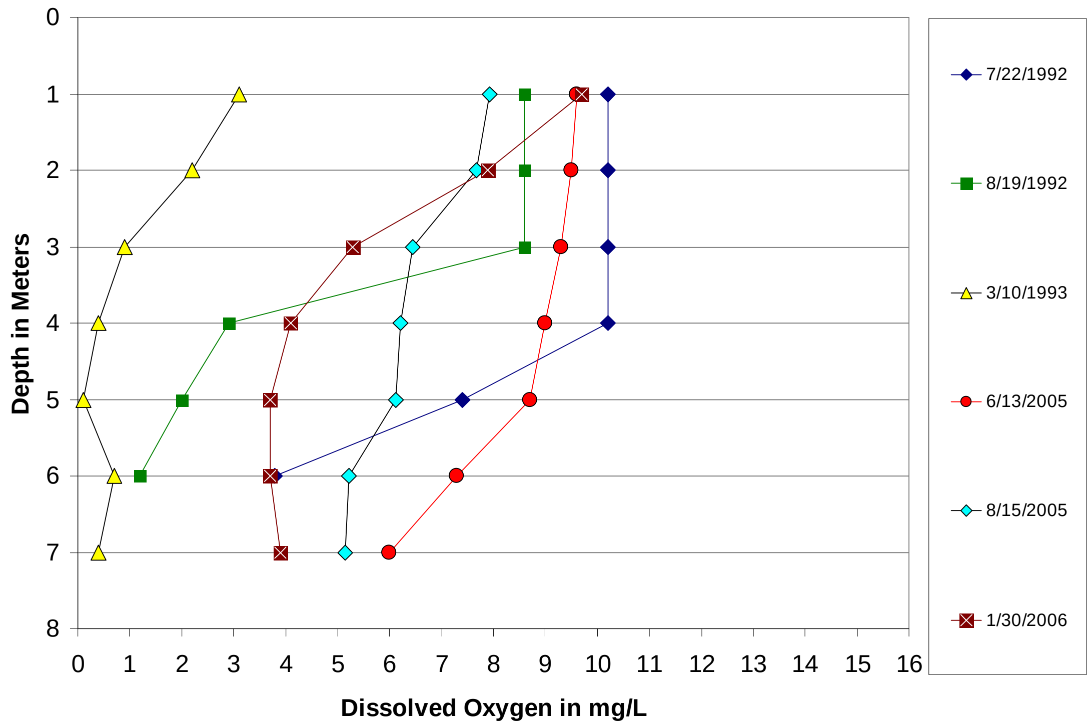


Figure 4. Dissolved Oxygen Profiles for Red Willow Lake from 1992 to 2006.

Table 1. Statistical Summary of Red Willow Lake's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	259	236	272	20
Total Ammonia as N	mg/L	3	0.033	0.020	0.055	0.019
Bicarbonate (HCO_3)	mg/L	3	300	258	332	38
Calcium (Ca)	mg/L	3	47.1	40.7	53.9	6.6
Carbonate (CO_3)	mg/L	3	8	1[1]	14	7
Chloride (Cl)	mg/L	3	4.3	3.6	5.2	0.8
Chlorophyll-a	µg/L	2	19.6	10.4	28.8	13.0
Specific Conductance	µmhos	3	561	516	639	68
Total Dissolved Solids	mg/L	3	321	291	357	34
Total Hardness as ($CaCO_3$)	mg/L	3	269	252	301	28
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0.0
Iron (Fe)	mg/L	3	0.068	0.026	0.093	0.037
Magnesium (Mg)	mg/L	3	36.7	32.8	40.4	3.8
Nitrate + Nitrite as N	mg/L	3	0.053	0.020	0.120	0.058
Total Kjeldahl Nitrogen as N	mg/L	3	0.838	0.783	0.888	0.053
Total Nitrogen as N	mg/L	3	0.891	0.803	0.962	0.081
pH		3	8.35	8.01	8.56	0.29
Total Phosphorus as P	mg/L	3	0.036	0.029	0.050	0.012
Potassium (K)	mg/L	3	8.3	7.5	9.5	1.0
Sodium (Na)	mg/L	3	13	12	15	2
Sulfate (SO4)	mg/L	3	54	47	68	11

[1]Equal to Minimum Reportable Limits

When compared to the historical water quality data collected from Red Willow Lake, the current data is higher in dissolved solids and lower in nutrient concentrations. For example, Red Willow Lake's historical average TDS, total nitrogen, and total phosphorus concentrations were 296 mg/L, 1.103 mg/L, and 0.067 mg/L (Table 2), respectively, compared to average concentrations of 321 mg/L, 0.891 mg/L, and 0.036 mg/L (Table 1), respectively for the 2005-2006 period.

Water quality data collected from Red Willow Lake in 2005-2006 was compared to the state's long term data set for natural and enhanced lakes in the Cultivated Plains region. Dissolved solids and nutrient concentrations at Red Willow were lower than most of the lakes in the Cultivated Plains region. Red Willow Lake's average total phosphorus concentration of 0.036 mg/L is approximately 2 fold less then the Cultivated Plains ecological region of 0.068 mg/L. The total nitrogen average of 0.891 mg/L is approximately half of the regional average of 1.440 mg/L (Table 3).

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Red Willow Lake, and that the ratio of total nitrogen to total phosphorus (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

Table 2. Statistical Summary of Red Willow Lake's Historical Water Quality Data Collected Between 1992 and 1993.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	7	207	194	257	22
Total Ammonia as N	mg/L	1	0.085	0.085	0.085	0
Bicarbonate (HCO_3)	mg/L	7	226	194	314	41
Calcium (Ca)	mg/L	7	30	25	39	5
Carbonate (CO_3)	mg/L	7	13	1[1]	22	8
Chloride (Cl)	mg/L	7	4.9	3.6	7.1	1.5
Chlorophyll-a	µg/L	2	7	6	8	1.4
Specific Conductance	µmhos	7	509	449	668	78
Total Dissolved Solids	mg/L	7	296	260	397	50
Total Hardness as ($CaCO_3$)	mg/L	7	241	207	324	41
Hydroxide (OH)	mg/L	5	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	7	0.030	0.019	0.049	0.010
Magnesium (Mg)	mg/L	7	40.2	32.5	54.8	8.5
Nitrate + Nitrite as N	mg/L	7	0.054	0.011	0.170	0.058
Total Kjeldahl Nitrogen as N	mg/L	8	0.993	0.589	1.480	0.359
Total Nitrogen as N	mg/L	7	1.103	0.759	1.575	0.332
pH		7	8.57	8.16	8.94	0.30
Total Phosphorus as P	mg/L	8	0.067	0.011	0.186	0.055
Potassium (K)	mg/L	7	11	8	16	3
Sodium (Na)	mg/L	7	14	11	18	3
Sulfate (SO4)	mg/L	7	70	52	107	22

[1]Equal to Minimum Reportable Limits

There are six water quality sample sets for Red Willow Lake between June 1992 and January 2006. The six samples used in this interpretation indicate that Red Willow Lake is nitrogen limited, and that the nutrient relationships are dynamic and variable depending on the time of the year and the natural processes occurring at the time of sampling (Figure 5).

The nitrogen to phosphorus ratio for Red Willow Lake ranged from a low of 1 to a high of 19 with an average of 9. Four of the six samples collected were below a ratio of 15 indicating nitrogen is most often the conservative nutrient.

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk measurements, and total phosphorus data collected during 2005-2006, Red Willow Lake's current trophic status is eutrophic (Figure 6). TSI scores ranged from a low of 39 based on total phosphorus, to a high of 64 based on chlorophyll-a. The trophic status score based on Secchi disk transparency was similar to that estimated by chlorophyll-a, at 53 (Figure 6).

A total of 11 total phosphorus samples, four chlorophyll-a samples, and four Secchi disk measurements collected during the open water periods from 1992 to 2006, were used to evaluate the trophic status of Red Willow Lake. Comparing historical and current data indicates that the trophic status of Red Willow Lake is stable (Figure 6).

Table 3. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lake's in the Cultivated Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	142	346	175	1120	180
Total Ammonia as N	mg/L	230	0.098	0.001[1]	1.620	0.208
Bicarbonate (HCO_3)	mg/L	142	363	171	1040	158
Calcium (Ca)	mg/L	142	45	16	108	23
Carbonate (CO_3)	mg/L	136	31	1[1]	181	39
Chloride (Cl)	mg/L	142	105	3[1]	1260	233
Chlorophyll-a	µg/L	185	10	2[1]	167	17
Specific Conductance	µmhos	161	1819	361	11500	2071
Total Dissolved Solids	mg/L	143	1376	191	9880	1786
Total Hardness as ($CaCO_3$)	mg/L	142	507	173	1820	284
Hydroxide (OH)	mg/L	111	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	138	0.095[1]	0.007	1.010	0.123
Magnesium (Mg)	mg/L	142	95.7	28.4	413.0	68.0
Nitrate + Nitrite as N	mg/L	175	0.047	0.001	0.540	0.078
Total Kjeldahl Nitrogen as N	mg/L	128	1.504	0.080	4.110	0.609
Total Nitrogen as N	mg/L	103	1.440	0.609	2.740	0.466
pH		142	8.55	7.75	9.33	0.36
Total Phosphorus as P	mg/L	230	0.068	0.004[1]	1.460	0.118
Potassium (K)	mg/L	142	30	8	179	37
Sodium (Na)	mg/L	142	255	5	2570	498
Sulfate (SO4)	mg/L	142	591	7	3880	807

[1]Equal to lower detection limit
[2]Data Collected from 49 Natural Lakes between 1991 and 2007

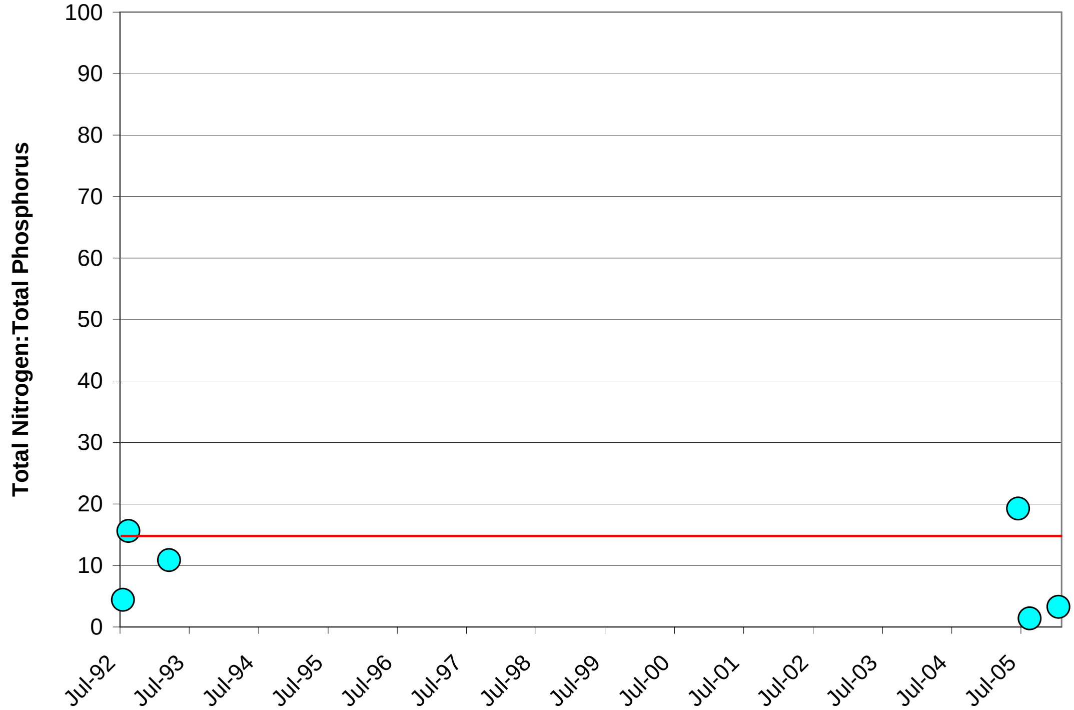


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Red Willow Lake (1992-2006).

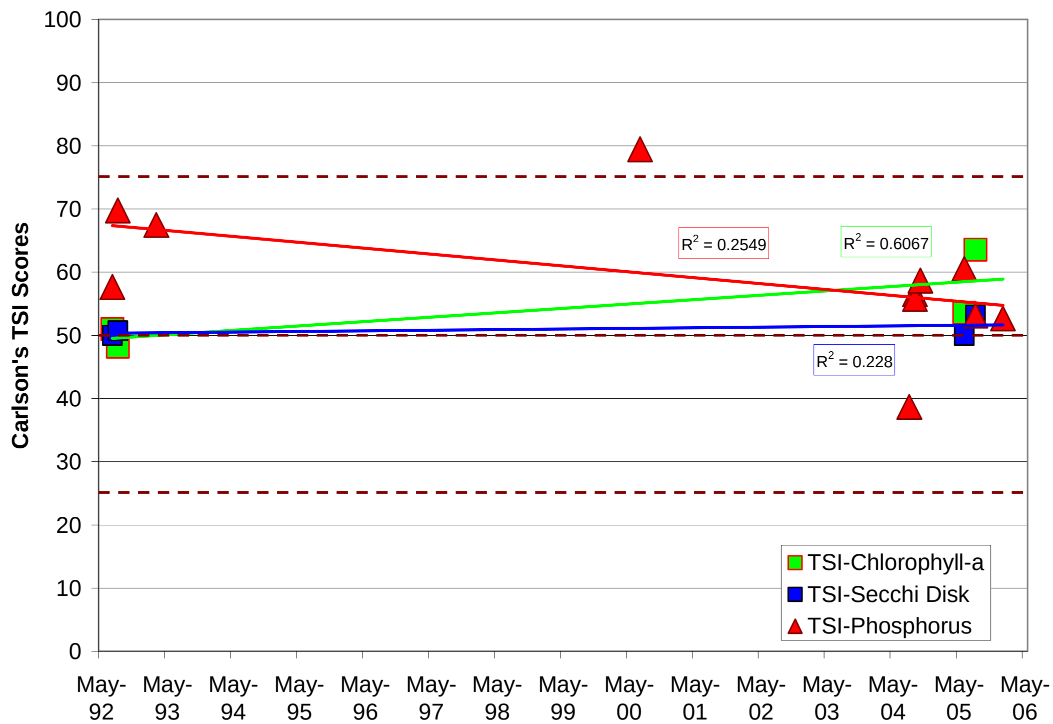


Figure 6. TSI Scores and Temporal Trends for Red Willow Lake from 1992 to 2006.

Castle Rock Dam, Hettinger County

BACKGROUND

Location: Castle Rock Dam is a small impoundment located 3½ miles west, and 1½ miles south of Mott, North Dakota (Figure 1). The reservoir is managed by the North Dakota Game and Fish Department.

Figure 1. Location of Castle Rock Dam.

Physiographic/Ecological Setting: Castle Rock Dam is an 11.6 acre impoundment on a tributary to the Cannonball River. The reservoir has a maximum depth of 13.5 feet and an average depth of 6.8 feet (Figure 2). Castle Rock Dam is located in the Northwestern Great Plains (NWGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The NWGP is the Missouri Plateau of the Great Plains (USEPA 1994). The watershed landscape is rolling plains. Flood plain slopes and hillsides are usually native grass, while the uplands and flood plains themselves have mostly been converted to small grains and alfalfa.

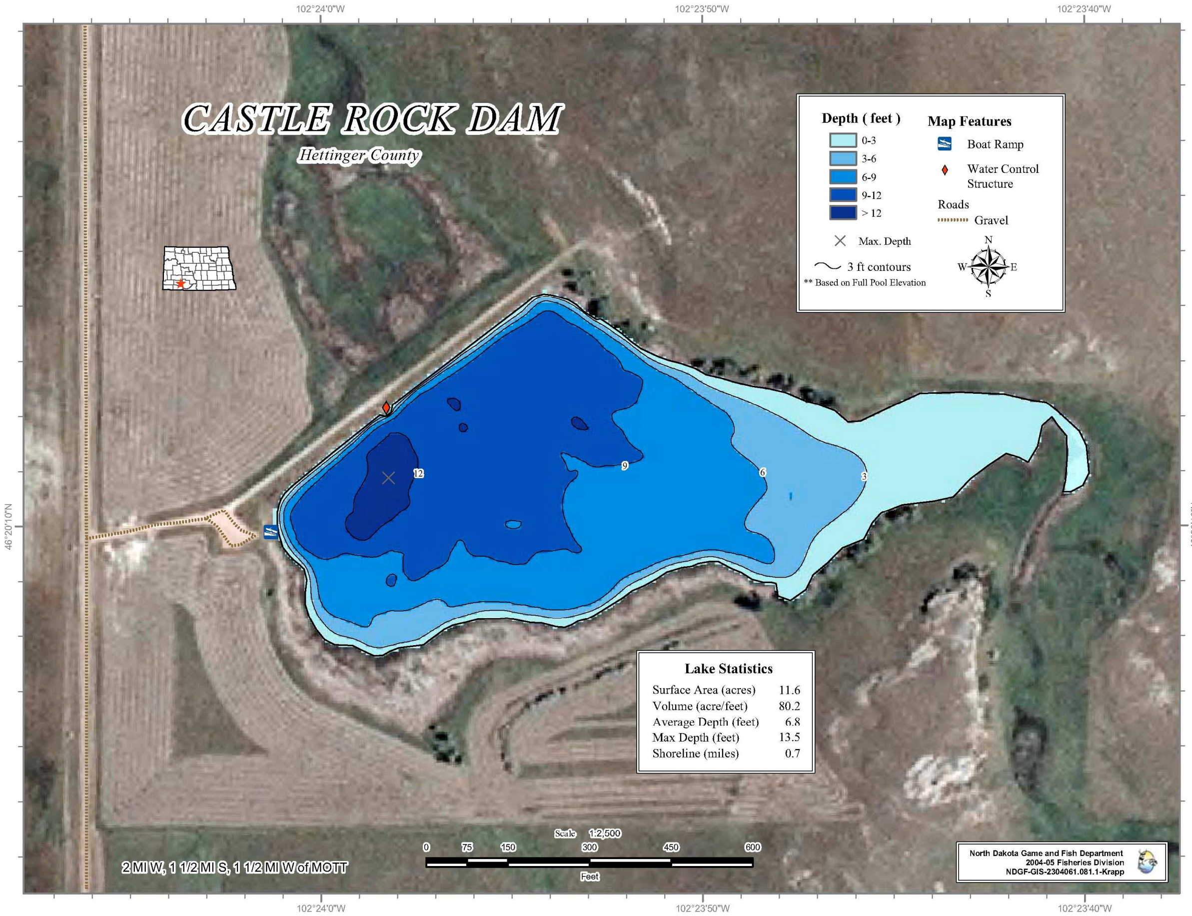


Figure 2. Contour Map of Castle Rock Dam (Map Courtesy of the North Dakota Game and Fish Department).

Construction History: Castle Rock was built by Jake Roemmick under the Agricultural Stabilization and Conservation Service program in 1968.

Recreational Facilities: Recreational facilities include a boat ramp and associated parking. Castle Rock Dam is a pack it in, pack it out location with fair to poor access.

Water Quality Standards Classification: Castle Rock Dam is classified in the state “Standards of Quality for Waters of the State” (NDDoH, 2007) as a class 4 lake. Class 4 lakes and reservoirs are defined as “Marginal Fisheries” or “waters capable of supporting a fishery on a short-term basis (e. g., put and take fishery).”

Historical and Current Fishery: Castle Rock Dam’s fishery is managed by the North Dakota Game and Fish Department. The current and historical fisheries include bluegill and rainbow trout.

Historical Water Quality Samples: Historical water quality data includes four water quality sample results collected in 1991, 2002, and 2003.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trend assessments for Castle Rock Dam have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There are two temperature and dissolved oxygen profiles for Castle Rock Dam collected by the NDG&F in 2005-2006. The profile data shows that Castle Rock Dam did not thermally stratified during the sampling periods but still experienced dissolved oxygen deficiencies under ice cover (Figures 3 and 4).

General Water Quality: Current and historical data indicate Castle Rock Dam is well buffered with total alkalinity as $CaCO_3$ concentrations ranging from 151 mg/L to 280 mg/L (Table 1). Castle Rock Dam is sodium sulfate dominated with an average sodium concentration of 77 mg/L and an average sulfate concentration of 634 mg/L. The average total dissolved solids (TDS) concentration and specific conductance measurements for the 2005-2006 sampling period were 1042 mg/L and 1420 µmhos/cm respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.758 mg/L and 0.189 mg/L respectively.

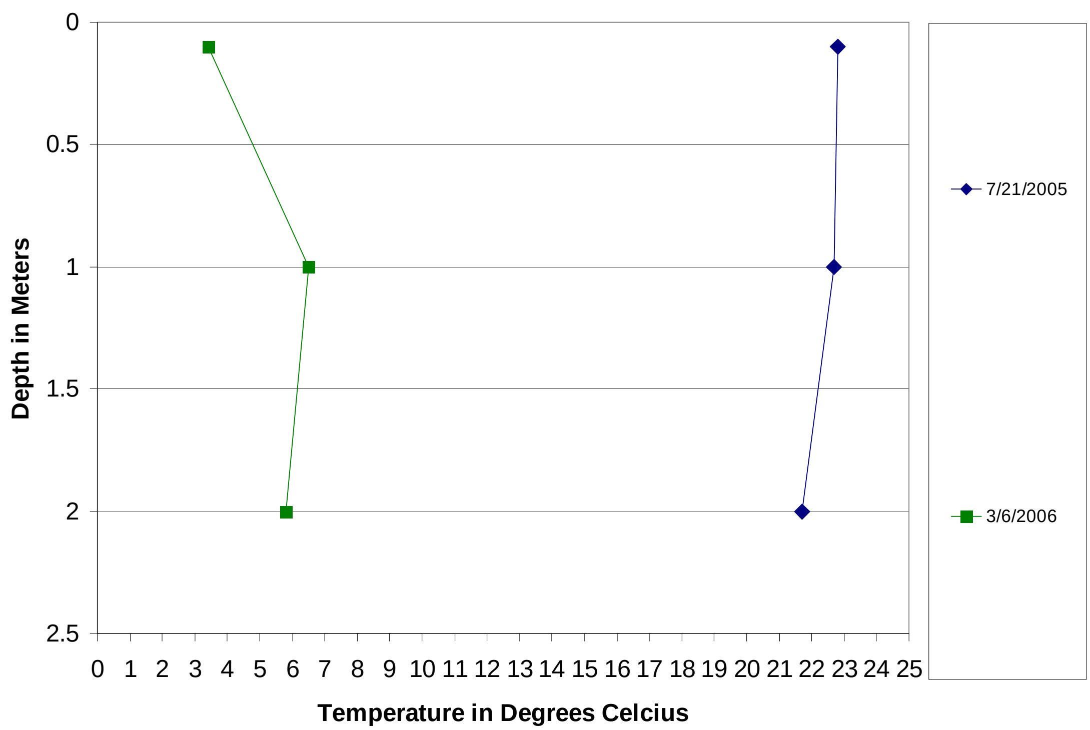


Figure 3. Temperature Profiles for Castle Rock Dam from 2005 to 2006.

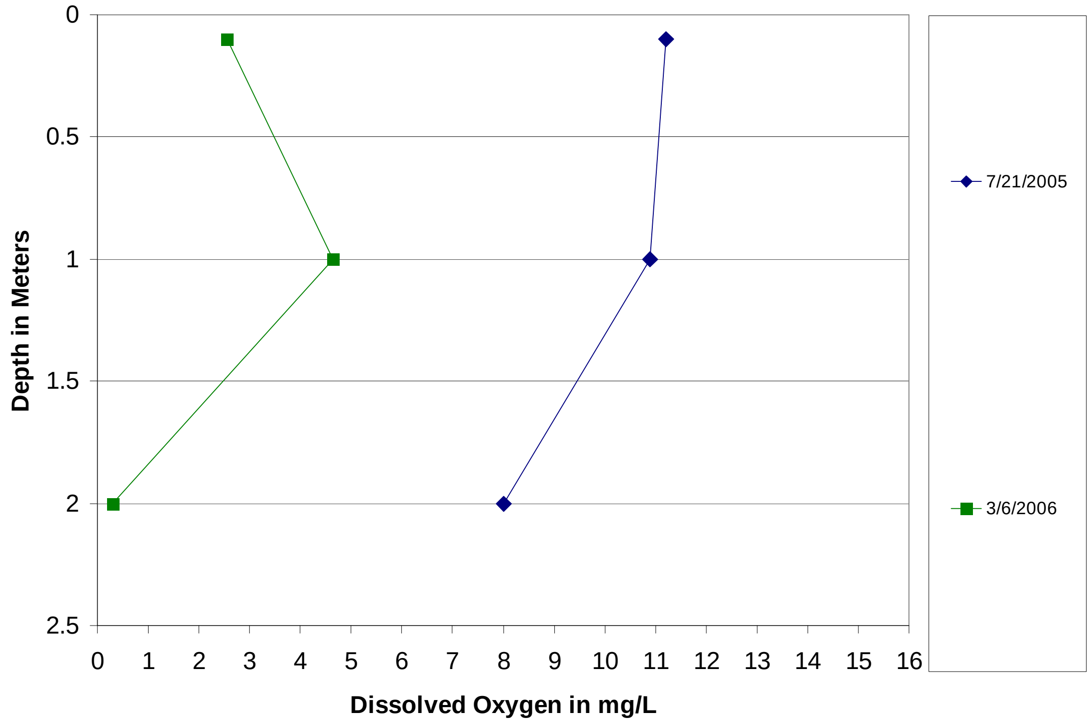


Figure 4. Dissolved Oxygen Profiles for Castle Rock Dam from 2005 to 2006.

In general, water quality variables are fairly consistent between the 1991, 2002-2003 and 2005-2006 sampling periods. Dissolved solid and phosphorus concentrations increased between 8 and 20 percent, while nitrogen decreased by 10 percent. These variations are likely due to changes in climate and annual precipitations and not changes in the inherent water quality of Castle Rock Dam (Table 2).

Castle Rock Dam's chemical makeup, while similar to the Rangeland Plains region's long term average, is slightly fresher (Table 3). Total dissolved solids concentrations averaged 1041 mg/L while the long term average is 1176 mg/L and total hardness averaged 673 mg/L, while the long term average is 397 mg/L.

Unlike dissolved solids, concentrations of total nitrogen and total phosphorus where above the long term average for reservoirs in the Rangeland Plains region. Total nitrogen concentrations averaged 1.758 mg/L, while the long term average is 1.472 mg/L and total phosphorus averaged 0.189 mg/L, while the long term average is 0.135 mg/L (Tables 1 and 3).

Table 1. Statistical Summary of Castle Rock Dam's 2005-2006 Water Quality Data.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	184	151	280	64
Total Ammonia as N	mg/L	4	0.027	0.010[1]	0.039	0.012
Bicarbonate (HCO_3)	mg/L	4	141	71	342	134
Calcium (Ca)	mg/L	4	61.5	49.3	90.7	20.1
Carbonate (CO_3)	mg/L	4	42	1[1]	58	27
Chloride (Cl)	mg/L	4	8	7	12	3
Chlorophyll-a	µg/L	1	12	12	12	0.0
Specific Conductance	µmhos	4	1420	1260	1840	280.3
Total Dissolved Solids	mg/L	4	1042	922	1380	225.7
Total Hardness as ($CaCO_3$)	mg/L	4	673	568	947	183.4
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0.0
Iron (Fe)	mg/L	4	0.272	0.116	0.376	0.112
Magnesium (Mg)	mg/L	4	127	108	175	32
Nitrate + Nitrite as N	mg/L	4	0.020	0.020	0.020	0
Total Kjeldahl Nitrogen as N	mg/L	4	1.738	1.500	2.410	0.449
Total Nitrogen as N	mg/L	4	1.758	1.520	2.430	0.449
pH		4	9.21	8.16	9.57	0.70
Total Phosphorus as P	mg/L	4	0.189	0.100	0.416	0.152
Potassium (K)	mg/L	4	24.0	20.6	32.7	5.8
Sodium (Na)	mg/L	4	77	65	106	20
Sulfate (SO4)	mg/L	4	634	579	797	108

[1]Equal to Minimum Reportable Limit

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Castle Rock Dam and that the weight ratio of total nitrogen to total phosphorus (N:P) in the lake's algae is approximately 15 to 1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There are five water quality sample sets for Castle Rock Dam between July 2002 and March 2006. The five samples used in this interpretation indicate that while Castle Rock Dam's nitrogen to phosphorus ratio is variable, nitrogen is most often the limiting nutrient (Figure 5). The nitrogen to phosphorus ratio for Castle Rock Dam ranged from a low of 6, to a high of 33, with an average of 18.

Table 2. Statistical Summary of Castle Rock Dam's Historical Water Quality Data Collected Between 1992 and 2003.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	169	166	172	3
Total Ammonia as N	mg/L	4	0.042	0.018	0.071	0.023
Bicarbonate (HCO_3)	mg/L	4	52	24	84	28
Calcium (Ca)	mg/L	4	51.6	47.5	55.0	3.8
Carbonate (CO_3)	mg/L	4	76	59	91	16
Chloride (Cl)	mg/L	4	9	7	10	1
Chlorophyll-a	µg/L	2	3[1]	3[1]	3[1]	0
Specific Conductance	µmhos	4	1510	1430	1590	87
Total Dissolved Solids	mg/L	4	1138	1070	1210	73
Total Hardness as ($CaCO_3$)	mg/L	4	704	654	747	47
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.067	0.029	0.122	0.046
Magnesium (Mg)	mg/L	4	140	130	148	9.1
Nitrate + Nitrite as N	mg/L	4	0.020	0.020	0.020	0
Total Kjeldahl Nitrogen as N	mg/L	4	1.713	1.580	1.820	0.116
Total Nitrogen as N	mg/L	4	1.733	1.600	1.840	0.116
pH		4	9.57	9.47	9.69	0.11
Total Phosphorus as P	mg/L	4	0.119	0.059	0.175	0.064
Potassium (K)	mg/L	4	21	19	23	2.2
Sodium (Na)	mg/L	4	93	82	103	11
Sulfate (SO4)	mg/L	4	718	681	767	43

[1]Equal to Minimum Reportable Limit

Trophic Status Assessment: Based on limited chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005-2006, Castle Rock Dam's trophic status is eutrophic (Figure 6). TSI scores ranged from a low of 51 based on Secchi disk transparency, to a high of 91 based on total phosphorus. The trophic status score based on chlorophyll-a was similar to that estimated by Secchi disk transparency at 55 (Figure 6).

A total of three chlorophyll-a samples, two Secchi disk transparency measurements, and five total phosphorus measurements collected from 2002 to 2006 were used to evaluate trends in the trophic status of Castle Rock Dam. Since Castle Rock Dam is nitrogen limited only chlorophyll-a concentrations and Secchi disk transparency measurements were used to estimate the trophic status of Castle Rock Dam. Based on a visual assessment Castle Rock Dam's trophic status is degrading (Figure 6).

Table 3. Statistical Summary of Water Quality Data[2] Collected from Reservoirs in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	408	309	101	982	130
Total Ammonia as N	mg/L	469	0.097	0.001[1]	2.440	0.200
Bicarbonate (HCO_3)	mg/L	408	318	14	1040	150
Calcium (Ca)	mg/L	408	50	5	160	26
Carbonate (CO_3)	mg/L	402	30	1[1]	197	30
Chloride (Cl)	mg/L	408	13.3	0.3	74.5	8.8
Chlorophyll-a	µg/L	321	21.2	1.5	218.0	27.9
Specific Conductance	µmhos	428	1733	262	5880	959
Total Dissolved Solids	mg/L	409	1176	147	5110	750
Total Hardness as ($CaCO_3$)	mg/L	408	397	45	1850	260
Hydroxide (OH)	mg/L	337	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	409	0.179	0.007	4.110	0.334
Magnesium (Mg)	mg/L	408	66.0	5.6	353.0	49.6
Nitrate + Nitrite as N	mg/L	395	0.048	0.001[1]	0.790	0.092
Total Kjeldahl Nitrogen as N	mg/L	359	1.556	0.365	7.720	0.779
Total Nitrogen as N	mg/L	302	1.472	0.405	4.840	0.562
pH		428	8.61	6.73	9.87	0.56
Total Phosphorus as P	mg/L	475	0.135	0.004	3.160	0.205
Potassium (K)	mg/L	408	14.6	4.2	39.2	6.3
Sodium (Na)	mg/L	408	239	3[1]	932	171
Sulfate (SO4)	mg/L	406	604	1[1]	3210	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 69 Reservoirs between 1991 and 2007

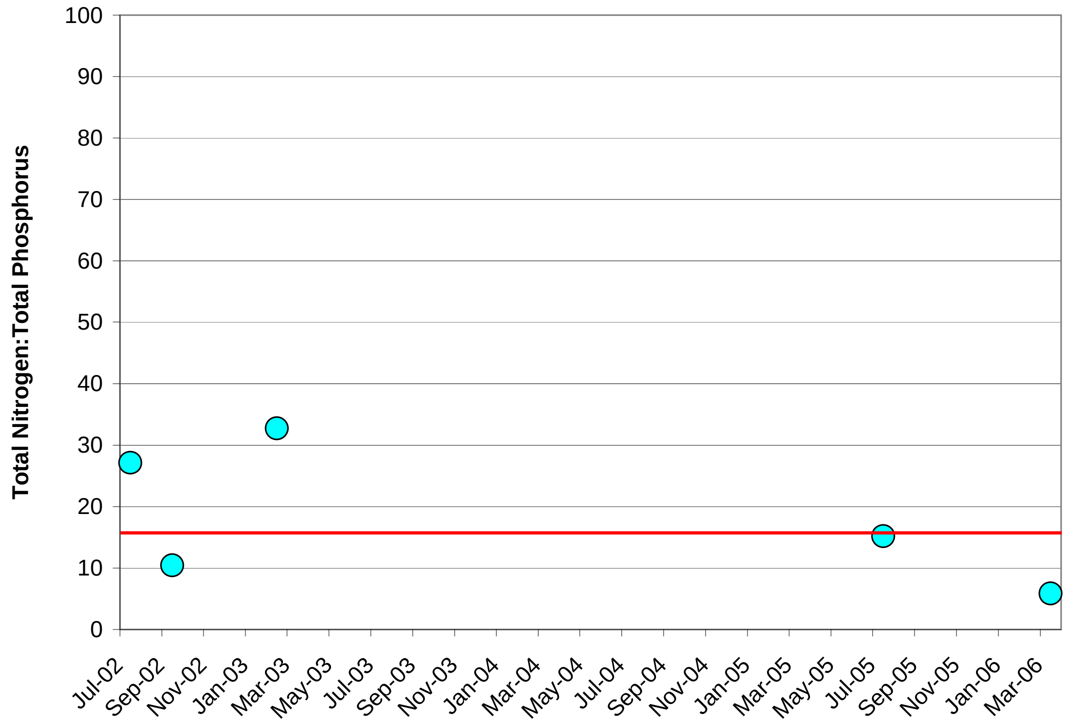


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Castle Rock Dam (2002-2006).

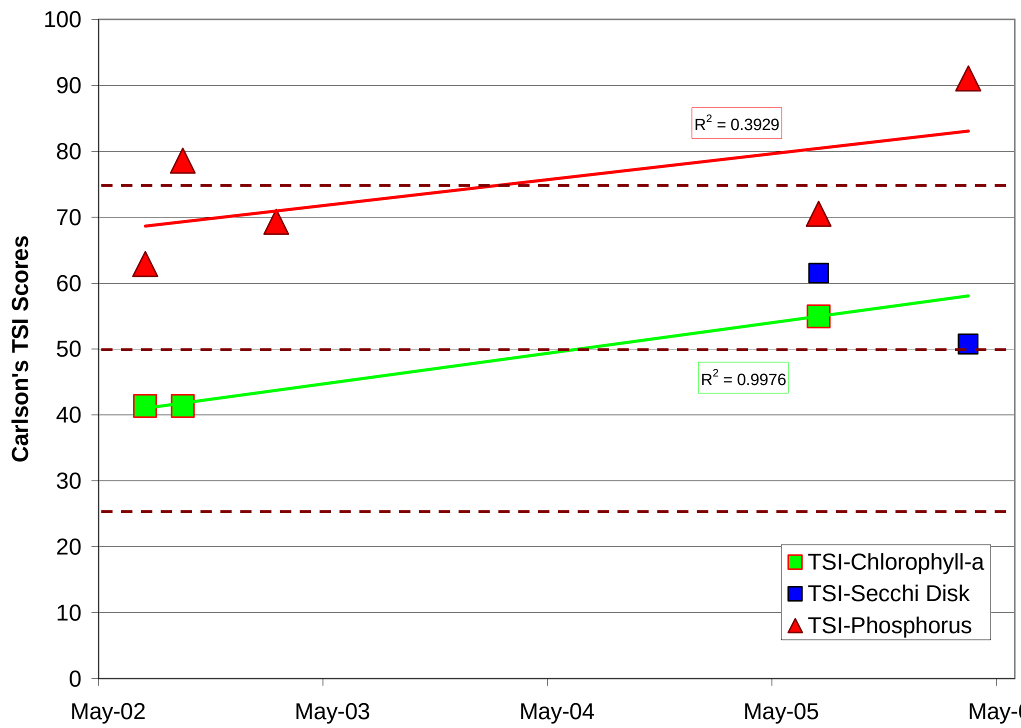


Figure 6. TSI Scores and Temporal Trends for Castle Rock Dam from 2002 to 2006.

Indian Creek Dam, Hettinger County

BACKGROUND

Location: Indian Creek Dam is a recreational impoundment managed by the North Dakota Game and Fish Department and Hettinger County Water Board. The reservoir lies approximately 60 miles east of the Montana border and 35 miles north of the South Dakota border. Directions to Indian Creek Dam from Regent are 1½ miles west, 2 miles south, 2 miles west, and finally 2 miles south (Figure 1).

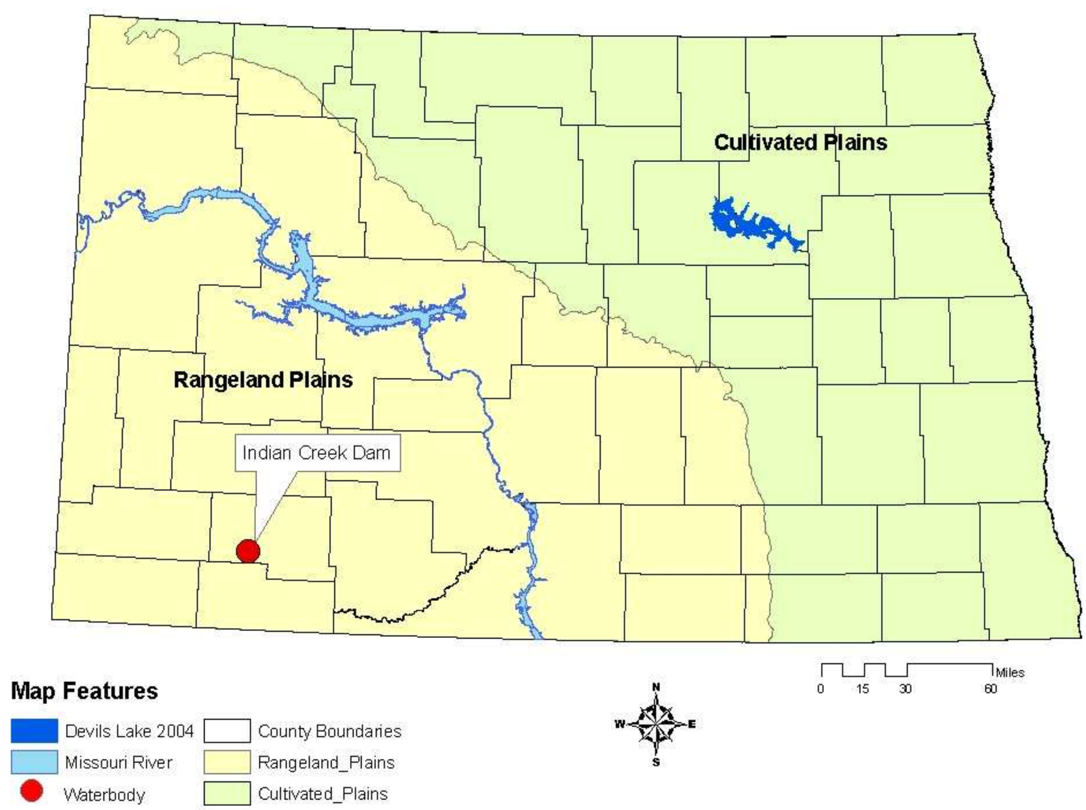


Figure 1. Location of Indian Creek Dam.

Physiographic/Ecological Setting: Indian Creek Dam is a 196 acre impoundment on a tributary to the Cannonball River. The reservoir has a maximum depth of 32 feet and an average depth of 12.3 feet (Figure 2). Indian Creek Dam is located in the Northwestern Great Plains (NWGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 2). The watershed landscape is rolling plains. Flood plain slopes and hillsides are usually native grass while the uplands and flood plains themselves have mostly been converted to small grains and alfalfa.

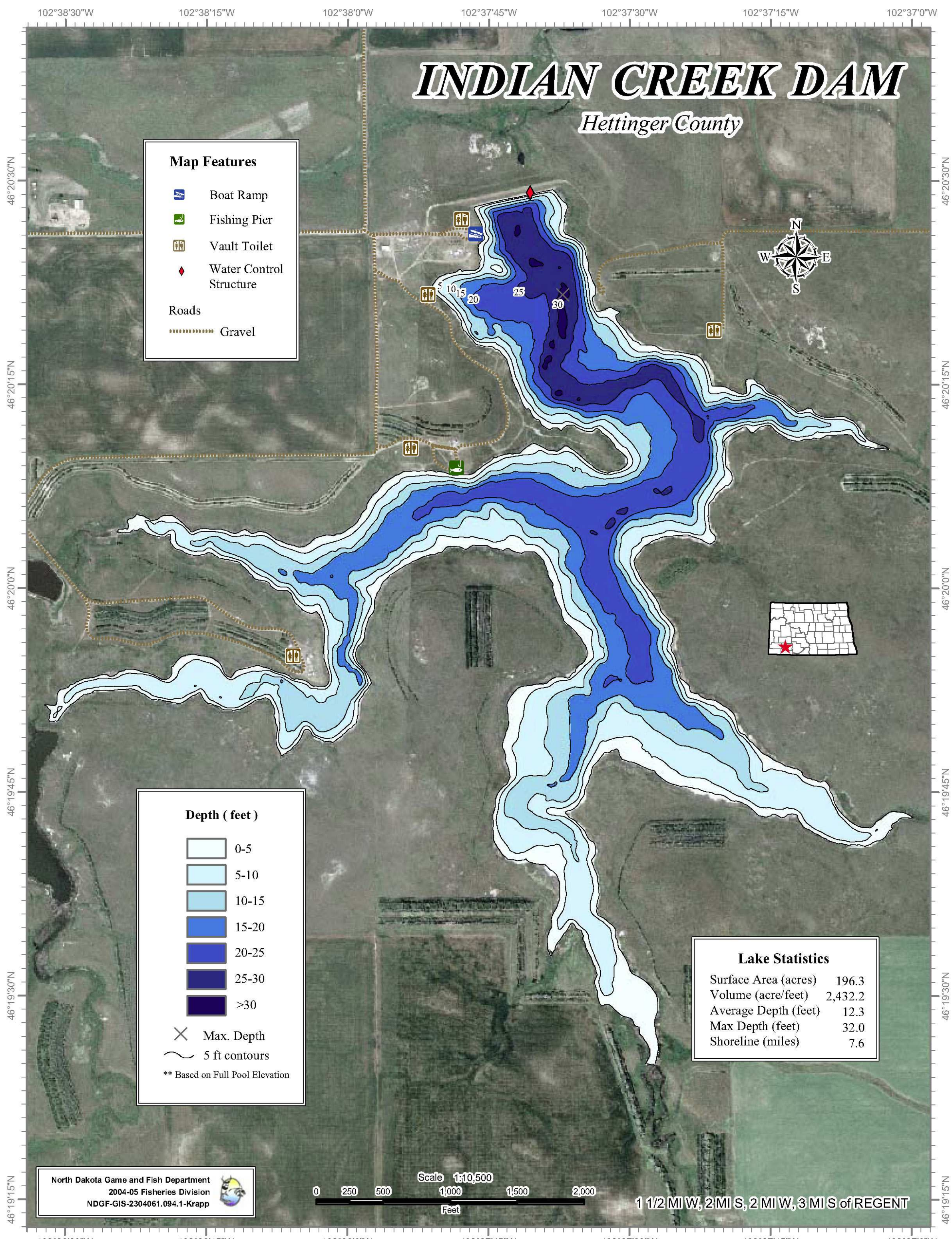


Figure 2. Contour Map of Indian Creek Dam (Map Courtesy of the North Dakota Game and Fish Department).

Construction History: Indian Creek was built in 1978 by the North Dakota Game and Fish Department, the State Water Commission, and Hettinger County. The dam was constructed to provide water based recreation in an area lacking natural lakes.

Recreational Facilities: Indian Creek Dam and the surrounding shoreline are owned by the North Dakota Game and Fish Department. The north half of the reservoir is managed by the Hettinger County Water Board and they maintain a boat ramp, swim beach, fishing pier, picnic areas with shelters, and vault toilets.

Water Quality Standards Classification: Sheep Creek Dam is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2007) as a class 2 lake. Class 2 lakes and reservoirs are defined as "Cool Water Fisheries" or "waters capable of supporting natural reproduction and growth of cool water fishes (e. g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: Indian Creek Dam's fishery is managed by the North Dakota Game and Fish Department. The historical fishery included rainbow trout, small mouth bass, northern pike, walleye, and bluegill. The current fishery is managed for bluegill, walleye and largemouth bass. Boats are restricted to idle speeds and no live bait fish are allowed.

Historical Water Quality Samples: Historical water quality data includes results from three water quality sample sets collected in 1991-1992.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trend assessments for Indian Creek Dam have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There are 22 temperature and dissolved oxygen profiles for Indian Creek Dam collected in two clusters between 1991-1992 (Figures 3 and 4) and 2001-2006 (Figures 3 through 8). The profile data shows that Indian Creek Dam is rarely thermally stratified but when it is, dissolved oxygen concentrations can decay rapidly below the metilimnion. Of the 22 profiles collected over five different years, on only three occasions (1/27/1992, 7/20/2004, and 9/22/2004) was Indian Creek not well oxygenated throughout the majority of the water column (Figures 4, 6, and 8).

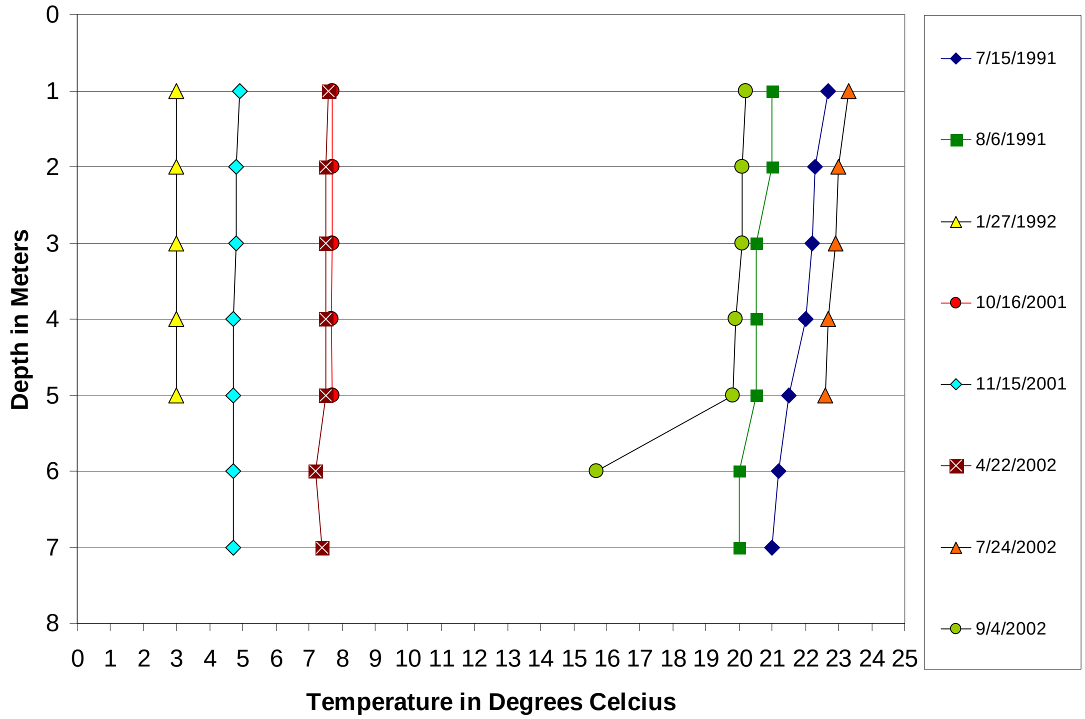


Figure 3. Temperature Profiles for Indian Creek Dam from 1991 to 2002.

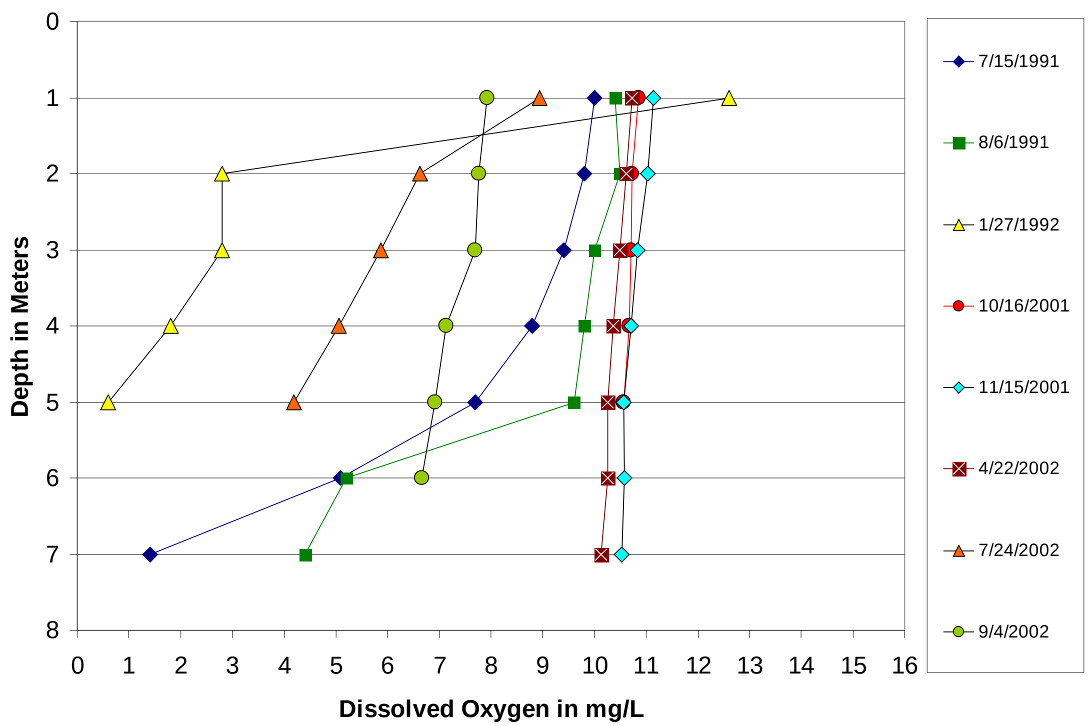


Figure 4. Dissolved Oxygen Profiles for Indian Creek Dam from 1991 to 2002.

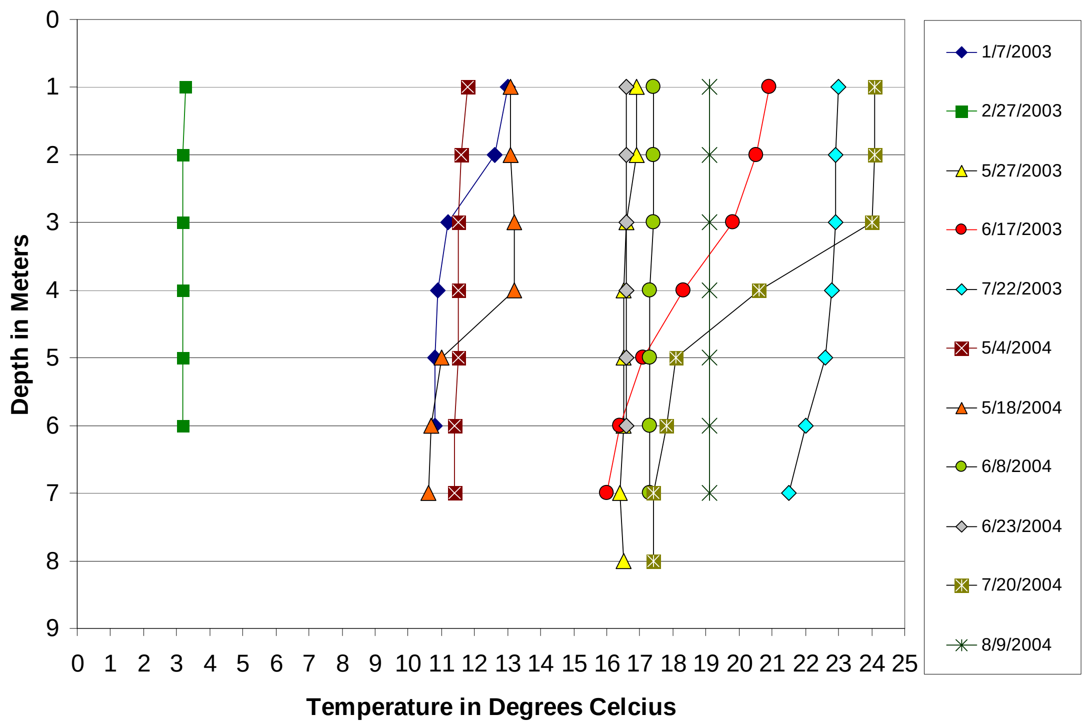


Figure 5. Temperature Profiles for Indian Creek Dam from 2003 to 2004.

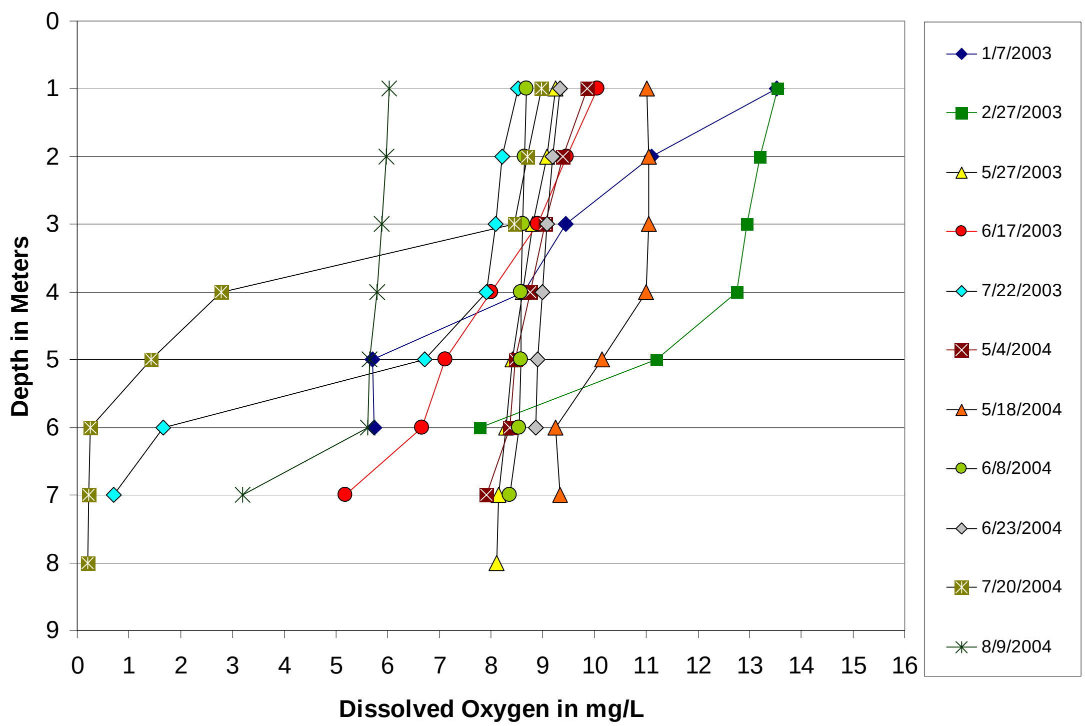


Figure 6. Dissolved Oxygen Profiles for Indian Creek Dam from 2003 to 2004.

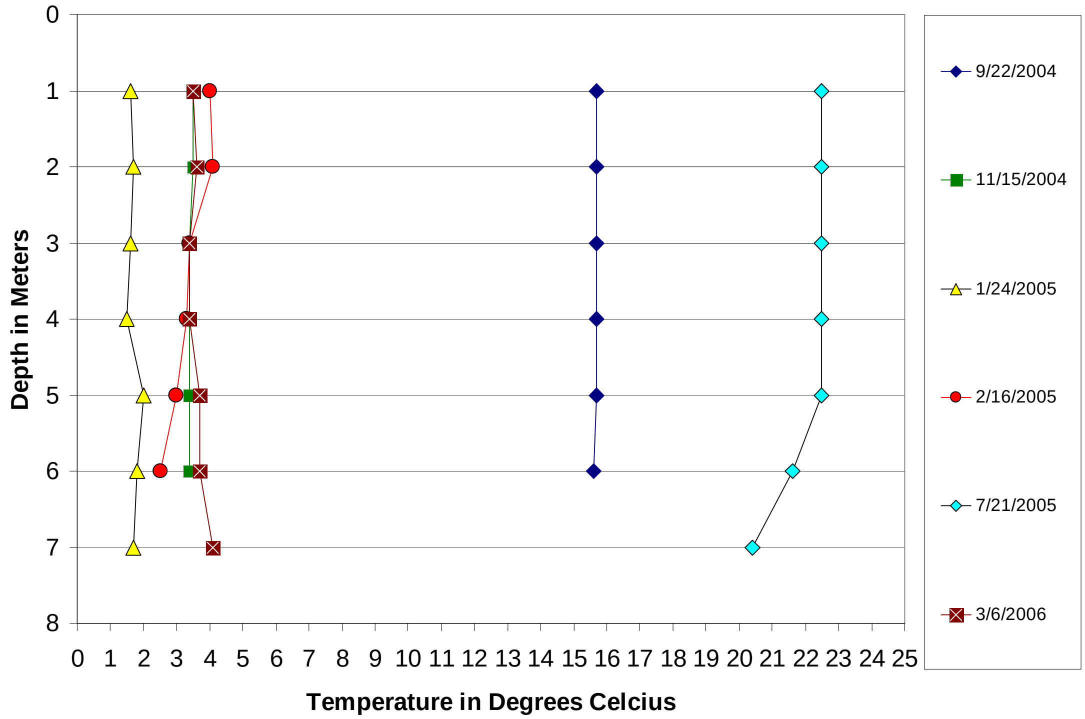


Figure 7. Temperature Profiles for Indian Creek Dam from 2004 to 2006.

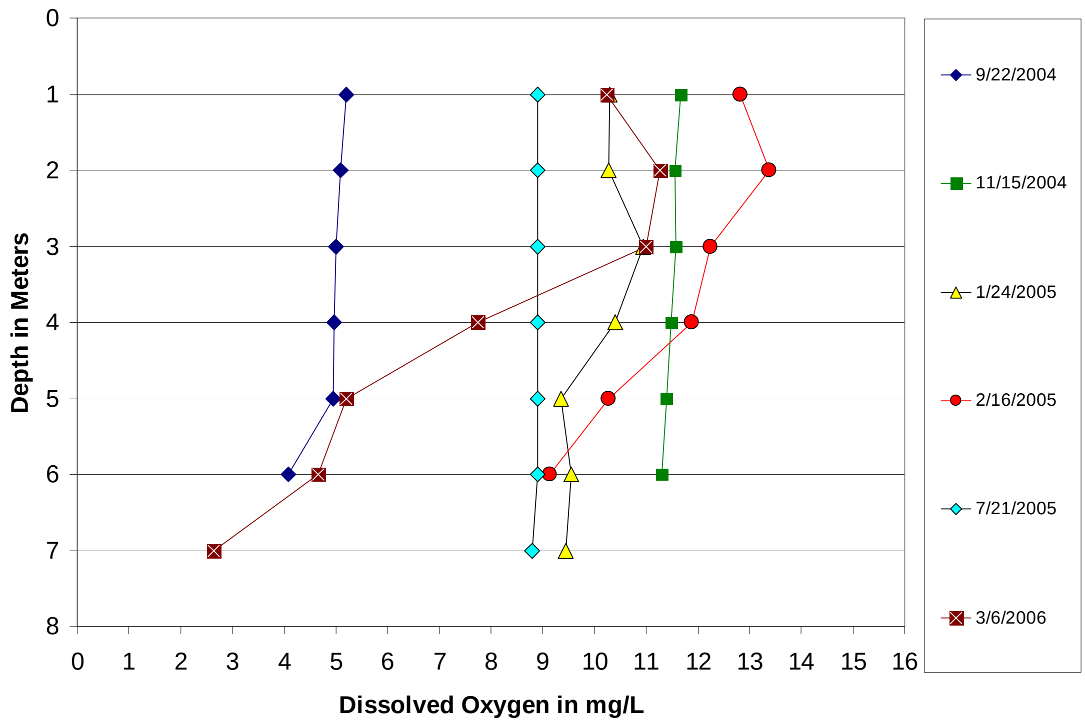


Figure 8. Dissolved Oxygen Profiles for Indian Creek Dam from 2004 to 2006.

General Water Quality: Data collected by the NDGF in 2005-2006 indicate Indian Creek Dam is well buffered with total alkalinity as $CaCO_3$ concentrations ranging from 268 mg/L to 371 mg/L (Table 1). Indian Creek Dam is sodium sulfate dominated with an average sodium concentration of 493 mg/L, and an average sulfate concentration of 1301 mg/L. The average total dissolved solids (TDS) concentration and specific conductance measurements for the 2005-2006 sampling period were 2181 mg/L and 2914 µmhos/cm respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.737 mg/L and 0.045 mg/L respectively.

Table 1. Statistical Summary of Indian Creek Dam's 2005-2006 Water Quality Data.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	18	308	268	371	29
Total Ammonia as N	mg/L	18	0.033	0.010[1]	0.153	0.040
Bicarbonate (HCO_3)	mg/L	18	317	228	443	64
Calcium (Ca)	mg/L	18	55.8	45.9	69.2	7.1
Carbonate (CO_3)	mg/L	18	28	1[1]	64	22
Chloride (Cl)	mg/L	18	21	18	26	2
Chlorophyll-a	µg/L	16	16	3[1]	76	17.6
Specific Conductance	µmhos	18	2914	2500	3500	289
Total Dissolved Solids	mg/L	18	2181	1900	2760	247
Total Hardness as ($CaCO_3$)	mg/L	18	563	472	713	64
Hydroxide (OH)	mg/L	18	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	18	0.096	0.029	0.165	0.035
Magnesium (Mg)	mg/L	18	102.9	86.1	138.0	13.2
Nitrate + Nitrite as N	mg/L	18	0.028	0.020	0.080	0.019
Total Kjeldahl Nitrogen as N	mg/L	18	1.708	1.300	2.900	0.368
Total Nitrogen as N	mg/L	18	1.737	1.320	2.920	0.366
pH		18	8.66	7.77	9.22	0.40
Total Phosphorus as P	mg/L	18	0.045	0.008	0.070	0.016
Potassium (K)	mg/L	18	21.7	18.9	27.3	2.5
Sodium (Na)	mg/L	18	493	421	678	68.6
Sulfate (SO4)	mg/L	18	1301	1120	1630	145.6

[1]Equal to Minimum Reportable Limit

There is an improving trend of nutrient concentrations from the historical data set and the current data set. The current average total nitrogen and total phosphorus concentrations are 1.737 mg/L and 0.045 mg/L respectively, and the historical averages are 2.977 mg/L and 0.191 mg/L respectively (Tables 1 and 2).

Table 2. Statistical Summary of Indian Creek Dam's Historical Water Quality Data Collected Between 1991-1992.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	420	396	466	39.6
Total Ammonia as N	mg/L	3	0.044	0.020	0.067	0.024
Bicarbonate (HCO_3)	mg/L	3	388	309	520	115
Calcium (Ca)	mg/L	3	46.8	42.8	52.9	5.3
Carbonate (CO_3)	mg/L	3	62	24	86	33
Chloride (Cl)	mg/L	3	25.7	22.3	29.4	3.6
Chlorophyll-a	µg/L	2	29	19	39	14
Specific Conductance	µmhos	3	2990	2280	3620	673
Total Dissolved Solids	mg/L	3	2190	1980	2600	355
Total Hardness as ($CaCO_3$)	mg/L	3	512	485	560	41
Hydroxide (OH)	mg/L		NC[2]	NC[2]	NC[2]	
Iron (Fe)	mg/L	3	0.204	0.102	0.314	0.106
Magnesium (Mg)	mg/L	3	96	90	104	7
Nitrate + Nitrite as N	mg/L	3	0.050	0.010[1]	0.145	0.082
Total Kjeldahl Nitrogen as N	mg/L	3	2.927	2.740	3.240	0.273
Total Nitrogen as N	mg/L	3	2.977	2.741	3.385	0.355
pH		3	9.00	8.50	9.30	0.4
Total Phosphorus as P	mg/L	3	0.191	0.129	0.274	0.075
Potassium (K)	mg/L	3	20.500	20.200	20.800	0.300
Sodium (Na)	mg/L	3	549	517	608	50.8
Sulfate (SO4)	mg/L	3	1200	1050	1500	259

[1]Equal to Minimum Reportable Limit
[2]No data collected

Indian Creek Dam's chemical makeup, while similar to the Rangeland Plains region's long term average, is more saline and harder then average (Table 3). Total dissolved solids concentrations averaged 2181 mg/L, while the long term average is 1176 mg/L and total hardness averaged 563 mg/L, while the long term average is 397 mg/L.

Unlike the dissolved solids, the concentration of total phosphorus was below the long term average for reservoirs in the rangeland plains ecological region. Total phosphorus concentrations averaged 0.045 mg/L, while the long term average is 0.135 mg/L.

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Indian Creek Dam and that the weight ratio of total nitrogen to total phosphorus (N:P) in the lake's algae is approximately 15 to 1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

Table 3. Statistical Summary of Water Quality Data[2] Collected from Reservoirs in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	408	309	101	982	130
Total Ammonia as N	mg/L	469	0.097	0.001[1]	2.440	0.200
Bicarbonate (HCO_3)	mg/L	408	318	14	1040	150
Calcium (Ca)	mg/L	408	50	5	160	26
Carbonate (CO_3)	mg/L	402	30	1[1]	197	30
Chloride (Cl)	mg/L	408	13.3	0.3	74.5	8.8
Chlorophyll-a	µg/L	321	21.2	1.5	218.0	27.9
Specific Conductance	µmhos	428	1733	262	5880	959
Total Dissolved Solids	mg/L	409	1176	147	5110	750
Total Hardness as ($CaCO_3$)	mg/L	408	397	45	1850	260
Hydroxide (OH)	mg/L	337	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	409	0.179	0.007	4.110	0.334
Magnesium (Mg)	mg/L	408	66.0	5.6	353.0	49.6
Nitrate + Nitrite as N	mg/L	395	0.048	0.001[1]	0.790	0.092
Total Kjeldahl Nitrogen as N	mg/L	359	1.556	0.365	7.720	0.779
Total Nitrogen as N	mg/L	302	1.472	0.405	4.840	0.562
pH		428	8.61	6.73	9.87	0.56
Total Phosphorus as P	mg/L	475	0.135	0.004	3.160	0.205
Potassium (K)	mg/L	408	14.6	4.2	39.2	6.3
Sodium (Na)	mg/L	408	239	3[1]	932	171
Sulfate (SO4)	mg/L	406	604	1[1]	3210	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 69 Reservoirs between 1991 and 2007

There are 23 water quality sample sets for Indian Creek Dam between July 1991 and March 2006. The 23 samples used in this interpretation indicate that while Indian Creek Dam's nitrogen to phosphorus ratio is variable, it is usually phosphorus limited (Figure 9). The nitrogen to phosphorus ratio for Indian Creek Dam ranged from a low of 10 to a high of 185 with an average of 45.

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2001-2005, Indian Creek Dam's trophic status is eutrophic (Figure 10). TSI scores ranged from a low of 34 based on total phosphorus, to a high of 73 based on chlorophyll-a measurements. The trophic status score, based on Secchi disk transparency, also indicates that the reservoir is eutrophic, with a score of 52.

A total of 23 phosphorus samples, 16 chlorophyll-a samples, and 4 Secchi disk transparency measurements collected from 1991-2005 were used to evaluate trends in the trophic status of Indian Creek Dam. Based on a visual assessment of the data, the trophic status of Indian Creek is improving (Figure 6).

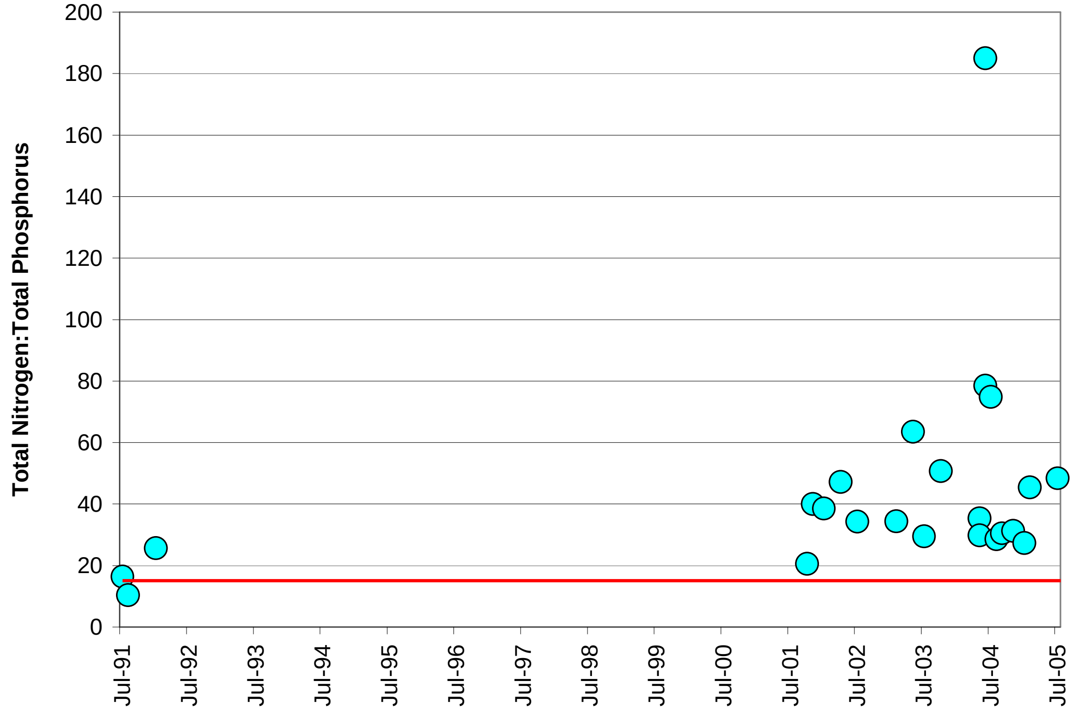


Figure 9. Total Nitrogen to Total Phosphorus Ratios in Indian Creek Dam (1991-2005).

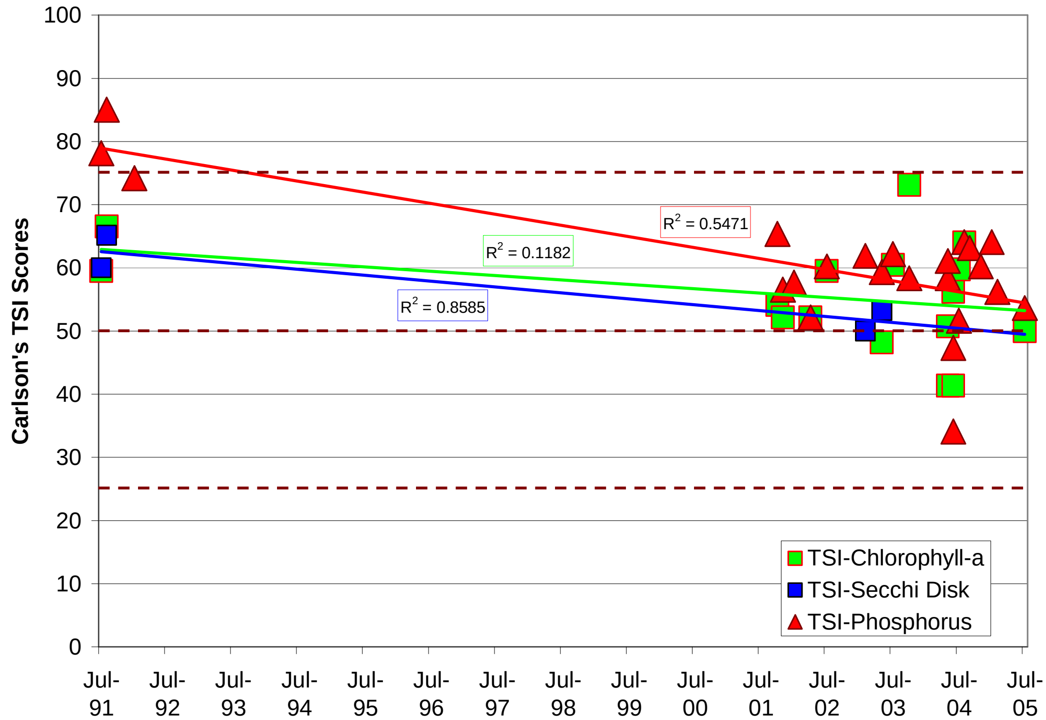


Figure 10. TSI Scores and Temporal Trends for Indian Creek Dam from 1991 to 2005.

Alkaline Lake, Kidder County

BACKGROUND

Location: Alkaline Lake is located in southeastern Kidder County, North Dakota. Tappen is the closest North Dakota community to Alkaline Lake. Alkaline Lake is 15 miles south and 3 miles east of Tappen. Alkaline Lake is managed by the North Dakota Game and Fish Department.

Figure 1. Location of Alkaline Lake.

Physiographic/Ecological Setting: Alkaline Lake is a relatively large prairie lake with a surface area of 5,438 acres, an average depth of 15.6 feet, and a maximum depth of 21 feet (Figure 2). Alkaline Lake is a glacial remnant lying within the Northwestern Glaciated Plains (NGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The NGP marks the western most extent of continental glacial advancement. The geological youthful landscape has significant surface irregularities and high concentrations of wetlands. The rise in elevation along the eastern edge of this ecoregion defines the boundary of the Great Plans and to the west the Northwestern Great Plans (USEPA 1994).

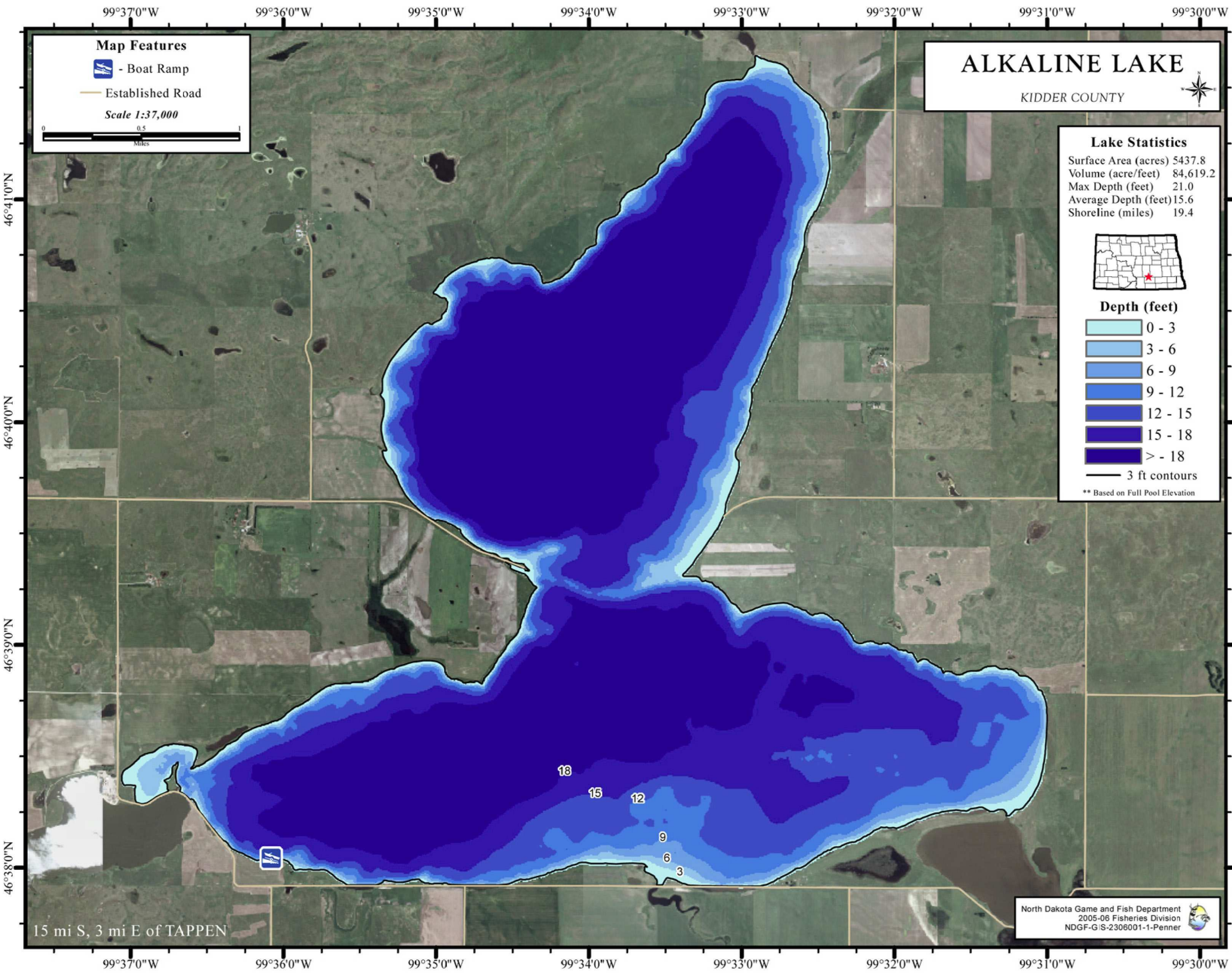


Figure 2. Contour Map of Alkaline Lake (Map Courtesy of North Dakota Game & Fish Department).

Recreational Facilities: Recreational facilities at Alkaline Lake include a cement boat ramp and associated parking. It is a pack it in pack it out recreation area with no restrooms or other facilities.

Water Quality Standards Classification: Alkaline Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2007) as a class 2 lake. Class 2 lakes and reservoirs are defined as "Cool Water Fisheries" or "waters capable of supporting natural reproduction and growth of cool water fishes (e.g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: Alkaline Lake's fishery is dependent on lake levels. When lake levels are consistently high, as they have been in recent years, the lake is an excellent walleye, northern pike, and yellow perch fishery.

Historical Water Quality Sampling: There is no historical water quality data available for Alkaline Lake.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trend assessments for Alkaline Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There were four temperature and dissolved oxygen profiles for Alkaline Lake collected from 2005 to 2006. During the 2005-2006 monitoring period, Alkaline Lake maintained adequate temperature and dissolved oxygen concentrations for sustaining aquatic life (Figures 3 and 4). The only period of thermal stratification documented was on February 9, 2006, beginning at 2 meters of depth and resulting in measurable but slow oxygen depletion rate.

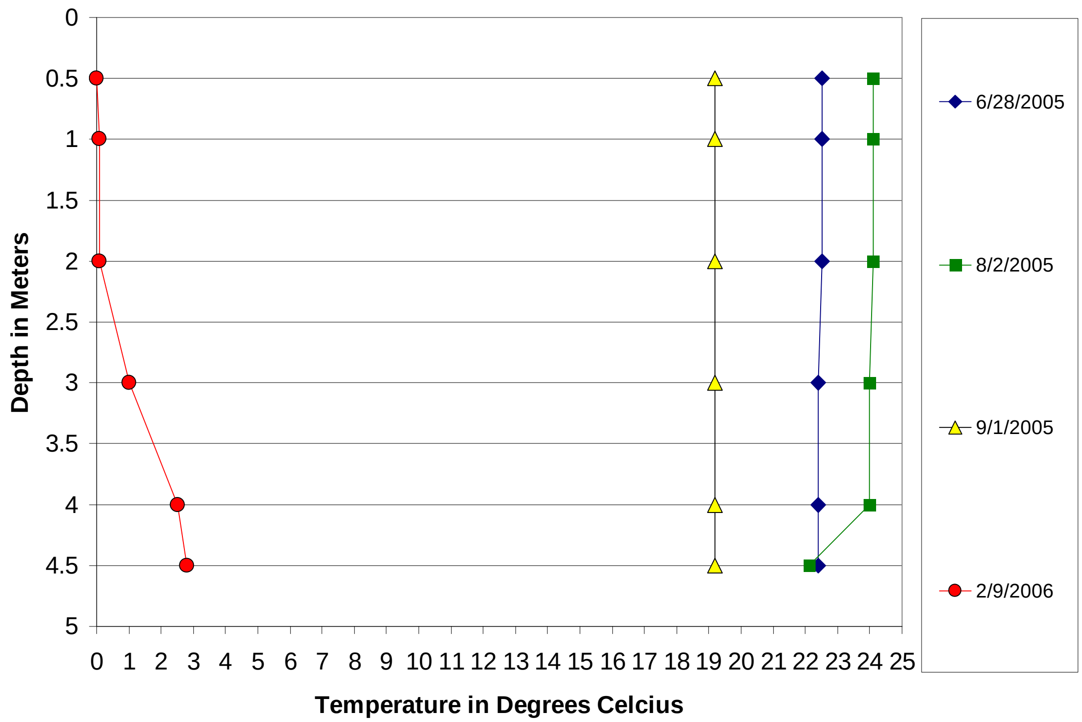


Figure 3. Temperature Profiles for Alkaline Lake from 2005 to 2006.

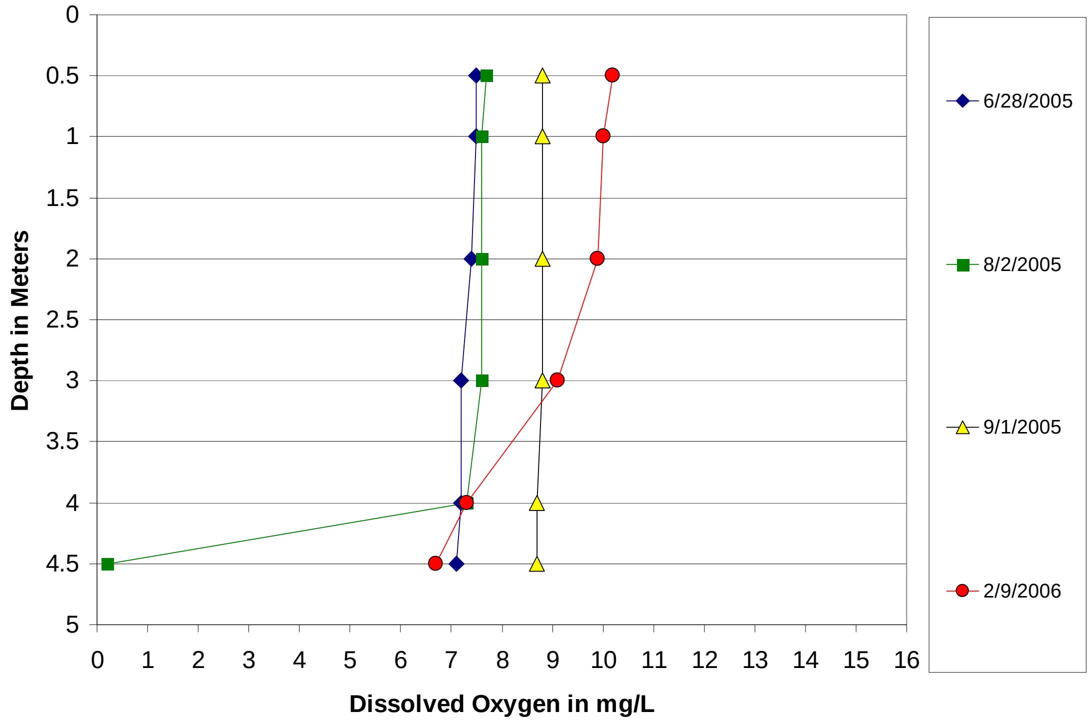


Figure 4. Dissolved Oxygen Profiles for Alkaline Lake from 2005 to 2006.

General Water Quality: Alkaline Lake is appropriately named as it is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 717 mg/L to 802 mg/L (Table 1). The average concentration of alkalinity for the four samples was 746 mg/L exceeding the Rangeland Plains regional average by more then a standard deviation (Table 2). Alkaline Lake is sodium sulfate dominated with an average sodium concentration of 871 mg/L, and an average sulfate concentration of 1537 mg/L. The average TDS concentration and specific conductance measurements for the 2005-2006 sampling period were 3263 mg/L and 4318 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 2.445 mg/L and 0.066 mg/L, respectively.

When compared to other enhanced and natural lakes in the Rangeland Plains region, Alkaline Lake contains above average concentrations of dissolved solids, nutrients and anions (Table 2). For example the regional average TDS, total nitrogen, and sulfate concentrations are 1588 mg/L, 1.826 mg/L, and 680 mg/L, respectively, compared to Alkaline Lake's average TDS, total nitrogen, and sulfate concentrations of 3263 mg/L, 2.445 mg/L, and 1538 mg/L, respectively (Table 1).

Table 1. Statistical Summary of Alkaline Lake's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	746	717	802	38
Total Ammonia as N	mg/L	4	0.017	0.010[1]	0.036	0.013
Bicarbonate (HCO_3)	mg/L	4	679	629	776	65
Calcium (Ca)	mg/L	4	15.7	11.8	21.1	4.1
Carbonate (CO_3)	mg/L	4	114	100	133	14
Chloride (Cl)	mg/L	4	130	118	153	15
Chlorophyll-a	µg/L	4	9.7	6.9	12.8	3.1
Specific Conductance	µmhos	4	4318	4060	4790	326
Total Dissolved Solids	mg/L	4	3263	3020	3600	274
Total Hardness as ($CaCO_3$)	mg/L	4	644	577	745	71
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.247	0.196	0.363	0.078
Magnesium (Mg)	mg/L	4	147	133	171	16
Nitrate + Nitrite as N	mg/L	4	0.025	0.020	0.040	0.010
Total Kjeldahl Nitrogen as N	mg/L	4	2.420	2.260	2.580	0.146
Total Nitrogen as N	mg/L	4	2.445	2.280	2.620	0.154
pH		4	8.99	8.91	9.06	0.06
Total Phosphorus as P	mg/L	4	0.066	0.050	0.096	0.021
Potassium (K)	mg/L	4	109.8	97.5	127.0	12.4
Sodium (Na)	mg/L	4	871	754	990	108
Sulfate (SO4)	mg/L	4	1538	1420	1720	131

[1]Equal to Minimum Reportable Limit

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Alkaline Lake and that the weight ratio of total nitrogen to total phosphorus (N:P) in the lake's algae is approximately 15 to 1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were 4 water quality sample results for Alkaline Lake collected between 2005 and 2006, where the N:P ratio could be calculated. The results from this analysis indicate that Alkaline Lake is phosphorus limited (Figure 5).

The nitrogen to phosphorus ratios for Alkaline Lake ranged from a low of 25 to a high of 52 with an average of 40 (Figure 5). All four samples collected displayed an N:P ratio greater than 15, indicating that phosphorus is limiting primary production at Alkaline Lake.

Table 2. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lakes in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	272	544	119	4770	130
Total Ammonia as N	mg/L	371	0.107	0.001[1]	2.230	0.200
Bicarbonate (HCO_3)	mg/L	272	489	145	2990	150
Calcium (Ca)	mg/L	272	44	1[1]	282	26
Carbonate (CO_3)	mg/L	262	89	1[1]	1420	30
Chloride (Cl)	mg/L	272	51	4[1]	1070	9
Chlorophyll-a	µg/L	250	22	2[1]	292	28
Specific Conductance	µmhos	272	2168	448	20100	959
Total Dissolved Solids	mg/L	272	1588	227	18200	750
Total Hardness as ($CaCO_3$)	mg/L	272	538	170	2370	260
Hydroxide (OH)	mg/L	200	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	273	0.193	0.001[1]	2.260	0.334
Magnesium (Mg)	mg/L	272	104	20	567	50
Nitrate + Nitrite as N	mg/L	332	0.036	0.002[1]	0.338	0.092
Total Kjeldahl Nitrogen as N	mg/L	340	1.950	0.080	8.500	0.779
Total Nitrogen as N	mg/L	278	1.826	0.269	5.520	0.562
pH		272	8.80	7.40	9.87	0.56
Total Phosphorus as P	mg/L	377	0.244	0.004[1]	1.940	0.205
Potassium (K)	mg/L	272	38	3[1]	356	6
Sodium (Na)	mg/L	272	331	17	4680	171
Sulfate (SO4)	mg/L	272	680	34	10500	501

[1]Equal to Minimum Reporting Limit.
[2]Data Collected from 48 Natural and Enhanced Lakes between 1991 and 2007

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus measurements, Alkaline Lake's trophic status is eutrophic (Figure 6). TSI scores ranged from a low of 50 based on chlorophyll-a, to a high of 70 based on total phosphorus. The average trophic status score for Secchi disk transparency was similar to that estimated by total phosphorus, at 63 (Figure 7).

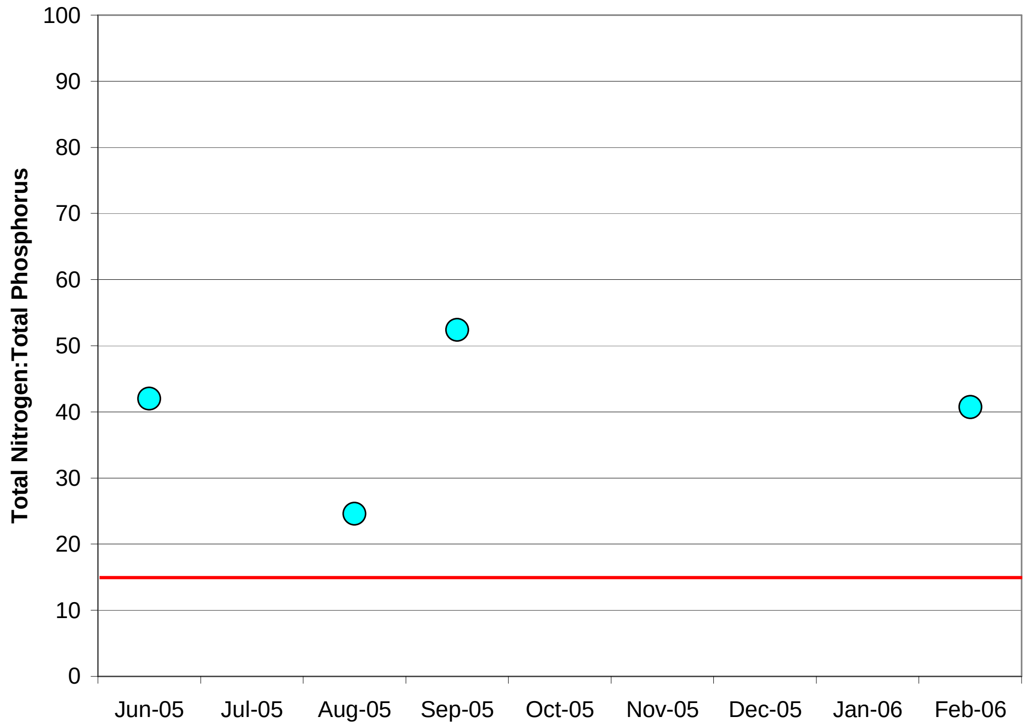


Figure 6. Total Nitrogen to Total Phosphorus Ratios in Alkaline Lake (2005-2006).

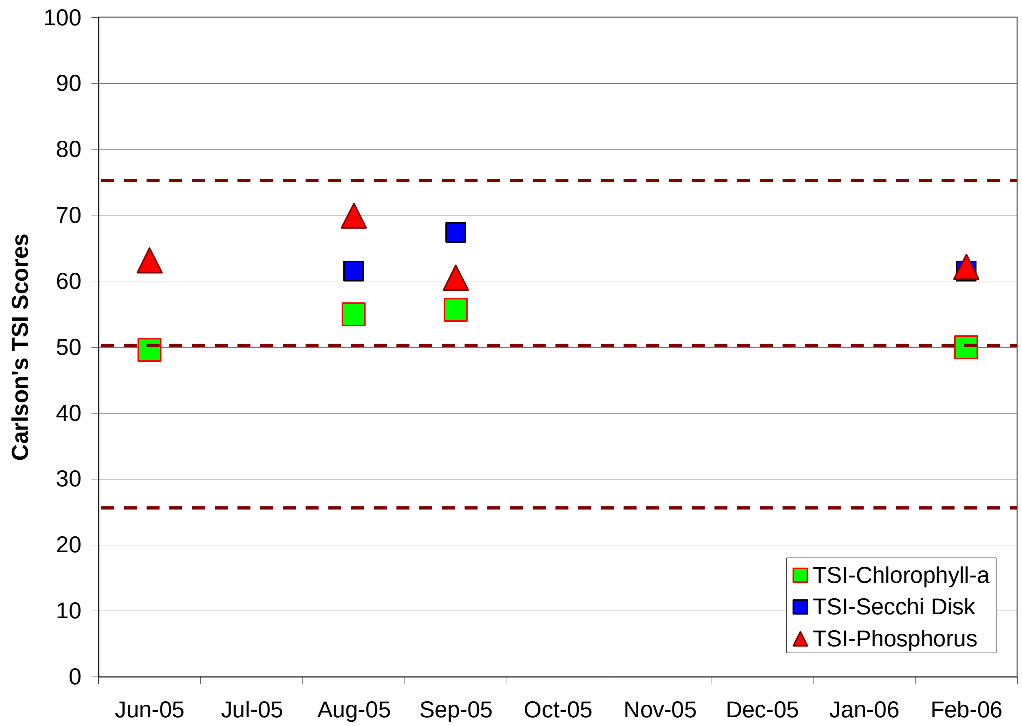


Figure 7. TSI Scores for Alkaline Lake from 2005 to 2006.

Horsehead Lake, Kidder County

BACKGROUND

Location: Horsehead Lake is a natural lake located 2 miles west and 6 miles south of Robinson, North Dakota. Horsehead Lake is managed by the North Dakota Game and Fish Department.

Figure 1. Location of Horsehead Lake.

Physiographic/Ecological Setting: Horsehead Lake is a large prairie lake with a surface area of 6,782.5 acres. It is estimated that Horsehead Lake has a maximum depth between 12 and 15 feet and an average depth of 5 to 7 feet (Figure 2). Horsehead Lake is a glacial remnant lying within the Northwestern Glaciated Plains (NGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The NGP marks the western most extent of continental glacial advancement. The geological youthful landscape has significant surface irregularities and high concentrations of wetlands. The rise in elevation along the eastern edge of this ecoregion defines the boundary of the Great Plans and to the west the Northwestern Great Plans (USEPA 1994).

Figure 2. Horsehead Lake.

Recreational Facilities: Horsehead Lake has no recreational facilities and no developed public assess. It is a pack it in pack it out lake with difficult access from county roads.

Water Quality Standards Classification: Horsehead Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2007) as a class 2 lake. Class 2 lakes and reservoirs are defined as "Cool Water Fisheries" or "waters capable of supporting natural reproduction and growth of cool water fishes (e. g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: Horsehead Lake's fishery is dependent on lake levels. When lake levels are consistently high the lake is a good northern pike fishery. Ice fishing and dark house spearing is the most common fish based recreation on Horsehead Lake.

Historical Water Quality Sampling: There is no historical water quality data available for Horsehead Lake.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trend assessments for Horsehead Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural and enhanced lakes in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There are four temperature and dissolved oxygen profiles for Horsehead Lake collected during the 2006-2007 monitoring period. During this brief monitoring period, Horsehead Lake maintained dissolved oxygen concentrations sufficient for sustaining aquatic life during the open water period but plunged to less then 1 mg/L by February 15, 2007 (Figures 3 and 4).

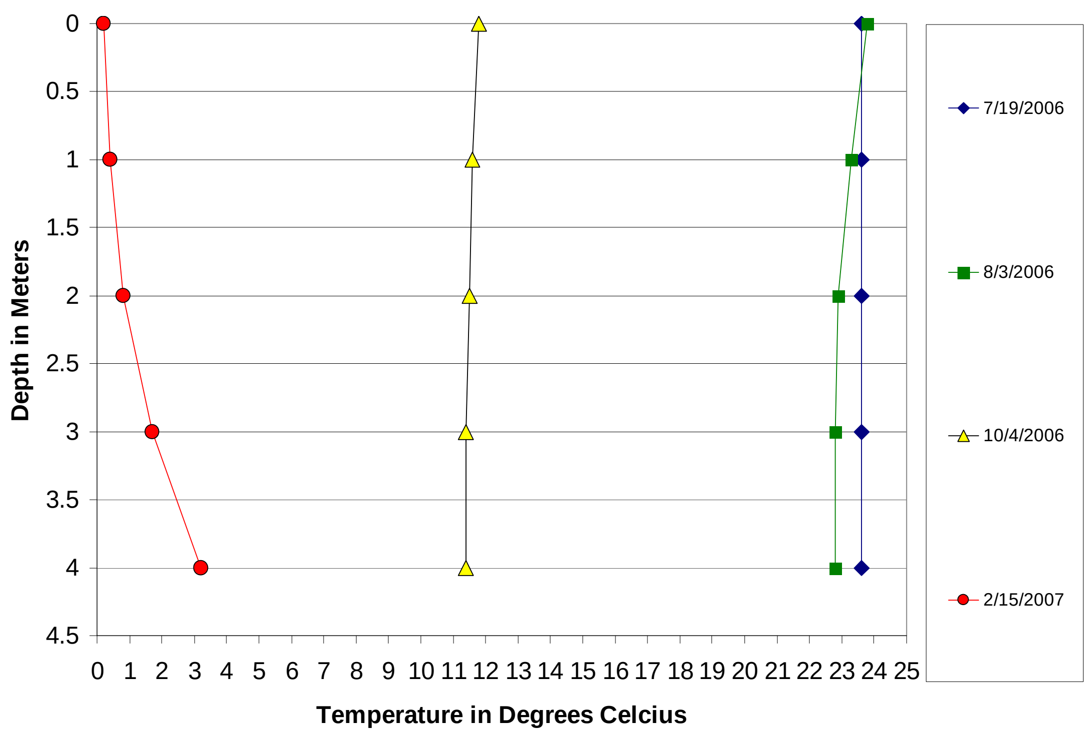


Figure 3. Temperature Profiles for Horsehead Lake from 2006 to 2007.

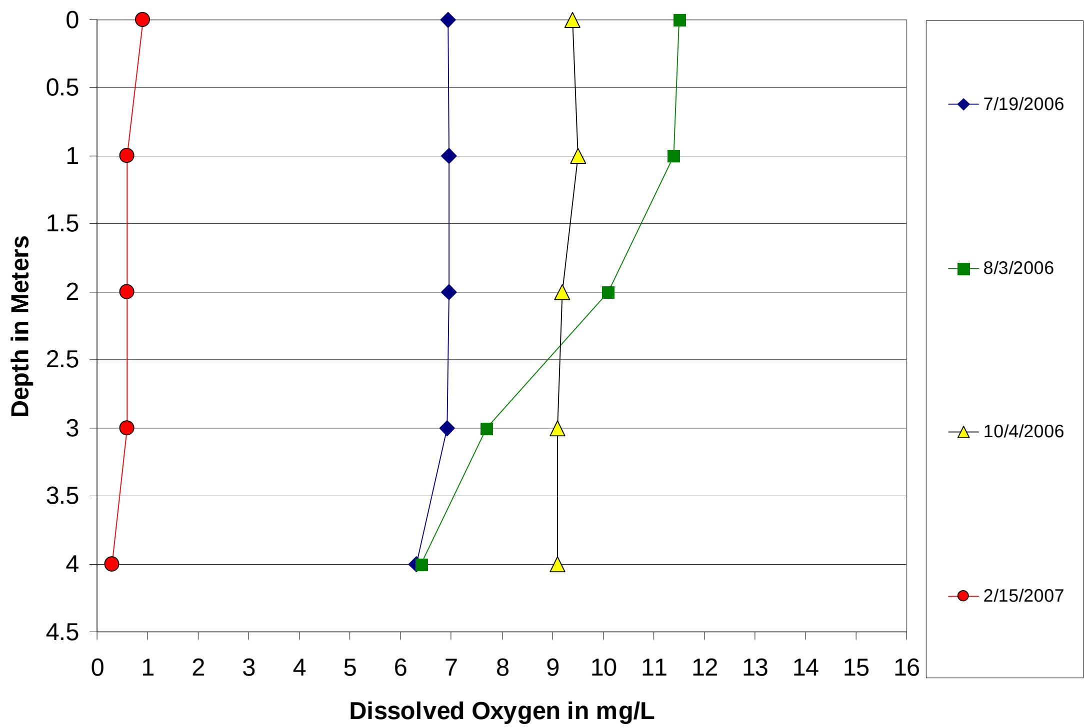


Figure 4. Dissolved Oxygen Profiles for Horsehead Lake from 2006 to 2007.

General Water Quality: Data collected by the NDGF in 2006-2007 indicate Horsehead Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 1250 mg/L to 1560 mg/L (Table 1). Horsehead Lake is sodium sulfate dominated with an average sodium concentration of 1370 mg/L, and an average sulfate concentration of 1163 mg/L. The average TDS concentration and specific conductance measurements for the 2006-2007 sampling period were 4080 mg/L and 5925 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 3.790 mg/L and 0.162 mg/L, respectively.

When compared to the Rangeland Plains regional average concentrations for natural and enhanced lakes, Horsehead Lake is higher in several parameters (Table 2). For example, the regional average TDS, total nitrogen, and bicarbonate concentrations are 1588 mg/L, 1.826 mg/L, and 489 mg/L, respectively, compared to Horsehead Lake's average TDS, total nitrogen, and bicarbonate concentrations of 4080 mg/L, 3.790 mg/L, and 1123 mg/L, respectively.

Table 1. Statistical Summary of Horsehead Lake's 2006-2007 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	1345	1250	1560	146
Total Ammonia as N	mg/L	4	0.109	0.010[1]	0.404	0.197
Bicarbonate (HCO_3)	mg/L	4	1123	1010	1390	1811
Calcium (Ca)	mg/L	4	13	11	13	1
Carbonate (CO_3)	mg/L	4	256	218	290	29
Chloride (Cl)	mg/L	4	549	491	667	80
Chlorophyll-a	µg/L	4	21	6	44	16
Specific Conductance	µmhos	4	5925	5480	6820	613
Total Dissolved Solids	mg/L	4	4080	3740	4740	451
Total Hardness as ($CaCO_3$)	mg/L	4	357	318	409	38
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0.0
Iron (Fe)	mg/L	4	0.259	0.092	0.372	0.123
Magnesium (Mg)	mg/L	4	79.1	70.51	91.3	8.8
Nitrate + Nitrite as N	mg/L	4	0.025	0.020	0.040	0.010
Total Kjeldahl Nitrogen as N	mg/L	4	3.765	3.330	4.650	0.604
Total Nitrogen as N	mg/L	4	3.790	3.350	4.690	0.614
pH		4	9.22	9.14	9.33	0.08
Total Phosphorus as P	mg/L	4	0.162	0.104	0.193	0.041
Potassium (K)	mg/L	4	95	88	105	7
Sodium (Na)	mg/L	4	1370	1270	1540	121
Sulfate (SO4)	mg/L	4	1163	1050	1380	148

[1]Equal to Minimum Reportable Limit

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Horsehead Lake and that the weight ratio of total nitrogen to total phosphorus (N:P) in algae is 15 to 1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were four water quality sample results for Horsehead Lake collected between July 2006 and February 2007, where the N:P ratio could be calculated. The results from this limited collection period indicate that Horsehead Lake is phosphorus limited (Figure 5).

The nitrogen to phosphorus ratio for Horsehead Lake ranged from a low of 25 to a high of 52 with an average of 40 (Figure 5). All four of the samples collected had an N:P ratio greater than 15, indicating that phosphorus is limiting primary production on Horsehead Lake.

Table 2. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lakes in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	272	544	119	4770	130
Total Ammonia as N	mg/L	371	0.107	0.001[1]	2.230	0.200
Bicarbonate (HCO_3)	mg/L	272	489	145	2990	150
Calcium (Ca)	mg/L	272	44	1[1]	282	26
Carbonate (CO_3)	mg/L	262	89	1[1]	1420	30
Chloride (Cl)	mg/L	272	51	4[1]	1070	9
Chlorophyll-a	µg/L	250	22	2[1]	292	28
Specific Conductance	µmhos	272	2168	448	20100	959
Total Dissolved Solids	mg/L	272	1588	227	18200	750
Total Hardness as ($CaCO_3$)	mg/L	272	538	170	2370	260
Hydroxide (OH)	mg/L	200	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	273	0.193	0.001[1]	2.260	0.334
Magnesium (Mg)	mg/L	272	104	20	567	50
Nitrate + Nitrite as N	mg/L	332	0.036	0.002[1]	0.338	0.092
Total Kjeldahl Nitrogen as N	mg/L	340	1.950	0.080	8.500	0.779
Total Nitrogen as N	mg/L	278	1.826	0.269	5.520	0.562
pH		272	8.80	7.40	9.87	0.56
Total Phosphorus as P	mg/L	377	0.244	0.004[1]	1.940	0.205
Potassium (K)	mg/L	272	38	3[1]	356	6
Sodium (Na)	mg/L	272	331	17	4680	171
Sulfate (SO4)	mg/L	272	680	34	10500	501

[1]Equal to Minimum Reporting Limit.
[2]Data Collected from 48 Natural and Enhanced Lakes between 1991 and 2007

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2006-2007, Horsehead Lake's trophic status is eutrophic (Figure 6). TSI scores ranged from a low of 49 based on chlorophyll-a, to a high of 80 based on total phosphorus. The trophic status score based on Sechhi disk transparency was similar to that estimated by chlorophyll-a, at 52 (Figure 6).

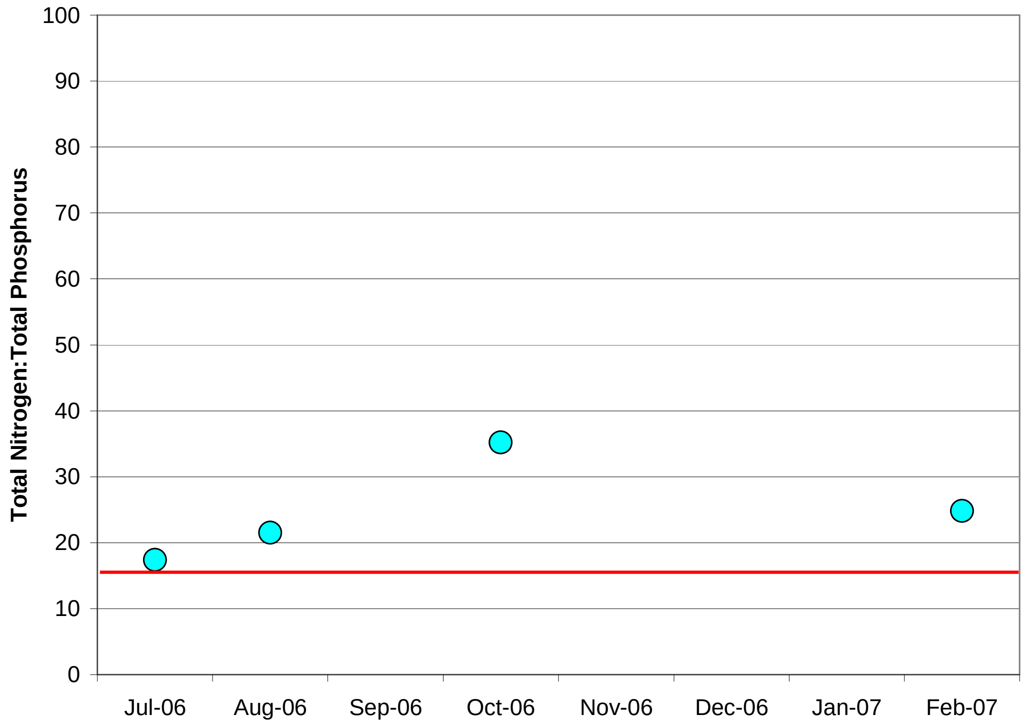


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Horsehead Lake (2006-2007).

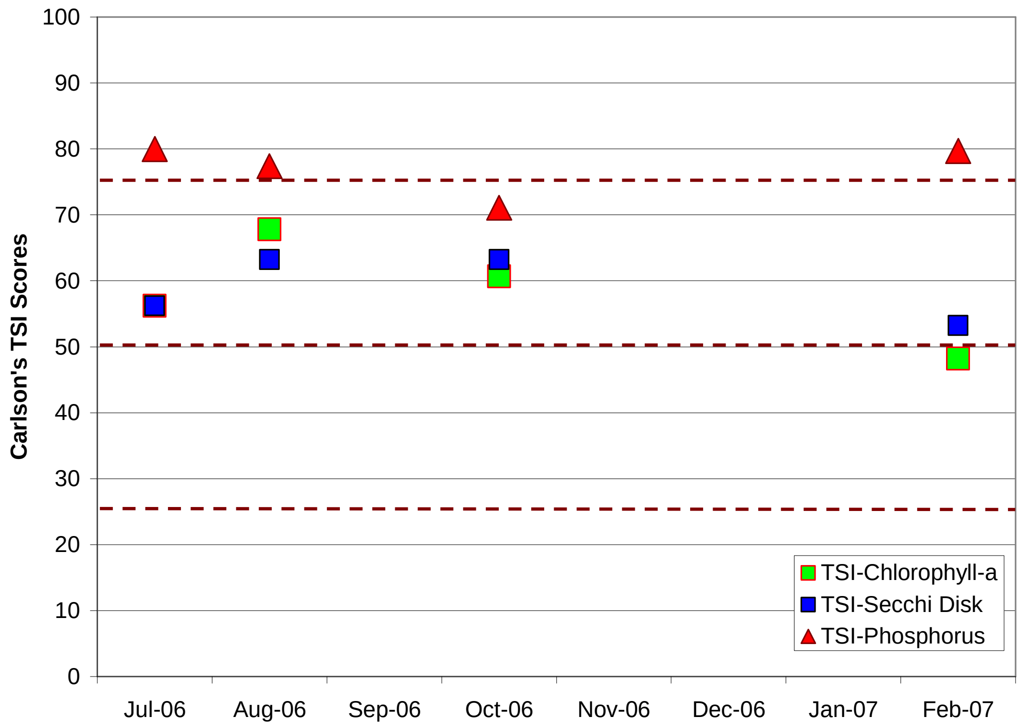


Figure 6. TSI Scores for Horsehead Lake from 2006-2007.

Lake Josephine, Kidder County

BACKGROUND

Location: Lake Josephine is a natural lake located 2 miles north of Tuttle, North Dakota (Figure 1). Lake Josephine is managed by the North Dakota Game and Fish Department.

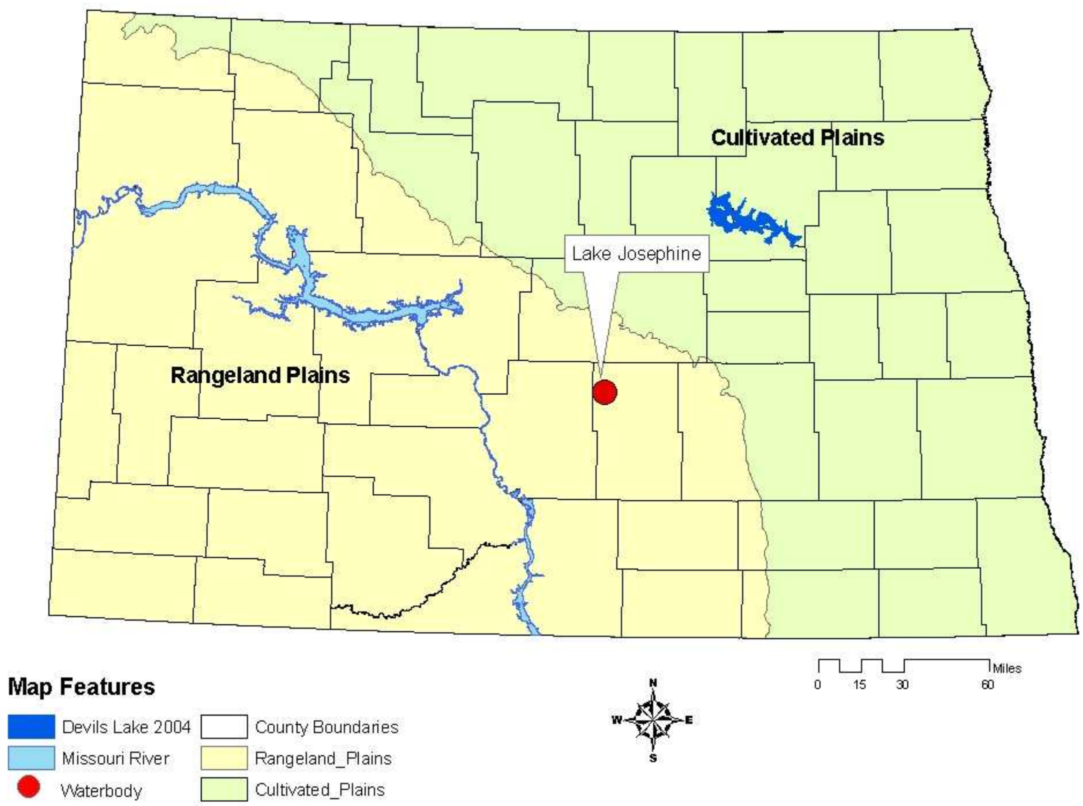


Figure 1. Location of Lake Josephine.

Physiographic/Ecological Setting: Lake Josephine has a surface area of 829 acres, a maximum depth of 22.6 ft, and an average depth 15.8 ft (Figure 2). The lake is located in the Northwestern Glaciated Plains (NGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The Northwestern Great Plains Ecological region is composed of the Missouri Coteau section of the Great Plains. It is a semiarid hilly region formed by the terminal advance of the last Wisconsin Ice age. The area is characterized by rises of 100 to 350 feet with many glacial lakes, ponds and wetlands at the feet of the rises to form a mosaic of the finest waterfowl resting and rearing area in the world (USEPA 1994).

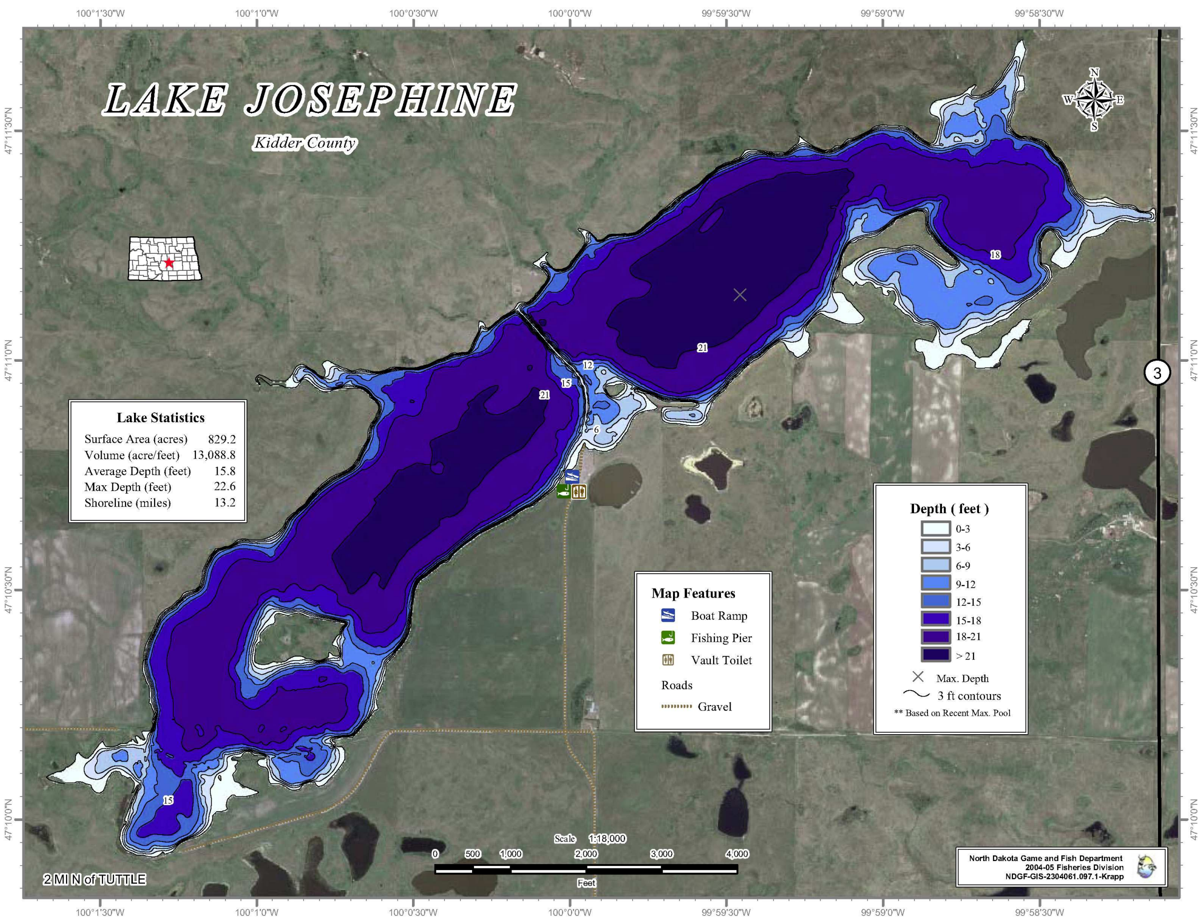


Figure 2. Contour Map of Lake Josephine (Map Courtesy of North Dakota Game and Fish Department).

Recreational Facilities: Recreational facilities at Lake Josephine include a cement boat ramp, boat and vehicle parking, a small park, a fishing pier, and vaulted restrooms. The boat dock and associated facilities are located on the south side of the lake.

Water Quality Standards Classification: Lake Josephine is classified in the state “Standards of Quality for Waters of the State” (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a “warm water fishery” or “waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present.”

Historical and Current Fishery: Lake Josephine’s fishery has included northern pike, walleye, yellow perch, white and black crappie, and bluegill. Northern pike, walleye, and yellow perch are currently managed at Lake Josephine.

Historical Water Quality Sampling: There is no historical water quality data available for Lake Josephine.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trend assessment for Lake Josephine have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural and enhanced in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There were four temperature and three dissolved oxygen profiles for Lake Josephine collected in 2005-2006 (Figures 3 and 4). The profile data shows Lake Josephine is normally not thermally stratified. However during thermal stratification on February 8, 2006, the lake experienced moderate oxygen decay, but did not drop below the state's water quality standard of 5 mg/L until just prior to the sediment-water interface. While the loss of dissolved oxygen during mid-winter thermal stratification is concerning, there does appear to be enough dissolved oxygen to maintain aquatic life in nearly the entire lake volume.

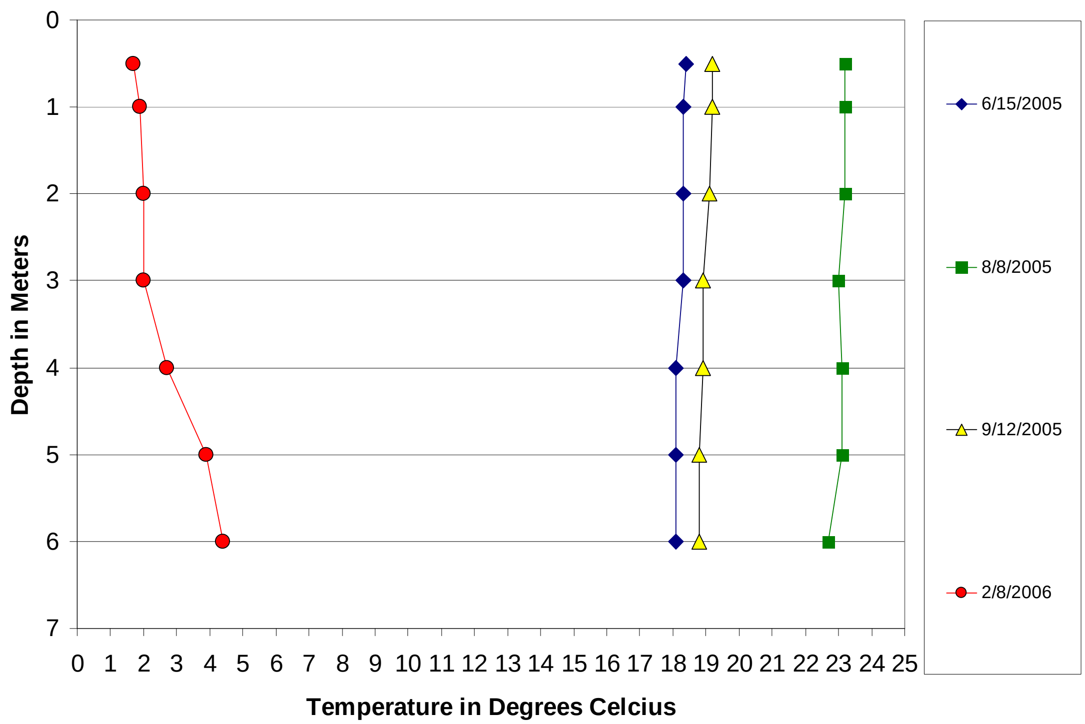


Figure 3. Temperature Profiles for Lake Josephine from 2005-2006.

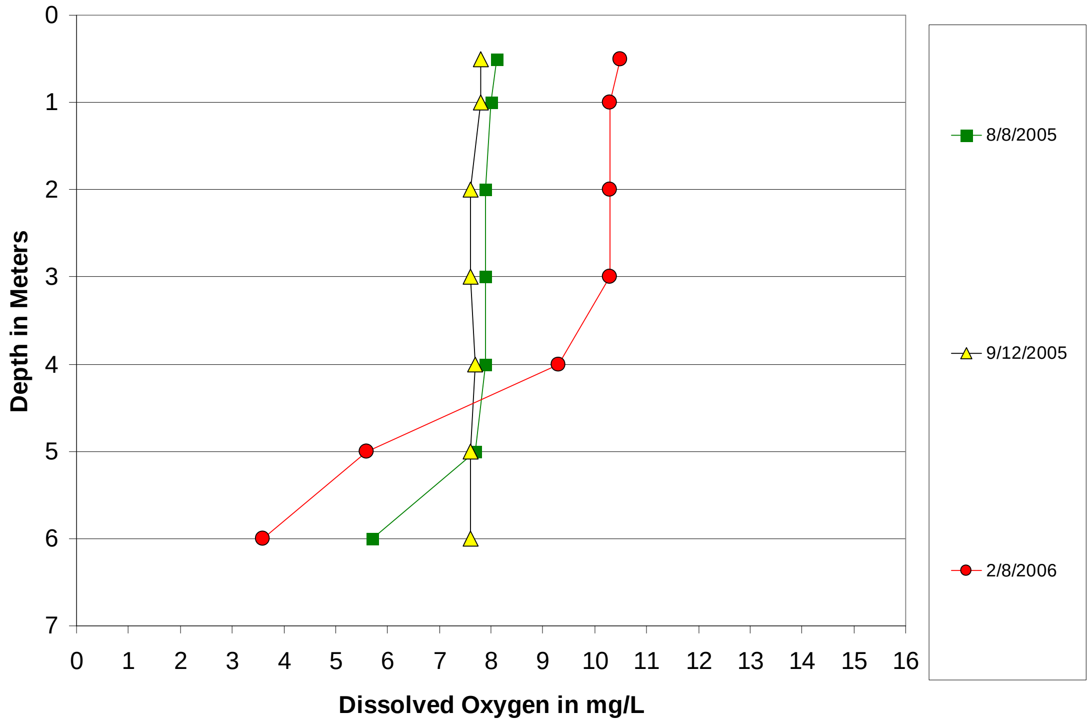


Figure 4. Dissolved Oxygen Profiles for Lake Josephine from 2005-2006.

General Water Quality: Data collected by the NDGF in 2005 and 2006 indicate Lake Josephine is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 591 to 691 mg/L (Table 1). Based on the 2005-2006 water quality data (Table 1), Lake Josephine is sodium bicarbonate dominated followed closely by sodium sulfates with an average bicarbonate concentration of 637 mg/L, an average sulfate concentration of 537 mg/L, and an average sodium concentration of 339 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 1440 mg/L and 2100 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.885 mg/L and 0.215 mg/L, respectively.

When compared to Rangeland Plains regional average Lake Josephine water quality is fairly average (Table 2). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations were 1588 mg/L, 1.826 mg/L, and 0.244 mg/L, respectively, compared to Lake Josephine's average TDS, total nitrogen, and total phosphorus concentrations of 1440 mg/L, 1.885 mg/L, and 0.215 mg/L, respectively.

Table 1. Statistical Summary of Lake Josephine's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	644	591	691	43
Total Ammonia as N	mg/L	4	0.016	0.010	0.021	0.006
Bicarbonate (HCO_3)	mg/L	4	637	568	695	53
Calcium (Ca)	mg/L	4	33.7	30.7	38.7	3.8
Carbonate (CO_3)	mg/L	4	73	56	87	13
Chloride (Cl)	mg/L	4	19	18	23	2
Chlorophyll-a	µg/L	4	12.5	9.3	18.0	3.8
Specific Conductance	µmhos	4	2100	1980	2370	182
Total Dissolved Solids	mg/L	4	1440	1330	1660	149
Total Hardness as ($CaCO_3$)	mg/L	4	422	386	501	53
Hydroxide (OH)	mg/L	4	1	1	1	0
Iron (Fe)	mg/L	4	0.357	0.298	0.476	0.083
Magnesium (Mg)	mg/L	4	82.2	75.1	98.3	10.9
Nitrate + Nitrite as N	mg/L	4	0.025	0.020	0.030	0.006
Total Kjeldahl Nitrogen as N	mg/L	4	1.860	1.570	2.160	0.243
Total Nitrogen as N	mg/L	4	1.885	1.600	2.190	0.243
pH		4	8.85	8.74	8.97	0.10
Total Phosphorus as P	mg/L	4	0.215	0.155	0.296	0.062
Potassium (K)	mg/L	4	41.7	36.3	50.2	6.0
Sodium (Na)	mg/L	4	339	307	412	49
Sulfate (SO4)	mg/L	4	537	499	621	57

[1]Equal to minimum reporting limit.

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Lake Josephine and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight, in algae is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were four water quality sample results for Lake Josephine collected between July 2005 and February 2006 where the N:P ration could be calculated. The results from this analysis indicate that Lake Josephine is nitrogen limited (Figure 5).

N:P ratios for Lake Josephine ranged from a low of 6 to a high of 14 with an average of 7.4. Of the four samples collected all were below an N:P ratio of 15 indicating nitrogen limitation.

Table 2. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lakes in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	272	544	119	4770	130
Total Ammonia as N	mg/L	371	0.107	0.001[1]	2.230	0.200
Bicarbonate (HCO_3)	mg/L	272	489	145	2990	150
Calcium (Ca)	mg/L	272	44	1[1]	282	26
Carbonate (CO_3)	mg/L	262	89	1[1]	1420	30
Chloride (Cl)	mg/L	272	51	4[1]	1070	9
Chlorophyll-a	µg/L	250	22	2[1]	292	28
Specific Conductance	µmhos	272	2168	448	20100	959
Total Dissolved Solids	mg/L	272	1588	227	18200	750
Total Hardness as ($CaCO_3$)	mg/L	272	538	170	2370	260
Hydroxide (OH)	mg/L	200	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	273	0.193	0.001[1]	2.260	0.334
Magnesium (Mg)	mg/L	272	104	20	567	50
Nitrate + Nitrite as N	mg/L	332	0.036	0.002[1]	0.338	0.092
Total Kjeldahl Nitrogen as N	mg/L	340	1.950	0.080	8.500	0.779
Total Nitrogen as N	mg/L	278	1.826	0.269	5.520	0.562
pH		272	8.796	7.400	9.870	0.564
Total Phosphorus as P	mg/L	377	0.244	0.004[1]	1.940	0.205
Potassium (K)	mg/L	272	38	3[1]	356	6
Sodium (Na)	mg/L	272	331	17	4680	171
Sulfate (SO4)	mg/L	272	680	34	10500	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 48 Natural and Enhanced Lakes between 1991 and 2007

Trophic Status Assessment: Based on chlorophyll-a and Secchi disk transparency data collected during 2005-2006, Lake Josephine's current trophic status is eutrophic. TSI scores ranged from a low 52 based on chlorophyll-a, to a high of 86 based on total phosphorus. The average trophic status score based on Secchi disk transparency was similar to that estimated by chlorophyll-a, at 60 (Figure 6).

A total of four total phosphorus samples, three chlorophyll-a samples, and four Secchi disk transparency measurements collected during the open water periods from 2005 to 2006 were used to evaluate trends in the trophic status of Lake Josephine. Since Lake Josephine is nitrogen limited, chlorophyll-a and Secchi disk transparency are the better indicators of trophic status at the lake.

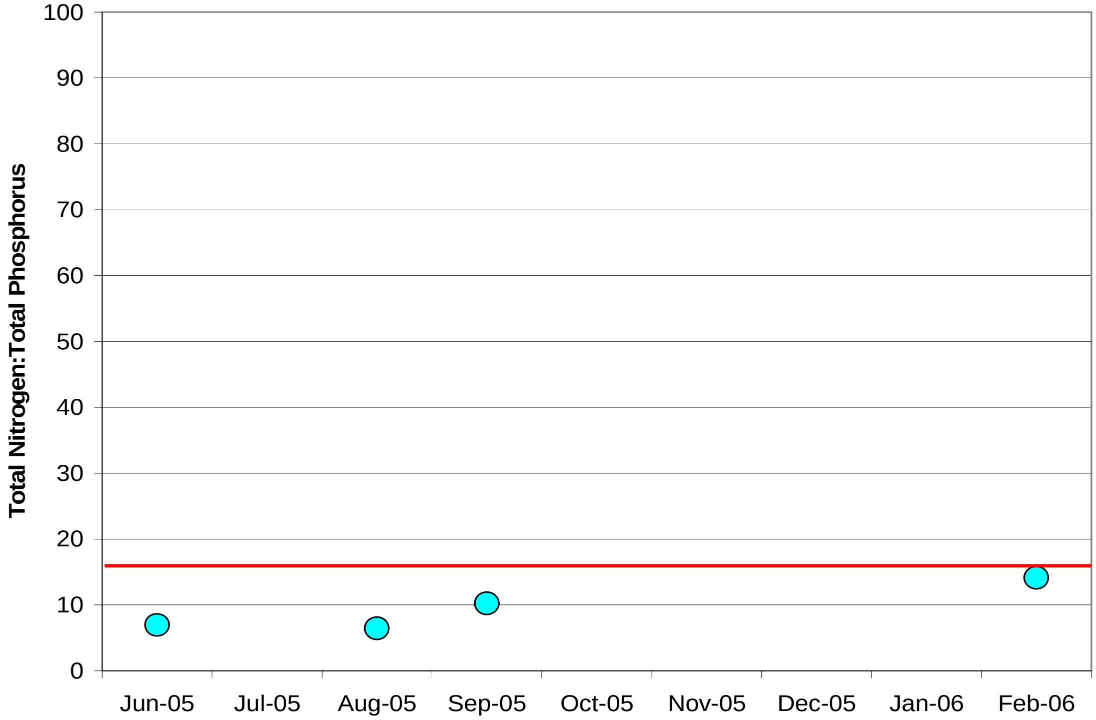


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Lake Josephine (2005-2006).

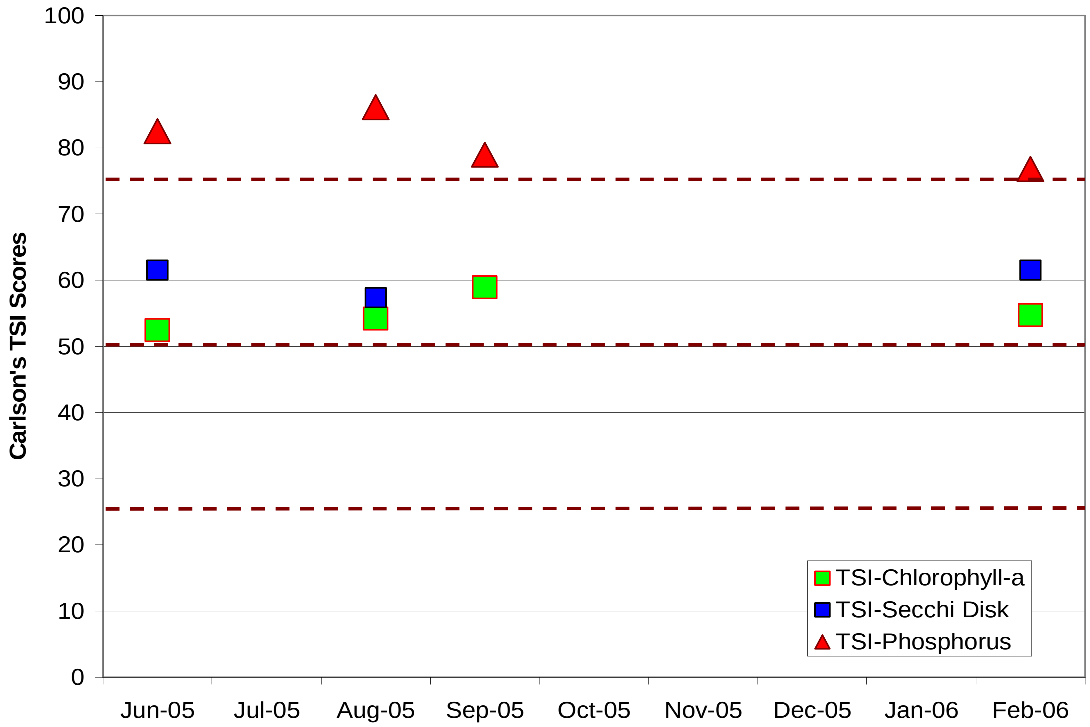


Figure 6. TSI Scores for Lake Josephine from 2005 to 2006.

Heinrich-Martin Dam, LaMoure County

BACKGROUND

Location: Heinrich-Martin Dam is a small impoundment on an unnamed tributary to the James River in southeastern North Dakota (Figure 1). Heinrich-Martin Dam is located 1 mile southeast of Adrian, North Dakota. The reservoir is managed by the North Dakota Game and Fish Department.

Figure 1. Location of Heinrich-Martin Dam.

Physiographic/Ecological Setting: Heinrich-Martin Dam is a 18.8 acre reservoir with a maximum depth of 34.9 feet and a mean depth of 14.0 feet (Figure 2). Heinrich-Martin Dam resides in the Northern Glaciated Plains Level III Ecoregion, part of the broader Cultivated Plains region (Figure 1). The Northern Glaciated Plains is characterized by flat to rolling landscape composed of glacial drift (USEPA 1994). This region is the transitional zone between tall and mixed grass prairie. The region has numerous wetlands essential for spring and fall migrations of wetland dependent birds. Flood plain slopes and hillsides are usually native grass while the uplands and flood plains proper have mostly been converted to small grains, row crops and alfalfa.

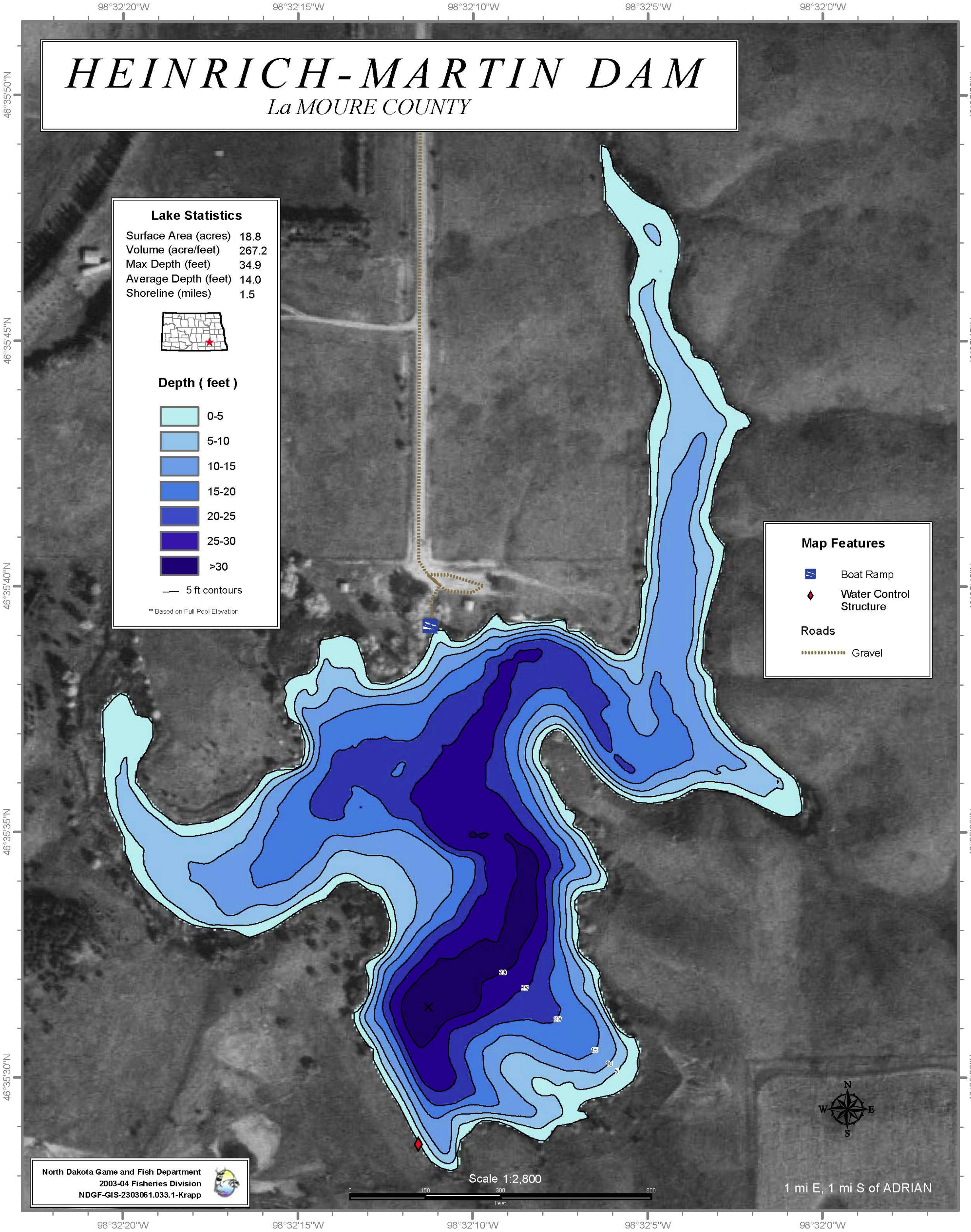


Figure 2. Contour Map of Heinrich-Martin Dam (Map Courtesy of North Dakota Game and Fish Department).

Construction History: Heinrich-Martin Dam was constructed through the combined efforts of the Dickey County Water Resources Board, the State Water Commission, and the North Dakota Game and Fish Department. The Dam was completed in 1965.

Water Quality Standards Classification: Heinrich-Martin Dam is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a "warm water fishery" or "waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present."

Recreational Facilities: Recreational facilities at Heinrich-Martin Dam include a boat ramp, parking, toilets, a picnic area, and walking shore access. Public access to the dam is from the north side of the lake.

Historical and Current Fishery: Heinrich-Martin Dam's historical fishery was smallmouth bass, rainbow trout, and bluegill. The current fishery consists of largemouth bass, bluegill, and crappie.

Historical Water Quality Samples: Historical water quality data includes three sample results collected in 1992 and 1993.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Heinrich-Martin Dam have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Cultivated Plains region.

Temperature and Dissolved Oxygen Profile Results: There are 11 temperature and dissolved oxygen profiles for Heinrich-Martin Dam collected in two clusters, 1992-1993 and 2005-2007 (Figures 3 and 4). The profile data shows that while Heinrich-Martin Dam has adequate dissolved oxygen above the metalimnion it experiences rapid oxygen depletion below. Of the 11 profiles collected, all but two had dissolved oxygen concentrations that declined below the state standard of 5 mg/L within 6 meters of depth and all but four within 4 meters of depth. The depth of thermal stratification ranged from 1 to 6 meters of depth at times leaving very little of the lake volume adequately oxygenated (Figures 3 and 4).

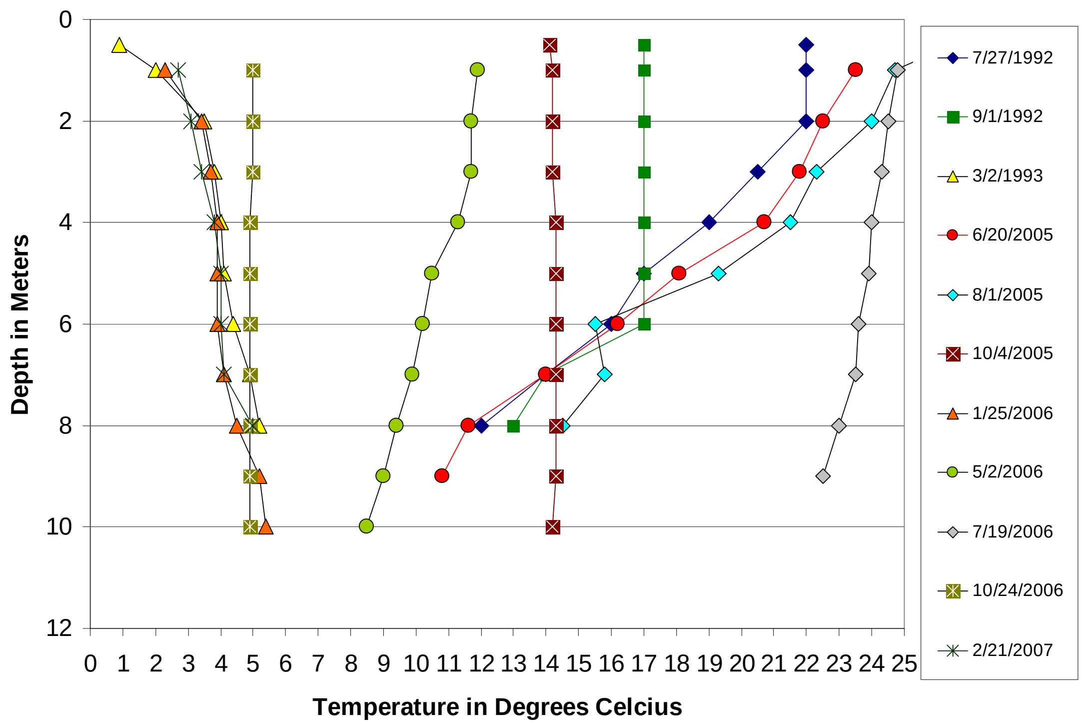


Figure 3. Temperature Profiles for Heinrich-Martin Dam from 1992 to 2007.

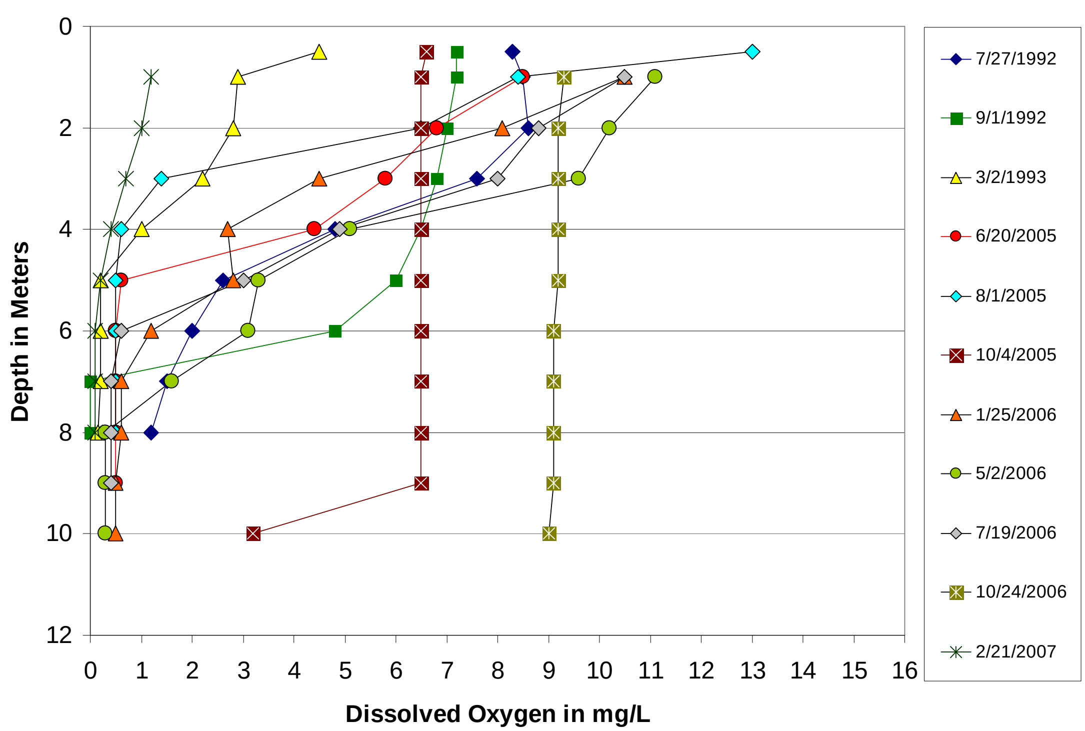


Figure 4. Dissolved Oxygen Profiles for Heinrich-Martin Dam from 1992 to 2007.

General Water Quality: Data collected by the NDG&F in 2005 through 2007 indicate Heinrich-Martin Dam is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 138 to 185 mg/L (Table 1). Heinrich-Martin Dam is sodium bicarbonate dominated with an average sodium concentration of 9 mg/L, and an average bicarbonate concentration of 194 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2007 sampling period were 419 mg/L and 684 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.313 mg/L and 0.069 mg/L, respectively.

Table 1. Statistical Summary of Heinrich-Martin Dam's 2005-2007 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	9	164	138	185	14
Total Ammonia as N	mg/L	9	0.065	0.010[1]	0.234	0.089
Bicarbonate (HCO_3)	mg/L	9	194	146	226	25
Calcium (Ca)	mg/L	9	63	46	92	13
Carbonate (CO_3)	mg/L	9	4	1[1]	14	5
Chloride (Cl)	mg/L	9	13.8	12.1	16.8	1.4
Chlorophyll-a	µg/L	9	39	1.5[1]	127	39
Specific Conductance	µmhos	9	684	562	859	89
Total Dissolved Solids	mg/L	9	419	337	548	61
Total Hardness as ($CaCO_3$)	mg/L	9	324	259	440	50
Hydroxide (OH)	mg/L	9	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	9	0.102	0.010[1]	0.474	0.141
Magnesium (Mg)	mg/L	9	40.5	34.8	50.9	5.1
Nitrate + Nitrite as N	mg/L	9	0.057	0.020[1]	0.200	0.066
Total Kjeldahl Nitrogen as N	mg/L	9	1.257	0.870	1.790	0.296
Total Nitrogen as N	mg/L	9	1.313	1.040	1.810	0.270
pH		9	8.13	7.50	8.63	0.40
Total Phosphorus as P	mg/L	9	0.069	0.025	0.143	0.041
Potassium (K)	mg/L	9	12.8	7.7	14.7	2.2
Sodium (Na)	mg/L	9	9	7	13	2
Sulfate (SO4)	mg/L	9	179	134	251	39

[1]Equal to Minimum Reportable Limit

When comparing historical water quality data from Heinrich-Martin Dam to current water quality data, there appears to be an increasing trend in both dissolved solids and nutrients (Table 2). Historical average TDS, total nitrogen, and total phosphorus concentrations were 138 mg/L, 1.043 mg/L, and 0.037 mg/L, respectively (Table 2), compared to average concentrations of 419 mg/L, 1.313 mg/L, and 0.069 mg/L, respectively.

When comparing Heinrich Martin Dam's 2005-2007 data set to the Cultivated Plains long term average, Heinrich Martin Dam is slightly fresher and contains fewer nutrients than the average reservoir (Table 3). The ecological regional average TDS, total nitrogen, and total phosphorus concentrations were 667 mg/L, 1.488 mg/L, and 0.322 mg/L, respectively (Table 3), compared to the Heinrich-Martin Dam's average concentrations of 419 mg/L, 1.313 mg/L, and 0.069 mg/L, respectively (Table 1).

Table 2. Statistical Summary of Heinrich-Martin Dam's Historical Water Quality Data Collected Between 1992 and 1993.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	127	112	158	26
Total Ammonia as N	mg/L	3	0.073	0.001[1]	0.206	0.115
Bicarbonate (HCO_3)	mg/L	3	150	121	193	38
Calcium (Ca)	mg/L	3	22	19	28	5
Carbonate (CO_3)	mg/L	0	NA[2]	NA[2]	NA[2]	0
Chloride (Cl)	mg/L	2	2.4	1.7	3.2	1.1
Chlorophyll-a	µg/L	2	9	7	11	2.8
Specific Conductance	µmhos	3	250	217	312	54
Total Dissolved Solids	mg/L	3	138	127	153	13
Total Hardness as ($CaCO_3$)	mg/L	3	104	95	121	14
Hydroxide (OH)	mg/L	0	NC[3]	NC[3]	NC[3]	0
Iron (Fe)	mg/L	3	0.125	0.097	0.176	0.045
Magnesium (Mg)	mg/L	3	11.8	11.2	12.5	0.6
Nitrate + Nitrite as N	mg/L	1	0.008	0.008	0.008	0
Total Kjeldahl Nitrogen as N	mg/L	3	1.035	0.990	1.080	0.064
Total Nitrogen as N	mg/L	1	1.043	1.043	1.043	0
pH		3	8.27	7.70	8.86	0.58
Total Phosphorus as P	mg/L	3	0.037	0.020[1]	0.065	0.024
Potassium (K)	mg/L	3	14.5	13.6	15.5	1.0
Sodium (Na)	mg/L	3	2	2	3	0.2
Sulfate (SO4)	mg/L	2	14	8	19	8

[1]Equal to Minimum Reportable Limit
[2]NA: Not Analyzed
[3]NC: Not Collected

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Heinrich-Martin Dam, and that the ratio of total nitrogen to total phosphorus (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

Twelve water quality sample results for Heinrich-Martin Dam between June 1992 and March 2007 indicate that Heinrich-Martin Dam's is phosphorus limited (Figure 5). The nitrogen to phosphorus ratio for Heinrich-Martin Dam ranged from a low of 8 to a high of 80, with an average of 31. Of the 12 samples collected on Heinrich-Martin Dam, all but two were above 15 indicating that phosphorus is limiting primary production.

Table 3. Statistical Summary of Water Quality Data[2] Collected from Reservoirs in the Cultivated Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	352	263	88	891	103
Total Ammonia as N	mg/L	463	0.131	0.001[1]	2.070	0.203
Bicarbonate (HCO_3)	mg/L	352	296	91	951	114
Calcium (Ca)	mg/L	352	65	19	169	22
Carbonate (CO_3)	mg/L	324	14	1[1]	93	16
Chloride (Cl)	mg/L	351	21	1[1]	113	18
Chlorophyll-a	µg/L	373	20	2[1]	388	31
Specific Conductance	µmhos	352	1021	217	3140	516
Total Dissolved Solids	mg/L	344	667	127	2300	387
Total Hardness as ($CaCO_3$)	mg/L	352	334	95	1090	121
Hydroxide (OH)	mg/L	280	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	350	0.137	0.007	3.190	0.216
Magnesium (Mg)	mg/L	352	42	11	161	20
Nitrate + Nitrite as N	mg/L	411	0.097	0.003	2.060	0.191
Total Kjeldahl Nitrogen as N	mg/L	376	1.476	0.207	4.410	0.642
Total Nitrogen as N	mg/L	315	1.488	0.418	3.220	0.587
pH		352	8.36	6.89	9.40	0.43
Total Phosphorus as P	mg/L	464	0.322	0.004[1]	1.380	0.267
Potassium (K)	mg/L	352	12	3[1]	35	5
Sodium (Na)	mg/L	352	97	2[1]	582	107
Sulfate (SO4)	mg/L	351	269	8	1350	217

[1]Equal to lower detection limit
[2]Data Collected from 40 Reservoirs between 1991 and 2007

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005-2007, Heinrich-Martin Dam's trophic status is eutrophic (Figure 6). TSI scores ranged from a low of 35 to a high of 78 based on chlorophyll-a. The trophic scores for Secchi disk transparency ranged from 44 to 73, and the scores for total phosphorus similarly ranged from 51 to 76 (Figure 6).

A total of 12 total phosphorus samples, 11 chlorophyll-a samples, and 11 Secchi disk transparency measurements collected during the open water periods from 1992-2007 were used to evaluate trends in the trophic status of Heinrich-Martin Dam. Based on a visual assessment, it appears that the trophic status of Heinrich-Martin Dam is stable to degrading (Figure 6).

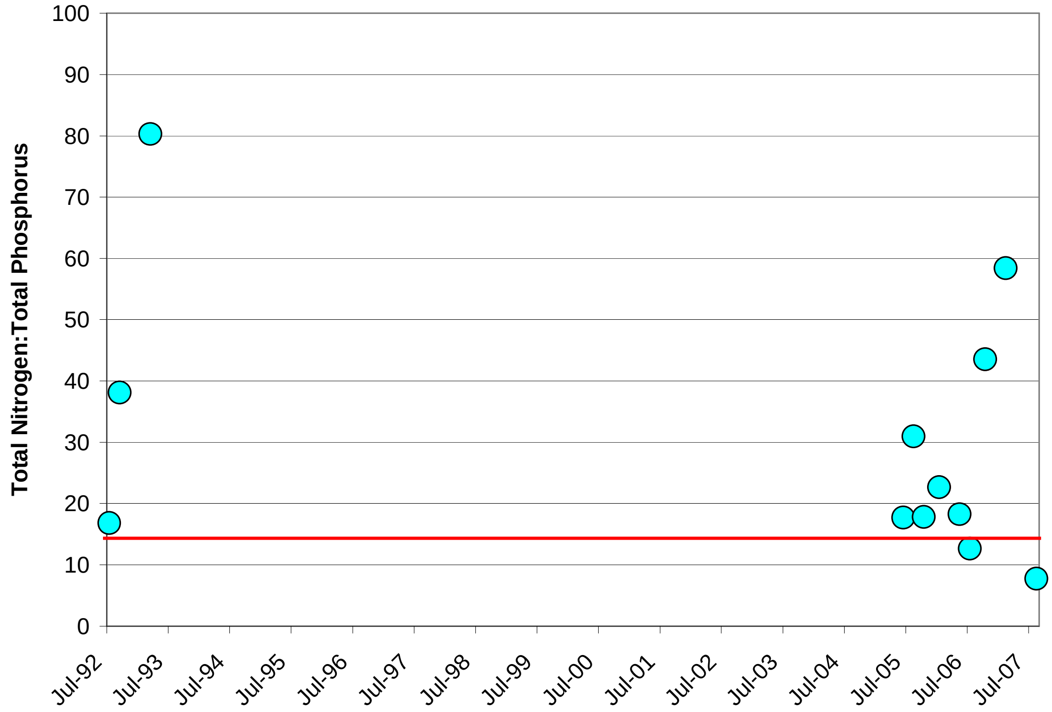


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Heinrich-Martin Dam (1992-2007).

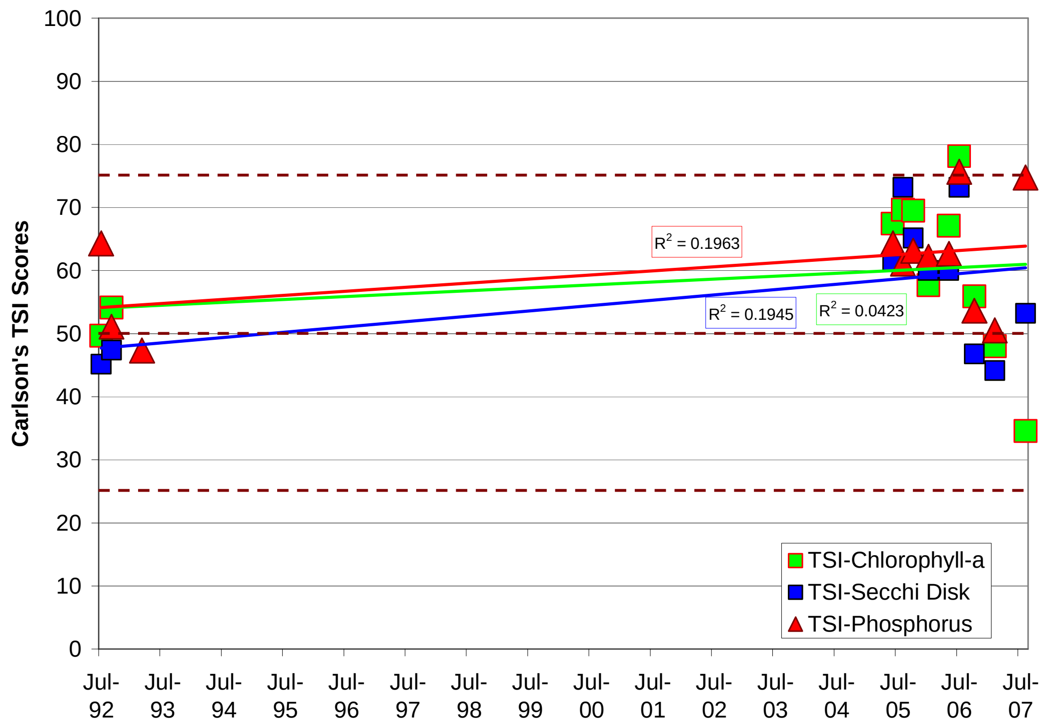


Figure 6. TSI Scores and Temporal Trends for Heinrich-Martin Dam from 1992-2007.

Kalmbach Lake, LaMoure County

BACKGROUND

Location: Kalmbach Lake is an enhanced natural lake located 4½ miles west and 1½ miles south of Jud, North Dakota (Figures 1). Kalmbach Lake is managed by the North Dakota Game and Fish Department.

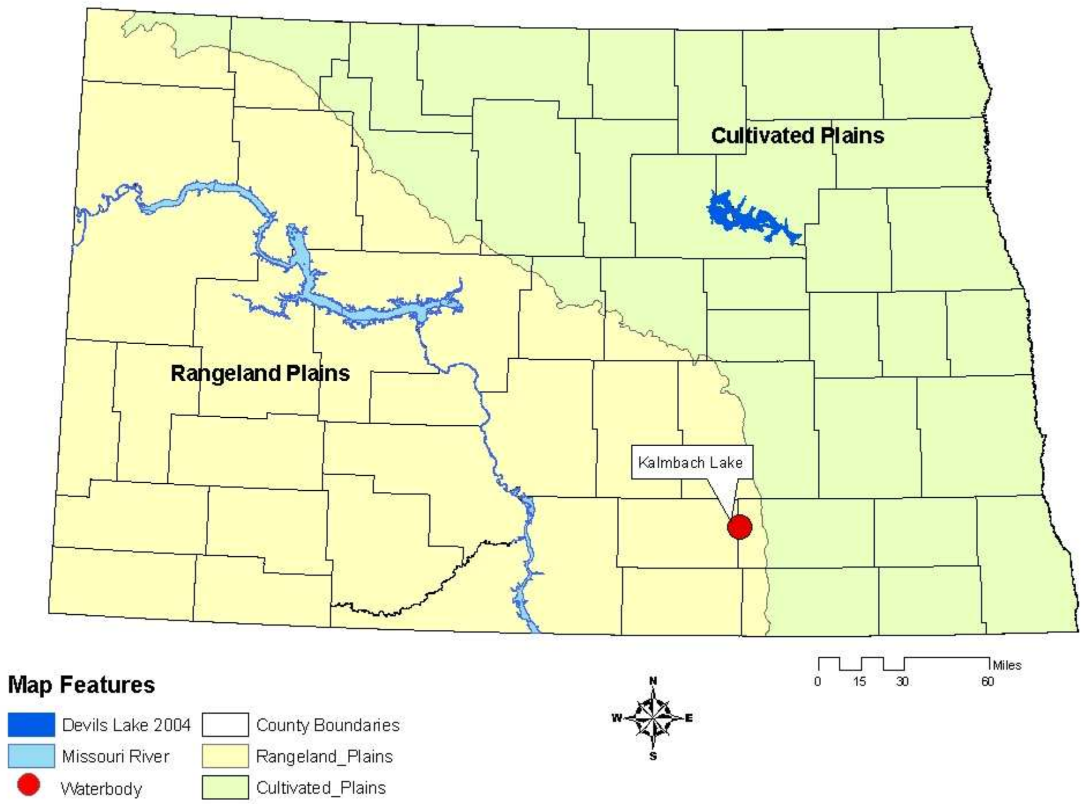


Figure 1. Location of Kalmbach Lake.

Physiographic/Ecological Setting: Kalmbach Lake is an enhanced prairie lake with a surface area of 569 acres, an average depth of 7.5 feet, and a maximum depth of 10.4 feet (Figure 2). Kalmbach Lake is a glacial remnant lying within the Northwestern Glaciated Plains (NGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The NGP marks the western most extent of continental glacial advancement. The geological youthful landscape has significant surface irregularities and high concentrations of wetlands. The rise in elevation along the eastern edge of this ecoregion defines the boundary of the Great Plains and to the west the Northwestern Great Plains (USEPA 1994).

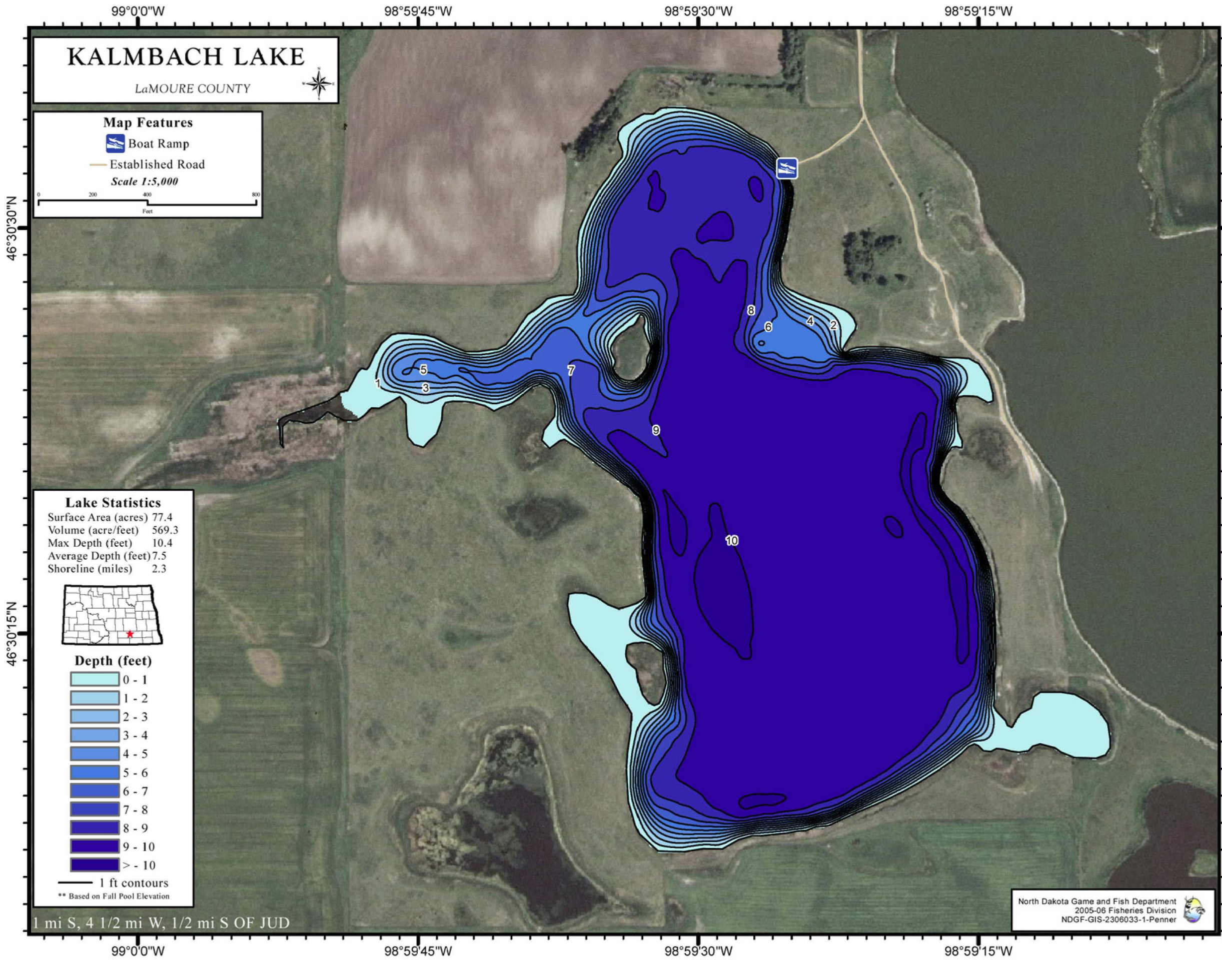


Figure 2. Contour Map of Kalmbach Lake (Map Courtesy of North Dakota Game and Fish Department).

Water Quality Standards Classification: Kalmbach Lake is classified in the state “Standards of Quality for Waters of the State” (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a “warm water fishery” or “waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present.”

Recreational Facilities: Recreational facilities at Kalmbach Lake include a boat ramp, parking, and walking shore access. Access to the lake is located at the northeast corner.

Historical and Current Fishery: Kalmbach Lake’s historical fishery consisted of smallmouth bass, rainbow trout, and bluegill. The lake’s current fishery manages northern pike and yellow perch.

Historical Water Quality Samples: There is no historical water quality data available for Kalmbach Lake.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Kalmbach Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural and enhanced lakes in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There were four temperature and dissolved oxygen profiles for Kalmbach Lake collected in 2005-2006 (Figures 3 and 4). The profile data from 2005-2006, shows that Kalmbach Lake did not thermally stratify. Kalmbach Lake has adequate dissolved oxygen concentrations to within one half meter of the sediment/water interface.

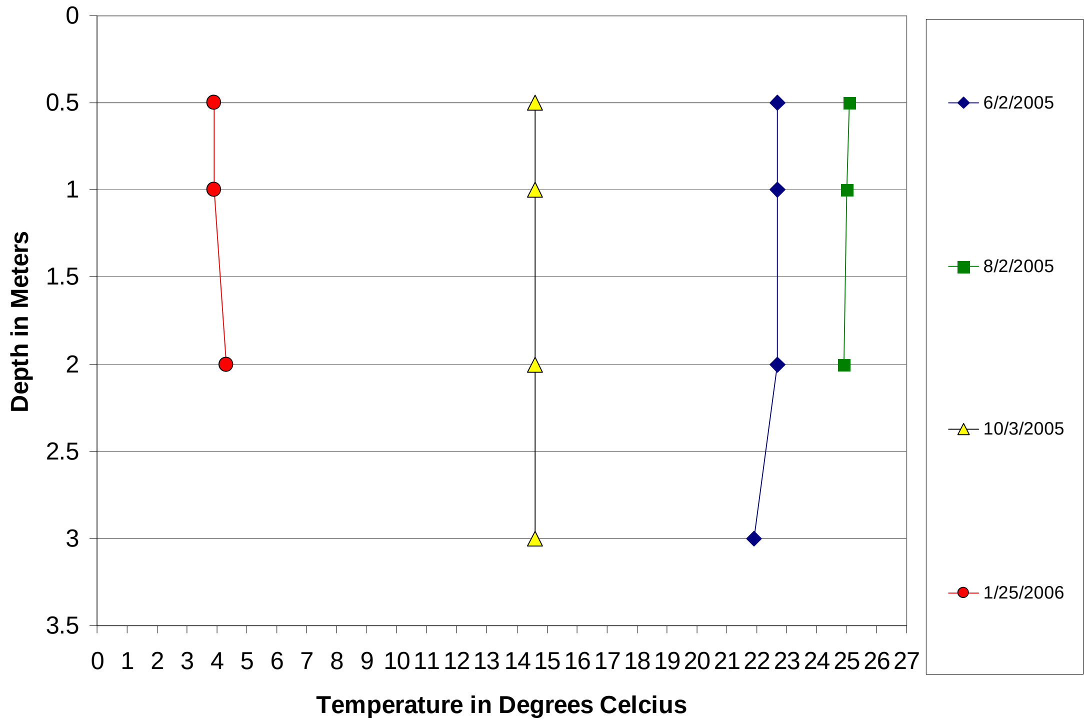


Figure 3. Temperature Profiles for Kalmbach Lake from 2005-2006.

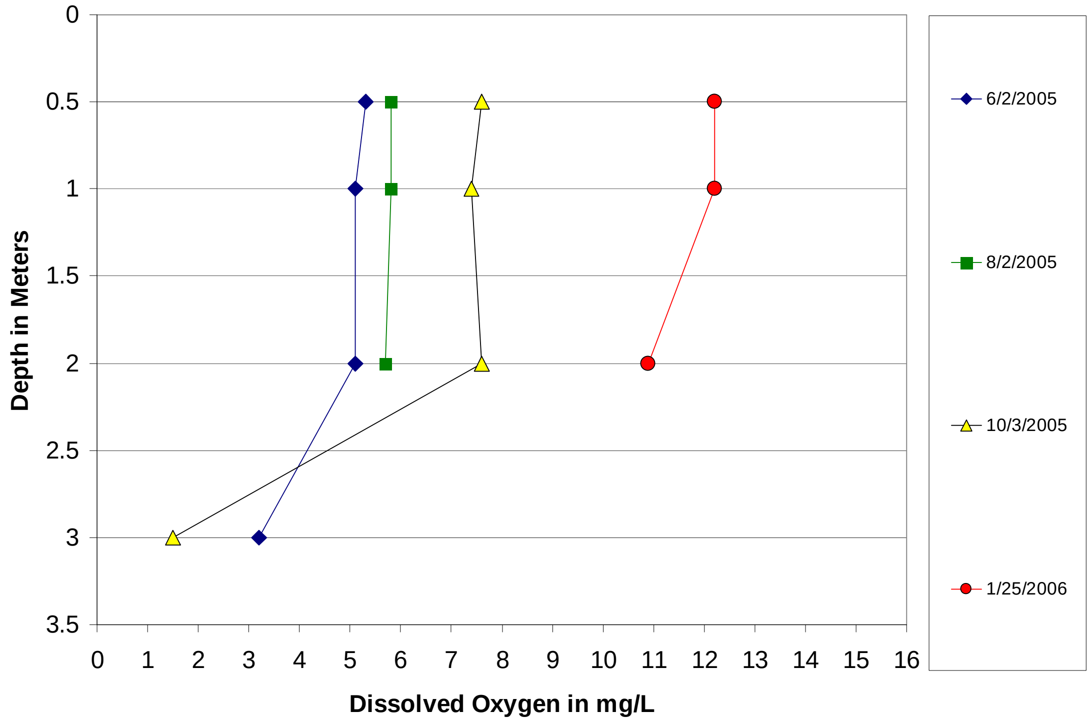


Figure 4. Dissolved Oxygen Profiles for Kalmbach Lake from 2005-2006.

General Water Quality: Data collected by the NDG&F in 2005 through 2006 indicate Kalmbach Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 179 mg/L to 244 mg/L (Table 1). Kalmbach Lake is sodium sulfate dominated with an average sodium concentration of 63 mg/L, and an average sulfate concentration of 320 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 657 mg/L and 1005 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.212 mg/L and 0.255 mg/L, respectively.

When comparing the 2005-2006 water quality data from Kalmbach Lake to the regional average, it appears Kalmbach Lake is fresher and less eutrophic than the average natural lake. The Rangeland Plain's regional average concentration of TDS, total nitrogen, and sulfates are 1588 mg/L, 1.826 mg/L, and 680 mg/L, respectively, compared to Kalmbach Lake's average TDS, total nitrogen, and sulfate concentrations of 657 mg/L, 1.212 mg/L, and 320 mg/L, respectively, for the 2005-2006 period.

Table 1. Statistical Summary of Kalmbach Lake's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	210	179	244	35
Total Ammonia as N	mg/L	4	0.024	0.010[1]	0.062	0.026
Bicarbonate (HCO_3)	mg/L	4	250	209	287	41
Calcium (Ca)	mg/L	4	56.9	48.6	62.3	6.4
Carbonate (CO_3)	mg/L	4	4	1[1]	7	3
Chloride (Cl)	mg/L	4	9	7	11	2
Chlorophyll-a	µg/L	4	9.2	4.5	12.3	3.4
Specific Conductance	µmhos	4	1005	799	1160	152
Total Dissolved Solids	mg/L	4	657	503	766	115
Total Hardness as ($CaCO_3$)	mg/L	4	388	305	431	57
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.177	0.049	0.313	0.108
Magnesium (Mg)	mg/L	4	59.6	44.6	67.6	10.8
Nitrate + Nitrite as N	mg/L	4	0.048	0.020[1]	0.130	0.055
Total Kjeldahl Nitrogen as N	mg/L	4	1.164	0.806	1.590	0.339
Total Nitrogen as N	mg/L	4	1.212	0.826	1.610	0.354
pH		4	8.33	8.24	8.41	0.09
Total Phosphorus as P	mg/L	4	0.255	0.190	0.303	0.055
Potassium (K)	mg/L	4	20.5	16.0	24.7	3.7
Sodium (Na)	mg/L	4	63	43	78	17
Sulfate (SO4)	mg/L	4	320	235	381	68

[1]Equal to Minimum Reportable Limit

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Kalmbach Lake, and that the ratio of total nitrogen to total phosphorus (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were four water quality sample results for Kalmbach Lake collected between June 2005 and January 2006, where the N:P ratio could be calculated (Figure 5). The results from this analysis indicate that Kalmbach Lake is nitrogen limited.

The nitrogen to phosphorus ratio for Kalmbach Lake ranged from a low of 4 to a high of 5, with an average of about 4.5. Of the 4 samples collected on Kalmbach Lake all were above an N:P ratio of 15, indicating that nitrogen is limiting primary production.

Table 2. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lakes in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	272	544	119	4770	130
Total Ammonia as N	mg/L	371	0.107	0.001[1]	2.230	0.200
Bicarbonate (HCO_3)	mg/L	272	489	145	2990	150
Calcium (Ca)	mg/L	272	44	1[1]	282	26
Carbonate (CO_3)	mg/L	262	89	1[1]	1420	30
Chloride (Cl)	mg/L	272	51	4[1]	1070	9
Chlorophyll-a	µg/L	250	22	2[1]	292	28
Specific Conductance	µmhos	272	2168	448	20100	959
Total Dissolved Solids	mg/L	272	1588	227	18200	750
Total Hardness as ($CaCO_3$)	mg/L	272	538	170	2370	260
Hydroxide (OH)	mg/L	200	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	273	0.193	0.001[1]	2.260	0.334
Magnesium (Mg)	mg/L	272	104	20	567	50
Nitrate + Nitrite as N	mg/L	332	0.036	0.002[1]	0.338	0.092
Total Kjeldahl Nitrogen as N	mg/L	340	1.950	0.080	8.500	0.779
Total Nitrogen as N	mg/L	278	1.826	0.269	5.520	0.562
pH		272	8.80	7.40	9.87	0.56
Total Phosphorus as P	mg/L	377	0.244	0.004[1]	1.940	0.205
Potassium (K)	mg/L	272	38	3[1]	356	6
Sodium (Na)	mg/L	272	331	17	4680	171
Sulfate (SO4)	mg/L	272	680	34	10500	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 48 Natural and Enhanced Lakes between 1991 and 2007

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected from 2005 to 2006, Kalmbach Lake's current trophic status is eutrophic (Figure 6). TSI scores ranged from a low of 45 based on chlorophyll-a, to a high of 86 based on total phosphorus. The trophic score based on Secchi disk transparency fell in the range of eutrophic lakes, at 63 (Figure 6).

A total of four total phosphorus, chlorophyll-a, and Secchi disk transparency measurements collected during the 2005-2006 open water periods, were used to evaluate the trophic status of Kalmbach Lake. Since Kalmbach Lake it is nitrogen limited a greater weight is given to chlorophyll-a concentrations and Secchi disk transparency measurements then total phosphorus concentrations.

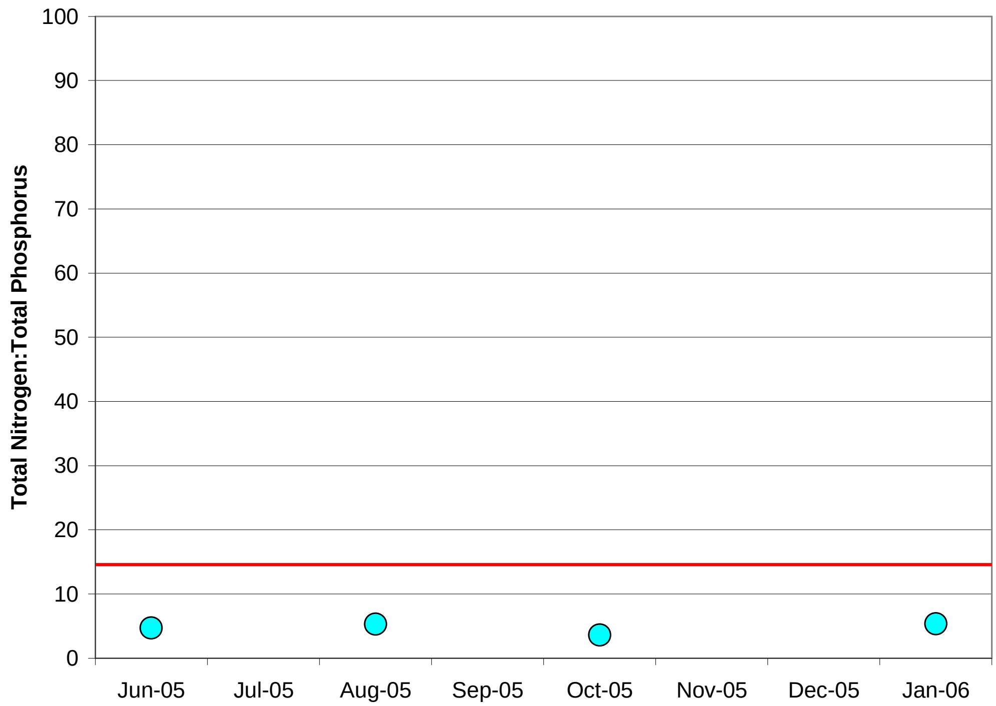


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Kalmbach Lake (2005-5006).

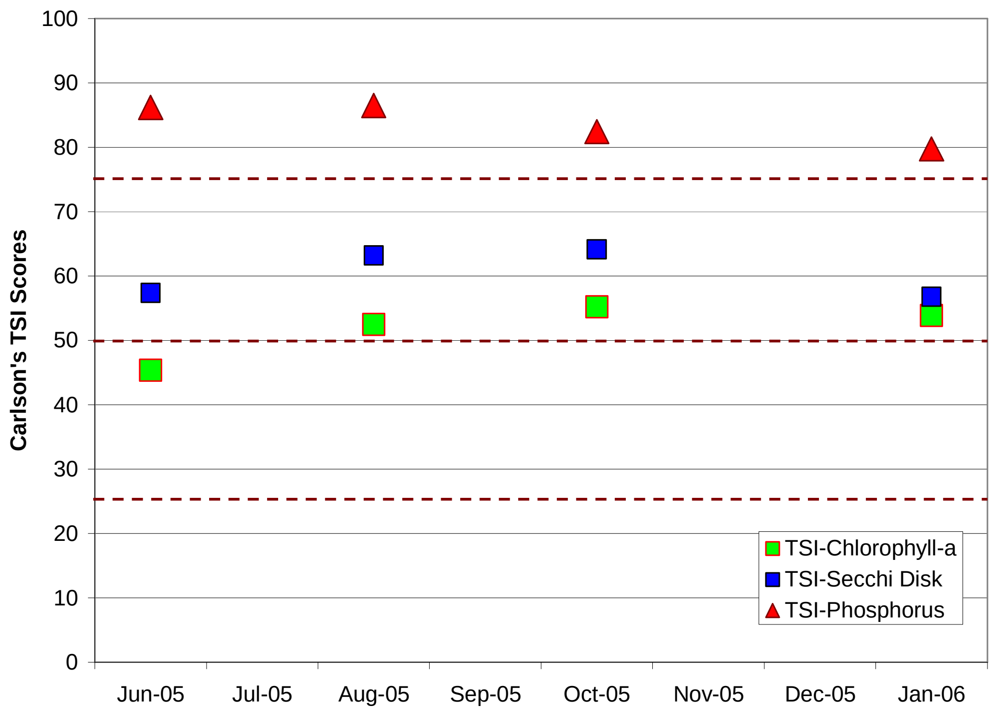


Figure 6. TSI Scores for Kalmbach Lake from 2005 to 2006.

Kulm-Edgeley Dam, LaMoure County

BACKGROUND

Location: Kulm-Edgeley Dam is a 333-acre impoundment on an unnamed tributary to the Maple River in southeastern North Dakota (Figures 1). Directions to Kulm-Edgeley Dam are to travel 4 miles west then 2 miles south of Edgeley, North Dakota. Kulm-Edgeley Dam is managed by the North Dakota Game and Fish Department.

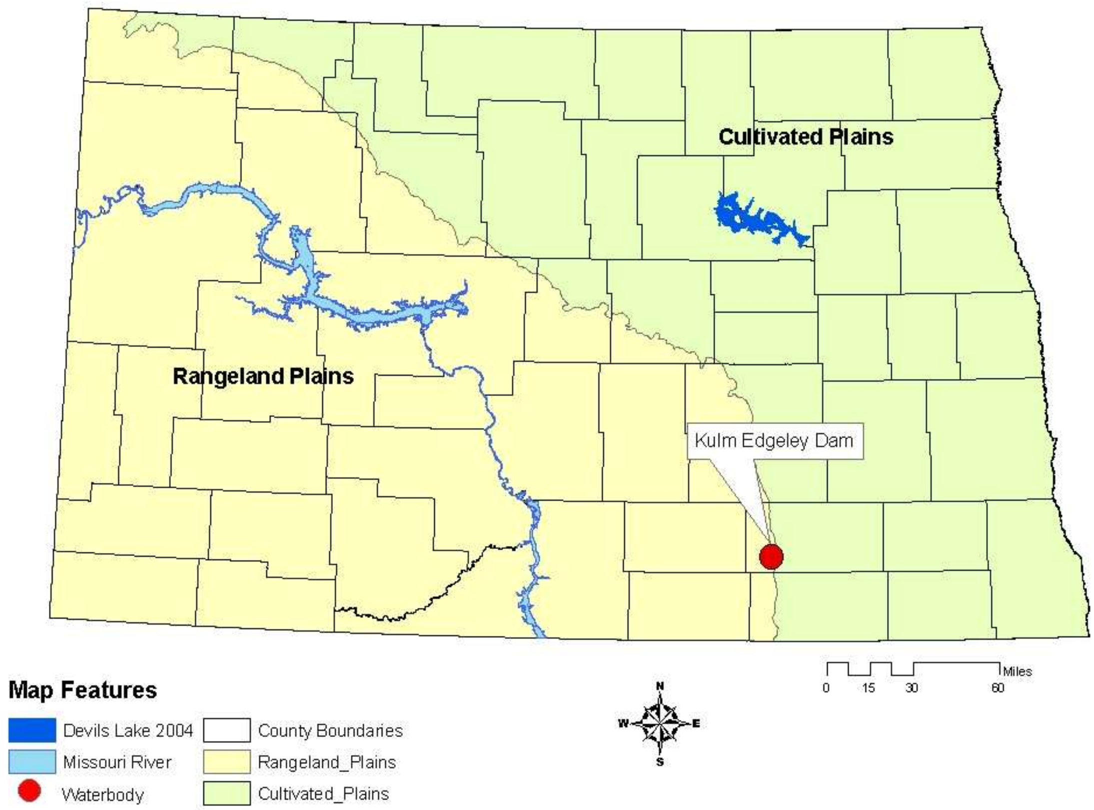


Figure 1. Location of Kulm-Edgeley Dam.

Physiographic/Ecological Setting: Kulm-Edgeley Dam is a 333 acre reservoir with a maximum depth of 28.1 feet and a mean depth of 11.8 feet (Figure 2). Kulm-Edgeley Dam resides in the Northwestern Glaciated Plains (NGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The NGP marks the western most extent of continental glacial advancement. The geological youthful landscape has significant surface irregularities and high concentrations of wetlands. The rise in elevation along the eastern edge of this ecoregion defines the boundary between the Great Plains and the Northwestern Great Plains ecoregions (USEPA 1994).

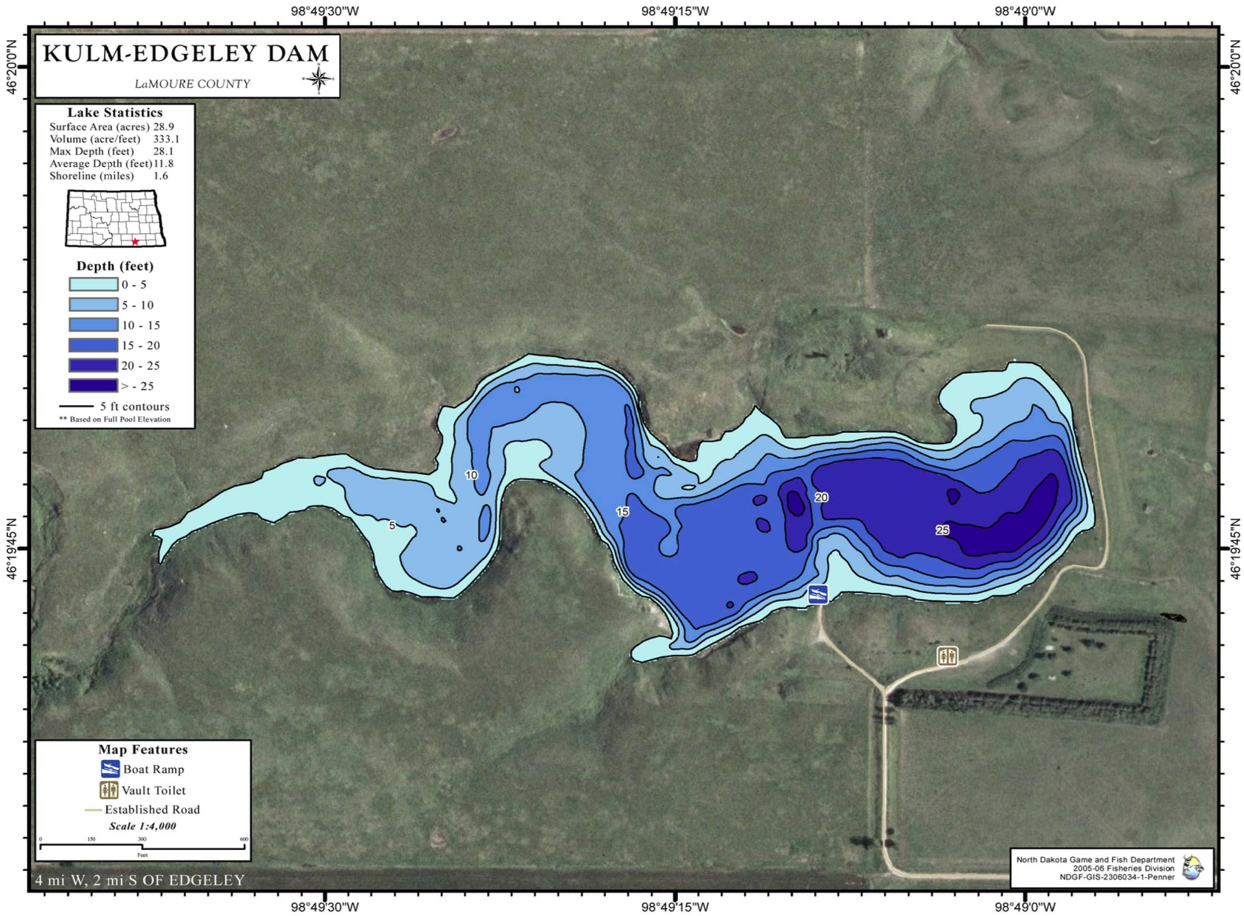


Figure 2. Contour Map of Kulm-Edgeley Dam (Map Courtesy of North Dakota Game and Fish Department).

Dam Construction: The dam was constructed in 1968 by damming a tributary to the Maple River.

Water Quality Standards Classification: Kulm-Edgeley Dam is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a "warm water fishery" or "waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present."

Recreational Facilities: Recreational facilities at Kulm-Edgeley Dam include a boat ramp, parking, a picnic area, toilets, and walking shore access.

Historical and Current Fishery: Kulm-Edgeley Dam's historical fishery has included walleye largemouth bass, rainbow trout, and bluegill. The current fishery at the reservoir consists of northern pike, walleye, and yellow perch.

Historical Water Quality Samples: Historical water quality data includes three sample results collected in 1991-1992.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Kulm-Edgeley Dam have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There were seven temperature and dissolved oxygen profiles for Kulm-Edgeley Dam collected in two clusters in 1991-1992 and 2005-2006 (Figures 3 and 4). The profile data shows that Kulm-Edgeley Dam has dissolved oxygen deficiencies in both summer and winter, with three of the seven profiles beginning with concentrations below the state standard of 5 mg/L and continuing to decline with depth. Additionally, Kulm-Edgeley Dam regularly thermally stratifies and the zone below thermal stratification quickly becomes anoxic leaving only shallow warm water for many fish species.

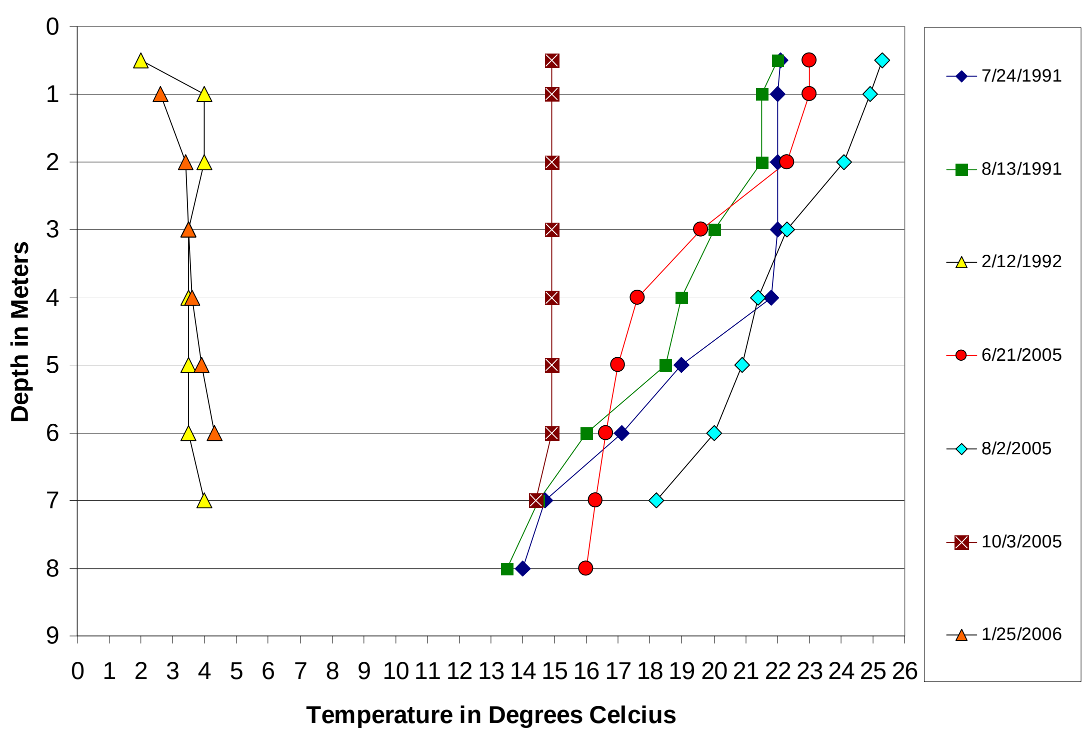


Figure 3. Temperature Profiles for Kulm-Edgeley Dam from 1991 to 2006.

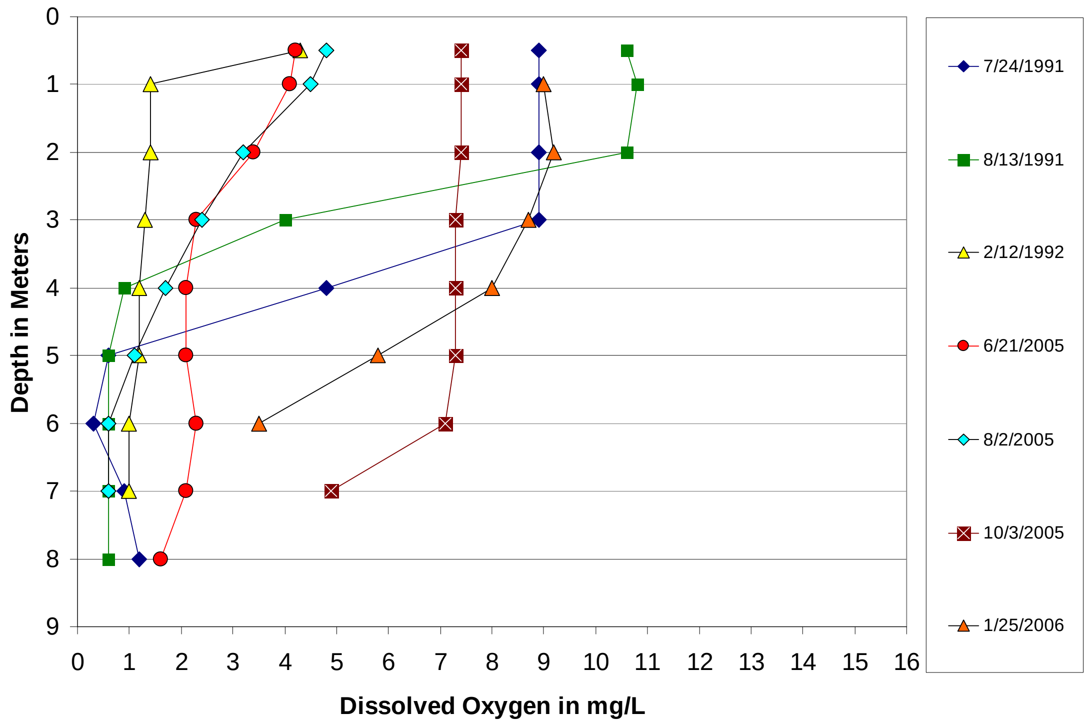


Figure 4. Dissolved Oxygen Profiles for Kulm-Edgeley Dam from 1991 to 2006.

General Water Quality: Data collected by the NDG&F in 2005-2006 indicate Kulm-Edgeley Dam is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 138 mg/L to 227 mg/L (Table 1). Kulm-Edgeley Dam is sodium sulfate dominated with an average sodium concentration of 63 mg/L and an average sulfate concentration of 319 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 640 mg/L and 968 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.743 mg/L and 0.711 mg/L, respectively.

When comparing historical water quality data from Kulm-Edgeley Dam to the reservoir's current water quality data, there appears to be some interesting changes (Table 2). The average total dissolved solids have increased from 319 mg/L to 640 mg/L, with the majority of this being made up from increases in sulfates that have increased from an average of 59 mg/L in 1991-1992 (Table 2) to an average of 319 mg/L in 2005-2006 (Tables 1).

Nutrient concentrations have also shifted. The average total phosphorus and total nitrogen concentration in 1991-1992 were 0.583 mg/L and 2.581 mg/L, respectively (Table 2), compared to concentrations of 0.711 mg/L and 1.743 mg/L in 2005-2006 (Table 1). The changes represent a 21 percent increase in total phosphorus and a 48 percent decrease in total nitrogen. While different hydraulic years could explain a fair amount of nutrient variability it would be difficult to explain the large change in dissolved solids and in particular sulfates.

Table 1. Statistical Summary of Kulm-Edgeley Dam's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	183	138	227	38
Total Ammonia as N	mg/L	4	0.226	0.156	0.412	0.124
Bicarbonate (HCO_3)	mg/L	4	224	169	277	46
Calcium (Ca)	mg/L	4	73.7	63.1	90.7	13.0
Carbonate (CO_3)	mg/L	4	1[1]	1[1]	1[1]	0
Chloride (Cl)	mg/L	4	9	7	12	2
Chlorophyll-a	µg/L	4	5.0	1.5[1]	13.2	5.5
Specific Conductance	µmhos	4	968	820	1140	136
Total Dissolved Solids	mg/L	4	640	542	762	94
Total Hardness as ($CaCO_3$)	mg/L	4	384	332	461	56
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.264	0.071	0.640	0.255
Magnesium (Mg)	mg/L	4	48.7	42.4	56.9	6.0
Nitrate + Nitrite as N	mg/L	4	0.163	0.090	0.270	0.085
Total Kjeldahl Nitrogen as N	mg/L	4	1.580	1.410	2.040	0.308
Total Nitrogen as N	mg/L	4	1.743	1.500	2.140	0.281
pH		4	8.08	7.93	8.28	0.15
Total Phosphorus as P	mg/L	4	0.711	0.522	0.847	0.156
Potassium (K)	mg/L	4	13.0	10.8	14.5	1.6
Sodium (Na)	mg/L	4	63	57	73	8
Sulfate (SO4)	mg/L	4	319	272	375	43

[1]Equal to Minimum Reportable Limit

When comparing Kulm-Edgeley Dam's 2005-2006 data to the Rangeland Plains regional averages, Kulm-Edgeley Dam has above average concentrations of dissolved solids but is within the normal range of variance. However the average total phosphorus concentration of 0.711 mg/L (Table 1) is more then five-fold than the average and twice the standard deviation (Table 3).

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Kulm-Edgeley Dam, and that the ratio of total nitrogen to total phosphorus (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were seven water quality sample results for Kulm-Edgeley Dam between July 1991 and January 2006, where the N:P ratio could be calculated. The results from this analysis indicate that Kulm-Edgeley Dam's is nitrogen limited (Figure 5).

The nitrogen to phosphorus ratio for Kulm-Edgeley Dam ranged from a low of 2 to a high of 6 with an average of 4. Of the seven samples collected on Kulm-Edgeley Dam, all were below 15 strongly indicating that nitrogen is the limiting nutrient.

Table 2. Statistical Summary of Kulm-Edgeley Dam's Historical Water Quality Data Collected Between 1991 and 1992.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	217	210	230	11
Total Ammonia as N	mg/L	3	0.320	0.040	0.877	0.483
Bicarbonate (HCO_3)	mg/L	3	204	157	281	67
Calcium (Ca)	mg/L	3	46	44	47	2
Carbonate (CO_3)	mg/L	2	45	41	49	6
Chloride (Cl)	mg/L	3	7.1	6.7	7.6	0.5
Chlorophyll-a	µg/L	2	34.0	32.0	36.0	2.8
Specific Conductance	µmhos	3	551	522	604	46
Total Dissolved Solids	mg/L	3	315	278	348	35
Total Hardness as ($CaCO_3$)	mg/L	3	216	211	222	6
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	3	0.092	0.038	0.145	0.054
Magnesium (Mg)	mg/L	3	24.7	24.3	25.2	0.5
Nitrate + Nitrite as N	mg/L	3	0.031	0.004[1]	0.084	0.046
Total Kjeldahl Nitrogen as N	mg/L	3	2.550	2.160	2.810	0.344
Total Nitrogen as N	mg/L	3	2.581	2.164	2.894	0.390
pH		3	9.00	8.30	9.40	0.61
Total Phosphorus as P	mg/L	3	0.583	0.530	0.653	0.063
Potassium (K)	mg/L	3	13.1	12.2	14.6	1.3
Sodium (Na)	mg/L	3	34	31	37	3
Sulfate (SO4)	mg/L	3	59	31	82	26

[1]Equal to Minimum Reportable Limit

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005-2006, Kulm-Edgeley Dam's trophic status is mesotrophic to eutrophic (Figure 6). TSI scores ranged from a low of 35 based on chlorophyll-a, to a high of 101 based on total phosphorus. The average trophic status score based on Secchi disk transparency was similar to that estimated by chlorophyll-a, at 50.

A total of six chlorophyll-a samples and four Secchi disk transparency measurements collected during the open water periods from 1991 to 2006 were used to evaluate trends in the trophic status of Kulm-Edgeley Dam. Since the reservoir is nitrogen limited, it would not be appropriate to use total phosphorus measurements as an indicator of trophic status. Based on a visual assessment of the data, Kulm-Edgeley Dam's trophic status is improving (Figure 6).

Table 3. Statistical Summary of Water Quality Data[2] Collected from Reservoirs in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	408	309	101	982	130
Total Ammonia as N	mg/L	469	0.097	0.001[1]	2.440	0.200
Bicarbonate (HCO_3)	mg/L	408	318	14	1040	150
Calcium (Ca)	mg/L	408	50	5	160	26
Carbonate (CO_3)	mg/L	402	30	1[1]	197	30
Chloride (Cl)	mg/L	408	13.3	0.3	74.5	8.8
Chlorophyll-a	µg/L	321	21.2	1.5	218.0	27.9
Specific Conductance	µmhos	428	1733	262	5880	959
Total Dissolved Solids	mg/L	409	1176	147	5110	750
Total Hardness as ($CaCO_3$)	mg/L	408	397	45	1850	260
Hydroxide (OH)	mg/L	337	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	409	0.179	0.007	4.110	0.334
Magnesium (Mg)	mg/L	408	66.0	5.6	353.0	49.6
Nitrate + Nitrite as N	mg/L	395	0.048	0.001[1]	0.790	0.092
Total Kjeldahl Nitrogen as N	mg/L	359	1.556	0.365	7.720	0.779
Total Nitrogen as N	mg/L	302	1.472	0.405	4.840	0.562
pH		428	8.61	6.73	9.87	0.56
Total Phosphorus as P	mg/L	475	0.135	0.004[1]	3.160	0.205
Potassium (K)	mg/L	408	14.6	4.2	39.2	6.3
Sodium (Na)	mg/L	408	239	3[1]	932	171
Sulfate (SO4)	mg/L	406	604	1[1]	3210	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 69 Reservoirs between 1991 and 2007

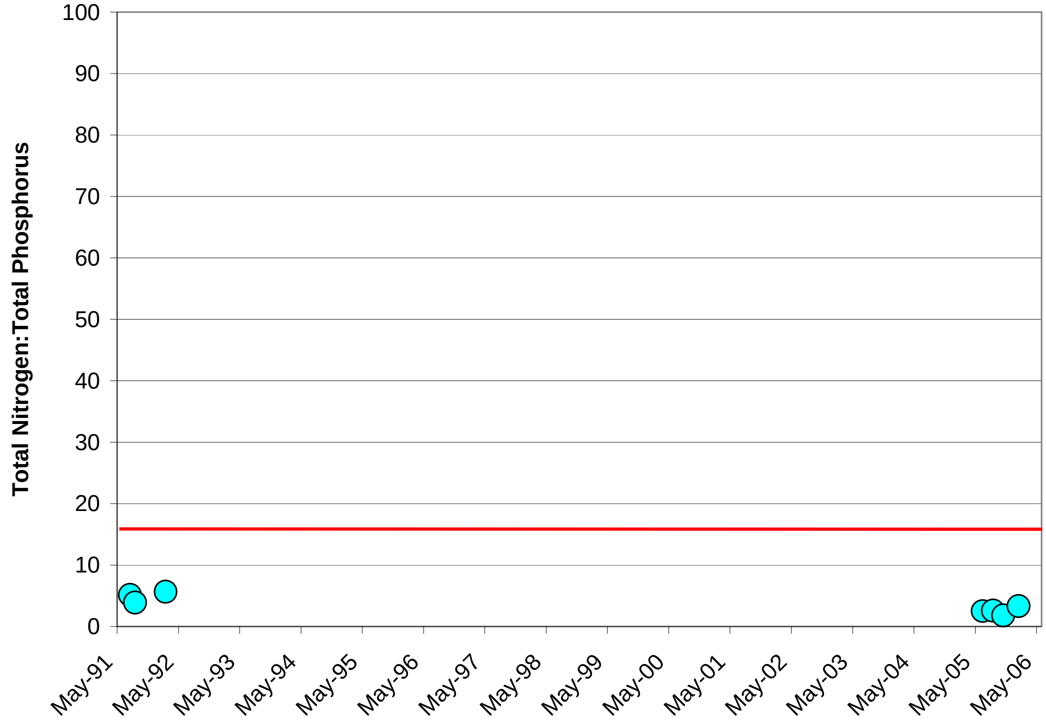


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Kulm-Edgeley Dam (1991-2006).

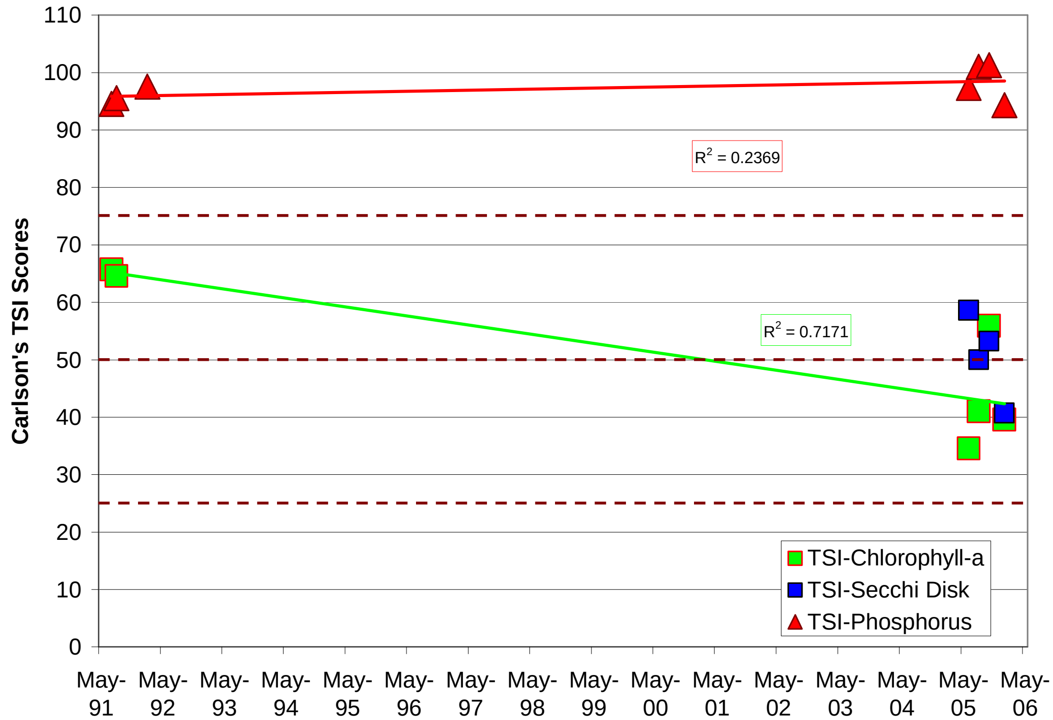


Figure 6. TSI Scores and Temporal Trends for Kulm-Edgeley Dam from 1991-2006.

Schlecht-Thom Dam, LaMoure County

BACKGROUND

Location: Schlecht-Thom Dam is a 16.2-acre impoundment on an unnamed tributary to the Maple River in LaMoure County, North Dakota (Figures 1). Schlecht-Thom Dam is located 5 miles west and 1/2 mile north of Edgeley. Shlecht-Thom Dam is owned by Reinhold Schlecht and managed by the North Dakota Game and Fish Department.

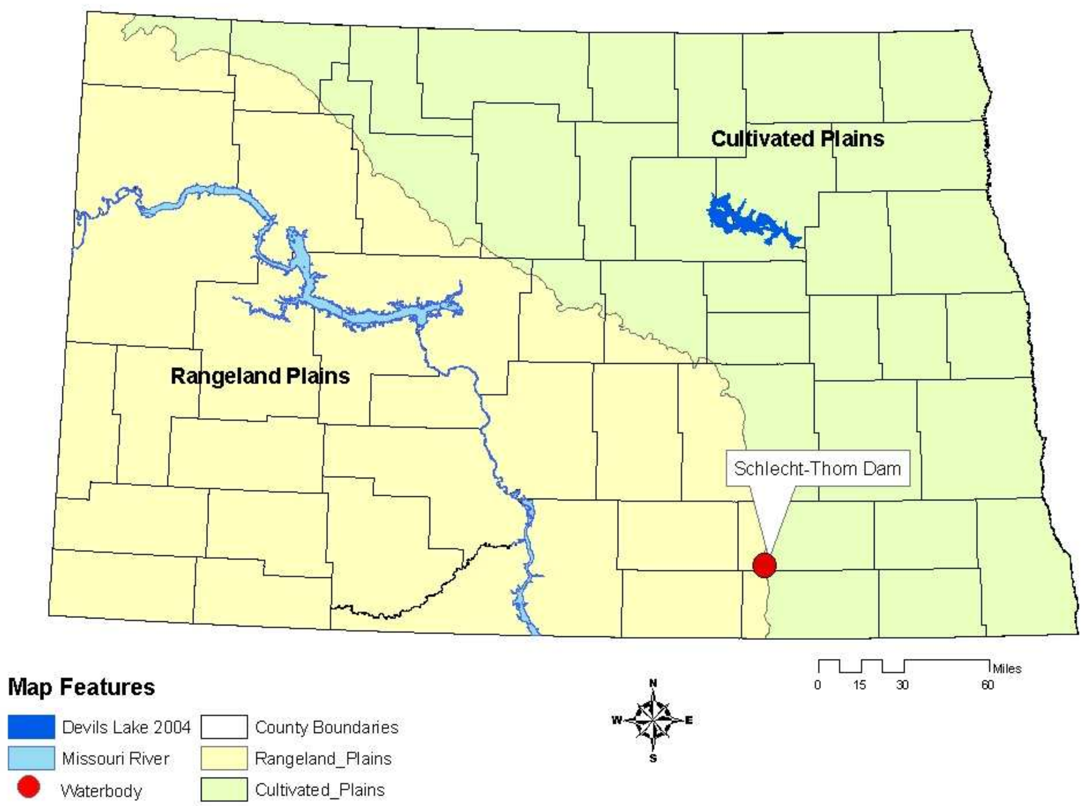


Figure 1. Location of Schlecht-Thom Dam.

Physiographic/Ecological Setting: Schlecht-Thom Dam is a 16.2 acre reservoir with a maximum depth of 23.8 feet and a mean depth of 8.8 feet (Figure 2). Schlecht-Thom Dam and its 1,885 acre watershed are in the Northwestern Glaciated Plains (NGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The NGP marks the western most extent of continental glacial advancement. The geological youthful landscape has significant surface irregularities and high concentrations of wetlands. The rise in elevation along the eastern edge of this ecoregion defines the boundary of the Great Plains and to the west the Northwestern Great Plains (USEPA 1994).

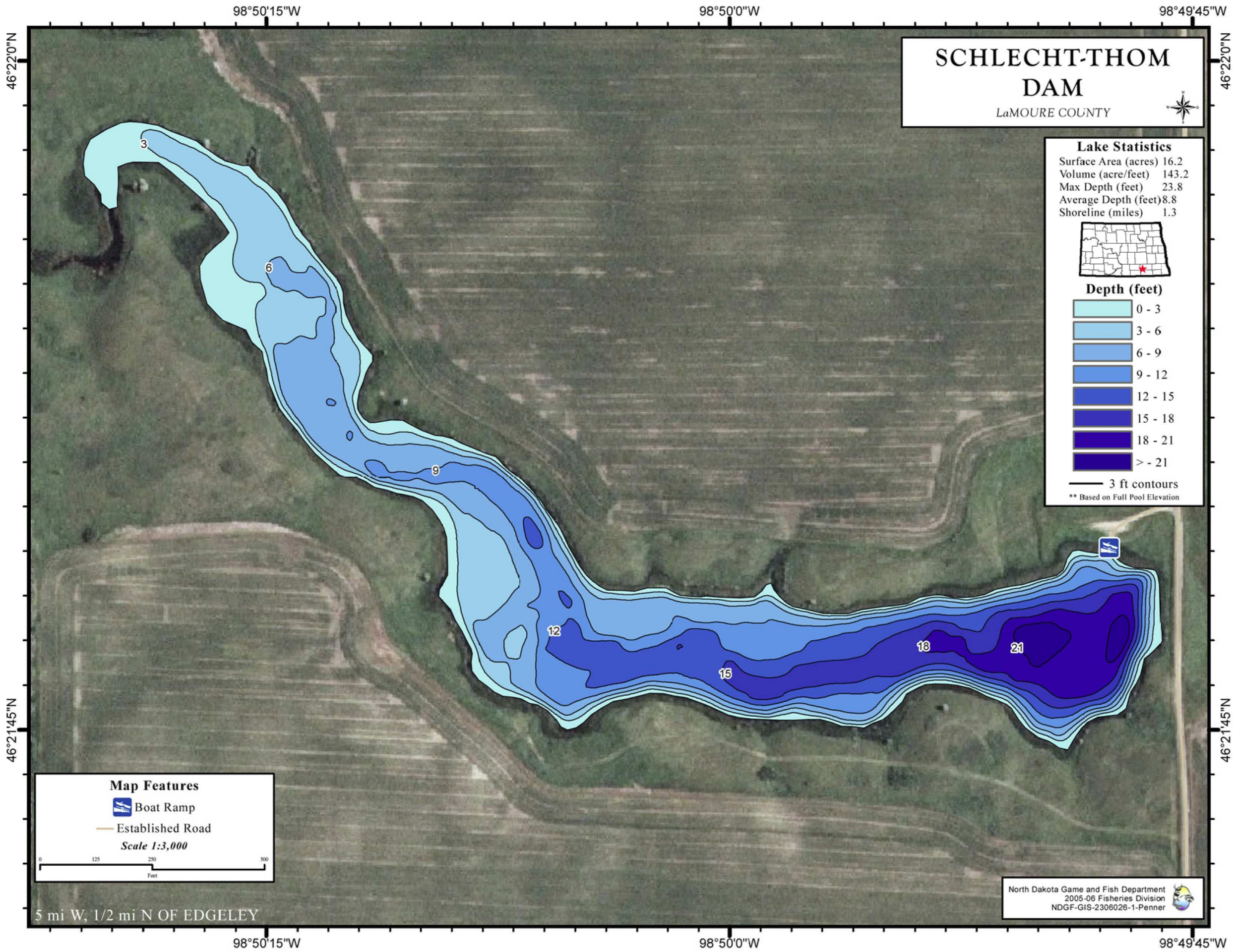


Figure 2. Contour Map of Schlecht-Thom Dam (Map Courtesy of North Dakota Game and Fish Department).

Construction History: Schlecht-Thom Dam was constructed in 1968 by damming a tributary to the Maple River. The dam was built through the combined efforts of the local land owners, the Soil Conservation Service, and the North Dakota Game and Fish Department.

Water Quality Standards Classification: Schlecht-Thom Dam is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a "warm water fishery" or "waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present."

Recreational Facilities: Recreational facilities at Schlecht-Thom Dam include a boat ramp, parking, a picnic area, and walking shore access. The entrance is located on the east side of the lake.

Historical and Current Fishery: Schlecht-Thom Dam's historical fishery has included walleye largemouth bass, rainbow trout, and bluegill. The current fishery at the reservoir consists of northern pike, largemouth bass, and yellow perch.

Historical Water Quality Samples: Historical water quality data includes three sample results collected in 1993-1994.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Schlecht-Thom Dam have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There were seven temperature and dissolved oxygen profiles for Schlecht-Thom Dam collected in two clusters in 1993-1994 and 2005-2006 (Figures 3 and 4). The profile data shows that Schlecht-Thom Dam has dissolved oxygen deficiencies in both summer and winter with three of the seven profiles beginning with concentrations below the state standard of 5 mg/L and continuing to decline with depth. Additionally, Schlecht-Thom Dam regularly thermally stratifies and the zone below thermal stratification quickly becomes anoxic leaving only shallow warm water for fish survival.

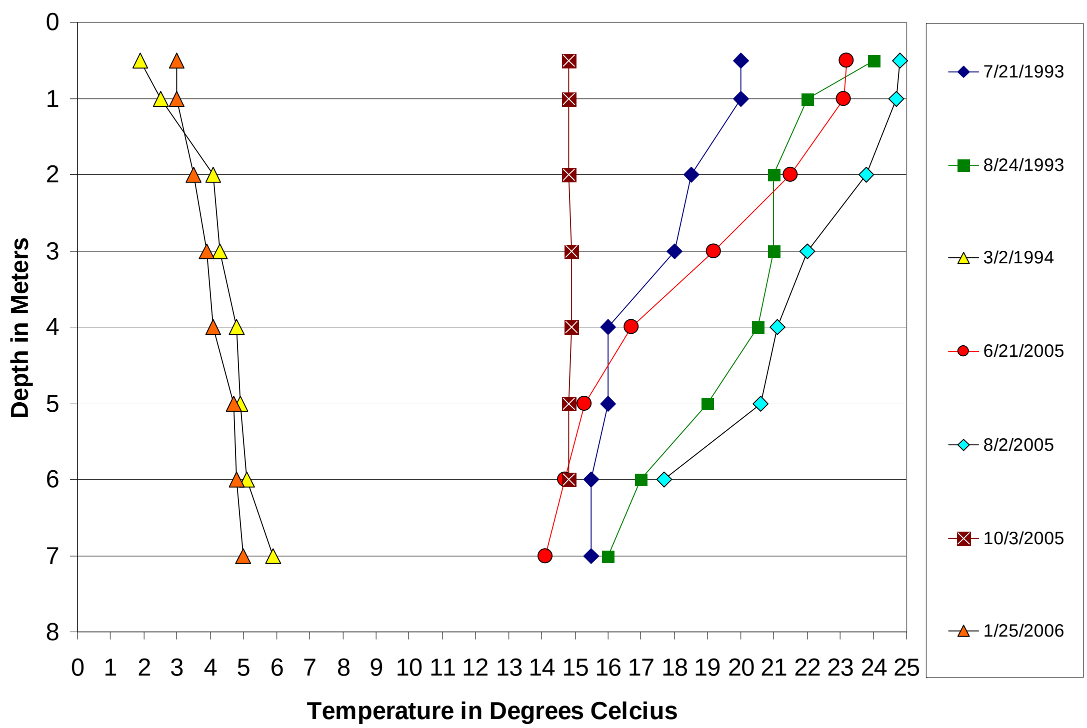


Figure 3. Temperature Profiles for Schlecht-Thom Dam from 1993 to 2006.

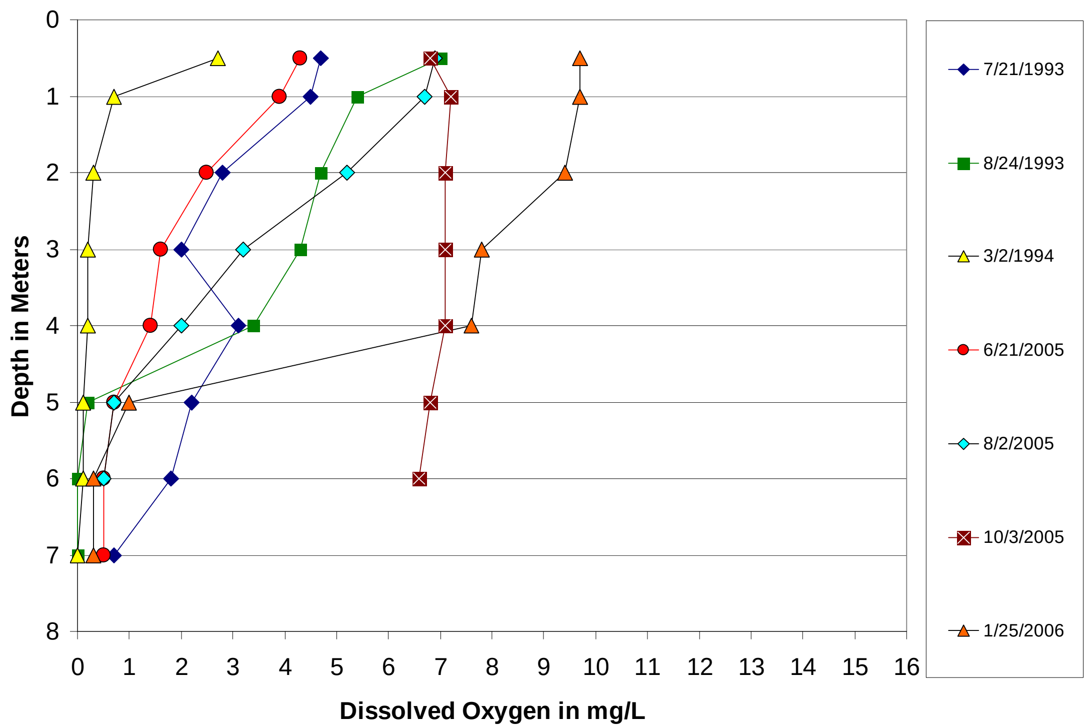


Figure 4. Dissolved Oxygen Profiles for Schlecht-Thom Dam from 1993 to 2006.

General Water Quality: Data collected by the NDG&F in 2005-2006 indicate Schlecht-Thom Dam is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 133 to 236 mg/L (Table 1). Schlecht-Thom Dam is sodium sulfate dominated with an average sodium concentration of 39 mg/L and an average sulfate concentration of 229 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 509 mg/L and 790 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.630 mg/L and 0.638 mg/L, respectively.

When comparing historical water quality data from Schlecht-Thom Dam (Table 2) to current water quality data (Table 1) there appears to be some interesting changes. An example is the increase in total dissolved solids concentrations from 327 mg/L to 509 mg/L. The majority of the increase in total dissolved solid concentrations has been in sulfates that have increased from 101 mg/L to 229 mg/L. Most other constitutes have remained fairly stable from 1993-1994 to 2005-2006.

When comparing Schlecht-Thom Dam's 2005-2006 data set to the Rangeland Plains regional average, Schlecht-Thom Dam has above average concentrations of dissolved solids but is within the standard deviation (Table 3). However the average total phosphorus concentration of 0.638 mg/L is more then four fold the Rangeland Plains average and more than double the standard deviation (Tables 1 and 3).

Table 1. Statistical Summary of Schlecht-Thom Dam's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	184	133	236	43
Total Ammonia as N	mg/L	4	0.146	0.049	0.261	0.092
Bicarbonate (HCO_3)	mg/L	4	225	163	288	52
Calcium (Ca)	mg/L	4	68.7	55.1	86.2	14.1
Carbonate (CO_3)	mg/L	4	1[1]	1[1]	1[1]	0
Chloride (Cl)	mg/L	4	6	5	8	1
Chlorophyll-a	µg/L	4	11.3	2.0	28.5	11.8
Specific Conductance	µmhos	4	790	622	986	157
Total Dissolved Solids	mg/L	4	509	397	645	107
Total Hardness as ($CaCO_3$)	mg/L	4	334	270	418	66
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.355	0.035	1.060	0.474
Magnesium (Mg)	mg/L	4	39.5	32.1	49.3	7.4
Nitrate + Nitrite as N	mg/L	4	0.113	0.050	0.210	0.069
Total Kjeldahl Nitrogen as N	mg/L	4	1.518	1.330	1.590	0.125
Total Nitrogen as N	mg/L	4	1.630	1.410	1.800	0.164
pH		4	8.08	7.95	8.24	0.14
Total Phosphorus as P	mg/L	4	0.638	0.435	0.803	0.152
Potassium (K)	mg/L	4	14.3	12.1	16.4	1.8
Sodium (Na)	mg/L	4	39	31	51	8
Sulfate (SO4)	mg/L	4	229	176	290	49

[1]Equal to Minimum Reportable Limit

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Schlecht-Thom Dam, and that the ratio of total nitrogen to total phosphorus (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

Seven water quality sample results for Schlecht-Thom Dam collected between July 1993 and January 2006 indicate that Schlecht-Thom Dam is nitrogen limited (Figure 5). The nitrogen to phosphorus ratio for Schlecht-Thom Dam ranged from a low of 2 to a high of 7 with an average of 3. Of the seven samples collected on Schlecht-Thom Dam, all were below an N:P ratio of 15 indicating that nitrogen is the limiting nutrient.

Table 2. Statistical Summary of Schlecht-Thom Dam's Historical Water Quality Data Collected Between 1993 and 1994.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	185	124	250	63
Total Ammonia as N	mg/L	3	0.320	0.172	0.505	0.170
Bicarbonate (HCO_3)	mg/L	3	226	152	305	77
Calcium (Ca)	mg/L	3	52	40	67	14
Carbonate (CO_3)	mg/L	3	1[1]	1[1]	1[1]	0
Chloride (Cl)	mg/L	3	5.1	3.3	7.0	1.9
Chlorophyll-a	µg/L	2	3.5	3.0	4.0	0.7
Specific Conductance	µmhos	3	534	369	749	195
Total Dissolved Solids	mg/L	3	327	244	448	107
Total Hardness as ($CaCO_3$)	mg/L	3	236	186	302	60
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	3	1.166	0.131	3.190	1.753
Magnesium (Mg)	mg/L	3	26.1	21.1	32.8	6.0
Nitrate + Nitrite as N	mg/L	3	0.459	0.070	1.400	0.632
Total Kjeldahl Nitrogen as N	mg/L	3	1.568	1.400	1.820	0.184
Total Nitrogen as N	mg/L	3	1.642	1.330	2.064	0.321
pH		3	7.55	7.37	7.80	0.22
Total Phosphorus as P	mg/L	3	0.498	0.332	0.607	0.146
Potassium (K)	mg/L	3	12.8	11.3	14.4	1.6
Sodium (Na)	mg/L	3	17	14	21	4
Sulfate (SO4)	mg/L	3	101	75	154	46

[1]Equal to Minimum Reportable Limit

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005-2006, Schlecht-Thom Dam's trophic status is eutrophic (Figure 6). TSI scores ranged from a low of 38 based on chlorophyll-a, to a high of 100 based on total phosphorus. The trophic status score based on Secchi disk transparency was similar to that estimated by chlorophyll-a, at 52 (Figure 6).

A total of seven chlorophyll-a samples and six Secchi disk transparency measurements collected during the open water periods from 1993 to 2006 were used to evaluate the trends in trophic status of Schlecht-Thom Dam. Based on a visual assessment of the data, Schlecht-Thom Dam's trophic status is stable (Figure 6).

Table 3. Statistical Summary of Water Quality Data[2] Collected from Reservoirs in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	408	309	101	982	130
Total Ammonia as N	mg/L	469	0.097	0.001[1]	2.440	0.200
Bicarbonate (HCO_3)	mg/L	408	318	14	1040	150
Calcium (Ca)	mg/L	408	50	5	160	26
Carbonate (CO_3)	mg/L	402	30	1[1]	197	30
Chloride (Cl)	mg/L	408	13.3	0.3	74.5	8.8
Chlorophyll-a	µg/L	321	21.2	1.5	218.0	27.9
Specific Conductance	µmhos	428	1733	262	5880	959
Total Dissolved Solids	mg/L	409	1176	147	5110	750
Total Hardness as ($CaCO_3$)	mg/L	408	397	45	1850	260
Hydroxide (OH)	mg/L	337	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	409	0.179	0.007	4.110	0.334
Magnesium (Mg)	mg/L	408	66.0	5.6	353.0	49.6
Nitrate + Nitrite as N	mg/L	395	0.048	0.001[1]	0.790	0.092
Total Kjeldahl Nitrogen as N	mg/L	359	1.556	0.365	7.720	0.779
Total Nitrogen as N	mg/L	302	1.472	0.405	4.840	0.562
pH		428	8.61	6.73	9.87	0.56
Total Phosphorus as P	mg/L	475	0.135	0.004[1]	3.160	0.205
Potassium (K)	mg/L	408	14.6	4.2	39.2	6.3
Sodium (Na)	mg/L	408	239	3[1]	932	171
Sulfate (SO4)	mg/L	406	604	1[1]	3210	501

[1]Equal to Minimum Reporting Limit

2Data Collected from 69 Reservoirs between 1991 and 2007

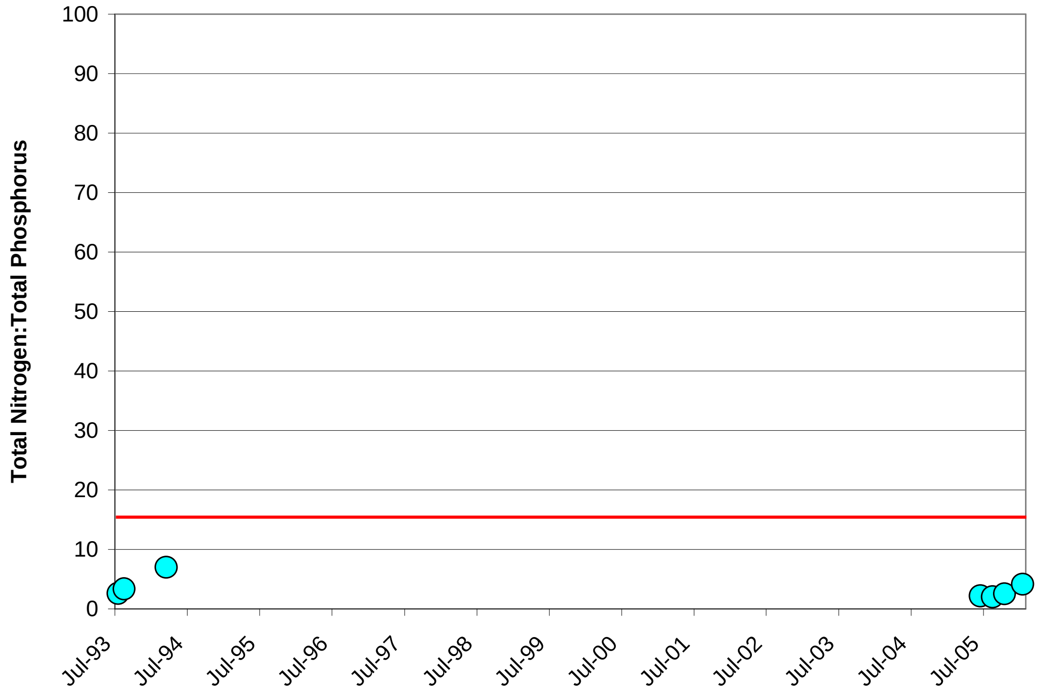


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Schlecht-Thom Dam (1993-2006).

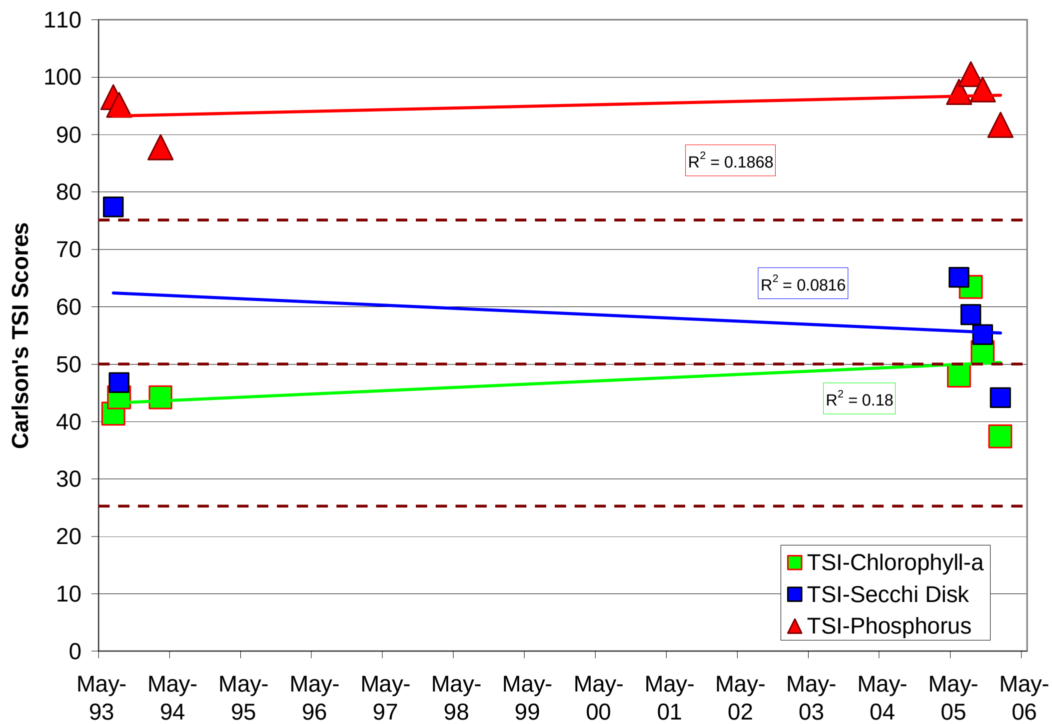


Figure 6. TSI Scores and Temporal Trends for Schlecht-Thom Dam from 1993-2006.

Schlecht-Weixel Dam, LaMoure County

BACKGROUND

Location: Schlecht-Weixel Dam is an 11.1-acre impoundment on an unnamed tributary to the Maple River, located 4 miles west of Jud, North Dakota. Schlecht-Weixel Dam is managed by the North Dakota Game and Fish Department.

Figure 1. Location of Schlecht-Weixel Dam.

Physiographic/Ecological Setting: Schlecht-Weixel Dam is an 11.1 acre reservoir with a maximum depth of 21.5 feet and a mean depth of 8.2 feet (Figure 2). Schlecht-Weixel Dam and its 680 acre watershed are in the Northwestern Glaciated Plains (NGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The NGP marks the western most extent of continental glacial advancement. The geological youthful landscape has significant surface irregularities and high concentrations of wetlands. The rise in elevation along the eastern edge of this ecoregion defines the boundary of the Great Plains and to the west the Northwestern Great Plains (USEPA 1994).

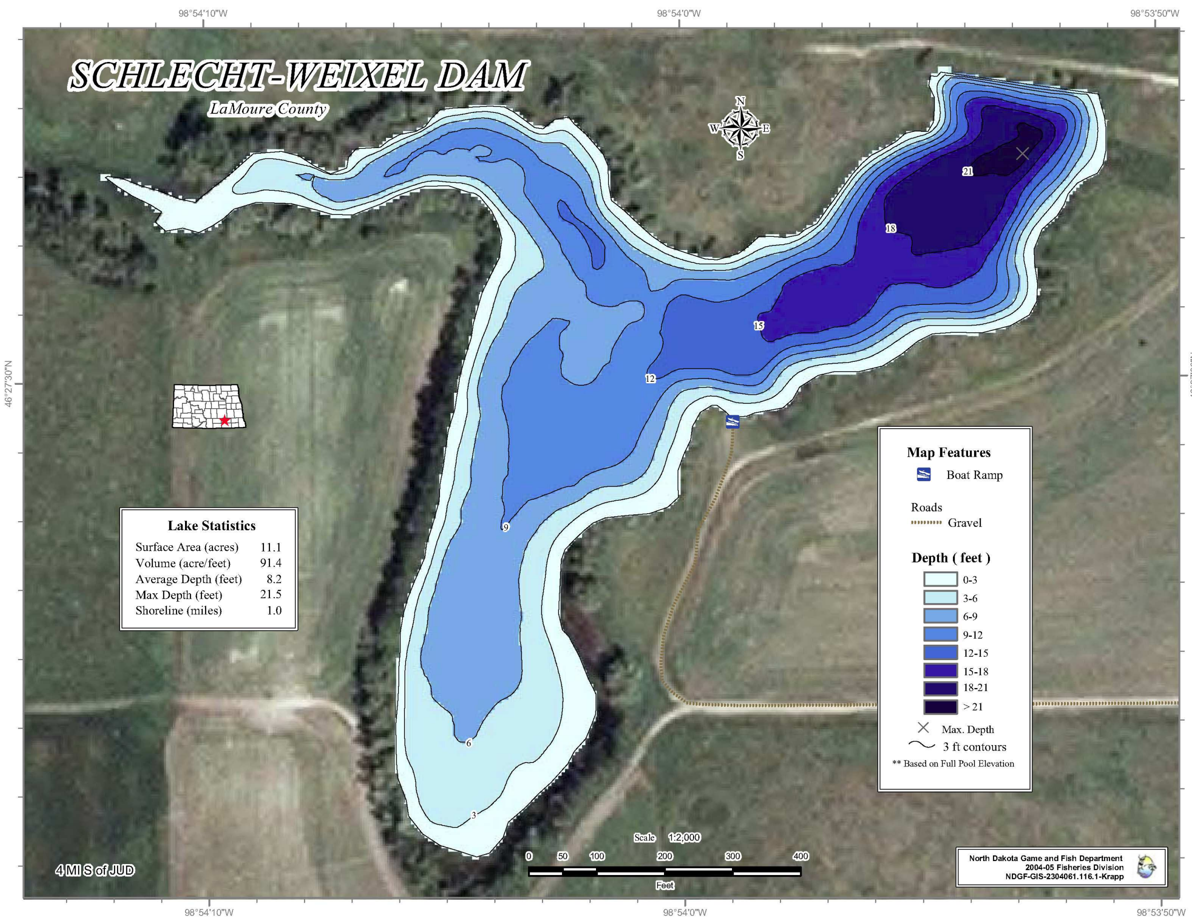


Figure 2. Contour Map of Schlecht-Weixel Dam (Map Courtesy of North Dakota Game and Fish Department).

Dam Construction: Schlecht-Weixel Dam was constructed in 1967 by damming a tributary to the Maple River. The dam was built through the combined efforts of the local land owner, the Soil Conservation Service, and the North Dakota Game and Fish Department. Cost share for the dam was provided by the Soul Conservation Service and Jacob Schlecht.

Water Quality Standards Classification: Schlecht-Weixel Dam is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a "warm water fishery" or "waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present."

Recreational Facilities: Recreational facilities at Schlecht-Weixel Dam include a boat ramp, parking, a picnic area, and walking shore access. The boat ramp is located on the east side of the reservoir.

Historical and Current Fishery: Schlecht-Weixel Dam's historical fishery has included walleye, largemouth bass, rainbow trout, and bluegill. The current fishery at the reservoir consists of northern pike, largemouth bass, and yellow perch.

Historical Water Quality Samples: Historical water quality data includes three sample results collected from 1993 to 1994.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Schlecht-Weixel Dam have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There are seven temperature and dissolved oxygen profiles for Schlecht-Weixel Dam collected in two clusters in 1993-1994 and 2005-2006 (Figures 3 and 4). The profile data shows that Schlecht-Weixel Dam has dissolved oxygen deficiencies in both summer and winter months with six of the seven profiles beginning with or rapidly declining to concentrations below the state standard of 5 mg/L and continuing to decline with depth. Additionally, Schlecht-Weixel Dam regularly thermally stratifies resulting in the zone below thermal stratification becoming anoxic leaving only shallow warm water for fish survival.

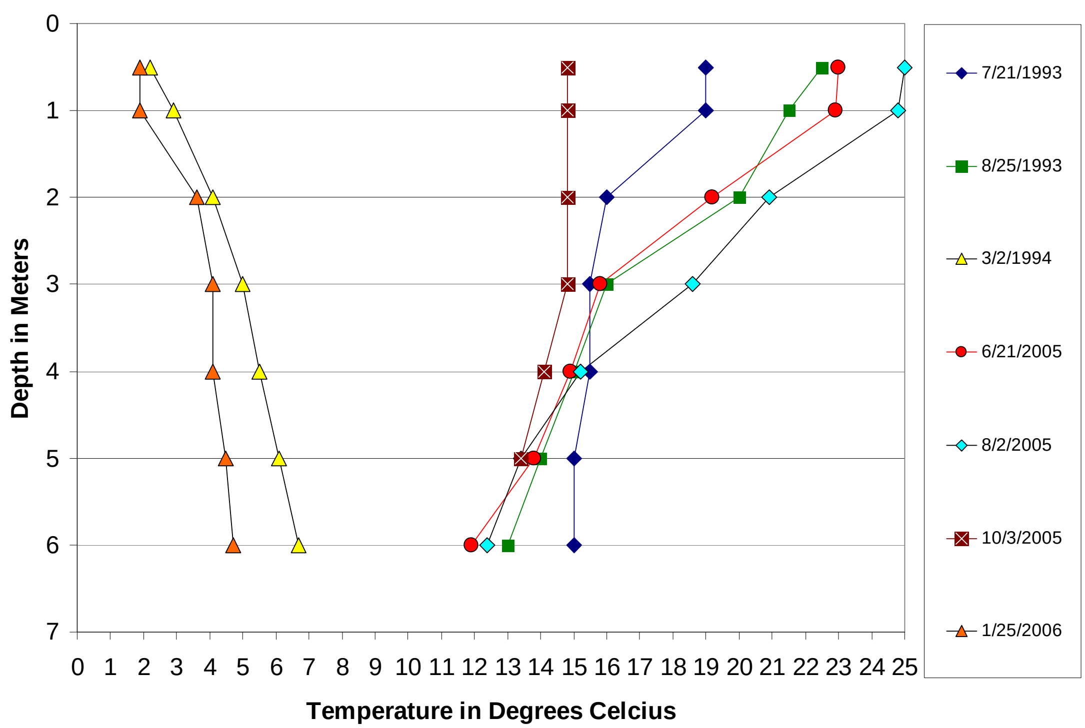


Figure 3. Temperature Profiles for Schlecht-Weixel Dam from 1993 to 2006.

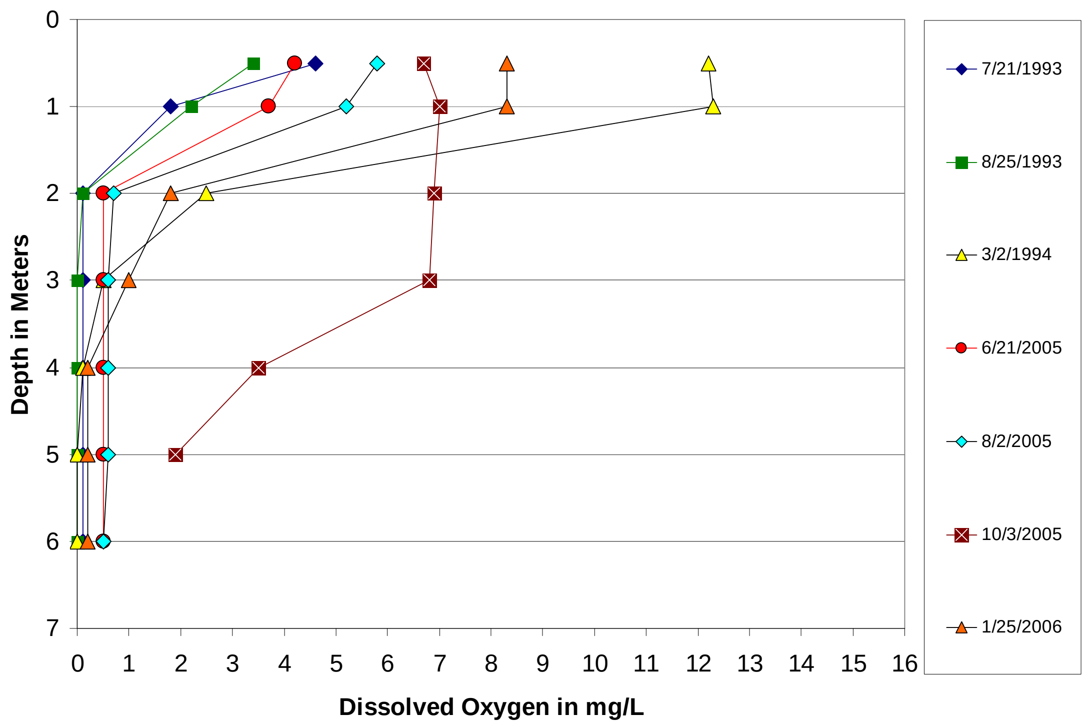


Figure 4. Dissolved Oxygen Profiles for Schlecht-Weixel Dam from 1993 to 2006.

General Water Quality: Data collected by the NDG&F in 2005-2006 indicate Schlecht-Weixel Dam is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 144 mg/L to 191 mg/L (Table 1). Schlecht-Weixel Dam is sodium bicarbonate dominated with an average sodium concentration of 16 mg/L and an average bicarbonate concentration of 202 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 272 mg/L and 471 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.843 mg/L and 0.352 mg/L, respectively.

When comparing historical water quality data (Table 2) from Schlecht-Weixel Dam to current water quality data (Table 1), there appears to be some interesting changes in the amount of total dissolved solids. Basically, total dissolved solids have increased from 178 mg/L to 272 mg/L, with the majority of this being made up from increases in sulfate and bicarbonate concentrations that have increased from 22 mg/L to 70 mg/L, and from 170mg/L to 202 mg/L, respectively. Most other constitutes have remained fairly stable between 1993-1994 and 2005-2006.

When comparing Schlecht-Weixel Dam's 2005-2006 data set to the Rangeland Plains regional average, the reservoir appears fairly average with the exception of phosphorus. The average total phosphorus concentration of 0.352 mg/L (Table 1) is about 3 fold higher than the Rangeland Plains average of 0.135 mg/L (Tables 3).

Table 1. Statistical Summary of Schlecht-Weixel Dam's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	166	144	191	19
Total Ammonia as N	mg/L	4	0.132	0.026	0.186	0.072
Bicarbonate (HCO_3)	mg/L	4	202	176	233	24
Calcium (Ca)	mg/L	4	43.4	39.6	50.3	4.7
Carbonate (CO_3)	mg/L	4	1[1]	1[1]	1[1]	0
Chloride (Cl)	mg/L	4	3	3	4	0
Chlorophyll-a	µg/L	4	40.3	3.9	95.1	38.7
Specific Conductance	µmhos	4	471	431	534	45
Total Dissolved Solids	mg/L	4	272	249	310	27
Total Hardness as ($CaCO_3$)	mg/L	4	193	178	223	20
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.194	0.046	0.422	0.173
Magnesium (Mg)	mg/L	4	20.6	19.1	23.7	2.1
Nitrate + Nitrite as N	mg/L	4	0.073	0.020	0.160	0.061
Total Kjeldahl Nitrogen as N	mg/L	4	1.770	1.470	1.980	0.215
Total Nitrogen as N	mg/L	4	1.843	1.630	2.000	0.155
pH		4	7.98	7.83	8.23	0.18
Total Phosphorus as P	mg/L	4	0.352	0.241	0.439	0.096
Potassium (K)	mg/L	4	16.0	14.2	18.1	1.7
Sodium (Na)	mg/L	4	16	14	17	2
Sulfate (SO4)	mg/L	4	70	65	79	6

[1]Equal to Minimum Reportable Limit

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Schlecht-Weixel Dam, and that the ratio of total nitrogen to total phosphorus (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

Seven water quality sample results for Schlecht-Weixel Dam between July 1993 and January 2006 indicate that Schlecht-Weixel Dam's is nitrogen limited (Figure 5). The nitrogen to phosphorus ratio for Schlecht-Weixel Dam ranged from a low of 4 to a high of 9 with an average of 6. Of the seven samples collected on Schlecht-Weixel Dam all were below 15 indicating that nitrogen is the limiting nutrient.

Table 2. Statistical Summary of Schlecht-Weixel Dam's Historical Water Quality Data Collected Between 1993 and 1994.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	139	110	187	42
Total Ammonia as N	mg/L	3	0.204	0.100	0.389	0.161
Bicarbonate (HCO_3)	mg/L	3	170	134	228	51
Calcium (Ca)	mg/L	3	35	28	49	12
Carbonate (CO_3)	mg/L	3	1[1]	1[1]	1[1]	0
Chloride (Cl)	mg/L	3	0.3	0.3	0.3	0.0
Chlorophyll-a	µg/L	2	5.9	3.0	8.8	4.1
Specific Conductance	µmhos	3	317	262	402	75
Total Dissolved Solids	mg/L	3	178	147	231	46
Total Hardness as ($CaCO_3$)	mg/L	3	142	113	199	50
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	3	0.367	0.165	0.501	0.178
Magnesium (Mg)	mg/L	3	13.3	10.5	18.7	4.7
Nitrate + Nitrite as N	mg/L	3	0.357	0.005	1.370	0.676
Total Kjeldahl Nitrogen as N	mg/L	3	1.836	1.200	3.400	1.046
Total Nitrogen as N	mg/L	3	1.874	1.244	3.408	1.027
pH		3	7.41	7.34	7.49	0.08
Total Phosphorus as P	mg/L	3	0.241	0.172	0.373	0.114
Potassium (K)	mg/L	3	14.8	11.5	18.7	3.6
Sodium (Na)	mg/L	3	4	3	6	1
Sulfate (SO4)	mg/L	3	22	20	25	3

[1]Equal to Minimum Reportable Limit

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005-2006, Schlecht-Weixel Dam's trophic status is eutrophic (Figure 6). TSI scores ranged from a low of 44 based on chlorophyll-a, to a high of 100 based on total phosphorus. The trophic data score based on Secchi disk transparency was similar to that estimated by chlorophyll-a, at 60 (Figure 6).

A total of seven chlorophyll-a samples and six Secchi disk transparency measurements collected during the open water periods from 1993 to 2006 were used to evaluate Schlecht-Weixel Dam trends in trophic status. Based on a visual assessment of the data Schlect-Weixel Dam's trophic status is stable or declining (Figure 6).

Table 3. Statistical Summary of Water Quality Data[2] Collected from Reservoirs in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	408	309	101	982	130
Total Ammonia as N	mg/L	469	0.097	0.001[1]	2.440	0.200
Bicarbonate (HCO_3)	mg/L	408	318	14	1040	150
Calcium (Ca)	mg/L	408	50	5	160	26
Carbonate (CO_3)	mg/L	402	30	1[1]	197	30
Chloride (Cl)	mg/L	408	13.3	0.3	74.5	8.8
Chlorophyll-a	µg/L	321	21.2	1.5	218.0	27.9
Specific Conductance	µmhos	428	1733	262	5880	959
Total Dissolved Solids	mg/L	409	1176	147	5110	750
Total Hardness as ($CaCO_3$)	mg/L	408	397	45	1850	260
Hydroxide (OH)	mg/L	337	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	409	0.179	0.007	4.110	0.334
Magnesium (Mg)	mg/L	408	66.0	5.6	353.0	49.6
Nitrate + Nitrite as N	mg/L	395	0.048	0.001[1]	0.790	0.092
Total Kjeldahl Nitrogen as N	mg/L	359	1.556	0.365	7.720	0.779
Total Nitrogen as N	mg/L	302	1.472	0.405	4.840	0.562
pH		428	8.61	6.73	9.87	0.56
Total Phosphorus as P	mg/L	475	0.135	0.004[1]	3.160	0.205
Potassium (K)	mg/L	408	14.6	4.2	39.2	6.3
Sodium (Na)	mg/L	408	239	3[1]	932	171
Sulfate (SO4)	mg/L	406	604	1[1]	3210	501

[1]Equal to Minimum Reporting Limit

[2]Data Collected from 69 Reservoirs between 1991 and 2007

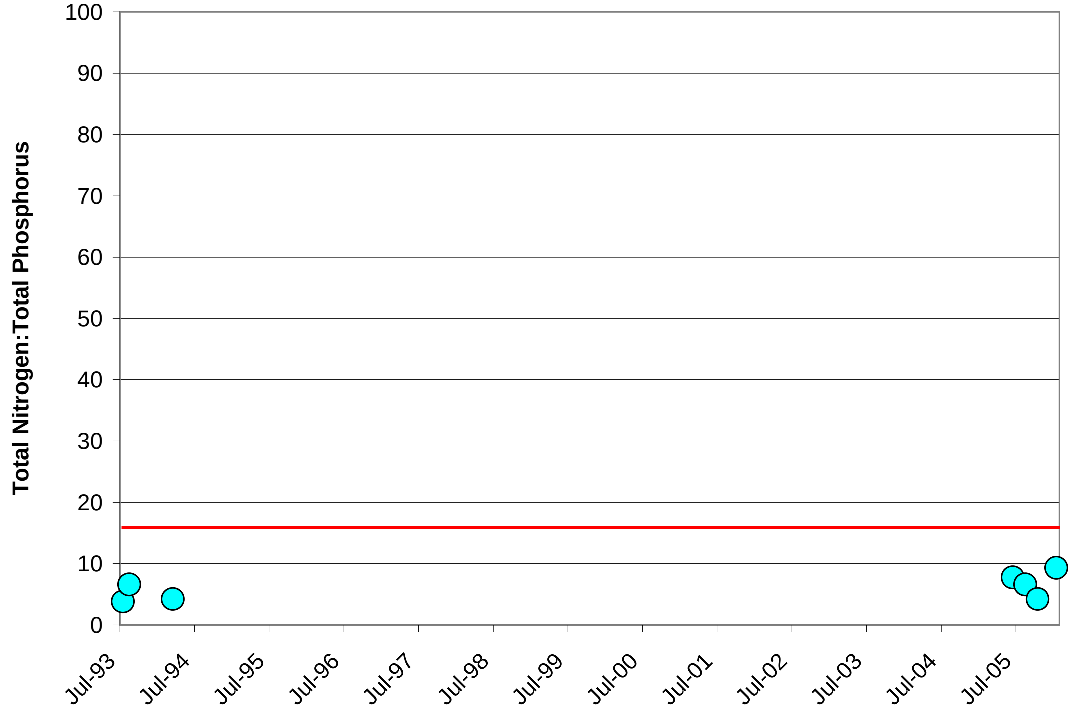


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Schlecht-Weixel Dam (1993-2006).

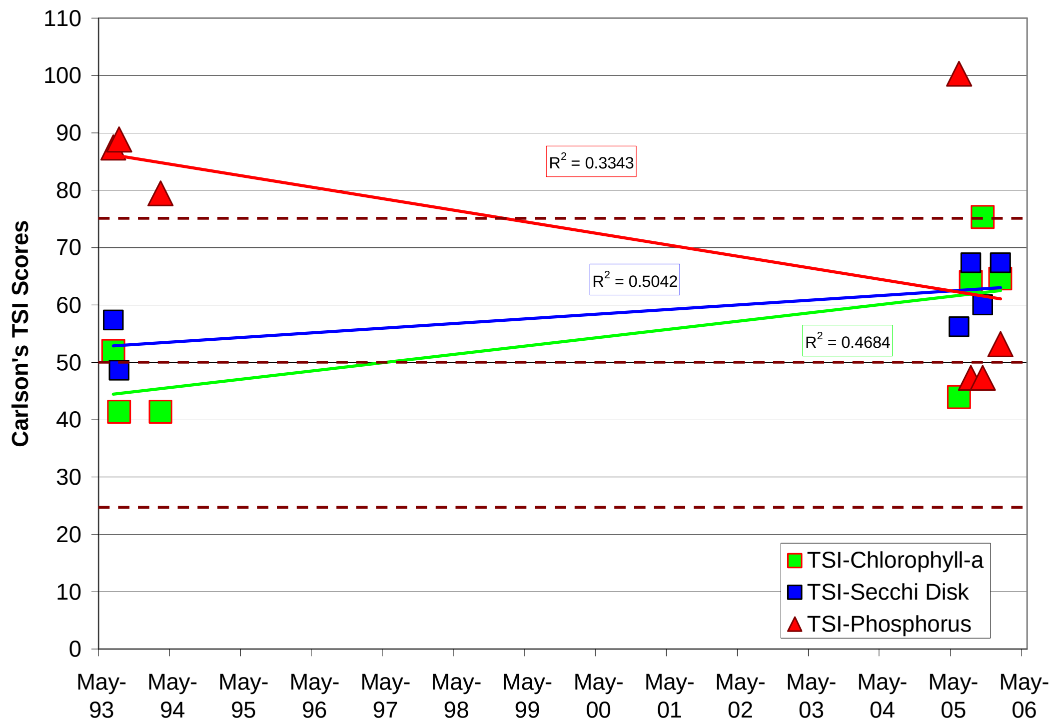


Figure 6. TSI Scores and Temporal Trends for Schlecht-Weixel Dam from 1993-2006.

Buffalo Lodge Lake, McHenry County

BACKGROUND

Location: Buffalo Lodge Lake is a natural lake located 3 miles east and 3 miles north of Granville, North Dakota. Buffalo Lodge Lake is managed by the North Dakota Game and Fish Department (Figure 1).

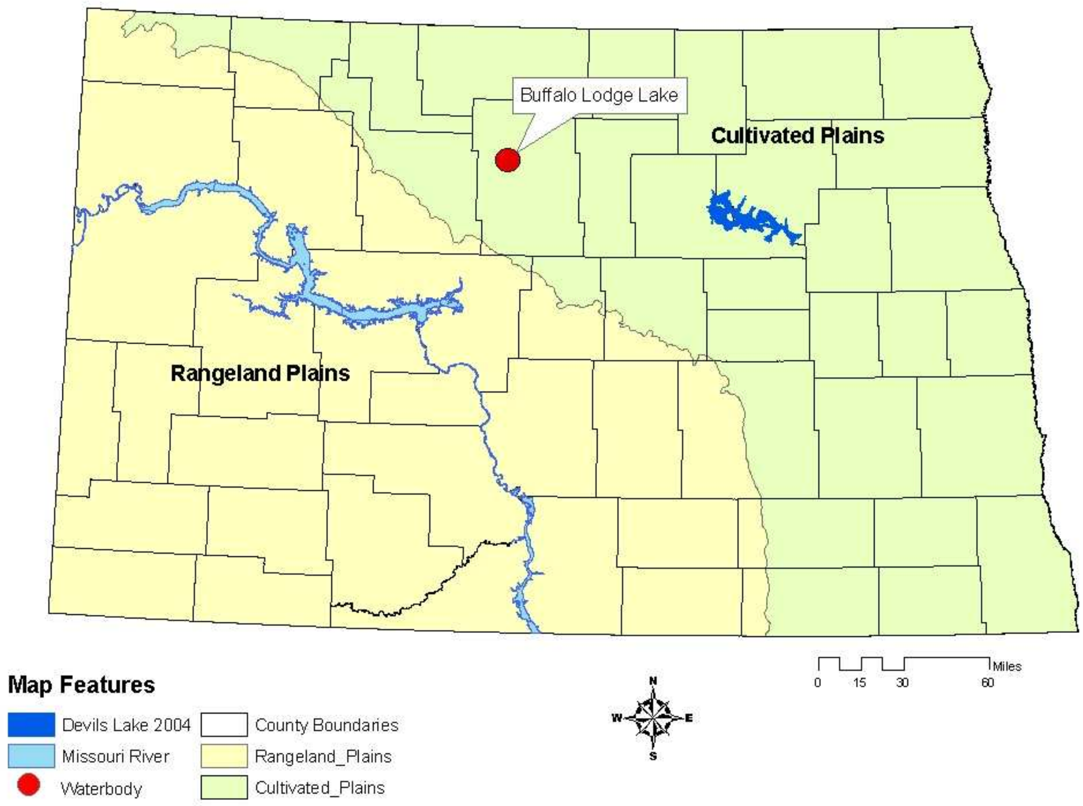


Figure 1. Location of Buffalo Lodge Lake.

Physiographic/Ecological Setting: Buffalo Lodge Lake has a surface area of 1,395 acres, a maximum depth of 13.6 ft, and an average depth of 8.9 ft (Figure 2). Buffalo Lodge Lake's watershed lies within the Northern Glaciated Plains Level III Ecoregion, part of the broader Cultivated Plains region (Figure 1). This region is the transitional zone between tall and mixed grass prairie. The region has numerous wetlands essential for spring and fall migrations of wetland dependent birds. Flood plain slopes and hillsides are usually native grass while the uplands and flood plains proper have mostly been converted to small grains, row crops and alfalfa.

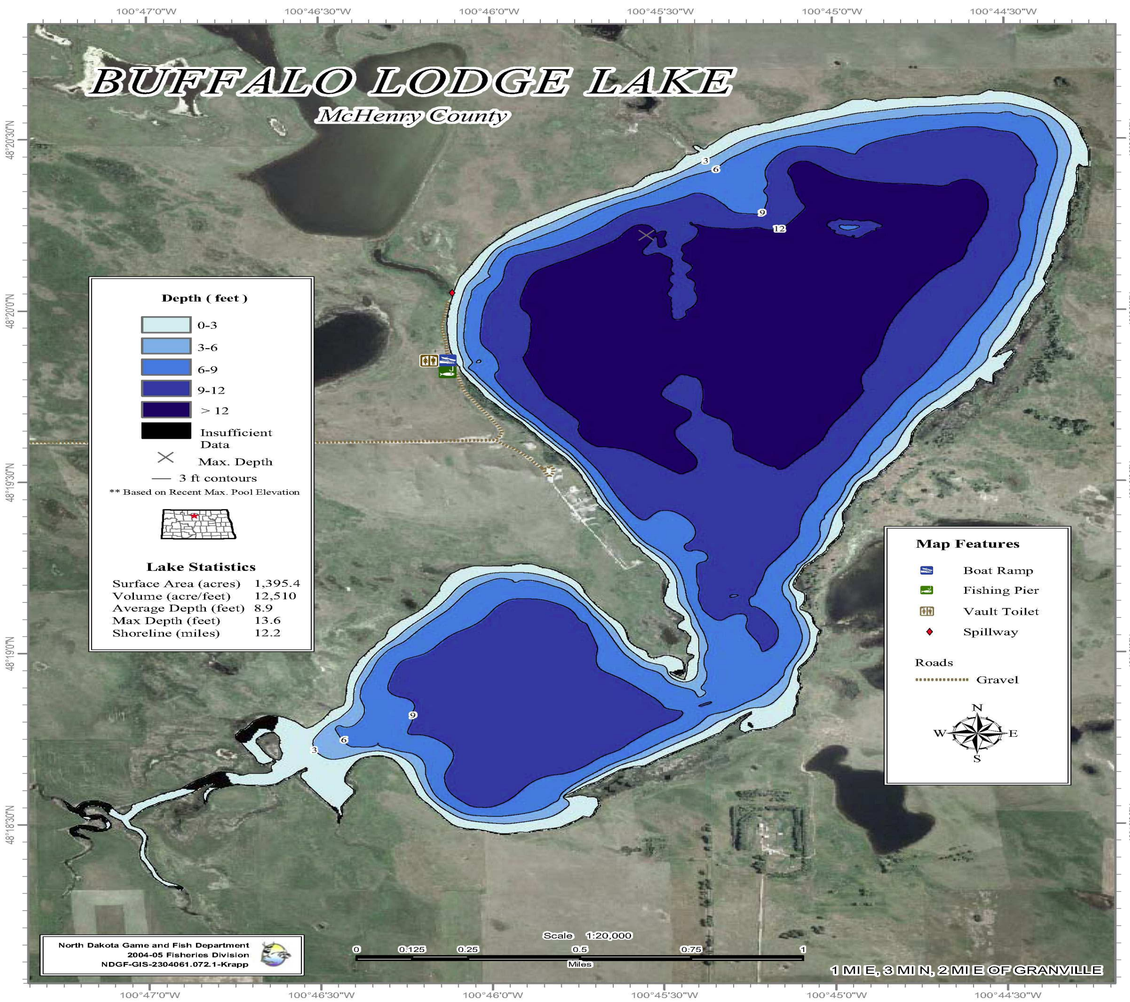


Figure 2. Contour Map of Buffalo Lodge Lake (Map Courtesy of North Dakota Game and Fish Department).

Recreational Facilities: Recreational facilities at Buffalo Lodge Lake include a boat ramp, boat and vehicle parking, and a fishing pier. Public access on the northwest shore includes a boat ramp, parking, vault toilet, and the fishing pier. Dark house spear fishing is also available at Buffalo Lodge Lake.

Water Quality Standards Classification: Buffalo Lodge Lake is classified in the "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 3 lake. Class 3 lakes are defined as a "warm water fishery" or "waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present."

Historical and Current Fishery: Buffalo Lodge Lake's fishery over time has included walleye, brook stickleback, fathead minnows, northern pike, and yellow perch, stocked by the NDG&F. Currently northern pike, walleye, and yellow perch are managed in Buffalo Lodge Lake.

Historical Water Quality Sampling: Historical water quality data includes results from three samples collected from 1995 and 1996.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Buffalo Lodge Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural or enhanced lakes in the Cultivated Plains region.

Temperature and Dissolved Oxygen Profile Results: There are seven temperature and dissolved oxygen profiles for Buffalo Lodge Lake. Temperature and dissolved oxygen profiles are presented for two time periods, 1995-1996 and 2005-2006 (Figures 3 and 4).

The profile data shows that Buffalo Lodge Lake usually has sufficient dissolved oxygen except during late winter. During late winter Buffalo Lodge Lake can have dissolved oxygen decay to below the state's water quality standard of 5 mg/L. Two of the seven profiles, collected on 2/22/1996 and 1/24/2006, dropped below the state standard of 5 mg/L.

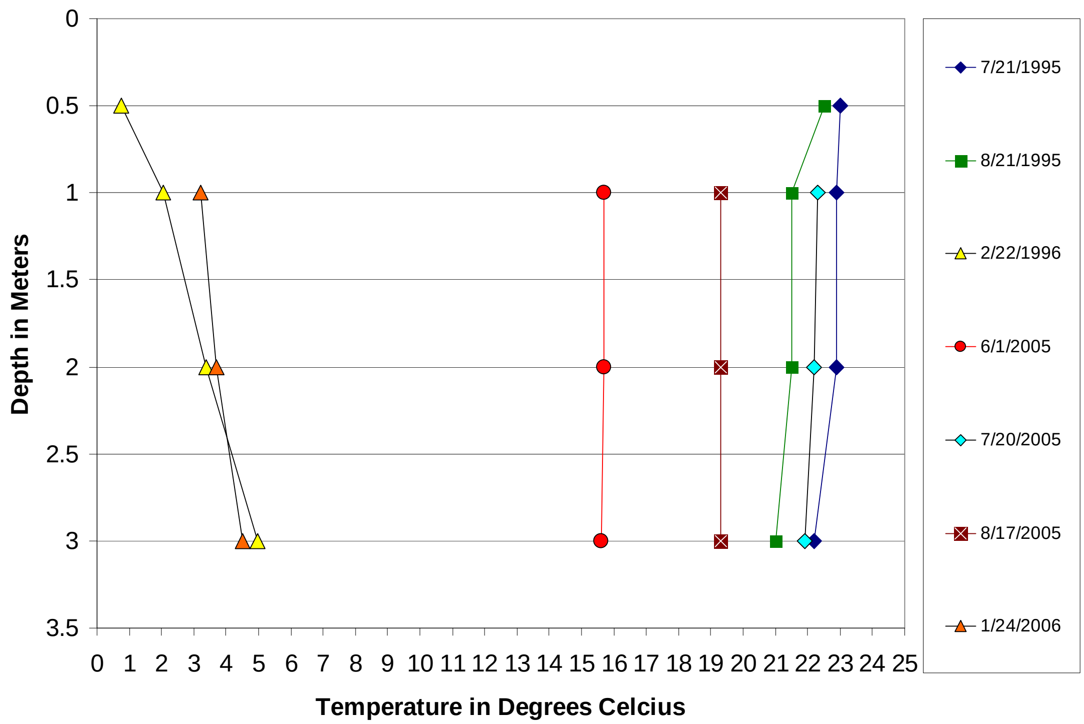


Figure 3. Temperature Profiles for Buffalo Lodge Lake from 1995 to 2006.

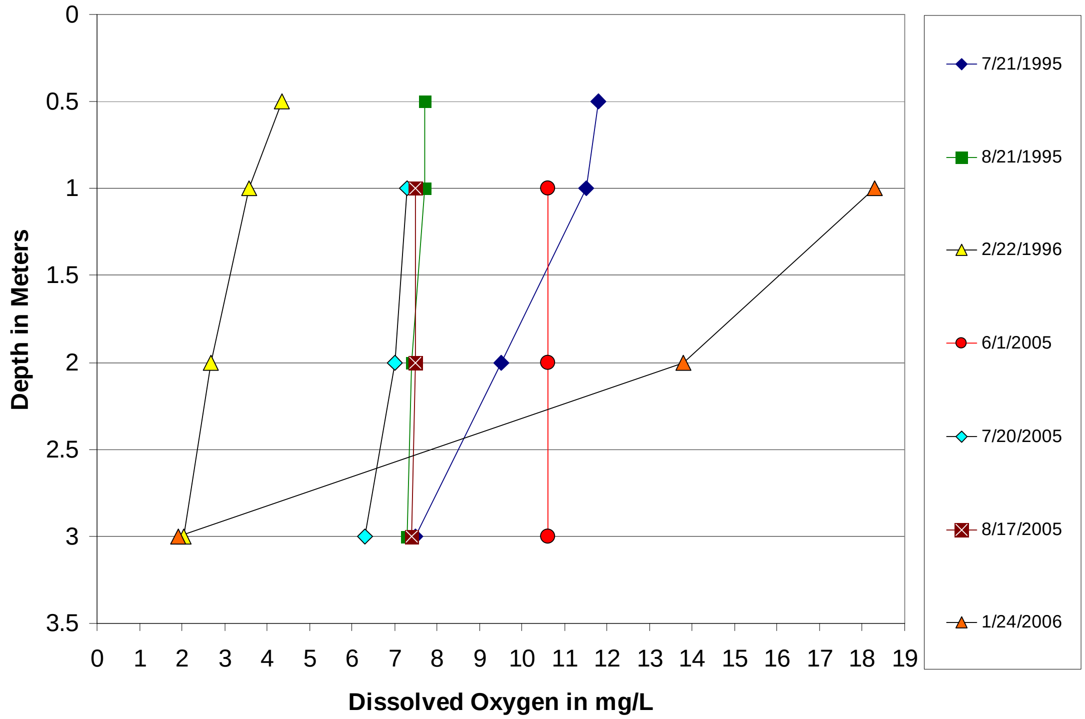


Figure 4. Dissolved Oxygen Profiles for Buffalo Lodge Lake from 1995 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006 indicate Buffalo Lodge Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 418 mg/L to 479 mg/L (Table 1). Based on the 2005-2006 water quality data (Table 1), Buffalo Lodge Lake is sodium bicarbonate dominated with an average sodium concentration of 184 mg/L and an average bicarbonate concentration of 473 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 1056 mg/L and 1590 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 2.105 mg/L and 0.129 mg/L, respectively.

When compared to historical water quality data for Buffalo Lodge Lake, it appears that concentrations of most water quality constituents have increased. For example, the average bicarbonate and sodium concentrations for the period 1995-1996 were 381 mg/L and 163 mg/L, respectively (Table 2), compared to average concentrations of 473 mg/L for bicarbonate and 184 mg/L for sodium recorded for the period 2005-2006 (Table 1).

While not greater then the standard deviation, the average total nitrogen concentrations and total phosphorus concentrations have decreased when compared to the historical data. The historical average for total nitrogen and total phosphorus concentrations were 2.753 mg/L and 0.178 mg/L (Table 2) respectively, compared to the current average concentrations of 2.105 mg/L for total nitrogen and 0.129 mg/L for total phosphorus (Table 1).

Table 1. Statistical Summary of Buffalo Lodge Lake's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	448	418	479	30
Total Ammonia as N	mg/L	4	0.016	0.010[1]	0.034	0.012
Bicarbonate (HCO_3)	mg/L	4	473	427	536	46
Calcium (Ca)	mg/L	4	50.8	46.1	59.4	5.9
Carbonate (CO_3)	mg/L	4	37	18	71	24
Chloride (Cl)	mg/L	4	50	47	56	4
Chlorophyll-a	µg/L	3	29.2	20.3	37.4	8.6
Specific Conductance	µmhos	4	1590	1500	1780	130
Total Dissolved Solids	mg/L	4	1056	993	1180	87
Total Hardness as ($CaCO_3$)	mg/L	4	501	468	572	48
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.228	0.080	0.482	0.189
Magnesium (Mg)	mg/L	4	91.0	84.6	103.0	8.6
Nitrate + Nitrite as N	mg/L	4	0.040	0.020	0.080	0.028
Total Kjeldahl Nitrogen as N	mg/L	4	2.065	1.730	2.300	0.275
Total Nitrogen as N	mg/L	4	2.105	1.750	2.360	0.289
pH		4	8.63	8.51	8.93	0.20
Total Phosphorus as P	mg/L	4	0.129	0.085	0.150	0.030
Potassium (K)	mg/L	4	24.6	20.8	26.7	2.6
Sodium (Na)	mg/L	4	184	173	203	14
Sulfate (SO4)	mg/L	4	387	360	446	40

[1]Equal to lower detection limit

When compared to the Cultivated Plains regional average Buffalo Lodge Lake is lower in dissolved solids and higher in nutrients then the average natural or enhanced lake. For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1376 mg/L, 1.440 mg/L, and 0.068 mg/L, respectively, compared to Buffalo Lodge Lake's average TDS, total nitrogen, and total phosphorus concentrations of 1056 mg/L, 2.105 mg/L and 0.129 mg/L, respectively.

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Buffalo Lodge Lake and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight, in algae is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There are seven water quality sample sets for Buffalo Lodge Lake between July 1995 and January 2006, where the N:P ratio could be calculated. The results from this analysis indicate that the limiting nutrient in Buffalo Lodge Lake is dynamic and dependent on several environmental factors (Figure 5).

Table 2. Statistical Summary of Buffalo Lodge Lake's Historical Water Quality Data Collected Between 1995 and 1996.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	354	308	444	78
Total Ammonia as N	mg/L	3	0.246	0.034	0.612	0.318
Bicarbonate (HCO_3)	mg/L	3	381	289	542	140
Calcium (Ca)	mg/L	3	55	49	64	8
Carbonate (CO_3)	mg/L	3	25	1[1]	43	22
Chloride (Cl)	mg/L	3	51.8	45.6	63.5	10.2
Chlorophyll-a	µg/L	2	45.0	34.0	56.0	15.6
Specific Conductance	µmhos	3	1537	1330	1880	299
Total Dissolved Solids	mg/L	3	1054	936	1280	196
Total Hardness as ($CaCO_3$)	mg/L	3	484	400	572	86
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	3	0.091	0.055	0.132	0.039
Magnesium (Mg)	mg/L	3	84.3	67.6	100.0	16.2
Nitrate + Nitrite as N	mg/L	3	0.066	0.015	0.140	0.066
Total Kjeldahl Nitrogen as N	mg/L	3	2.687	2.120	3.250	0.565
Total Nitrogen as N	mg/L	3	2.753	2.135	3.390	0.628
pH		3	8.57	7.86	9.02	0.62
Total Phosphorus as P	mg/L	3	0.178	0.111	0.301	0.107
Potassium (K)	mg/L	3	24.7	21.0	27.9	3.5
Sodium (Na)	mg/L	3	163	138	189	26
Sulfate (SO4)	mg/L	3	461	378	567	96

[1]Equal to lower detection limit

N:P ratios for Buffalo Lodge Lake ranged from a low of 12 to a high of 27 with an average of 18. Three of the seven samples collected were above a ratio of 15 indicating phosphorus limitation and the other four were below a ratio of 15 indicating nitrogen limitation.

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005, Buffalo Lodge Lake's current trophic status is eutrophic bordering on hypereutrophic. TSI scores ranged from a low of 60 based on chlorophyll-a, to a high of 77 based on Secchi disk transparency. The trophic status score based on total phosphorus was similar to that based on Secchi disk transparency, at 76 (Figure 6).

A total of five total phosphorus samples, five chlorophyll-a samples, and five Secchi disk transparency measurements collected during the open water periods from 1995 to 2006 were used to evaluate trends in the trophic status of Buffalo Lodge Lake. Based on a visual assessment of the data, Buffalo Lodge Lake's trophic status appears to be remaining stable (Figure 6).

Table 3. Statistical Summary of Water Quality from Natural and Enhanced Lake's in the Cultivated Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	142	346	175	1120	180
Total Ammonia as N	mg/L	230	0.098	0.001[1]	1.620	0.208
Bicarbonate (HCO_3)	mg/L	142	363	171	1040	158
Calcium (Ca)	mg/L	142	45	16	108	23
Carbonate (CO_3)	mg/L	136	31	1[1]	181	39
Chloride (Cl)	mg/L	142	105	3[1]	1260	233
Chlorophyll-a	µg/L	185	10	2[1]	167	17
Specific Conductance	µmhos	161	1819	361	11500	2071
Total Dissolved Solids	mg/L	143	1376	191	9880	1786
Total Hardness as ($CaCO_3$)	mg/L	142	507	173	1820	284
Hydroxide (OH)	mg/L	111	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	138	0.095[1]	0.007	1.010	0.123
Magnesium (Mg)	mg/L	142	95.7	28.4	413.0	68.0
Nitrate + Nitrite as N	mg/L	175	0.047	0.001	0.540	0.078
Total Kjeldahl Nitrogen as N	mg/L	128	1.504	0.080	4.110	0.609
Total Nitrogen as N	mg/L	103	1.440	0.609	2.740	0.466
pH		142	8.55	7.75	9.33	0.36
Total Phosphorus as P	mg/L	230	0.068	0.004[1]	1.460	0.118
Potassium (K)	mg/L	142	30	8	179	37
Sodium (Na)	mg/L	142	255	5	2570	498
Sulfate (SO4)	mg/L	142	591	7	3880	807

[1]Equal to lower detection limit
[2]Data Collected from 49 Natural Lakes between 1991 and 2007

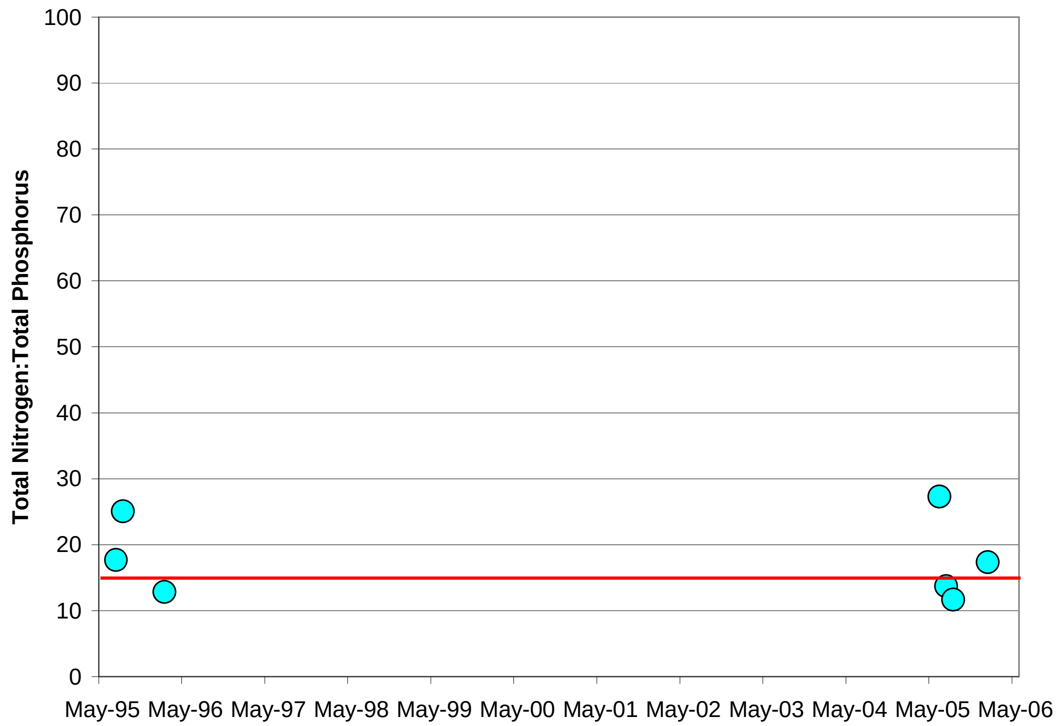


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Buffalo Lodge Lake (1995-2006).

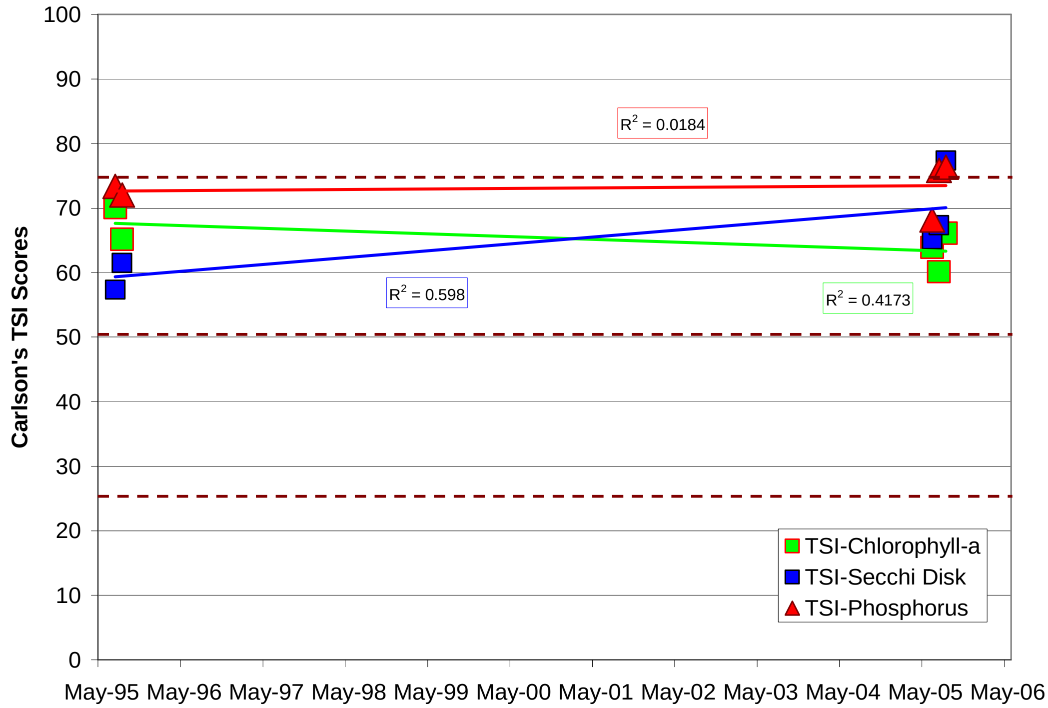


Figure 6. TSI Scores and Temporal Trends for Buffalo Lodge Lake from 1995 to 2006.

Cottonwood Lake, McHenry County

BACKGROUND

Location: Cottonwood Lake is a natural lake located 2½ miles north of Butte, North Dakota. Cottonwood Lake is managed by the North Dakota Game and Fish Department (Figure 1).

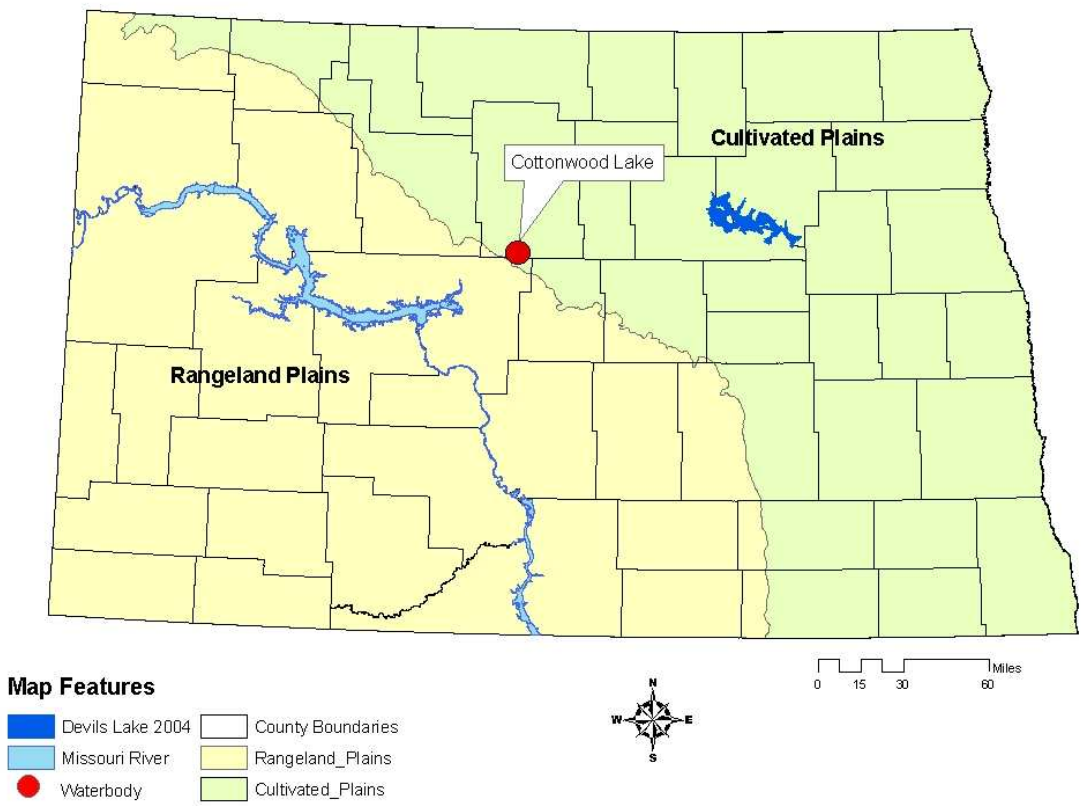


Figure 1. Location of Cottonwood Lake.

Physiographic/Ecological Setting: Cottonwood Lake has a surface area of 224.6 acres, a maximum depth of 13.0 ft, and an average depth 10.0 ft (Figure 2). Cottonwood Lake's watershed lies within the Northern Glaciated Plains Level III Ecoregion, part of the broader Cultivated Plains region (Figure 1). This region is the transitional zone between tall and mixed grass prairie. The region has numerous wetlands essential for spring and fall migrations of wetland dependent birds. Flood plain slopes and hillsides are usually native grass while the uplands and flood plains proper have mostly been converted to small grains, row crops and alfalfa.

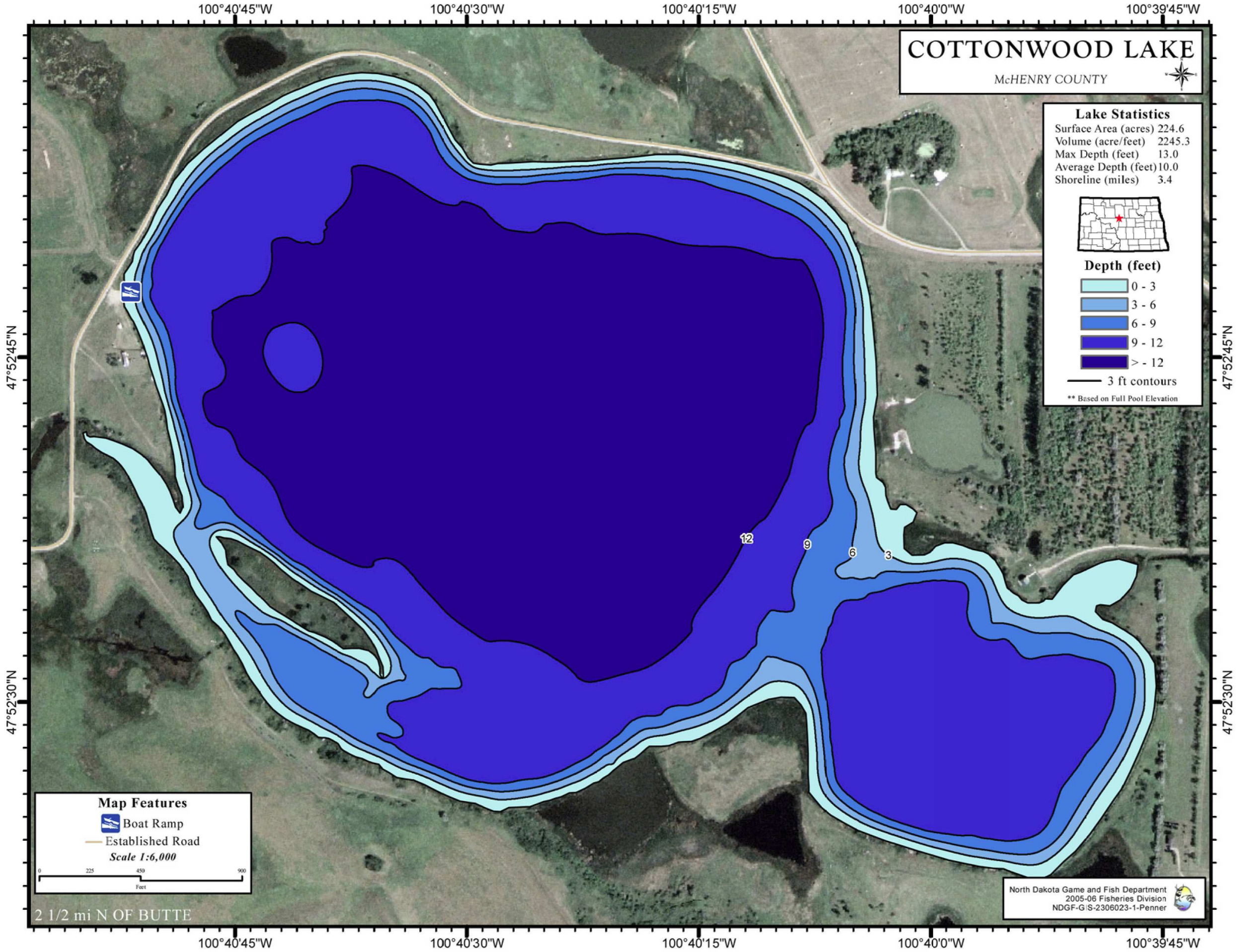


Figure 2. Contour Map of Cottonwood Lake (Map Courtesy of North Dakota Game and Fish Department).

Recreational Facilities: Recreational facilities at Cottonwood Lake include a boat ramp, boat and vehicle parking, and a fishing pier. Public access on the west shore includes the boat ramp, parking, and the fishing pier.

Water Quality Standards Classification: Cottonwood Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 3 lake. Class 3 lakes are defined as a "warm water fishery" or "waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present."

Historical and Current Fishery: Cottonwood Lake's fishery over time has included northern pike and yellow perch stocked by the NDG&F. Currently, northern pike, yellow perch, and fathead minnows are managed in Cottonwood Lake.

Historical Water Quality Sampling: There is no historical water quality data available for Cottonwood Lake.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Cottonwood Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural or enhanced lakes in the Cultivated Plains region.

Temperature and Dissolved Oxygen Profile Results: There were four temperature and dissolved oxygen profiles for Cottonwood Lake collected in 2005 and 2006 (Figures 3 and 4). The profile data shows that Cottonwood Lake is usually well oxygenated throughout but does experience some oxygen decay near the water-sediment interface.

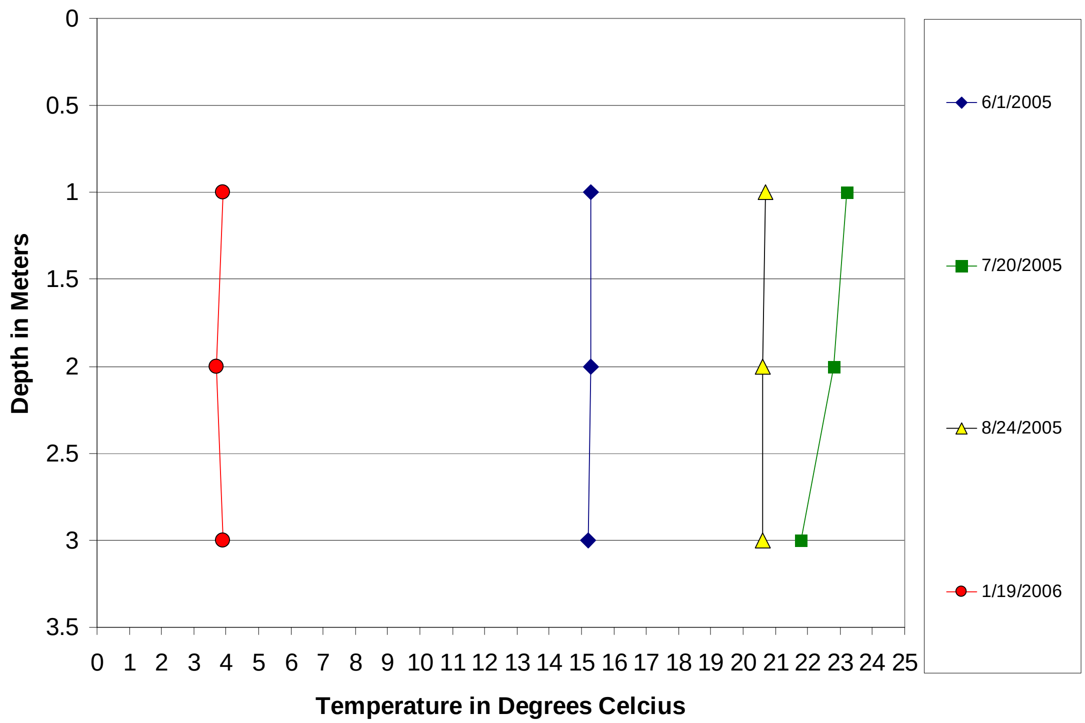


Figure 3. Temperature Profiles for Cottonwood Lake from 2005 to 2006.

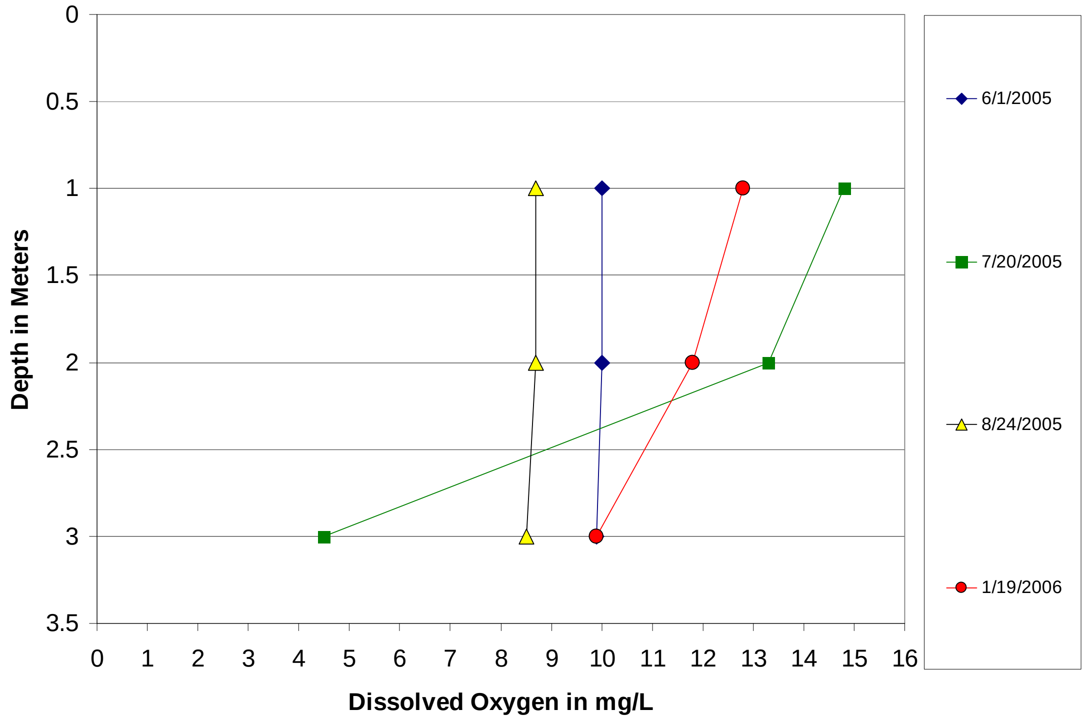


Figure 4. Dissolved Oxygen Profiles for Cottonwood Lake from 2005 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006 indicate Cottonwood Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 315 mg/L to 368 mg/L (Table 1). Based on the 2005-2006 water quality data (Table 1), Cottonwood Lake is sodium sulfate dominated with an average sodium concentration of 244 mg/L and an average sulfate concentration of 613 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 2183 mg/L and 1738 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.680 mg/L and 0.060 mg/L, respectively.

When compared to the Cultivated Plains regional water quality for natural and enhanced lakes Cottonwood Lake is higher in dissolved solids but about average for nutrients (Table 2). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1376 mg/L, 1.440 mg/L, and 0.068 mg/L, respectively, compared to Cottonwood Lake's average TDS, total nitrogen, and total phosphorus concentrations of 2183 mg/L, 1.680 mg/L, and 0.060 mg/L, respectively, for the period 2005-2006.

Table 1. Statistical Summary of Cottonwood Lake's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	331	315	368	25
Total Ammonia as N	mg/L	4	0.028	0.010[1]	0.046	0.021
Bicarbonate (HCO_3)	mg/L	4	311	269	372	46
Calcium (Ca)	mg/L	4	39.5	33.7	45.0	4.7
Carbonate (CO_3)	mg/L	4	46	34	61	12
Chloride (Cl)	mg/L	4	12	11	14	1
Chlorophyll-a	µg/L	3	46.9	5.6	104.0	51.1
Specific Conductance	µmhos	4	1738	1650	1960	149
Total Dissolved Solids	mg/L	4	2183	1140	5060	1921
Total Hardness as ($CaCO_3$)	mg/L	4	436	404	487	37
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.175	0.117	0.252	0.059
Magnesium (Mg)	mg/L	4	81.9	76.5	93.8	8.0
Nitrate + Nitrite as N	mg/L	3	0.033	0.020	0.060	0.023
Total Kjeldahl Nitrogen as N	mg/L	4	1.255	0.080	2.010	0.882
Total Nitrogen as N	mg/L	3	1.680	1.100	2.030	0.506
pH		4	8.94	8.76	9.13	0.18
Total Phosphorus as P	mg/L	4	0.060	0.028	0.097	0.035
Potassium (K)	mg/L	4	18.2	17.2	19.6	1.1
Sodium (Na)	mg/L	4	244	228	275	22
Sulfate (SO4)	mg/L	4	613	577	695	55

[1]Equal to lower detection limit

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Cottonwood Lake and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight, in algae is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There are three water quality sample sets for Cottonwood Lake between June 2005 and January 2006, where the N:P ratio could be calculated. The results from this analysis indicate that Cottonwood Lake is phosphorus limited (Figure 5).

N:P ratios for Cottonwood Lake ranged from a low of 21, to a high of 39, with an average of 28. All three of the samples collected were above a ratio of 15 indicating phosphorus limitation.

Table 2. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lake's in the Cultivated Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	142	346	175	1120	180
Total Ammonia as N	mg/L	230	0.098	0.001[1]	1.620	0.208
Bicarbonate (HCO_3)	mg/L	142	363	171	1040	158
Calcium (Ca)	mg/L	142	45	16	108	23
Carbonate (CO_3)	mg/L	136	31	1[1]	181	39
Chloride (Cl)	mg/L	142	105	3[1]	1260	233
Chlorophyll-a	µg/L	185	10	2[1]	167	17
Specific Conductance	µmhos	161	1819	361	11500	2071
Total Dissolved Solids	mg/L	143	1376	191	9880	1786
Total Hardness as ($CaCO_3$)	mg/L	142	507	173	1820	284
Hydroxide (OH)	mg/L	111	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	138	0.095[1]	0.007	1.010	0.123
Magnesium (Mg)	mg/L	142	95.7	28.4	413.0	68.0
Nitrate + Nitrite as N	mg/L	175	0.047	0.001	0.540	0.078
Total Kjeldahl Nitrogen as N	mg/L	128	1.504	0.080	4.110	0.609
Total Nitrogen as N	mg/L	103	1.440	0.609	2.740	0.466
pH		142	8.55	7.75	9.33	0.36
Total Phosphorus as P	mg/L	230	0.068	0.004[1]	1.460	0.118
Potassium (K)	mg/L	142	30	8	179	37
Sodium (Na)	mg/L	142	255	5	2570	498
Sulfate (SO4)	mg/L	142	591	7	3880	807

[1]Equal to lower detection limit
[2]Data Collected from 49 Natural Lakes between 1991 and 2007

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005-2006, Cottonwood Lake's current trophic status is eutrophic. TSI scores ranged from a low of 46, to a high of 77, based on Secchi disk transparency. The trophic status scores based on total phosphorus and chlorophyll-a, were within the range based on Secchi disk transparency, at 54 for total phosphorus and 64 for chlorophyll-a, respectively (Figure 6).

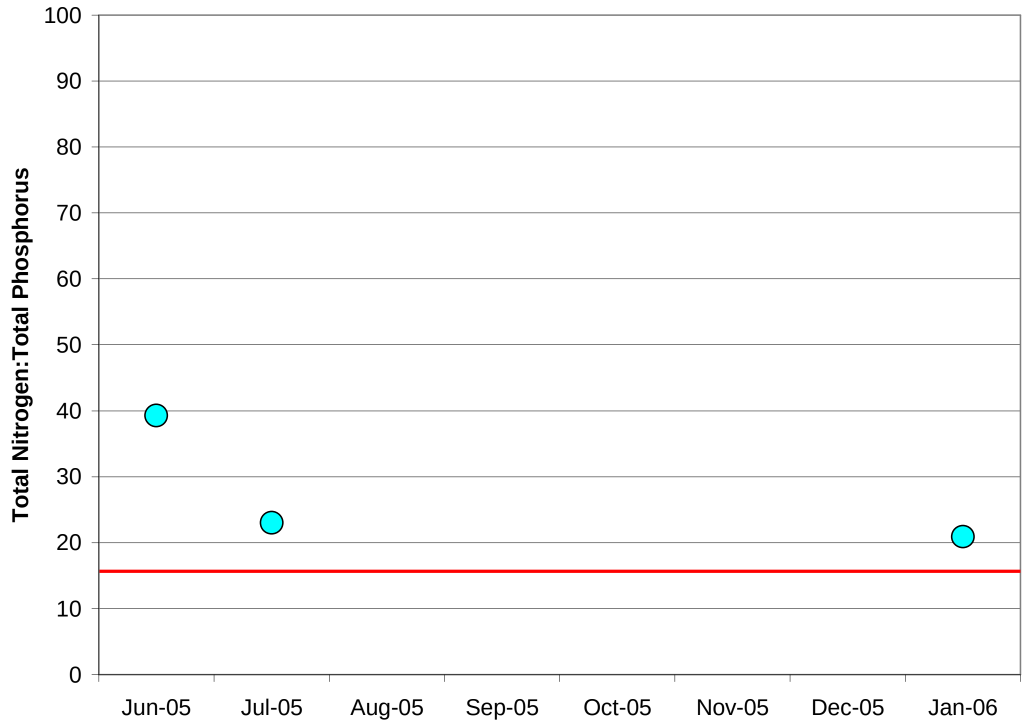


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Cottonwood Lake (2005-2006).

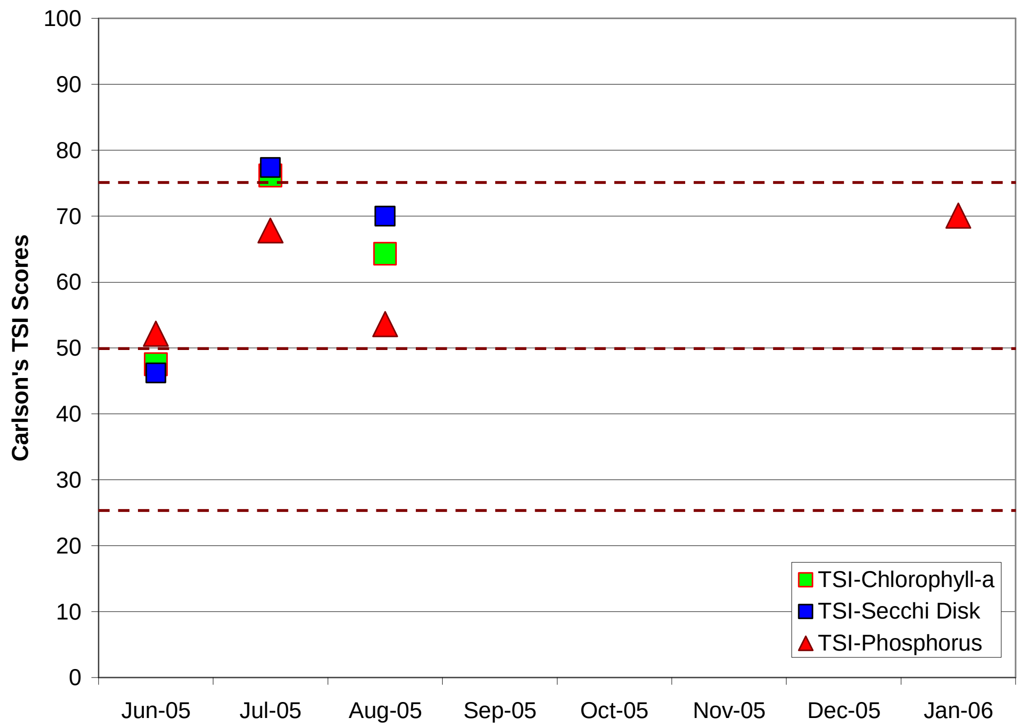


Figure 6. TSI Scores for Cottonwood Lake from 2005 to 2006.

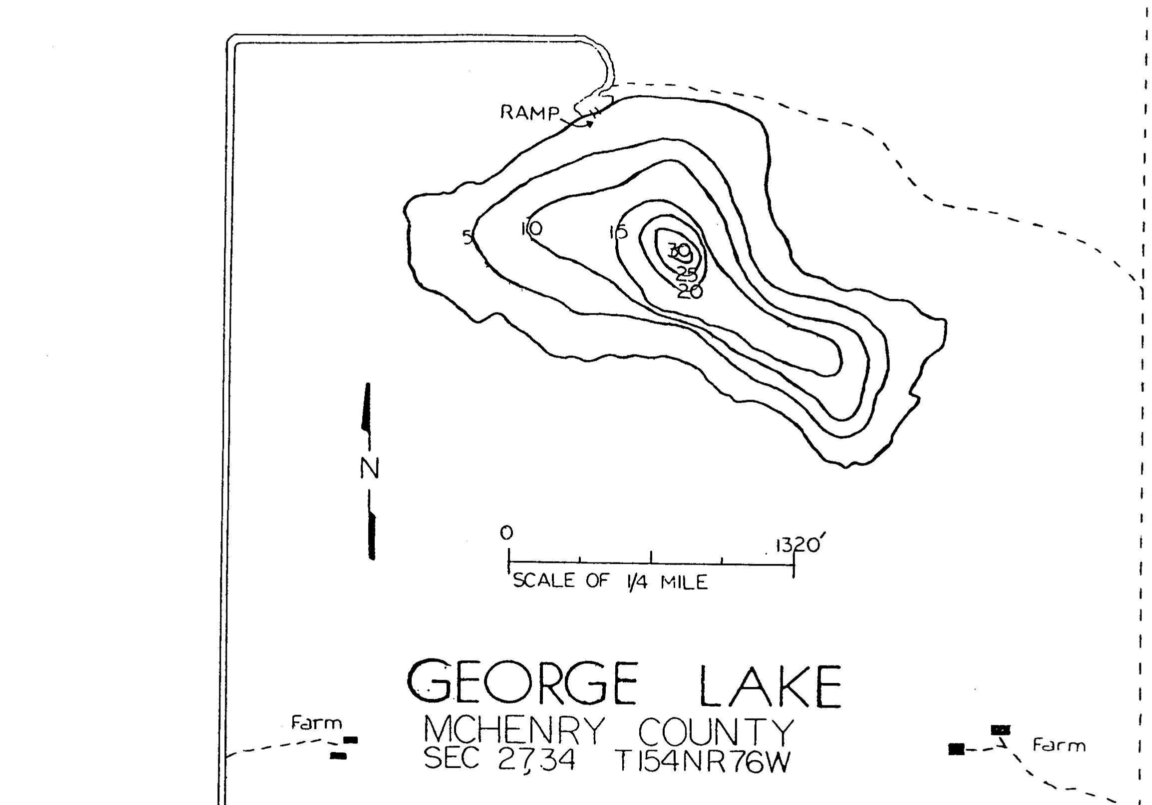
Lake George, McHenry County

BACKGROUND

Location: Lake George is a natural lake located 13 miles north and 1½ miles east of the junction of U.S. Highways 52 and 14. Lake George is managed by the North Dakota Game and Fish Department (Figure 1).

Figure 1. Location of Lake George.

Physiographic/Ecological Setting: Lake George has a surface area of 84.4 acres, a maximum depth of approximately 30 ft, and an average depth 7.8 ft (Figure 2). Lake George's watershed is 7,437 acres and lies within the Northern Glaciated Plains Level III Ecoregion, part of the broader Cultivated Plains region (Figure 1). This region is the transitional zone between tall and mixed grass prairie. The region has numerous wetlands essential for spring and fall migrations of wetland dependent birds. Flood plain slopes and hillsides are usually native grass while the uplands and flood plains proper have mostly been converted to small grains, row crops, and alfalfa



Contour	Acres	Ave. Depth	Acre-Feet
30	.6	0	0
25	1.3	3.6	4.75
20	2.8	5.4	15.0
15	11.7	4.4	51.2
10	27.0	5.5	148.0
5	46.0	7.9	330.5
Shoreline	84.4	7.8	656.5

Shoreline = 1.75 miles
Drainage Area = 8.8 sq. miles

Figure 2. Contour Map of Lake George (Map Courtesy of North Dakota Game and Fish Department).

Recreational Facilities: Recreational facilities at Lake George include a boat ramp, boat and vehicle parking, and a picnic area. Public access on the north shore includes the boat ramp, parking, and the picnic area.

Water Quality Standards Classification: Lake George is classified in the "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 3 lake. Class 3 lakes are defined as a "warm water fishery" or "waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present."

Historical and Current Fishery: Lake George's fishery over time has included northern pike and yellow perch stocked by the NDG&F. Currently both species are managed in Lake George.

Historical Water Quality Sampling: Historical water quality data includes results from three samples collected from 1995 through 1996.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Lake George have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural or enhanced lakes in the Cultivated Plains region.

Temperature and Dissolved Oxygen Profile Results: There were seven temperature and dissolved oxygen profiles for Lake George collected from 1995-2006. Temperature and oxygen profiles are presented for two time periods, 1995-1996 and 2005-2006 (Figures 3 and 4).

The temperature and dissolved oxygen profile data shows that during thermal stratification, Lake George experiences rapid oxygen decay, and frequently drops below the state's water quality standard of 5 mg/L. Five of the seven profiles, collected on 7/17/1995, 8/21/1995, 7/20/2005, 8/29/2005, and 1/19/2006, dropped below the state standard of 5 mg/L and one collected on 2/22/1996 was nearly anoxic from top to bottom.

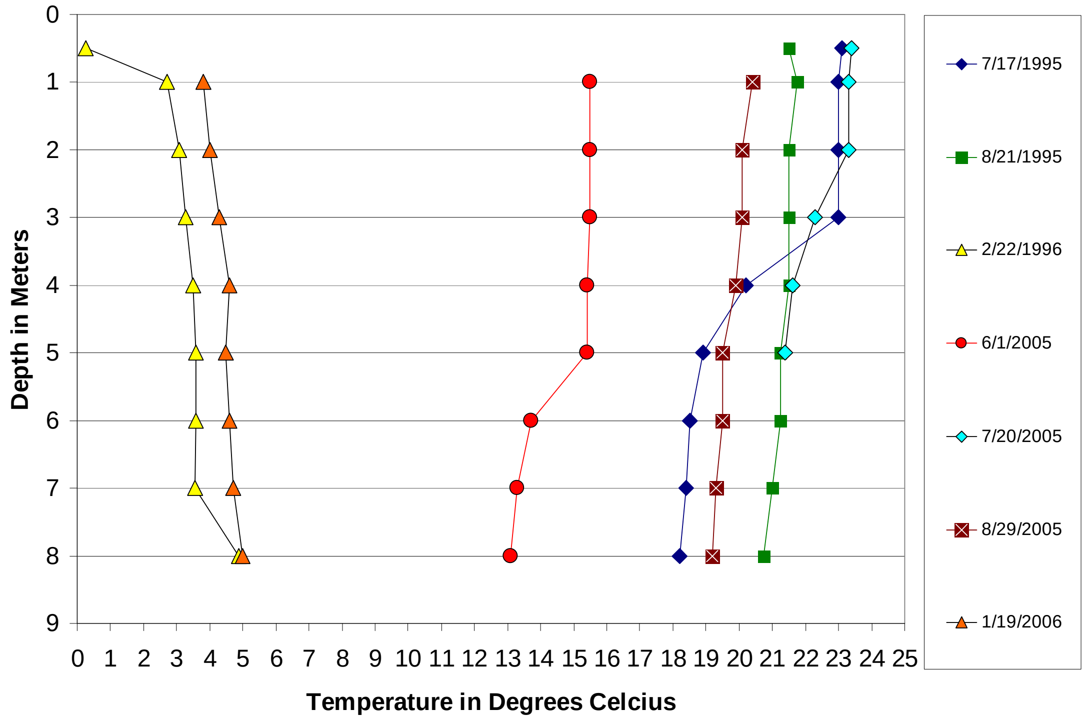


Figure 3. Temperature Profiles for Lake George from 1995 to 2006.

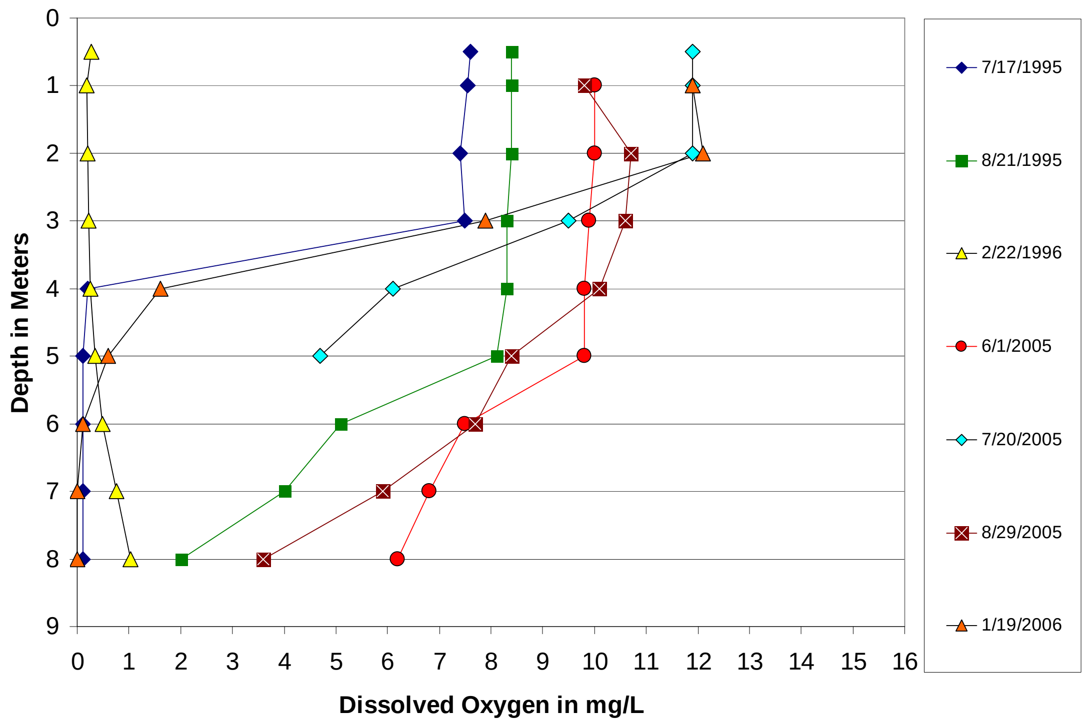


Figure 4. Dissolved Oxygen Profiles for Lake George from 1995 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006 indicate Lake George is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 350 mg/L to 416 mg/L (Table 1). Based on the 2005-2006 water quality data, Lake George is sodium bicarbonate dominated with an average sodium concentration of 73 mg/L and an average bicarbonate concentration of 363 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 400 mg/L and 687 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.810 mg/L and 0.039 mg/L, respectively.

Table 1. Statistical Summary of Lake George's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	380	350	416	32
Total Ammonia as N	mg/L	4	0.029	0.010[1]	0.086	0.038
Bicarbonate (HCO_3)	mg/L	4	363	286	465	79
Calcium (Ca)	mg/L	4	21.6	15.8	26.4	5.1
Carbonate (CO_3)	mg/L	4	49	21	72	21
Chloride (Cl)	mg/L	4	12	11	14	1
Chlorophyll-a	µg/L	3	20.3	8.0	26.7	10.7
Specific Conductance	µmhos	4	687	636	786	70
Total Dissolved Solids	mg/L	4	400	370	447	36
Total Hardness as ($CaCO_3$)	mg/L	4	238	211	273	27
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.163	0.085	0.271	0.079
Magnesium (Mg)	mg/L	4	44.6	41.6	50.9	4.2
Nitrate + Nitrite as N	mg/L	4	0.038	0.020	0.090	0.035
Total Kjeldahl Nitrogen as N	mg/L	4	1.773	1.460	2.070	0.250
Total Nitrogen as N	mg/L	4	1.810	1.480	2.090	0.251
pH		4	8.95	8.58	9.22	0.28
Total Phosphorus as P	mg/L	4	0.039	0.021	0.075	0.025
Potassium (K)	mg/L	4	10.3	9.2	11.4	0.9
Sodium (Na)	mg/L	4	73	69	83	6
Sulfate (SO4)	mg/L	4	9	7	11	2

[1]Equal to lower detection limit

When compared to historical water quality data for Lake George, it appears that concentrations of most water quality constituents have decreased. For example, the average bicarbonate and sodium concentrations for the period 1992-1996 were 552 mg/L and 89 mg/L, respectively (Table 2), compared to average concentrations of 363 mg/L for bicarbonate and 73 mg/L for sodium recorded for the period 2005-2006 (Table 1). The average total nitrogen concentrations and total phosphorus concentrations have also decreased when compared to the historical data. The historical average total nitrogen and total phosphorus concentrations were 2.600 mg/L and 0.043 mg/L (Table 2) respectively, compared to average concentrations of 1.810 mg/L for total nitrogen and 0.039 mg/L for total phosphorus.

Table 2. Statistical Summary of Lake George's Historical Water Quality Data Collected Between 1992 and 1996.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	486	422	589	90
Total Ammonia as N	mg/L	3	0.564	0.010[1]	1.620	0.915
Bicarbonate (HCO_3)	mg/L	3	552	454	719	145
Calcium (Ca)	mg/L	3	27	22	36	7
Carbonate (CO_3)	mg/L	3	21	1[1]	31	17
Chloride (Cl)	mg/L	3	17.7	14.7	22.3	4.0
Chlorophyll-a	µg/L	2	3.0	3.0	3.0	0.0
Specific Conductance	µmhos	3	922	793	1140	190
Total Dissolved Solids	mg/L	3	509	431	633	109
Total Hardness as ($CaCO_3$)	mg/L	3	289	243	356	59
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	3	0.266	0.219	0.338	0.064
Magnesium (Mg)	mg/L	3	53.5	45.6	65.0	10.2
Nitrate + Nitrite as N	mg/L	3	0.043	0.005[1]	0.120	0.066
Total Kjeldahl Nitrogen as N	mg/L	3	2.557	1.530	4.080	1.346
Total Nitrogen as N	mg/L	3	2.600	1.535	4.200	1.411
pH		3	8.45	8.00	8.71	0.39
Total Phosphorus as P	mg/L	3	0.043	0.018	0.073	0.028
Potassium (K)	mg/L	3	11.1	9.1	14.0	2.6
Sodium (Na)	mg/L	3	89	74	112	20
Sulfate (SO4)	mg/L	3	16	11	27	9

[1]Equal to lower detection limit

When compared to the Cultivated Plains regional water quality Lake George is fresher, higher in phosphorus but lower in nitrogen than most natural and enhanced lakes (Table 3). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1376 mg/L, 1.440 mg/L, and 0.068 mg/L, respectively (Table 3), compared to Lake George's average TDS, total nitrogen, and total phosphorus concentrations of 400 mg/L, 1.810 mg/L and 0.039 mg/L, respectively (Table 1).

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Lake George and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight, in algae is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There are seven water quality sample results for Lake George between July 1995 and January 2006, where the N:P ratio could be calculated. The results from this analysis indicate that Lake George is phosphorus limited (Figure 5).

N:P ratios for Lake George ranged from a low of 21 to a high of 317 with an average of 89. All seven of the samples collected were above a ratio of 15 indicating phosphorus limitation.

Table 3. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lake's in the Cultivated Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	142	346	175	1120	180
Total Ammonia as N	mg/L	230	0.098	0.001[1]	1.620	0.208
Bicarbonate (HCO_3)	mg/L	142	363	171	1040	158
Calcium (Ca)	mg/L	142	45	16	108	23
Carbonate (CO_3)	mg/L	136	31	1[1]	181	39
Chloride (Cl)	mg/L	142	105	3[1]	1260	233
Chlorophyll-a	µg/L	185	10	2[1]	167	17
Specific Conductance	µmhos	161	1819	361	11500	2071
Total Dissolved Solids	mg/L	143	1376	191	9880	1786
Total Hardness as ($CaCO_3$)	mg/L	142	507	173	1820	284
Hydroxide (OH)	mg/L	111	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	138	0.095[1]	0.007	1.010	0.123
Magnesium (Mg)	mg/L	142	95.7	28.4	413.0	68.0
Nitrate + Nitrite as N	mg/L	175	0.047	0.001	0.540	0.078
Total Kjeldahl Nitrogen as N	mg/L	128	1.504	0.080	4.110	0.609
Total Nitrogen as N	mg/L	103	1.440	0.609	2.740	0.466
pH		142	8.55	7.75	9.33	0.36
Total Phosphorus as P	mg/L	230	0.068	0.004[1]	1.460	0.118
Potassium (K)	mg/L	142	30	8	179	37
Sodium (Na)	mg/L	142	255	5	2570	498
Sulfate (SO4)	mg/L	142	591	7	3880	807

[1]Equal to lower detection limit
[2]Data Collected from 49 Natural Lakes between 1991 and 2007

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005-2006, Lake George's current trophic status is eutrophic. TSI scores ranged from a low of 48 based on total phosphorus, to a high of 73 based on Secchi disk transparency. The trophic status score based on chlorophyll-a was similar to that based on Secchi disk transparency, at 63 (Figure 6).

A total of seven total phosphorus samples, five chlorophyll-a samples, and five Secchi disk transparency measurements collected during the open water periods from 1995-2005 were used to evaluate trends in the trophic status of Lake George. Based on a visual assessment of the data, Lake George's trophic status appears to be degrading (Figure 6).

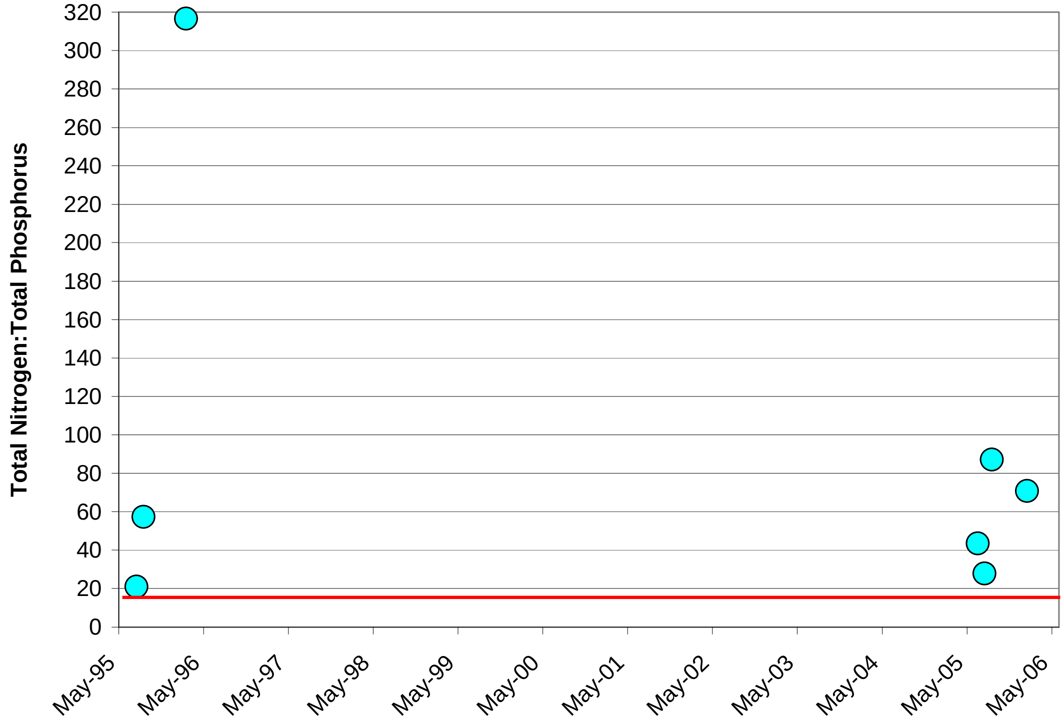


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Lake George (1995-2006).

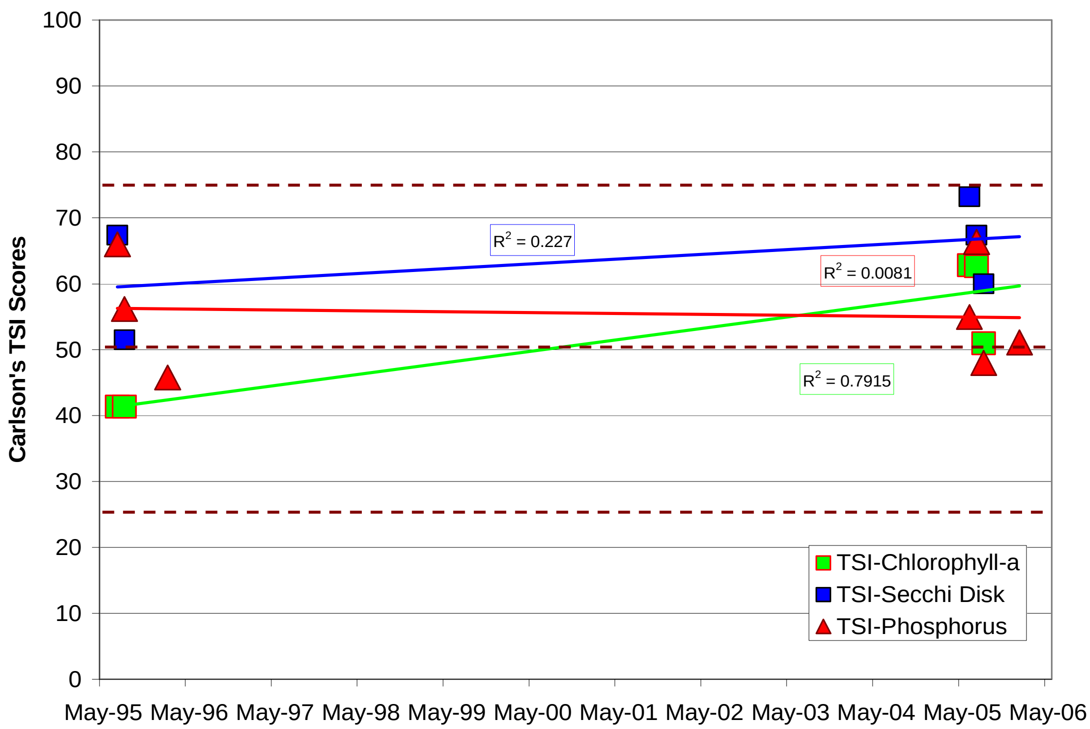


Figure 6. TSI Scores and Temporal Trends for Lake George from 1995 to 2006.

Blumhardt Dam, McIntosh County

BACKGROUND

Location: Blumhardt Dam is a small recreational impoundment located 7 miles north and 11½ miles east of Ashley, North Dakota (Figure 1). Blumhardt Dam is managed by the North Dakota Game and Fish Department.

Figure 1. Location of Blumhardt Dam.

Physiographic/Ecological Setting: Blumhardt Dam has a surface area of 16.5 acres, a maximum depth of 24.5 ft, and an average depth of 17.3 ft (Figure 2). Blumhardt Dam's watershed lies within the Northwestern Glaciated Plains (NGP) Level III Ecoregion, part of the broader Rangeland Plains region. The NGP marks the western most extent of continental glacial advancement. The geological youthful landscape has significant surface irregularities and high concentrations of wetlands. The rise in elevation along the eastern edge of this ecoregion defines the boundary of the Great Plains and to the west the Northwestern Great Plains (USEPA 1994).

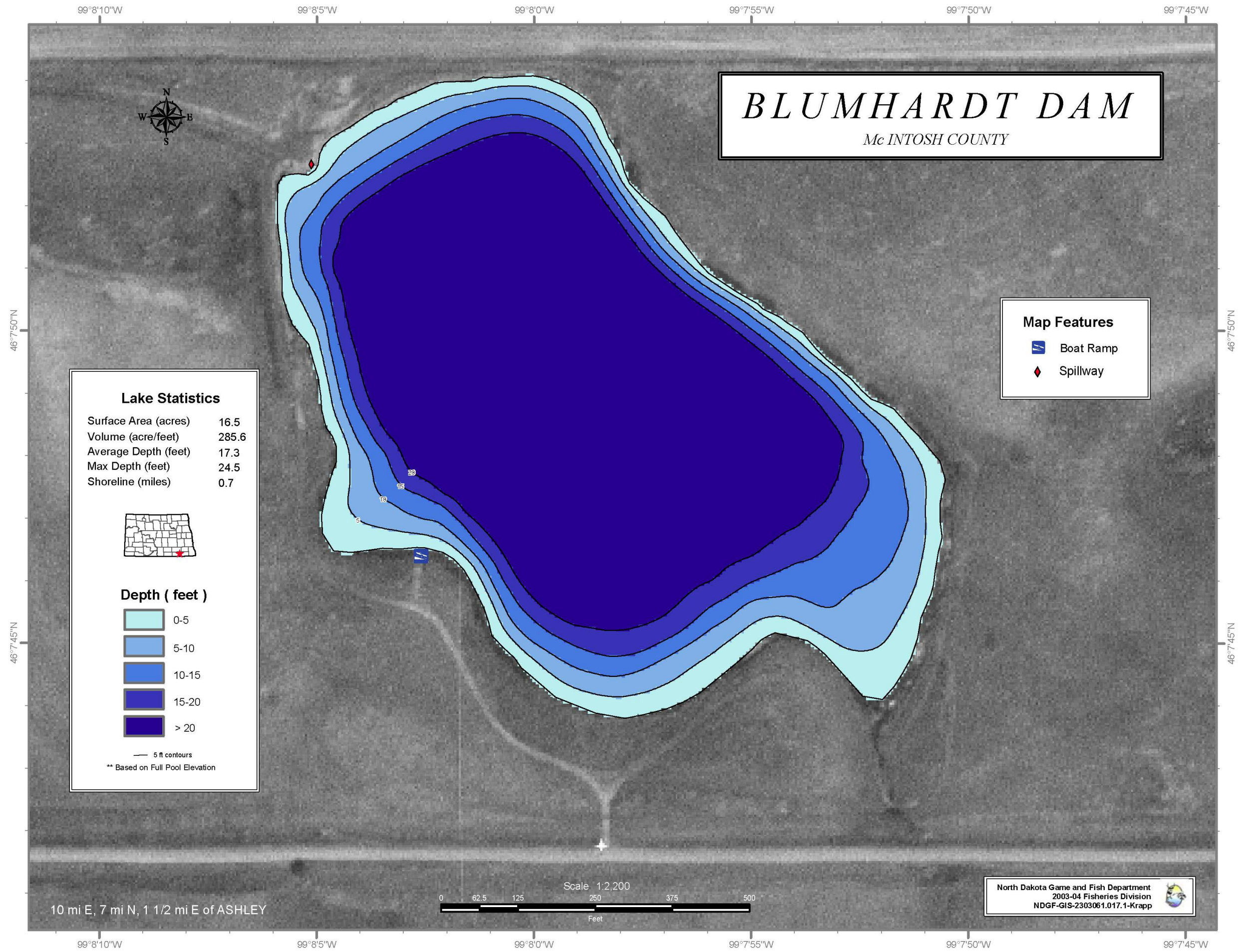


Figure 2. Contour Map of Blumhardt Dam (Map Courtesy of North Dakota Game and Fish Department).

Recreational Facilities: Recreational facilities at Blumhardt Dam include a boat ramp and boat and vehicle parking. Public access is on the southwest side of the lake from a good farm to market road.

Water Quality Standards Classification: Blumhardt Dam is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 2 lake or reservoir. Class 2 lakes or reservoirs are defined as a "cool water fishery" or "waters capable of supporting natural reproduction and growth of cool water fishes (e.g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: Blumhardt Dam's historical fishery included rainbow trout, brown trout, Chinook salmon, and largemouth bass stocked by the NDG&F. Currently rainbow trout and brown trout are managed in Blumhardt Dam.

Historical Water Quality Sampling: There is no historical water quality data available for Blumhardt Dam.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Blumhardt Dam have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There were 10 temperature and dissolved oxygen profiles for Blumhardt Dam collected from 2005-2007 (Figures 3 and 4). The profile data shows that during thermal stratification and during ice cover Blumhardt Dam experiences some deficiencies in dissolved oxygen, and occasionally drops below the state's water quality standard of 5 mg/L. Of the 10 profiles, five samples, collected on 8/2/2005, 1/25/2006, 7/19/2006, 2/21/2007, and 8/1/2007, dropped below the state standard of 5 mg/L. While the dissolved oxygen decay during these periods is concerning, there does appear to be enough dissolved oxygen to maintain aquatic life in the upper 2 to 3 meters of the water column in the worst of times.

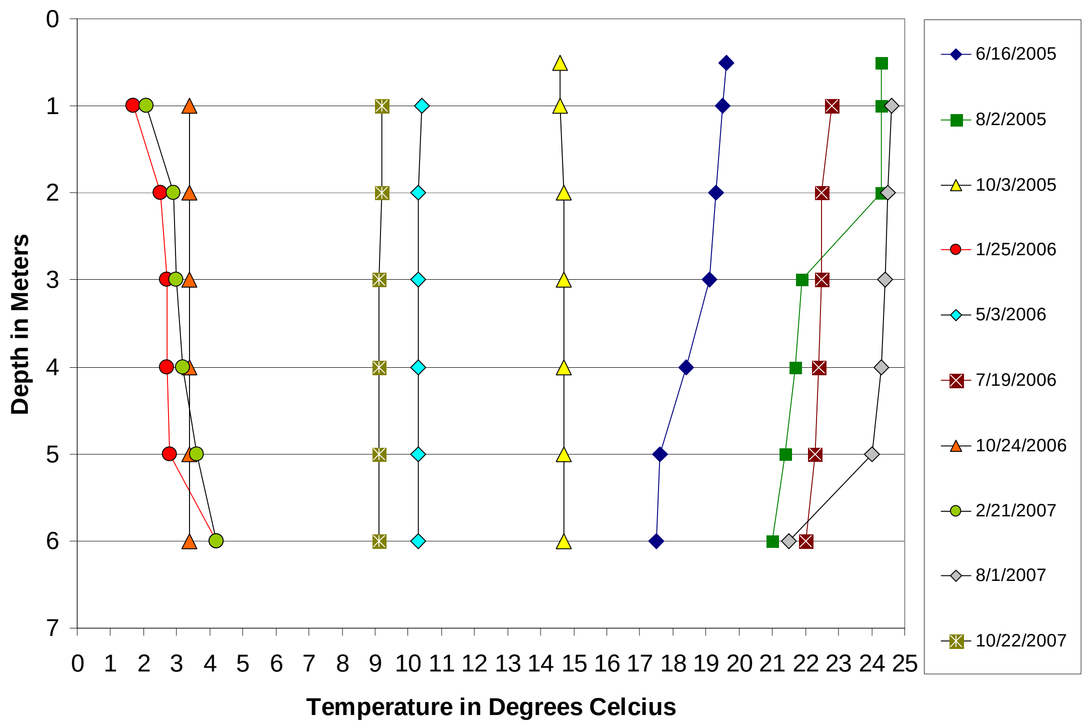


Figure 3. Temperature Profiles for Blumhardt Dam from 2005 to 2007.

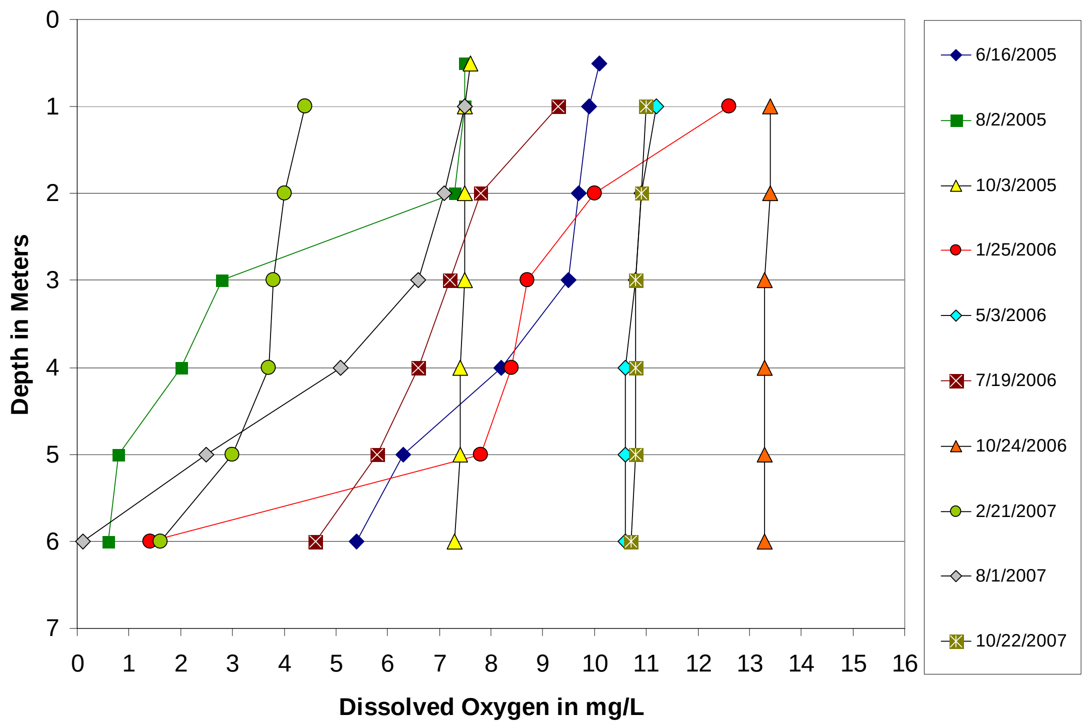


Figure 4. Dissolved Oxygen Profiles for Blumhardt Dam from 2005 to 2007.

General Water Quality: Water quality data collected by the NDG&F in 2005-2007 indicate Blumhardt Dam is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 190 mg/L to 254 mg/L (Table 1). Based on the 2005-2007 water quality data, Blumhardt Dam is sodium sulfate dominated with an average sodium concentration of 34 mg/L and an average sulfate concentration of 280 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2007 sampling period were 597 mg/L and 930 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.558 mg/L and 0.089 mg/L, respectively.

When compared to the Rangeland Plains regional water quality (Table 2), Blumhardt Dam on average is lower in dissolved solids and total phosphorus but slightly higher in nitrogen. For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1176 mg/L, 1.472 mg/L, and 0.135 mg/L, respectively, compared to Blumhardt Dam's average TDS, total nitrogen, and total phosphorus concentrations of 597 mg/L, 1.558 mg/L and 0.089 mg/L, respectively, for the period 2005-2007.

Table 1. Statistical Summary of Blumhardt Dam's 2005-2007 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	9	217	190	254	21
Total Ammonia as N	mg/L	9	0.042	0.010[1]	0.175	0.053
Bicarbonate (HCO_3)	mg/L	9	227	154	310	49
Calcium (Ca)	mg/L	9	46.3	35.4	56.7	8.0
Carbonate (CO_3)	mg/L	9	19	1[1]	38	16
Chloride (Cl)	mg/L	9	15	14	18	1
Chlorophyll-a	µg/L	9	32.6	1.5[1]	81.2	25.1
Specific Conductance	µmhos	9	930	827	1060	72
Total Dissolved Solids	mg/L	9	597	529	682	49
Total Hardness as ($CaCO_3$)	mg/L	9	429	368	505	44
Hydroxide (OH)	mg/L	9	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	9	0.173	0.010	0.885	0.277
Magnesium (Mg)	mg/L	9	76.2	65.4	88.3	7.6
Nitrate + Nitrite as N	mg/L	9	0.064	0.020	0.330	0.100
Total Kjeldahl Nitrogen as N	mg/L	9	1.493	0.950	1.940	0.321
Total Nitrogen as N	mg/L	9	1.558	1.170	1.960	0.272
pH		9	8.59	7.95	9.08	0.37
Total Phosphorus as P	mg/L	9	0.089	0.051	0.117	0.024
Potassium (K)	mg/L	9	13.6	8.8	16.0	2.3
Sodium (Na)	mg/L	9	34	29	37	3
Sulfate (SO4)	mg/L	9	280	252	318	23

[1]Equal to lower detection limit

Limiting Nutrient: The limiting nutrient is assessed based on the assumption that either nitrogen or phosphorus is limiting algal growth in Blumhardt Dam, and that the ratio of total nitrogen as N, to total phosphorus as P (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were nine water quality sample results for Blumhardt Dam collected between June 2005 and August 2007 where the N:P ratio could be calculated. The results from this analysis indicate that Blumhardt Dam is most often phosphorus limited (Figure 5).

The nitrogen to phosphorus ratio for Blumhardt Dam ranged from a low of 13 to a high of 28 with an average of 19. Of the nine samples collected, all but two samples were above a ratio of 15, indicating phosphorus is limiting primary production in Blumhardt Dam.

Table 2. Statistical Summary of Water Quality Data[2] Collected from Reservoir's in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	408	309	101	982	130
Total Ammonia as N	mg/L	469	0.097	0.001[1]	2.440	0.200
Bicarbonate (HCO_3)	mg/L	408	318	14	1040	150
Calcium (Ca)	mg/L	408	50	5	160	26
Carbonate (CO_3)	mg/L	402	30	1[1]	197	30
Chloride (Cl)	mg/L	408	13.3	0.3	74.5	8.8
Chlorophyll-a	µg/L	321	21.2	1.5	218.0	27.9
Specific Conductance	µmhos	428	1733	262	5880	959
Total Dissolved Solids	mg/L	409	1176	147	5110	750
Total Hardness as ($CaCO_3$)	mg/L	408	397	45	1850	260
Hydroxide (OH)	mg/L	337	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	409	0.179	0.007	4.110	0.334
Magnesium (Mg)	mg/L	408	66.0	5.6	353.0	49.6
Nitrate + Nitrite as N	mg/L	395	0.048	0.001[1]	0.790	0.092
Total Kjeldahl Nitrogen as N	mg/L	359	1.556	0.365	7.720	0.779
Total Nitrogen as N	mg/L	302	1.472	0.405	4.840	0.562
pH		428	8.61	6.73	9.87	0.56
Total Phosphorus as P	mg/L	475	0.135	0.004	3.160	0.205
Potassium (K)	mg/L	408	14.6	4.2	39.2	6.3
Sodium (Na)	mg/L	408	239	3[1]	932	171
Sulfate (SO4)	mg/L	406	604	1[1]	3210	501

[1]Equal to Minimum Reporting Limit

2Data Collected from 69 Reservoirs between 1991 and 2007

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected between 2005 and 2007, Blumhardt Dam's current trophic status is eutrophic. TSI scores ranged from a low of 35 based on chlorophyll-a measurements, to a high of 77 based on Secchi disk transparency. The average trophic status score based on total phosphorus was similar to that of Secchi disk transparency, at 68 (Figure 6).

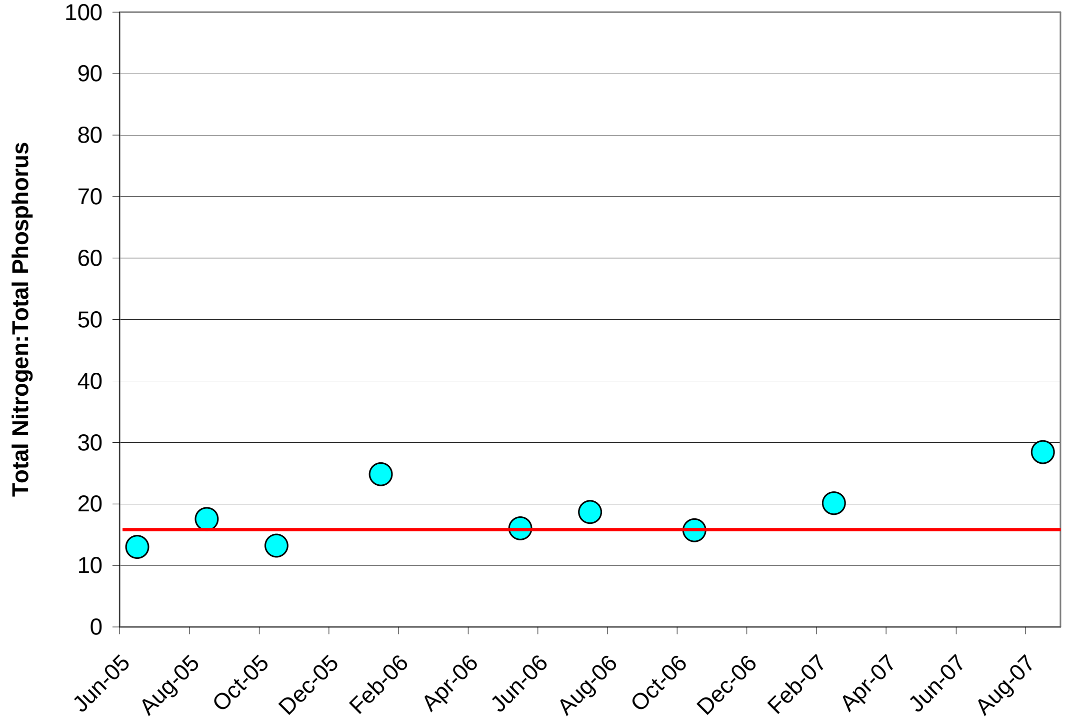


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Blumhardt Dam (2005-2007).

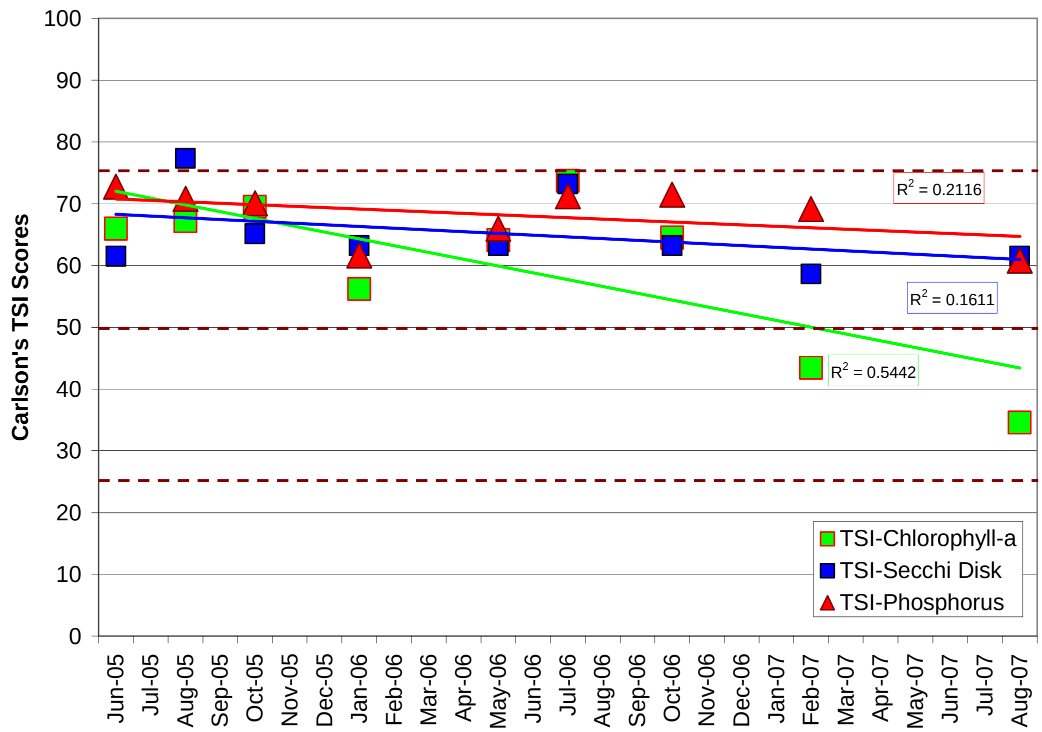


Figure 6. TSI Scores and Temporal Trends for Blumhardt Dam from 2005 to 2007.

Cold Water Lake, McIntosh County

BACKGROUND

Location: Cold Water Lake is a natural lake located 1 mile south and 15 miles east of Ashley, North Dakota (Figure 1). Cold Water Lake is managed by the North Dakota Game and Fish Department.

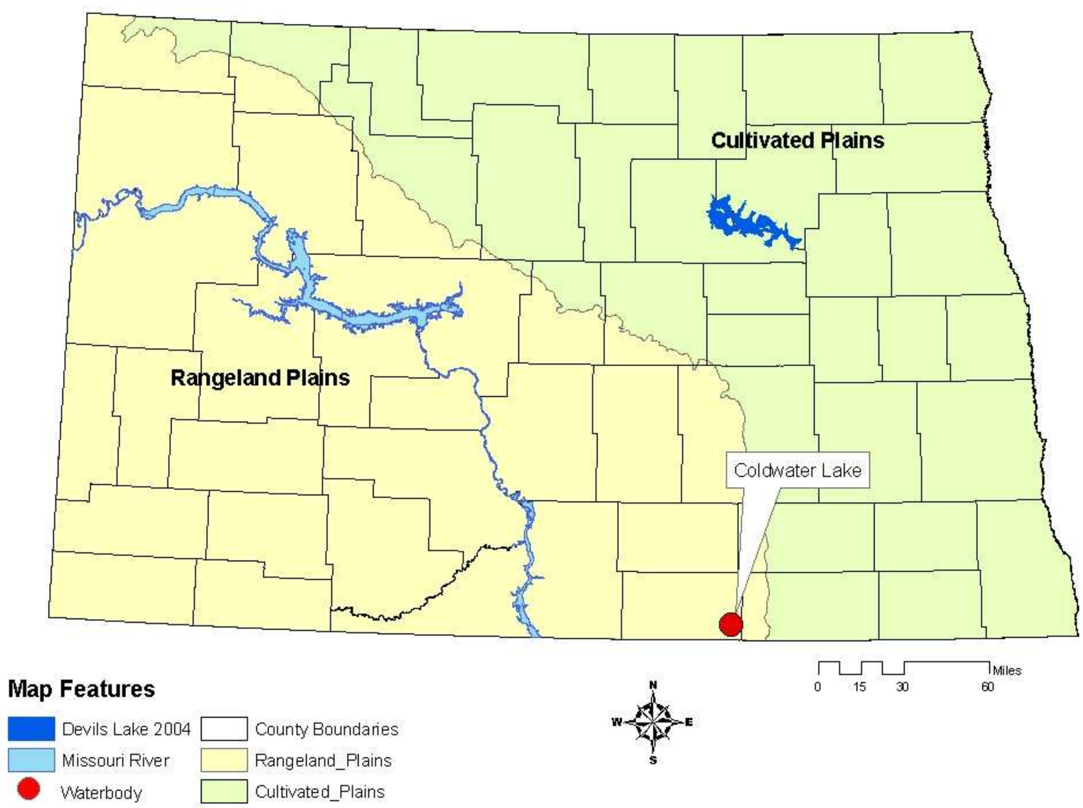


Figure 1. Location of Cold Water Lake.

Physiographic/Ecological Setting: Cold Water Lake has a surface area of 416 acres, a maximum depth of 26.4 ft, and an average depth of 7.6 ft (Figure 2). Cold Water Lake's watershed lies within the Northwestern Glaciated Plains (NGP) Level III Ecoregion, part of the broader Rangeland Plains region. The NGP marks the western most extent of continental glacial advancement. The geological youthful landscape has significant surface irregularities and high concentrations of wetlands. The rise in elevation along the eastern edge of this ecoregion defines the boundary of the Great Plains and to the west the Northwestern Great Plains (USEPA 1994).

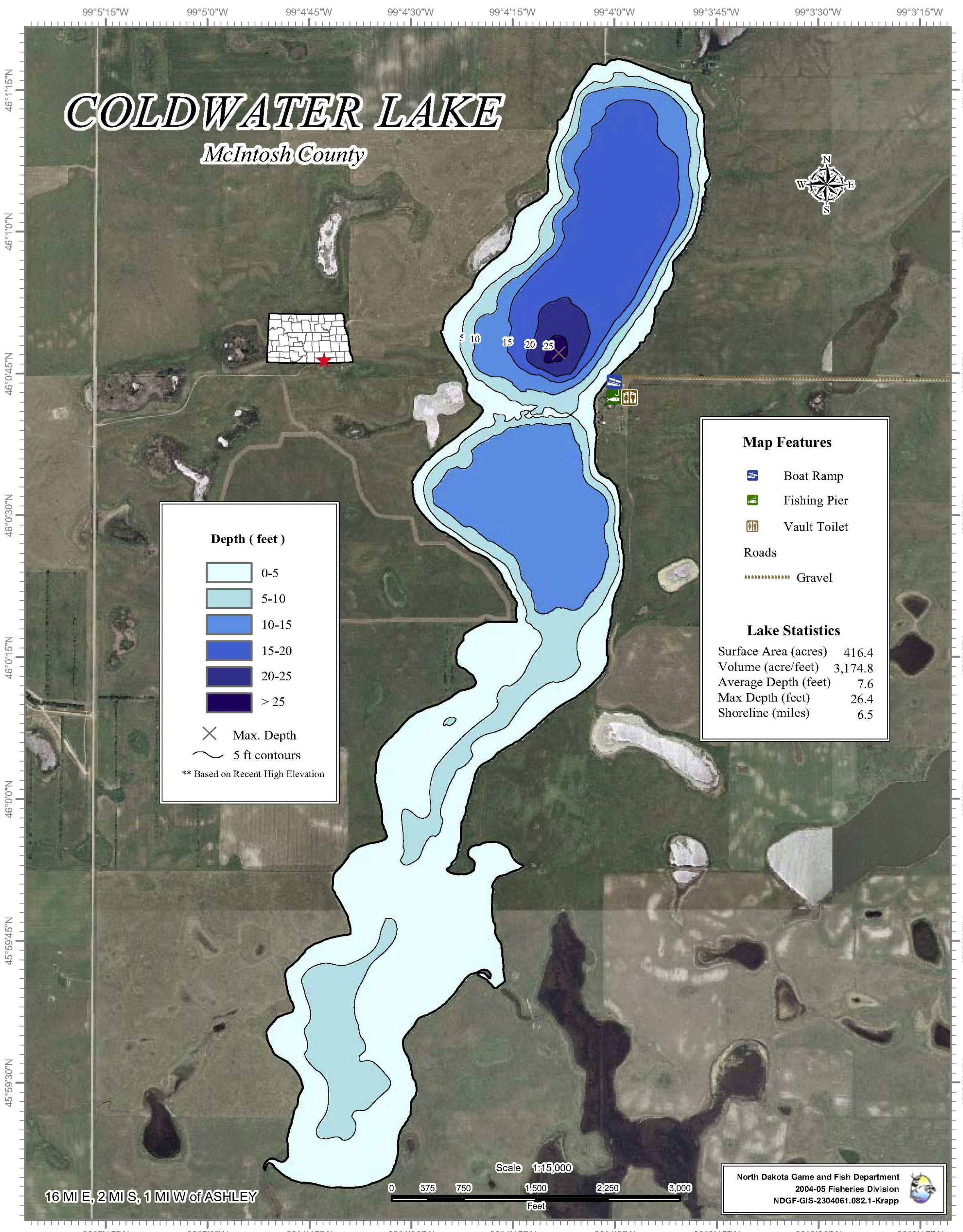


Figure 2. Contour Map of Cold Water Lake (Map Courtesy of North Dakota Game and Fish Department).

Recreational Facilities: Recreational facilities at Cold Water Lake include a boat ramp, a fishing pier, and boat and vehicle parking. Public access is on the east side of the lake, which includes parking, a vaulted toilet, the fishing pier, and the boat ramp. Dark house spear fishing is also available at Cold Water Lake.

Water Quality Standards Classification: Cold Water Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a "warm water fishery" or "waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present."

Historical and Current Fishery: Cold Water Lake's historical fishery included northern pike and walleye stocked by the NDG&F. Currently northern pike, yellow perch, and walleye are managed in Cold Water Lake.

Historical Water Quality Sampling: There is no historical water quality data available for Cold Water Lake.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Cold Water Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural or enhanced lakes in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There were four temperature and dissolved oxygen profiles for Cold Water Lake collected from 2005-2006 (Figures 3 and 4). The profile data shows that Cold Water Lake maintains adequate oxygen levels, and does not drop below the state's water quality standard of 5 mg/L. All four of the profiles collected on 6/16/2005, 8/2/2005, 10/3/2005, and 1/25/2006, stayed above the state standard of 5 mg/L. There appears to be enough dissolved oxygen to maintain aquatic life throughout all four seasons.

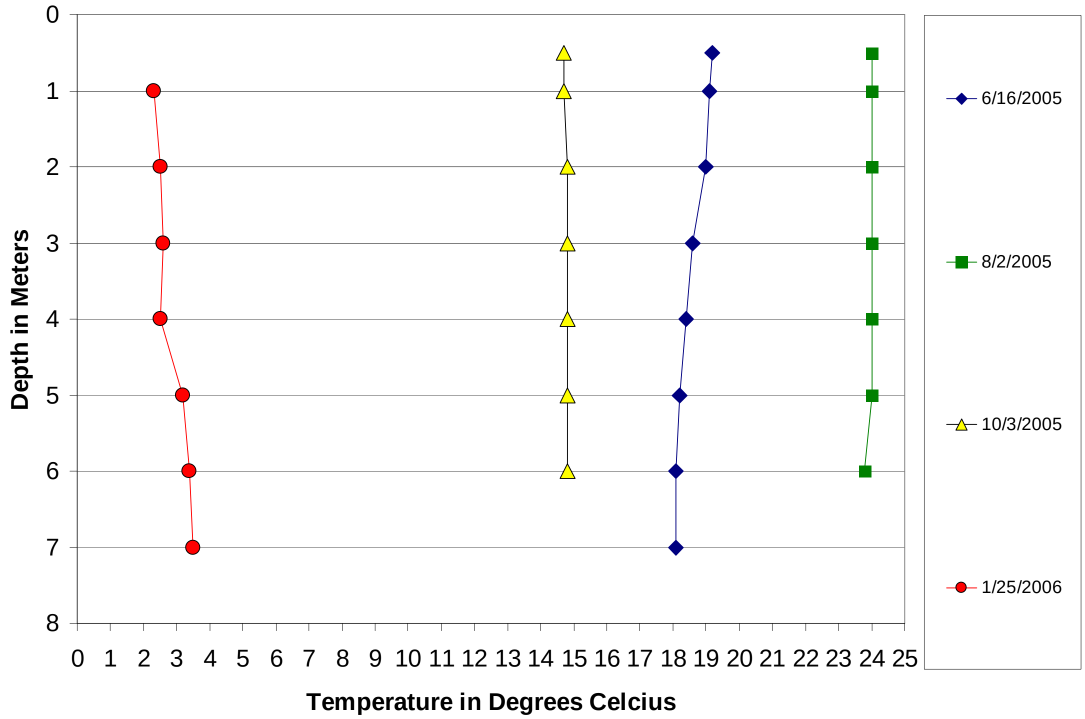


Figure 3. Temperature Profiles for Cold Water Lake from 2005 to 2006.

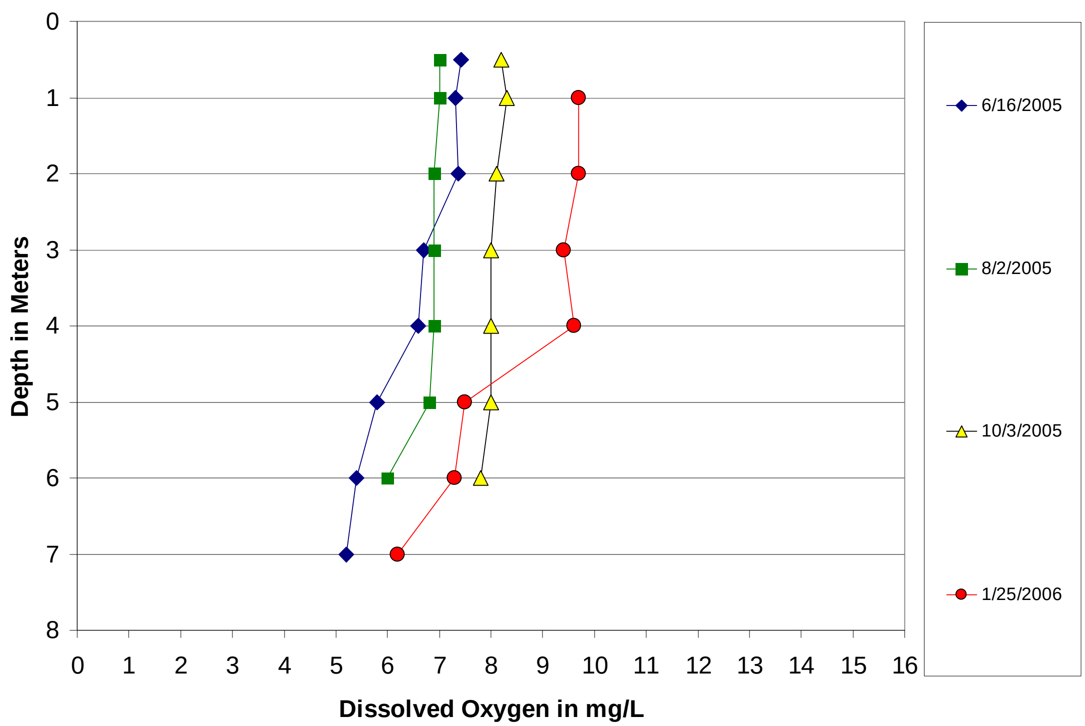


Figure 4. Dissolved Oxygen Profiles for Cold Water Lake from 2005 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006 indicate Cold Water Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 317 mg/L to 373 mg/L (Table 1). Based on the 2005-2006 water quality data (Table 1), Cold Water Lake is sodium sulfate dominated with an average sodium concentration of 125 mg/L and an average sulfate concentration of 906 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 1580 mg/L and 2130 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.858 mg/L and 0.029 mg/L, respectively.

When compared to the Rangeland Plains regional average concentrations (Table 2) Cold Water Lake is similar to that reported for most natural and enhanced lakes with the exception of phosphorus (Table 1). For example the regional average for TDS, total nitrogen, and total phosphorus concentrations are 1588 mg/L, 1.826 mg/L, and 0.244 mg/L, respectively, compared to Cold Water Lake's average TDS, total nitrogen, and total phosphorus concentrations of 1580 mg/L, 1.858 mg/L and 0.029 mg/L, respectively.

Table 1. Statistical Summary of Cold Water Lake's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	337	317	373	26
Total Ammonia as N	mg/L	4	0.027	0.010[1]	0.077	0.033
Bicarbonate (HCO_3)	mg/L	4	308	262	381	53
Calcium (Ca)	mg/L	4	37.7	29.9	44.8	7.1
Carbonate (CO_3)	mg/L	4	51	36	64	12
Chloride (Cl)	mg/L	4	42	38	47	4
Chlorophyll-a	µg/L	4	11.6	2.0[1]	20.1	8.2
Specific Conductance	µmhos	4	2130	2040	2330	135
Total Dissolved Solids	mg/L	4	1580	1510	1750	114
Total Hardness as ($CaCO_3$)	mg/L	4	984	902	1120	97
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.135	0.076	0.220	0.065
Magnesium (Mg)	mg/L	4	216.0	201.0	244.0	19.4
Nitrate + Nitrite as N	mg/L	4	0.030	0.020	0.060	0.020
Total Kjeldahl Nitrogen as N	mg/L	4	1.828	1.610	2.140	0.247
Total Nitrogen as N	mg/L	4	1.858	1.630	2.160	0.252
pH		4	8.80	8.57	9.00	0.19
Total Phosphorus as P	mg/L	4	0.029	0.024	0.036	0.006
Potassium (K)	mg/L	4	48.7	42.9	55.1	5.0
Sodium (Na)	mg/L	4	125	117	141	11
Sulfate (SO4)	mg/L	4	906	841	993	65

[1]Equal to lower detection limit

Table 2. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lake's in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	272	544	119	4770	130
Total Ammonia as N	mg/L	371	0.107	0.001[1]	2.230	0.200
Bicarbonate (HCO_3)	mg/L	272	489	145	2990	150
Calcium (Ca)	mg/L	272	44	1[1]	282	26
Carbonate (CO_3)	mg/L	262	89	1[1]	1420	30
Chloride (Cl)	mg/L	272	51	4[1]	1070	9
Chlorophyll-a	µg/L	250	22	2[1]	292	28
Specific Conductance	µmhos	272	2168	448	20100	959
Total Dissolved Solids	mg/L	272	1588	227	18200	750
Total Hardness as ($CaCO_3$)	mg/L	272	538	170	2370	260
Hydroxide (OH)	mg/L	200	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	273	0.193	0.001[1]	2.260	0.334
Magnesium (Mg)	mg/L	272	104	20	567	50
Nitrate + Nitrite as N	mg/L	332	0.036	0.002[1]	0.338	0.092
Total Kjeldahl Nitrogen as N	mg/L	340	1.950	0.080	8.500	0.779
Total Nitrogen as N	mg/L	278	1.826	0.269	5.520	0.562
pH		272	8.796	7.400	9.870	0.564
Total Phosphorus as P	mg/L	377	0.244	0.004[1]	1.940	0.205
Potassium (K)	mg/L	272	38	3[1]	356	6
Sodium (Na)	mg/L	272	331	17	4680	171
Sulfate (SO4)	mg/L	272	680	34	10500	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 48 Natural and Enhanced Lakes between 1991 and 2007

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Cold Water Lake, and that the ratio of total nitrogen as N, to total phosphorus as P (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were four water quality sample results for Cold Water Lake collected between June 2005 and January 2006 where the N:P ratio could be calculated. The results from this analysis indicate that Cold Water Lake is phosphorus limited (Figure 5). The nitrogen to phosphorus ratio for Cold Water Lake ranged from a low of 45 to a high of 86 with an average of 66. All of the samples collected were above a ratio of 15, indicating phosphorus is limiting primary production in Cold Water Lake.

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected between 2005 and 2006, Cold Water Lake's current trophic status is eutrophic. TSI scores ranged from a low of 37 based on chlorophyll-a measurements, to a high of 65 based on Secchi disk transparency. The average trophic status score based on total phosphorus was similar to that of Secchi disk transparency, at 53 (Figure 6).

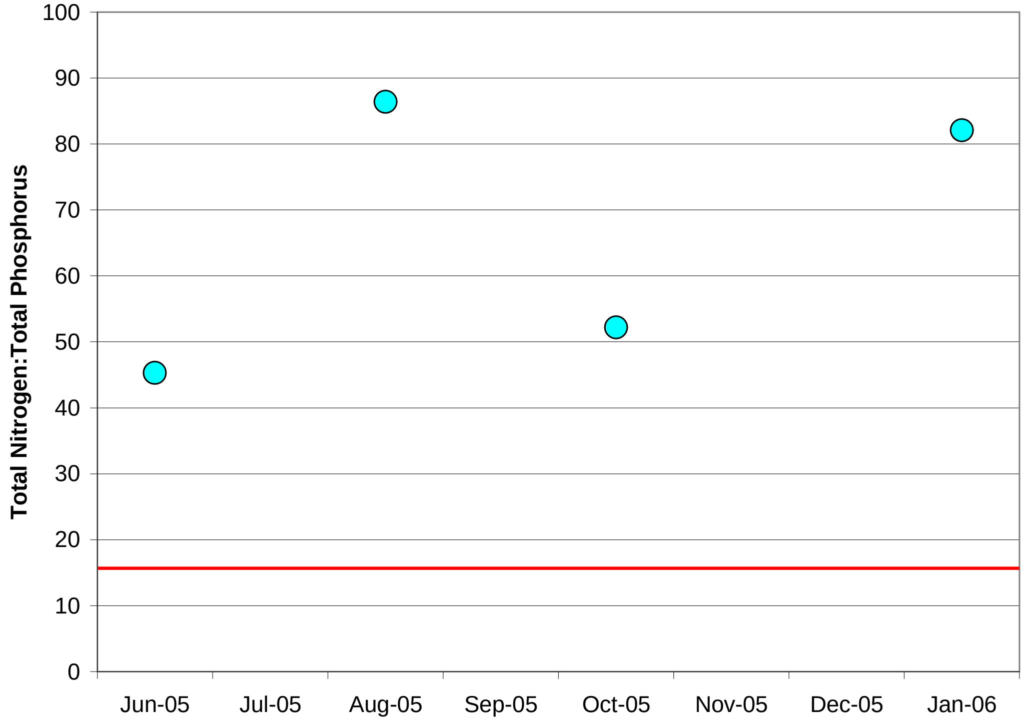


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Cold Water Lake (2005-2006).

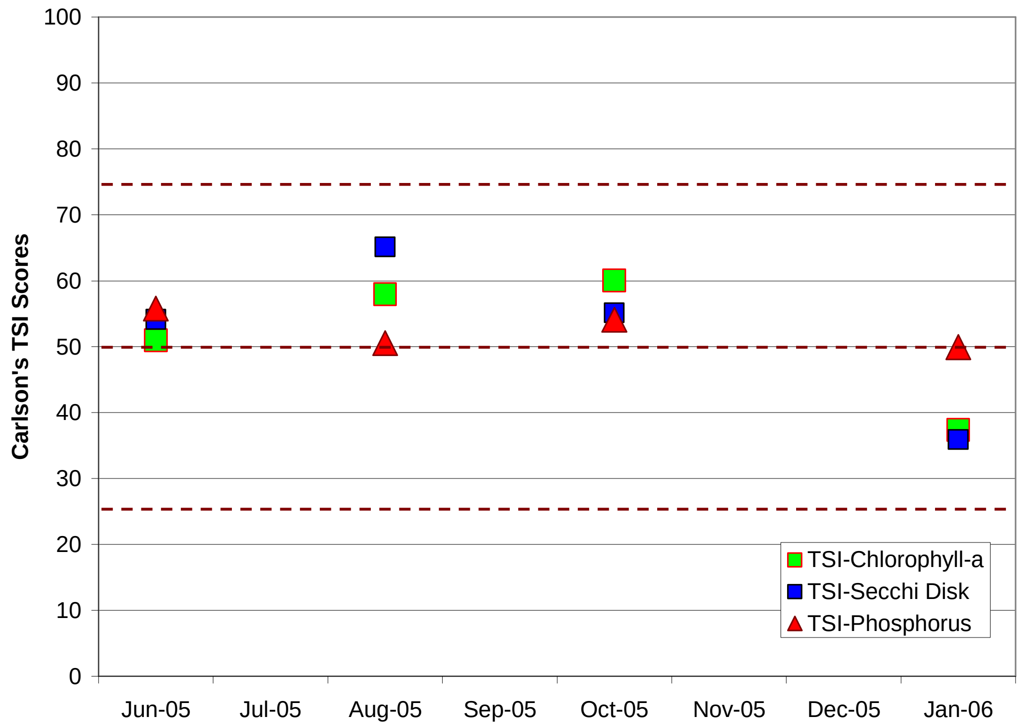


Figure 6. TSI Scores for Cold Water Lake from 2005 to 2006.

Dry Lake, McIntosh County

BACKGROUND

Location: Dry Lake is a natural lake located 3 miles west and 3½ miles north of Ashley, North Dakota (Figure 1). Dry Lake is managed by the North Dakota Game and Fish Department.

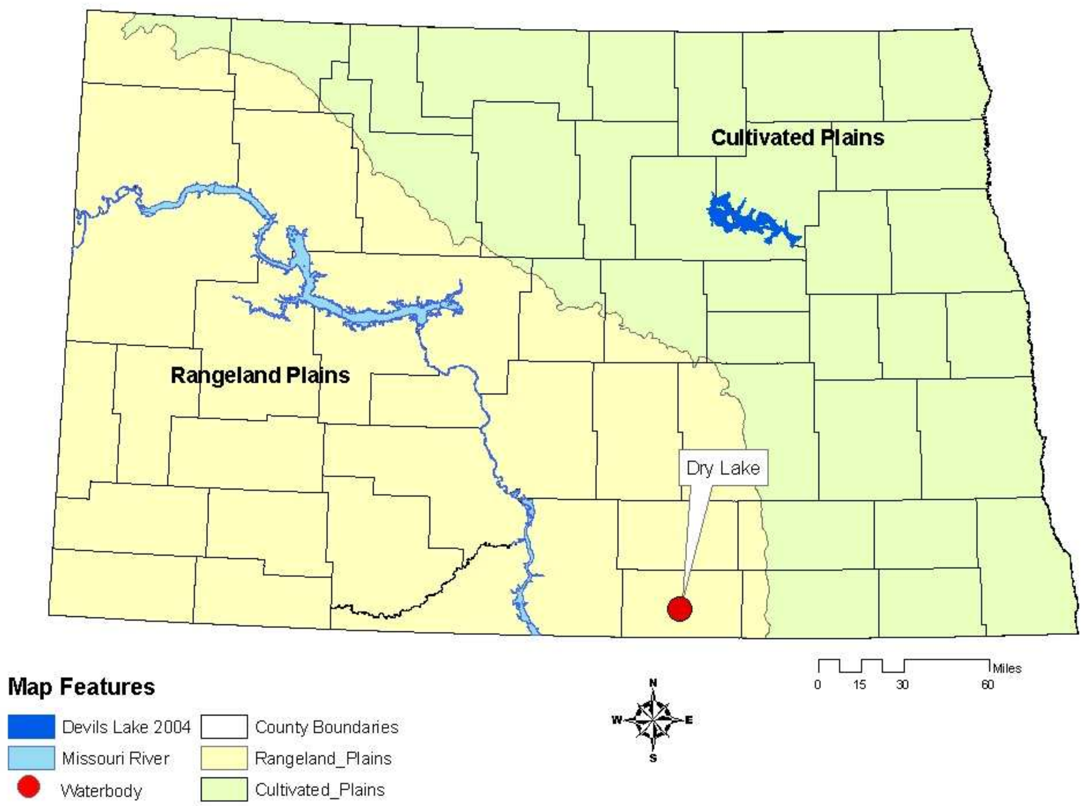


Figure 1. Location of Dry Lake.

Physiographic/Ecological Setting: Dry Lake has a surface area of 3,783 acres, a maximum depth of 19.8 ft, and an average depth of 12.5 ft (Figure 2). Dry Lake's watershed lies within the Northwestern Glaciated Plains (NGP) Level III Ecoregion, part of the broader Rangeland Plains region. The NGP marks the western most extent of continental glacial advancement. The geological youthful landscape has significant surface irregularities and high concentrations of wetlands. The rise in elevation along the eastern edge of this ecoregion defines the boundary of the Great Plains and to the west the Northwestern Great Plains (USEPA 1994).

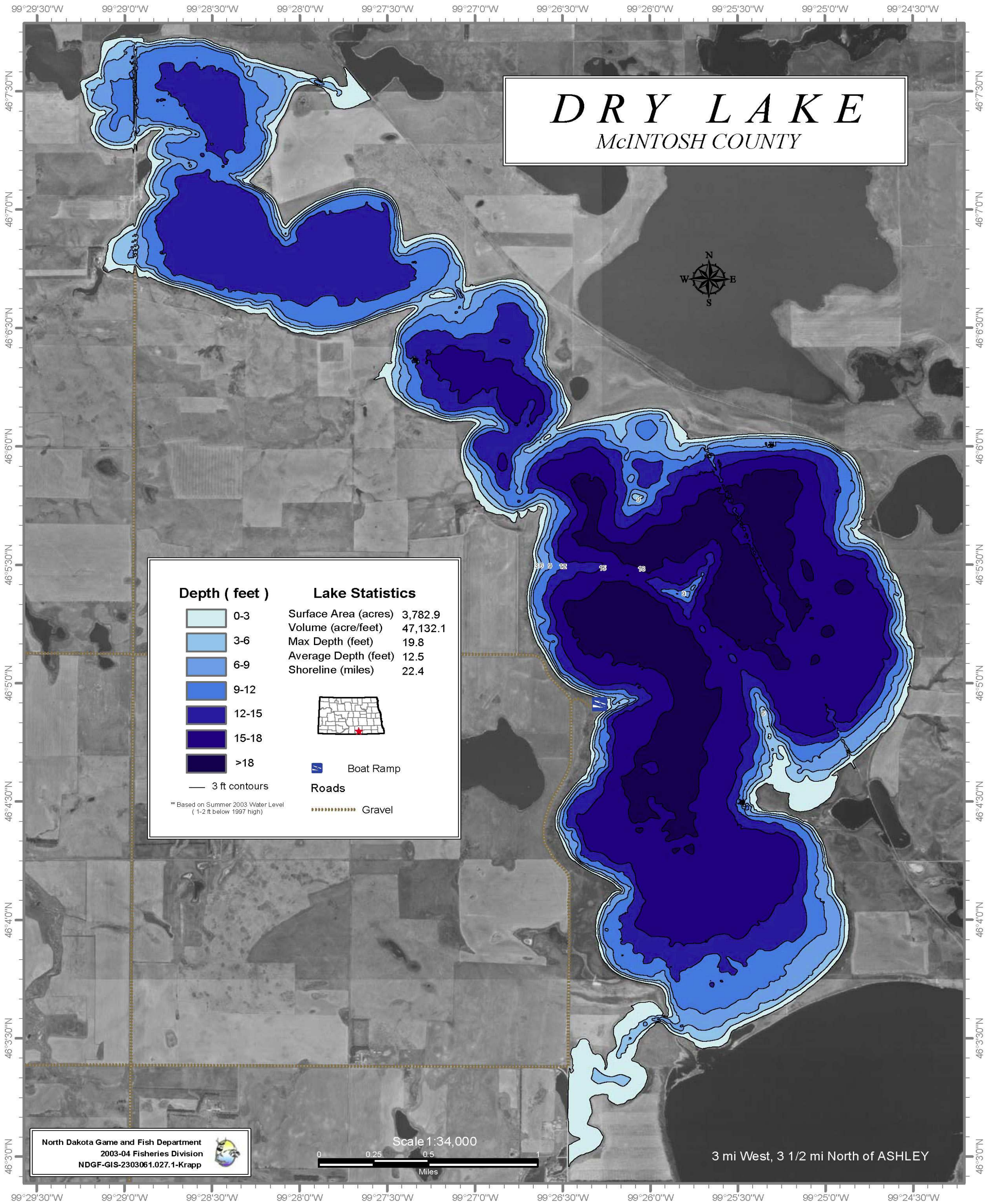


Figure 2. Contour Map of Dry Lake (Map Courtesy of North Dakota Game and Fish Department).

Recreational Facilities: Recreational facilities at Dry Lake include a boat ramp, and boat and vehicle parking. Public access is on the west side of the lake, which includes parking, and the boat ramp.

Water Quality Standards Classification: Dry Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 2 lake or reservoir. Class 2 lakes or reservoirs are defined as a "cool water fishery" or "waters capable of supporting natural reproduction and growth of cool water fishes (e.g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: Dry Lake was a shallow wetland up until the mid-1990s when above average precipitation filled the wetland to its current depth. The North Dakota Game and Fish Department has since stocked Dry Lake with northern pike, walleye, and yellow perch.

Historical Water Quality Sampling: There is no historical water quality data available for Dry Lake.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Dry Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural or enhanced lakes in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There were four temperature and dissolved oxygen profiles for Dry Lake collected in 2005 and 2006 (Figures 3 and 4). The profile data shows that during thermal stratification Dry Lake experiences gradual oxygen decay and occasionally drops below the state's water quality standard of 5 mg/L.

Of the four profiles, two samples, collected on 8/1/2005, and 2/9/2006, dropped below the state standard of 5 mg/L. While the loss of dissolved oxygen during these periods is concerning, there does appear to be enough dissolved oxygen to maintain aquatic life in the upper 4 meters of the water column.

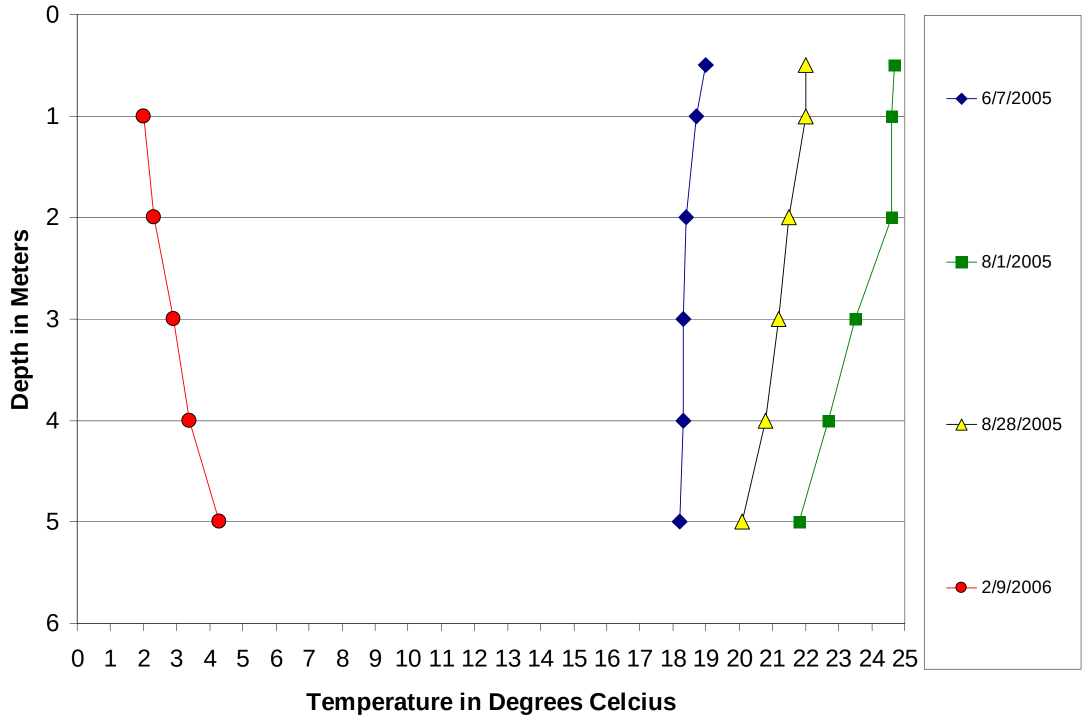


Figure 3. Temperature Profiles for Dry Lake from 2005 to 2006.

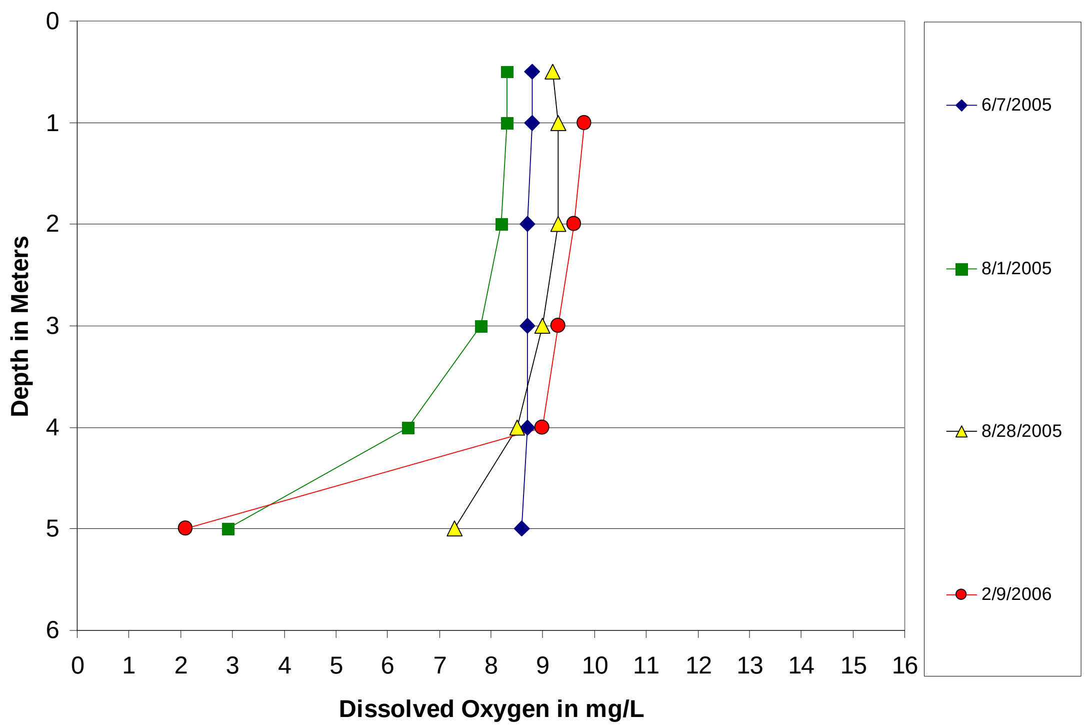


Figure 4. Dissolved Oxygen Profiles for Dry Lake from 2005 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006 indicate Dry Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 528 mg/L to 629 mg/L (Table 1). Based on the 2005-2006 water quality data (Table 1), Dry Lake is sodium bicarbonate dominated with an average sodium concentration of 345 mg/L and an average bicarbonate concentration of 547 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 1423 mg/L and 2128 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.990 mg/L and 0.792 mg/L, respectively.

When compared to the Rangeland Plains regional average (Table 2), Dry Lake is fairly representative of a natural or enhanced lake, with the exception of (Table 1). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1588 mg/L, 1.826 mg/L, and 0.244 mg/L, respectively, compared to Dry Lake's average TDS, total nitrogen, and total phosphorus concentrations of 1423 mg/L, 1.990 mg/L and 0.792 mg/L, respectively.

Table 1. Statistical Summary of Dry Lake's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	564	528	629	45
Total Ammonia as N	mg/L	4	0.027	0.010[1]	0.056	0.022
Bicarbonate (HCO_3)	mg/L	4	547	496	644	66
Calcium (Ca)	mg/L	4	47.0	43.1	56.1	6.1
Carbonate (CO_3)	mg/L	4	69	57	83	12
Chloride (Cl)	mg/L	4	73	68	86	8
Chlorophyll-a	µg/L	4	6.0	2.0[1]	10.4	3.4
Specific Conductance	µmhos	4	2128	2020	2420	195
Total Dissolved Solids	mg/L	4	1423	1310	1660	161
Total Hardness as ($CaCO_3$)	mg/L	4	415	376	498	56
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.479	0.112	0.717	0.258
Magnesium (Mg)	mg/L	4	72.2	65.3	86.9	9.9
Nitrate + Nitrite as N	mg/L	4	0.038	0.020	0.080	0.029
Total Kjeldahl Nitrogen as N	mg/L	4	1.953	1.530	2.240	0.302
Total Nitrogen as N	mg/L	4	1.990	1.550	2.270	0.313
pH		4	8.86	8.79	8.92	0.06
Total Phosphorus as P	mg/L	4	0.792	0.732	0.859	0.054
Potassium (K)	mg/L	4	54.6	47.9	66.6	8.3
Sodium (Na)	mg/L	4	345	309	415	50
Sulfate (SO4)	mg/L	4	489	456	566	52

[1]Equal to lower detection limit

Table 2. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lakes in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	272	544	119	4770	130
Total Ammonia as N	mg/L	371	0.107	0.001[1]	2.230	0.200
Bicarbonate (HCO_3)	mg/L	272	489	145	2990	150
Calcium (Ca)	mg/L	272	44	1[1]	282	26
Carbonate (CO_3)	mg/L	262	89	1[1]	1420	30
Chloride (Cl)	mg/L	272	51	4[1]	1070	9
Chlorophyll-a	µg/L	250	22	2[1]	292	28
Specific Conductance	µmhos	272	2168	448	20100	959
Total Dissolved Solids	mg/L	272	1588	227	18200	750
Total Hardness as ($CaCO_3$)	mg/L	272	538	170	2370	260
Hydroxide (OH)	mg/L	200	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	273	0.193	0.001[1]	2.260	0.334
Magnesium (Mg)	mg/L	272	104	20	567	50
Nitrate + Nitrite as N	mg/L	332	0.036	0.002[1]	0.338	0.092
Total Kjeldahl Nitrogen as N	mg/L	340	1.950	0.080	8.500	0.779
Total Nitrogen as N	mg/L	278	1.826	0.269	5.520	0.562
pH		272	8.796	7.400	9.870	0.564
Total Phosphorus as P	mg/L	377	0.244	0.004[1]	1.940	0.205
Potassium (K)	mg/L	272	38	3[1]	356	6
Sodium (Na)	mg/L	272	331	17	4680	171
Sulfate (SO4)	mg/L	272	680	34	10500	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 48 Natural and Enhanced Lakes between 1991 and 2007

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Dry Lake, and that the ratio of total nitrogen as N, to total phosphorus as P (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were four water quality sample results for Dry Lake collected between June 2005 and February 2006 where the N:P ratio could be calculated. The results from this analysis indicate that Dry Lake is most often nitrogen limited (Figure 5). The nitrogen to phosphorus ratio for Dry Lake ranged from a low of 2 to a high of 3 with an average of 2. All of the samples collected were below a ratio of 15, indicating nitrogen is limiting primary production in Dry Lake.

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected between 2005 and 2006, Dry Lake's current trophic status is eutrophic. TSI scores ranged from a low of 37 based on chlorophyll-a measurements in the middle of the winter to a high of 102 based on total phosphorus. The average trophic status score based on Secchi disk transparency was similar to that of chlorophyll-a, at 55 (Figure 6).

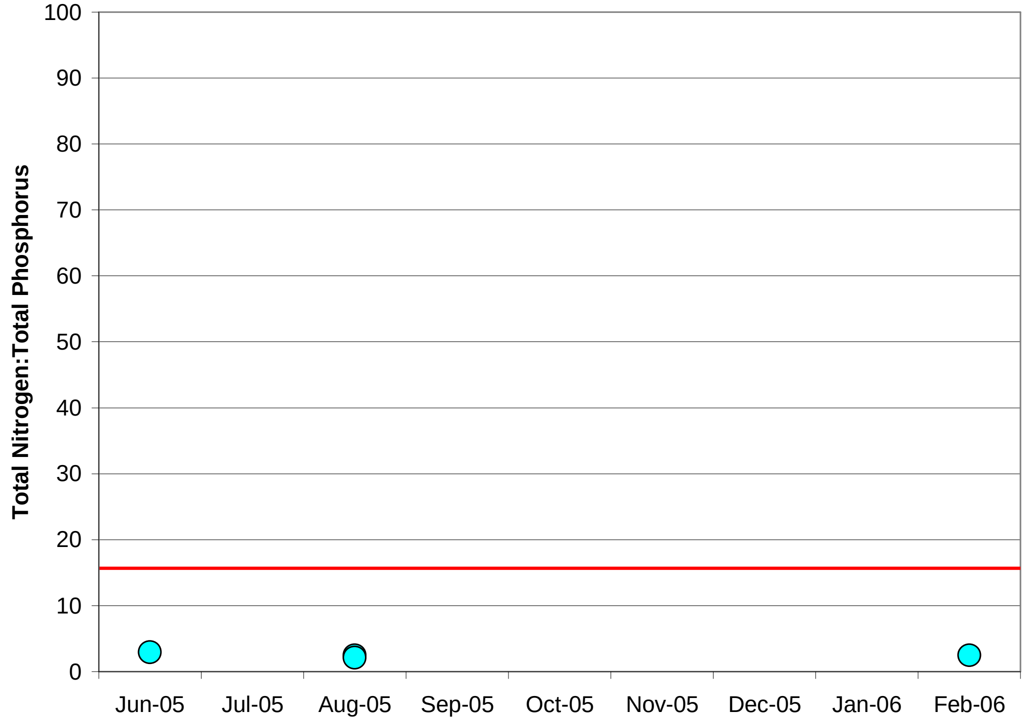


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Dry Lake (2005-2006).

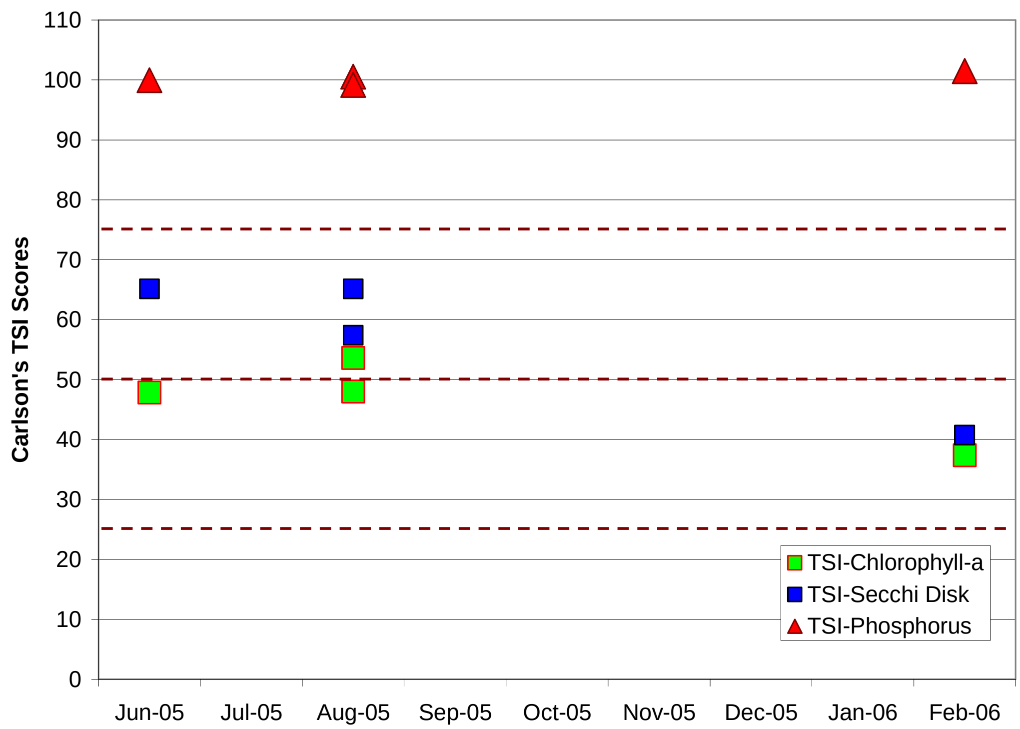


Figure 6. TSI Scores for Dry Lake from 2005 to 2006.

Green Lake, McIntosh County

BACKGROUND

Location: Green Lake is an enhanced, natural lake located 4 miles south and 3 miles east of Wishek, North Dakota (Figure 1). Green Lake is managed by the North Dakota Game and Fish Department.

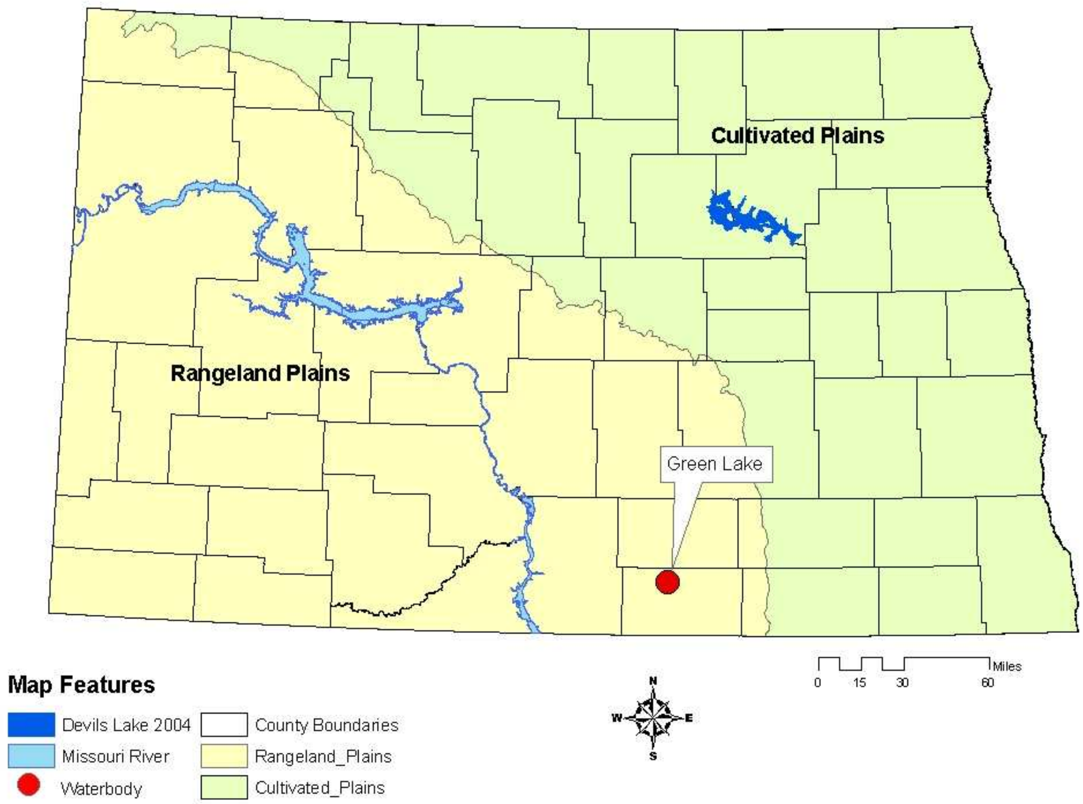


Figure 1. Location of Green Lake.

Physiographic/Ecological Setting: Green Lake has a surface area of 978 acres, a maximum depth of 11.5 ft, and an average depth of 7.2 ft (Figure 2). Green Lake's watershed is over 45,000 acres, and it lies within the Northwestern Glaciated Plains (NGP) Level III Ecoregion, part of the broader Rangeland Plains region. The NGP marks the western most extent of continental glacial advancement. The geological youthful landscape has significant surface irregularities and high concentrations of wetlands. The rise in elevation along the eastern edge of this ecoregion defines the boundary of the Great Plains and to the west the Northwestern Great Plains (USEPA 1994).

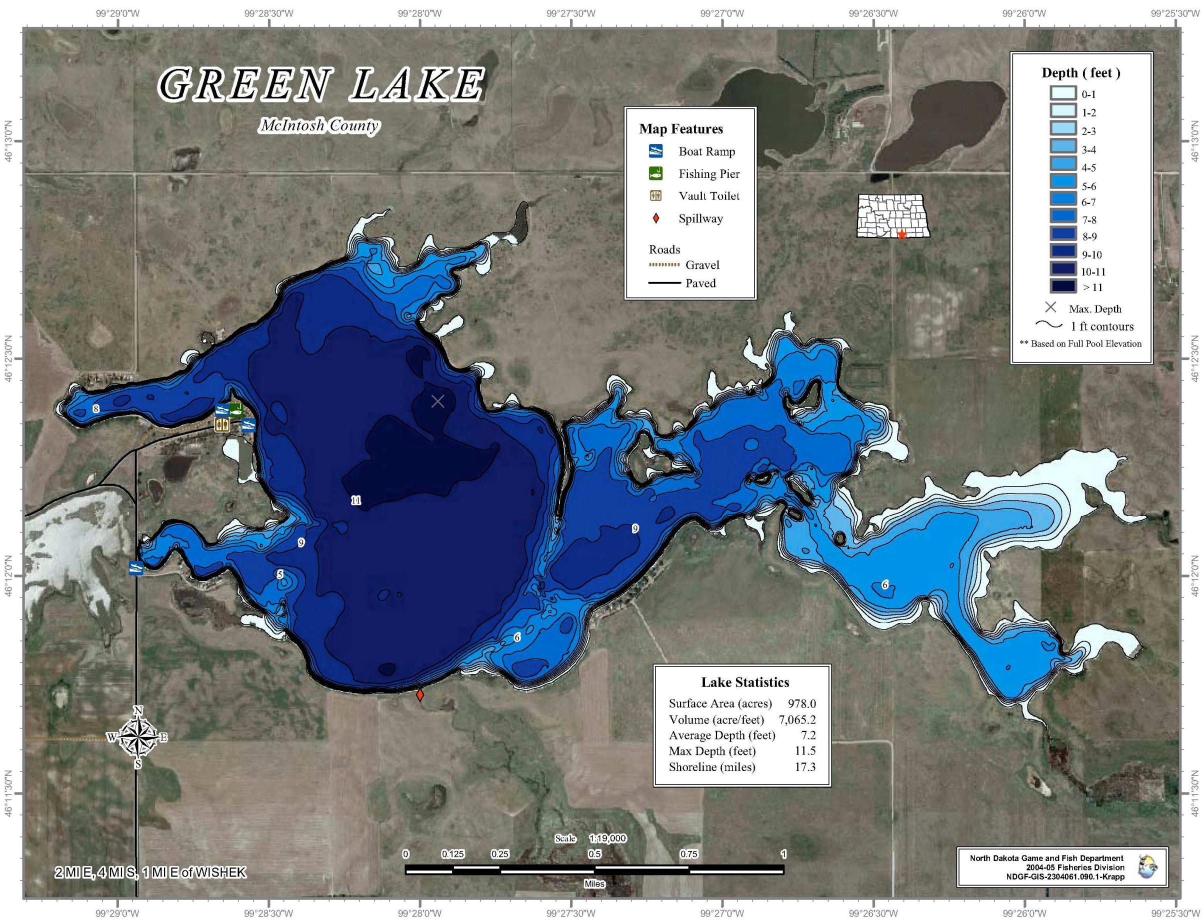


Figure 2. Contour Map of Green Lake (Map Courtesy of North Dakota Game and Fish Department).

Construction History: Green Lake is a natural lake enhanced with a small rolled earthen dam with a weir outlet control structure. The dam was eroded from wet years in the mid-1960s, so culverts were placed at the outlet. In 1973, a weir was placed at the outlet due to maintenance problems caused by the culverts.

Recreational Facilities: Recreational facilities at Green Lake include three boat ramps, a fishing pier, and boat and vehicle parking. Public access is on the west side of the lake, which includes parking, a vaulted toilet, a fishing pier, and all three boat ramps.

Water Quality Standards Classification: Green Lake is classified in the state “Standards of Quality for Waters of the State” (NDDoH, 2006) as a class 2 lake or reservoir. Class 2 lakes or reservoirs are defined as a “cool water fishery” or “waters capable of supporting natural reproduction and growth of cool water fishes (e.g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota.”

Historical and Current Fishery: Green Lake's historical fishery included northern pike, walleye, and yellow perch stocked by the NDG&F. Test netting has also produced white suckers, and black bullheads in Green Lake. Currently northern pike, yellow perch, and walleye are managed in Green Lake.

Historical Water Quality Sampling: Historical water quality data includes results from 11 samples collected from 1991 through 2002.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Green Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural or enhanced lakes in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There were nine temperature and dissolved oxygen profiles for Green Lake collected from 1991-2007. Temperature and oxygen profiles are presented for two time periods, 1991-1993, and 2006-2007(Figures 3 and 4).

The profile data shows that at times Green Lake experiences dissolved oxygen deficiencies, and occasionally drops below the state's water quality standard of 5 mg/L. Of the nine profiles, five samples, collected on 1/31/1991, 8/14/1991, 2/11/1992, 8/2/2006, and 2/14/2007, were below or dropped below the state standard of 5 mg/L.

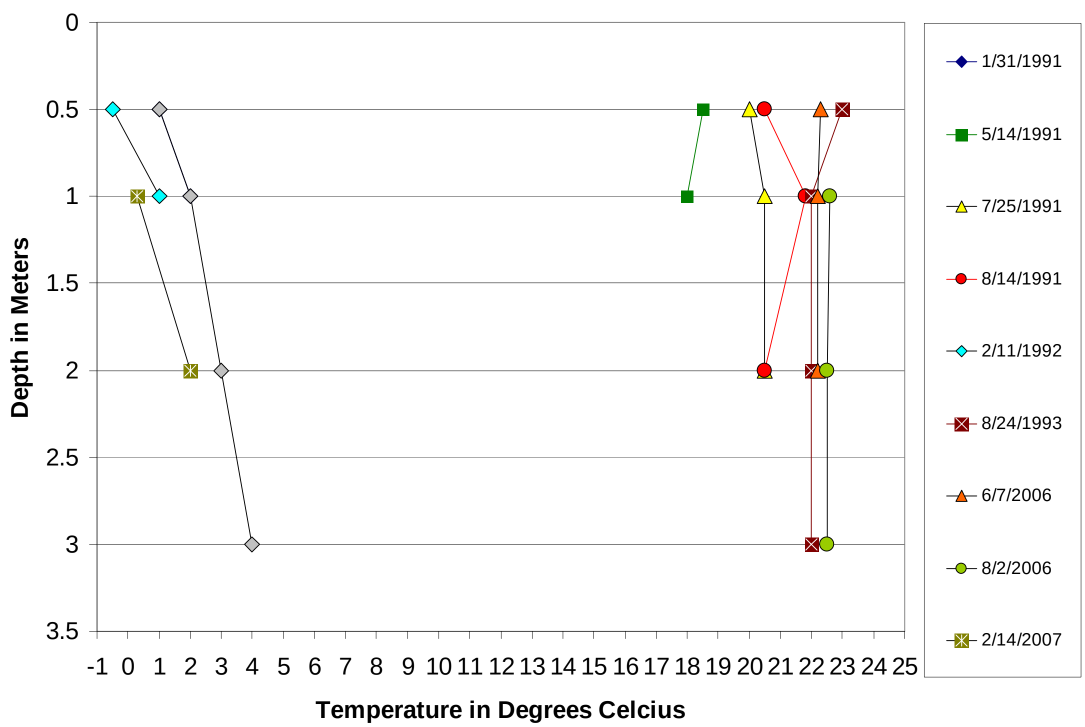


Figure 3. Temperature Profiles for Green Lake from 1991 to 2007.

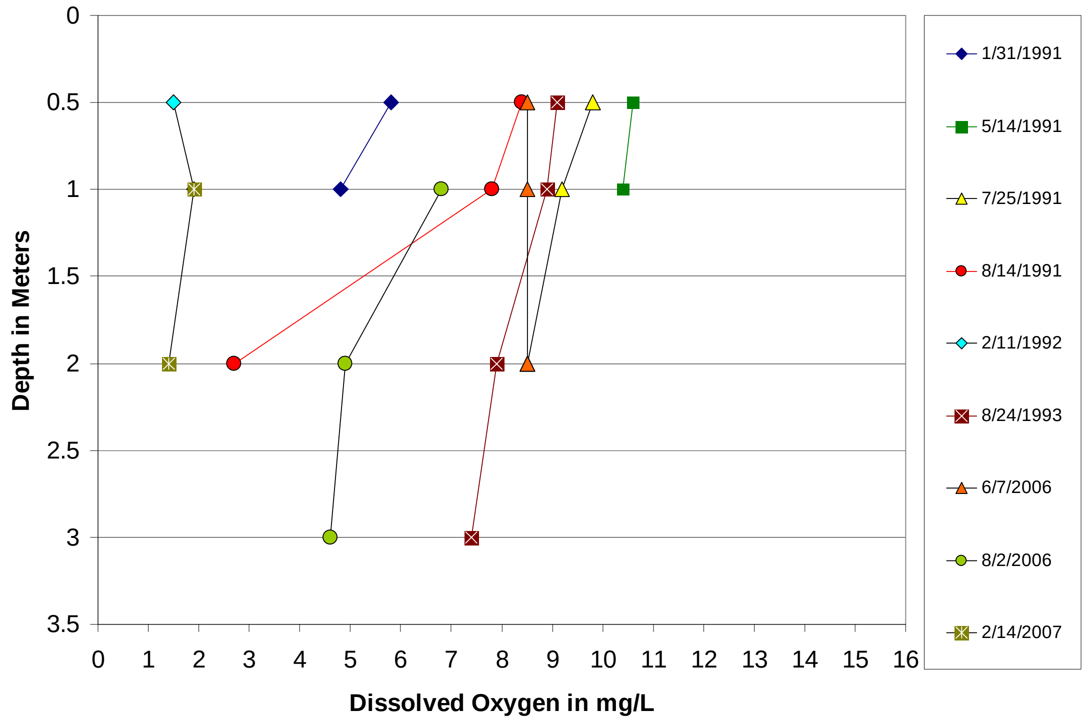


Figure 4. Dissolved Oxygen Profiles for Green Lake from 1991 to 2007.

General Water Quality: Water quality data collected by the NDG&F in 2006-2007 indicate Green Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 396 mg/L to 533 mg/L (Table 1). Based on the 2006-2007 water quality data (Table 1), Green Lake is sodium sulfate dominated with an average sodium concentration of 275 mg/L and an average sulfate concentration of 607 mg/L. The average TDS concentration and specific conductance measurement for the 2006-2007 sampling period were 1348 mg/L and 1945 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 3.368 mg/L and 0.294 mg/L, respectively.

When compared to historical water quality data for Green Lake (Table 2) to current (Table 1), it appears that the dissolved solids have increased while the nutrients have decreased. For example, the average sulfate and sodium concentrations for the period 1991-1993 were 401 mg/L and 242 mg/L, respectively, compared to the average concentrations of 607 mg/L for sulfate and 275 mg/L for sodium recorded for 2006-2007. The historical average for total nitrogen and total phosphorus concentrations is 5.122 mg/L and 0.676 mg/L respectively, compared to current average concentrations of 3.368 mg/L for total nitrogen and 0.294 mg/L for total phosphorus.

Table 1. Statistical Summary of Green Lake's 2006-2007 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	449	396	533	59
Total Ammonia as N	mg/L	4	0.108	0.010[1]	0.336	0.155
Bicarbonate (HCO_3)	mg/L	4	439	334	651	144
Calcium (Ca)	mg/L	4	37.8	25.4	50.3	12.4
Carbonate (CO_3)	mg/L	4	54	1[1]	91	38
Chloride (Cl)	mg/L	4	26	20	34	6
Chlorophyll-a	µg/L	4	37.1	8.5	80.6	30.7
Specific Conductance	µmhos	4	1945	1730	2430	326
Total Dissolved Solids	mg/L	4	1348	1180	1720	250
Total Hardness as ($CaCO_3$)	mg/L	4	491	414	610	85
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.242	0.132	0.522	0.188
Magnesium (Mg)	mg/L	4	96.2	82.9	120.0	16.5
Nitrate + Nitrite as N	mg/L	4	0.023	0.020	0.030	0.005
Total Kjeldahl Nitrogen as N	mg/L	4	3.345	2.100	4.770	1.116
Total Nitrogen as N	mg/L	4	3.368	2.120	4.790	1.117
pH		4	8.75	8.14	9.19	0.44
Total Phosphorus as P	mg/L	4	0.294	0.186	0.405	0.095
Potassium (K)	mg/L	4	34.0	28.6	37.4	4.2
Sodium (Na)	mg/L	4	275	230	351	53
Sulfate (SO4)	mg/L	4	607	492	811	141

[1]Equal to lower detection limit

When compared to regional average concentrations, it appears Green Lake is similar to that reported for all natural and enhanced lakes in the Rangeland Plains region, with the exception of nitrogen concentrations (Table 3). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1588 mg/L, 1.826 mg/L, and 0.244 mg/L, respectively, compared to Green Lake's average TDS, total nitrogen, and total phosphorus concentrations of 1348 mg/L, 3.368 mg/L and 0.294 mg/L, respectively, for the period 2006-2007.

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Green Lake, and that the ratio of total nitrogen as N, to total phosphorus as P (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were 9 water quality sample results for Green Lake collected between January 1991 and February 2007 where the N:P ratio could be calculated. The results from this analysis indicate that Green Lake is most often nitrogen limited (Figure 5).

The nitrogen to phosphorus ratio for Green Lake ranged from a low of 5 to a high of 16 with an average of 10. Of the nine samples collected, all but two samples were below a ratio of 15, indicating nitrogen is limiting primary production in Green Lake.

Table 2. Statistical Summary of Green Lake's Historical Water Quality Data Collected Between 1991 and 2002.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	11	443	248	835	188
Total Ammonia as N	mg/L	11	0.310	0.016	1.510	0.590
Bicarbonate (HCO_3)	mg/L	11	403	184	1020	298
Calcium (Ca)	mg/L	11	33	21	68	15
Carbonate (CO_3)	mg/L	9	83	10	117	48
Chloride (Cl)	mg/L	11	28.6	11.8	49.6	13.8
Chlorophyll-a	µg/L	2	221.5	151.0	292.0	99.7
Specific Conductance	µmhos	11	1625	783	3130	770
Total Dissolved Solids	mg/L	11	1074	477	2020	514
Total Hardness as ($CaCO_3$)	mg/L	11	326	176	697	153
Hydroxide (OH)	mg/L	2	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	11	0.245	0.087	0.463	0.120
Magnesium (Mg)	mg/L	11	59.5	27.7	128.0	28.7
Nitrate + Nitrite as N	mg/L	9	0.050	0.003[1]	0.338	0.109
Total Kjeldahl Nitrogen as N	mg/L	9	5.051	3.860	8.500	1.462
Total Nitrogen as N	mg/L	5	5.122	3.574	8.548	2.000
pH		11	9.07	8.20	9.70	0.64
Total Phosphorus as P	mg/L	11	0.676	0.483	1.200	0.258
Potassium (K)	mg/L	11	43.4	19.2	81.9	17.8
Sodium (Na)	mg/L	11	242	80	460	125
Sulfate (SO4)	mg/L	11	401	162	733	210

[1]Equal to lower detection limit

Trophic Status Assessment: Based on chlorophyll-a and Secchi disk transparency data collected between 2006 and 2007, Green Lake's current trophic status is eutrophic. TSI scores ranged from a low of 52 based on chlorophyll-a measurements, to a high of 74 based on secchi disk transparency (Figure 6).

A total of nine total phosphorus samples, six chlorophyll-a samples, and seven Secchi disk transparency measurements collected during the open water periods from 1991-2007 were used to evaluate trends in the trophic status of Green Lake. Based on a visual assessment of the data Green Lake's trophic status is improving (Figure 6).

Table 3. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lakes in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	272	544	119	4770	130
Total Ammonia as N	mg/L	371	0.107	0.001[1]	2.230	0.200
Bicarbonate (HCO_3)	mg/L	272	489	145	2990	150
Calcium (Ca)	mg/L	272	44	1[1]	282	26
Carbonate (CO_3)	mg/L	262	89	1[1]	1420	30
Chloride (Cl)	mg/L	272	51	4[1]	1070	9
Chlorophyll-a	µg/L	250	22	2[1]	292	28
Specific Conductance	µmhos	272	2168	448	20100	959
Total Dissolved Solids	mg/L	272	1588	227	18200	750
Total Hardness as ($CaCO_3$)	mg/L	272	538	170	2370	260
Hydroxide (OH)	mg/L	200	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	273	0.193	0.001[1]	2.260	0.334
Magnesium (Mg)	mg/L	272	104	20	567	50
Nitrate + Nitrite as N	mg/L	332	0.036	0.002[1]	0.338	0.092
Total Kjeldahl Nitrogen as N	mg/L	340	1.950	0.080	8.500	0.779
Total Nitrogen as N	mg/L	278	1.826	0.269	5.520	0.562
pH		272	8.796	7.400	9.870	0.564
Total Phosphorus as P	mg/L	377	0.244	0.004[1]	1.940	0.205
Potassium (K)	mg/L	272	38	3[1]	356	6
Sodium (Na)	mg/L	272	331	17	4680	171
Sulfate (SO4)	mg/L	272	680	34	10500	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 48 Natural and Enhanced Lakes between 1991 and 2007

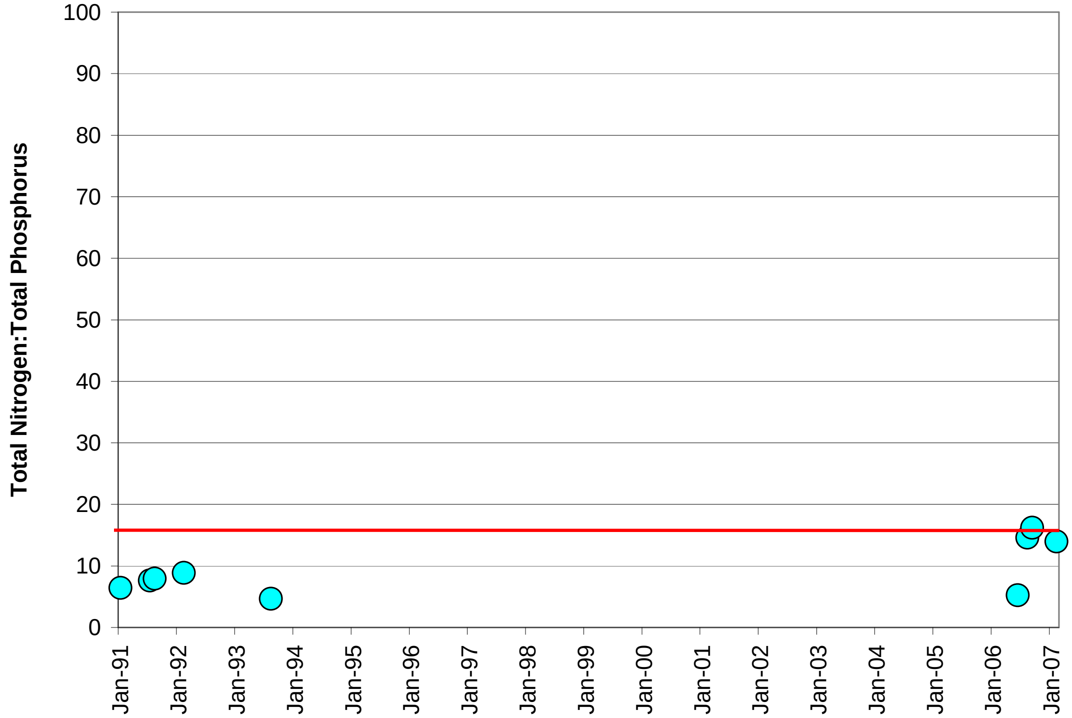


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Green Lake (1991-2007).

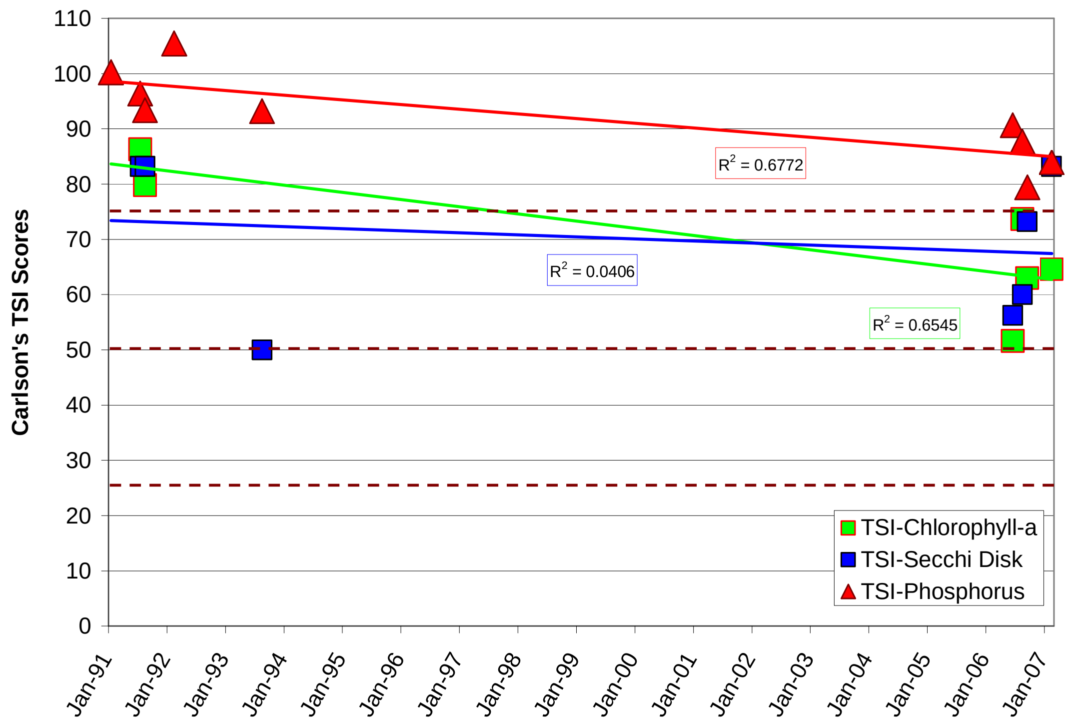


Figure 6. TSI Scores and Temporal Trends for Green Lake from 1991 to 2007.

Leland Dam, McKenzie County

BACKGROUND

Location: Leland Dam is a recreational impoundment located 4½ miles west and 20 miles south of Alexander, North Dakota (Figure 1). The reservoir is managed by the U.S. Forest Service and the North Dakota Game and Fish Department.

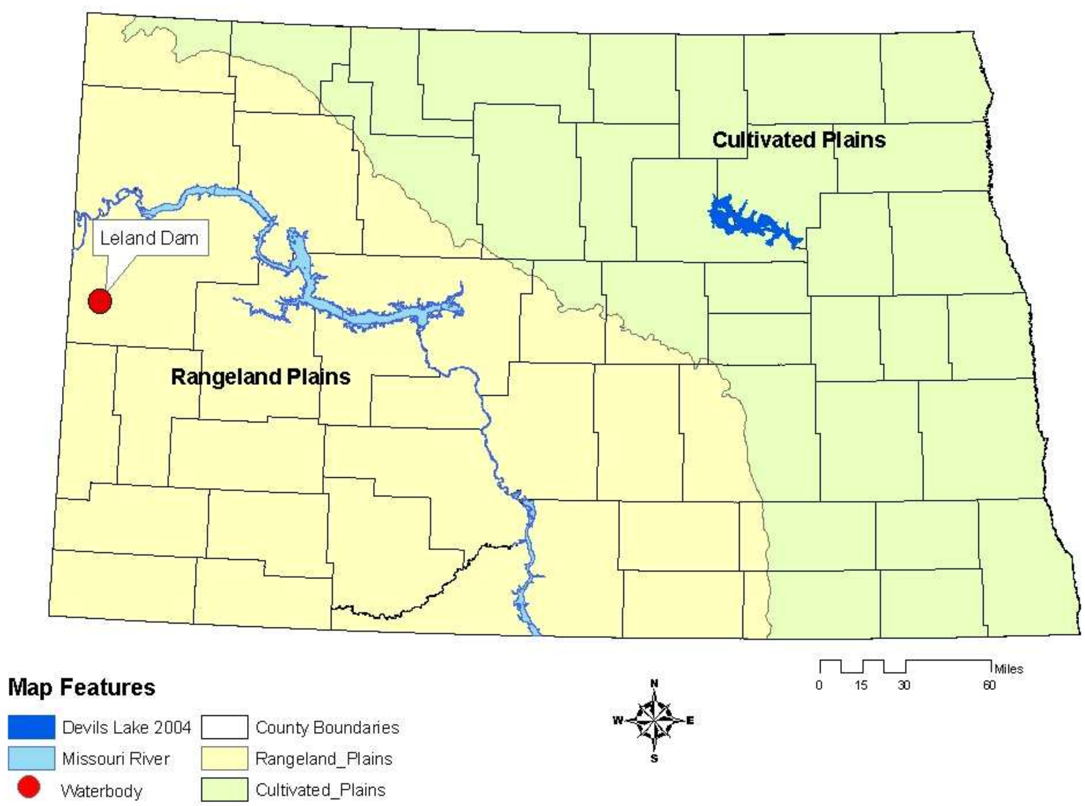


Figure 1. Location of Leland Dam.

Physiographic/Ecological Setting: Leland Dam has a surface area of 15.8 acres, a maximum depth of 22.7 ft, and an average depth 10.7 ft (Figure 2). The reservoir's watershed is 9,472 acres and it is located within the Northwestern Great Plains (NWGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). Leland Dam's watershed is rolling plains of native grasslands. Virtually all of Leland Dams watershed is in public ownership and managed for multiple-use by the U.S. Forest Service.

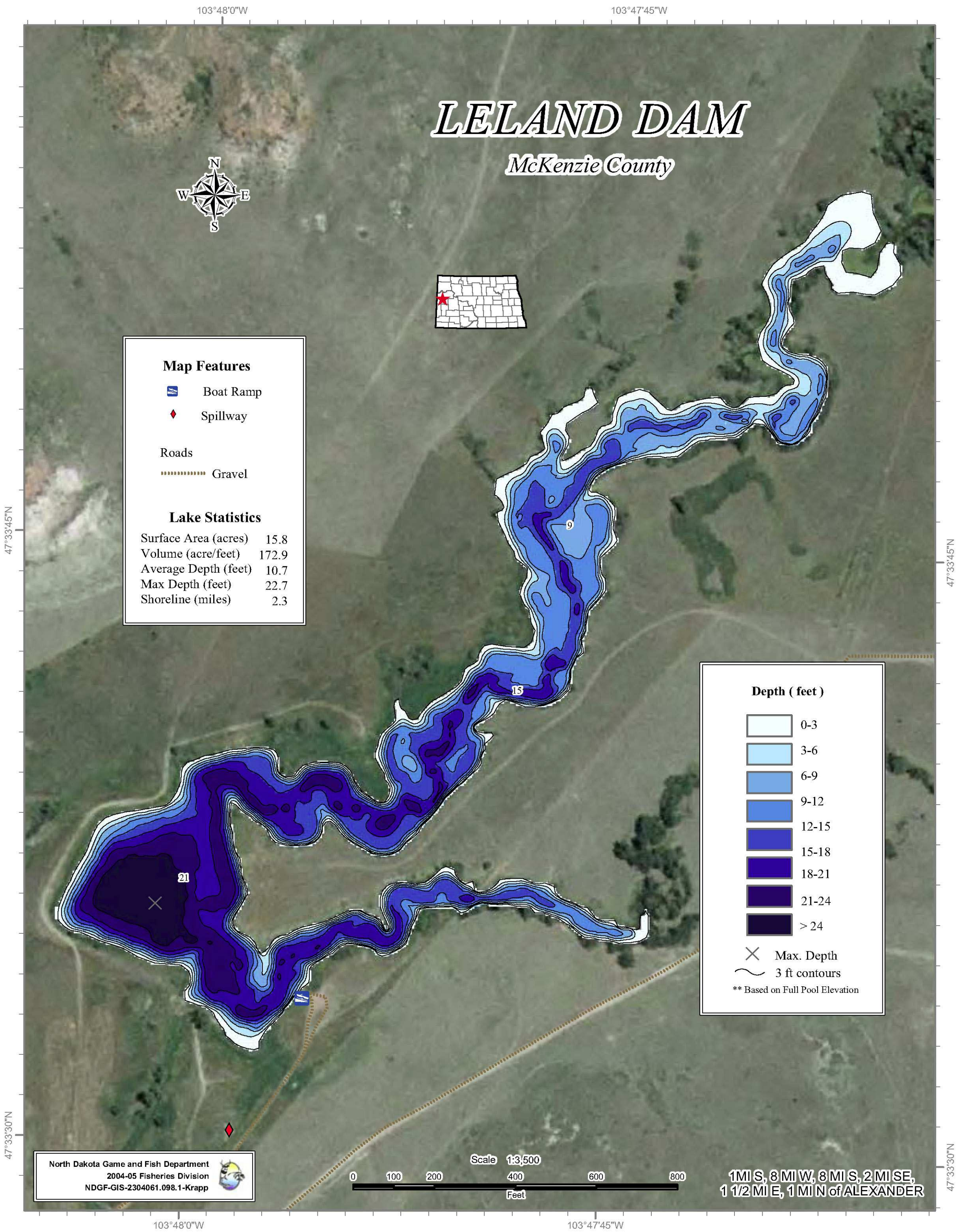


Figure 2. Contour Map of Leland Dam (Map Courtesy of North Dakota Game and Fish Department).

Construction History: Leland Dam is a small earthen structure on the Bennie Pierre Creek drainage in McKenzie County, North Dakota. The reservoir was constructed by the Leland family and engineered by the Soil Conservation Service for irrigation and recreation.

Recreational Facilities: Recreational facilities at Leland Dam include a metal boat ramp, and boat trailer and vehicle parking. Public access to Leland Dam is located on the south side of the lake. Restrictions on Leland Dam include the use of only electrical motors and prohibition of live baitfish.

Water Quality Standards Classification: Leland Dam is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 2 lake or reservoir. Class 2 lakes or reservoirs are defined as a "cool water fishery" or "waters capable of supporting natural reproduction and growth of cool water fishes (e.g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: Leland Dam's historical fishery included rainbow trout, bluegill, brook stickleback, fathead minnows, and largemouth bass, stocked by the NDG&F. Currently the fishery includes bluegill and largemouth bass.

Historical Water Quality Sampling: Historical water quality data includes results from four samples collected from 1994 through 1995.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Leland Dam have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There are twelve temperature and dissolved oxygen profiles for Leland Dam collected in two clusters between 1994-1996 and 2006-2007 (Figures 3 and 4). The profile data shows that under ice cover and during thermal stratification Leland Dam experiences rapid oxygen decay, often dropping below the state's water quality standard of 5 mg/L. The rapid and sometimes near complete loss of dissolved oxygen during these periods is concerning as there appears to be an inadequate amount of dissolved oxygen to maintain aquatic life throughout most of the water column and a significant amount of the lake volume.

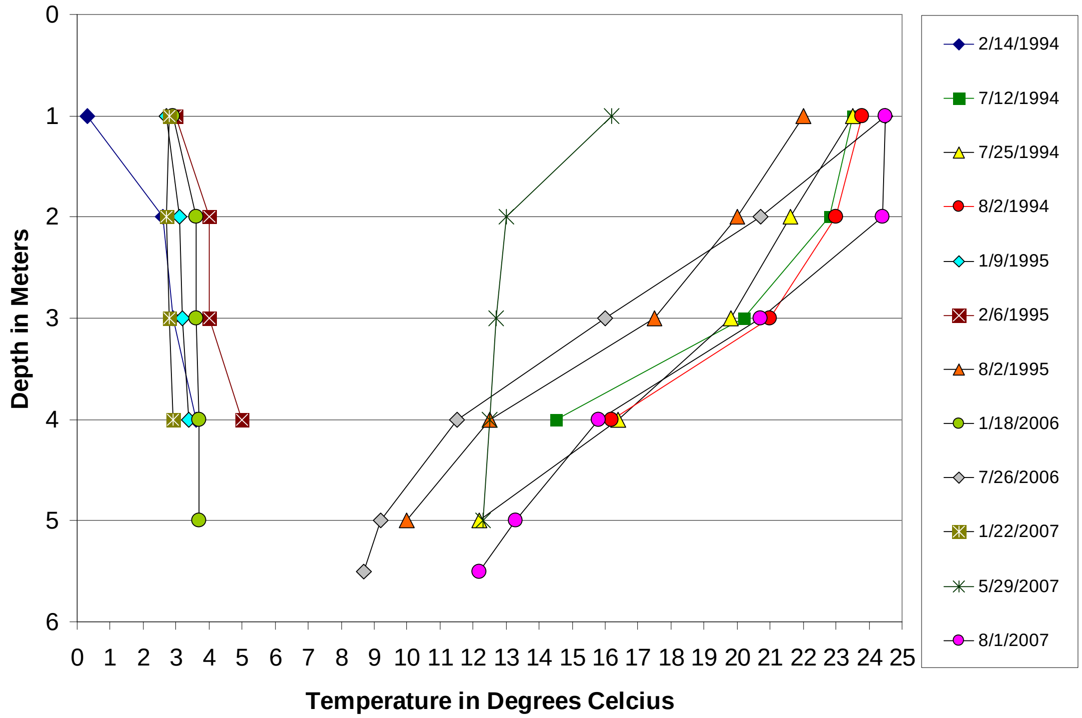


Figure 3. Temperature Profiles for Leland Dam from 1994 to 2007.

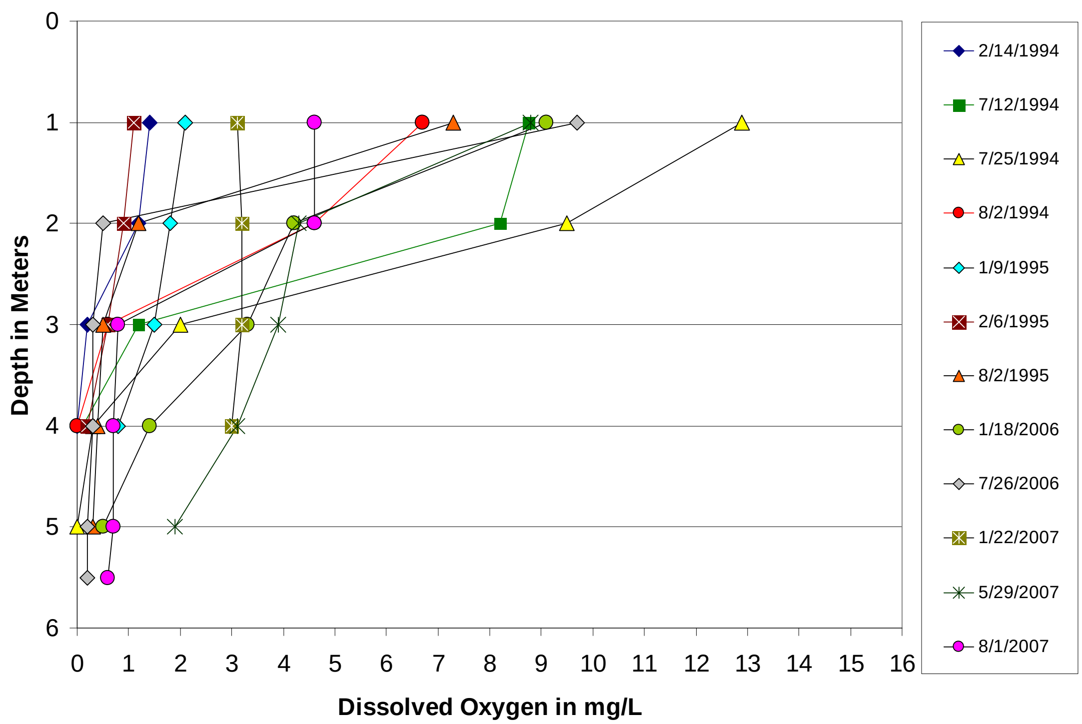


Figure 4. Dissolved Oxygen Profiles for Leland Dam from 1994 to 2007.

General Water Quality: Data collected by the NDGF in 2006 and 2007 indicate Leland Dam is well buffered with total alkalinity as $CaCO_3$ concentrations ranging from 101 mg/L to 208 mg/L (Table 1). Based on the 2006-2007 water quality data, Leland Dam is sodium bicarbonate dominated with an average sodium concentration of 68 mg/L and an average bicarbonate concentration of 153 mg/L. The average total dissolved solids (TDS) concentration and specific conductance measurement for the 2006-2007 sampling period were 284 mg/L and 480 µmhos/cm respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.188 mg/L and 0.052 mg/L respectively.

Table 1. Statistical Summary of Leland Dam's 2006-2007 Water Quality Data.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	5	146	101	208	44
Total Ammonia as N	mg/L	5	0.115	0.010[1]	0.438	0.185
Bicarbonate (HCO_3)	mg/L	5	153	117	211	38
Calcium (Ca)	mg/L	5	18.8	12.6	29.0	6.2
Carbonate (CO_3)	mg/L	5	12	1[1]	43	18
Chloride (Cl)	mg/L	5	2	1[1]	3	1
Chlorophyll-a	µg/L	5	12.1	1.5[1]	22.8	8.4
Specific Conductance	µmhos	5	480	348	795	183
Total Dissolved Solids	mg/L	5	284	202	488	118
Total Hardness as ($CaCO_3$)	mg/L	5	81	68	112	18
Hydroxide (OH)	mg/L	5	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	5	0.272	0.074	0.713	0.258
Magnesium (Mg)	mg/L	5	8.3	6.5	11.9	2.4
Nitrate + Nitrite as N	mg/L	5	0.038	0.020	0.070	0.019
Total Kjeldahl Nitrogen as N	mg/L	5	1.150	0.776	1.700	0.418
Total Nitrogen as N	mg/L	5	1.188	0.806	1.720	0.421
pH		5	8.46	7.66	9.35	0.70
Total Phosphorus as P	mg/L	5	0.052	0.033	0.076	0.016
Potassium (K)	mg/L	5	7.7	4.9	10.4	2.0
Sodium (Na)	mg/L	5	68	39	146	44
Sulfate (SO4)	mg/L	5	91	60	179	50

[1]Equal to lower detection limit

When comparing historical water quality data for Leland Dam (Table 2) to current data (Table 1), it appears that most water quality constituents have remained stable. For example, the average bicarbonate and sodium concentrations for the period 1994-1995 were 157 mg/L and 58 mg/L respectively, compared to the 2006-2007 average concentrations of 153 mg/L for bicarbonate and 68 mg/L for sodium. Total nitrogen and total phosphorus concentrations have also remained fairly stable with historical averages of 1.267 mg/L and 0.033 mg/L respectively, compared to the current averages of 1.188 mg/L for total nitrogen and 0.052 mg/L for total phosphorus.

Table 2. Statistical Summary of Leland Dam's Historical Water Quality Data Collected Between 1994 and 1995.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	139	113	164	29
Total Ammonia as N	mg/L	4	0.251	0.010[1]	0.493	0.278
Bicarbonate (HCO_3)	mg/L	4	157	113	200	49
Calcium (Ca)	mg/L	4	31	23	38	7
Carbonate (CO_3)	mg/L	4	7	1[1]	12	6
Chloride (Cl)	mg/L	4	1.7	0.3	3.0	1.6
Chlorophyll-a	µg/L	2	8.0	5.0	11.0	4.2
Specific Conductance	µmhos	4	467	397	529	71
Total Dissolved Solids	mg/L	4	301	243	352	58
Total Hardness as ($CaCO_3$)	mg/L	4	121	95	145	26
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.202	0.083	0.345	0.111
Magnesium (Mg)	mg/L	4	10.7	9.0	12.3	1.8
Nitrate + Nitrite as N	mg/L	3	0.005	0.005	0.006	0.001
Total Kjeldahl Nitrogen as N	mg/L	3	1.261	0.594	1.600	0.578
Total Nitrogen as N	mg/L	3	1.267	0.599	1.605	0.578
pH		4	7.86	6.74	8.90	1.18
Total Phosphorus as P	mg/L	4	0.033	0.004[1]	0.072	0.029
Potassium (K)	mg/L	4	9.0	7.8	10.3	1.3
Sodium (Na)	mg/L	4	58	49	64	8
Sulfate (SO4)	mg/L	4	105	78	124	22

[1]Equal to lower detection limit

In comparison to the Rangeland Plains regional averages (Table 3), Leland Dam is lower in dissolved solids and nutrient concentrations than most reservoirs (Table 1). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1176 mg/L, 1.472 mg/L, and 0.135 mg/L respectively, compared to Leland Dam's average TDS, total nitrogen, and total phosphorus concentrations of 284 mg/L, 1.188 mg/L, and 0.052 mg/L respectively, for the period 2006-2007.

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Leland Dam and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight, in algae is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

Table 3. Statistical Summary of Water Quality Data[2] Collected from Reservoirs in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	408	309	101	982	130
Total Ammonia as N	mg/L	469	0.097	0.001[1]	2.440	0.200
Bicarbonate (HCO_3)	mg/L	408	318	14	1040	150
Calcium (Ca)	mg/L	408	50	5	160	26
Carbonate (CO_3)	mg/L	402	30	1[1]	197	30
Chloride (Cl)	mg/L	408	13.3	0.3	74.5	8.8
Chlorophyll-a	µg/L	321	21.2	1.5	218.0	27.9
Specific Conductance	µmhos	428	1733	262	5880	959
Total Dissolved Solids	mg/L	409	1176	147	5110	750
Total Hardness as ($CaCO_3$)	mg/L	408	397	45	1850	260
Hydroxide (OH)	mg/L	337	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	409	0.179	0.007	4.110	0.334
Magnesium (Mg)	mg/L	408	66.0	5.6	353.0	49.6
Nitrate + Nitrite as N	mg/L	395	0.048	0.001[1]	0.790	0.092
Total Kjeldahl Nitrogen as N	mg/L	359	1.556	0.365	7.720	0.779
Total Nitrogen as N	mg/L	302	1.472	0.405	4.840	0.562
pH		428	8.61	6.73	9.87	0.56
Total Phosphorus as P	mg/L	475	0.135	0.004	3.160	0.205
Potassium (K)	mg/L	408	14.6	4.2	39.2	6.3
Sodium (Na)	mg/L	408	239	3[1]	932	171
Sulfate (SO4)	mg/L	406	604	1[1]	3210	501

[1]Equal to Minimum Reporting Limit.
[2]Data Collected from 69 Reservoirs between 1991 and 2007.

There were eight water quality sample results for Leland Dam collected between July 1994 and August 2007 where the N:P ratio could be calculated. The results from this analysis indicate that Leland Dam is most often phosphorus limited (Figure 5). N:P ratios for Leland Dam ranged from a low of 11 to a high of 151 with an average of 51. Of the eight samples collected on Leland Dam, all but one were above an N:P ratio of 15, indicating phosphorus limitation.

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2006-2007, Leland Dam's current trophic status is eutrophic. TSI scores ranged from a low of 35 based on chlorophyll-a, to a high of 67 based on total phosphorus. The trophic status scores based on Secchi disk transparency were similar to that estimated by total phosphorus at 60 (Figure 6).

A total of eight total phosphorus samples, seven chlorophyll-a samples, and six Secchi disk transparency measurements collected from 1994-2007 were used to evaluate trends in the trophic status of Leland Dam. Based on a visual assessment Leland Dam's trophic status is stable to trending upward towards hypereutrophic (Figure 6).

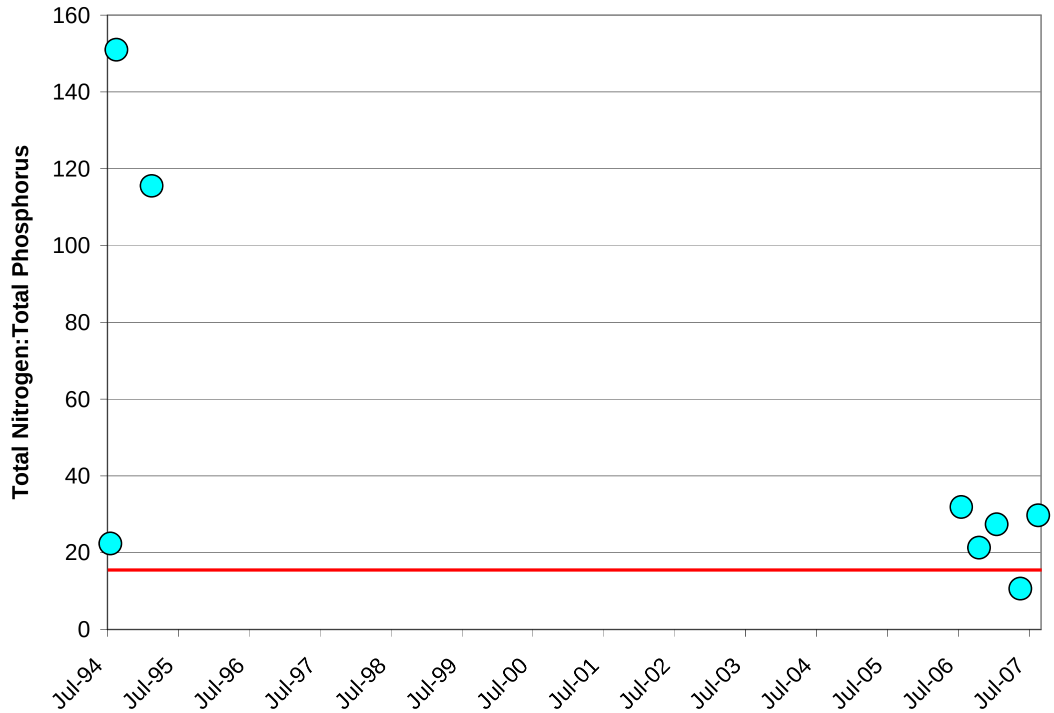


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Leland Dam (1994-2007).

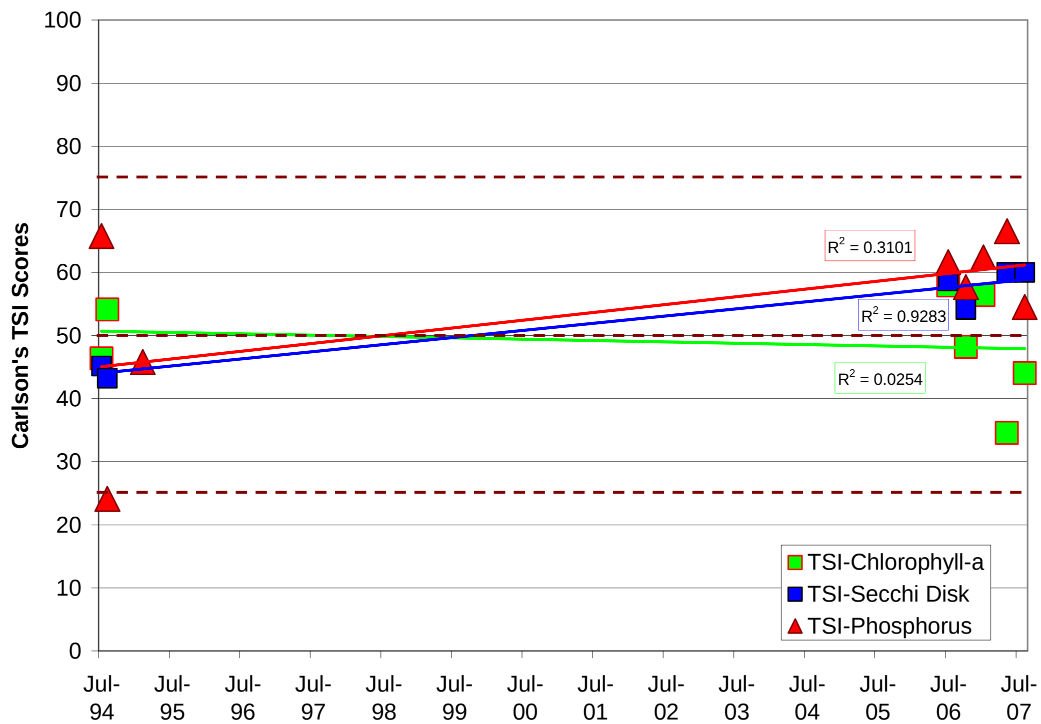


Figure 6. TSI Scores and Temporal Trends for Leland Dam from 1994 to 2007.

Sather Dam, McKenzie County

BACKGROUND

Location: Sather Dam is a recreational impoundment located 11 miles south, and 8 miles west of Alexander, North Dakota (Figure 1). The reservoir is managed by the US Forest Service and the North Dakota Game and Fish Department.

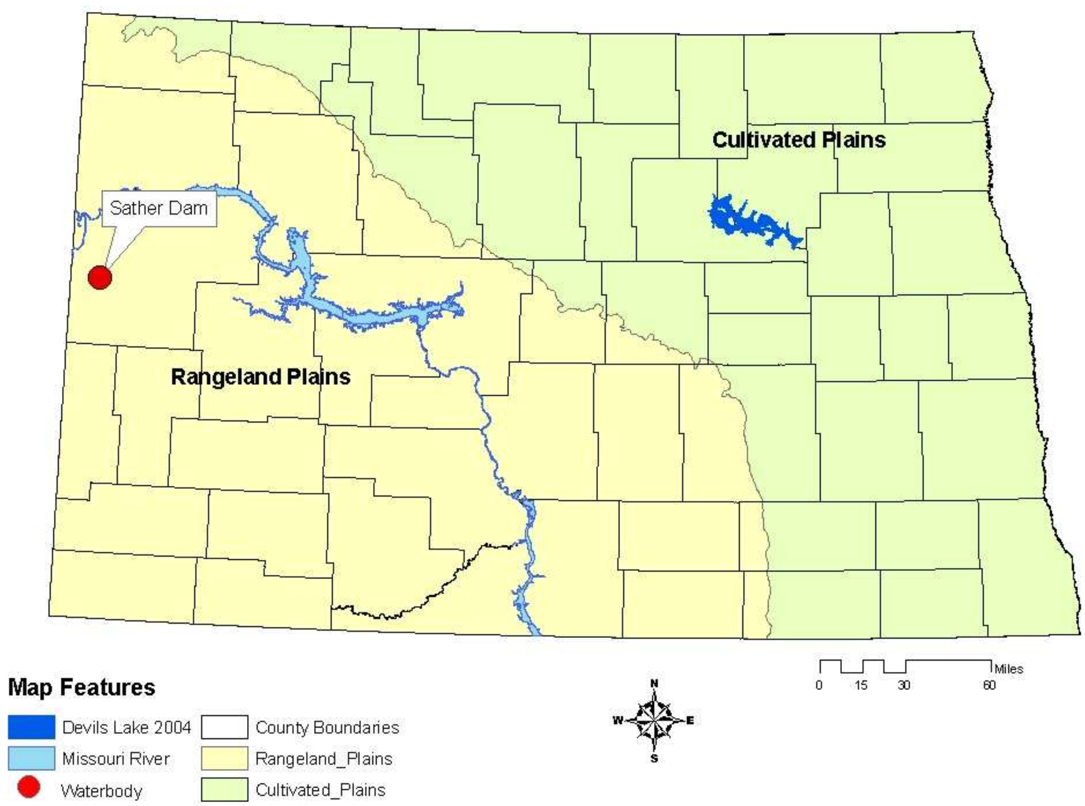


Figure 1. Location of Sather Dam.

Physiographic/Ecological Setting: Sather Dam has a surface area of 36.6 acres, a maximum depth of 19.1 ft, and an average depth of 9.9 ft (Figure 2). The reservoir's watershed is approximately 4,000 acres and it is located within the Northwestern Great Plains (NWGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The Sather Dam watershed's landscape is rolling plains of native grasslands. Virtually all of Sather Dam's watershed is in public ownership and managed for multiple-use by the U.S. Forest Service.

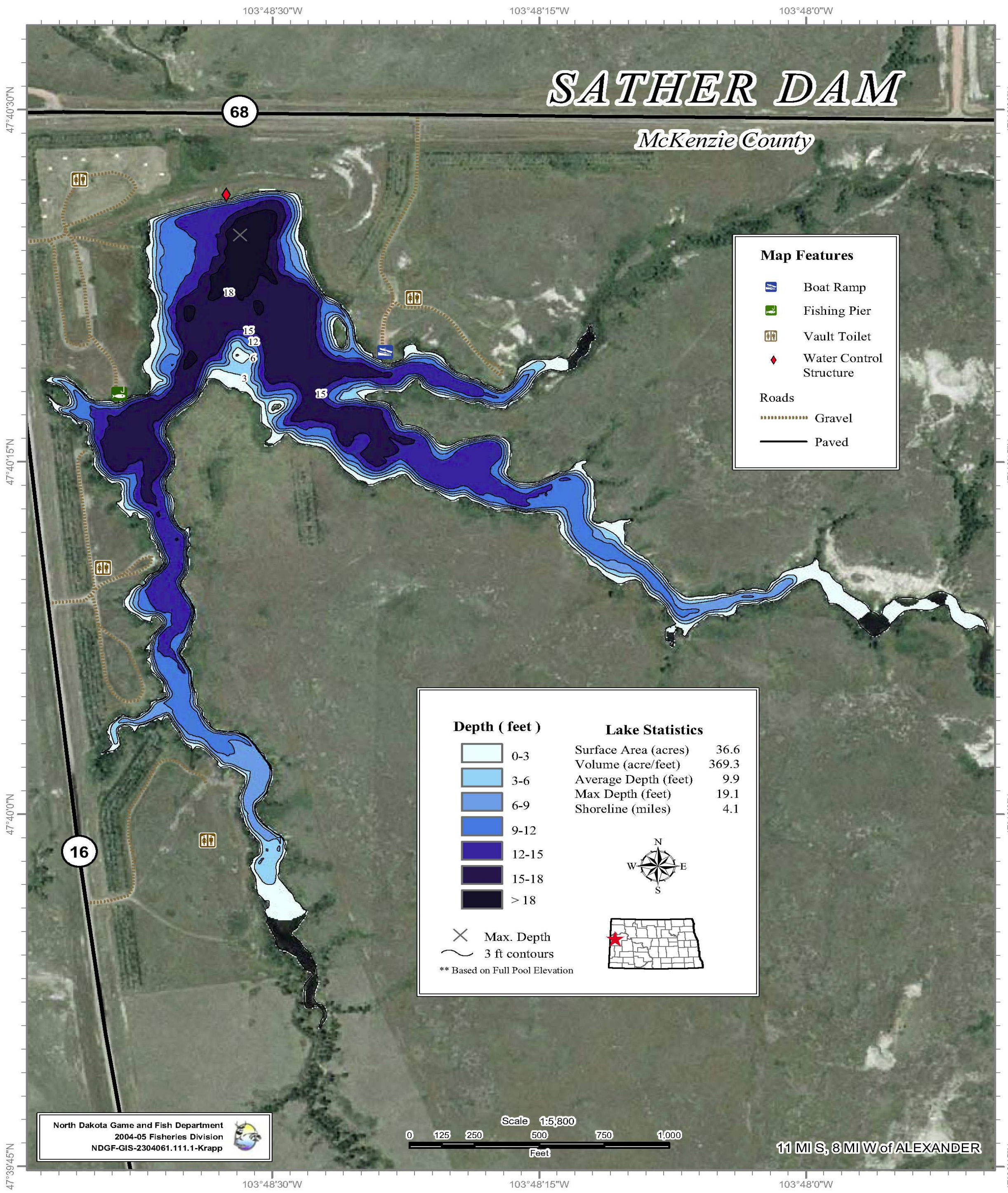


Figure 2. Contour Map of Sather Dam (Map Courtesy of North Dakota Game and Fish Department).

Construction History: Sather Dam was initially constructed as a low head dam in 1936. The dam was reconstructed for recreational purposes in 1963-1965. Sather Dam is maintained and owned by the United States Forest Service.

Recreational Facilities: Recreational facilities at Sather Dam include a cement boat ramp, boat trailer and vehicle parking, campground and a fishing pier. The parks on the north and west side of the lake include parking, restrooms, campgrounds and vault toilets. Restrictions on Sather Dam include the use of only electrical motors and prohibition of live baitfish.

Water Quality Standards Classification: Sather Dam is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 2 lake or reservoir. Class 2 lakes or reservoirs are defined as a "cool water fishery" or "waters capable of supporting natural reproduction and growth of cool water fishes (e.g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: Sather Dam's historical fishery included rainbow trout, brown trout, and largemouth bass, stocked by the NDG&F. Currently the fishery includes bluegill and largemouth bass.

Historical Water Quality Sampling: There is no historical water quality data available for Sather Dam.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Sather Dam have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There are five temperature and dissolved oxygen profiles for Sather Dam collected in 2006 and 2007 (Figures 3 and 4). The profiles show that during thermal stratification and under ice cover Sather Dam has dissolved oxygen deficiencies. During thermal stratification there is rapid oxygen decay below the metalimnion and under ice conditions there is a general condition of low oxygen concentrations (Figures 3 and 4). Under both circumstances dissolved oxygen is below or eventually drops below the state's water quality standard of 5 mg/L.

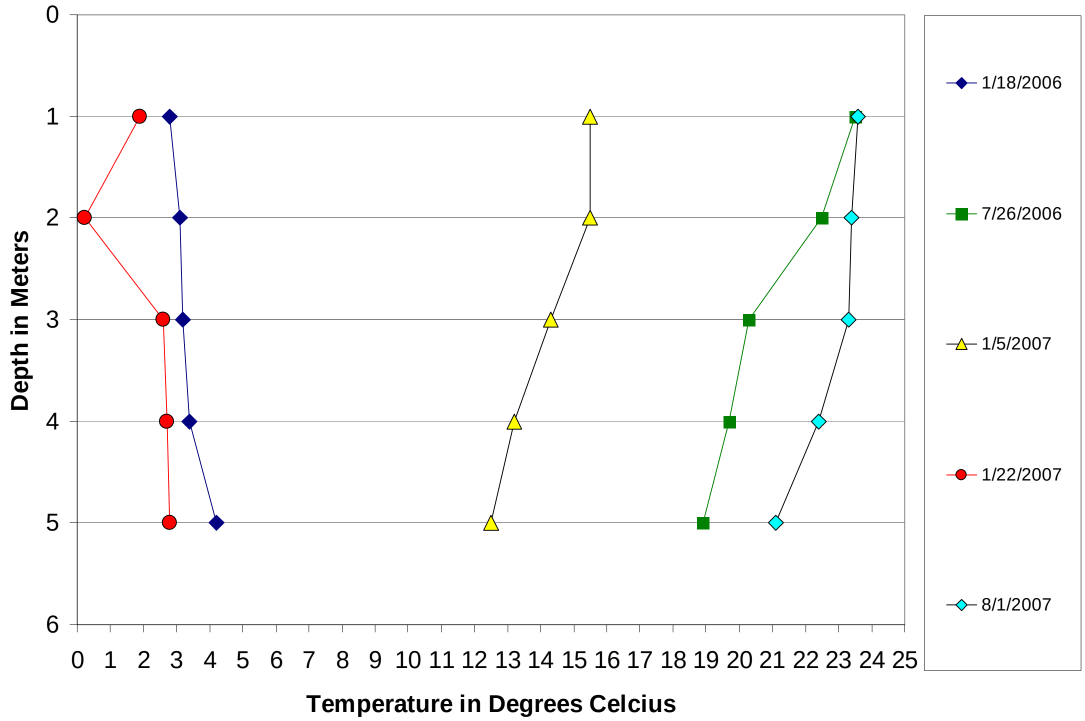


Figure 3. Temperature Profiles for Sather Dam from 2006 to 2007.

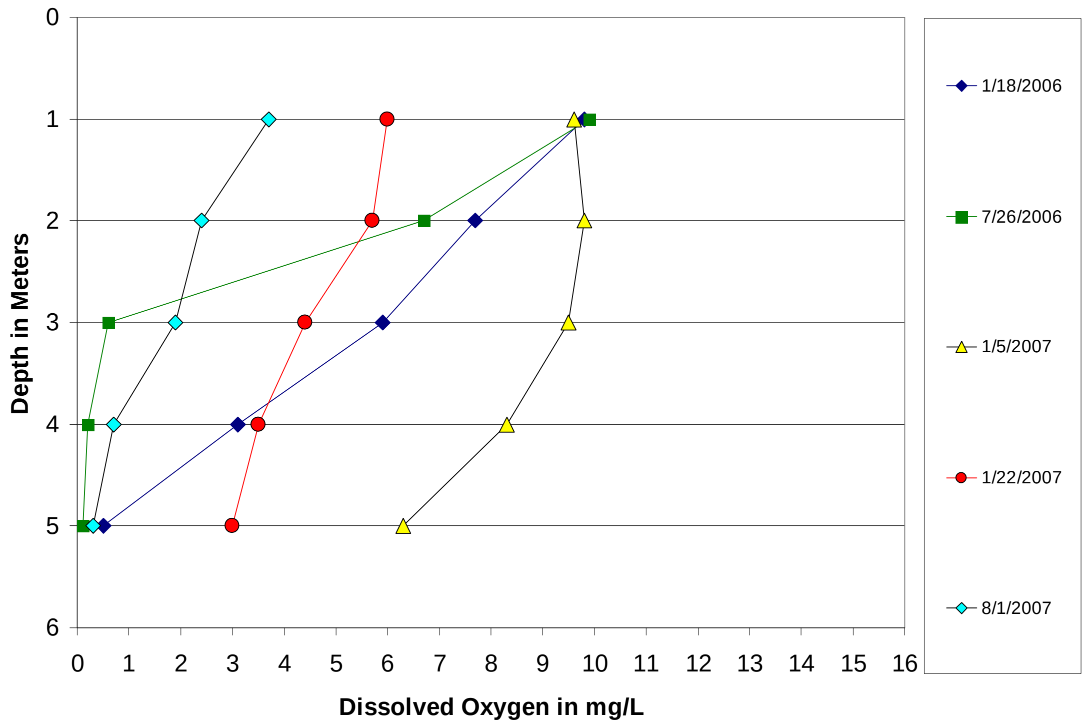


Figure 4. Dissolved Oxygen Profiles for Sather Dam from 2006 to 2007.

General Water Quality: Data collected by the NDGF in 2006 and 2007 indicate Sather Dam is well buffered with total alkalinity as $CaCO_3$ concentrations ranging from 114 mg/L to 305 mg/L (Table 1). Based on the 2006-2007 water quality data, Sather Dam is sodium bicarbonate dominated with an average sodium concentration of 131 mg/L and an average bicarbonate concentration of 238 mg/L. The average total dissolved solids (TDS) concentration and specific conductance measurement for the 2006-2007 sampling period were 465 mg/L and 759 µmhos/cm respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.415 mg/L and 0.052 mg/L respectively.

Table 1. Statistical Summary of Sather Dam's 2006-2007 Water Quality Data.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	5	220	114	305	69
Total Ammonia as N	mg/L	5	0.138	0.010[1]	0.485	0.197
Bicarbonate (HCO_3)	mg/L	5	238	103	372	96
Calcium (Ca)	mg/L	5	20.6	15.6	28.4	6.1
Carbonate (CO_3)	mg/L	5	15	1[1]	26	12
Chloride (Cl)	mg/L	5	3	1[1]	4	1
Chlorophyll-a	µg/L	5	26.2	1.5[1]	72.6	30.8
Specific Conductance	µmhos	5	759	351	1040	253
Total Dissolved Solids	mg/L	5	465	204	636	161
Total Hardness as ($CaCO_3$)	mg/L	5	97	68	134	26
Hydroxide (OH)	mg/L	5	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	5	0.381	0.110	0.669	0.222
Magnesium (Mg)	mg/L	5	11.1	6.6	15.4	3.1
Nitrate + Nitrite as N	mg/L	5	0.030	0.020	0.040	0.010
Total Kjeldahl Nitrogen as N	mg/L	5	1.385	0.937	2.010	0.392
Total Nitrogen as N	mg/L	5	1.415	0.957	2.050	0.398
pH		5	8.70	8.00	9.09	0.45
Total Phosphorus as P	mg/L	5	0.052	0.022	0.075	0.020
Potassium (K)	mg/L	5	9.3	7.4	11.7	1.9
Sodium (Na)	mg/L	5	131	46	172	52
Sulfate (SO4)	mg/L	5	156	56	219	61

[1]Equal to lower detection limit

When compared to the Rangeland Plains regional averages, Sather Dam is slightly lower in dissolved solids and nutrient concentrations than reported for most reservoirs (Table 2). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1176 mg/L, 1.472 mg/L, and 0.135 mg/L respectively, compared to Sather Dam's average TDS, total nitrogen, and total phosphorus concentrations of 465 mg/L, 1.415 mg/L, and 0.052 mg/L respectively.

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Sather Dam and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight in algae, is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were five water quality sample results for Sather Dam collected between July 2006 and August 2007 where the N:P ratio could be calculated. The results from this analysis indicate that Sather Dam is phosphorus limited (Figure 5). The N:P ratios for Sather Dam ranged from a low of 22 to a high of 60 with an average of 31. All five of the samples collected on Sather Dam were above an N:P ratio of 15 indicating phosphorus limitation.

Table 2. Statistical Summary of Water Quality Data[2] Collected from Reservoirs in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	408	309	101	982	130
Total Ammonia as N	mg/L	469	0.097	0.001[1]	2.440	0.200
Bicarbonate (HCO_3)	mg/L	408	318	14	1040	150
Calcium (Ca)	mg/L	408	50	5	160	26
Carbonate (CO_3)	mg/L	402	30	1[1]	197	30
Chloride (Cl)	mg/L	408	13.3	0.3	74.5	8.8
Chlorophyll-a	µg/L	321	21.2	1.5	218.0	27.9
Specific Conductance	µmhos	428	1733	262	5880	959
Total Dissolved Solids	mg/L	409	1176	147	5110	750
Total Hardness as ($CaCO_3$)	mg/L	408	397	45	1850	260
Hydroxide (OH)	mg/L	337	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	409	0.179	0.007	4.110	0.334
Magnesium (Mg)	mg/L	408	66.0	5.6	353.0	49.6
Nitrate + Nitrite as N	mg/L	395	0.048	0.001[1]	0.790	0.092
Total Kjeldahl Nitrogen as N	mg/L	359	1.556	0.365	7.720	0.779
Total Nitrogen as N	mg/L	302	1.472	0.405	4.840	0.562
pH		428	8.61	6.73	9.87	0.56
Total Phosphorus as P	mg/L	475	0.135	0.004	3.160	0.205
Potassium (K)	mg/L	408	14.6	4.2	39.2	6.3
Sodium (Na)	mg/L	408	239	3[1]	932	171
Sulfate (SO4)	mg/L	406	604	1[1]	3210	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 69 Reservoirs between 1991 and 2007.

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2006-2007, Sather Dam's current trophic status is eutrophic. TSI scores ranged from a low of 35, to a high of 67, based on chlorophyll-a. The trophic status scores based on total phosphorus and Secchi disk transparency were similar to the high score demonstrated by chlorophyll-a, at 63 and 66 respectively (Figure 6).

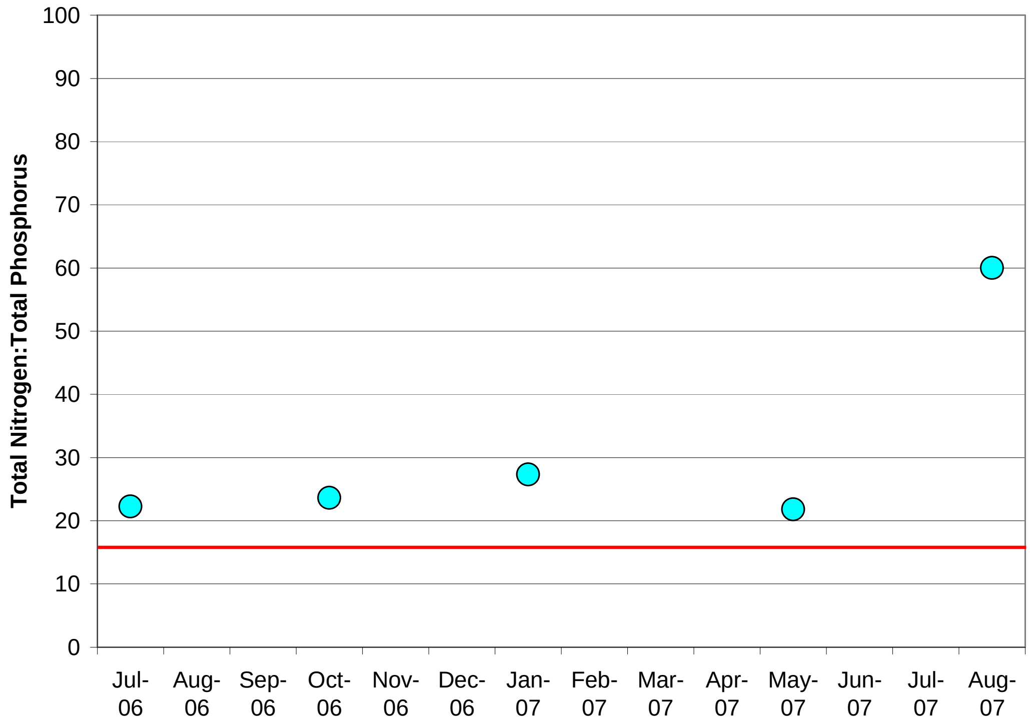


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Sather Dam (2006-2007).

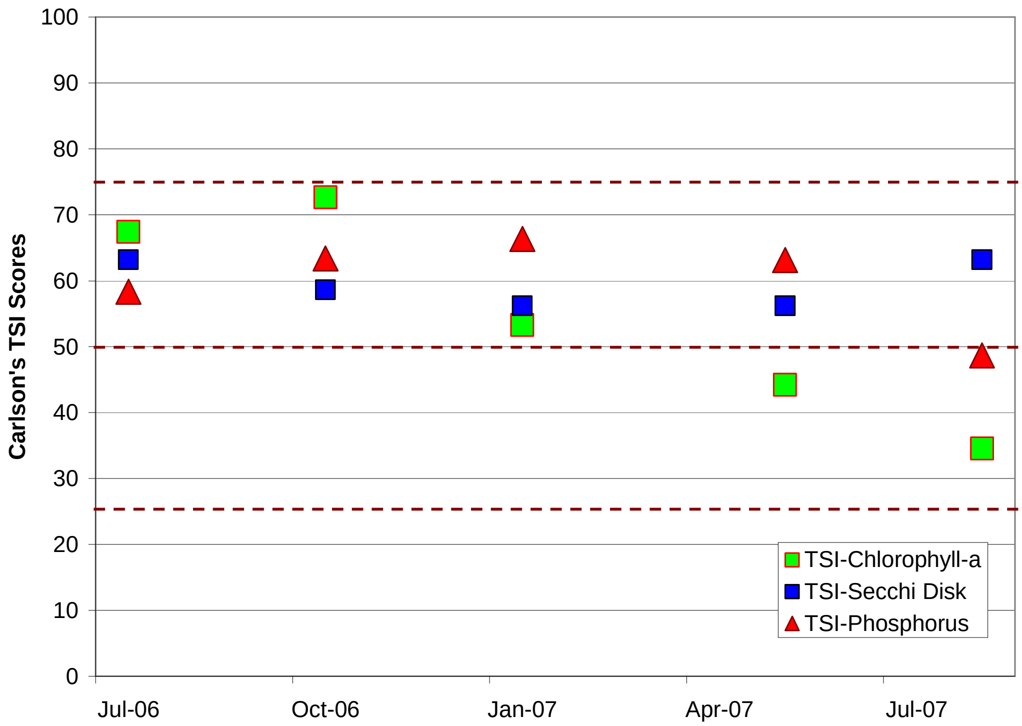


Figure 6. TSI Scores for Sather Dam from 2006 to 2007.

Brush Lake, McLean County

BACKGROUND

Location: Brush Lake is a natural glacial lake located 3 miles north of Mercer, North Dakota (Figure 1). Brush Lake is managed by the North Dakota Game and Fish Department.

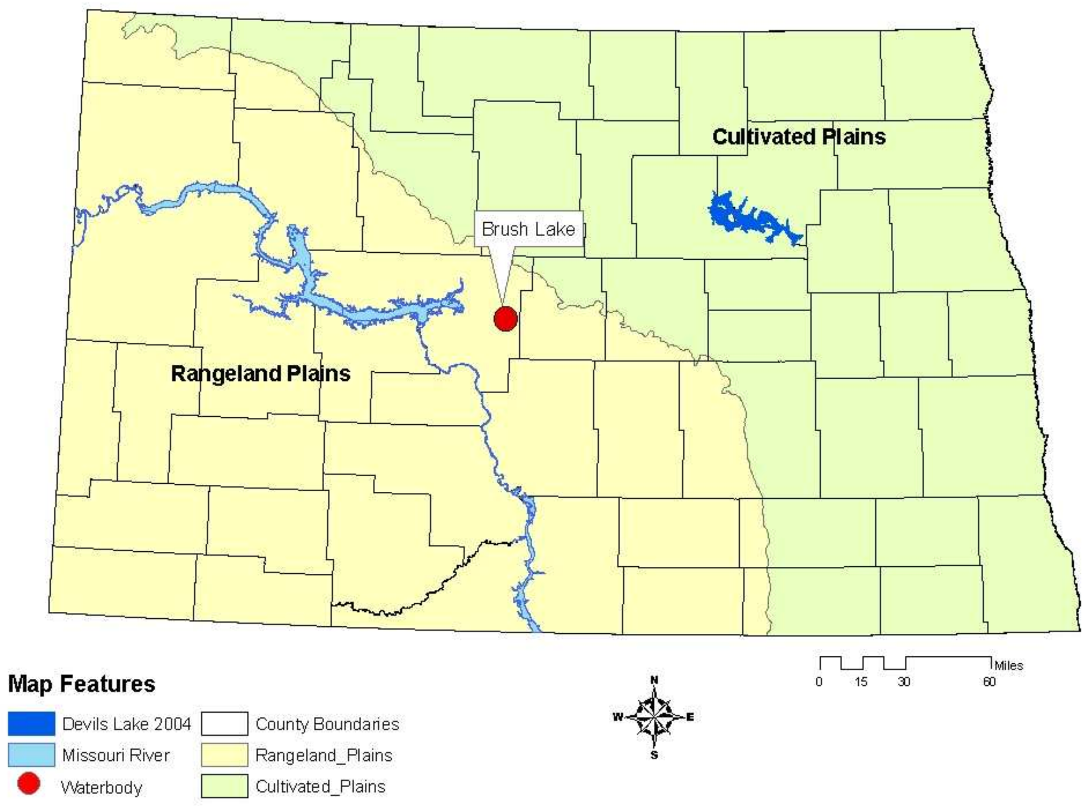


Figure 1. Location of Brush Lake.

Physiographic/Ecological Setting: Brush Lake has a surface area of 225 acres, a maximum depth of 21.8 ft, and an average depth of 10.6 ft (Figure 2). Brush Lake's watershed lies within the Northwestern Glaciated Plains (NGP) Level III Ecoregion, part of the broader Rangeland Plains region. The NGP marks the western most extent of continental glacial advancement. The geological youthful landscape has significant surface irregularities and high concentrations of wetlands. The rise in elevation along the eastern edge of this ecoregion defines the boundary of the Great Plains and to the west the Northwestern Great Plains (USEPA 1994).

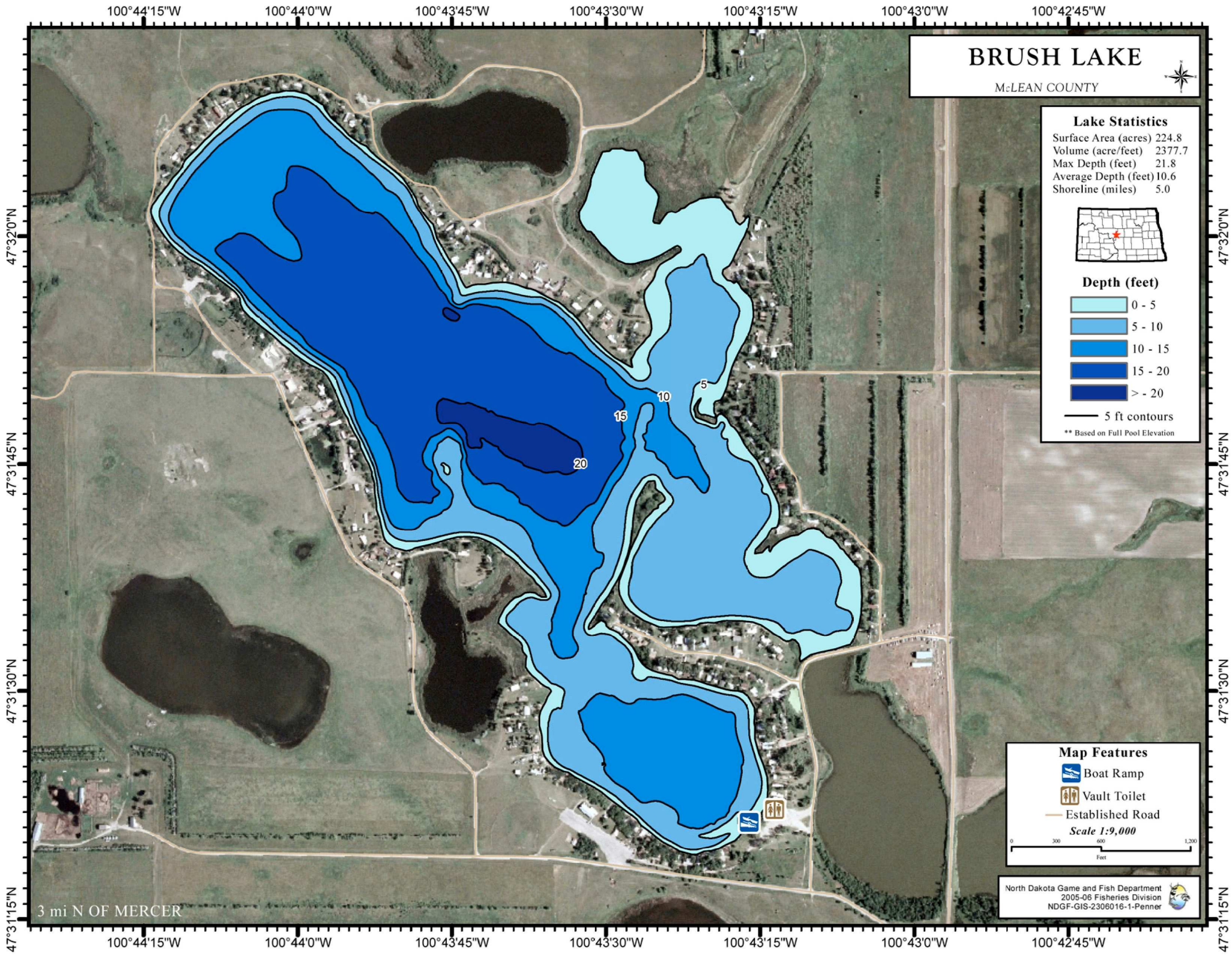


Figure 2. Contour Map of Brush Lake (Map Courtesy of North Dakota Game and Fish Department).

Recreational Facilities: Recreational facilities at Brush Lake include a boat ramp, and boat and vehicle parking. Lake cabins surround the majority of the perimeter of Brush Lake. A vault toilet is located at the boat ramp on the southeast side of the lake.

Water Quality Standards Classification: Brush Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a "warm water fishery" or "waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present."

Historical and Current Fishery: Brush Lake's historical fishery included northern pike, walleye, bluegill, yellow perch, smallmouth bass, and fathead minnows stocked by the NDG&F. Test netting has also produced white suckers, brook sticklebacks, largemouth bass and bullheads in Brush Lake. Currently northern pike, yellow perch, and walleye are managed in Brush Lake.

Historical Water Quality Sampling: Historical water quality data includes results from nine samples collected from 1991 through 2000.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Brush Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural or enhanced lakes in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There are eight temperature and dissolved oxygen profiles for Brush Lake collected from 1991-2006. Temperature and oxygen profiles are presented for two time periods, 1991-1992, and 2005-2006 (Figures 3 and 4).

The profile data shows that normally Brush Lake is well oxygenated during the open water period but does experiences oxygen decay under ice condition especially near the water-sediment interface. During these periods the dissolved oxygen concentrations do drop below the state's water quality standard of 5 mg/L at depths equal to thermal stratification. Of the eight profiles, three samples, collected on 8/1/1991, 1/28/1992, and 1/25/2006, dropped below the state standard of 5 mg/L. While the loss of dissolved oxygen during this period is concerning, there is enough dissolved oxygen to maintain aquatic life in the majority of the water column.

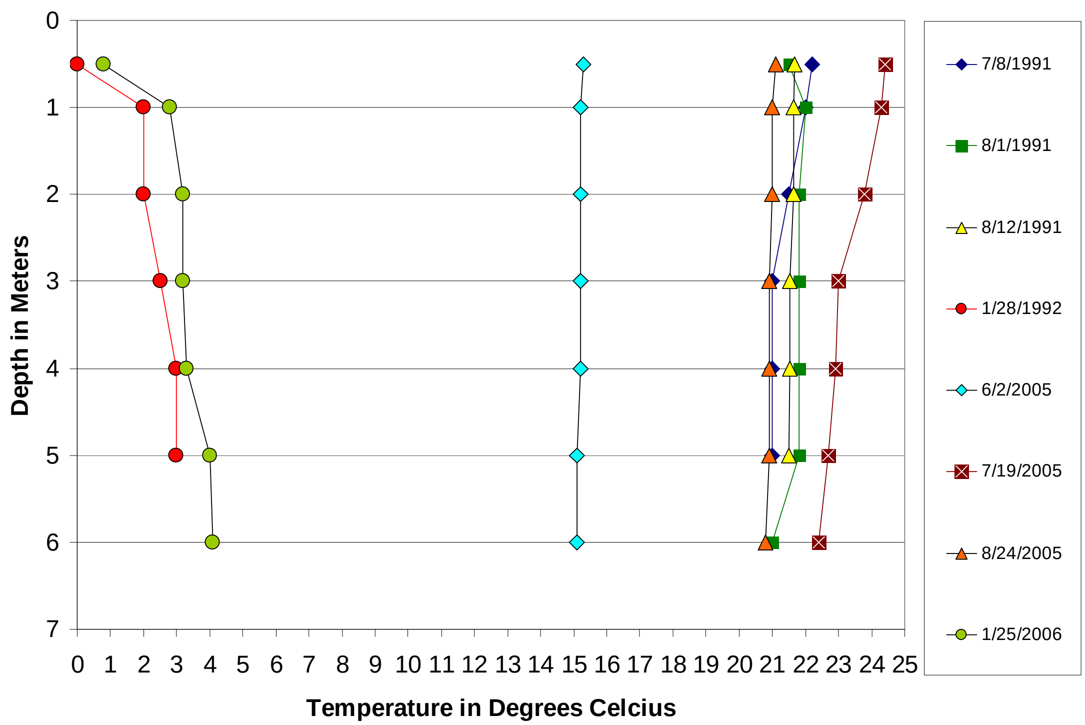


Figure 3. Temperature Profiles for Brush Lake from 1991 to 2006.

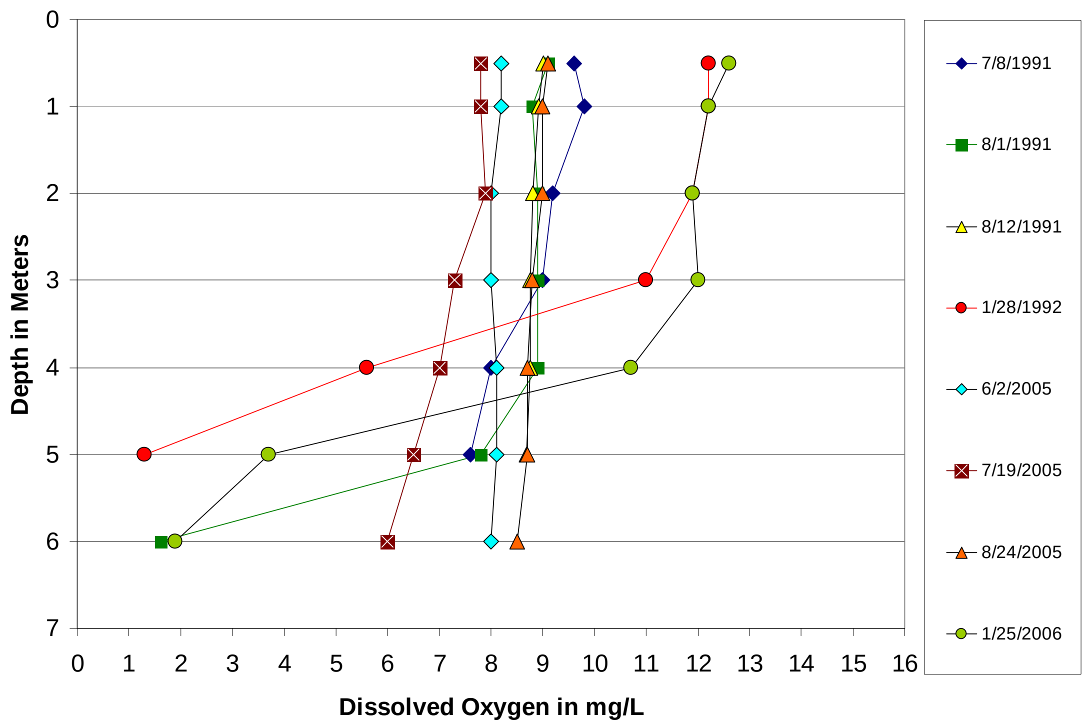


Figure 4. Dissolved Oxygen Profiles for Brush Lake from 1991 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006 indicate Brush Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 422 mg/L to 488 mg/L (Table 1). Based on the 2005-2006 water quality data (Table 1), Brush Lake is sodium bicarbonate dominated with an average sodium concentration of 149 mg/L and an average bicarbonate concentration of 449 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 774 mg/L and 1218 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.390 mg/L and 0.034 mg/L, respectively.

When comparing historical water quality data for Brush Lake (Table 2) to current data (Table 1) most water quality constituents have remained relatively stable. For example, the historical average bicarbonate and sodium concentrations were 499 mg/L and 145 mg/L, respectively, compared to the current averages of 449 mg/L for bicarbonate and 149 mg/L for sodium. The only notable exception is that the average total phosphorus concentration has decreased. The historical average total phosphorus concentration was 0.093 mg/L, compared to the current average of 0.034 mg/L.

Table 1. Statistical Summary of Brush Lake's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	447	422	488	29
Total Ammonia as N	mg/L	4	0.012	0.010[1]	0.018	0.004
Bicarbonate (HCO_3)	mg/L	4	449	401	554	71
Calcium (Ca)	mg/L	4	24.0	20.5	28.3	3.8
Carbonate (CO_3)	mg/L	4	47	21	59	18
Chloride (Cl)	mg/L	4	14	13	17	2
Chlorophyll-a	µg/L	3	10.4	2.0[1]	18.4	8.2
Specific Conductance	µmhos	4	1218	1140	1380	110
Total Dissolved Solids	mg/L	4	774	729	866	62
Total Hardness as ($CaCO_3$)	mg/L	4	348	323	397	34
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.087	0.051	0.142	0.040
Magnesium (Mg)	mg/L	4	69.9	66.0	79.4	6.4
Nitrate + Nitrite as N	mg/L	4	0.033	0.020	0.040	0.010
Total Kjeldahl Nitrogen as N	mg/L	4	1.358	1.240	1.470	0.124
Total Nitrogen as N	mg/L	4	1.390	1.260	1.500	0.128
pH		4	8.80	8.52	8.95	0.19
Total Phosphorus as P	mg/L	4	0.034	0.025	0.046	0.009
Potassium (K)	mg/L	4	20.0	18.9	21.6	1.2
Sodium (Na)	mg/L	4	149	141	162	9
Sulfate (SO4)	mg/L	4	228	212	263	24

[1]Equal to lower detection limit

When compared to the Rangeland Plains regional average for natural and enhanced lakes (Table 3) Brush Lake is lower in dissolved solids and nutrient concentrations lakes (Table 1). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1588 mg/L, 1.826 mg/L, and 0.244 mg/L, respectively, compared to Brush Lake's average TDS, total nitrogen, and total phosphorus concentrations of 774 mg/L, 1.390 mg/L and 0.034 mg/L, respectively.

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Brush Lake, and that the ratio of total nitrogen as N, to total phosphorus as P (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were 13 water quality sample results for Brush Lake collected between July 1991 and January 2006 where the N:P ratio could be calculated. The results from this analysis indicate that Brush Lake is most often phosphorus limited (Figure 5).

The nitrogen to phosphorus ratio for Brush Lake ranged from a low of 7 to a high of 82 with an average of 34. Of the 13 samples collected, all but three samples were above a ratio of 15, indicating phosphorus is limiting primary production in Brush Lake.

Table 2. Statistical Summary of Brush Lake's Historical Water Quality Data Collected Between 1991 and 2000.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	539	495	624	73
Total Ammonia as N	mg/L	9	0.024	0.010[1]	0.076	0.022
Bicarbonate (HCO_3)	mg/L	3	499	443	593	82
Calcium (Ca)	mg/L	3	15	14	17	2
Carbonate (CO_3)	mg/L	3	78	70	83	7
Chloride (Cl)	mg/L	3	15.3	13.7	17.7	2.1
Chlorophyll-a	µg/L	8	14.4	6.0	34.0	8.7
Specific Conductance	µmhos	3	1392	1295	1540	130
Total Dissolved Solids	mg/L	3	860	767	1010	131
Total Hardness as ($CaCO_3$)	mg/L	3	411	353	488	69
Hydroxide (OH)	mg/L	NC[2]	NC[2]	NC[2]	NC[2]	0
Iron (Fe)	mg/L	3	0.030	0.021	0.042	0.011
Magnesium (Mg)	mg/L	3	90.6	77.4	108.0	15.7
Nitrate + Nitrite as N	mg/L	8	0.025	0.005[1]	0.051	0.014
Total Kjeldahl Nitrogen as N	mg/L	9	1.796	0.990	3.110	0.786
Total Nitrogen as N	mg/L	6	1.347	1.010	1.520	0.186
pH		3	9.03	8.90	9.10	0.12
Total Phosphorus as P	mg/L	9	0.093	0.018	0.173	0.055
Potassium (K)	mg/L	3	27.0	23.7	30.9	3.6
Sodium (Na)	mg/L	3	145	124	172	25
Sulfate (SO4)	mg/L	3	241	217	284	37

[1]Equal to lower detection limit
[2]No data collected

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005-2006, Brush Lake's current trophic status is eutrophic. TSI scores ranged from a low of 37 based on chlorophyll-a measurements, to a high of 59 based on total phosphorus. The trophic status score based on Secchi disk transparency was similar to that of total phosphorus, at 57 (Figure 6).

A total of 13 total phosphorus samples, 11 chlorophyll-a samples, and five Secchi disk transparency measurements collected during the open water periods from 1991-2006 were used to evaluate trends in the trophic status of Brush Lake. Based on a visual assessment of the data Brush Lake's trophic status is stable to improving (Figure 6).

Table 3. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lakes in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	272	544	119	4770	130
Total Ammonia as N	mg/L	371	0.107	0.001[1]	2.230	0.200
Bicarbonate (HCO_3)	mg/L	272	489	145	2990	150
Calcium (Ca)	mg/L	272	44	1[1]	282	26
Carbonate (CO_3)	mg/L	262	89	1[1]	1420	30
Chloride (Cl)	mg/L	272	51	4[1]	1070	9
Chlorophyll-a	µg/L	250	22	2[1]	292	28
Specific Conductance	µmhos	272	2168	448	20100	959
Total Dissolved Solids	mg/L	272	1588	227	18200	750
Total Hardness as ($CaCO_3$)	mg/L	272	538	170	2370	260
Hydroxide (OH)	mg/L	200	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	273	0.193	0.001[1]	2.260	0.334
Magnesium (Mg)	mg/L	272	104	20	567	50
Nitrate + Nitrite as N	mg/L	332	0.036	0.002[1]	0.338	0.092
Total Kjeldahl Nitrogen as N	mg/L	340	1.950	0.080	8.500	0.779
Total Nitrogen as N	mg/L	278	1.826	0.269	5.520	0.562
pH		272	8.796	7.400	9.870	0.564
Total Phosphorus as P	mg/L	377	0.244	0.004[1]	1.940	0.205
Potassium (K)	mg/L	272	38	3[1]	356	6
Sodium (Na)	mg/L	272	331	17	4680	171
Sulfate (SO4)	mg/L	272	680	34	10500	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 48 Natural and Enhanced Lakes between 1991 and 2007

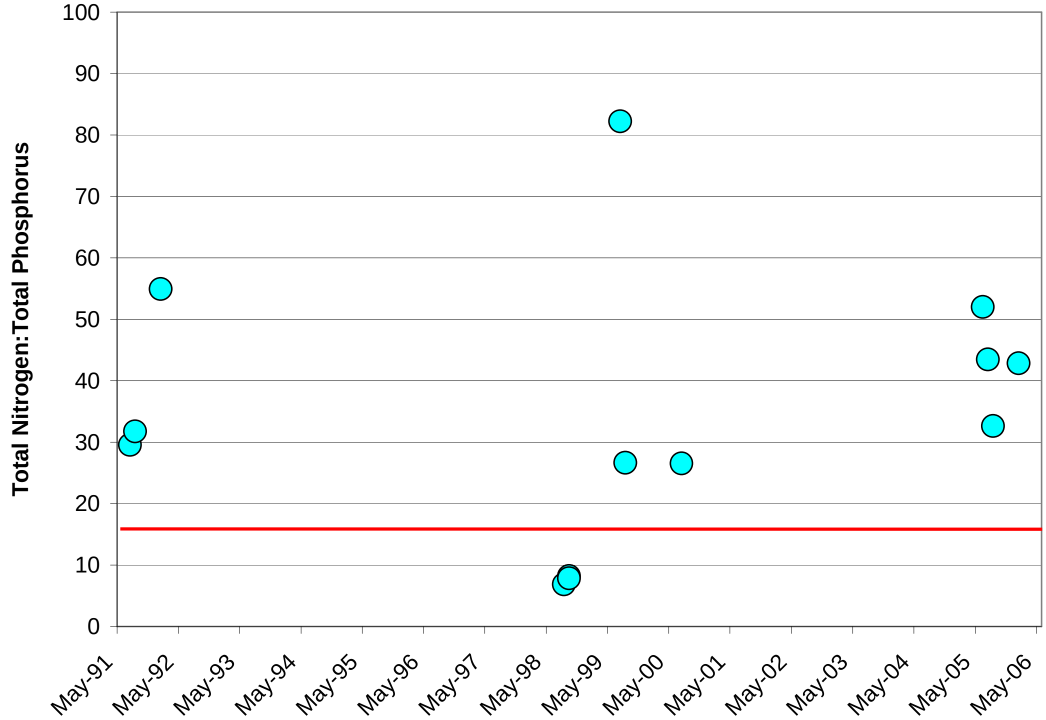


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Brush Lake (1991-2006).

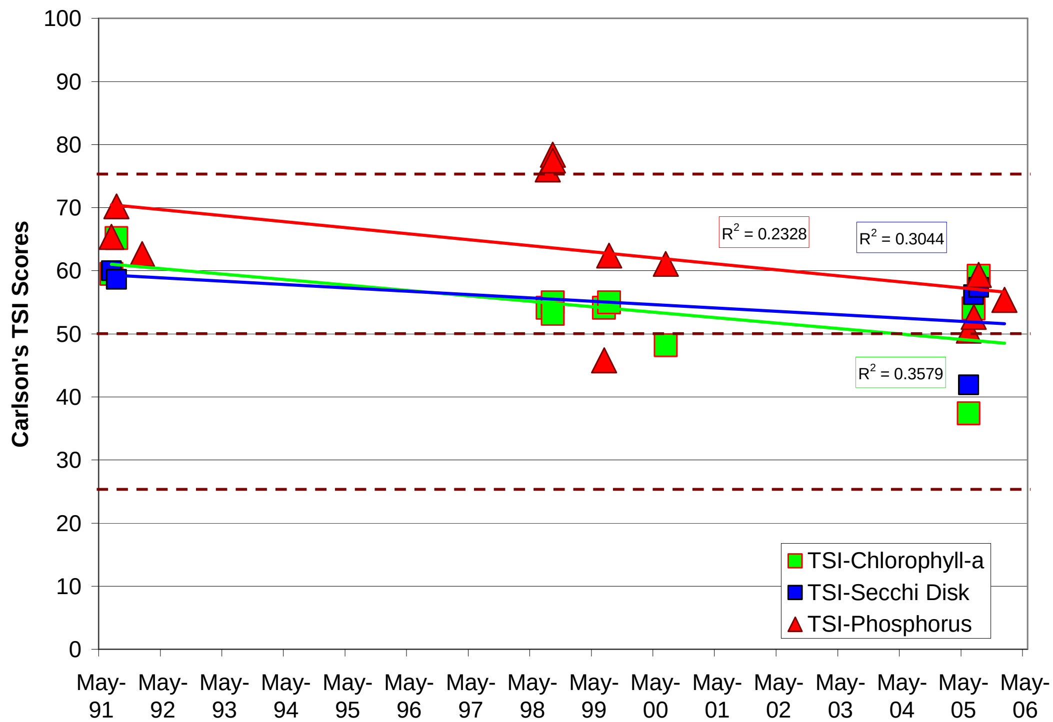


Figure 6. TSI Scores and Temporal Trends for Brush Lake from 1991 to 2006.

Crooked Lake, McLean County

BACKGROUND

Location: Crooked Lake is a natural glacial lake located ½ mile east and 11 miles north of Turtle Lake, North Dakota (Figure 1). Crooked Lake is managed by the North Dakota Game and Fish Department.

Figure 1. Location of Crooked Lake.

Physiographic/Ecological Setting: Crooked Lake has a surface area of 627 acres, a maximum depth of 17.6 ft, and an average depth of 9.2 ft (Figure 2). Crooked Lake's watershed lies within the Northwestern Glaciated Plains (NGP) Level III Ecoregion, part of the broader Rangeland Plains region. The NGP marks the western most extent of continental glacial advancement. The geological youthful landscape has significant surface irregularities and high concentrations of wetlands. The rise in elevation along the eastern edge of this ecoregion defines the boundary of the Great Plains and to the west the Northwestern Great Plains (USEPA 1994).

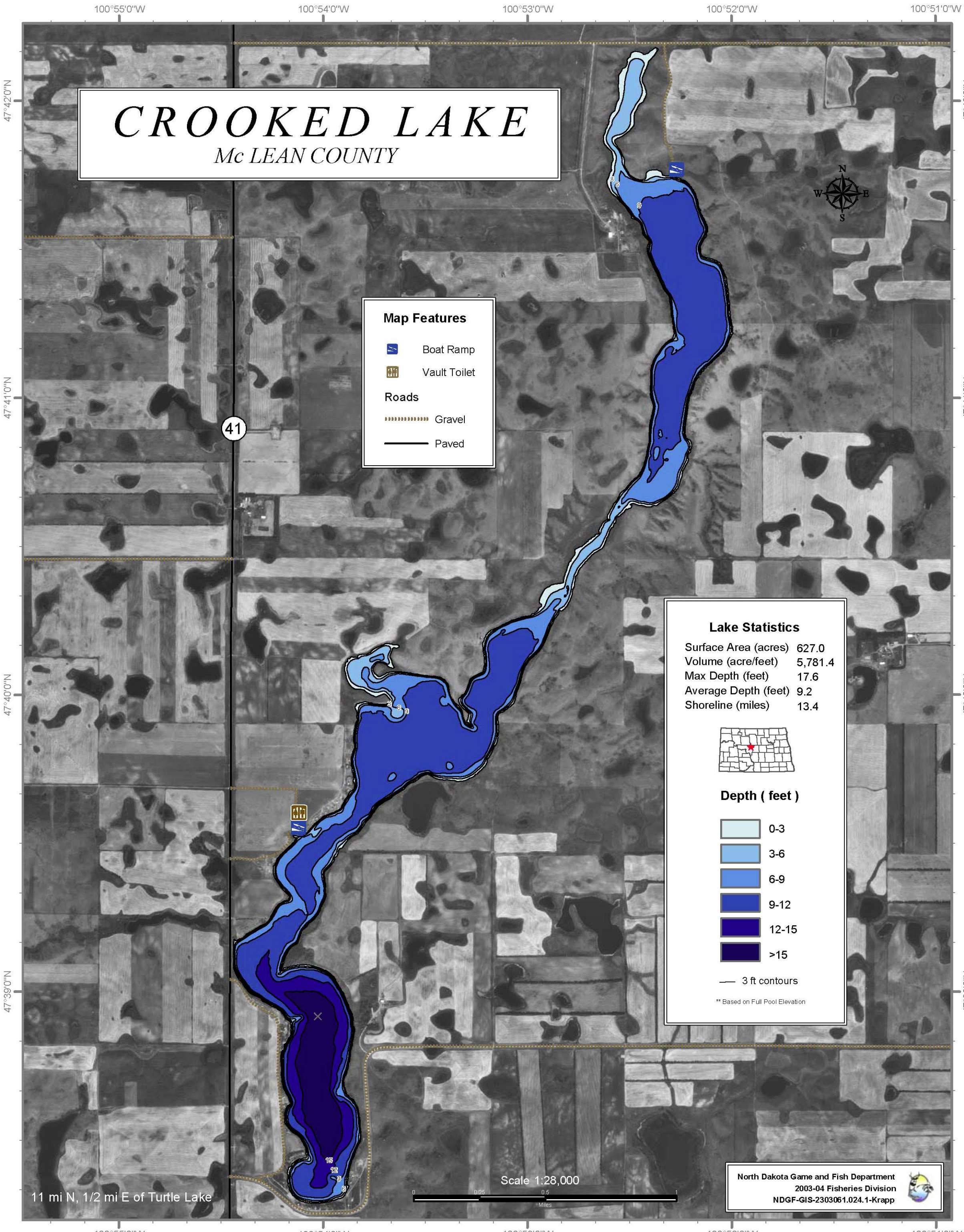


Figure 2. Contour Map of Crooked Lake (Map Courtesy of North Dakota Game and Fish Department).

Recreational Facilities: Recreational facilities at Crooked Lake include two boat ramps, and boat and vehicle parking. Public access is on the southwest and northeast sides of the lake, which includes parking, and the boat ramps. A vaulted toilet is located at the southwest ramp.

Water Quality Standards Classification: Crooked Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a "warm water fishery" or "waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present."

Historical and Current Fishery: Crooked Lake's historical fishery included northern pike, walleye, bluegill, yellow perch, smallmouth bass, and fathead minnows stocked by the NDG&F. Test netting has also produced white suckers, brook sticklebacks and channel catfish in Crooked Lake. Currently northern pike, yellow perch, and walleye are managed in Crooked Lake.

Historical Water Quality Sampling: Historical water quality data includes results from seven samples collected from 1991 through 1994.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Crooked Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural or enhanced lakes in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There were eight temperature and dissolved oxygen profiles for Crooked Lake collected from 1991-2006. Temperature and oxygen profiles are presented for three time periods, 1991-1992, 1994, and 2005-2006 (Figures 3 and 4).

The profile data shows that Crooked Lake rarely experiences thermal stratification during the open water period but does under ice cover. During the ice cover period Crooked Lake can experience rapid and near complete decay often dropping below the state's water quality standard of 5 mg/L. Of the eight profiles, two winter samples collected on 1/31/1992 and 2/16/1994, dropped below the state standard of 5 mg/L.

While the rapid loss of dissolved oxygen during the winters of 1992 and 1994 is concerning, the low dissolved oxygen might be more closely associated with a lack of depth due to the severe drought of the period then eutrophication. Once Crooked Lake regained it's normal or near normal pool depths it also regained an increase in dissolved oxygen concentrations (Figure 4).

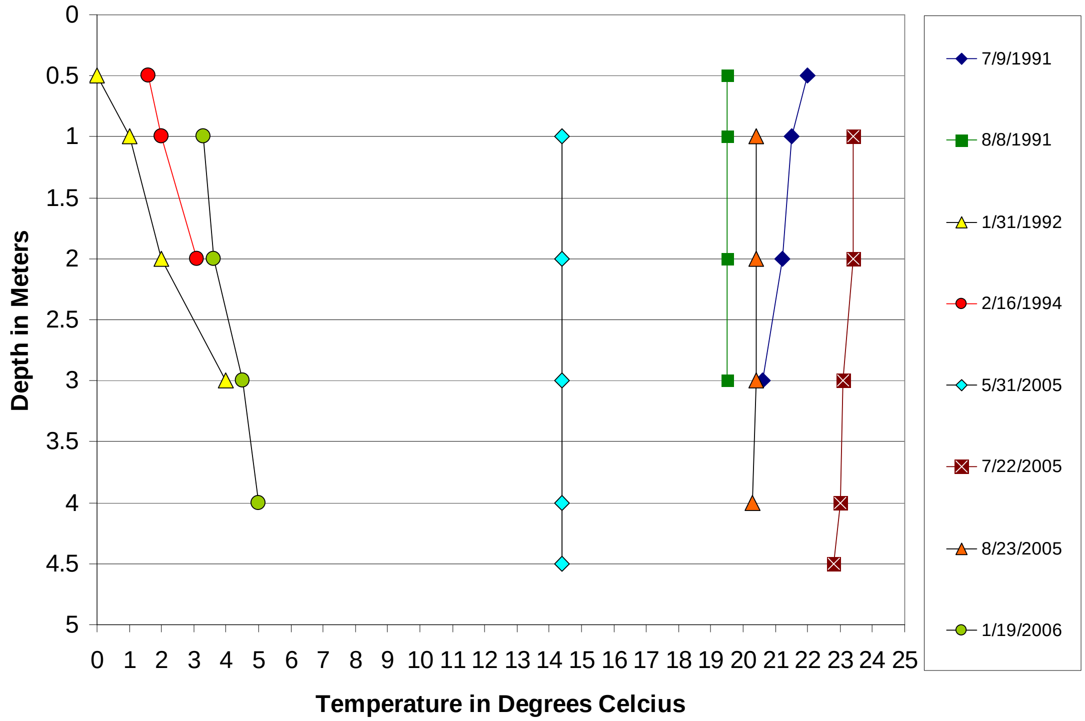


Figure 3. Temperature Profiles for Crooked Lake from 1991 to 2006.

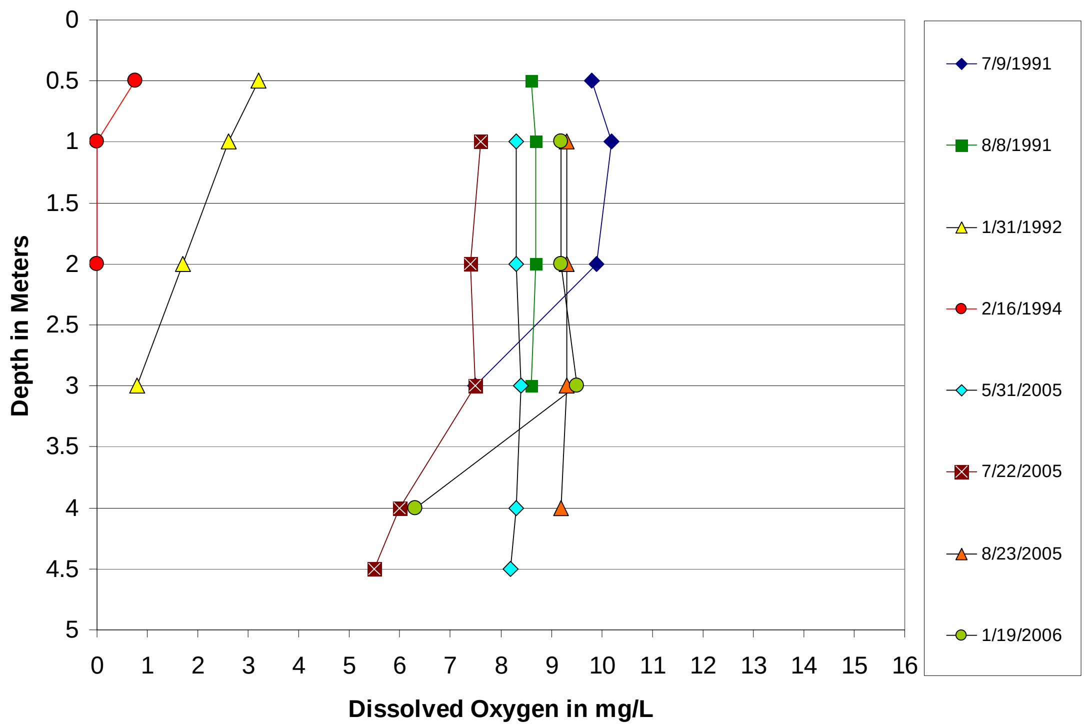


Figure 4. Dissolved Oxygen Profiles for Crooked Lake from 1991 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006 indicate Crooked Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 355 mg/L to 432 mg/L (Table 1). Based on the 2005-2006 water quality data (Table 1), Crooked Lake is sodium bicarbonate dominated with an average sodium concentration of 59 mg/L and an average bicarbonate concentration of 384 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 584 mg/L and 937 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.480 mg/L and 0.028 mg/L, respectively.

Table 1. Statistical Summary of Crooked Lake's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	383	355	432	34
Total Ammonia as N	mg/L	4	0.043	0.010[1]	0.103	0.044
Bicarbonate (HCO_3)	mg/L	4	384	322	512	86
Calcium (Ca)	mg/L	4	26.6	23.9	30.6	2.9
Carbonate (CO_3)	mg/L	4	41	7	64	24
Chloride (Cl)	mg/L	4	10	9	12	1
Chlorophyll-a	µg/L	3	14.4	3[1]	21.6	10.0
Specific Conductance	µmhos	4	937	871	1090	103
Total Dissolved Solids	mg/L	4	584	536	675	62
Total Hardness as ($CaCO_3$)	mg/L	4	414	385	479	44
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.087	0.062	0.122	0.026
Magnesium (Mg)	mg/L	4	84.4	77.9	97.8	9.1
Nitrate + Nitrite as N	mg/L	4	0.085	0.020	0.160	0.060
Total Kjeldahl Nitrogen as N	mg/L	4	1.395	1.180	1.730	0.263
Total Nitrogen as N	mg/L	4	1.480	1.250	1.890	0.295
pH		4	8.78	8.34	9.02	0.30
Total Phosphorus as P	mg/L	4	0.028	0.016	0.033	0.008
Potassium (K)	mg/L	4	14.6	12.2	17.2	2.1
Sodium (Na)	mg/L	4	59	53	68	7
Sulfate (SO4)	mg/L	4	158	144	188	20

[1]Equal to lower detection limit

When compared to historical water quality data for Crooked Lake (Table 2) to the current data (Table 1), it appears that concentrations of most water quality constituents have decreased. For example, the historical average bicarbonate and sodium concentrations were 670 mg/L and 242 mg/L, respectively, compared to average concentrations of 384 mg/L for bicarbonate and 59 mg/L for sodium recorded for the period 2005-2006. The average total nitrogen and total phosphorus concentrations have also decreased when compared to the historical data. The historical average total nitrogen and total phosphorus concentrations were 4.562 mg/L and 0.112 mg/L, respectively, compared to average concentrations of 1.480 mg/L for total nitrogen and 0.028 mg/L for total phosphorus.

Table 2. Statistical Summary of Crooked Lake's Historical Water Quality Data Collected Between 1991 and 1994.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	7	1023	825	1320	235
Total Ammonia as N	mg/L	6	0.216	0.001[1]	0.563	0.262
Bicarbonate (HCO_3)	mg/L	7	670	470	977	215
Calcium (Ca)	mg/L	7	10	7	16	4
Carbonate (CO_3)	mg/L	7	284	215	388	60
Chloride (Cl)	mg/L	7	35.1	24.8	51.4	11.5
Chlorophyll-a	µg/L	2	16.5	14.0	19.0	3.5
Specific Conductance	µmhos	7	2272	1802	3070	580
Total Dissolved Solids	mg/L	7	1704	1220	2500	573
Total Hardness as ($CaCO_3$)	mg/L	7	952	699	1360	277
Hydroxide (OH)	mg/L	2	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	7	0.052	0.027	0.075	0.018
Magnesium (Mg)	mg/L	7	225.3	165.0	321.0	65.2
Nitrate + Nitrite as N	mg/L	5	0.010	0.003	0.030	0.011
Total Kjeldahl Nitrogen as N	mg/L	5	4.326	3.390	6.140	1.070
Total Nitrogen as N	mg/L	3	4.562	3.394	6.170	1.439
pH		7	9.40	9.14	9.60	0.19
Total Phosphorus as P	mg/L	7	0.112	0.082	0.170	0.030
Potassium (K)	mg/L	7	49.5	35.5	73.6	16.4
Sodium (Na)	mg/L	7	242	157	391	100
Sulfate (SO4)	mg/L	7	528	330	857	236

[1]Equal to lower detection limit

Crooked Lake is lower in dissolved solids and nutrients (Table 1) than most natural or enhanced lakes in the Rangeland Plains region (Table 3). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1588 mg/L, 1.826 mg/L, and 0.244 mg/L, respectively, compared to Crooked Lake's average TDS, total nitrogen, and total phosphorus concentrations of 584 mg/L, 1.480 mg/L and 0.028 mg/L, respectively, for the period 2005-2006.

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Crooked Lake, and that the ratio of total nitrogen as N, to total phosphorus as P (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were eight water quality sample results for Crooked Lake collected between July 1991 and January 2006 where the N:P ratio could be calculated. The results from this analysis indicate that Crooked Lake is most often phosphorus limited (Figure 5).

The nitrogen to phosphorus ratio for Crooked Lake ranged from a low of 3 to a high of 78 with an average of 44. Of the eight samples collected, all but two samples were above a ratio of 15, indicating phosphorus is limiting primary production in Crooked Lake.

Table 3. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lakes in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	272	544	119	4770	130
Total Ammonia as N	mg/L	371	0.107	0.001[1]	2.230	0.200
Bicarbonate (HCO_3)	mg/L	272	489	145	2990	150
Calcium (Ca)	mg/L	272	44	1[1]	282	26
Carbonate (CO_3)	mg/L	262	89	1[1]	1420	30
Chloride (Cl)	mg/L	272	51	4[1]	1070	9
Chlorophyll-a	µg/L	250	22	2[1]	292	28
Specific Conductance	µmhos	272	2168	448	20100	959
Total Dissolved Solids	mg/L	272	1588	227	18200	750
Total Hardness as ($CaCO_3$)	mg/L	272	538	170	2370	260
Hydroxide (OH)	mg/L	200	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	273	0.193	0.001[1]	2.260	0.334
Magnesium (Mg)	mg/L	272	104	20	567	50
Nitrate + Nitrite as N	mg/L	332	0.036	0.002[1]	0.338	0.092
Total Kjeldahl Nitrogen as N	mg/L	340	1.950	0.080	8.500	0.779
Total Nitrogen as N	mg/L	278	1.826	0.269	5.520	0.562
pH		272	8.796	7.400	9.870	0.564
Total Phosphorus as P	mg/L	377	0.244	0.004[1]	1.940	0.205
Potassium (K)	mg/L	272	38	3[1]	356	6
Sodium (Na)	mg/L	272	331	17	4680	171
Sulfate (SO4)	mg/L	272	680	34	10500	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 48 Natural and Enhanced Lakes between 1991 and 2007

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005, Crooked Lake's current trophic status is eutrophic. TSI scores ranged from a low of 41 based on chlorophyll-a measurements, to a high of 62 based on Secchi disk transparency. The trophic status score based on total phosphorus was similar to that of Secchi disk transparency, at 55 (Figure 6).

A total of eight total phosphorus samples, five chlorophyll-a samples, and five Secchi disk transparency measurements collected during the open water periods from 1991-2006 were used to evaluate trends in the trophic status of Crooked Lake. Based on visual assessment of the data, Crooked Lake's trophic status is stable to improving (Figure 6).

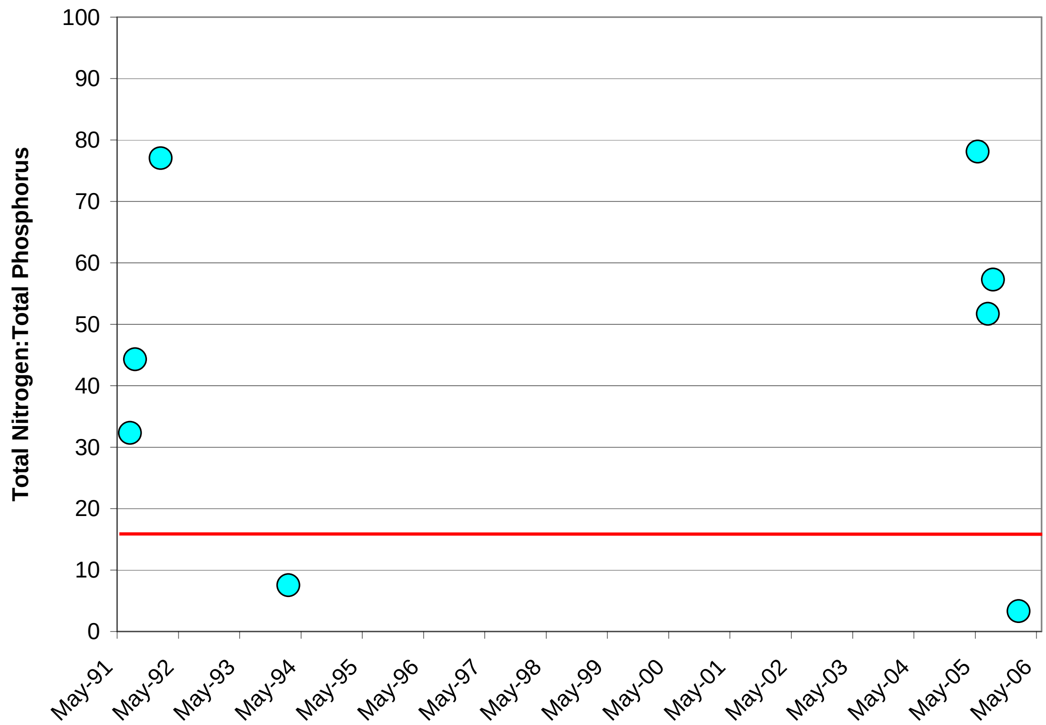


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Crooked Lake (1991-2006).

Figure 6. TSI Scores and Temporal Trends for Crooked Lake from 1991 to 2006.

East Park Lake, McLean County

BACKGROUND

Location: East Park Lake is an enhanced lake located 12 miles south of Mercer, ND, on the McClusky Canal. East Park Lake is managed by the North Dakota Game and Fish Department and the US Bureau of Reclamation (Figure 1).

Figure 1. Location of East Park Lake.

Physiographic/Ecological Setting: East Park Lake has a surface area of 137.2 acres, a maximum depth of 23.7 ft, and an average depth of 13.4 ft (Figure 2). East Park Lake's watershed is approximately 3,000 acres and it lies within the Northwestern Glaciated Plains (NGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The NGP marks the western most extent of continental glacial advancement. The geological youthful landscape has significant surface irregularities and high concentrations of wetlands. The rise in elevation along the eastern edge of this ecoregion defines the boundary of the Great Plains and to the west the Northwestern Great Plains (USEPA 1994).

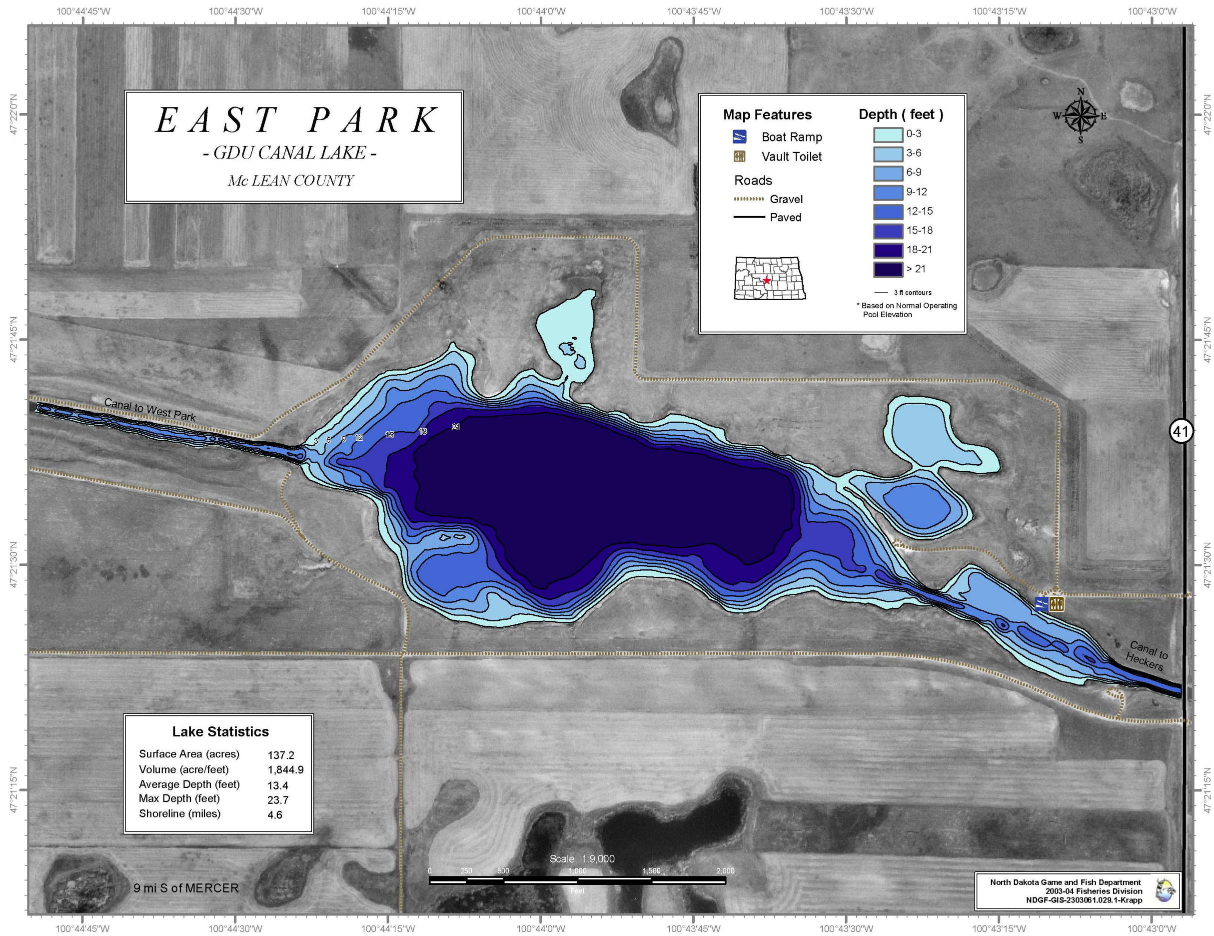


Figure 2. Contour Map of East Park Lake (Map Courtesy of North Dakota Game and Fish Department).

Construction History: East Park Lake is a manmade water body created by modifying a natural depression along the McClusky Canal. Construction on East Park Lake was completed in 1974 and filled the following year from surface and ground water discharges. After 1984, the canal was opened up, and the lake was refreshed with water from Lake Audubon.

Recreational Facilities: Public access to East Park Lake is usually reasonable; however, access can be limited by snow during the winter months. There is a boat dock and a vaulted toilet on the canal, just east of East Park Lake.

Water Quality Standards Classification: East Park Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 2 lake or reservoir. Class 2 lakes or reservoirs are defined as a "cool water fishery" or "waters capable of supporting natural reproduction and growth of cool water fishes (e.g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: Currently and historically, fish stocked into East Park Lake include northern pike, walleye, bluegill, largemouth bass, and yellow perch. Any additional species present in East Park Lake migrated from Lake Audubon and other lakes within the channel system.

Historical Water Quality Sampling: Historical water quality data includes results from five sample sets collected from 1990 through 1994.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for East Park Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural or enhanced lakes in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There were nine temperature and dissolved oxygen profiles for East Park Lake collected from 1990-2006. Temperature and oxygen profiles are presented for three time periods, 1990, 1992-1994, and 2005-2006 (Figures 3 and 4).

The profile data shows that East Park Lake is normally well oxygenated and that even during ice cover only experiences moderate oxygen decay. Of the nine profiles, only one sample, collected on 2/16/1994, dropped below the state standard of 5 mg/L.

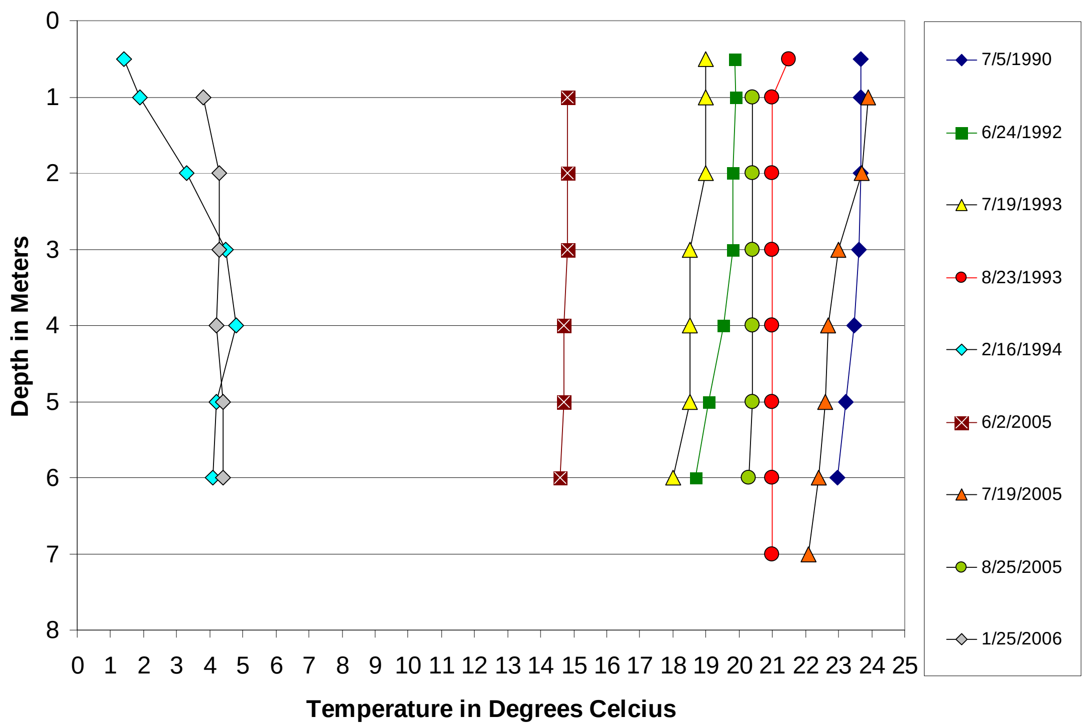


Figure 3. Temperature Profiles for East Park Lake from 1990 to 2006.

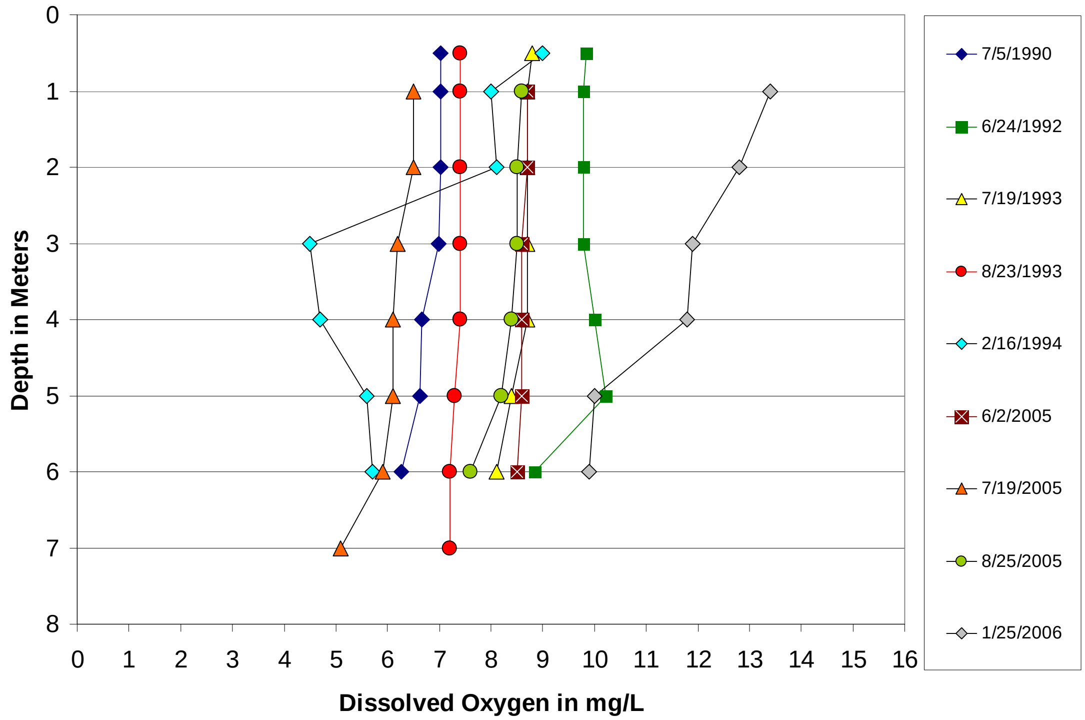


Figure 4. Dissolved Oxygen Profiles for East Park Lake from 1990 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006 indicate East Park Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 250 to 304 mg/L (Table 1). Based on the 2005-2006 water quality data (Table 1), East Park Lake is sodium sulfate dominated with an average sodium concentration of 152 mg/L and an average sulfate concentration of 446 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 914 mg/L and 1360 µmhos, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 0.966 mg/L and 0.044 mg/L, respectively.

When comparing historical water quality data (Table 2) to current (Table 1) from East Park Lake, it appears that concentrations of most water quality constituents have increased moderately. For example, the historical average sulfate and sodium concentrations were 294 mg/L and 106 mg/L, respectively, compared to average concentrations of 446 mg/L for sulfate and 152 mg/L for sodium. While not greater then a standard deviation the average total nitrogen concentrations have decreased and total phosphorus concentrations have increased when compared to the historical data. Historical average total nitrogen and total phosphorus concentrations were 1.033 mg/L and 0.023 mg/L, respectively, compared to average concentrations of 0.966 mg/L for total nitrogen and 0.044 mg/L for total phosphorus.

Table 1. Statistical Summary of East Park Lake's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	269	250	304	24
Total Ammonia as N	mg/L	4	0.073	0.042	0.099	0.024
Bicarbonate (HCO_3)	mg/L	4	305	289	347	28
Calcium (Ca)	mg/L	4	57.7	51.7	66.5	6.3
Carbonate (CO_3)	mg/L	4	12	7	18	5
Chloride (Cl)	mg/L	4	18	17	21	2
Chlorophyll-a	µg/L	3	9.9	2.8	23.9	12.1
Specific Conductance	µmhos	4	1360	1260	1560	138
Total Dissolved Solids	mg/L	4	914	840	1050	94
Total Hardness as ($CaCO_3$)	mg/L	4	412	372	481	48
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.228	0.049	0.393	0.147
Magnesium (Mg)	mg/L	4	65.0	59.1	76.6	7.9
Nitrate + Nitrite as N	mg/L	4	0.058	0.020	0.100	0.035
Total Kjeldahl Nitrogen as N	mg/L	4	0.908	0.791	1.060	0.125
Total Nitrogen as N	mg/L	4	0.966	0.861	1.080	0.121
pH		4	8.49	8.42	8.58	0.08
Total Phosphorus as P	mg/L	4	0.044	0.026	0.070	0.021
Potassium (K)	mg/L	4	12.0	11.2	13.4	1.0
Sodium (Na)	mg/L	4	152	144	164	10
Sulfate (SO4)	mg/L	4	446	404	521	55

[1]Equal to lower detection limit

When compared to the regional for all natural and enhanced lakes in the Rangeland Plains (Table 3) East Park Lake is slightly lower in dissolved solids and nutrient concentrations than the reported average (Table 3). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1588 mg/L, 1.826 mg/L, and 0.244 mg/L, respectively, compared to East Park Lake's average TDS, total nitrogen, and total phosphorus concentrations of 914 mg/L, 0.966 mg/L and 0.044 mg/L, respectively, for the period 2005-2006.

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in East Park Lake and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight, in algae is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were seven water quality sample results for East Park Lake collected between July 1993 and January 2006 where the N:P ratio could be calculated. The results from this analysis indicate that East Park Lake is most often phosphorus limited (Figure 5).

N:P ratios for East Park Lake ranged from a low of 15 to a high of 199 with an average of 56. Of the seven samples collected on East Park Lake, each one was at or above an N:P ratio of 15, indicating phosphorus limitation.

Table 2. Statistical Summary of East Park Lake's Historical Water Quality Data Collected Between 1990 and 1994.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	220	200	249	26
Total Ammonia as N	mg/L	3	0.103	0.036	0.211	0.095
Bicarbonate (HCO_3)	mg/L	3	254	220	304	44
Calcium (Ca)	mg/L	3	48	43	53	5
Carbonate (CO_3)	mg/L	3	8	1[1]	12	6
Chloride (Cl)	mg/L	3	15.3	14.4	16.9	1.4
Chlorophyll-a	µg/L	2	10.8	6.6	15.0	5.9
Specific Conductance	µmhos	3	1004	962	1080	66
Total Dissolved Solids	mg/L	3	644	590	724	71
Total Hardness as ($CaCO_3$)	mg/L	3	285	264	307	22
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	3	0.218	0.089	0.379	0.148
Magnesium (Mg)	mg/L	3	40.1	38.1	42.5	2.2
Nitrate + Nitrite as N	mg/L	3	0.033	0.011	0.066	0.029
Total Kjeldahl Nitrogen as N	mg/L	3	1.000	0.761	1.290	0.268
Total Nitrogen as N	mg/L	3	1.033	0.772	1.356	0.297
pH		3	8.35	7.97	8.57	0.33
Total Phosphorus as P	mg/L	3	0.023	0.004[1]	0.042	0.019
Potassium (K)	mg/L	3	6.7	6.4	6.9	0.3
Sodium (Na)	mg/L	3	106	97	121	13
Sulfate (SO4)	mg/L	3	294	270	332	33

[1]Equal to lower detection limit

Table 3. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lakes in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	272	544	119	4770	130
Total Ammonia as N	mg/L	371	0.107	0.001[1]	2.230	0.200
Bicarbonate (HCO_3)	mg/L	272	489	145	2990	150
Calcium (Ca)	mg/L	272	44	1[1]	282	26
Carbonate (CO_3)	mg/L	262	89	1[1]	1420	30
Chloride (Cl)	mg/L	272	51	4[1]	1070	9
Chlorophyll-a	µg/L	250	22	2[1]	292	28
Specific Conductance	µmhos	272	2168	448	20100	959
Total Dissolved Solids	mg/L	272	1588	227	18200	750
Total Hardness as ($CaCO_3$)	mg/L	272	538	170	2370	260
Hydroxide (OH)	mg/L	200	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	273	0.193	0.001[1]	2.260	0.334
Magnesium (Mg)	mg/L	272	104	20	567	50
Nitrate + Nitrite as N	mg/L	332	0.036	0.002[1]	0.338	0.092
Total Kjeldahl Nitrogen as N	mg/L	340	1.950	0.080	8.500	0.779
Total Nitrogen as N	mg/L	278	1.826	0.269	5.520	0.562
pH		272	8.796	7.400	9.870	0.564
Total Phosphorus as P	mg/L	377	0.244	0.004[1]	1.940	0.205
Potassium (K)	mg/L	272	38	3[1]	356	6
Sodium (Na)	mg/L	272	331	17	4680	171
Sulfate (SO4)	mg/L	272	680	34	10500	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 48 Natural and Enhanced Lakes between 1991 and 2007

Trophic Status Assessment: Based on limited chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005-2006, East Park Lake's current trophic status is eutrophic. TSI scores ranged from a low of 41 based on chlorophyll-a, to a high of 65 based on Secchi disk transparency and total phosphorus (Figure 6).

A total of seven total phosphorus samples, five chlorophyll-a samples and five Secchi disk transparency measurements collected during the open water periods from 1993-2006 were used to evaluate trends in the trophic status of East Park Lake. The trophic status of East Park Lake appears to be remaining relatively stable (Figure 6).

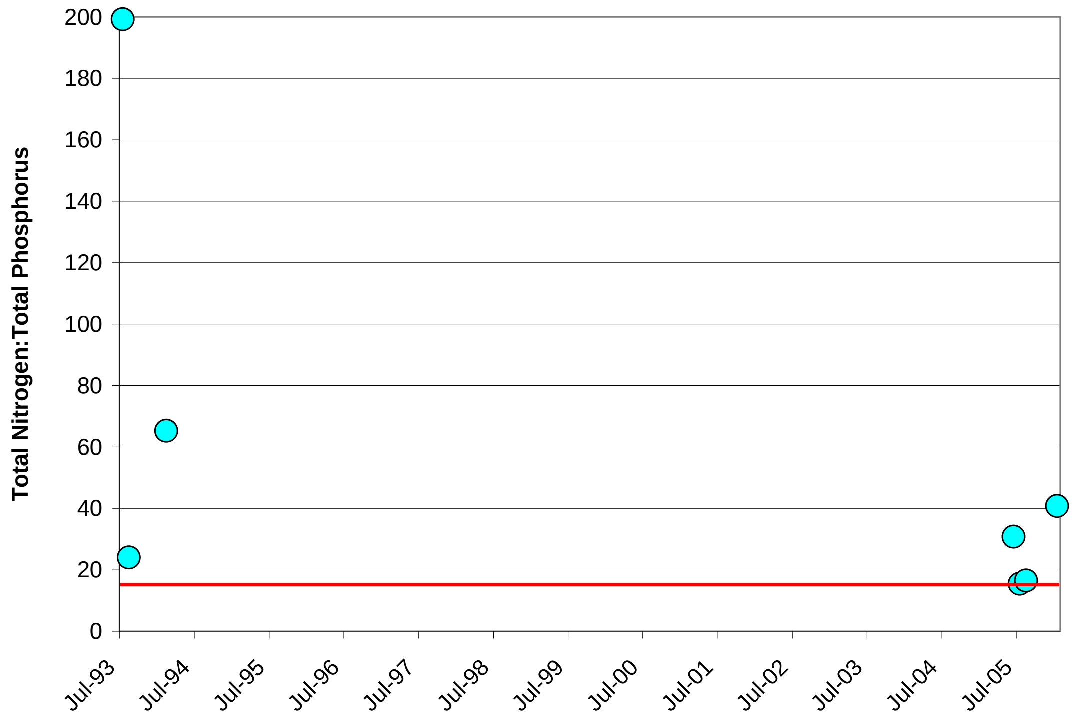


Figure 5. Total Nitrogen to Total Phosphorus Ratios in East Park Lake (1993-2006).

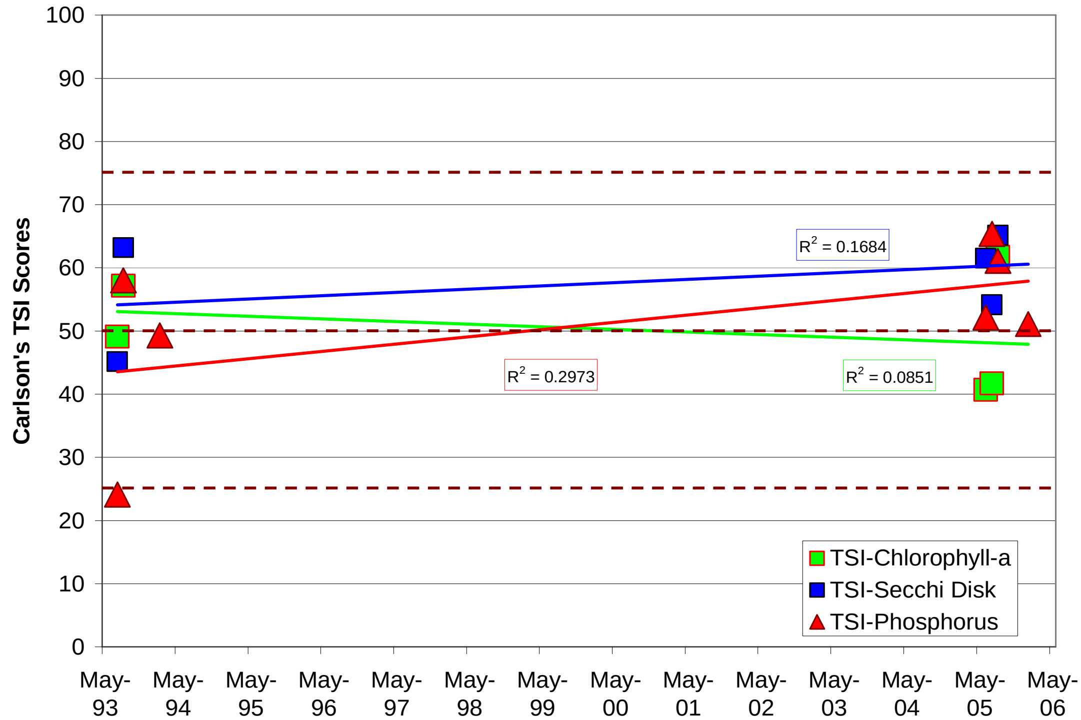


Figure 6. TSI Scores and Temporal Trends for East Park Lake from 1993 to 2006.

Lake Audubon, McLean County

BACKGROUND

Location: Lake Audubon is a large irrigation impoundment located just north of Coleharbor, North Dakota, on the east side of U.S. Highway 83 (Figure 1). The reservoir is managed by the Bureau of Reclamation, U.S. Fish and Wildlife Service, and the North Dakota Game and Fish Department.

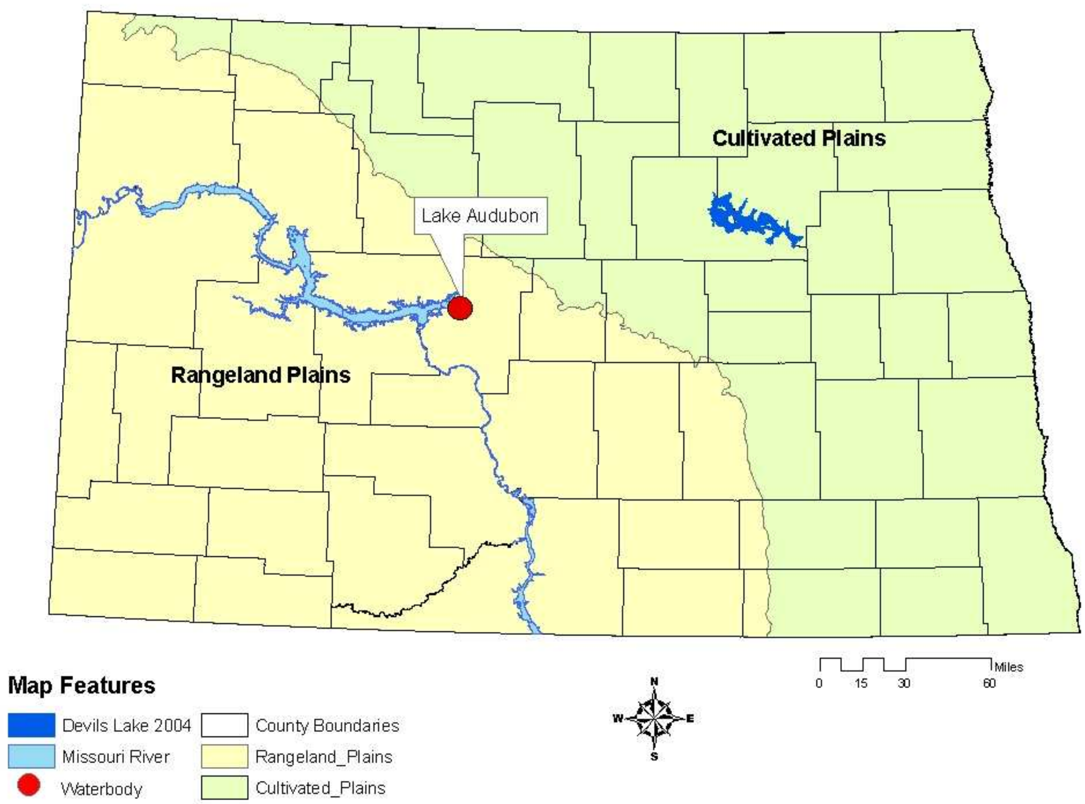


Figure 1. Location of Lake Audubon.

Physiographic/Ecological Setting: Lake Audubon has a surface area of 16,611.0 acres, a maximum depth of 59.9 ft, and an average depth of 19.2 ft (Figure 2). The reservoir's watershed is located within the Northwestern Great Plains (NWGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). Lake Audubon watershed's landscape is rolling plains. Flood plain slopes and hillsides are usually native grasslands, while the uplands and flood plains themselves have mostly been converted to small grains and alfalfa.

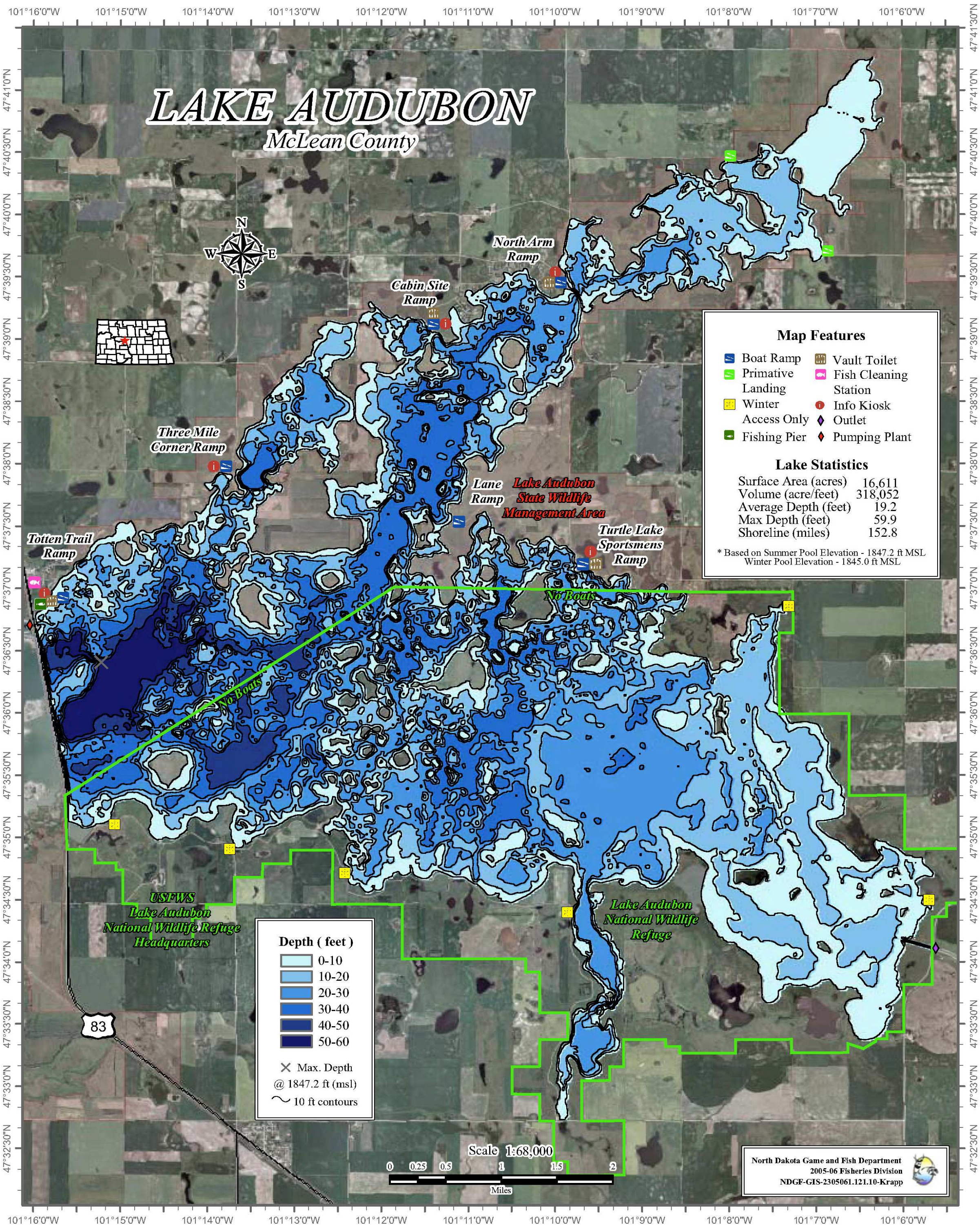


Figure 2. Contour Map of Lake Audubon (Map Courtesy of North Dakota Game and Fish Department).

Construction History: Lake Audubon was impounded in 1954 by the Snake Creek Embankment when U.S. Highway 83 was relocated. The Lake Audubon National Wildlife Refuge encompasses the southeastern portion of the lake (Figure 2). Lake Audubon is the irrigation reservoir for the McClusky Canal.

Recreational Facilities: Recreational facilities at Lake Audubon include six cement boat ramps, two primitive ramps, boat and vehicle parking, a fish cleaning station, five information kiosks, and a fishing pier. Four of the six ramps on the north side of the lake, include vaulted restrooms. There are several winter access points on the south side of the lake, that aren't accessible during the summer because they are part of the wildlife refuge.

Water Quality Standards Classification: Lake Audubon is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 2 lake or reservoir. Class 2 lakes or reservoirs are defined as a "cool water fishery" or "waters capable of supporting natural reproduction and growth of cool water fishes (e.g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: Lake Audubon's fishery over time has included nearly every fish stocked by the NDG&F. Currently, the fishery includes yellow perch, smallmouth bass, and walleye. Boats are restricted to idle speeds in the lake's north arm.

Historical Water Quality Sampling: There is no historical water quality data available for Lake Audubon.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Lake Audubon have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There are four temperature and dissolved oxygen profiles for Lake Audubon collected between 2005 and 2006 (Figures 3 and 4). The profile data shows that Lake Audubon is well oxygenated, and experiences only occasional and gradual oxygen decay near the sediment-water interface. Of the four profiles, only one collected on 7/18/2005, showed dissolved oxygen dropping below the state standard of 5 mg/L. This sag in dissolve oxygen occurred below the metalimnion, at a depth of 15 meters and within 1 meter of the bottom.

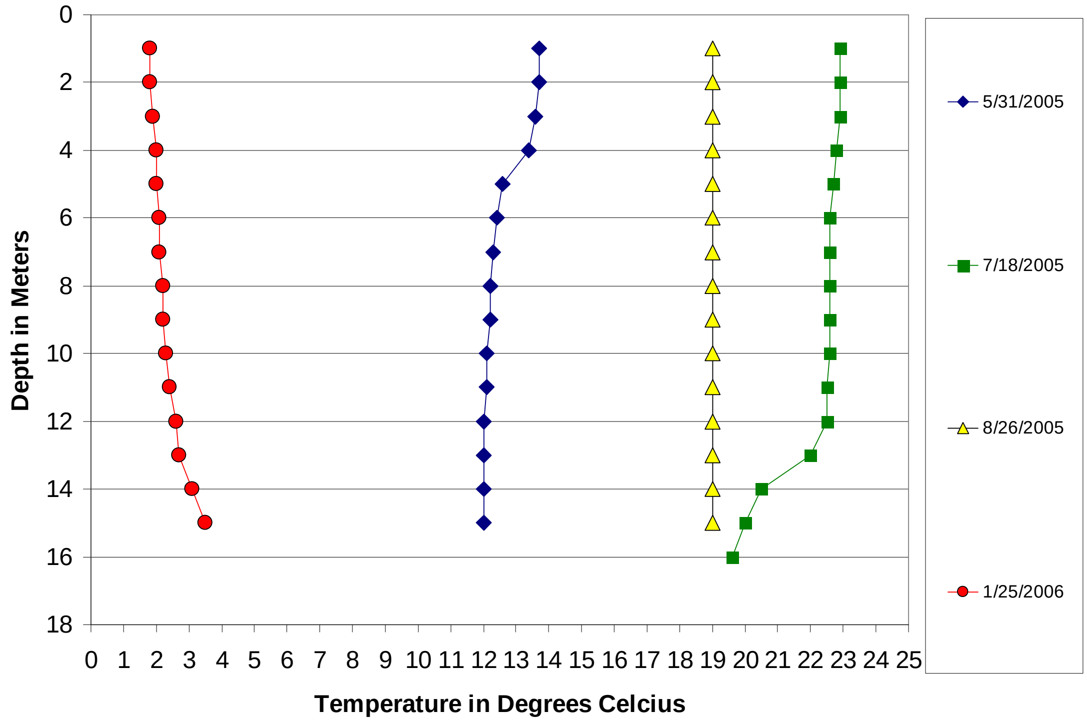


Figure 3. Temperature Profiles for Lake Audubon from 2005 to 2006.

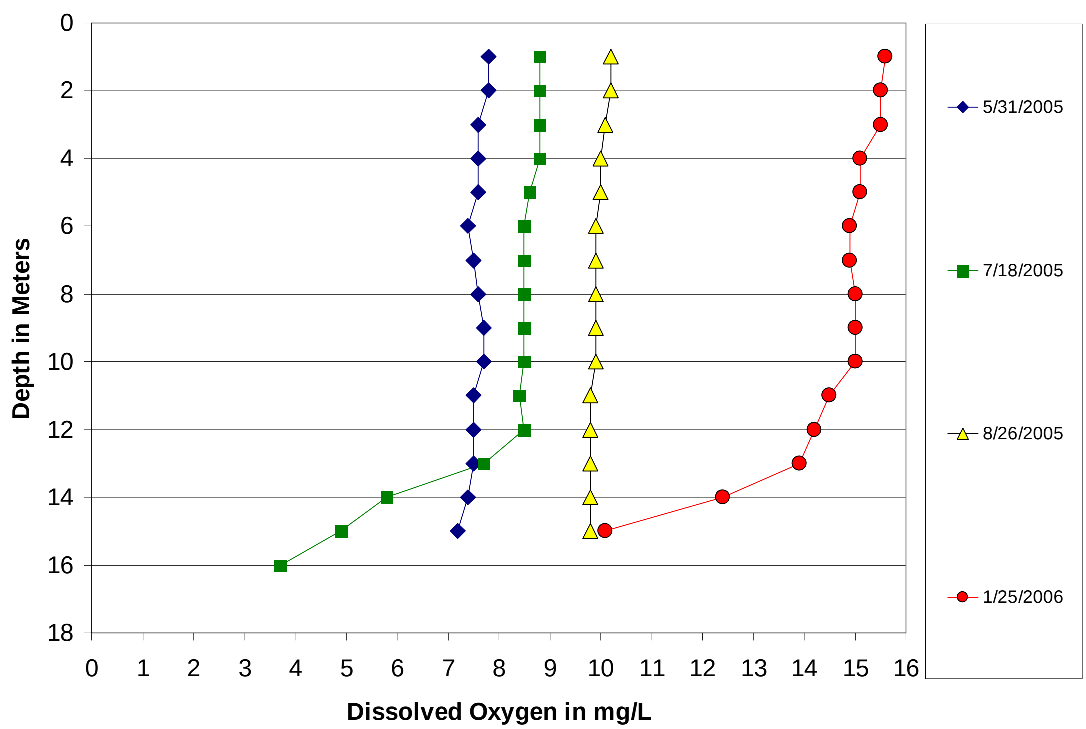


Figure 4. Dissolved Oxygen Profiles for Lake Audubon from 2005 to 2006.

General Water Quality: Data collected by the NDGF in 2005 and 2006 indicate Lake Audubon is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 213mg/L to 229 mg/L (Table 1). Based on the 2005-2006 water quality data (Table 1), Lake Audubon is sodium sulfate dominated with an average sodium concentration of 118 mg/L and an average sulfate concentration of 279 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 630 mg/L and 979 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 0.538 mg/L and 0.009 mg/L, respectively.

Table 1. Statistical Summary of Lake Audubon's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	219	213	229	7
Total Ammonia as N	mg/L	4	0.013	0.010[1]	0.016	0.003
Bicarbonate (HCO_3)	mg/L	4	247	233	270	16
Calcium (Ca)	mg/L	4	42.0	40.0	43.7	1.8
Carbonate (CO_3)	mg/L	4	10	5	14	5
Chloride (Cl)	mg/L	4	14	14	16	1
Chlorophyll-a	µg/L	3	2.0	1.5	3.0	0.9
Specific Conductance	µmhos	4	979	927	1070	63
Total Dissolved Solids	mg/L	4	630	601	682	36
Total Hardness as ($CaCO_3$)	mg/L	4	257	246	278	14
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.142	0.036	0.237	0.084
Magnesium (Mg)	mg/L	4	37.0	35.3	41.2	2.8
Nitrate + Nitrite as N	mg/L	4	0.115	0.020	0.360	0.164
Total Kjeldahl Nitrogen as N	mg/L	4	0.423	0.365	0.522	0.069
Total Nitrogen as N	mg/L	4	0.538	0.405	0.882	0.231
pH		4	8.50	8.37	8.59	0.09
Total Phosphorus as P	mg/L	4	0.009	0.006	0.016	0.005
Potassium (K)	mg/L	4	6.2	5.8	6.8	0.4
Sodium (Na)	mg/L	4	118	110	127	7
Sulfate (SO4)	mg/L	4	279	263	307	19

[1]Equal to lower detection limit

When compared to the Rangeland Plains regional average concentrations (Table 2) Lake Audubon is lower in dissolved solids and nutrient than most reservoirs (Table 1). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1176 mg/L, 1.472 mg/L, and 0.135 mg/L, respectively, compared to Lake Audubon's average TDS, total nitrogen, and total phosphorus concentrations of 630 mg/L, 0.538 mg/L and 0.009 mg/L, respectively, for the period 2005-2006.

Table 2. Statistical Summary of Water Quality Data[2] Collected from Reservoirs in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	408	309	101	982	130
Total Ammonia as N	mg/L	469	0.097	0.001[1]	2.440	0.200
Bicarbonate (HCO_3)	mg/L	408	318	14	1040	150
Calcium (Ca)	mg/L	408	50	5	160	26
Carbonate (CO_3)	mg/L	402	30	1[1]	197	30
Chloride (Cl)	mg/L	408	13.3	0.3	74.5	8.8
Chlorophyll-a	µg/L	321	21.2	1.5	218.0	27.9
Specific Conductance	µmhos	428	1733	262	5880	959
Total Dissolved Solids	mg/L	409	1176	147	5110	750
Total Hardness as ($CaCO_3$)	mg/L	408	397	45	1850	260
Hydroxide (OH)	mg/L	337	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	409	0.179	0.007	4.110	0.334
Magnesium (Mg)	mg/L	408	66.0	5.6	353.0	49.6
Nitrate + Nitrite as N	mg/L	395	0.048	0.001[1]	0.790	0.092
Total Kjeldahl Nitrogen as N	mg/L	359	1.556	0.365	7.720	0.779
Total Nitrogen as N	mg/L	302	1.472	0.405	4.840	0.562
pH		428	8.61	6.73	9.87	0.56
Total Phosphorus as P	mg/L	475	0.135	0.004	3.160	0.205
Potassium (K)	mg/L	408	14.6	4.2	39.2	6.3
Sodium (Na)	mg/L	408	239	3[1]	932	171
Sulfate (SO4)	mg/L	406	604	1[1]	3210	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 69 Reservoirs between 1991 and 2007

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Lake Audubon and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight, in algae is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were four water quality sample results for Lake Audubon collected between May 2005 and January 2006 where the N:P ratio could be calculated. The results from this analysis indicate that Lake Audubon is phosphorus limited (Figure 5). N:P ratios for Lake Audubon ranged from a low of 55 to a high of 68 with an average of 64. All four samples collected on Lake Audubon were above an N:P ratio of 15 indicating phosphorus limitation.

Trophic Status Assessment: Based on limited chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005-2006, Lake Audubon's current trophic status is mesotrophic. TSI scores ranged from a low of 30 based on total phosphorus, to a high of 56 based on Secchi disk transparency. The average trophic status score based on chlorophyll-a measurements was similar to that estimated based on total phosphorus, at 37 (Figure 6).

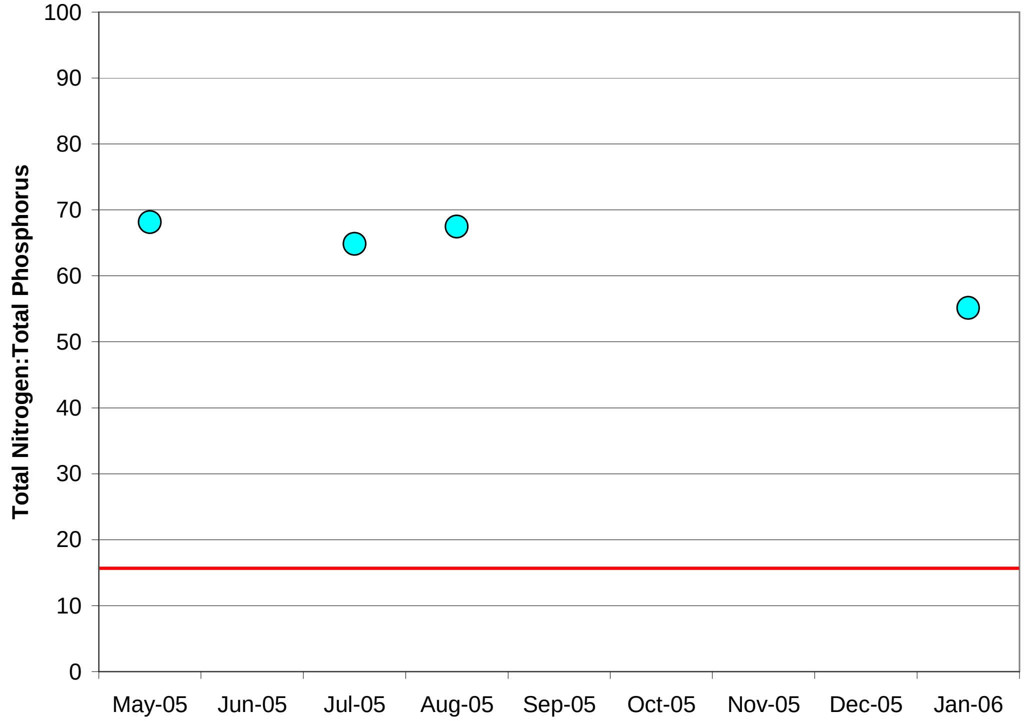


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Lake Audubon (2005-2006).

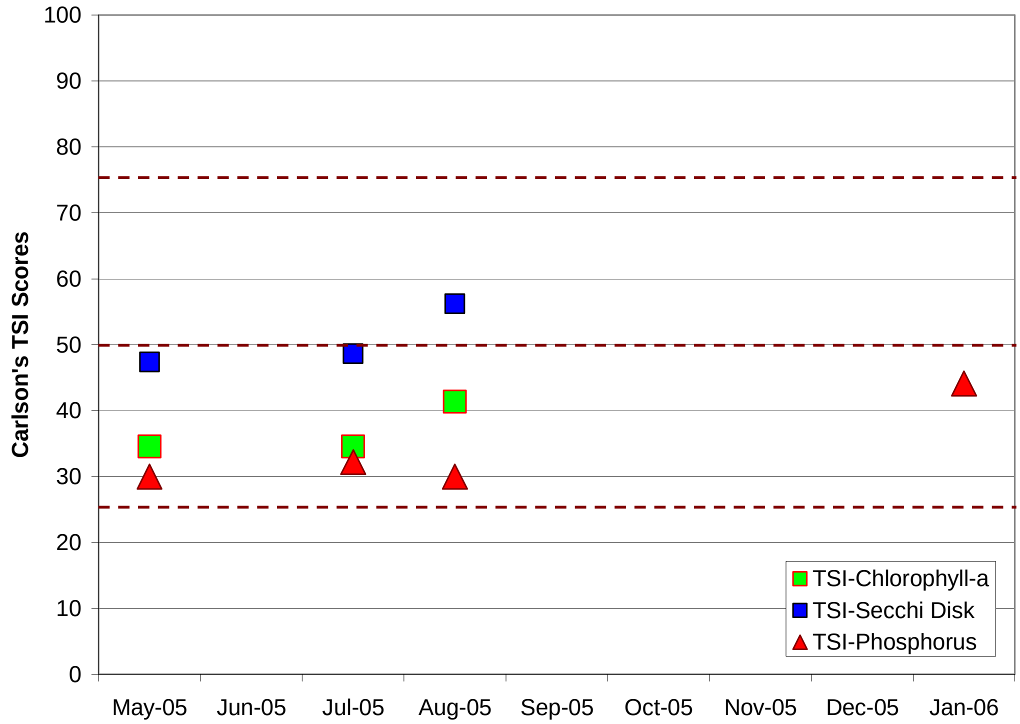


Figure 6. TSI Scores for Lake Audubon from 2005 to 2006.

Lake Brekken, McLean County

BACKGROUND

Location: Lake Brekken is an enhanced natural lake located 1½ miles north of Turtle Lake, North Dakota (Figure 1). Lake Brekken is managed by the North Dakota Game and Fish Department.

Figure 1. Location of Lake Brekken.

Physiographic/Ecological Setting: Lake Brekken has a surface area of 240.9 acres, a maximum depth of 20.7 ft and an average depth 16.0 ft (Figure 2). Lake Brekken's watershed lies within the Northwestern Glaciated Plains (NGP) Level III Ecoregion, part of the broader Rangeland Plains region. The NGP marks the western most extent of continental glacial advancement. The geological youthful landscape has significant surface irregularities and high concentrations of wetlands. The rise in elevation along the eastern edge of this ecoregion defines the boundary of the Great Plains and to the west the Northwestern Great Plains (USEPA 1994).

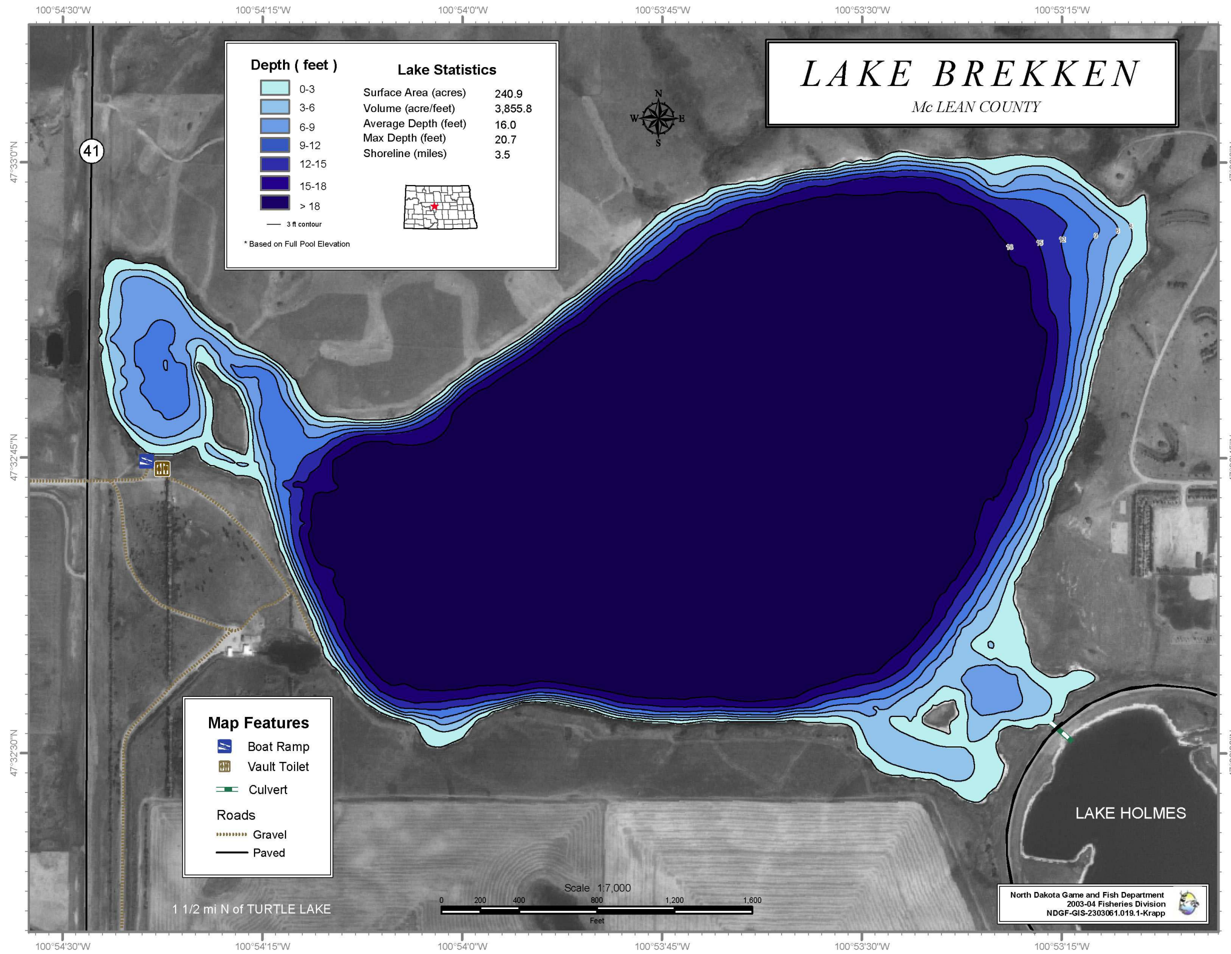


Figure 2. Contour Map of Lake Brekken (Map Courtesy of North Dakota Game and Fish Department).

Construction History: Lake Brekken is an enhanced water body, maintained by inflows from the McClusky Canal. Construction on the canal was completed in 1974 and Lake Brekken was filled sometime after completion.

Recreational Facilities: Recreational facilities at Lake Brekken include a boat ramp, and boat and vehicle parking. Public access is on the west side of the lake, which includes parking, a vaulted toilet, and the boat dock.

Water Quality Standards Classification: Lake Brekken is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 2 lake or reservoir. Class 2 lakes or reservoirs are defined as a "cool water fishery" or "waters capable of supporting natural reproduction and growth of cool water fishes (e.g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: Lake Brekken's fishery over time has included walleye, fathead minnows, yellow perch, and bluegill, stocked by the NDG&F. Currently, only walleye and bluegill are managed in Lake Brekken.

Historical Water Quality Sampling: Historical water quality data includes results from three samples collected in1992 and 1993 and eight temperature and dissolved oxygen profiles collected between 1992 and 1995.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Lake Brekken have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural or enhanced lakes in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There were 12 temperature and dissolved oxygen profiles for Lake Brekken collected from 1992-2006. Temperature and oxygen profiles are presented for two time periods, 1992-1995 and 2005-2006 (Figures 3 and 4).

The profile data shows that Lake Brekken is normally well oxygenated. Of the 12 profiles, only one profile site, collected on 8/23/2005 was below the state standard of 5 mg/L, with a solid top to bottom concentration of 4.9 mg/L.

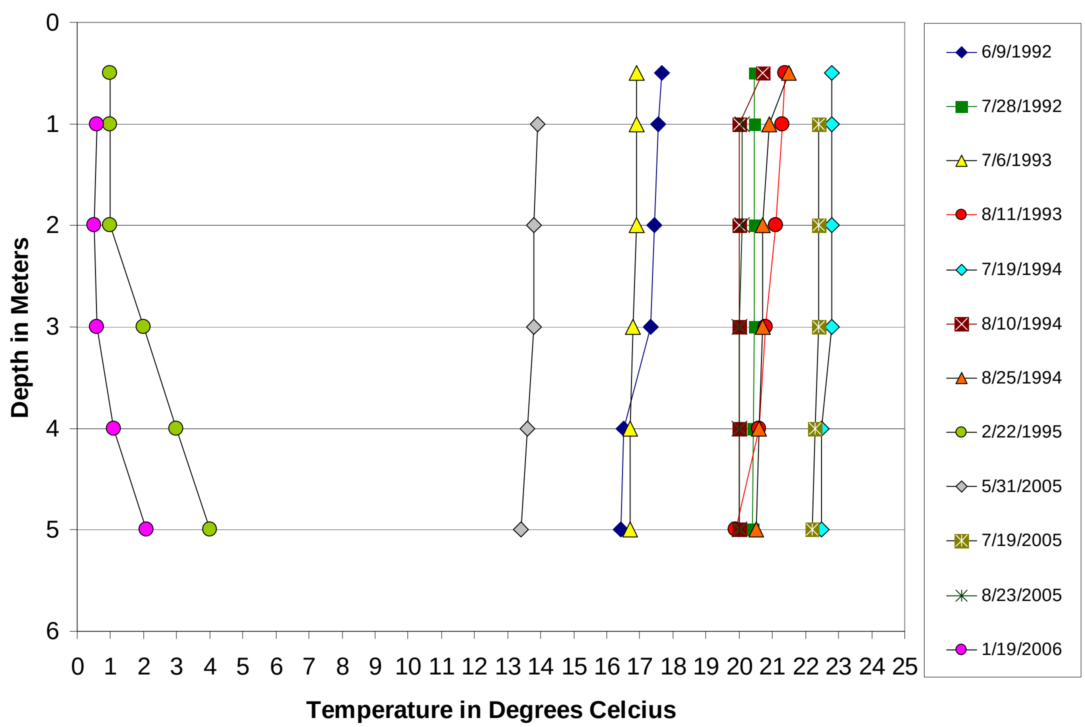


Figure 3. Temperature Profiles for Lake Brekken from 1992 to 2006.

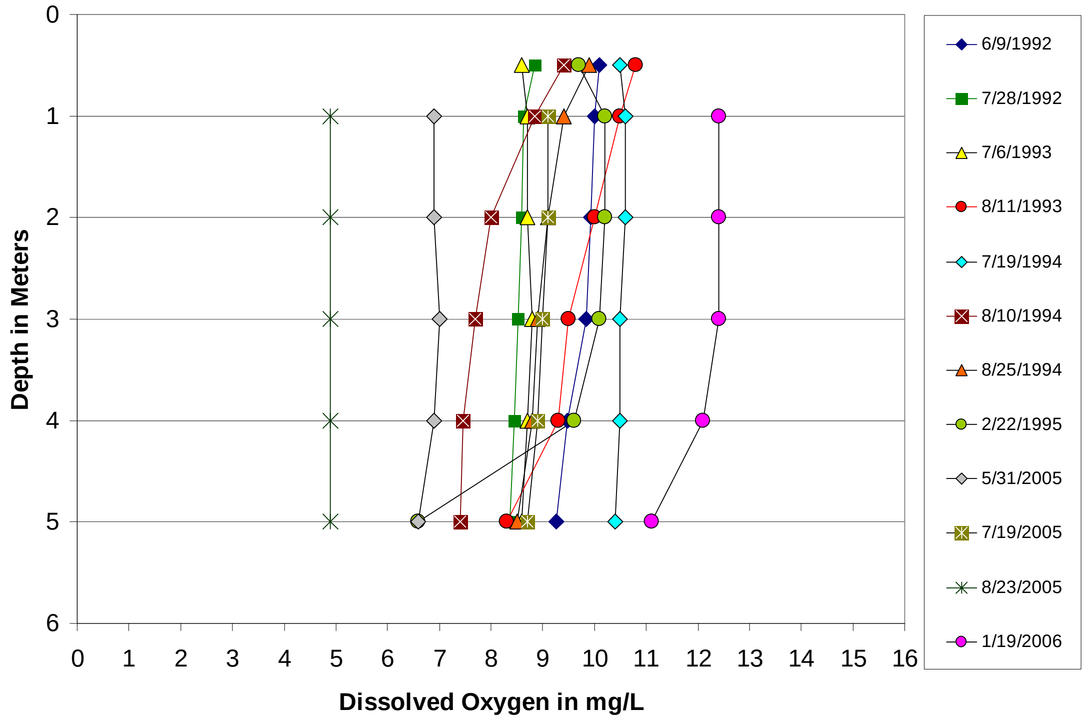


Figure 4. Dissolved Oxygen Profiles for Lake Brekken from 1992 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006 indicate Lake Brekken is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 501 to 542 mg/L (Table 1). Based on the 2005-2006 water quality data Lake Brekken is sodium sulfate dominated with an average sodium concentration of 886 mg/L and an average sulfate concentration of 1643 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 3040 mg/L and 4133 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.520 mg/L and 0.071 mg/L, respectively.

When compared to historical water quality data (Table 2) most water quality constituents in Lake Brekken have increased (Table 1). For example, the historical average sulfate and sodium concentrations were 857 mg/L and 443 mg/L, respectively, compared to the 2005-2006 average concentrations of 1643 mg/L for sulfate and 886 mg/L for sodium. The average total nitrogen and total phosphorus concentrations have also increased when compared to the historical data. The historical average for total nitrogen and total phosphorus concentrations were 1.175 mg/L and 0.051 mg/L, respectively, compared to the current average concentrations of 1.520 mg/L for total nitrogen and 0.071 mg/L for total phosphorus.

Table 1. Statistical Summary of Lake Brekken's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	517	501	542	18
Total Ammonia as N	mg/L	4	0.133	0.019	0.318	0.130
Bicarbonate (HCO_3)	mg/L	4	499	471	544	35
Calcium (Ca)	mg/L	4	34.1	30.2	37.7	3.1
Carbonate (CO_3)	mg/L	4	65	51	79	13
Chloride (Cl)	mg/L	4	68	65	75	5
Chlorophyll-a	µg/L	3	6.5	1.5[1]	15.0	7.4
Specific Conductance	µmhos	4	4133	4010	4430	201
Total Dissolved Solids	mg/L	4	3040	2890	3230	155
Total Hardness as ($CaCO_3$)	mg/L	4	367	353	383	13
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.778	0.432	1.660	0.591
Magnesium (Mg)	mg/L	4	68.5	66.8	72.3	2.5
Nitrate + Nitrite as N	mg/L	4	0.120	0.020	0.230	0.106
Total Kjeldahl Nitrogen as N	mg/L	4	1.400	1.210	1.500	0.132
Total Nitrogen as N	mg/L	4	1.520	1.230	1.670	0.201
pH		4	8.91	8.75	9.13	0.19
Total Phosphorus as P	mg/L	4	0.071	0.046	0.105	0.027
Potassium (K)	mg/L	4	29.6	26.9	32.0	2.2
Sodium (Na)	mg/L	4	886	834	971	61
Sulfate (SO4)	mg/L	4	1643	1560	1800	108

[1]Equal to lower detection limit

When compared to the Rangeland Plains regional average for natural and enhanced lakes, it appears Lake Brekken is higher in dissolved solids and sulfate concentrations than reported for all natural and enhanced lakes in the Rangeland Plains region (Table 3). For example, the regional average TDS and sulfate concentrations are 1588 mg/L and 680 mg/L, respectively, compared to Lake Brekken's average TDS and sulfate concentrations of 3040 mg/L, and 1643 mg/L, respectively, for the period 2005-2006.

Limiting Nutrient: The limiting nutrient is assessed based on the assumption that either nitrogen or phosphorus is limiting algal growth in Lake Brekken, and that the ratio of total nitrogen as N, to total phosphorus as P (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were seven water quality sample results for Lake Brekken collected between July 1994 and January 2006 where the N:P ration could be calculated. The results from this analysis indicate that Lake Brekken is most often phosphorus limited (Figure 5).

The nitrogen to phosphorus ratio for Lake Brekken ranged from a low of 15 to a high of 33 with an average of 24. All of the seven samples collected were at or above a ratio of 15, indicating phosphorus is limiting primary production.

Table 2. Statistical Summary of Lake Brekken's Historical Water Quality Data Collected Between 1992 and 1993.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	351	345	361	9
Total Ammonia as N	mg/L	3	0.070	0.015	0.148	0.069
Bicarbonate (HCO_3)	mg/L	3	362	336	388	26
Calcium (Ca)	mg/L	3	30	28	33	2
Carbonate (CO_3)	mg/L	3	32	17	42	13
Chloride (Cl)	mg/L	3	38.7	36.3	42.1	3.0
Chlorophyll-a	µg/L	2	34.5	26.0	43.0	12.0
Specific Conductance	µmhos	3	2453	2310	2590	140
Total Dissolved Solids	mg/L	3	1640	1480	1820	171
Total Hardness as ($CaCO_3$)	mg/L	3	254	235	269	17
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	3	0.119	0.072	0.163	0.046
Magnesium (Mg)	mg/L	3	43.7	39.6	48.4	4.4
Nitrate + Nitrite as N	mg/L	3	0.035	0.005	0.091	0.048
Total Kjeldahl Nitrogen as N	mg/L	3	1.140	0.989	1.300	0.156
Total Nitrogen as N	mg/L	3	1.175	1.080	1.310	0.120
pH		3	8.78	8.48	8.98	0.26
Total Phosphorus as P	mg/L	3	0.051	0.039	0.068	0.015
Potassium (K)	mg/L	3	16.0	14.1	19.2	2.8
Sodium (Na)	mg/L	3	443	383	534	80
Sulfate (SO4)	mg/L	3	857	764	943	90

[1]Equal to lower detection limit

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005-2006, Lake Brekken's current trophic status eutrophic. TSI scores ranged from a low of 35 based on chlorophyll-a measurements, to a high of 71 based on total phosphorus. The trophic status score based on Secchi disk transparency was similar to that of total phosphorus, at 63 (Figure 6).

A total of five total phosphorus samples, chlorophyll-a samples, and Secchi disk transparency measurements collected during the open water periods from 1994-2005 were used to evaluate trends in the trophic status of Lake Brekken. Based on a visual assessment of the data, Lake Brekken's trophic status is improving (Figure 6).

Table 3. Statistical Summary of Water Quality from Natural and Enhanced Lake's in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	272	544	119	4770	130
Total Ammonia as N	mg/L	371	0.107	0.001[1]	2.230	0.200
Bicarbonate (HCO_3)	mg/L	272	489	145	2990	150
Calcium (Ca)	mg/L	272	44	1[1]	282	26
Carbonate (CO_3)	mg/L	262	89	1[1]	1420	30
Chloride (Cl)	mg/L	272	51	4[1]	1070	9
Chlorophyll-a	µg/L	250	22	2[1]	292	28
Specific Conductance	µmhos	272	2168	448	20100	959
Total Dissolved Solids	mg/L	272	1588	227	18200	750
Total Hardness as ($CaCO_3$)	mg/L	272	538	170	2370	260
Hydroxide (OH)	mg/L	200	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	273	0.193	0.001[1]	2.260	0.334
Magnesium (Mg)	mg/L	272	104	20	567	50
Nitrate + Nitrite as N	mg/L	332	0.036	0.002[1]	0.338	0.092
Total Kjeldahl Nitrogen as N	mg/L	340	1.950	0.080	8.500	0.779
Total Nitrogen as N	mg/L	278	1.826	0.269	5.520	0.562
pH		272	8.796	7.400	9.870	0.564
Total Phosphorus as P	mg/L	377	0.244	0.004[1]	1.940	0.205
Potassium (K)	mg/L	272	38	3[1]	356	6
Sodium (Na)	mg/L	272	331	17	4680	171
Sulfate (SO4)	mg/L	272	680	34	10500	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 48 Natural and Enhanced Lakes between 1991 and 2007

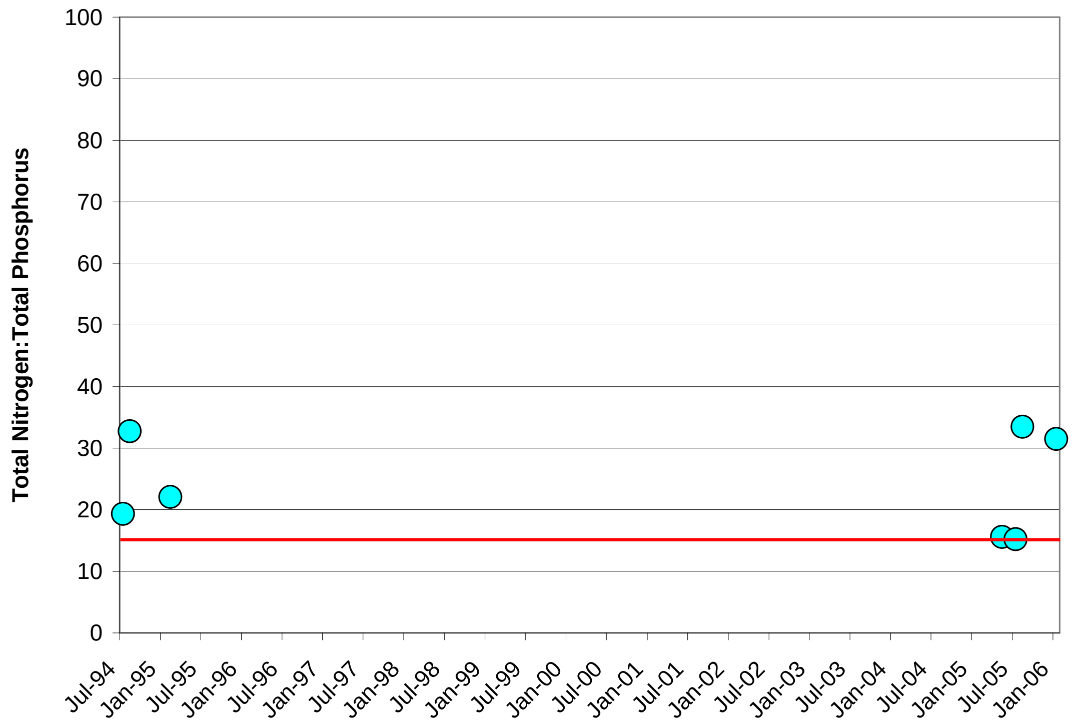


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Lake Brekken (1992-2006).

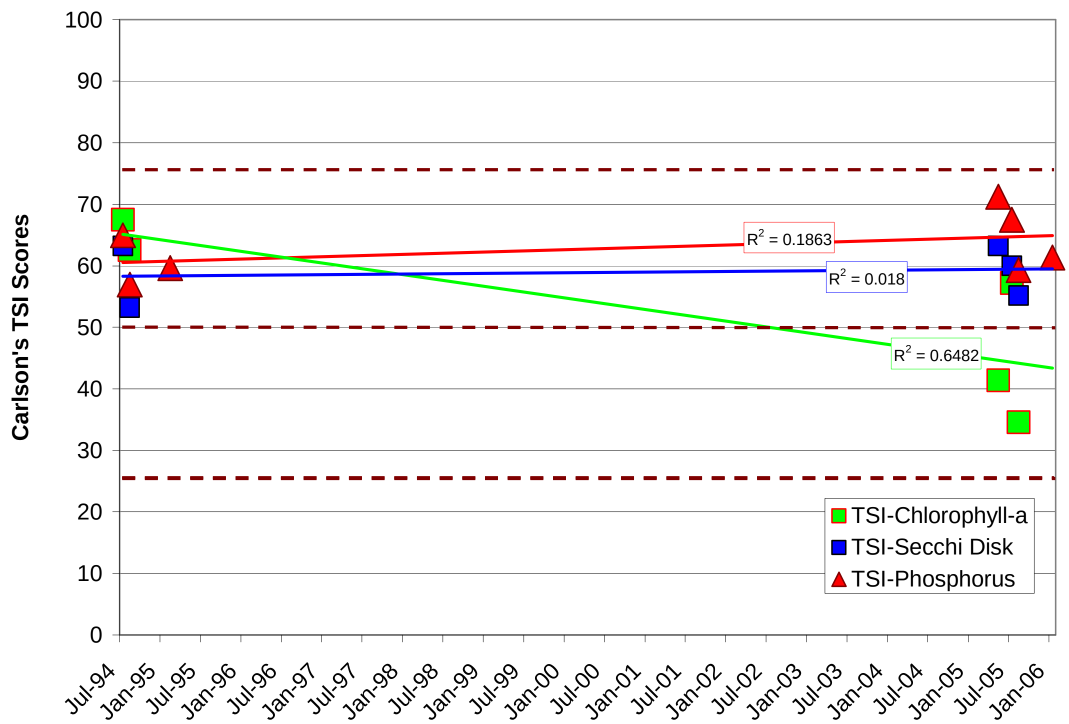


Figure 6. TSI Scores and Temporal Trends for Lake Brekken from 1994 to 2005.

Lake Holmes, McLean County

BACKGROUND

Location: Lake Holmes is an enhanced natural lake located 1 mile northeast of Turtle Lake, North Dakota (Figure 1). Lake Holmes is managed by the North Dakota Game and Fish Department.

Figure 1. Location of Lake Holmes.

Physiographic/Ecological Setting: Lake Holmes has a surface area of 404.8 acres, a maximum depth of 25.6 ft and an average depth 17.0 ft (Figure 2). Lake Holmes's watershed lies within the Northwestern Glaciated Plains (NGP) Level III Ecoregion, part of the broader Rangeland Plains region. The NGP marks the western most extent of continental glacial advancement. The geological youthful landscape has significant surface irregularities and high concentrations of wetlands. The rise in elevation along the eastern edge of this ecoregion defines the boundary of the Great Plains and to the west the Northwestern Great Plains (USEPA 1994).

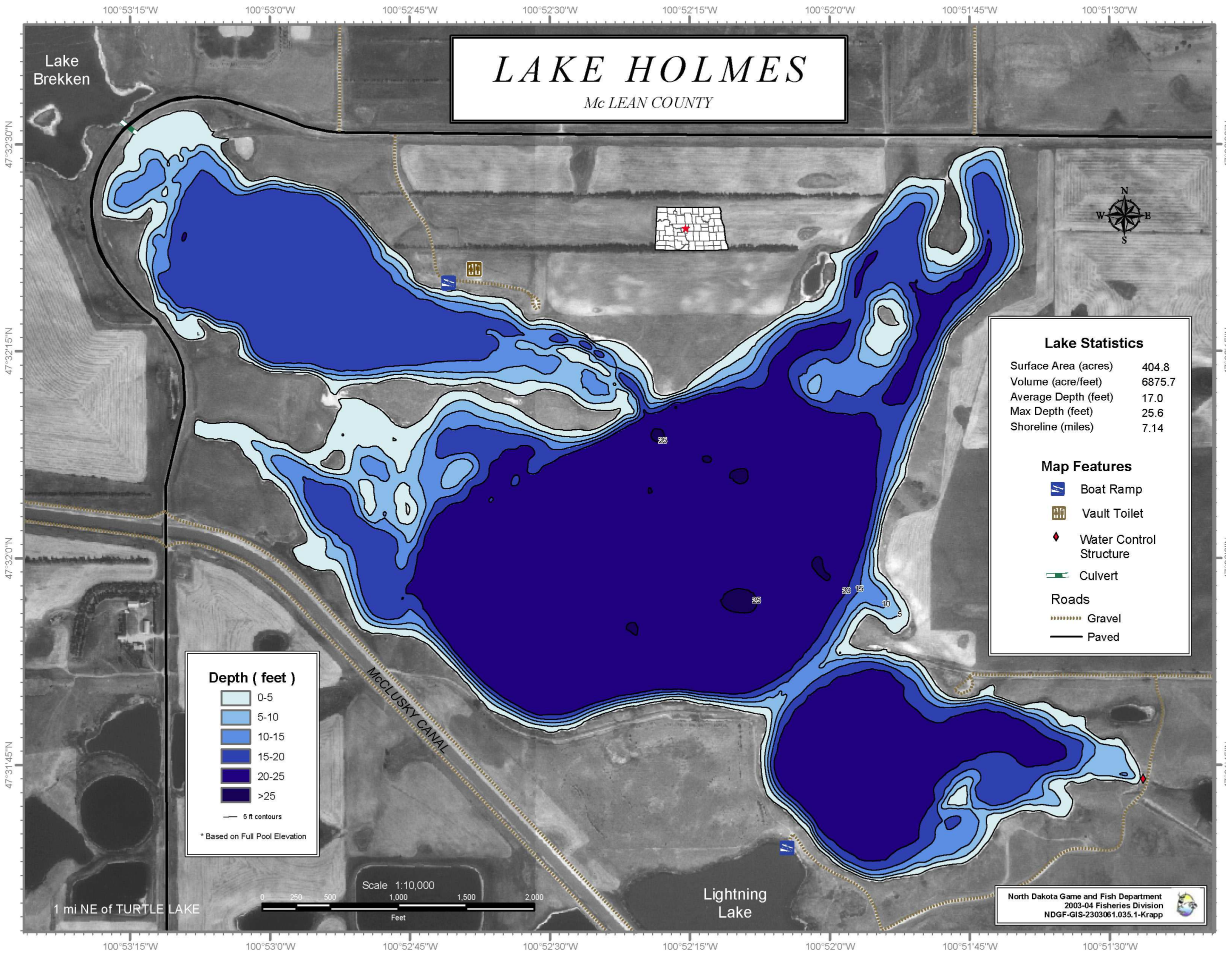


Figure 2. Contour Map of Lake Holmes (Map Courtesy of North Dakota Game and Fish Department).

Construction History: Lake Holmes is an enhanced water body, maintained by inflows from the McClusky Canal. Construction on the canal was completed in 1974 and Lake Brekken filled shortly after completion.

Recreational Facilities: Recreational facilities at Lake Holmes include a boat ramp, and boat and vehicle parking. Public access is on the northwest side of the lake, which includes parking, and the boat dock.

Water Quality Standards Classification: Lake Holmes is classified in the state “Standards of Quality for Waters of the State” (NDDoH, 2006) as a class 2 lake or reservoir. Class 2 lakes or reservoirs are defined as a “cool water fishery” or “waters capable of supporting natural reproduction and growth of cool water fishes (e.g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota.”

Historical and Current Fishery: Lake Holmes's fishery over time has included walleye, brown trout, rainbow trout, and bluegill stocked by the NDG&F. Currently, only walleye and bluegill are managed in Lake Holmes.

Historical Water Quality Sampling: Historical water quality data includes results from three samples collected from 1992 through 1993 and 8 temperature-dissolved oxygen profiles collected between 1992 and 1995.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Lake Holmes have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural or enhanced lakes in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There were 12 temperature and dissolved oxygen profiles for Lake Holmes collected from 1992-2006. Temperature and oxygen profiles are presented for two time periods, 1992-1995 and 2005-2006 (Figures 3 and 4). The profile data shows that Lake Holmes is always well oxygenated only dropping in concentration at the sediment-water interface. Of the 12 profiles, only four samples, collected on 8/11/1993, 7/19/1994, 8/10/1994, and 2/22/1995, dropped below the state standard of 5 mg/L and then only within ½ to 1 meter for the bottom.

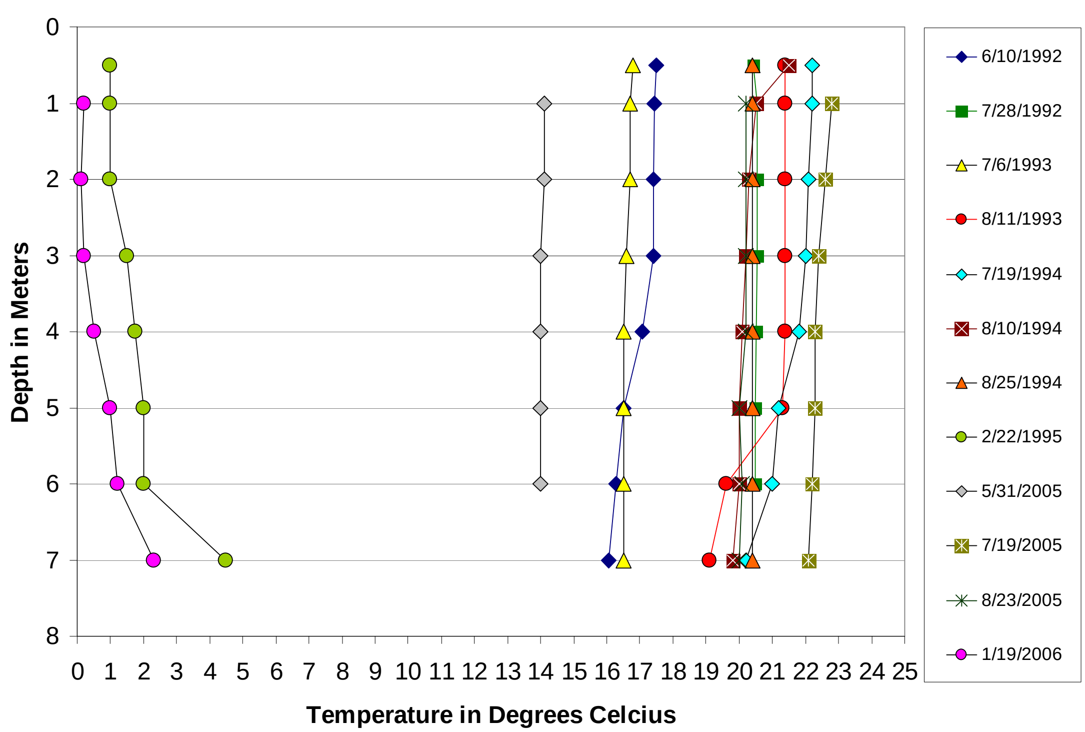


Figure 3. Temperature Profiles for Lake Holmes from 1992 to 2006.

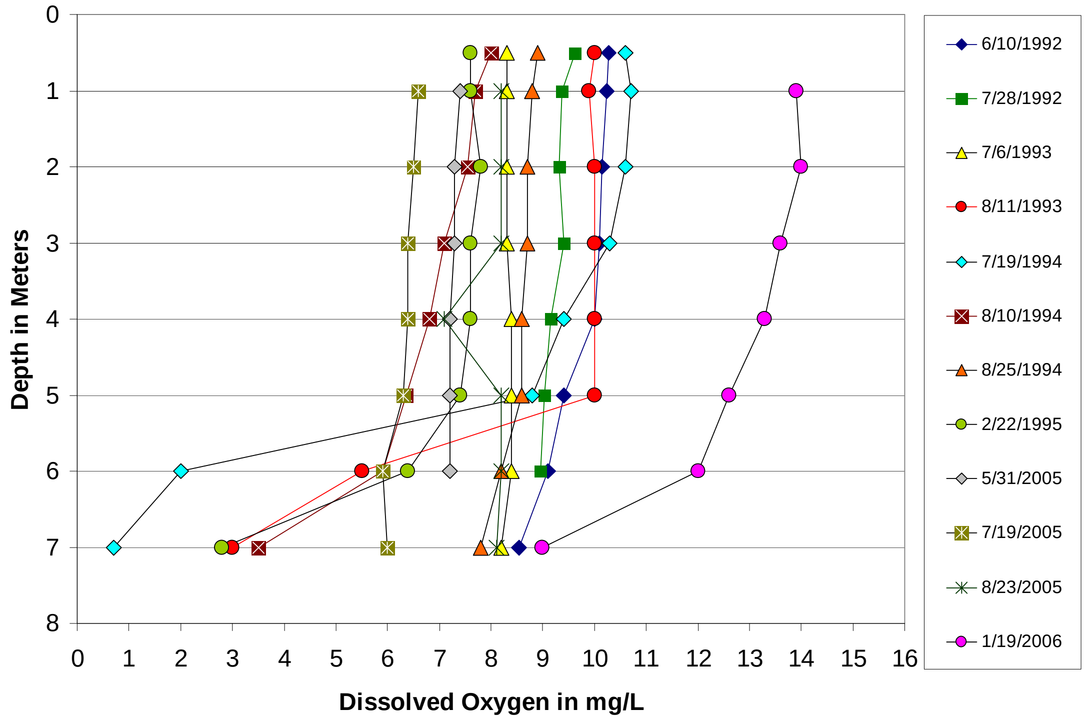


Figure 4. Dissolved Oxygen Profiles for Lake Holmes from 1992 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006 indicate Lake Holmes is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 679 mg/L to 731 mg/L (Table 1). Based on the 2005-2006 water quality data, Lake Holmes is sodium sulfate dominated with an average sodium concentration of 1503 mg/L and an average sulfate concentration of 2805 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 5033 mg/L and 6468 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 2.118 mg/L and 0.061 mg/L, respectively.

When current water quality data (Table 1) is compared to historical (Table 2) most of the water quality constituents have increased. For example, the historical average sulfate and sodium concentrations have gone from 2013 mg/L and 1023 mg/L, respectively, to 2805 mg/L for sulfate and 1503 mg/L for 2005-2006 (Table 2). The average total nitrogen and total phosphorus concentrations have fluctuated over time. The historical average total nitrogen and total phosphorus concentrations were 1.943 mg/L and 0.076 mg/L, respectively, compared to the current concentrations of 2.118 mg/L for total nitrogen and 0.061 mg/L for total phosphorus.

Compared to the Rangeland Plains regional average concentrations for natural and enhanced lakes, Lake Holmes is higher in total dissolved solids and nitrogen than average. For example, the regional average TDS and total nitrogen concentrations are 1588 mg/L and 1.826 mg/L, respectively, compared to Lake Holmes's average TDS and total nitrogen concentrations of 5033 mg/L, and 2.118 mg/L, respectively (Table 3).

Table 1. Statistical Summary of Lake Holmes's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	698	679	731	23
Total Ammonia as N	mg/L	4	0.096	0.012	0.286	0.128
Bicarbonate (HCO_3)	mg/L	4	650	604	700	39
Calcium (Ca)	mg/L	4	34.0	32.3	36.2	1.7
Carbonate (CO_3)	mg/L	4	99	88	118	13
Chloride (Cl)	mg/L	4	120	114	131	8
Chlorophyll-a	µg/L	3	12.6	1.5	29.4	14.8
Specific Conductance	µmhos	4	6468	6260	6970	338
Total Dissolved Solids	mg/L	4	5033	4800	5270	198
Total Hardness as ($CaCO_3$)	mg/L	4	493	467	518	27
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.220	0.080	0.367	0.148
Magnesium (Mg)	mg/L	4	99.2	93.8	104.0	5.6
Nitrate + Nitrite as N	mg/L	4	0.050	0.020	0.130	0.054
Total Kjeldahl Nitrogen as N	mg/L	4	2.068	1.720	2.900	0.561
Total Nitrogen as N	mg/L	4	2.118	1.740	3.030	0.614
pH		4	8.95	8.85	9.07	0.09
Total Phosphorus as P	mg/L	4	0.061	0.040	0.075	0.015
Potassium (K)	mg/L	4	50.3	47.0	54.9	3.7
Sodium (Na)	mg/L	4	1503	1360	1610	112
Sulfate (SO4)	mg/L	4	2805	2680	3040	161

[1]Equal to lower detection limit

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Lake Holmes, and that the ratio of total nitrogen as N, to total phosphorus as P (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were seven water quality sample results for Lake Holmes collected between July 1994 and January 2006 where the N:P ratio could be calculated. The results from this analysis indicate that Lake Holmes is most often phosphorus limited (Figure 5).

The nitrogen to phosphorus ratio for Lake Holmes ranged from a low of 20 to a high of 45 with an average of 32. All of the seven samples collected were above a ratio of 15, indicating phosphorus is limiting primary production.

Table 2. Statistical Summary of Lake Holmes's Historical Water Quality Data Collected Between 1992 and 1995.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	570	557	581	12
Total Ammonia as N	mg/L	3	0.139	0.022	0.317	0.157
Bicarbonate (HCO_3)	mg/L	3	545	516	595	43
Calcium (Ca)	mg/L	3	30	29	31	1
Carbonate (CO_3)	mg/L	3	74	42	91	28
Chloride (Cl)	mg/L	3	78.7	76.6	80.3	1.9
Chlorophyll-a	µg/L	2	39.5	29.0	50.0	14.8
Specific Conductance	µmhos	3	4797	4660	5010	187
Total Dissolved Solids	mg/L	3	3587	3510	3740	133
Total Hardness as ($CaCO_3$)	mg/L	3	338	317	362	23
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	3	0.098	0.063	0.145	0.042
Magnesium (Mg)	mg/L	3	63.8	59.2	69.5	5.2
Nitrate + Nitrite as N	mg/L	3	0.063	0.005	0.174	0.096
Total Kjeldahl Nitrogen as N	mg/L	3	1.880	1.720	2.020	0.151
Total Nitrogen as N	mg/L	3	1.943	1.730	2.194	0.234
pH		3	8.97	8.70	9.11	0.23
Total Phosphorus as P	mg/L	3	0.076	0.061	0.088	0.014
Potassium (K)	mg/L	3	33.7	30.9	39.0	4.6
Sodium (Na)	mg/L	3	1023	964	1120	85
Sulfate (SO4)	mg/L	3	2013	1980	2050	35

[1]Equal to lower detection limit

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005-2006, Lake Holmes's current trophic status is eutrophic. TSI scores ranged from a low of 35 based on chlorophyll-a measurements, to a high of 66 based on total phosphorus. The trophic status score based on Secchi disk transparency was similar to that of total phosphorus, at 57 (Figure 6).

A total of seven total phosphorus samples, five chlorophyll-a samples, and five Secchi disk transparency measurements collected during the open water periods from 1994-2006 were used to evaluate trends in the trophic status of Lake Holmes. Based on a visual assessment of the data Lake Holmes's trophic status is improving (Figure 6).

Table 3. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lakes in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	272	544	119	4770	130
Total Ammonia as N	mg/L	371	0.107	0.001[1]	2.230	0.200
Bicarbonate (HCO_3)	mg/L	272	489	145	2990	150
Calcium (Ca)	mg/L	272	44	1[1]	282	26
Carbonate (CO_3)	mg/L	262	89	1[1]	1420	30
Chloride (Cl)	mg/L	272	51	4[1]	1070	9
Chlorophyll-a	µg/L	250	22	2[1]	292	28
Specific Conductance	µmhos	272	2168	448	20100	959
Total Dissolved Solids	mg/L	272	1588	227	18200	750
Total Hardness as ($CaCO_3$)	mg/L	272	538	170	2370	260
Hydroxide (OH)	mg/L	200	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	273	0.193	0.001[1]	2.260	0.334
Magnesium (Mg)	mg/L	272	104	20	567	50
Nitrate + Nitrite as N	mg/L	332	0.036	0.002[1]	0.338	0.092
Total Kjeldahl Nitrogen as N	mg/L	340	1.950	0.080	8.500	0.779
Total Nitrogen as N	mg/L	278	1.826	0.269	5.520	0.562
pH		272	8.796	7.400	9.870	0.564
Total Phosphorus as P	mg/L	377	0.244	0.004[1]	1.940	0.205
Potassium (K)	mg/L	272	38	3[1]	356	6
Sodium (Na)	mg/L	272	331	17	4680	171
Sulfate (SO4)	mg/L	272	680	34	10500	501

[1]Equal to Minimum Reporting Limit

[2]Data Collected from 48 Natural and Enhanced Lakes between 1991 and 2007

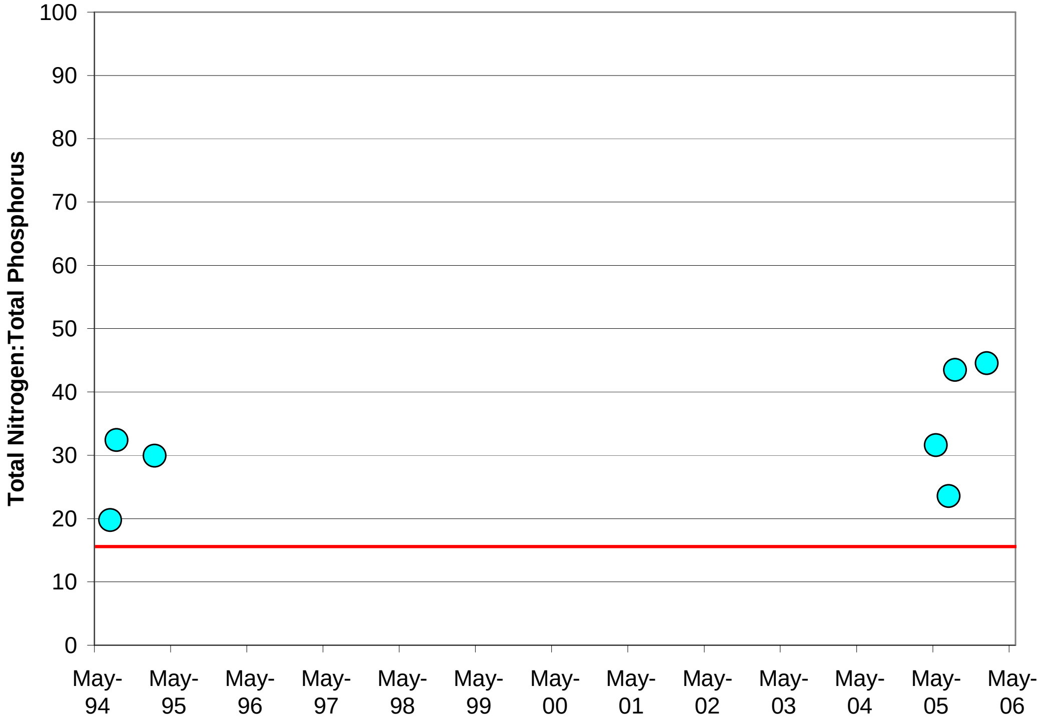


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Lake Holmes (1994-2006).

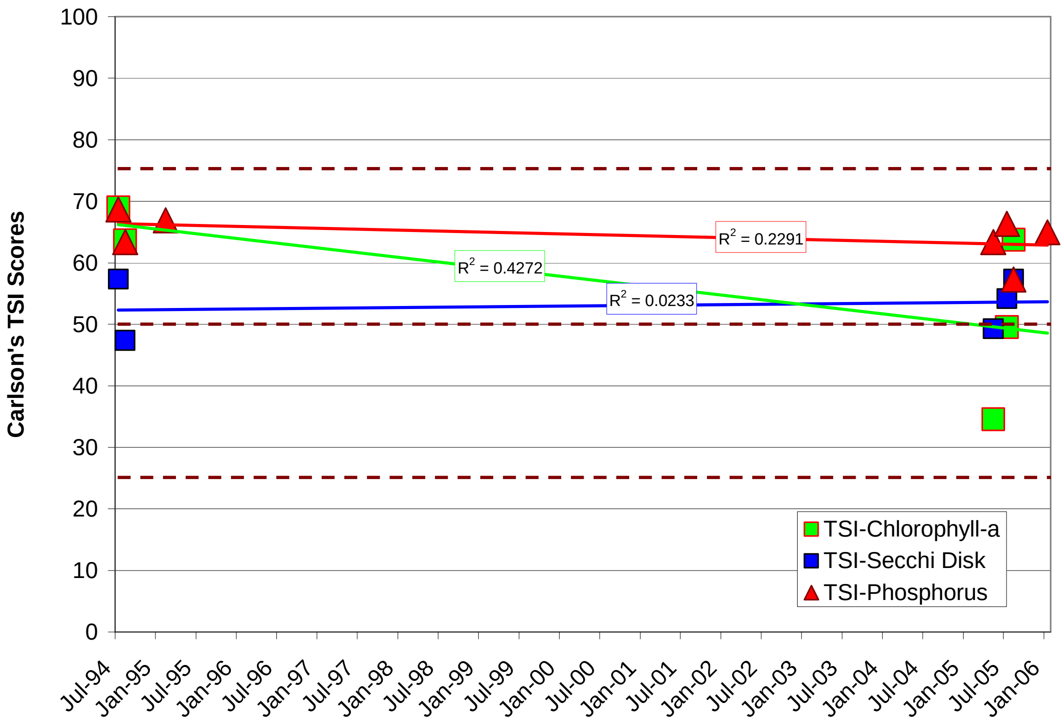


Figure 6. TSI Scores and Temporal Trends for Lake Holmes from 1994 to 2005.

Long Lake, McLean County

BACKGROUND

Location: Long Lake is a natural lake located 13 miles north and 2 miles east of Turtle Lake, North Dakota (Figure 1). Long Lake is managed by the North Dakota Game and Fish Department.

Figure 1. Location of Long Lake.

Physiographic/Ecological Setting: Long Lake has a surface area of 206 acres, a maximum depth of 8.0 ft and an average depth 5.1 ft (Figure 2). Long Lake's watershed is 2,625 acres, and lies within the Northwestern Glaciated Plains (NGP) Level III Ecoregion. The NGP marks the western most extent of continental glacial advancement. The geological youthful landscape has significant surface irregularities and high concentrations of wetlands. The rise in elevation along the eastern edge of this ecoregion defines the boundary of the Great Plains and to the west the Northwestern Great Plains (USEPA 1994).

Recreational Facilities: Recreational facilities at Long Lake include a boat ramp, and boat and vehicle parking. Public access is on the southeast side of the lake, which includes parking, and the boat dock.

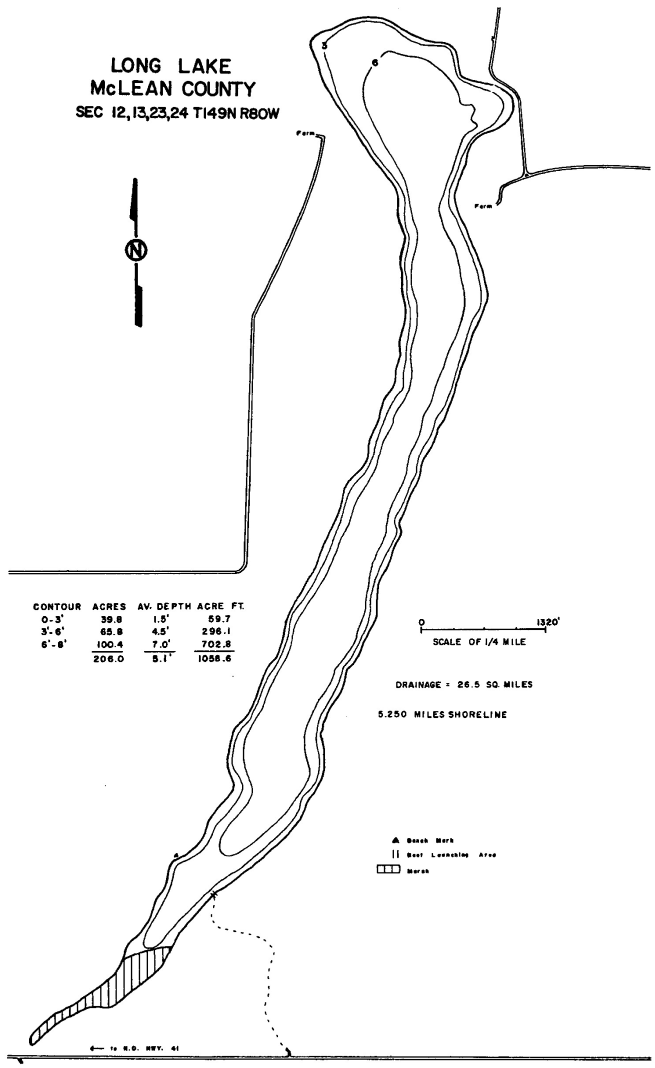


Figure 2. Contour Map of Long Lake (Map Courtesy of North Dakota Game and Fish Department).

Water Quality Standards Classification: Long Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 4 lake or reservoir. Class 4 lakes or reservoirs are defined as a "marginal fishery" or "waters capable of supporting a fishery on a short-term or seasonal basis (generally a "put and take" fishery).

Historical and Current Fishery: Long Lake's fishery over time has included walleye, northern pike, and yellow perch stocked by the NDG&F. Currently, only northern pike are managed in Long Lake.

Historical Water Quality Sampling: Historical water quality data includes results from three samples collected from 1991 and 1992.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Long Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural or enhanced lakes in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There are seven temperature and dissolved oxygen profiles for Long Lake collected from 1991-2006. Temperature and oxygen profiles are presented for two time periods, 1991-1992 and 2005-2006 (Figures 3 and 4).

The profile data shows that under ice cover Long Lake may experience a deficiency in dissolved oxygen concentrations and drop below the state's water quality standard of 5 mg/L. Of the seven profiles, only two samples, collected on 1/31/1992 and 1/19/2006, dropped below the state standard of 5 mg/L.

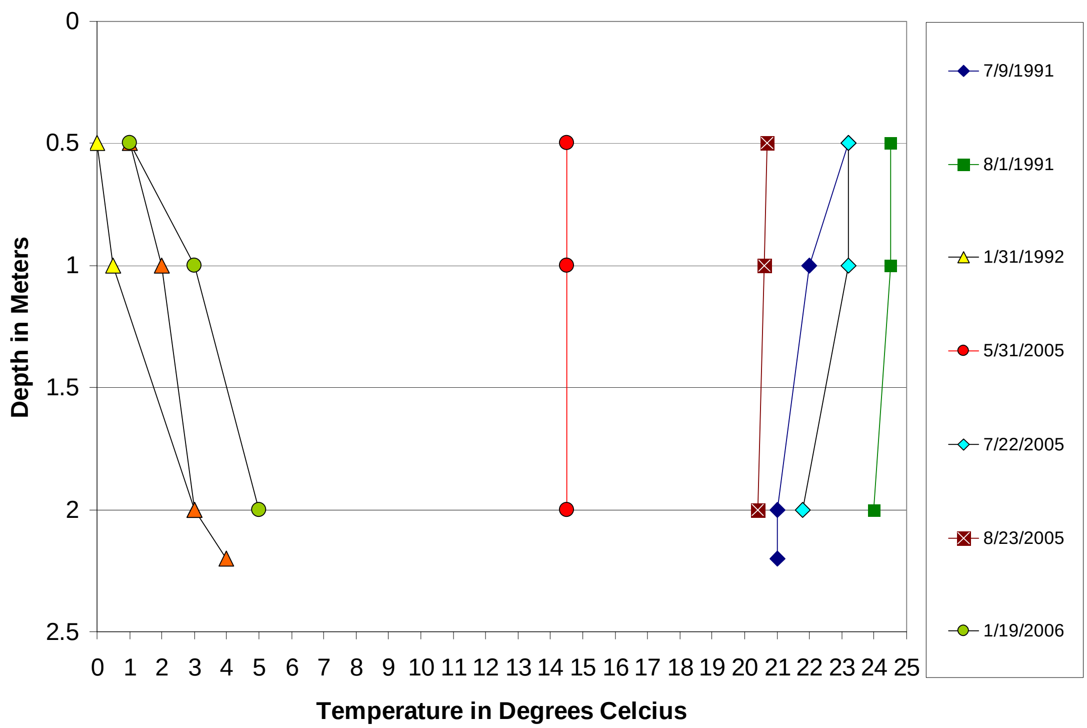


Figure 3. Temperature Profiles for Long Lake from 1991 to 2006.

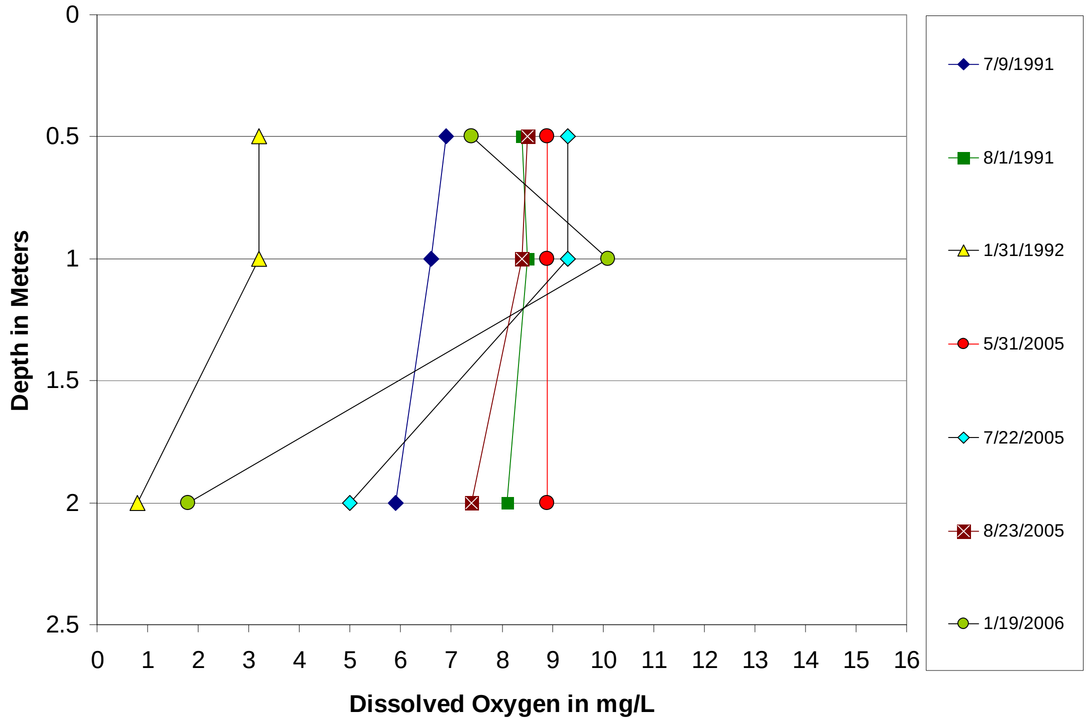


Figure 4. Dissolved Oxygen Profiles for Long Lake from 1991 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006 indicate Long Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 179 to 257 mg/L (Table 1). Based on the 2005-2006 water quality data (Table 1), Long Lake is sodium bicarbonate dominated with an average sodium concentration of 26 mg/L and an average bicarbonate concentration of 228 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 340 mg/L and 575 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 0.869 mg/L and 0.035 mg/L, respectively.

When compared to historical water quality data for Long Lake, concentrations of most water quality constituents have decreased. For example, the historical average bicarbonate and sodium concentrations were 324 mg/L and 41 mg/L, respectively (Table 2), compared to average concentrations of 228 mg/L for bicarbonate and 26 mg/L for sodium recorded for the period 2005-2006 (Table 1). The average total nitrogen and total phosphorus concentrations have also decreased when compared to the historical data. The historical average total nitrogen and total phosphorus concentrations were 1.987 mg/L and 0.097 mg/L (Table 2) respectively, compared to current average concentrations of 0.869 mg/L for total nitrogen and 0.035 mg/L for total phosphorus.

Table 1. Statistical Summary of Long Lake's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	206	179	257	36
Total Ammonia as N	mg/L	4	0.010[1]	0.010[1]	0.010[1]	0.000
Bicarbonate (HCO_3)	mg/L	4	228	188	314	59
Calcium (Ca)	mg/L	4	40.2	31.6	53.9	9.7
Carbonate (CO_3)	mg/L	4	12	1[1]	19	8
Chloride (Cl)	mg/L	4	5	4	6	1
Chlorophyll-a	µg/L	3	12.3	1.5[1]	33.4	18.3
Specific Conductance	µmhos	4	575	507	725	102
Total Dissolved Solids	mg/L	4	340	299	431	62
Total Hardness as ($CaCO_3$)	mg/L	4	259	226	334	50
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.086	0.056	0.109	0.023
Magnesium (Mg)	mg/L	4	38.6	35.0	48.3	6.5
Nitrate + Nitrite as N	mg/L	4	0.038	0.020[1]	0.090	0.035
Total Kjeldahl Nitrogen as N	mg/L	4	0.831	0.728	0.990	0.125
Total Nitrogen as N	mg/L	4	0.869	0.748	1.010	0.137
pH		4	8.48	7.85	8.77	0.43
Total Phosphorus as P	mg/L	4	0.035	0.023	0.045	0.010
Potassium (K)	mg/L	4	4.7	3.4	6.5	1.3
Sodium (Na)	mg/L	4	26	22	33	5
Sulfate (SO4)	mg/L	4	101	91	126	17

[1]Equal to lower detection limit

When compared to the Rangeland Plains regional average concentrations for natural and enhanced lakes, Long Lake is fresher and less eutrophic. For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1588 mg/L, 1.826 mg/L, and 0.244 mg/L, respectively, compared to Long Lake's average TDS, total nitrogen, and total phosphorus concentrations of 340 mg/L, 0.869 mg/L and 0.035 mg/L, respectively, for the period 2005-2006.

Limiting Nutrient: The limiting nutrient is assessed based on the assumption that either nitrogen or phosphorus is limiting algal growth in Long Lake, and that the ratio of total nitrogen as N, to total phosphorus as P (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were seven water quality sample results for Long Lake collected between July 1991 and January 2006 where the N:P ratio could be calculated. The results from this analysis indicate that Long Lake is most often phosphorus limited (Figure 5). The nitrogen to phosphorus ratio for Long Lake ranged from a low of 13 to a high of 33 with an average of 24. Of the seven samples collected, all but one sample were above a ratio of 15, indicating phosphorus is limiting primary production.

Table 2. Statistical Summary of Long Lake's Historical Water Quality Data Collected Between 1991 and 1992.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	314	268	399	73.7
Total Ammonia as N	mg/L	3	0.1[1]	0.001[1]	0.1[1]	0.0
Bicarbonate (HCO_3)	mg/L	3	344	264	487	124.1
Calcium (Ca)	mg/L	3	42.8	26.5	74.9	27.8
Carbonate (CO_3)	mg/L	2	29	23	35	0.0
Chloride (Cl)	mg/L	3	8.8	7.7	10.3	1.3
Chlorophyll-a	µg/L	2	6.5	3[1]	10	0.0
Specific Conductance	µmhos	3	780	700	936	135.1
Total Dissolved Solids	mg/L	3	454	390	560	92.2
Total Hardness as ($CaCO_3$)	mg/L	3	338	288	421	72.2
Hydroxide (OH)	mg/L	0	NC[2]	NC[2]	NC[2]	
Iron (Fe)	mg/L	3	0.44	0.01[1]	1.21	0.672
Magnesium (Mg)	mg/L	3	53.8	51.4	56.8	2.7
Nitrate + Nitrite as N	mg/L	3	0.037	0.005[1]	0.097	0.052
Total Kjeldahl Nitrogen as N	mg/L	3	1.84	1.17	2.41	0.627
Total Nitrogen as N	mg/L	3	1.880	1.267	2.415	0.578
pH		3	8.4	7.4	9.1	0.9
Total Phosphorus as P	mg/L	3	0.105	0.089	0.125	0.0
Potassium (K)	mg/L	3	8.0	6.6	9.6	1.5
Sodium (Na)	mg/L	3	39.2	36	41.1	2.8
Sulfate (SO4)	mg/L	3	107	87	130	21.7

[1]Equal to lower detection limit
[2]No data collected

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005 and 2006, Long Lake's current trophic status is eutrophic trending towards mesotrophic. TSI scores ranged from a low of 35 based on chlorophyll-a measurements, to a high of 67 based on Secchi disk transparency. The trophic status score based on total phosphorus was similar to that of Secchi disk transparency, at 54 (Figure 6).

A total of seven total phosphorus samples, five chlorophyll-a samples, and five Secchi disk transparency measurements collected during the open water periods from 1991-2006 were used to evaluate trends in the trophic status of Long Lake. Based on a visual assessment Long Lake's trophic status is stable (Figure 6).

Table 3. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lake's in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	272	544	119	4770	130
Total Ammonia as N	mg/L	371	0.107	0.001[1]	2.230	0.200
Bicarbonate (HCO_3)	mg/L	272	489	145	2990	150
Calcium (Ca)	mg/L	272	44	1[1]	282	26
Carbonate (CO_3)	mg/L	262	89	1[1]	1420	30
Chloride (Cl)	mg/L	272	51	4[1]	1070	9
Chlorophyll-a	µg/L	250	22	2[1]	292	28
Specific Conductance	µmhos	272	2168	448	20100	959
Total Dissolved Solids	mg/L	272	1588	227	18200	750
Total Hardness as ($CaCO_3$)	mg/L	272	538	170	2370	260
Hydroxide (OH)	mg/L	200	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	273	0.193	0.001[1]	2.260	0.334
Magnesium (Mg)	mg/L	272	104	20	567	50
Nitrate + Nitrite as N	mg/L	332	0.036	0.002[1]	0.338	0.092
Total Kjeldahl Nitrogen as N	mg/L	340	1.950	0.080	8.500	0.779
Total Nitrogen as N	mg/L	278	1.826	0.269	5.520	0.562
pH		272	8.796	7.400	9.870	0.564
Total Phosphorus as P	mg/L	377	0.244	0.004[1]	1.940	0.205
Potassium (K)	mg/L	272	38	3[1]	356	6
Sodium (Na)	mg/L	272	331	17	4680	171
Sulfate (SO4)	mg/L	272	680	34	10500	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 48 Natural and Enhanced Lakes between 1991 and 2007

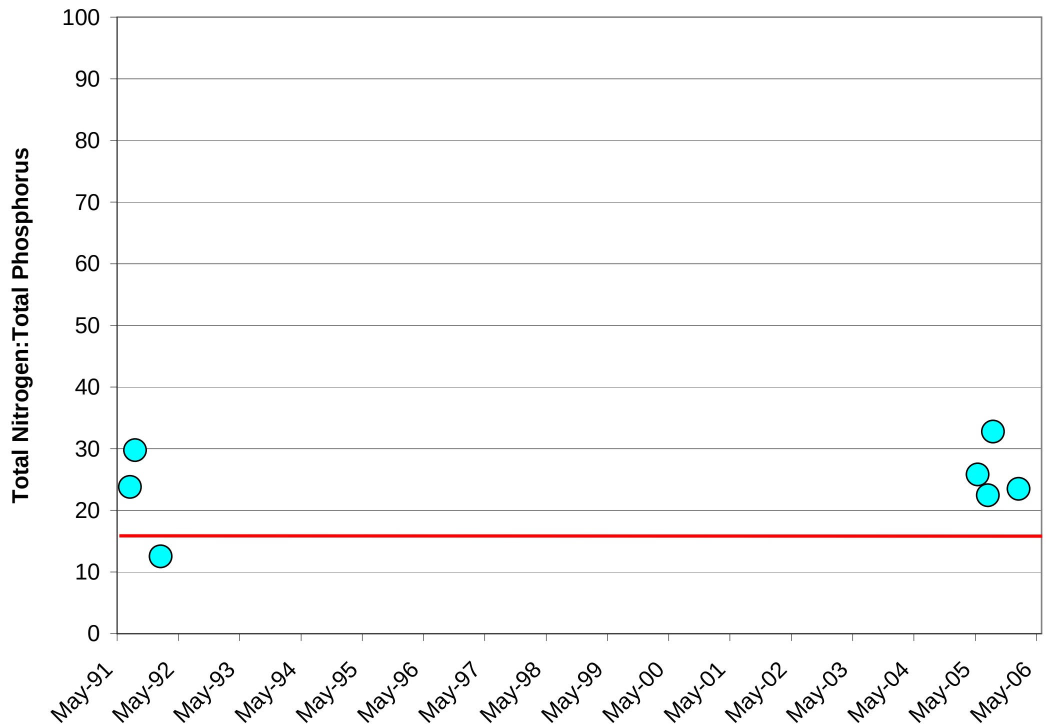


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Long Lake (1991-2006).

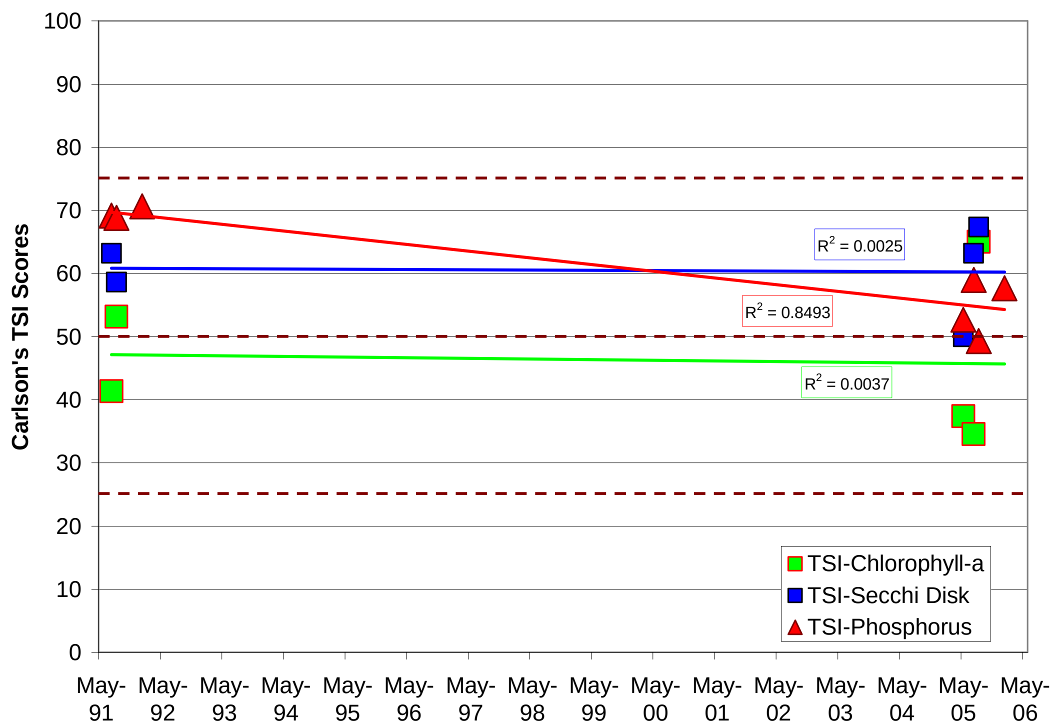


Figure 6. TSI Scores and Temporal Trends for Long Lake from 1991 to 2006.

Riverdale Spillway Pond, McLean County

BACKGROUND

Location: Riverdale Spillway Pond is an enhanced lake located 1 mile west and 1½ mile south of Riverdale, North Dakota, below the Garrison Dam. Riverdale Spillway Pond is managed by the North Dakota Game and Fish Department (Figure 1).

Figure 1. Location of Riverdale Spillway Pond.

Physiographic/Ecological Setting: Riverdale Spillway Pond has a surface area of 96.6 acres, a maximum depth of 70.9 ft, and an average depth of 25.7 ft (Figure 2). Riverdale Spillway Pond's watershed is approximately 500 acres and it lies within the Northwestern Glaciated Plains (NGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The NGP marks the western most extent of continental glacial advancement. The geological youthful landscape has significant surface irregularities and high concentrations of wetlands. The rise in elevation along the eastern edge of this ecoregion defines the boundary of the Great Plains and to the west the Northwestern Great Plains (USEPA 1994).

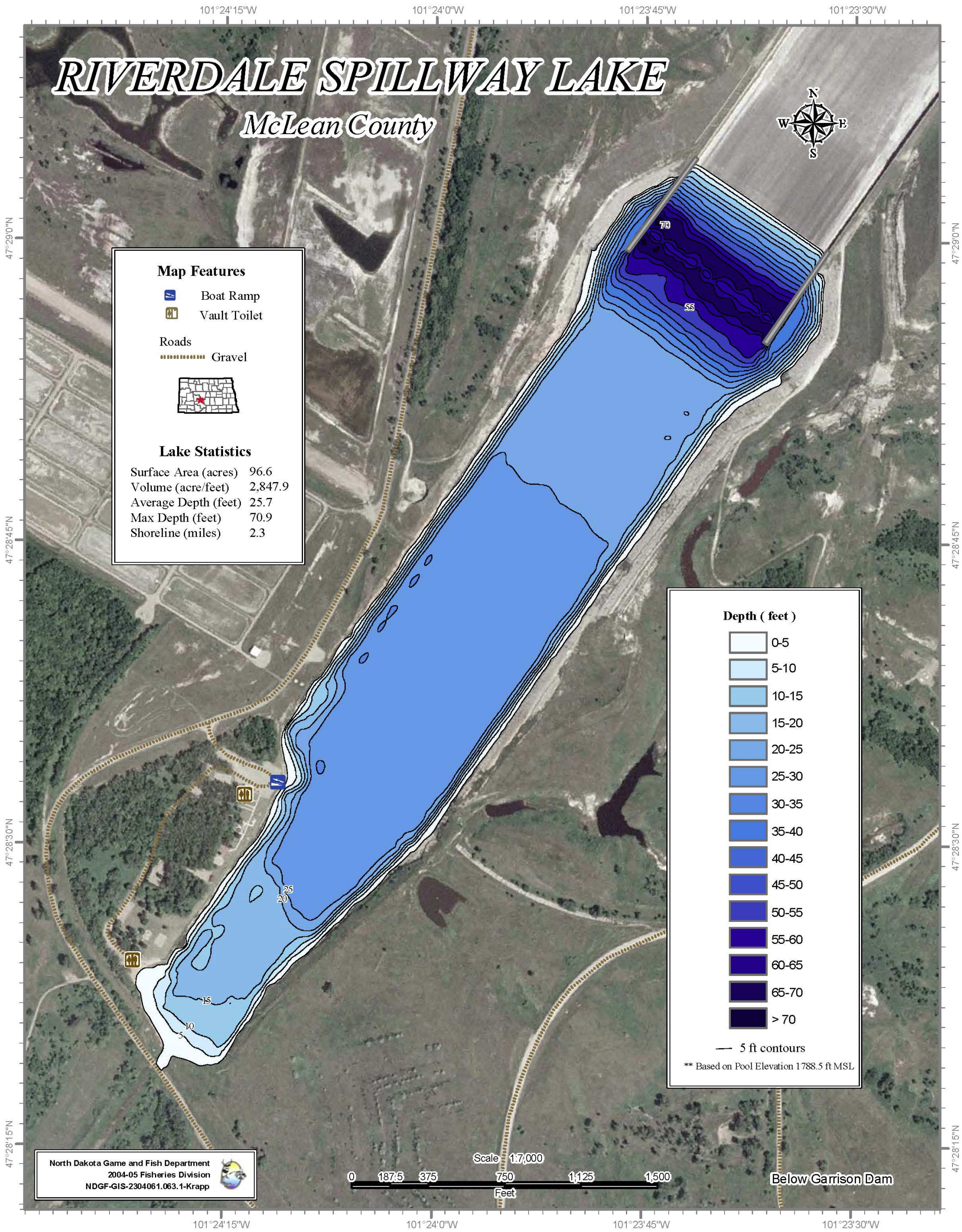


Figure 2. Contour Map of Riverdale Spillway Pond (Map Courtesy of North Dakota Game and Fish Department).

Construction History: Riverdale Spillway Pond is a manmade water body created by modifying a natural depression below the Garrison Dam. The rectangular shaped pond was created as a stilling basin for the dam's emergency spillway.

Recreational Facilities: Public access on the west side of Riverdale Spillway Pond is available during all four seasons. Public facilities include a small camping area, poured cement boat ramp, associated parking, and toilets.

Water Quality Standards Classification: Riverdale Spillway Pond is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 1 lake or reservoir. Class 1 lakes or reservoirs are defined as a "cold water fishery" or "waters capable of supporting growth of cold water fish species (e.g., salmonids) and associated aquatic biota."

Historical and Current Fishery: Riverdale Spillway Pond's historical fishery is not well known. Test nets have revealed yellow perch, bluegill, crappie, walleye, rainbow trout, northern pike, lake trout, carp, white suckers, smallmouth bass, freshwater drum, and chinook salmon. Current species managed by the lake's fishery include northern pike, walleye, sauger, rainbow trout, bluegill, and crappie.

Historical Water Quality Sampling: Historical water quality data includes results from three samples collected from 1992 through 1993.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Riverdale Spillway Pond have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural or enhanced lakes in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There were seven temperature and dissolved oxygen profiles for Riverdale Spillway Pond collected from 1992-2006. Temperature and oxygen profiles are presented for two time periods, 1992-1993 and 2005-2006 (Figures 3 and 4).

The temperature and dissolved oxygen profiles show that during thermal stratification Riverdale Spillway Pond experiences moderate oxygen decay and occasionally drops below the state's water quality standard of 5 mg/L, at depths of 15 meters or less. Of the seven profiles, all but one sample collected on 1/25/2006 dropped below the state standard of 5 mg/L. While the rapid loss of dissolved oxygen during these periods is concerning, there appears to be enough dissolved oxygen to maintain aquatic life in the upper 12 meters of the water column. Additionally at all times the lake has 5 to 10 meters of water with a temperature of less then 15 degrees and dissolved oxygen of greater then 5 mg/L, meeting the state's requirements for cold water habitat.

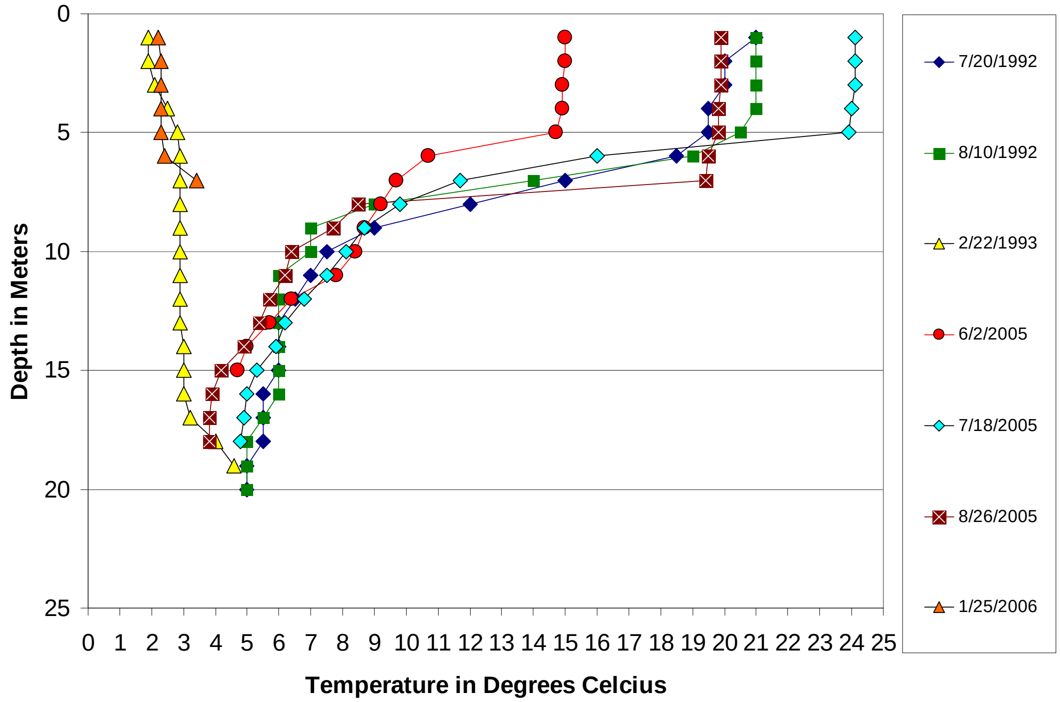


Figure 3. Temperature Profiles for Riverdale Spillway Pond from 1992 to 2006.

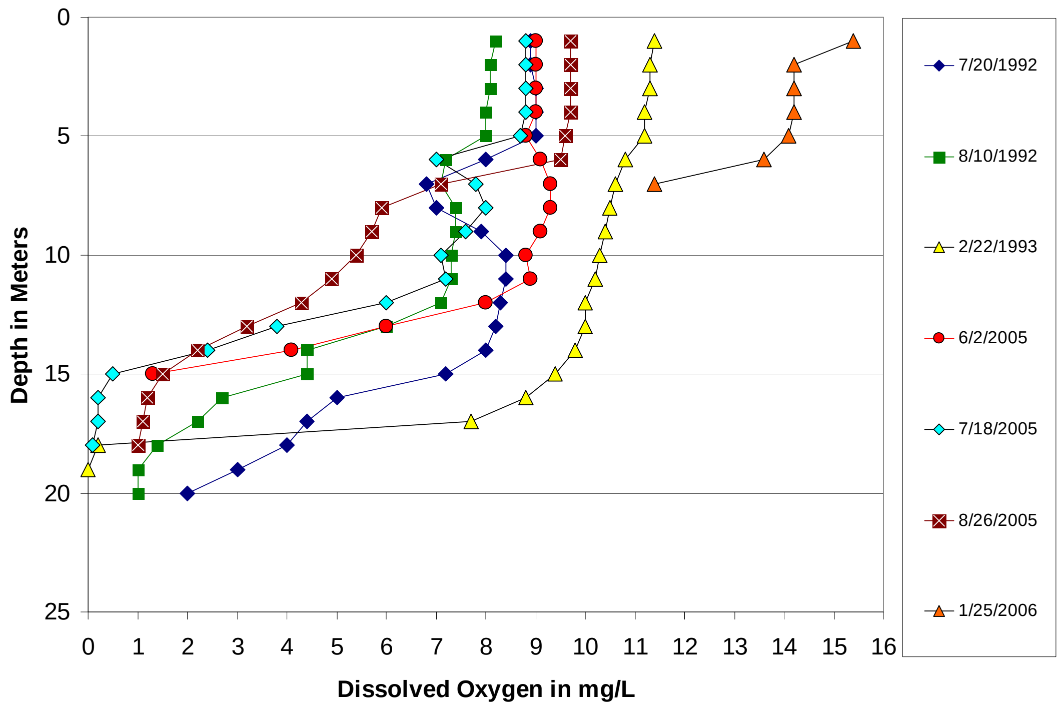


Figure 4. Dissolved Oxygen Profiles for Riverdale Spillway Pond from 1992 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006 indicate Riverdale Spillway Pond is well buffered with total alkalinity as $CaCO_3$ concentrations ranging from 234 to 251 mg/L (Table 1). Based on the 2005-2006 water quality data, Riverdale Spillway Pond is sodium bicarbonate dominated with an average sodium concentration of 156 mg/L and an average bicarbonate concentration of 270 mg/L. The average total dissolved solids (TDS) concentration and specific conductance measurement for the 2005-2006 sampling period were 1587 mg/L and 1003 µmhos/cm respectively. Average total nitrogen as N and total phosphorus as P concentrations were 0.357 mg/L and 0.009 mg/L respectively.

Table 1. Statistical Summary of Riverdale Spillway Pond's 2005-2006 Water Quality Data.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	241	234	251	7
Total Ammonia as N	mg/L	4	0.018	0.010[1]	0.041	0.015
Bicarbonate (HCO_3)	mg/L	4	270	255	295	17
Calcium (Ca)	mg/L	4	38.1	35.2	42.2	3.3
Carbonate (CO_3)	mg/L	4	12	6	15	4
Chloride (Cl)	mg/L	4	13	13	14	1
Chlorophyll-a	µg/L	3	2.3	1.5	4.0	1.4
Specific Conductance	µmhos	4	1003	972	1080	52
Total Dissolved Solids	mg/L	4	1587	622	4410	1882
Total Hardness as ($CaCO_3$)	mg/L	4	181	170	199	13
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.212	0.184	0.244	0.026
Magnesium (Mg)	mg/L	4	20.8	19.7	22.8	1.4
Nitrate + Nitrite as N	mg/L	3	0.097	0.020	0.220	0.108
Total Kjeldahl Nitrogen as N	mg/L	4	0.215	0.080	0.279	0.091
Total Nitrogen as N	mg/L	3	0.357	0.269	0.499	0.124
pH		4	8.56	8.40	8.68	0.12
Total Phosphorus as P	mg/L	4	0.009	0.004	0.018	0.007
Potassium (K)	mg/L	4	4.8	4.4	5.3	0.4
Sodium (Na)	mg/L	4	156	148	167	9
Sulfate (SO4)	mg/L	4	261	252	274	9

[1]Equal to lower detection limit

When comparing historical water quality data to the 2005-2006 water quality data for Riverdale Spillway Pond, it appears that water quality constituents have increased. For example, the historical average bicarbonate and sodium concentrations were 254 mg/L and 138 mg/L respectively (Table 2), compared to average concentrations of 270 mg/L for bicarbonate and 156 mg/L for sodium recorded for the period 2005-2006 (Table 1). The historical total nitrogen and total phosphorus concentrations were 0.589 mg/L and 0.044 mg/L respectively, compared to average concentrations of 0.357 mg/L for total nitrogen and 0.009 mg/L for total phosphorus.

Table 2. Statistical Summary of Riverdale Spillway Pond's Historical Water Quality Data Collected Between 1992 and 1993.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	227	220	240	11
Total Ammonia as N	mg/L	2	0.117	0.006[1]	0.228	0.157
Bicarbonate (HCO_3)	mg/L	3	254	238	281	24
Calcium (Ca)	mg/L	3	45	43	48	2
Carbonate (CO_3)	mg/L	3	12	6	15	5
Chloride (Cl)	mg/L	3	15.4	13.7	16.8	1.6
Chlorophyll-a	µg/L	2	3.0	3.0[1]	3.0	0.0
Specific Conductance	µmhos	3	956	934	989	29
Total Dissolved Solids	mg/L	3	605	592	621	15
Total Hardness as ($CaCO_3$)	mg/L	3	210	202	218	8
Hydroxide (OH)	mg/L	1	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	3	0.059	0.045	0.083	0.021
Magnesium (Mg)	mg/L	3	23.5	22.9	23.9	0.5
Nitrate + Nitrite as N	mg/L	1	0.007	0.007	0.007	
Total Kjeldahl Nitrogen as N	mg/L	2	0.265	0.250	0.280	0.021
Total Nitrogen as N	mg/L	2	0.589	0.287	0.890	0.426
pH		3	8.60	8.49	8.68	0.10
Total Phosphorus as P	mg/L	2	0.044	0.031	0.057	0.018
Potassium (K)	mg/L	3	3.8	3.1	4.5	0.7
Sodium (Na)	mg/L	3	138	136	142	3
Sulfate (SO4)	mg/L	3	242	233	247	8

[1]Equal to lower detection limit

When compared to the Rangeland Plains regional average for natural and enhanced lakes, Riverdale Spillway Pond is fresher and less eutrophic (Table 3). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1588 mg/L, 1.826 mg/L, and 0.244 mg/L respectively, compared to Riverdale Spillway Pond's average TDS, total nitrogen, and total phosphorus concentrations of 1587 mg/L, 0.357 mg/L, and 0.009 mg/L respectively, for the period 2005-2006.

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Riverdale Spillway Pond and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight in algae, is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were six water quality sample results for Riverdale Spillway Pond collected between July 1992 and January 2006 where the N:P ratio could be calculated. The results from this analysis indicate that Riverdale Spillway Pond is a dynamic water body that can either be nitrogen or phosphorus limited, depending on the time of year and other environmental factors (Figure 5).

Table 3. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lakes in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	272	544	119	4770	130
Total Ammonia as N	mg/L	371	0.107	0.001[1]	2.230	0.200
Bicarbonate (HCO_3)	mg/L	272	489	145	2990	150
Calcium (Ca)	mg/L	272	44	1[1]	282	26
Carbonate (CO_3)	mg/L	262	89	1[1]	1420	30
Chloride (Cl)	mg/L	272	51	4[1]	1070	9
Chlorophyll-a	µg/L	250	22	2[1]	292	28
Specific Conductance	µmhos	272	2168	448	20100	959
Total Dissolved Solids	mg/L	272	1588	227	18200	750
Total Hardness as ($CaCO_3$)	mg/L	272	538	170	2370	260
Hydroxide (OH)	mg/L	200	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	273	0.193	0.001[1]	2.260	0.334
Magnesium (Mg)	mg/L	272	104	20	567	50
Nitrate + Nitrite as N	mg/L	332	0.036	0.002[1]	0.338	0.092
Total Kjeldahl Nitrogen as N	mg/L	340	1.950	0.080	8.500	0.779
Total Nitrogen as N	mg/L	278	1.826	0.269	5.520	0.562
pH		272	8.796	7.400	9.870	0.564
Total Phosphorus as P	mg/L	377	0.244	0.004[1]	1.940	0.205
Potassium (K)	mg/L	272	38	3[1]	356	6
Sodium (Na)	mg/L	272	331	17	4680	171
Sulfate (SO4)	mg/L	272	680	34	10500	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 48 Natural and Enhanced Lakes between 1991 and 2007

N:P ratios for Riverdale Spillway Pond ranged from a low of 5 to a high of 84 with an average of 33. Of the seven samples collected on Riverdale Spillway Pond, two samples were below an N:P ratio of 15 (nitrogen limiting), two samples were equal to15, and two were above an N:P ratio of 15 (phosphorus limiting).

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected in 2005-2006, Riverdale Spillway Pond's current trophic status is mesotrophic. TSI scores ranged from a low of 24 based on total phosphorus, to a high of 59 based on Secchi disk transparency. The trophic status score based on average chlorophyll-a measurements, was in between that based on Secchi disk transparency and total phosphorus at 38 (Figure 6).

A total of six total phosphorus samples, five chlorophyll-a samples, and five Secchi disk transparency measurements collected from 1992-2006 were used to evaluate trends in the trophic status of Riverdale Spillway Pond. Based on a visual assessment, Riverdale Spillway Pond's trophic status is stable (Figure 6).

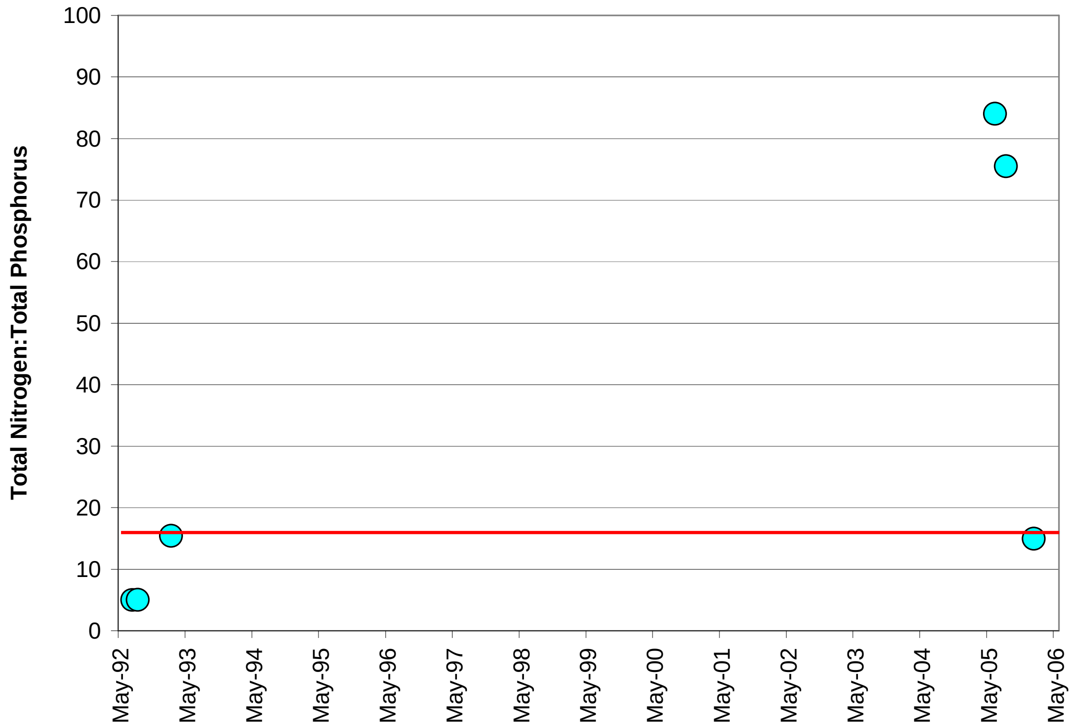


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Riverdale Spillway Pond (1992-2006).

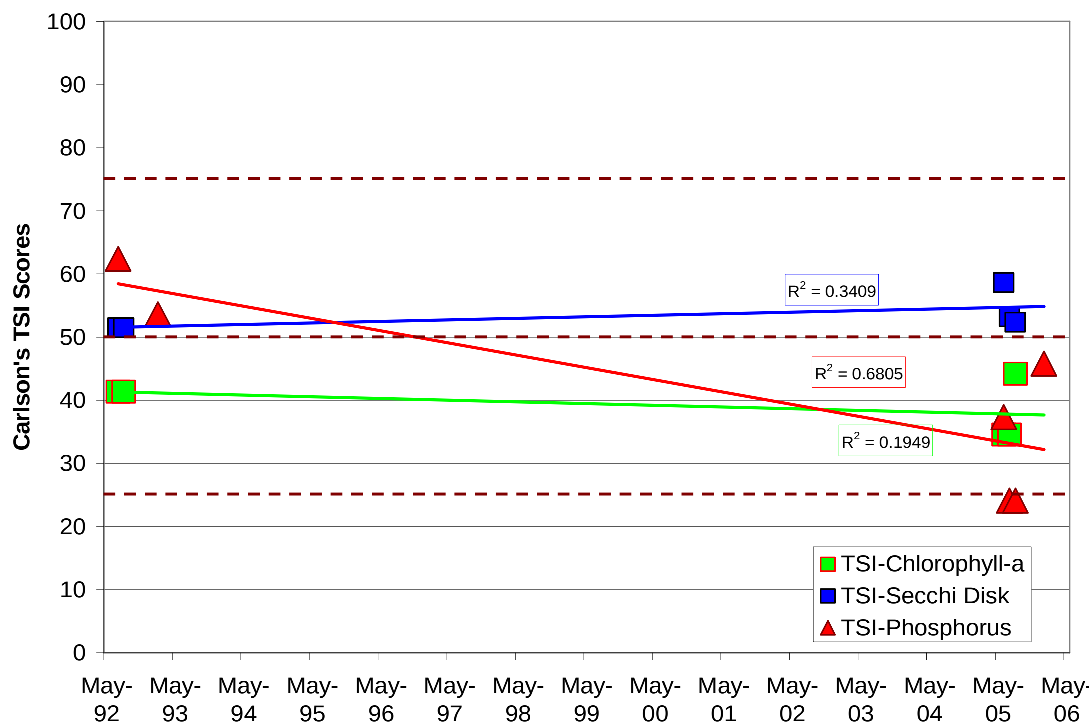


Figure 6. TSI Scores and Temporal Trends for Riverdale Spillway Pond from 1992 to 2006.

Strawberry Lake, McLean County

BACKGROUND

Location: Strawberry Lake is a recreational impoundment located 17½ miles north, and 2 miles east of Turtle Lake, North Dakota (Figure 1). Strawberry Lake is managed by the North Dakota Game and Fish Department.

Figure 1. Location of Strawberry Lake

Physiographic/Ecological Setting: Strawberry Lake has a surface area of 144.3 acres, a maximum depth of 20.8 ft, and an average depth of 10.5 ft (Figure 2). Strawberry Lake's watershed is approximately 2,680 acres and it lies within the Northwestern Glaciated Plains (NGP) Level III Ecoregion, part of the broader Rangeland Plains region. The NGP marks the western most extent of continental glacial advancement. The geological youthful landscape has significant surface irregularities and high concentrations of wetlands. The rise in elevation along the eastern edge of this ecoregion defines the boundary of the Great Plains and to the west the Northwestern Great Plains (USEPA 1994).

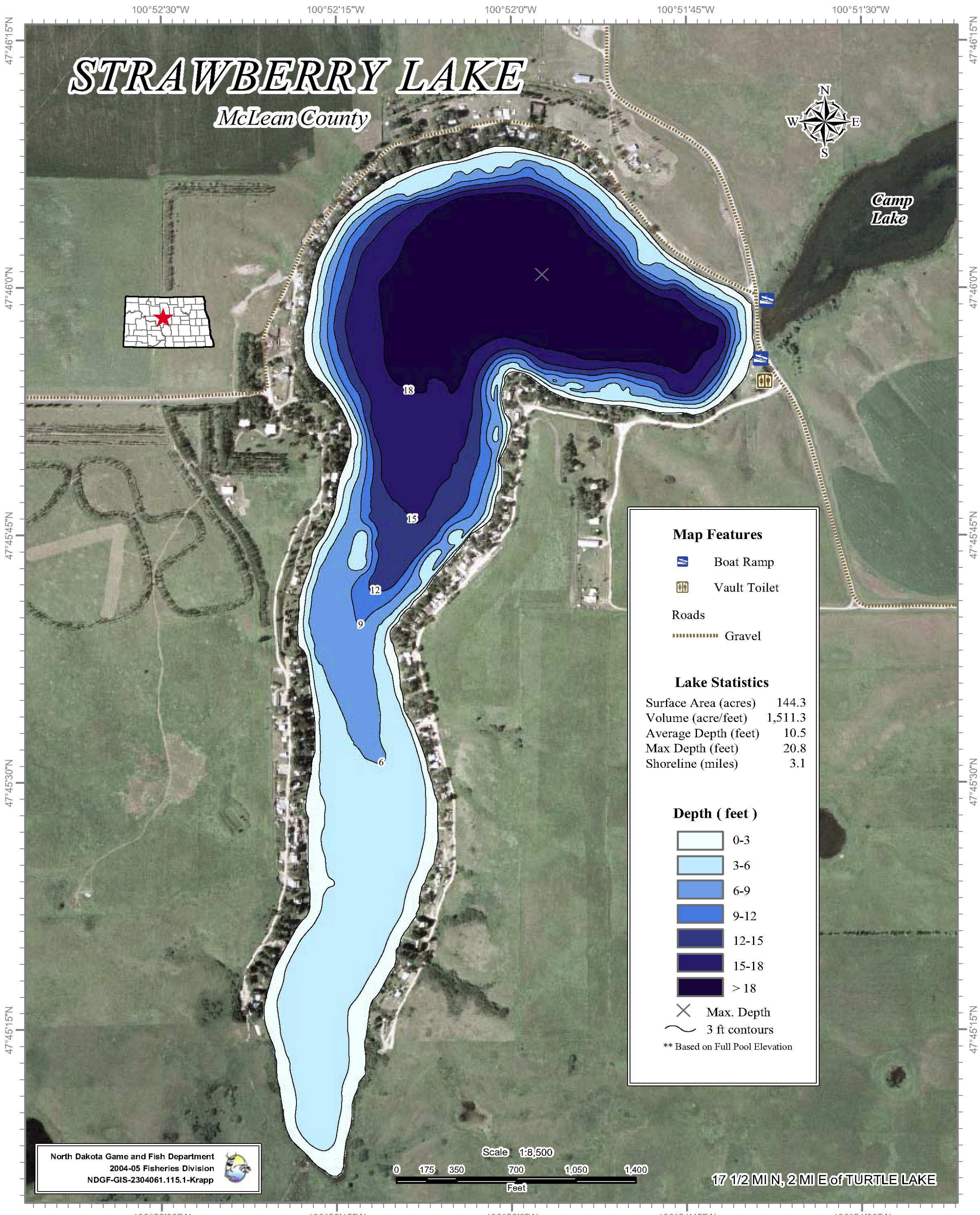


Figure 2. Contour Map of Strawberry Lake (Map Courtesy of North Dakota Game and Fish Department).

Construction History: Strawberry Lake was enhanced in 1932 by the construction of a dam and spillway at its outlet. The dam was built under the Works Protect Administration (WPA). In 1954 it was repaired and raised an additional two feet. In recent years, an aeration system was implemented on Strawberry Lake to improve water quality.

Recreational Facilities: Recreational facilities at Strawberry Lake include a boat ramp, boat and vehicle parking, and a beach located on the east side of the lake. Public access on the east side of the lake includes parking, vaulted restrooms, and a swimming beach. Lake cabins encompass about 80% of the lake's perimeter.

Water Quality Standards Classification: Strawberry Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a "warm water fishery" or "waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present."

Historical and Current Fishery: The fishery in Strawberry Lake was established in 1932 with the completion of the WPA dam. The original stocking included northern pike, black bass, bluegills, yellow perch, walleye and crappie. Other species present are shiners, fathead minnows, sticklebacks and bullheads. Currently, walleye, northern pike, and yellow perch, are the only species managed in Strawberry Lake's fishery.

Historical Water Quality Sampling: Historical water quality data includes results from three samples collected from 1991 through 1992.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Strawberry Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There are seven temperature and dissolved oxygen profiles for Strawberry Lake collected from 1991-2006. Temperature and oxygen profiles are presented for two time periods, 1991-1992 and 2005-2006 (Figures 3 and 4). The profile data shows that during thermal stratification Strawberry Lake experiences moderate oxygen decay, and occasionally drops below the state's water quality standard of 5 mg/L. Of the seven profiles, four samples, collected on 7/9/1991, 8/1/1991, 1/31/1992 and 7/22/2005, dropped below the state standard of 5 mg/L. While the rapid loss of dissolved oxygen during these periods is concerning, there does appear to be enough dissolved oxygen to maintain aquatic life in the upper four meters of the water column.

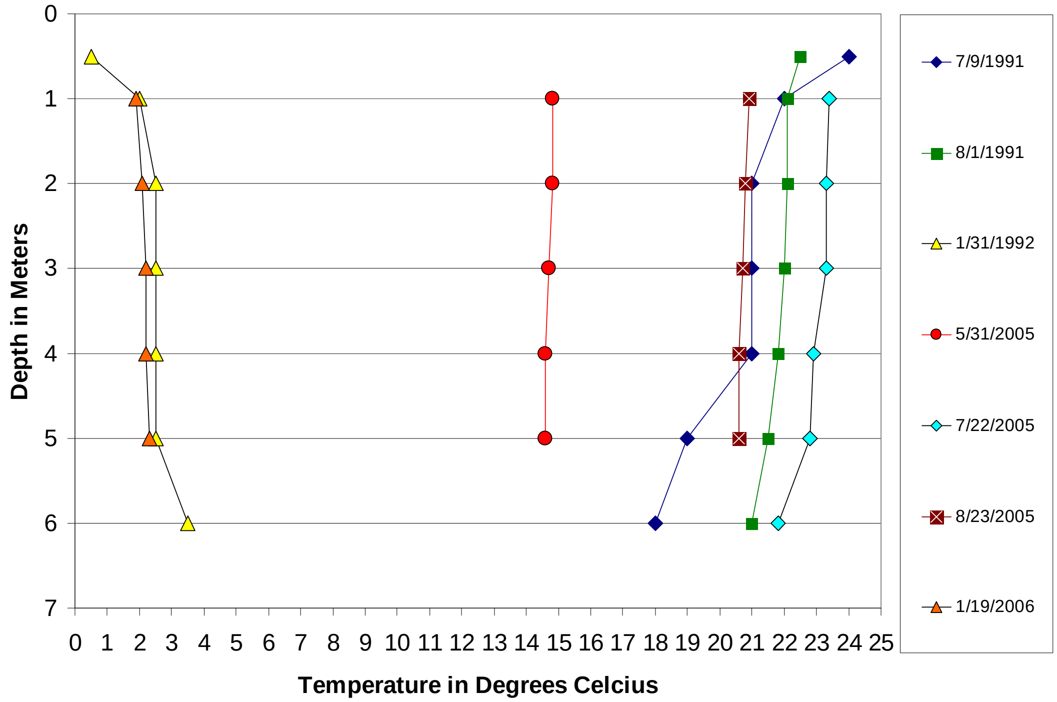


Figure 3. Temperature Profiles for Strawberry Lake from 1991 to 2006.

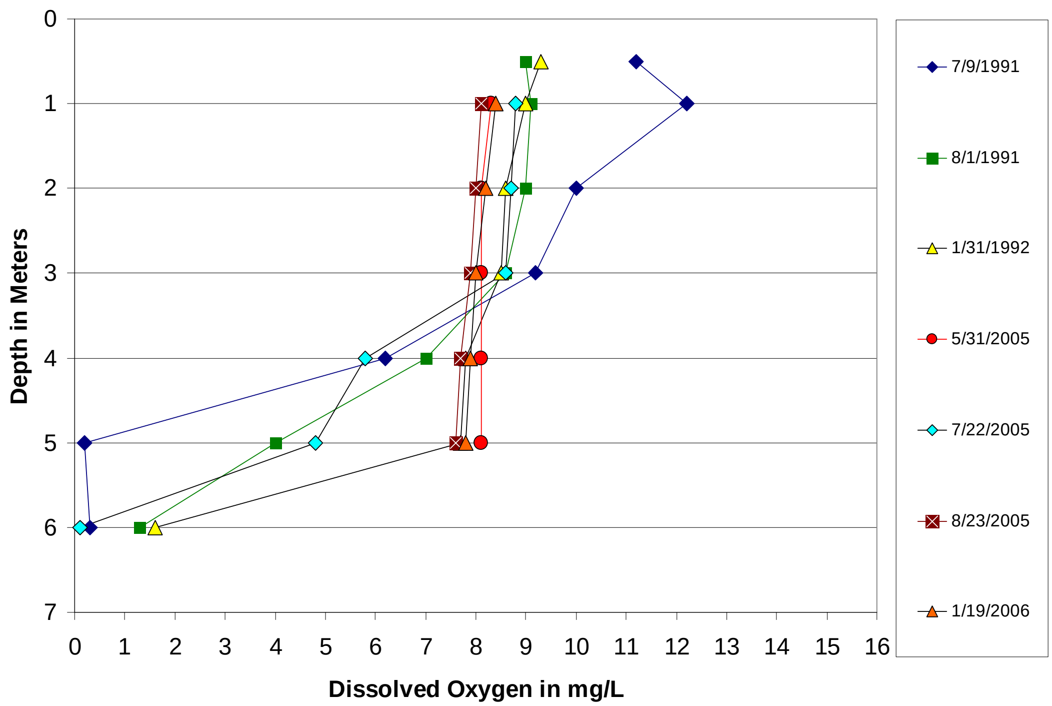


Figure 4. Dissolved Oxygen Profiles for Strawberry Lake from 1991 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006 indicate Strawberry Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 173 to 219 mg/L (Table 1). Based on the 2005-2006 water quality data (Table 1), Strawberry Lake is sodium bicarbonate dominated with an average sodium concentration of 19 mg/L and an average bicarbonate concentration of 215 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 290 mg/L and 504 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 0.478 mg/L and 0.016 mg/L, respectively.

Table 1. Statistical Summary of Strawberry Lake's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	188	173	219	21
Total Ammonia as N	mg/L	4	0.010[1]	0.010[1]	0.010[1]	0.000
Bicarbonate (HCO_3)	mg/L	4	215	187	267	37
Calcium (Ca)	mg/L	4	41.2	34.7	53.5	8.7
Carbonate (CO_3)	mg/L	4	7	1[1]	12	5
Chloride (Cl)	mg/L	4	4	4	5	1
Chlorophyll-a	µg/L	3	9.6	1.5	14.8	7.1
Specific Conductance	µmhos	4	504	463	585	55
Total Dissolved Solids	mg/L	4	290	268	343	35
Total Hardness as ($CaCO_3$)	mg/L	4	229	203	276	33
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.068	0.057	0.085	0.013
Magnesium (Mg)	mg/L	4	30.5	28.3	34.5	2.7
Nitrate + Nitrite as N	mg/L	4	0.025	0.020[1]	0.040	0.010
Total Kjeldahl Nitrogen as N	mg/L	4	0.453	0.360	0.555	0.085
Total Nitrogen as N	mg/L	4	0.478	0.380	0.575	0.089
pH		4	8.41	8.08	8.64	0.25
Total Phosphorus as P	mg/L	4	0.016	0.010	0.022	0.007
Potassium (K)	mg/L	4	3.7	3.1	4.5	0.6
Sodium (Na)	mg/L	4	19	17	21	2
Sulfate (SO4)	mg/L	4	78	72	91	9

[1]Equal to lower detection limit

When comparing historical water quality data for Strawberry Lake to current data most water quality constituents have remained stable. For example, the historical average bicarbonate and sodium concentrations were 214 mg/L and 19 mg/L, respectively (Table 2), compared to average concentrations of 215 mg/L for bicarbonate and 19 mg/L for sodium recorded for the period 2005-2006 (Table 1). The average total nitrogen and total phosphorus concentrations have decreased when compared to the historical data. The historical average for total nitrogen and total phosphorus concentrations is 1.514 mg/L and 0.059 mg/L (Table 2) respectively, compared to the current average concentration of 0.478 mg/L for total nitrogen and 0.016 mg/L for total phosphorus.

Table 2. Statistical Summary of Strawberry Lake's Historical Water Quality Data Collected Between 1991 and 1992.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	191	171	229	33
Total Ammonia as N	mg/L	3	0.109	0.001[1]	0.301	0.166
Bicarbonate (HCO_3)	mg/L	3	214	175	279	57
Calcium (Ca)	mg/L	3	34	26	45	10
Carbonate (CO_3)	mg/L	2	15	11	18	5
Chloride (Cl)	mg/L	3	5.5	4.9	6.3	0.7
Chlorophyll-a	µg/L	2	48.5	42.0	55.0	9.2
Specific Conductance	µmhos	3	486	448	553	58
Total Dissolved Solids	mg/L	3	259	227	314	48
Total Hardness as ($CaCO_3$)	mg/L	3	210	177	251	38
Hydroxide (OH)	mg/L	3	0.030	0.021	0.047	0.014
Iron (Fe)	mg/L	3	30.7	27.5	33.9	3.2
Magnesium (Mg)	mg/L	3	191	171	229	33
Nitrate + Nitrite as N	mg/L	3	0.008	0.004[1]	0.012	0.004
Total Kjeldahl Nitrogen as N	mg/L	3	1.507	1.160	1.830	0.336
Total Nitrogen as N	mg/L	3	1.514	1.172	1.837	0.333
pH		3	8.47	7.90	8.90	0.51
Total Phosphorus as P	mg/L	3	0.059	0.036	0.073	0.020
Potassium (K)	mg/L	3	4.3	4.0	4.5	0.3
Sodium (Na)	mg/L	3	19	18	19	1
Sulfate (SO4)	mg/L	3	52	34	69	18

[1]Equal to lower detection limit

When compared to the Rangeland Plains regional averages for natural and enhanced lakes Strawberry Lake is considerably fresher and less eutrophic. For example, the regional averages for TDS, total nitrogen, and total phosphorus are 1176 mg/L, 1.472 mg/L, and 0.135 mg/L, respectively, compared to Strawberry Lake's average for TDS, total nitrogen, and total phosphorus of 290 mg/L, 0.478 mg/L and 0.016 mg/L, respectively.

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Strawberry Lake and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight, in algae is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There are seven water quality sample sets for Strawberry Lake between July 1991 and January 2006, where the N:P ratio could be calculated. The results from this analysis indicate that Strawberry Lake is phosphorus limited (Figure 5).

N:P ratios for Strawberry Lake ranged from a low of 21 to a high of 43 with an average of 30. All seven samples collected were above a ratio of 15 indicating phosphorus is limiting primary production in Strawberry Lake.

Table 3. Statistical Summary of Water Quality Data[2] Collected from Reservoirs in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	408	309	101	982	130
Total Ammonia as N	mg/L	469	0.097	0.001[1]	2.440	0.200
Bicarbonate (HCO_3)	mg/L	408	318	14	1040	150
Calcium (Ca)	mg/L	408	50	5	160	26
Carbonate (CO_3)	mg/L	402	30	1[1]	197	30
Chloride (Cl)	mg/L	408	13.3	0.3	74.5	8.8
Chlorophyll-a	µg/L	321	21.2	1.5	218.0	27.9
Specific Conductance	µmhos	428	1733	262	5880	959
Total Dissolved Solids	mg/L	409	1176	147	5110	750
Total Hardness as ($CaCO_3$)	mg/L	408	397	45	1850	260
Hydroxide (OH)	mg/L	337	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	409	0.179	0.007	4.110	0.334
Magnesium (Mg)	mg/L	408	66.0	5.6	353.0	49.6
Nitrate + Nitrite as N	mg/L	395	0.048	0.001[1]	0.790	0.092
Total Kjeldahl Nitrogen as N	mg/L	359	1.556	0.365	7.720	0.779
Total Nitrogen as N	mg/L	302	1.472	0.405	4.840	0.562
pH		428	8.61	6.73	9.87	0.56
Total Phosphorus as P	mg/L	475	0.135	0.004	3.160	0.205
Potassium (K)	mg/L	408	14.6	4.2	39.2	6.3
Sodium (Na)	mg/L	408	239	3[1]	932	171
Sulfate (SO4)	mg/L	406	604	1[1]	3210	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 69 Reservoirs between 1991 and 2007

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005-2006, Strawberry Lake's current trophic status is mesotrophic to eutrophic. TSI scores ranged from a low of 35, to a high of 57 based on chlorophyll-a samples. The trophic status scores based on Secchi disk transparency and total phosphorus were similar to that estimated based on chlorophyll-a, ranging from 37 to 55 (Figure 6).

A total of seven total phosphorus samples, five chlorophyll-a samples, and five Secchi disk transparency measurements collected during the open water periods from 1991-2006 were used to evaluate trends in the trophic status of Strawberry Lake. Based on a visual assessment of the data Strawberry Lake's trophic status is improving (Figure 6).

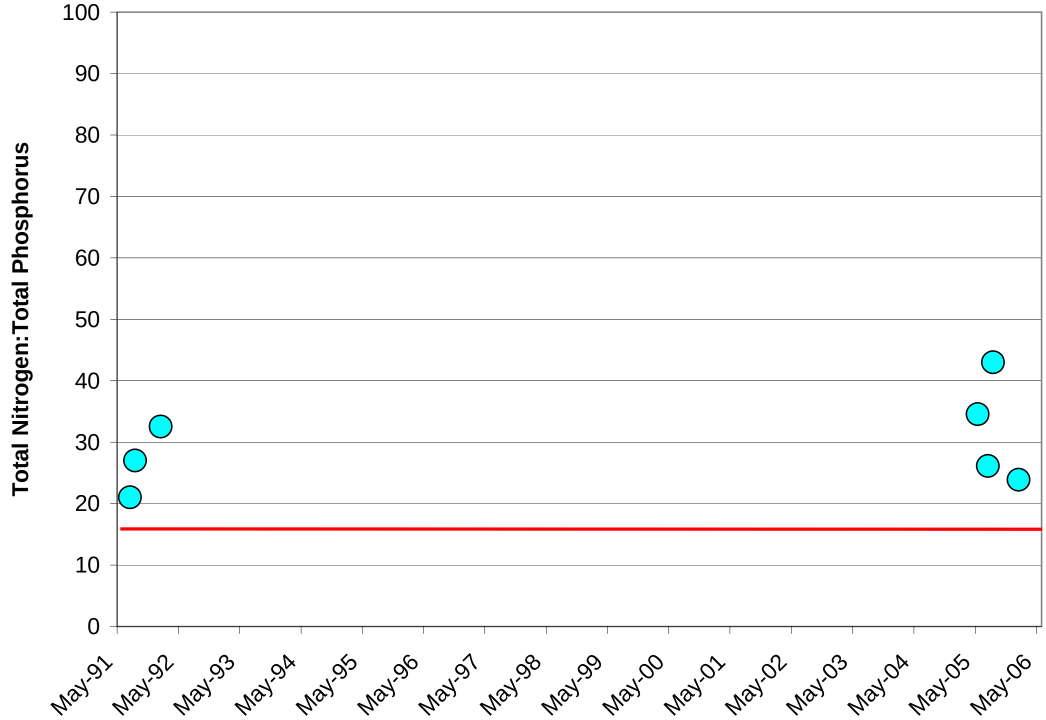


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Strawberry Lake (1991-2006).

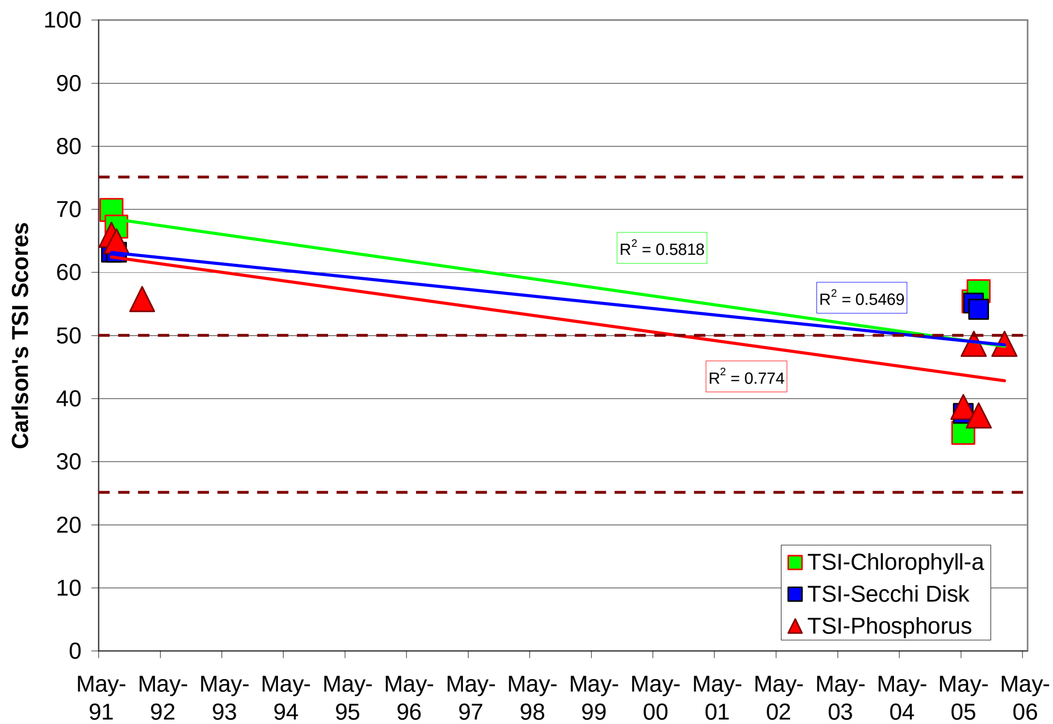


Figure 6. TSI Scores and Temporal Trends for Strawberry Lake from 1991-2006.

West Park Lake, McLean County

BACKGROUND

Location: West Park Lake is an enhanced lake located 12 miles south, and 2 miles west of Mercer, ND, on the McClusky Canal. West Park Lake is managed by the U.S. Bureau of Reclamation and the North Dakota Game and Fish Department (Figure 1).

Figure 1. Location of West Park Lake.

Physiographic/Ecological Setting: West Park Lake has a surface area of 275.9 acres, a maximum depth of 25.6 ft, and an average depth of 14.8 ft (Figure 2). West Park Lake's watershed is approximately 3,000 acres and it lies within the Northwestern Glaciated Plains (NGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The NGP marks the western most extent of continental glacial advancement. The geological youthful landscape has significant surface irregularities and high concentrations of wetlands. The rise in elevation along the eastern edge of this ecoregion defines the boundary of the Great Plains and to the west the Northwestern Great Plains (USEPA 1994).

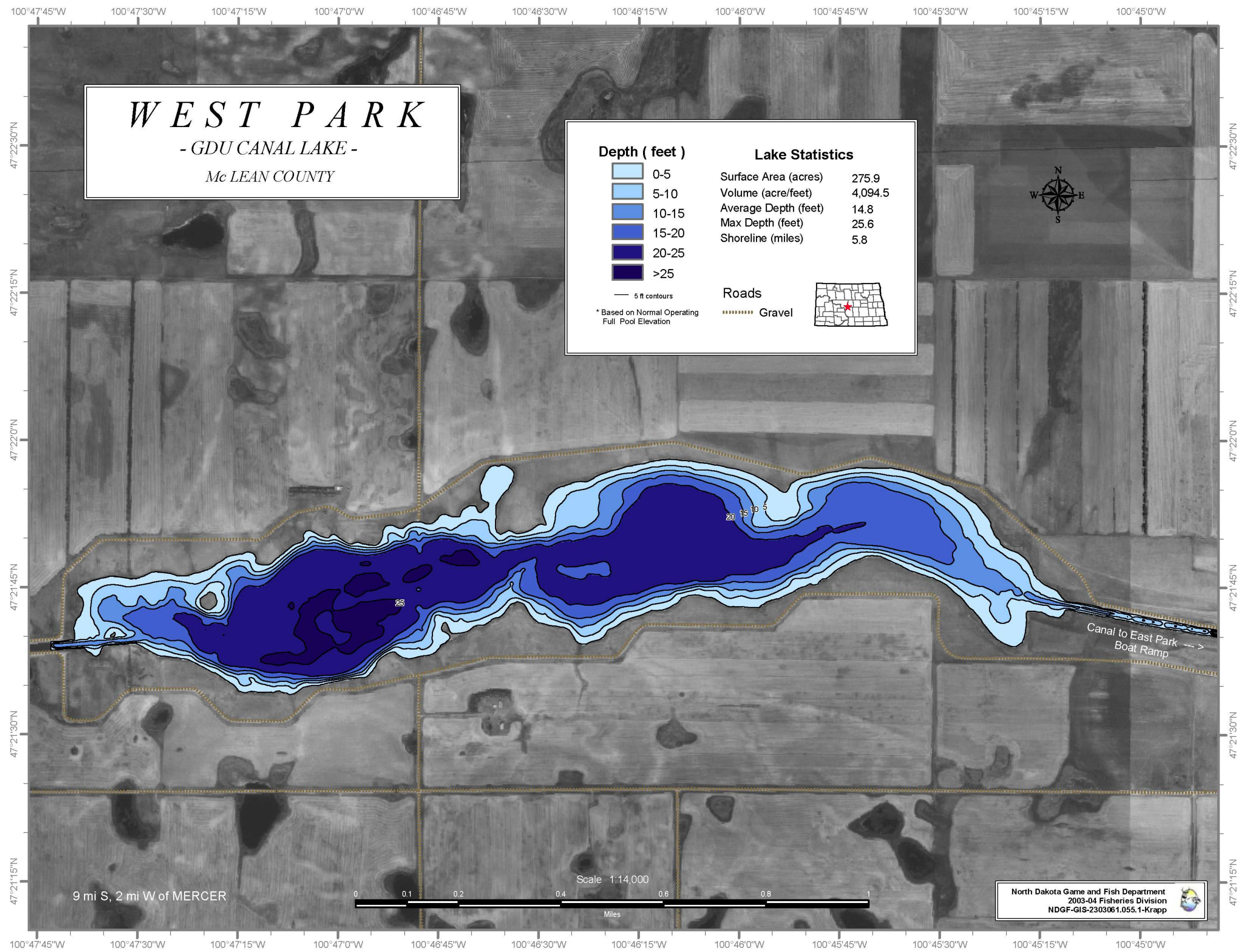


Figure 2. Contour Map of West Park Lake (Map Courtesy of North Dakota Game and Fish Department).

Construction History: West Park Lake is a manmade water body created by modifying a natural depression along the McClusky Canal. Construction on West Park Lake was completed in 1974 and filled the following year from surface and ground water discharges.

Recreational Facilities: Public access to West Park Lake is usually reasonable however access can be limited during the winter months. There are no recreational facilities at West Park Lake. Boating access into West Park Lake is from East Park Lake, through the McClusky Canal.

Water Quality Standards Classification: West Park Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 2 lake or reservoir. Class 2 lakes or reservoirs are defined as a "cool water fishery" or "waters capable of supporting natural reproduction and growth of cool water fishes (e.g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: West Park Lake's has a very diverse fishery with the potential for nearly every cool water species present in the state being found in it's waters. An incomplete list of current fish species are walleye, northern pike, muskellunge, black bullhead, large mouth bass, white sucker, fathead minnows, common carp, bigmouth buffalo, yellow perch, and bluegill. Historically, fish stocked into West Park Lake include northern pike, walleye, bluegill, fathead minnows, and largemouth bass. The additional species present in West Park Lake migrated from Lake Audubon and other lakes within the channel system.

Historical Water Quality Sampling: Historical water quality data includes results from three samples collected in 1993 and 1994.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for West Park Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural or enhanced lakes in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There are seven temperature and dissolved oxygen profiles for West Park Lake collected from 1993-2006. Temperature and oxygen profiles are presented for two time periods, 1993-1994 and 2005-2006 (Figures 3 and 4). The profile data shows that West Park Lake rarely thermally stratifies and that oxygen decay below the metalimnion is slow, rarely dropping below the state's water quality standard of 5 mg/L. Of the 7 profiles, two samples, collected on 2/16/1994 and 7/19/2005, dropped below the state standard of 5 mg/L.

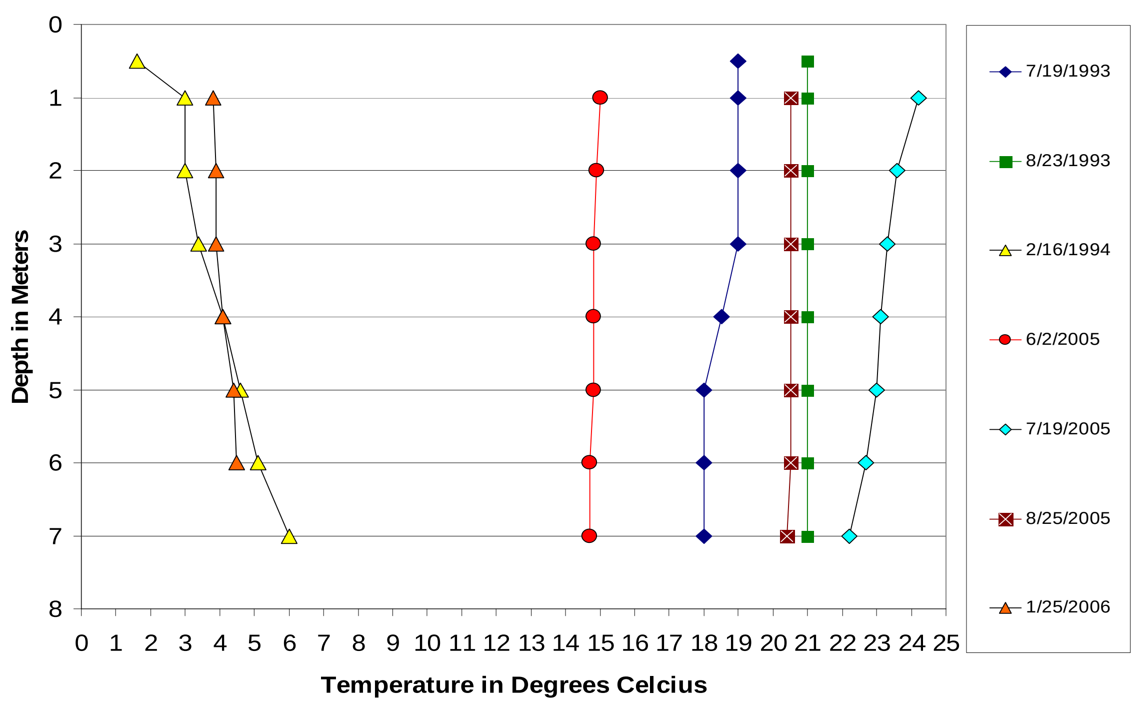


Figure 3. Temperature Profiles for West Park Lake from 1993 to 2006.

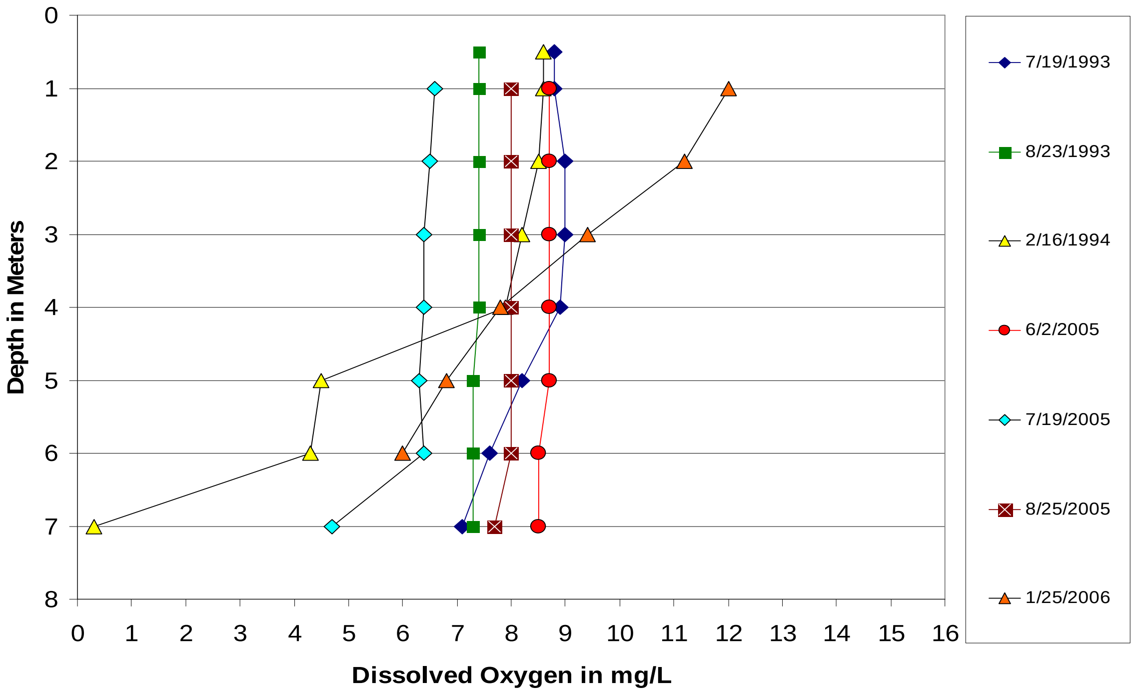


Figure 4. Dissolved Oxygen Profiles for West Park Lake from 1993 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006 indicate West Park Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 236 to 287 mg/L (Table 1). Based on the 2005-2006 water quality data (Table 1), West Park Lake is sodium sulfate dominated with an average sodium concentration of 139 mg/L and an average sulfate concentration of 371 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 793 mg/L and 1205 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 0.727 mg/L and 0.039 mg/L, respectively.

When compared to historical water quality data for West Park Lake, it appears that concentrations of most water quality constituents have increased. For example, the historical average sulfate and sodium concentrations were 284 mg/L and 104 mg/L, respectively (Table 2), compared to the 2005-2006 average concentrations of 371 mg/L for sulfate and 139 mg/L for sodium (Table 1). Average total nitrogen and total phosphorus concentrations have fluctuated when compared to the historical data. The historical average for total nitrogen and total phosphorus concentrations is 0.986 mg/L and 0.023 mg/L (Table 2) respectively, compared to the current average concentration of 0.727 for total nitrogen and 0.039 mg/L for total phosphorus.

When compared to the Rangeland Plains regional average for natural and enhanced lakes West Park Lake is fresher and less eutrophic (Table 3). For example, the regional average for TDS, total nitrogen, and total phosphorus concentrations are 1588 mg/L, 1.826 mg/L, and 0.244 mg/L, respectively, compared to West Park Lake's average TDS, total nitrogen, and total phosphorus concentrations of 793 mg/L, 0.727 mg/L and 0.039 mg/L, respectively.

Table 1. Statistical Summary of West Park Lake's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	257	236	287	22
Total Ammonia as N	mg/L	4	0.064	0.026	0.095	0.030
Bicarbonate (HCO_3)	mg/L	4	289	271	329	27
Calcium (Ca)	mg/L	4	49.7	44.9	55.1	4.2
Carbonate (CO_3)	mg/L	4	12	8	15	3
Chloride (Cl)	mg/L	4	17	16	19	1
Chlorophyll-a	µg/L	3	3.7	1.5	7.6	3.4
Specific Conductance	µmhos	4	1205	1130	1340	93
Total Dissolved Solids	mg/L	4	793	739	874	57
Total Hardness as ($CaCO_3$)	mg/L	4	340	311	378	28
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.241	0.058	0.508	0.195
Magnesium (Mg)	mg/L	4	52.4	48.3	58.4	4.3
Nitrate + Nitrite as N	mg/L	4	0.033	0.020	0.070	0.025
Total Kjeldahl Nitrogen as N	mg/L	4	0.694	0.609	0.788	0.073
Total Nitrogen as N	mg/L	4	0.727	0.629	0.808	0.077
pH		4	8.52	8.46	8.56	0.04
Total Phosphorus as P	mg/L	4	0.039	0.018	0.064	0.020
Potassium (K)	mg/L	4	9.1	8.9	9.6	0.3
Sodium (Na)	mg/L	4	139	133	147	6
Sulfate (SO4)	mg/L	4	371	346	412	29

[1]Equal to lower detection limit

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in West Park Lake and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight, in algae is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were seven water quality sample results for West Park Lake collected between July 1993 and January 2006 where the N:P ratio could be calculated. The results from this analysis indicate that West Park Lake is most often phosphorus limited (Figure 5).

N:P ratios for West Park Lake ranged from a low of 11 to a high of 226 with an average of 55. Of the seven samples collected on West Park Lake, all but two were above an N:P ratio of 15, indicating phosphorus limitation.

Table 2. Statistical Summary of West Park Lake's Historical Water Quality Data Collected Between 1993 and 1994.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	213	195	247	29
Total Ammonia as N	mg/L	3	0.097	0.042	0.202	0.091
Bicarbonate (HCO_3)	mg/L	3	242	207	302	52
Calcium (Ca)	mg/L	3	46	42	52	5
Carbonate (CO_3)	mg/L	3	9	1[1]	15	7
Chloride (Cl)	mg/L	3	15.8	13.7	17.1	1.9
Chlorophyll-a	µg/L	2	5.1	3.0	7.1	2.9
Specific Conductance	µmhos	3	977	923	1080	89
Total Dissolved Solids	mg/L	3	624	566	715	80
Total Hardness as ($CaCO_3$)	mg/L	3	273	250	298	24
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	3	0.081	0.052	0.118	0.034
Magnesium (Mg)	mg/L	3	38.3	35.6	40.9	2.7
Nitrate + Nitrite as N	mg/L	3	0.039	0.007	0.094	0.048
Total Kjeldahl Nitrogen as N	mg/L	3	0.947	0.449	1.530	0.546
Total Nitrogen as N	mg/L	3	0.986	0.466	1.624	0.588
pH		3	8.39	7.95	8.63	0.38
Total Phosphorus as P	mg/L	3	0.023	0.004[1]	0.036	0.017
Potassium (K)	mg/L	3	6.3	5.7	6.7	0.6
Sodium (Na)	mg/L	3	104	94	118	13
Sulfate (SO4)	mg/L	3	284	258	330	40

[1]Equal to lower detection limit

Trophic Status Assessment: Based on limited chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005 and 2006, West Park Lake's current trophic status is mesotrophic trending towards eutrophic. TSI scores ranged from a low of 35 based on chlorophyll-a, to a high of 70 based on Secchi disk transparency. The trophic status score based on total phosphorus was similar to that estimated based on Secchi disk transparency, at 64 (Figure 6).

A total of seven total phosphorus samples, five chlorophyll-a samples, and four Secchi disk transparency measurements collected during the open water periods from 1993-2006 were used to evaluate trends in the trophic status of West Park Lake. Based on a visual assessment West Park Lake's trophic status is stable (Figure 6).

Table 3. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lakes in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	272	544	119	4770	130
Total Ammonia as N	mg/L	371	0.107	0.001[1]	2.230	0.200
Bicarbonate (HCO_3)	mg/L	272	489	145	2990	150
Calcium (Ca)	mg/L	272	44	1[1]	282	26
Carbonate (CO_3)	mg/L	262	89	1[1]	1420	30
Chloride (Cl)	mg/L	272	51	4[1]	1070	9
Chlorophyll-a	µg/L	250	22	2[1]	292	28
Specific Conductance	µmhos	272	2168	448	20100	959
Total Dissolved Solids	mg/L	272	1588	227	18200	750
Total Hardness as ($CaCO_3$)	mg/L	272	538	170	2370	260
Hydroxide (OH)	mg/L	200	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	273	0.193	0.001[1]	2.260	0.334
Magnesium (Mg)	mg/L	272	104	20	567	50
Nitrate + Nitrite as N	mg/L	332	0.036	0.002[1]	0.338	0.092
Total Kjeldahl Nitrogen as N	mg/L	340	1.950	0.080	8.500	0.779
Total Nitrogen as N	mg/L	278	1.826	0.269	5.520	0.562
pH		272	8.796	7.400	9.870	0.564
Total Phosphorus as P	mg/L	377	0.244	0.004[1]	1.940	0.205
Potassium (K)	mg/L	272	38	3[1]	356	6
Sodium (Na)	mg/L	272	331	17	4680	171
Sulfate (SO4)	mg/L	272	680	34	10500	501

[1]Equal to Minimum Reporting Limit

[2]Data Collected from 48 Natural and Enhanced Lakes between 1991 and 2007

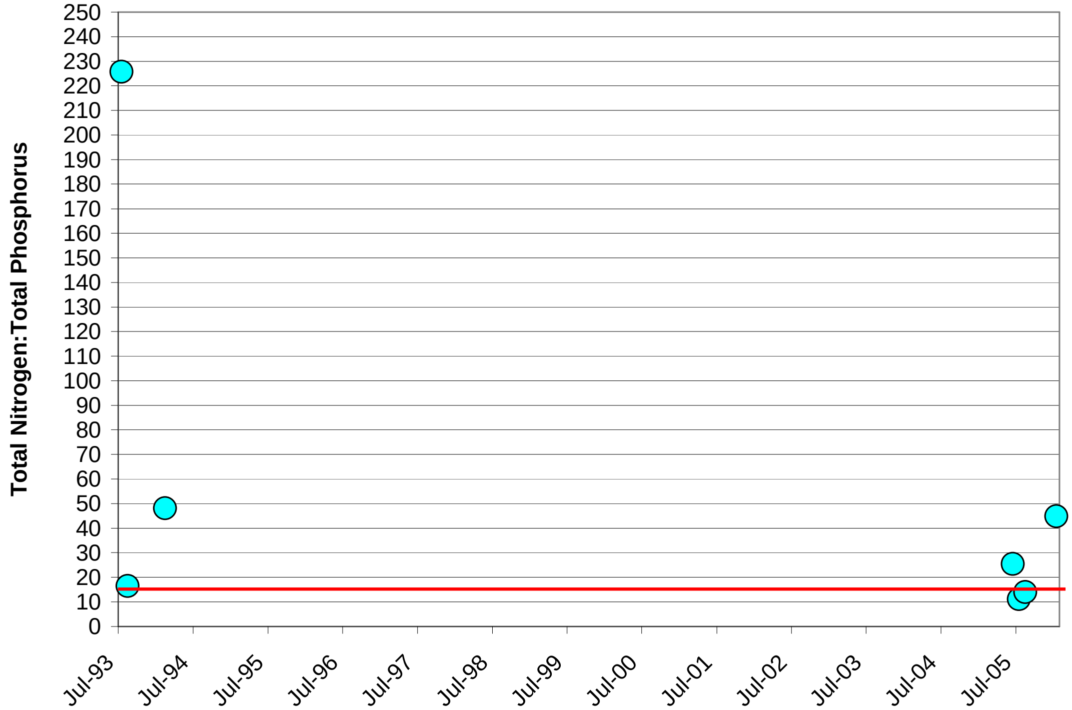


Figure 5. Total Nitrogen to Total Phosphorus Ratios in West Park Lake (1993-2006).

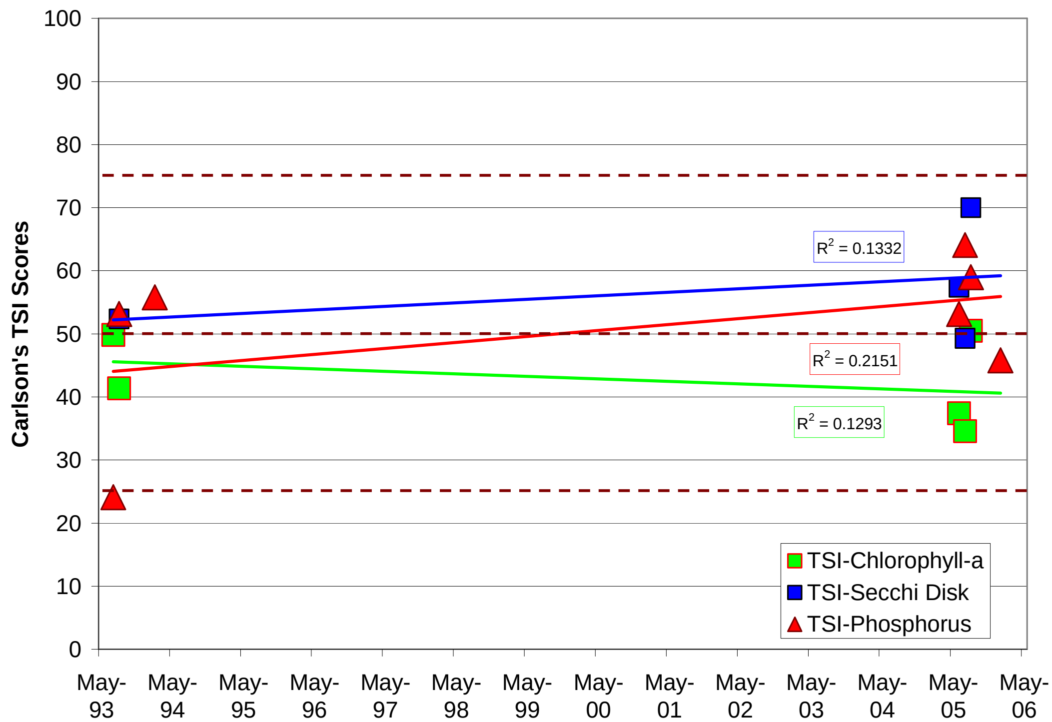


Figure 6. TSI Scores and Temporal Trends for West Park Lake from 1993 to 2006.

Fish Creek Dam, Morton County

BACKGROUND

Location: Fish Creek Dam is a small recreational impoundment on Fish Creek, located 9 miles south and 2 miles east of Interstate 94, Exit 134 (Figure 1). The reservoir is managed by the North Dakota Game and Fish Department.

Figure 1. Location of Fish Creek Dam.

Physiographic/Ecological Setting: Fish Creek Dam has a surface area of 51.9 acres, a maximum depth of 49.3 ft, and an average depth of 18.1 ft (Figure 2). The reservoir's watershed is located within the Northwestern Great Plains (NWGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The Fish Creek Dam watershed landscape is rolling plains. Flood plain slopes and hillsides are usually native grasslands, while the uplands and flood plains themselves have mostly been converted to small grains and alfalfa.

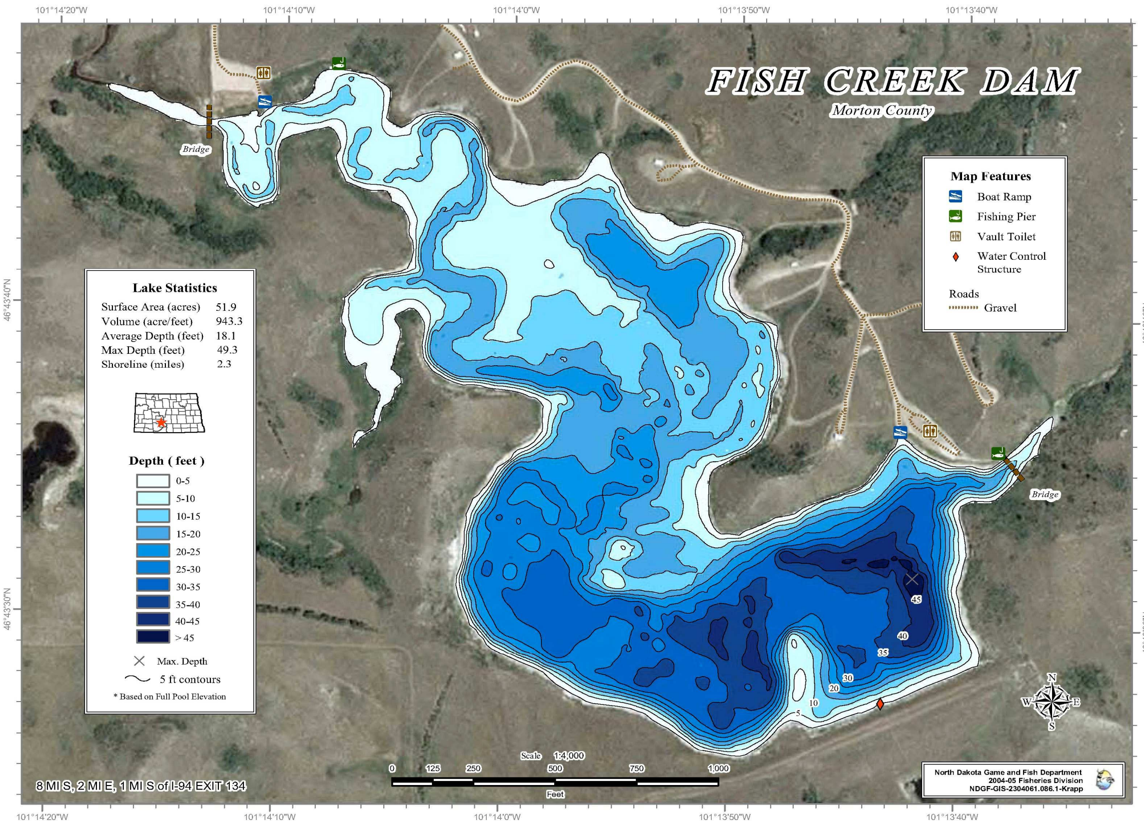


Figure 2. Contour Map of Fish Creek Dam (Map Courtesy of North Dakota Game and Fish Department).

Construction History: Fish Creek Dam was constructed in1971-1972 through the combined efforts of the Morton County Park Board, Morton County Water Management District, the North Dakota Game and Fish Department, the State Water Commission, and the Bureau of Outdoor Recreation. The Soil Conservation Service engineered the dam, which is made from rolled earth. At the time of completion, the lake's surface area was 56.5 acres, with an average depth of 20-24 feet, and a maximum depth of 45-50 feet.

Recreational Facilities: Recreational facilities at Fish Creek Dam include 2 cement boat ramps, boat and vehicle parking, picnic shelters, walking paths, fire pits, and 2 fishing piers. Several trails on the north side of the lake include parking, restrooms, camp grounds, and an information bulletin.

Water Quality Standards Classification: Fish Creek Dam is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 1 lake or reservoir. Class 1 lakes or reservoirs are defined as a "cold water fishery" or "waters capable of supporting growth of cold water fishes (e.g., salmonids) and associated aquatic biota."

Historical and Current Fishery: Fish Creek Dam's fishery originally was an excellent rainbow trout fishery. Due to the incidental introduction of white suckers, bullheads, and yellow perch, the North Dakota Game and Fish Department introduced largemouth bass and northern pike to try to control their blooming population. The NDGFD's attempts were unsuccessful and the lake was eradicated in 1991. Following the eradication, the fishery was restocked with largemouth and smallmouth bass, black crappie, rainbow trout, brown trout, fathead minnows, and brook stickleback.

Historical Water Quality Sampling: Historical water quality data includes results from three water quality samples collected in1993 and 1994.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Fish Creek Dam have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There are seven temperature and dissolved oxygen profiles for Fish Creek Dam collected intermittently between 1993 and 2006. Temperature and oxygen profiles are presented for two time periods, 1993-1994 and 2005-2006 (Figures 3 and 4).

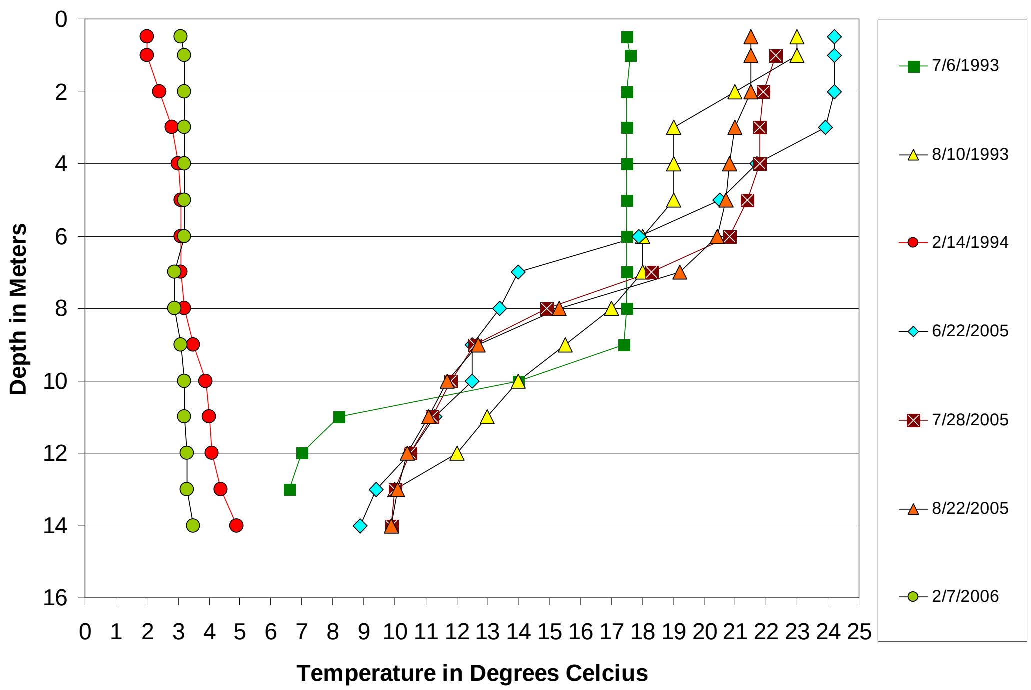


Figure 3. Temperature Profiles for Fish Creek Dam from 1993 to 2006.

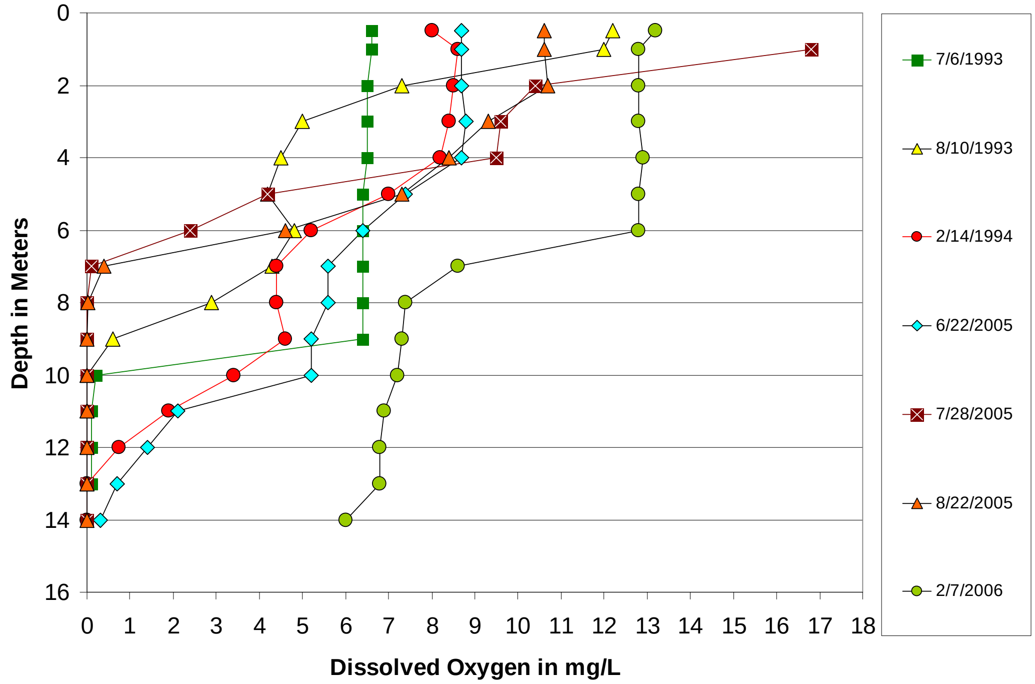


Figure 4. Dissolved Oxygen Profiles for Fish Creek Dam from 1993 to 2006.

The profile data shows that during thermal stratification Fish Creek Dam experiences rapid oxygen decay and frequently drops below the state's water quality standard of 5 mg/L. Of the seven profiles, six samples collected on 7/6/1993, 8/10/1993, 2/14/1994, 6/22/2005, 7/28/2005, and 8/22/2005 dropped below the state standard of 5 mg/L. While the rapid loss of dissolved oxygen during these periods is concerning, there does appear to be enough dissolved oxygen to maintain aquatic life in the upper 5 to 6 meters of the water column at all times.

General Water Quality: Data collected by the NDGF in 2005 and 2006 indicate Fish Creek Dam is well buffered with total alkalinity as $CaCO_3$ concentrations ranging from 297 to 346 mg/L (Table 1). Based on the 2005-2006 water quality data, Fish Creek Dam is sodium sulfate dominated with an average sodium concentration of 219 mg/L and an average sulfate concentration of 389 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 885 mg/L and 1345 µmhos/cm respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.380 mg/L and 0.045 mg/L respectively.

When compared to historical water quality data for Fish Creek Dam, it appears that concentrations of most mineral constituents have increased. For example the historical average sulfate and sodium concentrations were 137 mg/L and 97 mg/L respectively (Table 2), compared to average concentrations of 389 mg/L for sulfate and 219 mg/L for sodium recorded for the period 2005-2006 (Table 1).

Table 1. Statistical Summary of Fish Creek Dam's 2005-2006 Water Quality Data.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	313	297	346	22
Total Ammonia as N	mg/L	4	0.104	0.010[1]	0.267	0.117
Bicarbonate (HCO_3)	mg/L	4	323	277	406	61
Calcium (Ca)	mg/L	4	31.3	26.4	35.3	4.2
Carbonate (CO_3)	mg/L	4	29	8	46	20
Chloride (Cl)	mg/L	4	6	6	7	0
Chlorophyll-a	µg/L	4	29.0	1.5	88.1	40.8
Specific Conductance	µmhos	4	1345	1290	1480	90
Total Dissolved Solids	mg/L	4	885	849	982	65
Total Hardness as ($CaCO_3$)	mg/L	4	244	224	282	27
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.098	0.069	0.120	0.022
Magnesium (Mg)	mg/L	4	40.3	37.5	47.0	4.5
Nitrate + Nitrite as N	mg/L	4	0.093	0.020	0.230	0.099
Total Kjeldahl Nitrogen as N	mg/L	4	1.288	1.060	1.500	0.230
Total Nitrogen as N	mg/L	4	1.380	1.140	1.700	0.276
pH		4	8.80	8.44	9.08	0.31
Total Phosphorus as P	mg/L	4	0.045	0.026	0.066	0.020
Potassium (K)	mg/L	4	9.9	9.1	11.4	1.0
Sodium (Na)	mg/L	4	219	207	250	21
Sulfate (SO4)	mg/L	4	389	376	421	22

[1]Equal to lower detection limit

Unlike the average mineral component, total nitrogen and total phosphorus concentrations have decreased when compared to the historical data. Historical average total nitrogen and total phosphorus concentrations were 1.433 mg/L and 0.078 mg/L respectively (Table 2), compared to current average concentrations of 1.380 mg/L for total nitrogen and 0.045 mg/L for total phosphorus (Table 2).

When compared to reservoirs the Rangeland Plains region, Fish Creek Dam's water quality is composed of fewer minerals and nutrients (Table 3). For example, the regional average total dissolved solids (TDS), total nitrogen, and total phosphorus concentrations are 1176 mg/L, 1.472 mg/L, and 0.135 mg/L respectively, compared to Fish Creek Dam's average TDS, total nitrogen, and total phosphorus concentrations of 885 mg/L, 1.380 mg/L and 0.045 mg/L respectively, for the period 2005-2006.

Table 2. Statistical Summary of Fish Creek Dam's Historical Water Quality Data Collected Between 1993 and 1994.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	233	137	326	95
Total Ammonia as N	mg/L	3	0.168	0.030	0.282	0.128
Bicarbonate (HCO_3)	mg/L	3	265	167	339	88
Calcium (Ca)	mg/L	3	26	18	35	8
Carbonate (CO_3)	mg/L	3	10	1[1]	29	16
Chloride (Cl)	mg/L	3	2.3	0.3	3.4	1.7
Chlorophyll-a	µg/L	2	17.5	5.0	30.0	17.7
Specific Conductance	µmhos	3	676	445	934	246
Total Dissolved Solids	mg/L	3	429	265	603	169
Total Hardness as ($CaCO_3$)	mg/L	3	138	114	162	24
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	3	0.287	0.091	0.564	0.247
Magnesium (Mg)	mg/L	3	17.8	12.5	22.7	5.1
Nitrate + Nitrite as N	mg/L	3	0.085	0.010[1]	0.169	0.080
Total Kjeldahl Nitrogen as N	mg/L	3	1.349	0.866	2.020	0.600
Total Nitrogen as N	mg/L	3	1.433	1.035	2.030	0.526
pH		3	8.38	8.08	8.80	0.38
Total Phosphorus as P	mg/L	3	0.078	0.050	0.124	0.040
Potassium (K)	mg/L	3	6.8	5.9	8.3	1.3
Sodium (Na)	mg/L	3	97	56	156	52
Sulfate (SO4)	mg/L	3	137	78	197	60

[1]Equal to lower detection limit

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Fish Creek Dam and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight in algae, is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were seven water quality sample results for Fish Creek Dam collected between July 1993 and February 2006 where the N:P ratio could be calculated. The results from this analysis indicate that Fish Creek Dam is most often phosphorus limited (Figure 5).

N:P ratios for Fish Creek Dam ranged from a low of 10 to a high of 52 with an average of 30. Of the seven samples collected on Fish Creek Dam, all but one of the samples were above an N:P ratio of 15 indicating phosphorus limitation.

Table 3. Statistical Summary of Water Quality Data[2] Collected from Reservoirs in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	408	309	101	982	130
Total Ammonia as N	mg/L	469	0.097	0.001[1]	2.440	0.200
Bicarbonate (HCO_3)	mg/L	408	318	14	1040	150
Calcium (Ca)	mg/L	408	50	5	160	26
Carbonate (CO_3)	mg/L	402	30	1[1]	197	30
Chloride (Cl)	mg/L	408	13.3	0.3	74.5	8.8
Chlorophyll-a	µg/L	321	21.2	1.5	218.0	27.9
Specific Conductance	µmhos	428	1733	262	5880	959
Total Dissolved Solids	mg/L	409	1176	147	5110	750
Total Hardness as ($CaCO_3$)	mg/L	408	397	45	1850	260
Hydroxide (OH)	mg/L	337	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	409	0.179	0.007	4.110	0.334
Magnesium (Mg)	mg/L	408	66.0	5.6	353.0	49.6
Nitrate + Nitrite as N	mg/L	395	0.048	0.001[1]	0.790	0.092
Total Kjeldahl Nitrogen as N	mg/L	359	1.556	0.365	7.720	0.779
Total Nitrogen as N	mg/L	302	1.472	0.405	4.840	0.562
pH		428	8.61	6.73	9.87	0.56
Total Phosphorus as P	mg/L	475	0.135	0.004	3.160	0.205
Potassium (K)	mg/L	408	14.6	4.2	39.2	6.3
Sodium (Na)	mg/L	408	239	3[1]	932	171
Sulfate (SO4)	mg/L	406	604	1[1]	3210	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 69 Reservoirs between 1991 and 2007

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005-2006, Fish Creek Dam's current trophic status is eutrophic. TSI scores ranged from a low of 35, to a high of 75 based on chlorophyll-a samples. The average trophic status scores based on total phosphorus and Secchi disk transparency were both 56, similar to the average chlorophyll-a score of 53 (Figure 6).

A total of seven total phosphorus samples, six chlorophyll-a samples, and five Secchi disk transparency measurements collected from 1993-2006 were used to evaluate trends in the trophic status of Fish Creek Dam. Based on a visual assessment of the data, Fish Creek Dam's trophic status is stable (Figure 6).

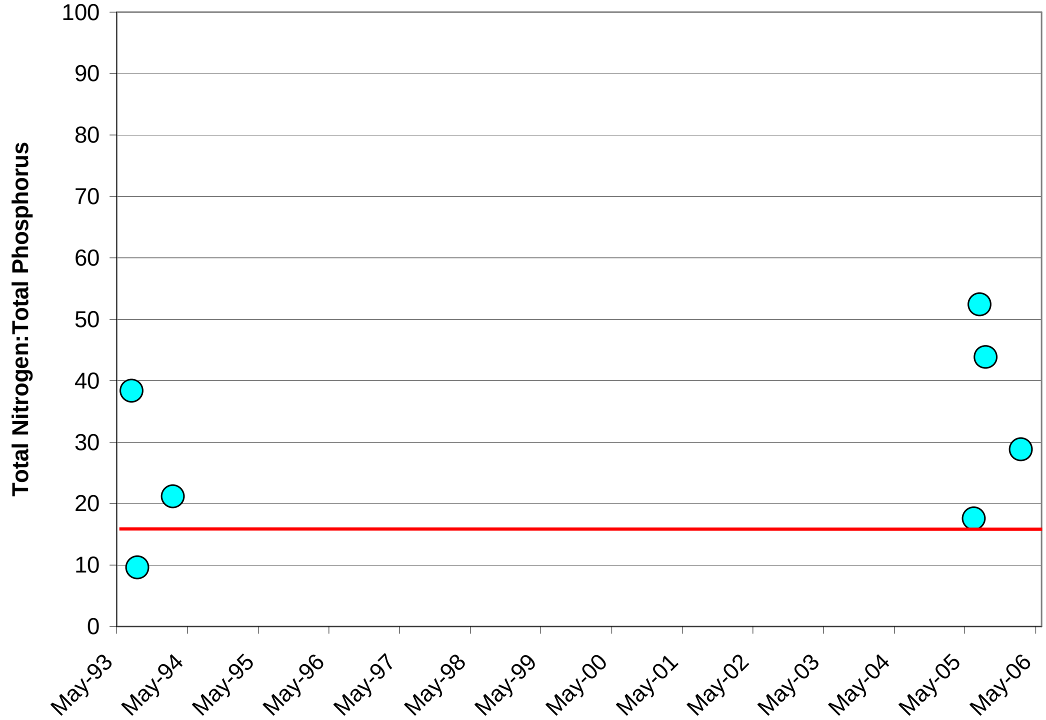


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Fish Creek Dam (1993-2006).

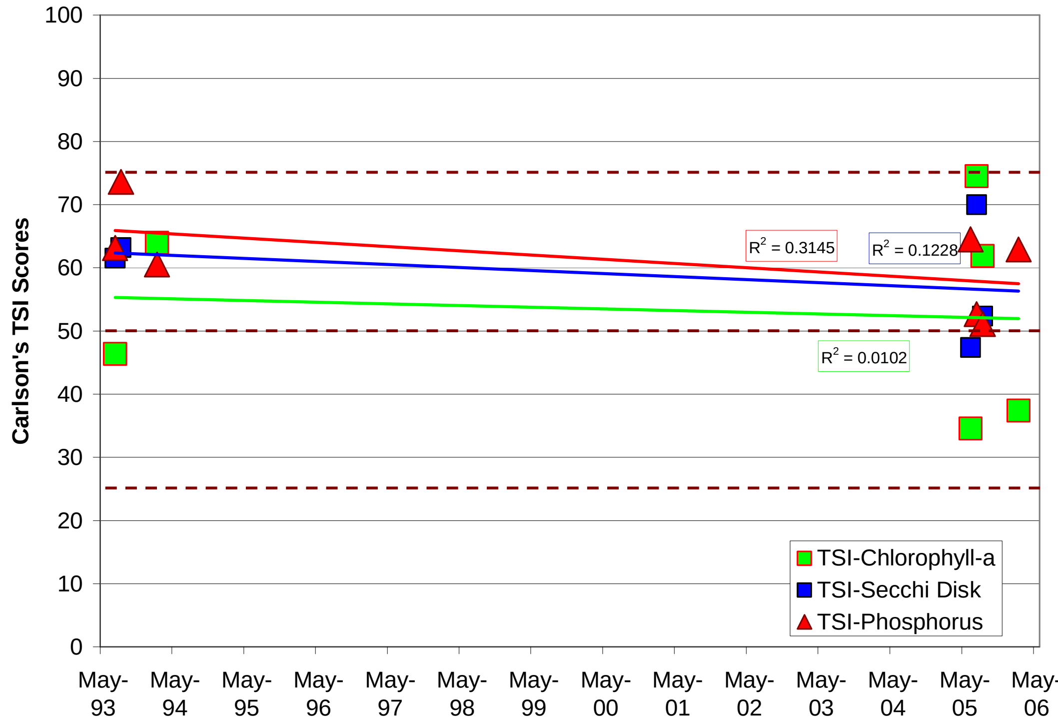


Figure 6. TSI Scores and Temporal Trends for Fish Creek Dam from 1993 to 2006.

East Arroda Dam, Oliver County

BACKGROUND

Location: East Arroda Dam is a small recreational impoundment on U.S. Highway 200A, located 1 mile east of Fort Clark, North Dakota (Figure 1). East Arroda Dam is managed by the North Dakota Game and Fish Department.

Figure 1. Location of East Arroda Dam.

Physiographic/Ecological Setting: East Arroda Dam has a surface area of 20.4 acres, a maximum depth of 34.8 ft, and an average depth 13.6 ft (Figure 2). The reservoir's watershed is located within the Northwestern Great Plains (NWGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The East Arroda Dam watershed landscape is rolling plains. Flood plain slopes and hillsides are usually native grasslands, while the uplands and flood plains themselves have mostly been converted to small grains and alfalfa.

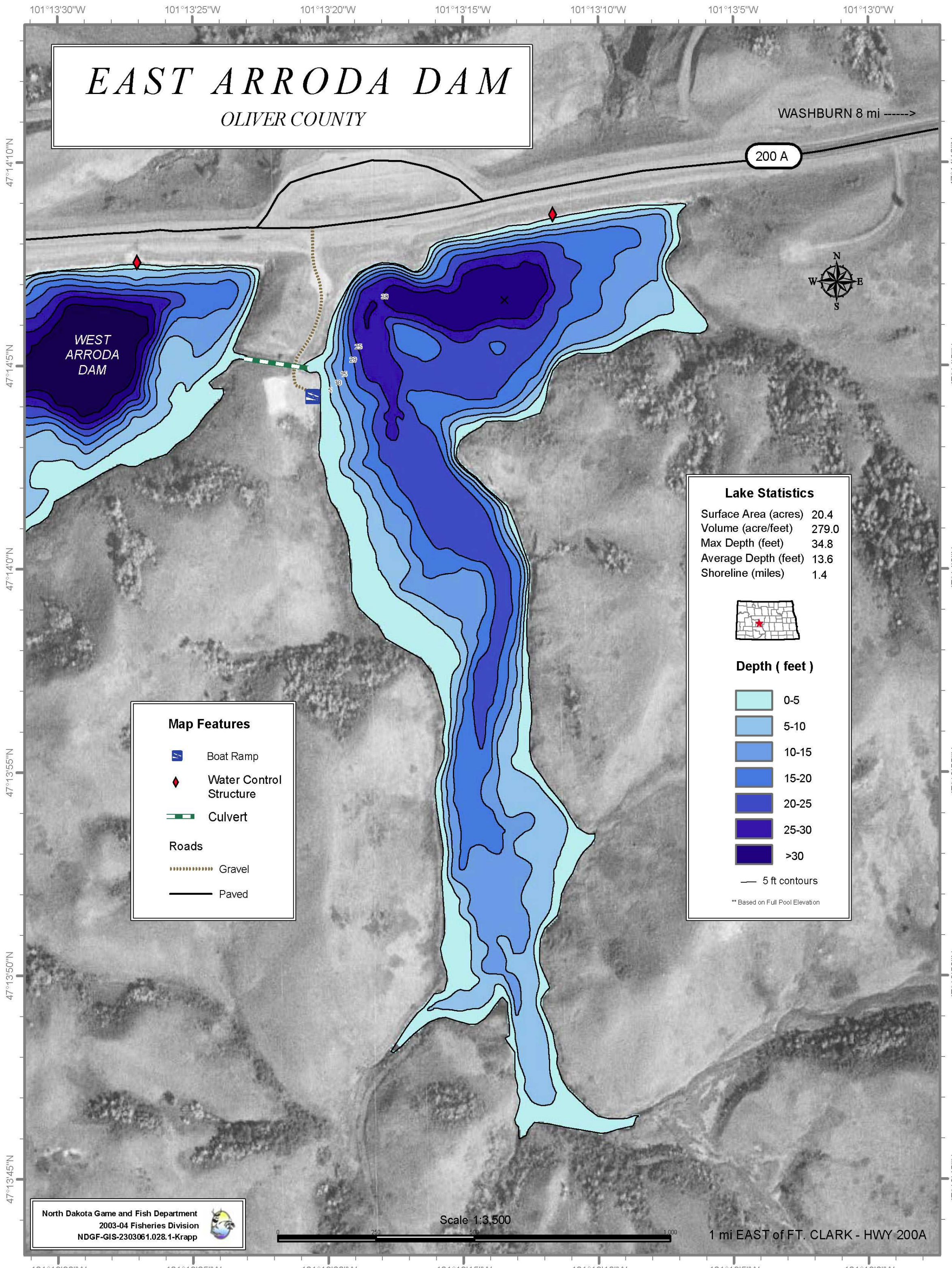


Figure 2. Contour Map of East Arroda Dam (Map Courtesy of North Dakota Game and Fish Department).

Construction History: East Arroda Dam was formed by the construction of US Highway 200A.

Recreational Facilities: Recreational facilities at East Arroda Dam include a cement boat ramp and boat and vehicle parking. Public access is on the northwest side of the lake, off of U.S. Highway 200A.

Water Quality Standards Classification: East Arroda Dam is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 2 lake or reservoir. Class 2 lakes or reservoirs are defined as a "cool water fishery" or "waters capable of supporting natural reproduction and growth of cool water fishes (e.g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: East Arroda Dam's historical fishery has included rainbow trout, crappie, and northern pike. The lakes current fishery includes northern pike and crappie.

Historical Water Quality Sampling: There is no historical water quality data available for East Arroda Dam.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for East Arroda Dam have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There were four temperature and dissolved oxygen profiles for East Arroda Dam collected between 2005 and 2006 (Figures 3 and 4). The profile data shows that during thermal stratification East Arroda Dam experiences rapid oxygen decay and frequently drops below the state's water quality standard of 5 mg/L. All four profiles, collected on 6/2/2005, 7/22/2005, 8/16/2005, and 1/25/2006 dropped below the state standard of 5 mg/L. While the rapid loss of dissolved oxygen during these periods is concerning, there does appear to be enough dissolved oxygen to maintain aquatic life in the upper three meters of the water column.

General Water Quality: Data collected by the NDGF in 2005 and 2006 indicate East Arroda Dam is well buffered with total alkalinity as $CaCO_3$ concentrations ranging from 501 to 602 mg/L (Table 1). Based on the 2005-2006 water quality data, East Arroda Dam is sodium sulfate dominated with an average sodium concentration of 536 mg/L and an average sulfate concentration of 836 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 1783 mg/L and 2628 µmhos/cm respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.333 mg/L and 0.048 mg/L respectively.

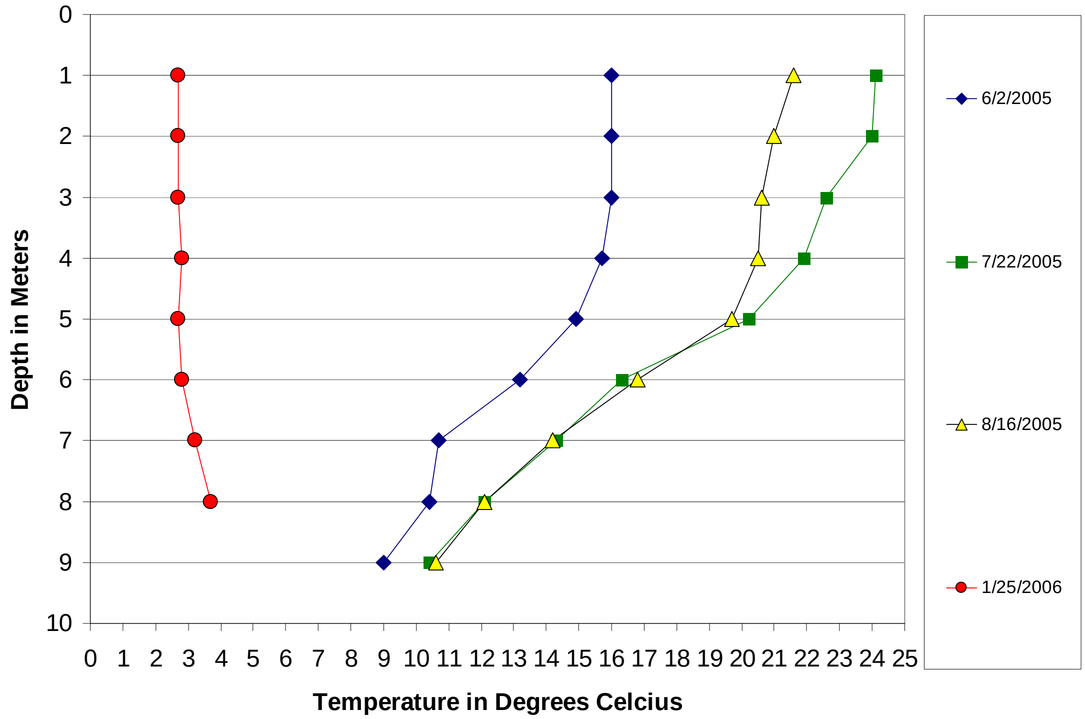


Figure 3. Temperature Profiles for East Arroda Dam from 2005 to 2006.

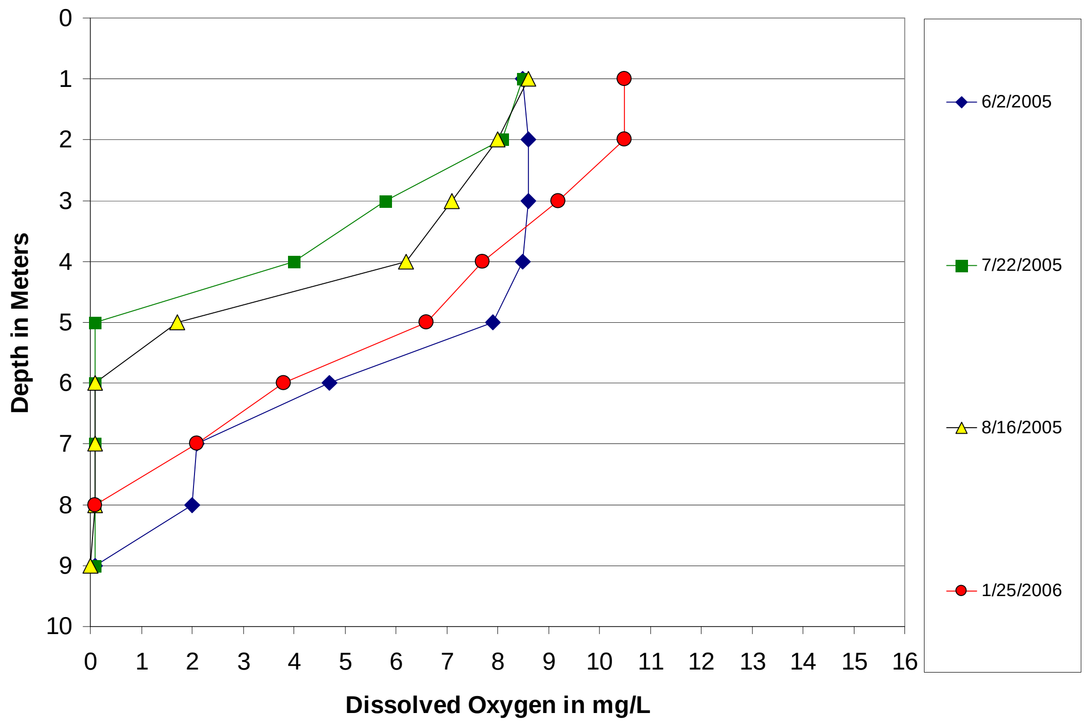


Figure 4. Dissolved Oxygen Profiles for East Arroda Dam from 2005 to 2006.

Table 1. Statistical Summary of East Arroda Dam's 2005-2006 Water Quality Data.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	533	501	602	46
Total Ammonia as N	mg/L	4	0.015	0.010[1]	0.031	0.011
Bicarbonate (HCO_3)	mg/L	4	526	485	610	58
Calcium (Ca)	mg/L	4	28.3	25.4	31.4	2.5
Carbonate (CO_3)	mg/L	4	62	48	71	10
Chloride (Cl)	mg/L	4	13	9	17	3
Chlorophyll-a	µg/L	3	3.9	3.6	4.3	0.4
Specific Conductance	µmhos	4	2628	2280	3020	303
Total Dissolved Solids	mg/L	4	1783	1530	2040	208
Total Hardness as ($CaCO_3$)	mg/L	4	229	213	242	12
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.171	0.147	0.215	0.032
Magnesium (Mg)	mg/L	4	38.3	36.4	41.7	2.4
Nitrate + Nitrite as N	mg/L	4	0.025	0.020	0.040	0.010
Total Kjeldahl Nitrogen as N	mg/L	4	1.308	1.240	1.410	0.079
Total Nitrogen as N	mg/L	4	1.333	1.260	1.450	0.088
pH		4	8.93	8.78	9.06	0.15
Total Phosphorus as P	mg/L	4	0.048	0.040	0.053	0.006
Potassium (K)	mg/L	4	11.1	10.0	12.7	1.1
Sodium (Na)	mg/L	4	536	455	612	65
Sulfate (SO4)	mg/L	4	836	683	968	117

[1]Equal to lower detection limit

When compared to the Rangeland Plains regional average for reservoirs East Arroda Dam is higher in dissolved solids but lower in nutrients. For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1176 mg/L, 1.472 mg/L, and 0.135 mg/L respectively, compared to East Arroda Dam's average TDS, total nitrogen, and total phosphorus concentrations of 1783 mg/L, 1.333 mg/L, and 0.048 mg/L respectively.

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in East Arroda Dam and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight in algae, is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were four water quality sample results for East Arroda Dam collected between June 2005 and January 2006 where the N:P ratio could be calculated. The results from this analysis indicate that East Arroda Dam is most often phosphorus limited (Figure 5).

N:P ratios for East Arroda Dam ranged from a low of 24 to a high of 32 with an average of 28. All four of the samples collected on East Arroda Dam were above an N:P ratio of 15, indicating phosphorus limitation.

Table 2. Statistical Summary of Water Quality from Reservoirs in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	408	309	101	982	130
Total Ammonia as N	mg/L	469	0.097	0.001[1]	2.440	0.200
Bicarbonate (HCO_3)	mg/L	408	318	14	1040	150
Calcium (Ca)	mg/L	408	50	5	160	26
Carbonate (CO_3)	mg/L	402	30	1[1]	197	30
Chloride (Cl)	mg/L	408	13.3	0.3	74.5	8.8
Chlorophyll-a	µg/L	321	21.2	1.5	218.0	27.9
Specific Conductance	µmhos	428	1733	262	5880	959
Total Dissolved Solids	mg/L	409	1176	147	5110	750
Total Hardness as ($CaCO_3$)	mg/L	408	397	45	1850	260
Hydroxide (OH)	mg/L	337	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	409	0.179	0.007	4.110	0.334
Magnesium (Mg)	mg/L	408	66.0	5.6	353.0	49.6
Nitrate + Nitrite as N	mg/L	395	0.048	0.001[1]	0.790	0.092
Total Kjeldahl Nitrogen as N	mg/L	359	1.556	0.365	7.720	0.779
Total Nitrogen as N	mg/L	302	1.472	0.405	4.840	0.562
pH		428	8.61	6.73	9.87	0.56
Total Phosphorus as P	mg/L	475	0.135	0.004	3.160	0.205
Potassium (K)	mg/L	408	14.6	4.2	39.2	6.3
Sodium (Na)	mg/L	408	239	3[1]	932	171
Sulfate (SO4)	mg/L	406	604	1[1]	3210	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 69 Reservoirs between 1991 and 2007

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005, East Arroda Dam's current trophic status is mesotrophic. TSI scores ranged from a low of 24 based on chlorophyll-a, to a high of 61 based on total phosphorus. The trophic status score based on Secchi disk transparency, was similar to that estimated based on total phosphorus at 55 (Figure 6).

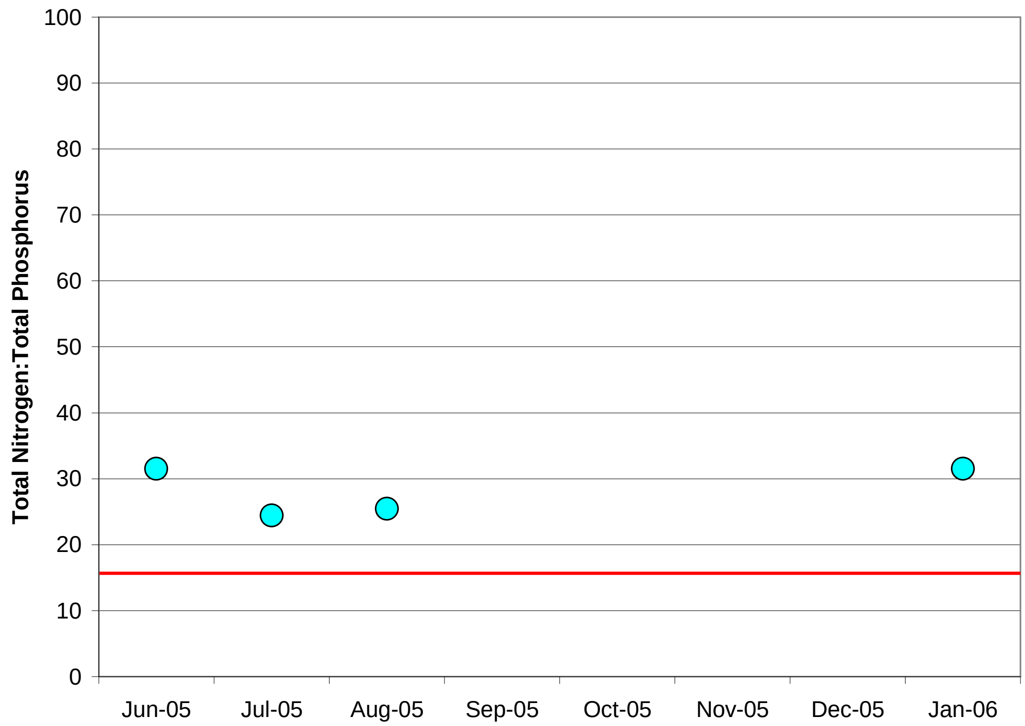


Figure 5. Total Nitrogen to Total Phosphorus Ratios in East Arroda Dam (2005-2006).

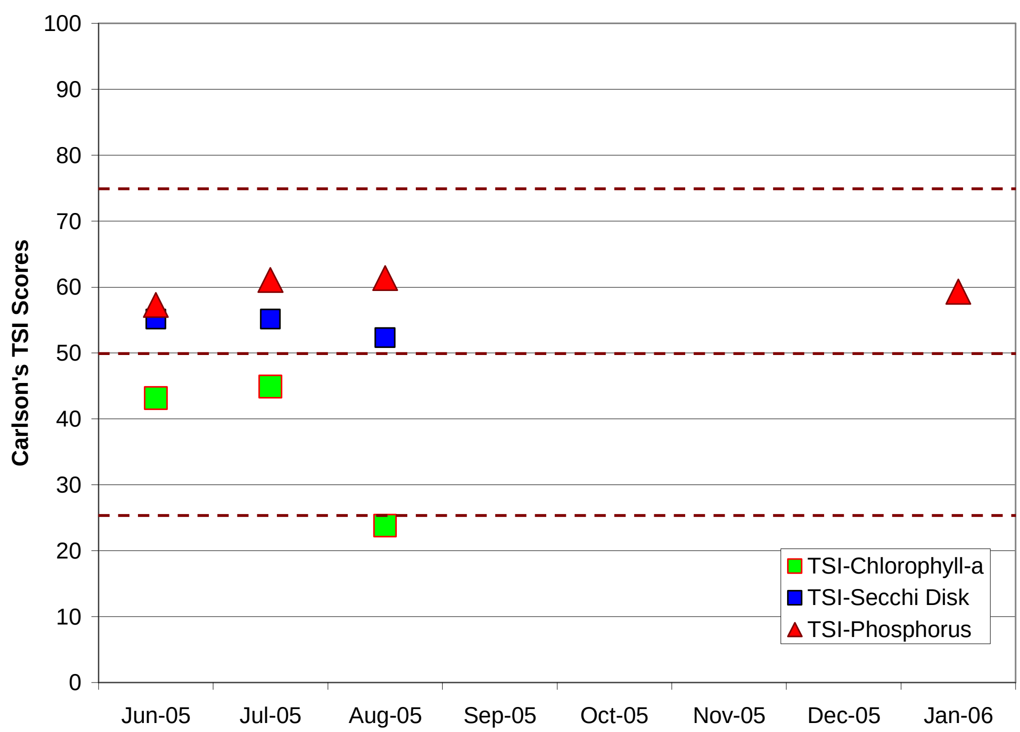


Figure 6. TSI Scores for East Arroda Dam from 2005 to 2006.

West Arroda Dam, Oliver County

BACKGROUND

Location: West Arroda Dam is a small recreational impoundment on U.S. Highway 200A, located 1 mile east of Fort Clark, North Dakota (Figure 1). West Arroda Dam is managed by the North Dakota Game and Fish Department.

Figure 1. Location of West Arroda Dam.

Physiographic/Ecological Setting: West Arroda Dam has a surface area of 23.5 acres, a maximum depth of 38.2 ft, and an average depth 17.3 ft (Figure 2). The reservoir's watershed is located within the Northwestern Great Plains (NWGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The West Arroda Dam watershed landscape is rolling plains. Flood plain slopes and hillsides are usually native grasslands, while the uplands and flood plains themselves have mostly been converted to small grains and alfalfa.

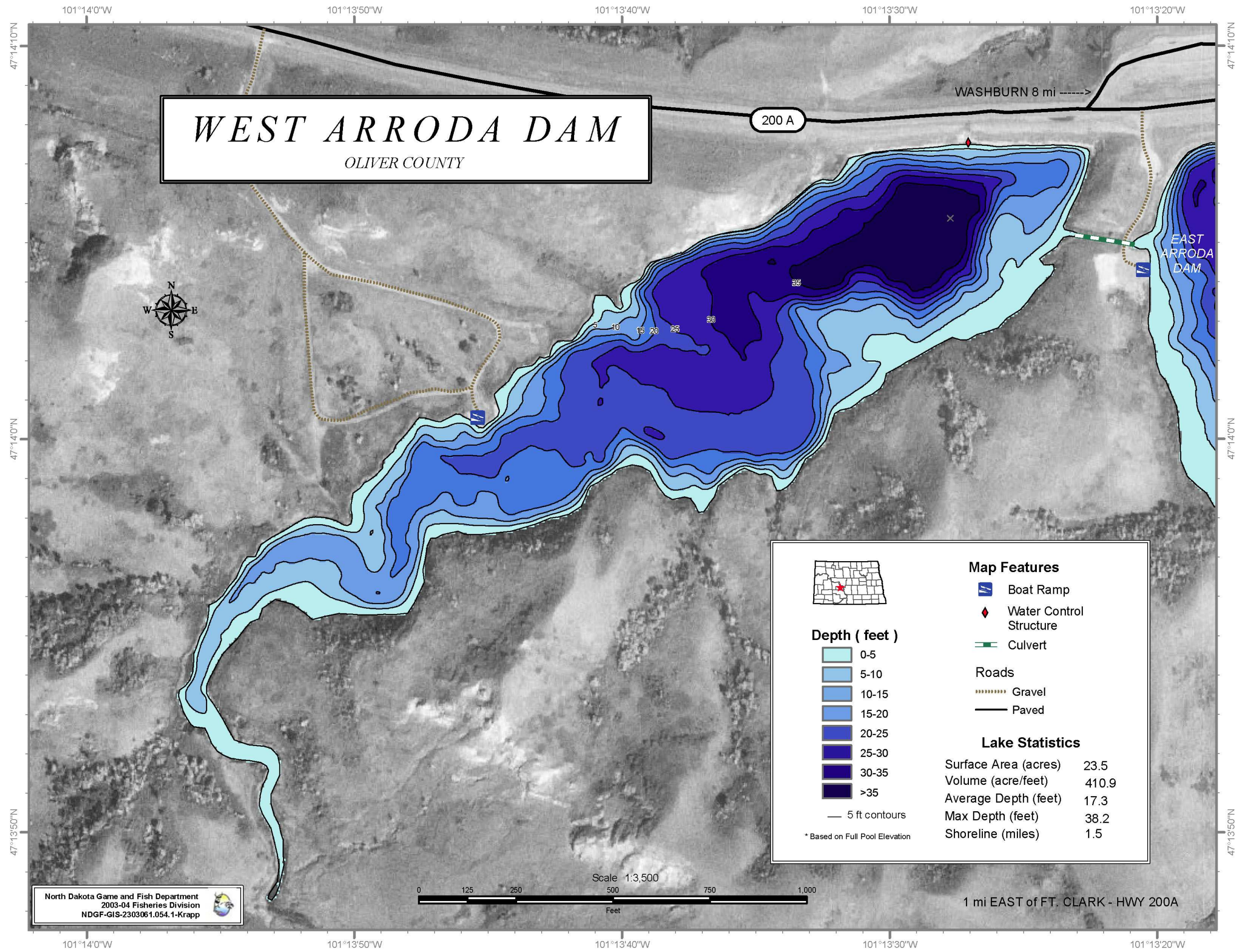


Figure 2. Contour Map of West Arroda Dam (Map Courtesy of North Dakota Game and Fish Department).

Construction History: West Arroda Lake was formed by the construction of US Highway 200A.

Recreational Facilities: Recreational facilities at West Arroda Dam include a cement boat ramp, and boat and vehicle parking. Public access is on the west side of the lake, off of U.S. Highway 200A.

Water Quality Standards Classification: West Arroda Dam is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 2 lake or reservoir. Class 2 lakes or reservoirs are defined as a "cool water fishery" or "waters capable of supporting natural reproduction and growth of cool water fishes (e.g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: West Arroda Dam's historical fishery has included rainbow trout, crappie, and northern pike. The lakes current fishery includes crappie and northern pike.

Historical Water Quality Sampling: There is no historical water quality data available for West Arroda Dam.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for West Arroda Dam have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There were four temperature and dissolved oxygen profiles for West Arroda Dam collected in 2005 and 2006 (Figures 3 and 4). The profile data shows that during thermal stratification West Arroda Dam experiences rapid oxygen decay and frequently drops below the state's water quality standard of 5 mg/L. All four profiles collected on 6/2/2005, 7/22/2005, 8/16/2005, and 1/25/2006 dropped below the state standard of 5 mg/L. While the rapid loss of dissolved oxygen during these periods is concerning, there does appear to be enough dissolved oxygen to maintain aquatic life in the upper 3 meters of the water column.

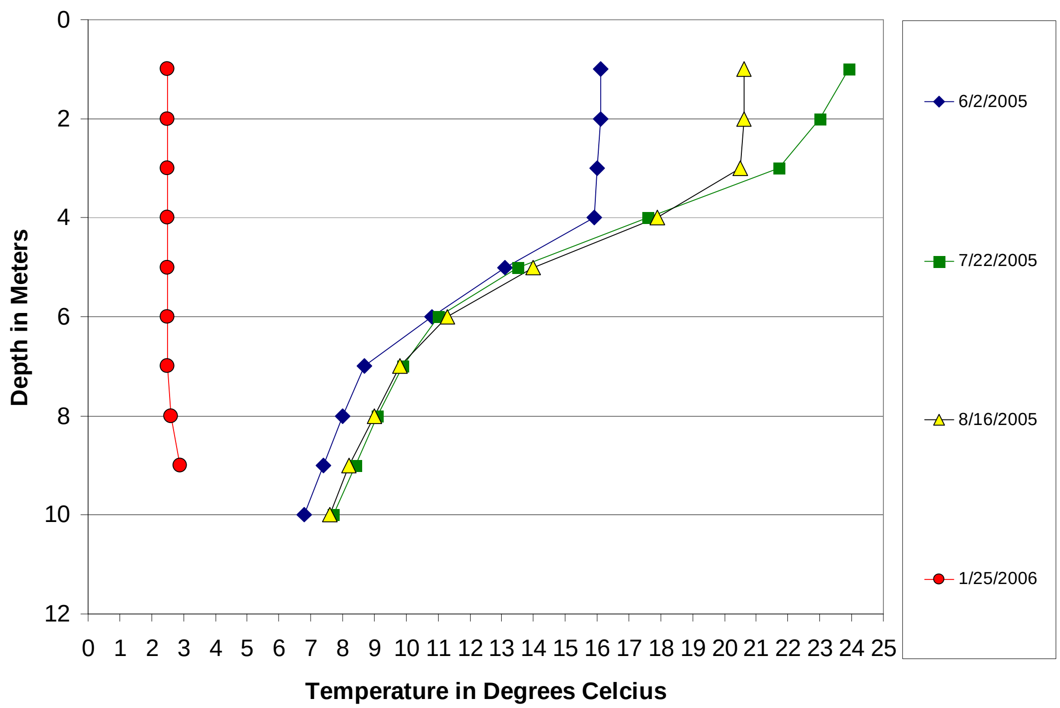


Figure 3. Temperature Profiles for West Arroda Dam from 2005 to 2006.

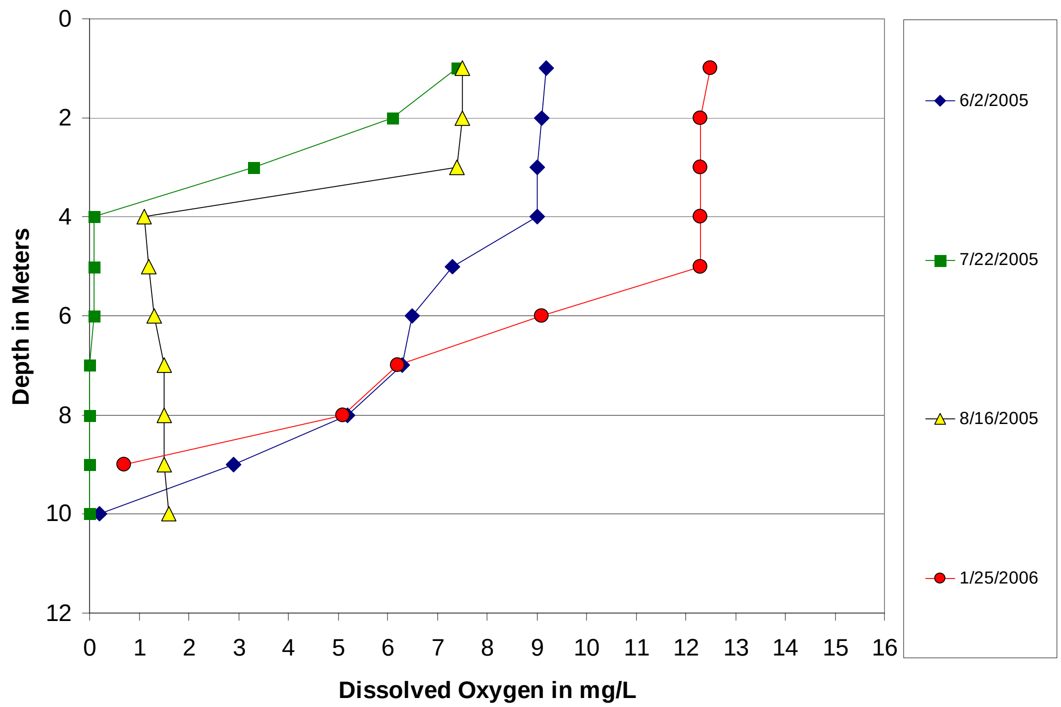


Figure 4. Dissolved Oxygen Profiles for West Arroda Dam from 2005 to 2006.

General Water Quality: Data collected by the NDGF in 2005 and 2006 indicate West Arroda Dam is well buffered with total alkalinity as $CaCO_3$ concentrations ranging from 508 to 594 mg/L (Table 1). Based on the 2005-2006 water quality data, West Arroda Dam is sodium sulfate dominated with an average sodium concentration of 495 mg/L and an average sulfate concentration of 755 mg/L. The average total dissolved solids (TDS) concentration and specific conductance measurement for the 2005-2006 sampling period were 1660 mg/L and 2453 µmhos/cm respectively. Average total nitrogen as N and total phosphorus as P concentrations were 2.173 mg/L and 0.037 mg/L respectively.

When compared to the Rangeland Plains regional average West Arroda Dam is higher in dissolved solids and total nitrogen, and slightly lower in total phosphorus concentrations (Table 2). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1176 mg/L, 1.472 mg/L, and 0.135 mg/L respectively, compared to West Arroda Dam's average TDS, total nitrogen, and total phosphorus concentrations of 1660 mg/L, 2.173 mg/L and 0.037 mg/L, respectively, for the period 2005-2006.

Table 1. Statistical Summary of West Arroda Dam's 2005-2006 Water Quality Data.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	538	508	594	38
Total Ammonia as N	mg/L	4	0.011	0.010[1]	0.013	0.001
Bicarbonate (HCO_3)	mg/L	4	535	494	613	55
Calcium (Ca)	mg/L	4	26.8	22.0	29.5	3.5
Carbonate (CO_3)	mg/L	4	59	50	71	9
Chloride (Cl)	mg/L	4	10	8	12	2
Chlorophyll-a	µg/L	3	4.3	2.8	7.1	2.4
Specific Conductance	µmhos	4	2453	2330	2610	144
Total Dissolved Solids	mg/L	4	1660	1570	1770	92
Total Hardness as ($CaCO_3$)	mg/L	4	223	203	234	14
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.130	0.101	0.194	0.043
Magnesium (Mg)	mg/L	4	37.8	36.0	40.8	2.2
Nitrate + Nitrite as N	mg/L	4	0.045	0.020	0.100	0.038
Total Kjeldahl Nitrogen as N	mg/L	4	2.128	1.160	4.740	1.746
Total Nitrogen as N	mg/L	4	2.173	1.180	4.840	1.784
pH		4	8.91	8.78	9.09	0.16
Total Phosphorus as P	mg/L	4	0.037	0.024	0.065	0.019
Potassium (K)	mg/L	4	10.7	9.7	11.8	0.9
Sodium (Na)	mg/L	4	495	469	522	29
Sulfate (SO4)	mg/L	4	755	706	800	46

[1]Equal to lower detection limit

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in West Arroda Dam and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight in algae, is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were four water quality sample results for West Arroda Dam collected between June 2005 and January 2006 where the N:P ration could be calculated. The results from this analysis indicate that West Arroda Dam is most often phosphorus limited (Figure 5).

N:P ratios for West Arroda Dam ranged from a low of 23 to a high of 186 with an average of 74. All of the four samples collected on West Arroda Dam were above an N:P ratio of 15, indicating phosphorus limitation.

Table 2. Statistical Summary of Water Quality from Reservoirs in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	408	309	101	982	130
Total Ammonia as N	mg/L	469	0.097	0.001[1]	2.440	0.200
Bicarbonate (HCO_3)	mg/L	408	318	14	1040	150
Calcium (Ca)	mg/L	408	50	5	160	26
Carbonate (CO_3)	mg/L	402	30	1[1]	197	30
Chloride (Cl)	mg/L	408	13.3	0.3	74.5	8.8
Chlorophyll-a	µg/L	321	21.2	1.5	218.0	27.9
Specific Conductance	µmhos	428	1733	262	5880	959
Total Dissolved Solids	mg/L	409	1176	147	5110	750
Total Hardness as ($CaCO_3$)	mg/L	408	397	45	1850	260
Hydroxide (OH)	mg/L	337	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	409	0.179	0.007	4.110	0.334
Magnesium (Mg)	mg/L	408	66.0	5.6	353.0	49.6
Nitrate + Nitrite as N	mg/L	395	0.048	0.001[1]	0.790	0.092
Total Kjeldahl Nitrogen as N	mg/L	359	1.556	0.365	7.720	0.779
Total Nitrogen as N	mg/L	302	1.472	0.405	4.840	0.562
pH		428	8.61	6.73	9.87	0.56
Total Phosphorus as P	mg/L	475	0.135	0.004	3.160	0.205
Potassium (K)	mg/L	408	14.6	4.2	39.2	6.3
Sodium (Na)	mg/L	408	239	3[1]	932	171
Sulfate (SO4)	mg/L	406	604	1[1]	3210	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 69 Reservoirs between 1991 and 2007.

Trophic Status Assessment: Based on limited chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005, West Arroda Dam's current trophic status is mesotrophic. TSI scores ranged from a low of 41 based on chlorophyll-a, to a high of 64 based on total phosphorus. The trophic status score based on Secchi disk transparency, was similar to that estimated based on total phosphorus at 53 (Figure 6).

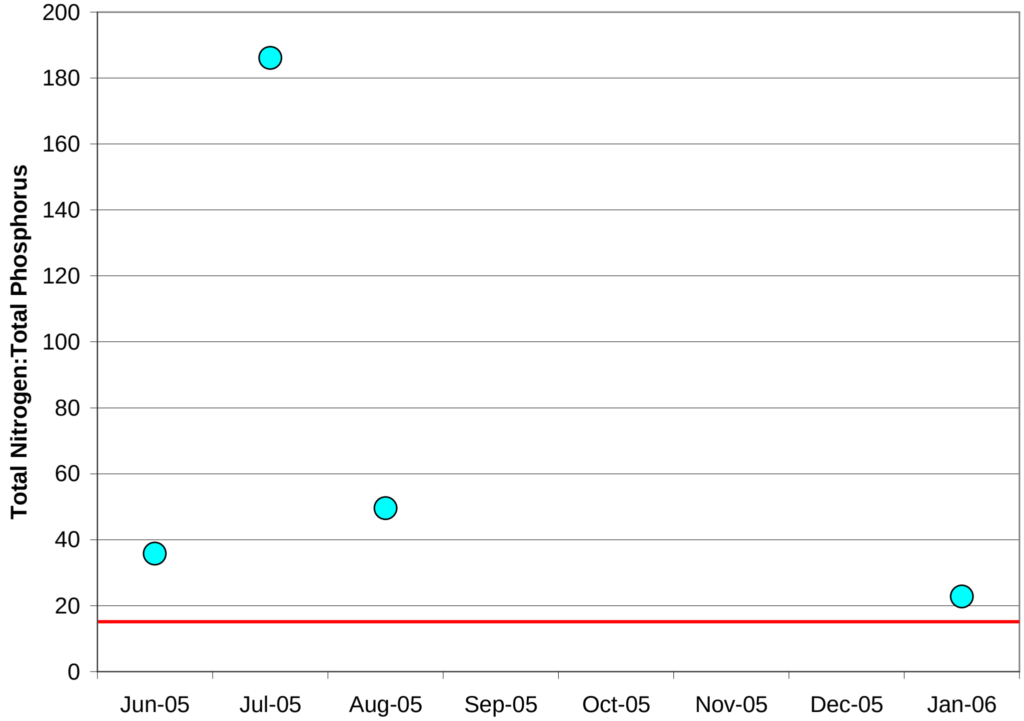


Figure 5. Total Nitrogen to Total Phosphorus Ratios in West Arroda Dam (2005-2006).

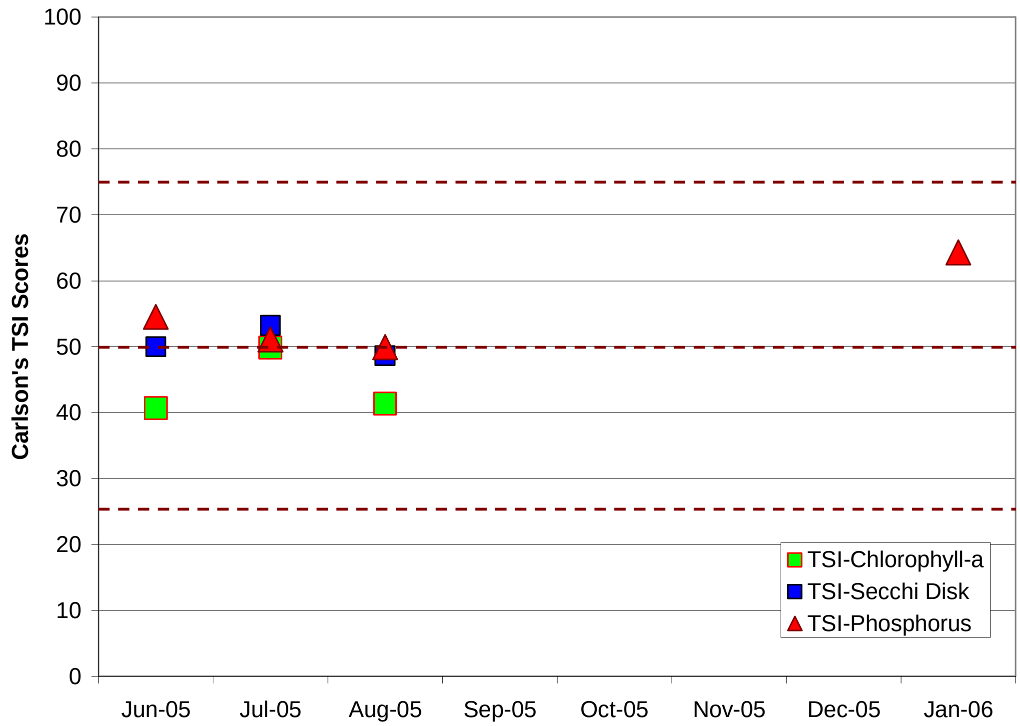


Figure 6. TSI Scores for West Arroda Dam from 2005 to 2006.

Nelson Lake, Oliver County

BACKGROUND

Location: Nelson Lake is a small recreational impoundment on Square Butte Creek, located 5 miles east and 3 miles south of Center, North Dakota (Figure 1). Nelson Lake is managed by the North Dakota Game and Fish Department.

Figure 1. Location of Nelson Lake.

Physiographic/Ecological Setting: Nelson Lake has a surface area of 572.8 acres, a maximum depth of 35.2 ft, and an average depth 15.6 ft (Figure 2). The reservoir's watershed is 92,160 acres and is located within the Northwestern Great Plains (NWGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The Nelson Lake watershed landscape is rolling plains. Flood plain slopes and hillsides are usually native grasslands, while the uplands and flood plains themselves have mostly been converted to small grains and alfalfa.

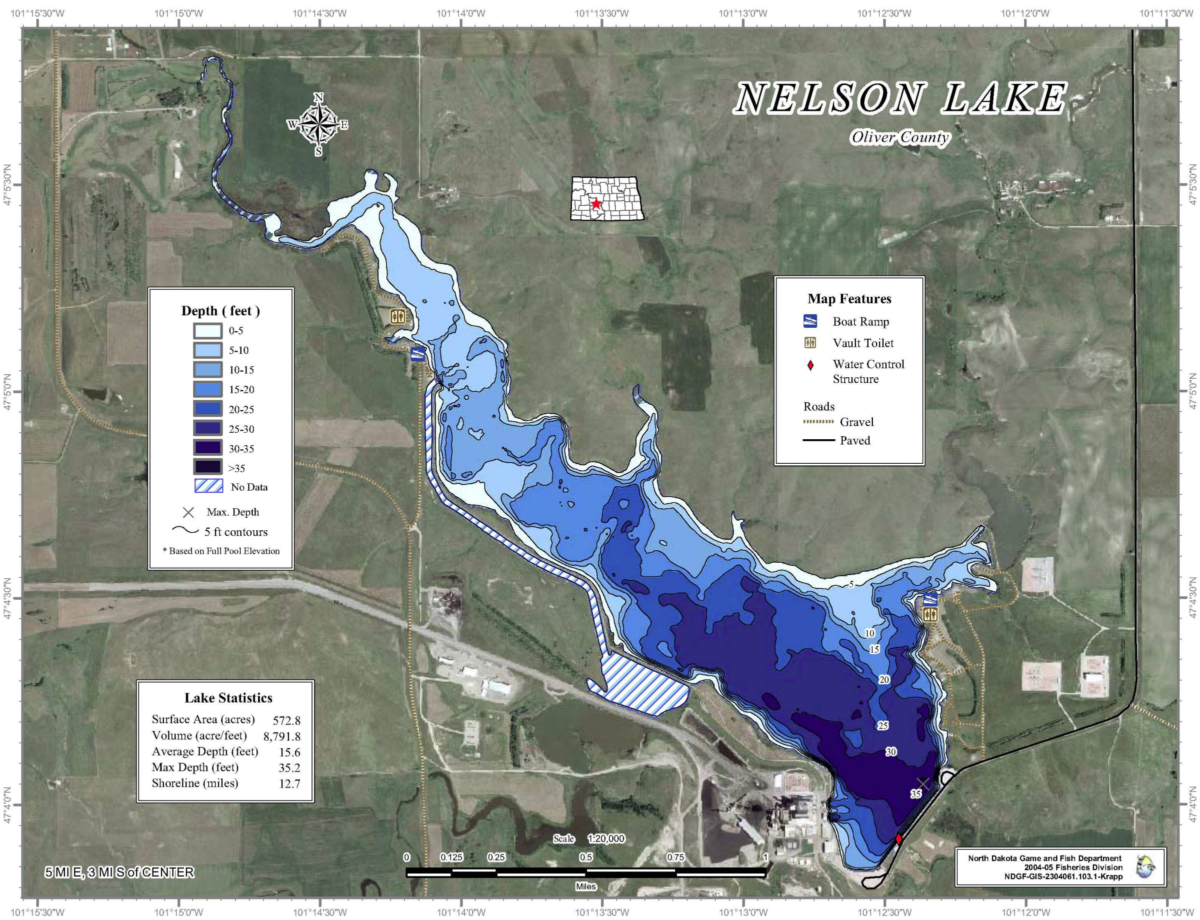


Figure 2. Contour Map of Nelson Lake (Map Courtesy of North Dakota Game and Fish Department).

Construction History: Nelson Lake is a cooling basin for the Milton R. Young Station, a coal-fired, steam-electric generating station that went on-line in 1970. Secondary uses for Nelson Lake include wild life propagation and water based recreation.

Recreational Facilities: Recreational facilities at Nelson Lake include two cement boat ramps, boat and vehicle parking, camping areas, and fire pits. There are two recreational areas on Nelson Lake located on the northwest and southeast corners of the lake. Each recreational area has a boat ramp and vaulted toilets.

Water Quality Standards Classification: Nelson Lake is classified in the state “Standards of Quality for Waters of the State” (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a “warm water fishery” or “waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present.”

Historical and Current Fishery: Nelson Lake's historical fishery has included bluegill, largemouth bass, white crappie, common carp, black crappie, northern pike, and white sucker. The lakes current fishery includes all of these and yellow perch.

Historical Water Quality Sampling: Historical water quality data includes results from three samples collected from 1993 through 1994.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Nelson Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There are seven temperature and dissolved oxygen profiles for Nelson Lake collected between 1993 and 2006. Temperature and oxygen profiles are presented for two time periods, 1993-1994 and 2005-2006 (Figures 3 and 4). The temperature and dissolved oxygen profiles show that during thermal stratification Nelson Lake experiences moderate oxygen decay and at greater depths occasionally drops below the state's water quality standard of 5 mg/L. Of the seven profiles, four samples collected on 8/9/1993, 6/2/2005, 7/22/2005, and 8/16/2005 dropped below the state standard of 5 mg/L. While the loss of dissolved oxygen during these periods is concerning, there does appear to be enough dissolved oxygen to maintain aquatic life in the first 6 meters of the water column.

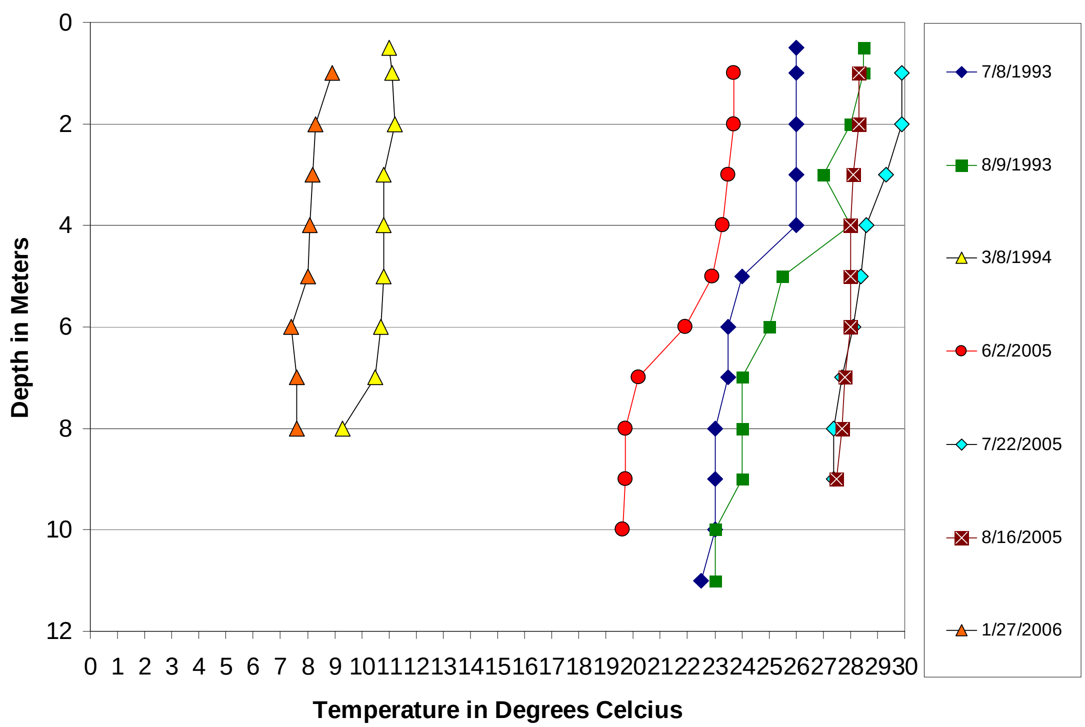


Figure 3. Temperature Profiles for Nelson Lake from 1993 to 2006.

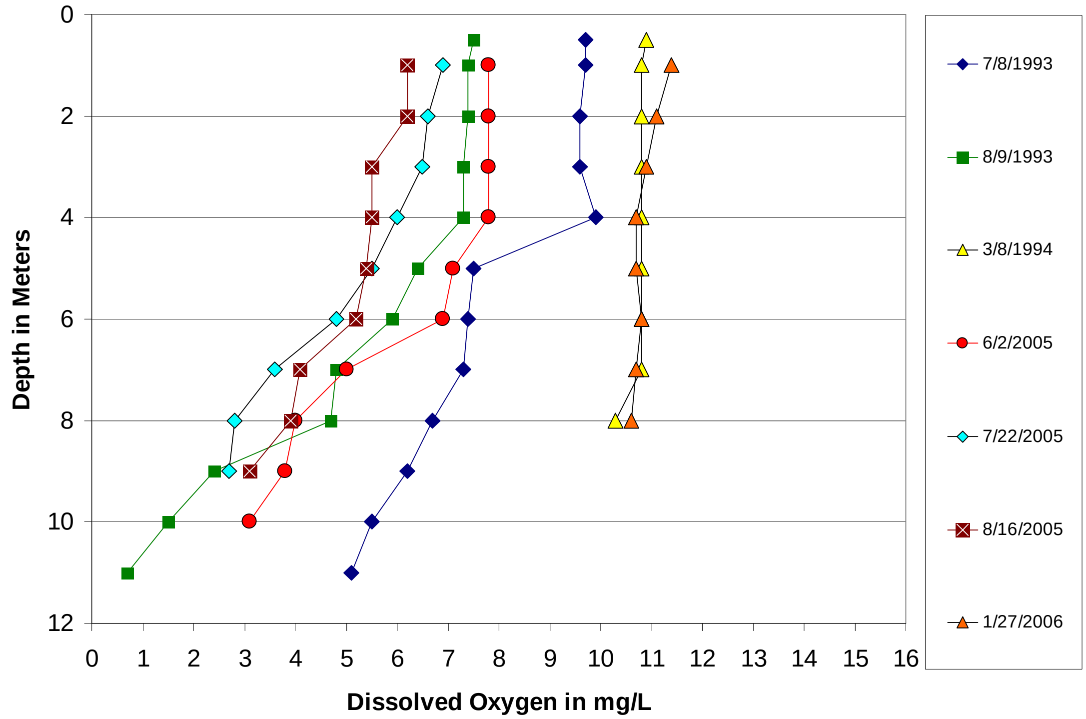


Figure 4. Dissolved Oxygen Profiles for Nelson Lake from 1993 to 2006.

General Water Quality: Data collected by the NDGF in 2005 and 2006 indicate Nelson Lake is well buffered with total alkalinity as $CaCO_3$ concentrations ranging from 365 to 425 mg/L (Table 1). Based on the 2005-2006 water quality data, Nelson Lake is sodium sulfate dominated with an average sodium concentration of 321 mg/L and an average sulfate concentration of 750 mg/L. The average total dissolved solids (TDS) concentration and specific conductance measurement for the 2005-2006 sampling period were 1493 mg/L and 2140 µmhos/cm respectively. Average total nitrogen as N and total phosphorus as P concentrations were 0.900 mg/L and 0.217 mg/L respectively.

When compared to historical water quality data for Nelson Lake it appears that concentrations of most water quality constituents have increased. For example, the historical average sulfate and sodium concentrations were 392 mg/L and 176 mg/L respectively (Table 2), compared to average concentrations of 750 mg/L for sulfate and 321 mg/L for sodium recorded for the period 2005-2006 (Table 1). The average total nitrogen and total phosphorus concentrations have fluctuated over time. The historical average for total nitrogen and total phosphorus concentrations is 1.330 mg/L and 0.121 mg/L respectively (Table 2) , compared to the 2005-2006 average of 0.900 for total nitrogen and 0.217 mg/L for total phosphorus.

Compared to the Rangeland Plains regional average for reservoirs Nelson Lake contains more dissolved solids but is similar in nutrient composition (Table 3). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1176 mg/L, 1.472 mg/L, and 0.135 mg/L, respectively (Table 3), compared to Nelson Lake's average TDS, total nitrogen, and total phosphorus concentrations of 1493 mg/L, 0.900 mg/L, and 0.217 mg/L respectively.

Table 1. Statistical Summary of Nelson Lake's 2005-2006 Water Quality Data.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	387	365	425	27
Total Ammonia as N	mg/L	4	0.011	0.010[1]	0.015	0.003
Bicarbonate (HCO_3)	mg/L	4	389	359	442	39
Calcium (Ca)	mg/L	4	65.5	60.2	71.3	5.3
Carbonate (CO_3)	mg/L	4	41	37	47	5
Chloride (Cl)	mg/L	4	29	25	37	5
Chlorophyll-a	µg/L	3	18.5	11.2	24.0	6.6
Specific Conductance	µmhos	4	2140	2000	2460	215
Total Dissolved Solids	mg/L	4	1493	1380	1720	154
Total Hardness as ($CaCO_3$)	mg/L	4	469	433	533	44
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.336	0.245	0.450	0.087
Magnesium (Mg)	mg/L	4	74.0	67.7	86.1	8.3
Nitrate + Nitrite as N	mg/L	4	0.055	0.020	0.160	0.070
Total Kjeldahl Nitrogen as N	mg/L	4	0.845	0.629	1.020	0.161
Total Nitrogen as N	mg/L	4	0.900	0.649	1.180	0.217
pH		4	8.78	8.66	8.84	0.08
Total Phosphorus as P	mg/L	4	0.217	0.153	0.284	0.060
Potassium (K)	mg/L	4	18.1	16.2	20.7	1.9
Sodium (Na)	mg/L	4	321	288	369	35
Sulfate (SO4)	mg/L	4	750	695	877	85

[1]Equal to lower detection limit

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Nelson Lake and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight in algae, is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were seven water quality sample results for Nelson Lake collected between July 1993 and January 2006 where the N:P ratio could be calculated. The results from this analysis indicate that Nelson Lake is most often nitrogen limited (Figure 5).

N:P ratios for Nelson Lake ranged from a low of 3 to a high of 13 with an average of 7. All seven of the samples collected on Nelson Lake were below an N:P ratio of 15, indicating nitrogen limitation.

Table 2. Statistical Summary of Nelson Lake's Historical Water Quality Data Collected Between 1993 and 1994.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	252	162	315	80
Total Ammonia as N	mg/L	3	0.029	0.010[1]	0.066	0.032
Bicarbonate (HCO_3)	mg/L	3	268	182	325	76
Calcium (Ca)	mg/L	3	54	36	63	15
Carbonate (CO_3)	mg/L	3	19	8	29	11
Chloride (Cl)	mg/L	3	16.3	8.7	27.0	9.6
Chlorophyll-a	µg/L	2	24.0	20.0	28.0	5.7
Specific Conductance	µmhos	3	1281	793	1870	546
Total Dissolved Solids	mg/L	3	844	507	1220	358
Total Hardness as ($CaCO_3$)	mg/L	3	293	183	375	99
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	3	0.568	0.142	1.190	0.551
Magnesium (Mg)	mg/L	3	38.6	22.7	53.3	15.3
Nitrate + Nitrite as N	mg/L	3	0.097	0.005[1]	0.280	0.159
Total Kjeldahl Nitrogen as N	mg/L	3	1.233	1.060	1.360	0.155
Total Nitrogen as N	mg/L	3	1.330	1.065	1.640	0.290
pH		3	8.63	8.46	8.78	0.16
Total Phosphorus as P	mg/L	3	0.121	0.083	0.167	0.043
Potassium (K)	mg/L	3	13.6	10.4	17.2	3.4
Sodium (Na)	mg/L	3	176	103	263	81
Sulfate (SO4)	mg/L	3	392	228	605	193

[1]Equal to lower detection limit

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005-2006, Nelson Lake's current trophic status is eutrophic. TSI scores ranged from a low of 54 based on chlorophyll-a, to a high of 86 based on total phosphorus. The trophic status score based on Secchi disk transparency, was in between that estimated based on total phosphorus and chlorophyll-a at 70 (Figure 6).

There were a total of seven total phosphorus samples, five chlorophyll-a samples, and five Secchi disk transparency measurements collected from 1993-2006. A visual evaluation of the data shows Nelson Lake's trophic condition is stable (Figure 6).

Table 3. Statistical Summary of Water Quality Data[2] Collected from Reservoirs in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	408	309	101	982	130
Total Ammonia as N	mg/L	469	0.097	0.001[1]	2.440	0.200
Bicarbonate (HCO_3)	mg/L	408	318	14	1040	150
Calcium (Ca)	mg/L	408	50	5	160	26
Carbonate (CO_3)	mg/L	402	30	1[1]	197	30
Chloride (Cl)	mg/L	408	13.3	0.3	74.5	8.8
Chlorophyll-a	µg/L	321	21.2	1.5	218.0	27.9
Specific Conductance	µmhos	428	1733	262	5880	959
Total Dissolved Solids	mg/L	409	1176	147	5110	750
Total Hardness as ($CaCO_3$)	mg/L	408	397	45	1850	260
Hydroxide (OH)	mg/L	337	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	409	0.179	0.007	4.110	0.334
Magnesium (Mg)	mg/L	408	66.0	5.6	353.0	49.6
Nitrate + Nitrite as N	mg/L	395	0.048	0.001[1]	0.790	0.092
Total Kjeldahl Nitrogen as N	mg/L	359	1.556	0.365	7.720	0.779
Total Nitrogen as N	mg/L	302	1.472	0.405	4.840	0.562
pH		428	8.61	6.73	9.87	0.56
Total Phosphorus as P	mg/L	475	0.135	0.004	3.160	0.205
Potassium (K)	mg/L	408	14.6	4.2	39.2	6.3
Sodium (Na)	mg/L	408	239	3[1]	932	171
Sulfate (SO4)	mg/L	406	604	1[1]	3210	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 69 Reservoirs between 1991 and 2007

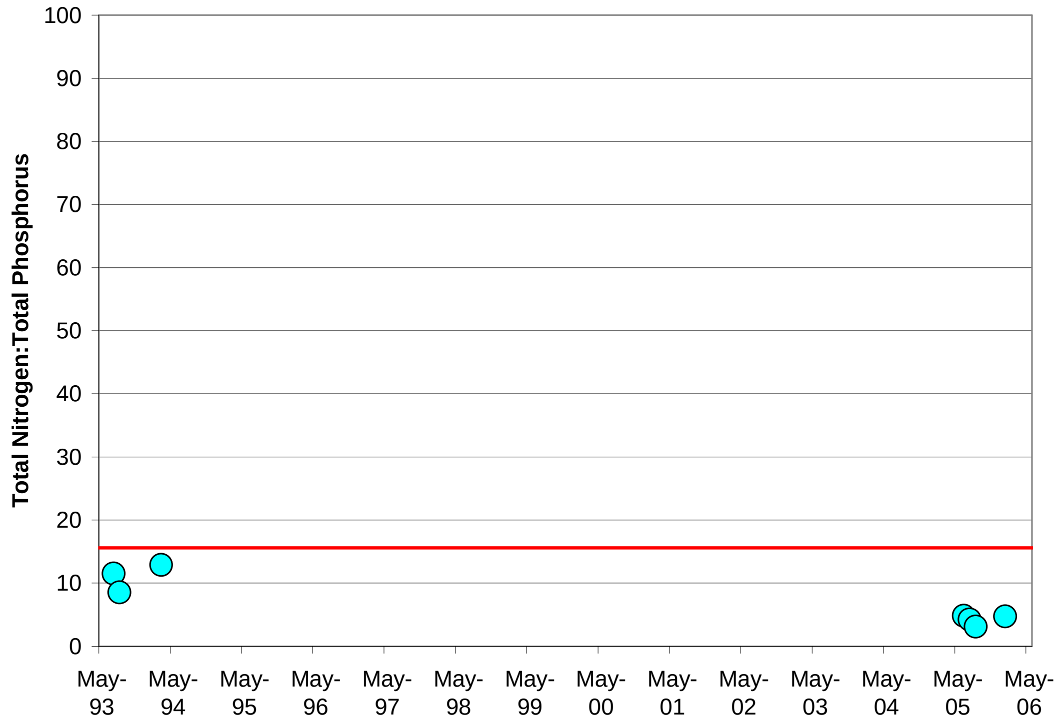


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Nelson Lake (1993-2006).

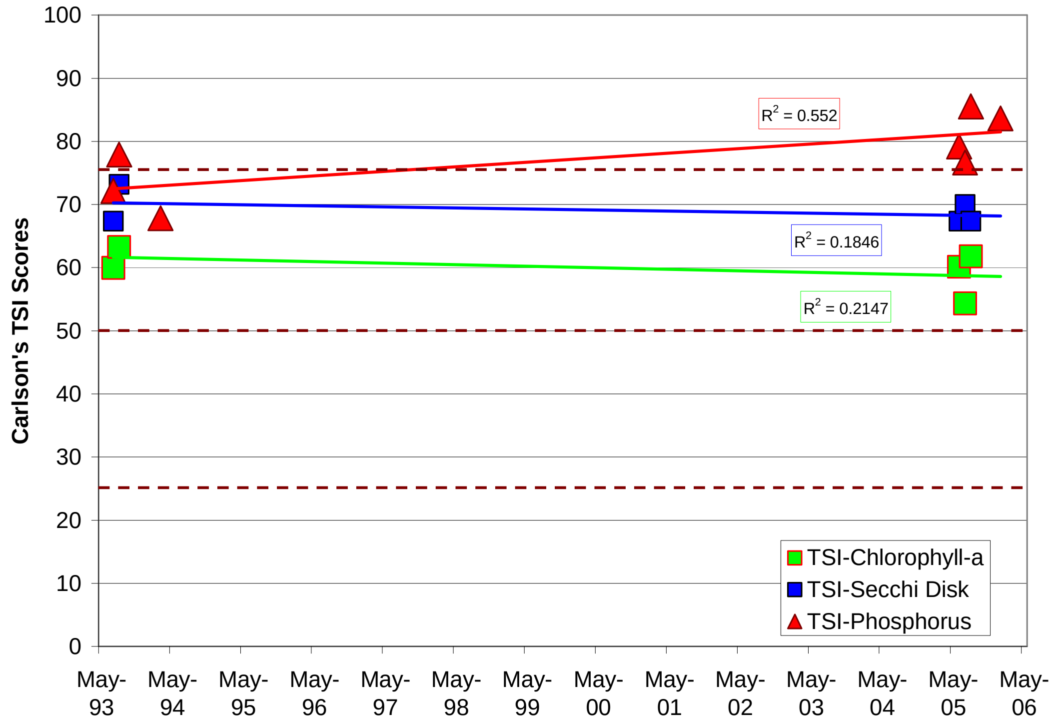


Figure 6. TSI Scores and Temporal Trends for Nelson Lake from 1993 to 2006.

Balta Dam, Pierce County

BACKGROUND

Location: Balta Dam is a recreational impoundment located on the south side of Balta, North Dakota (Figure 1). Balta Dam is managed by the North Dakota Game and Fish Department.

Figure 1. Location of Balta Dam.

Physiographic/Ecological Setting: Balta Dam has a surface area of 108 acres, a maximum depth of 15 feet, and an average depth of 7.9 ft (Figure 2). Balta Dam's watershed is 27,133 acres, and lies within the Northern Glaciated Plains Level III Ecoregion, part of the broader Cultivated Plains region (Figure 1). This region is the transitional zone between tall and mixed grass prairie. The region has numerous wetlands essential for spring and fall migrations of wetland dependent birds. Flood plain slopes and hillsides are usually native grass while the uplands and flood plains proper have mostly been converted to small grains, row crops and alfalfa.

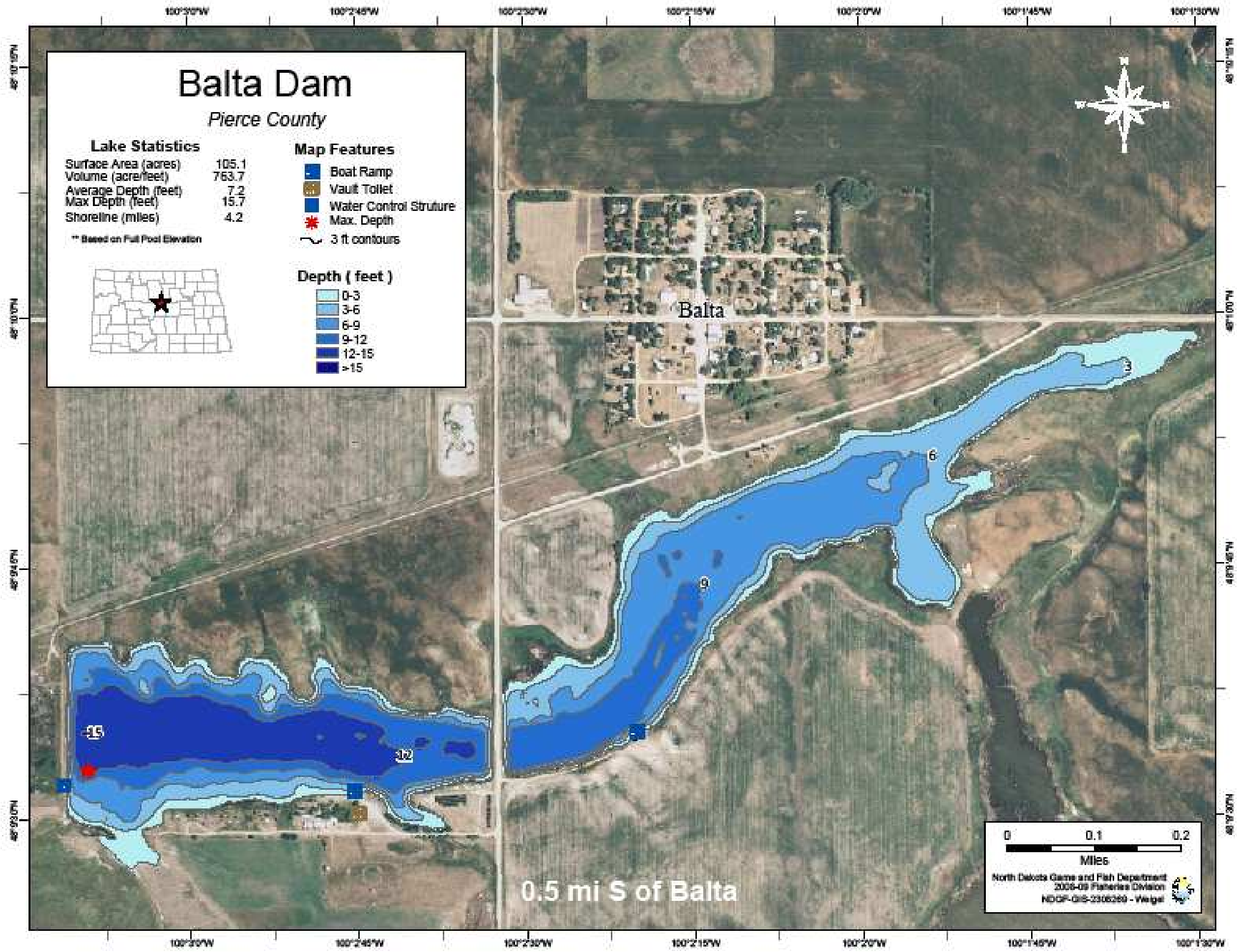


Figure 2. Contour Map of Balta Dam (Map Courtesy of North Dakota Game and Fish Department).

Construction History: Balta Dam was built under the Works Project Administration in the early 1930s. The spillway eventually washed out and in 1961 the entire dam was rebuilt by the NDG&F and the State Water Commission (SWC).

Recreational Facilities: Recreational facilities at Balta Dam include a boat ramp, a picnic area, and associated parking. Public access on the south side of the lake includes parking, vaulted restrooms, and a picnic area.

Water Quality Standards Classification: Balta Dam is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a "warm water fishery" or "waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present."

Historical and Current Fishery: Balta Dam's fishery over time has included walleye and northern pike, stocked by the NDG&F. Currently, both species are managed in Balta Dam.

Historical Water Quality Sampling: Historical water quality data includes results from four samples collected in 1992 and 1993.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Balta Dam have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural or enhanced lakes in the Cultivated Plains region.

Temperature and Dissolved Oxygen Profile Results: There are seven temperature and dissolved oxygen profiles for Balta Dam collected from 1992-2006. Temperature and oxygen profiles are presented for two time periods, 1992-1993 and 2005-2006 (Figures 3 and 4).

The temperature and dissolved oxygen profiles show that during thermal stratification and under ice, Balta Dam experiences deficiencies in oxygen and occasionally drops below the state's water quality standard of 5 mg/L. Of the seven profiles, three samples collected on 7/21/1992, 8/17/1992, and 1/24/2006 dropped below the state standard of 5 mg/L, and one collected on 3/03/1993 began and ended below a concentration of 5 mg/L.

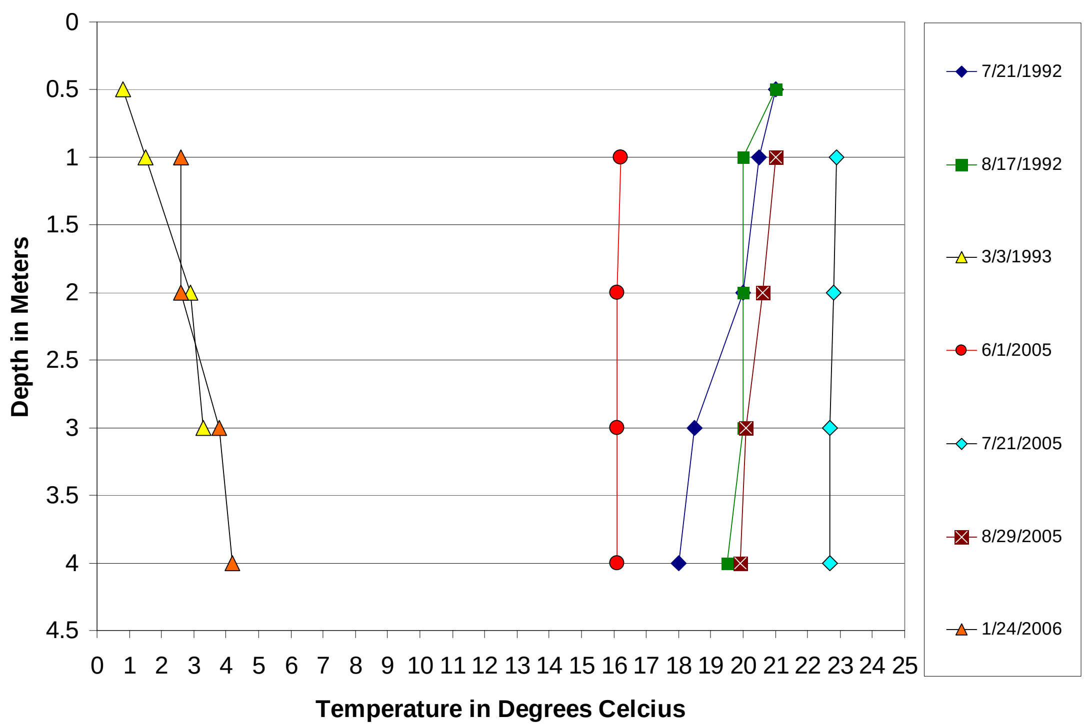


Figure 3. Temperature Profiles for Balta Dam From 1992 to 2006.

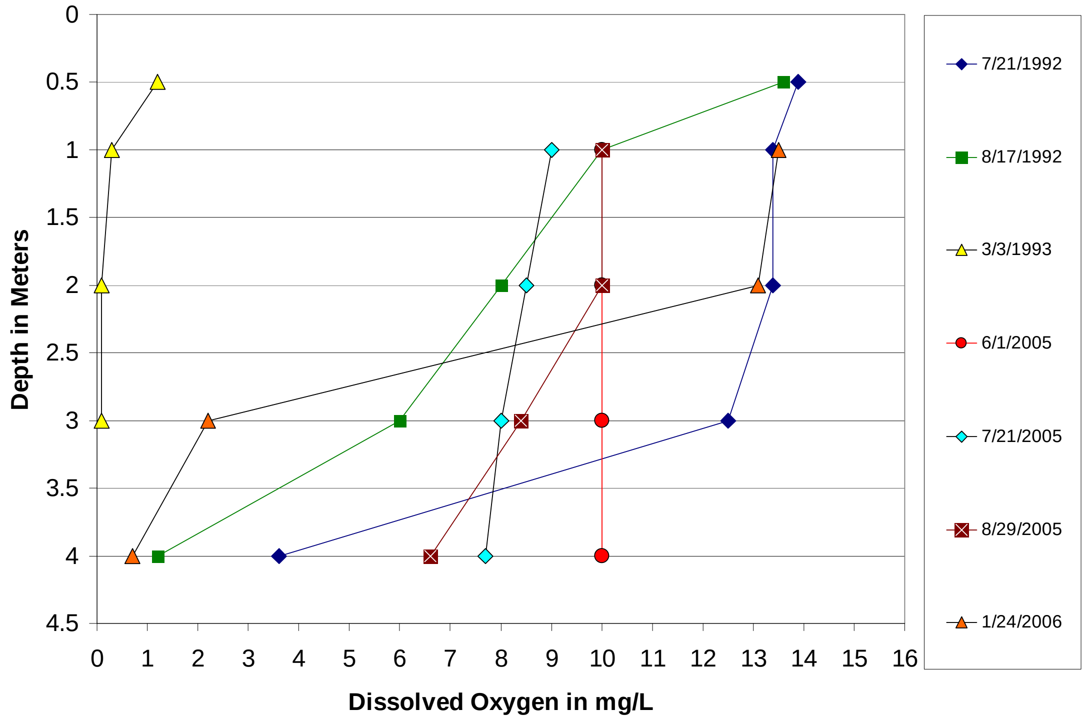


Figure 4. Dissolved Oxygen Profiles for Balta Dam From 1992 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006 indicate Balta Dam is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 636 to 760 mg/L (Table 1). Based on the 2005-2006 water quality data (Table 1), Balta Dam is sodium bicarbonate dominated with an average sodium concentration of 387 mg/L and an average bicarbonate concentration of 695 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 1295 mg/L and 1973 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 2.678 mg/L and 0.456 mg/L, respectively.

When compared to historical water quality data for Balta Dam, it appears that concentrations of most water quality constituents have increased. For example, the historical average bicarbonate and sodium concentrations were 372 mg/L and 159 mg/L, respectively (Table 2), compared to average concentrations of 695 mg/L for bicarbonate and 387 mg/L for sodium recorded for the period 2005-2006 (Table 1).

The average total nitrogen and total phosphorus concentrations have also increased when compared to the historical data. Historical average total nitrogen and total phosphorus concentrations were 2.015 mg/L and 0.197 mg/L (Table 2) respectively, compared to average concentrations of 2.678 mg/L for total nitrogen and 0.456 mg/L for total phosphorus.

Table 1. Statistical Summary of Balta Dam's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	685	636	760	54
Total Ammonia as N	mg/L	4	0.023	0.010[1]	0.052	0.020
Bicarbonate (HCO_3)	mg/L	4	695	654	806	74
Calcium (Ca)	mg/L	4	36.8	33.4	41.3	3.6
Carbonate (CO_3)	mg/L	4	69	57	87	14
Chloride (Cl)	mg/L	4	22	19	26	4
Chlorophyll-a	µg/L	3	53.5	32.0	66.8	18.8
Specific Conductance	µmhos	4	1973	1810	2280	210
Total Dissolved Solids	mg/L	4	1295	1190	1470	121
Total Hardness as ($CaCO_3$)	mg/L	4	275	255	318	29
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.174	0.090	0.283	0.085
Magnesium (Mg)	mg/L	4	44.4	40.5	52.2	5.3
Nitrate + Nitrite as N	mg/L	4	0.028	0.020	0.040	0.010
Total Kjeldahl Nitrogen as N	mg/L	4	2.650	2.280	2.860	0.267
Total Nitrogen as N	mg/L	4	2.678	2.300	2.900	0.275
pH		4	8.79	8.69	8.94	0.11
Total Phosphorus as P	mg/L	4	0.456	0.367	0.507	0.061
Potassium (K)	mg/L	4	10.4	9.2	11.3	0.9
Sodium (Na)	mg/L	4	387	353	431	33
Sulfate (SO4)	mg/L	4	380	346	452	49

[1]Equal to lower detection limit

When compared to the Cultivated Plains regional average, Balta Dam's water quality is similar to all natural and enhanced lakes in the Cultivated Plains region (Table 3). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1376 mg/L, 1.440 mg/L, and 0.068 mg/L, respectively, compared to Balta Dam's average TDS, total nitrogen, and total phosphorus concentrations of 1450 mg/L, 1.715 mg/L and 0.047 mg/L, respectively, for the period 2005-2006.

Table 2. Statistical Summary of Balta Dam's Historical Water Quality Data Collected Between 1992 and 1993.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	351	306	479	85
Total Ammonia as N	mg/L	4	0.289	0.011	0.994	0.471
Bicarbonate (HCO_3)	mg/L	4	372	288	585	142
Calcium (Ca)	mg/L	4	25	21	32	6
Carbonate (CO_3)	mg/L	3	37	34	42	4
Chloride (Cl)	mg/L	4	10.9	9.0	15.8	3.3
Chlorophyll-a	µg/L	3	17.7	14.0	22.0	4.0
Specific Conductance	µmhos	4	905	797	1220	210
Total Dissolved Solids	mg/L	4	585	512	787	135
Total Hardness as ($CaCO_3$)	mg/L	4	171	148	218	32
Hydroxide (OH)	mg/L	1	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.164	0.067	0.371	0.139
Magnesium (Mg)	mg/L	4	26.1	22.9	33.7	5.1
Nitrate + Nitrite as N	mg/L	2	0.005	0	0.009	0.006
Total Kjeldahl Nitrogen as N	mg/L	3	2.920	2.450	3.530	0.553
Total Nitrogen as N	mg/L	2	2.015	1.240	2.789	1.095
pH		4	8.81	7.83	9.24	0.66
Total Phosphorus as P	mg/L	4	0.197	0.144	0.269	0.053
Potassium (K)	mg/L	4	10.0	9.1	11.8	1.3
Sodium (Na)	mg/L	4	159	136	209	34
Sulfate (SO4)	mg/L	4	143	121	197	36

[1]Equal to lower detection limit

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Balta Dam and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight, in algae is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There are seven water quality sample sets for Balta Dam between July 1992 and January 2006, where the N:P ratio could be calculated. The results from this analysis indicate that Balta Dam is most often nitrogen limited (Figure 5).

N:P ratios for Balta Dam ranged from a low of 5 to a high of 20 with an average of 10. Of the seven profiles, all but one sample collected, were below a ratio of 15 indicating nitrogen is most often limiting primary production.

Table 3. Statistical Summary of Water Quality Data[2] Collected from Reservoirs in the Cultivated Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	352	263	88	891	103
Total Ammonia as N	mg/L	463	0.131	0.001[1]	2.070	0.203
Bicarbonate (HCO_3)	mg/L	352	296	91	951	114
Calcium (Ca)	mg/L	352	65	19	169	22
Carbonate (CO_3)	mg/L	324	14	1[1]	93	16
Chloride (Cl)	mg/L	351	21	1[1]	113	18
Chlorophyll-a	µg/L	373	20	2[1]	388	31
Specific Conductance	µmhos	352	1021	217	3140	516
Total Dissolved Solids	mg/L	344	667	127	2300	387
Total Hardness as ($CaCO_3$)	mg/L	352	334	95	1090	121
Hydroxide (OH)	mg/L	280	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	350	0.137	0.007	3.190	0.216
Magnesium (Mg)	mg/L	352	42	11	161	20
Nitrate + Nitrite as N	mg/L	411	0.097	0.003	2.060	0.191
Total Kjeldahl Nitrogen as N	mg/L	376	1.476	0.207	4.410	0.642
Total Nitrogen as N	mg/L	315	1.488	0.418	3.220	0.587
pH		352	8.36	6.89	9.40	0.43
Total Phosphorus as P	mg/L	464	0.322	0.004[1]	1.380	0.267
Potassium (K)	mg/L	352	12	3[1]	35	5
Sodium (Na)	mg/L	352	97	2[1]	582	107
Sulfate (SO4)	mg/L	351	269	8	1350	217

[1]Equal to lower detection limit
[2]Data Collected from 40 Reservoirs between 1991 and 2007

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005-2006, Balta Dam's current trophic status is eutrophic, bordering on hypereutrophic. TSI scores ranged from a low of 58 based on chlorophyll-a, to a high of 94 based on total phosphorus. The trophic status score based on secchi disk transparency was between that estimated by chlorophyll-a and total phosphorus, at 77 (Figure 6).

A total of seven total phosphorus samples, six chlorophyll-a samples, and six Secchi disk transparency measurements collected from 1992-2006 were used to evaluate trends in the trophic status of Balta Dam. Based on a visual assessment of trophic status indicators of chlorophyll-a samples and Secchi disk transparency, Balta Dam's trophic status is stable.

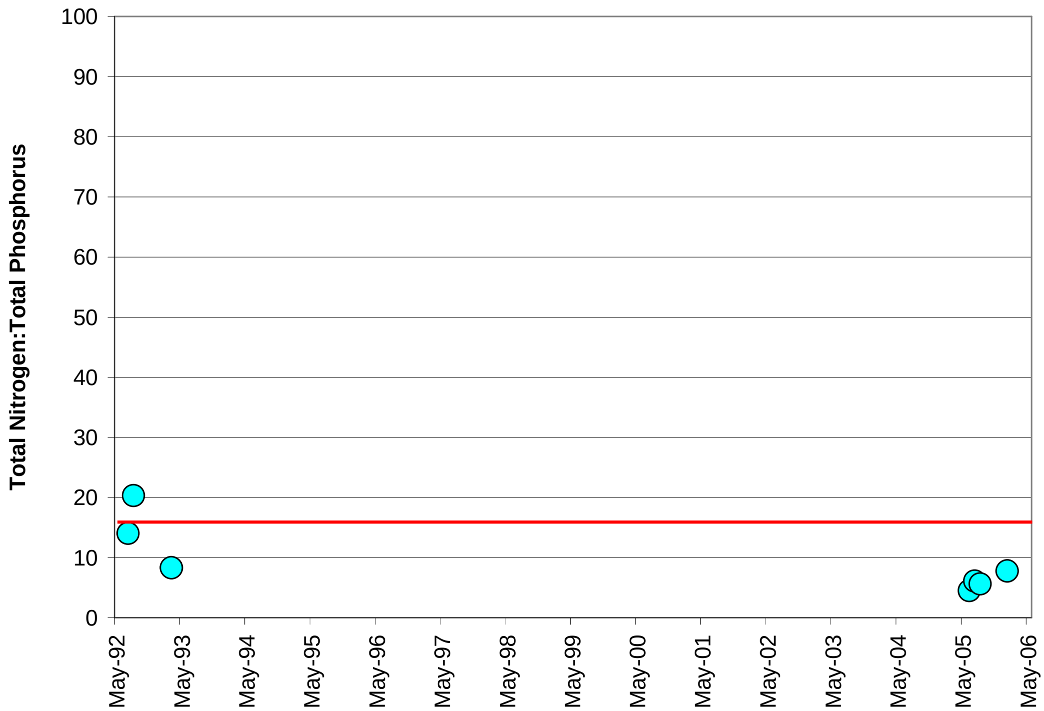


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Balta Dam (1992-2006).

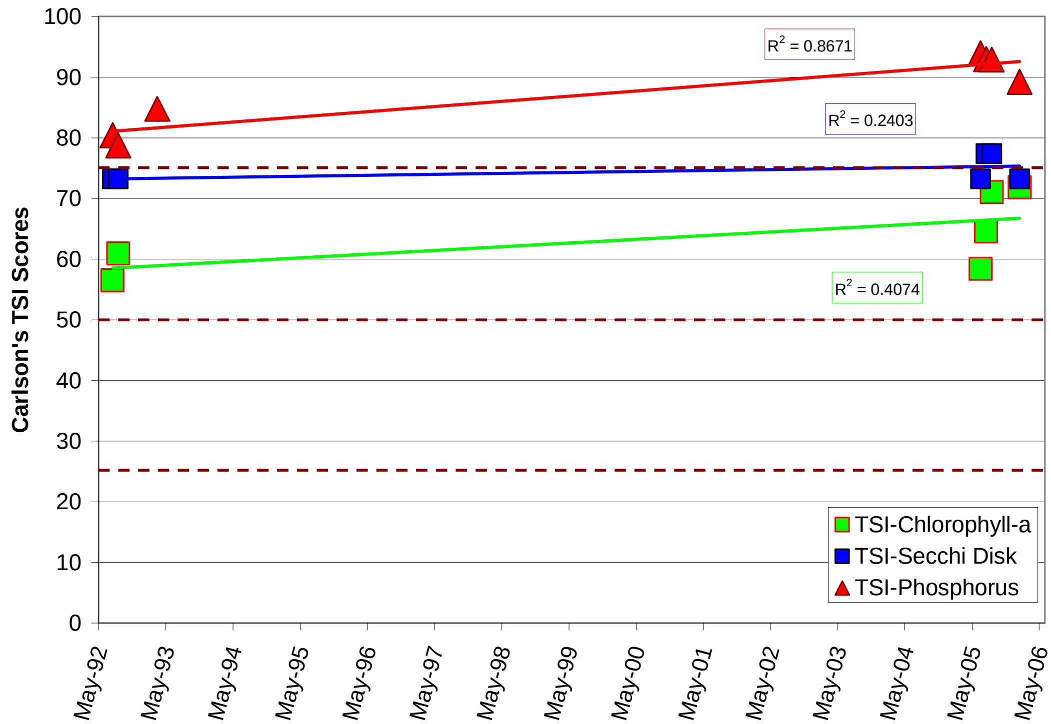


Figure 6. TSI Scores and Temporal Trends for Balta Dam from 1992 to 2006.

Lake Elsie, Richland County

BACKGROUND

Location: Lake Elsie is a natural lake located 1 mile south, and 1½ miles west of Hankinson, North Dakota (Figure 1). Lake Elsie is managed by the North Dakota Game and Fish Department.

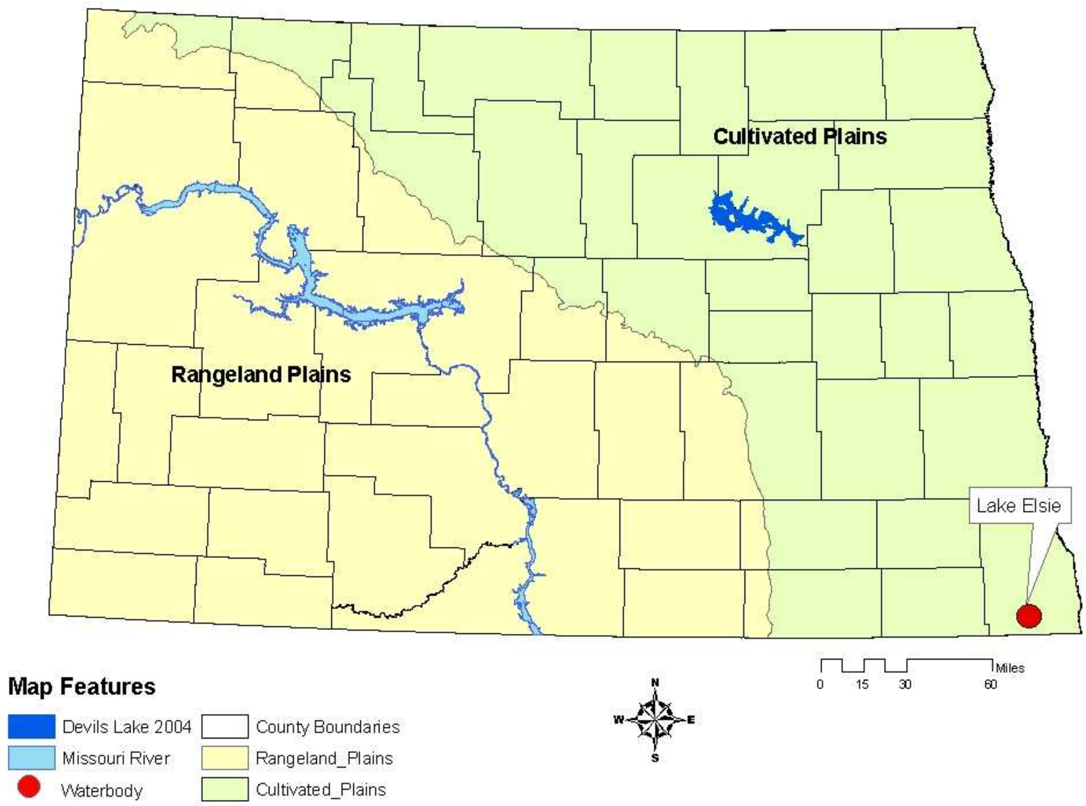


Figure 1. Location of Lake Elsie.

Physiographic/Ecological Setting: Lake Elsie has a surface area of 376.8 acres, a maximum depth of 23.6 ft, and an average depth of 8.4 ft (Figure 2). Lake Elsie's watershed is 4,529 acres, and lies on the edge of the Lake Agassiz Plains Level III Ecoregion, part of the broader Cultivated Plains region (Figure 1). This region is characterized by a flat landscape and contains some of the most fertile soils in North American. The natural tall grass prairie has been replaced by bean, corn, and sugar beet fields and the natural stream system with engineered drainage ditches.

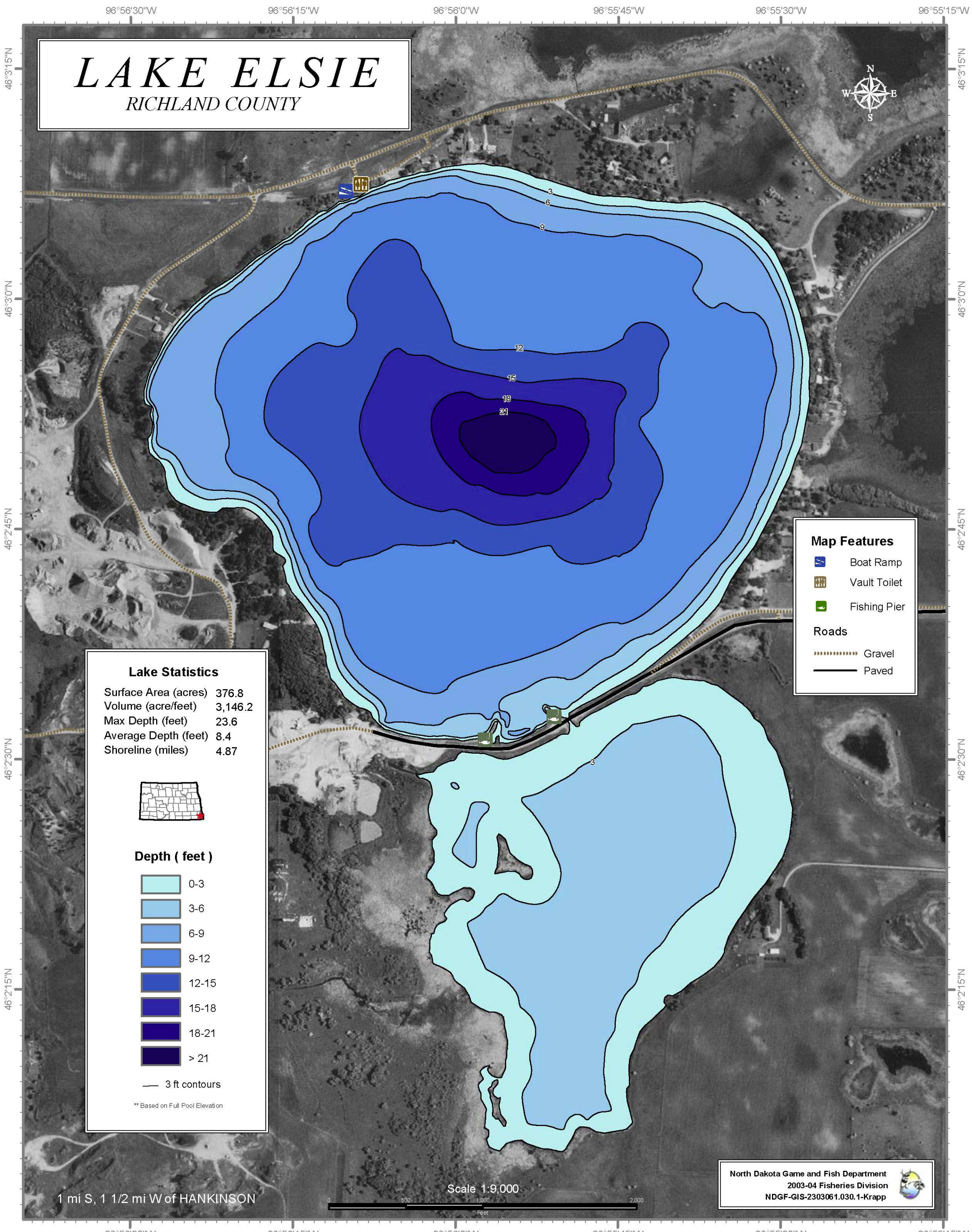


Figure 2. Contour Map of Lake Elsie (Map Courtesy of North Dakota Game and Fish Department).

Recreational Facilities: Recreational facilities at Lake Elsie include one boat ramp, boat and vehicle parking, and two fishing piers. Public access on the north side includes the boat dock and a vaulted toilet. Access on the south side of the lake includes both of the fishing piers.

Water Quality Standards Classification: Lake Elsie is classified in the state “Standards of Quality for Waters of the State” (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a “warm water fishery” or “waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present.”

Historical and Current Fishery: Lake Elsie’s current fishery is northern pike, walleye, and perch. Lake Elsie’s historical fishery also includes bluegill, and what use to be one of the best largemouth bass fisheries in the state. Silt loads from the gravel pit used during the construction of Interstate 29, deteriorated the largemouth bass fishery.

Historical Water Quality Sampling: Historical water quality data includes results from three samples collected from 1992 through 1993.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Lake Elsie have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural or enhanced lakes in the Cultivated Plains region.

Temperature and Dissolved Oxygen Profile Results: There are seven temperature and dissolved oxygen profiles for Lake Elsie collected from 1992-2006. Temperature and oxygen profiles are presented for two time periods, 1992-1993, and 2005-2006 (Figures 3 and 4). The temperature and dissolved oxygen profiles show that during winter months and below the metalimnion, Lake Elsie can experience oxygen deficiencies, and occasionally drops below the state’s water quality standard of 5 mg/L. Of the seven profiles, four samples, collected on 7/29/1992, 3/2/1993, 8/1/2005, and 1/25/2006, dropped or remained below the state standard of 5 mg/L. While the loss of dissolved oxygen during these periods is concerning, there does appear to be enough dissolved oxygen to maintain aquatic life at nearly all depths, and while stressed at all times of the year.

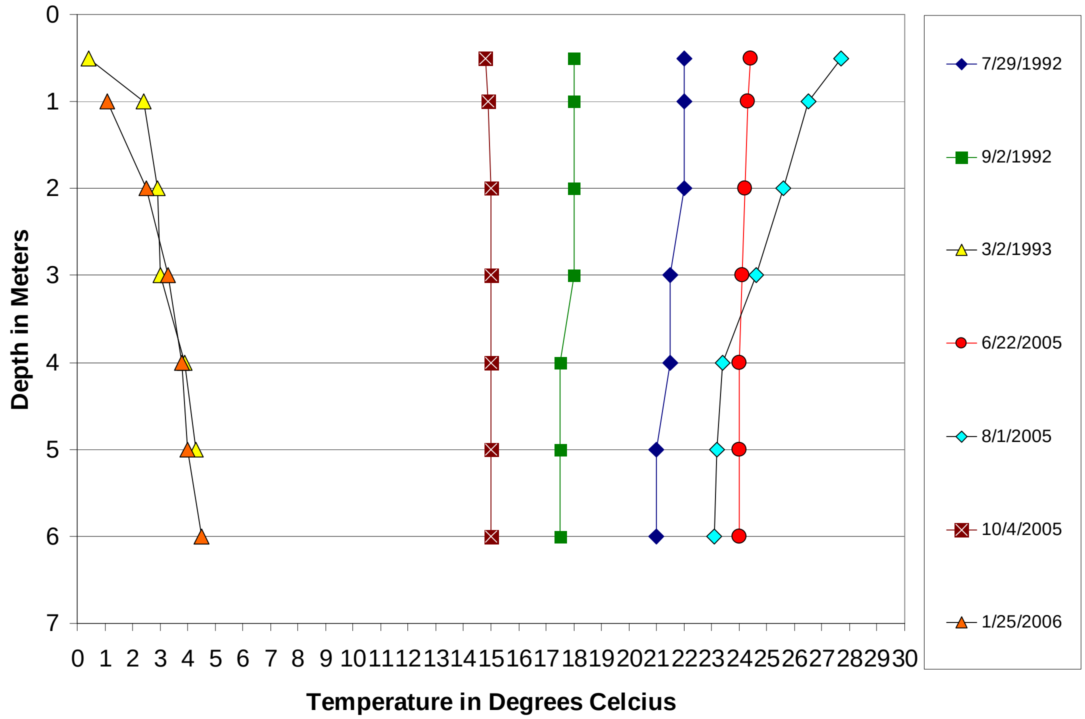


Figure 3. Temperature Profiles for Lake Elsie from 1992 to 2006.

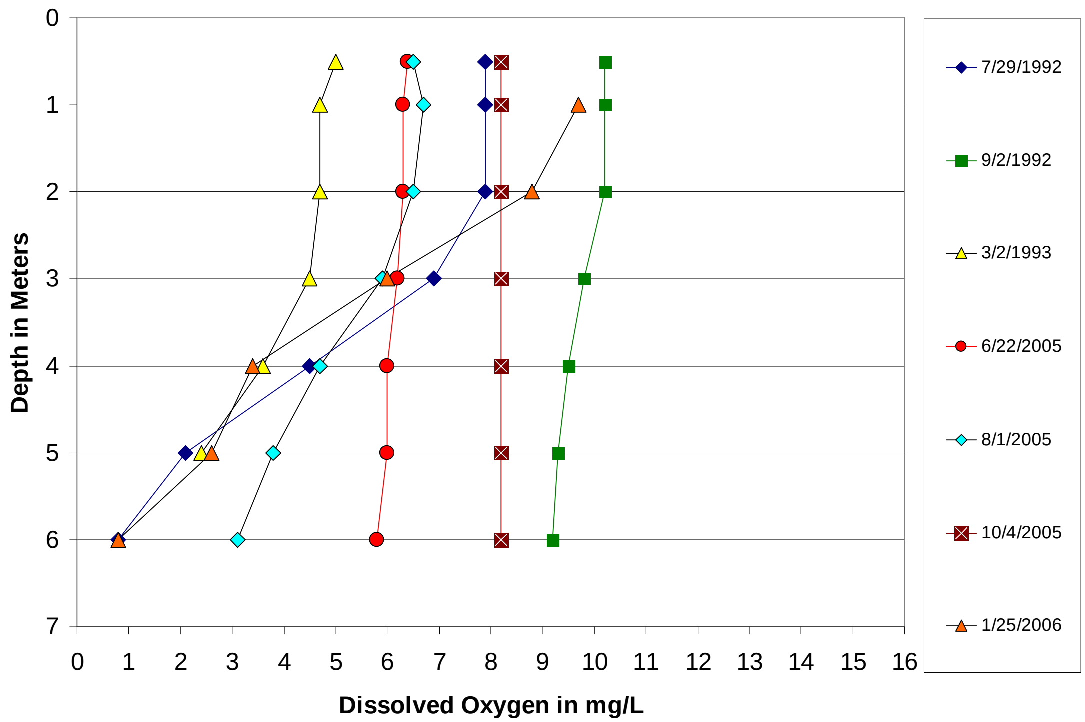


Figure 4. Dissolved Oxygen Profiles for Lake Elsie from 1992 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006 indicate Lake Elsie is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 179 to 217 mg/L (Table 1). Based on the 2005-2006 water quality data (Table 1), Lake Elsie is sodium bicarbonate dominated with an average sodium concentration of 20 mg/L and an average bicarbonate concentration of 235 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 515 mg/L and 799 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 0.838 mg/L and 0.009 mg/L, respectively.

Table 1. Statistical Summary of Lake Elsie's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	200	179	217	16
Total Ammonia as N	mg/L	4	0.159	0.011	0.288	0.115
Bicarbonate (HCO_3)	mg/L	4	235	204	265	25
Calcium (Ca)	mg/L	4	71.0	61.6	81.1	8.0
Carbonate (CO_3)	mg/L	4	5	1[1]	7	3
Chloride (Cl)	mg/L	4	8	8	9	0
Chlorophyll-a	µg/L	4	5.4	1.5	16.3	7.3
Specific Conductance	µmhos	4	799	750	838	37
Total Dissolved Solids	mg/L	4	515	475	537	28
Total Hardness as ($CaCO_3$)	mg/L	4	392	347	439	38
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.118	0.063	0.204	0.064
Magnesium (Mg)	mg/L	4	52.3	47.0	57.5	4.5
Nitrate + Nitrite as N	mg/L	4	0.213	0.060	0.520	0.215
Total Kjeldahl Nitrogen as N	mg/L	4	0.699	0.503	0.811	0.136
Total Nitrogen as N	mg/L	4	0.911	0.703	1.240	0.231
pH		4	8.35	8.11	8.49	0.17
Total Phosphorus as P	mg/L	4	0.021	0.007	0.030	0.010
Potassium (K)	mg/L	4	8.5	7.7	9.4	0.8
Sodium (Na)	mg/L	4	20	17	22	2
Sulfate (SO4)	mg/L	4	232	224	235	5

[1]Equal to lower detection limit

When compared to historical water quality data for Lake Elsie, most water quality constituents have decreased. For example, the historical average bicarbonate and sodium concentrations were 251 mg/L and 40 mg/L, respectively (Table 2), compared to average concentrations of 235 mg/L for bicarbonate, and 20 mg/L for sodium, recorded for the period 2005-2006 (Table 1).

Additionally, the average total nitrogen and total phosphorus concentrations have decreased when compared to the historical data. Historical average total nitrogen and total phosphorus concentrations were 1.729 mg/L and 0.050 mg/L (Table 2) respectively, compared to current average concentrations of 0.911 mg/L for total nitrogen and 0.021 mg/L for total phosphorus.

Table 2. Statistical Summary of Lake Elsie's Historical Water Quality Data Collected Between 1992 and 1993.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	211	195	236	22
Total Ammonia as N	mg/L	3	0.368	0.116	0.648	0.267
Bicarbonate (HCO_3)	mg/L	3	251	218	288	35
Calcium (Ca)	mg/L	3	95	90	100	5
Carbonate (CO_3)	mg/L	1	10	10	10	
Chloride (Cl)	mg/L	3	11.7	10.3	14.2	2.2
Chlorophyll-a	µg/L	2	19.0	7.0	31.0	17.0
Specific Conductance	µmhos	3	1266	1188	1410	125
Total Dissolved Solids	mg/L	3	859	810	918	55
Total Hardness as ($CaCO_3$)	mg/L	3	635	616	660	23
Hydroxide (OH)	mg/L	1	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	3	0.052	0.042	0.061	0.010
Magnesium (Mg)	mg/L	3	96.8	95.2	99.7	2.5
Nitrate + Nitrite as N	mg/L	2	0.039	0.017	0.060	0.030
Total Kjeldahl Nitrogen as N	mg/L	2	1.615	1.590	1.640	0.035
Total Nitrogen as N	mg/L	3	1.729	1.607	1.879	0.138
pH		3	8.18	7.76	8.46	0.37
Total Phosphorus as P	mg/L	3	0.050	0.047	0.053	0.003
Potassium (K)	mg/L	3	14.7	14.5	15.0	0.3
Sodium (Na)	mg/L	3	40	38	42	2
Sulfate (SO4)	mg/L	3	475	435	506	36

[1]Equal to lower detection limit

When compared to the Cultivated Plains regional average for natural and enhanced lakes, Lake Elsie's water quality is fresher and less eutrophic (Table 3). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1376 mg/L, 1.440 mg/L, and 0.068 mg/L, respectively, compared to Lake Elsie's average TDS, total nitrogen, and total phosphorus concentrations of 515 mg/L, 0.911 mg/L and 0.021 mg/L, respectively, for the period 2005-2006.

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Lake Elsie and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight, in algae is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There are seven water quality sample sets for Lake Elsie between July 1992 and January 2006, where the N:P ratio could be calculated. The results from this analysis indicate that Lake Elsie is phosphorus limited (Figure 5).

N:P ratios for Lake Elsie ranged from a low of 31 to a high of 177 with an average of 56. All seven samples collected were above a ratio of 15 indicating phosphorus is limiting primary production.

Table 3. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lakes in the Cultivated Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	142	346	175	1120	180
Total Ammonia as N	mg/L	230	0.098	0.001[1]	1.620	0.208
Bicarbonate (HCO_3)	mg/L	142	363	171	1040	158
Calcium (Ca)	mg/L	142	45	16	108	23
Carbonate (CO_3)	mg/L	136	31	1[1]	181	39
Chloride (Cl)	mg/L	142	105	3[1]	1260	233
Chlorophyll-a	µg/L	185	10	2[1]	167	17
Specific Conductance	µmhos	161	1819	361	11500	2071
Total Dissolved Solids	mg/L	143	1376	191	9880	1786
Total Hardness as ($CaCO_3$)	mg/L	142	507	173	1820	284
Hydroxide (OH)	mg/L	111	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	138	0.095[1]	0.007	1.010	0.123
Magnesium (Mg)	mg/L	142	95.7	28.4	413.0	68.0
Nitrate + Nitrite as N	mg/L	175	0.047	0.001	0.540	0.078
Total Kjeldahl Nitrogen as N	mg/L	128	1.504	0.080	4.110	0.609
Total Nitrogen as N	mg/L	103	1.440	0.609	2.740	0.466
pH		142	8.55	7.75	9.33	0.36
Total Phosphorus as P	mg/L	230	0.068	0.004[1]	1.460	0.118
Potassium (K)	mg/L	142	30	8	179	37
Sodium (Na)	mg/L	142	255	5	2570	498
Sulfate (SO4)	mg/L	142	591	7	3880	807

[1]Equal to lower detection limit
[2]Data Collected from 49 Natural Lakes between 1991 and 2007

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005-2006, Lake Elsie's current trophic status is mesotrophic. TSI scores ranged from a low of 24 based on chlorophyll-a, to a high of 67 based on Secchi disk transparency. The trophic status score based on total phosphorus, was in between that estimated based on Secchi disk transparency and chlorophyll-a, at 50 (Figure 6).

A total of seven total phosphorus samples, six chlorophyll-a samples, and six Secchi disk transparency measurements collected from 1992-2006 were used to evaluate trends in the trophic status of Lake Elsie. Based on a visual assessment of the data, Lake Elsie's trophic status has improved from 1992 to 2006 (Figure 6).

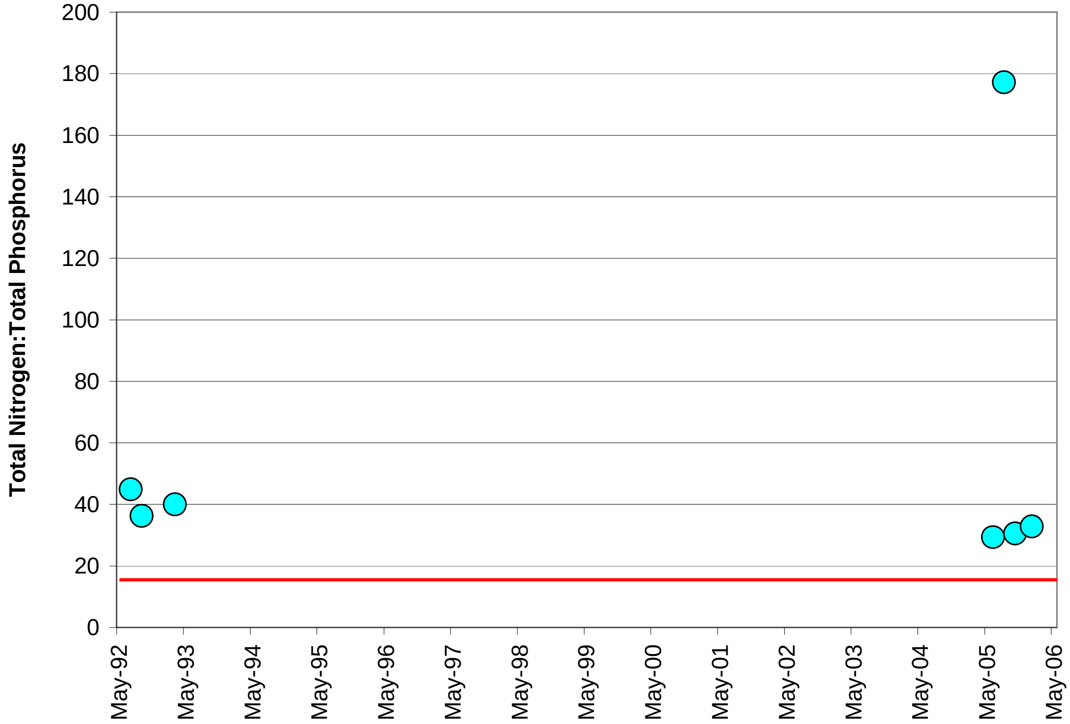


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Lake Elsie (1992-2006).

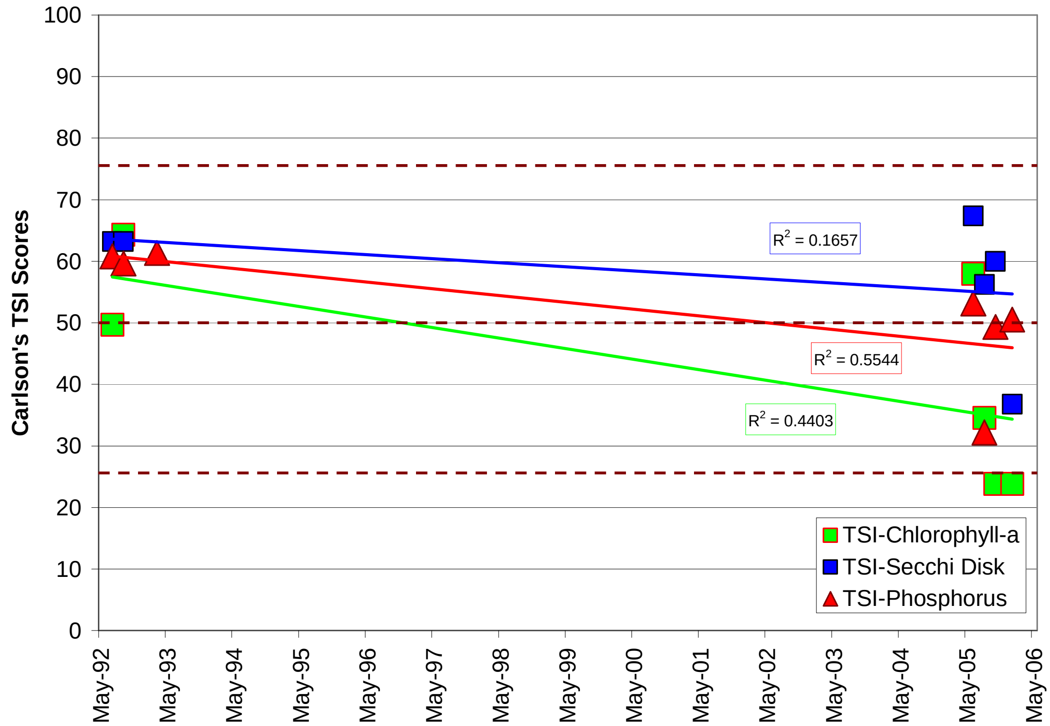


Figure 6. TSI Scores and Temporal Trends for Lake Elsie from 1992 to 2006.

Mooreton Pond, Richland County

BACKGROUND

Location: Mooreton Pond is a man-made lake located 2 miles east of Mooreton, North Dakota (Figure 1). Mooreton Pond is managed by the North Dakota Game and Fish Department.

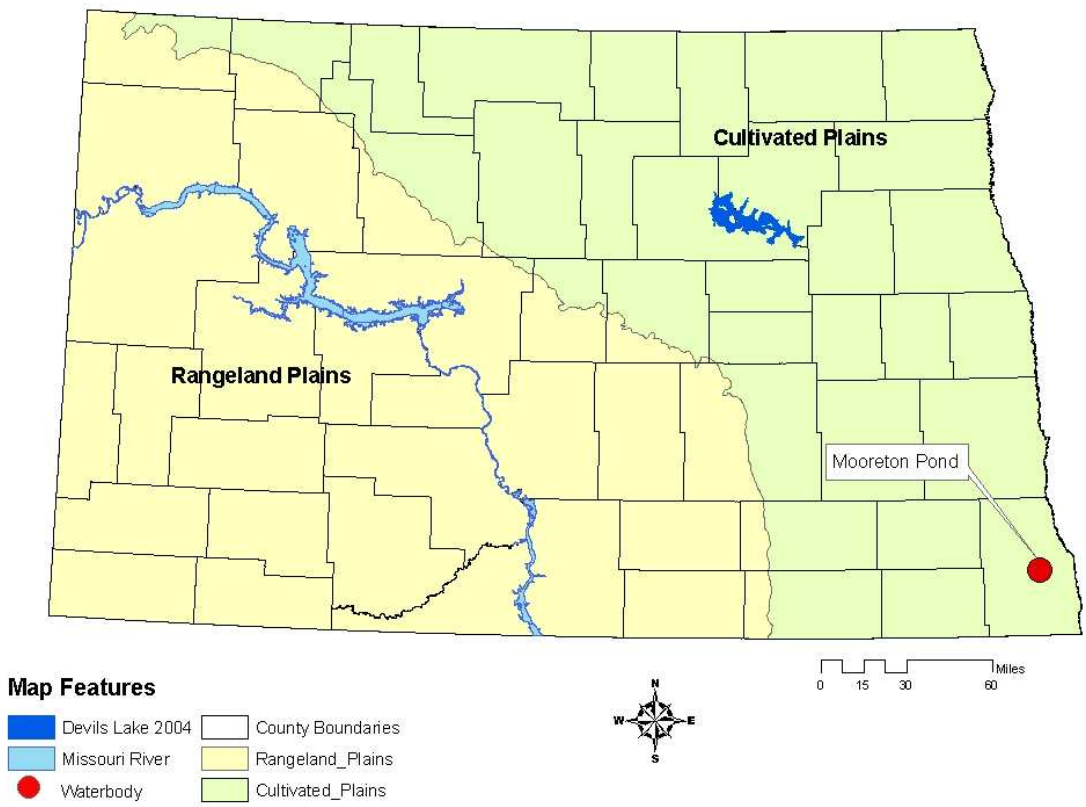


Figure 1. Location of Mooreton Pond.

Physiographic/Ecological Setting: Mooreton Pond has a surface area of 40.7 acres, a maximum depth of 21.0 ft and an average depth 14.3 ft (Figure 2). Mooreton Pond's watershed lies within the Lake Agassiz Plains Level III Ecoregion, part of the broader Cultivated Plains region (Figure 1). This region is characterized by a flat landscape and contains some of the most fertile soils in North American. The natural tall grass prairie has been replaced by bean, corn, and sugar beet fields and the natural stream system with engineered drainage ditches.

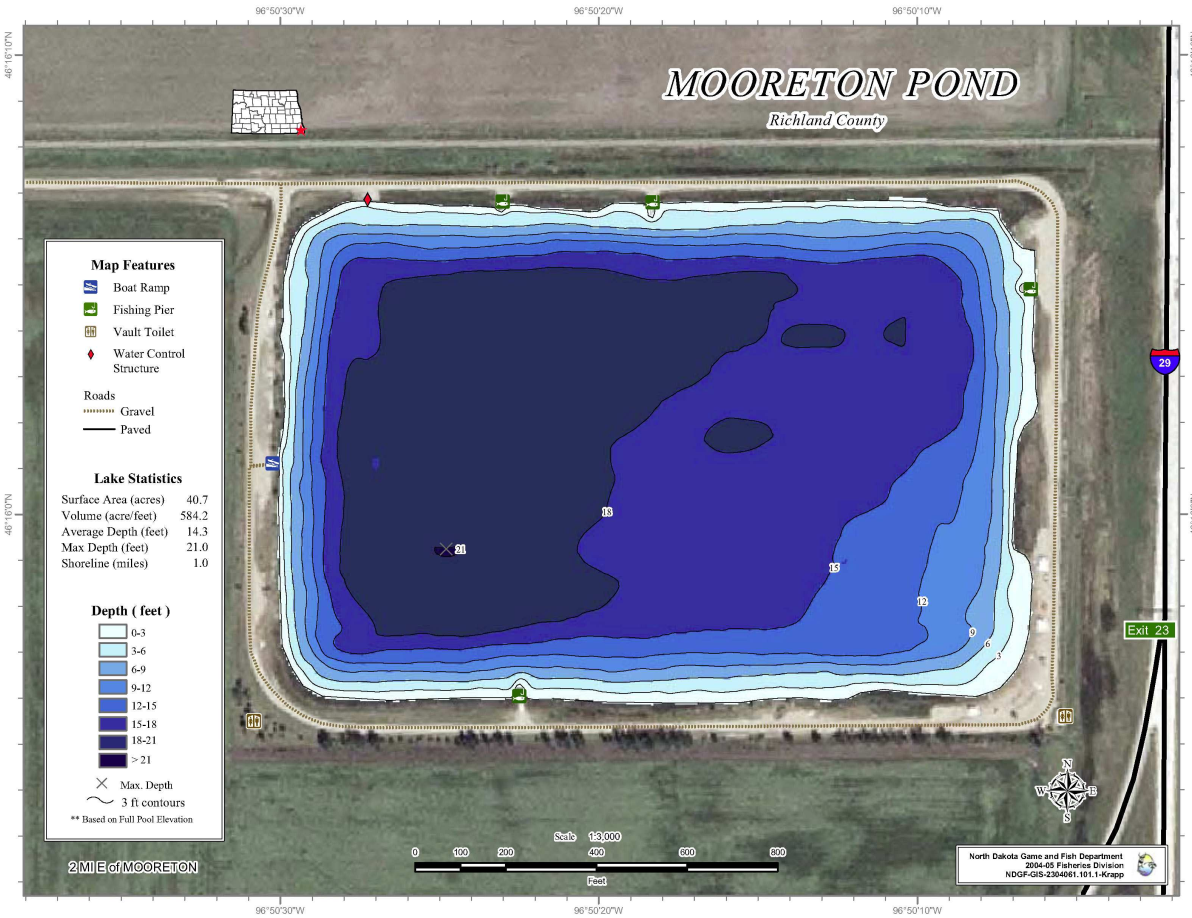


Figure 2. Contour Map of Mooreton Pond (Map Courtesy of North Dakota Game and Fish Department).

Construction History: Mooreton Pond is an abandoned gravel pit, dug during the construction of Interstate 29 in the 1960's and abandoned in the early 1970's.

Recreational Facilities: Recreational facilities at Mooreton Pond include one boat ramp, boat and vehicle parking, a large beach, and four fishing piers. Public access encompasses the entire lake. Boating regulations at Mooreton Pond prohibit the use of gas motors.

Water Quality Standards Classification: Mooreton Pond is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a "warm water fishery" or "waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present."

Historical and Current Fishery: Mooreton Pond's current fishery is rainbow trout, brown trout, and bluegill. The historical fishery includes smallmouth bass, largemouth bass, channel catfish, and yellow perch. Boats are restricted to electric motors.

Historical Water Quality Sampling: Historical water quality data includes results from seven samples collected in 2002 and 2003.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Mooreton Pond have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural and enhanced lakes in the Cultivated Plains region.

Temperature and Dissolved Oxygen Profile Results: There were eight temperature and dissolved oxygen profiles for Mooreton Pond collected from 2002-2005. Temperature and oxygen profiles are presented for two time periods, 2002-2003, and 2005 (Figures 3 and 4). The temperature and dissolved oxygen profiles show that Mooreton Pond experiences gradual oxygen decay below the metalimnion but remains above the state's water quality standard of 5 mg/L except at the water sediment interface.

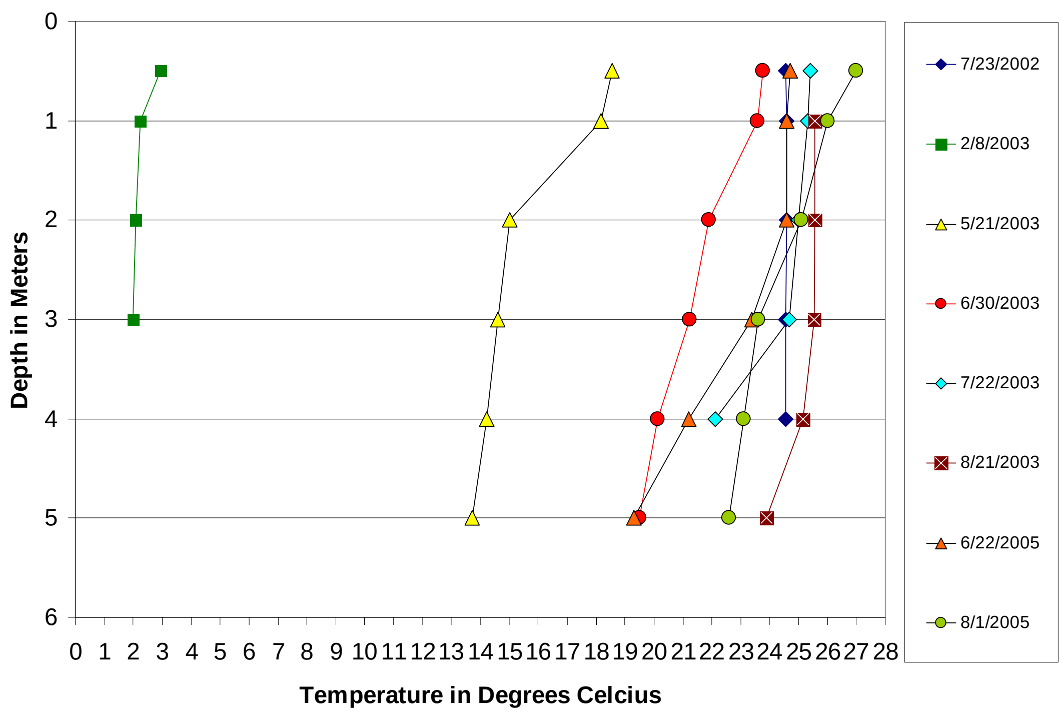


Figure 3. Temperature Profiles for Mooreton Pond from 2002 to 2005.

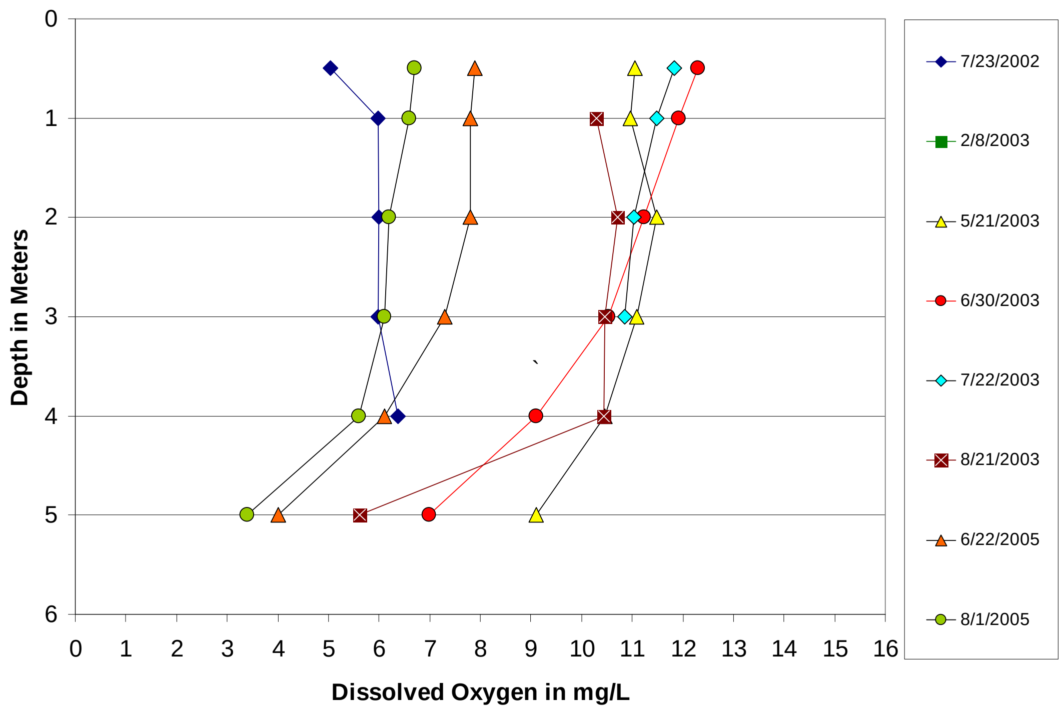


Figure 4. Dissolved Oxygen Profiles for Mooreton Pond from 2002 to 2005.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006 indicate Mooreton Pond is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 241 to 248 mg/L (Table 1). Based on the 2005-2006 water quality data (Table 1), Mooreton Pond is sodium sulfate dominated with an average sodium concentration of 870 mg/L and an average sulfate concentration of 1670 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 3245 mg/L and 4500 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 0.838 mg/L and 0.009 mg/L, respectively.

When compared to historical water quality data for Mooreton Pond, most water quality constituents have decreased slightly. For example, the historical average sulfate and sodium concentrations were 1765 mg/L and 891 mg/L, respectively (Table 2), compared to average concentrations of 1670 mg/L for sulfate and 870 mg/L for sodium recorded for the period 2005-2006 (Table 1). However, the average total nitrogen and total phosphorus concentrations have increased. Historical average total nitrogen and phosphorus concentrations were 0.737 mg/L and 0.008 mg/L, respectively (Table 2), compared to average concentrations of 0.838 mg/L for total nitrogen and 0.009 mg/L for total phosphorus, respectively.

Table 1. Statistical Summary of Mooreton Pond's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	2	245	241	248	5
Total Ammonia as N	mg/L	2	0.101	0.044	0.157	0.080
Bicarbonate (HCO_3)	mg/L	2	274	269	278	6
Calcium (Ca)	mg/L	2	83.2	81.5	84.9	2.4
Carbonate (CO_3)	mg/L	2	12	12	12	0
Chloride (Cl)	mg/L	2	363	360	366	4
Chlorophyll-a	µg/L	2	1.5	1.5[1]	1.5	0.0
Specific Conductance	µmhos	2	4500	4480	4520	28
Total Dissolved Solids	mg/L	2	3245	3240	3250	7
Total Hardness as ($CaCO_3$)	mg/L	2	580	568	592	17
Hydroxide (OH)	mg/L	2	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	2	0.204	0.167	0.241	0.052
Magnesium (Mg)	mg/L	2	90.4	88.5	92.3	2.7
Nitrate + Nitrite as N	mg/L	2	0.030	0.020	0.040	0.014
Total Kjeldahl Nitrogen as N	mg/L	2	0.808	0.729	0.886	0.111
Total Nitrogen as N	mg/L	2	0.838	0.749	0.926	0.125
pH		2	8.50	8.49	8.50	0.01
Total Phosphorus as P	mg/L	2	0.009	0.004[1]	0.014	0.007
Potassium (K)	mg/L	2	20.0	19.8	20.2	0.3
Sodium (Na)	mg/L	2	870	845	895	35
Sulfate (SO4)	mg/L	2	1670	1650	1690	28

[1]Equal to lower detection limit

When compared to the Cultivated Plains regional average for natural and enhanced lakes, Mooreton Pond is lower in nutrient content and higher in concentrations of dissolved solids (Table 3). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1376 mg/L, 1.440 mg/L, and 0.068 mg/L, respectively, compared to Mooreton Pond's average TDS, total nitrogen, and total phosphorus concentrations of 3245 mg/L, 0.838 mg/L and 0.009 mg/L, respectively, for the period 2005-2006.

Table 2. Statistical Summary of Mooreton Pond's Historical Water Quality Data Collected Between 2002 and 2003.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	6	256	245	286	15
Total Ammonia as N	mg/L	7	0.032	0.010[1]	0.072	0.028
Bicarbonate (HCO_3)	mg/L	6	286	275	310	13
Calcium (Ca)	mg/L	6	82	71	91	6
Carbonate (CO_3)	mg/L	6	13	8	19	4
Chloride (Cl)	mg/L	6	396.8	363.0	441.0	26.2
Chlorophyll-a	µg/L	3	3.0	3.0[1]	3.0	0.0
Specific Conductance	µmhos	6	4650	4530	5070	208
Total Dissolved Solids	mg/L	6	3403	3220	3660	170
Total Hardness as ($CaCO_3$)	mg/L	6	584	523	646	39
Hydroxide (OH)	mg/L	6	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	6	0.195	0.074	0.283	0.082
Magnesium (Mg)	mg/L	6	92.4	84.2	102.0	5.8
Nitrate + Nitrite as N	mg/L	7	0.023	0.020	0.040	0.008
Total Kjeldahl Nitrogen as N	mg/L	7	0.714	0.589	0.836	0.090
Total Nitrogen as N	mg/L	7	0.737	0.609	0.856	0.092
pH		6	8.50	8.42	8.60	0.06
Total Phosphorus as P	mg/L	8	0.008	0.004[1]	0.016	0.005
Potassium (K)	mg/L	6	19.9	19.3	20.9	0.6
Sodium (Na)	mg/L	6	891	807	975	70
Sulfate (SO4)	mg/L	6	1765	1570	1890	110

[1]Equal to lower detection limit

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Mooreton Pond and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight, in algae is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There are nine water quality sample sets for Mooreton Pond between September 2002 and August 2005, where the N:P ratio could be calculated. The results from this analysis indicate that Mooreton Pond is phosphorus limited (Figure 5).

N:P ratios for Mooreton Pond ranged from a low of 50 to a high of 195 with an average of 113. All nine samples collected were above a ratio of 15 indicating phosphorus is limiting primary production.

Table 3. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lakes in the Cultivated Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	142	346	175	1120	180
Total Ammonia as N	mg/L	230	0.098	0.001[1]	1.620	0.208
Bicarbonate (HCO_3)	mg/L	142	363	171	1040	158
Calcium (Ca)	mg/L	142	45	16	108	23
Carbonate (CO_3)	mg/L	136	31	1[1]	181	39
Chloride (Cl)	mg/L	142	105	3[1]	1260	233
Chlorophyll-a	µg/L	185	10	2[1]	167	17
Specific Conductance	µmhos	161	1819	361	11500	2071
Total Dissolved Solids	mg/L	143	1376	191	9880	1786
Total Hardness as ($CaCO_3$)	mg/L	142	507	173	1820	284
Hydroxide (OH)	mg/L	111	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	138	0.095[1]	0.007	1.010	0.123
Magnesium (Mg)	mg/L	142	95.7	28.4	413.0	68.0
Nitrate + Nitrite as N	mg/L	175	0.047	0.001	0.540	0.078
Total Kjeldahl Nitrogen as N	mg/L	128	1.504	0.080	4.110	0.609
Total Nitrogen as N	mg/L	103	1.440	0.609	2.740	0.466
pH		142	8.55	7.75	9.33	0.36
Total Phosphorus as P	mg/L	230	0.068	0.004[1]	1.460	0.118
Potassium (K)	mg/L	142	30	8	179	37
Sodium (Na)	mg/L	142	255	5	2570	498
Sulfate (SO4)	mg/L	142	591	7	3880	807

[1]Equal to lower detection limit
[2]Data Collected from 49 Natural Lakes between 1991 and 2007

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005, Mooreton Pond's current trophic status is mesotrophic. TSI scores ranged from a low of 24 based on total phosphorus, to a high of 60 based on Secchi disk transparency. The trophic status score based on chlorophyll-a was similar to that estimated by total phosphorus, at 35 (Figure 6).

A total of nine total phosphorus samples, four chlorophyll-a samples, and six Secchi disk transparency measurements collected during in 2002 to 2005 were used to evaluate trends in the trophic status of Mooreton Pond. Based on a visual assessment of the data Mooreton Pond's trophic status is improving (Figure 6).

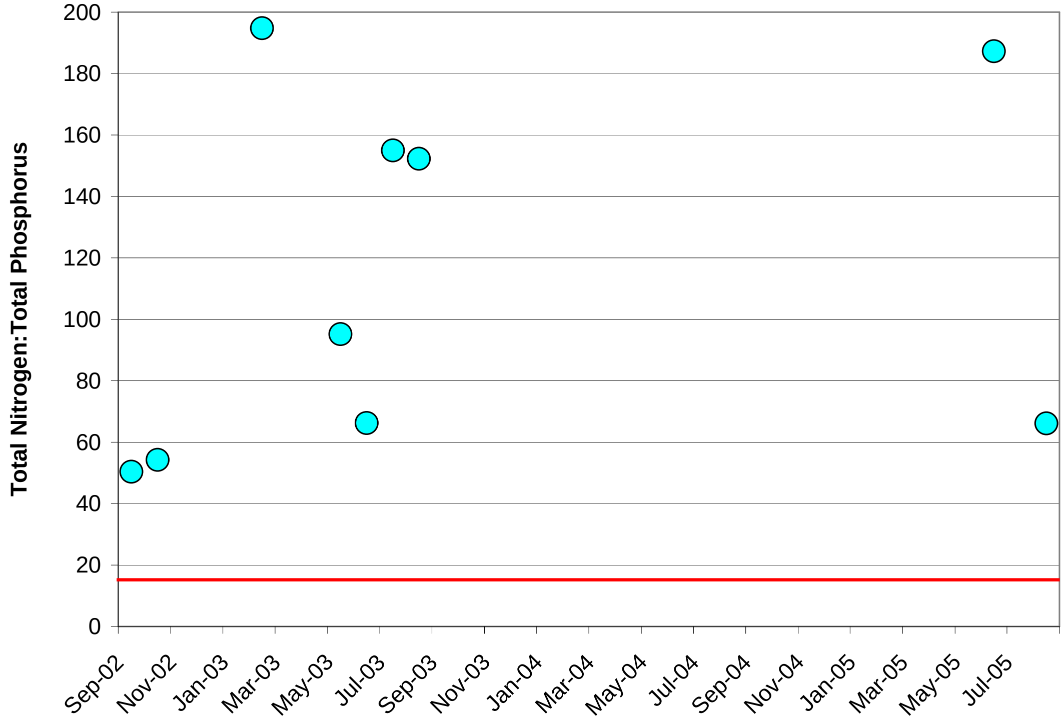


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Mooreton Pond (2002-2005).

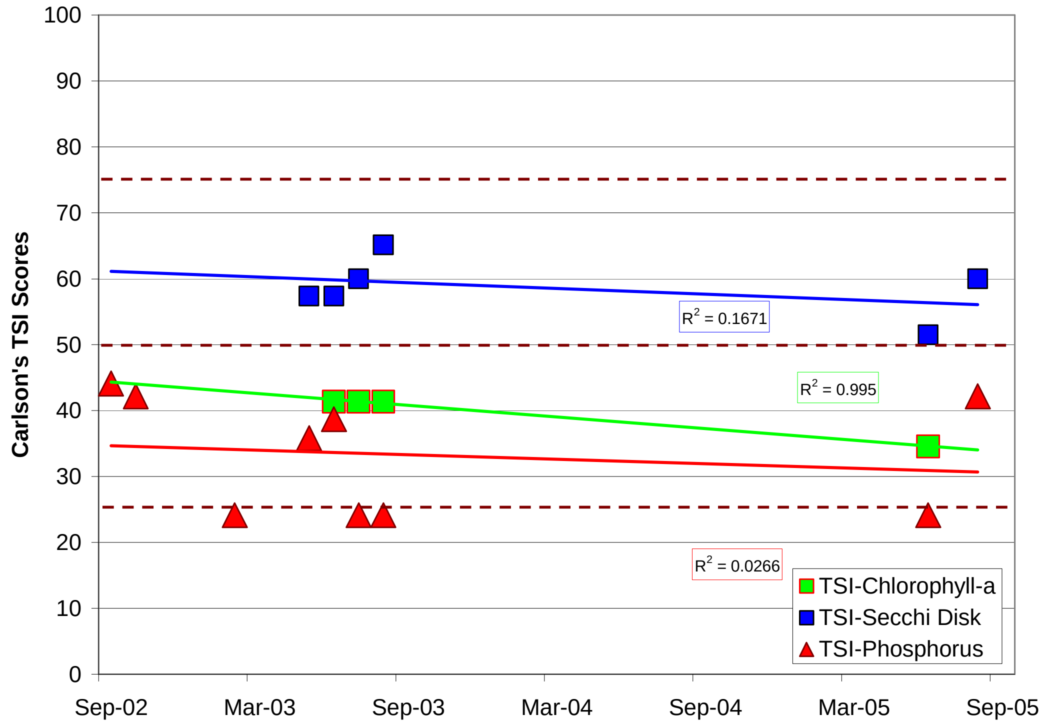


Figure 6. TSI Scores and Temporal Trends for Mooreton Pond from 2002 to 2005.

Dion Lake, Rolette County

BACKGROUND

Location: Dion Lake is a natural lake located on the eastern slope of the Turtle Mountains, 9 miles west, and 2 miles north of St. John, North Dakota. Dion Lake is managed by the North Dakota Game and Fish Department (Figure 1).

Figure 1. Location of Dion Lake.

Physiographic/Ecological Setting: Dion Lake has a surface area of 79.8 acres, a maximum depth of 20.1 ft, and an average depth of 11.2 ft (Figure 2). Dion Lake's watershed is 1,350 acres and lies within the Northern Glaciated Plains Level III Ecoregion, part of the broader Cultivated Plains region (Figure 1). This region is the transitional zone between tall and mixed grass prairie. The region has numerous wetlands essential for spring and fall migrations of wetland dependent birds. Flood plain slopes and hillsides are usually native grass while the uplands and flood plains proper have mostly been converted to small grains, row crops and alfalfa.

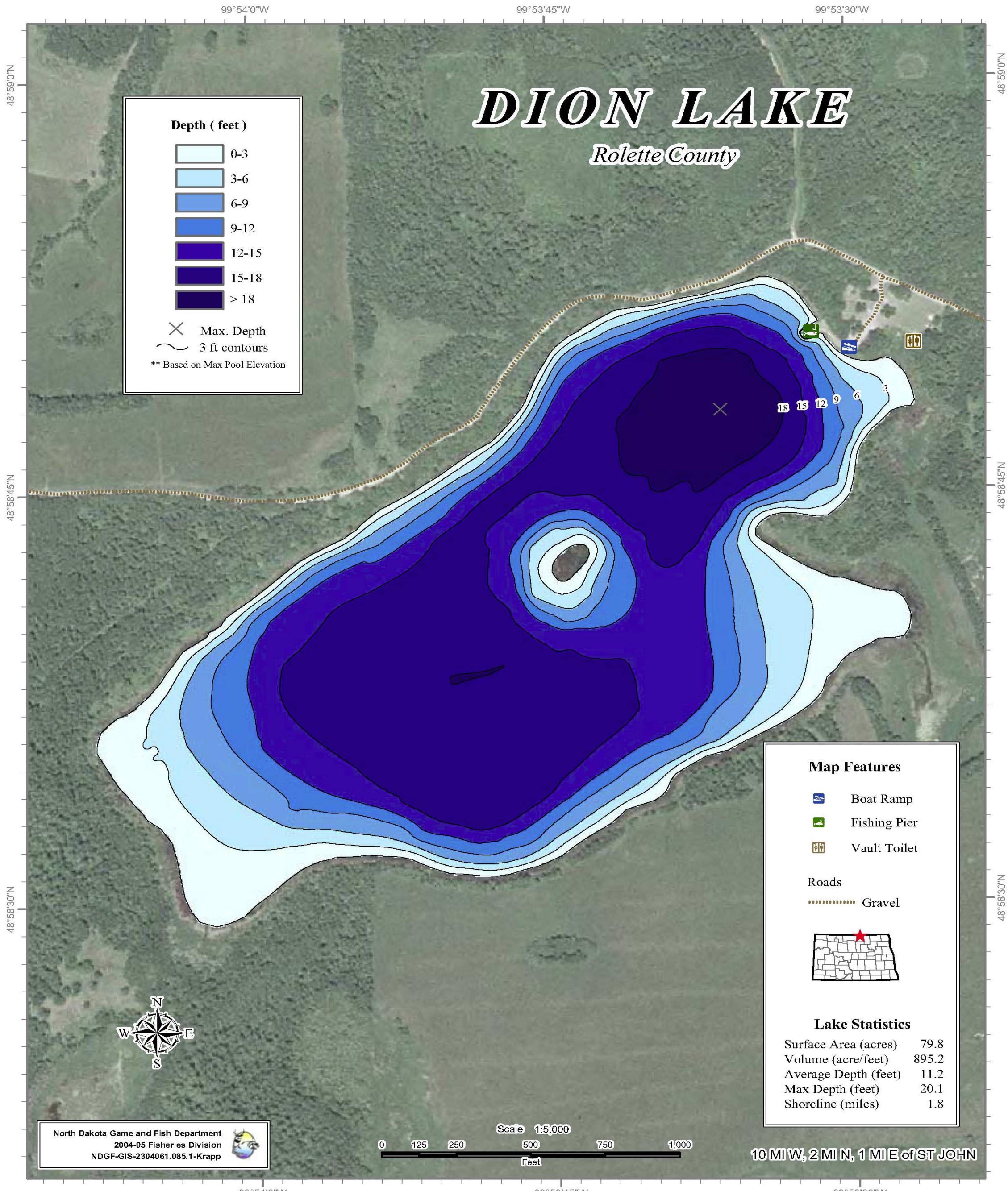


Figure 2. Contour Map of Dion Lake (Map Courtesy of North Dakota Game and Fish Department).

Recreational Facilities: Recreational facilities at Dion Lake include a boat ramp, boat and vehicle parking, and a fishing pier. Public access on the northeast shore includes a boat ramp, parking, vault toilet, and a fishing pier. Boats are restricted to idle speeds only.

Water Quality Standards Classification: Dion Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 2 lake. Class 2 lakes are defined as a "cool water fishery" or "waters capable of supporting natural reproduction and growth of cool water fishes (e.g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: Dion Lake's fishery over time has included walleye and yellow perch stocked by the NDG&F. Currently both species are managed in Dion Lake.

Historical Water Quality Sampling: Historical water quality data includes results from three samples collected from 1995 through 1996.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Dion Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural or enhanced lakes in the Cultivated Plains region.

Temperature and Dissolved Oxygen Profile Results: There are six temperature and dissolved oxygen profiles for Dion Lake collected from 1995-2006. Temperature and oxygen profiles are presented for two time periods, 1995-1996 and 2005-2006 (Figures 3 and 4). Dissolved oxygen and temperature profiles show that under ice cover condition and during thermal stratification, Dion Lake experiences deficiencies in dissolved oxygen and frequently drops below the state's water quality standard of 5 mg/L. Five of the dissolved oxygen profiles, collected on 7/19/1995, 8/23/1995, 6/20/2005, 8/16/2005, and 1/31/2006, dropped below the state standard of 5 mg/L and one collected on 2/21/1996 started and ended below the state standard of 5 mg/L. While the rapid loss of dissolved oxygen during thermal stratification is concerning, the real issue is the entire lack of adequate oxygen concentrations during late winter.

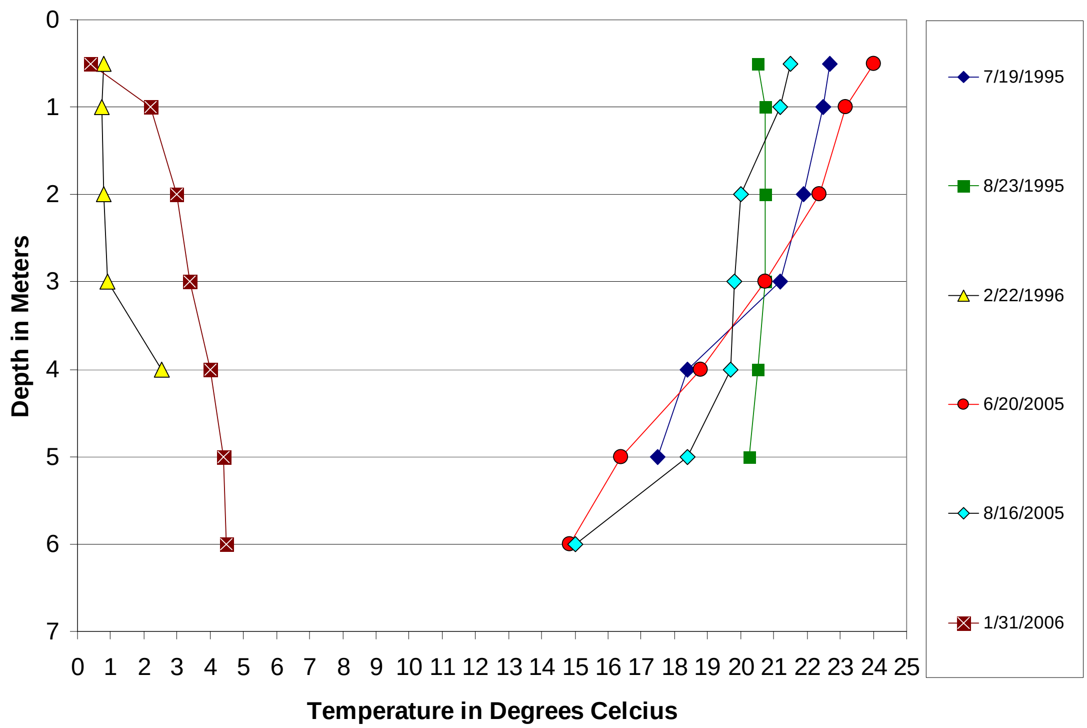


Figure 3. Temperature Profiles for Dion Lake from 1995 to 2006.

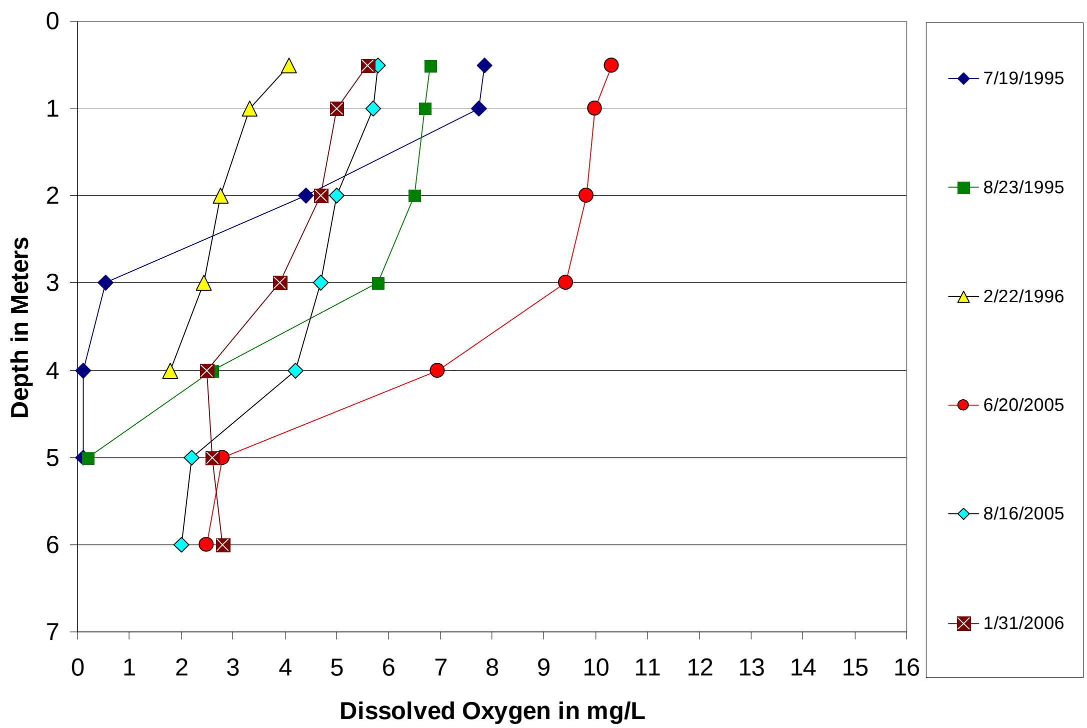


Figure 4. Dissolved Oxygen Profiles for Dion Lake from 1995 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006 indicate Dion Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 207 mg/L to 253 mg/L (Table 1). Based on the 2005-2006 water quality data (Table 1), Dion Lake is sodium bicarbonate dominated with an average sodium concentration of 8 mg/L and an average bicarbonate concentration of 269 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 365 mg/L and 628 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.537 mg/L and 0.030 mg/L, respectively.

Table 1. Statistical Summary of Dion Lake's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	224	207	253	25
Total Ammonia as N	mg/L	3	0.152	0.010[1]	0.437	0.247
Bicarbonate (HCO_3)	mg/L	3	269	240	308	35
Calcium (Ca)	mg/L	3	37.8	34.7	44.0	5.4
Carbonate (CO_3)	mg/L	3	3	1[1]	7	3
Chloride (Cl)	mg/L	3	4	3[1]	4	1
Chlorophyll-a	µg/L	2	5.9	2.7	9.1	4.5
Specific Conductance	µmhos	3	628	588	691	55
Total Dissolved Solids	mg/L	3	365	340	397	29
Total Hardness as ($CaCO_3$)	mg/L	3	316	290	341	26
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	3	0.063	0.037	0.099	0.032
Magnesium (Mg)	mg/L	3	53.8	49.3	56.2	3.9
Nitrate + Nitrite as N	mg/L	3	0.027	0.020	0.040	0.012
Total Kjeldahl Nitrogen as N	mg/L	3	1.510	1.210	1.970	0.404
Total Nitrogen as N	mg/L	3	1.537	1.230	2.010	0.416
pH		3	8.16	7.84	8.48	0.32
Total Phosphorus as P	mg/L	3	0.030	0.024	0.040	0.009
Potassium (K)	mg/L	3	14.9	12.2	16.2	2.3
Sodium (Na)	mg/L	3	8	7	8	0
Sulfate (SO4)	mg/L	3	111	104	115	6

[1]Equal to lower detection limit

When compared to historical water quality data for Dion Lake, it appears that concentrations of most water quality constituents have decreased. For example, the historical average bicarbonate and sodium concentrations were 277 mg/L and 9 mg/L, respectively (Table 2), compared to average concentrations of 269 mg/L for bicarbonate and 8 mg/L for sodium recorded for the period 2005-2006 (Table 1). Additionally, average total nitrogen concentrations and total phosphorus concentrations have also decreased when compared to the historical data. The historical average for total nitrogen and total phosphorus concentrations were 2.373 mg/L and 0.038 mg/L (Table 2) respectively, compared to current average concentrations of 1.537 mg/L for total nitrogen and 0.030 mg/L for total phosphorus.

Table 2. Statistical Summary of Dion Lake's Historical Water Quality Data Collected Between 1995 and 1996.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	243	217	285	37
Total Ammonia as N	mg/L	3	0.283	0.014	0.818	0.464
Bicarbonate (HCO_3)	mg/L	3	277	228	348	63
Calcium (Ca)	mg/L	3	45	37	58	11
Carbonate (CO_3)	mg/L	3	10	1[1]	18	9
Chloride (Cl)	mg/L	3	4.9	4.2	6.2	1.2
Chlorophyll-a	µg/L	2	12.0	8.0	16.0	5.7
Specific Conductance	µmhos	3	776	704	888	98
Total Dissolved Solids	mg/L	3	475	418	584	94
Total Hardness as ($CaCO_3$)	mg/L	3	391	330	494	90
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	3	0.029	0.014	0.049	0.018
Magnesium (Mg)	mg/L	3	67.8	57.4	85.0	15.0
Nitrate + Nitrite as N	mg/L	3	0.010	0.005	0.020	0.009
Total Kjeldahl Nitrogen as N	mg/L	3	2.363	1.890	3.000	0.573
Total Nitrogen as N	mg/L	3	2.373	1.895	3.020	0.581
pH		3	8.39	7.95	8.74	0.40
Total Phosphorus as P	mg/L	3	0.038	0.032	0.048	0.009
Potassium (K)	mg/L	3	18.2	15.4	23.4	4.5
Sodium (Na)	mg/L	3	9	7	12	2
Sulfate (SO4)	mg/L	3	183	159	226	37

[1]Equal to lower detection limit

When compared to the Cultivated Plains regional average fro natural and enhanced lakes, it appears Dion Lake has lower TDS, bicarbonate, and total phosphorus concentrations. The regional average concentrations for TDS, total nitrogen and total phosphorus are 1376 mg/L, 363 mg/L, and 0.068 mg/L, respectively (Table 3), compared to Dion Lake's average TDS, bicarbonate, and total phosphorus concentrations of 365 mg/L, 269 mg/L and 0.030 mg/L, respectively, for the period 2005-2006 (Table 1).

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Dion Lake and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight, in algae is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There are six water quality sample sets for Dion Lake collected between June 1995 and January 2006, where the N:P ratio could be calculated. The results from this analysis indicate that Dion Lake is phosphorus limited (Figure 5).

N:P ratios for Dion Lake ranged from a low of 47 to a high of 80 with an average of 60. All six of the samples collected were above a ratio of 15 indicating phosphorus limitation.

Table 3. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lakes in the Cultivated Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	142	346	175	1120	180
Total Ammonia as N	mg/L	230	0.098	0.001[1]	1.620	0.208
Bicarbonate (HCO_3)	mg/L	142	363	171	1040	158
Calcium (Ca)	mg/L	142	45	16	108	23
Carbonate (CO_3)	mg/L	136	31	1[1]	181	39
Chloride (Cl)	mg/L	142	105	3[1]	1260	233
Chlorophyll-a	µg/L	185	10	2[1]	167	17
Specific Conductance	µmhos	161	1819	361	11500	2071
Total Dissolved Solids	mg/L	143	1376	191	9880	1786
Total Hardness as ($CaCO_3$)	mg/L	142	507	173	1820	284
Hydroxide (OH)	mg/L	111	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	138	0.095[1]	0.007	1.010	0.123
Magnesium (Mg)	mg/L	142	95.7	28.4	413.0	68.0
Nitrate + Nitrite as N	mg/L	175	0.047	0.001	0.540	0.078
Total Kjeldahl Nitrogen as N	mg/L	128	1.504	0.080	4.110	0.609
Total Nitrogen as N	mg/L	103	1.440	0.609	2.740	0.466
pH		142	8.55	7.75	9.33	0.36
Total Phosphorus as P	mg/L	230	0.068	0.004[1]	1.460	0.118
Potassium (K)	mg/L	142	30	8	179	37
Sodium (Na)	mg/L	142	255	5	2570	498
Sulfate (SO4)	mg/L	142	591	7	3880	807

[1]Equal to lower detection limit
[2]Data Collected from 49 Natural Lakes between 1991 and 2007

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005-2006, Dion Lake's current trophic status is mesotrophic bordering on eutrophic. TSI scores ranged from a low of 40 based on chlorophyll-a, to a high of 57 based on total phosphorus. The trophic status score based on Secchi disk transparency was similar to that based on total phosphorus, at 51 (Figure 6).

A total of six total phosphorus samples, four chlorophyll-a samples, and five Secchi disk transparency measurements collected in 1995-2006 were used to evaluate trends in the trophic status of Dion Lake. Based on a visual assessment of the data Dion Lake's trophic status is stable or improving (Figure 6).

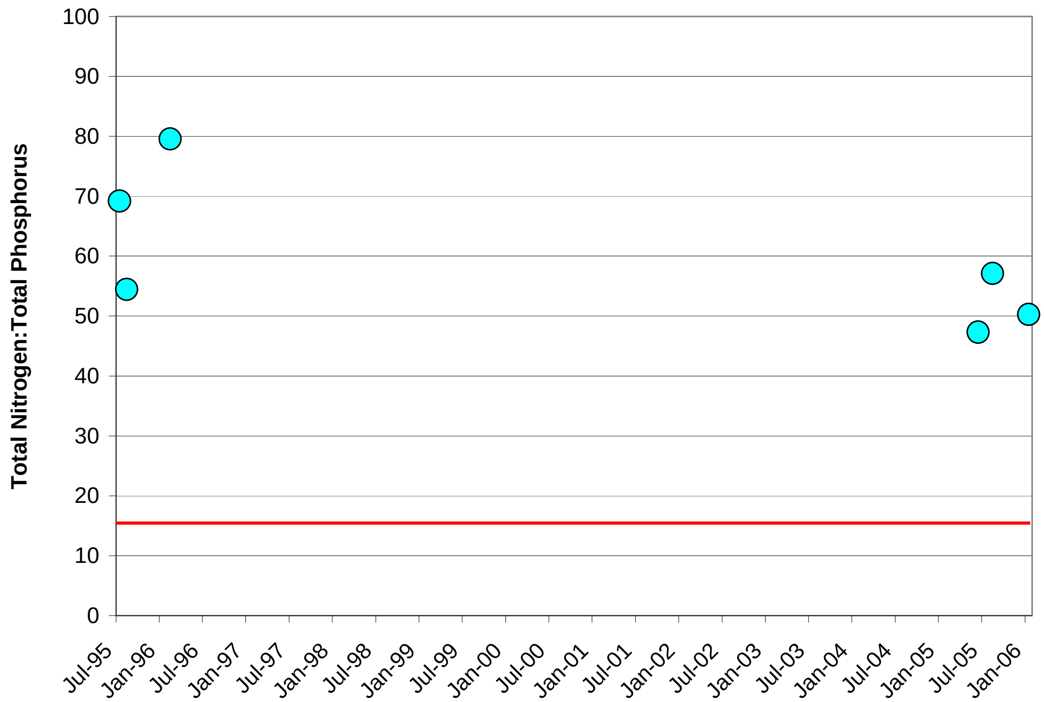


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Dion Lake (1995-2006).

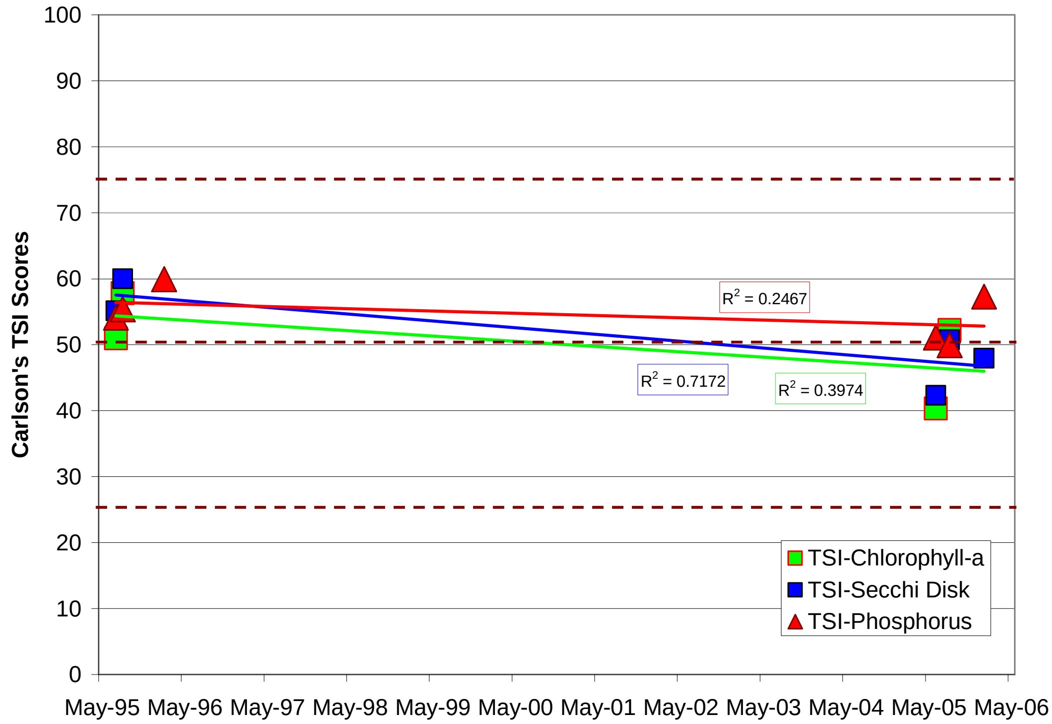


Figure 6. TSI Scores and Temporal Trends for Dion Lake from 1995 to 2006.

Lake Upsilon, Rolette County

BACKGROUND

Location: Lake Upsilon is a natural lake located on the eastern slope of the Turtle Mountains, 6 miles west, and 1 mile north of St. John, North Dakota. Lake Upsilon is managed by the North Dakota Game and Fish Department (Figure 1).

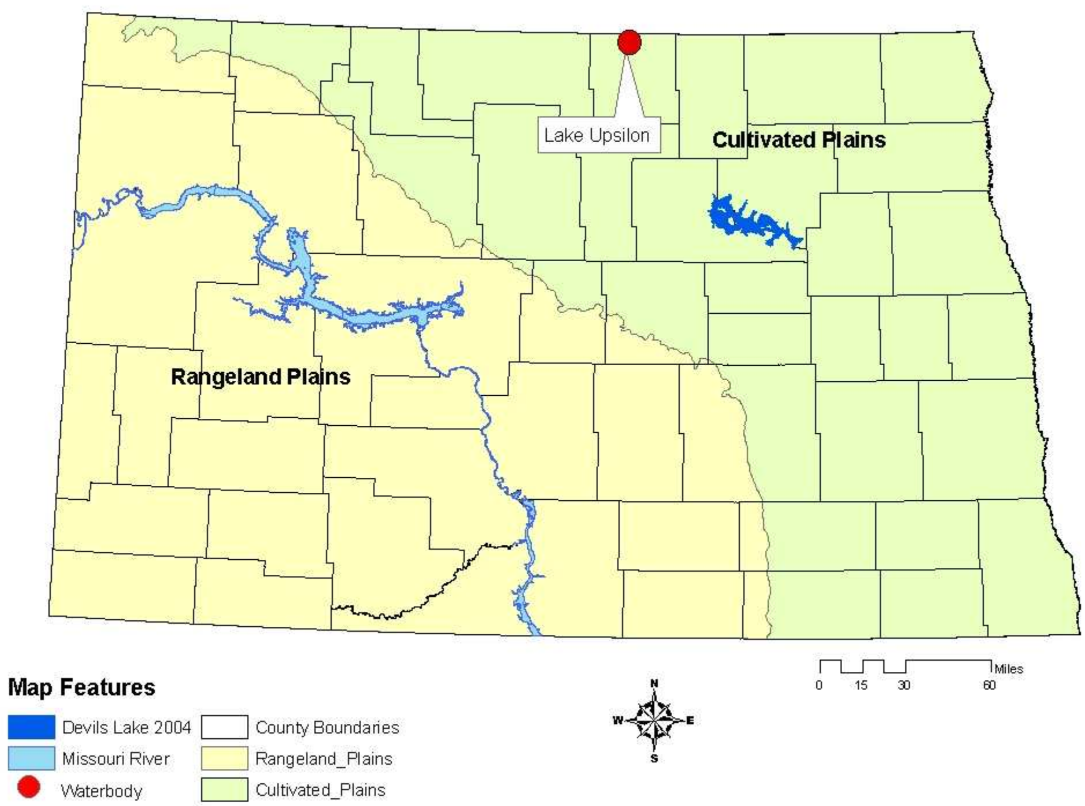


Figure 1. Location of Lake Upsilon.

Physiographic/Ecological Setting: Lake Upsilon has a surface area of 422.3 acres, a maximum depth of 27.1 ft, and an average depth of 11.3 ft (Figure 2). Lake Upsilon's watershed is 2,100 acres and lies within the Northern Glaciated Plains Level III Ecoregion, part of the broader Cultivated Plains region (Figure 1). This region is the transitional zone between tall and mixed grass prairie. The region has numerous wetlands essential for spring and fall migrations of wetland dependent birds. Flood plain slopes and hillsides are usually native grass while the uplands and flood plains proper have mostly been converted to small grains, row crops and alfalfa

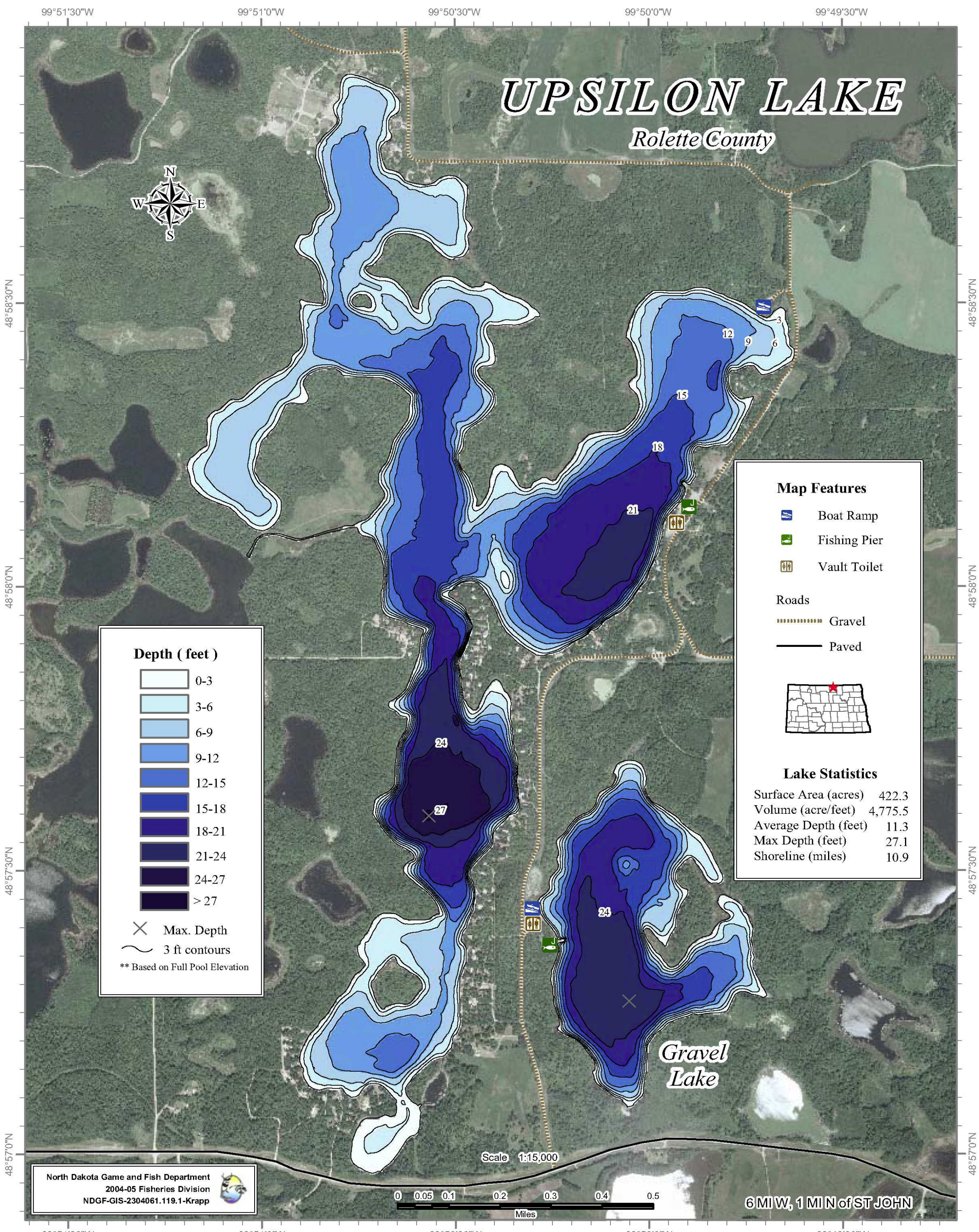


Figure 2. Contour Map of Lake Upsilon (Map Courtesy of North Dakota Game and Fish Department).

Recreational Facilities: Recreational facilities at Lake Upsilon include a boat ramp, boat and vehicle parking, and a fishing pier. Public access on the northeast shore includes a boat ramp, parking, vault toilet, and fishing pier.

Water Quality Standards Classification: Lake Upsilon is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 2 lake. Class 2 lakes are defined as a "cool water fishery" or "waters capable of supporting natural reproduction and growth of cool water fishes (e.g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: Lake Upsilon's fishery over time has included walleye, northern pike, and yellow perch stocked by the NDG&F. Currently, all three species are managed in Lake Upsilon.

Historical Water Quality Sampling: Historical water quality data includes results from 10 samples collected from 1995 through 1996.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Lake Upsilon have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural or enhanced lakes in the Cultivated Plains region.

Temperature and Dissolved Oxygen Profile Results: There were 6 temperature and dissolved oxygen profiles for Lake Upsilon collected from 1995-2006. Temperature and oxygen profiles are presented for two time periods, 1995-1996 and 2005-2006 (Figures 3 and 4). The temperature and dissolved oxygen profiles show that under ice cover conditions and during thermal stratification, Lake Upsilon experiences rapid oxygen decay, frequently dropping below the state's water quality standard of 5 mg/L. Five of the profiles, collected on 7/19/1995, 8/24/1995, 6/20/2005, 8/16/2005, and 1/31/2006, dropped below the state standard of 5 mg/L below the metalimnion and one collected on 2/21/1996 began and ended below state standard of 5 mg/L.

During the ice-free period, even though the lake experiences variable dissolved oxygen concentrations through the water column, there does appear to be enough dissolved oxygen to maintain aquatic life. However the profile collected on 2/21/1996 indicates the lake is at serious risk of winter kills.

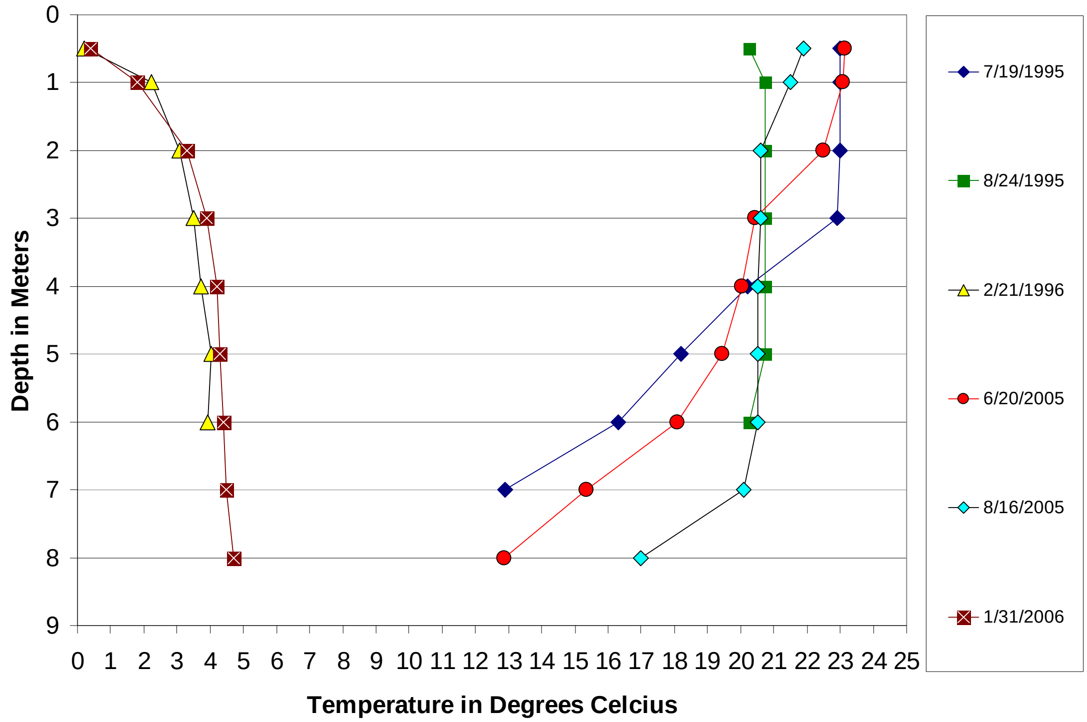


Figure 3. Temperature Profiles for Lake Upsilon from 1995 to 2006.

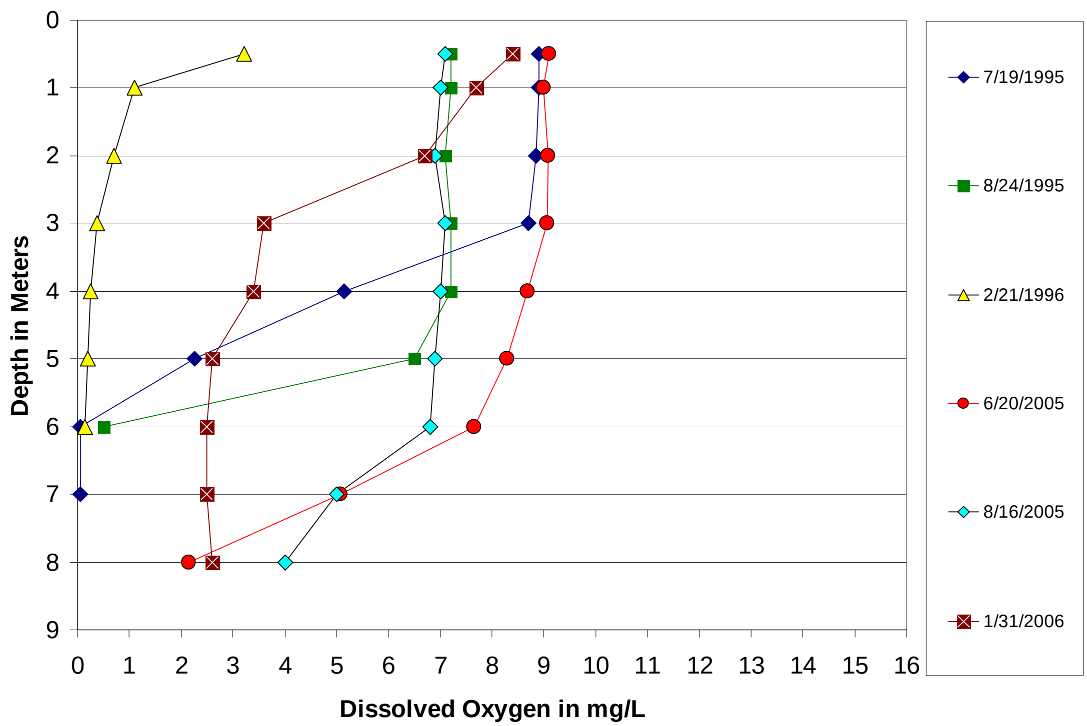


Figure 4. Dissolved Oxygen Profiles for Lake Upsilon from 1995 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006 indicate Lake Upsilon is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 241 to 278 mg/L (Table 1). Based on the 2005-2006 water quality data (Table 1), Lake Upsilon is sodium bicarbonate dominated with an average sodium concentration of 9 mg/L and an average bicarbonate concentration of 297 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 283 mg/L and 525 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.177 mg/L and 0.022 mg/L, respectively.

Table 1. Statistical Summary of Lake Upsilon's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	254	241	278	21
Total Ammonia as N	mg/L	3	0.105	0.010[1]	0.268	0.142
Bicarbonate (HCO_3)	mg/L	3	297	268	340	38
Calcium (Ca)	mg/L	3	29.8	27.5	34.4	4.0
Carbonate (CO_3)	mg/L	3	7	1[1]	13	6
Chloride (Cl)	mg/L	3	5	4	5	1
Chlorophyll-a	µg/L	2	2.5	1.5	3.5	1.4
Specific Conductance	µmhos	3	525	496	581	49
Total Dissolved Solids	mg/L	3	283	266	311	24
Total Hardness as ($CaCO_3$)	mg/L	3	270	250	293	22
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	3	0.043	0.039	0.046	0.004
Magnesium (Mg)	mg/L	3	47.6	44.0	50.4	3.3
Nitrate + Nitrite as N	mg/L	3	0.027	0.020	0.040	0.012
Total Kjeldahl Nitrogen as N	mg/L	3	1.150	1.000	1.320	0.161
Total Nitrogen as N	mg/L	3	1.177	1.020	1.360	0.172
pH		3	8.37	8.09	8.59	0.25
Total Phosphorus as P	mg/L	3	0.022	0.018	0.026	0.004
Potassium (K)	mg/L	3	10.2	8.5	11.2	1.5
Sodium (Na)	mg/L	3	9	9	9	0
Sulfate (SO4)	mg/L	3	28	27	31	2

[1]Equal to lower detection limit

When compared to historical water quality data for Lake Upsilon, most water quality constituents have decreased. For example, the historical average bicarbonate and sodium concentrations were 341 mg/L and 9.5 mg/L, respectively (Table 2), compared to average concentrations of 297 mg/L for bicarbonate and 9 mg/L for sodium recorded for the period 2005-2006 (Table 1).

Additionally, the average total nitrogen and phosphorus concentrations have decreased when compared to the historical data. Historical average total nitrogen and total phosphorus concentrations were 1.676 mg/L and 0.026 mg/L, respectively (Table 2), compared to current average concentrations of 1.177 mg/L and 0.047 mg/L for total nitrogen and total phosphorus, respectively.

Table 2. Statistical Summary of Lake Upsilon's Historical Water Quality Data Collected Between 1995 and 1996.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	296	268	342	40
Total Ammonia as N	mg/L	10	0.020	0.010[1]	0.043	0.015
Bicarbonate (HCO_3)	mg/L	3	341	293	417	66
Calcium (Ca)	mg/L	3	34	33	35	1
Carbonate (CO_3)	mg/L	3	10	1[1]	17	8
Chloride (Cl)	mg/L	3	4.8	3.6	5.6	1.0
Chlorophyll-a	µg/L	9	3.2	3.0[1]	5.0	0.7
Specific Conductance	µmhos	3	612	555	700	77
Total Dissolved Solids	mg/L	3	341	314	381	35
Total Hardness as ($CaCO_3$)	mg/L	3	332	315	343	15
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	3	0.019	0.009	0.028	0.010
Magnesium (Mg)	mg/L	3	59.7	56.7	61.8	2.7
Nitrate + Nitrite as N	mg/L	10	0.016	0.005	0.020	0.006
Total Kjeldahl Nitrogen as N	mg/L	10	1.656	1.232	2.530	0.381
Total Nitrogen as N	mg/L	10	1.676	1.240	2.580	0.379
pH		3	8.38	8.02	8.63	0.32
Total Phosphorus as P	mg/L	10	0.026	0.018	0.049	0.011
Potassium (K)	mg/L	3	12.4	12.0	13.0	0.6
Sodium (Na)	mg/L	3	10	9	10	0
Sulfate (SO4)	mg/L	3	41	37	49	7

[1]Equal to lower detection limit

When compared to the Cultivated Plains regional average for natural and enhanced lakes, Lake Upsilon has lower TDS, total nitrogen, and total phosphorus concentrations. The regional average TDS, total nitrogen and total phosphorus concentrations are 1376 mg/L, 1.440 mg/L, and 0.068 mg/L, respectively, compared to Lake Upsilon's average TDS, total nitrogen, and total phosphorus concentrations of 283 mg/L, 1.177 mg/L and 0.022 mg/L, respectively, for the period 2005-2006.

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Lake Upsilon and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight, in algae is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There are 13 water quality sample sets for Lake Upsilon between June 1995 and January 2006, where the N:P ratio could be calculated. The results from this analysis indicate that Lake Upsilon is phosphorus limited (Figure 5). The N:P ratios for Lake Upsilon ranged from a low of 44 to a high of 96 with an average of 66. All of the 13 samples collected were above a ratio of 15 indicating phosphorus limitation.

Table 3. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lakes in the Cultivated Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	142	346	175	1120	180
Total Ammonia as N	mg/L	230	0.098	0.001[1]	1.620	0.208
Bicarbonate (HCO_3)	mg/L	142	363	171	1040	158
Calcium (Ca)	mg/L	142	45	16	108	23
Carbonate (CO_3)	mg/L	136	31	1[1]	181	39
Chloride (Cl)	mg/L	142	105	3[1]	1260	233
Chlorophyll-a	µg/L	185	10	2[1]	167	17
Specific Conductance	µmhos	161	1819	361	11500	2071
Total Dissolved Solids	mg/L	143	1376	191	9880	1786
Total Hardness as ($CaCO_3$)	mg/L	142	507	173	1820	284
Hydroxide (OH)	mg/L	111	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	138	0.095[1]	0.007	1.010	0.123
Magnesium (Mg)	mg/L	142	95.7	28.4	413.0	68.0
Nitrate + Nitrite as N	mg/L	175	0.047	0.001	0.540	0.078
Total Kjeldahl Nitrogen as N	mg/L	128	1.504	0.080	4.110	0.609
Total Nitrogen as N	mg/L	103	1.440	0.609	2.740	0.466
pH		142	8.55	7.75	9.33	0.36
Total Phosphorus as P	mg/L	230	0.068	0.004[1]	1.460	0.118
Potassium (K)	mg/L	142	30	8	179	37
Sodium (Na)	mg/L	142	255	5	2570	498
Sulfate (SO4)	mg/L	142	591	7	3880	807

[1]Equal to lower detection limit
[2]Data Collected from 49 Natural Lakes between 1991 and 2007

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during the 2005-2006 sampling period, Lake Upsilon’s current trophic status is mesotrophic. TSI scores ranged from a low of 35 based on chlorophyll-a, to a high of 51 based on total phosphorus. The trophic status score based on Secchi disk transparency was similar to that based on total phosphorus, at 50 (Figure 6).

A total of 13 total phosphorus samples, 11 chlorophyll-a samples, and five Secchi disk transparency measurements collected in 1995-2006 were used to evaluate trends in the trophic status of Lake Upsilon. Based on a visual assessment of the data, Lake Upsilon’s trophic status is stable or improving (Figure 6).

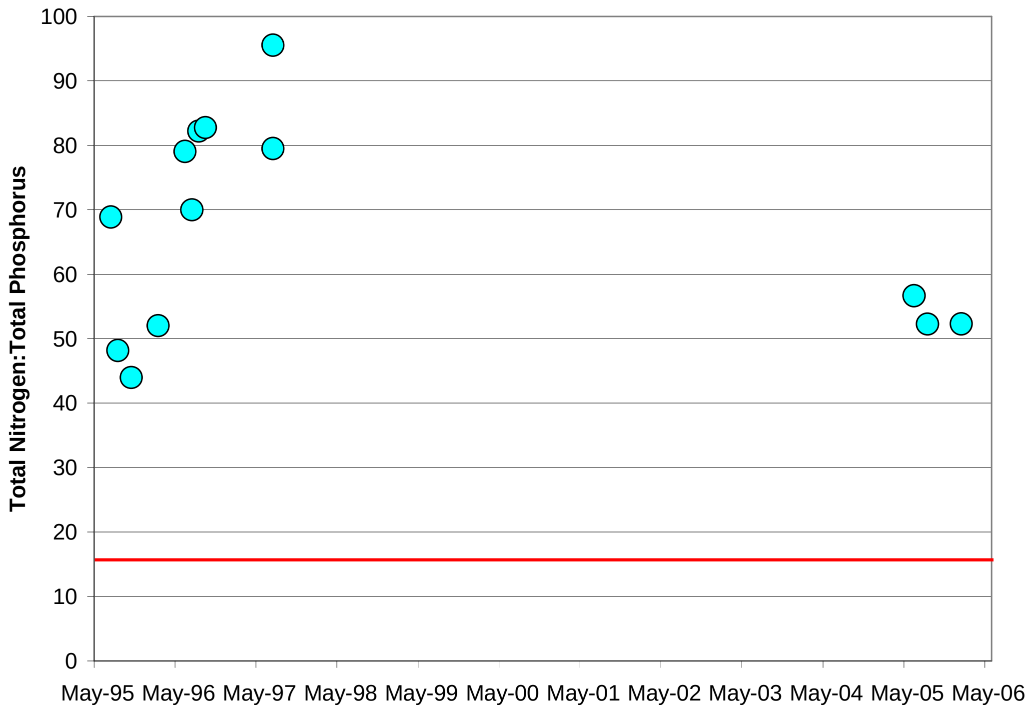


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Lake Upsilon (1995-2006).

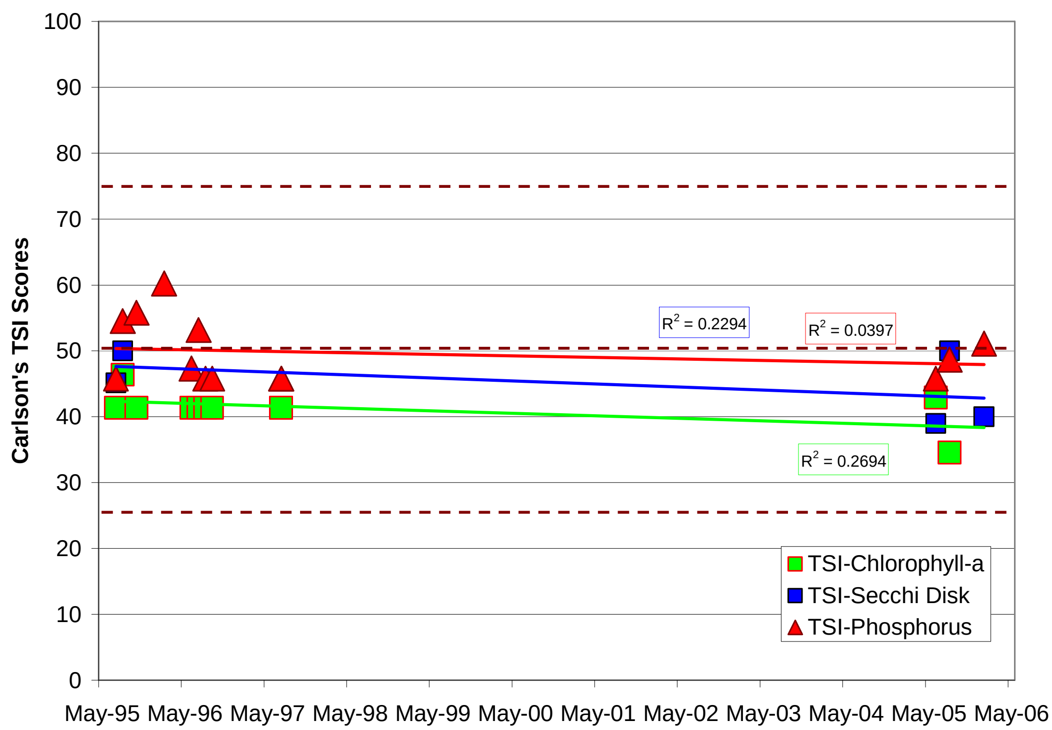


Figure 6. TSI Scores and Temporal Trends for Lake Upsilon from 1995 to 2006.

Heckers Lake, Sheridan County

BACKGROUND

Location: Heckers Lake is an enhanced, natural lake located 10 miles south, and 2 miles east of Mercer, ND, on the McClusky Canal. Heckers Lake is managed by the North Dakota Game and Fish Department (Figure 1).

Figure 1. Location of Heckers Lake.

Physiographic/Ecological Setting: Heckers Lake has a surface area of 229.6 acres, a maximum depth of 26.7 ft and an average depth 12.7 ft (Figure 2). Heckers Lake's watershed is approximately 6,100 acres and it lies within the Northwestern Glaciated Plains (NGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The NGP marks the western most extent of continental glacial advancement. The geologically youthful landscape has significant surface irregularities and high concentrations of wetlands. The rise in elevation along the eastern edge of this ecoregion defines the boundary of the Great Plains and to the west the Northwestern Great Plains (USEPA 1994).

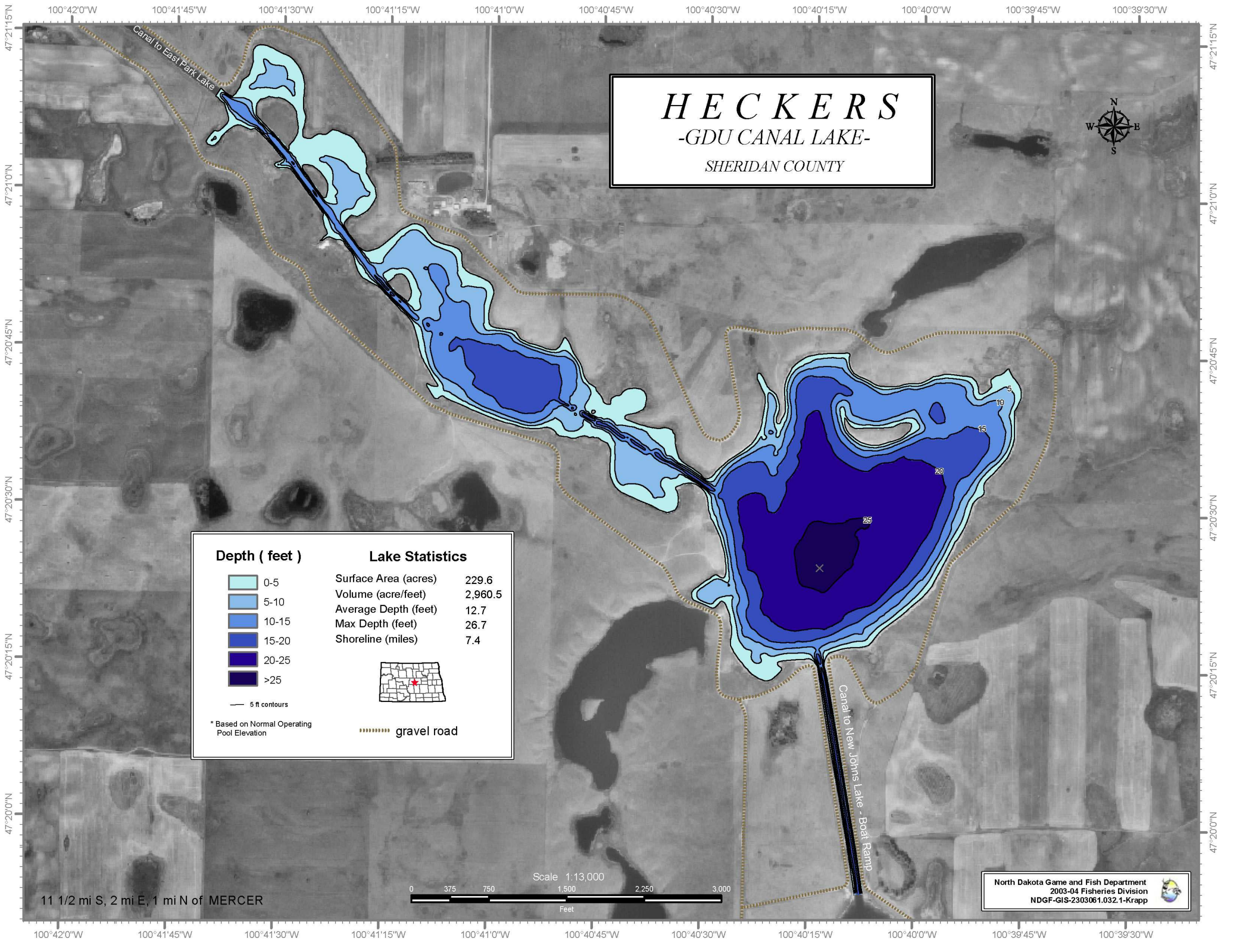


Figure 2. Contour Map of Heckers Lake (Map Courtesy of North Dakota Game and Fish Department).

Construction History: Heckers Lake is a manmade waterbody created by modifying a natural depression along the McClusky Canal. Construction on Heckers Lake was completed in 1974 and filled the following year from surface and ground water discharges. At the time of completion, Heckers Lake had a surface area of 159.7 acres, an average depth of 13.1 feet, and a maximum depth of 26.0 feet.

Recreational Facilities: Public access to Heckers Lake is usually good; however, access can be limited during the winter months. There is primitive camping available around the perimeter of Heckers Lake. Boat access into Heckers Lake is from New Johns Lake, through the McClusky Canal.

Water Quality Standards Classification: Heckers Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 2 lake or reservoir. Class 2 lakes or reservoirs are defined as a "cool water fishery" or "waters capable of supporting natural reproduction and growth of cool water fishes (e.g., northern pike and walleye) and associated aquatic biota. These waters are also capable of supporting the growth and marginal survival of cold water species and associated biota."

Historical and Current Fishery: Heckers Lake's has a very diverse fishery with the potential for nearly every cool water species present in the state being found in it's waters. An incomplete list of possible fish species are walleye, northern pike, muskellunge, tiger muskellunge, large mouth bass, crappie, yellow perch, and bluegill. Historically, fish stocked into Heckers Lake include northern pike, walleye, and largemouth bass. The additional species present in Heckers Lake migrated from New Johns Lake and other lakes within the channel system.

Historical Water Quality Sampling: Historical water quality data includes results from five samples collected from 1991 through 1994.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Heckers Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural or enhanced lakes in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There were nine temperature and dissolved oxygen profiles for Heckers Lake collected from 1991-2006. Temperature and oxygen profiles are presented for two time periods, 1991-1994 and 2005-2006 (Figures 3 and 4). The profile data shows that during thermal stratification Heckers Lake experiences moderate oxygen decay, rarely dropping below the state's water quality standard of 5 mg/L. Of the nine profiles, three samples, collected on 7/9/1993, 8/11/1993, and 2/17/1994, dropped below the state standard of 5 mg/L within 1 meter of the sediment water interface.

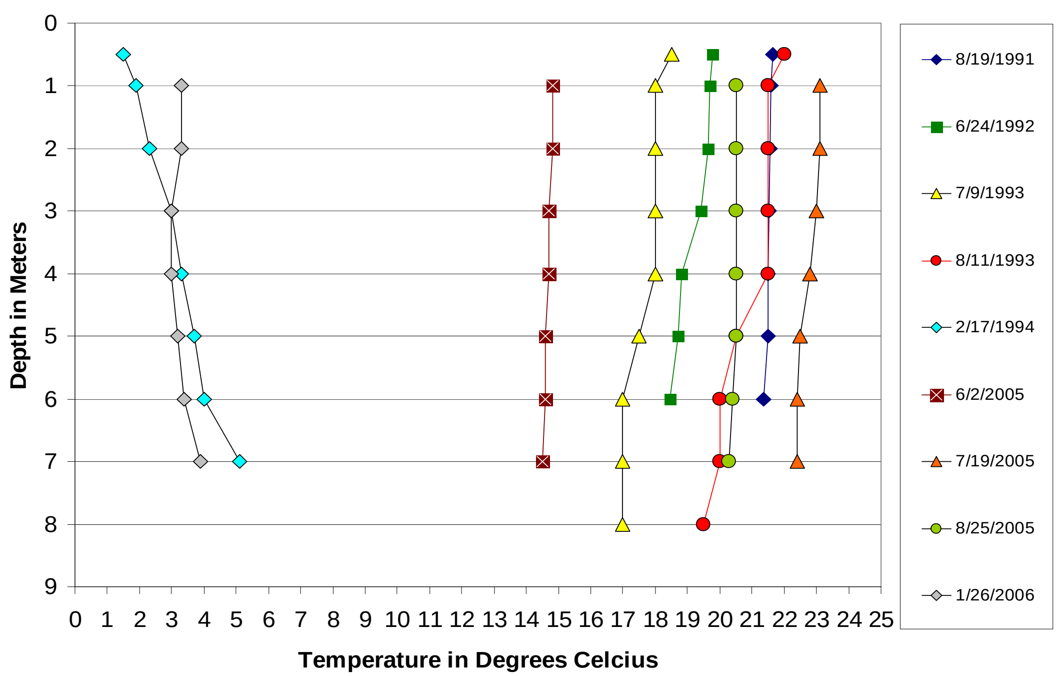


Figure 3. Temperature Profiles for Heckers Lake from 1991 to 2006.

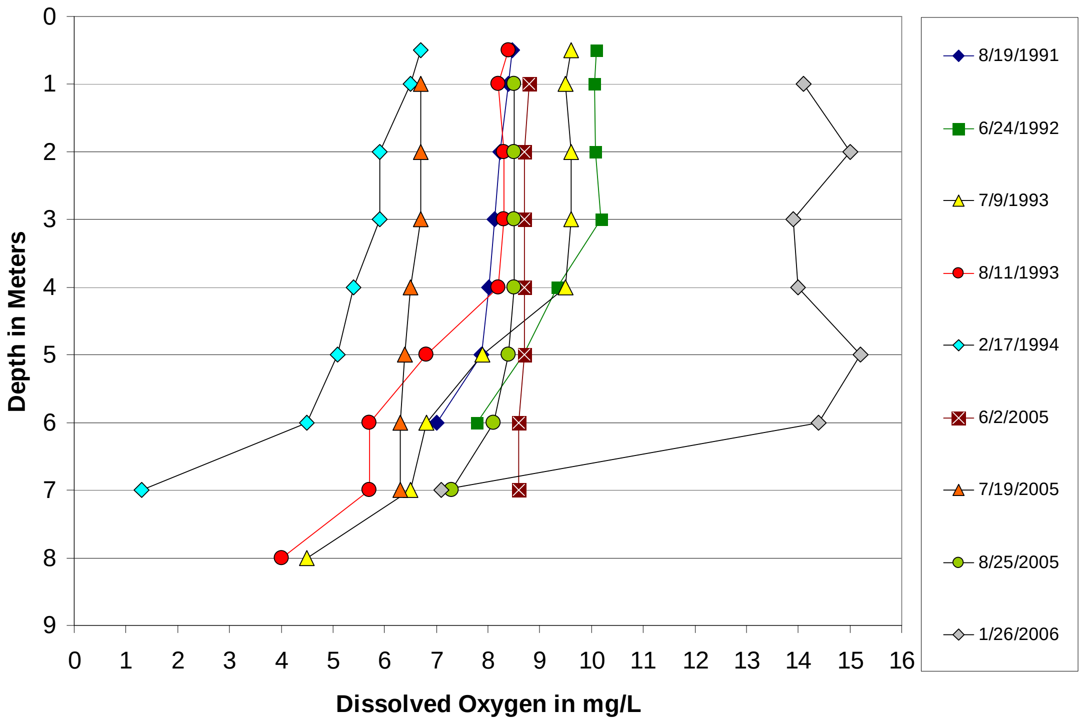


Figure 4. Dissolved Oxygen Profiles for Heckers Lake from 1991 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006 indicate Heckers Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 247 to 266 mg/L (Table 1). Based on the 2005-2006 water quality data (Table 1), Heckers Lake is sodium sulfate dominated with an average sodium concentration of 165 mg/L and an average sulfate concentration of 602 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 1113 mg/L and 1603 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 0.882 mg/L and 0.024 mg/L, respectively.

When compared to historical water quality data for Heckers Lake, it appears that concentrations of most water quality constituents have increased. For example, the historical average sulfate and sodium concentrations were 307 mg/L and 108 mg/L, respectively (Table 2), compared to average concentrations of 602 mg/L for sulfate and 165 mg/L for sodium recorded for the period 2005-2006 (Table 1).

Average total nitrogen and total phosphorus concentrations have decreased when compared to the historical data. Historical average total nitrogen and total phosphorus concentrations were 0.952 mg/L and 0.038 mg/L (Table 2) respectively, compared to current average concentrations of 0.882 mg/L for total nitrogen and 0.024 mg/L for total phosphorus.

Table 1. Statistical Summary of Heckers Lake's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	258	247	266	9
Total Ammonia as N	mg/L	4	0.068	0.017	0.130	0.047
Bicarbonate (HCO_3)	mg/L	4	295	283	325	20
Calcium (Ca)	mg/L	4	69.2	64.2	77.2	6.1
Carbonate (CO_3)	mg/L	4	10	1[1]	19	7
Chloride (Cl)	mg/L	4	19	18	21	1
Chlorophyll-a	µg/L	3	4.4	2.0	8.5	3.5
Specific Conductance	µmhos	4	1603	1520	1740	102
Total Dissolved Solids	mg/L	4	1113	1060	1190	64
Total Hardness as ($CaCO_3$)	mg/L	4	523	488	574	39
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.129	0.051	0.177	0.057
Magnesium (Mg)	mg/L	4	85.1	79.6	92.6	5.7
Nitrate + Nitrite as N	mg/L	4	0.080	0.020	0.180	0.077
Total Kjeldahl Nitrogen as N	mg/L	4	0.802	0.676	0.970	0.138
Total Nitrogen as N	mg/L	4	0.882	0.724	1.070	0.143
pH		4	8.29	7.59	8.60	0.47
Total Phosphorus as P	mg/L	4	0.024	0.015	0.031	0.007
Potassium (K)	mg/L	4	16.1	14.8	16.9	0.9
Sodium (Na)	mg/L	4	165	161	174	6
Sulfate (SO4)	mg/L	4	602	563	645	44

[1]Equal to lower detection limit

When compared to the Rangeland Plains regional averages, Heckers Lake has lower concentrations of TDS, total nitrogen, and total phosphorus. The Rangeland Plains regional averages for total dissolved solids, total nitrogen, and total phosphorus are 1588 mg/L, 1.826 mg/L, and 0.244 mg/L, respectively, compared to Heckers Lake's average TDS, total nitrogen, and total phosphorus concentrations of 1113 mg/L, 0.882 mg/L and 0.024 mg/L, respectively.

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Heckers Lake and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight, in algae is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were seven water quality sample results for Heckers Lake collected between July 1993 and January 2006 where the N:P ratio could be calculated. The results from this analysis indicate that Heckers Lake is phosphorus limited (Figure 5).

N:P ratios for Heckers Lake ranged from a low of 16 to a high of 48 with an average of 36. All of the seven samples collected on Heckers Lake were above an N:P ratio of 15, indicating phosphorus limitation.

Table 2. Statistical Summary of Heckers Lake's Historical Water Quality Data Collected Between 1991 and 1994.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	232	217	260	24
Total Ammonia as N	mg/L	3	0.149	0.045	0.230	0.095
Bicarbonate (HCO_3)	mg/L	3	264	237	317	46
Calcium (Ca)	mg/L	3	46	39	53	7
Carbonate (CO_3)	mg/L	3	10	1[1]	15	8
Chloride (Cl)	mg/L	3	16.4	15.3	18.2	1.6
Chlorophyll-a	µg/L	2	3.5	3.0[1]	4.0	0.7
Specific Conductance	µmhos	3	1031	903	1180	140
Total Dissolved Solids	mg/L	3	668	621	740	64
Total Hardness as ($CaCO_3$)	mg/L	3	291	262	320	29
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	3	0.048	0.038	0.058	0.010
Magnesium (Mg)	mg/L	3	43.0	40.1	45.6	2.8
Nitrate + Nitrite as N	mg/L	3	0.023	0.010[1]	0.049	0.023
Total Kjeldahl Nitrogen as N	mg/L	3	0.929	0.821	1.090	0.142
Total Nitrogen as N	mg/L	3	0.952	0.831	1.139	0.164
pH		3	8.39	8.08	8.57	0.27
Total Phosphorus as P	mg/L	3	0.038	0.028	0.055	0.015
Potassium (K)	mg/L	3	7.1	6.6	7.3	0.4
Sodium (Na)	mg/L	3	108	97	118	10
Sulfate (SO4)	mg/L	3	307	290	340	29

[1]Equal to lower detection limit

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005-2006, Heckers Lake's current trophic status is mesotrophic bordering on eutrophic. TSI scores ranged from a low of 37 based on chlorophyll-a, to a high of 56 based on Secchi disk transparency. The trophic status score based on total phosphorus was similar to that estimated based on Secchi disk transparency, at 54 (Figure 6).

A total of seven total phosphorus samples, five chlorophyll-a samples, and five Secchi disk transparency measurements collected during 1993-2006 were used to evaluate trends in the trophic status of Heckers Lake. Based on a visual assessment of the data, Heckers Lake's trophic status is stable (Figure 6).

Table 3. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lakes in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	272	544	119	4770	130
Total Ammonia as N	mg/L	371	0.107	0.001[1]	2.230	0.200
Bicarbonate (HCO_3)	mg/L	272	489	145	2990	150
Calcium (Ca)	mg/L	272	44	1[1]	282	26
Carbonate (CO_3)	mg/L	262	89	1[1]	1420	30
Chloride (Cl)	mg/L	272	51	4[1]	1070	9
Chlorophyll-a	µg/L	250	22	2[1]	292	28
Specific Conductance	µmhos	272	2168	448	20100	959
Total Dissolved Solids	mg/L	272	1588	227	18200	750
Total Hardness as ($CaCO_3$)	mg/L	272	538	170	2370	260
Hydroxide (OH)	mg/L	200	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	273	0.193	0.001[1]	2.260	0.334
Magnesium (Mg)	mg/L	272	104	20	567	50
Nitrate + Nitrite as N	mg/L	332	0.036	0.002[1]	0.338	0.092
Total Kjeldahl Nitrogen as N	mg/L	340	1.950	0.080	8.500	0.779
Total Nitrogen as N	mg/L	278	1.826	0.269	5.520	0.562
pH		272	8.796	7.400	9.870	0.564
Total Phosphorus as P	mg/L	377	0.244	0.004[1]	1.940	0.205
Potassium (K)	mg/L	272	38	3[1]	356	6
Sodium (Na)	mg/L	272	331	17	4680	171
Sulfate (SO4)	mg/L	272	680	34	10500	501

[1]Equal to Minimum Reporting Limit

[2]Data Collected from 48 Natural and Enhanced Lakes between 1991 and 2007

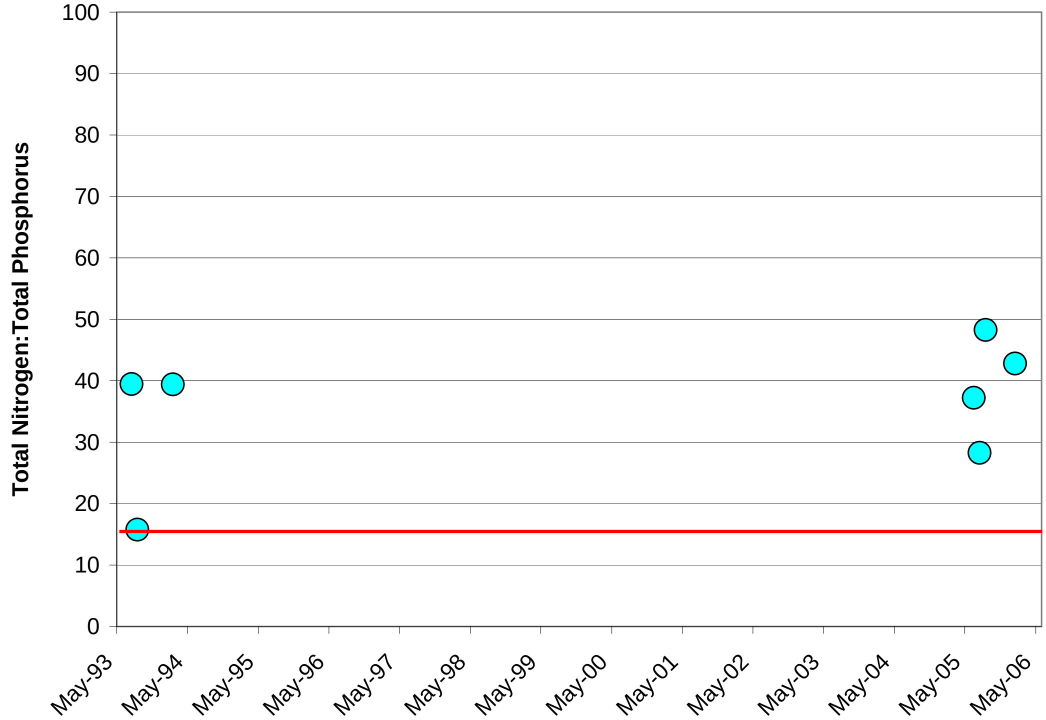


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Heckers Lake (1993-2006).

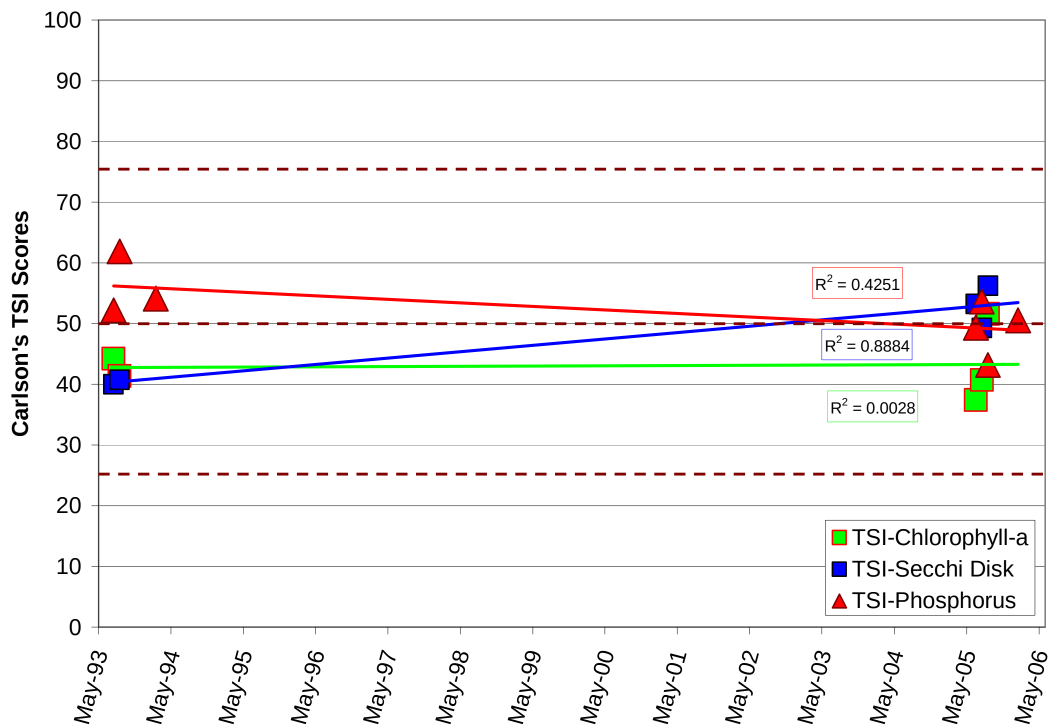


Figure 6. TSI Scores and Temporal Trends for Heckers Lake from 1993 to 2006.

Froelich Dam, Sioux County

BACKGROUND

Location: Froelich Dam is a small recreational impoundment on the Standing Rock Reservation located 9 miles north and 2 miles west of Selfridge, North Dakota (Figure 1). Froelich Dam is managed by the North Dakota Game and Fish Department.

Figure 1. Location of Froelich Dam.

Physiographic/Ecological Setting: Froelich Dam has a surface area of 166.4 acres, a maximum depth of 32.6 ft, and an average depth 10.9 ft (Figure 2). The reservoir's watershed is 4,160 acres and it is located within the Northwestern Great Plains (NWGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The Froelich Dam watershed landscape is rolling plains. Flood plain slopes and hillsides are usually native grasslands, while the uplands and flood plains themselves have mostly been converted to small grains and alfalfa.

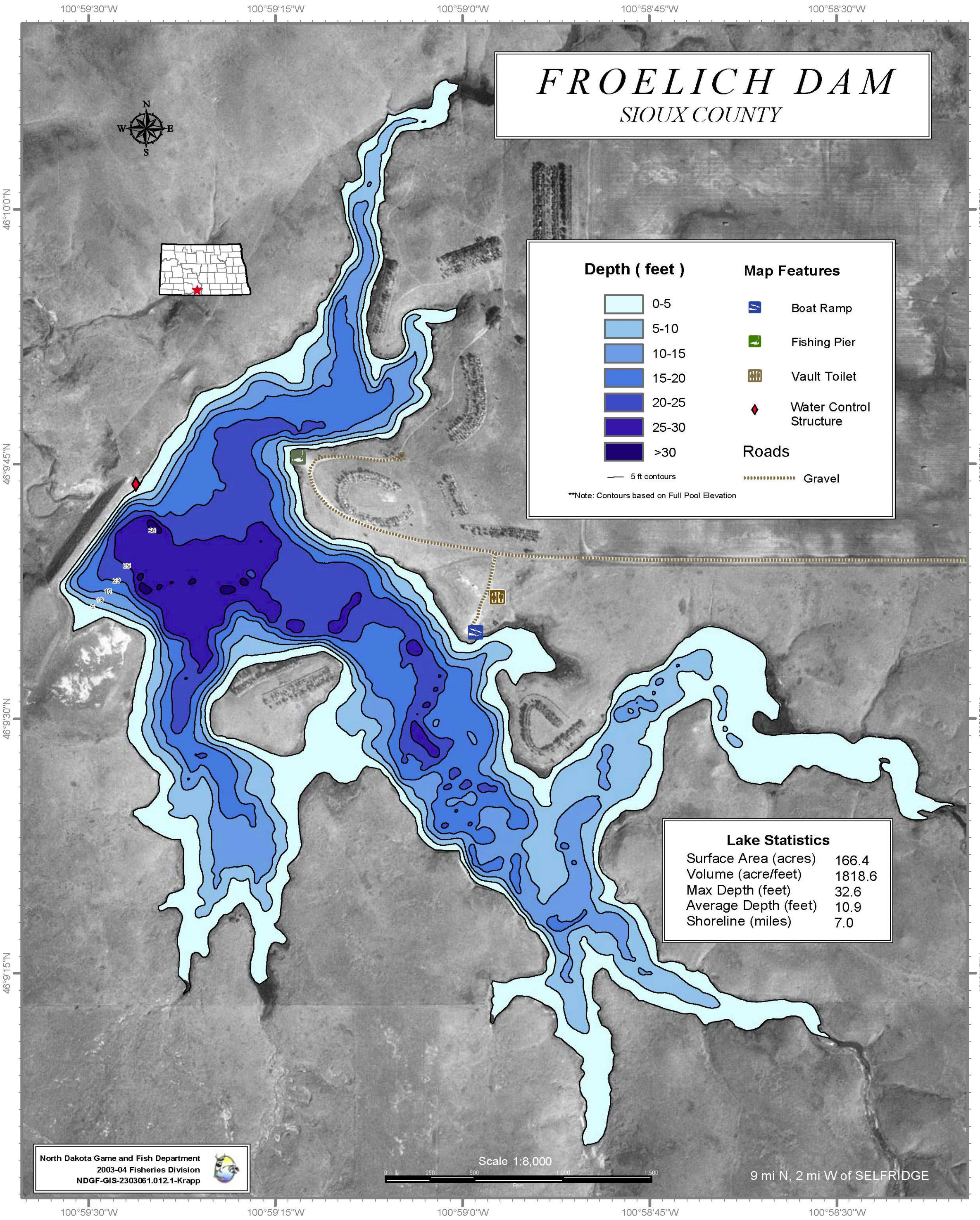


Figure 2. Contour Map of Froelich Dam (Map Courtesy of North Dakota Game and Fish Department).

Construction History: Froelich Dam is a small earthen structure located on an unnamed tributary to the Cannonball River. Froelich Dam was completed in 1962, but failed to fill until 1964.

Recreational Facilities: Recreational facilities at Froelich Dam include a cement boat ramp, boat and vehicle parking, and a fishing pier. Public access on the north side of the lake includes parking, restrooms, and the fishing pier.

Water Quality Standards Classification: Froelich Dam is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a "warm water fishery" or "waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present."

Historical and Current Fishery: Froelich Dam's historical and current fishery includes northern pike, yellow perch, and walleye.

Historical Water Quality Sampling: Historical water quality data includes results from three samples collected from 1992 through 1993.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Froelich Dam have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There were seven temperature and dissolved oxygen profiles for Froelich Dam collected intermittently between 1992 and 2007. Temperature and oxygen profiles are presented for two time periods, 1992-1993 and 2006-2007 (Figures 3 and 4). The profile data shows that during thermal stratification Froelich Dam experiences rapid oxygen decay and occasionally drops below the state's water quality standard of 5 mg/L. Of the seven profiles, five samples collected on 7/9/1992, 8/6/1992, 2/12/1993, 7/24/2006, and 2/13/2006 dropped below the state standard of 5 mg/L. While the rapid loss of dissolved oxygen during these periods is concerning, there does appear to be enough dissolved oxygen to maintain aquatic life in the upper 2 to 5 meters of the water column.

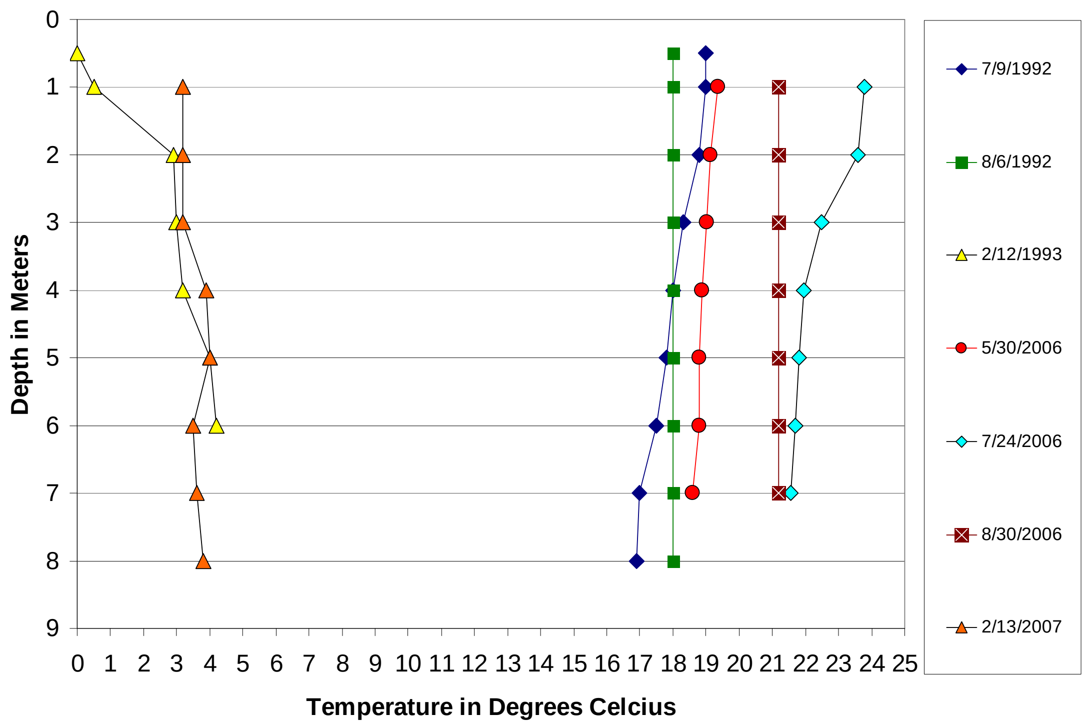


Figure 3. Temperature Profiles for Froelich Dam from 1992 to 2007.

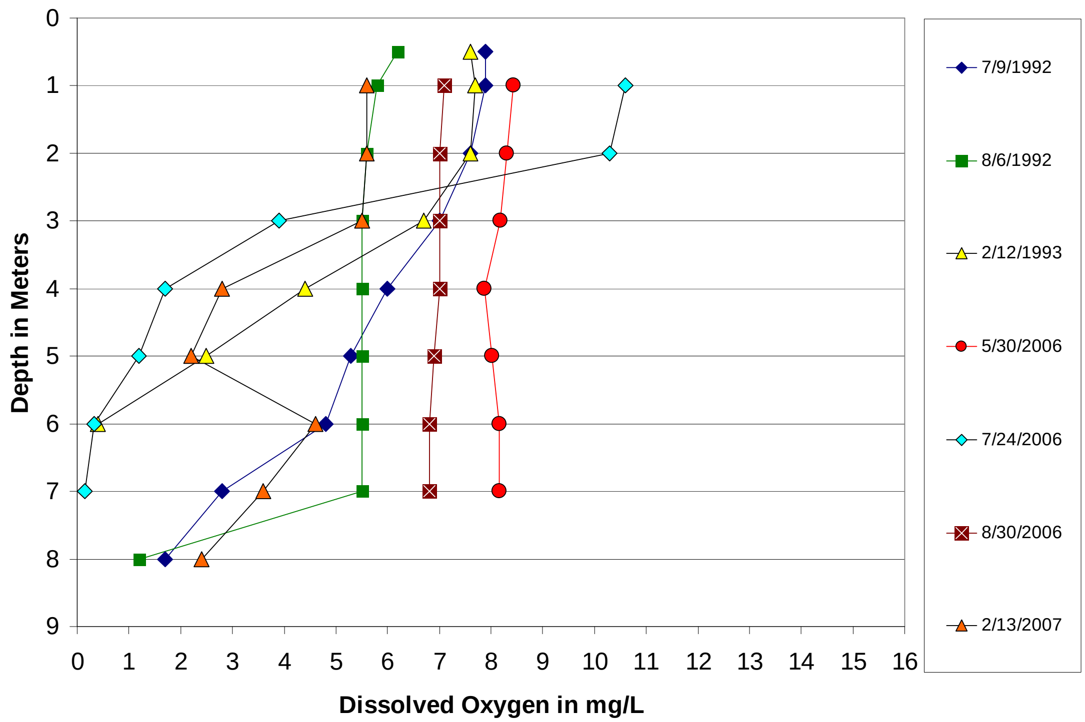


Figure 4. Dissolved Oxygen Profiles for Froelich Dam from 1992 to 2007.

General Water Quality: Data collected by the NDGF in 2006 and 2007 indicate Froelich Dam is well buffered with total alkalinity as $CaCO_3$ concentrations ranging from 328 to 431 mg/L (Table 1). Based on the 2006-2007 water quality data, Froelich Dam is sodium bicarbonate dominated with an average sodium concentration of 157 mg/L and an average bicarbonate concentration of 352 mg/L. The average total dissolved solids (TDS) concentration and specific conductance measurement for the 2006-2007 sampling period were 441 mg/L and 777µmhos/cm respectively. Average total nitrogen as N and total phosphorus as P concentrations were 2.795 mg/L and 0.265 mg/L respectively.

Table 1. Statistical Summary of Froelich Dam's 2006-2007 Water Quality Data.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	368	328	431	45
Total Ammonia as N	mg/L	4	0.187	0.010[1]	0.610	0.287
Bicarbonate (HCO_3)	mg/L	4	352	236	526	124
Calcium (Ca)	mg/L	4	11.2	8.5	13.5	2.5
Carbonate (CO_3)	mg/L	4	48	1[1]	90	39
Chloride (Cl)	mg/L	4	6	4	8	2
Chlorophyll-a	µg/L	4	47.1	9.9	118.0	50.8
Specific Conductance	µmhos	4	777	695	907	91
Total Dissolved Solids	mg/L	4	441	396	530	61
Total Hardness as ($CaCO_3$)	mg/L	4	53	45	62	8
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.294	0.102	0.710	0.282
Magnesium (Mg)	mg/L	4	6.1	5.6	6.8	0.5
Nitrate + Nitrite as N	mg/L	4	0.063	0.020[1]	0.190	0.085
Total Kjeldahl Nitrogen as N	mg/L	4	2.733	1.940	3.390	0.742
Total Nitrogen as N	mg/L	4	2.795	1.960	3.580	0.795
pH		4	9.04	8.20	9.64	0.64
Total Phosphorus as P	mg/L	4	0.265	0.135	0.473	0.145
Potassium (K)	mg/L	4	11.3	10.3	12.6	1.0
Sodium (Na)	mg/L	4	157	138	189	22
Sulfate (SO4)	mg/L	4	26	20	38	8

[1]Equal to lower detection limit

When compared to historical water quality data for Froelich Dam, it appears that concentrations of most water quality constituents have increased in the reservoir. For example, the historical average bicarbonate and sodium concentrations were 372 mg/L and 127 mg/L respectively, compared to the average 2006-2007 concentrations of 352 mg/L for bicarbonate and 157 mg/L for sodium (Table 2).

While not significant, average total nitrogen and total phosphorus concentrations have decreased when compared to the historical data. Historical average total nitrogen and total phosphorus concentrations were 3.294 mg/L and 0.398 mg/L (Table 2) respectively, compared to the 2006-2007 average concentrations of 2.795 mg/L for total nitrogen and 0.265 mg/L for total phosphorus.

Table 2. Statistical Summary of Froelich Dam's Historical Water Quality Data Collected Between 1992 and 1993.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	330	305	379	42
Total Ammonia as N	mg/L	3	0.230	0.123	0.349	0.113
Bicarbonate (HCO_3)	mg/L	3	372	324	463	79
Calcium (Ca)	mg/L	3	14	12	15	1
Carbonate (CO_3)	mg/L	2	24	23	24	1
Chloride (Cl)	mg/L	3	4.6	3.7	5.8	1.1
Chlorophyll-a	µg/L	2	6.5	3.0[1]	10.0	4.9
Specific Conductance	µmhos	3	642	593	739	84
Total Dissolved Solids	mg/L	3	382	349	430	43
Total Hardness as ($CaCO_3$)	mg/L	3	59	53	63	6
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	3	6.133	5.600	6.400	0.462
Magnesium (Mg)	mg/L	2	0.1	0.01[1]	0.1	0.0
Nitrate + Nitrite as N	mg/L	2	2.950	2.700	3.200	0.354
Total Kjeldahl Nitrogen as N	mg/L	3	3.213	2.700	3.740	0.520
Total Nitrogen as N	mg/L	3	3.294	2.738	3.875	0.569
pH		3	8.73	8.23	9.03	0.43
Total Phosphorus as P	mg/L	3	0.398	0.261	0.647	0.216
Potassium (K)	mg/L	3	10.5	9.9	11.0	0.6
Sodium (Na)	mg/L	3	127	117	135	9
Sulfate (SO4)	mg/L	3	21	16	30	8

[1]Equal to lower detection limit

When compared to the Rangeland Plains regional average, it appears Froelich Dam's water contains lower concentrations of general chemistry analytes and higher concentrations of nutrients (Table 3). For example, the Rangeland Plains regional average TDS, total nitrogen, and total phosphorus concentrations are 1176 mg/L, 1.472 mg/L, and 0.135 mg/L respectively, compared to Froelich Dam's 2005-2006 average TDS, total nitrogen, and total phosphorus concentrations of 441 mg/L, 2.795 mg/L, and 0.265 mg/L respectively.

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Froelich Dam and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight in algae, is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

Table 3. Statistical Summary of Water Quality Data[2] Collected from Reservoirs in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	408	309	101	982	130
Total Ammonia as N	mg/L	469	0.097	0.001[1]	2.440	0.200
Bicarbonate (HCO_3)	mg/L	408	318	14	1040	150
Calcium (Ca)	mg/L	408	50	5	160	26
Carbonate (CO_3)	mg/L	402	30	1[1]	197	30
Chloride (Cl)	mg/L	408	13.3	0.3	74.5	8.8
Chlorophyll-a	µg/L	321	21.2	1.5[1]	218.0	27.9
Specific Conductance	µmhos	428	1733	262	5880	959
Total Dissolved Solids	mg/L	409	1176	147	5110	750
Total Hardness as ($CaCO_3$)	mg/L	408	397	45	1850	260
Hydroxide (OH)	mg/L	337	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	409	0.179	0.007	4.110	0.334
Magnesium (Mg)	mg/L	408	66.0	5.6	353.0	49.6
Nitrate + Nitrite as N	mg/L	395	0.048	0.001[1]	0.790	0.092
Total Kjeldahl Nitrogen as N	mg/L	359	1.556	0.365	7.720	0.779
Total Nitrogen as N	mg/L	302	1.472	0.405	4.840	0.562
pH		428	8.61	6.73	9.87	0.56
Total Phosphorus as P	mg/L	475	0.135	0.004	3.160	0.205
Potassium (K)	mg/L	408	14.6	4.2	39.2	6.3
Sodium (Na)	mg/L	408	239	3[1]	932	171
Sulfate (SO4)	mg/L	406	604	1[1]	3210	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 69 Reservoirs between 1991 and 2007

There were seven water quality sample results for Froelich Dam collected between July 1992 and February 2007 where the N:P ratio could be calculated. The results from this analysis indicate that Froelich Dam is most often nitrogen limited (Figure 5).

N:P ratios for Froelich Dam ranged from a low of 6, to a high of 16, with an average of 11. Of the seven samples collected on Froelich Dam, all but one were below a N:P ratio of 15, indicating nitrogen is limiting primary production in Froelich Dam.

Trophic Status: Based on limited chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2006-2007, Froelich Dam's current trophic status is eutrophic to hypereutrophic. TSI scores ranged from a low of 48 based on Secchi disk transparency, to a high of 93 based on total phosphorus. The trophic status score based on chlorophyll-a, was in between that estimated based on total phosphorus and Secchi disk transparency at 69 (Figure 6).

A total of seven total phosphorus samples, six chlorophyll-a samples, and five Secchi disk transparency measurements collected from 1992 to 2007 were used to evaluate trends in the trophic status of Froelich Dam. Based on a visual assessment of the data , Froelich Dam's trophic status is stable or declining.

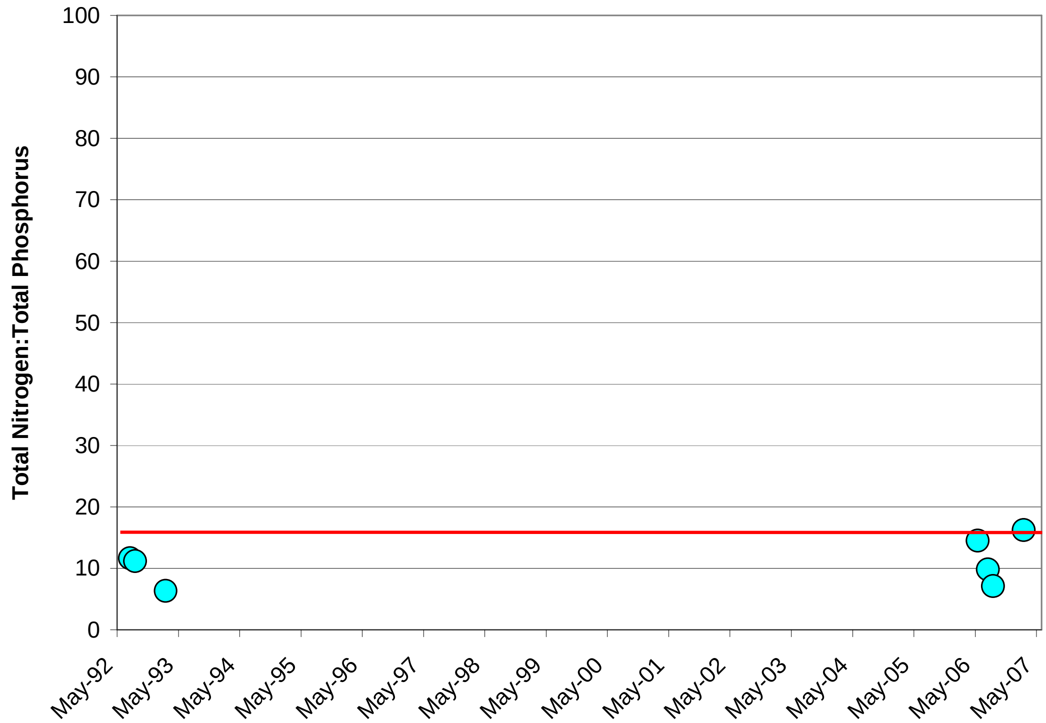


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Froelich Dam (1992-2007).

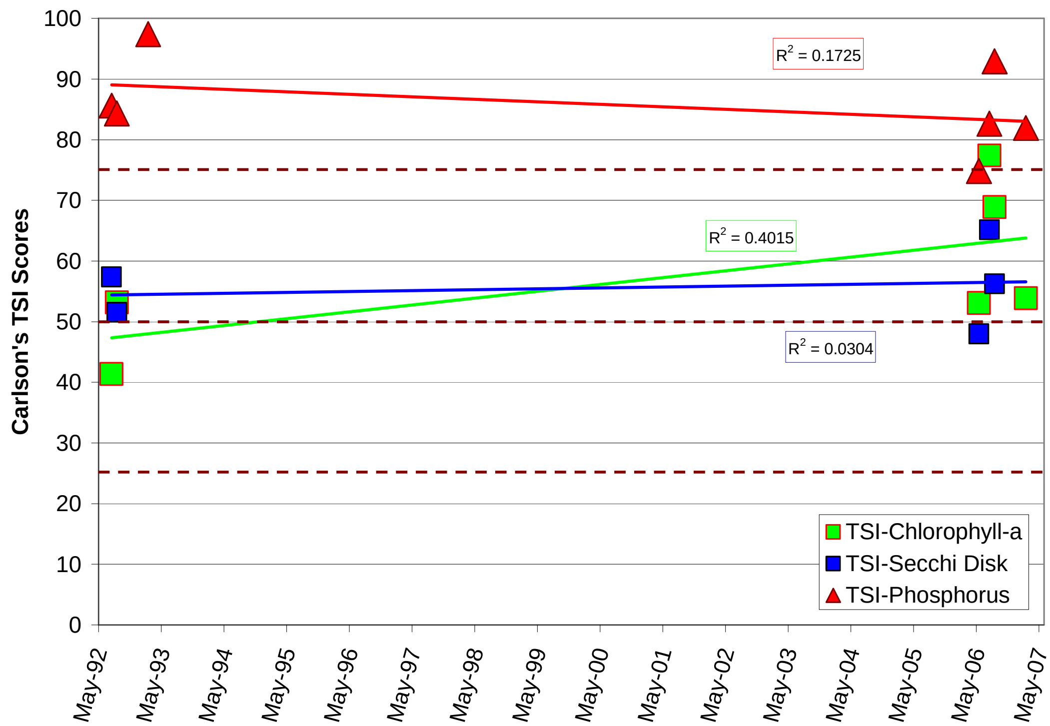


Figure 6. TSI Scores and Temporal Trends for Froelich Dam from 1992 to 2007.

Cedar Lake, Slope County

BACKGROUND

Location: Cedar Lake is a small recreational impoundment on Cedar Creek located 13 miles north and 2 miles west of Reeder, North Dakota (Figure 1). The reservoir is managed by the North Dakota Game and Fish Department.

Figure 1. Location of Cedar Lake.

Physiographic/Ecological Setting: Cedar Lake has a surface area of 219.4 acres, a maximum depth of 14.4 ft, and an average depth of 5.1 ft (Figure 2). The reservoir's watershed is located in the Northwestern Great Plains Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The Cedar Lake watershed landscape is rolling plains. Flood plain slopes and hillsides are usually native grasslands, while the uplands and flood plains themselves have mostly been converted to small grains and alfalfa.

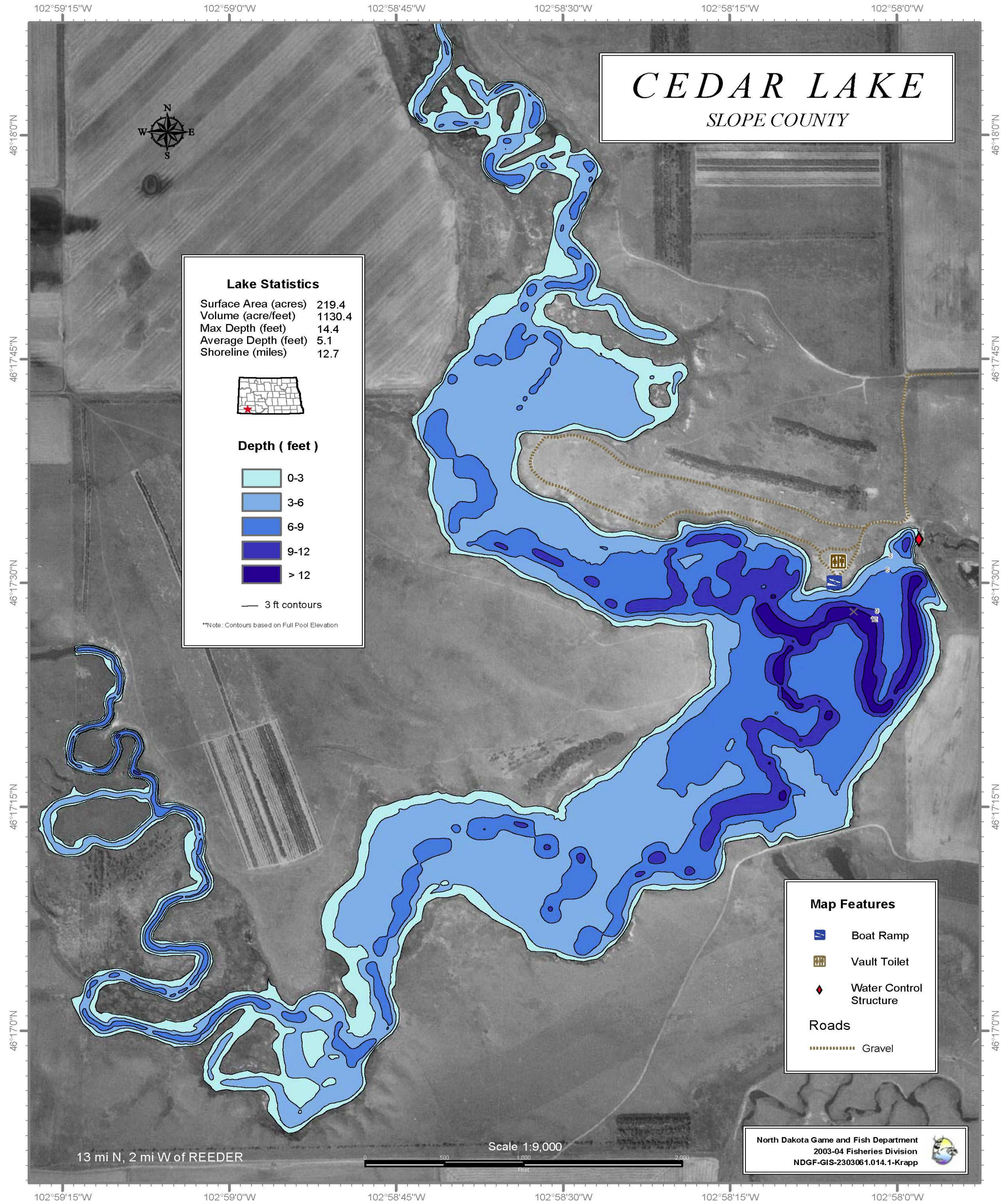


Figure 2. Contour Map of Cedar Lake (Map Courtesy of North Dakota Game and Fish Department).

Construction History: The dam at Cedar Lake was built in 1935 by the Civilian Conservation Corp for recreational purposes. When originally constructed, the reservoir had a surface area of 198.5 acres and a maximum depth of 18 feet

Recreational Facilities: Recreational facilities at Cedar Lake include a cement boat ramp, and boat and vehicle parking. Public access on the north side of the lake includes parking, a restroom, and the boat ramp.

Water Quality Standards Classification: Cedar Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a "warm water fishery" or "waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present."

Historical and Current Fishery: Cedar Lake's fishery currently and historically includes northern pike, yellow perch, and walleye.

Historical Water Quality Sampling: Historical water quality data includes results from eight samples collected from 1991 through 1997.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Cedar Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There are two temperature and dissolved oxygen profiles for Cedar Lake collected in the summer of 2005 and winter of 2006 (Figures 3 and 4). The profile data shows that Cedar Lake has an oxygen deficiency both during thermal stratification and under ice where rapid oxygen decay occurs. During these periods and depths dissolved oxygen is below the state's water quality standard of 5 mg/L. Of the two profiles, both samples collected on 7/20/2005 and 6/6/2006, either dropped below the state standard of 5 mg/L or were constantly below.

General Water Quality: Data collected by the NDGF in 2005 and 2006 indicate Cedar Lake is well buffered with total alkalinity as $CaCO_3$ concentrations ranging from 432 mg/L to 575 mg/L (Table 1). Based on the 2005-2006 water quality data, Cedar Lake is sodium sulfate dominated with an average sodium concentration of 611 mg/L and an average sulfate concentration of 1640 mg/L. The average total dissolved solids (TDS) concentration and specific conductance measurement for the 2005-2006 sampling period were 2830 mg/L and 3613 µmhos/cm respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.817 mg/L and 0.090 mg/L respectively.

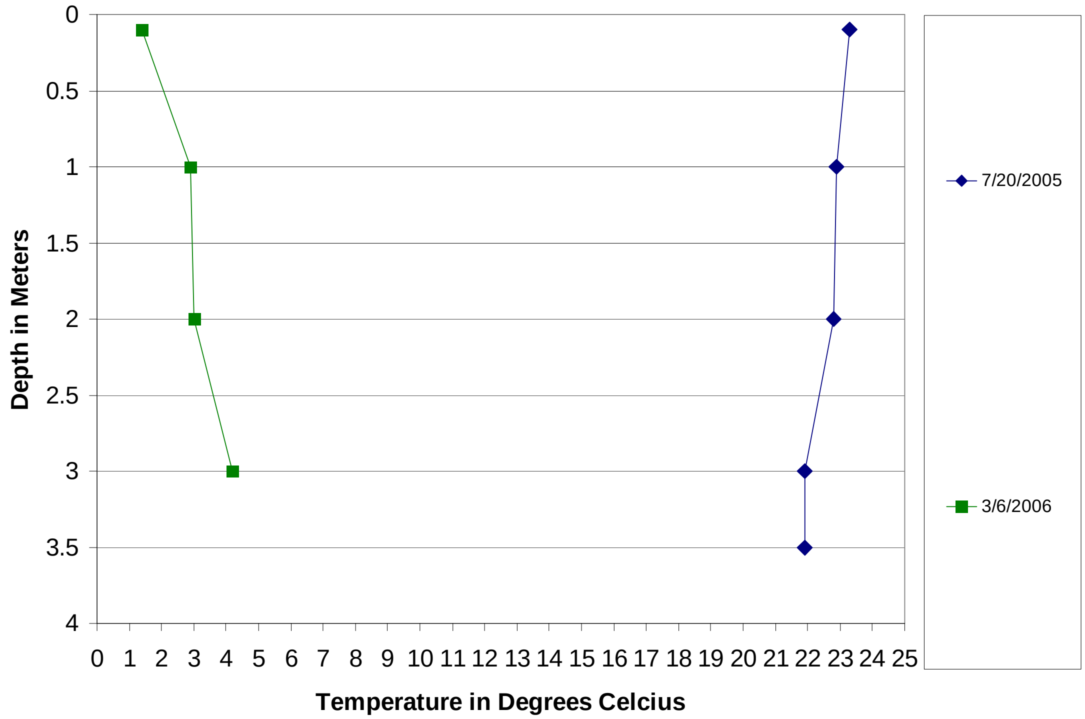


Figure 3. Temperature Profiles for Cedar Lake from 2005 to 2006.

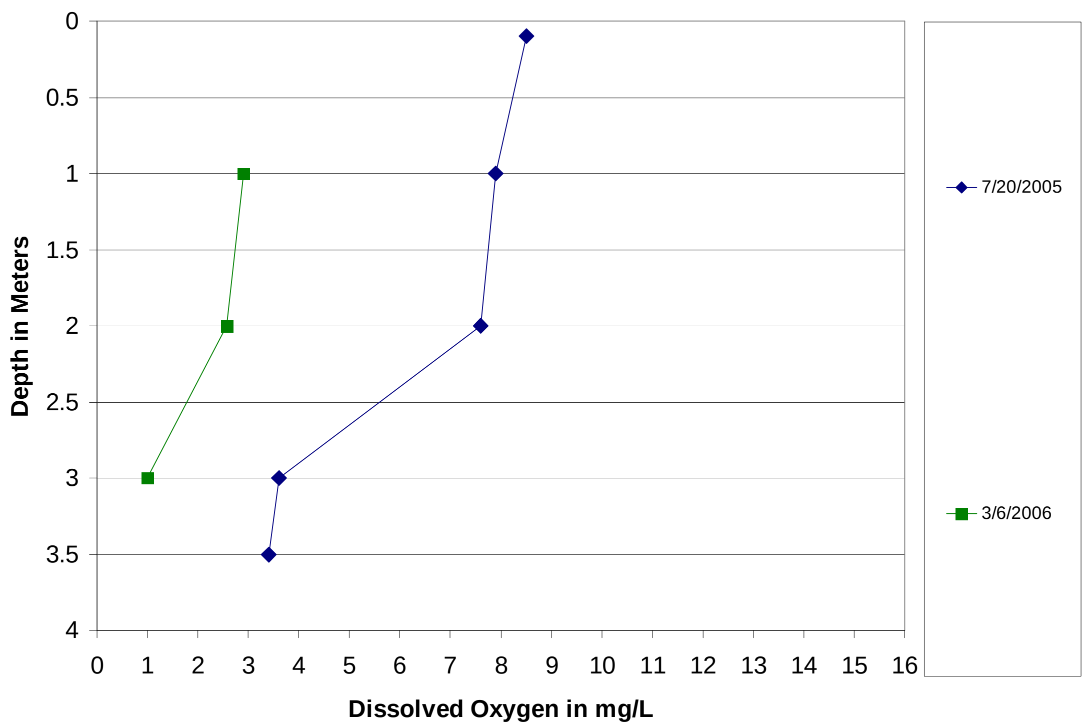


Figure 4. Dissolved Oxygen Profiles for Cedar Lake from 2005 to 2006.

Table 1. Statistical Summary of Cedar Lake's 2005-2006 Water Quality Data.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	480	432	575	82
Total Ammonia as N	mg/L	3	0.026	0.022	0.034	0.007
Bicarbonate (HCO_3)	mg/L	3	512	455	624	97
Calcium (Ca)	mg/L	3	121.3	113.0	135.0	11.9
Carbonate (CO_3)	mg/L	3	36	34	38	2
Chloride (Cl)	mg/L	3	17	14	22	4
Chlorophyll-a	µg/L	1	21.4	21.4	21.4	
Specific Conductance	µmhos	3	3613	3280	4280	577
Total Dissolved Solids	mg/L	3	2830	2530	3380	477
Total Hardness as ($CaCO_3$)	mg/L	3	845	768	979	116
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	3	0.657	0.482	0.753	0.152
Magnesium (Mg)	mg/L	3	131.7	118.0	156.0	21.1
Nitrate + Nitrite as N	mg/L	3	0.020	0.020	0.020	0.000
Total Kjeldahl Nitrogen as N	mg/L	3	1.797	1.540	2.310	0.445
Total Nitrogen as N	mg/L	3	1.817	1.560	2.330	0.445
pH		3	8.56	8.54	8.59	0.03
Total Phosphorus as P	mg/L	3	0.090	0.069	0.133	0.037
Potassium (K)	mg/L	3	20.1	19.4	21.0	0.8
Sodium (Na)	mg/L	3	611	545	726	100
Sulfate (SO4)	mg/L	3	1640	1460	1970	286

[1]Equal to lower detection limit

When compared to historical water quality data, it appears that concentrations of most water quality constituents have increased. For example, the historical average sulfate and sodium concentrations were 1450 mg/L and 559 mg/L, respectively (Table 2), compared to average concentrations of 1640 mg/L for sulfate and 611 mg/L for sodium recorded for the period 2005-2006 (Table 1).

While not outside the standard deviation average total nitrogen and total phosphorus concentrations have decreased when compared to the historical data. The historical average total nitrogen and total phosphorus concentrations were 3.105 mg/L and 0.174 mg/L respectively, compared to the 2005-2006 total nitrogen and total phosphorus averages are 1.817 mg/L and 0.090 mg/L respectively.

When compared to Rangeland Plains regional average concentrations, it appears Cedar Lake is harder and more eutrophic then most reservoirs in the Rangeland Plains region (Table 3). For example, the regional average TDS, total nitrogen, and sulfate concentrations are 1176 mg/L, 1.472 mg/L, and 604 mg/L respectively, compared to Cedar Lake's average TDS, total nitrogen, and sulfate concentrations of 2830 mg/L, 1.817 mg/L and 1640 mg/L respectively, for the period 2005-2006.

Table 2. Statistical Summary of Cedar Lake's Historical Water Quality Data Collected Between 1992 and 1997.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	2	495	492	497	4
Total Ammonia as N	mg/L	8	0.055	0.010[1]	0.149	0.053
Bicarbonate (HCO_3)	mg/L	2	555	503	607	74
Calcium (Ca)	mg/L	2	89	86	92	4
Carbonate (CO_3)	mg/L	1	48	48	48	
Chloride (Cl)	mg/L	2	22.9	22.7	23.1	0.3
Chlorophyll-a	µg/L	2	13.0	3.0[1]	23.0	14.1
Specific Conductance	µmhos	2	3560	3560	3560	0
Total Dissolved Solids	mg/L	2	2560	2550	2570	14
Total Hardness as ($CaCO_3$)	mg/L	2	722	702	741	28
Hydroxide (OH)	mg/L		NC[2]	NC[2]	NC[2]	
Iron (Fe)	mg/L	2	0.195	0.184	0.206	0.016
Magnesium (Mg)	mg/L	2	121.0	118.0	124.0	4.2
Nitrate + Nitrite as N	mg/L	8	0.027	0.020	0.045	0.009
Total Kjeldahl Nitrogen as N	mg/L	4	3.083	1.200	7.720	3.104
Total Nitrogen as N	mg/L	4	3.105	1.230	7.740	3.102
pH		2	8.45	8.20	8.70	0.35
Total Phosphorus as P	mg/L	8	0.174	0.018	0.586	0.197
Potassium (K)	mg/L	2	20.6	19.8	21.4	1.1
Sodium (Na)	mg/L	2	559	539	579	28
Sulfate (SO4)	mg/L	2	1450	1430	1470	28

[1]Equal to lower detection limit
[2]No data collected

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Cedar Lake and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight in algae, is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were eight water quality sample results for Cedar Lake collected between July 1991 and March 2006 where the N:P ratio could be calculated. The results from this analysis indicate that Cedar Lake was nitrogen limited in the early 1990's but in more recent times (1996 to 2006), the reservoir has been phosphorus limited (Figure 5).

N:P ratios for Cedar Lake ranged from a low of 3 to a high of 25 with an average of 15. Of the eight samples collected on Cedar Lake, half of the samples were below an N:P ratio of 15, indicating nitrogen limitation, and half were above an N:P ratio of 15, indicating phosphorus limitation.

Table 3. Statistical Summary of Water Quality Data[2] Collected from Reservoirs in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	408	309	101	982	130
Total Ammonia as N	mg/L	469	0.097	0.001[1]	2.440	0.200
Bicarbonate (HCO_3)	mg/L	408	318	14	1040	150
Calcium (Ca)	mg/L	408	50	5	160	26
Carbonate (CO_3)	mg/L	402	30	1[1]	197	30
Chloride (Cl)	mg/L	408	13.3	0.3	74.5	8.8
Chlorophyll-a	µg/L	321	21.2	1.5	218.0	27.9
Specific Conductance	µmhos	428	1733	262	5880	959
Total Dissolved Solids	mg/L	409	1176	147	5110	750
Total Hardness as ($CaCO_3$)	mg/L	408	397	45	1850	260
Hydroxide (OH)	mg/L	337	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	409	0.179	0.007	4.110	0.334
Magnesium (Mg)	mg/L	408	66.0	5.6	353.0	49.6
Nitrate + Nitrite as N	mg/L	395	0.048	0.001[1]	0.790	0.092
Total Kjeldahl Nitrogen as N	mg/L	359	1.556	0.365	7.720	0.779
Total Nitrogen as N	mg/L	302	1.472	0.405	4.840	0.562
pH		428	8.61	6.73	9.87	0.56
Total Phosphorus as P	mg/L	475	0.135	0.004	3.160	0.205
Potassium (K)	mg/L	408	14.6	4.2	39.2	6.3
Sodium (Na)	mg/L	408	239	3[1]	932	171
Sulfate (SO4)	mg/L	406	604	1[1]	3210	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 69 Reservoirs between 1991 and 2007

Trophic Status Assessment: Based on limited chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005-2006, Cedar Lake's current trophic status is eutrophic. TSI scores ranged from a low of 60 based on chlorophyll-a, to a high of 75 based on total phosphorus. The trophic status score based on Secchi disk transparency was similar to that of total phosphorus at 73 (Figure 6).

A total of eight total phosphorus samples, three chlorophyll-a samples, and three Secchi disk transparency measurements collected during 1991-2006 were used to evaluate trends in the trophic status of Cedar Lake. Based on a visual assessment, Cedar Lakes' trophic status is stable (Figure 6).

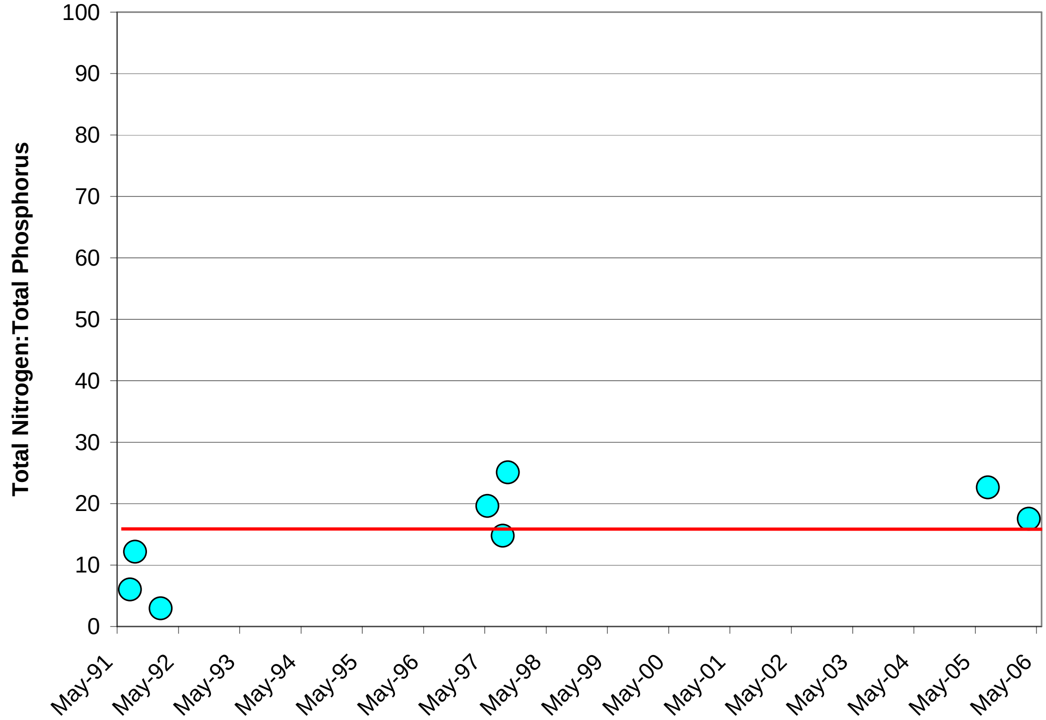


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Cedar Lake (1991-2006).

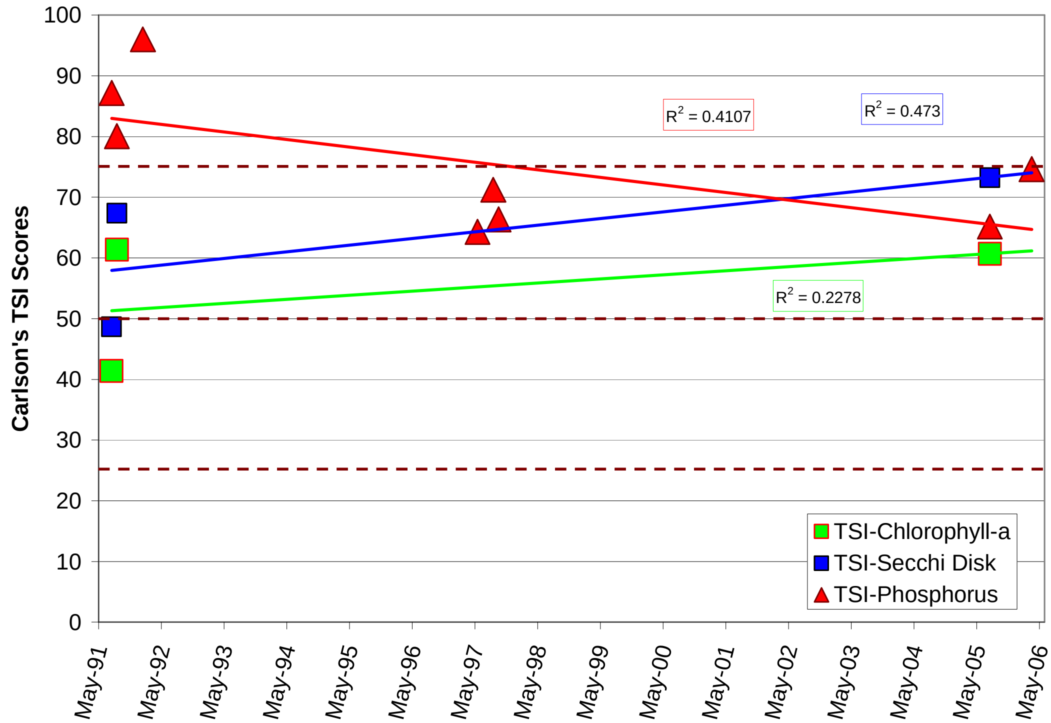


Figure 6. TSI Scores and Temporal Trends for Cedar Lake from 1991 to 2006.

Belfield Dam, Stark County

BACKGROUND

Location: Belfield Dam is a small recreational water body located on the southwestern edge of the town of Belfield, North Dakota (Figure 1). Belfield Dam is managed by the North Dakota Game and Fish Department.

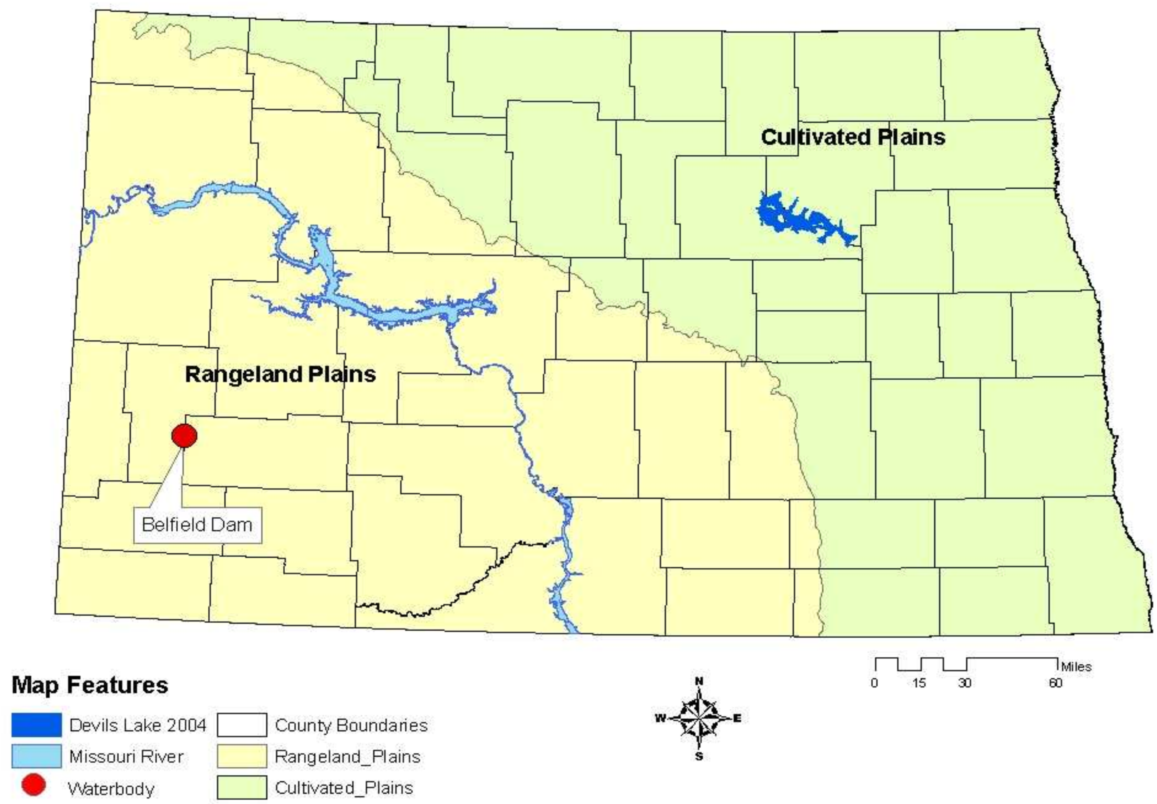


Figure 1. Location of Belfield Dam.

Physiographic/Ecological Setting: Belfield Dam has a surface area of 7.13 acres, a maximum depth of 17.4 ft, and an average depth of 8.5 ft (Figure 2). The reservoir's watershed is located in the Northwestern Great Plains (NWGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The Belfield Dam watershed landscape is rolling plains. Flood plain slopes and hillsides are usually native grasslands, while the uplands and flood plains themselves have mostly been converted to small grains and alfalfa.

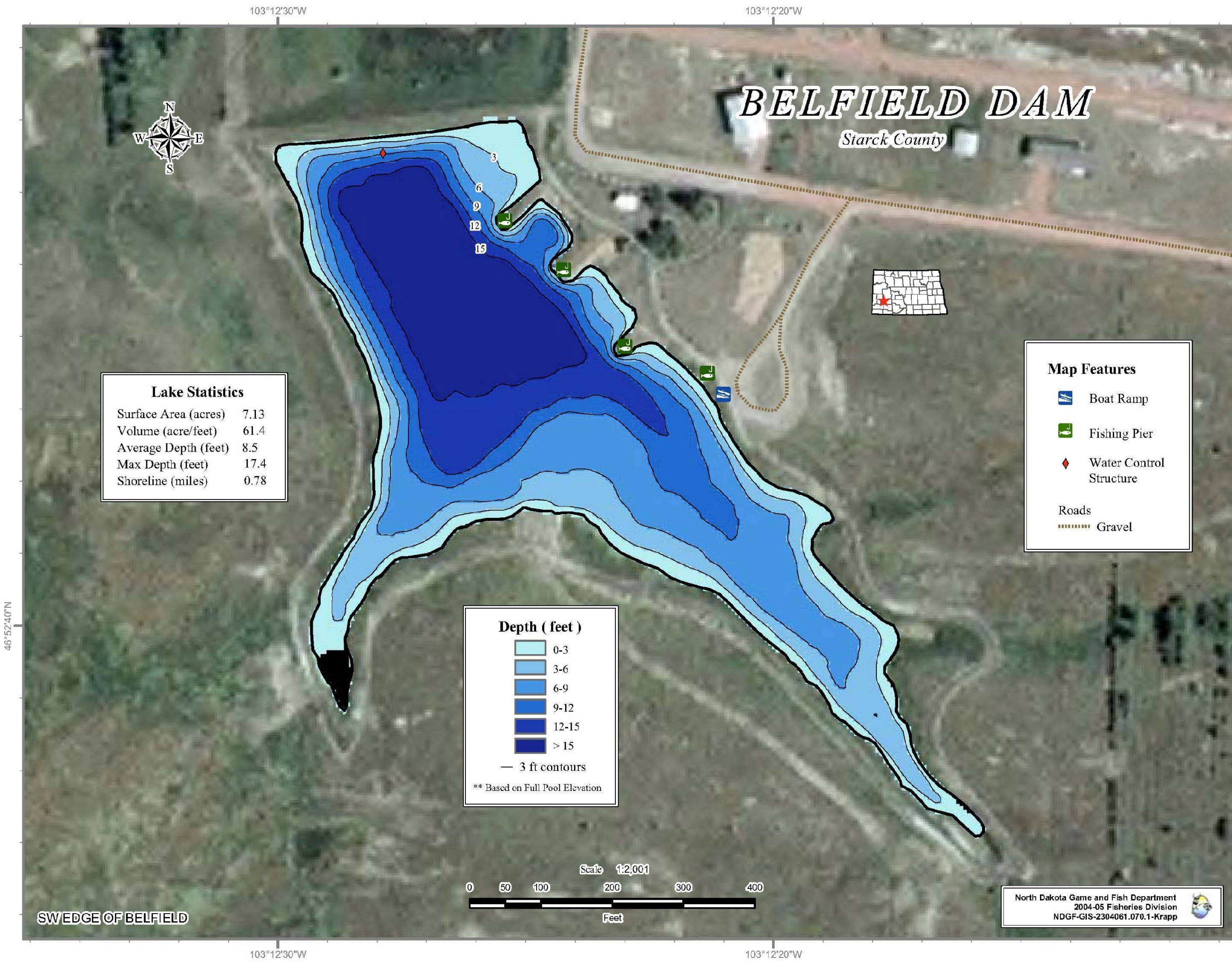


Figure 2. Contour Map of Belfield Dam (Map Courtesy of North Dakota Game and Fish Department).

Construction History: Belfield Dam was originally constructed in the mid-1900s, by the Northern Pacific Railroad. Belfield Dam was reconstructed in 1993 in order to accommodate fish.

Recreational Facilities: Recreational facilities at Belfield Dam include a boat ramp, boat and vehicle parking, and 4 fishing piers. Public access on the northeast side of the lake includes parking, restrooms, and all 4 fishing piers.

Water Quality Standards Classification: Belfield Dam is classified in the state “Standards of Quality for Waters of the State” (NDDoH, 2006) as a class 1 lake or reservoir. Class 1 lakes or reservoirs are defined as a “cold water fishery” or “waters capable of supporting growth of cold water fish species (e.g., salmonids) and associated aquatic biota.”

Historical and Current Fishery: Belfield Dam’s fishery includes trout, largemouth bass, and bluegill. The use or introduction of live baitfish is prohibited.

Historical Water Quality Sampling: There is no historical water quality data available for Belfield Dam.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Belfield Dam have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There are two temperature and dissolved oxygen profiles for Belfield Dam collected in 2005 and 2006 (Figures 3 and 4). The profile data shows that during thermal stratification Belfield Dam experiences rapid oxygen decay that drops below the state's water quality standard of 5 mg/L. While the rapid loss of dissolved oxygen during this period is concerning, there does appear to be enough dissolved oxygen to maintain aquatic life in the upper two meters of the water column.

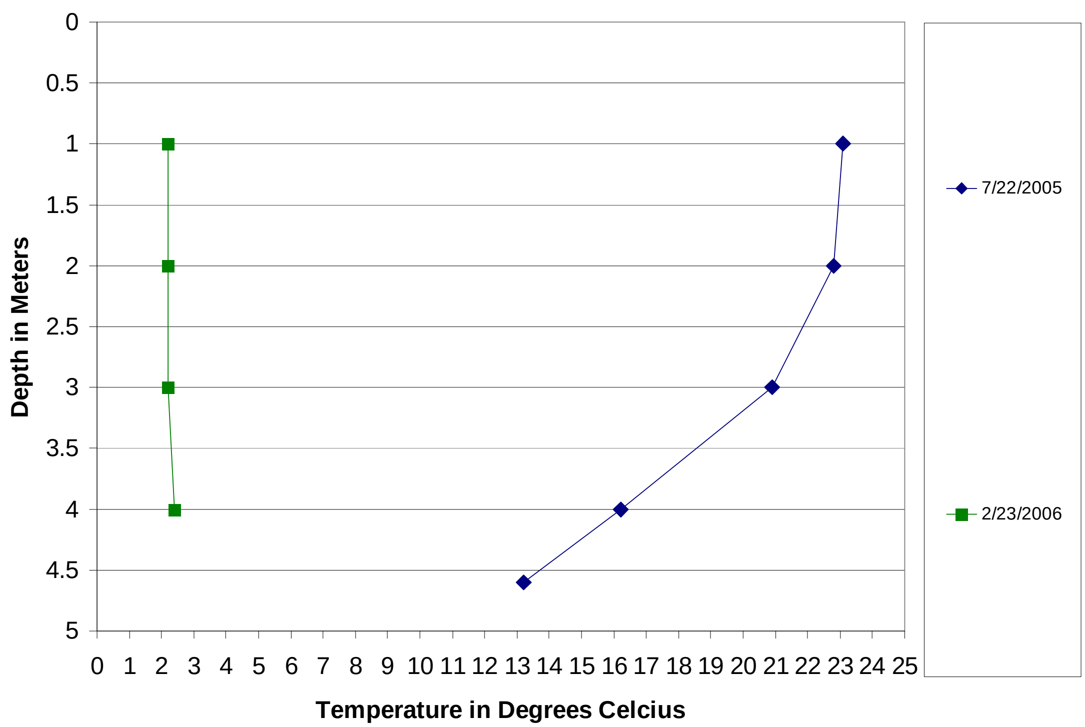


Figure 3. Temperature Profiles for Belfield Dam from 2005 to 2006.

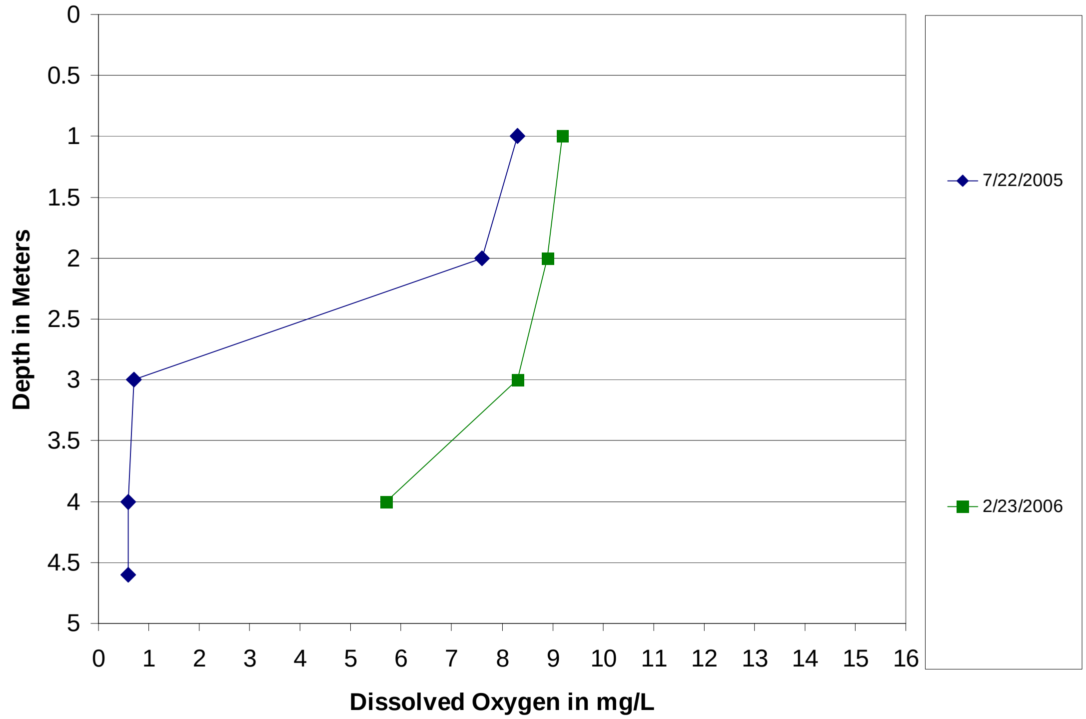


Figure 4. Dissolved Oxygen Profiles for Belfield Dam from 2005 to 2006.

General Water Quality: Data collected by the NDGF in 2005 and 2006 indicate Belfield Dam is well buffered with total alkalinity as $CaCO_3$ concentrations ranging from 224 to 306 mg/L (Table 1). Based on the 2005-2006 water quality data, Belfield Dam is sodium sulfate dominated with an average sodium concentration of 641 mg/L and an average sulfate concentration of 1850 mg/L. The average total dissolved solids (TDS) concentration and specific conductance measurement for the 2005-2006 sampling period were 2885 mg/L and 3740 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.620 mg/L and 0.040 mg/L, respectively.

When compared to other reservoirs in the Rangeland Plains region, Belfield Dam contains higher concentrations of most constituents (Table 2). For example, the regional average TDS, total nitrogen, and sulfate concentrations are 1176 mg/L, 1.472 mg/L, and 604 mg/L respectively, compared to Belfield Dam's average TDS, total nitrogen, and sulfate concentrations of 2885 mg/L, 1.620 mg/L and 1850 mg/L respectively, for the period 2005-2006.

Table 1. Statistical Summary of Belfield Dam's 2005-2006 Water Quality Data.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	2	265	224	306	58
Total Ammonia as N	mg/L	2	0.018	0.010[1]	0.025	0.011
Bicarbonate (HCO_3)	mg/L	2	314	254	373	84
Calcium (Ca)	mg/L	2	95.5	78.0	113.0	24.7
Carbonate (CO_3)	mg/L	2	6	1[1]	10	6
Chloride (Cl)	mg/L	2	10	8	13	3
Chlorophyll-a	µg/L	1	18.4	18.4	18.4	
Specific Conductance	µmhos	2	3740	3090	4390	919
Total Dissolved Solids	mg/L	2	2885	2320	3450	799
Total Hardness as ($CaCO_3$)	mg/L	2	681	557	805	175
Hydroxide (OH)	mg/L	2	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	2	0.191	0.129	0.253	0.088
Magnesium (Mg)	mg/L	2	107.5	87.9	127.0	27.6
Nitrate + Nitrite as N	mg/L	2	0.030	0.020[1]	0.040	0.014
Total Kjeldahl Nitrogen as N	mg/L	2	1.590	1.540	1.640	0.071
Total Nitrogen as N	mg/L	2	1.620	1.580	1.660	0.057
pH		2	8.21	7.89	8.52	0.45
Total Phosphorus as P	mg/L	2	0.040	0.039	0.041	0.001
Potassium (K)	mg/L	2	18.7	16.3	21.0	3.3
Sodium (Na)	mg/L	2	641	524	757	165
Sulfate (SO4)	mg/L	2	1850	1470	2230	537

[1]Equal to lower detection limit

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Belfield Dam and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight in algae, is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were two water quality sample results for Belfield Dam collected between July 2005 and February 2006 where the N:P ratio could be calculated. The results from these samples indicate that Belfield Dam is phosphorus limited (Figure 5).

N:P ratios for Belfield Dam ranged from a low of 40 to a high of 41 with an average of 40.5. Of the two samples collected on Belfield Dam, both samples were above an N:P ratio of 15, indicating phosphorus limitation.

Table 2. Statistical Summary of Water Quality Data[2] Collected from Reservoirs in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	408	309	101	982	130
Total Ammonia as N	mg/L	469	0.097	0.001[1]	2.440	0.200
Bicarbonate (HCO_3)	mg/L	408	318	14	1040	150
Calcium (Ca)	mg/L	408	50	5	160	26
Carbonate (CO_3)	mg/L	402	30	1[1]	197	30
Chloride (Cl)	mg/L	408	13.3	0.3	74.5	8.8
Chlorophyll-a	µg/L	321	21.2	1.5	218.0	27.9
Specific Conductance	µmhos	428	1733	262	5880	959
Total Dissolved Solids	mg/L	409	1176	147	5110	750
Total Hardness as ($CaCO_3$)	mg/L	408	397	45	1850	260
Hydroxide (OH)	mg/L	337	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	409	0.179	0.007	4.110	0.334
Magnesium (Mg)	mg/L	408	66.0	5.6	353.0	49.6
Nitrate + Nitrite as N	mg/L	395	0.048	0.001[1]	0.790	0.092
Total Kjeldahl Nitrogen as N	mg/L	359	1.556	0.365	7.720	0.779
Total Nitrogen as N	mg/L	302	1.472	0.405	4.840	0.562
pH		428	8.61	6.73	9.87	0.56
Total Phosphorus as P	mg/L	475	0.135	0.004	3.160	0.205
Potassium (K)	mg/L	408	14.6	4.2	39.2	6.3
Sodium (Na)	mg/L	408	239	3[1]	932	171
Sulfate (SO4)	mg/L	406	604	1[1]	3210	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 69 Reservoirs between 1991 and 2007

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005-2006, Belfield Dam's current trophic status is eutrophic. TSI scores ranged from a low of 57 based on total phosphorus, to a high of 59 based on chlorophyll-a. The trophic status score based on Secchi disk transparency was similar to that estimated based on chlorophyll-a and total phosphorus at 58 (Figure 6).

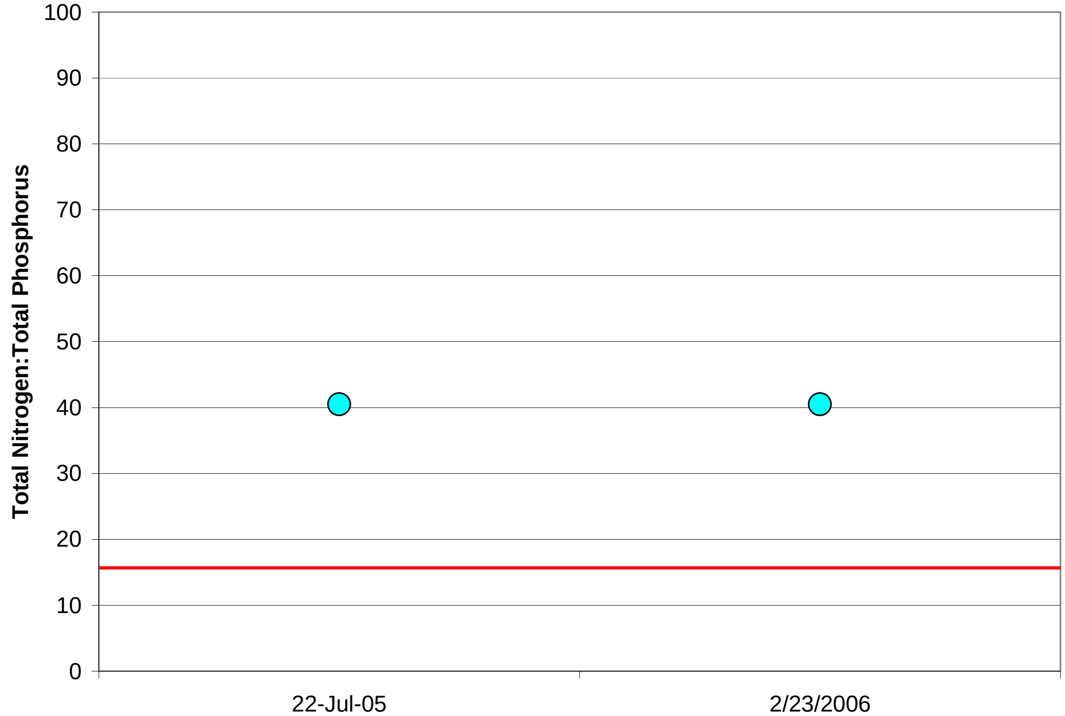


Figure 5. Total Nitrogen to Total Phosphorus Ratios in Belfield Dam (2005-2006).

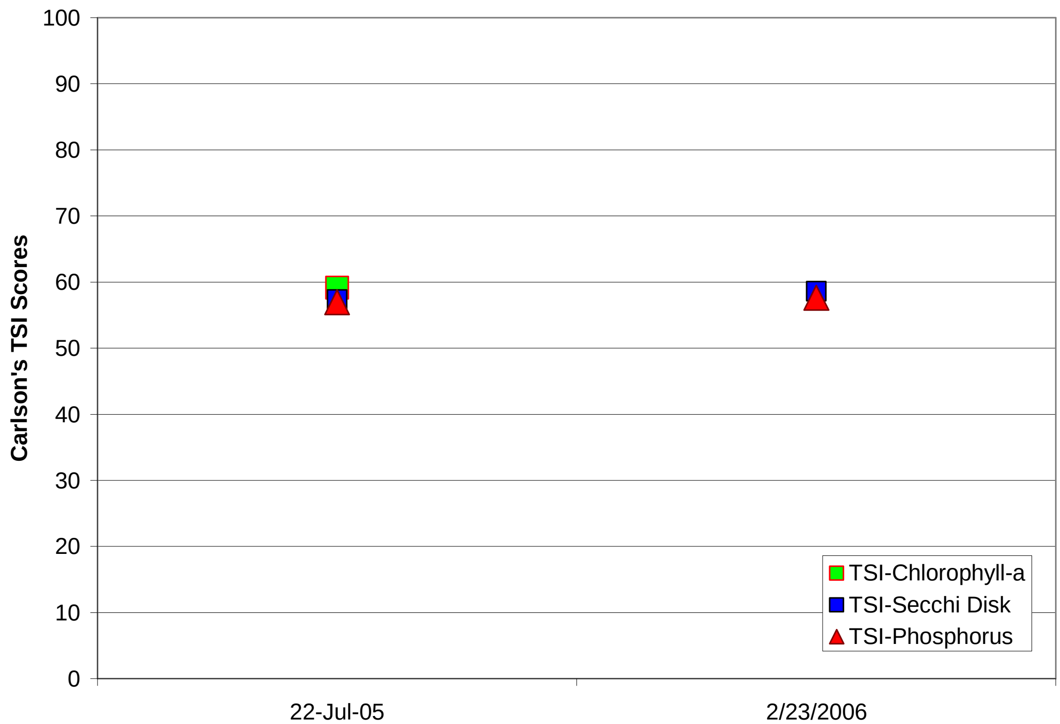


Figure 6. TSI Scores for Belfield Dam from 2005 to 2006.

Dickinson Dike, Stark County

BACKGROUND

Location: Dickinson Dike is located on the southwestern North Dakota (Figure 1). It is a 19 acre recreational water body on the western edge of the town of Dickinson and is jointly managed by the City and the North Dakota Game and Fish Department.

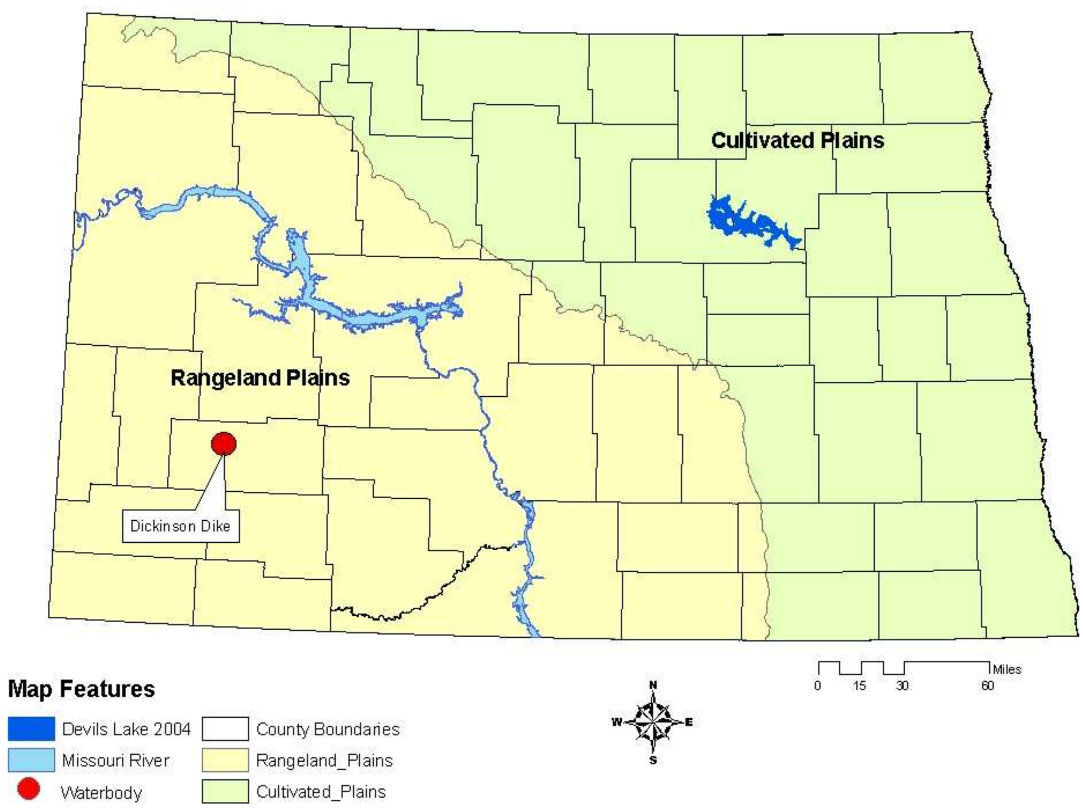


Figure 1. Location of Dickinson Dike.

Physiographic/Ecological Setting: Dickinson Dike is an 18.8 acre reservoir on an oxbow of the Heart River (Figure 2). Dickinson Dike has been enhanced by a dam on the eastern edge of the waterbody. The reservoir and contributing watershed lies within the Northwestern Great Plains (NWGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1).

The NWGP is the Missouri Plateau of the Great Plains (USEPA 1994). The 2280 acre watershed is approximately 10 percent urban and 90 percent rural. The rural section is both industrial and residential and rural is agricultural. The landscape is rolling with native grasses on the slopes and flood plains and small grains and alfalfa on the more level uplands.

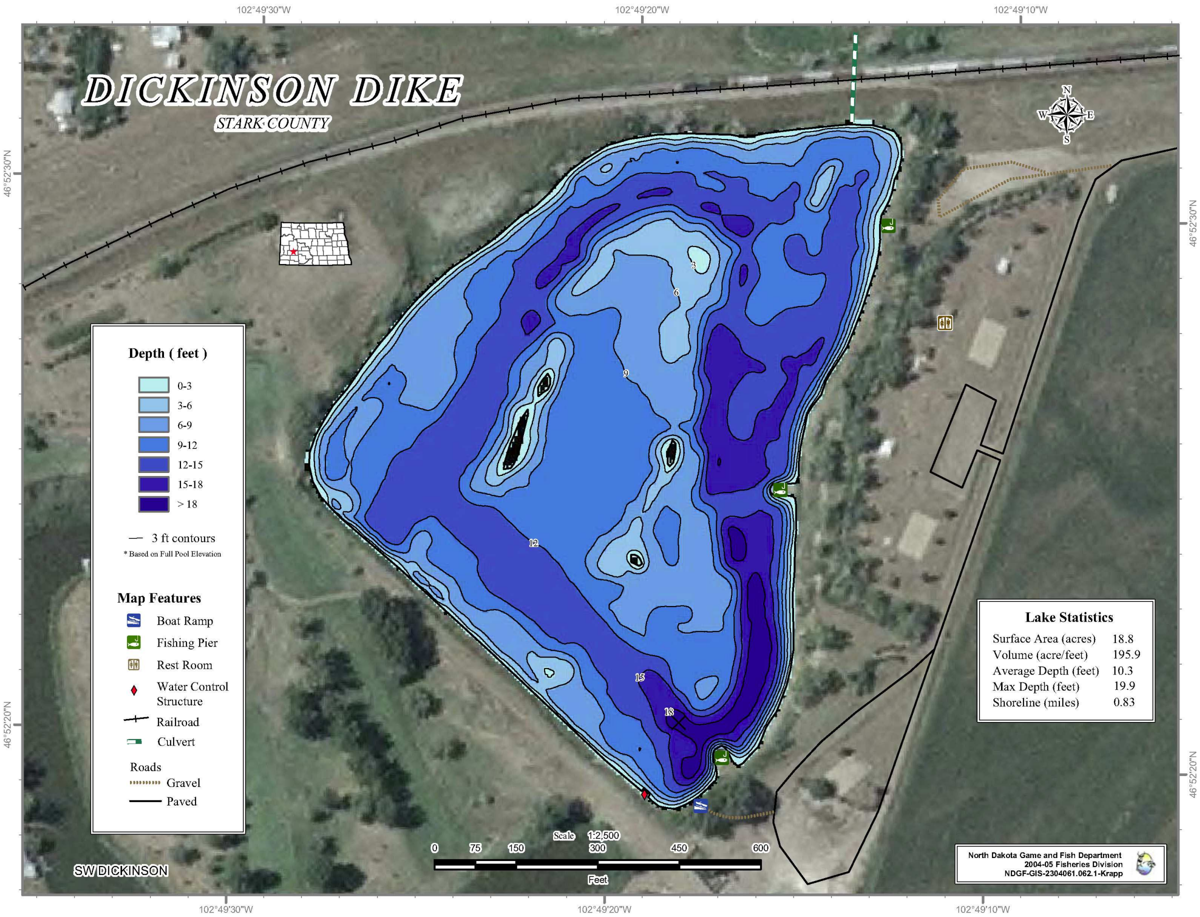


Figure 2. Contour Map of Dickinson Dike (Map Courtesy of North Dakota Game and Fish Department).

Construction History: Dickinson Dike was first built by the Northern Pacific Railroad in the early 1900's to provide water for stream locomotion. Originally known as the Queen City Dam, it was constructed by diking off a disserted oxbow of the Heart River resulting in a 22 acre impoundment with a maximum depth of 18 feet and average depth of 7.7 feet. In 2004 the City of Dickinson and the North Dakota Game and Fish Department began a restoration project on Dickinson Dike. The restoration plan called for draining and physically deepening the reservoir and developing a watershed plan to assist in protection of the small dam for future generations.

Recreational Facilities: Recreational facilities at Dickinson Dike include a cement boat ramp, boat and vehicle parking, fishing piers, and vault toilets.

Water Quality Standards Classification: Dickinson Dike is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 1 lake or reservoir. Class 1 lakes or reservoirs are defined as a "cold water fishery" or "waters capable of supporting growth of cold water fish species (e.g., salmonids) and associated aquatic biota."

Historical and Current Fishery: Dickinson Dike's fishery over time has been a struggle consisting of multiple stockings followed by eradications. Species most often stocked have been rainbow trout, but other species include brown trout, bluegill, and largemouth bass. Current fishery is rainbow trout, largemouth bass, and bluegill. Watercraft are restricted to electric motors and no live bait fish are allowed.

Historical Water Quality Sampling: Historical water quality data includes results from seven water quality sample sets collected between 1993 and 2002.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Dickinson Dike have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profiles: There are 20 temperature and 22 dissolved oxygen profiles for Dickinson Dike collected intermittently between 1993 and 2007 (Figures 3 through 6). The profile data shows that historically during winter months of relatively dry years, the dissolved oxygen concentration were inadequate throughout most if not the entire water column being below the state's standard of 5 mg/L (Figure 4). However after renovation of the reservoir dissolved oxygen remained above the state standard except at the sediment water interface (Figure 6).

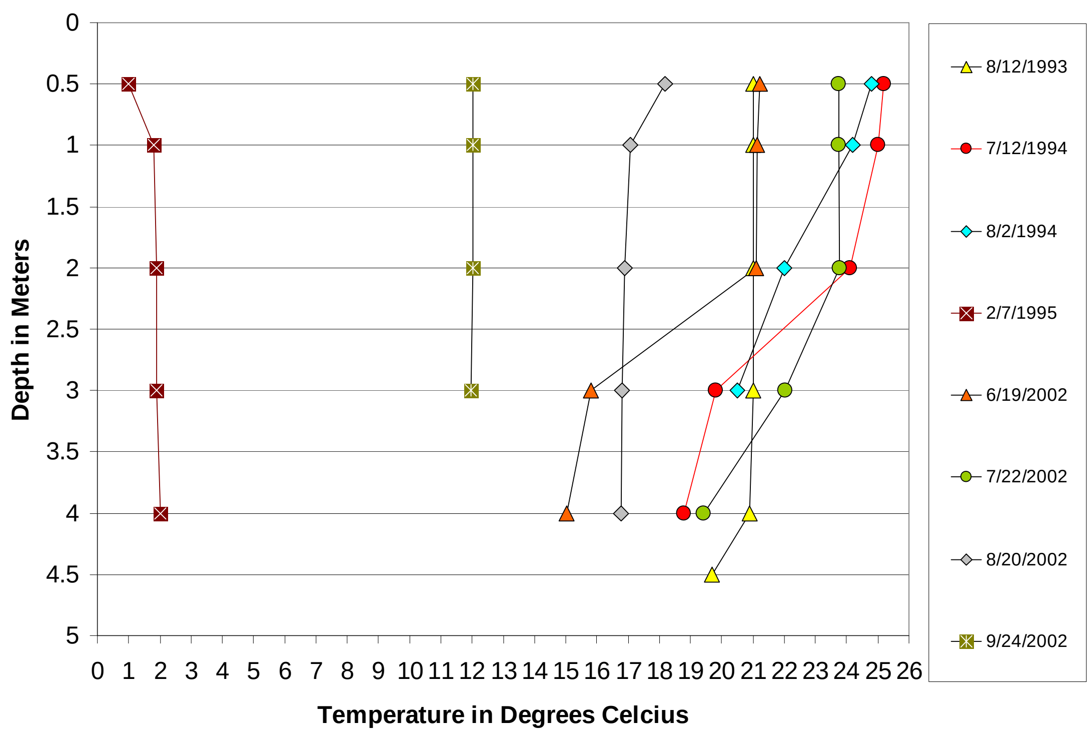


Figure 3. Dickinson Dike's Temperature Profiles From 1993 to 2002.

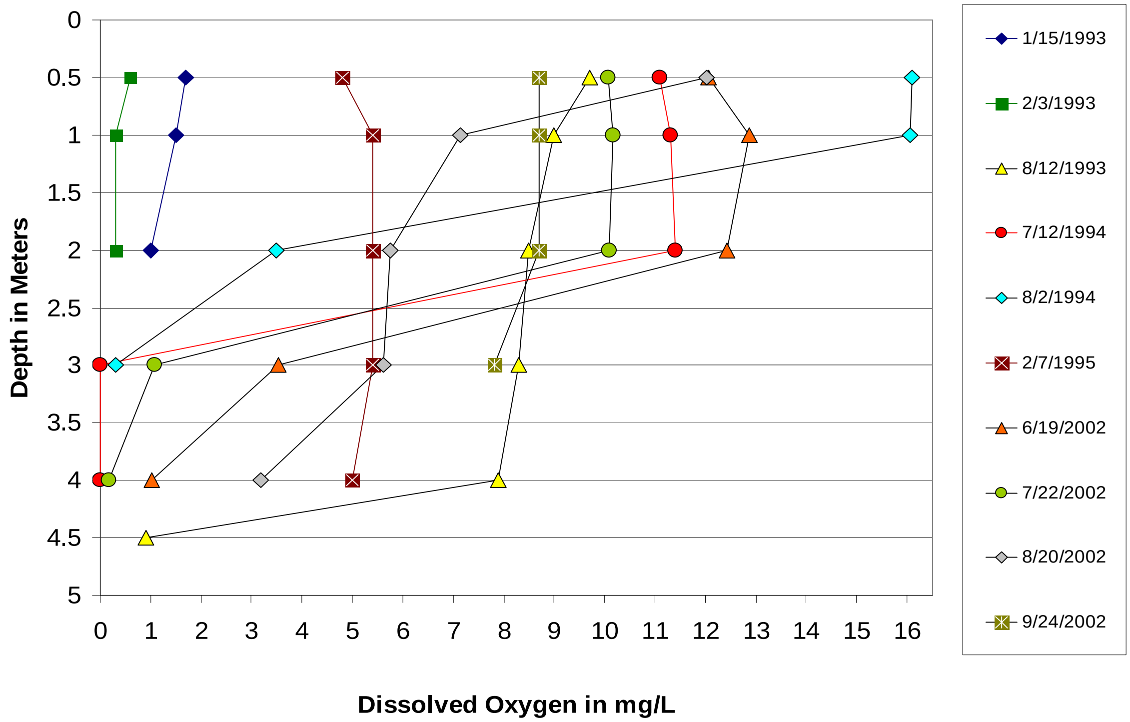


Figure 4. Dickinson Dike's Dissolved Oxygen Profiles From 1993 to 2002.

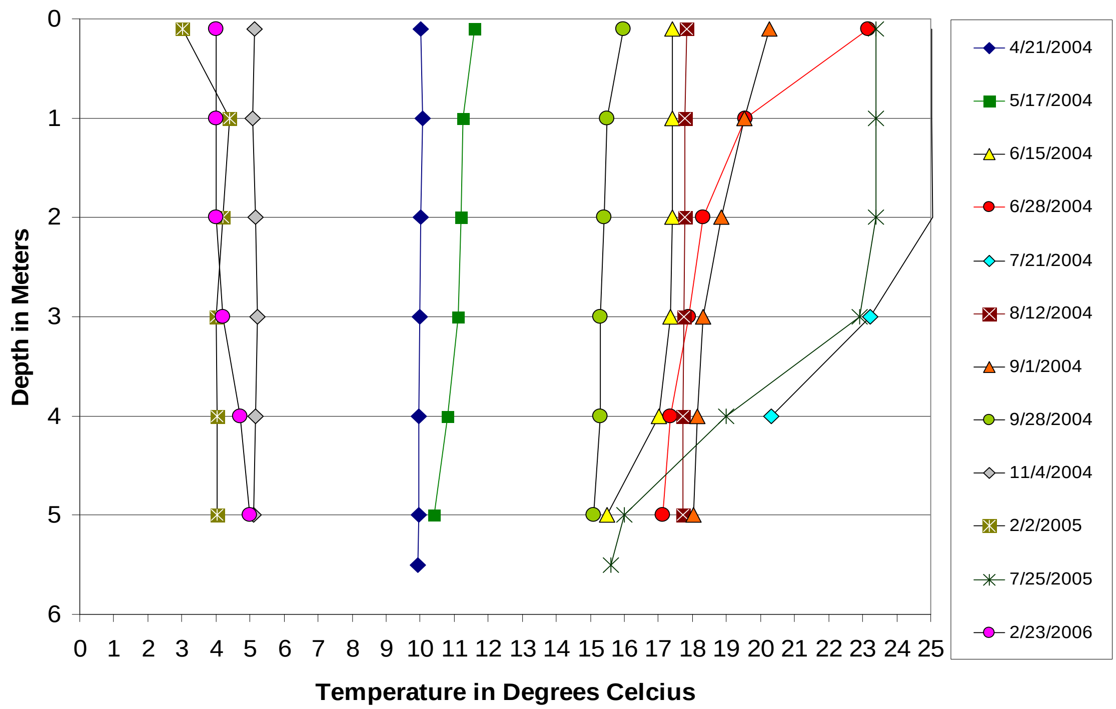


Figure 5. Dickinson Dike's Temperature Profiles From 2004 to 2006.

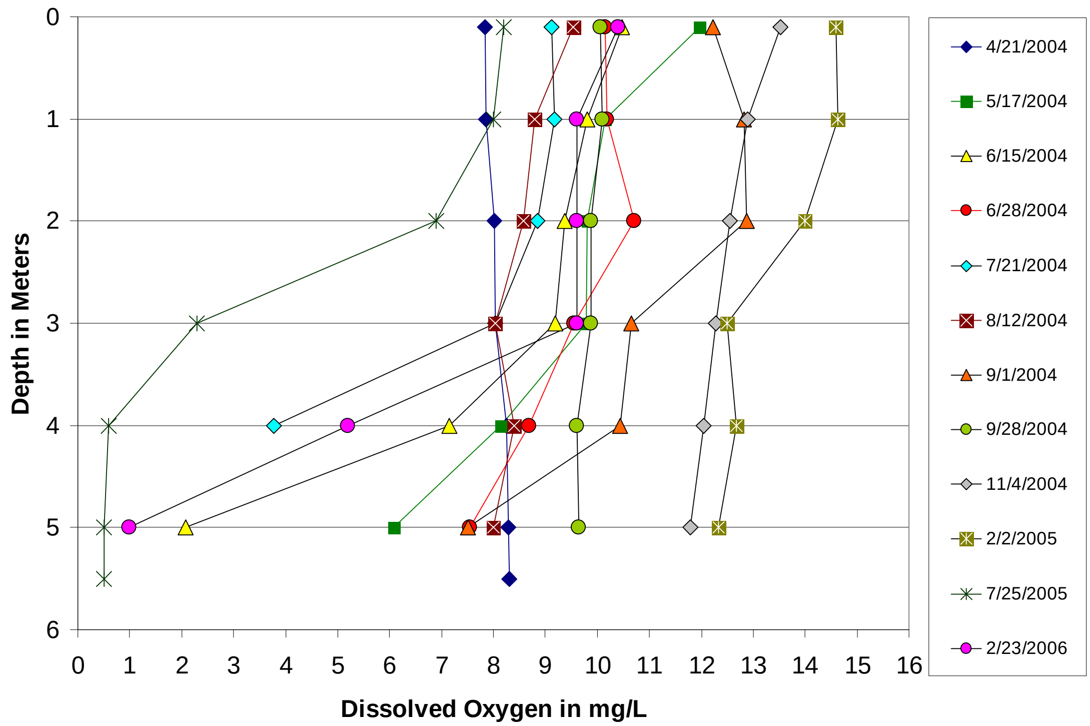


Figure 6. Dickinson Dike's Dissolved Oxygen Profiles From 2004 to 2006.

General Water Quality: Data collected by the NDG&F in 2005 and 2006 indicate Dickinson Dike is well buffered with total alkalinity as $CaCO_3$ concentrations ranging from 143 to 233 mg/L (Tables 1). Dickinson Dike is sodium sulfate dominated with a 2005-2006 average sodium and sulfate concentration of 104 and 217 mg/L respectfully.

The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 520 mg/L and 813 µmhos/cm respectively. Average total nitrogen as N and total phosphorus as P concentrations were 0.909 mg/L and 0.042 mg/L respectively.

Historical water quality data collected prior to reservoir renovation shows Dickinson Dike with similar in chemical make up with a few notable exceptions (Table 2). Historically Dickinson Dike was always well buffered with a similar average total alkalinity concentration of 186 mg/L but sodium bicarbonate dominated with average concentration of sodium and bicarbonate of 73 mg/L and 142 mg/L, respectively, followed by sulfate with an average concentration of 117 mg/L.

Historical averages for total dissolved solids and specific conductivity were less then the current concentrations at 365 mg/L and 608 µmhos/cm respectively. The average total nitrogen and total phosphorus concentrations were higher then the current concentrations by 25 and 50 percent respectively, with concentrations of 1.258 mg/l and 0.094 mg/L.

Table 1. Statistical Summary of Dickinson Dike's 2005-2006 Water Quality. Data Collected by the North Dakota Game and Fish Department.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	10	180	143	233	26
Total Ammonia as N	mg/L	10	0.0483	0.01[1]	0.167	0.056
Bicarbonate (HCO_3)	mg/L	10	180	102	285	54
Calcium (Ca)	mg/L	10	34.6	16.2	55.1	13.2
Carbonate (CO_3)	mg/L	10	20	1[1]	35	13
Chloride (Cl)	mg/L	10	19.5	13.6	27.7	3.8
Chlorophyll-a	µg/L	8	8.3	1.5[1]	39.2	12.3
Specific Conductance	µmhos	10	813	568	888	92
Total Dissolved Solids	mg/L	10	520	371	598	63
Total Hardness as ($CaCO_3$)	mg/L	10	186	123	249	37
Hydroxide (OH)	mg/L	10	1[1]	1[1]	1[1]	0.0
Iron (Fe)	mg/L	10	0.141	0.042	0.311	0.101
Magnesium (Mg)	mg/L	10	24.1	19.8	27.1	2.7
Nitrate + Nitrite as N	mg/L	10	0.065	0.02[1]	0.27	0.08
Total Kjeldahl Nitrogen as N	mg/L	10	0.844	0.56	1.05	0.15
Total Nitrogen as N	mg/L	10	0.909	0.62	1.3	0.2
pH		10	8.78	7.67	9.52	0.58
Total Phosphorus as P	mg/L	10	0.042	0.004[1]	0.101	0.029
Potassium (K)	mg/L	10	10.8	6.9	13	1.6
Sodium (Na)	mg/L	10	104	74	123	16.1
Sulfate (SO4)	mg/L	10	217	126	254	47

[1]Equal to lower detection limit

Water quality data collected in 2005-2006 compared to the state's long term data set for the reservoirs in the Rangeland Plains Ecological region indicates that Dickinson Dike has lower concentrations of nearly every constitute (Table 3). The average concentration of total dissolved solids and specific conductance for reservoirs in the Rangeland Plains region is approximately double Dickinson Dike's concentrations at 1176 mg/L and 1733 µmhos/cm, and the total nitrogen and total phosphorus concentrations are 75 percent and 3 fold less then the Rangeland Plains regional average.

Limiting Nutrient: The limiting nutrient assessment is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Dickinson Dike and that the weight ratio of total nitrogen to total phosphorus (N:P) in Dickinson Dike's algae is approximately 15 to 1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There are 19 water quality sample sets for Dickinson Dike between July 1994 and February 2007. The 19 samples used in this interpretation indicate that while Dickinson Dike is most often phosphorus limited, the nutrient relationships on Dickinson Dike are variable based on the time of the year and the natural processes occurring at the time of sampling (Figure 7).

Table 2. Statistical Summary of Dickinson Dike's Historical Water Quality Data Collected Between 1993 and 2002.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	7	186	149	262	38
Total Ammonia as N	mg/L	7	0.086	0.01[1]	0.304	0.099
Bicarbonate (HCO_3)	mg/L	7	142	14	320	100
Calcium (Ca)	mg/L	7	20.1	12.2	34.9	9.2
Carbonate (CO_3)	mg/L	7	42	1[1]	83	33
Chloride (Cl)	mg/L	7	10.6	7.2	21.6	5
Chlorophyll-a	µg/L	5	204	4	664	296
Specific Conductance	µmhos	7	608	498	823	110
Total Dissolved Solids	mg/L	7	365	297	574	96
Total Hardness as ($CaCO_3$)	mg/L	7	140	119	206	35
Hydroxide (OH)	mg/L	7	1[1]	1[1]	1[1]	0.0
Iron (Fe)	mg/L	7	0.098	0.01	0.329	0.112
Magnesium (Mg)	mg/L	7	21.9	19.5	30.7	3.9
Nitrate + Nitrite as N	mg/L	7	0.06	0.005	0.251	0.09
Total Kjeldahl Nitrogen as N	mg/L	7	1.977	0.768	1.67	0.29
Total Nitrogen as N	mg/L	7	1.258	0.868	1.921	0.348
pH		7	8.95	7.28	9.87	1
Total Phosphorus as P	mg/L	7	0.094	0.004[1]	0.178	0.063
Potassium (K)	mg/L	7	7.86	1.6	12.5	3.7
Sodium (Na)	mg/L	7	72.7	58.6	117	21
Sulfate (SO4)	mg/L	7	117	84	211	43

[1]Equal to lower detection limit

The nitrogen to phosphorus ratio for Dickinson Dike ranged from a low of 12 to a high of 203 with an average of 35. Of the 17 samples collected on Dickinson Dike all but three of the samples were above 15 indicating nitrogen limitation.

Trophic Status Assessment: Based on Carlson's Trophic Status Index (TSI) Dickinson Dike's trophic status is mesotrophic with periodic voyages into the eutrophic range (Figure 8). Carlson's TSI is a simple index that estimates a lake's current or potential trophic status based on the three indicators, chlorophyll-a, Secchi disk transparency, and total phosphorus concentrations in the epilmnion.

A total of 19 phosphorus samples, 14 chlorophyll-a samples, and four Secchi disk measurements were used in this interpretation. Based on a visual assessment of the data Dickinson Dike's trophic status is improving (Figure 6).

Table 3. Statistical Summary of Water Quality from Reservoirs in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	408	309	101	982	130
Total Ammonia as N	mg/L	469	0.097	0.001[1]	2.440	0.200
Bicarbonate (HCO_3)	mg/L	408	318	14	1040	150
Calcium (Ca)	mg/L	408	50	5	160	26
Carbonate (CO_3)	mg/L	402	30	1[1]	197	30
Chloride (Cl)	mg/L	408	13.3	0.3	74.5	8.8
Chlorophyll-a	µg/L	321	21.2	1.5[1]	218.0	27.9
Specific Conductance	µmhos	428	1733	262	5880	959
Total Dissolved Solids	mg/L	409	1176	147	5110	750
Total Hardness as ($CaCO_3$)	mg/L	408	397	45	1850	260
Hydroxide (OH)	mg/L	337	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	409	0.179	0.007	4.110	0.334
Magnesium (Mg)	mg/L	408	66.0	5.6	353.0	49.6
Nitrate + Nitrite as N	mg/L	395	0.048	0.001[1]	0.790	0.092
Total Kjeldahl Nitrogen as N	mg/L	359	1.556	0.365	7.720	0.779
Total Nitrogen as N	mg/L	302	1.472	0.405	4.840	0.562
pH		428	8.61	6.73	9.87	0.56
Total Phosphorus as P	mg/L	475	0.135	0.004	3.160	0.205
Potassium (K)	mg/L	408	14.6	4.2	39.2	6.3
Sodium (Na)	mg/L	408	239	3[1]	932	171
Sulfate (SO4)	mg/L	406	604	1[1]	3210	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 69 Reservoirs between 1991 and 2007

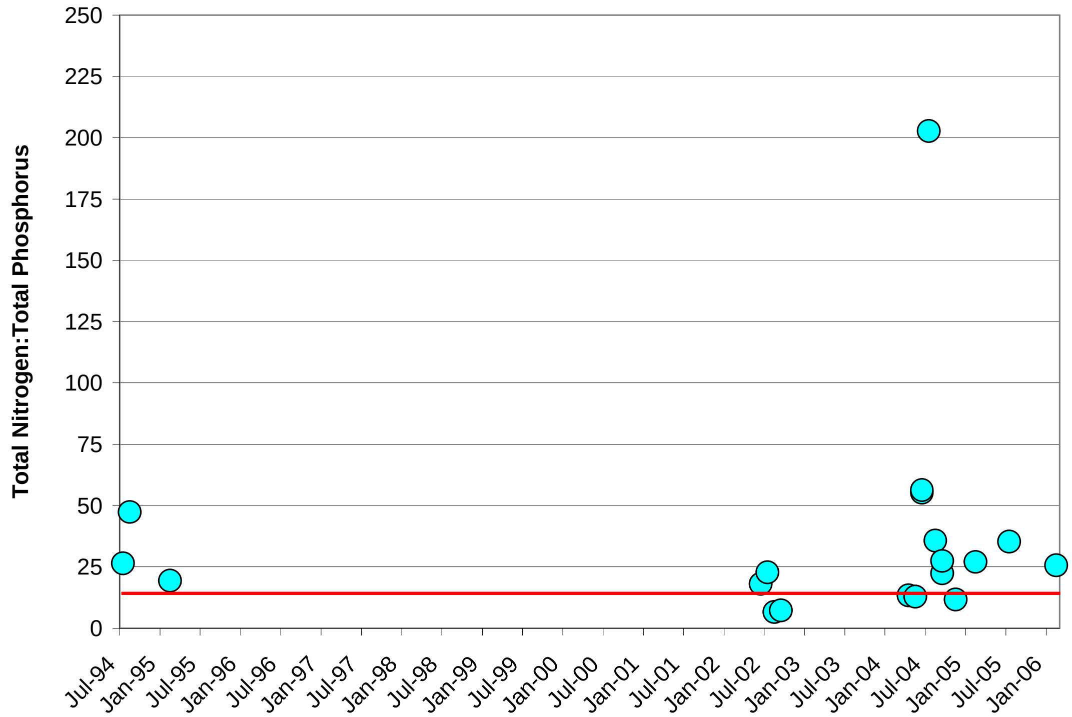


Figure 7. Total Nitrogen to Total Phosphorus Ratios in Dickinson Dike (1994-2007).

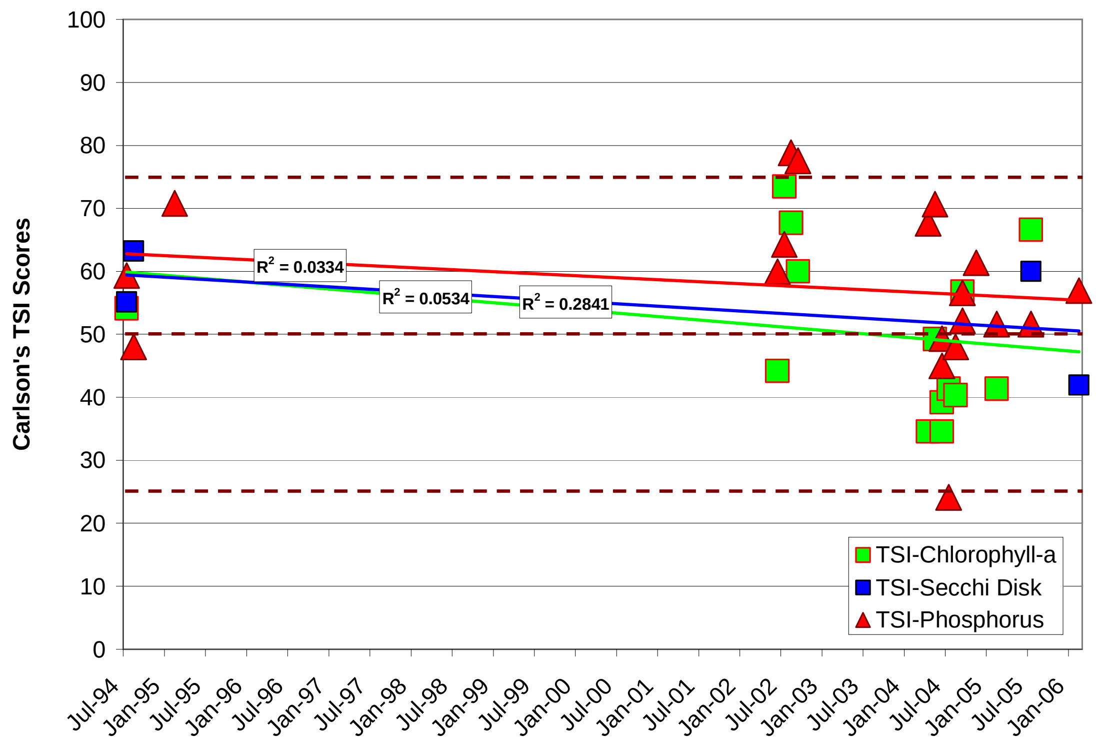


Figure 8. TSI Scores and Temporal Trends for Dickinson Dike from 1994 to 2007.

Patterson Lake, Stark County

BACKGROUND

Location: Patterson Lake is a large recreational impoundment on the Heart River located on the southwestern edge of the town of Dickinson (Figure 1). The reservoir is managed by the North Dakota Game and Fish Department.

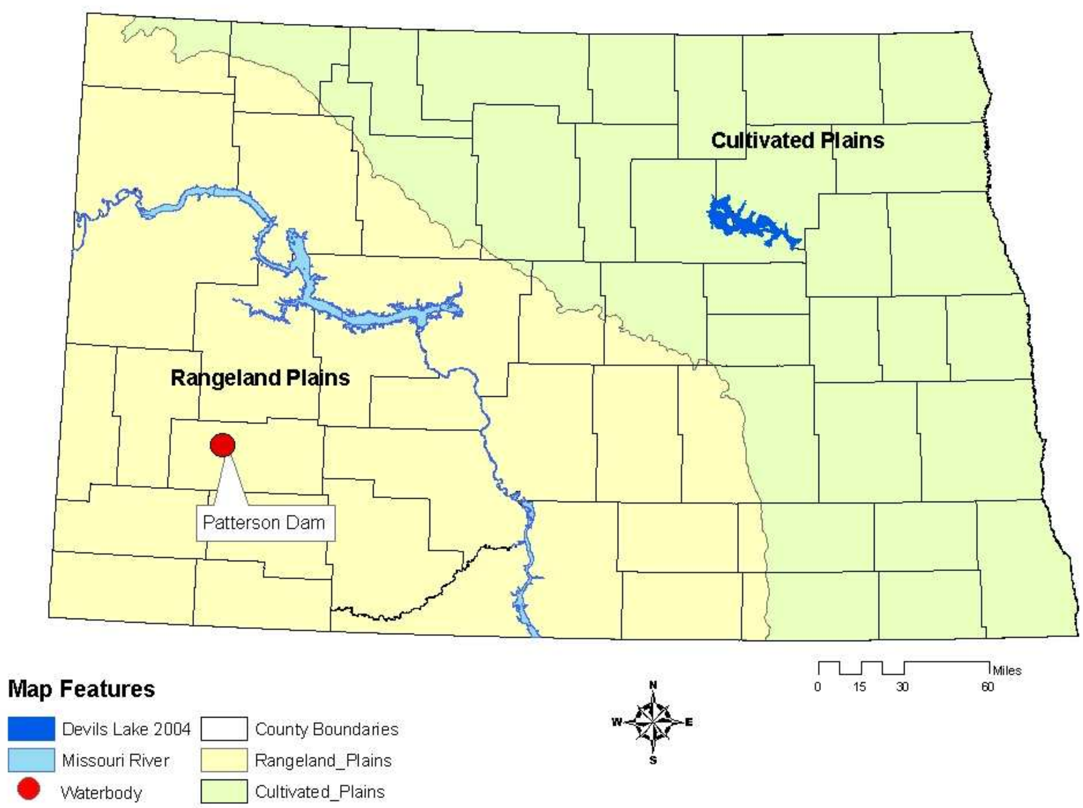


Figure 1. Location of Patterson Lake.

Physiographic/Ecological Setting: Patterson Lake has a surface area of 956.1 acres, a maximum depth of 26.9 ft, and an average depth 9.0 ft (Figure 2). The reservoir's watershed is located within the Northwestern Great Plains (NWGP) Level III Ecoregion, part of the broader Rangeland Plains region (Figure 1). The Patterson Lake watershed landscape is rolling plains. Flood plain slopes and hillsides are usually native grasslands, while the uplands and flood plains themselves have mostly been converted to small grains and alfalfa.

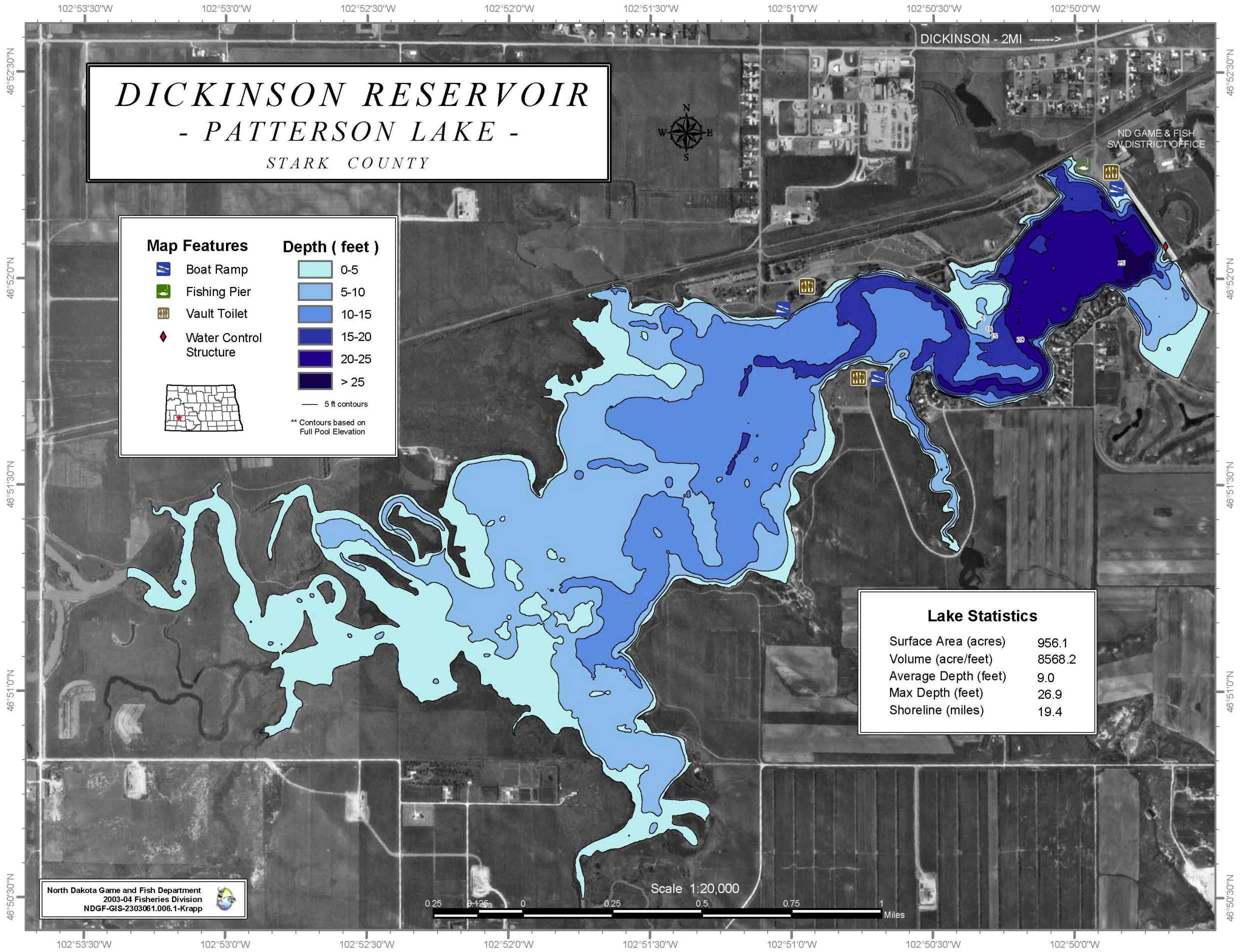


Figure 2. Contour Map of Patterson Lake (Map Courtesy of North Dakota Game and Fish Department).

Construction History: Patterson Lake is a Bureau of Reclamation project completed in 1950 to supply potable water for the city of Dickinson, irrigation for the local area, downstream flood protection, and water-based recreation. The rolled earthen structure dams the Heart River approximately 1 mile southwest of the town of Dickinson.

Recreational Facilities: Recreational facilities at Patterson Lake include 3 cement boat ramps, boat and vehicle parking, a city park, a swimming beach, and a fishing pier. The city park on the north side of the lake includes parking, restrooms, camp grounds, and a swimming beach.

Water Quality Standards Classification: Patterson Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a "warm water fishery" or "waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present."

Historical and Current Fishery: Patterson Lake's fishery over time has included nearly every fish stocked by the NDG&F. Currently, the fishery includes northern pike, yellow perch, crappie, largemouth bass, and walleye.

Historical Water Quality Sampling: Historical water quality data includes results from 15 samples collected from 1992 through 2002.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Patterson Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for reservoirs in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There are 12 temperature and dissolved oxygen profiles for Patterson Lake collected intermittently between 1992 and 2006. Temperature and oxygen profiles are presented for three time periods, 1992-1993, 2000-2001, and 2005-2006 (Figures 3 and 4). The profile data shows that during thermal stratification Patterson Lake experiences rapid oxygen decay and occasionally drops below the state's water quality standard of 5 mg/L. Of the 12 profiles, seven samples collected on 8/9/1992, 2/17/1993, 1/30/2001, 7/25/2005, 2/7/2006, 2/23/2006, and 3/7/2006 dropped below the state standard of 5 mg/L. While the rapid loss of dissolved oxygen during these periods is concerning, there does appear to be enough dissolved oxygen to maintain aquatic life in the upper two meters of the water column.

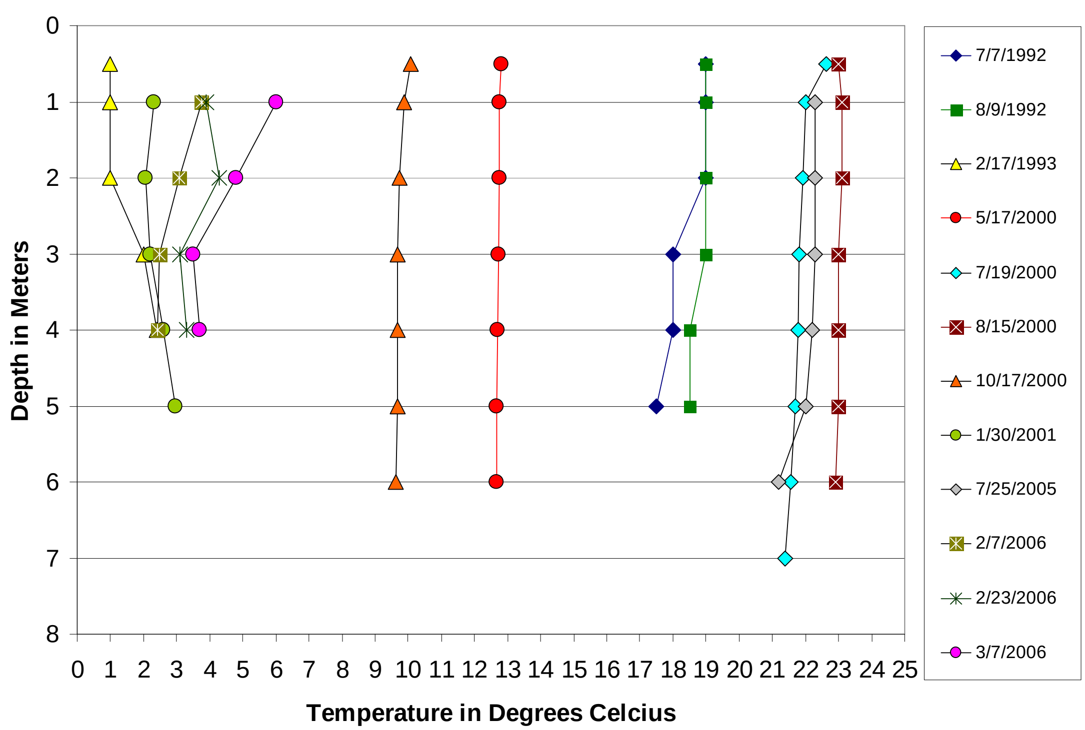


Figure 3. Temperature Profiles for Patterson Lake from 1992 to 2006.

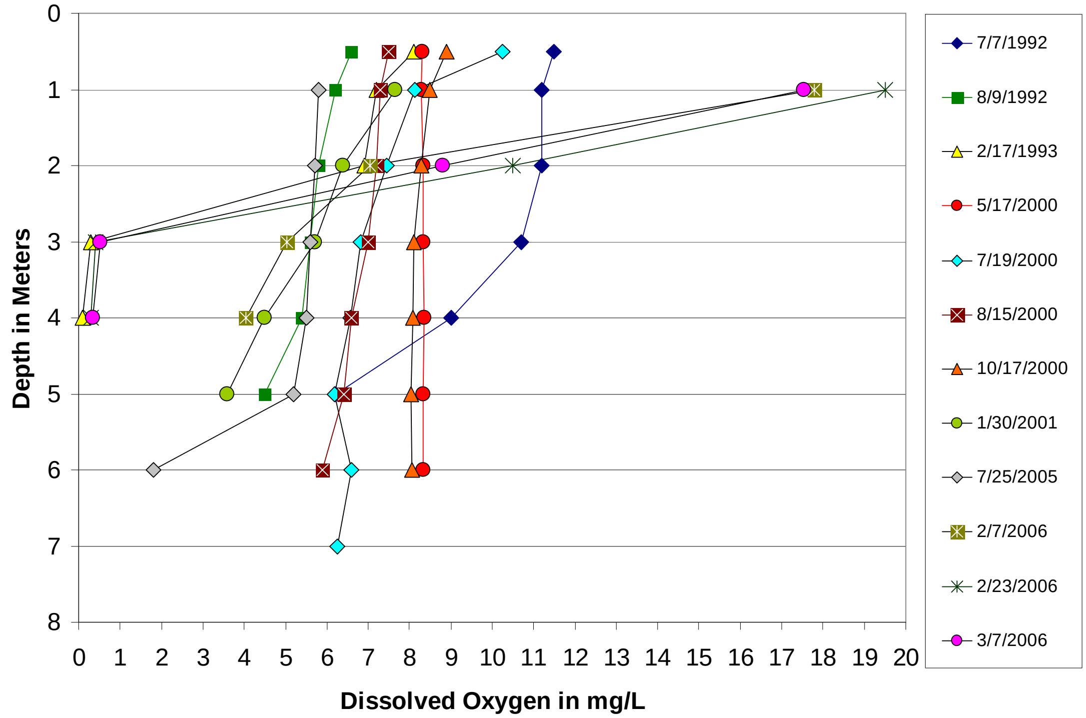


Figure 4. Dissolved Oxygen Profiles for Patterson Lake from 1992 to 2006.

General Water Quality: Data collected by the NDGF in 2005 and 2006 indicate Patterson Lake is well buffered with total alkalinity as $CaCO_3$ concentrations ranging from 189 to 387 mg/L (Table 1). Based on the 2005-2006 water quality data, Patterson Lake is sodium sulfate dominated with an average sodium concentration of 250 mg/L and an average sulfate concentration of 452 mg/L.

The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 1005 mg/L and 1489 µmhos/cm respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.093 mg/L and 0.125 mg/L respectively.

When compared to historical water quality data for Patterson Lake, it appears that concentrations of most water quality constituents have decreased. For example, the historical average sulfate and sodium concentrations were 665 mg/L and 314 mg/L respectively (Table 2), compared to average concentrations of 452 mg/L for sulfate and 250 mg/L for sodium recorded for the period 2005-2006 (Table 1).

While not significant, average total nitrogen and phosphorus concentrations have also decreased when compared to the historical data. Historical average total nitrogen and total phosphorus concentrations were 1.565 mg/L and 0.193 mg/L respectively (Table 2), compared to average concentrations of 1.093 mg/L and 0.125 mg/L for total nitrogen and total phosphorus respectively.

Table 1. Statistical Summary of Patterson Lake's 2005-2006 Water Quality Data.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	316	189	387	110
Total Ammonia as N	mg/L	3	0.010	0.010[1]	0.010	0.000
Bicarbonate (HCO_3)	mg/L	3	380	231	472	130
Calcium (Ca)	mg/L	3	58.8	36.4	72.2	19.5
Carbonate (CO_3)	mg/L	3	3	1[1]	8	4
Chloride (Cl)	mg/L	3	10	6	13	4
Chlorophyll-a	µg/L	1	4.0	4.0	4.0	
Specific Conductance	µmhos	3	1489	977	1820	450
Total Dissolved Solids	mg/L	3	1005	626	1250	333
Total Hardness as ($CaCO_3$)	mg/L	3	282	177	346	92
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	3	1.516	0.203	4.110	2.247
Magnesium (Mg)	mg/L	3	32.7	20.8	40.2	10.4
Nitrate + Nitrite as N	mg/L	3	0.123	0.020[1]	0.330	0.179
Total Kjeldahl Nitrogen as N	mg/L	3	0.970	0.770	1.090	0.174
Total Nitrogen as N	mg/L	3	1.093	1.070	1.110	0.021
pH		3	8.10	7.78	8.38	0.30
Total Phosphorus as P	mg/L	3	0.125	0.096	0.182	0.049
Potassium (K)	mg/L	3	11.4	9.7	12.6	1.5
Sodium (Na)	mg/L	3	250	143	321	94
Sulfate (SO4)	mg/L	3	452	293	562	141

[1]Equal to lower detection limit

When compared to regional average concentrations, it appears Patterson Lake is slightly lower than that reported for all reservoirs in the Rangeland Plains region (Table 3). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1176 mg/L, 1.472 mg/L, and 0.135 mg/L respectively, compared to Patterson Lake's average TDS, total nitrogen, and total phosphorus concentrations of 1005 mg/L, 1.093 mg/L, and 0.125 mg/L respectively, for the period 2005-2006.

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Patterson Lake and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight in algae, is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were 17 water quality sample results for Patterson Lake collected between July 1992 and February 2006 where the N:P ratio could be calculated. The results from this analysis indicate that while Patterson Lake is most often nitrogen limited, the N:P relationships in Patterson Lake are dynamic and variable based on the time of the year and the natural processes occurring at the time of sampling (Figure 5).

Table 2. Statistical Summary of Patterson Lake's Historical Water Quality Data Collected Between 1991 and 2002.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	12	298	111	536	118
Total Ammonia as N	mg/L	11	0.206	0.010[1]	0.395	0.152
Bicarbonate (HCO_3)	mg/L	12	333	136	646	140
Calcium (Ca)	mg/L	12	52	25	84	18
Carbonate (CO_3)	mg/L	12	15	1[1]	39	15
Chloride (Cl)	mg/L	12	14.0	5.8	26.2	5.9
Chlorophyll-a	µg/L	13	21.5	3.0	68.0	25.3
Specific Conductance	µmhos	12	1827	567	2840	795
Total Dissolved Solids	mg/L	12	1278	335	2030	586
Total Hardness as ($CaCO_3$)	mg/L	12	294	113	483	117
Hydroxide (OH)	mg/L	9	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	12	0.894	0.031	3.280	1.106
Magnesium (Mg)	mg/L	12	40.0	11.6	66.6	18.0
Nitrate + Nitrite as N	mg/L	8	0.125	0.001[1]	0.440	0.183
Total Kjeldahl Nitrogen as N	mg/L	7	1.595	0.856	2.910	0.693
Total Nitrogen as N	mg/L	5	1.565	0.876	2.360	0.541
pH		12	8.41	7.46	9.00	0.51
Total Phosphorus as P	mg/L	12	0.193	0.082	0.367	0.092
Potassium (K)	mg/L	12	11.7	7.9	14.0	1.8
Sodium (Na)	mg/L	12	314	62	514	152
Sulfate (SO4)	mg/L	12	665	141	1130	342

[1]Equal to lower detection limit

N:P ratios for Patterson Lake ranged from a low of 4 to a high of 17 with an average of 9.5. Of the 17 samples collected on Patterson Lake, all but three of the samples were below an N:P ratio of 15 indicating nitrogen limitation.

Trophic Status Assessment: Based on chlorophyll-a, data collected from July 1993 and July 2005, Patterson Lake's trophic status is eutrophic. TSI chlorophyll-a scores ranged from a low of 41 to a high of 72 and an average of 53 (Figure 6).

A total of 15 total phosphorus samples, 13 chlorophyll-a samples, and seven Secchi disk transparency measurements collected between 1991 and 2005 were used to evaluate trends in the trophic status of Patterson Lake. Based on a visual assessment of the data, Patterson Lake's trophic status is stable (Figure 6).

Table 3. Statistical Summary of Water Quality from Reservoirs in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	408	309	101	982	130
Total Ammonia as N	mg/L	469	0.097	0.001[1]	2.440	0.200
Bicarbonate (HCO_3)	mg/L	408	318	14	1040	150
Calcium (Ca)	mg/L	408	50	5	160	26
Carbonate (CO_3)	mg/L	402	30	1[1]	197	30
Chloride (Cl)	mg/L	408	13.3	0.3	74.5	8.8
Chlorophyll-a	µg/L	321	21.2	1.5	218.0	27.9
Specific Conductance	µmhos	428	1733	262	5880	959
Total Dissolved Solids	mg/L	409	1176	147	5110	750
Total Hardness as ($CaCO_3$)	mg/L	408	397	45	1850	260
Hydroxide (OH)	mg/L	337	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	409	0.179	0.007	4.110	0.334
Magnesium (Mg)	mg/L	408	66.0	5.6	353.0	49.6
Nitrate + Nitrite as N	mg/L	395	0.048	0.001[1]	0.790	0.092
Total Kjeldahl Nitrogen as N	mg/L	359	1.556	0.365	7.720	0.779
Total Nitrogen as N	mg/L	302	1.472	0.405	4.840	0.562
pH		428	8.61	6.73	9.87	0.56
Total Phosphorus as P	mg/L	475	0.135	0.004	3.160	0.205
Potassium (K)	mg/L	408	14.6	4.2	39.2	6.3
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[1]Equal to Minimum Reporting Limit

[2]Data Collected from 69 Reservoirs between 1991 and 2007

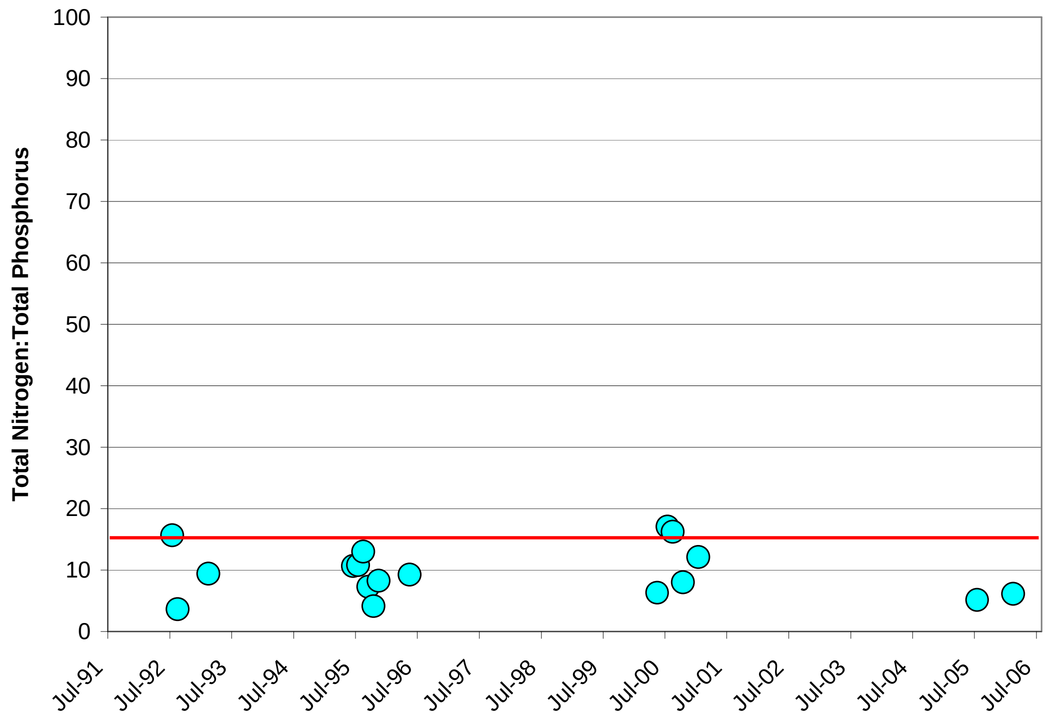

Figure 5. Total Nitrogen to Total Phosphorus Ratios in Patterson Lake (1992-2006).

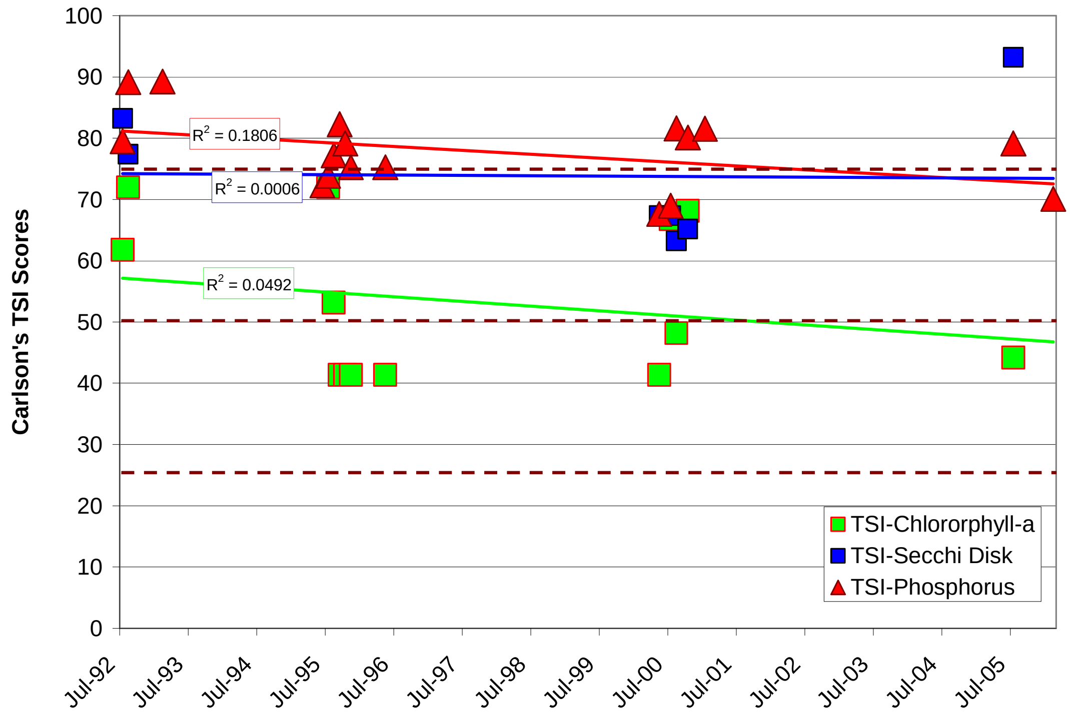

Figure 6. TSI Scores and Temporal Trends for Patterson Lake from 1991 to 2005.

South Golden Lake, Steele County

BACKGROUND

Location: South Golden Lake is an enhanced, natural lake located 10 miles east, 3 miles north, and ½ mile west of Finley, North Dakota (Figure 1). South Golden Lake is managed by the North Dakota Game and Fish Department.

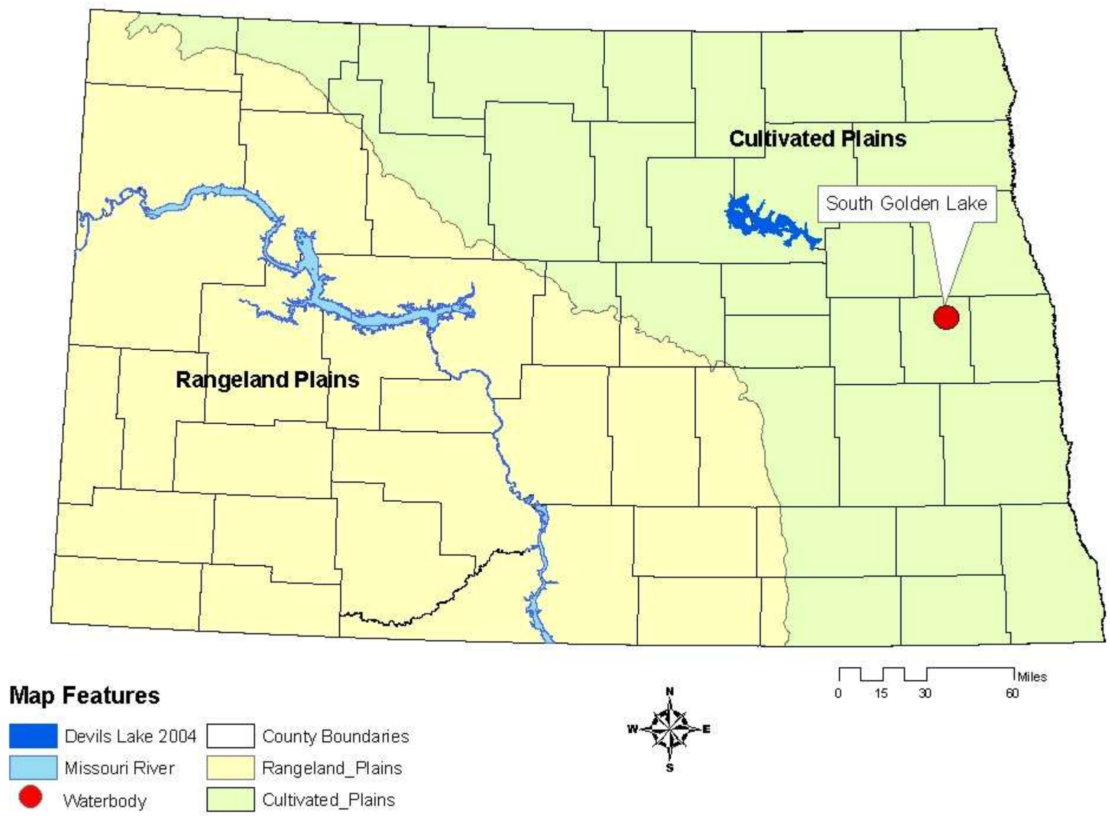

Figure 1. Location of South Golden Lake.

Physiographic/Ecological Setting: South Golden Lake has a surface area of 327.1 acres, a maximum depth of 18.0 ft and an average depth 12.6 ft (Figure 2). South Golden Lake's watershed is 10,940 acres and it lies in the Northern Glaciated Plains Level III Ecoregion, part of the broader Cultivated Plains region (Figure 1). This region is the transitional zone between tall and mixed grass prairie. The region has numerous wetlands essential for spring and fall migrations of wetland dependent birds. Flood plain slopes and hillsides are usually native grass while the uplands and flood plains proper have mostly been converted to small grains, row crops and alfalfa.

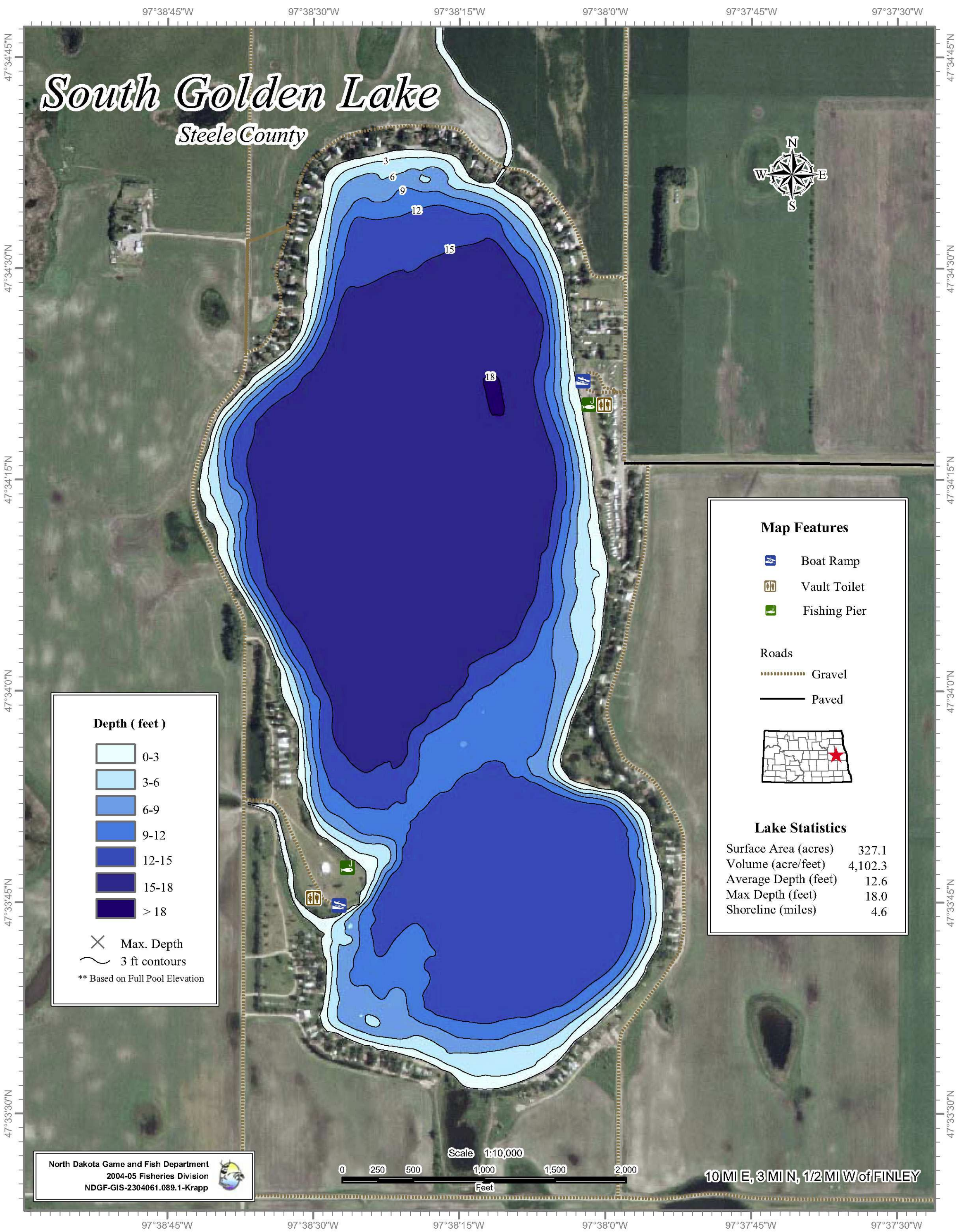

Figure 2. Contour Map of South Golden Lake (Map Courtesy of North Dakota Game & Fish Department).

Construction History: South Golden Lake is a natural wetland located on the western edge of the Red River Valley physiographic region. It was too shallow to support a fishery when in 1956 a diversion dam and canal system was constructed on Beaver Creek to divert flows to South Golden Lake. South Golden Lake was enhanced by this project to a surface area of 323.5 acres and a maximum depth of 18 feet (Figure 2). A second restoration project was initiated in the 1980's involving the use of Golden Rush Lake as a nutrient filtration system.

Recreational Facilities: Recreational facilities at South Golden Lake include two boat ramps, boat and vehicle parking, and two fishing piers. Public access on the southeast side of the lake includes parking, vaulted restrooms, and a fishing pier. The northwest side of the lake also includes parking, an additional boat ramp, a swimming beach, and a fishing pier.

Water Quality Standards Classification: South Golden Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a "warm water fishery" or "waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present."

Historical and Current Fishery: South Golden Lake's fishery over time has included walleye, northern pike, and yellow perch stocked by the NDG&F. Currently, all three species are managed in South Golden Lake.

Historical Water Quality Sampling: Historical water quality data includes results from 48 samples collected from 1990 through 2007.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for South Golden Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural or enhanced lakes in the Cultivated Plains region.

Temperature and Dissolved Oxygen Profile Results: There are six temperature and dissolved oxygen profiles for South Golden Lake collected from 1991-2006. Temperature and oxygen profiles are presented for two time periods, 1991-1992, and 2005-2006 (Figures 3 and 4). The profile data shows that South Golden Lake does not experience thermal stratifications. It also identifies that dissolved oxygen concentrations can be deficient during late winter (Figure 4).

Of the six temperature and dissolved oxygen profiles collected only on 2/27/1992, was the water column consistently below the state standard for dissolved oxygen concentration of 5 mg/L. While the low dissolved oxygen during this period is concerning, there does appear to be enough dissolved oxygen to maintain aquatic life in the upper 3 meters of the water column.

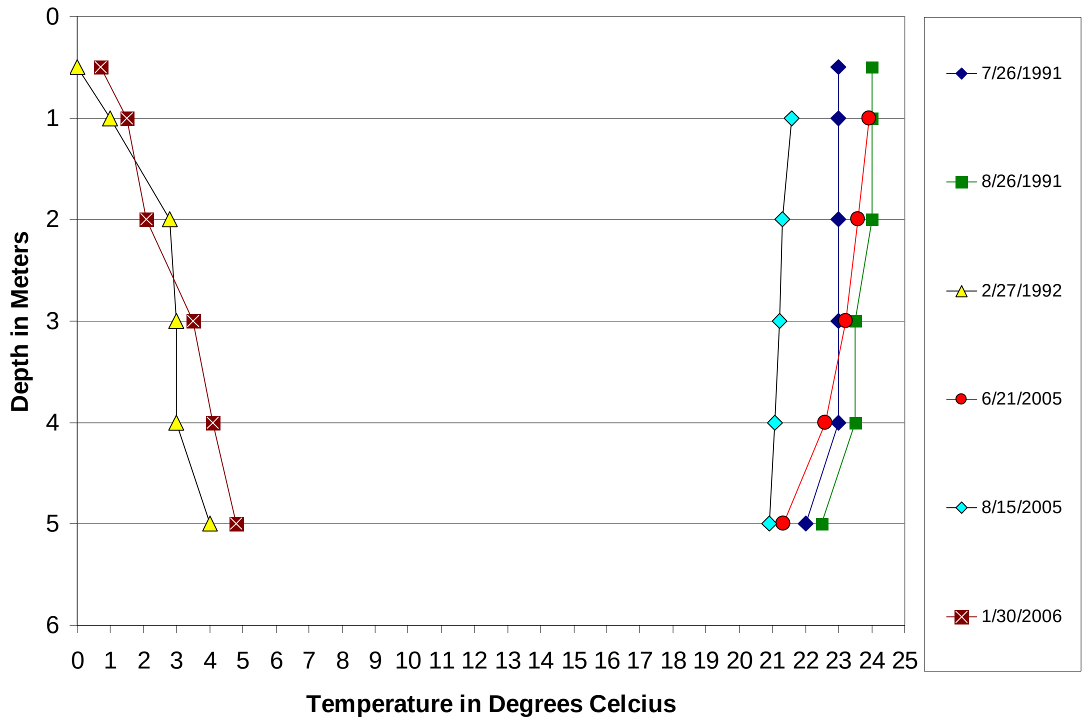

Figure 3. Temperature Profiles for South Golden Lake from 1991 to 2006.

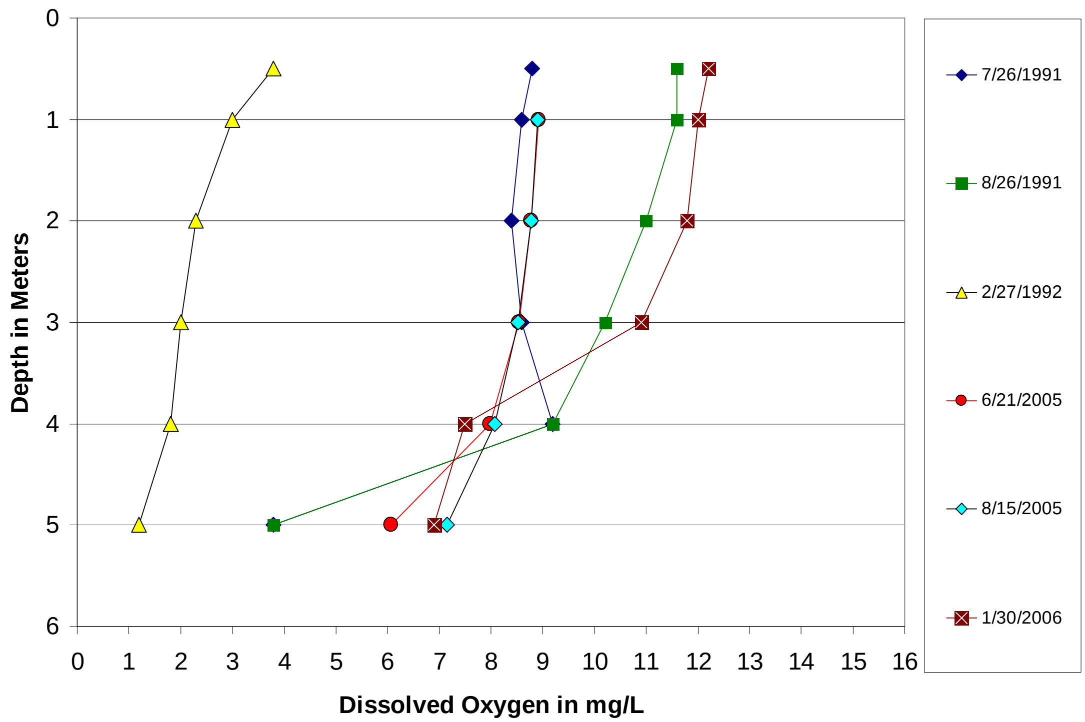

Figure 5. Dissolved Oxygen Profiles for South Golden Lake from 1991 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006 indicate South Golden Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 201 mg/L to 224 mg/L (Table 1). Based on the 2005-2006 water quality data (Table 1), South Golden Lake is sodium sulfate dominated with an average sodium concentration of 111 mg/L and an average sulfate concentration of 628 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 1110 mg/L and 1550 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.134 mg/L and 0.039 mg/L, respectively.

Table 1. Statistical Summary of South Golden Lake's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	3	210	201	224	13
Total Ammonia as N	mg/L	3	0.061	0.010[1]	0.159	0.085
Bicarbonate (HCO_3)	mg/L	3	232	191	273	41
Calcium (Ca)	mg/L	3	101.1	97.2	105.0	3.9
Carbonate (CO_3)	mg/L	3	12	1[1]	29	15
Chloride (Cl)	mg/L	3	27	26	29	2
Chlorophyll-a	µg/L	2	14.6	7.3	21.9	10.3
Specific Conductance	µmhos	3	1550	1480	1670	104
Total Dissolved Solids	mg/L	3	1110	1060	1190	70
Total Hardness as ($CaCO_3$)	mg/L	3	665	637	703	34
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	3	0.100	0.058	0.176	0.066
Magnesium (Mg)	mg/L	3	100.2	95.7	107.0	6.0
Nitrate + Nitrite as N	mg/L	3	0.057	0.020[1]	0.120	0.055
Total Kjeldahl Nitrogen as N	mg/L	3	1.077	0.921	1.320	0.213
Total Nitrogen as N	mg/L	3	1.134	0.951	1.440	0.267
pH		3	8.42	8.10	8.73	0.32
Total Phosphorus as P	mg/L	3	0.039	0.035	0.048	0.008
Potassium (K)	mg/L	3	17.0	15.3	17.9	1.5
Sodium (Na)	mg/L	3	111	106	115	5
Sulfate (SO4)	mg/L	3	628	600	677	42

[1]Equal to lower detection limit

When compared to historical (1991-2002) water quality data for South Golden Lake, it appears that concentrations of most water quality constituents have remained stable. For example, the average sulfate and sodium concentrations for the period 1991-2002 were 498 mg/L and 111 mg/L, respectively (Table 2), compared to average concentrations of 628 mg/L for sulfate and 111 mg/L for sodium recorded for the period 2005-2006 (Table 1). While not significant, average phosphorus concentrations have decreased when compared to the historical data. Historical (1991-2002) average total phosphorus concentration was 0.112 mg/L, respectively (Table 2), compared to an average concentration of 0.039 mg/L for total phosphorus, respectively.

Table 2. Statistical Summary of South Golden Lake's Historical Water Quality Data Collected Between 1991 and 2002.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	9	213	175	259	24
Total Ammonia as N	mg/L	29	0.067	0.010[1]	0.925	0.170
Bicarbonate (HCO_3)	mg/L	9	238	200	316	38
Calcium (Ca)	mg/L	9	79	61	105	15
Carbonate (CO_3)	mg/L	8	13	1[1]	28	9
Chloride (Cl)	mg/L	9	29.3	24.0	37.0	4.1
Chlorophyll-a	µg/L	27	20.8	3.0[1]	167.0	31.9
Specific Conductance	µmhos	28	1269	967	1583	126
Total Dissolved Solids	mg/L	10	925	756	1120	126
Total Hardness as ($CaCO_3$)	mg/L	9	524	422	678	88
Hydroxide (OH)	mg/L	3	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	9	0.093	0.023	0.194	0.063
Magnesium (Mg)	mg/L	9	79.2	65.3	101.0	12.8
Nitrate + Nitrite as N	mg/L	28	0.024	0.006	0.095	0.017
Total Kjeldahl Nitrogen as N	mg/L	21	1.634	0.922	4.110	0.715
Total Nitrogen as N	mg/L	15	1.360	0.942	2.090	0.299
pH		9	8.40	7.80	8.80	0.30
Total Phosphorus as P	mg/L	29	0.112	0.020[1]	0.299	0.076
Potassium (K)	mg/L	9	19.0	15.9	23.1	2.1
Sodium (Na)	mg/L	9	111	85	141	17
Sulfate (SO4)	mg/L	9	498	390	623	82

[1]Equal to lower detection limit

When compared to regional average concentrations, it appears South Golden Lake is slightly lower than that reported for all natural and enhanced lakes in the Cultivated Plains region (Table 3). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1376 mg/L, 1.440 mg/L, and 0.068 mg/L, respectively, compared to South Golden Lake's average TDS, total nitrogen, and total phosphorus concentrations of 1110 mg/L, 1.134 mg/L and 0.039 mg/L, respectively, for the period 2005-2006.

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in South Golden Lake and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight, in algae is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

Table 3. Statistical Summary of Water Quality from Natural and Enhanced Lake's in the Cultivated Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	142	346	175	1120	180
Total Ammonia as N	mg/L	230	0.098	0.001[1]	1.620	0.208
Bicarbonate (HCO_3)	mg/L	142	363	171	1040	158
Calcium (Ca)	mg/L	142	45	16	108	23
Carbonate (CO_3)	mg/L	136	31	1[1]	181	39
Chloride (Cl)	mg/L	142	105	3[1]	1260	233
Chlorophyll-a	µg/L	185	10	2[1]	167	17
Specific Conductance	µmhos	161	1819	361	11500	2071
Total Dissolved Solids	mg/L	143	1376	191	9880	1786
Total Hardness as ($CaCO_3$)	mg/L	142	507	173	1820	284
Hydroxide (OH)	mg/L	111	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	138	0.095[1]	0.007	1.010	0.123
Magnesium (Mg)	mg/L	142	95.7	28.4	413.0	68.0
Nitrate + Nitrite as N	mg/L	175	0.047	0.001	0.540	0.078
Total Kjeldahl Nitrogen as N	mg/L	128	1.504	0.080	4.110	0.609
Total Nitrogen as N	mg/L	103	1.440	0.609	2.740	0.466
pH		142	8.55	7.75	9.33	0.36
Total Phosphorus as P	mg/L	230	0.068	0.004[1]	1.460	0.118
Potassium (K)	mg/L	142	30	8	179	37
Sodium (Na)	mg/L	142	255	5	2570	498
Sulfate (SO4)	mg/L	142	591	7	3880	807

[1]Equal to lower detection limit
[2]Data Collected from 49 Natural Lakes between 1991 and 2007

There are 48 water quality sample sets for South Golden Lake between January 1991 and March 2006, where the N:P ration could be calculated. The results from this analysis indicate that South Golden Lake is most often phosphorus limited (Figure 5).

N:P ratios for South Golden Lake ranged from a low of 5 to a high of 101 with an average of 27. The majority of the samples collected were above a ratio of 15 indicating phosphorus is limiting primary production.

Trophic Status Assessment: Based on limited chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005, South Golden Lake's current trophic status is mesotrophic to eutrophic. TSI scores ranged from a low of 37 based on Secchi disk transparency, to a high of 61 based on Chlorophyll-a. The trophic status score based on total phosphorus was similar to that of Chlorophyll-a, at 55 (Figure 6).

A total of 44 total phosphorus samples, 29 Chlorophyll-a samples, and three Secchi disk transparency measurements collected from 1991-2005, were used to evaluate trends in the trophic status of South Golden Lake. Based on a visual assessment of the data, South Golden Lake's trophic status is improving (Figure 6).

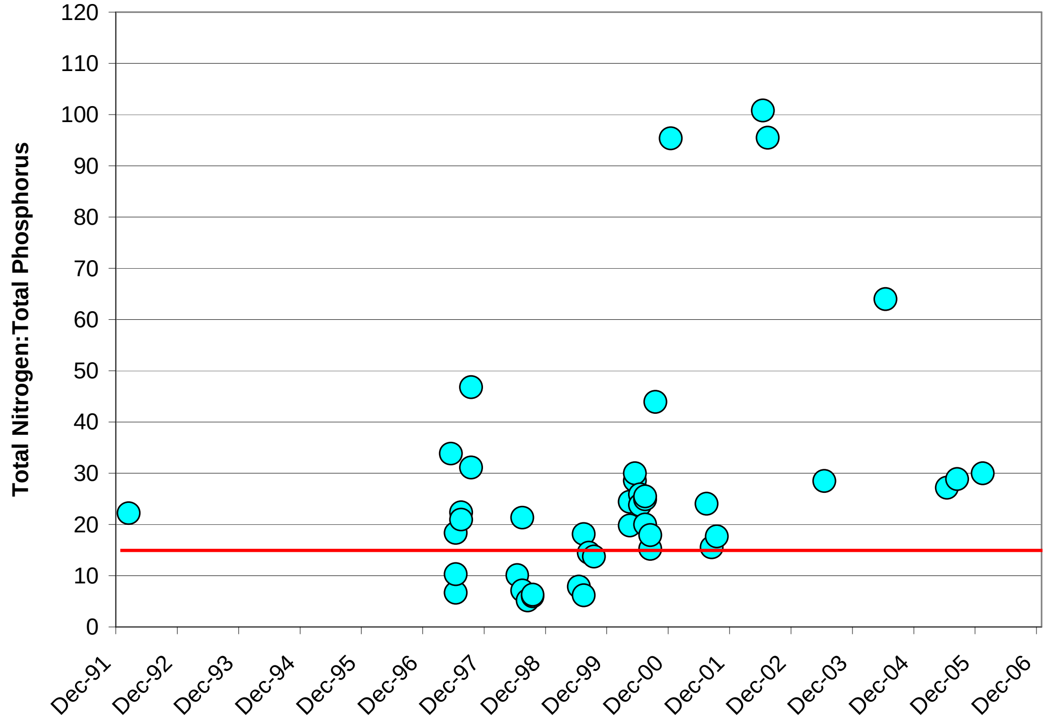

Figure 5. Total Nitrogen to Total Phosphorus Ratios in South Golden Lake (1991-2006).

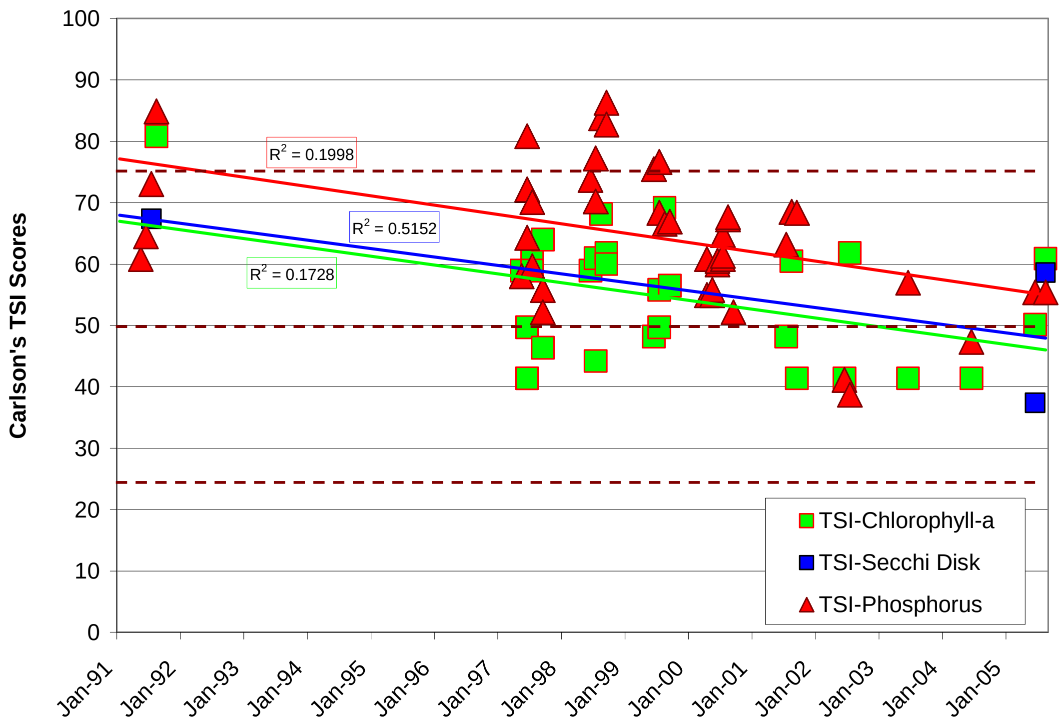

Figure 6. TSI Scores and Temporal Trends for South Golden Lake from 1991 to 2005.

Spiritwood Lake, Stutsman County

BACKGROUND

Location: Spiritwood Lake is a natural lake located 10 miles north and 4 miles east of Jamestown, North Dakota (Figure 1). Spiritwood Lake is managed by the North Dakota Game and Fish Department.

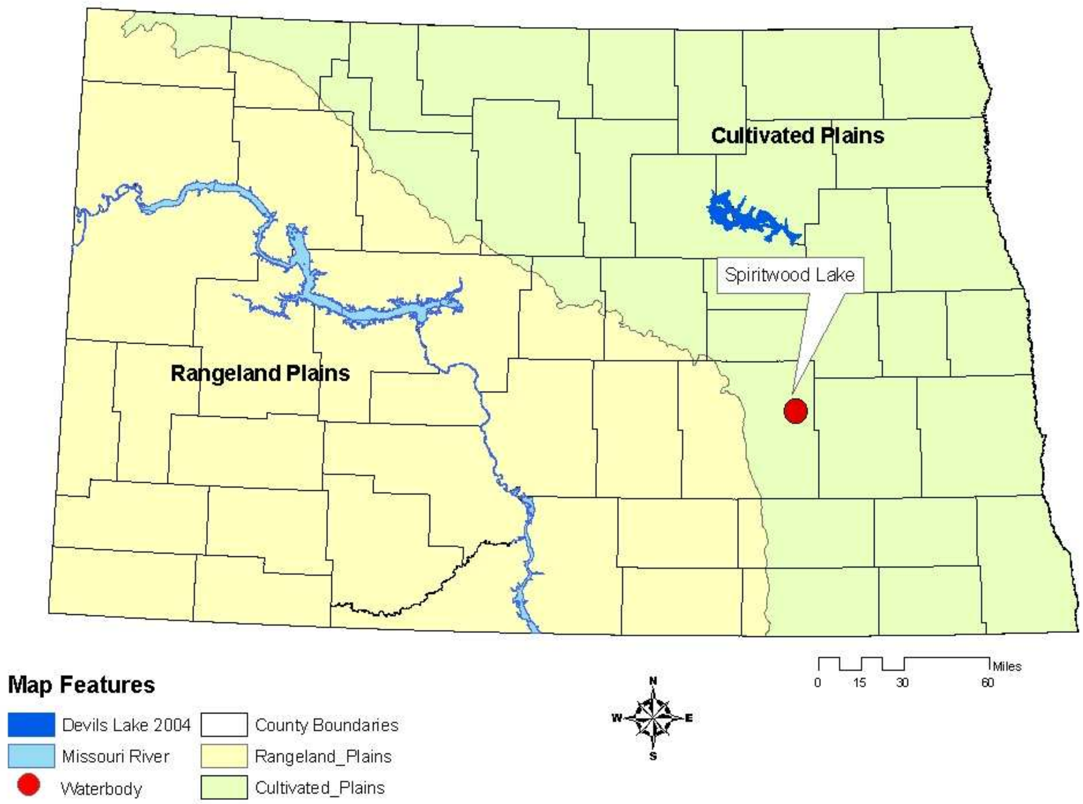

Figure 1. Location of Spiritwood Lake.

Physiographic/Ecological Setting: Spiritwood Lake has a surface area of 488.8 acres, a maximum depth of 55.5 ft and an average depth 31.0 ft (Figure 2). Spiritwood Lake's watershed lies within the Northern Glaciated Plains Level III Ecoregion, part of the broader Cultivated Plains region (Figure 1). This region is the transitional zone between tall and mixed grass prairie. The region has numerous wetlands essential for spring and fall migrations of wetland dependent birds. Flood plain slopes and hillsides are usually native grass while the uplands and flood plains proper have mostly been converted to small grains, row crops and alfalfa.

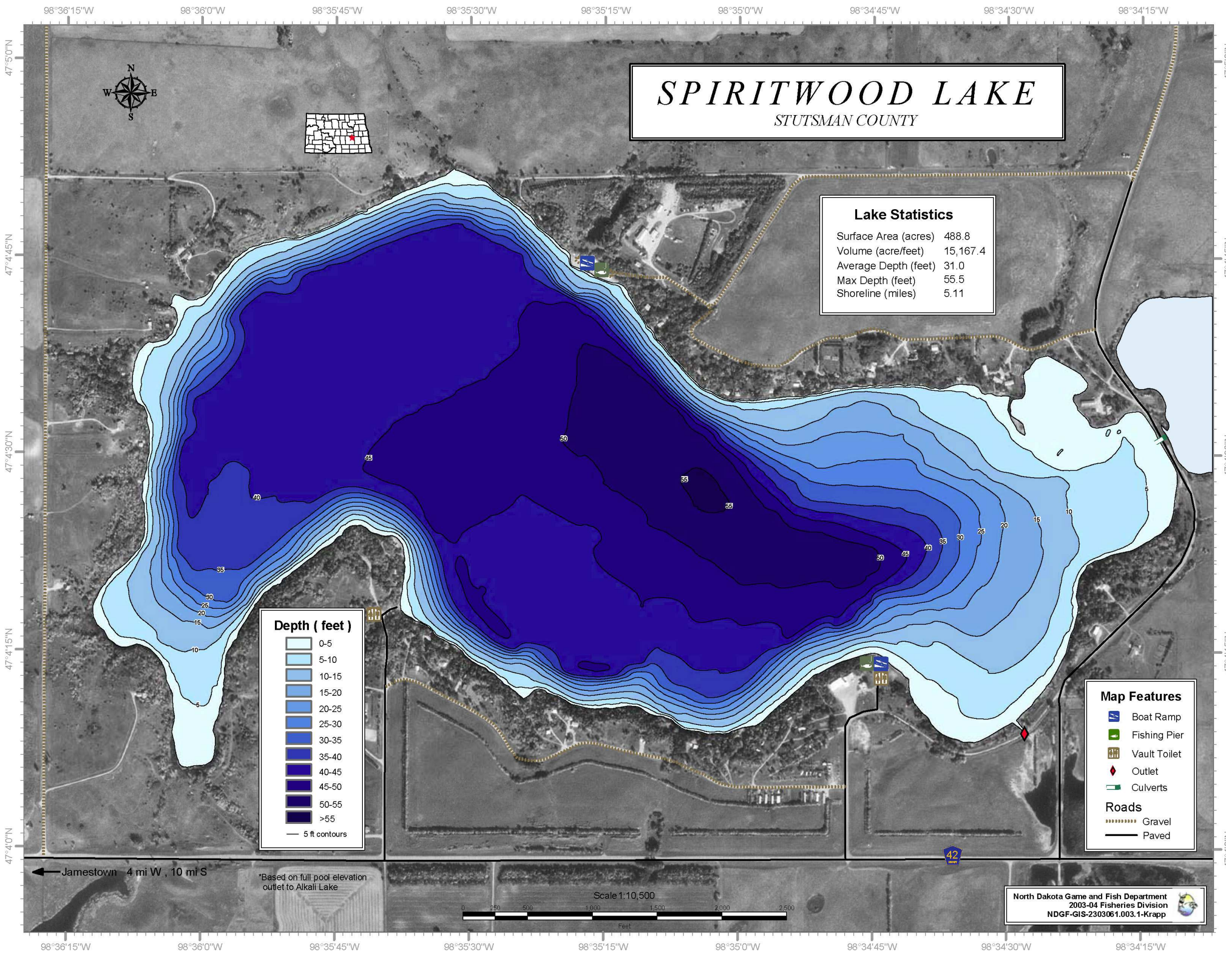

Figure 2. Contour Map of Spiritwood Lake (Map Courtesy of North Dakota Game and Fish Department).

Recreational Facilities: Recreational facilities at Spiritwood Lake include two boat ramps, boat and vehicle parking, and two fishing piers. Public access on the southeast side of the lake includes parking, vaulted restrooms, and a fishing pier. The north side of the lake also includes parking, an additional boat ramp, and a fishing pier.

Water Quality Standards Classification: Spiritwood Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a "warm water fishery" or "waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present."

Historical and Current Fishery: Spiritwood Lake's fishery over time has included walleye, northern pike, and yellow perch stocked by the NDG&F. Currently, all three species are managed in Spiritwood Lake.

Historical Water Quality Sampling: Historical water quality data includes results from 12 samples collected from 1990 through 2007.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Spiritwood Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural or enhanced lakes in the Cultivated Plains region.

Temperature and Dissolved Oxygen Profile Results: There were 12 temperature and dissolved oxygen profiles for Spiritwood Lake collected from 1990-2007. Temperature and oxygen profiles are presented for three time periods, 1990-1991, 1996, and 2006-2007 (Figures 3 and 4).

The profile data shows that during thermal stratification Spiritwood Lake experiences rapid oxygen decay, and occasionally drops below the state's water quality standard of 5 mg/L. Of the 12 profiles, seven samples, collected on 2/21/1990, 9/14/1990, 8/22/1996, 1/26/2006, 7/19/2006, 2/21/2007, and 8/1/2007, dropped below the state standard of 5 mg/L. While the rapid loss of dissolved oxygen during these periods is concerning, there does appear to be sufficient dissolved oxygen to maintain aquatic life in the upper four to six meters of the water.

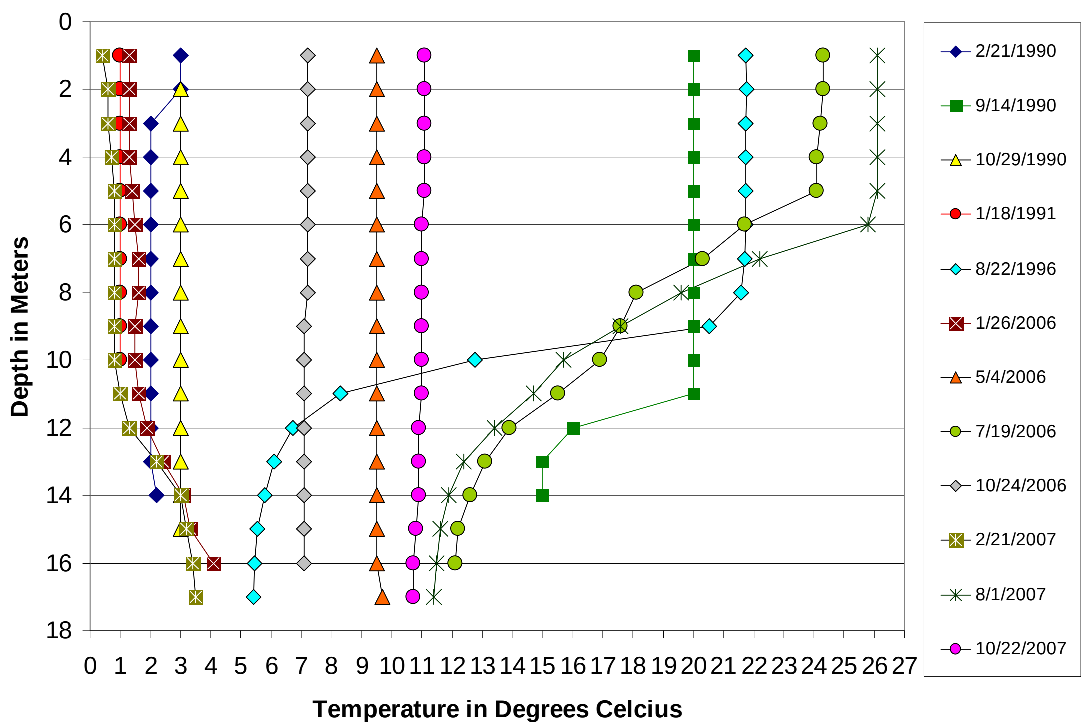

Figure 3. Temperature Profiles for Spiritwood Lake from 1990 to 2007.

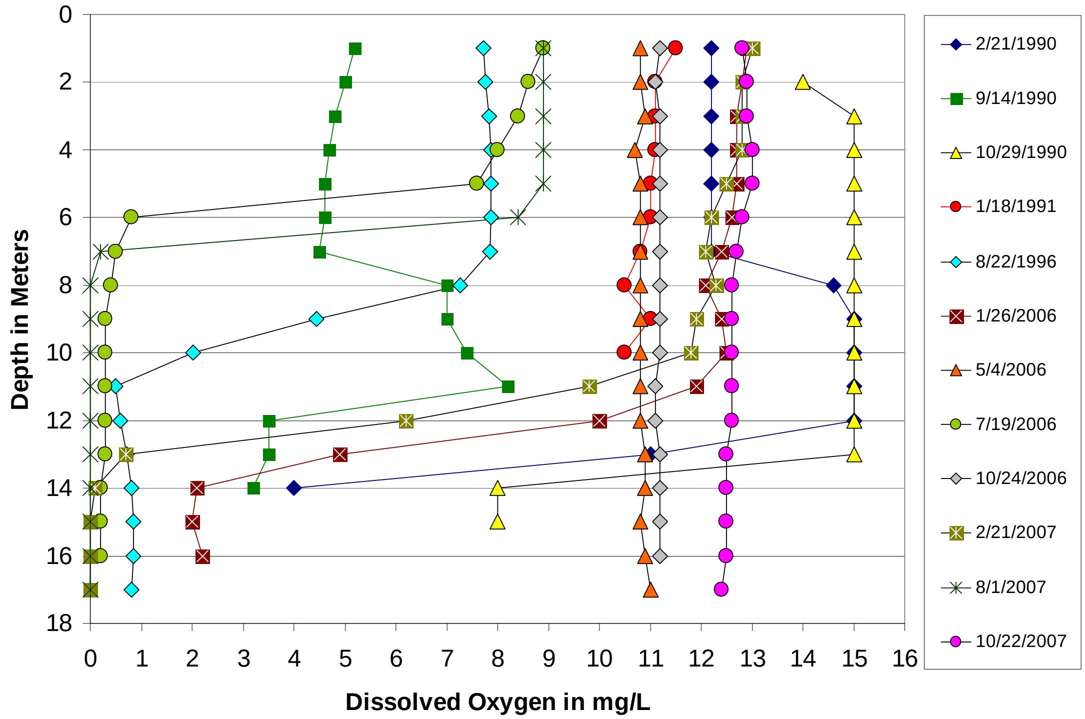

Figure 4. Dissolved Oxygen Profiles for Spiritwood Lake From 1990 to 2007.

General Water Quality: Water quality data collected by the NDG&F in 2006-2007 indicate Spiritwood Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 241 to 336 mg/L (Table 1). Based on the 2006-2007 water quality data (Table 1), Spiritwood Lake is sodium sulfate dominated with an average sodium concentration of 232 mg/L and an average sulfate concentration of 757 mg/L. The average TDS concentration and specific conductance measurement for the 2006-2007 sampling period were 1450 mg/L and 2083 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.715 mg/L and 0.047 mg/L, respectively.

When compared to historical (1992-2002) water quality data for Spiritwood Lake, it appears that concentrations of most water quality constituents have remained stable. For example, the average sulfate and sodium concentrations for the period 1992-2002 were 721 mg/L and 226 mg/L, respectively (Table 2), compared to average concentrations of 757 mg/L for sulfate and 232 mg/L for sodium recorded for the period 2006-2007 (Table 1).

While not significant, average total nitrogen and total phosphorus concentrations have slightly fluctuated when compared to the historical data. Historical (1992-2002) average total nitrogen and total phosphorus concentrations were 2.670 mg/L and 0.018 mg/L, respectively (Table 2), compared to average concentrations of 1.715 mg/L for total nitrogen and 0.047 mg/L for total phosphorus.

Table 1. Statistical Summary of Spiritwood Lake's 2006-2007 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	6	278	241	336	34
Total Ammonia as N	mg/L	6	0.132	0.010[1]	0.317	0.116
Bicarbonate (HCO_3)	mg/L	6	308	227	405	61
Calcium (Ca)	mg/L	6	39.7	32.3	46.6	6.3
Carbonate (CO_3)	mg/L	6	15	2[1]	33	11
Chloride (Cl)	mg/L	6	98	95	103	3
Chlorophyll-a	µg/L	6	4.7	1.5[1]	12.1	4.3
Specific Conductance	µmhos	6	2083	1980	2220	83
Total Dissolved Solids	mg/L	6	1450	1370	1570	71
Total Hardness as ($CaCO_3$)	mg/L	6	611	543	688	48
Hydroxide (OH)	mg/L	6	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	6	0.138	0.015	0.596	0.225
Magnesium (Mg)	mg/L	6	124.3	110.0	139.0	9.5
Nitrate + Nitrite as N	mg/L	6	0.077	0.020[1]	0.170	0.055
Total Kjeldahl Nitrogen as N	mg/L	6	1.638	1.320	2.160	0.348
Total Nitrogen as N	mg/L	6	1.715	1.340	2.260	0.370
pH		6	8.56	8.32	8.83	0.19
Total Phosphorus as P	mg/L	6	0.047	0.008	0.149	0.051
Potassium (K)	mg/L	6	29.2	20.9	31.9	4.2
Sodium (Na)	mg/L	6	232	212	250	14
Sulfate (SO4)	mg/L	6	757	726	812	37

[1]Equal to lower detection limit

When compared to the regional average Spiritwood Lake is comparable to that reported for most natural and enhanced lakes in the Cultivated Plains region (Table 3). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1376 mg/L, 1.440 mg/L, and 0.068 mg/L, respectively, compared to Spiritwood Lake's average TDS, total nitrogen, and total phosphorus concentrations of 1450 mg/L, 1.715 mg/L and 0.047 mg/L, respectively, for the period 2006-2007.

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Spiritwood Lake and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight, in algae is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There are eight water quality sample sets for Spiritwood Lake between March 1996 and August 2007, where the N:P ration could be calculated. The results from this analysis indicate that Spiritwood Lake is most often phosphorus limited (Figure 5).

N:P ratios for Spiritwood Lake ranged from a low of 13 to a high of 168 with an average of 64. All but two samples collected were above a ratio of 15 indicating phosphorus is limiting primary production.

Table 2. Statistical Summary of Spiritwood Lake's Historical Water Quality Data Collected in 1996.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	1	364	364	364	
Total Ammonia as N	mg/L	1	0.010[1]	0.010[1]	0.010[1]	
Bicarbonate (HCO_3)	mg/L	1	302	302	302	
Calcium (Ca)	mg/L	1	39	39	39	
Carbonate (CO_3)	mg/L	1	70	70	70	
Chloride (Cl)	mg/L	1	104.0	104.0	104.0	
Chlorophyll-a	µg/L		NC[2]	NC[2]	NC[2]	
Specific Conductance	µmhos	1	2120	2120	2120	
Total Dissolved Solids	mg/L	1	1460	1460	1460	
Total Hardness as ($CaCO_3$)	mg/L	1	574	574	574	
Hydroxide (OH)	mg/L	1	1[1]	1[1]	1[1]	
Iron (Fe)	mg/L	1	0.007	0.007	0.007	
Magnesium (Mg)	mg/L	1	116.0	116.0	116.0	
Nitrate + Nitrite as N	mg/L	2	0.030	0.020[1]	0.040	0.014
Total Kjeldahl Nitrogen as N	mg/L	2	2.640	1.510	3.770	1.598
Total Nitrogen as N	mg/L	2	2.670	1.550	3.790	1.584
pH		1	8.89	8.89	8.89	
Total Phosphorus as P	mg/L	1	0.018	0.018	0.018	
Potassium (K)	mg/L	1	33.4	33.4	33.4	
Sodium (Na)	mg/L	1	226	226	226	
Sulfate (SO4)	mg/L	1	721	721	721	

[1]Equal to lower detection limit
[2]No data collected

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2006-2007, Spiritwood Lake's current trophic status is mesotrophic to eutrophic. TSI scores ranged from a low of 35 based on Chlorophyll-a, to a high of 63 based on Secchi disk transparency. The trophic status score based on total phosphorus was 57 similar to that estimated based on Secchi disk transparency (Figure 6).

A total of six total phosphorus samples, six Chlorophyll-a samples, and four Secchi disk transparency measurements collected during the open water periods from 2006-2007 were used to evaluate trends in the trophic status of Spiritwood Lake. Based on a visual assessment of the data, Spiritwood Lake's trophic status is stable.

Table 3. Statistical Summary of Water Quality from Natural and Enhanced Lake's in the Cultivated Plains Ecological Region of North Dakota.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	142	346	175	1120	180
Total Ammonia as N	mg/L	230	0.098	0.001[1]	1.620	0.208
Bicarbonate (HCO_3)	mg/L	142	363	171	1040	158
Calcium (Ca)	mg/L	142	45	16	108	23
Carbonate (CO_3)	mg/L	136	31	1[1]	181	39
Chloride (Cl)	mg/L	142	105	3[1]	1260	233
Chlorophyll-a	µg/L	185	10	2[1]	167	17
Specific Conductance	µmhos	161	1819	361	11500	2071
Total Dissolved Solids	mg/L	143	1376	191	9880	1786
Total Hardness as ($CaCO_3$)	mg/L	142	507	173	1820	284
Hydroxide (OH)	mg/L	111	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	138	0.095[1]	0.007	1.010	0.123
Magnesium (Mg)	mg/L	142	95.7	28.4	413.0	68.0
Nitrate + Nitrite as N	mg/L	175	0.047	0.001	0.540	0.078
Total Kjeldahl Nitrogen as N	mg/L	128	1.504	0.080	4.110	0.609
Total Nitrogen as N	mg/L	103	1.440	0.609	2.740	0.466
pH		142	8.55	7.75	9.33	0.36
Total Phosphorus as P	mg/L	230	0.068	0.004[1]	1.460	0.118
Potassium (K)	mg/L	142	30	8	179	37
Sodium (Na)	mg/L	142	255	5	2570	498
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[1]Equal to lower detection limit
[2]Data Collected from 49 Natural Lakes between 1991 and 2007

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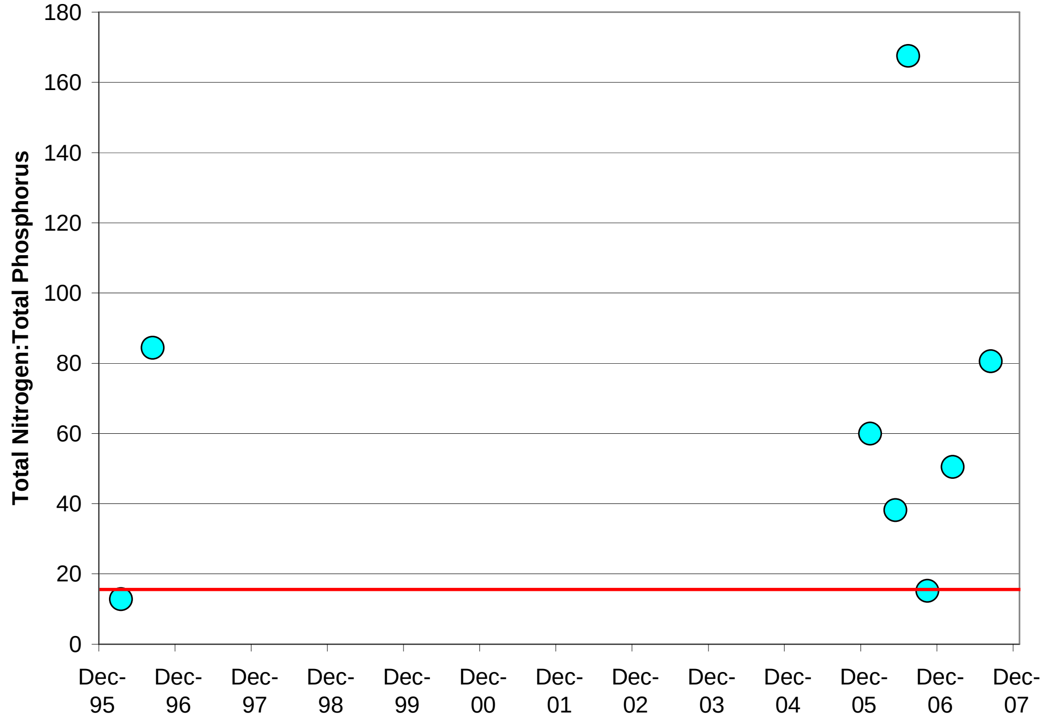

Figure 5. Total Nitrogen to Total Phosphorus Ratios in Spiritwood Lake (1996-2007).

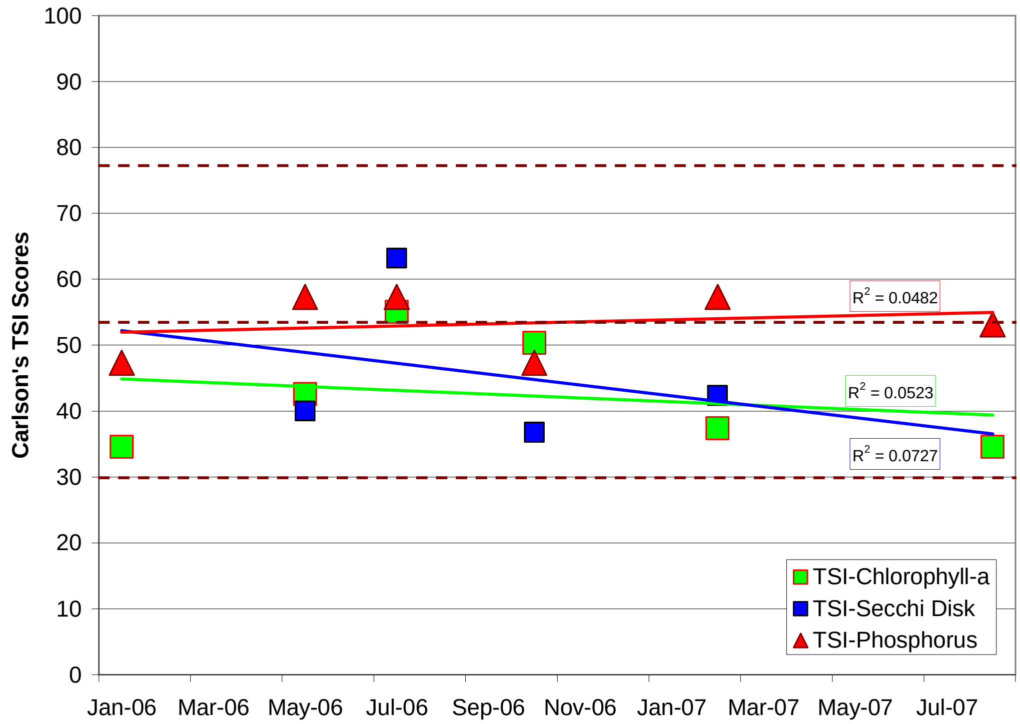

Figure 6. TSI Scores and Temporal Trends for Spiritwood Lake from 2006 to 2007.

Hiddenwood Lake, Ward County

BACKGROUND

Location: Hiddenwood Lake is a natural lake located 7 miles south of Makoti, North Dakota (Figure 1). Hiddenwood Lake is managed by the North Dakota Game and Fish Department.

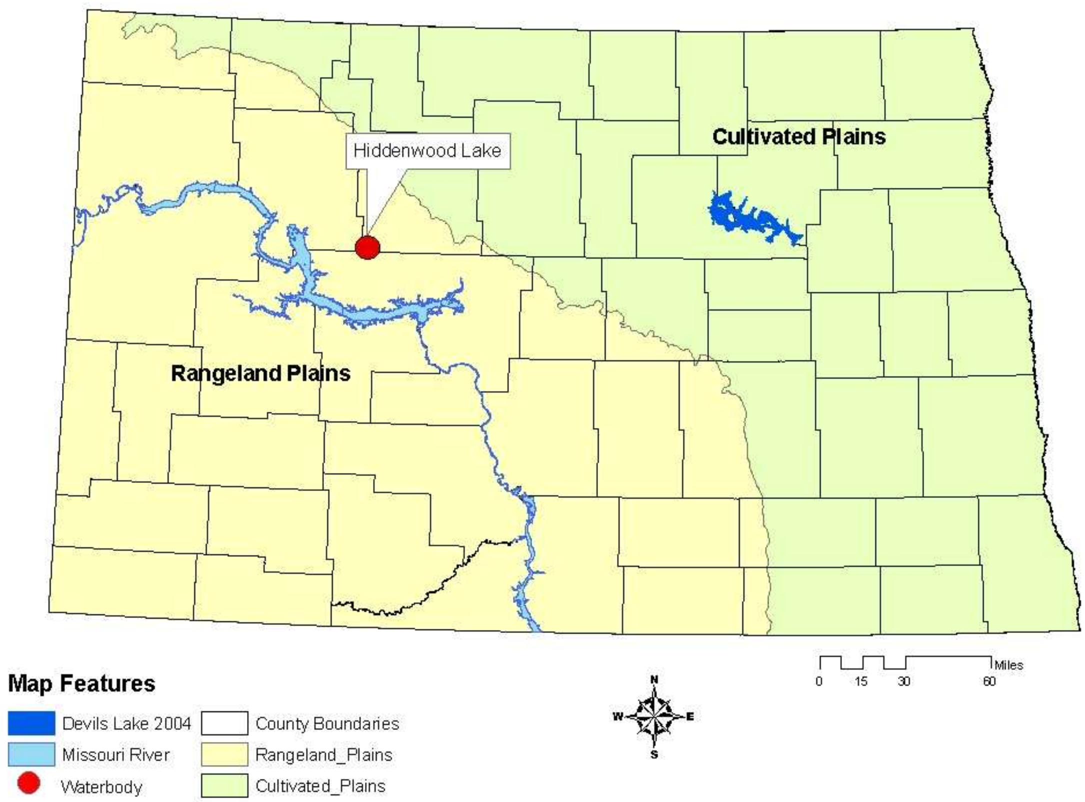

Figure 1. Location of Hiddenwood Lake.

Physiographic/Ecological Setting: Hiddenwood Lake has a surface area of 127.9 acres, a maximum depth of 17.9 ft, and an average depth of 13.7 ft (Figure 2). Hiddenwood Lake's watershed lies within the Northwestern Glaciated Plains (NGP) Level III ecoregion, part of the broader Rangeland Plains region. The NGP marks the western most extent of continental glacial advancement. The geological youthful landscape has significant surface irregularities and high concentrations of wetlands. The rise in elevation along the eastern edge of this ecoregion defines the boundary of the Great Plains and to the west the Northwestern Great Plains (USEPA 1994).

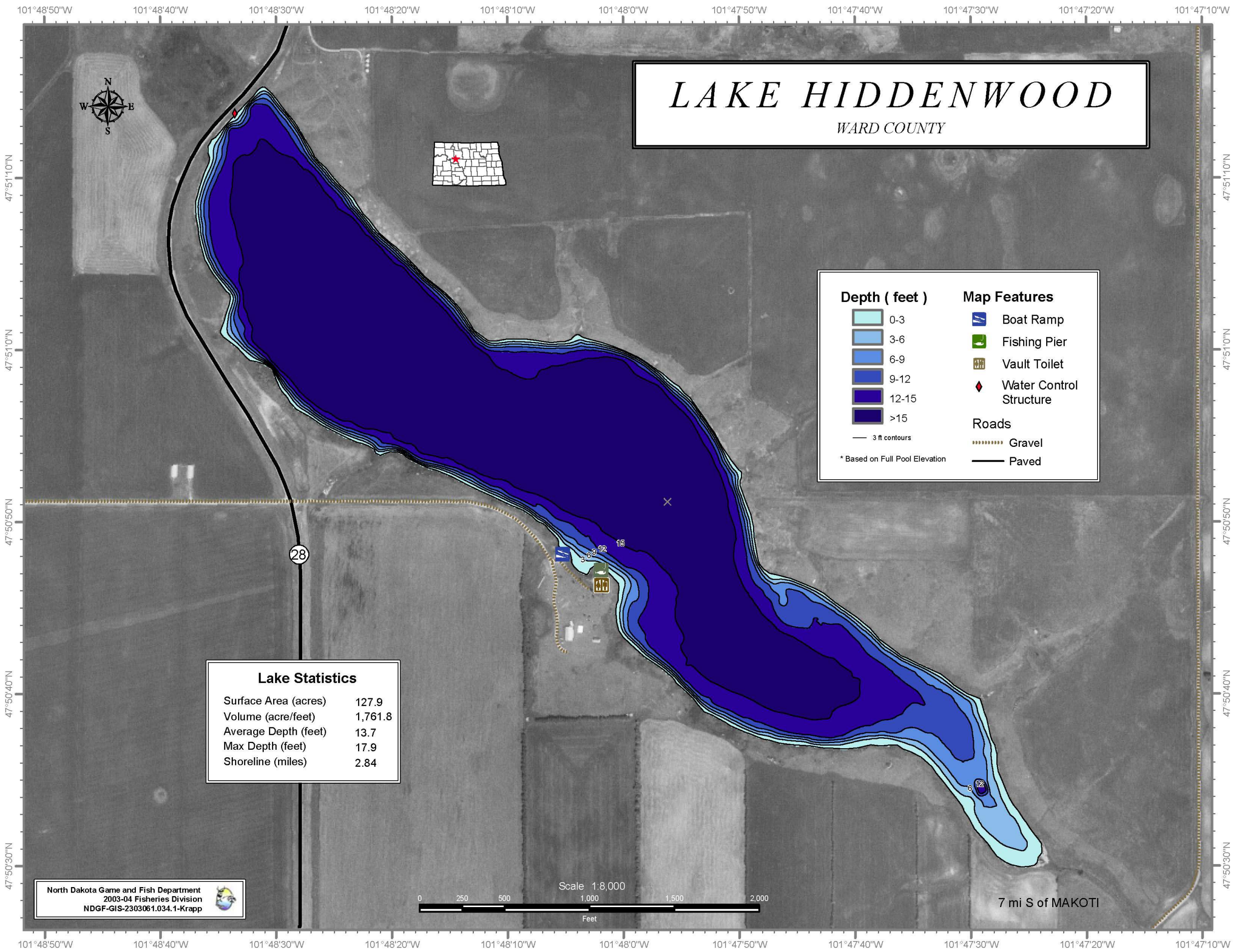

Figure 2. Contour Map of Hiddenwood Lake (Map Courtesy of North Dakota Game and Fish Department).

Recreational Facilities: Recreational facilities at Hiddenwood Lake include a boat ramp, boat and vehicle parking, and a fishing pier. Public access is on the southwest side of the lake, which includes parking, vaulted restrooms, and a fishing pier.

Water Quality Standards Classification: Hiddenwood Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a "warm water fishery" or "waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present."

Historical and Current Fishery: Hiddenwood Lake's fishery over time has included walleye, northern pike, and yellow perch stocked by the NDG&F. Currently, all three species are managed in Hiddenwood Lake.

Historical Water Quality Sampling: Historical water quality data includes results from five samples collected from 1992 through 1993.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Hiddenwood Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural or enhanced lakes in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There were seven temperature and dissolved oxygen profiles for Hiddenwood Lake collected from 1992-2006. Temperature and oxygen profiles are presented for two time periods, 1992-1993 and 2005-2006 (Figures 3 and 4).

The profile data shows that Hiddenwood Lake is normally well oxygenated and not thermally stratified. Of the seven oxygen profiles collected all remained above the state's water quality standard of 5 mg/L, with the exception of the very bottom depth on March 3, 1993.

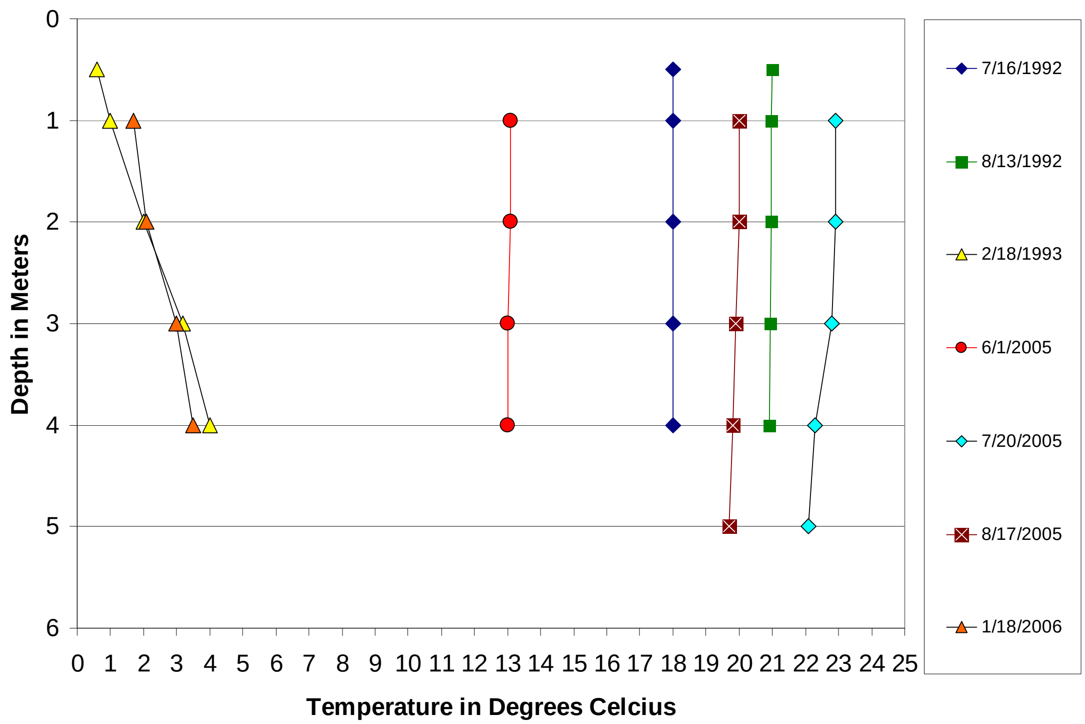

Figure 3. Temperature Profiles for Hiddenwood Lake from 1992 to 2006.

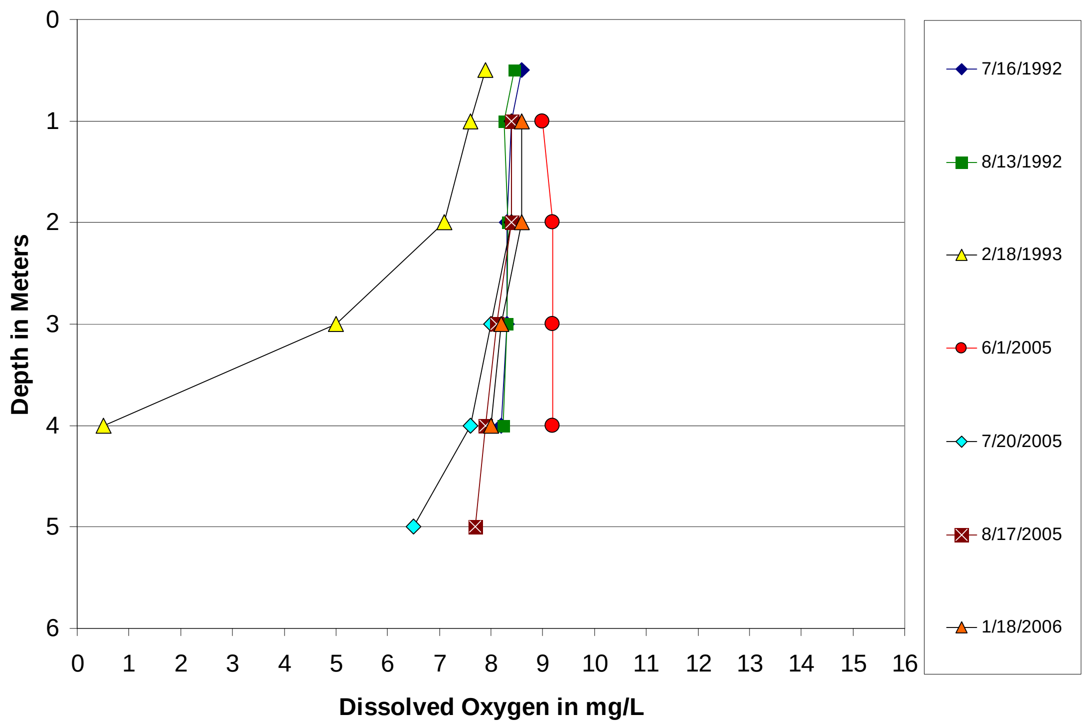

Figure 4. Dissolved Oxygen Profiles for Hiddenwood Lake from 1992 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006 indicate Hiddenwood Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 281 to 340 mg/L (Table 1). Based on the 2005-2006 water quality data (Table 1), Hiddenwood Lake is sodium bicarbonate dominated with an average sodium concentration of 41 mg/L and an average bicarbonate concentration of 302 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 543 mg/L and 884 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 0.906 mg/L and 0.013 mg/L, respectively.

When compared to historical water quality data for Hiddenwood Lake, it appears that concentrations of most water quality constituents have decreased. For example, the historical average bicarbonate and sodium concentrations were 393 mg/L and 53 mg/L, respectively (Table 2), compared to average concentrations of 302 mg/L for bicarbonate and 41 mg/L for sodium recorded for the period 2005-2006 (Table 1).

Average total nitrogen and total phosphorus concentrations have also decreased when compared to the historical data. Historical average total nitrogen and total phosphorus concentrations were 1.201 mg/L and 0.058 mg/L, respectively (Table 2), compared to current average concentrations of 0.906 mg/L and 0.013 mg/L for total nitrogen and total phosphorus, respectively.

Table 1. Statistical Summary of Hiddenwood Lake's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	300	281	340	27
Total Ammonia as N	mg/L	4	0.016	0.010[1]	0.030	0.010
Bicarbonate (HCO_3)	mg/L	4	302	282	349	32
Calcium (Ca)	mg/L	4	33.2	29.0	39.1	4.9
Carbonate (CO_3)	mg/L	4	32	30	34	2
Chloride (Cl)	mg/L	4	19	18	22	2
Chlorophyll-a	µg/L	3	6.6	2.0[1]	13.0	5.7
Specific Conductance	µmhos	4	884	828	995	77
Total Dissolved Solids	mg/L	4	543	510	612	48
Total Hardness as ($CaCO_3$)	mg/L	4	408	378	464	40
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	4	0.110	0.099	0.123	0.011
Magnesium (Mg)	mg/L	4	79.0	74.3	88.9	6.8
Nitrate + Nitrite as N	mg/L	4	0.035	0.020[1]	0.080	0.030
Total Kjeldahl Nitrogen as N	mg/L	4	0.871	0.801	0.950	0.061
Total Nitrogen as N	mg/L	4	0.906	0.821	1.030	0.088
pH		4	8.77	8.68	8.85	0.07
Total Phosphorus as P	mg/L	4	0.013	0.009	0.017	0.004
Potassium (K)	mg/L	4	11.3	9.4	13.8	1.8
Sodium (Na)	mg/L	4	41	39	45	3
Sulfate (SO4)	mg/L	4	178	168	197	13

[1]Equal to lower detection limit

When compared to regional average concentrations, it appears Hiddenwood Lake is lower than that reported for all natural and enhanced lakes in the Rangeland Plains region (Table 3). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1588 mg/L, 1.826 mg/L, and 0.244 mg/L, respectively, compared to Hiddenwood Lake's average TDS, total nitrogen, and total phosphorus concentrations of 543 mg/L, 0.906 mg/L and 0.013 mg/L, respectively, for the period 2005-2006.

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Hiddenwood Lake, and that the ratio of total nitrogen as N, to total phosphorus as P (N:P), based on weight, in algae is approximately 15:1. When the N:P ratio is less then 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There were seven water quality sample results for Hiddenwood Lake collected between July 1992 and January 2006 where the N:P ratio could be calculated. The results from this analysis indicate that Hiddenwood Lake is phosphorus limited (Figure 5).

Table 2. Statistical Summary of Hiddenwood Lake's Historical Water Quality Data Collected Between 1992 and 1993.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	5	383	358	464	45
Total Ammonia as N	mg/L	5	0.176	0.015	0.759	0.326
Bicarbonate (HCO_3)	mg/L	5	393	356	518	70
Calcium (Ca)	mg/L	5	36	34	40	2
Carbonate (CO_3)	mg/L	5	37	24	45	8
Chloride (Cl)	mg/L	5	13.4	11.5	16.5	2.1
Chlorophyll-a	µg/L	2	7.5	7.0	8.0	0.7
Specific Conductance	µmhos	5	988	932	1160	97
Total Dissolved Solids	mg/L	5	627	585	745	67
Total Hardness as ($CaCO_3$)	mg/L	5	465	452	492	16
Hydroxide (OH)	mg/L		NC[2]	NC[2]	NC[2]	
Iron (Fe)	mg/L	5	0.052	0.001[1]	0.074	0.029
Magnesium (Mg)	mg/L	5	91.0	89.3	95.5	2.5
Nitrate + Nitrite as N	mg/L	3	0.009	0.002[1]	0.013	0.006
Total Kjeldahl Nitrogen as N	mg/L	4	1.355	0.990	1.660	0.281
Total Nitrogen as N	mg/L	2	1.201	1.002	1.400	0.281
pH		5	8.83	8.59	8.98	0.16
Total Phosphorus as P	mg/L	5	0.058	0.018	0.119	0.041
Potassium (K)	mg/L	5	15.2	14.1	16.1	0.9
Sodium (Na)	mg/L	5	53	52	56	2
Sulfate (SO4)	mg/L	5	188	169	242	31

[1]Equal to lower detection limit
[2]No Data Collected

The nitrogen to phosphorus ratio for Hiddenwood Lake ranged from a low of 18 to a high of 103 with an average of 57. All seven samples collected were above a ratio of 15 indicating phosphorus is limiting primary production.

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005 and 2006, Hiddenwood Lake's current trophic status is mesotrophic to eutrophic. TSI scores ranged from a low of 36 based on total phosphorus, to a high of 56 based on chlorophyll-a. The trophic status score based on Secchi disk transparency was similar to that of chlorophyll-a, at 52 (Figure 6).

A total of seven total phosphorus samples, five chlorophyll-a samples, and five Secchi disk transparency measurements collected during 1992-2006 were used to evaluate trends in the trophic status of Hiddenwood Lake. Based on a visual assessment of the data, Hiddenwood Lake's trophic status is stable or improving.

Table 3. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lakes in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	272	544	119	4770	130
Total Ammonia as N	mg/L	371	0.107	0.001[1]	2.230	0.200
Bicarbonate (HCO_3)	mg/L	272	489	145	2990	150
Calcium (Ca)	mg/L	272	44	1[1]	282	26
Carbonate (CO_3)	mg/L	262	89	1[1]	1420	30
Chloride (Cl)	mg/L	272	51	4[1]	1070	9
Chlorophyll-a	µg/L	250	22	2[1]	292	28
Specific Conductance	µmhos	272	2168	448	20100	959
Total Dissolved Solids	mg/L	272	1588	227	18200	750
Total Hardness as ($CaCO_3$)	mg/L	272	538	170	2370	260
Hydroxide (OH)	mg/L	200	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	273	0.193	0.001[1]	2.260	0.334
Magnesium (Mg)	mg/L	272	104	20	567	50
Nitrate + Nitrite as N	mg/L	332	0.036	0.002[1]	0.338	0.092
Total Kjeldahl Nitrogen as N	mg/L	340	1.950	0.080	8.500	0.779
Total Nitrogen as N	mg/L	278	1.826	0.269	5.520	0.562
pH		272	8.796	7.400	9.870	0.564
Total Phosphorus as P	mg/L	377	0.244	0.004[1]	1.940	0.205
Potassium (K)	mg/L	272	38	3[1]	356	6
Sodium (Na)	mg/L	272	331	17	4680	171
Sulfate (SO4)	mg/L	272	680	34	10500	501

[1]Equal to Minimum Reporting Limit

[2]Data Collected from 48 Natural and Enhanced Lakes between 1991 and 2007

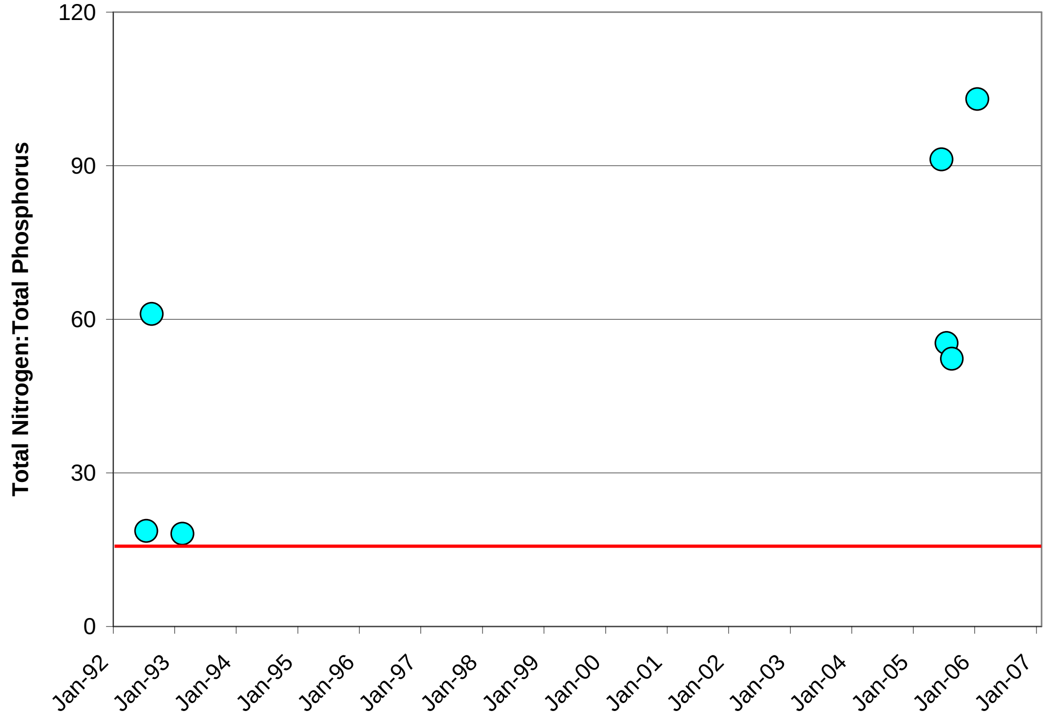

Figure 5. Total Nitrogen to Total Phosphorus Ratios in Hiddenwood Lake (1992-2006).

Figure 6. TSI Scores and Temporal Trends for Hiddenwood Lake from 1992 to 2006.

Makoti Lake, Ward County

BACKGROUND

Location: Makoti Lake is a natural lake located 5 miles south of Makoti, in the southwestern corner of Ward County, North Dakota (Figure 1). Makoti Lake is managed by the North Dakota Game and Fish Department.

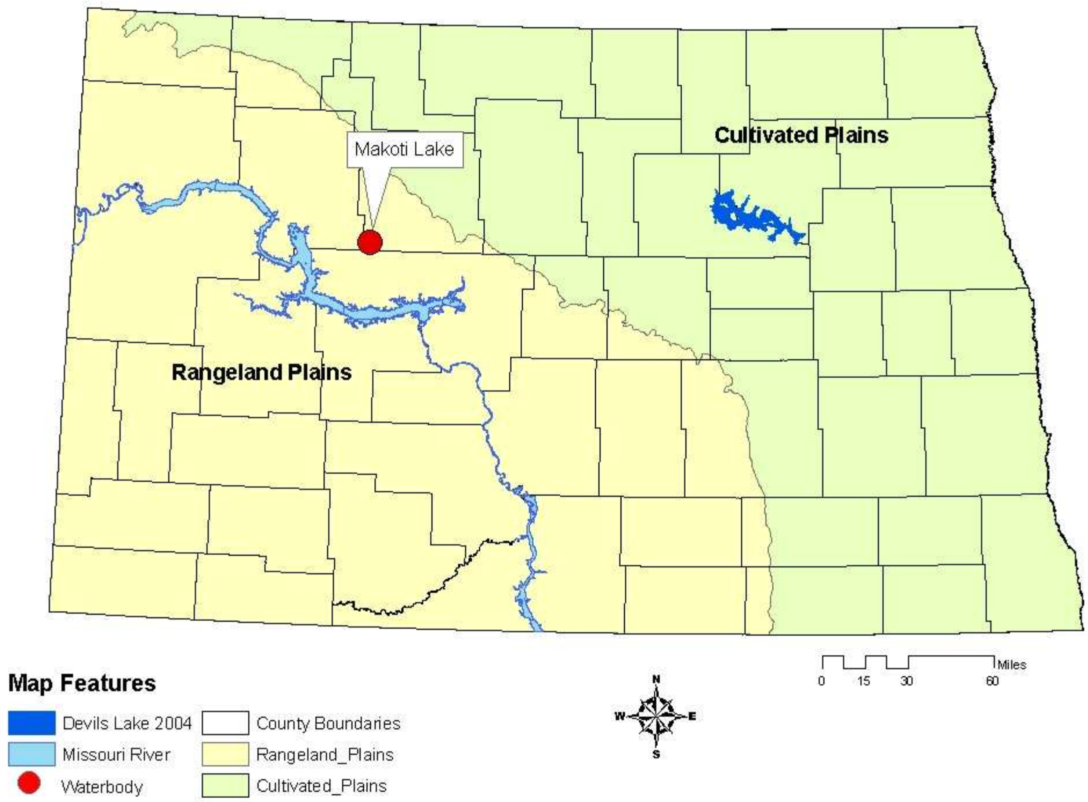

Figure 1. Location of Makoti Lake.

Physiographic/Ecological Setting: Makoti Lake has a surface area of 288.4 acres and an average depth 7.9 ft (Figure 2). Makoti Lake's watershed lies within the Northwestern Glaciated Plains (NGP) Level III Ecoregion, part of the broader Rangeland Plains Region (Figure 1). The NGP marks the western most extent of continental glacial advancement. The geological youthful landscape has significant surface irregularities and high concentrations of wetlands. The rise in elevation along the eastern edge of this ecoregion defines the boundary of the Great Plains and to the west the Northwestern Great Plains (USEPA 1994).

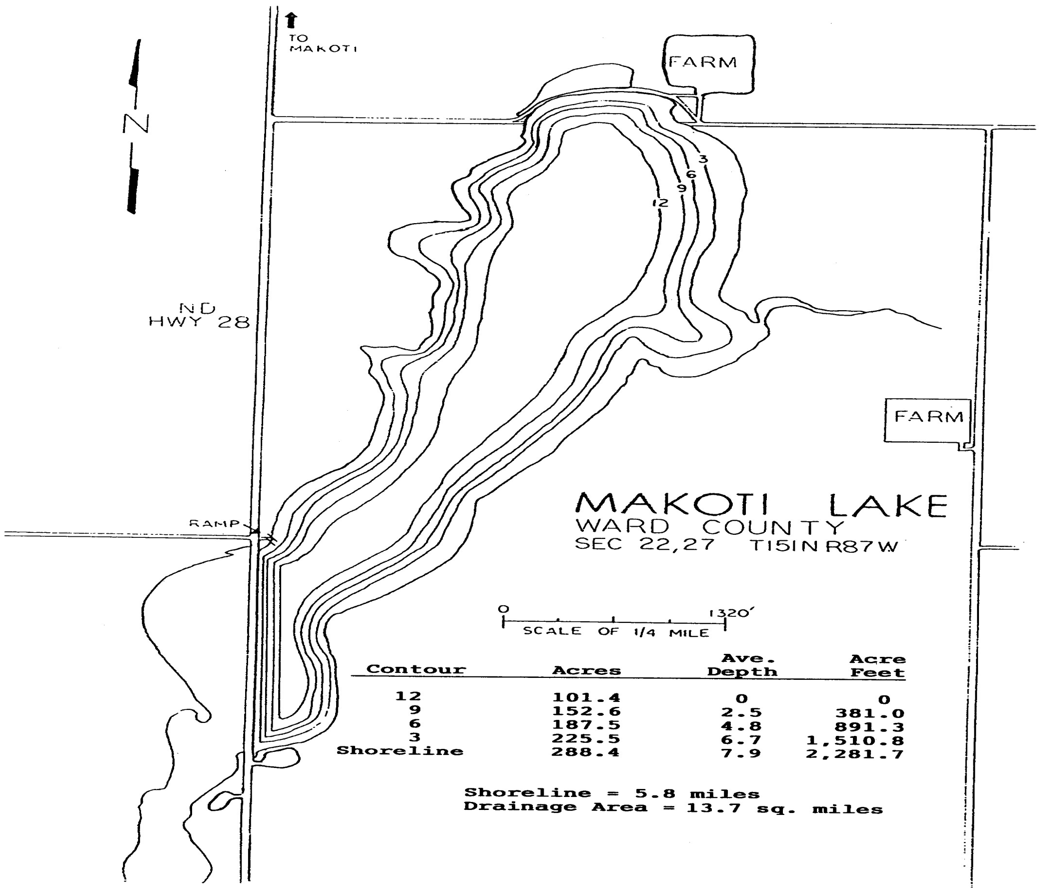

Figure 2. Contour Map of Makoti Lake (Map Courtesy of North Dakota Game and Fish Department).

Recreational Facilities: Recreational facilities at Makoti Lake include a boat ramp, with limited boat and vehicle parking on the northwest side of the lake.

Water Quality Standards Classification: Makoti Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 4 lake or reservoir. Class 4 lakes or reservoirs are defined as a "marginal fishery" or "waters capable of supporting a fishery on a short-term or seasonal basis (generally a "put and take" fishery)."

Historical and Current Fishery: Makoti Lake's fishery has included northern pike and yellow perch stocked by the NDG&F. Currently, both species are managed in Makoti Lake.

Historical Water Quality Sampling: There is no historical water quality data available for Makoti Lake.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for Makoti Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural or enhanced lakes in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There were four temperature and dissolved oxygen profiles for Makoti Lake collected from 2005-2006. The profile data shows that Makoti Lake does not thermally stratify (Figure 3) and has dissolved oxygen deficiency during the ice cover period. During the ice cover period Makoti Lake's dissolved oxygen begins and ends below the state's water quality standard of 5 mg/L.

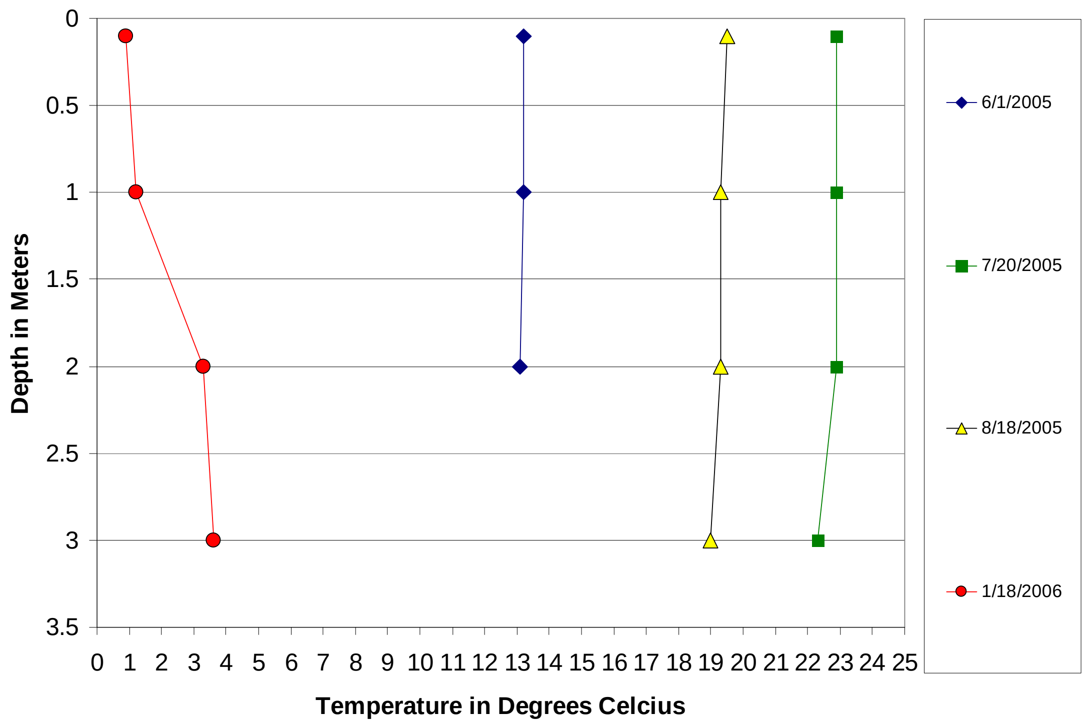

Figure 3. Temperature Profiles for Makoti Lake from 2005 to 2006.

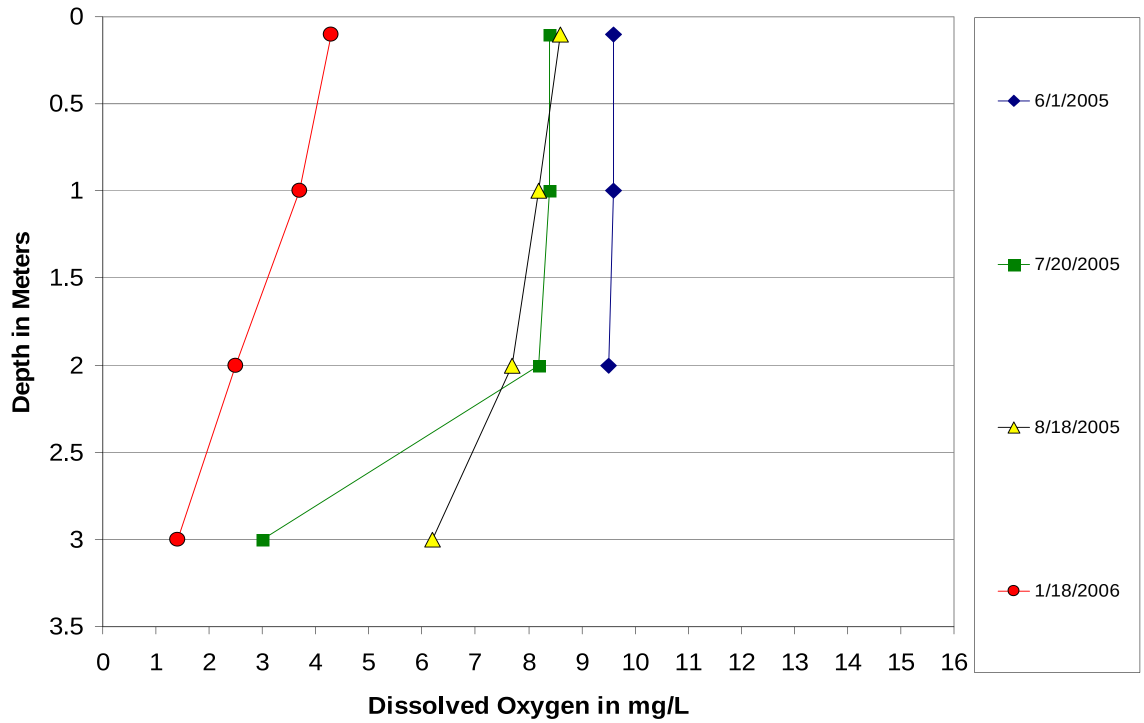

Figure 4. Dissolved Oxygen Profiles for Makoti Lake from 2005 to 2006.

General Water Quality: Water quality data collected by the NDG&F in 2005-2006 indicate Makoti Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 571 to 722 mg/L (Table 1). Based on the 2005-2006 water quality data (Table 1), Makoti Lake is sodium sulfate dominated with an average sodium concentration of 285 mg/L and an average sulfate concentration of 859 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2006 sampling period were 1868 mg/L and 2553 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 3.968 mg/L and 0.144 mg/L, respectively.

When comparing Makoti Lake's general water chemistry to the Rangeland Plains Regional average, Makoti Lake's constituents are generally higher (Table 2). For example, the regional average TDS, total nitrogen, and sulfate concentrations are 1588 mg/L, 1.826 mg/L, and 680 mg/L, respectively, compared to Makoti Lake's average TDS, total nitrogen, and sulfate concentrations of 1868 mg/L, 3.968 mg/L and 859 mg/L, respectively.

Table 1. Statistical Summary of Makoti Lake's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	4	625	571	722	69
Total Ammonia as N	mg/L	4	0.225	0.010[1]	0.848	0.415
Bicarbonate (HCO_3)	mg/L	4	563	488	757	130
Calcium (Ca)	mg/L	4	27.6	23.7	33.3	4.1
Carbonate (CO_3)	mg/L	4	98	61	120	26
Chloride (Cl)	mg/L	4	45	40	53	5
Chlorophyll-a	µg/L	3	95.7	11.2	172.0	80.7
Specific Conductance	µmhos	4	2553	2360	2940	266
Total Dissolved Solids	mg/L	4	1868	1710	2160	200
Total Hardness as ($CaCO_3$)	mg/L	4	901	812	1060	109
Hydroxide (OH)	mg/L	4	1[1]	1[1]	1[1]	0.0
Iron (Fe)	mg/L	4	0.132	0.064	0.237	0.074
Magnesium (Mg)	mg/L	4	202.0	183.0	237.0	23.9
Nitrate + Nitrite as N	mg/L	4	0.033	0.020	0.060	0.019
Total Kjeldahl Nitrogen as N	mg/L	4	3.935	3.550	4.930	0.665
Total Nitrogen as N	mg/L	4	3.968	3.570	4.990	0.683
pH		4	8.93	8.62	9.06	0.21
Total Phosphorus as P	mg/L	4	0.144	0.128	0.155	0.011
Potassium (K)	mg/L	4	73.3	67.7	82.6	6.5
Sodium (Na)	mg/L	4	285	260	325	28
Sulfate (SO4)	mg/L	4	859	788	992	91

[1]Equal to lower detection limit

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in Makoti Lake and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight, in algae is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There are four water quality sample sets for Makoti Lake between June 2005 and January 2006, where the N:P ratio could be calculated. The results from this analysis indicate that Makoti Lake is most often phosphorus limited (Figure 5).

N:P ratios for Makoti Lake ranged from a low of 23 to a high of 35 with an average of 35. All four samples collected were above a ratio of 15 indicating phosphorus is limiting primary production.

Table 2. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lakes in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	272	544	119	4770	130
Total Ammonia as N	mg/L	371	0.107	0.001[1]	2.230	0.200
Bicarbonate (HCO_3)	mg/L	272	489	145	2990	150
Calcium (Ca)	mg/L	272	44	1[1]	282	26
Carbonate (CO_3)	mg/L	262	89	1[1]	1420	30
Chloride (Cl)	mg/L	272	51	4[1]	1070	9
Chlorophyll-a	µg/L	250	22	2[1]	292	28
Specific Conductance	µmhos	272	2168	448	20100	959
Total Dissolved Solids	mg/L	272	1588	227	18200	750
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Hydroxide (OH)	mg/L	200	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	273	0.193	0.001[1]	2.260	0.334
Magnesium (Mg)	mg/L	272	104	20	567	50
Nitrate + Nitrite as N	mg/L	332	0.036	0.002[1]	0.338	0.092
Total Kjeldahl Nitrogen as N	mg/L	340	1.950	0.080	8.500	0.779
Total Nitrogen as N	mg/L	278	1.826	0.269	5.520	0.562
pH		272	8.796	7.400	9.870	0.564
Total Phosphorus as P	mg/L	377	0.244	0.004[1]	1.940	0.205
Potassium (K)	mg/L	272	38	3[1]	356	6
Sodium (Na)	mg/L	272	331	17	4680	171
Sulfate (SO4)	mg/L	272	680	34	10500	501

[1]Equal to Minimum Reporting Limit
[2]Data Collected from 48 Natural and Enhanced Lakes between 1991 and 2007

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005 and 2006, Makoti Lake's current trophic status is eutrophic to hypereutrophic. TSI scores ranged from a low of 54 based on chlorophyll-a, to a high of 93 based on Secchi disk transparency. The trophic status score based on total phosphorus was in between the scores based on chlorophyll-a and Secchi disk transparency at 76 (Figure 6).

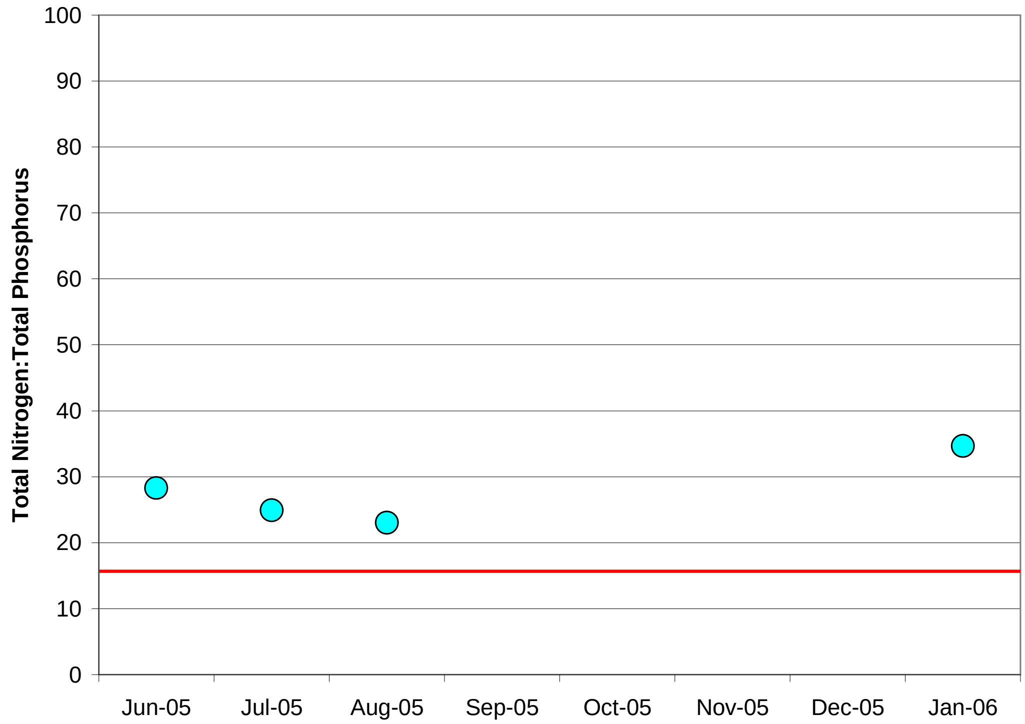

Figure 5. Total Nitrogen to Total Phosphorus Ratios in Makoti Lake (2005-2006).

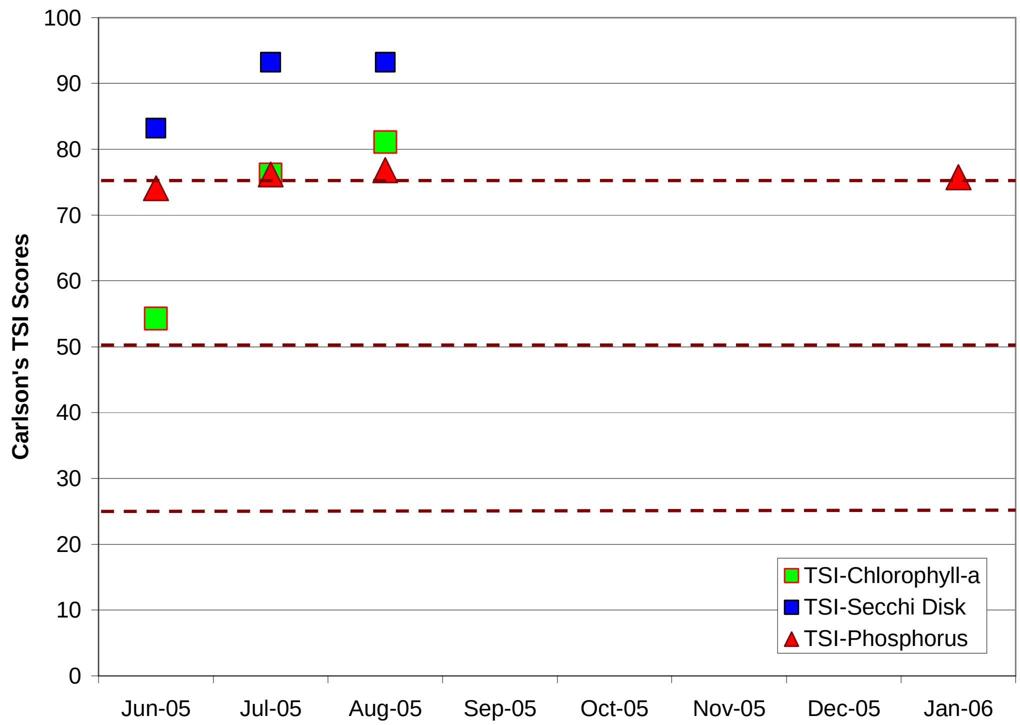

Figure 6. TSI Scores for Makoti Lake from 2005 to 2006.

North Carlson Lake, Ward County

BACKGROUND

Location: North Carlson Lake is a natural lake located 8 miles east of Ryder, North Dakota (Figure 1). North Carlson Lake is managed by the North Dakota Game and Fish Department.

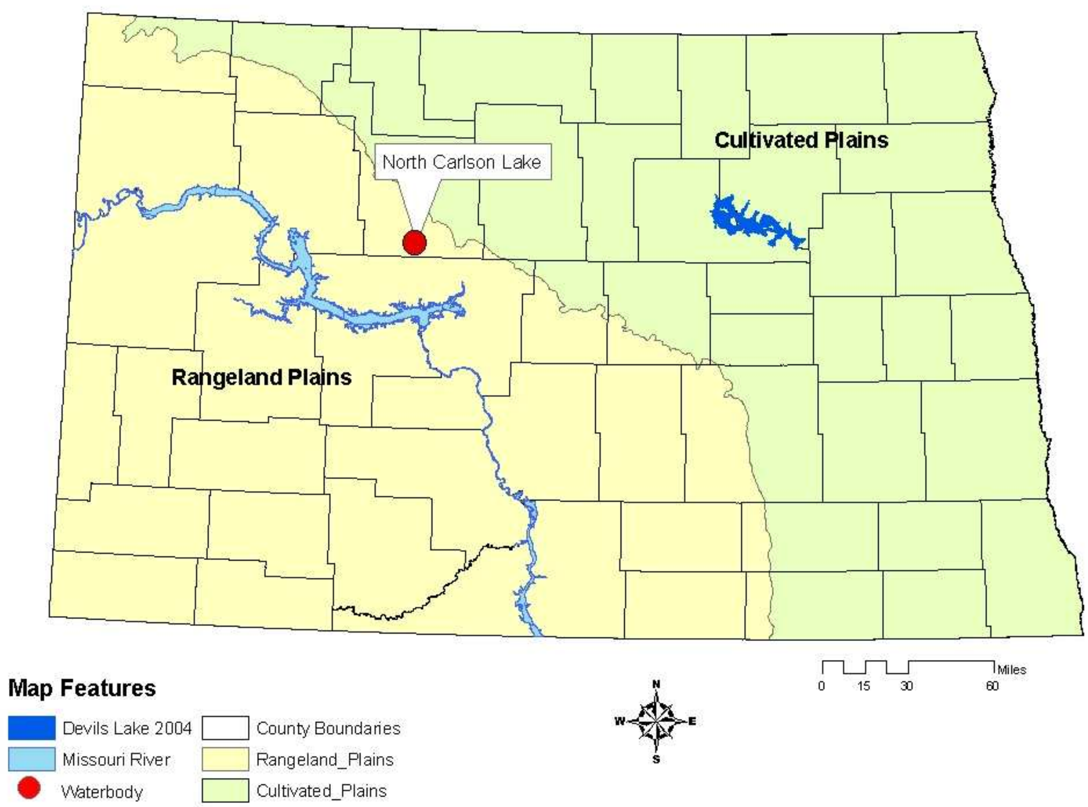

Figure 1. Location of North Carlson Lake

Physiographic/Ecological Setting: North Carlson Lake has a surface area of 85.3 acres, a maximum depth of 24.2 ft, and an average depth of 9.1 ft (Figure 2). North Carlson Lake's watershed is approximately 1,300 acres and it lies within the Northwestern Glaciated Plains (NGP) Level III Ecoregion, part of the broader Rangeland Plains Region (Figure 1). The NGP marks the western most extent of continental glacial advancement. The geological youthful landscape has significant surface irregularities and high concentrations of wetlands. The rise in elevation along the eastern edge of this ecoregion defines the boundary of the Great Plains and to the west the Northwestern Great Plains (USEPA 1994).

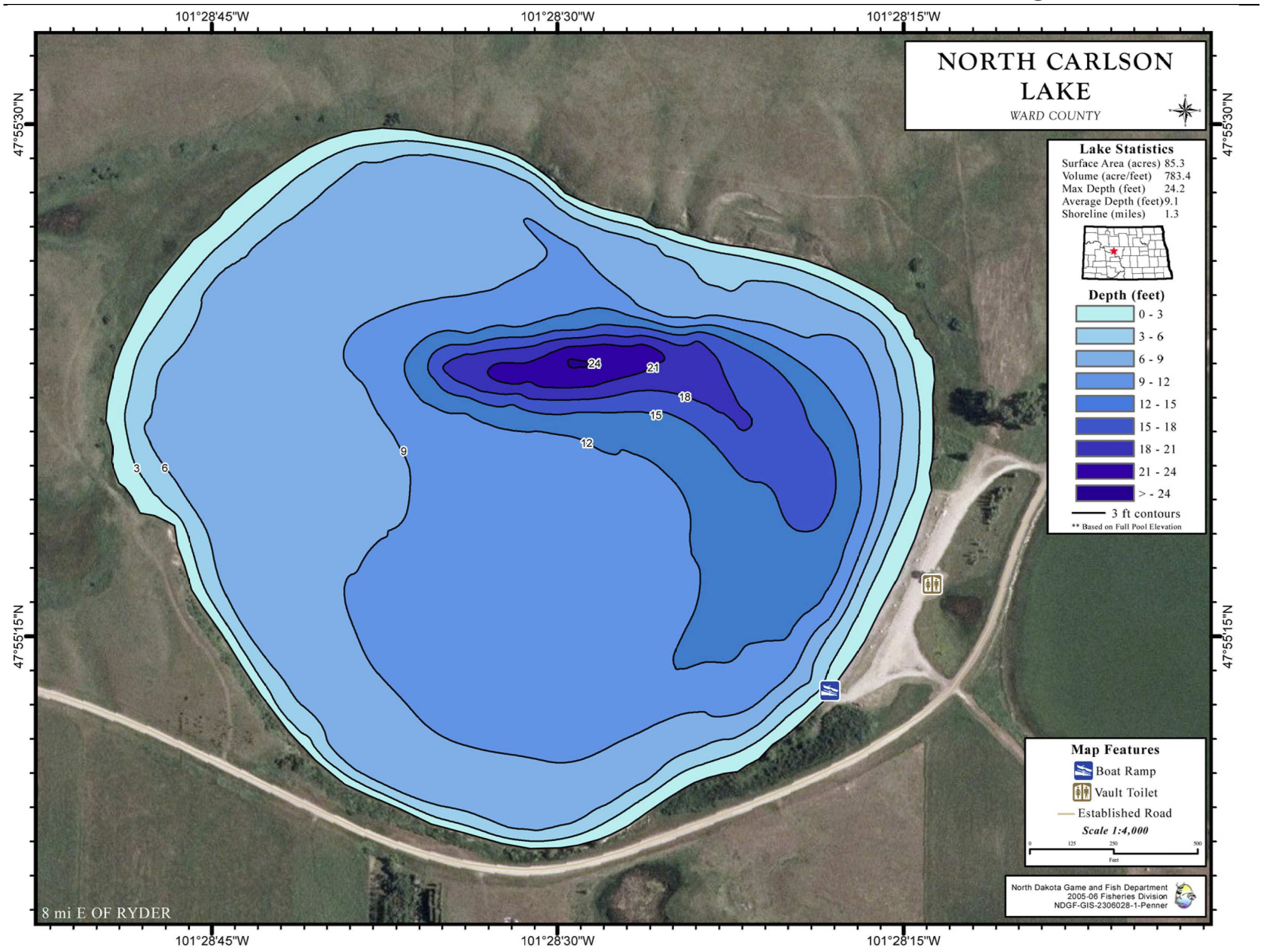

Figure 2. Contour Map of North Carlson Lake (Map Courtesy of North Dakota Game and Fish Department).

Recreational Facilities: Recreational facilities at North Carlson Lake include a boat ramp, boat and vehicle parking, and a beach located on the east side of the lake. Public access on the east side of the lake includes parking, vaulted restrooms, and a swimming beach.

Water Quality Standards Classification: North Carlson Lake is classified in the state "Standards of Quality for Waters of the State" (NDDoH, 2006) as a class 3 lake or reservoir. Class 3 lakes or reservoirs are defined as a "warm water fishery" or "waters capable of supporting natural reproduction and growth of warm water fishes (e.g., largemouth bass and bluegill) and associated aquatic biota. Some cool water species may also be present."

Historical and Current Fishery: North Carlson Lake's fishery over time has included northern pike and yellow perch stocked by the NDG&F. Currently, the only species managed in North Carlson Lake is northern pike.

Historical Water Quality Sampling: Historical data includes results from six temperature and dissolved oxygen profiles, and one water quality sample collected from 1990 through 1992.

WATER QUALITY MONITORING RESULTS

The water quality analysis and trends assessments for North Carlson Lake have been presented in four general categories: 1) temperature and dissolved oxygen profile results; 2) general water quality characterization; 3) nutrient limitation; and 4) trophic status. Where appropriate, results have been compared to the regional data for natural or enhanced lakes in the Rangeland Plains region.

Temperature and Dissolved Oxygen Profile Results: There were 10 temperature and dissolved oxygen profiles for North Carlson Lake collected from 1990-2006. Temperature and oxygen profiles are presented for two time periods, 1990-1992 and 2005-2006 (Figures 3 and 4). The profile data shows that during thermal stratification North Carlson Lake experiences gradual oxygen decay, but rarely drops below the state's water quality standard of 5 mg/L. Of the 10 profiles, four samples, collected on 7/12/1990, 7/10/1991, 8/21/1991 and 1/30/1992, dropped below the state standard of 5 mg/L. While the loss of dissolved oxygen during these periods is concerning, there does appear to be enough dissolved oxygen to maintain aquatic life in the upper two thirds to three quarters of the water column.

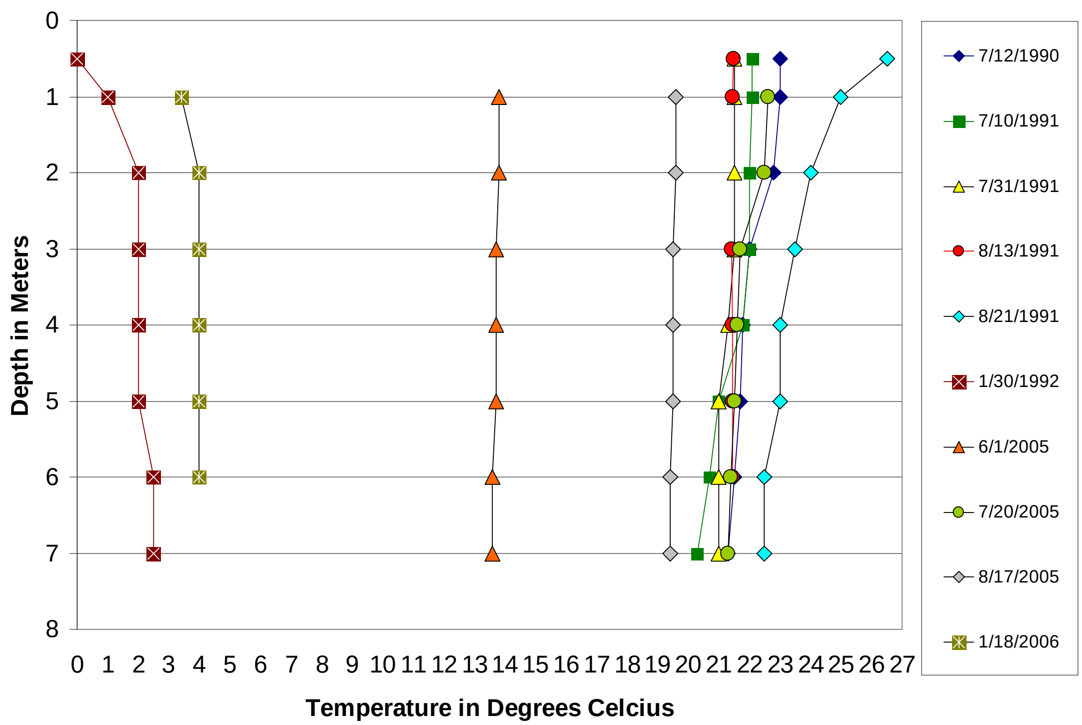

Figure 3. Temperature Profiles for North Carlson Lake from 1990 to 2006.

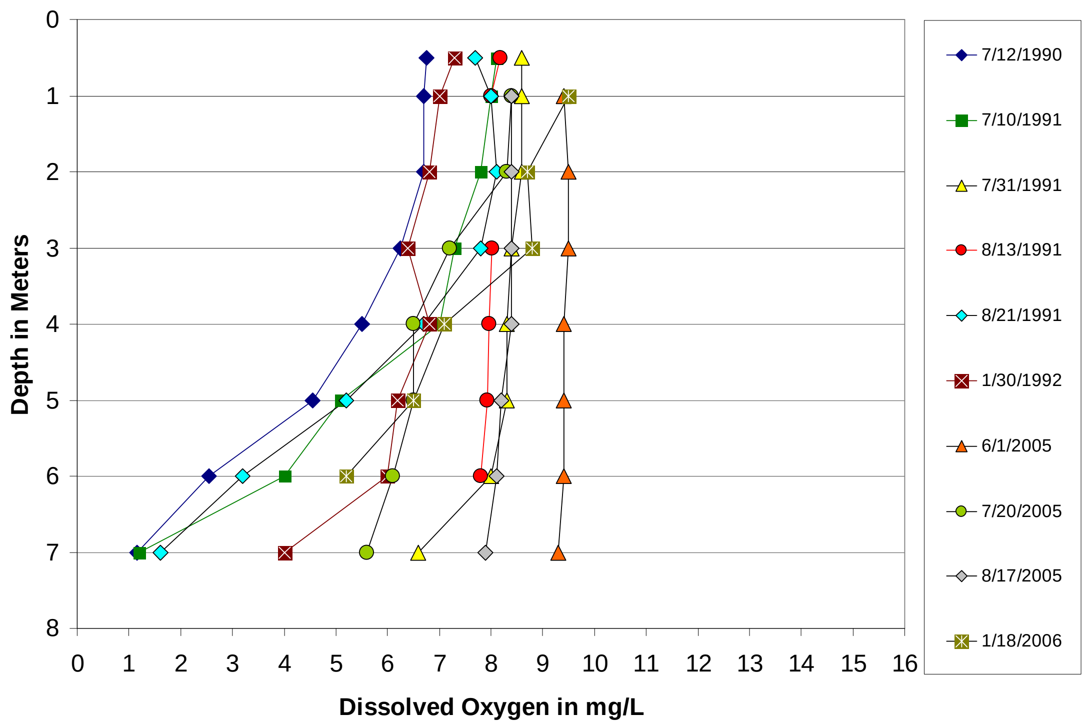

Figure 4. Dissolved Oxygen Profiles for North Carlson Lake from 1990 to 2006.

General Water Quality: Water quality data collected by the NDG&F and the First District Health Unit in 2005-2007 indicate North Carlson Lake is well buffered with alkalinity as $CaCO_3$ concentrations ranging from 510 to 615 mg/L (Table 1). Based on the 2005-2007 water quality data (Table 1), North Carlson Lake is sodium sulfate dominated with an average sodium sulfate concentration of 549 mg/L. The average TDS concentration and specific conductance measurement for the 2005-2007 sampling period were 1298 mg/L and 1889 µmhos/cm, respectively. Average total nitrogen as N and total phosphorus as P concentrations were 1.46 mg/L and 0.021 mg/L, respectively.

When compared to historical water quality data for North Carlson Lake, it appears that concentrations of most water quality constituents have decreased. For example, the historical average sulfate and sodium concentrations were 653 mg/L and 299 mg/L, respectively, compared to current average concentrations of 549 mg/L for sulfate and 254 mg/L for sodium recorded for the period 2005-2007 (Tables 1 and 2).

Table 1. Statistical Summary of North Carlson Lake's 2005-2006 Water Quality Data.

Parameter	Units	N	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	9	550	510	615	32
Total Ammonia as N	mg/L	10	0.021	0.010[1]	0.118	0.034
Bicarbonate (HCO_3)	mg/L	9	491	441	576	47
Calcium (Ca)	mg/L	9	12.0	9.2	17.5	2.7
Carbonate (CO_3)	mg/L	9	88	69	114	13
Chloride (Cl)	mg/L	9	10	9	10	0.0
Chlorophyll-a	µg/L	8	13.8	6.0	30.0	8.1
Specific Conductance	µmhos	9	1889	1790	2100	101
Total Dissolved Solids	mg/L	9	1298	1220	1470	75
Total Hardness as ($CaCO_3$)	mg/L	9	524	488	620	39
Hydroxide (OH)	mg/L	9	1[1]	1[1]	1[1]	0.0
Iron (Fe)	mg/L	10	0.089	0.050	0.138	0.031
Magnesium (Mg)	mg/L	9	120.0	112.0	140.0	8.6
Nitrate + Nitrite as N	mg/L	10	0.025	0.020[1]	0.050	0.010
Total Kjeldahl Nitrogen as N	mg/L	10	1.431	1.130	1.700	0.202
Total Nitrogen as N	mg/L	10	1.456	1.160	1.750	0.207
pH		9	9.03	8.86	9.18	0.09
Total Phosphorus as P	mg/L	10	0.021	0.004[1]	0.034	0.009
Potassium (K)	mg/L	9	22.0	19.6	25.2	1.6
Sodium (Na)	mg/L	9	254	237	290	18
Sulfate (SO4)	mg/L	9	549	511	621	35

[1]Equal to lower detection limit

Average total nitrogen and total phosphorus concentrations have also decreased when compared to the historical data. Historical average total nitrogen and total phosphorus concentrations were 3.424 mg/L and 0.044 mg/L, respectively, compared to average concentrations of 1.456 mg/L and 0.021 mg/L for total nitrogen and total phosphorus, respectively (Tables 1 and 2).

When compared to Rangeland Plains Regional average concentrations, it appears North Carlson Lake has lower concentrations of most analytes reported for all natural and enhanced lakes in the region (Table 3). For example, the regional average TDS, total nitrogen, and total phosphorus concentrations are 1588 mg/L, 1.826 mg/L, and 0.244 mg/L, respectively, compared to North Carlson Lake's average TDS, total nitrogen, and total phosphorus concentrations of 1298 mg/L, 1.456 mg/L and 0.021 mg/L, respectively, for the period 2005-2007.

Limiting Nutrient: The limiting nutrient analysis is based on the assumption that either nitrogen or phosphorus is limiting algal growth in North Carlson Lake and that the ratio of total nitrogen as N to total phosphorus as P (N:P), based on weight, in algae is approximately 15 to 1. When the N:P ratio is less than 15:1, nitrogen is assumed to be the limiting nutrient and when it exceeds 15:1, the limiting nutrient is assumed to be phosphorus.

There are 14 water quality sample sets for North Carlson Lake between July 1991 and September 2007, where the N:P ratio could be calculated. The results from this analysis indicate that North Carlson Lake is most often phosphorus limited (Figure 5).

Table 2. Statistical Summary of North Carlson Lake's Historical Water Quality Data Collected in 1992.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	1	749	749	749	
Total Ammonia as N	mg/L	1	0.567	0.567	0.567	
Bicarbonate (HCO_3)	mg/L	1	764	764	764	
Calcium (Ca)	mg/L	1	15	15	15	
Carbonate (CO_3)	mg/L	1	74	74	74	
Chloride (Cl)	mg/L	1	14.5	14.5	14.5	
Chlorophyll-a	µg/L	3	5.7	3.0[1]	11.0	4.6
Specific Conductance	µmhos	1	2290	2290	2290	
Total Dissolved Solids	mg/L	1	1610	1610	1610	
Total Hardness as ($CaCO_3$)	mg/L	1	662	662	662	
Hydroxide (OH)	mg/L		NC[2]	NC[2]	NC[2]	
Iron (Fe)	mg/L	1	0.045	0.045	0.045	
Magnesium (Mg)	mg/L	1	152.0	152.0	152.0	
Nitrate + Nitrite as N	mg/L	1	0.324	0.324	0.324	
Total Kjeldahl Nitrogen as N	mg/L	1	3.100	3.100	3.100	
Total Nitrogen as N	mg/L	1	3.424	3.424	3.424	
pH		1	8.70	8.70	8.70	
Total Phosphorus as P	mg/L	1	0.044	0.044	0.044	
Potassium (K)	mg/L	1	27.7	27.7	27.7	
Sodium (Na)	mg/L	1	299	299	299	
Sulfate (SO4)	mg/L	1	653	653	653	

[1]Equal to lower detection limit
[2]No data collected

The N:P ratios for North Carlson Lake ranged from a low of 42 to a high of 290 with an average of 84. All 14 samples collected were above a ratio of 15 indicating phosphorus is limiting primary production.

Trophic Status Assessment: Based on chlorophyll-a, Secchi disk transparency, and total phosphorus data collected during 2005-2007, North Carlson Lake's current trophic status is eutrophic. TSI scores ranged from a low of 24 based on total phosphorus to a high of 64 based on chlorophyll-a. The trophic status score based on Secchi disk transperancy was similar to that estimated based on chlorophyll-a, at 62 (Figure 6).

A total of 14 total phosphorus samples, 11 chlorophyll-a samples, and five Secchi disk transparency measurements collected during 1991-2007 were used to evaluate trends in the trophic status of North Carlson Lake. Based on a visual assessment, North Carlson Lake's trophic status is stable.

Table 3. Statistical Summary of Water Quality Data[2] Collected from Natural and Enhanced Lakes in the Rangeland Plains Ecological Region of North Dakota.

Parameter	Units	n	Average	Minimum	Maximum	Standard Deviation
Total Alkalinity ($CaCO_3$)	mg/L	272	544	119	4770	130
Total Ammonia as N	mg/L	371	0.107	0.001[1]	2.230	0.200
Bicarbonate (HCO_3)	mg/L	272	489	145	2990	150
Calcium (Ca)	mg/L	272	44	1[1]	282	26
Carbonate (CO_3)	mg/L	262	89	1[1]	1420	30
Chloride (Cl)	mg/L	272	51	4[1]	1070	9
Chlorophyll-a	µg/L	250	22	2[1]	292	28
Specific Conductance	µmhos	272	2168	448	20100	959
Total Dissolved Solids	mg/L	272	1588	227	18200	750
Total Hardness as ($CaCO_3$)	mg/L	272	538	170	2370	260
Hydroxide (OH)	mg/L	200	1[1]	1[1]	1[1]	0
Iron (Fe)	mg/L	273	0.193	0.001[1]	2.260	0.334
Magnesium (Mg)	mg/L	272	104	20	567	50
Nitrate + Nitrite as N	mg/L	332	0.036	0.002[1]	0.338	0.092
Total Kjeldahl Nitrogen as N	mg/L	340	1.950	0.080	8.500	0.779
Total Nitrogen as N	mg/L	278	1.826	0.269	5.520	0.562
pH		272	8.796	7.400	9.870	0.564
Total Phosphorus as P	mg/L	377	0.244	0.004[1]	1.940	0.205
Potassium (K)	mg/L	272	38	3[1]	356	6
Sodium (Na)	mg/L	272	331	17	4680	171
Sulfate (SO4)	mg/L	272	680	34	10500	501

[1]Equal to Minimum Reporting Limit

[2]Data Collected from 48 Natural and Enhanced Lakes between 1991 and 2007

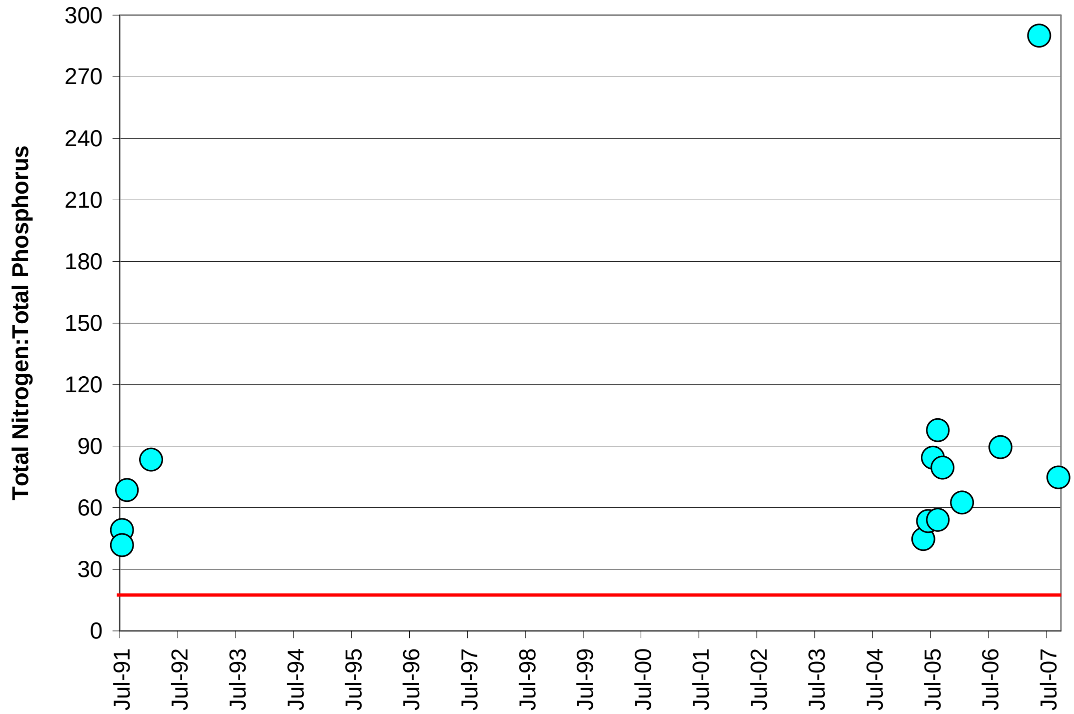

Figure 5. Total Nitrogen to Total Phosphorus Ratios in North Carlson Lake (1991-2007).

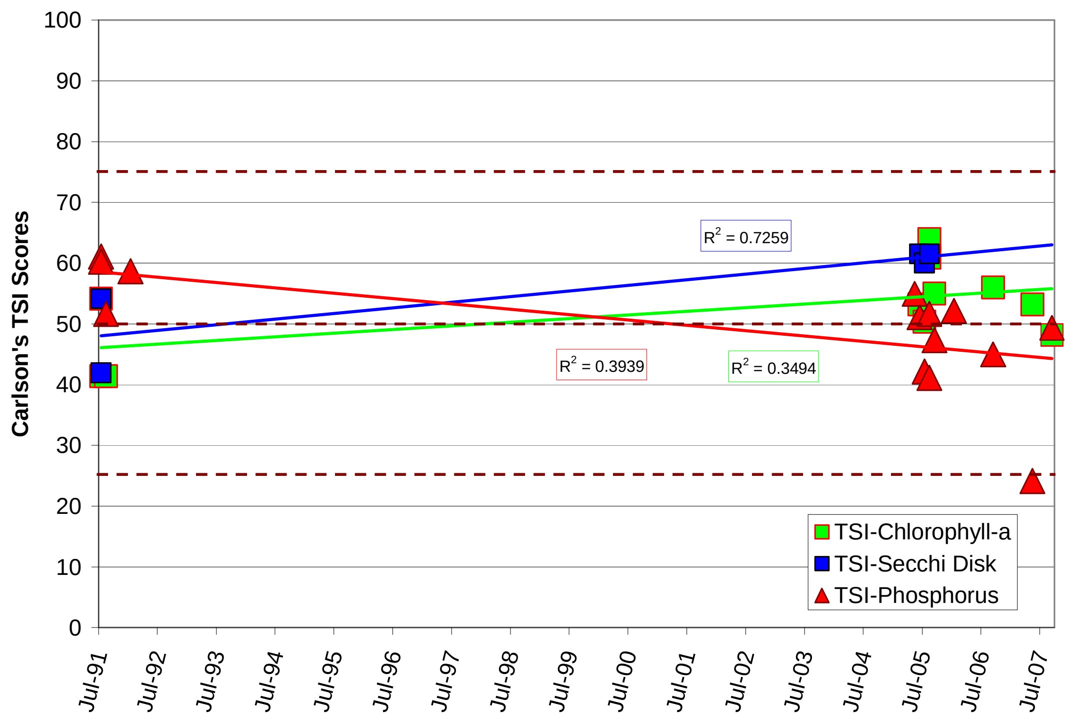

Figure 6. TSI Scores and Temporal Trends for North Carlson Lake from 1991-2007.

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APPENDIX A

Sampling and Analysis Plan
for the
North Dakota Game and Fish Department
Fisheries Division
District Lake Monitoring and Assessment Project

Sampling and Analysis Plan
for the
North Dakota Game and Fish Department
Fisheries Division
District Lake Monitoring and Assessment Project

Prepared by the
North Dakota Department of Health
Division of Water Quality

March 2005

Revised
March 2007

A. PROJECT GOAL

The goal of this long-term monitoring and assessment project is to: 1) monitor the chemical, physical and biological character of the state's lakes and reservoirs; 2) use chemical, physical and biological indicators to assess the current water quality condition and trophic status of monitored lakes and reservoirs; 3) to determine spatial differences among lakes and reservoirs; and 4) determine temporal trends in lake water quality by comparing project data to Lake Water Quality Assessmemt data or other historic water quality data. Assessment information generated from this project will be used by both the North Dakota Game and Fish Department and the North Dakota Department of Health's Division of Water Quality to prioritize lakes, reservoirs and their watersheds for lake maintenance and improvement projects (i.e., Save Our Lakes, Total Maximum Daily Loads, Section 319 Non-point Source Management Program).

B. PROJECT ORGANIZATION AND RESPONSIBILITIES

The District Lakes Monitoring and Assessment Project (project) is a cooperative effort between the North Dakota Game and Fish Department's Fisheries Division (NDGF) and the North Dakota Department of Health Division of Water Quality's Surface Water Quality Managment Program (SWQMP). Overall project management, quality assurance oversight, training and reporting will be the responsibility of Mike Ell, Program Manager for SWQMP. Pete Wax is the Designated Project Manager (DPM) for the SWQMP. As DPM, Pete Wax will work with Mike Ell and NDGF staff and will be responsible for providing training, equipment and supplies to NDGF field staff, data analysis and reporting. The North Dakota Department of Health's Division of Laboratory Services-Chemistry will provide analytical support for the project.

Overall project coordination for the NDGF will be responsibility of Scott Gangl, Fisheries Management and Research Section Leader. All field sampling activities and tasks, including collecting field measurements and water quality sampling, will be the responsibility of each District Fisheries Supervisor. Field sampling will be divided among the six NDGF District field offices. Samples collected by NDGF District staff will be shipped to the Division of Laboratory Services-Chemistry laboratory (2635 East Main, P.O. Box 937, Bismarck, ND 58502-0937). Field measurement data will be recorded in the field and entered into an EXCEL spreadsheet file by NDGF District staff. Once entered into the EXCEL spreadsheet the data will be transfered via email to Mike Ell at mell@state.nd.us or Pete Wax at pwax@state.nd.us.

Project contact information for North Dakota Department of Health and NDGF project personnel is provided in Table 1.

Table 1. Summary of Project Personnel.

Name	Organization	Mailing Address	Phone Number	Email
Mike Ell	NDDH, SWQMP	918 East Divide Ave, 4th Floor Bismarck, ND 58501-1947	701.328.5214	mell@nd.gov
Pete Wax	NDDH, SWQMP	918 East Divide Ave, 4th Floor Bismarck, ND 58501-1947	701.328.5268	pwax@nd.gov
Lydia Fewless	NDDH, Chemistry	2635 East Main, P.O. Box 937, Bismarck, ND 58502-0937	701.328.6142	lfewless@nd.gov
Scott Gangl	NDGF, Fisheries Division	100 N. Bismarck ExpresswayBismarck, ND 58501-5095	701.328.6323	sgangl@nd.gov
Gene Van Eeckhout	NDGF, Southeast District	3320 E. Lakeside Road PO Box 309Jamestown, ND 58402-0309	701.253.6482	gvaneeckhout@nd.gov
Randy Hiltner	NDGF, Northeast District	7928 45th Street NEDevils Lake, ND 58301-8501	701.662.3617	rhiltner@nd.gov
Paul Bailey	NDGF, South-Central District	100 N. Bismarck Expressway Bismarck, ND 58501-5095	701.328.6688	pbailey@nd.gov
Jason Lee	NDGF, North-Central District	406 Dakota Ave.Riverdale, ND 58565	701.654.7475	jalee@nd.gov
Jeff Hendrickson	NDGF, Southwest District	225 30th Ave. SWDickinson, ND 58601-7227	701.227.7431	jhendric@nd.gov
Fred Ryckman	NDGF, Northwest District	13932 West Front StreetWilliston, ND 58801-8602	701.774.4320	fryckman@nd.gov

C. SAMPLING LOCATIONS AND FREQUENCY

1. Sampling Locations

Sixty lakes within five of the six NDFG districts were targeted for sampling in 2005/2006 (Table 2). No lakes were targeted for sampling in the Northwest District during 2005/2006. Ten lakes were targeted for sampling in 2006/2007 (Table 3). No lakes were targeted for sampling in the Northeast, North-Central or Southwest Districts in 2006/2007.

2. Sampling Frequency

Samples will be collected from each lake or reservoir two to four times per year and will be coordinated with existing NDGF district lake sampling activities (e.g., standard adult fish population sampling, summer water quality sampling, fall reproduction sampling and winter water quality sampling).

At a minimum two samples will be collected during the year, one during the summer (June, July and/or August) and one during the winter under ice cover (January or February). A sampling frequency for each district is provided in Tables 2-4.

D. SAMPLING PROCEDURES

The following monitoring objectives and tasks are intended to achieve the goals of the project.

Task 1: Secchi Disk Transparency Readings

Objective: Estimate each lake♣s trophic status by measuring Secchi disk depth transparency.

> **Sample location:** Secchi disk transparency will be measured at one location in each lake sampled. The location should be near the deepest area of the lake or reservoir.
>
> **Sampling frequency:** Measurements will be taken during the open water sampling period each time the lake is sampled. Secchi disk transparency measurements should be taken in full daylight (10:00 am - 6:00 pm).
>
> **Standard operating procedure:** Standard operating procedures for measuring Secchi disk transparency are detailed Appendix A.
>
> **QA/QC:** Quality assurance/quality control will be maintained by ensuring that all field personnel taking measurements are adequately trained.

Task 2: Lake Temperature and Dissolved Oxygen Profile Measurements

Objective: To characterize temperature and dissolved oxygen concentrations in the lakes water column and to determine the extent of thermal stratification.

> **Samples location:** Temperature and dissolved oxygen profile measurements are taken at one location in each lake sampled. The location should be near the deepest area of the lake or reservoir. Measurements are taken at 1-meter depth intervals throughout the water column.
>
> **Sample frequency:** Temperature and dissolved oxygen profile measurements will be taken each time the lake is sampled.

Table 2. List of 2005/2006 NDGF District Lake Monitoring and Assessment Project Lakes and Reservoirs.

Southeast District[1]		Northeast District[2]		South-Central District[1]	
Lake Name	**STORET ID**	**Lake Name**	**STORET ID**	**Lake Name**	**STORET ID**
Blumhardt Lake	381000	Dion Lake	381280	Alkaline Lake	385361
Clausen Springs Lake	380691	Lake Upsilon	380641	Dry Lake	385346
Coldwater Lake	381020	Larimore Dam	381250	Fish Creek Dam	380720
Lake Elsie	380710	Mt. Carmel Dam	381080	Lake Josephine	381180
Heinrich-Martin Dam	380750	Red Willow Lake	380500		
Kalmbach Dam	380780	South Golden Lake	380531		
Kulm-Edgeley Dam	380790				
Moon Lake	380825				
Moores Lake	380830				
Mooreton Pond	385207				
Schlecht-Thom Dam	380890				
Schlecht-Weixel Dam	380895				
Wilson Dam	381400				

[1] Sampled four times during 2005/2006 - once during standard adult population sampling (June/July), once during summer water quality (July/August), once during fall reproduction sampling (August/September), and once during winter water quality (January/February).
[2] Sampled three times during 2005/2006 - once during standard adult population sampling (June/July), once during summer water quality (July/August), and once during winter water quality (January/February).
[3] Sampling schedule identified as other (hypolimnetic draw downs, etc.).

Table 2 (con•t). List of 2005/2006 NDGF District Lake Monitoring and Assessment Project Lakes and Reservoirs.

North-Central District[1]		North-Central District[1]		Southwest District[3]	
Lake Name	**STORET ID**	**Lake Name**	**STORET ID**	**Lake Name**	**STORET ID**
East Arroda Lake	385347	Lake George	383000	Belfield Dam	385349
West Arroda Lake	380985	Hiddenwood Lake	381370	Camel Hump Dam	380670
Lake Audubon	380990	Lake Holmes	381430	Castle Rock Dam	380680
Balta Dam	380975	Long Lake (Bottineau County)	381185	North Lemmon Lake	380850
Lake Brekken	381425	Long Lake (McLean County)	381335	Patterson Lake	380865
Brush Lake	380560	Makoti Lake	385348	Raleigh Reservoir	385350
Buffalo Lodge Lake	383005	Lake Metigoshe	380612	Cedar Dam	380687
Cottonwood Lake	381025	Nelson Lake	380840	Dickinson Dike	385313
Crooked Lake	381030	North Carlson Lake	381345	Indian Creek Dam	380765
New Johns Lake	381390	Pelican Lake (Bottineau County)	381190	Mirror Lake	380630
Heckers Lake	381395	Riverdale Spillway Pond	381315	Sheep Creek Dam	380910
East Park Lake	381380	Strawberry Lake (Bottineau County)	381195		
West Park Lake	381385	Strawberry Lake (McLean County)	380520		

[1] Sampled four times during 2005/2006 - once during standard adult population sampling (June/July), once during summer water quality (July/August), once during fall reproduction sampling (August/September), and once during winter water quality (January/February).
[2] Sampled three times during 2005/2006 - once during standard adult population sampling (June/July), once during summer water quality (July/August), and once during winter water quality (January/February).
[3] Sampling schedule identified as other (hypolimnetic draw downs, etc.).

Table 3. List of 2006/2007 NDGF District Lake Monitoring and Assessment Project Lakes and Reservoirs.

Southeast District[1]		South-Central District[1]		Northwest District[1]	
Lake Name	**STORET ID**	**Lake Name**	**STORET ID**	**Lake Name**	**STORET ID**
Blumhardt Lake	381000	Frohlich Dam	380730	Leland Dam	381435
Heinrich-Martin Dam	380750	Green Lake	381045	Sather Dam	380885
Moon Lake	380825	Horse Head Lake	385394		
Spiritwood Lake	380600	Rice Lake (Emmons County)	385393		

[1] Sampled four times during 2006/2007 - once during standard adult population sampling (June/July), once during summer water quality (July/August), once during fall reproduction sampling (August/September), and once during winter water quality (January/February).

Standard operating procedure: Standard operating procedures for taking temperature and dissolved oxygen profile measurements are described in Appendix B.

QA/QC: Quality assurance/quality control will be maintained by ensuring that all field personnel taking measurements are adequately trained and all field equipment (e.g., temperature and dissolved oxygen meters) are properly maintained and calibrated.

Task 3: Lake Water Quality Sampling

Objective: To characterize the chemical, physcial, and biological quality of lakes and to assess general water quality conditions and the trophic status of lakes.

Sample location(s): One composite 0-6 ft surface water quality sample will be collected from the deepest area of the lake or reservoir. For lakes and reservoirs sampled in the Southwest District, three discrete samples will be collected from the water column. One near the surface at 1-meter, one near the bottom and one at mid-depth, immediately below the themocline.

Sample frequency and depth: Water quality samples will be collected each time the lake is sampled during the open water period. During the winter period, a single sub-surface sample will be collected. Samples will be analyzed for general chemistry, ICP metals, nutrients and chlorophyll-a (Table 4).

SOP: Standard operating procedures for collecting the 0-6 ft composite water column sample are detailed in Appendix D (SOP for phytoplankton and chlorophyll-a samples). Standard operating procedures for the collection of samples in the Southwest District and all of those collected under ice are described in Appendix C.

QA/QC: Field duplicate samples will be collected once during the sampling season. In addition, QA/QC will be maintained by ensuring that all field personnel collecting samples are adequately trained.

Task 4: Lake Appearance and Suitability Survey

Objective: Determine trends in appearance and aesthetic quality of lake.

Sample locations: Survey information will be a summary of the entire lake. A feel for the appearance and recreational suitability should be obtainable on the boat ride to and from the water quality and Secchi disk sampling location. It is important to view a large area of the lake for this survey as phytoplankton and some types of aquatic vegetation can be transported by wind and wave action. The survey form is provided in Appendix E.

Sample frequency: The survey will be filled out at the same time Secchi disk transparency measurements are taken.

QA/QC: Quality assurance/quality control will be maintained by ensuring that all field personnel recording information are adequately trained.

Table 4. Summary of District Lake Monitoring Project Water Quality Variables.

Water Quality Variables	Sample Container	Preservation
Nutrients - Total Nitrogen - Total Phosphorus - Total Kjeldahl Nitrogen - Nitrate/nitrite - Ammonia	500 mL bottle	2 mL Sulfuric acid Store on ice at 4EC
General Chemistry - Hardness - Alkalinity - Bicarbonate - Carbonate - Hydroxide - Chloride - Sulfate - Conductivity - pH	1 liter cubitainer	Store on ice at 4EC
ICP Metals - Sodium - Potassium - Magnesium - Calcium - Iron	250 mL bottle	2 mL Nitric acid Store on ice at 4EC
Chlorophyll-a	Filtered, stored in petri dish and wrapped in aluminum foil	Store on ice at 4EC

E. REPORTING

Objectives: To ensure the data readily available to natural resource professionals (e.g, fisheries managers, watershed coordinators) and the public. To provide an assessment of a lake♣s general water quality character, it♣s trophic status, and attainment of it♣s beneficial uses. To determine spacial (i.e., differences among lakes and reservoirs) and temporal (compared to Lake Water Quality Assessmemt data) trends in water quality

Data Managment: The SWQMP will store and manage data. The data will be stored by the SWQMP in an Access 2000 database known as SID (Samples Identification Database). The data will also be stored in EPA♣s STORET database.

Reporting: The SWQMP will work will NDGF District personnel in the analysis of lake and reservoir data and in the compilation of a 2-4 page summary report for each lake or reservoir. Each report will provide a summary of project water quality data (e.g., temperature and dissolved oxygen profiles, summary water quality statistics, and trophic status assessment).