MARSHALL COUNTY LAKES ASSESSMENT PROJECT

FINAL REPORT
FOR
NORTH BUFFALO LAKE
MARSHALL COUNTY, SOUTH DAKOTA

South Dakota Watershed Protection Program
Division of Financial and Technical Assistance
South Dakota Department of Environment and Natural Resources
Steven M. Pirner, Secretary

November 2008

SECTION 319 NONPOINT SOURCE POLLUTION CONTROL PROGRAM
ASSESSMENT/PLANNING PROJECT FINAL REPORT

MARSHALL COUNTY LAKES ASSESSMENT PROJECT

FINAL REPORT FOR
NORTH BUFFALO LAKE

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Sponsor

Marshall Conservation District

11/6/08

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Marshall Conservation District

South Dakota Department of Environment and Natural Resources

South Dakota Department of Game, Fish & Parks

USDA Natural Resource Conservation Service

Prairie Agricultural Research, Inc.

Sol Brich created the water and sediment map.

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EXECUTIVE SUMMARY

PROJECT TITLE: Marshall County Lakes Assessment Project

PROJECT START DATE: 4/1/02	PROJECT COMPLETION DATE: 3/15/07
FUNDING:	TOTAL BUDGET: $192,000.00
TOTAL EPA GRANT:	$165,000.00 amended to $120,000.00
TOTAL EXPENDITURE OF EPA FUNDS:	$79,981.22
NONFEDERAL MATCH	
State Natural Resources Fee Funds	$25,000.00
Marshall Con. District	1,003.50
BUDGET REVISIONS:	Decrease $165,000 EPA funds to $120,000
TOTAL EXPENDITURES:	$105,984.72

SUMMARY ACCOMPLISHMENTS

The Marshall County Lakes Assessment Project was conducted because a number of lakes in the County were placed on the 1996-2006 303(d) lists for an increasing TSI trend, siltation, nutrients and aquatic nuisances (algae). The primary goal for the project was to determine sources of impairment to Nine Mile Lake, South Red Iron Lake, and North and South Buffalo Lakes, and provide sufficient background data to drive a Section 319 Implementation Project. This report is about North Buffalo Lake.

An EPA section 319 grant provided a majority of the funding for this project. The State of South Dakota provided non-federal matching funds/in-kind services for the project.

Water quality monitoring indicated a trophic state relatively similar to other lakes in the region. The median growing-season Secchi-chlorophyll *a* Trophic State Index (TSI) was less than the target TSI which indicates support of the lake's beneficial uses. The lake did not exhibit significant thermal stratification. Dissolved oxygen concentrations were usually above the water quality standard but there was one sample day where the dissolved oxygen concentrations from the lake surface to the bottom were less than the 5.0 mg/l criterion. The standards criteria for nitrate, unionized ammonia, conductivity, total suspended solids, and fecal coliform bacteria were not exceeded. Seasonality was indicated by typical temperature changes throughout the year and by seasonal changes in some parameter concentrations. An aquatic macrophyte survey was completed for the lake. Aquatic macrophytes were not considered a major problem in the lake.

The results from the BATHTUB model were used to establish a total annual load of 62.5 kg/year for total phosphorus, which will maintain the lake under the target Secchi-chlorophyll *a* TSI target of 63.4

The Annualized Agricultural Non-point Source computer model (AnnAGNPS) was not used because the lake was already meeting its TSI target. In-lake restoration techniques such as aeration/circulation were recommended to alleviate the low dissolved oxygen concentrations. Best Management Practices were also recommended for maintaining the lakes water quality and for improving dissolved oxygen concentrations.

INTRODUCTION

Purpose

The purpose of this assessment is to determine a total annual phosphorus and management strategies that will maintain the lake in an acceptable condition.

General Lake Description

North Buffalo Lake is a 107.58-acre natural lake located in Marshall County, South Dakota (Figure 1). The lake is primarily used for fishing. The average depth of the lake is three meters (10 feet) and it has a maximum depth of 3.7 meters (12 feet). A few homes are located adjacent to the lake. All use septic systems.

One small unnamed tributary that receives drainage from primarily grazing lands and some cropland acres enters the lake. Depending on water levels, the lake is also connected to South Buffalo Lake and water usually flows from South Buffalo Lake into North Buffalo Lake. North Buffalo Lake drains into Almos Lake, which eventually drains to South Red Iron Lake.

Lake Identification and Location

Lake Name: North Buffalo Lake	State: South Dakota
County: Marshall	Township: 125N
Range: 53W	Sections: 3, 4, 9, and 10
Nearest Municipality: Eden	Latitude: 45.632857
Longitude: -97.289597	EPA Region: VIII
Primary Tributary: Unnamed	Receiving Body of Water: Almos Lake
HUC Code: 101600100	HUC Name: North Big Sioux Coteau

Beneficial Uses and Water Quality Standards

The State of South Dakota has assigned all of the water bodies that are within its borders a set of beneficial uses. With these assigned uses are sets of standards for various physical and chemical properties. These standards must be maintained for the water body to satisfy its assigned beneficial uses. All bodies of water in the state receive the beneficial uses of fish and wildlife propagation, recreation, and stock watering. Following is the list of beneficial uses assigned to North Buffalo Lake:

(5) Warmwater semi-permanent fish life propagation;
(7) Immersion recreation;
(8) Limited contact recreation; and
(9) Fish and wildlife propagation, recreation, and stock watering.

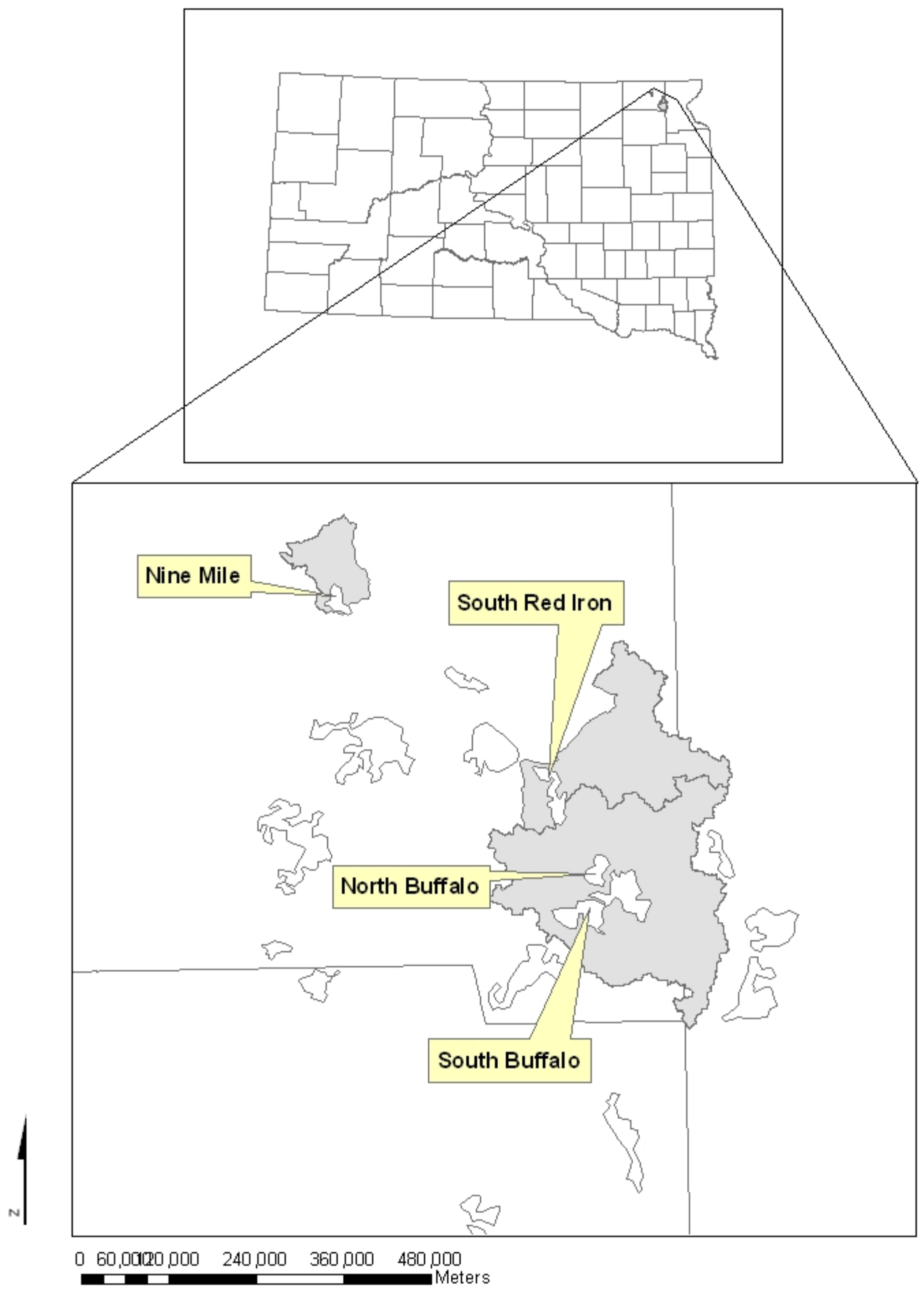

Figure 1. Lakes and their watersheds in the Marshall County Lakes Assessment Project.

With each of these uses are sets of water quality standard criteria that must not be exceeded in order to maintain these uses. The following tables list those parameters measured during this study that must be considered when maintaining the beneficial uses as well as the concentrations for each parameter. When multiple standards for a parameter exist, the most restrictive criterion is used. Additional "narrative" standards that may apply can be found in the "Administrative Rules of South Dakota: Articles 74:51:01:05; 06; 08; and 09". These contain language that generally prohibits the presence of materials causing pollutants to form, visible pollutants, and nuisance aquatic life. Carlson's (1977) trophic state indices are used during this study as a measure of beneficial use support. The indices are based on total phosphorus, Secchi disk transparency and chlorophyll *a*. The critical values for beneficial use status were derived from a SDDENR study of South Dakota lakes and from regionality of various lake attributes (Lorenzen, 2005). North Buffalo Lake is listed in the state's 2006 303(d) list and was identified as supporting its beneficial uses.

During 2008, refinement of the 303(d) listing criteria eliminated the use of TSI values as a means to measure beneficial use attainment. However, the TSIs are still used as a general means of judging overall lake water quality and setting annual phosphorus loads.

Table 1. State beneficial use standards for North Buffalo Lake, Marshall County, North Dakota.

Parameters	mg/l (except where noted)	Beneficial Use Requiring this Standard
Alkalinity *($CaCO_3$)*	≤ 750 *(mean)*, ≤ 1,313 *(single sample)*	Wildlife Propagation and Stock Watering
Coliform, fecal *(per 100 ml)* May 1 to Sept 30	≤ 200 *(Geo.mean)*, ≤ 400 *(single sample)*	Immersion Recreation
Conductivity *(µmhos/cm @ 25 °C)*	≤ 4,000 *(mean,)* ≤ 7,000 *(single sample)*	Wildlife Propagation and Stock Watering
Nitrogen, Total ammonia as N	$(0.411/(1+10^{7.204-pH}))+(58.4/(1+10^{pH-7.204}))$ *(single sample)*	Warmwater Semi-permanent Fish Propagation
Nitrogen, nitrates as N	≤ 50 *(mean)*, ≤ *88 (single sample)*	Wildlife Propagation and Stock Watering
Oxygen, dissolved	≥ 5.0	Immersion and Limited Contact Recreation
pH (standard units)	≥ 6.5 - ≤ 9.0	Warmwater Semi-permanent Fish Propagation
Solids, suspended	≤ 90 *(mean)*, ≤ 158 *(single sample)*	Warmwater Semi-permanent Fish Propagation
Temperature	≤ 32.22 C	Warmwater Semi-permanent Fish Propagation

The incoming tributary and outlet tributary of North Buffalo Lake have the beneficial uses of: (9) Fish and wildlife propagation, recreation, and stock watering; and (10) Irrigation

In order for these to maintain their uses, there are four standards that must be maintained. These standards, along with their numeric criteria, are listed in Table 3.

Table 2. State water quality standards for the incoming tributary and outlet tributary of North Buffalo Lake.

Parameters	Criterion, mg/l (except where noted)
Nitrate	≤ 50 (mean), ≤ 88 (single sample)
Alkalinity	≤ 750 (mean), ≤ 1,313 (single sample)
pH	≥ 6.5 and ≤ 9.5
Conductivity	≤ 4,000 (mean), ≤ 7,000 (single sample)

Recreational Uses

The South Dakota Department of Game, Fish, and Parks provides a list of public facilities that are maintained at area lakes (Table 4). Most of the larger and more frequently used lakes in the area have adequate facilities, as does North Buffalo Lake.

Table 3. Comparison of recreational uses on lakes near North Buffalo Lake.

Lake	State Parks	Ramps	Boating	Campground	Fishing	Picnic Tables	Swimming	Nearest Municipality
White Lake		X	X		X		X	Britton
Nine Mile		X	X		X		X	Lake City
North Red Iron		X	X		X		X	Lake City
South Buffalo		X	X		X		X	Lake City
Roy Lake	X	X	X	X	X	X	X	Lake City
North Buffalo		**X**	**X**		**X**		**X**	**Lake City**

Watershed

North Buffalo Lake's 18,733-acre watershed is characterized by rolling mixed-grass prairie, pastureland with a small portion in cultivation. The two major soil associations found in the watershed are of the Renshaw-Fordville-Sioux and the Forman-Aastad-Buse associations (USDA, 1975). The Renshaw-Fordville-Sioux association is characterized by nearly level to steep, well-drained to excessively drained, loamy soils underlain by sand and gravel. The Forman-Aastad-Buse association is characterized by nearly level to sloping, well drained and moderately well drained, loamy soils formed in glacial till.

Land use in the watershed is primarily agricultural grazing with some cropland. Small grains and hay are the main crops on cultivated lands. The average annual precipitation in Britton is 20.68 inches, of which most usually falls in April through September. Tornadoes and severe thunderstorms strike occasionally. These storms are local and of short duration and occasionally produce heavy rainfall events

History

North Buffalo Lake is a natural lake so named because it is located in Buffalo Township. The lake is also approximately nine miles northeast of Lake City and five miles east of Eden, the nearest municipality.

Previous water quality data indicated the lake had not had any water quality problems in the past. The 2000, 2002, 2004, and 2006 South Dakota Reports to Congress listed the lake as fully meeting its beneficial uses for those criteria having data to compare and unknown for those not having data. The Marshall Conservation District was concerned enough about the quality of the lakes in the area that they agreed to sponsor a four-lake assessment in Marshall County. North Buffalo Lake was included in the assessment because it was felt the lake would eventually need proactive measures to maintain its beneficial uses.

Threatened and Endangered Species

The only species on the federal list of threatened and endangered species likely to occur in the North Buffalo Lake watershed is the bald eagle (*Haliaeetus leucocephalis*), which is listed as threatened. No bald eagles were encountered during this study; however, care should be taken when conducting mitigation projects in the watershed.

Nesting bald eagles have not been documented in the project area but there could be eagles migrating through the area, especially during the fall waterfowl migration. Any mitigation processes that take place should avoid the destruction of large trees that may be used as eagle perches, particularly if an eagle is observed using the tree as a perch or roost.

PROJECT GOALS, OBJECTIVES, AND ACTIVITIES

<u>Planned and Actual Milestones, Products, and Completion Dates</u>

Objective 1. Lake Sampling and Sediment Survey

The lake water sampling commenced June, 2002 and continued through May 2003. Spring samples were collected during March, April and May of 2003. Bimonthly samples were collected during June, July and August. Only a cursory sediment survey was conducted because the local funding base is unlikely to support dredging.

Objective 2. Tributary Sampling

Immediately after the start of the project, the local coordinator began sampling the tributaries. Detailed cross-sectional and water velocity data were collected along with daily stage readings from OTT and ISCO stage recorders. These data were used to develop stage/discharge relationships so water flows could be calculated. These flows, as well as lake and tributary water quality data, were entered into the BATHTUB computer model to assess the nutrient and sediment loads to the lake.

Objective 3. Quality Assurance/Quality Control (QA/QC)

Duplicate and blank samples were collected during the course of the project to provide defendable proof that sample data were collected in a scientific and reproducible manner. QA/QC data collection began in June of 2002 and was completed as planned.

Objective 4. AnnAGNPS Modeling

Prairie Agricultural Research, Inc. toured the watershed and made initial determinations for the AnnAGNPS model. The NRCS office located in Britton made available information concerning land use information. The AnnAGNPS modeling was not completed because the lake was already meeting its target TSI.

Objective 5. Public Participation

The public was kept informed of the project through monthly meetings of the Marshall Conservation District.

Objectives 6 and 7. Restoration Alternatives and Final Report

The completion of the restoration alternatives and final report for North Buffalo Lake was delayed due to DENR personnel having other commitments.

Evaluation of Goal Achievements

A comparison of the planned and actual objective completion dates is given in Table 4. The project was generally on schedule except for the completion of the final report, which was delayed due to the project officer having other commitments.

Table 4. Proposed and actual objective completion dates for the Marshall County Lakes Assessment Project.

	6/02	7/02	8/02	9/02	10/02	11/02	12/02	1/03	2/03	3/03	4/03	503	6/03	7/03	8/03-12/06
Objective 1															
Lake Sampling															
Objective 2															
Tributary Sampling															
Objective 3															
QA/QC															
Objective 4															
Modeling															
Objective 5															
Public Participation															
Objective 6 & 7															
Final Report															

Monitoring Methods and Results

<u>OBJECTIVE 1 – Lake Sampling and Sediment Survey</u>

In-lake Sampling Schedule, Methods, and Materials

One sampling site was chosen to monitor North Buffalo Lake (Figure 2). Sampling began in June, 2002, and was conducted on a bimonthly basis during June, July, and August, and monthly during other months. Water samples were collected from the lake surface and near the bottom of the lake with a Van Dorn sampler. The samples were filtered, preserved, and packed in ice for shipping to the State Health Lab in Pierre, SD according to the "Standard Operating Procedures for Field Samplers" (Stueven, et al., 2000). The laboratory analyzed the samples for the following parameters:

Fecal coliform bacteria	Alkalinity
Total solids	Total suspended solids
Total volatile suspended solids	Ammonia
Nitrate	Total Kjeldahl Nitrogen (TKN)
Total phosphorus	Total dissolved phosphorus
E. coli	Chlorophyll *a*

Personnel conducting the sampling at each of the sites recorded the following observations.

Precipitation	Wind
Odor	Septic conditions
Dead fish	Film
Width	Water depth
Ice cover	Water color

Parameters measured in the field by sampling personnel were:

Water temperature	Air temperature
Specific conductance	Dissolved oxygen
Field pH	Secchi depth

Original data may be found in Appendix A.

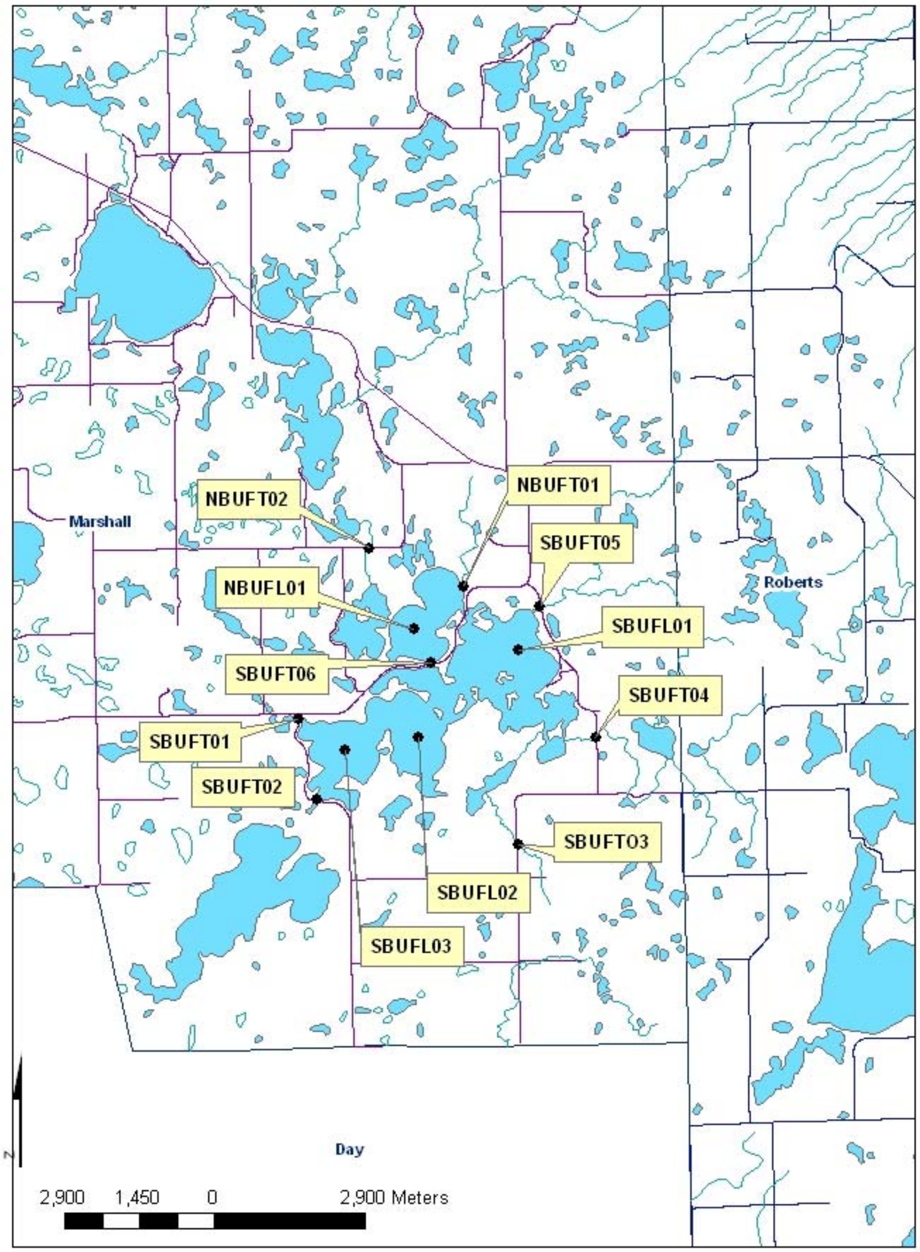

Figure 2. Sampling sites for North and South Buffalo Lakes and their watersheds.

In-lake Water Quality Results

Water Temperature

The water temperature in North Buffalo Lake exhibited seasonal variations that are consistent with its geographic location, steadily increasing in the spring and summer and consistently decreasing in the fall and winter (Figure 3). It can be reasonably expected that during most years the lake temperatures would be within a few degrees of the project data at their respective dates.

North Buffalo Lake showed no significant thermal stratification during the study except during August 27, 2002, when the temperature difference between the surface and bottom was 3.84 degrees. Most temperature readings near the lake's surface and bottom differed by two degrees or less (Figure 3). The water quality standard criterion for temperature was not exceeded.

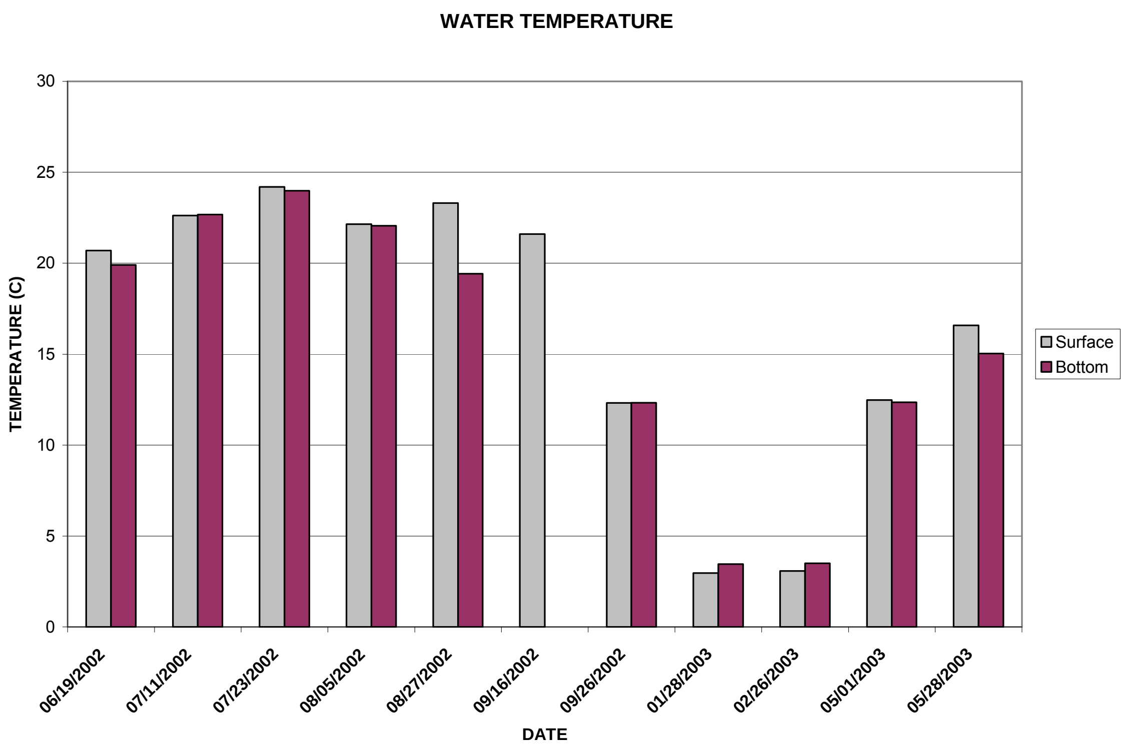

Figure 3. In-lake surface and bottom water temperatures for North Buffalo Lake, Marshall County, South Dakota, 2002/2003.

Dissolved Oxygen

Dissolved oxygen (DO) levels in North Buffalo Lake were sufficient to maintain the minimum requirement for the local managed fishery but oxygen depletion did occur throughout the water column during January 28, 2003 (see Figure 4 and Appendix A).

During the study, six out of thirty-one readings (19.4%) had DO levels below 5.0 mg/l, the DO criterion for maintaining warmwater semi-permanent fish life propagation. This was most likely due to bacteria using oxygen during the decomposition of organic matter in the lake. Dead fish were not noticed during the time of oxygen depletion and fish kills have not been reported to SDDENR during the past ten years.

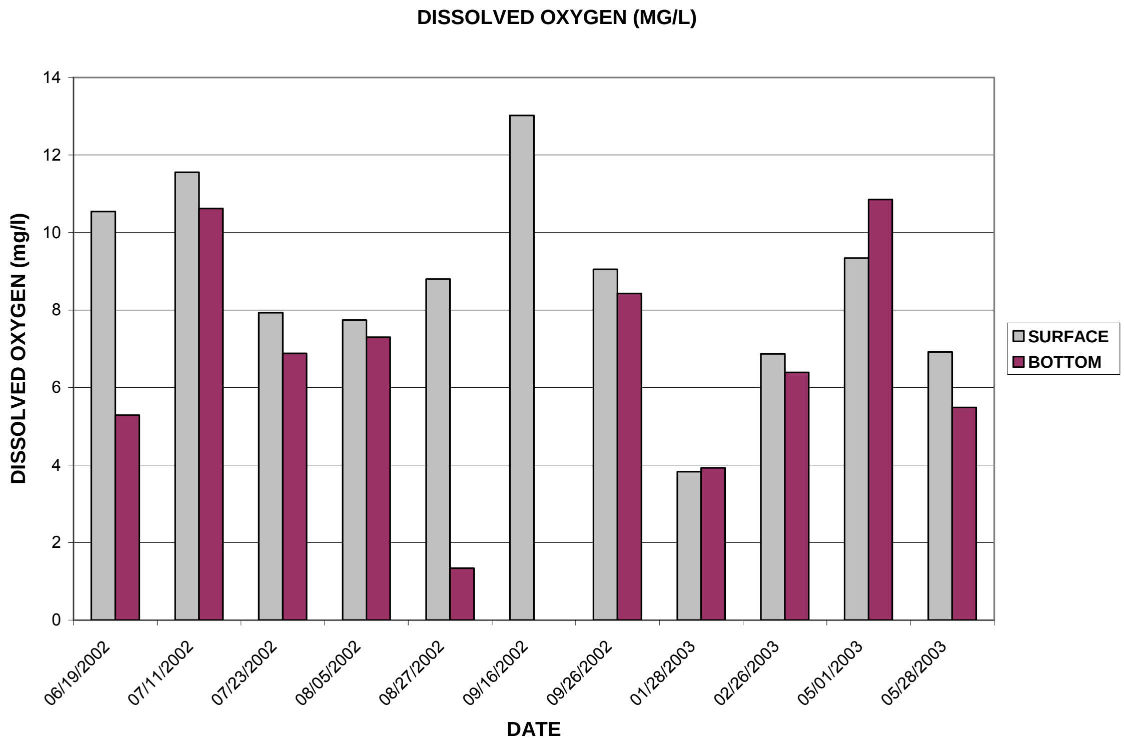

Figure 4. In-lake surface and bottom dissolved oxygen concentrations for North Buffalo Lake, Marshall County, South Dakota, 2002/2003.

<u>pH</u>

pH is a measure of free hydrogen ions (H+) or potential hydrogen. More simply, it indicates the balance between acids and bases in water. It is measured on a logarithmic scale between 0 and 14. At neutral (pH of 7) acid ions (H+) equal the base ions (OH-). Values less than 7 are considered acidic (more H+ ions) and greater than 7 are basic (more OH- ions). Algal and macrophyte photosynthesis act to increase a lake's pH. The decomposition of organic matter will reduce pH. The extent to which this occurs is affected by the lakes ability to buffer against changes in pH. The presence of high alkalinity (>200 mg/l) represents considerable buffering capacity and will reduce the effects of both photosynthesis and decay in producing large fluctuations in pH.

pH values in North Buffalo Lake ranged from 7.85 to 10.15 and averaged 9.12 (Appendix A). However, the project coordinator indicated during the project that the YSI meter used to measure pH was operating abnormally. The YSI pH probe was eventually replaced but it was felt that much of the pH data were suspect. All four lakes monitored under the Marshall County Lakes Assessment Project exhibited a number of pH values greater than 9.0 and some as high as 10. This is not considered normal for lakes in this area of South Dakota. Algae are often implicated in causing higher pH values but none of these lakes had excessively high chlorophyll *a* concentrations. In addition, historical data show pH values in these lakes averaged 8.5-8.7 with only a couple of occurrences above 9.0 (Table 18 in Appendix A). Because of this, it was decided not to use the pH data obtained during the project. Given the historical data, pH was not considered problematic in these lakes.

Specific Conductance

Specific conductance ranged from 383 to 658 μS/cm and usually did not differ between the surface and bottom measurements (Figure 5). State standards for fish and wildlife propagation and stock watering require that conductivity not equal or exceed 7,000 μS/cm on any single day. All specific conductance readings at North Buffalo Lake were less than the state standard criterion.

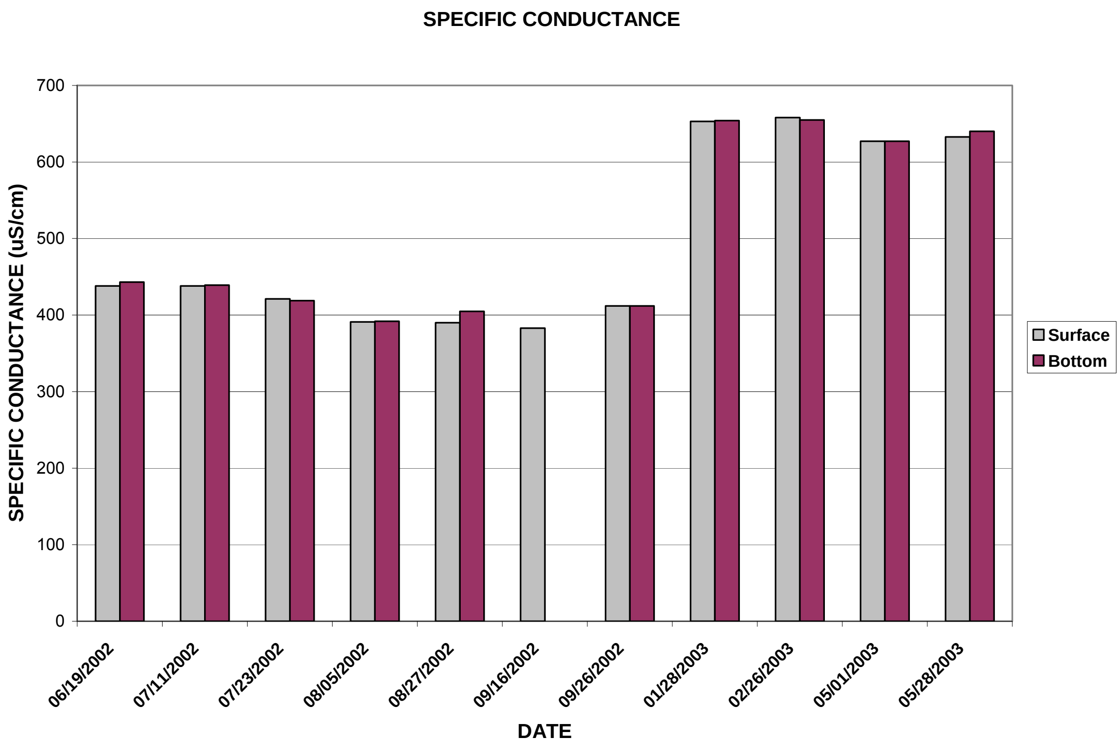

Figure 5. In-lake surface and bottom specific conductance for North Buffalo Lake, Marshall County, South Dakota, 2002/2003.

Secchi Depth

Secchi depth is the most commonly used method to determine water clarity. The two primary causes for low Secchi readings are suspended solids and algae. Higher Secchi readings are found in lakes that have clearer water, which is often associated with lower nutrient levels and "cleaner" water.

Secchi transparency readings in North Buffalo Lake averaged 1.03 meters with the greatest readings found during February, 2003 (Figure 6). This was probably due to an algae die-off during the winter and a settling of dead algae and other suspended matter to the bottom during ice cover. The mean Secchi transparency reading during the primary growing season (May 15 through September 15) was 0.79 meter, equivalent to a TSI value of 63.4. This indicates eutrophic conditions but the TSI was not considered indicative of a problem. The target growing-season median Secchi-chlorophyll *a* TSI is 63.4 (Lorenzen, 2005) and the Secchi TSI was equal to this.

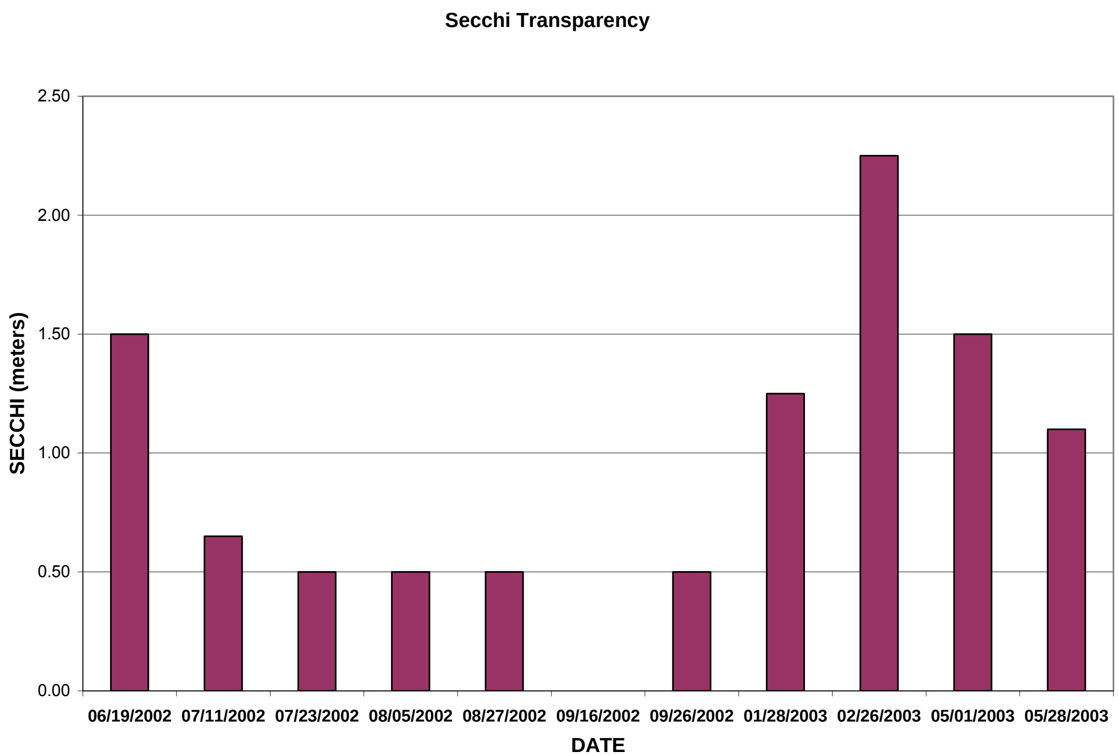

Figure 6. Secchi transparency depths for North Buffalo Lake, Marshall County, South Dakota, 2002/2003.

Alkalinity

A lake's total alkalinity affects the ability of its water to buffer against changes in pH. Total alkalinity consists of all dissolved electrolytes (ions) with the ability to accept and neutralize protons (Wetzel, 2000). Due to the abundance of carbon dioxide (CO_2) and carbonates, most freshwater contains bicarbonates as their primary source of alkalinity. It is commonly found in concentrations as high as 200 mg/l or greater. Total alkalinity is also used in the estimation procedure for calculating the amount of alum necessary for phosphorus precipitation.

The total alkalinity in North Buffalo Lake averaged 250 mg/l and ranged from 210 mg/l to 305 mg/l. There was little difference in total alkalinity in samples collected from the surface or the bottom (Figure 7). The total alkalinity concentrations are typical for lakes in South Dakota. The alkalinity standard criterion was never exceeded.

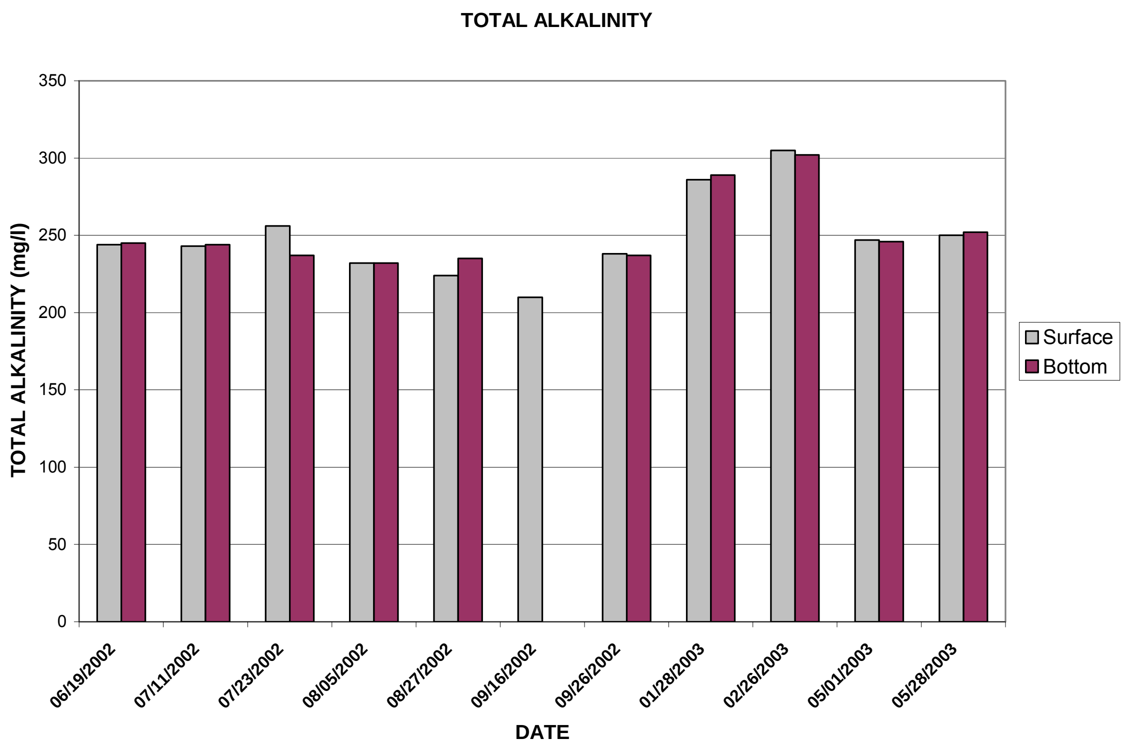

Figure 7. In-lake surface and bottom total alkalinity concentrations for North Buffalo Lake, Marshall County, South Dakota, 2002/2003.

Solids

Solids can be separated into four separate fractions; total solids, total dissolved solids (TDS), total suspended solids (TSS), and total volatile suspended solids (TVSS). Total solids are the sum of all forms of material including suspended and dissolved as well as organic and inorganic materials that are found in a given volume of water.

North Buffalo Lake exhibited some seasonality in total solids concentrations with slightly higher values during the winter (Figure 7). This was likely due to an increase in dissolved solids because the total suspended solids (presumably algae) had decreased substantially during this time of the year. Total solids ranged from 368 mg/l to 470 mg/l and averaged 403 mg/l. TSS concentrations in North Buffalo Lake exhibited similar seasonality with lower concentrations during the winter, probably a result of algae die-off and a settling-out of suspended particles (Figure 8). TSS concentrations ranged from 3 mg/l to 44 mg/l and averaged 20.7 mg/l. The maximum value may have been due to the sampling device hitting the bottom. TVSS comprised about 63% of the total suspended solids. Algae likely comprised the bulk of the organic matter in the lake.

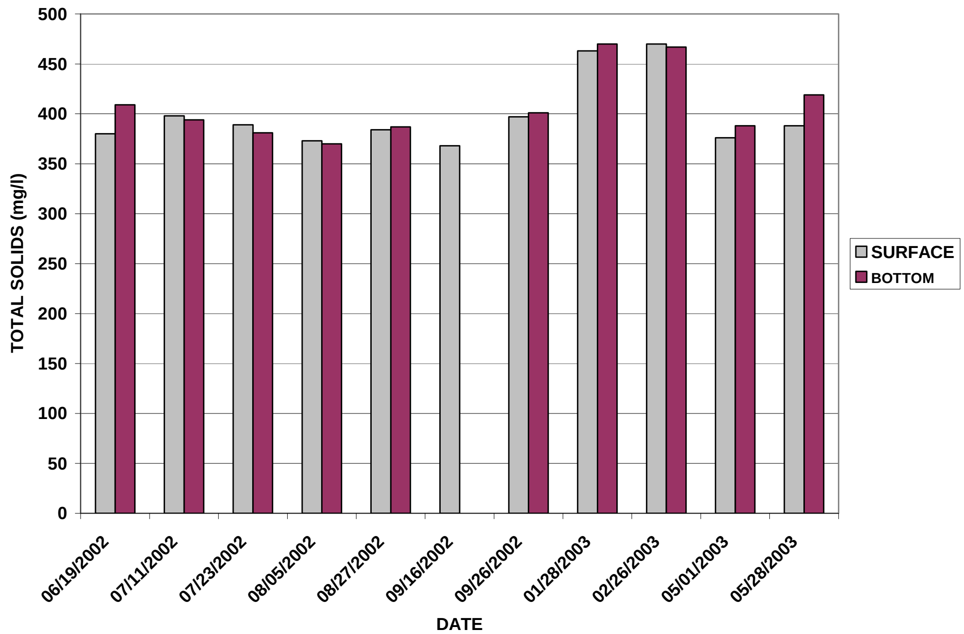

Figure 8. In-lake surface and bottom total solids concentrations for North Buffalo Lake, Marshall County, South Dakota, 2002/2003.

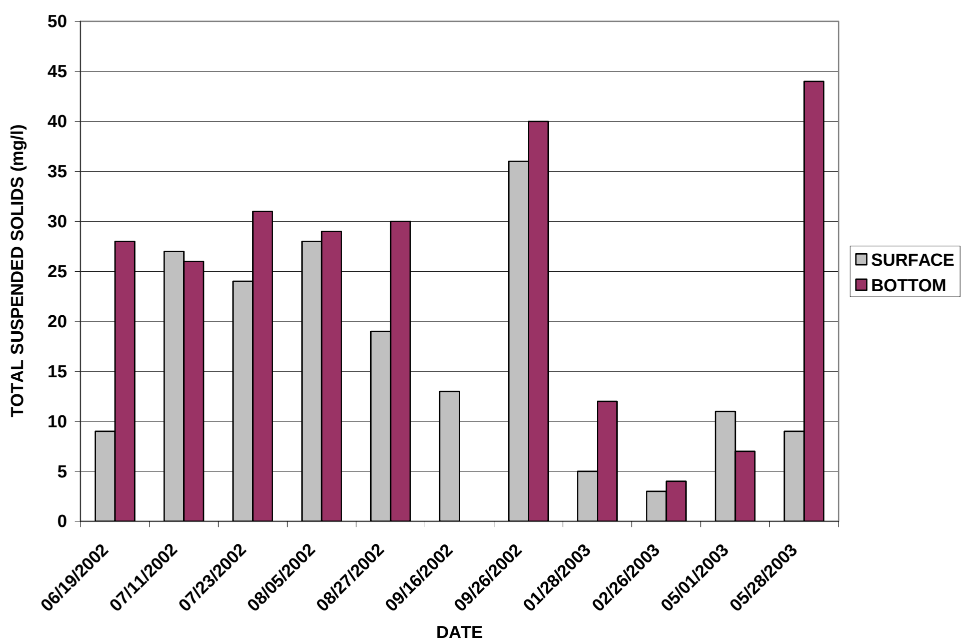

Figure 9. In-lake surface and bottom total suspended solids concentrations for North Buffalo Lake, Marshall County, South Dakota, 2002/2003.

Nitrogen

All twenty-one samples collected from North Buffalo Lake and analyzed for nitrates had concentrations at or below the 0.1 mg/l detection limit (see Appendix A). Ammonia concentrations were at or below the 0.02 mg/l detection limit sixteen out of twenty-one samples (76% of the samples). Ammonia concentrations averaged 0.042 mg/l and ranged from below the 0.02 mg/l detection limit to 0.16 mg/l (see Appendix A 7). The median concentration was 0.02 mg/l. The water quality standard criterion for total ammonia was not exceeded in any of the samples

Total nitrogen in North Buffalo Lake averaged 1.28 mg/l and ranged from 0.82 mg/l to 1.70 mg/l. Organic nitrogen comprised about 89% of the total nitrogen. This was likely due to macrophyte debris, algae and other organic matter in the lake.

Phosphorus

The average in-lake total phosphorus concentration during the assessment was 0.053 mg/l. Total phosphorus concentrations greater than 0.02 mg/l are generally regarded as indicative of eutrophic conditions (USEPA, 1974) and so North Buffalo Lake could be considered eutrophic. Total phosphorus concentrations were generally highest during July and August (Table 5).

Total dissolved phosphorus (TDP) in North Buffalo Lake averaged .014 mg/l and ranged from .009 to .030 mg/l (Table 5). TDP comprised about 31% of the total phosphorus and did not exhibit much seasonality.

Table 5. Total and total dissolved phosphorus concentrations (mg/l) for North Buffalo Lake, Marshall County, South Dakota during 2002/2003.

	TOTAL PHOSPHORUS		TOTAL DISSOLVED PHOSPHORUS	
Date	NBUFL01 Surface	NBUFL01 Bottom	NBUFL01 Surface	NBUFL01 Bottom
6/19/02	.032	.048	.012	.010
7/11/02	.067	.060	.012	.012
7/23/02	.074	.070	.030	.010
8/05/02	.071	.071	.010	.009
8/27/02	.046	.085	.010	.011
9/16/02	.022		.012	
9/26/02	.081	.076	.013	.014
1/28/03	.031	.038	.014	.016
2/27/03	.035	.036	.022	.022
4/29/03	.044	.042	.019	.016
5/28/03	.036	.056	.011	.013

Fecal Coliform Bacteria

North Buffalo Lake is listed for the beneficial use of immersion recreation which requires that no single sample exceed 400 colonies/100ml or the 30-day geometric mean (consisting of at least 5 samples) not exceed 200 colonies/100ml. No exceedences of the state standard criterion were observed during the project. Samples collected and analyzed by the State Health Lab for fecal coliform were at or below the detection limit of 10 colonies per 100 ml except for one sample (20 colonies/100 ml) (see Appendix A).

Limiting Nutrients

Two primary nutrients are required for cellular growth in organisms, phosphorus and nitrogen. Nitrogen is difficult to limit in aquatic environments due to its highly soluble nature and algal uptake of nitrogen from the atmosphere. Phosphorus is easier to control, making it the primary nutrient targeted for reduction when attempting to control eutrophication. The ideal ratio of nitrogen-to-phosphorus for aquatic plant growth is 10:1 (EPA, 1990). Ratios higher than 10:1 indicate a phosphorus-limited system. Those that are less than 10:1 represent nitrogen-limited systems.

The average total nitrogen (TN) to total phosphorus (TP) ratio for the water samples collected from North Buffalo Lake was 27.21 with a range of 13.67 to 65.45 (Appendix A). All of the TN:TP ratios calculated for the lake were greater than 10 and indicated phosphorus limitation. There was little seasonality to the TN:TP ratios.

Chlorophyll *a*

The data indicated relatively low concentrations throughout the project. (Table 6). Chlorophyll *a* concentrations in South Dakota lakes are often as high as 100 µg/l, but in North Buffalo Lake, the growing-season chlorophyll *a* concentration only averaged 14.85 µg/l. This level indicates eutrophic conditions (USEPA, 1974). The growing season chlorophyll *a* concentrations correlated well with in-lake total phosphorus concentrations (Figure 10).

Table 6. Chlorophyll *a* concentrations (µg/l) for site NBUFL01 in North Buffalo Lake, Marshall County, South Dakota during 2002/2003.

Date	Chlorophyll *a* (µg/l)	Date	Chlorophyll *a* (µg/l)
6/19/02	3.30	9/26/02	24.03
7/11/02	21.93	2/26/03	1.70
7/23/02	27.63	5/01/03	1.70
8/05/02	16.22	5/28/03	1.40
8/27/02	9.41	8/27/02	9.41

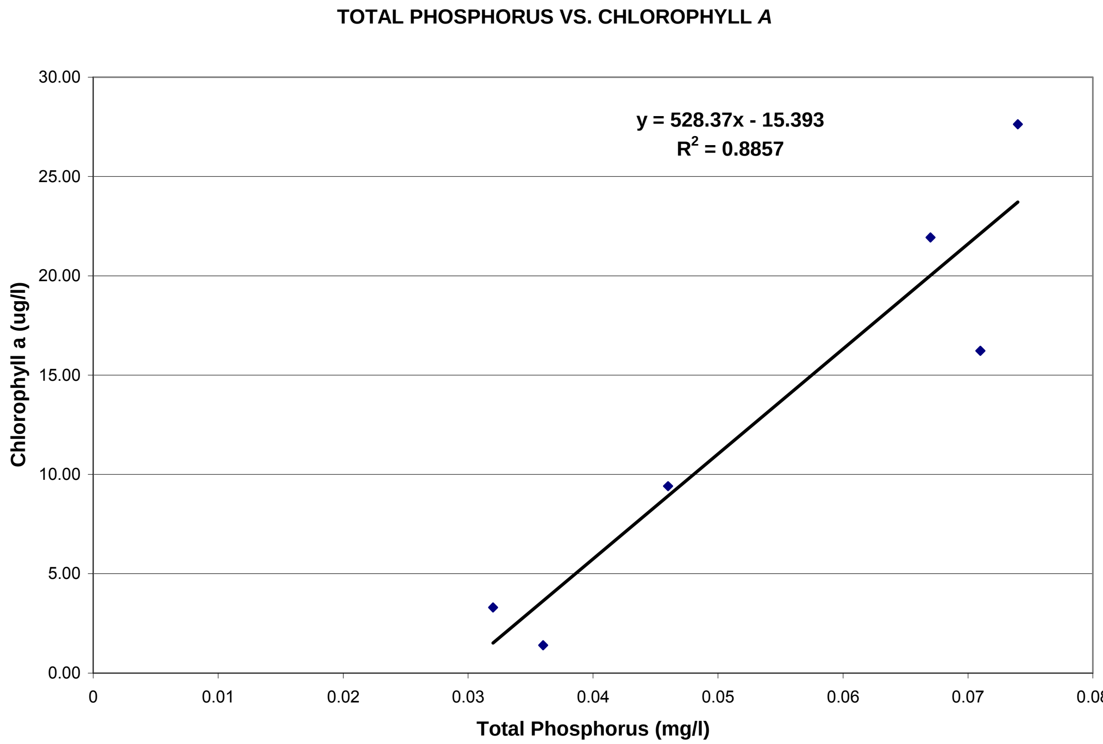

Figure 10. Regression between growing-season total phosphorus and chlorophyll a in North Buffalo Lake, 2002/2003.

Trophic State

Trophic state relates to the degree of nutrient enrichment of a lake and its ability to produce aquatic macrophytes and algae. The most widely used and commonly accepted method for determining the trophic state of a lake is Carlson's (1977) Trophic State Index (TSI). It is based on Secchi depth, total phosphorus, and chlorophyll *a* in surface waters. The values for each of the aforementioned parameters are averaged to give the lake's trophic state.

Lakes with TSI values less than 35 are generally considered to be oligotrophic and contain very small amounts of nutrients, little plant life, and are generally very clear. Lakes that have a score of 35 to 50 are considered mesotrophic and have more nutrients and primary production than oligotrophic lakes (Table 7). Eutrophic lakes have a score between 50 and 65 and are subject to algal blooms and have large amounts of primary production. Hyper-eutrophic lakes receive scores greater than 65 and are subject to frequent and massive blooms of algae that severely impair their beneficial use and aesthetic beauty.

During the study the average growing season trophic state numerical value for North Buffalo Lake was 58.81, placing it in the eutrophic category. This TSI was based on surface total phosphorus, Secchi transparency, and chlorophyll *a*.

Table 7. Trophic state and TSI values.

TROPHIC STATE	TSI NUMERIC RANGE
OLIGOTROPHIC	0-35
MESOTROPHIC	36-50
EUTROPHIC	51-65
HYPER-EUTROPHIC	66-100

Lorenzen (2005) recognized the problems with using total phosphorus in TSIs and developed TSI targets based on the fish life classification of a lake. During 2008, refinement of the 303(d) listing criteria eliminated the use of TSI values as a means to measure beneficial use attainment. However, the TSIs are still used as a general means of judging overall lake water quality and setting annual phosphorus loads.

For a lake with a semi-permanent fish life propagation use, full support of the use is obtained at a median growing-season Secchi-chlorophyll *a* TSI of $\leq$63.4. The median growing-season Secchi-chlorophyll *a* TSI for North Buffalo Lake was 60.86 and indicated the lake was meeting its target TSI value.

Sediment Survey

Because it was felt that the local financial base was insufficient to support dredging in the lake, only a cursory sediment survey was conducted. During March 2003 a total of seven holes were drilled through the ice. At each hole, the water depth was recorded and a piece of rebar was pushed into the sediment as far as possible and the length of rebar from the end back to the surface ice was noted. The difference between that measurement and the water depth equals the sediment depth.

Figure 11 shows the test holes and the corresponding water and sediment depths. Water depth ranged from 0 to 12 feet (3.11 meters) with an average depth of 11.1 feet (3.38 meters). This corresponded well with historical data of mean and maximum depths of 10 and 12 feet respectively (State Lakes Preservation Committee, 1977).

The sediment depths ranged from 1 to 11.5 feet (3.51 meters) with an average sediment depth of 8.4 feet (2.56 meters). The greater sediment depths are somewhat puzzling because most lakes surveyed in South Dakota have sediment depths in the 3 to 6 foot range and there is no clear reason for North Buffalo Lake to have such large sediment depths. Lake depth could be increased, possibly up to 43%, if this sediment was removed, which would extend the life of the lake. This might also remove sediment that could otherwise release nutrients into the water column.

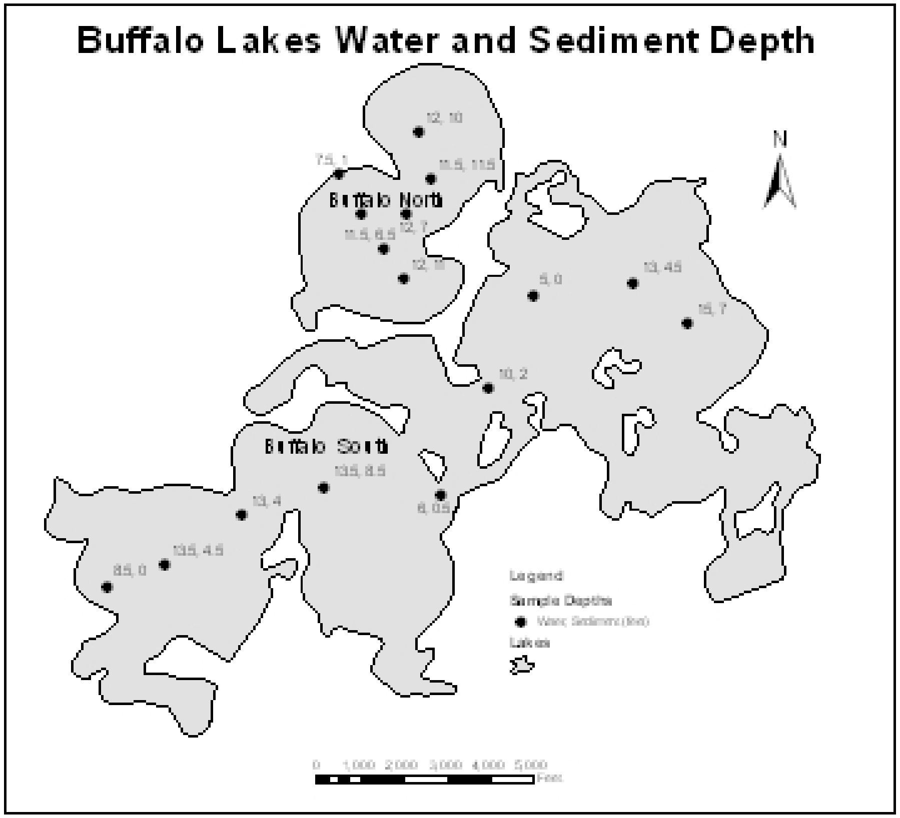

Figure 11. Water and sediments depths at the test holes in North Buffalo Lake, Marshall County, South Dakota, 2003.

Elutriate Testing

Elutriate tests were run on samples collected from a single site in the lake during 5/18/2004. Sediment was collected with a Petite Ponar sampler and water was collected with a Van Dorn sampler. The samples were shipped to the State Health Lab for analysis. The sediment was mixed with lake water and the resultant elutriate was analyzed for the same parameters as the receiving water.

The elutriate and receiving water tests indicated many of the parameters were below their respective detection limits and none of the results indicated problematic conditions concerning these parameters (Table 8).

Table 8. Elutriate test results for North Buffalo Lake, Marshall County, South Dakota, during 5/18/2004.

Parameter	Receiving Water	Elutriate Sample	Unit
COD	32.3	48.4	mg/l
Phosphorus, total	0.012	0.016	mg/l
TKN	0.91	1.95	mg/l
Hardness	750	620	mg/l
Nitrate	<0.1	0.1	mg/l
Nitrite	<0.02	0.02	mg/l
Ammonia	<0.02	0.03	mg/l
Aluminum	<0.5	2.6	µg/l
Zinc	<3.0	6.4	µg/l
Silver	<0.2	<0.2	µg/l
Selenium	1.3	1.4	µg/l
Nickel	1.3	1.3	µg/l
Mercury, total	<0.1	<0.1	µg/l
Lead	<0.1	<0.1	µg/l
Copper	17.8	1.0	µg/l
Cadmium	<0.2	<0.2	µg/l
Arsenic	0.006	0.006	µg/l
Alachlor	< 0.100	< 0.100	µg/l
Chlordane	< 0.500	< 0.500	µg/l
Endosulfan II	< 0.500	< 0.500	µg/l
Atrazine	< 0.100	< 0.100	µg/l
Endrin	< 0.500	< 0.500	µg/l
Heptachlor	< 0.400	< 0.400	µg/l
Heptachlor Epoxide	< 0.500	< 0.500	µg/l
Methoxychlor	< 0.500	< 0.500	µg/l
Toxaphene	< 0.100	< 0.100	µg/l
Aldrin	< 0.500	< 0.500	µg/l
Dieldrin	< 0.500	< 0.500	µg/l
Aroclor 1016	< 0.100	< 0.100	µg/l
Aroclor 1221	< 0.100	< 0.100	µg/l
Aroclor 1232	< 0.100	< 0.100	µg/l
Aroclor 1242	< 0.100	< 0.100	µg/l
Aroclor 1248	< 0.100	< 0.100	µg/l
Aroclor 1254	< 0.100	< 0.100	µg/l
Aroclor 1260	< 0.100	< 0.100	µg/l
Diazinon	< 0.500	< 0.500	µg/l

DDD	< 0.500	< 0.500	µg/l

Table 8. Continued.

Parameter	Receiving Water	Elutriate Sample	Unit
DDT	< 0.500	< 0.500	µg/l
DDE	< 0.800	< 0.800	µg/l
BETA BHC	< 0.500	< 0.500	µg/l
GAMMA BHC	< 0.500	< 0.500	µg/l
ALPHA BHC	< 0.500	< 0.500	µg/l

Macrophyte Survey

A macrophyte/shoreline condition survey was conducted during August 2003. Twelve locations were established approximately equidistant from each other around the perimeter of the lake. At each location, the bank stability, vegetative cover, and vegetative zone width were rated from 0 to 10 (10 being the optimal condition). Three macrophyte survey points were also established at each location with the nearest point being approximately ten feet from the shoreline and the farthest point 30-40 feet away from the shoreline. At each point, a weighted garden rake (tined portion with one foot of handle) was thrown in four directions. The relative percent recovery of plant species on the rake was noted and the relative plant density at each point was judged from the four rake pulls.

The shoreline of North Buffalo Lake was rated as being in marginal to optimal condition. The rating scores for bank stability, vegetative cover, and vegetative zone width averaged scores of 10.0, 7.2, and 4.0 respectively (with scores of 9-10 being optimal, 6-8 as suboptimal, 3-5 as marginal, and 0-2 as poor). Bank stability was optimal but some cut banks, livestock grazing, and some natural rock or old rip-rap contributed to the lower score for the vegetative cover and vegetative zone width.

The macrophyte survey indicated light density of emergent vegetation, cattails (*Typha* spp.) and bulrush (*Scirpus* spp.) along the lake's shoreline. The emergent vegetation was not considered a problem for the lake users. Submergent vegetation consisted of a scattered to moderate mix of coontail (*Ceratophyllum demersum*) and sago pondweed (*Potamogeton pectinatus* L.). Decay of this vegetation may periodically contribute to low oxygen concentrations in the lake.

Long-Term Trends

Little historical data exist for North Buffalo Lake so data from the South Dakota statewide lake sampling program as well as data from this assessment were included in the trend analysis. North Buffalo Lake is listed on the state's 2006 303(d) list as an unimpaired water body with a stable TSI trend. The regression line shown in Figure 12 shows a downward trend but the r^2 value was so low as to lead one to conclude the trend may not exist. It is likely that the spread of data during this assessment contributed to the low r² value. More data need to be gathered before a meaningful trend line can be developed.

Lorenzen's (2005) TSI target for full support was a median growing season Secchi-chlorophyll *a* TSI of $\leq$ 63.4. The data appear to be equally greater than and less than this target but at least it is promising that the TSI values generated from 2006 data were below the target value.

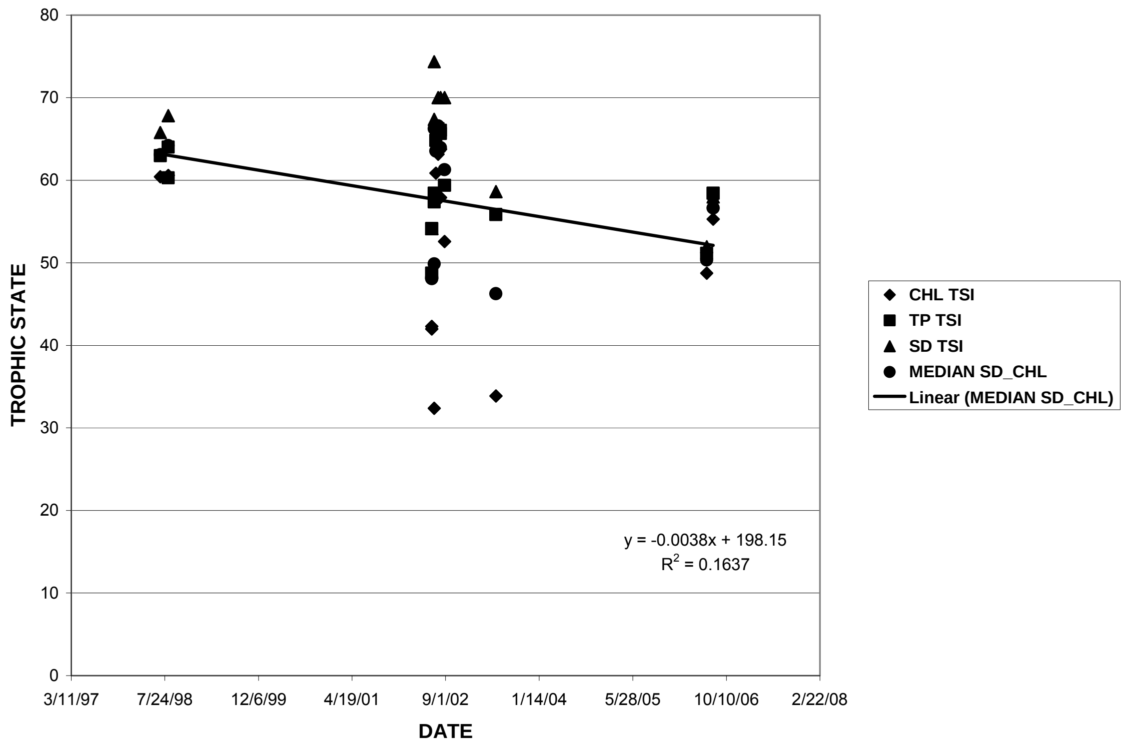

Figure 12. Growing-season total phosphorus, Secchi transparency and chlorophyll *a* trophic state indices in North Buffalo Lake, South Dakota; with trend line for median Secchi-chlorophyll *a* TSI.

OBJECTIVE 2 – Tributary Water Chemistry and Loadings to North Buffalo Lake

Tributary Sampling Schedule, Methods, and Materials

Three tributary monitoring sites were selected for North Buffalo Lake (two tributaries and one outlet) (Figure 2). Model 4630 ISCO stage recorders were installed at sites NBUFT01 and NBUFT02. Site SBUFT06 was equipped with an OTT Thalimedes type stage recorder. Water stages were monitored and recorded for each of the sites. A Marsh-McBirney Model 210D flow meter was used to determine flows at various stages during spring run-off. The stages and flows were then used to create a stage/discharge relationship for each site. Site NBUFT01 did not flow during the study.

Sampling at the tributary sites began June 17, 2002 and continued until flows stopped. Most samples were collected with the "grab" method by holding the sample bottle under the water until filled. The water samples were then filtered, preserved, and packed in ice for shipping to the State Health Lab in Pierre, SD according to the "Standard Operating Procedures for Field Samplers" (Stueven, et al., 2000).

The laboratory analyzed the samples for the following parameters:

Fecal coliform bacteria
Total solids
Total suspended solids
Nitrate
Total phosphorus
E. coli
Alkalinity
Total volatile suspended solids
Ammonia
Total Kjeldahl Nitrogen (TKN)
Total dissolved phosphorus

Personnel conducting the sampling at each of the sites recorded precipitation, odor, presence of dead fish, wind speed, septic conditions, surface film, ice cover, and water color and depth.

Parameters measured in the field by sampling personnel included water temperature, air temperature, specific conductance, dissolved oxygen, and field pH.

Tributary Sampling Results

Fecal Coliform Bacteria

Approximately 60% of the samples had fecal coliform bacteria concentrations at or below 10 colonies/100 ml (see Appendix A). Although no fecal coliform standard exists for the tributaries, one of the twenty samples had a concentration above the 400 colonies/100 ml criterion for immersion recreation. This higher concentration is thought to be due to livestock or sample contamination.

Specific Conductance

Specific conductance in the tributaries ranged from 293 to 700 µS/cm (Appendix A). The state standard criterion for specific conductance is 7,000 µS/cm for a single sample. Specific conductance measurements in the tributary and outlet site never exceeded this criterion. Generally, specific conductance was greatest during the spring runoff period.

Alkalinity

Alkalinity concentrations in North Buffalo Lake tributary and outlet site ranged from 173 mg/l to 284 mg/l (Appendix A). These concentrations are generally typical of water bodies in South Dakota. The state standard criterion for alkalinity is a maximum of 750 mg/l as a geometric mean or 1,313 mg/l in a single sample. None of the samples collected at the tributary sites exceeded the criterion.

Solids

Total solids ranged from 312 to 425 mg/l (Appendix A). These data are not unusual for streams in South Dakota. Total suspended solids concentrations ranged from 2 to 30 mg/l and usually comprised less than 3% or less of the total solids. There is no state standard for total suspended solids that applies to the tributary and outlet site.

Seasonality was not readily apparent although samples collected during May were generally greater in total solids and suspended solids concentrations than samples collected during the summer.

Nitrogen

The total inorganic nitrogen concentrations ranged from 0.12 to 0.40 mg/l. Seasonality was not apparent (Table 9). Total organic nitrogen concentrations ranged from 0.65 to 1.35 mg/l and averaged 82% of the total nitrogen concentration. Seasonality was also not apparent in the total organic nitrogen concentrations.

Table 9. Total inorganic and organic nitrogen concentrations (mg/l) for North Buffalo Lake tributaries, Marshall County, South Dakota during 2002/2003.

	TOTAL INORGANIC NITROGEN (mg/l)			TOTAL ORGANIC NITROGEN (mg/l)		
Date	SBUFT06 (inlet)	NBUFT01 (inlet)	NBUFT02 (outlet)	SBUFT06 (inlet)	NBUFT01 (inlet)	NBUFT02 (outlet)
6/17/02	0.12	No flow	0.13	1.04	No flow	1.3
7/15/02	0.12	No flow	0.12	1.26	No flow	1.11
8/13/02	0.12	No flow	0.13	0.8	No flow	0.65
10/01/02	0.12	No flow	0.12	1.07	No flow	1.34
4/03/03	0.12	No flow	0.35	0.93	No flow	1.16
4/16/03	0.12	No flow	0.12	1.27	No flow	0.92
4/24/03	0.12	No flow	0.12	1.14	No flow	0.9
4/30/03	0.12	No flow	0.12	1.11	No flow	1.6
5/06/03	0.12	No flow	0.16	1.12	No flow	1.4
5/13/03	0.12	No flow	0.12	1.32	No flow	1.2
5/21/03	0.40	No flow	0.12	0.84	No flow	1.25
5/29/03	0.12	No flow	0.15	1.26	No flow	1.35
Mean	0.14	No flow	0.15	1.10	No flow	1.18

Phosphorus

Total phosphorus concentrations in the tributary and outlet site ranged from 0.029 to 0.24 mg/l and averaged 0.047 to 0.083 mg/l (Table 10). Total dissolved phosphorus averaged 29% of the total phosphorus in the incoming tributaries.

The inlet showed typical seasonality whith greater concentrations during the first flush of spring runoff. The outlet site did not show any particular seasonality

Table 10. Total phosphorus and total dissolved phosphorus concentrations (mg/l) for North Buffalo Lake tributaries, Marshall County, South Dakota during 2002/2003.

	TOTAL PHOSPHORUS (mg/l)			TOTAL DISSOLVED PHOSPHORUS (mg/l)		
Date	SBUFT06 (inlet)	NBUFT01 (inlet)	NBUFT02 (outlet)	SBUFT06 (inlet)	NBUFT01 (inlet)	NBUFT02 (outlet)
6/17/02	0.037	No flow	0.104	0.019	No flow	0.045
7/15/02	0.056	No flow	0.061	0.011	No flow	0.017
8/13/02	0.045	No flow	0.061	0.009	No flow	0.017
10/01/02	0.04	No flow	0.059	0.01	No flow	0.033
4/03/03	0.062	No flow	0.088	0.01	No flow	0.015
4/16/03	0.079	No flow	0.06	0.012	No flow	0.016
4/24/03	0.043	No flow	0.06	0.017	No flow	0.013
4/30/03	0.041	No flow	0.072	0.015	No flow	0.017
5/06/03	0.038	No flow	0.235	0.01	No flow	0.022
5/13/03	0.053	No flow	0.071	0.012	No flow	0.016
5/21/03	0.029	No flow	0.038	0.013	No flow	0.018
5/29/03	0.046	No flow	0.089	0.013	No flow	0.021
Mean	0.047	No flow	0.083	0.013	No flow	0.021

Tributary flows and phosphorus loading using the BATHTUB model

Site NBUFT01 did not flow during the study. Tributary stage-flow relationships for sites NBUFT02 (the outlet) and SBUFT06 (the other inlet) were developed from measured stream stages and from flows based on velocity readings and cross-sectional measurements. The strength of the relationships between stage and flow were determined by the r^2 value of the regression equation.

The r^2 value for site NBUFT02 was only 0.22 so rather than use the regression to calculate the flows for Site NBUFT02, measured flows (based on velocity readings and cross-sectional measurements) were used to represent the daily flows for each time interval during the study and an annual flow was estimated (Scheider, et al., 1979).

Atmospheric data came from a South Dakota State University database (http://climate.sdstate.edu/climate_site/climate.htn) where precipitation data were collected from Britton, South Dakota. The precipitation total for the study period compared favorably with the long term average precipitation (20.13" vs. 20.68") so these data are considered representative of annual precipitation. The Britton evaporation data were not available and so evaporation was based on the Brookings evaporation:precipitation ratio.

The summer of 2002 comprised most of the total measured inflow (Table 11). It is fairly typical for South Dakota lakes where water inflows (and nutrient and sediment loadings) peak during the spring and early summer. The lack of inflows during the spring of 2003 at site SBUFT06 (the outlet of South Buffalo Lake) is because that lake was low and not yet high enough to spill into North Buffalo Lake.

Table 11. Monthly total water inflows/outflows (acre-feet) for North Buffalo Lake, Marshall County, South Dakota, 2002/2003.

Month/Year	**NBUFT01 inflow**	**SBUFT06 inflow**	**Avg. Ann. Ppt.**	**NBUFT02 outflow**	**Avg. Ann. Evap.**
½June, 2002	0	290.054	5.758	145.621	
July 2002	0	257.976	82.485	157.746	
August 2002	0	61.285	72.615	217.731	
September 2002	0	0	13.865	168.566	
October 2002	0	0	41.830	0	
November 2002	0	0	1.645	0	
December 2002	0	0	8.225	0	
January 2003	0	0	3.995	0	
February 2003	0	0	3.760	0	
March 2003	0	0	4.230	0	
April 2003	0	0	71.440	107.750	
May 2003	0	0.445	91.650	78.116	
½June , 2003	0	0	71.558	4.443	
Total (Ac-ft)	**0**	**609.760**	**473.056**	**879.973**	**433.036**

The Army Corps of Engineers BATHTUB program (Walker, 1999) was used to predict Secchi depth, and concentrations of phosphorus, nitrogen, and chlorophyll *a* in North Buffalo Lake. A model was selected that most closely predicted current in-lake conditions and TSIs. These estimates were used in determining a total phosphorus load for the lake.

The BATHTUB model produced good agreement between the observed and predicted total phosphorus concentration and TP TSI (Table 12). No progressive decreases in total phosphorus loads in the tributaries were modeled because the predicted TSI already meets the target TSI of 63.4.

The total phosphorus mass balance for North Buffalo Lake was as follows:

Precipitation	13.1 kg/yr	Advective outflow	-13.9 kg/yr		
Tributary inflows	35.3 kg/yr	Outflow	47.9 kg/yr		
Total inflow	48.4 kg/yr	Total outflow	34.0 kg/yr	Retention	14.4 kg/yr

Table 12. Predicted and Observed Values Ranked Against CE Model Development Dataset.

North Buffalo Lake						
Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	**1**	**Near Dam**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	44.1	0.28	46.4%	50.0	0.42	51.9%
TOTAL N MG/M3	1043.0	1.10	52.5%	1043.0	1.10	52.5%
C.NUTRIENT MG/M3	37.9	0.38	53.0%	41.5	0.69	57.5%
CHL-A MG/M3	21.1	0.48	85.3%	14.9	0.70	72.4%
SECCHI M	1.1	0.29	50.4%	0.8	0.53	34.0%
ORGANIC N MG/M3	752.3	0.34	81.7%	1100.0	0.12	95.1%
TP-ORTHO-P MG/M3	69.4	0.36	81.2%	37.0	0.51	58.7%
ANTILOG PC-1	467.1	0.64	68.9%	540.6	0.61	72.7%
ANTILOG PC-2	12.0	0.24	88.2%	7.9	0.61	65.5%
(N - 150) / P	20.2	1.31	60.1%	17.9	1.35	52.9%
INORGANIC N / P	290.7	4.04	98.9%	0.1	2.15	0.0%
TURBIDITY 1/M	1.5	0.39	85.1%	1.5	0.39	85.1%
ZMIX * TURBIDITY	4.6	0.39	68.3%	4.6	0.39	68.3%
ZMIX / SECCHI	2.8	0.29	17.3%	3.8	0.51	34.8%
CHL-A * SECCHI	23.0	0.31	87.4%	11.7	0.88	57.8%
CHL-A / TOTAL P	0.5	0.29	92.0%	0.3	0.81	74.3%
FREQ(CHL-a>10) %	81.4	0.25	85.3%	62.9	0.66	72.4%
FREQ(CHL-a>20) %	41.1	0.73	85.3%	21.5	1.54	72.4%
FREQ(CHL-a>30) %	19.0	1.11	85.3%	7.4	2.18	72.4%
FREQ(CHL-a>40) %	9.0	1.42	85.3%	2.8	2.67	72.4%
FREQ(CHL-a>50) %	4.4	1.67	85.3%	1.2	3.07	72.4%
FREQ(CHL-a>60) %	2.3	1.88	85.3%	0.5	3.40	72.4%
CARLSON TSI-P	58.8	0.07	46.4%	60.6	0.10	51.9%
CARLSON TSI-CHLA	60.5	0.08	85.3%	57.1	0.12	72.4%
CARLSON TSI-SEC	58.8	0.07	49.6%	63.4	0.12	66.0%

Based on the BATHTUB model results, the total annual phosphorus load was set at 62.5 kg/yr. This load produced a Secchi-chlorophyll *a* TSI of 63.35 and will ensure meeting the target TSI of 63.4.

OBJECTIVE 3 - Quality Assurance Reporting

Quality Assurance/ Quality Control (QA/QC) samples were collected for at least 10% of the total number of samples taken. Forty-five samples were taken from North Buffalo Lake and its tributaries. Three sets of blanks and duplicates samples were collected during the project for QA/QC purposes (Table 13). The industrial statistic "%I" was used to assess the data precision; where precision (%I) = difference between duplicate analytical values divided by the sum of the values, multiplied by 100. Values greater than 10% were considered problematic and further investigation may be needed to correct the problem.

The field blanks were consistently at or below the detection limits of the parameters tested except for total and dissolved phosphorus. This may be due to laboratory error, contamination of the water used for the blank samples, or perhaps not rinsing the sample bottle well enough with distilled water. Because most of the blank samples were satisfactory, it is felt that no further action needs to be taken to investigate reasons for the errant data.

The duplicate samples were generally satisfactory except for fecal coliform bacteria, which had average %I value greater than 10% There is no obvious reason for these results so further investigation may be needed to resolve this issue. These data should not be used or at least used with great caution.

Table 13. Field blanks and duplicates for the North Buffalo Lake assessment.

StationID	SampleDate	Relative Depth	Type	Alka, mg/l	Fecal Col., #/100ml	E. Coli, #/100ml	NH3, mg/l	TKN, mg/l	NO3, mg/l	Diss P, mg/l	Total P, mg/l	TS, mg/l	TSS, mg/l	VSS, mg/l
NBUFL01	08/05/2002	Surface	Blank	<6	<10	<1	<0.02	<.32	<0.1	<0.002	0.003	<7	<1	<1
NBUFL01	08/05/2002	Surface	Sample	232	<10	1	<0.02	1	<0.1	0.01	0.071	373	28	20
NBUFL01	08/05/2002	Surface	Replicate	230	<10	<1	<0.02	0.86	<0.1	0.01	0.073	381	28	21
%I				0.43	0.00	0.00	0.00	7.53	0.00	0.00	1.39	1.06	0.00	2.44
NBUFL01	08/05/2002	Bottom	Blank	<6			<0.02	<.32	<0.1	<0.002	0.002	<7	<1	<1
NBUFL01	08/05/2002	Bottom	Sample	232			<0.02	1.53	<0.1	0.009	0.073	370	29	20
NBUFL01	08/05/2002	Bottom	Replicate	231			<0.02	1.19	<0.1	0.01	0.072	372	28	20
%I				0.22			0.00	12.50	0.00	5.26	0.69	0.27	1.75	0.00
NBUFT02	04/16/2003		Blank	<7	<10	<1	<0.02	<.11	<0.1	<.002	<.002	<7	<1	<1
NBUFT02	04/16/2003		Sample	245	20	34.1	<0.02	0.94	<0.1	0.016	0.06	358	4	3
NBUFT02	04/16/2003		Replicate	244	10	37.3	<0.02	0.95	<0.1	0.016	0.063	364	5	4
%I				0.20	33.33	4.48	0.00	0.53	0.00	0.00	2.44	0.83	11.11	14.29
Average %I				0.28	16.67	2.24	0.00	6.85	0.00	1.75	1.51	0.72	6.43	5.58

OBJECTIVE 4- Annualized Agricultural Non-Point Source Model (AnnAGNPS)

AnnAGNPS is a data intensive watershed model that routes sediment and nutrients through a watershed by utilizing land uses and topography. The watershed is broken up into cells of varying sizes based on topography. Each cell is then assigned a primary land use and soil type. Best Management Practices (BMPs) are then simulated by altering the land use in the individual cells and reductions in nutrient and sediment loads are calculated at the outlet to the watershed.

The AnnAGNPS model was not used because the lake is already meeting its target TSI of 63.4. However, to maintain the condition of the lake the current effort to implement Best Management Practices (BMPs) through the U.S. Department of Agriculture or other cost-share programs should continue. Potential nutrient and sediment reductions in this watershed will be largely dependent on the willingness of the small number of landowners to participate in these programs

OBJECTIVE 5 - Public Participation

State Agencies

The South Dakota Department of Environment and Natural Resources (SDDENR) was the primary state agency involved in the completion of this assessment. SDDENR provided equipment as well as technical assistance throughout the project.

The South Dakota Department of Game, Fish and Parks provided information about threatened and endangered species and a copy of the latest Fishery Report on North Buffalo Lake.

Federal Agencies

The Environmental Protection Agency (EPA) provided the primary source of funds for the completion of the assessment on North Buffalo Lake. The Natural Resource Conservation Service (NRCS) provided technical assistance. The Farm Service Agency allowed access to historical records to obtain data for this project report.

Local Governments; Industry, Environmental, and other Groups; and General Public

The Marshall Conservation District sponsored the project, provided project accounting, and hired a consulting firm, Prairie Agricultural Research, to do the field work. Public involvement primarily consisted of monthly meetings of the Marshall Conservation District.

Table 14 shows the funding sources, the budgeted amounts from each of these sources, total expenditures, and the percentage that was utilized. In-kind match came primarily from the Marshall Conservation District (CD) for utilizing their time to manage and direct the project. The project was completed using only about 72% of the proposed budget. This was probably due to fewer samples being collected than what was proposed and a general overestimation of project costs.

Table 14. Funding sources and funds utilization for the Marshall County Lakes Assessment Project.

Organization	Amount in the Budget	Spent	In-Kind	% utilized
EPA 319	165,000.00 amended to 120,000.00	79,981.22	0	67%
SDDENR	25,000.00	25,000.000	0	100%
Marshall CD	2,000.00	0	1,003.50	50%

RECOMMENDATIONS

There are a limited number of lake restoration techniques available to lake managers and the bulk of these are summarized by Cooke, et al. (1986). A number of lake restoration strategies were reviewed for their applicability to the North Buffalo Lake situation and each one is discussed below.

Lake Restoration Techniques Rejected for North Buffalo Lake

Dilution/flushing

Dilution/flushing is a technique to reduce algal biomass by introducing water of lower nutrient concentration while concurrently increasing water exchange (flushing) in the lake. This category was not considered a viable option for North Buffalo Lake because there is no source of dilution water nearby and because algae are currently not a problem.

Lake Drawdown

Lake drawdown is sometimes used to control aquatic macrophytes. Because North Buffalo Lake is a natural lake with no controllable outlet, this technique is not recommended at this time.

Biological Controls

Use of biological controls to control algae or aquatic macrophytes is considered experimental and is in need of additional studies to refine the technique. As such, biological controls are not recommended. Also, macrophytes were not a problem.

Hypolimnetic Withdrawal

Withdrawal of water from the hypolimnion is done to remove nutrient-laden water that might otherwise be available for algal growth. Withdrawals may also be used to improve dissolved oxygen conditions in the lake by replenishing the hypolimnion with well-oxygenated epilimnetic water. This would improve conditions for aquatic life at the bottom of the lake.

Hypolimnetic withdrawal for North Buffalo Lake is not recommended at this time because the lake doesn't stratify.

Phosphorus Inactivation and Bottom Sealing with Aluminum Sulfate

This technique is not recommended because the lake is currently meeting its TSI target and does not need extensive nutrient controls.

Surface/Sediment Covers

Various materials have been used for rooted aquatic plant control. Sediment covers are not recommended because macrophytes are not a problem.

Macrophyte/Algae Control by Application of Herbicides/Algicides

Use of herbicides and algicides has been shown to be an effective means to control nuisance aquatic macrophytes and algae. This technique is not recommended because macrophytes and algae were not a problem in the lake.

Macrophyte Control by Mechanical Harvesting

Harvesting nuisance aquatic plants has been a common lake restoration technique. This technique is not recommended because macrophytes were not a problem in the lake.

Sediment Removal for Nutrient Control/Lake Longevity

Sediment removal is sometimes used to remove nutrient-rich sediments that might release nutrients during anaerobic conditions. The idea is to remove enough sediment until a "new" layer of sediment is exposed that contains lower concentrations of nutrients than what was removed or that has a lower nutrient release rate. In addition, organic matter in the overlying sediment might be removed, resulting in less bacterial decomposition of organic matter and less oxygen depletion in the hypolimnion.

Sediment removal for nutrient control is not recommended because the lake is meeting its TSI target and the lake is not in need of such a drastic (and expensive) measure of nutrient control. The lake's longevity may be extended by dredging. The cursory sediment survey indicated average sediment depth to be 8.4 feet. This is considered relatively high and suggests that dredging should be considered. But it is questionable whether there are local funding sources to support this strategy and so this technique is not recommended unless a financial package is created that supports this activity.

Techniques Recommended for Consideration

Watershed conservation practices/animal waste management

The lake is currently meeting its target TSI of 63.4 and does not need extensive watershed conservation practices or Animal Waste Management facilities (AWMs). However, in order to maintain the beneficial use support status, it is recommended that the current effort to promote and implement existing and new BMPs and AWMs through the USDA programs or other cost-share program continue.

In addition, nutrients, especially phosphorus, have been shown to increase eutrophication in lakes and reservoirs throughout the country increasing oxygen depletion caused by decomposition of algae and aquatic plants (Carpenter et al., 1998). Carpenter et al. (1998) and Bertram (1993) also indicate that reductions in nutrients will eventually lead to the reversal of eutrophication and attainment designated beneficial uses. Nurnberg (1995, 1995a, 1996, 1997), developed a model that quantified duration (days) and extent of lake oxygen depletion, referred to as an anoxic factor (AF). This model showed that AF is positively correlated with average annual local phosphorous (TP) concentrations. The AF may also be used to quantify response to watershed restoration measures. Nurnberg also developed several regression models that show nutrients (P and N) control all trophic state indicators related to oxygen and phytoplankton in lakes/reservoirs. North Buffalo Lake's morphological characteristics are well within those Nurnberg used to develop regression models Nurnberg's dataset ranges were: $\bar{z}$ mean depth (m), 1.8 – 200; A_o lake surface area (hectares), 1.0 – $8.2*10^6$ and $\bar{z} / A_o^{0.5}$ (m/km^2), 0.14 – 48.1. The dataset for North Buffalo Lake were: $\bar{z}$ (m), 2.0; A_o (hectares), 114.12; and $\bar{z} / A_o^{0.5}$ (m/km^2), 0.19. This supports SDDENR conclusions that nutrients can affect dissolved oxygen concentrations in North Buffalo Lake. Thus, reduction in nutrient (phosphorus) loads to the lake will improve dissolved oxygen concentrations and over all water quality in the lake. South Dakota's approach to treat the sources of nutrients and reduce/eliminate nutrient loads to impaired waters is consistent with accepted watershed strategies to treat sources rather than symptoms (low dissolved oxygen).

However, controlling nutrient loads to North Buffalo Lake will be difficult and in-lake treatments, such as aeration, should also be considered to alleviate low DO conditions. Adding oxygen (air) to the lake will break up stratification and increase conversion of organic matter improving dissolved oxygen concentrations throughout the lake profile. Two lakes in South Dakota, Stockade Lake in Custer County and Lake Waggoner in Haakon County, have or have had aeration systems installed to break up stratification to improve water quality. The Stockade Lake aeration system was put into service in 1999 and operates only during the summer months during thermal stratification. SD GF&P monitoring results indicate aeration during the summer did not allow the lake to stratify, improving the dissolved oxygen profile and increasing fish habitat during the summer. Improved water quality especially dissolved oxygen concentrations has been observed in Stockade Lake in recent years based on SD GF&P monitoring data and current SD DENR statewide lake assessment data (SD GF&P, 2004, SD GF&P, 2005, SD GF&P, 2005a and SD DENR, 1996).

Waggoner Lake installed a mechanical aeration system in the mid 1990s to break up thermal stratification and improve drinking water taste. This system successfully operated during the summer months through 2002 when the City of Philip switched its drinking water source from Waggoner Lake to West River/Lyman Jones rural water.

<u>Aeration/Circulation</u>

Aeration and circulation are well known techniques for preventing oxygen depletion in a lake. Numerous aeration/circulation units are available and the proper sizing and use of the unit(s) must be done by someone who is knowledgeable about the particular unit. Frequent monitoring (including the winter months) for dissolved oxygen must be undertaken in order to know when to aerate and when to cease operation. Otherwise, an aeration system should be set up to continuously operate. The target dissolved oxygen concentration is 5.0 mg/l.

ASPECTS OF THE PROJECT THAT DID NOT WORK WELL

All of the objectives proposed for the project were met in an acceptable fashion and in a reasonable time frame except for the preparation of the final report. This was due to DENR personnel having other commitments.

The decision not to use the pH data would have been made easier if all of the calibration information was documented. E-mails and/or written notes concerning telephone conversations between the project officer and the project coordinator that clearly describe the calibration information and any problems with the pH probe would have provided documentation and helped initiate corrective actions when the problems arose. Project coordinators may not know what readings might be considered abnormal so it is imperative that the project officer have access to the data (and calibration information) as soon as possible so corrective measures can be initiated.

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APPENDIX A

Water Quality Data for North Buffalo Lake

Table 15. Water quality data for North Buffalo Lake, Marshall County, South Dakota.

StationID	SampleDate	Relative Depth	Air Temp. ºC	Water Temp. ºC	DO, mg/l	pH	Secchi, m	Spec. Cond.	Chl.*a* ug/l	Alka, mg/l	Fecal Col., #/100ml	E. Coli, #/100ml	NH3, mg/l	TKN, mg/l	NO3, mg/l	TN, mg/l	Diss P, mg/l	Total P, mg/l	TS, mg/l	TDS, mg/l	TSS, mg/l	VSS, mg/l	TN:TP	CHL TSI	SEC TSI	TP TSI
NBUFL01	06/19/2002	Surface	23.33	20.7	10.54	8.35	1.50	438	3.30	244	<10	1	<0.02	1.09	<0.1	1.19	0.012	0.032	380	271	9	8	37.19	42.28		54.15
NBUFL0	06/19/2002	Bottom	23.33	19.9	5.29	7.85		443		245			0.03	0.94	0.1	1.04	0.01	0.048	409	381	28	11	21.67			60.00
NBUFL0	07/11/2002	Surface	15.55	22.63	11.55	8.4	0.65	438	21.93	243	<10	1	<0.02	1	<0.1	1.1	0.012	0.067	398	371	27	12	16.42	60.86	66.22	64.81
NBUFL0	07/11/2002	Bottom	15.55	22.67	10.62	8.15		439		244			<0.02	0.72	<0.1	0.82	0.012	0.06	394	368	26	13	13.67			63.22
NBUFL0	07/23/2002	Surface	18.33	24.2	7.93	9.44	0.50	421	27.63	256	<10	<1	<0.02	1.17	<0.1	1.27	0.03	0.074	389	365	24	15	17.16	63.13	70.00	66.25
NBUFL0	07/23/2002	Bottom	18.33	23.99	6.88	9.19		419		237			<0.02	1.21	<0.1	1.31	0.01	0.07	381	350	31	16	18.71			65.44
NBUFL0	08/05/2002	Surface	19.44	22.15	7.74	9.4	0.50	391	16.22	232	<10	1	<0.02	1	<0.1	1.1	0.01	0.071	373	345	28	20	15.49	57.90	70.00	65.65
NBUFL0	08/05/2002	Bottom	19.44	22.06	7.3	9.01		392		232			<0.02	1.53	<0.1	1.63	0.009	0.073	370	341	29	20	22.33			66.05
NBUFL0	08/27/2002	Surface	22.77	23.31	8.8	9.9	0.50	390	9.41	224	<10	<1	<0.02	1	<0.1	1.1	0.01	0.046	384	365	19	13	23.91	52.56	70.00	59.39
NBUFL0	08/27/2002	Bottom	22.77	19.42	1.34	9.54		405		235			<0.02	1.24	<0.1	1.34	0.011	0.085	387	357	30	22	15.76			68.24
NBUFL0	09/16/2002	Surface	23.33	21.6	13.02	8.71		383	24.03	210	<10	<1	<0.02	1.34	<0.1	1.44	0.012	0.022	368	355	13	10	65.45	61.76		48.74
NBUFL0	09/26/2002	Surface	6.66	12.32	9.05	9.66	0.50	412		238	<10	<1	<0.02	1.6	<0.1	1.7	0.013	0.081	397	361	36	26	20.99		70.00	67.55
NBUFL0	09/26/2002	Bottom	0.66	12.33	8.43	9.53		412		237			<0.02	1.27	<0.1	1.37	0.014	0.076	401	361	40	24	18.03			66.63
NBUFL0	01/28/2003	Surface	-10	2.97	3.93	10.13	1.25	653		286	<10	<1	0.11	1.12	<0.1	1.22	0.014	0.031	463	458	5	5	39.35		56.78	53.69
NBUFL0	01/28/2003	Bottom	-10	3.46	3.83	10.15		654		289			0.11	1.24	<0.1	1.34	0.016	0.038	470	458	12	5	35.26			56.63
NBUFL0	02/26/2003	Surface	-12.8	3.08	6.87	9.15	2.25	658	3.70	305	<10	<1	0.15	1.34	0.1	1.44	0.022	0.035	470	467	3	<1	41.14	43.40	48.30	55.44
NBUFL0	02/26/2003	Bottom	-12.8	3.5	6.39	9.24		655		302			0.16	1.25	0.1	1.35	0.022	0.036	467	463	4	2	37.50			55.85
NBUFL0	05/01/2003	Surface	12.22	12.47	9.34	8.87	1.50	627	1.70	247	20	<1	<0.02	1.1	<0.1	1.2	0.019	0.044	376	365	11	6	27.27	35.77	54.15	58.74
NBUFL0	05/01/2003	Bottom	12.22	12.35	10.85	8.91		627		246			<0.02	1.28	<0.1	1.38	0.016	0.042	388	381	7	6	32.86			58.07
NBUFL0	05/28/2003	Surface	13.44	16.58	6.92	9.03	1.10	633	1.40	250	<10	<1	<0.02		<0.1	0.1	0.011	0.036	388	379	9	9	2.78	33.87	58.62	55.85
NBUFL0	05/28/2003	Bottom	13.44	15.04	5.49	8.95		640		252			<0.02	1.24	<0.1	1.34	0.013	0.056	419	375	44	14	23.93			62.22

Table 16. Water quality data for North Buffalo Lake's tributaries, Marshall County, South Dakota.

StationID	SampleDate	Air Temp. ºC	Water Temp. ºC	DO, mg/l	pH	Secchi, m	Spec. Cond.	Chl.*a* ug/l	Alka, mg/l	Fecal Col., #/100 ml	E. Coli, #/100ml	NH3, mg/l	TKN, mg/l	NO3, mg/l	TN, mg/l	Diss P, mg/l	Total P, mg/l	TS, mg/l	TDS, mg/l	TSS, mg/l	VSS, mg/l	TN:TP
NBUFT02	06/17/2002	25.5	23.14	11.13	8.56		437		255	100	82.3	0.03	1.33	0.1	1.43	0.045	0.104	411	381	30	14	13.75
NBUFT02	07/15/2002	23.88							229	50	36.9	<0.02	1.13	<0.1	1.23	0.017	0.061	348	341	7	5	20.16
NBUFT02	08/13/2002	20	20.19	6.78	9.29		350		226	860	1120	0.03	0.68	<0.1	0.78	0.017	0.061	361	353	8	5	12.79
NBUFT02	10/01/2002	11.66	12.65	5.12	9.53		337		250	60	55.4	<0.02	1.36	0.1	1.46	0.033	0.059	394	385	9	3	24.75
NBUFT02	04/03/2003	-2.77	0.77	23.98	8.53		429		196	<2	<1	0.25	1.41	<0.1	1.51	0.015	0.088	267	254	13	4	17.16
NBUFT02	04/16/2003	2.22	7.69	11.8	8.32		482		245	20	34.1	<0.02	0.94	<0.1	1.04	0.016	0.06	358	354	4	3	17.33
NBUFT02	04/24/2003	11.66	10.86	10.22	8.48		507		256	<10	2	<0.02	0.92	<0.1	1.02	0.013	0.06	379	373	6	1	17.00
NBUFT02	04/30/2003	9.44	10.38	8.37	8.06		685		271	40	11	<0.02	1.62	<0.1	1.72	0.017	0.072	407	393	14	6	23.89
NBUFT02	05/06/2003	8.88	9.44	10.91	8.36		682		271	<10	4.1	0.06	1.46	<0.1	1.56	0.022	0.235	415	402	13	7	6.64
NBUFT02	05/13/2003	15		10.81			679		272	<10	<1	<0.02	1.22	<0.1	1.32	0.016	0.071	414	401	13	6	18.59
NBUFT02	05/21/2003	14.44	12.31	10.02	8.57		691		276	60	28.5	<0.02	1.27	<0.1	1.37	0.018	0.038	410	399	11	3	36.05
NBUFT02	05/29/2003	21.66	18.84	5.7	8.02		700		284	10	16.9	0.05	1.4	<0.1	1.5	0.021	0.089	425	405	20	8	16.85
SBUFT06	06/17/2002	25	22.58	13.43	8.25		388		208	<10	<1	<0.02	1.06	<0.1	1.16	0.019	0.037	355	350	5	4	31.35
SBUFT06	07/15/2002	25.55	25.21	16.18	8.59		384		189	<10	1	<0.02	1.28	<0.1	1.38	0.011	0.056	359	337	22	15	24.64
SBUFT06	08/13/2002	20.55	22.3	9.89	9.75		319		173	<10	1	<0.02	0.82	<0.1	0.92	0.009	0.045	336	326	10	9	20.44
SBUFT06	10/01/2002	12.77	13.75	6.04	9.57		293		190	<10	4.1	<0.02	1.09	<0.1	1.19	0.01	0.04	344	334	10	4	29.75
SBUFT06	04/03/2003	-2.22	4.13	8.75	8.75		462		181	<10	<1	<0.02	0.95	<0.1	1.05	0.01	0.062	312	310	2	1	16.94
SBUFT06	04/16/2003	1.11	9.79	12.6	8.63		437		201	20	4.1	<0.02	1.29	<0.1	1.39	0.012	0.079	355	332	23	12	17.59
SBUFT06	04/24/2003	11.66	10.52	11.92	8.86		452		203	<10	1	<0.02	1.16	<0.1	1.26	0.017	0.043	353	347	6	2	29.30
SBUFT06	04/30/2003	9.99	12.12	10.29	8.73		582		205	<10	1	<0.02	1.13	<0.1	1.23	0.015	0.041	356	349	7	2	30.00
SBUFT06	05/06/2003	9.44	11.02	11.53	8.66		588		208	<10	1	<0.02	1.14	<0.1	1.24	0.01	0.038	346	335	11	6	32.63
SBUFT06	05/13/2003	14.44	12.15	10.14			588		210	20	21.3	<0.02	1.34	<0.1	1.44	0.012	0.053	370	348	22	11	27.17
SBUFT06	05/21/2003	14.44	14.18	10.32	8.93		593		211	<10	15.5	0.3	1.14	<0.1	1.24	0.013	0.029	371	347	24	11	42.76
SBUFT06	05/29/2003	21.66	18.47	10.06	8.78		578		214	<10	8.5	<0.02	1.28	<0.1	1.38	0.013	0.046	375	359	16	7	30.00

Table 17. Profile data for site NBUFL01 in North Buffalo Lake, Marshall County, South Dakota.

Date	Depth	Temp	SpCond	DO%	DO Conc	pH
06/19/2002	0.902	20.69	0.438	117.7	10.54	8.3
06/19/2002	1.914	20.64	0.439	117.2	10.51	8.12
06/19/2002	2.924	20.6	0.438	115.7	10.38	8.1
06/19/2002	3.452	19.9	0.443	58.1	5.29	7.86
07/11/2002	1.098	22.63	0.438	133.8	11.55	8.4
07/11/2002	2.07	22.66	0.439	128	11.04	8.27
07/11/2002	3.055	22.66	0.439	127.1	10.96	7.85
07/11/2002	3.285	22.67	0.439	123.2	10.62	8.15
08/05/2002	0.989	22.15	0.391	88.9	7.74	9.41
08/05/2002	1.990	22.12	0.392	88.2	7.69	9.07
08/05/2002	2.977	22.09	0.392	87.0	7.59	9.15
08/05/2002	3.464	22.06	0.392	83.7	7.30	9.32
08/27/2002	1.02	23.31	0.39	103.2	8.8	9.89
08/27/2002	2.001	21.29	0.392	100.1	8.86	9.9
08/27/2002	3.018	19.47	0.405	21	1.93	9.63
08/27/2002	3.315	19.42	0.405	14.6	1.34	9.56
09/26/2002	1.025	12.32	0.412	78.9	8.43	9.68
09/26/2002	2.023	12.33	0.412	82.9	8.86	9.63
09/26/2002	3.012	12.33	0.412	84	8.97	9.56
09/26/2002	3.249	12.33	0.412	84.7	9.05	9.49
01/28/2003	1.079	2.94	0.653	29.2	3.93	10.12
01/28/2003	2.013	3.12	0.655	29.2	3.91	10.13
01/28/2003	2.998	3.15	0.654	29.1	3.9	10.14
01/28/2003	3.716	3.37	0.654	28.8	3.83	10.15
02/26/2003	0.806	3.11	0.658	51.3	6.87	9.18
02/26/2003	1.832	3.45	0.654	49.5	6.57	9.23
02/26/2003	2.864	3.51	0.655	48.2	6.39	9.24
05/28/2003	1.103	16.57	0.633	71.1	6.92	9.05
05/28/2003	2.097	16.55	0.633	71.6	6.97	9.07
05/28/2003	3.094	16.51	0.633	71.8	7	9.07
05/28/2003	3.605	15.32	0.64	54.9	5.49	8.98

Table 18. Historical pH data and averages for North Buffalo Lake, North Red Iron Lake, and North and North Buffalo Lakes, Marshall County, South Dakota.

Nine Mile			N. Buffalo			S. Buffalo			S. Red Iron		
Date	pH	Ref.	Date	pH	Ref.	Date	pH	Ref.	Date	pH	Ref.
8/25/69	8	2	7/30/65	8.5	2	10/21/64	8.3	1	10/21/64	8.6	1
6/25/70	8.3	2	7/30/65	8.6	2	2/12/65	7.4	1	2/12/65	8.2	1
1989	8.96	4	7/30/65	8.6	2	5/21/65	8.3	1	5/21/65	7.6	1
6/28/91	8.8	5	11/26/65	8.7	2	9/10/65	8.7	1	9/10/65	8.7	1
6/28/91	8.85	5	11/26/65	8.7	2	8/25/69	8.5	2	8/25/69	8.7	2
9/10/91	8.08	5	2/11/66	8.2	2	6/25/70	8.6	2	4/29/74	8.5	2
9/10/91	7.83	5	2/11/66	8	2	8/13/79	8.6	3	4/29/74	8.4	2
7/7/93	8.8	5	2/11/66	7.9	2	8/13/79	8.6	3	7/10/74	8.9	2
7/7/93	8.76	5	4/24/66	8.4	2	1989	8.89	4	7/10/74	8.8	2
8/17/93	8.3	5	4/24/66	8.4	2	6/26/91	9.2	5	9/18/74	8.9	2
8/17/93	8.23	5	4/24/66	8.4	2	6/26/91	9.25	5	9/18/74	8.9	2
6/27/00	8.65	5	8/25/69	8.5	2	9/11/91	8.7	5	4/29/74	8.5	2
6/27/00	8.65	5	6/30/98	8.6	5	9/11/91	6.5	5	4/29/74	8.4	2
6/27/00	8.63	5	6/30/98	8.67	5	8/4/92	8.74	5	7/10/74	8.8	2
6/27/00	8.66	5	6/30/98	8.68	5	8/4/92	8.74	5	7/10/74	8.7	2
6/27/00	8.63	5	6/30/98	8.64	5	9/2/92	9.02	5	9/18/74	8.9	2
6/27/00	8.64	5	6/30/98	8.59	5	9/2/92	9.01	5	9/18/74	8.9	2
6/27/00	8.64	5	6/30/98	8.63	5	6/23/99	8.77	5	8/10/79	8.6	3
6/27/00	8.63	5	6/30/98	8.65	5	6/23/99	8.78	5	8/10/79	8.6	3
6/27/00	8.63	5	6/30/98	8.68	5	6/23/99	8.78	5	1989	9.37	4
6/27/00	8.62	5	6/30/98	8.66	5	6/23/99	8.74	5	6/26/91	9.11	5
5/27/03	8.86	5	6/30/98	8.66	5	6/23/99	8.76	5	6/26/91	9.08	5
5/27/03	8.92	5	6/30/98	8.67	5	6/23/99	8.74	5	9/10/91	8.61	5
6/16/04	8.7	5	8/11/98	8.53	5	6/23/99	8.75	5	9/10/91	8.65	5
6/16/04	8.7	5	8/11/98	8.97	5	6/23/99	8.75	5	7/7/93	8.62	5
7/20/04	8.7	5	8/11/98	9.01	5	6/23/99	8.76	5	7/7/93	8.65	5
	8.58		8/11/98	8.99	5	6/23/99	8.76	5	8/17/93	8.14	5
			8/11/98	8.74	5	7/1/03	8.41	5	8/17/93	7.85	5
			8/11/98	8.33	5	7/1/03	8.41	5	6/23/99	8.75	5
			8/11/98	9	5	7/1/03	8.44	5	6/23/99	8.71	5
			8/11/98	9	5	7/1/03	8.45	5	6/23/99	8.76	5
			8/11/98	9	5	7/1/03	8.51	5	6/23/99	8.73	5
			8/11/98	8.37	5	7/1/03	8.51	5	6/23/99	8.64	5
			8/11/98	8.79	5	7/1/03	8.53	5	6/23/99	8.75	5
			8/11/98	8.98	5	7/1/03	8.54	5	6/23/99	8.79	5
			8/11/98	8.99	5	7/1/03	8.68	5	6/23/99	8.79	5
			7/2/02	8.65	5	7/1/03	8.68	5	6/23/99	8.78	5
			7/2/02	8.64	5	7/1/03	8.68	5	6/23/99	8.78	5
			7/2/02	8.63	5	7/1/03	8.63	5	6/23/99	8.78	5
			7/2/02	8.63	5	8/5/03	8.49	5	6/23/99	8.78	5
			7/2/02	8.63	5	8/5/03	8.5	5	6/23/99	8.78	5
			7/2/02	8.62	5	8/5/03	8.49	5	8/4/99	8.65	5
			7/2/02	8.62	5	8/5/03	8.47	5	8/4/99	8.64	5
			7/2/02	8.61	5	8/5/03	8.45	5	8/4/99	8.56	5
			7/2/02	8.63	5	8/5/03	8.47	5	8/4/99	8.66	5
			7/2/02	8.64	5	8/5/03	8.46	5	8/4/99	8.67	5
			7/2/02	8.63	5	8/5/03	8.44	5	8/4/99	8.66	5
			7/2/02	8.62	5	8/5/03	8.57	5	8/4/99	8.62	5
			7/2/02	8.63	5	8/5/03	8.56	5	8/4/99	8.6	5
			8/5/02	8.85	5	8/5/03	8.56	5	8/4/99	8.52	5
			8/5/02	8.86	5	8/5/03	8.53	5	8/4/99	8.61	5
			8/5/02	8.86	5	8/5/03	8.52	5	8/4/99	8.62	5
			8/5/02	8.82	5		**8.57**		8/4/99	8.63	5
			8/5/02	8.82	5				8/4/99	8.6	5
			8/5/02	8.86	5				8/4/99	8.58	5
			8/5/02	8.87	5				8/4/99	8.65	5
			8/5/02	8.86	5				8/4/99	8.65	5
			8/5/02	8.8	5				8/4/99	8.64	5
			8/5/02	8.86	5				8/4/99	8.65	5
			8/5/02	8.87	5				7/1/03	8.43	5
			8/5/02	8.87	5				7/1/03	8.41	5
			8/5/02	8.81	5				7/1/03	8.4	5
				8.68					7/1/03	8.35	5

Table 18. Continued.

Nine Mile			N. Buffalo			S. Buffalo			S. Red Iron		
Date	pH	Ref.	Date	pH	Ref.	Date	pH	Ref.	Date	pH	Ref.
									7/1/03	8.3	5
									7/1/03	8.24	5
									7/1/03	8.22	5
									7/1/03	8.19	5
									7/1/03	8.18	5
									7/1/03	8.16	5
									7/1/03	8.2	5
									7/1/03	8.41	5
									7/1/03	8.37	5
									7/1/03	8.34	5
									7/1/03	8.35	5
									8/5/03	8.46	5
									8/5/03	8.44	5
									8/5/03	8.44	5
									8/5/03	8.42	5
									8/5/03	8.41	5
									8/5/03	8.47	5
									8/5/03	8.47	5
									8/5/03	8.46	5
									8/5/03	8.44	5
									8/5/03	8.5	5
									8/5/03	8.51	5
									8/5/03	8.51	5
									8/5/03	8.49	5
										8.57	

References: 1 – Petri, L.R. and L. R. Larson, no date. 2 – State Lakes Preservation Committee, 1977. 3 – Koth, 1981. 4 – Stueven and Stewart, 1996. 5 – SDDENR, 1991-2003, unpublished data.

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