PHASE I
WATERSHED ASSESSMENT
FINAL REPORT

BURKE LAKE
GREGORY 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

April 2006

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

BURKE LAKE ASSESSMENT FINAL REPORT

Prepared By

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Sponsor

City of Burke

4/30/06

This project was conducted in cooperation with the State of South Dakota and the United States Environmental Protection Agency, Region 8.

Grant # 99818502

ACKNOWLEDGEMENTS

The cooperation of the following organizations is gratefully appreciated. The assessment of Burke Lake and its watershed could not have been completed without their assistance.

City of Burke

South Dakota Department of Environment and Natural Resources

South Central Water Development District

Randall Resource Conservation and Development

South Dakota Department of Game, Fish & Parks

USDA Natural Resource Conservation Service

Credit is also given to Sean Kruger for writing the ANNAGNPS modeling section, Sol Brich for creating the lake and sediment depth maps, and Andrew Repsys for information about Burke Lake's algae.

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ABBREVIATIONS

AFO's	Animal Feeding Operations
ANNAGNPS	Annualized Agricultural Non-Point Source
BMP	Best Management Practice
CPUE	Catch per Unit Effort
CV	Coefficient of Variance
DC	District Conservationist
DO	Dissolved Oxygen
IJC	International Joint Commission
NPS	Non-point Source
NRCS	Natural Resources Conservation Service
NTU	Nephelometric Turbidity Units
Q WTD C	Flow Weighted Concentration
SDDENR	South Dakota Department of Environment and Natural Resources
SDGF&P	South Dakota Department of Game Fish & Parks
TKN	Total Kjeldahl Nitrogen
TSI	Trophic Status Index
µmhos/cm	micromhos/centimeter
USGS	United States Geologic Survey

EXECUTIVE SUMMARY

PROJECT TITLE: Burke Lake Assessment

PROJECT START DATE: 1/27/03 PROJECT COMPLETION DATE: 8/1/05

FUNDING:	TOTAL BUDGET: $52,000.00
TOTAL EPA GRANT:	$31,175.00
TOTAL EXPENDITURE OF EPA FUNDS:	$17,474.00
NONFEDERAL MATCH	
City of Burke	$4,297.91
South Central Water Dev. District	$1,500.00
Randall Resource Conserv. & Dev.	$1,500.00
BUDGET REVISIONS:	None
TOTAL EXPENDITURES:	$24,771.91

SUMMARY ACCOMPLISHMENTS

The Burke Lake Assessment Project was conducted because Burke Lake was placed on the 303(d) list for an increasing TSI trend, sediment and nutrient loading, and accumulated sediment problems. The primary goal for the project was to determine sources of impairment to Burke Lake, and provide sufficient background data to drive a Section 319 Implementation Project.

An EPA section 319 grant provided a majority of the funding for this project. The State, the City of Burke, the South Central Water Development District, and the Randall Resource Conservation & Development 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 lake exhibited thermal stratification and dissolved oxygen concentrations were often below the water quality standard. The water quality standard criteria for pH were exceeded a number of times. The standards criteria for nitrate, unionized ammonia, conductivity, 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. Aquatic macrophyte, algae, and sediment surveys were completed for the lake. Aquatic macrophytes were not deemed a problem. Sediment amounts in the lake were not considered unusual for a South Dakotan reservoir but removing those sediments could increase the lake volume, extend the life of the lake, and possibly alleviate internal nutrient loading and oxygen deficits in the lake.

Using the FLUX and BATHTUB computer models, seasonality was indicated with the greatest sediment and nutrient loadings occurring during the spring run-off period. The results from these models were also used to establish a total maximum annual load of 7 kg/year for total phosphorus, which is an 88% reduction of the measured annual phosphorus load. Achievement of this load should support the lake's beneficial uses.

The Annualized Agricultural Non-point Source computer model (ANNAGNPS) was used to judge the effect of implementing various agricultural BMPs on nutrient and sediment loading to the lake. Aside from a small agricultural waste facility adjacent to the lake, it was determined that only a 5% or so reduction of the total phosphorus loading to the lake would be accomplished by BMP implementation in the watershed. Consequently, the only "external" lake restoration technique deemed reasonable was phosphorus removal from the tributaries by chemical precipitation. In-lake restoration techniques such as aeration, phosphorus precipitation and bottom sealing, sediment removal, and algaecides were also recommended for consideration.

INTRODUCTION

Purpose

The purpose of this assessment is to determine the sources of impairment to Burke Lake in Gregory County, South Dakota and the tributaries in its watershed. These tributaries carry sediment and nutrients that enter the lake.

No large streams enter the lake but there are three tributaries to the lake. Coon Creek is the major tributary. The watershed is primarily grazing lands with some cropland acres. One farm has a feeder cattle operation adjacent to the lake. A spring fed tributary flows through this operation. The tributaries carry sediment loads and nutrient loads, which are thought to degrade water quality in the lake and cause eutrophication.

The purpose of this assessment is to determine the sources of impairment to Burke Lake and its tributaries, determine a total maximum daily load that will maintain full support of its beneficial uses, and recommend strategies to restore the lake.

General Lake Description

Burke Lake is a 27-acre man-made impoundment located in Gregory County, South Dakota (Figure 1). Burke Lake was constructed as a WPA project in the 1936. The dam impounds water from three small tributaries. The lake is primarily used for fishing. The average depth of the lake is 1.8 meters (5.8 feet) and it has a maximum depth of six meters (20 feet). The outlet for the lake empties into Coon Creek, which flows to the Missouri River.

Lake Identification and Location

Lake Name: Burke Lake	State: South Dakota
County: Gregory	Township: 97N
Range: 71W	Sections: 33-34
Nearest Municipality: Burke	Latitude: 43.176111
Longitude: -99.257777	EPA Region: VIII
Primary Tributary: Coon Creek	Receiving Body of Water: Coon Creek
HUC Code: 10140101	HUC Name: Fort Randall Reservoir

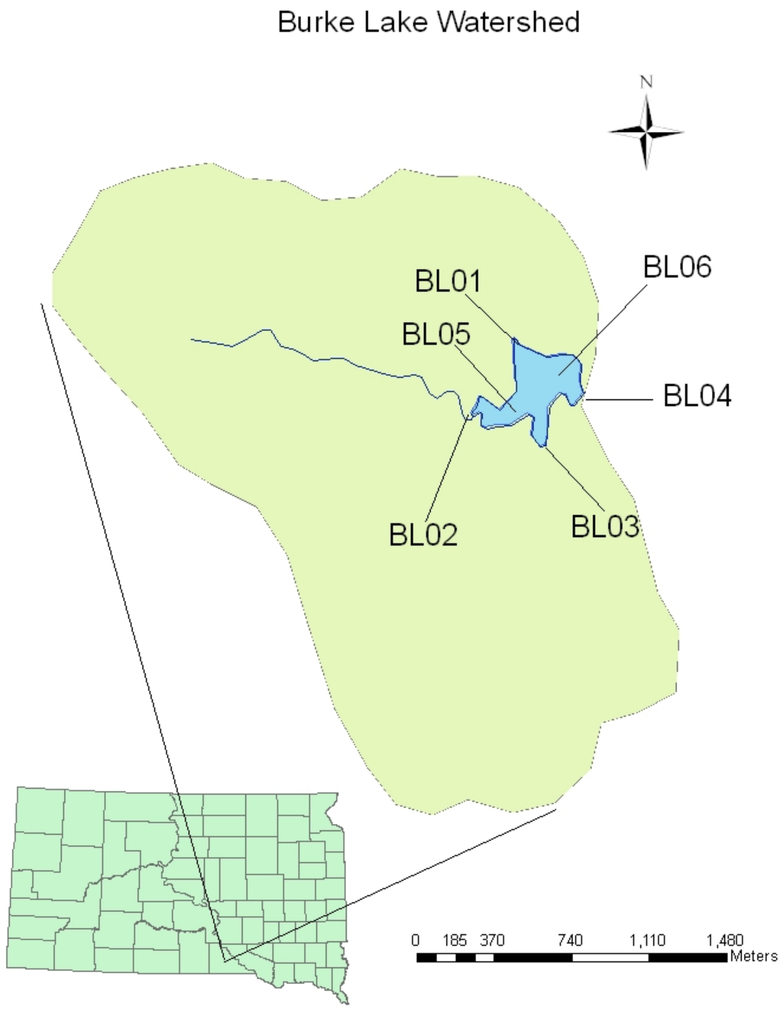

Figure 1. Burke Lake and its watershed, Gregory County, South Dakota.

Trophic Status Comparison

Developed by Carlson (1977), the Trophic State Index, or TSI, is a numerical value from 0 to 100 that allows a lake's productivity to be easily quantified and compared to other lakes. Higher TSI values correlate with higher levels of primary productivity. A comparison of Burke Lake to other lakes in the area (Table 1) shows that a high rate of productivity is common for the region. The values provided in Table 1 were taken from a statewide lake assessment final report (Stueven and Stewart, 1996).

Table 1. TSI comparison of Burke Lake and other area lakes.

Lake	Nearest Municipality	Year/TSI	Mean Trophic State
Platte	Platte	1992/65.15	Hypereutrophic
Geddes	Geddes	1994/76.38	Hypereutrophic
Andes	Lake Andes	1993/79.19	Hypereutrophic
Corsica	Lake City	1992/76.83	Hypereutrophic
Burke Lake	**Burke**	**1994/82.28**	**Hypereutrophic**

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 waterbody 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 the beneficial uses assigned to Burke Lake.

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

With each of these uses are sets of water quality standards 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 standard 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 existence 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 disc 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).

Individual parameters as well as the lake's TSI value determine the support of these beneficial uses. Burke Lake is listed in the state 2005 303(d) list and was identified as not supporting its beneficial uses.

Table 2. State beneficial use standards for Burke Lake, Gregory County, South 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	≤ 26.67 C	Warmwater Semi-permanent Fish Propagation

The tributaries of Burke Lake have the beneficial uses of:

(9) Fish and wildlife propagation, recreation, and stock watering, and

(10) Irrigation

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

Table 3. State water quality standards for Coon Creek and the other unnamed tributary of Burke 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 provide a list of public facilities that are maintained at area lakes (Table 4). In contrast to other regional lakes, Burke Lake has relatively more facilities. It had a small swimming beach but it has not been maintained because the lakes water quality has been too poor for swimming.

Table 4. Comparison of recreational uses on lakes in south central South Dakota.

Lake	State Parks	Ramps	Boating	Camping	Fishing	Picnicking	Swimming	Nearest Municipality
Platte Lake		X	X		X	X		Platte
Geddes Lake		X	X		X			Geddes
Lake Andes					X			Lake Andes
Corsica Lake		X	X	X	X	X		Corsica
Burke Lake	**X**	**X**	**X**	**X**	**X**	**X**		**Burke**

Watershed

Burke Lake and its 1,568-acre watershed are located three miles east of the City of Burke, Gregory County, South Dakota. The watershed is characterized by rolling short-grass prairie and rangeland with a small portion in cultivation. The major soil associations found in the watershed are of the Anselmo-Holt-Tasselk association. These are well drained loamy soils on the uplands underlain by sand and gravel. The Ogallala aquifer lies under the watershed.

Land use in the watershed is primarily agricultural grazing with some cropland. Small grains and hay are the main crops on cultivated lands. One animal feeding area is located in the watershed. The Burke Lake Recreation Area consists of 206 acres and provides habitat for a variety of wildlife.

The average annual precipitation in the watershed is 22 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 rain fall events

History

Burke Lake was constructed in the 1936 as a Works Project Administration (WPA) project with trees planted around the lake in 1949. In 1967, the City of Burke deeded the lake to the State of South Dakota with the understanding the state would develop the lake as a recreation area.

City of Burke records indicated the lake experienced algae and aquatic vegetation problems since the late 1950s. After receiving complaints alleging a dairy operation located adjacent to the lake was polluting Burke Lake, DENR inspected the operation in 1986. DENR requested that a plan for controlling the runoff from the dairy operation be developed and implemented by the owner. No significant action was taken by the owner.

Following additional concerns by the City of Burke, DENR initiated a diagnostic/feasibility study in 1989. The study documented the water quality of the lake, identified pollutant sources, and recommended lake restoration strategies. Lake restoration activities consequently began, which included lake dredging and working with the dairy operation. The dairy operator eventually ceased his dairy operation and switched to feeder cattle, which aren't confined as often as the dairy cattle are. The lake dredging occurred during 1992/1993 and removed approximately 150,000 cubic yards of sediment. These activities did not dramatically improve the lake and subsequent water quality problems prompted the city of Burke to request the current study. In addition, the 1996 South Dakota Report to Congress, 305(b) water quality assessment and the 2004 and 2006 South Dakota Integrated Reports described the water quality of Burke Lake as being impacted by non-point source agricultural pollution. Recreational users of Burke Lake report algae blooms and odors associated with decaying vegetation.

PROJECT GOALS, OBJECTIVES, AND ACTIVITIES

Planned and Actual Milestones, Products, and Completion Dates

Objective 1. Lake Sampling and Sediment Survey

The lake water sampling commenced April, 2003 and continued through July 2004. Spring samples were collected during March, April and May of 2003. Bimonthly samples were during June and August but other demands on the City personnel prevented bi-monthly sampling during July. The sediment survey was conducted during the winter of 2003/2004.

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 Stevens stage recorders. These data were used to develop stage/discharge relationships so water flows could be calculated. These flows were entered into computer models (FLUX and BATHTUB) that were used to assess the nutrient and sediment loads to the lake. Measurable water flow was present from March through mid-summer, 2003 and these data were used in this report.

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 March of 2003 and was completed as planned.

Objective 4. ANNAGNPS Modeling

DENR personnel toured the watershed and made initial determinations for the ANNAGNPS model. The NRCS office located in Lake Andes made available information concerning land use information.

Objective 5. Public Participation

The public was kept informed of the project through monthly meetings of the City of Burke. One landowner, the one with the cattle operation adjacent to the lake, was kept informed of the projects progress through casual discussions while DENR personnel were at the lake.

Objectives 6 and 7. Restoration Alternatives and Final Report

The completion of the restoration alternatives and final report for Burke Lake in Gregory County was delayed due to DENR personnel having other commitments.

Evaluation of Goal Achievements

The goal of the watershed assessment project for Burke Lake was to determine and document sources of impairment to the lake and to develop feasible restoration strategies. This was accomplished through the collection of tributary and lake data and aided by the completion of the ANNAGNPS watershed modeling. Through data analysis and modeling, identification of impairment sources was made and restoration strategies that target areas in greatest need were developed. A comparison of the planned and actual objective completion dates is given in Table 5.

Table 5. Proposed and actual objective completion dates for the Burke Lake Assessment Project.

	2/03	3/03	4/03	5/03	6/03	7/03	8/03	9/03	10/03	11/03	12/03	1/04	2/04	3/04	4/04	5/04	6/04	7/04	5/05	6/05	4/06
Objective 1																					
Lake Sampling																					
Objective 2																					
Tributary Sampling																					
Objective 3																					
QA/QC																					
Objective 4																					
Modeling																					
Objective 5																					
Public Participation																					
Objective 6 & 7																					
Final Report																					
Proposed Complet.																					
Actual Completion																					

MONITORING METHODS AND RESULTS

OBJECTIVE 1 – Lake Sampling and Sediment Survey

In-lake Sampling Schedule, Methods, and Materials

Sampling began in March 12, 2003, and was conducted on a monthly basis at the two in-lake sites until July 14, 2004. Water samples were collected with a Van Dorn sampler from the surface at site BL05 and from the surface and near the bottom of site BL06. 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/nitrite	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
Dead fish	Film
Width	Water depth
Ice cover	Water color

Parameters measured in the field by sampling personnel were:

Water temperature	Air temperature
Conductivity	Dissolved oxygen
Field pH	Secchi depth

Biological samples were taken quarterly and the water samples were analyzed for algae The algae were counted and identified by DENR personnel.

Original data may be found in Appendix A and Appendix B.

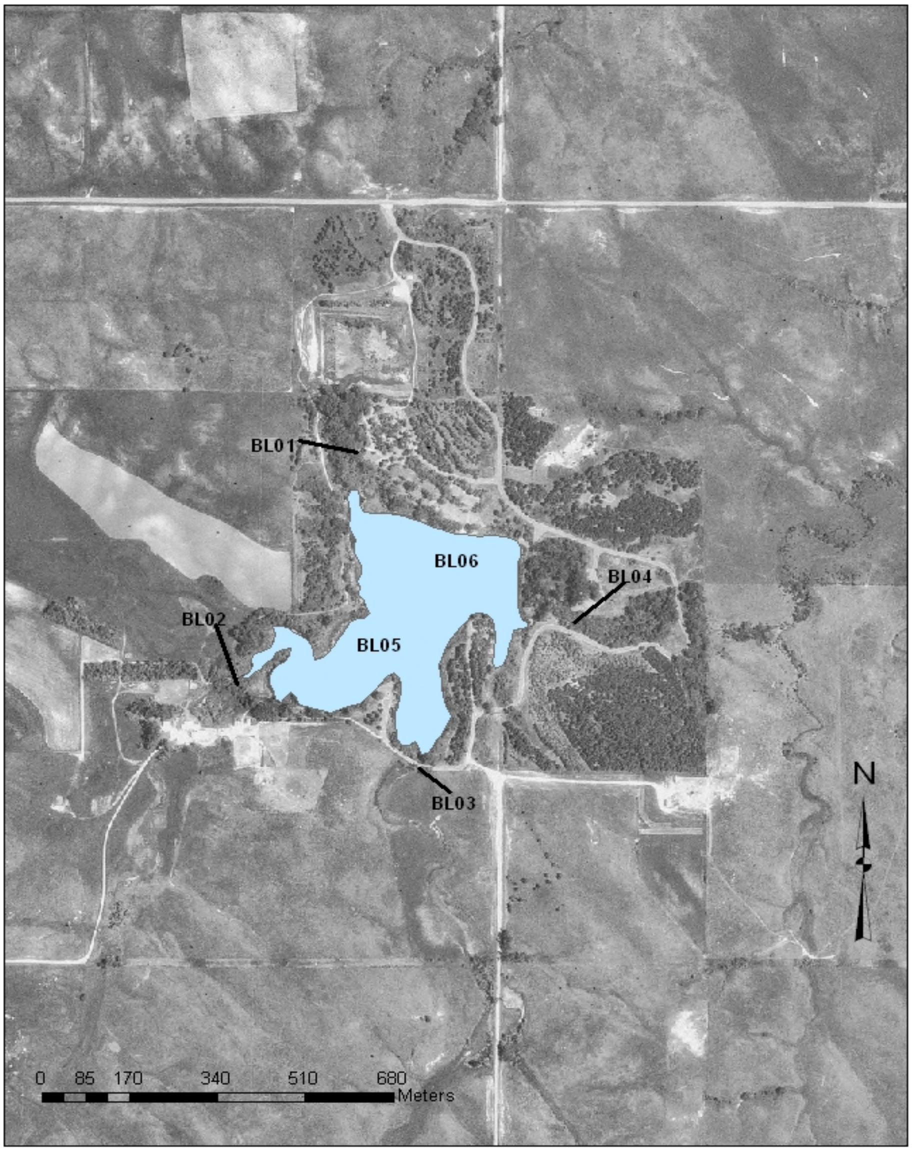

Figure 2. Burke Lake sampling sites.

In-lake Water Quality Results

<u>Water Temperature</u>

Water temperature is of great importance to any aquatic ecosystem. Many organisms and biological processes are temperature sensitive. Blue-green algae tend to dominate warmer waters while green algae do better under cooler conditions. Water temperature also plays a role in physical conditions. Oxygen dissolves in higher concentrations in cooler water. The toxicity of un-ionized ammonia is also related to warmer temperatures.

The surface water temperature in Burke Lake exhibited little variation between the sites BL05 and BL06. Temperatures showed 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 in-lake temperatures would be within a few degrees of the project data at their respective dates.

The lowest water temperatures were recorded during the winter and the highest temperature was 29ºC, during July, 2003. This was lower than the state standard that requires water temperature to be less than or equal to 32.22°C (90ºF).

Burke Lake showed thermal stratification during the summer but by late August, the lake had warmed throughout the water column and stratification ceased (Figures 3 and 4). The greatest difference between surface and bottom temperatures was 12 ºC and occurred on July 15, 2003.

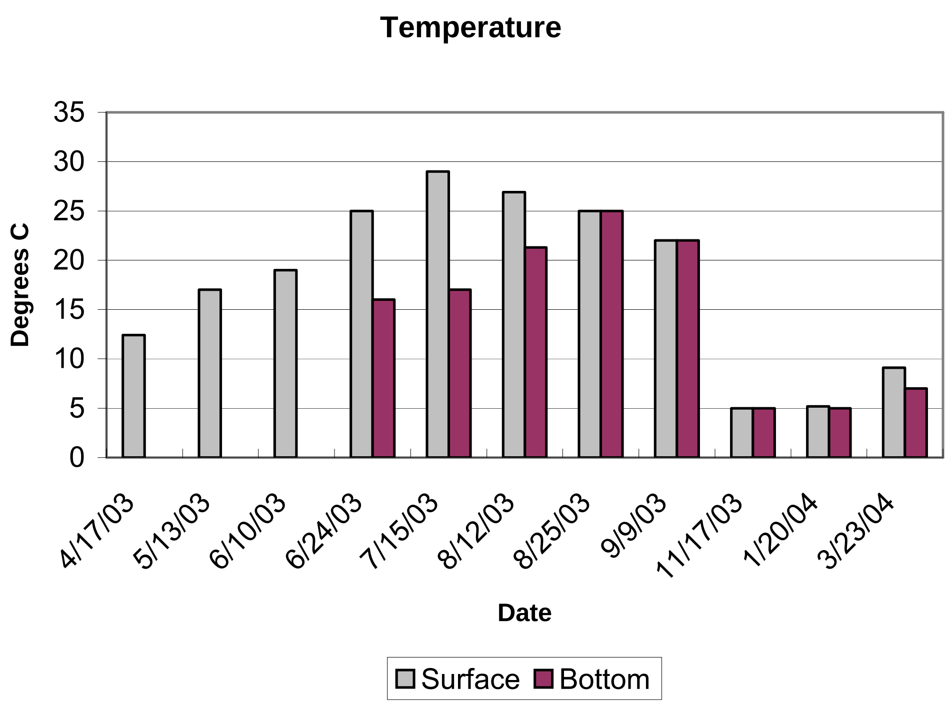

Figure 3. Water temperatures for site BL06, Burke Lake, Gregory County, South Dakota, 2003/2004.

Dissolved Oxygen

There are many factors that influence the concentration of dissolved oxygen (DO) in a water body. Temperature is one of the most important of these factors. As the temperature of water increases, its ability to hold DO decreases. Daily and seasonal fluctuations in DO may occur in response to algal and bacterial action (Bowler, 1998).

During winters with heavy snowfall, light penetration may be reduced to the point that the algae and aquatic macrophytes in the lake cannot produce enough oxygen to keep up with consumption (respiration) rates. This results in oxygen depletion and may ultimately lead to a fish kill.

Dissolved oxygen (DO) levels at the surface of Burke Lake were often sufficient to maintain the minimum requirement for the local managed fishery but oxygen depletion did occur during the project (see Figure 4, Figure 5 and Appendix B). DO depletion was not limited to the lake bottom but occurred throughout the water column. Fifty-two percent of the meter readings had DO levels below 5.0 mg/l, the DO criterion for maintaining warm water semi-permanent fish life propagation. Approximately 23% of the lake surface readings and 71% of the lake bottom readings were less than 5 mg/l. This was most likely due to bacteria using oxygen during the decomposition of organic matter on the bottom of the lake.

Fish kills have occurred at Burke Lake in the past and were probably due to oxygen depletion. This is not unexpected. According to the SD Water Quality Standards SDCL 74:51:01:01(60), a lake classified for warm-water semi-permanent fish life propagation may suffer occasional fish kills because of critical natural conditions. Dead fish were not seen during this study.

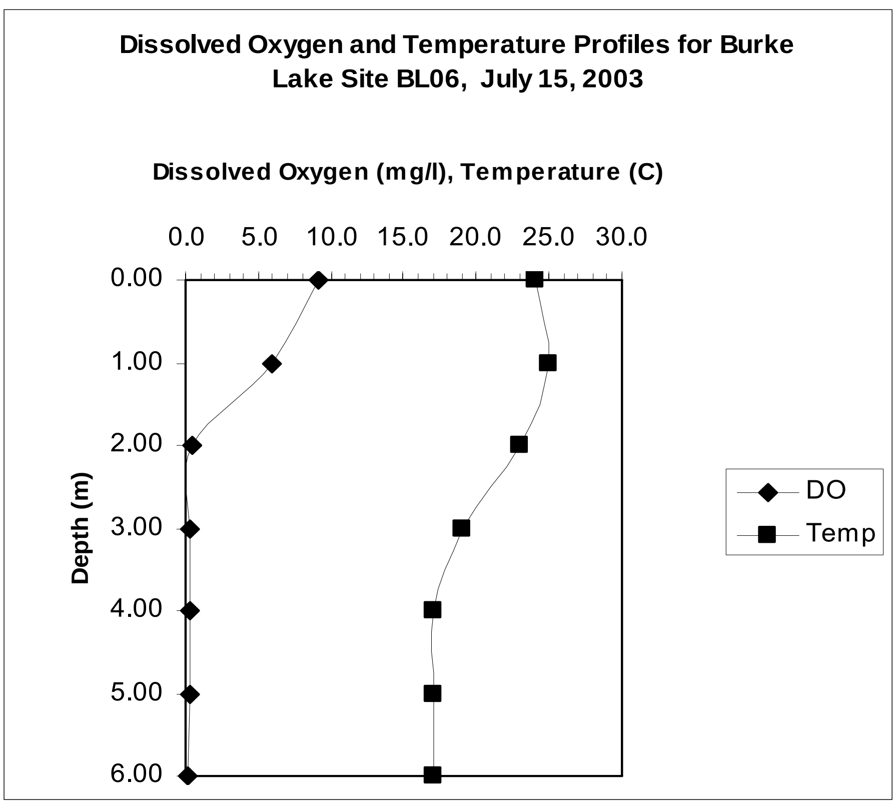

Figure 4. Stratification of dissolved oxygen and temperature at Burke Lake Site BL06, July 15, 2003.

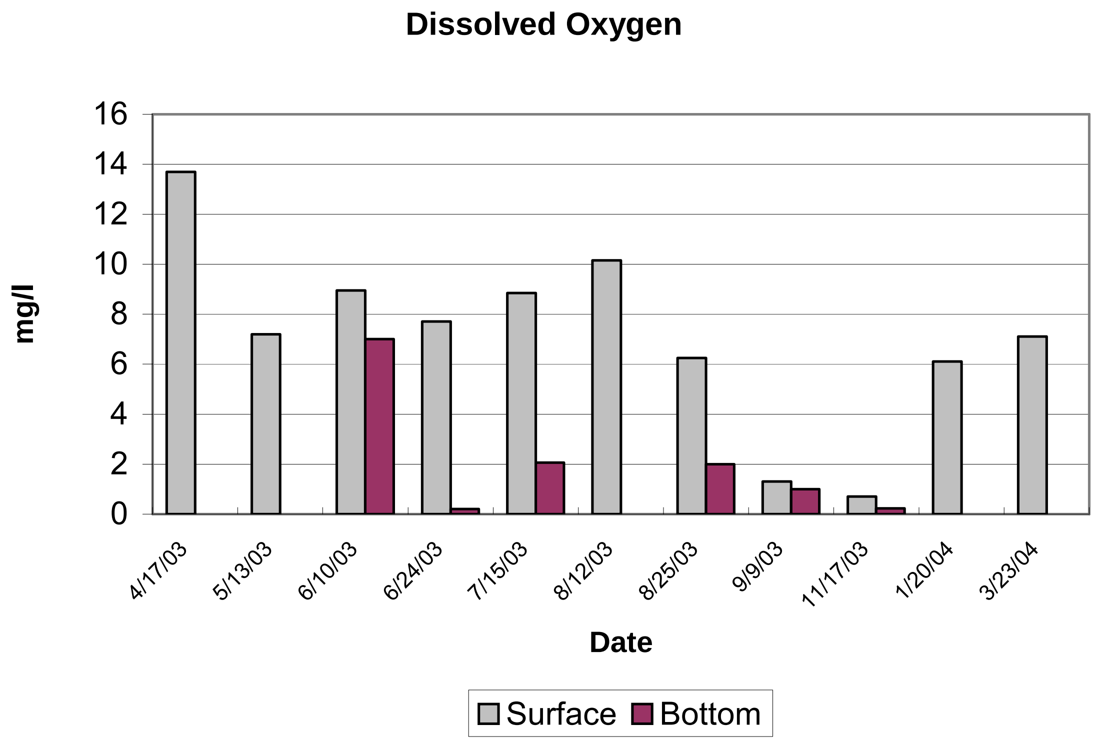

Figure 5. Average dissolved oxygen concentrations for Burke Lake, Gregory County, South Dakota, 2003/2004.

A hypolimnetic oxygen deficit was calculated for Burke Lake using equation 9.1 in Cooke et al. (1986):

ODR mg m^{-2} day^{-1} = $((XDO_{t1} - XDO_{t2})/ t_2 - t_1) \cdot Z_h$

Where: XDO_{t1} = mean dissolved oxygen at the beginning of stratification (April 17, 2003, 7670 mg/m^3)
XDO_{t2} = mean dissolved oxygen prior to time when DO less than 1.0 mg/l (May 13, 2003, 3250 mg/m^3)
$t_2 - t_1$ = time elapsed in days (26 days)
Z_h = mean depth of hypolimnion (3 meters)

The hypolimnetic oxygen deficit was calculated to be 510 mg m^{-2} day^{-1}. Wetzel (2000) suggested using oxygen deficit rates cautiously and so this rate should only be considered a "ball park" estimate for Burke Lake and used accordingly.

pH

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 the pH. The extent to which this occurs is affected by the lakes ability to buffer against changes in pH. The presence of a 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 Burke Lake ranged from 7.11 to 9.43 and averaged 8.69 (see Appendix A). There was little seasonal variation in pH although some higher values occurred during the growing season (Figure 6). One-third (10 out of 30) of the samples were outside the acceptable pH criteria for maintaining the semi-permanent fish life propagation use. Because there is no other logical reason for these exceedences and because most of the exceedences occurred at the surface during the growing season, it is believed that algae blooms caused the increases in pH. Controlling algae should alleviate the elevated pH problem. Again, SD Chapter 74:51:01:01 (60) recognizes that a lake classified for warm-water semi-permanent fish life propagation may suffer occasional fish kills because of critical natural conditions.

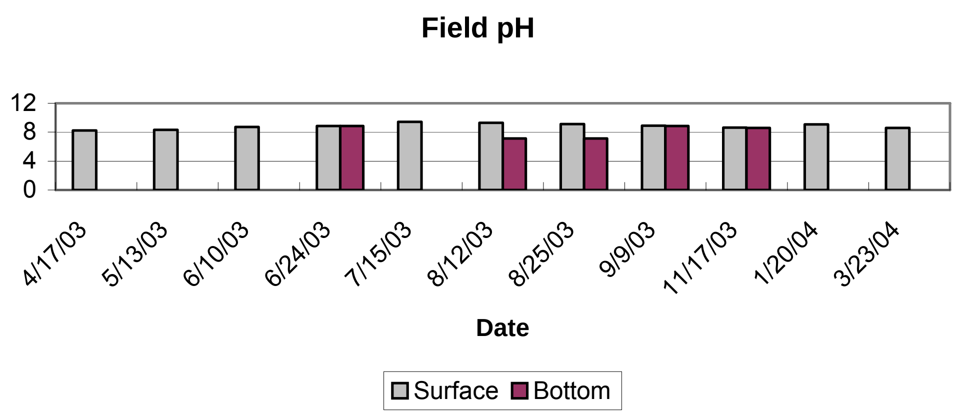

Figure 6. Average pH values for Burke Lake, Gregory County, South Dakota, 2003/2004.

Regression analysis between "growing season" chlorophyll *a* values and pH values produced a weak relationship between pH and chlorophyll *a* (R^2 value of .49) (Figure 7). Using the regression equation, 70 mg/m³ chlorophyll *a* produces a pH of 8.99. The pH criterion is 9.0 so controlling algae (chlorophyll *a* concentrations) to levels less than 70 mg/m³ should keep the pH levels below the 9.0 standard criterion. A chlorophyll *a* concentration of 70 mg/m³ is equal to a chlorophyll *a* based trophic state index (TSI) of 72.25.

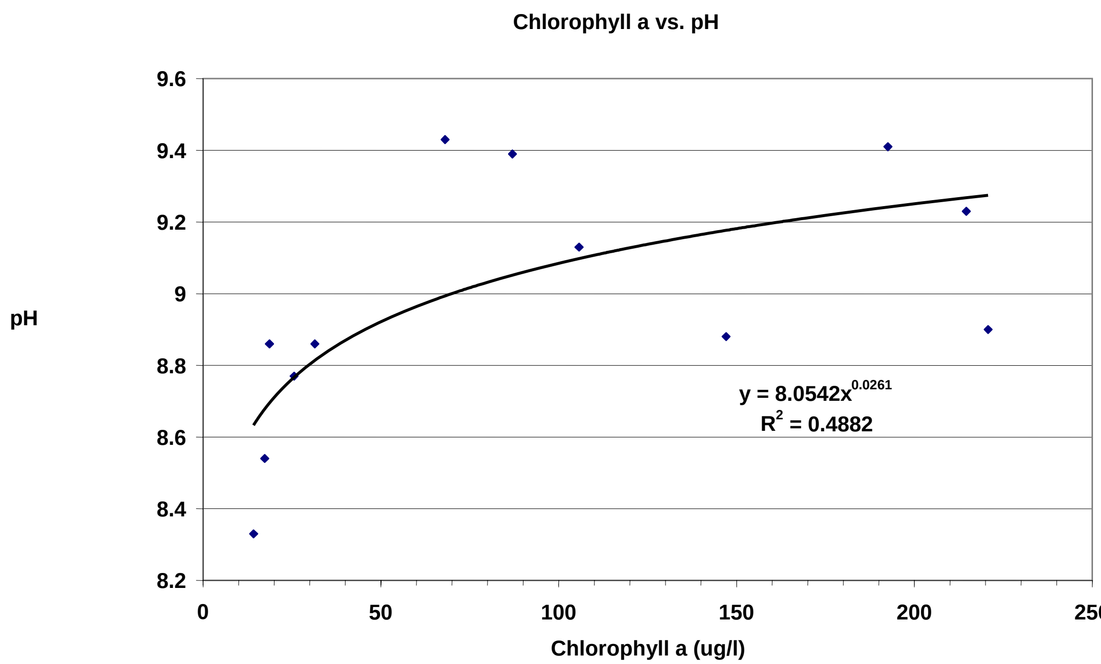

Figure 7. Relationship between chlorophyll *a* vs. pH in Burke Lake during the growing season of 2003.

Conductivity

Conductivity is a measure of water's ability to conduct electricity, which is a function of the total number of ions present. As ions increase, increases in conductivity reflect the total concentration of dissolved ions in the water body. This may also be used to indicate hardness. It is measured in µmhos/cm, and is sensitive to changes in temperature.

The meter used during this study performed erratically and the meter was eventually discarded and conductivity measurements ceased. Only three conductivity readings were taken and they ranged from 261 to 294 µmho/cm. None of these readings exceeded the standard. State standards for fish and wildlife propagation and stock watering require that conductivity does not equal or exceed 7,000 µmho/cm on any single day. All conductivity readings at Burke Lake were less than the state standard.

Secchi Depth

Secchi depth is the most commonly used method to determine water clarity. No regulatory standard for this parameter exists; however, Secchi transparency is an important tool in determining the trophic state (TSI) of a lake. 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 Burke Lake averaged 0.74 meters with the greatest readings found during March, 2003 (Figure 8). This is probably due to the late winter/early spring conditions being unfavorable for algae growth. The mean Secchi transparency reading during the primary growing season (May 15 through September 15) was 0.55 meters, equivalent to a TSI value of 68.63. This was below the mean TSI value of 80.49 for waters within the northwestern glaciated plains ecoregion (Stueven, et al., 2000), which means that Burke Lake had better water clarity than most lakes in the region.

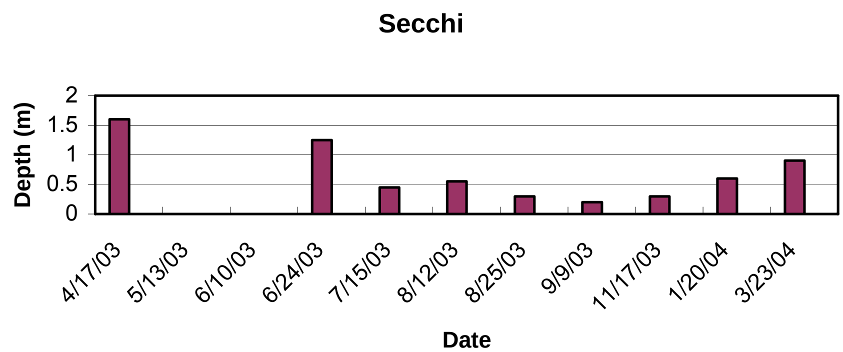

Figure 8. Average Secchi depths for Burke Lake, Gregory County, South Dakota, 2003/2004.

Alkalinity

A lakes 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 alkalinty is also used in the estimation procedure for calculating the amount of alum necessary for phosphorus precipitation.

The total alkalinity in Burke Lake averaged around 166 mg/l (Figure 9) and varied from a low of 125 mg/l during July 14, 2004 to a peak value of 217 mg/l during January 20, 2004. The bottom samples had slightly higher values. The total alkalinity concentrations are typical for lakes in South Dakota. The alkalinity standard was never exceeded.

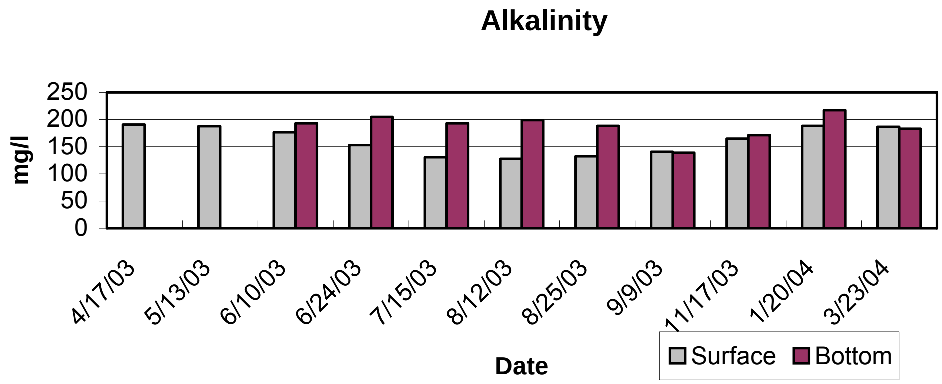

Figure 9. Average alkalinity concentrations for Burke Lake, Gregory County, South Dakota, 2003/2004.

Solids

Solids can be separated into four separate fractions; total solids, dissolved solids, suspended solids, and volatile suspended solids. 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.

Suspended solids consist of particles of soil and organic matter that may be deposited in stream channels and lakes in the form of silt. Silt deposition into a stream bottom buries and destroys the complex bottom habitat. This habitat destruction reduces the diversity of aquatic insect, snail, and crustacean species. In addition to reducing stream habitat, large amounts of silt may also fill-in lake basins. As silt deposition reduces the water depth in a lake, a couple of things occur. Wind-induced wave action increases turbidity levels by suspending solids from the bottom that had previously settled out. Shallow water increases and maintains higher temperatures. Shallow water may also allow for the establishment of beds of aquatic macrophytes.

Burke Lake exhibited relatively stable total solids concentrations throughout the year with slightly higher values during the fall and winter (Table 6). Total solids ranged from 214 mg/l to 378 mg/l and averaged 253.4 mg/l. Suspended solids concentrations in Burke Lake exhibited some seasonality with higher concentrations during the summer, probably a result of summer algae. Suspended solids concentrations ranged from 4 mg/l to 120 mg/l and averaged 22.1 mg/l. The 120 mg/l value came from a sample collected at the lake bottom and may be due to inadvertent collection of sediment in the sample.

Volatile suspended solids followed the same temporal trend as total suspended solids and comprised about 72% of the total suspended solids. This was not completely unexpected considering the lake is relatively protected from the wind and inorganic solids are generally not stirred up from the sediment except on very windy days. Algae and leaf litter from nearby trees likely comprise the bulk of the organic matter in the lake.

Table 6. Total and suspended solids concentrations for Burke Lake, Gregory County, South Dakota, 2003.

	Total Solids			Total Suspended Solids		
Date	BL05 Surface	BL06 Surface	BL06 Bottom	BL05 Surface	BL06 Surface	BL06 Bottom
4/17/03	284	282		6	6	
5/13/03	267	273		4	7	
6/10/03	262	256		5	4	
6/24/03	233	226	290	11	9	19
7/15/03	236	239	289	23	24	22
8/12/03	251	258	292	46	42	26
8/25/03	258	257	274	36	43	28
9/9/03	263	259	266	36	33	33
11/17/03	282	287	378	22	21	120
1/20/04	300	298	326	18	18	4
3/23/04	277	278	282	11	11	14
6/2/04	244	241	248	8	12	9
7/14/04	214	217		27	30	

Nitrogen

Nitrogen is assessed in four forms: nitrate/nitrite, ammonia, and total Kjeldahl nitrogen (TKN). From these four forms, total, organic, and inorganic nitrogen may be calculated. Nitrogen compounds are major cellular components of organisms. Because its availability may be less than the biological demand, environmental sources may limit productivity in freshwater ecosystems. Nitrogen is difficult to manage because it is highly soluble and very mobile. In addition, some forms of algae fix atmospheric nitrogen, adding it to the nutrient supply in the lake. Ammonia and nitrate/nitrite are the most readily available forms of nitrogen for plant growth.

All thirty-six of the samples collected from Burke Lake and analyzed for nitrates/nitrites 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 twenty-seven times (75% of the samples). Ammonia concentrations averaged 0.65 mg/l and ranged from below the 0.02 mg/l detection limit to 7.27 mg/l (Table 7). The median concentration was 0.02 mg/l. Of the nine ammonia concentrations above the detection limit, seven of these were from lake bottom samples and all but one of those had dissolved oxygen levels around 2 mg/l or less. So the elevated ammonia levels at the lake bottom were probably a result from the decay of organic matter under anaerobic conditions.

The water quality standard for total ammonia was not exceeded in thirty-five of thirty six samples. The remaining sample was lacking a pH reading so comparison of that sample to a standard was not possible.

Total nitrogen in Burke Lake averaged 2.61 mg/l and ranged from 0.63 mg/l to 8.16 mg/l; which is typical of lakes in South Dakota. Organic nitrogen comprised about 81% of the total nitrogen. This was likely due to algae in the lake.

Table 7. Total ammonia concentrations (mg/l) for Burke Lake, Gregory County, South Dakota during 2003/2004.

Date	BL05 Surface	BL06 Surface	BL06 Bottom
4/17/03	<0.02	<0.02	
5/13/03	<0.02	<0.02	
6/10/03	<0.02	<0.02	0.18
6/24/03	<0.02	<0.02	1.13
7/15/03	<0.02	<0.02	1.58
8/12/03	<0.02	<0.02	4.41
8/25/03	<0.02	<0.02	7.27
9/9/03	<0.02	<0.02	<0.02
11/17/03	0.31	0.31	0.31
1/20/04	<0.02	<0.02	0.96
3/23/04	<0.02	<0.02	<0.02
6/2/04	<0.02	<0.02	<0.02
7/14/04	<0.02	<0.02	

Phosphorus

Phosphorus is one of the macro-nutrients required for primary production. When compared with carbon, nitrogen, and oxygen, it is the least abundant (Wetzel, 2000). Phosphorus loading to lakes can be of an internal or external nature. External loading refers to surface runoff over land, dust, and precipitation. Internal loading refers to the release of phosphorus from the bottom sediments to the water column of the lake. Total phosphorus is the sum of all attached and dissolved phosphorus in the lake. The attached phosphorus is directly related to the amount of total suspended solids present. An increase in the amount of suspended solids increases the fraction of attached phosphorus.

The average in-lake total phosphorus concentration during the assessment was 0.3 mg/l. Total phosphorus concentrations greater than 0.2 mg/l are generally regarded as indicative of eutrophic conditions (USEPA, 1974). Eutrophic conditions indicate high lake productivity and an excess amount of phosphorus in the lake. This is typical for a lake in South Dakota, where an excess of phosphorus seems to be the norm. Total phosphorus concentrations were generally lowest during the spring and highest during the summer, and bottom samples were usually higher in total phosphorus concentration than the surface samples (Table 8). Some of this difference may be due to release of phosphorus from the sediments and some from sediment disturbance during sampling.

Total dissolved phosphorus is the unattached portion of the total phosphorus load. It is found in solution, but readily binds to soil particles when they are present. Total dissolved phosphorus, including soluble reactive phosphorus, is more readily available to plant life.

Table 8. Total and total dissolved phosphorus concentrations (mg/l) for Burke Lake, Gregory County, South Dakota during 2003/2004.

	Total Phosphorus (mg/l)			Total Dissolved Phosphorus (mg/l)		
Date	**BL05 Surface**	**BL06 Surface**	**BL06 Bottom**	**BL05 Surface**	**BL06 Surface**	**BL06 Bottom**
4/17/03	.046	.043		0.016	0.014	
5/13/03	.044	.052		0.026	0.028	
6/10/03	.106	.106		0.051	0.062	
6/24/03	.083	.122	.827	0.053	.053	.783
7/15/03	.168	.174	.916	0.031	.041	.707
8/12/03	.297	.317	1.33	0.031	.044	.660
8/25/03	.342	.333	1.56	0.027	.044	.896
9/9/03	.280	.284	.288	0.040	.038	.045
11/17/03	.244	.243	.352	0.063	.060	.056
1/20/04	.192	.174	.412	0.031	.043	.337
3/23/04	.099	.091	.124	0.024	.022	.024
6/2/04	.164	.178	.187	0.092	.098	.095
7/14/04	.140	.142		0.033	.033	

Total dissolved phosphorus (TDP) in Burke Lake averaged .142 mg/l and ranged from .014 to .896 mg/l (Table 8). TDP comprised about 38% of the total phosphorus and did not exhibit much seasonality.

Fecal Coliform Bacteria

Burke 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) be no more then 200 colonies/100ml. No exceedences of the state standard were observed during the project. Samples collected and analyzed by the State Health Lab for fecal coliform were consistently at or below the detection limit of 10 colonies per 100 ml (see Appendix A). The only sample collected that indicated the presence of fecal coliform was collected on June 24, 2003 and had a concentration of 30 colonies per 100 ml.

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 lake eutrophication. The ideal ratio of nitrogen to phosphorus for aquatic plant growth is 10:1

(EPA, 1990). Ratios higher than 10 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 Burke Lake was 11.9 with a range of 3.3 to 18.7 (Appendix A). Eight of the thirty-four TN:TP ratios calculated for the lake were below 10 and all of these were from bottom samples. All other samples were above 10 and indicated phosphorus limitation. There was little seasonality to the TN:TP ratios.

Chlorophyll *a*

There were a limited number of samples analyzed for chlorophyll *a*. The data indicated relatively low concentrations during the spring and large algae blooms during August and September of 2003 (Table 9). The concentrations were typical of other lakes in the ecoregion and indicated hyper-eutrophic conditions.

Table 9. Chlorophyll *a* concentrations (mg/l) for Burke Lake, Gregory County, South Dakota during 2003/2004.

Date	BL05 Surface	BL06 Surface
4/17/03	6.09	8.87
5/13/03	4.91	14.22
6/10/03	25.63	17.36
6/24/03	31.48	18.67
7/15/03	86.99	68.09
8/12/03	214.59	192.56
9/9/03	220.76	147.06
11/17/03	67.08	70.69
1/20/04	143.18	121.35
3/23/04	26.43	13.72
7/14/04	112.78	105.73

The growing season chlorophyll *a* concentrations coincided well with in-lake total phosphorus concentrations (Figure 10).

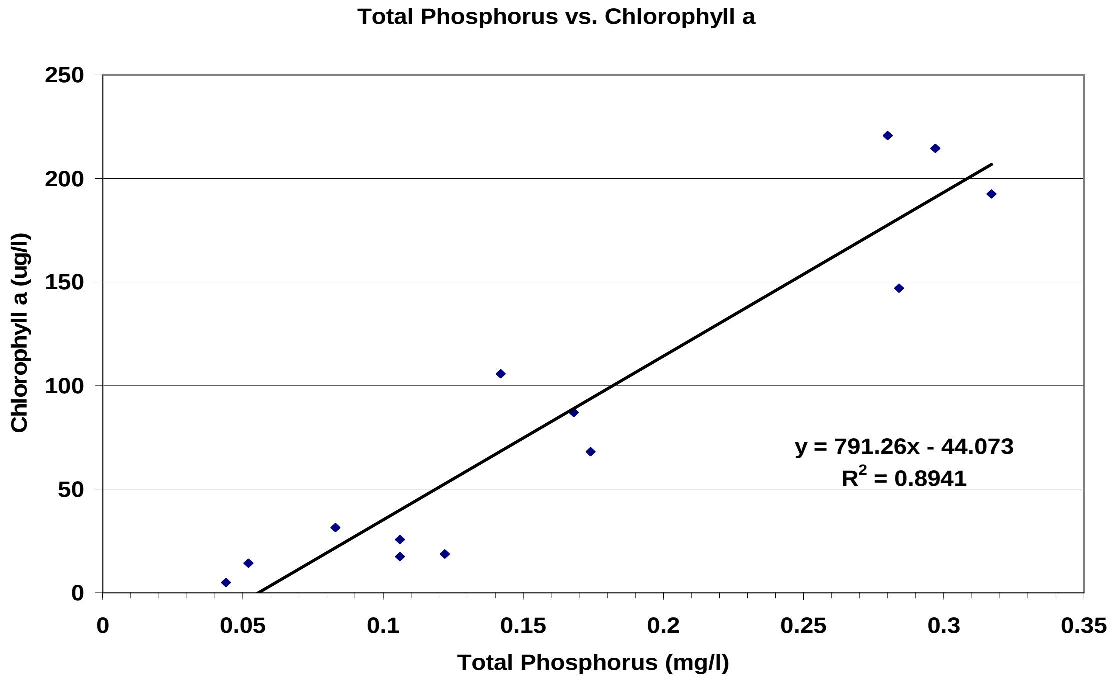

Figure 10. Regression between growing-season total phosphorus and chlorophyll a in Burke Lake, 2004.

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 lakes 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 10). 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 for Burke Lake was 75.0, placing it within the hyper-eutrophic category and as not supporting its uses. This TSI was based on total phosphorus, Secchi transparency, and chlorophyll *a*.

Table 10. 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 narrative standard targets based on the fish life classification of a lake. 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 TSI of ≤63.4. The median growing-season Secchi-Chlorophyll TSI for Burke lake was 75.88 and indicated the lake was not meeting its target TSI value.

Phytoplankton

Algae populations were not extensively monitored during the study and only a few samples were collected. However, limited data collected during previous statewide monitoring efforts and during the current study provided insights into the algae of Burke Lake. The original data (algae counts and identifications) are available from SDDENR. The summarized data indicate a predominance of blue-green algae during the summer of 2001 (Table 11). During the current project, the algae during the winter and early spring were dominated by flagellates and blue-green algae. The summer of 2004 was dominated by green algae. This was considered an oddity because blue-green algae usually dominate during the summer months. This may be perceived as a slight improvement given that under certain conditions, some blue-green algae can produce toxins. Future monitoring efforts may reveal whether the reservoir has improved to the point where green algae consistently dominate over blue-green algae.

Table 11. Percentages of various algal groups in Burke Lake.

Date	Site	Flagellate Algae	Unident Algae	Blue-green Algae	Non-motile Green Algae	Diatoms
6/27/01	Composite	<1	<1	99.69	<1	<1
8/15/01	Composite	<1	<1	99.10	<1	<1
4/17/03	BL05	55.29	10.28	30.84	1.56	2.03
4/17/03	BL06	63.96	8.26	23.03	1.85	2.90
5/13/03	BL05	35.37	4.62	42.70	1.73	15.58
5/13/03	BL06	28.70	3.61	<1	41.52	25.27
2/10/04	BL05	28.89	3.76	43.22	23.67	<1
2/10/04	BL06	64.61	2.60	26.12	3.70	3.07
7/14/04	BL05	3.89	4.84	33.35	<1	57.83
7/14/04	BL06	1.27	4.03	44.29	<1	50.35

Sediment Survey

The amount of soft sediment in the bottom of a lake may be used as an indicator of the volume of erosion occurring in its watershed and along its shoreline. The soft sediment on the bottom of lakes is often rich in phosphorus. When lakes turn over in the spring and fall, sediment and the nutrients are suspended in the water column making them available for plant growth. The accumulation of sediments in the bottom of lakes may also have a negative impact on fish and aquatic invertebrates. Sediment accumulation may often cover bottom habitat used by these species. The end result may be a reduction in the diversity of aquatic insect, snail, and crustacean species.

A sediment survey was conducted on Burke Lake during February, 2004. A total of 55 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.

Figures 11 and 12 provide contour maps of water depth and sediment depth. Water depth ranged from 0 to 18 feet (5.49 meters). Only a small area near the dam had depths of twelve feet or more whereas most of the reservoir had water depths of 4-6 feet (1.22-1.83 meters). The sediment depths ranged from 0 to 8 feet (2.44 meters) but were mostly around 2-4 feet (0.61-1.22 meters). These sediment depths are not considered unusual for a South Dakotan reservoir. Lake depth could be increased, possibly up to 40%, if this sediment was removed. This might remove sediment that could otherwise release nutrients into the water column, and extend the life of the lake.

Figure 11. Water depths for Burke Lake, Gregory County, South Dakota, 2004.

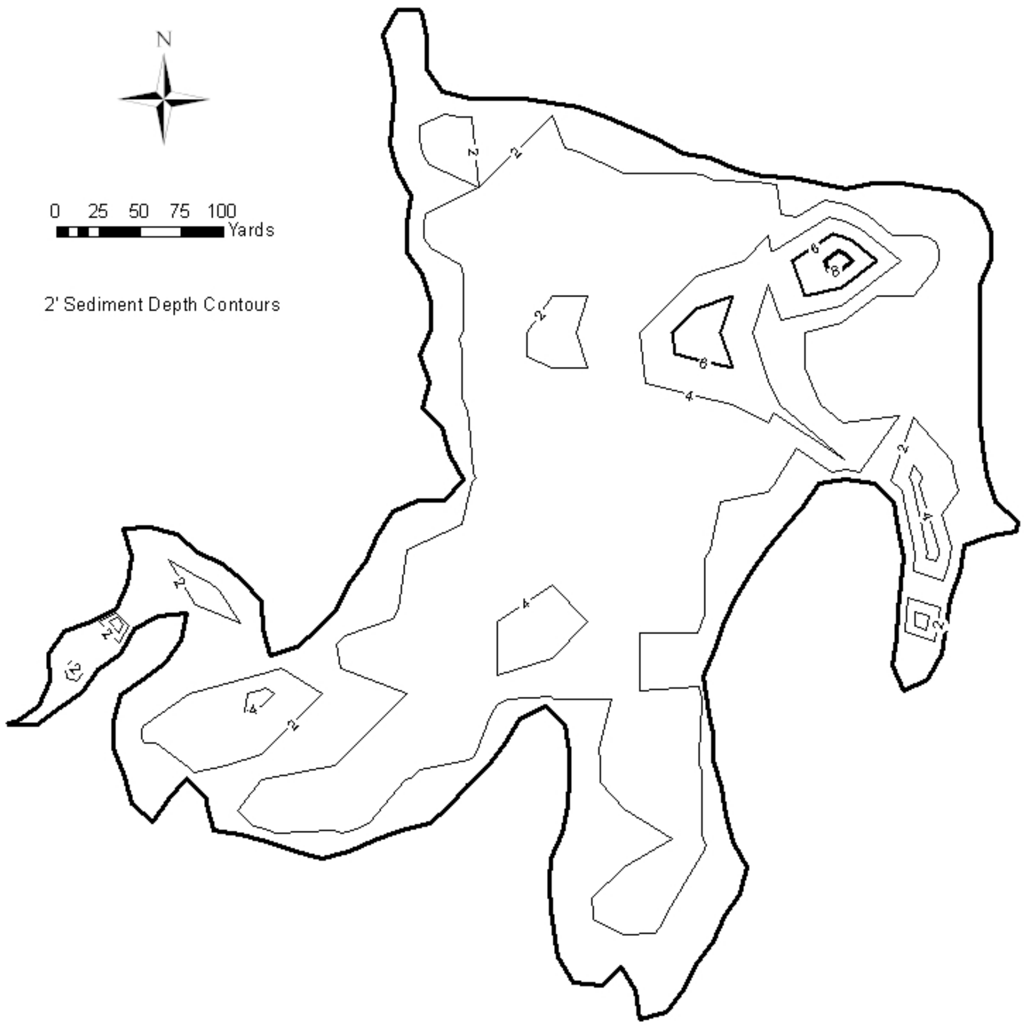

Figure 12. Sediment depths for Burke Lake, Gregory County, South Dakota, 2004.

Elutriate Testing

Elutriate tests were run on sediment and water samples collected from the two in-lake sites during 5/13/2003. 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 (Tables 12 and 13).

Table 12. Parameters that were at or below their respective detection limits for Burke Lake elutriate test samples, 5/13/2003.

Alachlor	Chlorodane	Endrin	Heptachlor
Heptachlor Epoxide	Methoxychlor	Toxaphene	Aldrin
Dieldrin	PCB screen (various Arochlors)	Diazinon	DDD
DDT	DDE	Beta BHC	Gamma BHC
Alpha BHC	Endosulfan II	Atrazine	Cadmium
Lead	Silver	Selenium	Total Mercury
Nitrite			

Table 13. Elutriate test results for Burke Lake, Gregory County, South Dakota, during 5/13/2003.

Parameter	**Receiving Water**		**Elutriate Water**	
	BL05	**BL06**	**BL05**	**BL06**
COD (mg/l)	35.4	25.6	35.4	37.4
Total Phosphorus (mg/l)	0.025	0.028	0.021	0.043
TKN (mg/l)	0.58	0.80	1.38	1.94
Hardness (mg/l)	190	230	170	180
Nitrate (mg/l)	<0.1	<0.1	0.1	0.3
Ammonia (mg/l)	<0.02	<0.02	0.11	0.71
Aluminum (µg/l)	2.6	1.3	48.3	22.3
Arsenic (mg/l)	0.002	0.002	0.002	0.005
Copper (µg/l)	3.7	3.0	3.3	1.1
Nickel (µg/l)	2.0	1.8	1.8	2.0
Zinc (µg/l)	<0.4	2.2	2.0	3.2

Macrophyte Survey

A macrophyte/shoreline condition survey was conducted during August 2003. Eleven 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 Burke Lake was judged optimal. The rating scores for bank stability, vegetative cover, and vegetative zone width averaged scores of 10.0, 9.4, and 8.25 respectively. This is not surprising given the lake is surrounded by a State Park, an abundance of trees cuts the wind and minimizes excessive shoreline erosion, and the shoreline gets little use and disturbance.

The macrophyte survey indicated sparse to moderate growth of emergent vegetation, cattails (Typha spp.) and bulrush (Scirpus spp.) along the lake's shoreline. Submergent vegetation consisted of a mix of coontail (Ceratophyllum demersum) and sego pondweed (Potamogeton pectinatus L.). Areas devoid of submergent vegetation were limited to an area along the dam face and in depths greater than seven feet. Neither the emergent or the submergent vegetation was considered a problem for the lake users. However, decay of this organic matter may contribute to low oxygen concentrations periodically occurring in the lake.

Threatened and Endangered Species

A number of species on the federal list of threatened and endangered species are known to have occurred in Gregory County. The American burying beetle (Nicrophorous americanus), pallid sturgeon (Scaphirhynchus albus), whooping crane (Grus americana), least tern (Sterna antillarum), piping plover (Charadrius melodus), and the bald eagle (Haliaeetus leucocephalis) have been sited in the county. However, only the bald eagle, whooping crane, and the american burying beetle are likely to occur in the Burke Lake watershed. The other species are mostly limited to the Missouri River area. None of the above species were encountered during this study.

Nesting bald eagles could migrate through the area, especially during seasonal migrations. 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. Small wetland areas should not be disturbed if whooping cranes are observed in them.

OBJECTIVE 2 – Tributary Water Chemistry and Loadings to Burke Lake

Tributary Sampling Schedule, Methods, and Materials

Three tributary monitoring sites were selected for the Burke Lake Assessment Project (Figure 2). The sites were selected to determine which portions of the watershed were contributing the greatest amount of nutrient and sediment load to the lake. One site, BL01, never flowed during the study. The other two sites were equipped with Stevens Type F stage recorders. Water stages were monitored and recorded for each of the sites. A March-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.

Sampling at the tributary sites began March 12, 2003 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	Alkalinity
Total solids	Total volatile suspended solids
Total suspended solids	Ammonia
Nitrate	Total Kjeldahl nitrogen (TKN)
Total phosphorus	Total dissolved phosphorus
E coli	

Personnel conducting the sampling at each of the sites recorded the following visual observations of weather and stream characteristics.

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

Parameters measured in the field by sampling personnel were:

Water temperature	Air temperature
Conductivity	Dissolved oxygen
Field pH	

Total nutrient and sediment loads were calculated with the use of the Army Corps of Engineers eutrophication model known as FLUX (Walker, 1999). FLUX uses individual sample data in correlation with daily discharges to develop loading calculations for total phosphorus, total nitrogen, and total solids.

Tributary Sampling Results

Fecal Coliform Bacteria

Fecal coliform are bacteria that are found in the digestive tract of warm-blooded animals. Some common types of bacteria are *E. coli*, *Salmonella,* and *Streptococcus,* which are associated with livestock, wildlife, and human waste (Novotny, 1994). Major sources of fecal coliform bacteria in the Burke Lake drainage are most likely cattle, wildlife, and humans (septic systems).

Approximately 55% of the samples had fecal coliform bacteria concentrations at or below 10 colonies/100 ml (Table 14). Although no fecal coliform standard exists for the tributaries, 14.6% of the samples (8 samples) had concentrations above the 400 colonies/100 ml criterion for immersion recreation and 3.6% (2 samples) were above the 2000 colonies/100 ml criterion for limited contact recreation. The high counts at Sites BL02 and BL03 are thought to be due to livestock or possibly a septic system.

Table 14. Fecal coliform concentrations in Burke Lake tributaries, Gregory County, South Dakota during 2003/2004.

Date	BL02	BL03	BL04
3/12/03	170	6	6
3/20/03	4	<10	<2
3/27/03	2	2	<2
4/3/03	2	4	24
4/9/03	26	<2	<2
4/17/03	48.8	<10	<10
4/23/03	20	<10	<10
5/1/03	140	20	<10
5/13/03	80	<10	20
6/10/03	220	480	630
7/15/03	180		2100
8/12/03	1800		
3/23/04	<10	10	<10
3/30/04	<10	<10	20
4/13/04	<10	10	<10
5/3/04	10	<10	<10
5/17/04	870	680	<10
6/2/04	120	20	220
6/14/04	410		80
7/14/04	400		2700
Mean	226.7	80.88	309.3

Alkalinity

Total alkalinity affects waters' ability to buffer against changes in pH. Total alkalinity consists of all dissolved species 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 the primary source of alkalinity. It is commonly found in concentrations as high as 200 mg/l.

Alkalinity concentrations in Burke Lakes tributaries varied from as high as 275 mg/l to as low as 167 mg/l (Table 15). The state standard for alkalinity is a maximum of 750 mg/l as a geometric mean or 1,313 mg/l in a single sample, which the tributary sites did not exceed in any of their samples. The mean concentrations from the sampling sites ranged from 204 mg/l to 236 mg/l. These concentrations are generally typical of waterbodies in South Dakota.

Table 15. Total alkalinity concentrations (mg/l) for Burke Lake tributaries, Gregory County, South Dakota during 2003/2004.

Date	BL02	BL03	BL04
3/12/03	187	186	193
3/20/03	238	190	194
3/27/03	233	201	197
4/3/03	224	200	233
4/9/03	227	173	201
4/17/03	239	226	197
4/23/03	237	223	217
5/1/03	253	202	197
5/13/03	241	223	197
6/10/03	248	250	213
7/15/03	250		238
8/12/03	264		
3/23/04	210	187	194
3/30/04	233	200	189
4/13/04	218	210	212
5/3/04	233	241	214
5/17/04	234	220	179
6/2/04	247	275	185
6/14/04	247		167
7/14/04	259		267
Mean	236	213	204

Solids

Total solids are the sum of all dissolved and suspended as well as organic and inorganic materials. Dissolved solids are typically found in higher concentrations in groundwater. Table 16 lists the total solids and suspended solids concentrations found in the Burke Lake tributaries.

The mean total solids concentrations for the tributaries ranged from 284 to 348 mg/l with site BL02 having the greatest mean (348 mg/l). There was no clear seasonal pattern to the total solids concentrations although the samples taken during the summer sometimes had higher concentrations.

Table 16. Total solids and suspended solids concentrations (mg/l) for Burke Lake tributaries, Gregory County, South Dakota during 2003/2004.

	Total Solids (mg/l)			Suspended Solids (mg/l)		
Date	**BL02**	**BL03**	**BL04**	**BL02**	**BL03**	**BL04**
3/12/03	307	269	295	4	3	7
3/20/03	363	263	285	5	6	7
3/27/03	336	260	288	5	<1	8
4/3/03	315	259	316	3	5	6
4/9/03	332	232	285	<1	<1	3
4/17/03	354	295	289	27	7	11
4/23/03	331	294	304	14	6	7
5/1/03	342	262	284	5	5	10
5/13/03	338	285	283	9	4	5
6/10/03	342	250	314	1	<1	16
7/15/03	386		427	22		98
8/12/03	433			39		
3/23/04	319	187	286	<1	<1	8
3/30/04	353	200	284	<1	<1	8
4/13/04	320	210	293	5	1	7
5/3/04	330	241	294	4	2	7
5/17/04	356	220	261	7	3	11
6/2/04	337	275	258	4	7	6
6/14/04	364		248	6		11
7/14/04	404		389	72		56
Mean	348	284	299	11.75	4.13	15.37

Total suspended solids concentrations ranged from <1 to 98 mg/l and usually comprised only about 2% or less of the total solids. There is no State standard for total suspended solids that applies to the tributaries.

Nitrogen

Nitrogen is analyzed in four forms: nitrate/nitrite, ammonia, and total Kjeldahl nitrogen (TKN). From these four forms, total, organic, and inorganic nitrogen may be calculated. Nitrogen compounds are major cellular components of organisms. Because its availability may be less than the biological demand, environmental sources may limit productivity in freshwater ecosystems. Nitrogen is difficult to manage because it is highly soluble and very mobile in water.

Inorganic nitrogen is the form of nitrogen most readily available for plant growth. The total inorganic nitrogen concentrations were highest during the April-March spring run-off period and decreased to levels generally at or below 0.12 mg/l throughout the summer (Table 17). The 0.12 mg/l concentration is equal to the 0.1 mg/l detection limit for nitrate/nitrite plus the .02 mg/l detection limit for ammonia. These low values are probably a reflection of diminished runoff during the summer months.

Total organic nitrogen concentrations averaged 77% of the total nitrogen concentration with slightly lower (40-60%) percentages during the spring run-off period.

Table 17. Total inorganic and organic nitrogen concentrations (mg/l) for Burke Lake tributaries, Gregory County, South Dakota during 2003/2004.

	Total Inorganic nitrogen			Total Organic Nitrogen		
Date	**BL02**	**BL03**	**BL04**	**BL02**	**BL03**	**BL04**
3/12/03	.32	.12	.12	1.03	0.65	1.24
3/20/03	.23	.12	.12	0.78	0.48	1.03
3/27/03	.12	.12	.12	0.57	0.19	1.11
4/3/03	.12	.12	.15	0.55	0.35	0.84
4/9/03	.12	.12	.12	0.68	0.15	0.90
4/17/03	.12	.12	.12	0.26	0.09	0.77
4/23/03	.12	.12	.18	0.33	0.32	0.70
5/1/03	.12	.12	.12	1.01	0.57	0.90
5/13/03	.22	.12	.12	0.61	0.24	0.71
6/10/03	.12		.33	0.80	0.72	0.99
7/15/03	.15		.66	0.62		0.61
8/12/03	.13			1.14		
3/23/04	.32	.12	.12	0.56	0.40	1.11
3/30/04	.12	.12	.12	0.96	0.63	1.42
4/13/04	.22	.12	.12	0.34	0.26	0.87
5/3/04	.12	.12	.12	0.27	0.23	0.74
5/17/04	.12	.12	.12	1.12	0.73	1.25
6/2/04	.12	.12	.17	0.96	1.11	1.29
6/14/04	.13		.12	0.84		1.21
7/14/04	.12		.67	2.21		0.98
Mean	.158	.120	.196	.782	.445	.983

Phosphorus

Phosphorus is one of the macronutrients required for primary production. In comparison to carbon, nitrogen, and oxygen, it is the least abundant in natural systems (Wetzel, 2000). Phosphorus loading to lakes can be of an internal or external nature. External loading refers to surface runoff, dust, and precipitation. Internal loading refers to the transfer of phosphorus from the bottom sediments to the water column of the lake. Total phosphorus is the sum of all attached and dissolved phosphorus in the lake. The attached phosphorus is directly related to the amount of total suspended solids present. An increase in the amount of suspended solids increases the fraction of attached phosphorus.

Total dissolved phosphorus is the unattached portion of the total phosphorus load. It is found in solution, but readily adsorbs to soil particles when they are present. Total dissolved phosphorus, including soluble reactive phosphorus, is more readily available to plant life.

The total phosphorus concentrations in the tributaries ranged from 0.052 to 0.851 mg/l and averaged .238 mg/l (Table 18). The greatest concentrations generally occurred at Site BL02 and peaked during the summer.

Total dissolved phosphorus (Appendix A) averaged 87% of the total phosphorus in the incoming tributaries and about 61% in the outlet. Total dissolved phosphorus seasonality was similar to that of total phosphorus with summer peaks.

Table 18. Total phosphorus concentrations (mg/l) for Burke Lake tributaries, Gregory County, South Dakota during 2003/2004.

Date	BL02	BL03	BL04
3/12/03	.317	.117	.084
3/20/03	.198	.092	.084
3/27/03	.185	.089	.109
4/3/03	.192	.098	.162
4/9/03	.170	.082	.052
4/17/03	.333	.116	.079
4/23/03	.323	.119	.128
5/1/03	.198	.107	.081
5/13/03	.393	.128	.083
6/10/03	.294	.123	.237
7/15/03	.499		.348
8/12/03	.670		
3/23/04	.253	.093	.111
3/30/04	.155	.101	.106
4/13/04	.242	.100	.136
5/3/04	.292	.122	.161
5/17/04	.356	.124	.121
6/2/04	.309	.161	.169
6/14/04	.577		.184
7/14/04	.851		.304
Mean	.340	.111	.144

Tributary flows and phosphorus loading using the FLUX and BATHTUB models

Table 19 exhibits the total inflows and outflow calculated for Burke Lake during 2003. Atmospheric data came from a South Dakota State University database (http://climate.sdstate.edu/climate_site/climate.htn) where the precipitation data were collected from Gregory, South Dakota and the evaporation data from a weather station in Pickstown, approximately 55 miles east of Gregory. These data indicated precipitation accumulations for 2003 were approximately 10% less than the long term average. Therefore, the measured phosphorus loads to the lake during the study may not represent the long-term average and be a slightly underestimation of long-term average phosphorus loads. Detailed information on the calculation of flow data can be obtained from DENR upon request.

The months of March through June comprised the bulk of the total measured inflow. This is typical of South Dakota where water inflows (and nutrient and sediment loadings) peak during the spring and early summer.

The total inflow plus precipitation was nearly equal to the outflow plus evaporation (181.80 vs. 181.92 acre-ft. respectively). Interestingly, the flows from Site BL02 were not as high as those from Site BL03 during the main spring run-off event but were generally greater in the following months. This was probably due to the effect of the beaver dam on flows at Site BL02.

The flow data were used in the Army Corps of Engineers BATHTUB model (Walker, 1999). BATHTUB provides numerous models for the calculation of in-lake concentrations of phosphorus, nitrogen, chlorophyll *a*, and Secchi depth. Models are selected that most closely predict current in-lake conditions from the loading data provided. These estimates are used in determining a TMDL for the lake. In addition, reductions in the phosphorus concentration of the tributaries can be modeled to predict changes in trophic state.

Table 19. Monthly total water inflows/outflows (acre-feet) for Burke Lake, Gregory County, South Dakota, 2003.

Month	BL02 inflow	BL03 inflow	BL04 outflow	Avg. Ann. Precip.	Avg. Ann. Evap.
January	0	0	0	1.3725	-
February	0	0	0	0.8550	-
March	17.17	67.21	35.63	1.3275	-
April	12.54	5.25	37.58	6.8175	-
May	9.80	2.57	26.66	11.79	1.2150
June	9.22	1.34	12.64	9.7425	12.735
July	2.52	0.42	2.06	2.6100	12.6675
August	0.88	0	0.06	7.785	20.70
September	0	0	0.55	2.205	15.39
October	1.30	0.83	1.74	2.880	-
November	0.92	0.55	0.55	0.3782	-
December	0	0	1.74	1.5300	-
Total (Ac-ft)	**54.34**	**78.17**	**119.21**	**49.29**	**62.71**

The BATHTUB model produced excellent agreement between the observed and predicted phosphorus, chlorophyll a, and Secchi TSIs (Table 20). The predicted total phosphorus loads indicate that the tributary monitored with Site BL02 had approximately twice the phosphorus load as the tributary monitored with Site BL03 even though Site BL03 had the greatest flow (21.0 vs. 10.4 kg total phosphorus/yr respectively) (Table 21). Precipitation comprised about 9.4% of the total phosphorus load. The in-lake total phosphorus predicted by the model was 185.1 mg/m^3. This resulted in total phosphorus, chlorophyll *a*, and Secchi based TSI values of 79.4, 73.4, and 67.6 respectively.

The target TSI for Burke Lake is 63.4 and is based on a growing season Secchi-chlorophyll TSI. The BATHTUB model, however, predicts <u>average</u> TSI values rather than <u>median</u> values. A comparison of the predicted average Secchi-chlorophyll TSI to the observed Secchi-chlorophyll TSI was 70.5 versus 72.0 respectively. The difference between the two (1.5 TSI units) was not considered large enough to justify resetting the target TSI and so the predicted average Secchi-chlorophyll TSI values from the model can be compared to the target TSI value of 63.4.

Modeling the progressive decrease in total phosphorus loads in the tributaries produced TSI values that also progressively decreased (Figure 13). The target Secchi-Chlorophyll *a* TSI of 63.4 was reached when the initial phosphorus load in the tributaries were decreased by nearly 88%.

Table 20. **Predicted & Observed Values Ranked Against CE Model Development Dataset.**

	Predicted Values			Observed Values		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	185.1	0.31	93.3%	193.4	0.57	94.0%
TOTAL N MG/M3	2639.3	0.56	93.5%	2639.3	0.56	93.5%
C.NUTRIENT MG/M3	138.1	0.31	95.5%	141.5	0.57	95.7%
CHL-A MG/M3	78.4	0.29	99.7%	86.9	0.97	99.8%
SECCHI M	0.6	0.29	21.2%	0.6	0.74	18.7%
ORGANIC N MG/M3	1949.5	0.29	99.7%	2520.0	0.59	99.9%
TP-ORTHO-P MG/M3	137.3	0.33	94.5%	152.8	0.75	95.7%
ANTILOG PC-1	3865.8	0.47	98.2%	4700.2	0.74	98.8%
ANTILOG PC-2	17.5	0.10	97.2%	18.6	0.84	97.8%
(N - 150) / P	13.5	0.67	36.5%	12.9	0.82	34.1%
INORGANIC N / P	14.4	2.52	23.4%	2.9	18.09	1.0%
TURBIDITY 1/M	0.1	0.20	1.1%	0.1	0.20	1.1%
ZMIX * TURBIDITY	0.1	0.20	0.0%	0.1	0.20	0.0%
ZMIX / SECCHI	3.1	0.30	22.3%	3.3	0.72	25.9%
CHL-A * SECCHI	46.1	0.10	98.3%	47.8	1.22	98.5%
CHL-A / TOTAL P	0.4	0.32	88.7%	0.4	1.12	90.4%
FREQ(CHL-a>10) %	99.9	0.00	99.7%	99.9	0.00	99.8%
FREQ(CHL-a>20) %	97.1	0.03	99.7%	98.0	0.07	99.8%
FREQ(CHL-a>30) %	89.2	0.09	99.7%	92.0	0.24	99.8%
FREQ(CHL-a>40) %	78.1	0.17	99.7%	82.7	0.47	99.8%
FREQ(CHL-a>50) %	66.1	0.25	99.7%	71.9	0.71	99.8%
FREQ(CHL-a>60) %	54.8	0.33	99.7%	61.3	0.95	99.8%
CARLSON TSI-P	79.4	0.06	93.3%	80.1	0.10	94.0%
CARLSON TSI-CHLA	73.4	0.04	99.7%	74.4	0.13	99.8%
CARLSON TSI-SEC	67.6	0.06	78.8%	68.6	0.15	81.3%

Table 21. BATHTUB predicted total phosphorus loads for Burke Lake, Gregory County, South Dakota, during 2003 and after an 88% TP load Reduction.

Load Component	Original Predicted Load (kg/yr)	Load After 88% Reduction (kg/yr)
Tributary 1 (Site BL02)	21.0	2.5
Tributary 2 (Site BL03)	10.4	1.2
Precipitation	3.3	3.3
Total Inflow	34.7	7.0
Outflow (Site BL04)	26.8	10.0
Advective outflow	-17.3	-6.4
Total Outflow	9.5	3.5
Retention	25.2	3.5

The total phosphorus loads after the tributary total phosphorus loads were decreased by 88% are given in Table 21. At the target TSI of 63.4, the annual total phosphorus load from all external sources should be at least 7.0 kg/yr. Given an original tributary load of 31.4 kg/yr, approximately 24.4 kilograms of phosphorus needs to be removed from the tributary loads to reach a TMDL load of 7.0 kg/yr. This is probably not attainable through typical watershed conservation practices and other measures, such as phosphorus inactivation or phosphorus removal, may be necessary to reach the target TSI.

Although the lake was a phosphorus sink, internal phosphorus loading could also be significant. Given the tendency of Burke Lake to experience oxygen deficits, it is not unrealistic to assume that internal phosphorus loading can occur and be a significant phosphorus source during times of oxygen depletion. Sediment removal or phosphorus inactivation/bottom sealing might alleviate problems due to internal phosphorus loads.

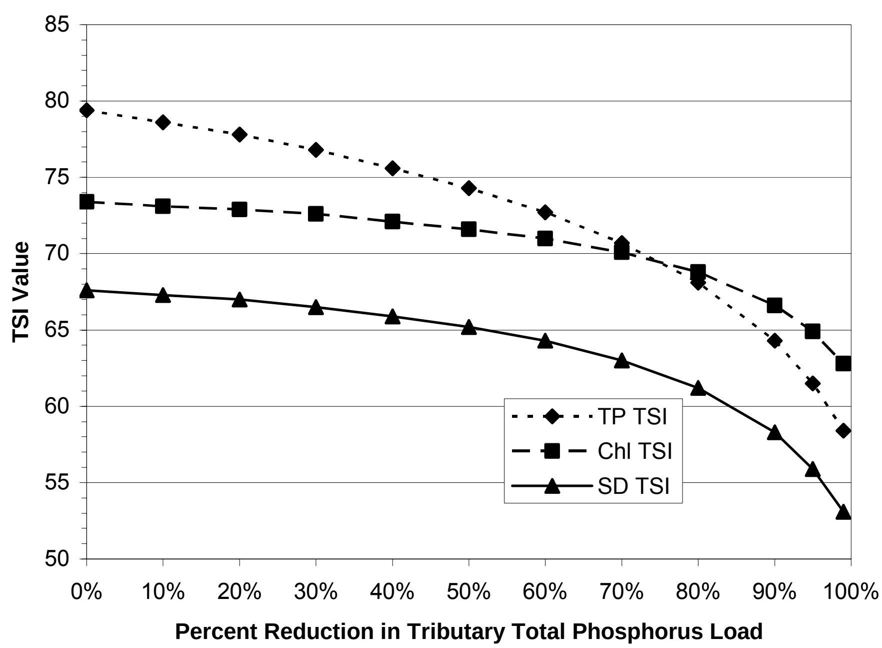

Figure 13. Graphical presentation of trophic state values in response to incremental percent reductions in total phosphorus loads from sites BL02 and BL03.

Long-Term Trends

Data from this report are included in Figure 14 as well as TSI values calculated during previous sampling efforts. The trend of the TSI values is towards a decrease in TSI value and hence an improvement in lake quality. Burke Lake is listed on the state's 303(d) list as an impaired water body with a declining trend in water quality as a result of nutrients, sediment, and algal growth. Figure 13 partially contradicts this. The total phosphorus and Secchi TSIs showed an improvement in water quality whereas the chlorophyll *a* TSI showed a slight decrease in water quality (increased TSI). Even so, the current condition of the reservoir is such that regardless of the trend, it is still in need of restoration.

Lorenzen's (2005) TSI target for full support was a median growing season Secchi-Chlorophyll *a* TSI of ≤ 63.4. It appears that the Secchi TSI may eventually reach that target by 2010 or so but the chlorophyll *a* TSI is trending upward. Reductions in nutrient and sediment load to the lake may help to reverse this trend. To shift the lakes trophic state toward the target TSI of 63.4, the chlorophyll *a* TSI needs to be decreased by approximately ten TSI units. The Secchi TSI is closer to the target value and it is thought that any significant decrease in algae would also likely be accompanied by an increase in Secchi transparency (decrease in Secchi TSI).

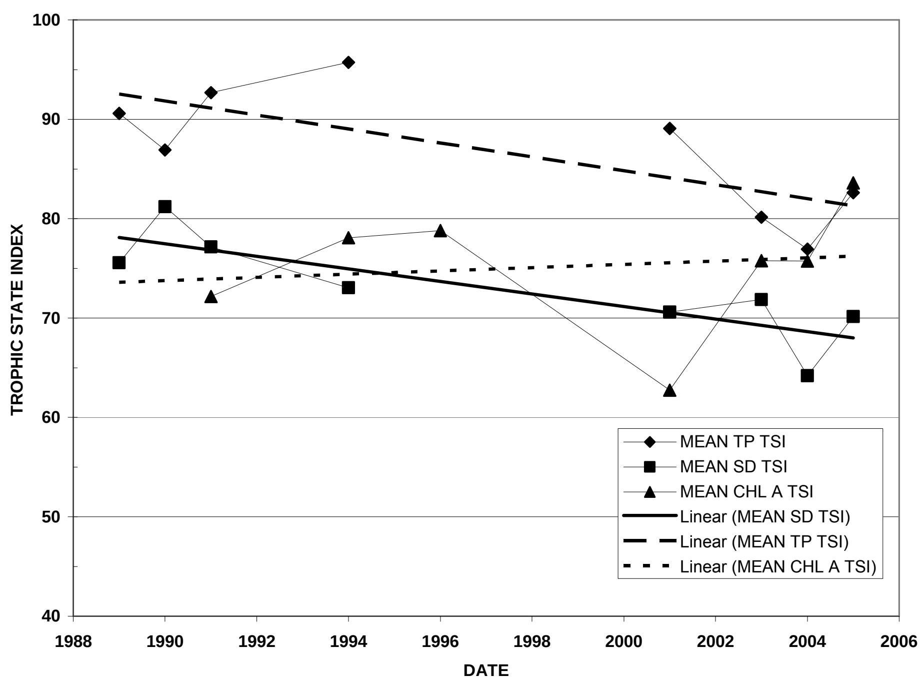

Figure 14. Mean growing-season total phosphorus, Secchi transparency and chlorophyll *a* trophic state indices in Burke Lake, South Dakota.

<u>OBJECTIVE 3 - Quality Assurance Reporting</u>

Quality Assurance/ Quality Control (QA/QC) samples were collected for at least 10% of the total number of samples taken. One hundred and six samples were collected during the project and an additional eight blank samples and ten duplicate samples were collected from the lake and tributaries sites for QA/QC purposes (Table 22). 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. These two parameters were consistently slightly above the detection limit. 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. Five of the fecal coliform samples were acceptable and three weren't, with a mean I% of 11.44%. However, the median I% was 5% so a large I% can greatly influence the mean value. There are no obvious reasons for these results so further investigation may be needed to resolve this issue.

Table 22. Field blanks and duplicates for the Burke Lake assessment project.

SITE	DATE	Type	DEPTH	TALKA	TSOL	TSSOL	VSS	AMMO	NIT	TKN	TP	TDP	FEC	EColi
QA/QC	5/1/03	Blank		<6	<7	<1	<1	<0.02	<0.1	<0.11	<0.002	0.004	<10	<1
BL04	5/13/03	Blank	SURFACE	<6	<7	1	<1	<0.02	<0.1	<0.11	0.003	0.004	<10	<1
BL04	5/13/03	Sample	SURFACE	197	283	5	3	<0.02	<0.1	0.73	0.083	0.055	20	19.7
BL04	5/13/03	Duplicate	SURFACE	88	338	7	3	<0.02	<0.1	0.58	0.076	0.048	<10	16.8
%I				38.25%	8.86%	16.67%	0%	0%	0%	7.18%	4.4%	6.8%	33%	7.95%
BL05	5/13/03	Sample	SURFACE	188	267	4	2	<0.02	<0.1	0.70	0.044	0.026	<10	1
BL05	5/13/03	Duplicate	SURFACE	190	274	5	2	<0.02	<0.1	0.63	0.041	0.024		
%I				0.53%	1.29%	11.11%	0%	0%	0%	5.26%	3.53%	4.0%		
BL06	5/13/03	Duplicate	SURFACE	190	273	6	3	<0.02	<0.1	0.86	0.047	0.023	10	2
BL06	5/13/03	Sample	SURFACE	187	273	7	3	<0.02	<0.1	0.65	0.052	0.028	<10	<1
%I				0.8%	0%	7.69%	0%	0%	0%	13.91%	5.05%	9.8%	0%	33%
BL05	6/10/03	Blank	SURFACE	<6	<7	<1	<1	<0.02	<0.1	<0.11	<0.002	0.003	<10	<1
BL05	6/10/03	Sample	SURFACE	177	262	5	4	<0.02	<0.1	1.08	0.106	0.051	<10	<1
BL05	6/10/03	Duplicate	SURFACE	176	268	4	3	<0.02	<0.1	1.21	0.103	0.048	<10	<1
%I				0.28%	1.13%	11.11%	14.29%	0%	0%	5.68%	1.44%	3.03%	0%	0%
BL05	9/9/03	Blank	SURFACE	<6	<7	<1	<1	<0.02	<0.1	<0.11	0.002	0.007	<10	<1
BL05	9/9/03	Sample	SURFACE	140	263	36	35	<0.02	<0.1	3.88	0.280	0.040		
BL05	9/9/03	Duplicate	SURFACE	141	260	35	34	<0.02	<0.1	3.57	0.290	0.039	<10	<1
%I				0.36%	0.65%	1.41%	1.45%	0%	0%	4.16%	1.75%	1.27%		
BL03	3/30/04	Blank	SURFACE	<6	<7	<1	<1	<0.02	<0.1	<0.23	0.003	0.005	<10	<1
BL03	3/30/04	Sample	SURFACE	200	279	1	<1	<0.02	<0.1	0.65	0.101	0.099	<10	1
BL03	3/30/04	Duplicate	SURFACE	202	274	3	2	<0.02	<0.1	0.58	0.099	0.100	10	<1
%I				0.5%	0.9%	25%	50%	0%	0%	5.69%	1.0%	1.0%	0%	0%
BL04	5/3/04	Blank	SURFACE	<6	<7	<1	<1	<0.02	<0.1	<0.23	0.002	0.005	<10	<1
BL04	5/3/04	Sample	SURFACE	214	294	7	4	<0.02	<0.1	0.76	0.161	0.120	<10	9.7

BL04	5/3/04	Duplicate	SURFACE	211	293	7	4	<0.02	<0.1	0.59	0.159	0.117	20	9.8
%I				0.71%	0.17%	0%	0%	0%	0%	12.59%	0.63%	1.27%	33%	0.51%
BL02	6/14/04	Sample	SURFACE	247	364	6	5	0.03	0.1	0.87	0.577	0.521	410	326
Table 21. Continued.	DATE	Type	DEPTH	TALK	TSOL	TSS	VSS	AMMO	NIT	TKN	TP	TDP	FEC	EColi
BL02	6/14/04	Sample	SURFACE	247	364	6	5	0.03	0.1	0.87	0.577	0.521	410	326
BL02	6/14/04	Duplicate	SURFACE	247	358	6	4	0.04	0.1	0.87	0.422	0.508	300	326
%I				0%	0.83%	0%	11.11%	14.29%	0%	0%	15.52%	1.26%	15.49%	0%
BL04	6/14/04	Blank	BOTTOM	<6	<7	<1	<1	<0.02	<0.1	<0.23	0.002	0.003	<10	<1
BL04	6/14/04	Sample	BOTTOM	167	248	11	3	0.05	0.1	1.23	0.184	0.144	80	67.7
BL04	6/14/04	Duplicate	BOTTOM	167	246	9	4	0.06	0.1	1.37	0.192	0.145	100	95.9
%I				0%	0.4%	10%	14.29%	9.09%	0%	5.38%	2.13%	0.35%	10%	17.2%
BL06	7/14/04	Blank	SURFACE	<6	<7	<1	<1	<0.02	<0.1	<0.23	<0.002	0.003	<10	<1
BL06	7/14/04	Sample	SURFACE	125	217	30	20	<0.02	<0.1	2.26	0.142	0.033	<10	<1
BL06	7/14/04	Duplicate	SURFACE	126	217	27	23	<0.02	<0.1	2.40	0.137	0.032	<10	<1
%I				0.4%	0%	5.26%	6.98%	0%	0%	3.0%	1.79%	1.54%	0%	0%
AVG %I				4.18	1.42	8.82	9.81	2.33	0	6.29	3.72	3.03	11.44	7.33

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 are calculated at the outlet to the watershed.

The input data set for AnnAGNPS Pollutant Loading Model consists of 33 sections of data, which can be supplied by the user in a number of ways. This model execution utilized; digital elevation maps (DEM's) to determine cell and reach geometry, SSURGO soil layers to determine primary soil types and the associated NASIS data tables for each soils properties, and primary land use based on remotely sensed data obtained from the EROS data center. Impoundment data was obtained from analysis of the National Wetlands Inventory (NWI). Weather data was generated using a synthetic weather generator based on climate information from the closest stations. Mean annual precipitation for this watershed is about 21 inches.

It is important to note that these model results are based on 25 simulated years of data with precipitation ranging from 13.8 to 26.4 inches per year. None of these represent the project period, they are instead representations of what may typically occur on any given year or series of years, and when analyzed as a group provides a risk analysis for practices in the watershed.

The land use data used for this model was derived from LANDSAT imagery collected during the years 2000 and 2001 and modified during a visual driving survey of the watershed. Analysis of this imagery was completed by the EROS Data Center and compiled into land use combinations for each cell. These combinations were derived by selecting the most prevalent land use in each cell for each year and then combined into a two year code.

Table 23 indicates the land uses in the Burke Lake Watershed before and after field reconnaissance. After a field recon and for the model purposes, approximately 4% of the land is cropped with an additional 79% used for pasture and rangeland. The remaining 17% are split between hay ground, forest, wetland, and urban (residential) areas. The field reconnaissance indicated 3 major errors, a corn field misidentified as grassland, grassland misidentified as grass and wheat mix, and hay ground misidentified as grass and beans.

Table 23. Burke Lake watershed land use percentages.

	Original Estimates		Estimates after Field Reconnaissance	
Land Use Type	Number of Cells	Percent of Watershed	Number of Cells	Percent of Watershed
Cropland	15	19%	3	4%
Hay	5	6%	5	6%
Rangeland	52	64%	64	86%
Trees	3	4%	3	2%
Urban	2	2%	2	1%
Water	4	5%	4	1%

A number of management scenarios or simulations were completed for the Burke Lake watershed. Comparative simulations were completed to calculate the load reaching the lake from each land use in the watershed (Table 24).

Table 24. Nutrient load sources for the Burke Lake watershed.

	Percent		lbs/acre	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Cropland/Hayland	57%	62%	1.57	1.00
Rangeland/Trees	13%	31%	0.04	0.06
Urban	27%	6%	7.50	0.92
Water				
AFO (total pound)	2%	2%	8.00	4.00
Estimated Totals	1	1	0.27	0.16

The watershed is characterized by primarily native rangeland with a forested area immediately adjacent to the lake. Long term range condition was difficult to determine, however during the project a majority of it remained in fair to good condition. Nutrient loadings per acre for rangeland should be about 0.04 and 0.06 pounds per acre for nitrogen and phosphorus respectively. Degraded range conditions may result in loadings per acre of .69 and .19 pounds per acre of nitrogen and phosphorus respectively.

Improving each acre of range condition may result in 0.1 pounds of phosphorus reduction.

Fertilizer practices for the cropped portions of the watershed were uncertain so conservative application estimates were assumed. Even at these moderate rates, these acres appear to be a substantial contributor of phosphorus, accounting for over half of the nutrient load, assuming that rangeland is in relatively good condition.

The only feeding operation in the watershed has changed. During a previous USEPA funded 319 project, the landowner decided to switch from a dairy operation to feeder cattle. This resulted in fewer cattle near the lake for shorter durations. This operation is relatively small and only accounted for two percent of the nutrient load. However, it is known that the ANNAGNPS model is relatively insensitive to small feeding operations having less than 100 head or so and the FLUX/BATHTUB models indicated that Site BL02 was the major nutrient source to the lake. So there is still some evidence that this operation could be a problem. Nevertheless, significant, additional voluntary changes to this operation may be difficult because of economic constraints on the owner.

Potential reductions in this watershed will be largely dependent on the willingness of the small number of landowners to participate in programs. It is unlikely that cropland will be converted to rangeland eliminating this as the primary potential reduction. Improving range conditions will likely only result in minimal reductions to the lake of five percent or less. Changing from a dairy operation to feeder cattle yielded reductions of phosphorus from five to ten percent but additional reductions are unlikely. A five percent reduction in phosphorus may be the best attainable level of control given the current watershed conditions.

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 Burke Lake.

Federal Agencies

The Environmental Protection Agency (EPA) provided the primary source of funds for the completion of the assessment on Burke 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 Public at Large

The South Central Water Development District and the Randall Resource Conservation and Development provided financial assistance. The City of Burke sponsored the project, provided project accounting, and used City personnel to do the field work. Public involvement primarily consisted of monthly meetings of the City of Burke. One individual, the person with the operation adjacent to the lake, was kept appraised of the project.

Table 25 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 City of Burke with City employees using their time to manage and direct the project and to do the water sampling. The project was completed with only using about 48% of the proposed budget ($24,772 spent/$52,000 budgeted). This was probably due to less samples being collected than what was proposed and a general overestimation of project costs.

Table 25. Funding sources and funds utilization for the Burke Lake Assessment Project.

Organization	Amount in the Budget	Amount Spent	In-Kind Contributed	% utilized
Federal EPA 319	31,175.00	17,474.00	0	56%
South Dakota Dept. Env. & Nat. Res.	10,650.00	0	0	0%
City of Burke	10,175.00	0	4,297.91	42%
South Central Water Development District	0	1,500.00	0	100%
Randall RC&D	0	1,500.00	0	100%

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). Eleven general categories were reviewed for their applicability to the Burke Lake situation and each one is discussed below. Table 26 at the end of this section summarizes those techniques recommended for consideration for use in Burke Lake.

Lake Restoration Techniques Rejected for Burke Lake

<u>Watershed conservation practices/animal waste management</u>

The ANNAGNPS model runs indicated the watershed was in good shape and that implementation of watershed BMPs would only result in a five percent reduction of total phosphorus loading. The one cattle operation adjacent to the lake that may still be a nutrient source has economic constraints that may preclude this operation from doing any more than it already has. Therefore, implementation of typical watershed conservation practices is not recommended as a means to restore the lake. However, implementation of BMPs may still provide a means to prevent the watershed from becoming a greater source of nutrients and sediment, and current efforts by the local Conservation District and the Natural Resource Conservation Service (NRCS) should continue.

<u>Dilution/flushing</u>

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 Burke Lake because there is no source of dilution water nearby. Pumping water from the best dilution source, the Missouri River, was considered cost prohibitive.

<u>Lake Drawdown/Plant Harvesting</u>

Lake drawdown and plant harvesting are two techniques used to control aquatic macrophytes. Because macrophtyes were not deemed a problem in Burke Lake these techniques are not recommended at this time. If aquatic macrophytes become a problem in the future, these techniques should be reconsidered.

<u>Biological Controls</u>

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.

Surface/Sediment Covers

Various materials have been used for rooted aquatic plant control. Because aquatic macrophytes were not deemed a problem in the lake, these techniques are not recommended.

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 Burke Lake is not recommended. There may be some merit in this technique for reducing in-lake TP because by mid to late summer, the TP concentrations in the deepest part of the lake were quite higher in the hypolimnion than at the surface (refer to Table 8, Site BL06). But by midsummer the inflow of tributary water is diminished and there is little likelihood of keeping the lake full during the time when hypolimnetic withdrawal would be most effective. So the positive effects of hypolimnetic withdrawal may be offset by having a more shallow lake subject to wind mixing (especially in the shallow areas of the lake that are currently only about four feet deep).

Techniques in Need of Further Investigation

Sediment Removal for Nutrient Control

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.

There is some evidence that internal loading of phosphorus has occurred in Burke Lake. The midsummer hypolimnetic concentration of phosphorus was much greater than the phosphorus concentrations at the surface. This was likely due to either internal loading from the sediments or recycling of phosphorus from dead algae and leaf litter. What isn't known is how much of a problem internal loading is. Further data are needed to quantify internal phosphorus loading.

A previous dredging effort at Burke Lake during 1993 removed approximately 150,000 cubic yards of sediment but water quality monitoring did not indicate any noticeable effect on water quality. The effort did deepen the main basin by three to four feet. The shallow arms of the lake were not dredged.

Nevertheless, lake dredging is a known lake restoration method and deepening Burke Lake would remove nutrient and organics laden sediment that would otherwise contribute to the algae and dissolved oxygen problems in the lake. However, dredging should be conducted in a manner that does not create more sediment surface area relative to the overlying water (e.g. creating ridges or irregularities in the lake bottom); otherwise dredging might actually exacerbate the problem..

Sediment Removal for Organics Control

There has been discussion among SDDENR investigators that organic matter originating from the watershed (especially from the original dairy operation) is still decomposing at the bottom of the lake and creating oxygen deficits. It is not known if this is the case and there are currently no data to support or refute this hypothesis. Elutriate samples were taken during the current study and the chemical oxygen demand (COD) concentrations for the receiving water sample and the elutriate sample were identical; 35.4 mg/l. TKN concentrations were higher in the elutriate sample (1.38 mg/l) versus the receiving water (0.58 mg/l) but neither value was considered excessive. Additional monitoring of the lake is needed before this technique is recommended. Lake and sediment samples should be analyzed for biochemical oxygen demand (BOD) and perhaps total organic carbon (TOC).

Techniques Recommended for Consideration

Phosphorus Removal from the Tributaries

The BATHTUB model indicated an 88% reduction in tributary phosphorus concentration was needed for Burke Lake to meet its Sec-Chl TSI target of 63.4. This means the external phosphorus loading rate must be decreased by 24.4 kg/yr to meet an acceptable annual loading rate 7.0 kg/yr. The ANNAGNPS model indicated that watershed controls will only result in a five percent or so reduction in phosphorus loading. The lack of significant phosphorus reductions through typical watershed conservation practices leaves phosphorus removal from the tributaries as the only possible treatment of “external” nutrient sources.

Pretreatment of tributary waters with aluminum sulfate or iron is not a well known lake restoration technique nor is it extensively documented. Cooke et al. (1986) reviewed the technique and found a number of cases where a significant portion (70-99%) of the incoming phosphorus was reduced.

This technique may provide enough phosphorus removal to meet the 7.0 kg/yr TMDL. Additional information is needed to determine if there is enough space to set up the chemical drip station(s), settling basins, etc. Effective dosages also need to be estimated from test titrations of the tributary water with the type of chemical used.

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 which makes it very useful for TMDL development. 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. Burke Lake's morphological characteristics are well within those Nurnberg used to develop regression models (Nurnberg ranges: $\bar{z}$ 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; Burke Lake values: $\bar{z}$ (m), 1.8; A_o (hectares), 10.9 and $\bar{z} / A_o^{0.5}$ (m/km^2), 0.55) which support SDDENR conclusions that nutrients affect dissolved oxygen concentrations and algal populations in Burke Lake. Thus reduction in nutrient (phosphorus) loads to the lake will improve dissolved oxygen concentrations and overall water quality in Burke 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 Burke Lake will be difficult and in-lake treatments, such as aeration, should 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 breakup stratification to improve water quality. 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 increasing fish habitat during the summer. Improved water quality especially dissolved oxygen concentrations has been observed in Stockade Lake in resent years and 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 1990's to breakup 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.

Phosphorus Inactivation and Bottom Sealing with Aluminum Sulfate

If external controls of phosphorus are not used then the algae in the lake might be controlled by reducing the amount of phosphorus available in the water. Phosphorus precipitation with aluminum sulfate has been shown to effectively remove phosphorus from the water column (Cooke et al., 1986). The resultant floc may also sink to the bottom of the lake and form a seal that effectively prevents or reduces phosphorus exchange between the lake bottom and the overlying water.

To reach the median growing-season Secchi-Chlorophyll *a* TSI target value of 63.4, the chlorophyll *a* concentration needs to be at least 25 mg/m^3. And according to the relationship between total phosphorus and chlorophyll *a* in Figure 10, a growing-season total phosphorus concentration of .087 mg/l results in a chlorophyll *a* concentration of 25 mg/m^3. This means that the average growing-season total phosphorus concentration of .218 mg/l must be reduced by 60 percent to reach 0.87 mg/l. This reduction appears to be within the range of phosphorus reductions found in previous lake restoration efforts using alum precipitation (Cooke et al., 1986).

Additional information is needed to determine proper dosage, application technique (application barge vs. land based sprayers), etc. The proper authorizations should be obtained before this technique is begun.

As stated in the previous strategy, controlling phosphorus may also help alleviate the low DO problems in the lake.

Aeration/Circulation

Aeration and circulation are well known techniques for preventing oxygen depletion in a lake. This study determined the hypolimnetic oxygen deficit to be approximately 510 mg/m^2-day and any aeration/circulation of the lake should compensate for this deficit.

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 occur 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.

Algaecides/Herbicides

Use of algaecides and herbicides has been shown to be an effective means to control nuisance algae and aquatic macrophytes. However, it is well known that these controls are short lived and there is often a need for repeated treatment.

The use of algaecides or herbicides in Burke Lake is recommended for consideration on an "as needed" basis only and not as a long-term solution. Applicators should consult SDDENR, the SD Department of Game, Fish & Parks, and the SD Department of Agriculture to obtain the proper authorizations. These products should only be applied according the manufacturer's specifications and recommendations. Typically, the product is applied and the results are usually evident within a few days.

To reach the median growing-season Secchi-Chlorophyll *a* TSI target of 63.4, the chlorophyll *a* concentration needs to be at least 25 mg/m³. This concentration relates to a Secchi transparency value of 1.14 meters according to the relationship given in Figure 15. The median Secchi-Chlorophyll *a* TSI based on 25 mg/m³ chlorophyll *a* and 1.136 meter Secchi transparency is 60.17, which provides a slight measure of safety from the target value of 63.4. This chlorophyll *a* concentration (25 mg/m³) is also more than adequate to help meet the pH standard criterion of 9.0. According to the regression equation in Figure 7, 70 mg/m³ chlorophyll *a* relates to a pH of 8.99. So getting the in-lake growing-season chlorophyll *a* concentration down to 25 mg/m³ should meet the TSI based target and meet the pH standard criterion.

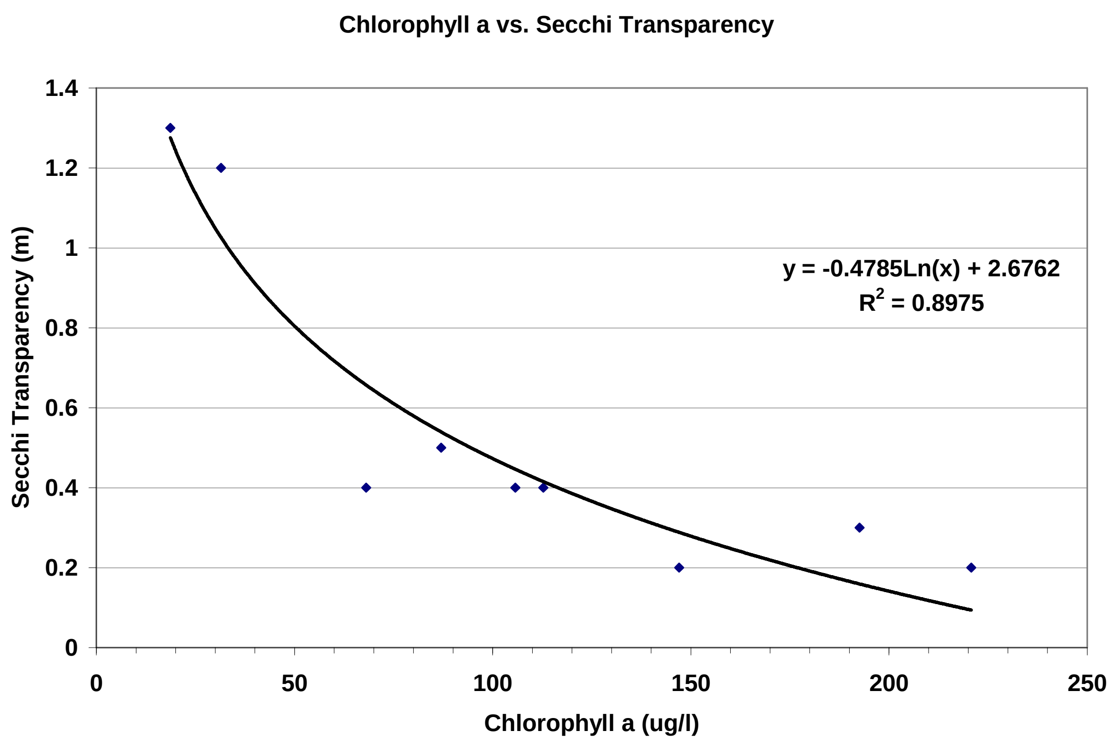

Figure 15. Regression between growing-season chlorophyll *a* concentration and Secchi transparency in Burke Lake, 2003.

It is recommended that Secchi transparency be monitored in the lake at least once a week during the summer. If the Secchi transparency is less than 1.14 meters, then application of the algaecide should be considered.

Sediment Removal for Lake Longevity

One process of lake aging is the gradual sedimentation and filling of a lake. This could eventually lead to shallower depths, increased fish kills due to oxygen depletion, and other negative impacts to the lakes beneficial uses. This study determined that nearly 40% of the lake depth is occupied by sediment. Although stopping or slowing sedimentation through the use of watershed BMPs is an obvious strategy, this study also concluded that there was little to be done in the watershed. Therefore, it is clear that removing sediment from a lake is an option to extend the life of the lake and maintain lake conditions related to lake depth and volume. Secondary benefits of sediment removal might be the removal of phosphorus rich sediment that may release nutrients to the lake and improved dissolved oxygen through the removal of organics that decompose and create oxygen deficits.

Table 26. Summary of recommended lake restoration techniques for Burke Lake.

Restoration Technique	Action	Targets	Comments
Phosphorus removal from tributaries by chemical precipitation.	Reduce incoming TP by 24.4 kg/yr. to reach acceptable loading rate of 7.0 kg/yr. Chemical amounts to be determined by titrations and existing water chemistry.	TP load of 7.0 kg/yr results in meeting Sec-Chl TSI target of 63.4. Also ensures pH of less than 9.0. May help alleviate low DO problems.	Based on BATHTUB modeling and chlorophyll *a* – pH relationship.
In-lake phosphorus precipitation and bottom sealing.	Decrease growing-season in-lake TP concentration by 0.131 mg/l Chemical amounts to be determined by titrations and existing water chemistry.	TP decrease to an in-lake TP concentration of .087 mg/l results in Sec-Chl TSI target of 63.4. Also ensures pH of less than 9.0	Based on TP – chlorophyll a relationship. Based on chlorophyll *a* – Secchi relationship. Based on chlorophyll *a* – pH relationship.
Aeration/circulation.	Aerate lake to compensate for hypolimnetic oxygen deficit rate of 510 mg/m^2-day.	Aerate until DO concentration is at least 5.0 mg/l.	Frequent monitoring of DO recommended for initiation and continuation of aeration.
Algaecides.	Decrease chlorophyll *a* to concentration of 25 mg/m^3.	Decreasing chlorophyll *a* to 25 mg/m^3 results in Secchi of 1.14 meters and Sec-Chl TSI target of 63.4. Also ensures pH of less than 9.0	Based on chlorophyll *a* – Secchi relationship. Monitor Secchi frequently. Use Secchi transparency target of 1.14 m to determine effectiveness or need for repeated treatment.
Sediment removal for lake longevity	Remove any amount of sediment to extend lake life.	Maintain minimal amount of sediment in the lake.	Success implied. Possible nutrient control.

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.

There was a problem collecting accurate water velocity/cross-sectional data at one site. This was due to the nature of the tributary. This tributary was spring fed, flowed through a cattle operation, and ended up in a wetland area before entering the lake. Unfortunately, this tributary had no reasonable alternative monitoring site location and one is forced to deal with whatever problems arise because of the location.

Another aspect that should be considered is the use of personnel who already have permanent full-time duties. As a cost saving measure and a means to accrue in-kind match, this project was supposed to use City employees for the water sampling. But during the project, sewer line failures within the City of Burke forced these employees to prioritize their time towards the City's needs instead of the project. The sampling effort then suffered until DENR personnel took over the sampling duties. It is recommended, if at all possible, that assessment projects use personnel hired specifically for the project instead of trying to cut corners and use personnel already having other duties.

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APPENDIX A

Water Quality Data for the Burke Lake Assessment Project

Table 27. Water quality data for Burke Lake, Gregory County, South Dakota.

BL05

DATE	DEPTH	WAT T°	AIR T°	CONDO umhoc/cm	Secchi m	DO mg/l	pH	ALKA mg/l	TS mg/l	TSS mg/l	VSS mg/l	NH3 mg/l	N03 mg/l	TKN mg/l	TP mg/l	TDP mg/l	FC #/100ml	E COLI #/100ml	CHL A ug/l	TN mg/l	TIN mg/l	TON mg/l	TPTSI	SDTSI	CHTSI
4/17/2003	S	12.14		298	1.6	8.9	8.26	190	284	6	<1	<0.02	<0.1	0.61	0.046	0.016	<10	<1	6.09	0.71	0.12	0.59	59.39	53.22	48.29
5/13/2003	S	20	15			7.2		188	267	4	2	<0.02	<0.1	0.7	0.044	0.026	<10	1	4.91	0.8	0.12	0.68	58.74		46.18
6/10/2003	S	20.50				9.25	8.77	177	262	5	4	<0.02	<0.1	1.08	0.106	0.051	<10	<1	25.63	1.18	0.12	1.06	71.43		62.39
6/24/2003	S	25.1	29.4		1.2	8.4	8.86	153	233	11	7	<0.02	<0.1	1.45	0.083	0.053	<10	<1	31.48	1.55	0.12	1.43	67.90	57.37	64.41
7/15/2003	S	29.40			0.5	8.5	9.39	132	236	23	22	<0.02	<0.1	2.47	0.168	0.031	<10	<1	86.99	2.57	0.12	2.45	78.07	70.00	74.38
8/12/2003	S	26.8	26.7		0.8	8.3	9.23	128	251	46	44	<0.02	<0.1	4.5	0.297	0.031	10	3.1	214.59	4.6	0.12	4.48	86.30	63.22	83.24
8/25/2003	S	25	25		0.3	6.2	9.1	133	258	36	35	<0.02	<0.1	3.6	0.342	0.027	<10	<1		3.7	0.12	3.58	88.33	77.37	
9/9/2003	S	22	23.9		0.2	2.4	8.9	140	263	36	35	<0.02	<0.1	3.88	0.28	0.04	<10	<1	220.76	3.98	0.12	3.86	85.44	83.22	83.52
11/17/2003	S	5	10		0.3	0.4	8.69	164	282	22	18	0.31	<0.1	3.63	0.244	0.063	<10	3	67.08	3.73	0.41	3.32	83.46	77.37	71.83
1/20/2004	S	4.9	4		0.6	12	9.33	187	300	18	12	<0.02	<0.1	2.02	0.192	0.031			143.18	2.12	0.12	2	80.00	67.37	79.27
3/23/2004	S	9	15.6		0.9	7.1	9.03	186	277	11	10	<0.02	<0.1	1.41	0.099	0.024	<10	<1	26.43	1.51	0.12	1.39	70.44	61.52	62.69
6/2/2004	S				1.4			163	244	8	7	<0.02	0.1	1.56	0.164	0.092	<10	1		1.66	0.12	1.54	77.73	55.15	
7/14/2004	S			266	0.4		9.15	126	214	27	20	<0.02	<0.1	2.35	0.14	0.033	10	1	112.78	2.45	0.12	2.33	75.44	73.22	76.93

BL06

DATE	DEPTH	WAT T°	AIR T°	CONDO umhoc/cm	Secchi m	DO mg/l	pH	ALKA mg/l	TS mg/l	TSS mg/l	VSS mg/l	NH3 mg/l	N03 mg/l	TKN mg/l	TP mg/l	TDP mg/l	FC #/100ml	E COLI #/100ml	CHL A ug/l	TN mg/l	TIN mg/l	TON mg/l	TPTSI	SDTSI	CHTSI
4/17/2003	S	12.41		294	1.6	9.61	8.17	191	282	6	1	<0.02	<0.1	0.53	0.043	0.014	<10	1	8.87	0.63	0.12	0.51	58.41	53.22	51.98
5/13/2003	S	17	15			7.2	8.33	187	273	7	3	<0.02	<0.1	0.65	0.052	0.028	<10	<1	14.22	0.75	0.12	0.63	61.15		56.61
6/10/2003	S	19				8.65	8.54	176	256	4	4	<0.02	<0.1	1.05	0.106	0.062	<10	<1	17.36	1.15	0.12	1.03	71.43		58.57
6/10/2003	B							193	287	9	7	0.18	<0.1	1.15	0.342	0.406	10	<1		1.25	0.28	0.97	88.33		
6/24/2003	S	25	29.4		1.3	7	8.86	153	226	9	5	<0.02	<0.1	1.41	0.122	0.053	<10	<1	18.67	1.51	0.12	1.39	73.46	56.21	59.28
6/24/2003	B	16				7	8.86	205	290	19	8	1.13	<0.1	2.63	0.827	0.783	30	14.3		2.73	1.23	1.5	101.07		
7/15/2003	S	29	26.7		0.4	9.2	9.43	129	239	24	23	<0.02	<0.1	2.34	0.174	0.041	<10	<1	68.09	2.44	0.12	2.32	78.58	73.22	71.98
7/15/2003	B	17				0.2		193	289	22	13	1.58	<0.1	2.91	0.916	0.707	10	4.1		3.01	1.68	1.33	102.55		
8/12/2003	S	26.9	26.7		0.3	12	9.41	127	258	42	40	<0.02	<0.1	4.77	0.317	0.044	<10	6.3	192.56	4.87	0.12	4.75	87.24	77.37	82.18
8/12/2003	B	21.3				2.06	7.11	199	292	26	16	4.41	<0.1	5.96	1.33	0.66				6.06	4.51	1.55	107.93		
8/25/2003	S	25	25		0.3	6.3	9.16	132	257	43	39	<0.02	<0.1	3.87	0.333	0.044	<10	3.1		3.97	0.12	3.85	87.95	77.37	
8/25/2003	B	25					7.13	188	274	28	22	7.27	<0.1	8.06	1.56	0.896				8.16	7.37	0.79	110.23		
9/9/2003	S	22	23.9		0.2	0.2	8.88	141	259	33	32	<0.02	<0.1	3.78	0.284	0.038	<10	<1	147.06	3.88	0.12	3.76	85.65	83.22	79.53
9/9/2003	B	22				2	8.84	139	266	33	32	<0.02	<0.1	3.39	0.288	0.045				3.49	0.12	3.37	85.85		
11/17/2003	S	5	10		0.3	1	8.6	166	287	21	20	0.31	<0.1	3.22	0.243	0.06	<10	1	70.69	3.32	0.41	2.91	83.40	77.37	72.35
11/17/2003	B	5				1	8.6	171	378	120	48	0.31	<0.1	3.52	0.352	0.056				3.62	0.41	3.21	88.75		
1/20/2004	S	5.2	4		0.91	0.2	8.8	190	298	18	11	<0.02	<0.1	1.86	0.174	0.043	<10	<1	121.35	1.96	0.12	1.84	78.58	61.36	77.65
1/20/2004	B	5				0.2	7.16	217	326	4	1	0.96	<0.1	2.15	0.412	0.337				2.25	1.06	1.19	91.02		
3/23/2004	S	9.1	15.6		0.91		8.98	187	278	11	9	<0.02	<0.1	1.38	0.091	0.022	<10	<1	13.72	1.48	0.12	1.36	69.23	61.36	56.26
3/23/2004	B	7					8.1	183	282	14	13	<0.02	<0.1	0.74	0.124	0.024				0.84	0.12	0.72	73.69		
6/2/2004	S				1.4			164	241	12	7	<0.02	0.1	1.73	0.178	0.098	<10	<1		1.83	0.12	1.71	78.91	55.15	
6/2/2004	B							164	248	9	6	<0.02	0.1	1.6	0.187	0.095				1.7	0.12	1.58	79.62		
7/14/2004	S			261	0.4		9.13	125	217	30	20	<0.02	<0.1	2.26	0.142	0.033	<10	<1	105.73	2.36	0.12	2.24	75.65	73.22	76.29

Table 28. Water quality data for Burke Lake's tributaries, Gregory County, South Dakota.

BL02

DATE	WAT T°	AIR T°	CONDO umho/cm	DO mg/l	pH	ALKA mg/l	TS mg/l	TSS mg/l	VSS mg/l	NH3 mg/l	NO3 mg/l	FC #/100ml	E COLI #/100ml	TP mg/l	TDP mg/l	TN mg/l	TIN mg/l	TON mg/l	TN:TP
3/12/2003	4	-6.1				187	307	4	3	<0.02	0.3	170	248	0.32	0.27	1.35	0.32	1.03	4.2587
3/20/2003	1.56		274	9.62	7.69	238	363	5	1	0.03	0.2	4	6.2	0.20	0.17	1.01	0.23	0.78	5.101
3/27/2003	3.96		290	10.62	8.32	233	336	5	4	<0.02	0.1	2	6.3	0.19	0.17	0.69	0.12	0.57	3.7297
4/3/2003						224	315	3	<1	<0.02	0.1	2	3.1	0.19	0.17	0.67	0.12	0.55	3.4896
4/9/2003	3.16		269	12.5	7.79	227	332	<1	<1	<0.02	0.1	26	47.1	0.17	0.17	0.8	0.12	0.68	4.7059
4/17/2003	5.66		299	8.74	8.3	239	354	27	7	<0.02	<0.1	48.8	30	0.33	0.32	0.38	0.12	0.26	1.1411
4/23/2003	9.73		311	8.34	8.28	237	331	14	6	<0.02	<0.1	20	8.4	0.32	0.30	0.45	0.12	0.33	1.3932
5/1/2003	9	17		7.4	7.94	253	342	5	4	<0.02	<0.1	140	201	0.20	0.17	1.13	0.12	1.01	5.7071
5/13/2003	12.5	15		7	7.73	241	338	9	5	<0.02	0.2	80	65	0.39	0.31	0.83	0.22	0.61	2.112
6/10/2003	15	19		5.8	7.72	248	342	1	<1	<0.02	<0.1	220	125	0.29	0.25	0.92	0.12	0.8	3.1293
7/15/2003	20	27.2		1.5	7.24	250	386	22	10	0.05	<0.1	180	921	0.50	0.40	0.77	0.15	0.62	1.5431
8/12/2003	19.4	26.7		7	7.47	264	433	39	13	0.03	<0.1	1800	1410	0.67	0.53	1.27	0.13	1.14	1.8955
3/23/2004	7.7	15.6		8.1	8.05	210	319	<1	<1	<0.02	0.3	<10	2	0.25	0.22	0.88	0.32	0.56	3.4783
3/30/2004	7.4				8.11	233	353	<1	<1	<0.02	<0.1	<10	1	0.16	0.15	1.08	0.12	0.96	6.9677
4/13/2004						218	320	5	<1	<0.02	0.2	<10	4.1	0.24	0.23	0.56	0.22	0.34	2.314
5/3/2004						233	330	4	3	<0.02	<0.1	10	17.3	0.29	0.26	0.39	0.12	0.27	1.3356
5/17/2004						234	356	7	3	<0.02	<0.1	870	980	0.36	0.13	1.24	0.12	1.12	3.4831
6/2/2004						247	337	4	4	<0.02	0.1	120	51.2	0.31	0.27	1.08	0.12	0.96	3.4951
6/14/2004		21.1				247	364	6	5	0.03	0.1	410	326	0.58	0.52	0.97	0.13	0.84	1.6811
7/14/2004		27.2	487		7.33	259	404	72	32	<0.02	<0.1	400	285	0.85	0.53	2.33	0.12	2.21	2.738

BL03

DATE	WAT T°	AIR T°	CONDO umho/cm	DO mg/l	pH	ALKA mg/l	TS mg/l	TSS mg/l	VSS mg/l	NH3 mg/l	NO3 mg/l	FC #/100ml	E COLI #/100ml	TP mg/l	TDP mg/l	TN mg/l	TIN mg/l	TON mg/l	TN:TP
3/12/2003	4	-6.1				186	269	3	2	<0.02	<0.1	6	9.8	0.12	0.08	0.77	0.12	0.65	6.5812
3/20/2003	3.54		215	12.49	7.95	190	263	6	2	<0.02	<0.1	<10	1	0.09	0.08	0.6	0.12	0.48	6.5217
3/27/2003	4.73		226	10.92	8.12	201	260	<1	<1	<0.02	<0.1	2	1	0.09	0.08	0.31	0.12	0.19	3.4831
4/3/2003						200	259	5	4	<0.02	<0.1	4	7.4	0.10	0.09	0.47	0.12	0.35	4.7959
4/9/2003	5		188	13.35	8.21	173	232	<1	<1	<0.02	<0.1	<2	1	0.08	0.08	0.27	0.12	0.15	3.2927
4/17/2003	6.15		258	10.85	8.3	226	295	7	1	<0.02	<0.1	<10	1	0.12	0.11	0.21	0.12	0.09	1.8103
4/23/2003	9.29		274	9.08	8.24	223	294	6	5	<0.02	<0.1	<10	71.2	0.12	0.11	0.44	0.12	0.32	3.6975
5/1/2003	9.7	17		8.8	8.02	202	262	5	4	<0.02	<0.1	20	16	0.11	0.11	0.69	0.12	0.57	6.4486
5/13/2003	15.1	15		6.2	7.68	223	285	4	3	<0.02	<0.1	<10	2	0.13	0.11	0.36	0.12	0.24	2.8125
6/10/2003	21.2	16.2		8	7.69	250	335	<1	<1	<0.02	<0.1	480	548	0.12	0.12	0.84	0.12	0.72	6.8293
3/23/2004	12.3	15.6		6.1	8.68	187	256	1	<1	<0.02	<0.1	10	1	0.09	0.09	0.52	0.12	0.4	5.5914
3/30/2004	5.5				8.02	200	279	1	<1	<0.02	<0.1	<10	1	0.10	0.10	0.75	0.12	0.63	7.4257
4/13/2004						210	275	5	1	<0.02	<0.1	10	3.1	0.10	0.10	0.38	0.12	0.26	3.8
5/3/2004						241	312	5	2	<0.02	<0.1	<10	2	0.12	0.11	0.35	0.12	0.23	2.8689
5/17/2004						220	304	4	3	<0.02	<0.1	680	649	0.12	0.12	0.85	0.12	0.73	6.8548
6/2/2004						275	365	11	7	<0.02	<0.1	20	43.2	0.16	0.12	1.23	0.12	1.11	7.6398

Table 28. Continued.

BL04

DATE	WAT T°	AIR T°	CONDO umho/cm	DO mg/l	pH	ALKA mg/l	TS mg/l	TSS mg/l	VSS mg/l	NH3 mg/l	NO3 mg/l	FC #/100ml	E COLI #/100ml	TP mg/l	TDP mg/l	TN mg/l	TIN mg/l	TON mg/l	TN:TP
3/12/2003	4	-6.1				193	295	7	6	<0.02	0.1	6	7.4	0.08	0.06	1.36	0.12	1.24	16.19
3/20/2003						194	285	7	4	<0.02	<0.1	<2	1	0.08	0.02	1.15	0.12	1.03	13.69
3/27/2003	6.95		257	10.39	8.21	197	288	8	5	<0.02	0.1	<2	2	0.11	0.06	1.23	0.12	1.11	11.284
4/3/2003						233	316	6	2	0.05	0.1	24	22.6	0.16	0.10	0.99	0.15	0.84	6.1111
4/9/2003	8.04		272	11.97	8.71	201	285	3	2	<0.02	<0.1	<2	2	0.05	0.03	1.02	0.12	0.9	19.615
4/17/2003	10.98		289	11.49	8.21	197	289	11	3	<0.02	<0.1	<10	1	0.08	0.04	0.89	0.12	0.77	11.266
4/23/2003	10.2		298	9.16	8.16	217	304	7	5	0.08	<0.1	<10	2	0.13	0.09	0.88	0.18	0.7	6.875
5/1/2003	12.9	17		8.65	8.09	197	284	10	4	<0.02	<0.1	<10	4.1	0.08	0.05	1.02	0.12	0.9	12.593
5/13/2003	13.8	15		8.2	7.98	197	283	5	3	<0.02	<0.1	20	19.7	0.08	0.06	0.83	0.12	0.71	10
6/10/2003	16.9	19		6.8	7.66	213	314	16	7	0.23	<0.1	630	613	0.24	0.16	1.32	0.33	0.99	5.5696
7/15/2003	19.3	16.2		6	8.12	238	427	98	27	0.26	0.4	2100	2420	0.35	0.22	1.27	0.66	0.61	3.6494
3/23/2004	12.1	15.6		6.3	8.7	194	286	8	7	<0.02	<0.1	<10	1	0.11	0.04	1.23	0.12	1.11	11.081
3/30/2004	9.9				8.25	189	284	8	6	<0.02	<0.1	20	1	0.11	0.05	1.54	0.12	1.42	14.528
4/13/2004						212	293	7	<1	<0.02	<0.1	<10	16	0.14	0.10	0.99	0.12	0.87	7.2794
5/3/2004						214	294	7	4	<0.02	<0.1	<10	9.7	0.16	0.12	0.86	0.12	0.74	5.3416
5/17/2004						179	261	11	7	<0.02	<0.1	<10	20.1	0.12	0.07	1.37	0.12	1.25	11.322
6/2/2004						185	258	6	2	0.07	0.1	220	153	0.17	0.14	1.46	0.17	1.29	8.6391
6/14/2004		21.1				167	248	11	3	<0.02	<0.1	80	67.7	0.18	0.14	1.33	0.12	1.21	7.2283
7/14/2004			518		7.75	267	389	56	19	0.27	0.4	2700	2420	0.30	0.19	1.65	0.67	0.98	5.4276

APPENDIX B

TEMPERATURE AND DISSOLVED OXYGEN PROFILES FOR BURKE LAKE

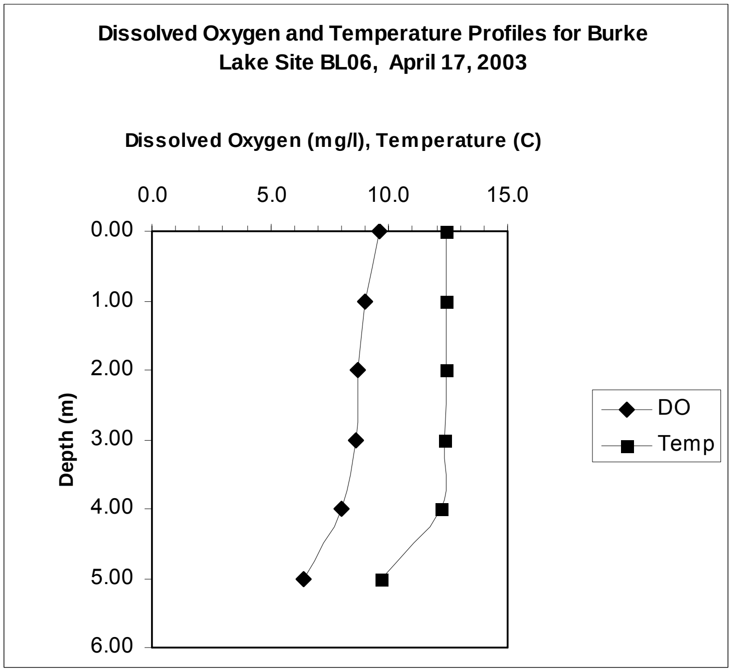

Figure 16. Dissolved oxygen and temperature profiles for Burke Lake Site BL06, April 17, 2003.

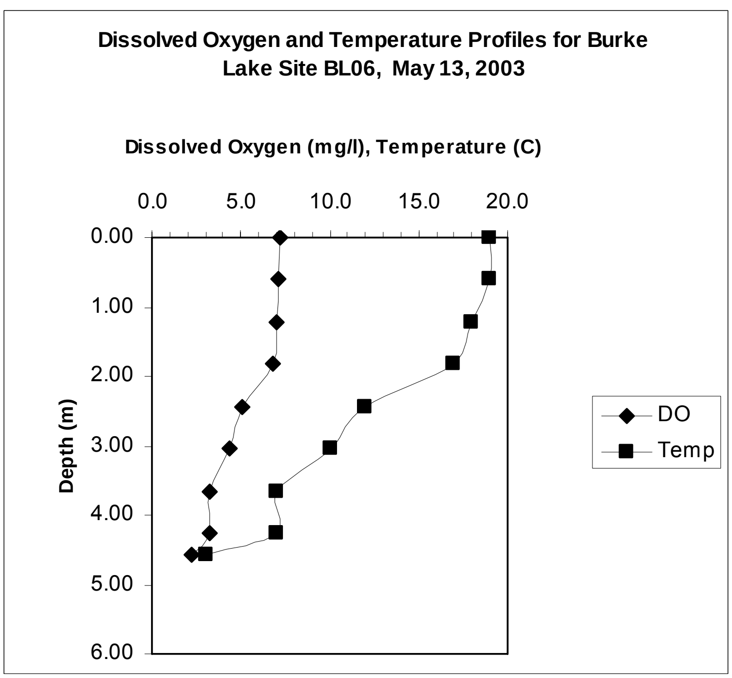

Figure 17. Dissolved oxygen and temperature profiles for Burke Lake Site BL06, May, 13, 2003.

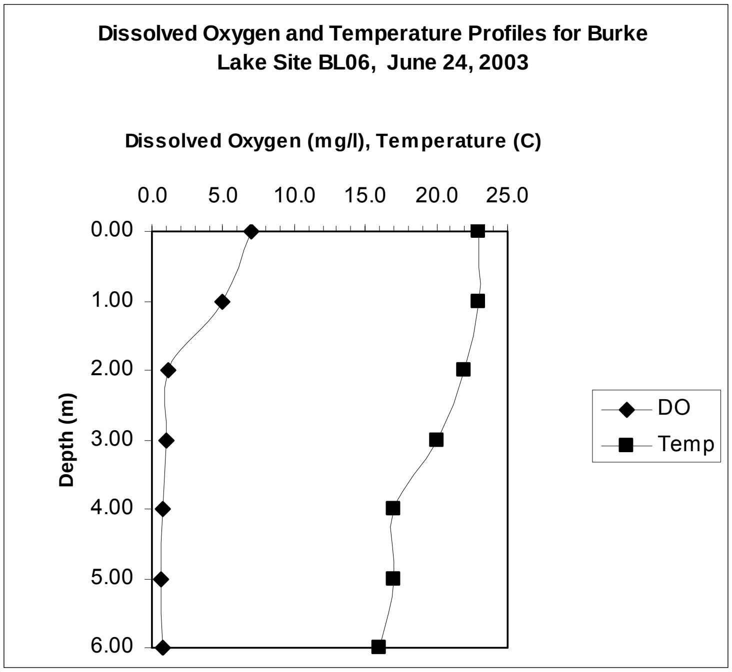

Figure 18. Dissolved oxygen and temperature profiles for Burke Lake Site BL06, June 24, 2003.

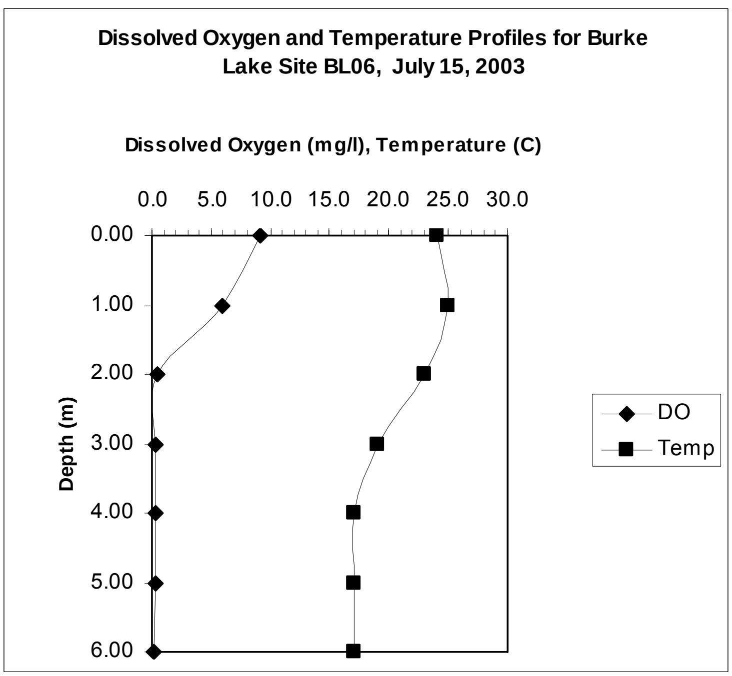

Figure 19. Dissolved oxygen and temperature profiles for Burke Lake Site BL06, July 15, 2003.

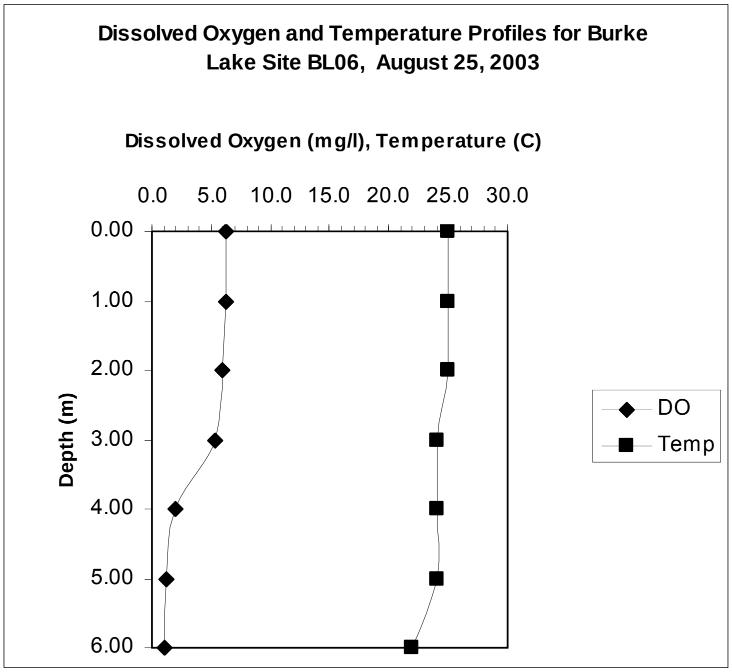

Figure 20. Dissolved oxygen and temperature profiles for Burke Lake Site BL06, August 25, 2003.

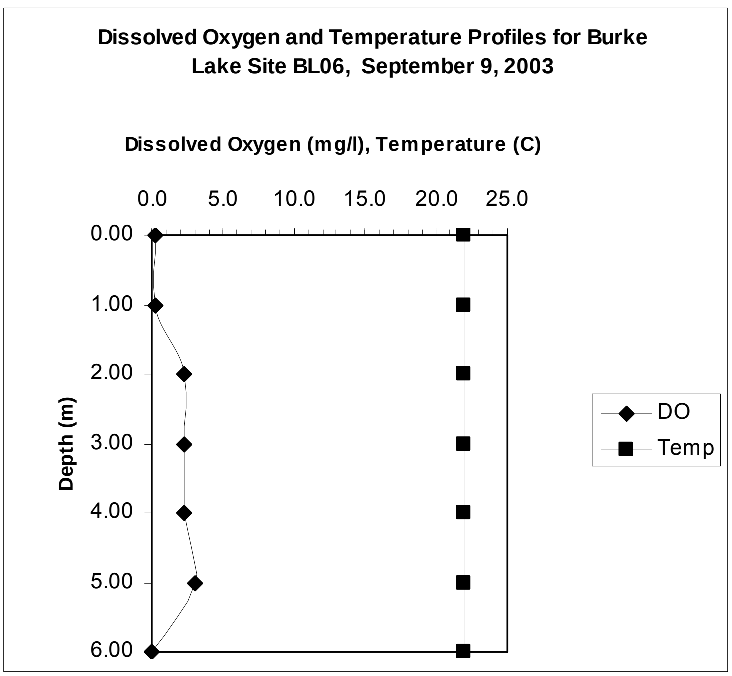

Figure 21. Dissolved oxygen and temperature profiles for Burke Lake Site BL06, September 9, 2003.

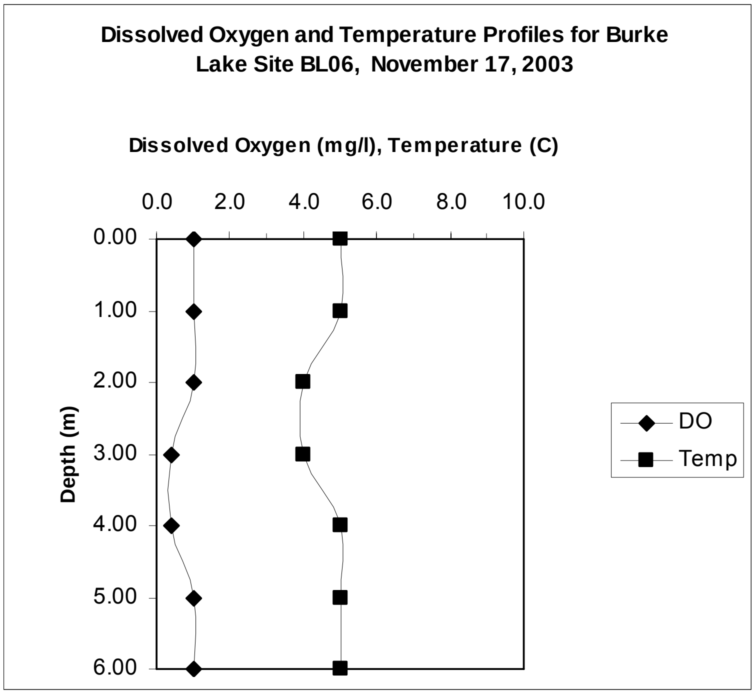

Figure 22. Dissolved oxygen and temperature profiles for Burke Lake Site BL06, November 17, 2003.

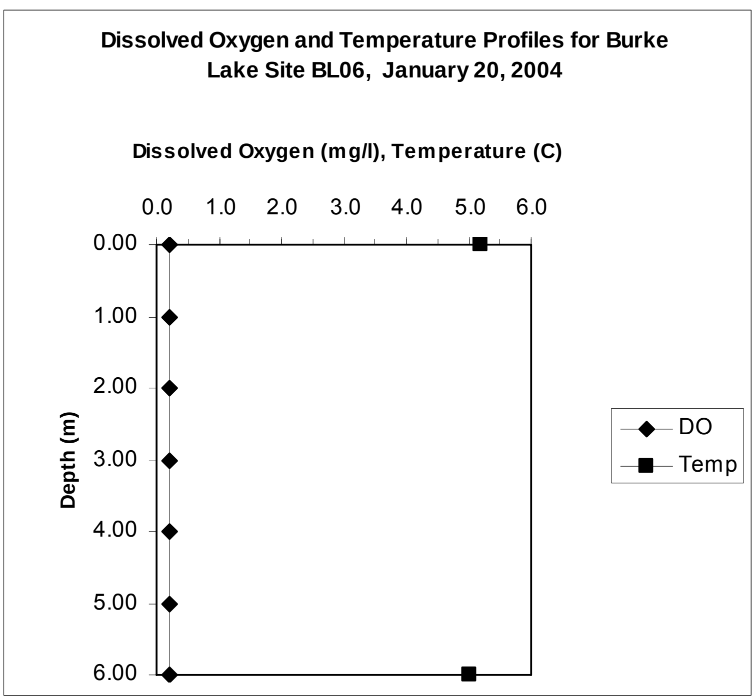

Figure 23. Dissolved oxygen and temperature profiles for Burke Lake Site BL06, January 20, 2004.

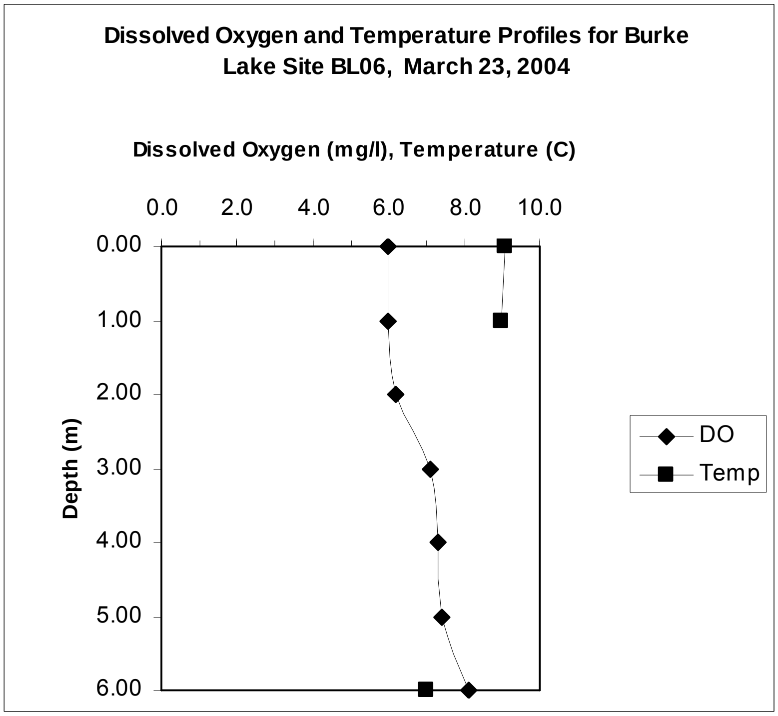

Figure 24. Dissolved oxygen and temperature profiles for Burke Lake Site BL06, March 23, 2004.

APPENDIX C

TMDL Summary for Burke Lake, Gregory County, South Dakota

Plus

USEPA comments on the Final Report and TMDL Summary, and DENR's Responses

(HUC 10140101)

GREGORY COUNTY, SOUTH DAKOTA

SOUTH DAKOTA DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES

APRIL, 2006

Burke Lake Total Maximum Daily Load

Waterbody Type:	**Lake (impounded)**
303(d) Listing Parameter:	**Dissolved oxygen, pH, and Trophic State Index (TSI)**
Designated Uses:	**Warm water semi-permanent fish life propagation, Immersion recreation, Limited contact recreation, and Fish and Wildlife propagation, recreation and stock watering**
Size of Waterbody:	**27 acres**
Size of Watershed :	**1,568 acres**
Water Quality Standards:	**Narrative and numeric**
Indicators:	**Median growing-season Secchi-chlorophyll *a* TSI, dissolved oxygen, pH**
Analytical Approach:	**ANNAGNPS, BATHTUB, FLUX**
Location:	**HUC Code: 10140101**
Action:	***88* % reduction in external phosphorus load, increase dissolved oxygen to 5.0 mg/l, decrease in-lake chlorophyll *a* concentration to 25 mg/m³, decrease in-lake total phosphorus concentration to .087 mg/l.**
Target:	**Median growing-season Secchi-chlorophyll *a* TSI $\leq$ 63.4 average during the growing season, pH of 9.0, dissolved oxygen of 5.0 mg/l, 7.0 kg/yr external TP load.**

Objective:

The purpose of this TMDL summary is to clearly document and quantify the causes of beneficial use non-support with Burke Lake. In addition, it documents the concern and support by the public for studying and restoring Burke Lake to full beneficial use status. The TMDL was developed in accordance with Section 303(d) of the federal Clean Water Act and guidance developed by EPA.

Introduction

Burke Lake is a 27-acre man-made impoundment located in Gregory County, South Dakota (Figure 1). The 1998 South Dakota 303(d) Waterbody List identified Burke Lake for TMDL development because of an unsatisfactory trophic state index (TSI), increasing eutrophication trend, nutrient and sediment loading, and accumulated sediment. The 303(d) listing has continued on through to the most recent 2006 Integrated Report.

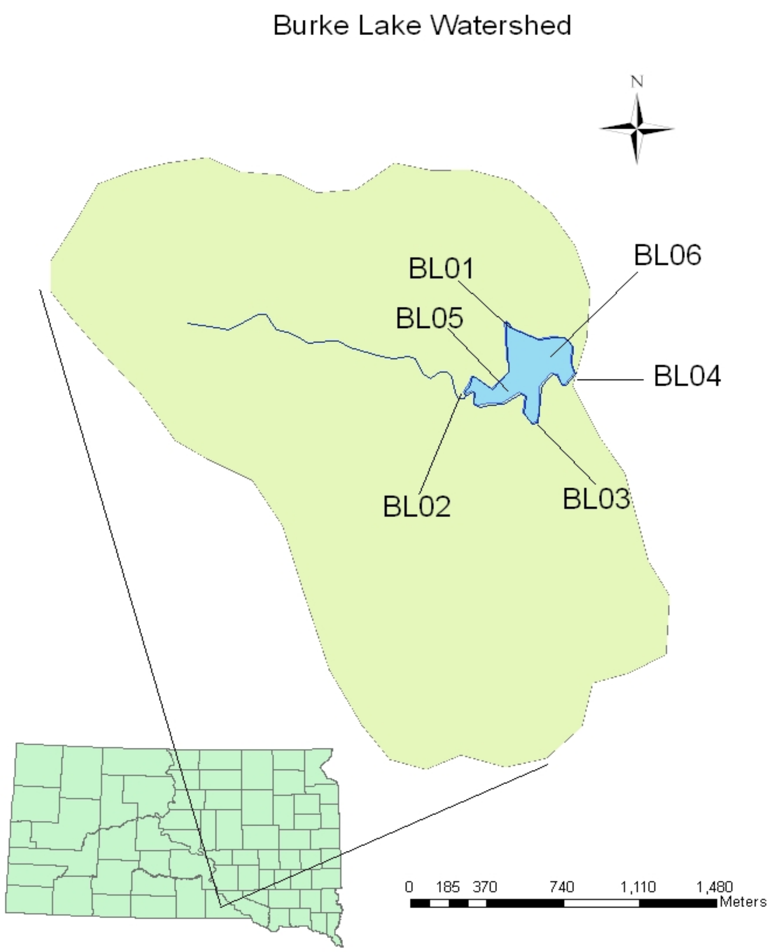

Figure 1. Burke Lake Dam watershed.

The lake has an average depth of 5.8 feet (1.8 meters), a maximum depth of 20 feet (6 meters). The lake outlet drains into Coon Creek, which eventually reaches the Missouri River.

Problem Identification

Three tributaries flow into the lake and these drain predominantly grazing lands with some cropland acres. A feeder cattle operation is located adjacent to the lake. The stream carries nutrient loads, which degrade water quality in the lake and cause increased eutrophication. The algae appear to be related to pH and occasionally cause pH to exceed the standard criterion of 9.0. Bacteria decomposing organic matter on the bottom of the lake is causing oxygen depletion, which may ultimately contribute to fish kills. The assessment study did not find impairment to Burke Lake from macrophytes.

Description of Applicable Water Quality Standards & Numeric Water Quality Targets

Burke Lake has been assigned the following beneficial uses by the state of South Dakota Surface Water Quality Standards regulations: warmwater semi-permanent fish life propagation; immersion recreation; limited contact recreation; and fish and wildlife propagation, recreation and stock watering. Along with these assigned uses are narrative and numeric criteria that define the desired water quality of the lake. These criteria must be maintained for the lake to satisfy its assigned beneficial uses.

Individual parameters, including the lake's Trophic State Index (TSI) (Carlson, 1977) value, determine the support of beneficial uses and compliance with standards. A gradual increase in fertility of the water due to nutrients entering the lake from external sources is a sign of eutrophication. Burke Lake was identified as not supporting its beneficial uses in the 1998 South Dakota 305(b) Water Quality Assessment, the 2004 South Dakota Integrated Report, and in "Targeting Impaired Lakes in South Dakota" (Lorenzen, 2005).

South Dakota has several applicable narrative standards that may be applied to the undesired eutrophication of lakes and streams. Administrative Rules of South Dakota Article 74:51 contains language that prohibits the existence of materials causing pollutants to form, visible pollutants, taste and odor producing materials, and nuisance aquatic life.

The South Dakota Department of Environment and Natural Resources (SD DENR) also uses surrogate measures. SD DENR developed a protocol that established desired TSI levels for lakes based on a fish classification approach. To assess the trophic status of a lake, Lorenzen (2005) used the median growing season Secchi-Chlorophyll *a* TSI. This protocol was used to assess impairment and determine a numeric target for Burke Lake. For Burke Lake the surrogate standards are mean growing season Sec-Chl TSI values of $\leq$ 63.4 for full support and $\geq$ 63.5 for non-support.

During the assessment Burke Lake had a mean growing season (May 15 – September 15) Sec-Chl TSI of 75.88, which is indicated of hyper-eutrophy and non-support of beneficial uses. Monitoring indicated the primary cause of the high productivity is high phosphorus loads from the watershed.

To reach the TSI target level of 63.4, an 88% reduction in total phosphorus loading is needed which translates to an annual total phosphorus load (TMDL) of 7 kg/yr.

Pollutant Assessment

Point Sources
There are no point sources of pollutants of concern in this watershed.

Nonpoint Sources/ Background Sources
The BATHTUB model predicted a total phosphorus loading rate of 34.7 kg/yr. This load is deemed to come from either non-point or natural sources. The sediment survey of the lake did not reveal any unusual or extreme sediment accumulation in the lake, although deepening the reservoir will extend the life of the lake and remove legacy phosphorus.

Linkage Analysis
Water quality data were collected from two in-lake sites two tributary sites and the outlet within the Burke Lake watershed. Samples collected at each site were taken according to South Dakota's EPA approved Standard Operating Procedures for Field Samplers. Water samples were sent to the State Health Laboratory in Pierre for analysis. Quality Assurance/Quality Control samples were collected on at least 10% of the samples according to South Dakota's EPA approved Clean Lakes Quality Assurance/Quality Control Plan. Details concerning water sampling techniques, analysis, and quality control are addressed in the final report.

The impacts of phosphorus reductions on the condition of Burke Lake were calculated using BATHTUB, an Army Corps of Engineers model. The model predicted that an 88% reduction of phosphorus from the incoming tributaries is necessary to get the lake to a TSI of 63.4. However, precipitation data indicated that 2003 was about 10% less than the long-term average precipitation and so the "measured" phosphorus loads may not represent an actual long-term average and may slightly underestimate a long-term average total phosphorus load.

The Annualized Agriculture Nonpoint Pollution Source (ANNAGNPS) model was used to assess various land use scenarios and their effect of nutrient and sediment loading. The ANNAGNPS feeding area subroutine was used to provide comparative values for each of the animal feeding operations located in the watershed. Results from the ANNAGNPS modeling indicated only a 5% or so reduction in phosphorus loading was likely from BMP implementation and the animal operation adjacent to the lake was not a significant problem. Consequently it was felt that phosphorus removal from the tributaries by chemical precipitation was the only possibility as an external lake restoration strategy.

Relationships between chlorophyll *a* and total phosphorus, and chlorophyll *a* and pH were established and used in formulating in-lake restoration strategies and targets.

TMDL and Allocations

0 kg/yr.	(WLA) point sources
7 kg/yr.	(LA) nonpoint sources + natural
Implicit	(MOS)
7 kg/yr.	(TMDL) target load

Wasteload Allocations (WLAs)
There are no point sources of pollutants of concern in this watershed. Therefore, the "wasteload allocation" component of these TMDLs is considered a zero value.

Load Allocations (LAs)

A total maximum annual phosphorus loading rate of 7.0 kg/yr is needed to meet the target TSI goal to maintain the lakes beneficial uses. This is attained by an 88% reduction in phosphorus loading from the tributaries. Total phosphorus loading must be reduced by 24.4 kg/yr to result in a TMDL load of 7 kg/yr.

In-lake Targets

In-lake targets were established based on state water quality standards and relationships between chlorophyll *a* and pH, total phosphorus and chlorophyll *a*, and chlorophyll *a* and Secchi transparency.

Parameter	Target
Dissolved oxygen	5.0 mg/l
pH	9.0
Secchi transparency	1.14 meters
Total phosphorus	0.87 mg/m^3
Chlorophyll *a*	25.0 mg/m^3
Median growing-season	
Secchi-chlorophyll a TSI	63.4

Seasonal Variation

Different seasons of the year can yield differences in water quality due to changes in precipitation and agricultural practices. Seasonality was determined for the tributaries with most the nutrient and sediment loading occurring during the spring run-off period. Seasonality in the lake was typical for a lake in south central South Dakota with summer peaks in algae. Thermal stratification and oxygen depletion at the bottom of the lake occurred during the summer.

Margin of Safety

The margin of safety was implicit as conservative estimations were used in the development of the lake restoration strategies. It was recommended that additional restoration activities such as external pretreatment of the tributaries with chemical precipitation, in-lake phosphorus precipitation, lake aeration, algicides, and sediment removal were also recommended as lake restoration strategies.

Critical Conditions

The impairments to Burke Lake are most severe during the late summer. This is the result of warm water temperatures and peak algal growth, and resultant decomposition of organic matter on the bottom of the lake.

Follow-Up Monitoring

As part of the implementation effort, in-lake monitoring should be used to measure Secchi transparency, chlorophyll a levels (algae), pH, and dissolved oxygen and total phosphorus concentrations. If pretreatment of the tributaries is implemented, tributary flows should be monitored and water samples taken and analyzed for total phosphorus. Total phosphorus loads should be determined. Once the implementation project is completed, the lake will be monitored as part of South Dakota's Statewide Lakes Assessment Project to see if the TMDL and full support of the beneficial uses was achieved.

Public Participation

Efforts taken to gain public education, review, and comment during development of the TMDL involved:

1. Monthly meetings of the City of Burke.
2. Individual contact with landowners in the watershed.

The findings from these public meetings and comments have been taken into consideration in development of the Burke Lake TMDL.

Implementation Plan

The South Dakota DENR is working with the Gregory County Conservation District and the South Dakota Department of Game, Fish & Parks to develop and initiate an implementation project. It is expected that USEPA Section 319 funds will be used to assistance with the lake restoration efforts.

Lake restoration strategies recommended for consideration include:

Phosphorus removal from the tributaries by chemical precipitation,
In-lake phosphorus removal and bottom sealing with aluminum sulfate,
Aeration/circulation,
Algicides, and
Sediment removal for lake longevity.

Enclosure 3

EPA REGION VIII TMDL REVIEW FORM

Document Name:	**Burke Lake**
Submitted by:	**Gene Stueven, SD DENR**
Date Received:	**November 27, 2006**
Review Date:	**June 25, 2007**
Reviewer:	**Vern Berry, EPA**
Formal or Informal Review?	**Formal – Final Approval**

This document provides a standard format for EPA Region 8 to provide comments to the South Dakota Department of Environment and Natural Resources on TMDL documents provided to the EPA for either official formal or informal review. All TMDL documents are measured against the following 12 review criteria:

1. Water Quality Impairment Status
2. Water Quality Standards
3. Water Quality Targets
4. Significant Sources
5. Technical Analysis
6. Margin of Safety and Seasonality
7. Total Maximum Daily Load
8. Allocation
9. Public Participation
10. Monitoring Strategy
11. Restoration Strategy
12. Endangered Species Act Compliance

Each of the 12 review criteria are described below to provide the rational for the review, followed by EPA's comments. This review is intended to ensure compliance with the Clean Water Act and also to ensure that the reviewed documents are technically sound and the conclusions are technically defensible.

1. Water Quality Impairment Status

Criterion Description – Water Quality Impairment Status

TMDL documents must include a description of the listed water quality impairments. ***While the 303(d) list identifies probable causes and sources of water quality impairments, the information contained in the 303(d) list is generally not sufficiently detailed to provide the reader with an adequate understanding of the impairments. TMDL documents should include a thorough description/summary of all available water quality data such that the water quality impairments are clearly defined and linked to the impaired beneficial uses and/or appropriate water quality standards.***

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☐ Partially satisfies criterion. Questions or comments provided below need to be addressed.
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SUMMARY – Burke Lake is a 27 acre man-made impoundment located in the Fort Randall Reservoir watershed of the Missouri River Basin, Gregory County, South Dakota. It is listed on SD's 2006 303(d) list as impaired (SD-MI-L-BURKE_01) for trophic state index (TSI), dissolved oxygen and pH due to nonpoint sources and is ranked as priority 1 (i.e., high priority) for TMDL development. The watershed drains predominantly agricultural land. Approximately 4% of the landuse is cropland/hayland, 79% is rangeland and pasture, and 17% is roads, residences, trees and water in the watershed. The mean growing season Secchi-Chl-a TSI during the period of the project assessment was 75.88. Also, the pH and the dissolved oxygen water quality standards were not met. Based on this data Burke Lake is not currently meeting its designated beneficial use for warmwater semi-permanent fish life propagation.

2. Water Quality Standards

Criterion Description – Water Quality Standards

The TMDL document must include a description of all applicable water quality standards for all affected jurisdictions. TMDLs result in maintaining and attaining water quality standards. Water quality standards are the basis from which TMDLs are established and the TMDL targets are derived, including the numeric, narrative, use classification, and antidegradation components of the standards.

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SUMMARY – Burke Lake is impaired for dissolved oxygen, pH and TSI. TSI is a surrogate measure used to determine whether the narrative standards are being met. South Dakota has applicable narrative standards that may be applied to the undesirable eutrophication of lakes. Data from Burke Lake indicates problems with nutrient enrichment and nuisance algal blooms, which are typical signs of the eutrophication process. The narrative standards being implemented in this TMDL are:

> "*Materials which produce nuisance aquatic life may not be discharged or caused to be discharged into surface waters of the state in concentrations that impair a beneficial use or create a human health problem.*" (See ARSD §74:51:01:09)

"*All waters of the state must be free from substances, whether attributable to human-induced point source discharges or nonpoint source activities, in concentration or combinations which will adversely impact the structure and function of indigenous or intentionally introduced aquatic communities.*" (See ARSD §74:51:01:12)

The numeric standard for dissolved oxygen is $\geq$ 5.0 mg/L (single sample minimum).

The numeric standard for pH is $\geq$ 6.5 - $\leq$ 9.0 standard units.

Other applicable water quality standards are included on pages 3 and 4 of the assessment report.

3. Water Quality Targets

Criterion Description – Water Quality Targets

Quantified targets or endpoints must be provided to address each listed pollutant/water body combination. Target values must represent achievement of applicable water quality standards and support of associated beneficial uses. For pollutants with numeric water quality standards, the numeric criteria are generally used as the TMDL target. For pollutants with narrative standards, the narrative standard must be translated into a measurable value. At a minimum, one target is required for each pollutant/water body combination. It is generally desirable, however, to include several targets that represent achievement of the standard and support of beneficial uses (e.g., for a sediment impairment issue it may be appropriate to include targets representing water column sediment such as TSS, embeddeness, stream morphology, up-slope conditions and a measure of

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SUMMARY – Water quality targets for this TMDL are based on interpretation of narrative provisions found in State water quality standards. In June 2005, SD DENR published *Targeting Impaired Lakes in South Dakota*. This document proposed targeted median growing season Secchi disk/chlorophyll *a* Trophic State Index (TSI) values for each beneficial use designation category. In South Dakota algal blooms can limit contact and immersion recreation beneficial uses. Also algal blooms can deplete oxygen levels which can affect aquatic life uses. SD DENR considers several algal species to be nuisance aquatic species. TSI measurements can be used to estimate how much algal production may occur in lakes. Therefore, TSI is used as a measure of the narrative standard in order to determine whether beneficial uses are being met.

Burke Lake currently has a mean Secchi-Chl-a TSI of 75.88. Nutrient reduction response modeling was conducted with BATHTUB, an Army Corps of Engineers eutrophication response model. The results of the modeling show that an 88% reduction in the total phosphorus loading from the watershed would be necessary to meet the beneficial use based Secchi-Chl-a TSI target of less than $\leq$ 63.4. This target will fully support its beneficial uses.

The water quality targets used in this TMDL are: **maintain a mean annual growing season Secchi-Chl-a TSI $\leq$ 63.4; dissolved oxygen $\geq$ 5.0 mg/L; and pH $\geq$ 6.5 - $\leq$ 9.0 standard units.**

4. Significant Sources

Criterion Description – Significant Sources

TMDLs must consider all significant sources of the stressor of concern. All sources or causes of the stressor must be identified or accounted for in some manner. The detail provided in the source assessment step drives the rigor of the allocation step. In other words, it is only possible to specifically allocate quantifiable loads or load reductions to each significant source when the relative load contribution from each source has been estimated. Ideally, therefore, the pollutant load from each significant source should be quantified. This can be accomplished using site-specific monitoring data, modeling, or application of other assessment techniques. If insufficient time or resources are available to accomplish this step, a phased/adaptive management approach can be employed so long as the approach is clearly defined in the document.

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SUMMARY – The TMDL identifies the major sources of phosphorus as coming from nonpoint source agricultural landuses within the watershed. In particular, a loading analysis was done for nutrients and sediment considering various agricultural land use and land management factors. Cropland and pastureland are the primary sources identified. Approximately 4% of the landuse is cropland and 79% is rangeland and pasture in the watershed.

5. Technical Analysis

Criterion Description – Technical Analysis

*TMDLs must be supported by an appropriate level of technical analysis. It applies to **all** of the components of a TMDL document. It is vitally important that the technical basis for **all** conclusions be articulated in a manner that is easily understandable and readily apparent to the reader. Of particular importance, the cause and effect relationship between the pollutant and impairment and between the selected targets, sources, TMDLs, and allocations needs to be supported by an appropriate level of technical analysis.*

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SUMMARY – The technical analysis addresses the needed phosphorus reduction to achieve the desired water quality. The TMDL recommends an 88% reduction in average annual total phosphorus loads to Burke Lake. Based on the loads measured during the period of the assessment the total phosphorus load should be 7 kg/yr to achieve the desired Secchi-Chl-a TSI target. This reduction is based in large part on the BATHTUB mathematical modeling of the Lake and its predicted response to nutrient load reductions.

The FLUX model was used to develop nutrient and sediment loadings for the Burke Lake inlet and outlet sites. This information was used to derive export coefficients for nutrients and sediment to target areas within the watershed with excessive loads of these pollutants.

The Annualized Agricultural Non-Point Source Model (AnnAGNPS) model was used to simulate alterations in land use practices and the resulting nutrient reduction response. The nutrient loading source analysis, that was used to identify potential controls in the watershed, was based on the identification of targeted or "critical" cells. A portion (approximately five percent) of the initial load reductions under this TMDL will be achieved through controls on the critical cells within the watershed to improve pasture conditions or improve tillage practices. Additional methods, such as phosphorus precipitation, sediment removal, alum treatment, will need to be implemented to meet the water quality target.

Improvements in the dissolved oxygen concentration of the lake can be achieved through hypolimnetic aeration (i.e., mechanical aeration), and through reduction of organic loading to the lake as a result of proposed BMP implementation. Also, the pH excursions should be corrected by lowering phosphorus concentration (to lower the chlorophyll *a* concentration to 25 mg/m^3 or less) in the lake.

6. Margin of Safety and Seasonality

Criterion Description – Margin of Safety/Seasonality

A margin of safety (MOS) is a required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving water body (303(d)(1)(c)). The MOS can be implicitly expressed by incorporating a margin of safety into conservative assumptions used to develop the TMDL. In other cases, the MOS can be built in as a separate component of the TMDL (in this case, quantitatively, a TMDL = WLA + LA + MOS). In all cases, specific documentation describing the rational for the MOS is required.

Seasonal considerations, such as critical flow periods (high flow, low flow), also need to be considered when establishing TMDLs , targets, and allocations.

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SUMMARY – A margin of safety is included through conservative assumptions in the derivation of the target and in the modeling. Additionally, more BMPs were specified than are necessary to meet the targets, and ongoing monitoring has been proposed to assure water quality goals are achieved. Seasonality was adequately considered by evaluating the cumulative impacts of the various seasons on water quality and by proposing BMPs that can be tailored to seasonal needs.

7. TMDL

Criterion Description – Total Maximum Daily Load
TMDLs include a quantified pollutant reduction target. According to EPA regulations (see 40 CFR. 130.2(i)). TMDLs can be expressed as mass per unit of time, toxicity, % load reduction, or other measure. TMDLs must address, either singly or in combination, each listed pollutant/water body combination.

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SUMMARY – The TMDL established for Burke Lake is a 7 kg/yr total phosphorus load to the lake (88% reduction in annual total phosphorus load). This is the "measured load" which is based on the flow and concentration data collected during the period of the assessment. The annual loading will vary from year-to-year; therefore, this TMDL is considered a long term average percent reduction in phosphorus loading.

For parameters such as phosphorus, for which narrative water quality criteria often apply, attainment of WQS cannot always be judged on a daily basis. Assessment of cumulative loading impacts is necessary to understand how to achieve WQS and to estimate the allowable loading capacity; therefore identifying long-term allocations for such situations is appropriate and informative from a management perspective. For TMDLs in which it is determined that a non-daily allocation is more meaningful in understanding the pollutant/waterbody dynamics, EPA recommends that practitioners identify and include such an allocation, as well as a daily load expression with the final TMDL submission. Unfortunately, EPA's draft technical guidance for developing daily loads was not released until after the final Burke Lake TMDL was submitted for approval.

The TMDL targets, calculations and loads developed by SD DENR for the Burke Lake TMDL are based on an annual timeframe rather than a "daily" load. EPA recognizes that, under the specific circumstances, the state may deem this the most appropriate timeframe (i.e., the TSI water quality target is based on an interpretation of narrative water quality standards which naturally does not include an averaging period). EPA notes that the Burke Lake TMDL calculations for phosphorus can be readily approximated to a daily format through simple division of the annual loads by the number of days in a year**.** For Burke Lake this would be a daily load of 0.02 kg/day of phosphorus. However, simply dividing an annual load by 365 would produce an "average" daily load that would not match the actual phosphorus load reaching the lake on a given day. EPA's draft technical guidance for developing daily loads mentions that because many TMDLs are developed for precipitation-driven parameters, one number will often not represent an adequate daily load value. Instead, the guidance recommends that a range of values might need to be presented to account for allowable differences in loading due to seasonal or flow-related conditions (e.g., daily maximum and daily median).

8. Allocation

Criterion Description – Allocation

TMDLs apportion responsibility for taking actions or allocate the available assimilative capacity among the various point, nonpoint, and natural pollutant sources. Allocations may be expressed in a variety of ways such as by individual discharger, by tributary watershed, by source or land use category, by land parcel, or other appropriate scale or dividing of responsibility. A performance based allocation approach, where a detailed strategy is articulated for the application of BMPs, may also be appropriate for nonpoint sources.

In cases where there is substantial uncertainty regarding the linkage between the proposed allocations and achievement of water quality standards, it may be necessary to employ a phased or adaptive management approach (e.g., establish a monitoring plan to determine if the proposed allocations are, in fact, leading to the desired water quality improvements).

Allocating load reductions to specific sources is generally the most contentious and politically sensitive component of the TMDL process. It is also the step in the process where management direction is provided to actually achieve the desired load reductions. In many ways, it is a prioritization of restoration activities that need to occur to restore water quality. For these reasons, every effort should be made to be as detailed as possible and also, to base all conclusions

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SUMMARY – This TMDL addresses the need to achieve further reductions in nutrients to attain water quality goals in Burke Lake. The allocation for the TMDL is a "load allocation" attributed to nonpoint sources. There are no point source contributions that drain to Burke Lake in this watershed. The source allocations for phosphorus are assigned to runoff from cropland and range/pastureland. Additional methods, such as phosphorus precipitation, sediment removal, alum treatment, will need to be implemented to meet the water quality target. There is a desire to move forward with controls in the areas of the basin where there is confidence that phosphorus reductions can be achieved through BMP implementation within the watershed.

9. Public Participation

Criterion Description – Public Participation

The fundamental requirement for public participation is that all stakeholders have an opportunity to be part of the process. Notifications or solicitations for comments regarding the TMDL should clearly identify the product as a TMDL and the fact that it will be submitted to EPA for review. When the final TMDL is submitted to EPA for review, a copy of the comments received by the state should be also submitted to EPA..

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SUMMARY – The State's submittal includes a summary of the public participation process that has occurred which describes the ways the public has been given an opportunity to be involved in the TMDL development process. In particular, the State has encouraged participation through public meetings in the watershed, individual contact with residents in the watershed, and included widespread solicitation of comments on the draft TMDL during the public notice period. The draft TMDL was also posted on DNER's website to solicit comments during the public notice period. The level of public participation is found to be adequate.

10. Monitoring Strategy

Criterion Description – Monitoring Strategy

TMDLs may have significant uncertainty associated with selection of appropriate numeric targets and estimates of source loadings and assimilative capacity. In these cases, a phased TMDL approach may be necessary. For Phased TMDLs, it is EPA's expectation that a monitoring plan will be included as a component of the TMDL documents to articulate the means by which the TMDL will be evaluated in the field, and to provide supplemental data in the future to address any uncertainties that may exist when the document is prepared.

At a minimum, the monitoring strategy should:

- *Articulate the monitoring hypothesis and explain how the monitoring plan will test it.*
- *Address the relationships between the monitoring plan and the various components of the TMDL (targets, sources, allocations, etc.).*
- *Explain any assumptions used.*
- *Describe monitoring methods.*
- *Define monitoring locations and frequencies, and list the responsible parties.*

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SUMMARY – Burke Lake will continue to be monitored through the statewide lake assessment project. Post-implementation monitoring will be necessary to assure the TMDLs for phosphorus, dissolved oxygen, and pH have been reached and improvement of the beneficial use occurs.

11. Restoration Strategy

Criterion Description – Restoration Strategy *At a minimum, sufficient information should be provided in the TMDL document to demonstrate that if the TMDL were implemented, water quality standards would be attained or maintained. Adding additional detail regarding the proposed approach for the restoration of water quality is not currently a regulatory requirement, but is considered a value added component of a TMDL document.*

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SUMMARY – The South Dakota DENR is working with the Gregory County Conservation District and the SD Department of Game, Fish and Parks to develop a plan for an implementation project for Burke Lake. The implementation of various best management practices throughout the watershed is expected to meet the WQ and TMDL targets/goals. This includes improvement in pastureland/cropland conditions, installation of an in-lake aeration system and other possible controls mentioned on pages 45 – 50 of the report. Mechanical aeration is needed to meet the TMDL goal for dissolved oxygen.

12. Endangered Species Act Compliance

Criterion Description – Endangered Species Act Compliance EPA's approval of a TMDL may constitute an action subject to the provisions of Section 7 of the Endangered Species Act ("ESA"). EPA will consult, as appropriate, with the US Fish and Wildlife Service (USFWS) to determine if there is an effect on listed endangered and threatened species pertaining to EPA's approval of the TMDL. The responsibility to consult with the USFWS lies with EPA and is not a requirement under the Clean Water Act for approving TMDLs. States are encouraged, however, to participate with FWS and EPA in the consultation process and, most importantly, to document in its TMDLs the potential effects (adverse or beneficial) the TMDL may have on listed as well as candidate and proposed species under the

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SUMMARY – EPA has received ESA Section 7 concurrence from the FWS for this TMDL.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 8
1595 Wynkoop Street
DENVER, CO 80202-1129
Phone 800-227-8917
http://www.epa.gov/region08

August 8, 2007

Ref: 8EPR-EP

Steven M. Pirner, Secretary
Department of Environment & Natural Resources
Joe Foss Building
523 East Capitol
Pierre, SD 57501-3181

Re: TMDL Approvals
Bear Butte Creek; SD-BF-R-BEAR_BUTTE_02
Burke Lake; SD-MI-L-BURKE_01
Center Lake; SD-CH-L-CENTER_01
Richmond Lake; SD-JA-L-RICHMOND_01

Dear Mr. Pirner:

We have completed our review, and have received Endangered Species Act Section 7 concurrence from the U.S. Fish and Wildlife Service, on the total maximum daily loads (TMDLs) as submitted by your office for the waterbodies listed in the enclosure to this letter. In accordance with the Clean Water Act (33 U.S.C. 1251 *et. seq*.), we approve all aspects of the TMDLs as developed for the water quality limited waterbodies as described in Section 303(d)(1). Based on our review, we feel the separate elements of the TMDLs listed in the enclosed table adequately address the pollutants of concern as given in the table, taking into consideration seasonal variation and a margin of safety.

Some of the TMDLs listed in the enclosed table may be for waters not found on the State's current Section 303(d) waterbody list. EPA understands that such waters would have been included on the list had the state been aware, at the time the list was compiled, of the information developed in the context of calculating these TMDLs. This information demonstrates that the non-listed water is in fact a water quality limited segment in need of a TMDL. The state need not include these waters that have such TMDLs associated with them on its next Section 303(d) list for the pollutant covered by the TMDL.

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Thank you for submitting these TMDLs for our review and approval. If you have any questions, the most knowledgeable person on my staff is Vern Berry and can be reached at
(303) 312-6234.

Sincerely,

signed by Terry Anderson, Acting ARA

Carol Rushin
Assistant Regional Administrator
Office of Ecosystems Protection and Remediation

APPROVED TMDLS

4 Pollutant TMDLs completed
6 causes addressed from the 2006 303(d) list
0 Determinations made that no pollutant TMDL was needed

Waterbody Name & AU ID	TMDL Parameter/ Pollutant (303(d) list cause)	Water Quality Goal/Endpoint	TMDL WLA / LA / MOS	Section 303(d)1 or 303(d)3 TMDL	Supporting Documentation (not an exhaustive list of supporting documents)
Bear Butte Creek (from Strawberry Creek to mouth)* SD-BF-R-BEAR_BUTTE_02	Total Suspended Solids (TSS)	TSS ≤ 158 mg/L in any one sample	2,400 tons/yr TSS (61% reduction in average annual TSS loads) LA = 2,400 tons/yr WLA = 0 tons/yr MOS = implicit	Section 303(d)(1)	? Section 319 Nonpoint Source Pollution Control Program Assessment/Planning Project Final Report, Bear Butte Creek Watershed Assessment, (SD DENR, 2007)
Burke Lake* SD-MI-L-BURKE_01	Phosphorus (TSI, pH, dissolved oxygen**)	Maintain a mean annual Secchi disk-chlorophyll-a TSI at or below 63.4; dissolved oxygen ≥ 5.0; pH 6.5 ≥ - ≤ 9.0	7 kg/yr total phosphorous (88% reduction in average annual total phosphorous loads) LA = 7 kg/yr WLA = 0 MOS = implicit	Section 303(d)(1)	? Watershed Assessment Final Report, Burke Lake, Gregory County, South Dakota (SD DENR, April 2006)
Center Lake* SD-CH-L-CENTER_01	Phosphorus (TSI) Impairment causes pH, water temperature and dissolved oxygen will be addressed in another document.	Maintain a mean annual Secchi disk-chlorophyll-a TSI at or below 48.0	14.3 kg/yr total phosphorous (70% reduction in average annual total phosphorous loads) LA = 14.3 kg/yr WLA = 0 MOS = implicit	Section 303(d)(1)	? Section 319 Nonpoint Source Pollution Control Program Assessment/Planning Project Final Report, Center Lake Watershed Assessment Final Report and TMDL, (SD DENR, Oct. 2006)

Richmond Lake* SD-JA-L-RICHMOND_01	Phosphorus (TSI)	Maintain a mean annual Secchi disk-chlorophyll-a TSI at or below 61.5	557.6 kg/yr total phosphorous (20% reduction in average annual total phosphorous loads) LA = 557.6 kg/yr WLA = 0 MOS = implicit	Section 303(d)(1)	? Watershed Assessment Final Report, Richmond Lake, Brown County, South Dakota (SD DENR, July 2006)

* An asterisk indicates the waterbody has been included on the State's Section 303(d) list of waterbodies in need of TMDLs.

** Improvements in the dissolved oxygen concentration of the lake can be achieved through reduction of organic loading to the lake as a result of proposed BMP implementation. The TMDL contains a linkage analysis between phosphorous loading and low dissolved oxygen in lakes and reservoirs.

Thirty copies of this document were printed by the Department of Environment and Natural Resources at a cost of $4.82 per copy.