PHASE I
WATERSHED ASSESSMENT FINAL REPORT
AND TMDL

OAKWOOD LAKES WATERSHED ASSESSMENT
BROOKINGS 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

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Project Sponsor and Prepared By

East Dakota Water Development District

State of South Dakota
Mike Rounds, Governor

December 2005

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

EPA Grants # C9998185-96 and # C9998185-00

EXECUTIVE SUMMARY

PROJECT TITLE: Oakwood Lakes Watershed Assessment

START DATE: April 01, 2001 **COMPLETION DATE:** 12/31/06

FUNDING: **TOTAL BUDGET:** $330,576 (projected)

TOTAL EPA GRANT: $150,243

TOTAL EXPENDITURES OF EPA FUNDS: $150,243 (through 12/31/06)

TOTAL SECTION 319 MATCH ACCRUED: $205,846.36 (through 12/31/06)

BUDGET REVISIONS:

Original EPA Grant:	$172,243
Grant Reductions:	$ 22,000
Revised EPA Grant:	$150,243

TOTAL EXPENDITURES: $356,089.36 (through 12/31/06)

****Note:** these amounts represent the total cost for the North-Central Big Sioux River Watershed Assessment project
which also covered the assessment of Oakwood Lakes

SUMMARY ACCOMPLISHMENTS

The Oakwood Lakes watershed assessment project began in April of 2001 in conjunction with the North-Central Big Sioux River Watershed Assessment Project. This assessment continued through December of 2005 when data analysis and compilation into a final report was completed. The Oakwood Lake watershed assessment was conducted as a result of East Oakwood Lake being placed on the 1998 South Dakota 303(d) impaired waterbody list. Excess nutrients, siltation, and noxious aquatic plants were cited as the primary problems. Additionally, West Oakwood Lake was listed on the 2002 South Dakota 303(d) Waterbody List for not supporting its beneficial uses due to TSI impairment. Both East Oakwood Lake and West Oakwood Lake have been identified as impaired on subsequent impaired waterbody lists to include the most recent 2006 South Dakota Integrated Report for Surface Water Quality Assessment.

This watershed project met all of its milestones in a timely manner, with the exception of completing the final report. This was delayed due to an additional watershed assessment (Central Big Sioux River Watershed Assessment, South Dakota) being completed. An EPA section 319 grant provided a majority of the funding for this project. The Department of Environment and Natural Resources and East Dakota Water Development District provided matching funds for the project.

Water quality monitoring and watershed modeling resulted in the identification of nutrient impairment as related to TSI trend in both East Oakwood Lake and West Oakwood Lake. Additionally, there were a number of pH exceedences identified in East Oakwood Lake. The sources of these impairments may be addressed through best management practices (BMPs) such as shoreline buffers and riparian management, as well as in-lake management of rough fish biomass.

The long term goal for this project was to locate and document sources of non-point source pollution in the Oakwood Lakes watershed and provide feasible restoration alternatives for the improvement of water quality. Through identification of sources of impairment in the watershed, this goal was accomplished.

ACKNOWLEDGEMENTS

The cooperation of the following organizations and individuals is gratefully appreciated. The assessment of the Central Big Sioux River and its watershed could not have been completed without the cooperation of the landowners in the study area - their cooperation is greatly appreciated.

Brookings County Conservation District
Natural Resource Solutions
Sioux Falls Health Lab
South Dakota Department of Environment and Natural Resources
South Dakota Department of Game, Fish and Parks
South Dakota Geological Survey
South Dakota State University, Water Resource Institute
United States Department of Agriculture, Farm Service Agency, Brookings
United States Department of Agriculture, Natural Resource Conservation Service
United States Fish and Wildlife Service
United States Geological Survey

East Dakota Water Development staff that contributed to the development of this report:
Technical Staff: Deb Springman, Becky Banks, Mark Hanson, Craig Milewski,
Dray Walter
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ABBREVIATIONS

AFOs	Animal Feeding Operations – *facility where animals are confined, fed, or maintained for a total of 45 days in any 12 month period, and where vegetation is not sustained in the normal growing season over any portion of the lot or facility*
AGNPS	Agricultural Non-Point Source – *an event-based, watershed-scale model developed to simulate runoff, sediment, chemical oxygen demand, and nutrient transport in surface runoff from ungaged agricultural watersheds*
BMP	Best Management Practice – *an agricultural practice that has been determined to be an effective, practical means of preventing or reducing nonpoint source pollution*
BSR	Big Sioux River
CFU	Colony Forming Units
CV	Coefficient of Variance – *a statistical term used to describe the amount of variation within a set of measurements for a particular test*
DO	Dissolved Oxygen
EDWDD	East Dakota Water Development District
IBI	Index of Biological Integrity
IPI	Index of Physical Integrity
MOS	Margin of Safety – *an index indicating the amount beyond the minimum necessary*
MPN	Most Probably Number
NGP	Northern Glaciated Plains
NPDES	National Pollution Discharge Elimination System
NPS	Nonpoint Source
NRCS	Natural Resources Conservation Service
NTU	Nephelometric Turbidity Units – *measure of the concentration of size of suspended particles (cloudiness) based on the scattering of light transmitted or reflected by the medium*
SD	South Dakota
SDDENR	South Dakota Department of Environment and Natural Resources
SDGFP	South Dakota Department of Game Fish & Parks
SDSU	South Dakota State University
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load – *a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and an allocation of the amount to the pollutant's sources*
TSS	Total Suspended Solids
µmhos/cm	microhmos/centimeter – *unit of measurement for conductivity*
USFWS	United States Fish and Wildlife Service
USGS	United States Geologic Survey
WQ	Water Quality – *term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose*
WRI	Water Resource Institute

INTRODUCTION

PURPOSE

The purpose of this assessment is to determine the sources of impairment and develop restoration alternatives for East Oakwood Lake and West Oakwood Lake in northwestern Brookings County, South Dakota. Both lakes make up a chain of lakes called Oakwood Lakes. West Oakwood Lake is comprised of two interconnected lakes, Johnson Lake and Lake Tetonkaha. These lakes are connected to East Oakwood Lake by a series of culverts. The watershed of these lakes encompasses a small portion of the greater Big Sioux River Watershed. This assessment was completed in conjunction with the North-Central Big Sioux River Watershed Assessment Project.

Direct runoff into the lakes, as well as intermittent tributaries, contribute loadings of sediment and nutrients primarily related to seasonal snow melt or rainfall events. East Oakwood Lake was initially listed in the 1998 South Dakota 303(d) Waterbody List as hypereutrophic and not supporting of its designated uses and has subsequently been listed to include the most recent 2006 Integrated Report. Excessive nutrients, siltation, and noxious aquatic plants were identified as the problems in the original listing. High TSI value is the reason for its current listing. West Oakwood Lake was first listed in the 2002 303(d) Impaired Waterbody List as not supporting of its designated uses due to high TSI value (Table 1). This lake has also been listed subsequent years to include the most recent 2006 Integrated Report (SD DENR 2006). Through water quality monitoring (chemical and biological), stream gaging, and land use analysis, sources of impairment were determined and feasible alternatives for restoration efforts were developed.

The South Dakota 303(d) Waterbody List identifies this chain of lakes as a priority for the development of a Total Maximum Daily Load (TMDL) for the pollutants of concern. The final assessment report and associated TMDLs will serve as the foundation for restoration projects that can be developed and implemented to meet the designated uses and water quality standards of the Oakwood chain of lakes and its watershed. This project is intended to be the initial phase of a restoration implementation project.

Table 1. 303(d) Listing of Locations Not Meeting Water Quality Criteria

Years Listed	Lake	EDWDD Sites	Basis	Cause	Source
1998 2002 2004 2006	East Oakwood Lake	L1, L2	Lake Assessment	Nutrients Siltation Noxious Aquatic Plants Algal Growth TSI	Non-Point Sources
2002 2004 2006	West Oakwood Lake	L10, L11, L12	Lake Assessment	TSI	Non-Point Sources

GENERAL WATERSHED DESCRIPTION

The Oakwood Lakes watershed is approximately 55,040 acres (86 square miles) in size and is located in the northwest corner of Brookings County, South Dakota (Figure 1). This watershed lies within the North-Central Big Sioux River watershed and includes East Oakwood Lake, West Oakwood Lake (includes Johnson Lake and Lake Tetonkaha), and numerous intermittent tributaries which carry water during spring snowmelt or rainfall events. The Oakwood chain of lakes drains into the Big Sioux River by way of Mill Creek. The Big Sioux River is a permanent, natural river that flows north to south along the eastern edge of South Dakota and drains into the Missouri River at Sioux City, Iowa.

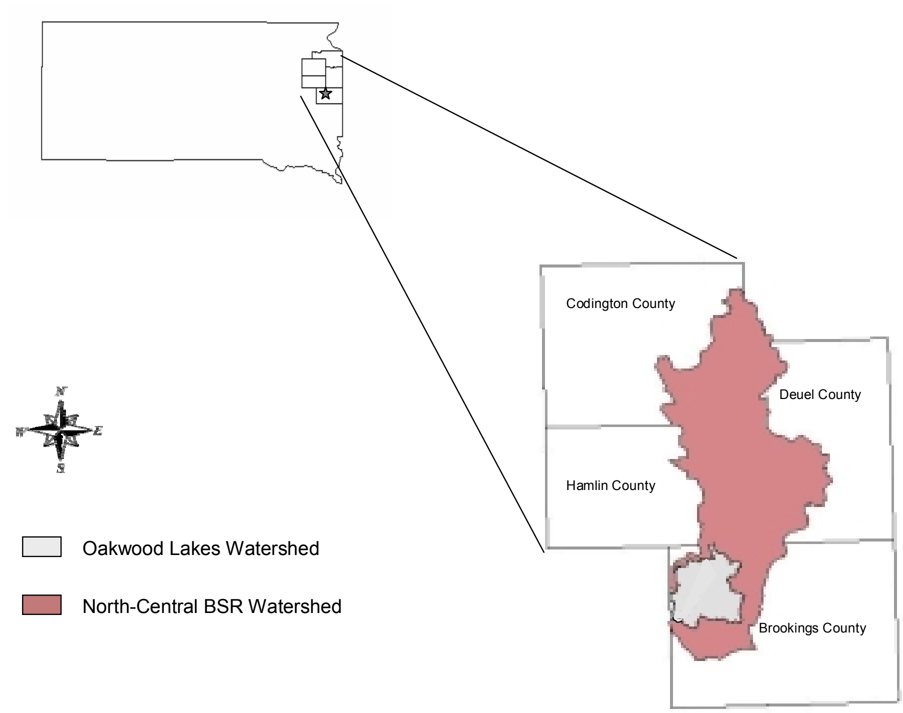


Figure 1. Location of the Oakwood Lakes Watershed

Geology and Soils

The drainage of the Oakwood Lakes watershed is poor with many potholes and sloughs. The relief in the area is minimal. The land elevation in the study area is approximately 1,600 feet above mean sea level.

The surficial materials and bedrock mainly consist of glacial till over Cretaceous shales. Soils within the watershed are derived from a variety of parent materials. Upland soils are relatively fine-grained and have developed over glacial till or eolian (loess) deposits. Coarse-grained soils are found along present or former water courses, and are derived from glacial outwash or alluvial sediments.

Climate

The average annual precipitation in the Oakwood Lakes watershed is 22.8 inches, of which 78 percent typically falls during the growing season of April through September (Figures 2 and 3). Tornadoes and severe thunderstorms strike occasionally. These storms are often of only local extent, short in duration, and occasionally produce heavy rainfall. The average seasonal snowfall is 30.2 inches per year (SDSU 2003).

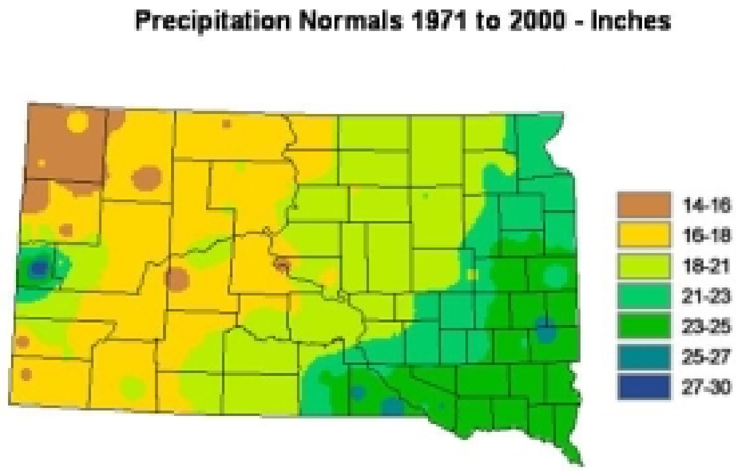


Figure 2. South Dakota Precipitation Normals in Inches from 1971 to 2000

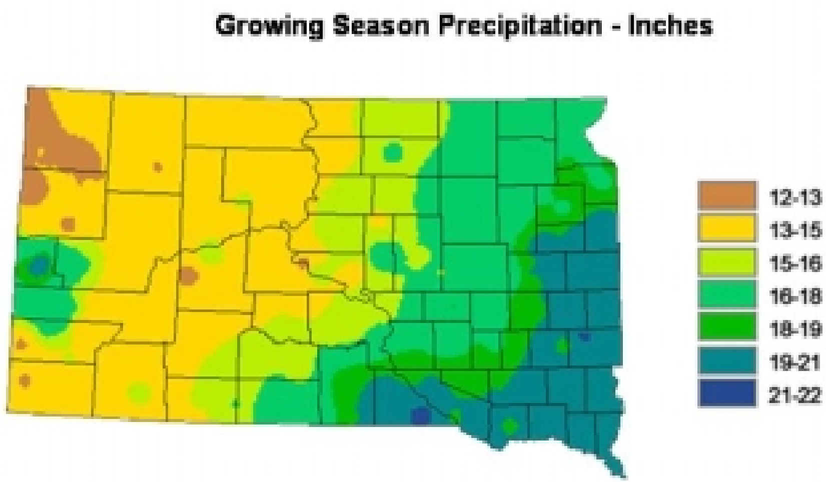


Figure 3. South Dakota Growing Season Precipitation in Inches from 1971 to 2000

Land Use, Population, & History

Land use in the watershed is predominantly agricultural (Figure 4). Approximately 73 percent of the area is cropland, such as corn, soybeans, and small grains, and 20 percent is rangeland. There are 51 animal feeding operations comprised of more than 8,600 animals with 80 percent cattle presence. There are no NPDES facilities located within this watershed. Residential development is limited to the area around the south end of Lake Tetonkaha and scattered farm dwellings throughout the watershed. Many of the residences located around Lake Tetonkaha are seasonal. The majority of the watershed lies within Oakwood Township, with a population of 189 people.

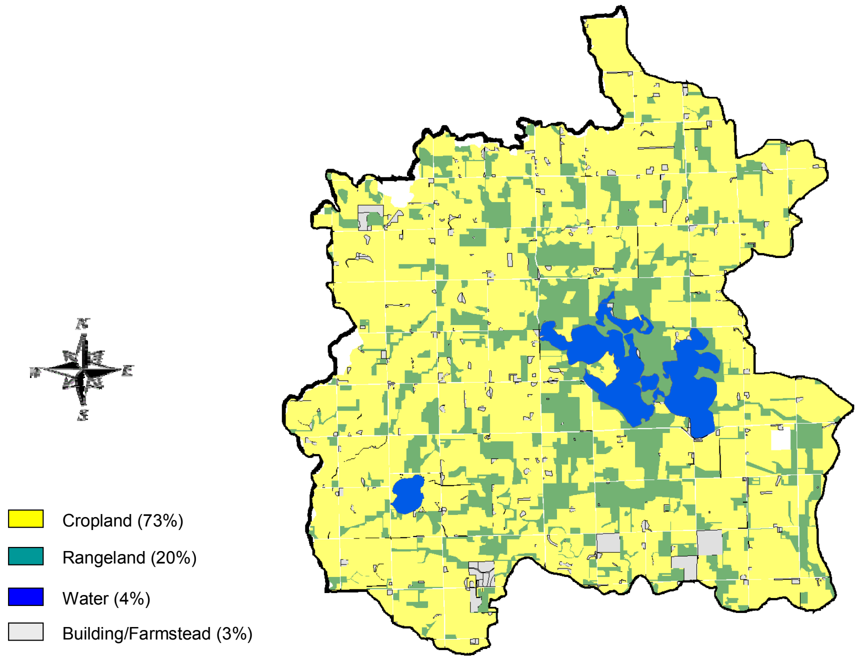


Figure 4. Landuse in the Oakwood Lakes Watershed

The area around the chain of lakes was once used as a summer camp and an annual gathering spot for Native Americans. In 1869, Samuel Mortimer built a log cabin that still stands today at the entrance of Oakwood Lakes State Park.

PROJECT DESCRIPTION

The naturally occurring Oakwood chain of lakes is located within the Northern Glaciated Plains (NGP) ecoregion (Omernik 1987). This chain includes East Oakwood Lake and a meander of two lakes, Johnson Lake and Lake Tetonkaha which are also known as West Oakwood Lake. A description of this region is provided in Table 2. Of the ten monitoring sites, five were setup as in-lake monitoring sites and the remaining five were setup to monitor the inlets and outlets of the three lakes (Figure 5 and Table 3).

Table 2. Description of the Northern Glaciated Plains Ecoregion

Ecoregion	Physiography	Potential Natural Vegetation	Land Use and Land Cover	Climate	Soil Order
Big Sioux Basin	Surficial geology of glacial till. Rolling landscape with defined stream network and few wetlands.	Tallgrass prairie: Big bluestem, little bluestem, switchgrass, indiangrass, sideoats gramma, and lead plant. Riparian areas: willows and cordgrass to the north and some woodland south.	Row crop agriculture of mostly corn and soybean. Some small grain and alfalfa.	Mean annual rainfall of 20-22 inches. Frost-free from 110-140 free days.	Mollisols

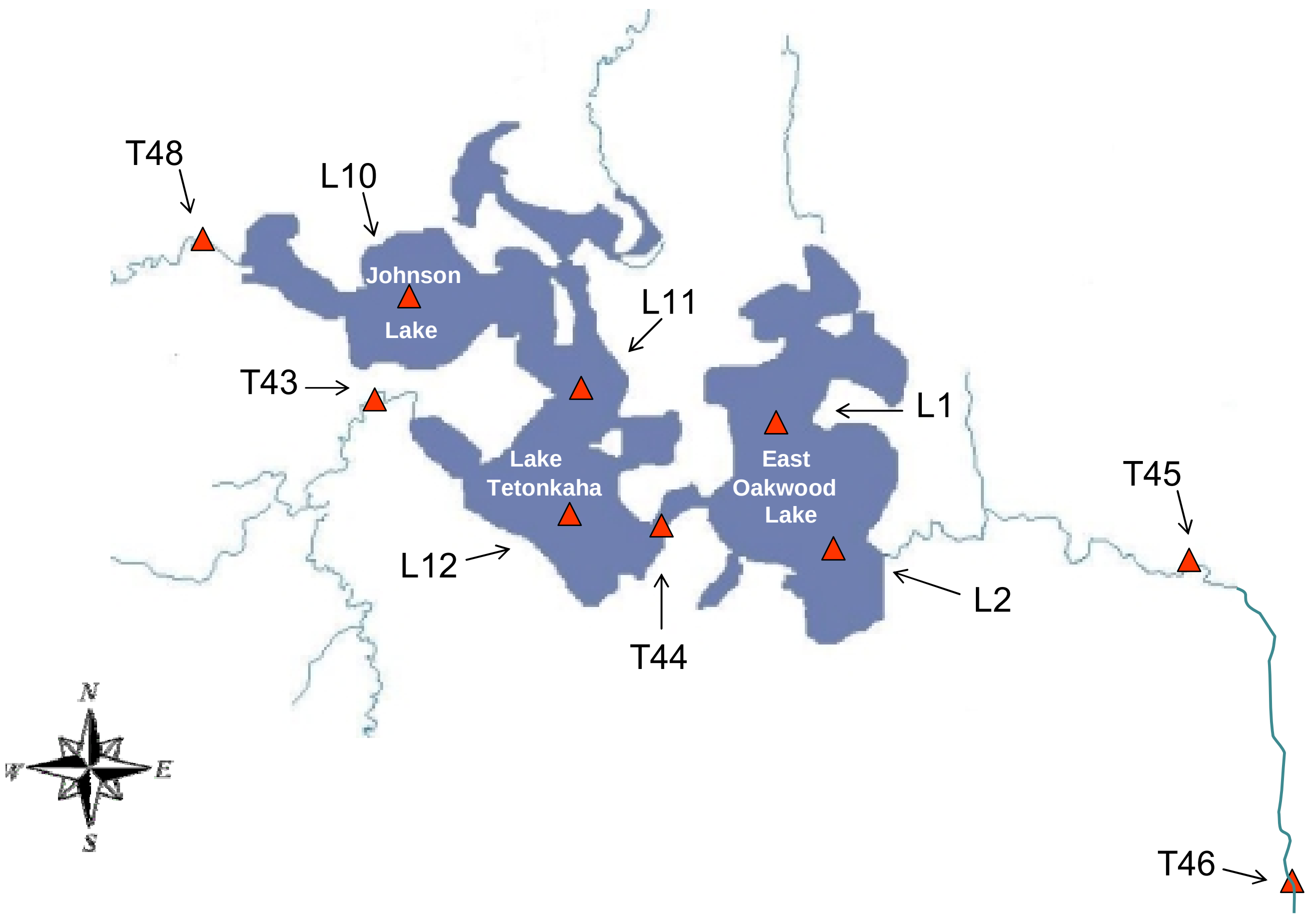


Figure 5. Location of Monitoring Sites

Table 3. Location of the Monitoring Sites

Oakwood Lake Watershed Assessment Project Water Quality Sampling/Stream Gaging Sites						
Location Number	***Descriptive Name***	***Latitude***	***Longitude***	***WQ Samples***	***Gaging Station***	***Miscellaneous Information***
T43	East Oakwood Lake tributary I	44 26 30	097 00 55	Yes	Yes	
T44	East Oakwood Lake tributary II	44 26 20	096 58 55	Yes	Yes	Connection to Lake Tetonkaha (W. Oakwood)
T45	East Oakwood Lake outlet creek I	44 26 00	096 56 50	Yes	Yes	Former DENR WQM site
T46	East Oakwood Lake outlet creek II	44 23 05	096 55 05	Yes	Yes	Former DENR WQM site
T48	East Oakwood Lake Inlet 3			Yes	Yes	
L1	East Oakwood Lake I	44 26 35	096 58 15	Yes	No	North basin site
L2	East Oakwood Lake II	44 26 10	096 58 05	Yes	No	South basin site
L10	Johnson Lake	44 27 08	097 00 27	Yes	No	
L11	North Tetonkaha Lake	44 26 41	096 59 26	Yes	No	
L12	South Tetonkaha Lake	44 26 08	096 59 40	Yes	No	

BENEFICIAL USES

The State of South Dakota has assigned all of the water bodies that are situated within its borders a set of beneficial uses. Beneficial use means the purpose or benefit to be derived from a water body. Under state and federal law, the beneficial use of water is to be protected from degradation. Of the eleven beneficial uses, two are assigned to all streams in the state ((9) fish and wildlife propagation, recreation and stock watering, and (10) irrigation) and one is assigned to all lakes in the state ((9) fish and wildlife propagation, recreation and stock watering). A set of standards is applied to the Oakwood chain of lakes and their tributaries. These standards must be met to maintain the beneficial uses for a particular water body. According to the 1998 South Dakota 305(b) water quality assessment, several designated beneficial uses assigned to East Oakwood Lake are impaired by excessive nutrients, siltation, and noxious aquatic plants. Probable sources of these problems are identified in the report as on-site wastewater systems and agricultural related activities. Assessment monitoring has show both East Oakwood Lake and West Oakwood Lake are not supporting of their beneficial uses due to exceeding the TSI values.

All lake sites are assigned beneficial uses five, seven, eight, and nine. The inlets/outlets are assigned beneficial uses nine and ten (Table 4). Designated beneficial uses and coinciding numeric water quality standards (not to be exceeded) for the Oakwood Lakes watershed are listed in Table 5.

(5) Warmwater Semi-permanent Fish Life Propagation

(7) Immersion Recreation

(8) Limited Contact Recreation

(9) Fish & Wildlife Propagation, Recreation, & Stock Watering

(10) Irrigation

Table 4. Monitoring Sites and Their Beneficial Use Classification

		Beneficial Use Classification						
Water Body	**Site ID**	**1**	**5**	**6**	**7**	**8**	**9**	**10**
East Oakwood Lake Trib 1	T43						■	■
East Oakwood Lake Trib 2	T44						■	■
East Oakwood Lake Outlet 1	T45						■	■
East Oakwood Lake Outlet 2	T46						■	■
East Oakwood Lake Inlet 3	T48						■	■
East Oakwood Lake	L1, L2		■		■	■	■	
Tetonkaha Lake	L11, L12		■		■	■	■	
Johnson Lake	L10		■		■	■	■	

Table 5. Numeric Criteria Assigned to Beneficial Uses of Surface Waters in the Oakwood Lakes Watershed

Parameters (mg/L) except where noted	**5** Warmwater semi permanent fish life propagation	**7** Immersion recreation	**8** Limited contact recreation	**9** Fish & wildlife propagation, recreation & stock watering	**10** Irrigation
Fecal Coliform (per 100 mL) May 1 - Sept. 30		≤ 200 (mean) ≤ 400 (single sample)	≤ 1,000 (mean) ≤ 2,000 (single sample)		
Specific Conductivity (umhos/cm @ 25° C)				≤ 4,000[1]/ 7,000[2]	≤ 2,500[1]/ 4,375[2]
Total Ammonia Nitrogen as N	≤ result of the Equation[3]				
Nitrogen, Nitrates as N				≤ 50[1]/ 88[2]	
Dissolved oxygen	≥ 5.0	≥ 5.0	≥ 5.0		
pH (standard units)	≥ 6.5 to ≤ 9.0			≥ 6.0 to ≤ 9.5	
Suspended solids	≤ 90[1]/ 158[2]				
Total dissolved solids				≤ 2,500[1]/ 4,375[2]	
Temperature (°F)	≤ 90				

Note: [1] 30-day average [2] daily maximum
[3] $(0.411 \div (1+10^{7.204-pH}) + (58.4 \div 1+10^{pH-7.204}))$ in accordance with ARSD 74:51:01, Appendix A, Equation 2

RECREATIONAL USE

Oakwood Lakes State Park is situated among the three lakes and provides recreational activities such as fishing, swimming, boating, picnicking, camping, and hiking (Table 6). During the winter of 2000-2001 both East Oakwood Lake and West Oakwood Lake experienced a winterkill of fish. Severe winter kills occur in this chain of lakes approximately every 8 to 10 years. The 2004 State Fisheries Survey for East Oakwood Lake is located in Appendix A and the 2004 survey for West Oakwood Lake is located in Appendix B.

Table 6. Recreational Uses of Oakwood Lakes

Lake	Boat Ramp	Public Dock	Shore Fishing	Public Toilets	Swimming
East Oakwood	X		X		X
West Oakwood	X	X	X	X	X

THREATENED AND ENDANGERED SPECIES

Information from the South Dakota Natural Heritage Program (2004) and the USFWS (2004) were used to construct the following table (Table 7) of rare, threatened, and endangered species that may occur within the Oakwood Lakes watershed. The Whooping crane, American burying beetle, Dakota skipper, and Western prairie fringed orchid have historically been found to occur in Brookings County and could possibly still be in the area. The Bald eagle, Topeka shiner, Central mudminnow, Northern redbelly dace, and Northern redbelly snake are listed species that are commonly found within the area. However, none of these species were encountered during the study.

Table 7. Endangered, Threatened, and Candidate Species of the Oakwood Lakes Area

Name	***Scientific Name***	***Category***	***Status***		***Occurrence***
			Federal	***State***	
Whooping crane	*Grus americana*	Bird	FE	SE	Rare
Bald eagle	*Haliaeetus leucocephalus*	Bird	FT	SE	Common
Topeka shiner	*Notrophis topeka*	Fish	FE		Common
Central mudminnow	*Umbra limi*	Fish		SR	Common
Northern redbelly dace	*Phoxinus eos*	Fish		ST	Common
American burying beetle	*Nicrophorus americanus*	Insect	FE	SR	Rare
Dakota skipper	*Hesperia dacotae*	Insect	FC	SR	Rare
Northern redbelly Snake	*Storeria occipitomaculata occipitomaculata*	Reptile		SR	Common
Western prairie fringed orchid	*Plantanthera praeclara*	Plant	FT		Rare

KEY TO CODES:
FE= Federal Endangered
SE=State Endangered
FT= Federal Threatened
ST=State Threatened
FC=Federal Candidate
SR=State Rare

PROJECT GOALS, OBJECTIVES, AND MILESTONES

GOALS

The goals of this assessment project were to:

1) Determine and document sources of impairments of the Oakwood Lakes portion of the North-Central Big Sioux River watershed
2) Identify feasible restoration alternatives to support watershed implementation projects to improve water quality within the watershed
3) Develop TMDLs based on identified pollutant impairments

Impairments cited in the 1998 and the 2000 305(b) Water Quality Assessment Report and the 1998 and 2002 South Dakota 303(d) Waterbody List for this portion of the BSR watershed are excessive nutrients, siltation, and noxious aquatic plants. In the 2004 and 2006 Integrated Report, both East Oakwood Lake and West Oakwood Lake are cited as impaired due to high TSI values.

Goals were accomplished through the collection of tributary and lake data in combination with the completion of the FLUX, BATHTUB, AnnAGNPS, and the Agricultural Non-Point Source (AGNPS) watershed modeling tools. Through data analysis and modeling, the identification of impairment sources was possible. The identification of these impairment sources will aid the State's non-point source (NPS) program by allowing strategic targeting of funds to portions of the watershed that will provide the greatest benefit per expenditure.

OBJECTIVES

Objective 1. Water Quality Assessment

Water sampling of five in-lake sites and five tributary (inlet/outlet) sites began in June 2001. Water samples were collected from tributary sites from June 2001 to October 2001 and from April 2002 to October 2002. Sampling of East Oakwood Lake occurred from July 2001 to October 2001 and from April 2002 to September 2002. Because they were added onto the project in the fall of 2003, Johnson Lake and Lake Tetonkaha were sampled from April 2004 to October 2004 (Table 8).

Detailed level and flow data were entered into a database that was used to assess the nutrient and solids loadings. Thalimedies hydrometers (OTTs) were installed at pre-selected monitoring sites along the tributaries and lake levels were monitored using previously established benchmarks.

Objective 2. Quality Assurance/ Quality Control (QA/QC)

Duplicate and blank samples consisted of ten percent of all samples and were collected during the course of the project to provide defendable proof that sample data were collected in a scientific and reproducible manner. QA/QC data collection began in June of 2001 and was completed on schedule in October of 2004 (Table 8).

Objective 3. Watershed Modeling

Four models were incorporated into this project to analyze and predict loadings. The FLUX model was used to calculate loadings and concentrations in monthly, yearly, and daily increments for the tributaries (inlet/outlet) from sample concentration data and continuous flow records. The BATHTUB model was used to predict changes in water quality parameters related to eutrophication (i.e. phosphorus, nitrogen, chlorophyll-*a*, and transparency). Reductions of phosphorus and nitrogen watershed loading were modeled to generate an in-lake reduction curve. AGNPS was used to model feedlot runoff loads and to help pinpoint areas of concern. This model assessed the pollution potential of feedlots in the area based on animal numbers, condition of feedlot, proximity to water, soils, rainfall events, and topography. Model outputs included feedlot rating, chemical oxygen demand, and phosphorus loadings. The AnnAGNPS model is a more extensive variation of the AGNPS model and was used to simulate the transport of surface water, sediment, and nutrients through the watershed. The current condition of the watershed was modeled and used to compare the effects of implementing various conservation alternatives over time (Table 8).

Objective 4. Information and Outreach

Project updates were provided monthly to the EDWDD Board of Directors. Assessments of the condition of the animal feeding operations located within the project area were conducted by contacting landowners individually (Table 8).

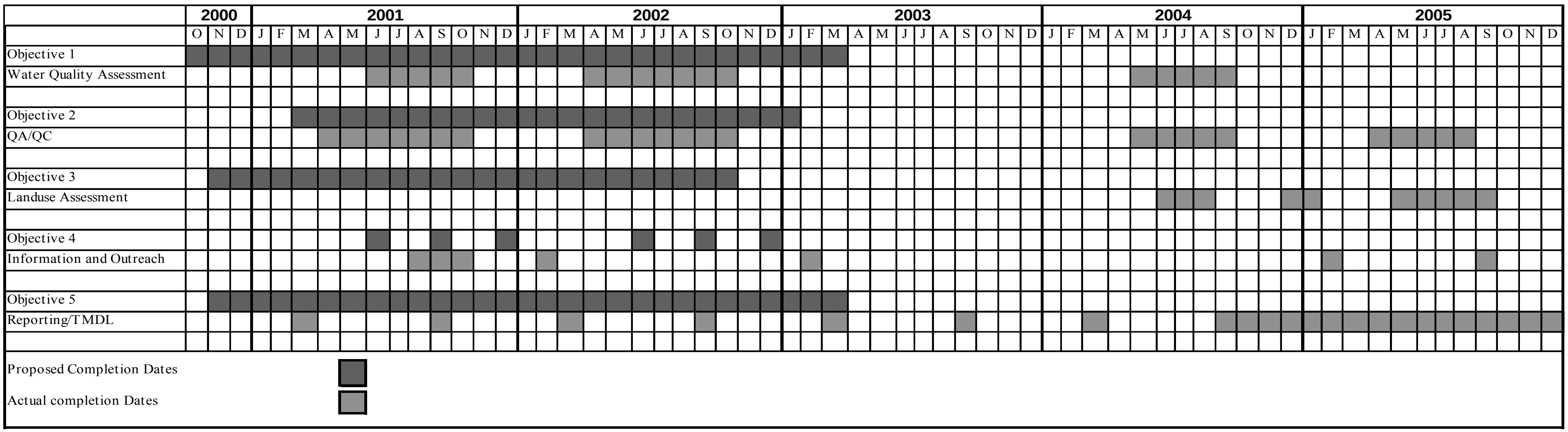
Objective 5. Reporting/TMDL Determination

When a waterbody is listed on a state's 303(d) list, TMDLs must be developed for that waterbody at levels that meet water quality standards that support the designated beneficial uses, shown previously on page 7. A TMDL is a tool or target value that is based on the linkages between water quality conditions and point and non-point sources of pollution. Based upon these linkages, maximum allowable levels of pollution are allocated to the different sources of pollution so that water quality standards are attainable. Sources that exceed maximum allowable levels (or loadings), as shown on Table 5, must be addressed in an implementation plan that calls for management actions that reduce loadings (1998, 2002 303(d) Waterbody List and the 2004, 2006 SD Integrated Report). Furthermore, an implementation plan can call for protection of areas that are below allowable levels. Identifying the causes and sources of water quality impairments is a continuation of the process that placed the waterbody on the 303(d) list. In the case of the Oakwood Lakes watershed, the hypereutophic state of these lakes, which is linked to excess nutrients, siltation, and noxious aquatic plants from the probable non-point sources identified in the 305(b) water quality assessment, guided the strategy for this assessment.

MILESTONES

The Oakwood Lakes Assessment Project was scheduled to start in October 2000. However, due to monitoring equipment needing to be purchased and additional staff needing to be hired, water quality monitoring was delayed until June of 2001. The following table shows the proposed completion dates versus the actual completion dates of the project goals, objectives, and activities.

Table 8. Milestones - Proposed and Actual Completion Dates



METHODS

ENVIRONMENTAL INDICATORS

Water Quality Monitoring

Water samples were collected from five in-lake sites and five tributary sites. The samples were scheduled for collection to coincide with spring runoff, storm events, and during base flow conditions. A total of 154 samples were collected from June 2001 through October 2004. This included 124 standard samples, 15 blank standard samples, and 15 duplicate standard samples. An additional 27 chlorophyll-*a* samples were also collected (includes TPO4 and TDPO4).

A regular schedule of sampling occurred April through October of 2001 and again April through October of 2002 at sites T43, T44, T45, T46, T48, L1, and L2. During the summer of 2003, algae and chlorophyll-a sampling were completed on East Oakwood Lake as it had not been scheduled for completion during the 2001-2002 sampling period. In the fall of 2003, two more lakes were added to the project, Johnson Lake (L10) and Lake Tetonkaha (L11 and L12). With this sampling, supplementary water samples of total phosphorus and total dissolved phosphorus were collected for the analysis of the macrophyte and phytoplankton surveys in 2003, on East Oakwood Lake. Standard water quality samples, as well as extra TPO4 and TDPO4, were collected during phytoplankton sampling on Johnson Lake and Lake Tetonkaha during the summer of 2004. Aquatic plant sampling was completed on Johnson Lake and Lake Tetonkaha in 2004.

Field measurements included dissolved oxygen, pH, turbidity, air temperature, water temperature, conductivity, salinity, stage, benchmarks, and general climatic information. A Hanna Instruments 9025 meter was used to measure pH. Salinity, dissolved oxygen, water temperature, and conductivity were measured using a YSI 85 meter. Turbidity was measured using a LaMotte 2020 turbidity meter and a mercury thermometer was used to measure air temperature. Benchmarks were documented using a stadia rod and survey equipment. A Secchi disk was used to survey the water clarity of the lakes.

The Water Resource Institute (WRI) at South Dakota State University (SDSU), performed analysis on all samples collected from July 2001 to September 2002. This included total solids, total suspended solids (TSS), ammonia, nitrate-N, total Kjeldahl nitrogen, organic nitrogen, total phosphorus, and total dissolved phosphorous. The Sioux Falls Health Laboratory analyzed all fecal coliform bacteria samples collected in 2001 and 2002. All water quality samples collected in 2003 and 2004 were analyzed by the State Health Lab in Pierre, South Dakota. Appendix C contains the grab sample data for each monitoring site.

Both East Oakwood Lake and West Oakwood Lake were also monitored by the State of South Dakota as part of the SD DENR lake assessment monitoring program. However, the water quality data collected by the SD DENR was minimal. This data was not included in the analysis portion of this project because different sampling techniques were used. Table 9 depicts the SD DENR sites that coincided with EDWDD monitoring sites.

Table 9. Project Sites Coinciding with DENR Monitoring Locations

EDWDD Site	DENR Site	Lake
L1, L2	SWLAZZZ 9613	East Oakwood
L10	SWLAZZZ 9616	Johnson
L11, L12	SWLAZZZ 9615	Tetonkaha

Description of Parameters

Water quality was sampled according to the SD DENR protocols (Stueven et al. 2000). Water quality analyses by the WRI Lab, the Sioux Falls Health Lab, and the State Health Lab provided concentrations for a standard suite of parameters (Tables 10 and 11). The detection limits are set by the specific lab based on lab equipment sensitivity.

Table 10. Water Quality Parameters and Lab Detect Limits of the WRI Lab and the Sioux Falls Health Lab

Parameter	Abbreviation	Units	Lower Detect Limit
Total suspended solids	TSS	mg/L	1
Total solids	TotSol	mg/L	1
Nitrates	NO2NO3	mg/L	0.01
Ammonia-nitrogen	NH3N	mg/L	0.01
Organic nitrogen	OrgNtr	mg/L	0.01
TKN	TKN	mg/L	0.01
Total phosphorus	TPO4	mg/L	0.01
Total dissolved phosphorus	TDPO4	mg/L	0.01
Fecal Coliform*	Fecal	cfu/100 mL	<1, <10, <100

* tested by Sioux Falls Health Lab

Table 11. Water Quality Parameters and Lab Detect Limits for the State Health Lab

Parameter	Abbreviation	Units	Lower Detect Limit
Alkalinity-M	Alk-M	mg/L	< 6.0
Alkalinity-P	Alk-P	mg/L	0
Total suspended solids	TSS	mg/L	< 1.0
Total solids	TotSol	mg/L	< 7.0
Volatile Total Suspended Solids	VTSS	mg/L	< 1.0
Nitrates	NO2NO3	mg/L	< 0.1
Ammonia-nitrogen	NH3N	mg/L	< 0.02
TKN	TKN	mg/L	< 0.11
Total phosphorus	TPO4	mg/L	< 0.002
Total dissolved phosphorus	TDPO4	mg/L	< 0.003
Fecal coliform bacteria	Fecal	count/100 mL	< 10.0
E coli	Ecoli	mpn/100 mL	< 1.0

Alkalinity

Alkalinity is a measure of the buffering capacity of water, or the capacity of water to neutralize acid. Alkalinity does not refer to pH, but instead refers to the ability of water to resist change in pH. Waters with low alkalinity are very susceptible to changes in pH. Waters with high alkalinity are able to resist major changes in pH. Lakes with high alkalinity have high pH values while lakes with low alkalinity have low pH values. The hardness of the water is usually determined by the amount of calcium and magnesium salts present in water and is associated with the presence of carbonates. Hard water lakes are generally more productive than soft water lakes and can accept more input of salts, nutrients, and acids to their system without change than can soft water lakes. The range of pH values associated with M-alkalinity (methyl orange indicator) is 4.2 to 4.5. The range of pH values associated with P-alkalinity (phenolphthalein indicator) is 8.2 to 8.5.

Total Suspended Solids

TSS is the portion of total solids that are suspended in solution, whereas dissolved solids make up the rest of the total. Suspended solids include silt and clay particles, plankton, algae, fine organic debris, and other particulate matter. Higher TSS can increase surface water temperature and decrease water clarity. Suspended solids are the materials that do not pass through a filter, e.g. sediment and algae. Subtracting suspended solids from total solids derives total dissolved solids concentrations. Suspended volatile solids are that portion of suspended solids that are organic (organic matter that burns in a 500^{o} C muffle furnace).

Total Solids

Total Solids are materials, suspended or dissolved, present in natural water. Sources of total solids include industrial discharges, sewage, fertilizers, road runoff, and soil erosion.

Volatile Total Suspended Solids

Volatile solids are those solids lost on ignition (heating to 500 degrees C.) They are useful to the treatment plant operator because they give a rough approximation of the amount of organic matter present in the solid fraction of wastewater, activated sludge and industrial wastes. Volatile solids measure the sediments which are able to be burned off of a dried sediment sample. Volatile solids are those solids lost on ignition (heating to 500 degrees C.) They are useful because they give a rough approximation of the amount of organic matter present in the water sample. ‘‘Fixed solids’’ is the term applied to the residue of total, suspended, or dissolved solids after heating to dryness for a specified time at a specified temperature. The weight loss on ignition is called ‘‘volatile solids.’’

Nitrate-Nitrite

Nitrate and nitrite are inorganic forms of nitrogen easily assimilated by algae and other macrophytes. Sources of nitrate and nitrite can be from agricultural practices and direct input from septic tanks, precipitation, groundwater, and from decaying organic matter. Nitrate-nitrite can also be converted from ammonia through denitrification by bacteria. The process increases with increasing temperature and decreasing pH.

Ammonia

Ammonia is the nitrogen product of bacterial decomposition of organic matter and is the form of nitrogen most readily available to plants for uptake and growth. Sources of ammonia in the watershed may come from animal feeding areas, decaying organic matter, bacterial conversion of other nitrogen compounds, or industrial and municipal surface water discharges.

Total Ammonia Nitrogen as N

Ammonia nitrogen is present in surface and ground water supplies. Ammonia nitrogen is a dissolved inorganic form of nitrogen. This nitrogen associated with ammonia is a nutrient for algae and macrophytes. High levels may indicate excessive algae growth, macrophyte growth, and/or presence of sanitary waste, and can be detrimental to aquatic life.

Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen (TKN) is used to calculate organic nitrogen. TKN minus ammonia derives organic nitrogen. Sources of organic nitrogen can include release from dead or decaying organic matter, septic systems or agricultural waste. Organic nitrogen is broken down to more usable ammonia and other forms of inorganic nitrogen by bacteria.

Total Nitrogen

Total nitrogen is the sum of nitrate-nitrite and TKN concentrations. Total nitrogen is used mostly in determining the limiting nutrient, either nitrogen or phosphorus. Nitrogen was analyzed in four forms: nitrate/ nitrite, ammonia, and Total Kjeldahl Nitrogen (TKN). From these four forms, total, organic, and inorganic nitrogen may be calculated. Nitrate and nitrite levels are usually caused from fertilizer application runoff. High ammonia concentrations are directly related to sewage and fecal runoff. Nitrogen is difficult to manage because it is highly soluble and very mobile in water.

Total Phosphorus

Phosphorus differs from nitrogen in that is not as water-soluble and will attach to fine sediments and other substrates. Once attached, it is less available for uptake and utilization. Phosphorus can be natural from geology and soil, from decaying organic matter, waste from septic tanks or agricultural runoff. Nutrients such as phosphorus and nitrogen tend to accumulate during low flows because they are associated with fine particles whose transport is dependent upon discharge (Allan 1995). These nutrients are also retained and released on stream banks and floodplains within the watershed. Phosphorus will remain in the sediments unless released by increased stage, discharge, or current.

Total Dissolved Phosphorus

Total dissolved phosphorus is the fraction of total phosphorus that is readily available for use by algae. Dissolved phosphorus will attach to suspended materials if they are present in the water column and if they are not already saturated with phosphorus. Dissolved phosphorus is readily available to algae for uptake and growth.

Fecal Coliform Bacteria

Fecal coliform are bacteria that are found in the environment and are used as indicators of possible sewage contamination because they are commonly found in human and animal feces. They indicate the possible presence of pathogenic bacteria, viruses, and protozoans that also live in human and animal digestive systems. These bacteria can enter the river and tributaries by runoff from feedlots, pastures, sewage treatment plants, and seepage from septic tanks.

E. Coli

Escherichia coli is a type of fecal coliform bacteria that is found in the intestines of healthy humans and animals. The presence of *E. coli* in water is a strong indication of recent sewage or animal waste contamination, which may contain disease causing organisms.

Dissolved Oxygen

Dissolved oxygen is important for the growth and reproduction of fish and other aquatic life. Solubility of oxygen generally increases as temperature decreases, and decreases with lowing atmospheric pressure. Stream morphology, turbulence, and flow can also have an affect on oxygen concentrations. Dissolved oxygen concentrations are not uniform within or between stream reaches. A stream with running water will contain more dissolved oxygen than still water. Cold water holds more oxygen than warm water. Dissolved oxygen levels of at least 4-5 mg/L are needed to support a wide variety of aquatic life. Very few species can exist at levels below 3 mg/L.

pH

pH is based on a scale from 0 to 14. On this scale, 0 is the most acidic value, 14 is the most alkaline value, and 7 represents neutral. A change of 1 pH unit represents a 10-fold change in acidity or alkalinity. The range of freshwater is 2-12. pH is a measure of hydrogen ion activity, the more free hydrogen ions (more acidic), the lower the pH in water. Values outside the standard (pH 6.0 – 9.5) do not meet water quality standards.

Water Temperature

Water temperature affects aquatic productivity and water chemistry, including the levels of DO and un-ionized ammonia. Temperature extremes are especially important in determining productivity of aquatic life from algae to fish.

Conductivity

Conductivity is the measurement of the conductive material in the sample without regard to temperature. In streams and rivers, conductivity is affected primarily by the geology of the area through which the water flows. Streams that run through areas with granite bedrock tend to have lower conductivity, and areas with clay soils tend to have higher conductivity. In lakes, geology of the watershed establishes the ranges of conductivity. In general, a higher conductivity indicates that more material is dissolved material, which may contain more contaminants.

Specific Conductivity

Also known as temperature compensated conductivity which automatically adjusts the reading to a calculated value which would have been read if the sample had been at 25^{o} C. The ability of water to conduct an electrical current, which is the measure of the quantity of ions in the water. It is determined by the presence of inorganic dissolved solids, such as salts. Specific conductivity is generally found to be a good measure of the concentration of total dissolved solids (TDS) and salinity.

Salinity

Salinity is the natural concentration of salts in water. This is influenced by the geologic formations underlying the area. Salinity is lower in areas underlain by igneous formations and higher in areas underlain by sedimentary formations.

Turbidity (NTU)

Turbidity or water clarity is a measure of how much the passage of light is restricted by suspended particles. Turbidity is measured in nephelometric turbidity units (NTUs). High NTU levels may increase temperatures; lower dissolved oxygen levels, and reduce photosynthesis. High NTU levels can clog fish gills, which lowers growth rate and resistance to disease; and it can smother fish eggs and macro invertebrates. Sources of turbidity include soil erosion, waste discharge, urban runoff, eroding stream banks, and excessive algae growth.

Secchi Disk

A Secchi disk is a flat, with black and white alternating quadrants that used to measure the transparency of water. The disk is lowered into water by a rope until the pattern on the disk is no longer visible. The deeper the measurement, the clearer the water.

Water Quality Sampling

Water quality was sampled in accordance with the SD DENR Water Resource Assistance Program protocols (Stueven et al. 2000). Samples were filtered and preserved as appropriate and then packed in ice for delivery to its destination for analysis. Stream, climatic, and weather conditions were also recorded at the time of sampling. See Appendix D for water quality field data sheet.

Tributary (inlet/outlet) Sampling

Water quality samples were collected between the spring of 2001 and the fall of 2002, during base flows and storm events. The Water Resource Institute at South Dakota State University in Brookings, South Dakota performed the analysis of total solids, total suspended solids, ammonia, nitrate-N, total Kjeldahl nitrogen, organic nitrogen, total phosphorus, and total dissolved phosphorus. The Sioux Falls Health Laboratory in Sioux Falls, South Dakota analyzed all fecal coliform bacteria samples.

In-Lake Sampling

East Oakwood Lake Samples were collected between the spring of 2001 and the fall of 2002. Samples were colleted at the surface and one meter from the bottom using a Van Dorn sampler. Water samples were delivered to the WRI Lab at SDSU in Brookings, South Dakota for analysis. In 2003, a column sampler was used to collect total phosphorus and total dissolved phosphorus samples from East Oakwood Lake. These samples were delivered to the State Health Laboratory in Pierre, South Dakota for analysis. With the addition of West Oakwood Lake in the fall of 2003, water samples were collected from Johnson Lake and Lake Tetonkaha in 2004. These samples were collected using a column sampler and were also sent to the State Health Laboratory in Pierre, South Dakota for analysis (Table 12).

Table 12. Sampling Years and Laboratories that Processed the Samples

	2001*	2002*	2003**	2004**
Tributary	X	X		
East Oakwood Lake	X	X	TPO4 & TDPO4	
Tetonkaha Lake				X
Johnson Lake				X
Laboratory	WRI	WRI	SHL	SHL

WRI = Water Resource Institute   * Van Dorn Sampler used
SHL = State Health Lab   ** Column Sampler used

Biological Monitoring (Tributaries)

Macroinvertebrate Sampling

Sampling of macroinvertebrates with cone and flat rock baskets occurred in the tributaries sites from late August to mid October of 2002. Four baskets were placed at each site for a period of 45 days ± 3 days
(Table 13). Construction, deployment, and retrieval of rock baskets were conducted according to the SD DENR protocols (Stueven et al. 2000). Sorting, identification, and enumeration of macroinvertebrates occurred at the lowest practical taxonomic level (See Appendix E for outsource contracts and laboratory procedures). Three of the four baskets, at each site, were chosen for collection and were composited into a voucher jar. Candidate metrics were calculated for the entire North-Central Big Sioux River watershed and reduced to a set of core metrics for site by site scoring.

Table 13. Deployment and Retrieval Dates for Rock Baskets by Site

Site	Site Name	Method	Deployment Date	Retreival Date	# Days Colonized
T43	East Oakwood Lake Trib 1	---------------------DRY------------------------			
T44	East Oakwood Lake Trib 2	Cone	8/28/2002	10/10/2002	44
T45	East Oakwood Lake Outlet 1	Flat	8/28/2002	10/10/2002	44
T46	East Oakwood Lake Outlet 2	Flat	8/29/2002	10/11/2002	44
T48	E. Oakwood Lake Inlet 3	Cone	8/29/2002	10/11/2002	44

Macroinvertebrate Index of Biological Integrity (IBI)

A macroinvertebrate IBI was previously established by EDWDD during the North-Central Big Sioux River Watershed Assessment Project. Those same methods were applied to this project as there are currently no established reference sites for data comparison. The following steps were taken in developing an index score for each site

Candidate metrics were chosen to represent the categories of abundance richness, composition, tolerance/intolerance, and feeding (Table 14). The EPA Rapid Bioassessment Protocols for Use in Streams and Rivers aided in developing these procedures (Barbour et al. 1999). Core metrics were then chosen in each category through a process of comparative descriptive analysis (Table 15). The basis of this selection was the ability of each metric to discriminate between sites least impacted and sites most impacted. Comparative descriptive analysis was done using box and whisker plots, analyzing all data from all the monitoring sites at the same time for each of the five categories (abundance, richness, composition, tolerance, and feeding). Box plots that yielded a good spread and differing means were chosen as metrics in each category. Coefficients of variation (CVs) were found by dividing the standard deviation (SD) by the mean. CVs also aided in the selection of the core metrics.

Table 14. Candidate Macroinvertebrate Metrics Calculated for the NCBSRWA

Category	#	Metric	Responseto Disturbance
Abundance Measures	1	Abundance	Decrease
	2	Corrected Abundance	Variable
	3	EPT Abundance	Decrease
Richness Measures	4	Total No. Taxa	Decrease
	5	Number of EPT Taxa	Decrease
	6	Number of Ephemeroptera Taxa	Decrease
	7	Number of Trichoptera Taxa	Decrease
	8	Number of Plecoptera Taxa	Decrease
	9	Number of Diptera Taxa	Decrease
	10	Number of Chironomidae Taxa	Decrease
Composition Measures	11	Ratio EPT/Chironomidae Abundance	Decrease
	12	% EPT	Decrease
	13	% Ephemeroptera	Decrease
	14	% Plecoptera	Decrease
	15	% Trichoptera	Decrease
	16	% Coleoptera	Decrease
	17	% Diptera	Increase
	18	% Oligochaeta	Variable
	19	% Baetidae	Increase
	20	% Hydropsychidae	Increase
	21	% Chironomidae	Increase
	22	% Gastropoda	Decrease
	23	Shannon-Weiner Index	Decrease
Tolerance/Intolerance Measures	24	Number of Intolerant Taxa	Decrease
	25	% Intolerant Organisms	Decrease
	26	Number of Tolerant Taxa	Increase
	27	% Tolerant Organisms	Increase
	28	% Burrowers	Increase
	29	% Chironimidae + Olgochaeta	Increase
	30	Hilsenhoff Biotic Index	Increase
	31	% Dominant Taxon	Increase
	32	% Hydropsychidae to Trichoptera	Increase
	33	% Baetidae to Ephemeroptera	Increase
Feeding Measures	34	% individuals as Gatherers and filterers	Decrease
	35	% Gatherers	Decrease
	36	% Filterers	Increase
	37	% Shredders	Decrease
	38	% Scrapers	Decrease
	39	Ratio Scrapers/(Scrapers+Filterers)	Decrease
	40	Number of Gatherer Taxa	Decrease
	41	Number of Filterer Taxa	Decrease
	42	Number of Shredder Taxa	Decrease
	43	Number of Scraper Taxa	Decrease
	44	Individuals as Clingers	Decrease
	45	Number of Clinger Taxa	Decrease
	46	% Clingers	Decrease
	47	Number of Predator Organisms	Variable
	48	Number of Predator Taxa	Variable
	49	% Predators	Variable

Table 15. Core Macroinvertebrate Metrics Calculated for the BSR and Tributaries in the NCBSRW

Category	#	Metric	Response to Disturbance
Abundance Measures	1	Abundance	Decrease
Richness Measures	2	Total Number of Taxa	Decrease
	3	Number of EPT Taxa	Decrease
	4	Number of Diptera Taxa	Decrease
Composition Measures	5	% EPT	Decrease
	6	% Diptera	Increase
	7	% Chironomidae	Increase
Tolerance/Intolerance Measures	8	% Tolerant Organisms	Increase
	9	% Chironomidae + Oligochaeta	Increase
	10	% Hydropsychidae/Trichoptera	Increase
Feeding Measures	11	% Gatherers	Decrease
	12	% Filterers	Increase
	13	% Clingers	Decrease

Once the core metrics in Table 23 were chosen, best value percentiles were calculated. The 95th percentile was used as a basis for best value for those metrics that decreased with impairment. Those metrics that increased with impairment were given a 5th percentile as a basis for best value. Once either the 95th or 5th percentile standard was set for each metric, the actual measured metric value was compared to the standard best value to find the standardized metric score. Standardized metric scores range from 0 to 100, with 0 being very poor and 100 being excellent.

Decrease in response to impairment:

measured metric value ÷ (standard best value – 0) x 100 = standardized metric score

Increase in response to impairment:

(100 - measured metric value) ÷ (100 - standard best value) x 100 = standardized metric score

After each of the core metrics were scored, the standardized metric scores were averaged for each monitoring site and served as the final index value for that site.

Biological Monitoring (Lakes)

Algae Sampling

In-lake algae sampling occurred once in mid-June and once in mid-August during the regularly scheduled water quality sampling. Samples from East Oakwood Lake were collected during the summer of 2003 and samples from West Oakwood Lake (Johnson Lake and Lake Tetonkaha) were collected during the summer of 2004. A surface water sample was collected at a depth of approximately one meter at three different locations on each lake, to include the established monitoring sites. The three samples were equally combined into one overall sample and then preserved with Lugol's iodine. Samples from each of the three lakes were collected and shipped to the SD DENR for analysis. Algae sampling was conducted according to SD DENR protocols (Stueven et al. 2000).

Chlorophyll-*a* Sampling

Chlorophyll-*a* was sampled at each monitoring location on each lake. Sampling occurred once per month in April, May and September, and twice per month (every other week) in June, July, and August, during the regularly scheduled water quality sampling. However, in June, July, and August, when chlorophyll-*a* sampling did not correspond with regular water quality sampling, the sampling also included chlorophyll-*a*, total phosphorus, total dissolved phosphorus, water temperature, Secchi depth, turbidity, pH, dissolved oxygen, salinity, conductivity, specific conductivity, and air temperature. At each location, a column sampler was used to collect the sample which was stored in a light impenetrable brown bottle. The sample was filtered using a 1.0 micron glass fiber filter with the volume of sample annotated. The filter containing the chlorophyll-*a* sample was wrapped in aluminum foil, placed on ice, and shipped to the SD DENR in Pierre, South Dakota for analysis. Chlorophyll-*a* was sampled according to the SD DENR protocols (Stueven et al. 2000). Two of the three lakes (East Oakwood Lake and Lake Tetonkaha) were also monitored for chlorophyll-*a* by the state of South Dakota as part of the SD DENR assessment monitoring program. The SD DENR sampled East Oakwood Lake twice during the summer of 2002 and Lake Tetonkaha twice during the summers of 2000 and 2004.

Aquatic Plant Sampling

Aquatic plants were surveyed in East Oakwood Lake, Johnson Lake, and Lake Tetonkaha. East Oakwood Lake was surveyed from July 31 to August 8, 2003. The shoreline was divided into 29 transects (Figure 6). A survey was conducted on Lake Tetonkaha and Johnson Lake from July 28 to August 13, 2004. The shoreline of Johnson Lake was divided into 20 transects and the shoreline of Lake Tetonkaha was divided into 29 transects (Figures 7 and 8). A buoy attached to a 100 m floating rope, marked in 10 m increments, was used to sample each transect. One end of the rope was staked to the shoreline, and the other end was attached to an anchored buoy which was positioned perpendicular to the shoreline. Lake depth was annotated at the buoy and also at each 10 m increment that was sampled. Starting at the 10 m increment closest to the shoreline, a vegetation rake was cast from the boat in four directions (north, south, east, and west) and slowly retrieved. After each cast, vegetation caught in the tines was identified and recorded. This process was repeated at successive 10 m increments until no vegetation in any of the four directions was documented. A sample of each species was kept and later taken to Dr. Gary Larson at SDSU for verification. Other data recorded included GPS coordinates, identifying transect features on map, date, time, bank stability, shoreline vegetation, riparian zone width, and Secchi depth.

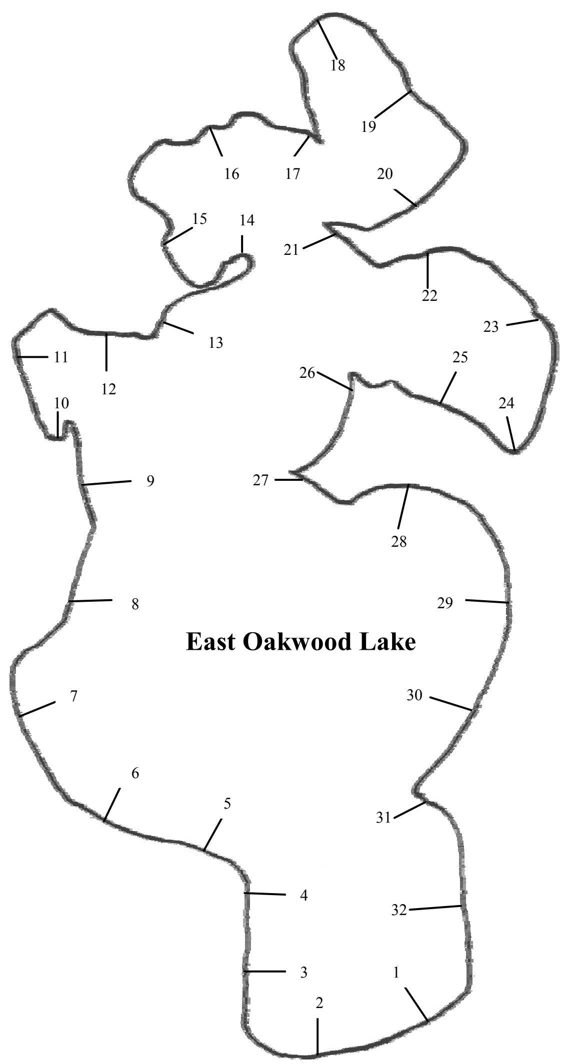


Figure 6. Diagram of the East Oakwood Lake Vegetation Sampling Transects

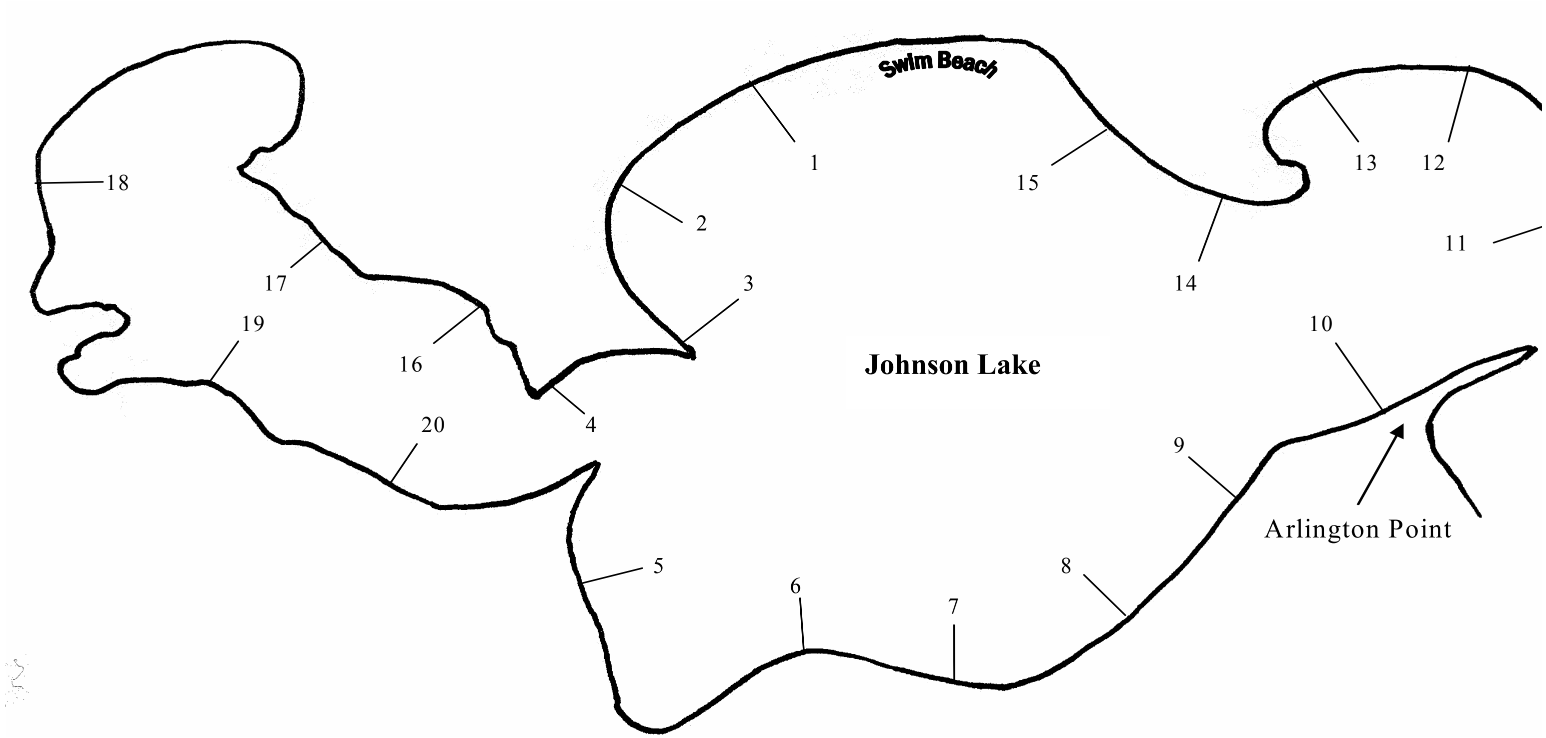


Figure 7. Diagram of the Johnson Lake Vegetation Sampling Transects

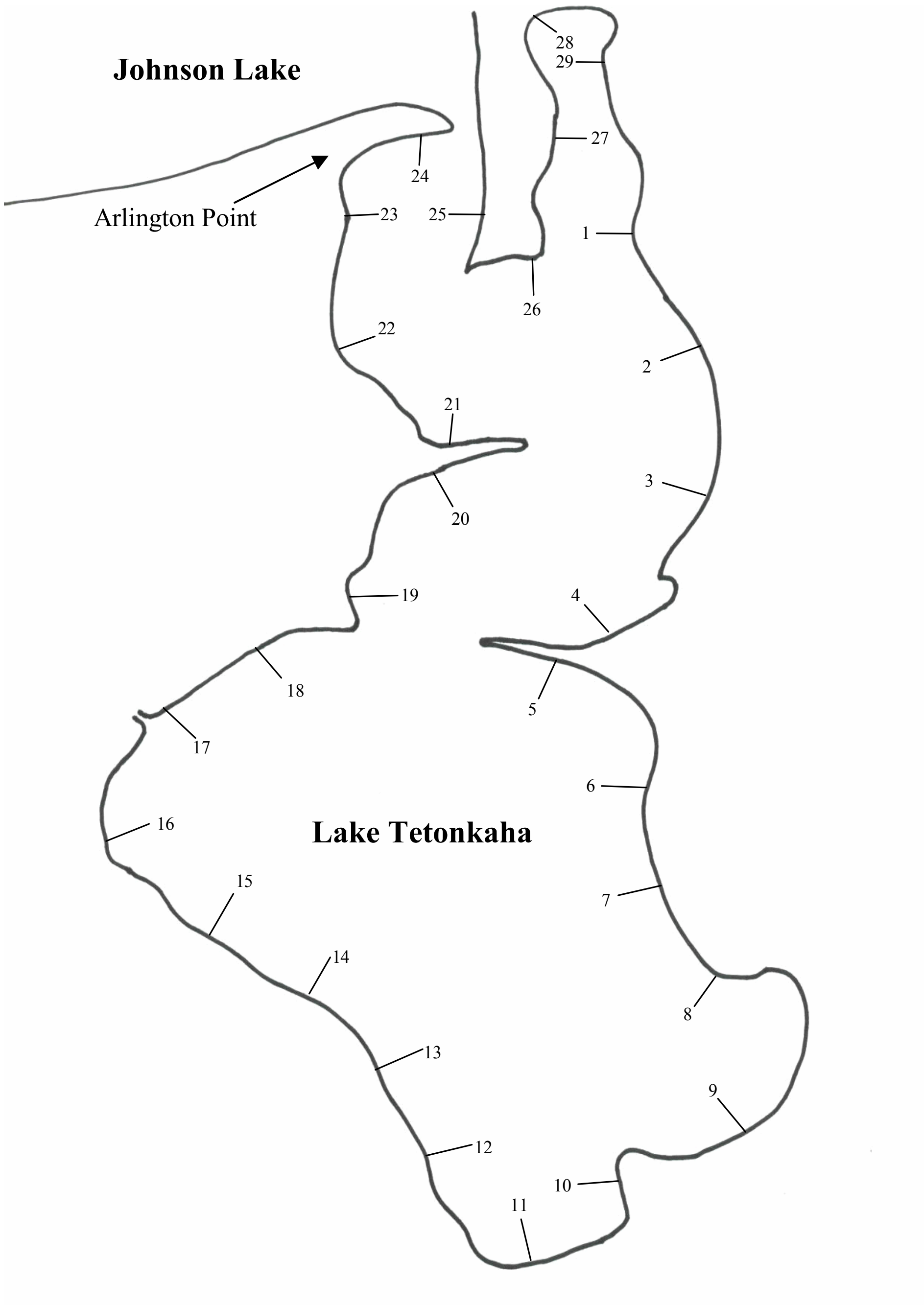


Figure 8. Diagram of Lake Tetonkaha Vegetation Sampling Transects

Hydrologic Monitoring

Tributary

Five tributary monitoring sites were selected among the inlets and outlets of the lakes in the watershed and continuous stream flow records were collected using flow meters. Two inlet sites (T48 and T43) and three outlet sites (T44, T45, and T46) were selected to determine which portions of the watershed were contributing the greatest amount of nutrient and sediment loads to the lakes. Each tributary site was equipped with a Thalimedies OTT hydrometer (Table 16) and water stages were monitored and recorded to the nearest 1/100th of a foot.

Table 16. Stage Recorder Start and End Dates

Site	Site Name	Start Date	End Date	Recorder Type
T43	East Oakwood Lake Trib 1	05/29/01	10/30/01	OTT Thalimedes Hydrometer
		04/05/01	10/31/02	OTT Thalimedes Hydrometer
T44	East Oakwood Lake Trib 2	06/01/01	10/30/01	OTT Thalimedes Hydrometer
		04/05/02	10/31/02	OTT Thalimedes Hydrometer
T45	East Oakwood Lake Outlet 1	05/29/01	10/30/01	OTT Thalimedes Hydrometer
		04/05/02	10/31/02	OTT Thalimedes Hydrometer
T46	East Oakwood Lake Outlet 2	05/29/01	10/30/01	OTT Thalimedes Hydrometer
		04/05/02	10/31/02	OTT Thalimedes Hydrometer
T48	E. Oakwood Lake Inlet #3	05/31/01	10/30/01	OTT Thalimedes Hydrometer
		04/05/02	10/31/02	OTT Thalimedes Hydrometer

A USGS top setting wading rod with a pygmy current meter and a CMD 9000 digimeter were used to determine flows at various stages. Each tributary site was also installed with a USGS Style C staff gauge as a quality control check for the installed meters. Recorded stages and flows were used to create stage-discharge tables and curves for each tributary (Gorden et al. 1992). Stage-discharge tables, curves, and equations can be found in the Results Section.

In-Lake

Hydrologic monitoring of each lake consisted of tracking lake levels using existing benchmarks established by the SD DENR, Water Rights Program. A location description of each benchmark is shown in Table 17.

Table 17. Oakwood Lakes Benchmark Locations

Waterbody	Location
East Oakwood Lake	Located in the NW Section 8 T111N-R51W, approximately 0.80 mile into the State Park, on the south side of the curve in the road, 1' east of the OHWM sign, a standard OHWM disk
Lake Tetonkaha	Located in the NW Section 8 T111N-R51W, approximately 0.80 mile into the State Park, on the south side of the curve in the road, 1' east of the OHWM sign, a standard OHWM disk
Johnson Lake	Located in the NE of Section 6 T111N-R51W, on road to the picnic grounds between Mortimer Slough and West Oakwood Lakes, in the northwest part of the park on the northeast side of the parking area, 1' west of the OHWM sign, standard OHWM disk

Hydrologic Budgets

The hydrologic budget estimates how much water entered and exited the lake during the study period. All inputs of water must equal all outputs of water in a hydrologic cycle. However monitoring all possible inputs of water to a lake is very difficult. Thus, an estimate of water load to the lake is necessary to balance the equation.

The hydrologic inputs to East Oakwood Lake and West Oakwood Lake come from sources to include precipitation, tributary runoff, and groundwater. Water quality data from tributary runoff was collected from July 2001 to September 2002. Estimates of tributary runoff were calculated using the results of the FLUX modeling. Rainfall for the year 2003 was collected from the Brookings, South Dakota field station and used to calculate precipitation inflows. The following equations were used to determine the inputs for the hydrologic budget:

Precipitation:

amount of precipitation (feet) × surface area of the lake = precipitation inflow

Groundwater:

outflows - inflows = groundwater inflow

The hydrologic outputs come from sources such as evaporation, advective flow, and change in storage. East Oakwood Lake water quality data was collected from July 2001 to September 2003. Evaporation data was measured from the nearest weather station which is located two miles north of Brookings, South Dakota. The following equations were used to find the outputs of the hydrologic budget:

Evaporation:

amount of evaporation (feet) × surface area of the lake = evaporation volume

Change In Storage:

first benchmark reading – last benchmark reading = change in storage

change in storage × surface area of the lake = change in storage

TSI Computation

Carlson's (1977) Trophic State Index was used to quantify the trophic condition of each lake. In-lake data for chlorophyll-*a* and Secchi depth was applied to Carlson's equations. The formulas used are below:

$$TSI\ (Chlorophyll\text{-}a) = 10 \times (6 - ((2.04 - (0.68\ (LN\ (CHL)))/\ (LN\ 2)))$$

$$TSI\ (Secchi\ Disk) = 10 \times (6 - (LN\ SD) / (LN\ 2))$$

CHL = Chlorophyll-*a* in mg/m^3
SD = Secchi depth in meters

TSI values typically range from 0 to 100, indicating increasing productivity as the index score increases.

QUALITY ASSURANCE AND DATA MANAGEMENT

Approximately 10 percent of the water samples were collected for quality assurance/quality control purposes in accordance with South Dakota's EPA approved Non-point Source Quality Assurance/Quality Control Plan. A total of 154 water samples were collected from nine monitoring sites. There were a total of 30 QA/QC samples consisting of 15 duplicates and 15 blanks.

QA/QC results were entered into a computer database and screened for data errors. Overall, the duplicates produced very similar results to the sample itself, with the exception of fecal coliform counts, TSS, ammonia, and nitrate-nitrite. Variations among duplicate bacteria samples may have occurred because of bacteria variability. Differences in the results from 2001-2002 containing nitrogen (nitrate-nitrite, organic nitrogen, TKN) may be attributed to the use of reverse osmosis water for cleaning and filtering and also due to faulty lab equipment used by the WRI lab in the analysis. Unfortunately, the WRI lab director was unable to come up with a correction factor due to the randomness of the errors. A copy of WRI lab director's memo is located in Appendix F.

Field blanks did register a few detectable limits of nutrients and sediments. The sediment detects may be due to inadequate rinsing of bottles or the quality of rinsing water. Sources of the nitrogen problems may have been the quality of the rinsing water, but more likely due to faulty lab equipment used for the analysis. See Appendix G for field duplicates and blanks.

ASSESSMENT OF SOURCES

Point Sources

Wastewater Treatment Facilities (NPDES)

There were no NPDES facilities identified in this watershed.

Non Point Sources

Agricultural Runoff

Agricultural runoff was taken into account when the AnnAGNPS model calculated landuse scenarios for sediment and nutrient reductions, and also when AGNPS was used to perform ratings on the feedlots in the study area. This information was then incorporated as part of the process of prioritizing watershed areas for fecal reduction.

Background Wildlife Contribution

As part of the background contribution of fecal coliform bacteria, wildlife was taken into consideration. A general estimate of wildlife fecal coliform bacteria loading was derived from assessing total deer contributions. Deer are the largest of the wild animals occupying the study area and factual information was readily available about this animal. Using 2002 deer population numbers (Huxoll 2002) for Brookings County, estimates of deer per square mile were calculated. Two monitoring site locations were used to calculate this contribution. They were chosen because neither site was influenced by any other monitoring locations within the study area (See the Results Section).

The average deer per square mile was multiplied by the square miles of the township the monitoring sites (T43 and T45) were located in, giving number of deer per township.

deer/square mile × square miles/township = deer/township

Then the number of deer per township was multiplied by the number of days monitored and then multiplied by the CFU/deer/day (MPCA 2002) to calculate total CFU's per township from deer.

deer/township × # monitoring days × CFU/deer/day = CFU’s per township (from deer)

To determine the percent deer contribution of fecal coliform bacteria, CFU’s per township per deer were divided by the total CFU’s monitored, multiplied by 100.

[CFU’s per township ÷ CFU’s monitored] × 100 = % deer contribution of fecal coliform bacteria

Failing Septic Systems Contribution

As part of the background contribution from fecal coliform bacteria, rural households were assessed for their contribution of the total fecal concentration in the watershed. The average number of people per household (MPCA 2002) was multiplied by the number of rural and seasonal households within the watershed. This provided an estimate of the number of people living in the watershed area. According to the US EPA (2002) failure rates of onsite septic systems range from 10 to 20 percent, with the majority of these failures occurring with systems 30 or more years old. Due to this fact, 20 percent of the households within the vicinity of each monitoring site were used to figure septic contribution. The average number of people per household (MPCA 2002) was multiplied by 20 percent of the total number of households within the watershed. This represented the number maximum number of people that may be contributing to the fecal coliform bacteria load.

average number of people per household × # of households (20%) = total number of people

Then the total number of people was multiplied by the number of days monitored and then multiplied by the CFU/person/day to calculate total CFU’s per monitored site being contributed by failing septics.

total number of people per area × # monitoring days ×CFU/people/day = CFU’s per area (from people)

To determine the percent of fecal coliform bacteria contributed by failing septics, CFU’s per area (from people) were divided by the total CFU’s monitored in the stream and then multiplied by 100 to find a percent of septic contribution.

[CFU’s per area ÷ CFU’s monitored] × 100 = % septic system contribution of fecal coliform bacteria

Modeling

Five basic modeling and assessment techniques (FLUX, BATHTUB, AGNPS, AnnAGNPS, and FDI) were used to analyze the data for this assessment project (Table 18). Each technique generates an independent set of information and is described below in further detail.

Table 18. Modeling and Assessment Techniques and Outputs

Modeling Techniques	Outputs
FLUX Model	Loadings for WQ Parameters Concentrations for WQ Parameters
BATHTUB Model	Trophic State Index (TSI) Values Reduction Response Model
AGNPS	Total Phosphorus and Nitrogen Chemical Oxygen Demand (COD) Feedlot Rating
AnnAGNPS	Phosphorus Yield (attached & soluable) Nitrogen Yield (attached & soluable) Sediment Yield
Flow Duration Interval	Hydrologic Condition Targets and Loads Load Reductions by Flow Regime

FLUX Model

Total nutrient and sediment loads were calculated using the Army Corps of Engineers Eutrophication Model known as FLUX (Walker 1999). FLUX uses individual sample data in correlation with daily discharges to develop six loading calculations. For each monitoring site, loads and concentrations of total suspended solids, as well as water quality parameters were calculated by the model. The FLUX model uses data obtained from 1) grab-sample water quality concentrations with an instantaneous flow and 2) continuous flow records. Loadings and concentrations were calculated by month and stratified into low and high flows. Coefficients of variation (CV) were used to determine what method of calculation was appropriate for each parameter at each site (Results Section). Each water quality parameter was computed by site as daily, monthly and yearly concentrations and loadings. See Appendix H for monthly concentrations by site, and Appendix I for monthly loadings by site.

Water quality, sampled according to Stueven et al. (2000), was analyzed at South Dakota State University, Water Quality Laboratory and the State Health Laboratory. Water quality analyses provided concentrations for a standard suite of parameters previously mentioned. Continuous streamflow records for tributary sites were derived using stage records and stage-discharge curves (Appendix J).

BATHTUB Model

The BATHTUB model was used to predict in-lake responses to tributary loadings. Input data for the model consisted of general lake morphology, tributary loading data, and current in-lake water quality. Tributary loading data was calculated for the inlets of the lake using average water quality results. The BATHTUB model is predictive in that it will assess impacts of changes in water and/or nutrient loadings. The model assumes if nutrient concentrations were reduced, the overall TSI values for total phosphorus, chlorophyll-*a*, and Secchi disk would be reduced, indicating improvement in water quality. Existing tributary nutrient concentrations were reduced by successive ten percent increments and modeled to create an in-lake reduction curve. This model was used to assess both East Oakwood Lake and West Oakwood Lake.

AGNPS Feedlot Model

The Agricultural Non-Point Source Pollution (AGNPS) model is a GIS-integrated water quality model that predicts non-point source pollutant loadings within agricultural watersheds. ArcView GIS software was used to spatially analyze feedlots and their pollution potential.

Watersheds dominated by agricultural land uses, pasturing cattle in stream drainages, runoff from manure application, and runoff from concentrated animal feeding operations can influence fecal coliform bacteria concentrations. The AGNPS feedlot assessment assumed the probable sources of fecal coliform bacteria loadings were related to agricultural land use (upland and riparian), use of streams for stock watering, and animal feeding operations.

The methods used to determine loadings and reductions of fecal coliform bacteria in the Oakwood Lakes watershed could serve as an integrated measure of runoff from feedlots and land uses. Pollutant frequency was measured using the density of feedlots located upstream of a monitoring site. A feedlot score, based on proximity to the receiving waters, provided an indicator of potential fecal coliform bacteria input to that water. Upland and riparian land uses provided an indicator of the availability of upland areas available for pastured livestock. A complete methodology report can be found in Appendix K.

AnnAGNPS Landuse Model

The AnnAGNPS model expands the capabilities of the AGNPS model described above. This model is intended to be used as a tool to evaluate non-point source pollution from agricultural watersheds ranging in size up to 740,000 acres. With this model the watershed is divided into homogenous land areas or cells based on soil type, land use, and land management. AnnAGNPS simulates the transport of surface water, sediment, nutrients, and pesticides through the watershed. The current condition of the watershed can be modeled and used to compare the effects of implementing various conservation alternatives over time within the watershed. The results of the AnnAGNPS model can be found in the Results Section.

Flow Duration Intervals

Flow duration intervals were constructed for fecal coliform bacteria and total suspended solids at all monitored tributary sites. This method calculates fecal coliform bacteria, (concentration) x (flow), except uses zones based on hydrologic conditions and the medians of the fecal coliform bacteria grab sample data. By defining hydrologic conditions, targeting specific restoration efforts is easier. The five hydrologic conditions are (1) High Flows (0-10%), (2) Moist Conditions (10-40%), (3) Mid-Range Flows (40-60%), (4) Dry Conditions (60-90%), and (5) Low Flows (90-100%).

Two major accumulations of data were used to calculate reductions: (1) discharge data and (2) water quality samples. Table 19 lists the years of record used for the construction of the flow duration interval graphs.

Table 19. Flow Duration Interval Graph Dates

	Grab Data (May-Sep) Years		Discharge Data Years	
Site	EDWDD	DENR	EDWDD	USGS
* T43	2001-2002	----	2001-2002	----
* T44	2001-2002	----	2001-2002	----
* T45	2001-2002	----	2001-2002	----
* T46	2001-2002	----	2001-2002	----
* T48	2001-2002	----	2001-2002	----
* Numeric Standard for Fecal Coliform Bacteria Does Not Apply				

The target line was graphed along 21 points using percentiles of the target load at matching flows. Similarly, grab samples were plotted using the instantaneous flow at the time the sample was taken. Medians and 90th percentiles were calculated, per zone, for grab sample data. Samples collected during rain events are indicated with an 'X'. Those samples indicated with a red box are exceedences of the allowable load.

To find the percent reduction per hydrologic condition, the median of the allowable load within a hydrologic zone (target) was divided by the median of the sampled load at that particular hydrologic condition (site value) and then subtracted from 1.

$$1 - [(\text{Target}) \div (\text{Site Value})] = \%\ \text{reduction}$$

To find the reduction with a 10% margin of safety applied the following equation was used:

$$100 - [(\text{Target} \div 1.1) \div (\text{Site Value})] \times 100 = \%\ \text{reduction with MOS}$$

These curves are developed using an average daily, long-term record of stream flow. These flows are then ranked from highest to lowest. The percent of days each flow was exceeded was calculated by dividing each rank by the number of flow data points.

$$\text{rank} \div \text{number of data points} = \text{percent of days the flow was exceeded}$$

Next, a load needs to be calculated. This is done by multiplying each average daily flow by the water quality standard for the parameter and multiplying by the conversion factor.

$$\text{flow (cfs)} \times \text{standard (mg/L)} \times \text{conversion factor} = \text{load}$$

The conversion factor for converting the mg/L to pounds per day for TSS is 5.396, as shown by the following formula:

$$\frac{\text{mg}}{\text{L}} \times \frac{1\ \text{L}}{0.0353146667\ \text{ft}^3} \times \frac{86400\ \text{sec}}{1\ \text{day}} \times \frac{\text{ft}^3}{\text{sec}} \times \frac{1\ \text{lb}}{453592.37\ \text{mg}} = \text{lbs/day}$$

The conversion factor for converting cfu/100mL to colonies per day for fecal coliform bacteria is 24,468,480 as shown by the following formula:

$$\frac{\text{col}}{\text{day}} \times \frac{28320\ \text{mL}}{1\ \text{ft}^3} \times \frac{86400\ \text{sec}}{1\ \text{day}} \times \frac{\text{ft}^3}{\text{sec}} = \text{col/day}$$

RESULTS

WATER QUALITY MONITORING

The data was evaluated based on the specific criteria that the DENR developed for listing water bodies in the 1998 and 2002 South Dakota 303(d) Waterbody List, and in the 2004 and the 2006 Integrated Report. The EPA approved listing criteria used by the state of South Dakota during the assessment to determine if a waterbody is meeting its beneficial uses, is contained in the following paragraph. It should be noted that EPA guidance, in reference to TMDL targets, are based on the acute criteria of any one sample, which was used in establishing targets for the TMDLs of this assessment.

Use support was based on the frequency of exceedences of water quality standards (if applicable) for the following chemical and field parameters. A stream or lake with only a slight exceedence (10% or less violations for each parameter) is considered to meet water quality criteria for that parameter. The EPA established the following general criteria in the 1992 305(b) Report Guidelines (SD DENR 2000) suitable for determining use support of monitored streams.

Fully supporting	≤ 10 % of samples violate standards
Not supporting	> 10 % of samples violate standards

This general criteria is based on collecting 20 or more samples per monitoring location. Many of the monitoring sites were sampled less than 20 times. For those monitoring sites with less than 20 samples, the following criteria will apply:

Fully supporting	≤ 25 % samples violate standards
Not supporting	> 25 % of samples violate standards

Use support assessment for fishable use (fish life propagation) primarily involved monitoring levels of the following major parameters: dissolved oxygen, total ammonia nitrogen as N, water temperature, pH, and suspended solids. Use support for swimmable uses and limited contact recreation involved monitoring the levels fecal coliform bacteria (May 1 – September 30) and dissolved oxygen. If more than one beneficial use is assigned for the same parameter (i.e. fecal coliform bacteria) at a particular monitoring site, the more stringent criteria will apply. The use support for monitoring sites will be discussed further in the Assessment Section. The results for the following parameters are summarized below for all the assessed tributaries (T43, T44, T45, T46, and T48) and lakes in the watershed (L1, L2, L10, L11, and L12).

Tributary Seasonal Trends

Water quality parameters vary depending upon season due to changes in temperature, precipitation, and agricultural practices. Table 20 shows the average seasonal concentration for each parameter at Site T44, which is an inlet of East Oakwood Lake. Table 21 shows the average seasonal contribution for each parameter for Sites T45 and T46, which are located on an East Oakwood Lake outlet that drains into the Big Sioux River. Table 22 shows the average seasonal contribution for each parameter at Sites T43 and T48, which are inlets of West Oakwood Lake.

Table 20. Average Seasonal Concentrations (East Oakwood Lake Inlet)

	East Oakwood Inlet (from West Oakwood Lk)		
	Spring (Apr-May)	Summer (Jun-Aug)	Fall (Sept-Oct)
Parameter (mg/L)	T44	T44	T44
Diss. Oxygen	16.3	9.5	7.3
TSS	18	31	23
TotSol	898	965	1006
TDS	880	934	983
Nitrates	0.057	0.068	0.049
Ammonia	0.09	0.354	0.426
TKN	1.667	3.265	3.481
TPO4	0.117	0.281	0.265
TDPO4	0.043	0.089	0.076
Org Nitrogen	1.577	2.912	3.055

Table 21. Average Seasonal Concentrations (East Oakwood Lake Outlet)

	East Oakwood Outlet					
	Spring (Apr-May)		Summer (Jun-Aug)		Fall (Sept-Oct)	
Parameter (mg/L)	T45	T46	T45	T46	T45	T46
Diss. Oxygen	13.0	13.3	6.6	6.7	10.8	12
TSS	38	62	15	40	16	36.8
TotSol	832	823	979	989	1002	1147
TDS	795	761	964	949	986	1110
Nitrates	0.225	0.258	0.111	0.275	0.158	0.079
Ammonia	0.128	0.186	0.155	0.18	0.334	0.209
TKN	1.479	0.186	1.281	0.18	1.66	0.209
TPO4	0.182	0.261	0.164	0.298	0.192	0.195
TDPO4	0.101	0.135	0.134	0.167	0.133	0.067
Org Nitrogen	1.351	1.36	1.126	1.629	1.326	1.686

Table 22. Average Seasonal Concentrations (West Oakwood Lake Inlets)

	West Oakwood Inlets					
	Spring (Apr-May)		Summer (Jun-Aug)		Fall (Sept-Oct)	
Parameter (mg/L)	T43	T48	T43	T48	T43	T48
Diss. Oxygen	13.5	18.4	11.2	6.8	14.1	10.1
TSS	52	23	71	24	24	20
TotSol	1117	1374	1071	1124	1328	1054
TDS	1065	1351	1012	1100	1312	1035
Nitrates	0.361	0.496	0.592	0.334	0.059	0.05
Ammonia	0.131	0.051	0.128	0.299	0.269	0.286
TKN	1.377	1.329	1.933	2.572	1.417	2.774
TPO4	0.316	0.21	0.579	0.22	0.261	0.133
TDPO4	0.194	0.14	0.455	0.128	0.14	0.032
Org Nitrogen	1.246	1.277	1.846	2.102	1.283	2.488

The tributaries exhibited the highest dissolved oxygen concentrations (averaged) in the spring. The cooler water temperatures and higher flows contributed to the higher dissolved oxygen concentrations. Throughout the sampling period, average dissolved oxygen levels for the tributaries did not fall below 6.6 mg/L.

Higher total and dissolved solids were observed during the fall at all of the tributaries except Site T48 (Site T48 had higher concentration during the spring). The higher concentrations can be attributed to rainfall events which cause erosion of soils and runoff from agricultural lands and harvested crops.

Higher nitrate-nitrite concentrations occurred during the summer season at all of the tributaries except T46 (the highest average concentration of nitrate-nitrite at Site T46 occurred during the spring season). The highest summer average concentration of nitrate-nitrite was 0.592 mg/L at Site T43. The highest average concentrations of total Kjeldahl nitrogen and of organic nitrogen occurred in the fall at all the tributaries.

Total phosphorus and total dissolved phosphorus concentrations were highest during the summer months. The highest average summer concentration of total phosphorus entering East Oakwood Lake was from Site T44 (an inlet of East Oakwood Lake) with concentrations of 0.281 mg/L. The highest average summer concentration of total phosphorus entering West Oakwood Lake was from Site T43 (an inlet of West Oakwood Lake) with concentrations of 0.579 mg/L. Phosphorus contributions can increase the amount of algae growing in a lake, which in-turn causes reduced water clarity.

Tributary Water Quality Results

Chemical Parameters

Fecal Coliform Bacteria

Fecal coliform bacteria ranged from a no detect at East Oakwood Lake Tributary (T44) and East Oakwood Lake Inlet (T48), to a maximum of 13,000 cfu/100mL at East Oakwood Lake Outlet (T46) (Table 23). There are no fecal coliform bacteria standards for these tributary sites.

Table 23. Tributary Sites Fecal Coliform Bacteria Results

Fecal Coliform Bacteria cfu/100mL										
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
T43	East Oakwood Lake Trib 1	6	2755	340	10000	1500	----**	----	----
T44	East Oakwood Lake Trib 2	11	120	nd	950	nd	----	----	----
T45	East Oakwood Lake Outlet 1	11	1541	40	7800	730	----**	----	----
T46	East Oakwood Lake Outlet 2	11	3476	20	13000	2200	----**	----	----
T48	East Oakwood Lake Inlet 3	10	891	nd	5000	35	----**	----	----

Use support was determined by season (May 1 to September 30)
---- denotes no standard or beneficial use assigned
----** denotes no standard or beneficial use assigned, but there are violations if a standard were applicable

Total Solids

.

Total solids ranged from a minimum of 572 mg/L at East Oakwood Lake Outlet 2 (T46), to a maximum of 1,995 mg/L at East Oakwood Lake Inlet (T48). There are no total solids standards assigned to these tributary sites (Table 24).

Table 24. Tributary Sites Total Solids Results

Total Solids mg/L										
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
T43	East Oakwood Lake Trib 1	9	1143	667	1710	1288	----	----	----
T44	East Oakwood Lake Trib 2	14	962	824	1089	953	----	----	----
T45	East Oakwood Lake Outlet 1	14	954	698	1356	955	----	----	----
T46	East Oakwood Lake Outlet 2	14	999	572	1370	997	----	----	----
T48	East Oakwood Lake Inlet 3	14	1157	830	1995	1118	----	----	----

---- denotes no standard or beneficial use assigned

Total Suspended Solids

Total suspended solids ranged from a minimum of 4 mg/L at several sites, to a maximum of 153 mg/L at East Oakwood Lake Tributary (T43). There are no total suspended solids standards assigned to these tributary sites (Table 25).

Table 25. Tributary Sites Total Suspended Solids Results

Total Suspended Solids mg/L									
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
T43	East Oakwood Lake Trib 1	9	47	8	153	31	----	----	----
T44	East Oakwood Lake Trib 2	14	26	4	93	15	----	----	----
T45	East Oakwood Lake Outlet 1	14	20	4	58	17	----	----	----
T46	East Oakwood Lake Outlet 2	14	44	4	148	33	----	----	----
T48	East Oakwood Lake Inlet 3	14	22	4	74	15	----	----	----

---- denotes no standard or beneficial use assigned

Total Dissolved Solids (TDS)

Total dissolved solids ranged from a minimum of 476 mg/L at East Oakwood Lake Outlet 2 (T46), to a maximum of 1,988 mg/L at East Oakwood Lake Inlet (T48). A single grab sample daily maximum of 4,375 mg/L was used to determine the percent violations and assess for the beneficial use support of (9) Fish and Wildlife, Propagation, Recreation and Stock Watering for all tributary sites. Using this criterion, all sites are fully supporting of this parameter (Table 26).

Table 26. Tributary Sites Total Dissolved Solids Results

Total Dissolved Solids mg/L									
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
T43	East Oakwood Lake Trib 1	9	1096	656	1696	1280	0	0	Full
T44	East Oakwood Lake Trib 2	14	937	820	1012	938	0	0	Full
T45	East Oakwood Lake Outlet 1	14	934	640	1340	928	0	0	Full
T46	East Oakwood Lake Outlet 2	14	955	476	1340	976	0	0	Full
T48	East Oakwood Lake Inlet 3	14	1135	820	1988	1103	0	0	Full

Note: The standard is ≤ 4,375 mg/L for beneficial use (9)

Total Ammonia Nitrogen as N

Total ammonia nitrogen as N ranged from a minimum of 0.019 mg/L at East Oakwood Lake Outlet 2 (T46), to a maximum of 1.456 mg/L at East Oakwood Lake Tributary (T44). There are no ammonia standards assigned to these tributary sites (Table 27).

Table 27. Tributary Sites Total Ammonia Nitrogen as N Results

Ammonia Nitrogen as N mg/L										
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
T43	East Oakwood Lake Trib 1	9	0.130	0.062	0.198	0.128	----	----	----
T44	East Oakwood Lake Trib 2	14	0.318	0.030	1.456	0.221	----	----	----
T45	East Oakwood Lake Outlet 1	14	0.201	0.068	0.456	0.143	----	----	----
T46	East Oakwood Lake Outlet 2	14	0.190	0.019	0.326	0.217	----	----	----
T48	East Oakwood Lake Inlet 3	14	0.242	0.032	0.738	0.192	----	----	----
---- denotes no standard or beneficial use assigned									

Nitrate-Nitrite

Nitrate-nitrite ranged from a minimum of 0.024 mg/L at the East Oakwood Lake Outlet (T45), to a maximum of 2.462 mg/L at the East Oakwood Lake Inlet (T48). A single grab sample daily maximum of 88 mg/L was used to determine the percent violations and assess for the beneficial use support of (9) Fish and Wildlife Propagation, Recreation and Stock Watering for all tributary sites. Using this criterion, all sites are fully supporting of this parameter (Table 28).

Table 28. Tributary Sites Nitrate-Nitrite Results

Nitrate-Nitrite as Nitrogen mg/L									
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
T43	East Oakwood Lake Trib 1	9	0.396	0.043	1.406	0.360	0	0	Full
T44	East Oakwood Lake Trib 2	14	0.060	0.042	0.129	0.057	0	0	Full
T45	East Oakwood Lake Outlet 1	14	0.124	0.024	0.556	0.065	0	0	Full
T46	East Oakwood Lake Outlet 2	14	0.216	0.043	0.642	0.090	0	0	Full
T48	East Oakwood Lake Inlet 3	14	0.329	0.037	2.462	0.059	0	0	Full
Note: standard is ≤ 88 mg/L for beneficial use (9)									

Total Kjeldahl Nitrogen (TKN)

Total Kjeldahl nitrogen ranged from a minimum of 0.781 mg/L at East Oakwood Lake Outlet 1 (T45), to a maximum of 6.412 mg/L at East Oakwood Lake Tributary (T44). There are no total Kjeldahl nitrogen standards assigned to these tributary sites (Table 29).

Table 29. Tributary Sites Total Kjeldahl Nitrogen (TKN) Results

Total Kjeldahl Nitrogen									
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
T43	East Oakwood Lake Trib 1	9	1.651	1.121	2.520	1.554	----	----	----
T44	East Oakwood Lake Trib 2	14	2.984	1.376	6.412	2.336	----	----	----
T45	East Oakwood Lake Outlet 1	14	1.432	0.781	2.271	1.365	----	----	----
T46	East Oakwood Lake Outlet 2	14	1.777	1.001	2.405	1.942	----	----	----
T48	East Oakwood Lake Inlet 3	14	2.363	1.022	4.314	2.184	----	----	----
---- denotes no standard or beneficial use assigned									

Organic Nitrogen

Organic nitrogen ranged from a minimum of 0.514 mg/L at East Oakwood Lake Outlet 1 (T45), to a maximum of 6.106 mg/L at East Oakwood Lake Tributary (T44). There are no organic nitrogen standards assigned to these tributary sites (Table 30).

Table 30. Tributary Sites Organic Nitrogen Results

Organic Nitrogen mg/L										
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
T43	East Oakwood Lake Trib 1	9	1.521	1.051	2.330	1.356	----	----	----
T44	East Oakwood Lake Trib 2	14	2.666	1.222	6.106	2.056	----	----	----
T45	East Oakwood Lake Outlet 1	14	1.231	0.514	1.928	1.176	----	----	----
T46	East Oakwood Lake Outlet 2	14	1.588	0.982	2.188	1.701	----	----	----
T48	East Oakwood Lake Inlet 3	14	2.121	0.990	4.084	1.751	----	----	----

---- denotes no standard or beneficial use assigned

Total Phosphorus

Total phosphorus ranged from a minimum of 0.030 mg/L at East Oakwood Lake Inlet (T48), to a maximum of 0.787 mg/L at East Oakwood Lake Tributary (T43). There are no total phosphorus standards assigned to these tributary sites (Table 31).

Table 31. Tributary Sites Total Phosphorus Results

Total Phosphorus mg/L									
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
T43	East Oakwood Lake Trib 1	9	0.420	0.162	0.787	0.378	----	----	----
T44	East Oakwood Lake Trib 2	14	0.241	0.086	0.589	0.196	----	----	----
T45	East Oakwood Lake Outlet 1	14	0.176	0.073	0.377	0.153	----	----	----
T46	East Oakwood Lake Outlet 2	14	0.261	0.066	0.596	0.227	----	----	----
T48	East Oakwood Lake Inlet 3	14	0.193	0.030	0.337	0.192	----	----	----

---- denotes no standard or beneficial use assigned

Total Dissolved Phosphorus

Total dissolved phosphorus ranged from a minimum of 0.003 mg/L at East Oakwood Lake Tributary (T44), to a maximum of 0.732 mg/L at East Oakwood Lake Tributary (T43). There are no total dissolved phosphorus standards assigned to these tributary sites (Table 32).

Table 32. Tributary Sites Total Dissolved Phosphorus Results

Total Dissolved Phosphorous mg/L									
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
T43	East Oakwood Lake Trib 1	9	0.298	0.119	0.732	0.255	----	----	----
T44	East Oakwood Lake Trib 2	14	0.076	0.003	0.170	0.060	----	----	----
T45	East Oakwood Lake Outlet 1	14	0.123	0.017	0.220	0.119	----	----	----
T46	East Oakwood Lake Outlet 2	14	0.132	0.022	0.413	0.095	----	----	----
T48	East Oakwood Lake Inlet 3	14	0.103	0.004	0.326	0.051	----	----	----

---- denotes no standard or beneficial use assigned

Field Parameters

Dissolved Oxygen

Dissolved oxygen ranged from a minimum of 2.1 mg/L at East Oakwood Lake Outlet (T45), to a maximum of 20.0 mg/L at East Oakwood Lake Tributary (T44) and East Oakwood Lake Inlet (T48). There are no dissolved oxygen standards assigned to these tributary sites (Table 33).

Table 33. Tributary Sites Dissolved Oxygen Results

Dissolved Oxygen mg/L										
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
T43	East Oakwood Lake Trib 1	9	12.6	5.9	17.3	12.5	----	----	----
T44	East Oakwood Lake Trib 2	13	10.6	3.3	20.0	9.4	----**	----	----
T45	East Oakwood Lake Outlet 1	13	9.0	2.1	17.4	9.7	----**	----	----
T46	East Oakwood Lake Outlet 2	13	9.5	3.0	17.4	9.9	----**	----	----
T48	East Oakwood Lake Inlet 3	14	10.2	3.6	20.0	8.1	----**	----	----

---- denotes no standard or beneficial use assigned for dissolved oxygen, and no violations if they were applicable
----** denotes no standard or beneficial use assigned for dissolved oxygen, but there are violations if a standard were applicable

pH

pH ranged from a minimum of 7.4 units at East Oakwood Lake Outlet 2 (T46), to a maximum of 9.3 units at East Oakwood Lake Tributary (T44) and East Oakwood Lake Inlet (T48). A single grab sample daily maximum of the most restrictive standard of ≥ 6.0 to ≤ 9.5 was used to determine the percent violations at and assess for the beneficial use support of (9) Fish and Wildlife Propagation, Recreation and Stock Watering. Using this criterion, all tributary sites are fully supporting of this parameter (Table 34).

Table 34. Tributary Sites pH Results

pH units									
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
T43	East Oakwood Lake Trib 1	9	8.1	7.8	8.4	8.2	0	0	Full
T44	East Oakwood Lake Trib 2	13	8.5	7.7	9.3	8.5	0	0	Full
T45	East Oakwood Lake Outlet 1	13	8.0	7.5	8.5	8.1	0	0	Full
T46	East Oakwood Lake Outlet 2	13	7.8	7.4	8.2	7.9	0	0	Full
T48	East Oakwood Lake Inlet 3	13	8.3	7.6	9.3	8.3	0	0	Full

Note: The standard is ≥ 6.0 to ≤ 9.5 for beneficial use (9)

Air Temperature

Air temperature ranged from a minimum of 0.5º C at the East Oakwood Lake Inlet (T48) to a maximum of 34.0º C Site T43 and Site T45. There are no air temperatures standards assigned to these tributary sites (Table 35).

Table 35. Tributary Sites Air Temperature Results

Air Temperature C°									
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
T43	East Oakwood Lake Trib 1	9	19.7	9.5	34.0	16.0	----	----	----
T44	East Oakwood Lake Trib 2	14	18.5	1.0	35.5	19.5	----	----	----
T45	East Oakwood Lake Outlet 1	14	19.4	9.0	34.0	19.3	----	----	----
T46	East Oakwood Lake Outlet 2	14	21.0	8.0	36.5	21.1	----	----	----
T48	East Oakwood Lake Inlet 3	14	18.9	0.5	37.0	17.5	----	----	----

---- denotes no standard or beneficial use assigned

Water Temperature

Water temperature ranged from a minimum of 4.0º C at East Oakwood Lake Inlet (T48), to a maximum of 27.0º C at East Oakwood Lake Tributary (T44). There are no water temperatures standards assigned to these tributary sites (Table 36).

Table 36. Tributary Sites Water Temperature Results

Water Temperature C°									
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
T43	East Oakwood Lake Trib 1	9	14.5	6.0	25.4	11.9	----	----	----
T44	East Oakwood Lake Trib 2	14	17.1	6.1	27.0	19.9	----	----	----
T45	East Oakwood Lake Outlet 1	14	15.8	6.4	24.5	17.0	----	----	----
T46	East Oakwood Lake Outlet 2	14	16.7	5.8	25.3	20.4	----	----	----
T48	East Oakwood Lake Inlet 3	14	16.2	4.0	25.9	20.2	----	----	----
---- denotes no standard or beneficial use assigned									

Conductivity

Conductivity ranged from a minimum of 446 µmhos/cm at the East Oakwood Lake Outlet 2 (T46), to a maximum of 1,540 µmhos/cm at the East Oakwood Lake Inlet (T48). There are no conductivity standards assigned to these tributary sites (Table 37).

Table 37. Tributary Sites Conductivity Results

Conductivity µS/cm									
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
T43	East Oakwood Lake Trib 1	9	1036	651	1432	1079	----	----	----
T44	East Oakwood Lake Trib 2	14	1005	761	1229	1044	----	----	----
T45	East Oakwood Lake Outlet 1	14	1006	608	1445	1002	----	----	----
T46	East Oakwood Lake Outlet 2	14	1020	446	1388	1056	----	----	----
T48	East Oakwood Lake Inlet 3	14	1162	656	1540	1209	----	----	----
---- denotes no standard or beneficial use assigned									

Specific Conductivity

Specific conductivity ranged from a minimum of 878 µmhos/cm at East Oakwood Lake Outlet (T45), to a maximum of 2,255 µmhos/cm at East Oakwood Lake Inlet (T48). A single grab sample daily maximum of 4,375 µmhos/cm (most stringent) was used to determine the percent violations and assess for the beneficial use support of beneficial use (9) Fish and Wildlife Propagation, Recreation and Stock Watering and (10) Irrigation. Using this criterion all tributary sites are fully supporting of this parameter (Table 38).

Table 38. Tributary Sites Specific Conductivity Results

Specific Conductivity µS/cm									
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
T43	East Oakwood Lake Trib 1	9	1325	890	2020	1127	0	0	Full
T44	East Oakwood Lake Trib 2	14	1186	1113	1263	1192	0	0	Full
T45	East Oakwood Lake Outlet 1	14	1220	878	1586	1210	0	0	Full
T46	East Oakwood Lake Outlet 2	14	1216	660	1607	1281	0	0	Full
T48	East Oakwood Lake Inlet 3	14	1406	1026	2255	1365	0	0	Full
NOTE: The more restrictive standard of ≤ 4,375 umhos/cm is applied for beneficial uses of (9) and (10)									

Salinity

Salinity ranged from a minimum of 0.3 ppt at East Oakwood Lake Outlet 2 (T46), to a maximum of 1.4 ppt at East Oakwood Lake Outlet (T45). There are no salinity standards assigned to these tributary sites (Table 39).

Table 39. Tributary Sites Salinity Results

		Salinity ppt							
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
T43	East Oakwood Lake Trib 1	9	0.7	0.4	1.0	0.6	----	----	----
T44	East Oakwood Lake Trib 2	14	0.6	0.6	0.6	0.6	----	----	----
T45	East Oakwood Lake Outlet 1	14	0.7	0.5	1.4	0.6	----	----	----
T46	East Oakwood Lake Outlet 2	14	0.6	0.3	0.8	0.7	----	----	----
T48	East Oakwood Lake Inlet 3	14	0.7	0.5	1.2	0.7	----	----	----

---- denotes no standard or beneficial use assigned

Turbidity – NTU

Turbidity ranged from a minimum of 1.3 NTU at East Oakwood Lake Tributary (T44), to a maximum of 65.1 NTU at East Oakwood Lake Outlet 2 (T46). There are no turbidity standards assigned to these tributary sites (Table 40).

Table 40. Tributary Sites Turbidity (NTU) Results

		NTU							
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
T43	East Oakwood Lake Trib 1	9	17.9	5.3	57.1	13.1	----	----	----
T44	East Oakwood Lake Trib 2	14	19.6	1.3	65.0	9.2	----	----	----
T45	East Oakwood Lake Outlet 1	14	10.7	2.4	35.5	7.1	----	----	----
T46	East Oakwood Lake Outlet 2	14	25.2	3.1	65.1	24.7	----	----	----
T48	East Oakwood Lake Inlet 3	14	16.8	2.6	60.0	9.2	----	----	----

---- denotes no standard or beneficial use assigned

In-Lake Seasonal Trends

Typically water quality parameters will vary with season due to changes in temperature, precipitation, and agricultural practices. Table 41 shows the average seasonal concentration for each parameter at East Oakwood Lake. Table 42 shows the average seasonal concentration for each parameter at West Oakwood Lakes.

East Oakwood Lake

Overall, average concentrations show an increase from the spring season to the fall season. All parameters, except nitrates, have the highest concentrations during the fall season (Sept-Oct). Ammonia concentrations doubled from the spring season to the summer season. Sources of in-lake ammonia concentrations could be tributary loading, livestock wading in the lake, animal feeding areas, decomposition of organic matter, or runoff from applied manure (fertilizer). Average total phosphorus and total dissolved phosphorus concentrations were highest in the fall season. Phosphorus levels can contribute to algae density and in some cases algal blooms. Total solids and total dissolved solids were also higher in the fall, causing higher turbidity.

Table 41. Average Seasonal Concentrations from East Oakwood Lake

	East Oakwood Lake		
	Spring (Apr-May)	Summer (Jun-Aug)	Fall (Sept-Oct)
Parameter (mg/L)			
Diss. Oxygen	15.4	8.5	9.4
TSS	3	15	20
TotSol	868	951	957
TDS	865	936	937
Nitrates	0.039	0.06	0.049
Ammonia	0.057	0.165	0.185
TKN	1.074	1.954	2.814
TPO4	0.059	0.188	0.19
TDPO4	0.035	0.058	0.067
Org Nitrogen	1.014	1.831	2.629

West Oakwood Lake

Average concentrations of total solids and total dissolved solids were highest in the summer season and continued to stay high into the fall season. Ammonia and TKN concentrations were the highest during the fall season. Average concentrations of organic nitrogen were highest during the summer season. Possible sources of organic nitrogen in stream samples may include vegetation from the watershed, algae growth, and animal waste.

Total phosphorus and total dissolved phosphorus average concentrations were highest during the summer season. Phosphorus is present in all aquatic systems. Phosphorus-bearing rocks and organic matter decomposition are natural sources. Other potential sources include manmade fertilizers, domestic sewage, and agricultural sources (SD DENR 2000).

Table 42. Average Seasonal Concentrations from West Oakwood Lake

	West Oakwood Lake		
	Spring (Apr-May)	Summer (Jun-Aug)	Fall (Sept-Oct)
Parameter (mg/L)			
Diss. Oxygen	7.49	8.94	12.22
TSS	22	44	37
TotSol	1161	1248	1240
TDS	1139	1196	1203
Nitrates	0	0	0
Ammonia	0.197	0.06	0.502
TKN	3.253	4.34	4.773
TPO4	0.135	0.26	0.217
TDPO4	0.025	0.039	0.025
Org Nitrogen	3.057	4.28	4.272

In-Lake Water Quality Results

Chemical Parameters

Fecal Coliform Bacteria

East Oakwood Lake fecal coliform bacteria ranged from no detect (several sites) to a maximum of 230 cfu/100mL (L1-S). West Oakwood Lake fecal coliform bacteria ranged from no detect (several sites) to a maximum of 30 cfu/100ml (L11-North Lake Tetonkaha).

A single grab sample daily maximum of 400 cfu/100mL (most stringent) was used to determine the percent violations and assess for the beneficial use support of (7) Immersion Recreation for all sites on both East Oakwood Lake and West Oakwood Lake. Based on this criterion, both lakes are fully supporting of this parameter (Table 43).

Table 43. Oakwood Lakes Fecal Coliform Bacteria Results

Fecal Coliform Bacteria cfu/100mL										
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
L1-S	East Oakwood Lake 1-Surface	9	27	nd	230	nd	0	0	Full
L1-B	East Oakwood Lake 1-Bottom	8	28	nd	100	nd	0	0	Full
L2-S	East Oakwood Lake 2-Surface	9	19	nd	100	nd	0	0	Full
L2-B	East Oakwood Lake 2-Bottom	9	28	nd	100	10	0	0	Full
L10	Johnson Lake	5	nd	nd	nd	nd	0	0	Full
L11	North Tetonkaha Lake	5	8	nd	30	nd	0	0	Full
L12	South Tetonkaha Lake	5	6	nd	20	nd	0	0	Full

Use support was determined by season (May 1 to September 30)
Note: The more restrictive standard of 400 cfu/100mL is applied for beneficial uses (7) and (8)

Total Solids

East Oakwood Lake total solids ranged from a minimum of 786 mg/L (L1-S-East Oakwood Lake 1 Surface) to a maximum of 1,034 mg/L at the same site. West Oakwood Lake total solids ranged from a minimum of 1,139 mg/L (L10-Johnson Lake and L11-North Tetonkaha) to a maximum of 1,290 mg/L at site L10. There is no standard or assigned beneficial use for this parameter (Table 44).

Table 44. Oakwood Lakes Total Solids Results

Total Solids mg/L									
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
L1-S	East Oakwood Lake 1-Surface	11	930	786	1034	964	----	----	----
L1-B	East Oakwood Lake 1-Bottom	9	945	830	1028	963	----	----	----
L2-S	East Oakwood Lake 2-Surface	11	925	794	1017	929	----	----	----
L2-B	East Oakwood Lake 2-Bottom	10	938	838	1016	938	----	----	----
L10	Johnson Lake	7	1238	1139	1290	1258	----	----	----
L11	North Tetonkaha Lake	7	1215	1139	1269	1226	----	----	----
L12	South Tetonkaha Lake	7	1210	1144	1264	1206	----	----	----

---- denotes no standard or beneficial use assigned

Total Suspended Solids

East Oakwood Lake total suspended solids ranged from a minimum of 1 mg/L (L1-B-East Oakwood Lake 1 Bottom and L2-S-East Oakwood Lake 2 Surface) to a maximum of 46 mg/L (L1-B and L2-B). West Oakwood Lake total suspended solids ranged from a minimum of 15 mg/L (L10-Johnson Lake) to a maximum of 64 mg/L at site L10.

A single grab sample daily maximum of 158 mg/L (most stringent) was used to determine the percent violations and assess for the beneficial use support of (5) Warm Water Semi-permanent Fish Life Propagation for all East Oakwood Lake and West Oakwood Lake sites. Based on this criterion, both lakes are fully supporting of this parameter (Table 45).

Table 45. Oakwood Lakes Total Suspended Solids Results

Total Suspended Solids mg/L										
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
L1-S	East Oakwood Lake 1-Surface	11	13	2	45	9	0	0	Full
L1-B	East Oakwood Lake 1-Bottom	9	13	1	46	13	0	0	Full
L2-S	East Oakwood Lake 2-Surface	11	12	1	41	9	0	0	Full
L2-B	East Oakwood Lake 2-Bottom	10	15	2	46	9	0	0	Full
L10	Johnson Lake	7	41	15	64	39	0	0	Full
L11	North Tetonkaha Lake	7	42	25	62	37	0	0	Full
L12	South Tetonkaha Lake	7	35	17	58	35	0	0	Full
Note: The standard is 158 mg/L For beneficial use (5)									

Total Dissolved Solids (TDS)

East Oakwood Lake TDS ranged from a minimum of 784 mg/L (L1-S-East Oakwood Lake 1 Surface) to a maximum of 1,020 mg/L at sites L1-S and L1-B. West Oakwood TDS ranged from a minimum of 1,114 mg/L (L11-North Lake Tetonkaha) to a maximum of 1,239 mg/L at Site L10.

A single grab sample daily maximum of 4,375 mg/L was used to determine the percent violations and assess for the beneficial use support of (9) Fish and Wildlife, Propagation, Recreation and Stock Watering for all sites on East Oakwood Lake and West Oakwood Lake. Using this criterion, both lakes are fully supporting of this parameter (Table 46).

Table 46. Oakwood Lakes Total Dissolved Solids Results

Total Dissolved Solids mg/L									
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
L1-S	East Oakwood Lake 1-Surface	11	917	784	1020	932	0	0	Full
L1-B	East Oakwood Lake 1-Bottom	9	932	828	1020	948	0	0	Full
L2-S	East Oakwood Lake 2-Surface	11	913	792	1008	912	0	0	Full
L2-B	East Oakwood Lake 2-Bottom	10	923	836	1008	910	0	0	Full
L10	Johnson Lake	7	1197	1124	1239	1208	0	0	Full
L11	North Tetonkaha Lake	7	1173	1114	1224	1176	0	0	Full
L12	South Tetonkaha Lake	7	1175	1127	1220	1171	0	0	Full
Note: The standard is 4375 mg/L for beneficial use (9)									

Total Ammonia Nitrogen as N

East Oakwood Lake total ammonia nitrogen as N ranged from a minimum of 0.030 (L2-S-East Oakwood Lake 2 Surface) to a maximum of 0.390 mg/L (L1-S-East Oakwood Lake 1 Surface). West Oakwood Lake total ammonia nitrogen as N ranged from a no detect (several sites) to a maximum of 1.010 mg/L at site L12.

A single grab sample daily maximum of ammonia nitrogen as N ≤ result of equation $(0.411 \div (1+10^{7.204-pH})) + (58.4 \div (1+10^{pH-7.204}))$ was used to determine the percent violations and assess for the beneficial use support of (5) Warmwater Semi-permanent Fish Life Propagation. Using this criterion, both East Oakwood Lake and West Oakwood Lake are fully supporting of this parameter (Table 47).

Table 47. Oakwood Lakes Total Ammonia Nitrogen as N Results

Ammonia Nitrogen as N mg/L										
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
L1-S	East Oakwood Lake 1-Surface	11	0.177	0.037	0.390	0.176	0	0	Full
L1-B	East Oakwood Lake 1-Bottom	9	0.152	0.045	0.344	0.129	0	0	Full
L2-S	East Oakwood Lake 2-Surface	11	0.139	0.030	0.262	0.124	0	0	Full
L2-B	East Oakwood Lake 2-Bottom	10	0.120	0.031	0.214	0.101	0	0	Full
L10	Johnson Lake	7	0.190	nd	0.670	nd	0	0	Full
L11	North Tetonkaha Lake	7	0.227	nd	0.940	0.140	0	0	Full
L12	South Tetonkaha Lake	7	0.259	nd	1.010	0.180	0	0	Full
Note: The standard is Ammonia N ≤ result of (0.411÷(1+107.204-pH)) + (58.4÷(1+10pH-7.204)) for beneficial use (5)									

Nitrate-Nitrite

East Oakwood Lake nitrate-nitrite ranged from a minimum of 0.014 mg/L (L2-S-East Oakwood Lake 2 Surface) to a maximum of 0.078 mg/L at site L1-B. West Oakwood Lake nitrate-nitrite was undetectable at all sites. All samples collected were below the State Health Laboratory detection limit of 0.1 mg/L nitrate-nitrite concentration.

A single grab sample daily maximum of 88 mg/L was used to determine the percent violations and assess for the beneficial use support of (9) Fish and Wildlife Propagation, Recreation and Stock Watering for all East Oakwood Lake and West Oakwood Lake monitoring sites. Using this criterion, both lakes are fully supporting of this parameter (Table 48).

Table 48. Oakwood Lakes Nitrate-Nitrite Results

Nitrate-Nitrite as Nitrogen mg/L									
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
L1-S	East Oakwood Lake 1-Surface	11	0.049	0.018	0.075	0.050	0	0	Full
L1-B	East Oakwood Lake 1-Bottom	9	0.052	0.016	0.078	0.051	0	0	Full
L2-S	East Oakwood Lake 2-Surface	11	0.053	0.014	0.076	0.056	0	0	Full
L2-B	East Oakwood Lake 2-Bottom	10	0.050	0.015	0.074	0.052	0	0	Full
L10	Johnson Lake	7	nd	nd	nd	nd	0	0	Full
L11	North Tetonkaha Lake	7	nd	nd	nd	nd	0	0	Full
L12	South Tetonkaha Lake	7	nd	nd	nd	nd	0	0	Full
Note: The standard is ≤ 88 mg/L for beneficial use (9)									

Total Kjeldahl Nitrogen (TKN)

East Oakwood Lake TKN ranged from a minimum of 0.945 mg/L (L2-S East Oakwood Lake 2 Surface) to a maximum of 4.015 mg/L (L1-B East Oakwood Lake 1 Bottom). West Oakwood Lake TKN ranged from a minimum of 2.720 mg/L (L12-South Lake Tetonkaha) to a maximum 5.030 mg/L at site L11. There is no standard or assigned beneficial use for this parameter (Table 49).

Table 49. Oakwood Lakes Total Kjeldahl Nitrogen (TKN) Results

Total Kjeldahl Nitrogen									
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
L1-S	East Oakwood Lake 1-Surface	11	1.979	0.949	3.971	1.674	----	----	----
L1-B	East Oakwood Lake 1-Bottom	9	2.111	0.959	4.015	1.616	----	----	----
L2-S	East Oakwood Lake 2-Surface	11	1.941	0.945	3.820	1.712	----	----	----
L2-B	East Oakwood Lake 2-Bottom	10	2.040	0.963	3.723	1.560	----	----	----
L10	Johnson Lake	7	4.219	2.830	4.990	4.630	----	----	----
L11	North Tetonkaha Lake	7	4.203	2.750	5.030	4.340	----	----	----
L12	South Tetonkaha Lake	7	4.039	2.720	4.700	4.290	----	----	----

---- denotes no standard or beneficial use assigned

Organic Nitrogen

East Oakwood Lake organic nitrogen ranged from a minimum of 0.912 mg/L (L1-S-East Oakwood Lake 1 Surface and L2-S-East Oakwood Lake 2 Surface) to a maximum of 3.969 mg/L at site L1-B. West Oakwood Lake organic nitrogen ranged from a minimum of 2.720 mg/L (L12-South Lake Tetonkaha) to a maximum 4.920 mg/L at site L10. There is no standard or assigned beneficial use for this parameter (Table 50).

Table 50. Oakwood Lakes Organic Nitrogen Results

Organic Nitrogen mg/L									
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
L1-S	East Oakwood Lake 1-Surface	11	1.803	0.912	3.816	1.478	----	----	----
L1-B	East Oakwood Lake 1-Bottom	9	1.959	0.914	3.969	1.506	----	----	----
L2-S	East Oakwood Lake 2-Surface	11	1.802	0.912	3.675	1.450	----	----	----
L2-B	East Oakwood Lake 2-Bottom	10	1.920	0.920	3.665	1.416	----	----	----
L10	Johnson Lake	7	4.029	2.830	4.920	4.320	----	----	----
L11	North Tetonkaha Lake	7	3.976	2.750	4.590	4.090	----	----	----
L12	South Tetonkaha Lake	7	3.780	2.720	4.480	3.810	----	----	----

---- denotes no standard or beneficial use assigned

Total Phosphorus

East Oakwood Lake total phosphorus ranged from a minimum of 0.032 mg/L (L1-B East Oakwood Lake 1 Bottom) to a maximum of 0.261 mg/L (L2-B-East Oakwood Lake 2 Bottom). West Oakwood total phosphorus ranged from a minimum of 0.088 mg/L (L12-South Lake Tetonkaha) to a maximum 0.694 mg/L at Site L10.

There is no standard or assigned beneficial use for this parameter. Phosphorous is an essential nutrient for the production of crops and comes from commercial fertilizers and livestock waste. It is also the primary nutrient for algae growth in lakes and streams. Since a standard for total phosphorous has not been established, data was compared to the total phosphorus range found in lakes located in the same ecoregion in Minnesota (MPCA 2004). The recommended range for total phosphorus in the Northern Glaciated Plains ecoregion is 0.122 mg/L to 0.160 mg/L (Table 51).

Table 51. Oakwood Lakes Total Phosphorus Results

Total Phosphorus mg/L									
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
L1-S	East Oakwood Lake 1-Surface	11	0.158	0.042	0.236	0.153	----	----	----
L1-B	East Oakwood Lake 1-Bottom	9	0.166	0.032	0.222	0.187	----	----	----
L2-S	East Oakwood Lake 2-Surface	11	0.155	0.034	0.234	0.182	----	----	----
L2-B	East Oakwood Lake 2-Bottom	10	0.156	0.037	0.261	0.139	----	----	----
*L1	East Oakwood Lake 1	9	0.169	0.093	0.246	0.155	----	----	----
*L2	East Oakwood Lake 2	9	0.168	0.086	0.250	0.166	----	----	----
L10	Johnson Lake	10	0.303	0.133	0.694	0.267	----	----	----
L11	North Tetonkaha Lake	10	0.191	0.093	0.278	0.196	----	----	----
L12	South Tetonkaha Lake	10	0.184	0.088	0.252	0.200	----	----	----

---- denotes no standard or beneficial use assigned
* denotes data collected during the summer of 2003

Total Dissolved Phosphorus

East Oakwood Lake total dissolved phosphorus ranged from a minimum of 0.014 mg/L (L1-East Oakwood Lake 1 Integrated and L2-East Oakwood Lake 2 Integrated) to a maximum of 0.163 mg/L (L2-S-East Oakwood Lake 2 Surface). West Oakwood Lake total dissolved phosphorus ranged from a minimum of 0.018 mg/L (L10-Johnson Lake and L11-Lake Tetonkaha) to a maximum 0.091 mg/L at site L10. There is no standard or assigned beneficial use for this parameter (Table 52).

Table 52. Oakwood Lakes Total Dissolved Phosphorus Results

Total Dissolved Phosphorous mg/L									
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
L1-S	East Oakwood Lake 1-Surface	11	0.077	0.023	0.139	0.076	----	----	----
L1-B	East Oakwood Lake 1-Bottom	9	0.082	0.018	0.138	0.080	----	----	----
L2-S	East Oakwood Lake 2-Surface	11	0.070	0.021	0.163	0.069	----	----	----
L2-B	East Oakwood Lake 2-Bottom	10	0.073	0.023	0.135	0.084	----	----	----
*L1	East Oakwood Lake 1	9	0.028	0.014	0.051	0.021	----	----	----
*L2	East Oakwood Lake 2	9	0.025	0.014	0.050	0.021	----	----	----
L10	Johnson Lake	10	0.042	0.018	0.091	0.034	----	----	----
L11	North Tetonkaha Lake	10	0.031	0.018	0.065	0.029	----	----	----
L12	South Tetonkaha Lake	10	0.028	0.019	0.046	0.026	----	----	----

---- denotes no standard or beneficial use assigned
* denotes data collected during the summer of 2003

Field Parameters

Dissolved Oxygen

East Oakwood Lake dissolved oxygen ranged from a minimum of 2.9 mg/L (L2-B) to > 20 mg/L (L1 and L2). West Oakwood Lake dissolved oxygen ranged from a minimum of 5.9 mg/L (L11-North Lake Tetonkaha) to > 20 mg/L (L10-Johnson Lake).

A single grab sample daily maximum of ≥ 5 mg/L (most stringent) was used to determine the percent violations and assess for the beneficial use support of (5), (7), and (8) for all in-lake sites. Using the 2006 Integrated Report listing criterion for lakes, both East Oakwood Lake and West Oakwood Lake are fully supporting of this parameter (Table 53). Note that only surface samples are used to identify impairments (SDDENR 2006). Forty surface samples were collected from East Oakwood with three surface exceedances for a violation rate of 7.5%.

Table 53. Oakwood Lakes Dissolved Oxygen Results (units are mg/L)

Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
L1-S	East Oakwood Lake 1-Surface	11	11.2	3.9	19.0	10.8	1	9	Full
L1-B	East Oakwood Lake 1-Bottom	9	9.9	3.5	19.1	8.1	2	22	Full
L2-S	East Oakwood Lake 2-Surface	11	11.0	3.0	18.7	10.2	2	18	Full
L2-B	East Oakwood Lake 2-Bottom	10	10.3	2.9	19.0	9.0	2	20	Full
*L1	East Oakwood Lake 1	9	10.0	5.2	>20	8.4	0	0	Full
*L2	East Oakwood Lake 2	9	10.2	6.0	>20	8.9	0	0	Full
L10	Johnson Lake	10	9.5	6.3	>20	7.7	0	0	Full
L11	North Tetonkaha Lake	10	9.3	5.9	12.1	9.7	0	0	Full
L12	South Tetonkaha Lake	10	9.0	7.1	11.9	8.6	0	0	Full

Note: The standard is ≥ 5.0 mg/L for beneficial uses (5), (7), and (8). Surface samples are used to determine impairment.
* denotes data collected during the summer of 2003

pH

East Oakwood Lake pH ranged from a minimum of 7.7 (L1-S-East Oakwood Lake 1 Surface and L1-B-East Oakwood Lake 1 Bottom) to a maximum of 9.5 (L1-East Oakwood Lake 1 and L2-East Oakwood Lake 2). West Oakwood Lake pH ranged from a minimum of 6.9 (L10-Johnson Lake) to a maximum of 9.3 (L11-North Lake Tetonkaha and L12-South Lake Tetonkaha).

A single grab sample daily maximum of the most restrictive standard of ≥ 6.5 to ≤ 9.0 was used to determine the percent violations at and assess for the beneficial use support of (5) Warmwater Semi-permanent Fish Life Propagation for all sites on East Oakwood Lake and West Oakwood Lake. Using this criterion, West Oakwood Lake is fully supporting of this parameter. However, East Oakwood Lake (combined surface and bottom samples from 2001, 2002, and 2003) had a 17 percent violation rate (out of 59 samples) which means this lake is not supporting of this parameter (Table 54).

Table 54. Oakwood Lakes pH Results

Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
L1-S	East Oakwood Lake 1-Surface	11	8.6	7.7	9.2	8.6	3	27	Not
L1-B	East Oakwood Lake 1-Bottom	9	8.6	7.7	9.2	8.6	1	11	Full
L2-S	East Oakwood Lake 2-Surface	11	8.6	7.9	9.2	8.5	1	9	Full
L2-B	East Oakwood Lake 2-Bottom	10	8.6	7.9	9.2	8.6	1	10	Full
*L1	East Oakwood Lake 1	9	8.8	8.4	9.5	8.7	2	22	Full
*L2	East Oakwood Lake 2	9	8.8	8.3	9.5	8.8	2	22	Full
L10	Johnson Lake	10	8.2	6.9	9.2	8.2	1	10	Full
L11	North Tetonkaha Lake	10	8.3	7.7	9.3	8.3	1	10	Full
L12	South Tetonkaha Lake	10	8.3	7.4	9.3	8.3	2	20	Full

Note: The more restrictive standard of ≥ 6.5 to ≤ 9.0 units is applied for beneficial uses (5) and (9)
* denotes data collected during the summer of 2003

Air Temperature

East Oakwood Lake air temperature ranged from a minimum of 7.0^o C (at several sites) to a maximum of 33.0^o C at Site L2. West Oakwood Lake air temperature ranged from a minimum of 4.3^o C (L10-Johnson Lake) to a maximum 28.0^o C at Sites L11 and L12. There is no standard or assigned beneficial use for this parameter (Table 55).

Table 55. Oakwood Lakes Air Temperature Results

		Air Temperature C°							
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
L1-S	East Oakwood Lake 1-Surface	11	18.1	7.0	25.0	22.0	----	----	----
L1-B	East Oakwood Lake 1-Bottom	9	18.5	7.0	25.0	22.0	----	----	----
L2-S	East Oakwood Lake 2-Surface	11	18.6	7.0	25.0	21.0	----	----	----
L2-B	East Oakwood Lake 2-Bottom	10	18.2	7.0	25.0	19.5	----	----	----
*L1	East Oakwood Lake 1	9	20.6	10.0	30.0	20.0	----	----	----
*L2	East Oakwood Lake 2	9	21.1	9.6	33.0	20.0	----	----	----
L10	Johnson Lake	9	17.0	4.3	26.0	19.0	----	----	----
L11	North Tetonkaha Lake	9	18.0	4.7	28.0	19.5	----	----	----
L12	South Tetonkaha Lake	9	19.3	4.7	28.0	21.0	----	----	----

---- denotes no standard or beneficial use assigned

* denotes data collected during the summer of 2003

Water Temperature

East Oakwood Lake water temperature ranged from a minimum of 4.1^o C (L2-S and L2-B) to a maximum of 26.5^o C (several sites). West Oakwood Lake water temperature ranged from a minimum of 6.9^o C (L10 Johnson Lake and L11 North Lake Tetonkaha) to a maximum of 25.9^o C at Site L10.

A single grab sample daily maximum temperature of 32.2^o C was used to determine the percent violations and assess for the beneficial use support of (5) for all in-lake sites. Both East Oakwood Lake and West Oakwood Lake are fully supporting of this parameter when this criteria is applied (Table 56).

Table 56. Oakwood Lakes Water Temperature Results

		Water Temperature C°							
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
L1-S	East Oakwood Lake 1-Surface	11	17.6	4.2	26.5	21.5	0	0	Full
L1-B	East Oakwood Lake 1-Bottom	9	19.1	4.2	26.4	21.5	0	0	Full
L2-S	East Oakwood Lake 2-Surface	11	17.7	4.1	26.5	21.9	0	0	Full
L2-B	East Oakwood Lake 2-Bottom	10	18.1	4.1	26.5	21.7	0	0	Full
*L1	East Oakwood Lake 1	9	19.1	10.8	24.9	20.4	0	0	Full
*L2	East Oakwood Lake 2	9	18.8	10.2	25.1	20.2	0	0	Full
L10	Johnson Lake	10	17.0	6.9	25.9	18.2	0	0	Full
L11	North Tetonkaha Lake	10	17.0	6.9	25.7	18.2	0	0	Full
L12	South Tetonkaha Lake	10	17.3	7.2	25.4	18.5	0	0	Full

Note: The standard is ≤ 32.2° C for beneficial use (5)

* denotes data collected during the summer of 2003

Conductivity

East Oakwood Lake conductivity ranged from a minimum of 747 µmhos/cm (L2-S-East Oakwood Lake 2 Surface and L2-B-East Oakwood Lake 2 Bottom) to a maximum of 1,283 µmhos/cm (L2-S and L2-B). West Oakwood Lake conductivity ranged from a minimum of 881 µmhos/cm (L10-Johnson Lake) to a maximum 1,432 µmhos/cm at site L10. There is no standard or assigned beneficial use for this parameter (Table57).

Table 57. Oakwood Lakes Conductivity Results

Conductivity µS/cm									
Site	**Stream**	**# of Samples**	**Mean**	**Min**	**Max**	**Median**	**Violations of WQS**	**Percent Violating**	**Use Support**
L1-S	East Oakwood Lake 1-Surface	11	996	750	1238	1041	----	----	----
L1-B	East Oakwood Lake 1-Bottom	9	1037	749	1238	1086	----	----	----
L2-S	East Oakwood Lake 2-Surface	11	1003	747	1229	1064	----	----	----
L2-B	East Oakwood Lake 2-Bottom	10	1015	747	1229	1073	----	----	----
*L1	East Oakwood Lake 1	9	1093	841	1279	1125	----	----	----
*L2	East Oakwood Lake 2	9	1089	839	1283	1120	----	----	----
L10	Johnson Lake	10	1173	881	1432	1216	----	----	----
L11	North Tetonkaha Lake	10	1170	936	1383	1207	----	----	----
L12	South Tetonkaha Lake	10	1161	938	1370	1190	----	----	----

---- denotes no standard or beneficial use assigned
* denotes data collected during the summer of 2003

Specific Conductivity

East Oakwood Lake specific conductivity ranged from a minimum of 1,051 µmhos/cm (L1-S-East Oakwood Lake 1 Surface) to a maximum of 1,284 µmhos/cm at site L2. West Oakwood Lake specific conductivity ranged from a minimum of 1,320 µmhos/cm (L12-South Tetonkaha) to a maximum of 1,429 µmhos/cm at site L11.

A single grab sample daily maximum of 7,000 µmhos/cm was used to determine the percent violations and assess for the beneficial use support of (9) Fish and Wildlife Propagation , Recreation, and Stock Watering. Using this criterion, both East Oakwood Lake and West Oakwood Lake are fully supporting this parameter (Table 58).

Table 58. Oakwood Lakes Specific Conductivity Results

Specific Conductivity µS/cm									
Site	**Stream**	**# of Samples**	**Mean**	**Min**	**Max**	**Median**	**Violations of WQS**	**Percent Violating**	**Use Support**
L1-S	East Oakwood Lake 1-Surface	11	1159	1051	1246	1154	0	0	Full
L1-B	East Oakwood Lake 1-Bottom	9	1173	1117	1247	1182	0	0	Full
L2-S	East Oakwood Lake 2-Surface	11	1171	1113	1247	1168	0	0	Full
L2-B	East Oakwood Lake 2-Bottom	10	1172	1112	1247	1176	0	0	Full
*L1	East Oakwood Lake 1	9	1231	1162	1281	1234	0	0	Full
*L2	East Oakwood Lake 2	9	1232	1165	1284	1232	0	0	Full
L10	Johnson Lake	10	1382	1340	1420	1392	0	0	Full
L11	North Tetonkaha Lake	10	1376	1340	1429	1369	0	0	Full
L12	South Tetonkaha Lake	10	1364	1320	1424	1362	0	0	Full

NOTE: The more restrictive standard of ≤ 4,375 umhos/cm is applied for beneficial uses of (9) and (10)
* denotes data collected during the summer of 2003

Salinity

East Oakwood Lake salinity ranged from a minimum of 0.5 ppt (L1-S-East Oakwood Lake 1 Surface) to a maximum of 0.6 ppt (several sites). All salinity measurements of West Oakwood Lake were 0.7 ppt. There is no standard or assigned beneficial use for this parameter (Table 59).

Table 59. Oakwood Lakes Salinity Results

		Salinity ppt							
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
L1-S	East Oakwood Lake 1-Surface	11	0.6	0.5	0.6	0.6	----	----	----
L1-B	East Oakwood Lake 1-Bottom	9	0.6	0.6	0.6	0.6	----	----	----
L2-S	East Oakwood Lake 2-Surface	11	0.6	0.6	0.6	0.6	----	----	----
L2-B	East Oakwood Lake 2-Bottom	10	0.6	0.6	0.6	0.6	----	----	----
*L1	East Oakwood Lake 1	9	0.6	0.6	0.6	0.6	----	----	----
*L2	East Oakwood Lake 2	8	0.6	0.6	0.6	0.6	----	----	----
L10	Johnson Lake	10	0.7	0.7	0.7	0.7	----	----	----
L11	North Tetonkaha Lake	10	0.7	0.7	0.7	0.7	----	----	----
L12	South Tetonkaha Lake	10	0.7	0.7	0.7	0.7	----	----	----

---- denotes no standard or beneficial use assigned
* denotes data collected during the summer of 2003

Turbidity – NTU

East Oakwood Lake turbidity ranged from a minimum of 0.3 NTU (L1-S-East Oakwood Lake 1 Surface and L1-B-East Oakwood Lake 1 Bottom) to a maximum of 45.0 NTU (L1-S and L1-B). West Oakwood Lake turbidity ranged from a minimum of 5.9 NTU (L12-South Lake Tetonkaha) to a maximum 56.1 NTU (L10-Johnson Lake) for all in-lake sites. There is no standard or assigned beneficial use for this parameter (Table 60).

Table 60. Oakwood Lakes Turbidity (NTU) Results

		NTU							
Site	Stream	# of Samples	Mean	Min	Max	Median	Violations of WQS	Percent Violating	Use Support
L1-S	East Oakwood Lake 1-Surface	11	13.3	0.3	45.0	9.4	----	----	----
L1-B	East Oakwood Lake 1-Bottom	9	15.9	0.3	45.0	13.7	----	----	----
L2-S	East Oakwood Lake 2-Surface	11	11.7	0.5	36.0	6.8	----	----	----
L2-B	East Oakwood Lake 2-Bottom	10	12.6	0.6	34.0	11.3	----	----	----
*L1	East Oakwood Lake 1	9	21.9	7.8	40.0	25.0	----	----	----
*L2	East Oakwood Lake 2	9	21.3	8.0	37.0	23.0	----	----	----
L10	Johnson Lake	10	32.0	7.7	56.1	37.0	----	----	----
L11	North Tetonkaha Lake	10	31.0	7.8	50.0	32.5	----	----	----
L12	South Tetonkaha Lake	10	26.7	5.9	40.0	33.3	----	----	----

---- denotes no standard or beneficial use assigned
* denotes data collected during the summer of 2003

HYDROLOGIC MONITORING

Bathymetric maps of Oakwood Lakes were created by SD Department of Game, Fish, and Parks. This map (Appendix L) shows the depths of West Oakwood Lake and East Oakwood Lake.

Annual Hydrologic Loading Budget

As mentioned in the Methods Section of the report, inflow and outflow sources were monitored from 2001 through 2002. Two inflows and one outflow were monitored at West Oakwood Lake. One inflow and one outflow were monitored at East Oakwood Lake.

East Oakwood Lake

Inflow sources of East Oakwood Lake included precipitation, tributary, and groundwater (Figure 9). Tributary (T44) inflow contributed 10,746 acre-ft (41 percent). Precipitation contributed 841 acre-ft (3 percent). Groundwater contributed an estimated 14,332 acre-ft (56 percent).

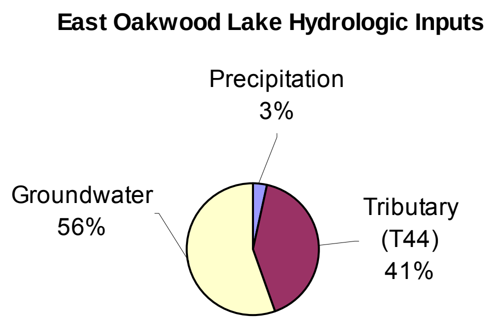


Figure 9. East Oakwood Lake Hydrologic Inputs

West Oakwood Lake

Inflow sources of West Oakwood Lake included precipitation, tributaries, and groundwater (Figure 10). Tributary flow (T43 and T48) contributed the largest portion with 9,153 acre-ft (74 percent). Groundwater was estimated at 1,755 acre-ft (14 percent) and precipitation with 1,439 acre-ft (12 percent).

Outflow sources of West Oakwood Lake included evaporation, tributary, and change in storage. Tributary (T44) outflow was 10,746 acre-ft. Other outflows included evaporation (1,404 acre-ft) and change in storage (197 acre-ft).

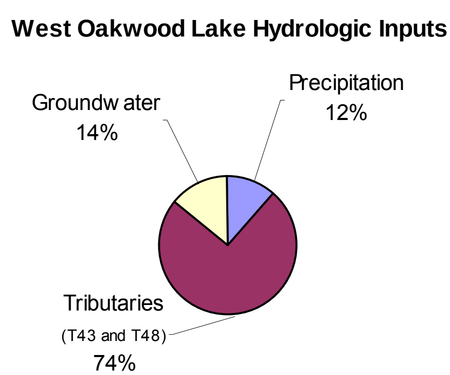


Figure 10. West Oakwood Lake Hydrologic Inputs

Nutrient and Sediment Budgets

Suspended Solids Budget

The loading of total suspended solids into East Oakwood Lake was derived from Site T44. It is estimated that Site T44 contributed 272,804 kg of total suspended solids to East Oakwood Lake. At the outflow (T45) total suspended solids measured 512,776 kg. This leaves a difference of 239,972 kg of total suspended solids which is attributed to an un-monitored source.

The total suspended solids loading into West Oakwood Lake was derived from Sites T43 and T48. The total contribution from these tributaries was 910,716 kg. After subtracting the outflow load from the inflow load, an estimated 637,912 kg/yr of TSS remained within West Oakwood Lake.

Nitrogen Budget

Sources contributing to the nitrogen load of East Oakwood Lake included tributary inflow and groundwater. The total contribution from tributary (T44) inflow was 39,732 kg of nitrogen. Groundwater contributed an estimated 20,870 kg of total nitrogen to the lake. Nitrogen leaving the lake through the outflow (T45) measured 49,786 kg. After the outflow was subtracted from the inflow, an estimated 10,816 kg of total nitrogen was retained within East Oakwood Lake.

Sources of nitrogen load to West Oakwood Lake included tributary inflow and groundwater. The total contribution of total nitrogen from the tributaries (T43 and T48) was 37,270 kg. After the outflow was subtracted from the inflow, an estimated 95 kg of total nitrogen remained within West Oakwood Lake.

Phosphorus Budget

Sources of phosphorus loads into East Oakwood Lake included tributary inflow, groundwater, and precipitation. The total contribution from tributary (T44) inflow was 3,019 kg of phosphorus. Groundwater contributed 459 kg of phosphorus and precipitation was estimated to contribute 31 kg of phosphorus to the lake. Phosphorus leaving the lake through the outflow (T45) measured 6,898 kg. This leaves a difference of 3,388 kg of phosphorus which is attributed to an un-monitored source.

Sources of phosphorus load into West Oakwood Lake included tributary inflow, groundwater, and precipitation. The total contribution from tributary (T43 and T48) inflow was 5,427 kg of phosphorus. Groundwater contributed 56 kg of phosphorus and precipitation was estimated to contribute 53 kg of phosphorus to the lake. After outflow was subtracted from inflow, an estimated 491 kg of total phosphorus remained within West Oakwood Lake.

BIOLOGICAL MONITORING

Tributary Biological Results

Macroinvertebrate Sampling

Macroinvertebrate sampling occurred at four of the five tributary sites. The exception was Site T43, which went dry before the macroinvertebrates could be collected. Laboratory work and compilation of the results for each metric were outsourced to the researchers at Natural Resource Solutions. Table 61, 62, 63, and 64 are the results of the macroinvertebrate scoring. Appendix M contains more details about the findings at each location.

Table 61. Site T44 Macroinvertebrate Scoring

Site T44					
Metric	**Response to Impairment**	**Percentile for "best" value**	**Standard (best value)**	**Measured metric value**	**Standardized Metric score**
Abundance	Decrease	95th	324	299	93
Taxa Richness	Decrease	95th	26	15	45
EPT Richness	Decrease	95th	5	3	27
Diptera Richness	Decrease	95th	10	5	45
% EPT	Decrease	95th	37.4	5.4	8
% Diptera	Increase	5th	16.4	88.0	17
% Chironomidae	Increase	5th	15.1	87.6	17
% Tolerant	Increase	5th	70.6	97.7	3
% Chironomidae + Oligochaeta	Increase	5th	35.5	88.6	16
% Hydropsychidae/Trichoptera	Increase	5th	0	100.0	0
% Gatherers	Decrease	95th	74.4	20.4	29
% Filterers	Increase	5th	5.1	72.9	28
% Clingers	Decrease	95th	17.9	0.7	2
			Final index value for this site:		**25**

Table 62. Site T45 Macroinvertebrate Scoring

Site T45					
Metric	**Response to Impairment**	**Percentile for "best" value**	**Standard (best value)**	**Measured metric value**	**Standardized Metric score**
Abundance	Decrease	95th	324	276	85
Taxa Richness	Decrease	95th	26	15	45
EPT Richness	Decrease	95th	5	2	18
Diptera Richness	Decrease	95th	10	6	55
% EPT	Decrease	95th	37.4	3.3	5
% Diptera	Increase	5th	16.4	55.4	62
% Chironomidae	Increase	5th	15.1	54.3	62
% Tolerant	Increase	5th	70.6	98.2	2
% Chironomidae + Oligochaeta	Increase	5th	35.5	55.4	62
% Hydropsychidae/Trichoptera	Increase	5th	0	100.0	0
% Gatherers	Decrease	95th	74.4	71.0	100
% Filterers	Increase	5th	5.1	5.8	97
% Clingers	Decrease	95th	17.9	0.4	1
			Final index value for this site:		**46**

Table 63. Site T46 Macroinvertebrate Scoring

Site T46					
Metric	**Response to Impairment**	**Percentile for "best" value**	**Standard (best value)**	**Measured metric value**	**Standardized Metric score**
Abundance	Decrease	95th	324	280	87
Taxa Richness	Decrease	95th	26	16	48
EPT Richness	Decrease	95th	5	2	18
Diptera Richness	Decrease	95th	10	5	45
% EPT	Decrease	95th	37.4	1.4	2
% Diptera	Increase	5th	16.4	40.4	83
% Chironomidae	Increase	5th	15.1	33.9	90
% Tolerant	Increase	5th	70.6	87.9	13
% Chironomidae + Oligochaeta	Increase	5th	35.5	84.6	21
% Hydropsychidae/Trichoptera	Increase	5th	0	0.0	100
% Gatherers	Decrease	95th	74.4	56.8	81
% Filterers	Increase	5th	5.1	20.4	82
% Clingers	Decrease	95th	17.9	3.6	9
			Final index value for this site:		**52**

Table 64. Site T48 Macroinvertebrate Scoring

Site T48					
Metric	**Response to Impairment**	**Percentile for "best" value**	**Standard (best value)**	**Measured metric value**	**Standardized Metric score**
Abundance	Decrease	95th	324	314	97
Taxa Richness	Decrease	95th	26	15	45
EPT Richness	Decrease	95th	5	3	27
Diptera Richness	Decrease	95th	10	4	36
% EPT	Decrease	95th	37.4	7.6	11
% Diptera	Increase	5th	16.4	44.9	77
% Chironomidae	Increase	5th	15.1	44.3	76
% Tolerant	Increase	5th	70.6	98.4	2
% Chironomidae + Oligochaeta	Increase	5th	35.5	44.6	77
% Hydropsychidae/Trichoptera	Increase	5th	0	16.7	83
% Gatherers	Decrease	95th	74.4	50.3	71
% Filterers	Increase	5th	5.1	41.7	60
% Clingers	Decrease	95th	17.9	1.9	5
			Final index value for this site:		**51**

In-Lake Biological Results

Algae Sampling

Algae were sampled once in June and once in August at each lake (East Oakwood, Johnson, and Tetonkaha) by the East Dakota Water Development District. East Oakwood Lake was sampled in the summer of 2003. Johnson Lake and Lake Tetonkaha were sampled during the summer of 2004. Table 65 represents the algal density by date and by lake. Table 66 represents the algal biovolume by date and by lake. A complete list of algal species identified in each lake can be found in Appendix N.

Table 65. Algal Density by Lake and Date Sampled

Algal Density (cells/mL)						
	16-Jun-03		10-Jun-04			
	East Oakwood	Percent	Johnson	Percent	Tetonkaha	Percent
Flagellated Algae	4,609	0.67	7,649	1.87	9,311	1.15
Blue-Green Algae	672,794	97.26	392,217	95.66	793,842	97.62
Diatoms	6,976	1.01	3,630	0.89	1,536	0.19
Non Motile Green Algae	6,051	0.87	5,598	1.37	8,070	0.99
Unidentified Algae	1,320	0.19	930	0.23	420	0.05
Total Algal Density	**691,750**		**410,024**		**813,179**	

	11-Aug-03		12-Aug-04			
	East Oakwood	Percent	Johnson	Percent	Tetonkaha	Percent
Flagellated Algae	3,848	0.15	3,355	0.11	1,244	0.03
Blue-Green Algae	2,468,430	99.21	3,152,837	99.58	3,900,560	99.86
Diatoms	3,782	0.15	7,980	0.25	3,326	0.09
Non Motile Green Algae	9,348	0.38	1,300	0.04	524	0.01
Unidentified Algae	2,720	0.11	800	0.03	350	0.01
Total Algal Density	**2,488,128**		**3,166,272**		**3,906,004**	

East Oakwood Lake total phytoplankton density ranged from 691,750 cells/mL (June) to 2,488,128 cells/mL (August). Total phytoplankton density in Johnson Lake ranged from 410,024 cells/mL (June) to 3,166,272 cells/mL (August). Lake Tetonkaha total phytoplankton density ranged from 813,179 cells/mL (June) to 3,906,004 cells/mL (August). In all lakes, blue-green algae showed the highest density with the *Oscillatoria agardhii* species being the most dense. This species persisted with the highest density throughout the summer in all lakes, except for Lake Tetonkaha where the *Phormidium* species became the most dominant in August. This species, however, was also present in the other three lakes.

Table 66. Algal Biovolume by Lake and Date Sampled

Algal Biovolume (μm^3/mL)						
	16-Jun-03		10-Jun-04			
	East Oakwood	Percent	Johnson	Percent	Tetonkaha	Percent
Flagellated Algae	479,314	1.68	406,320	2.97	606,069	3.95
Blue-Green Algae	26,643,381	93.16	11,935,344	87.11	14,005,562	91.39
Diatoms	975,710	3.41	827,550	6.04	332,350	2.17
Non Motile Green Algae	460,552	1.61	503,792	3.68	368,160	2.40
Unidentified Algae	39,600	0.14	27,900	0.20	12,600	0.08
Total Algal Density	**28,598,557**		**13,700,906**		**15,324,741**	

	11-Aug-03		12-Aug-04			
	East Oakwood	Percent	Johnson	Percent	Tetonkaha	Percent
Flagellated Algae	428,650	0.45	266,403	0.23	140,365	0.10
Blue-Green Algae	93,386,947	98.13	115,644,362	98.29	143,680,069	99.46
Diatoms	476,420	0.50	1,431,074	1.22	487,100	0.34
Non Motile Green Algae	794,010	0.83	286,118	0.24	144,443	0.10
Unidentified Algae	81,600	0.09	24,000	0.02	10,500	0.01
Total Algal Density	**95,167,627**		**117,651,957**		**144,462,477**	

East Oakwood Lake total phytoplankton biovolume ranged from 39,600 µm³/mL in June to 93,386,947 µm³/mL in August. Johnson Lake total phytoplankton biovolume ranged from 24,000 µm³/mL in August to 115,644,362 µm³/mL in August. Lake Tetonkaha total phytoplankton biovolume ranged from 10,500 µm³/mL in August and 143,680,069 µm³/mL in August.

Throughout the summer blue-green algae dominated the biovolume in all lakes. The species of blue-green algae with the most biovolume in all of the lakes was *Oscillatoria agarhii*, a nuisance species. Other nuisance species found in all of the lakes included *Anabaena* and *Microcystis.*

All algae samples were incorporated into the following graphs (Figures 11 through 16). All of the lakes were sampled in June and August. By far, blue-green algae dominated. Flagellated algae, blue-green algae, non-motile green algae, diatoms, and unidentified algae were compared among the lakes. More detailed graphs of each lake can be found in the Analysis Section of this report.

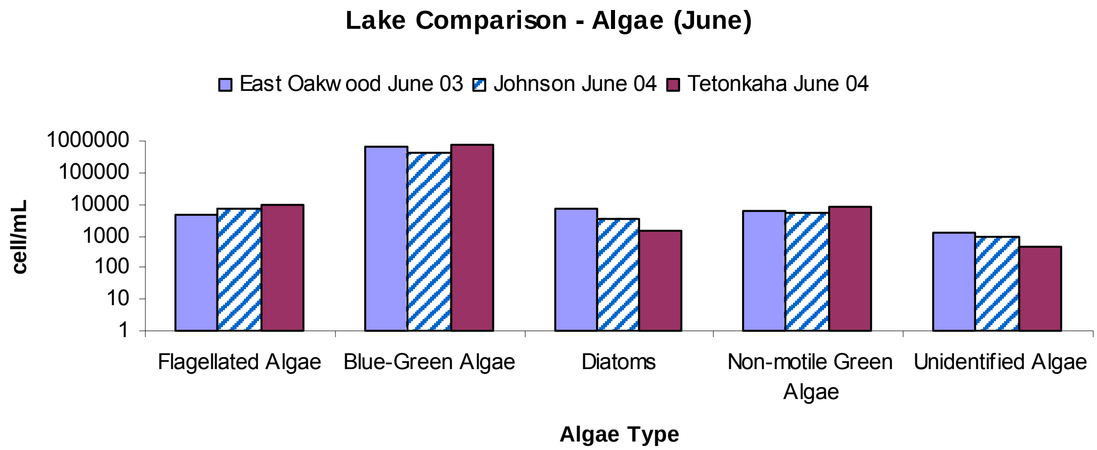


Figure 11. Total Algae Cells per Milliliter by Algae Type for East Oakwood Lake and West Oakwood Lake (Johnson and Tetonkaha) in June

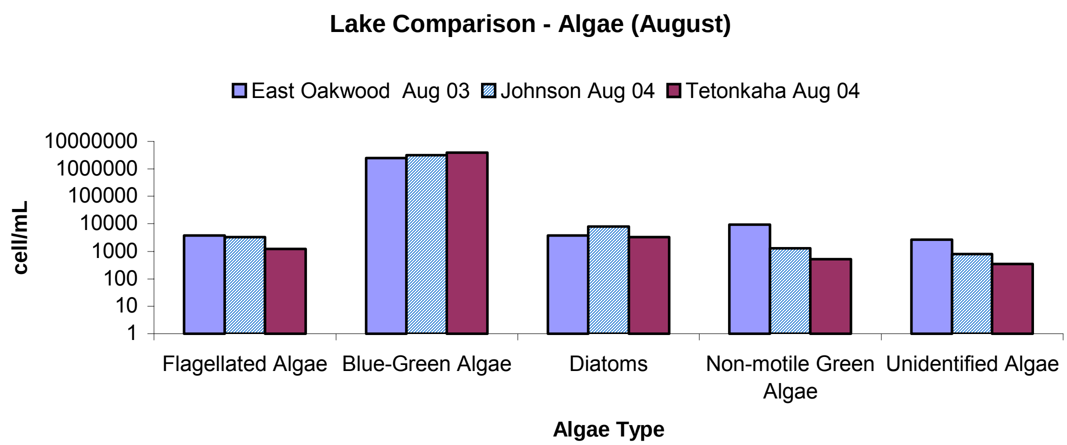


Figure 12. Total Algae Cells per Milliliter by Algae Type for East Oakwood Lake and West Oakwood Lake (Johnson and Tetonkaha) in August

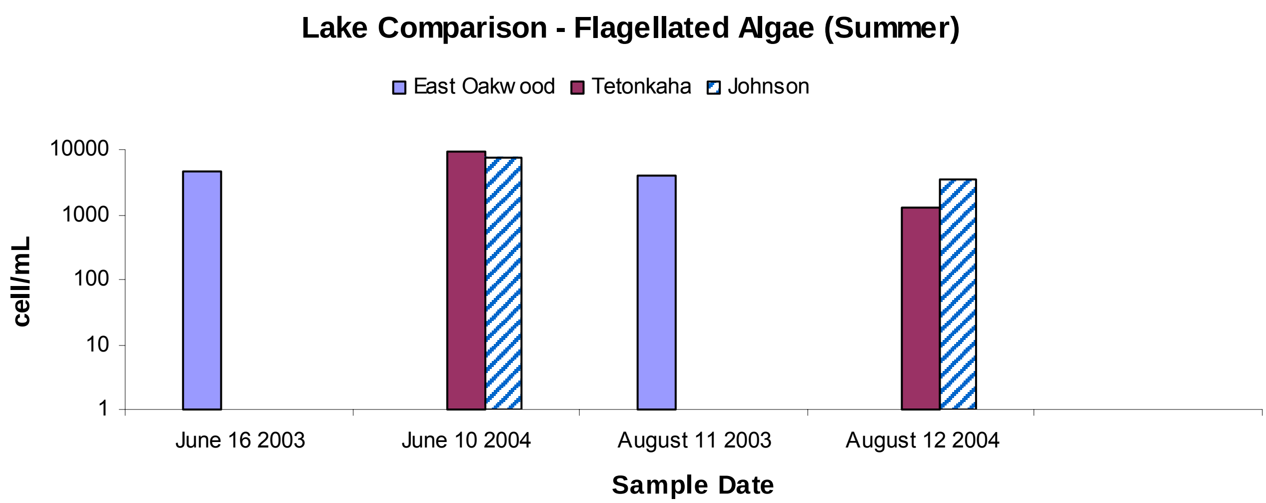


Figure 13. Total Flagellated Algae Cells per Milliliter by Sample Date for East Oakwood Lake and West Oakwood Lake (Johnson and Tetonkaha)

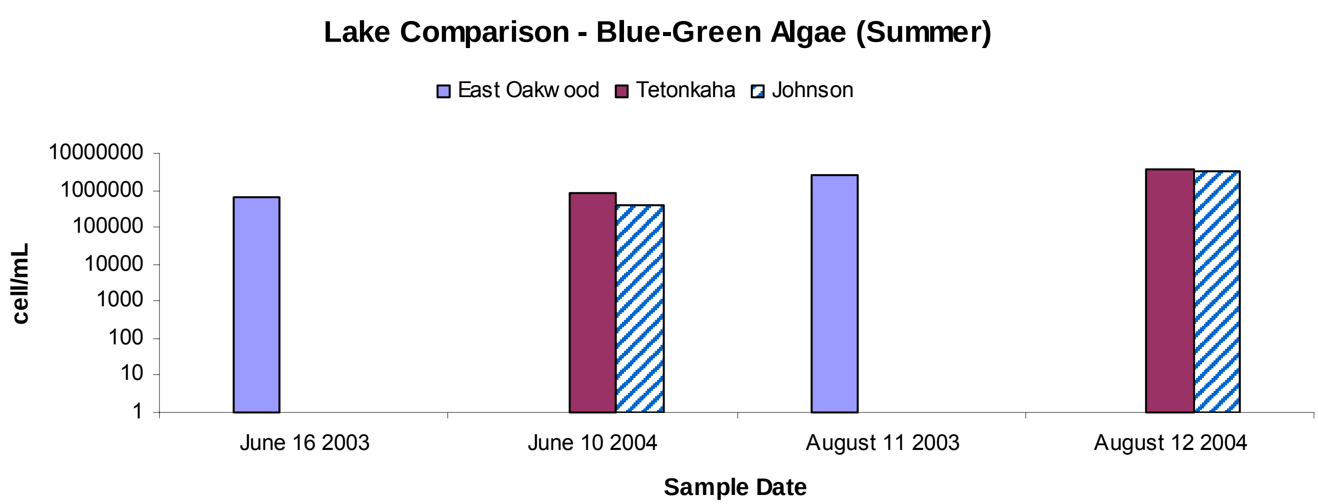


Figure 14. Total Blue-Green Algae Cells per Milliliter by Sample Date for East Oakwood Lake and West Oakwood Lake (Johnson and Tetonkaha)

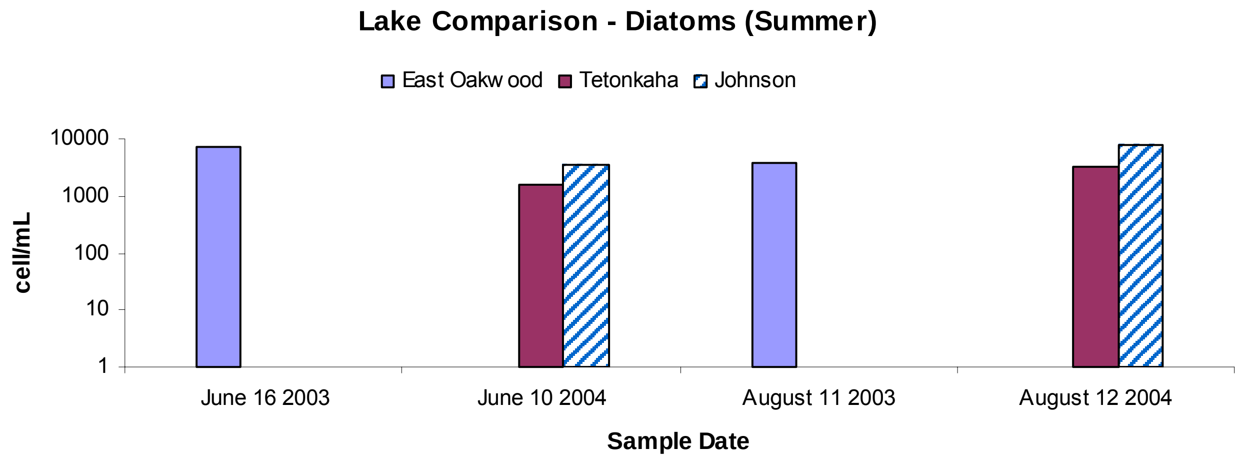


Figure 15. Total Diatoms Algae Cells per Milliliter by Sample Date for East Oakwood Lake and West Oakwood Lake (Johnson and Tetonkaha)

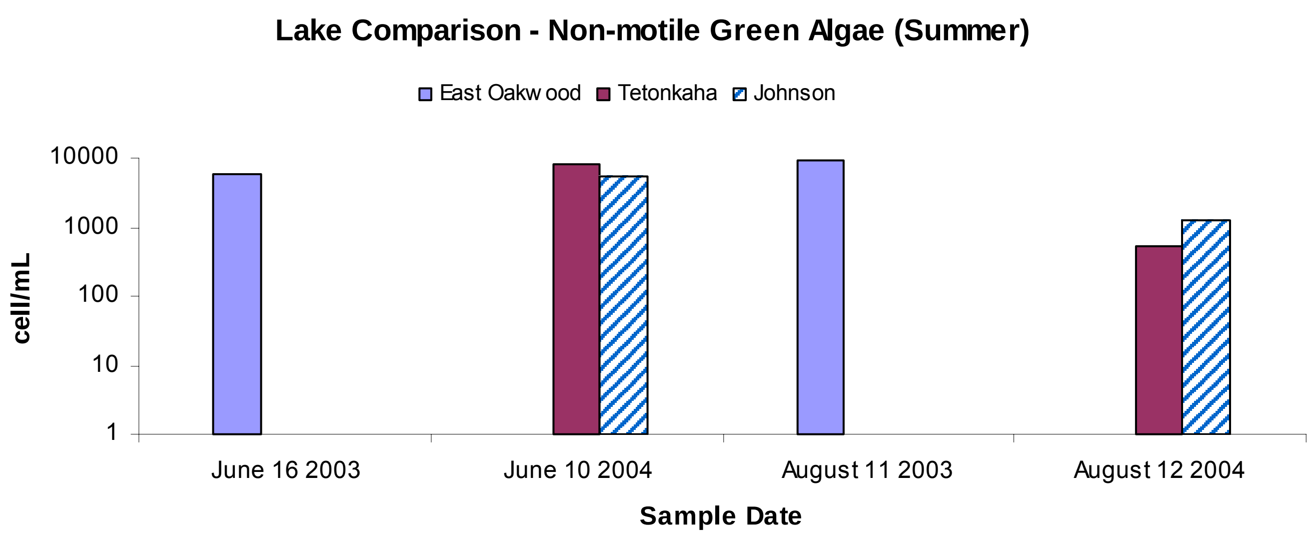


Figure 16. Total Non-Motile Green Algae Cells per Milliliter by Sample Date for East Oakwood Lake and West Oakwood Lake (Johnson and Tetonkaha)

Chlorophyll-*a* Sampling

Chlorophyll-*a* samples were collected at all in-lake sampling sites during the project (Figure 17). Overall, the chlorophyll-*a* concentration for all lakes were relatively high. The maximum chlorophyll-*a* concentration (258.23 mg/m^3) sampled in West Oakwood Lake was collected at Site L11 on August 12, 2004. The maximum chlororphyll-*a* concentration (179.85 mg/m^3) sampled in East Oakwood Lake was collected at Site L1 on August 11, 2003.

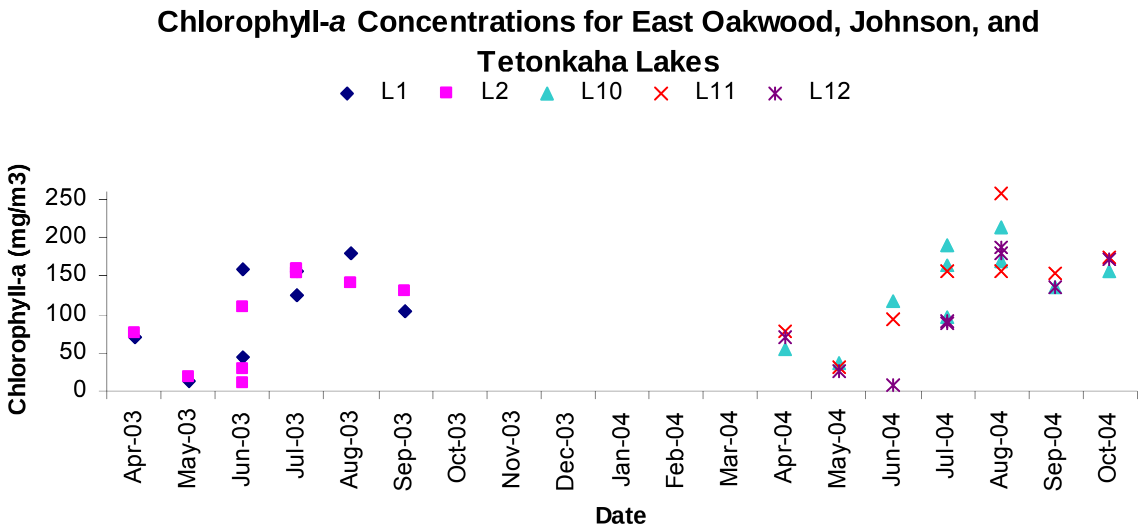


Figure 17. Monthly In-Lake Chlorophyll-*a* Concentrations by Date and Sampling Site for East Oakwood Lake and West Oakwood Lake (Johnson and Tetonkaha)

Aquatic Plant Sampling

An aquatic macrophyte survey was conducted on East Oakwood Lake and West Oakwood Lake (includes Johnson Lake and Lake Tetonkaha). A shoreline survey of East Oakwood Lake, along 32 transects, identified only one emergent aquatic plant (cattails). Poor emergent plant diversity is typical of lakes within this ecoregion (SD DENR 2000a). Leafy pondweed (*Potamogeton foliosus*), clasping leaf pondweed (*Potamogeton richardsonii*), and sago pondweed (*Potamogeton pectinatus*) were identified at 14 transect sampling locations (Table 67 and Figure 18). Additionally *Chara* sp. (a type of algae) was also identified during the aquatic plant survey.

Table 67. Submergent Plant Species Identified in East Oakwood Lake

Common Name	Genus	Species	Habitat
Leafy Pondweed	*Potamogeton*	*foliosus*	Submergent
Claspingleaf Pondweed	*Potamogeton*	*richardsonii*	Submergent
Sago Pondweed	*Potamogeton*	*pectinatus*	Submergent
Cattails	*Typha*	*spp.*	Emergent

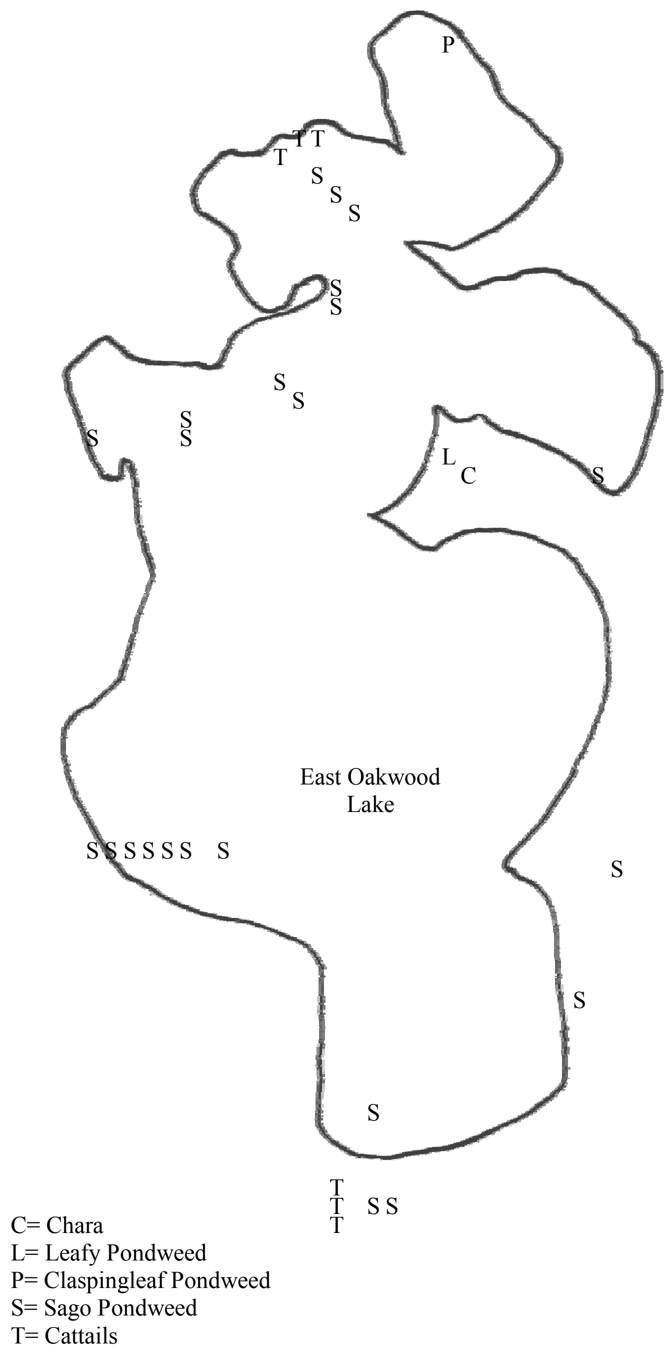


Figure 18. Location of Aquatic Plant Species in East Oakwood Lake

Lake Tetonkaha was divided into 29 transects. Cattails (*Typha spp*), sago pondweed (*Potamogeton pectinatus*), and bulrushes (*Scirpus spp*) were identified during the shoreline survey. Of the three shoreline species, sago pondweed (*Potamogeton pectinatus*) was identified at four transect sampling locations. Only six transect sampling locations yielded submergent vegetation (Figure 19).

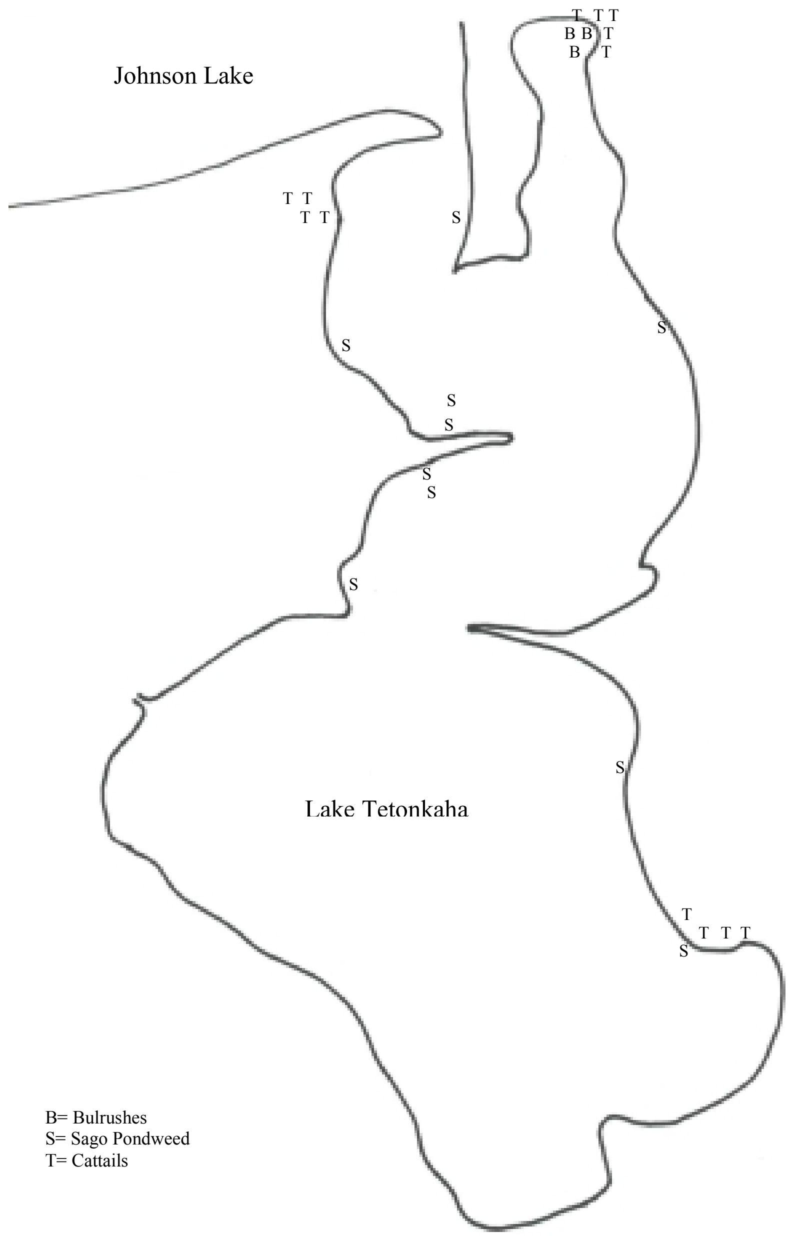


Figure 19. Location of Aquatic Plant Species in Lake Tetonkaha

Cattails (*Typha spp*) and sago pondweed (*Potamogeton pectinatus*) were identified during the shoreline survey of Johnson Lake. Submergent macrophyte species were sampled using 20 transects throughout the lake. One of the three shoreline species, sago pondweed (*Potamogeton pectinatus*) was identified at six of the 20 transect sampling locations (Figure 20).

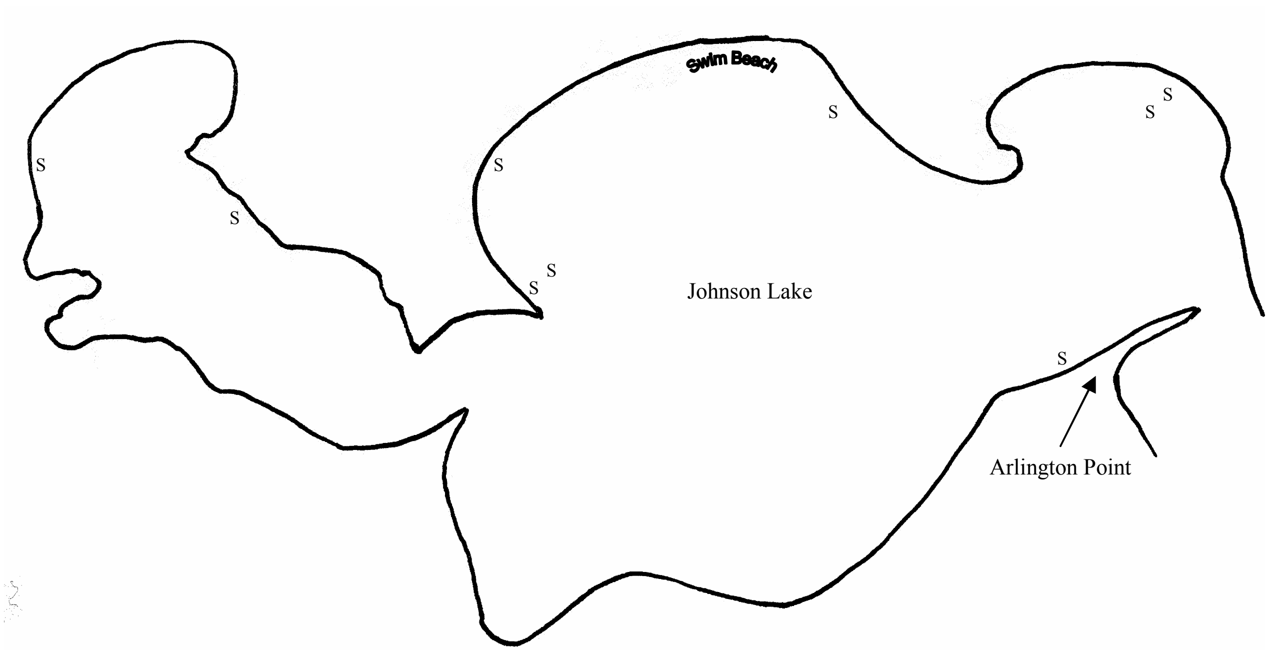


Figure 20. Location of Aquatic Plant Species in Johnson Lake

TSI COMPUTATION

Carlson's (1977) Trophic State Index (TSI) for chlorophyll-*a* and Secchi depth was calculated for both East Oakwood and West Oakwood Lake. TSI values for East Oakwood Lake are plotted by sampling date in Figure 21 and TSI values for West Oakwood Lake are plotted by sampling date in Figure 22. Beneficial use categories show that the majority of the samples do not meet the TSI criteria to support a warmwater semi-permanent fishery. In 2003, East Oakwood Lake median TSI values (Secchi depth plus chlorophyll-*a* TSI daily values) ranged from 60.8 to 83.8 with and overall median value of 75.7. Secchi depth TSI values ranged from 65.1 to 93.2 and chlorophyll-*a* TSI values ranged from 56.5 to 81.5.

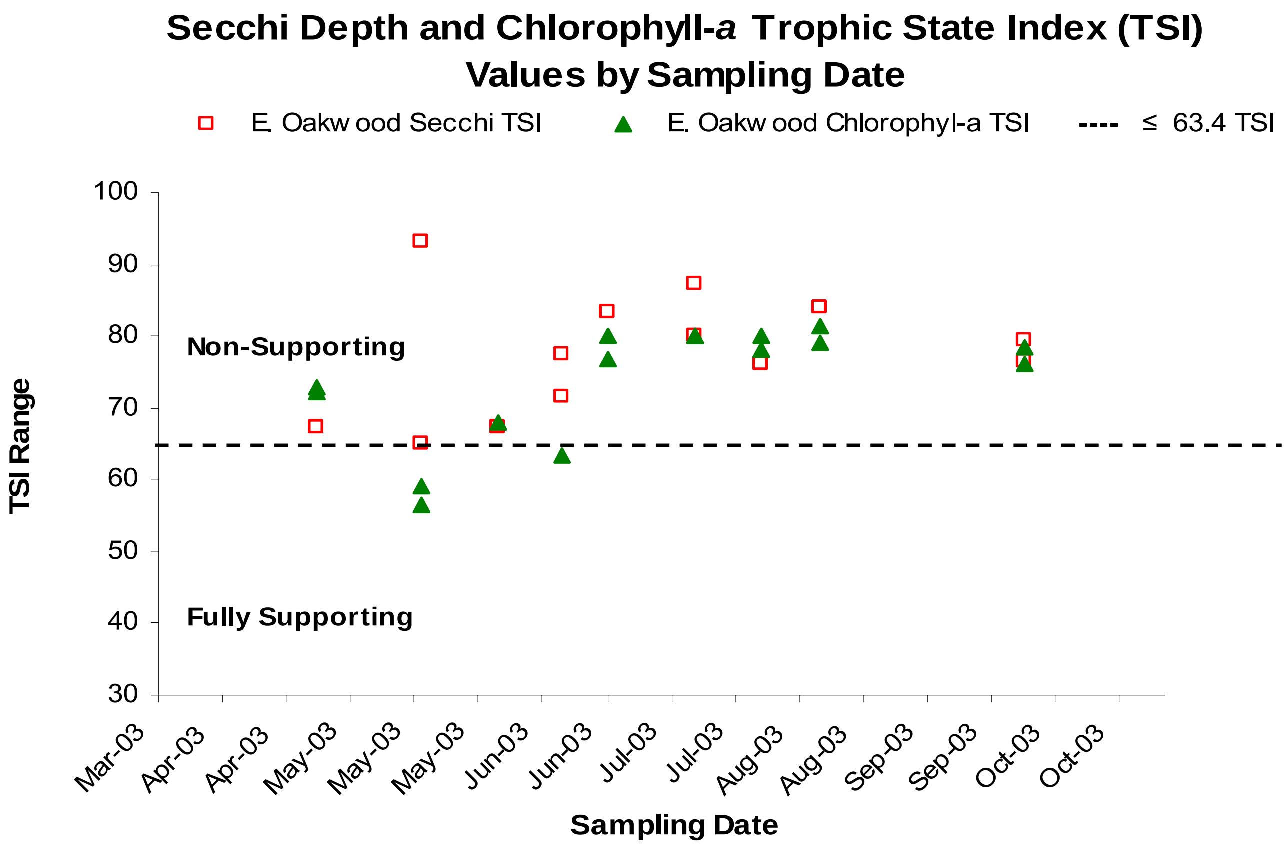


Figure 21. East Oakwood Lake TSI Values by Beneficial Use Support

In 2004, West Oakwood Lake median observed TSI values (Secchi depth plus chlorophyll-*a* TSI daily values) ranged from 59.9 to 84.1 with and overall median TSI value of 76.7. Secchi depth TSI values ranged from 66.8 to 83.2 and chlorophyll-*a* TSI values ranged from 50.1 to 85.1.

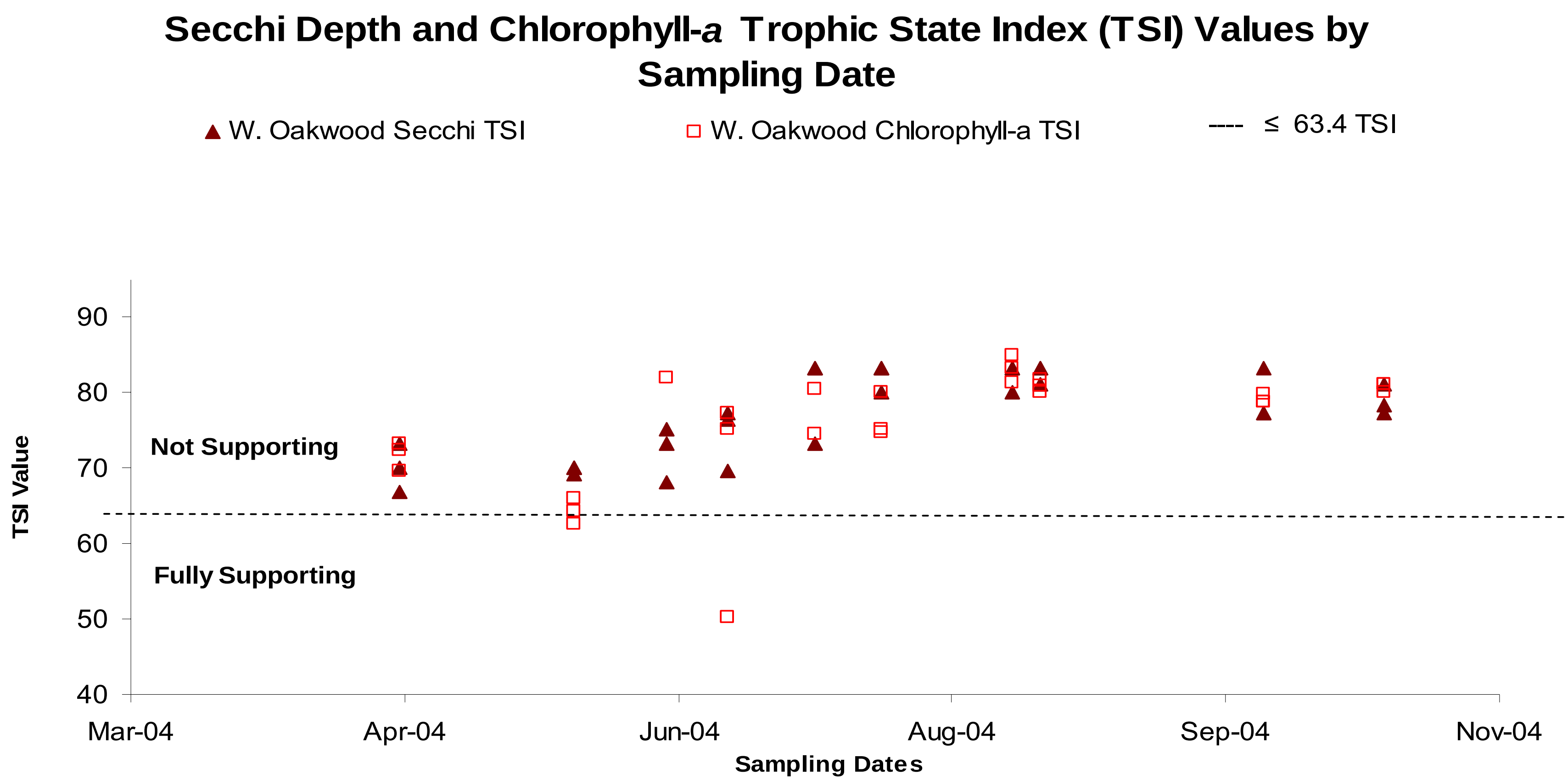


Figure 22. West Oakwood Lake TSI Values by Beneficial Use Support

ASSESSMENT OF SOURCES

Point Sources

There are no municipalities or known point sources located within this watershed.

Non-Point Sources

Agricultural Runoff

Agricultural runoff was taken into account when the AnnAGNPS model calculated sediment and nutrient loadings using different landuse scenarios. Agricultural runoff was also taken into account when AGNPS was used to perform ratings of the feedlots in the study area. This information was then incorporated in the process of prioritizing watershed areas for fecal coliform bacteria reduction.

Background Wildlife Contribution

The average contribution of fecal coliform bacteria from deer is estimated at 8.4 percent watershed wide (Table 68). This number assumes 100 percent of the fecal coliform bacteria from deer is delivered into the receiving waters. Therefore, due to its unrealistic 100 percent delivery only for deer, it will represent all wildlife contributions in this watershed for this project.

Table 68. Wildlife Contributions of Fecal Coliform Bacteria

Wildlife Background CFU's								
Site	Deer/Sq. Mile	Sq. Miles	Deer	Days	CFU's/deer/day	CFU's	Total CFU's	% deer
T43	3.41	35.1	120	306	5.00E+08	1.83E+13	2.04E+14	9.0
T45	3.41	35.1	120	210	5.00E+08	1.26E+13	1.60E+14	7.9
							Average	8.4

Failing Septic Systems Contribution

The calculated average contribution of fecal coliform bacteria from failing rural septic systems is 1.1 percent watershed wide (Table 69). This table takes into account rural households (not on a lake) and residential households (on a lake). According to the US EPA (2002) failure rates of onsite septic systems range from 10 to 20 percent, with a majority of these failures occurring with systems 30 or more years old. This percentage assumes 20 percent of the estimated rural septic systems are failing and reaching the receiving waters. The exact number of onsite septic systems in the study area is unknown. There are several seasonal homes located along the shoreline of Lake Tetonkaha. There are approximately 75 developed lots that are mainly (about 70 %) summer homes. A resort and trailer park are also located along the southern shoreline of Lake Tetonkaha (personal comm. John Gustafson, Century 21 Real Estate). Further investigation of the shoreline residences is recommended. Until there is better factual data on the conditions of the rural septic systems in this area, the 1.1 percent average will be used.

Table 69. Failing Septic System Contribution of Fecal Coliform Bacteria

Failing Septic Contribution									
Area	**People/ Household**	**Number of Households**	**20%**	**People**	**Days**	**CFUs/person/ day**	**CFU's**	**Total CFUs**	**Percent People**
Rural	2.5	24	4.8	12	153	2.00E+09	3.67E+12	3.04E+14	1.2
Residential	2.5	85	17	43	153	2.00E+09	1.30E+13	1.28E+15	1.0
								Average	1.1

Modeling

FLUX Modeling

The FLUX Model (Army Corps of Engineers Loading Model) was used to estimate the nutrient loadings for each site. These loads and their standard errors (CV) were calculated (Table 70). Sample data (discharge and water quality) collected during this project were utilized in the calculation of the loads and concentrations. For each tributary site sampled, monthly loadings and concentrations for each sampled parameter is detailed in Appendices H and I.

Table 70. FLUX Yearly Loads and Concentrations by Water Quality Parameter and Site

T43

Parameter	Concentration (ppb)	FLUX Load Kg/Yr	CV
SuspSol	81908	809695	0.321
TotSol	946485	9356424	0.055
DisSol	833295	8237498	0.035
NO2NO3	763	7542	0.339
NH3N	132	1303	0.200
Orgntr	1589	15706	0.186
TKN	1719	16994	0.187
TotPO4	448	4425	0.168
TotDisPO4	341	3372	0.126
Fecal	4139000	40915800	0.516
DO	9973	98588	0.186

T44

Parameter	Concentration (ppb)	FLUX Load Kg/Yr	CV
SuspSol	20346	272804	0.242
TotSol	933774	12520360	0.021
DisSol	911815	12225910	0.017
NO2NO3	69	929	0.104
NH3N	500	6698	0.463
Orgntr	2333	31287	0.125
TKN	2894	38803	0.125
TotPO4	225	3019	0.147
TotDisPO4	81	1088	0.220
Fecal	255518	3426077	0.739
DO	9270	124299	0.170

T45

Parameter	Concentration (ppb)	FLUX Load Kg/Yr	CV
SuspSol	16668	512776	0.451
TotSol	841838	25898320	0.037
DisSol	822683	25309020	0.042
NO2NO3	186	5733	0.294
NH3N	182	5606	0.210
Orgntr	1246	38344	0.089
TKN	1432	44054	0.081
TotPO4	227	6991	0.109
TotDisPO4	173	5327	0.056
Fecal	1080120	33320100	0.320
DO	6441	198706	0.195

T46

Parameter	Concentration (ppb)	FLUX Load Kg/Yr	CV
SuspSol	51535	1012483	0.541
TotSol	780717	15338260	0.018
DisSol	765524	15039770	0.023
NO2NO3	438	8605	0.067
NH3N	228	4477	0.089
Orgntr	1567	30791	0.077
TKN	1782	35020	0.074
TotPO4	374	7343	0.164
TotDisPO4	248	4878	0.119
Fecal	4068350	79928300	0.231
DO	9224	181219	0.229

T48

Parameter	Concentration (ppb)	FLUX Load Kg/Yr	CV
SuspSol	21111	101021	0.236
TotSol	1154362	5523810	0.057
DisSol	1133251	5422789	0.060
NO2NO3	460	2201	0.166
NH3N	224	1070	0.189
Orgntr	1950	9333	0.064
TKN	2201	10533	0.052
TotPO4	209	1002	0.110
TotDisPO4	126	603	0.175
Fecal	1034105	4948359	0.416
DO	10266	49123	0.145

BATHTUB Modeling

The BATHTUB model calculated the median observed and predicted TSI values (chlorophyll-*a* and Secchi depth) for East Oakwood Lake and West Oakwood Lake (Table 71). West Oakwood Lake was modeled as three segments: 1) Johnson Lake, 2) North Lake Tetonkaha, and 3) South Lake Tetonkaha. The observed TSI values are based on in-lake data. The predicted TSI values are based on in-lake data and watershed nutrient loading calculating the interaction between the lake and watershed area. North Lake Tetonkaha had the highest observed TSI value at 78.0 and a predicted TSI value of 77.3. South

Lake Tetonkaha observed TSI value was 77.4 with a predicted TSI value of 77.5. Johnson Lake observed TSI value was 77.4 with a predicted TSI value of 76.8. East Oakwood Lake observed TSI value was 67.4 with a predicted TSI value of 72.5.

Table 71. Observed and Predicted Median Trophic State Index (TSI) Values Calculated Using the BATHTUB Model

	Observed TSI	Predicted TSI
East Oakwood Lake	67.4	72.5
Johnson Lake	77.4	76.8
North Lake Tetonkaha	78.0	77.3
South Lake Tetonkaha	77.4	77.5

The BATHTUB model also calculated the response of each lake to reductions in watershed loading. Watershed nutrient loading concentrations were reduced by 10 percent increments and modeled to create an in-lake reduction curve (Figure 23).

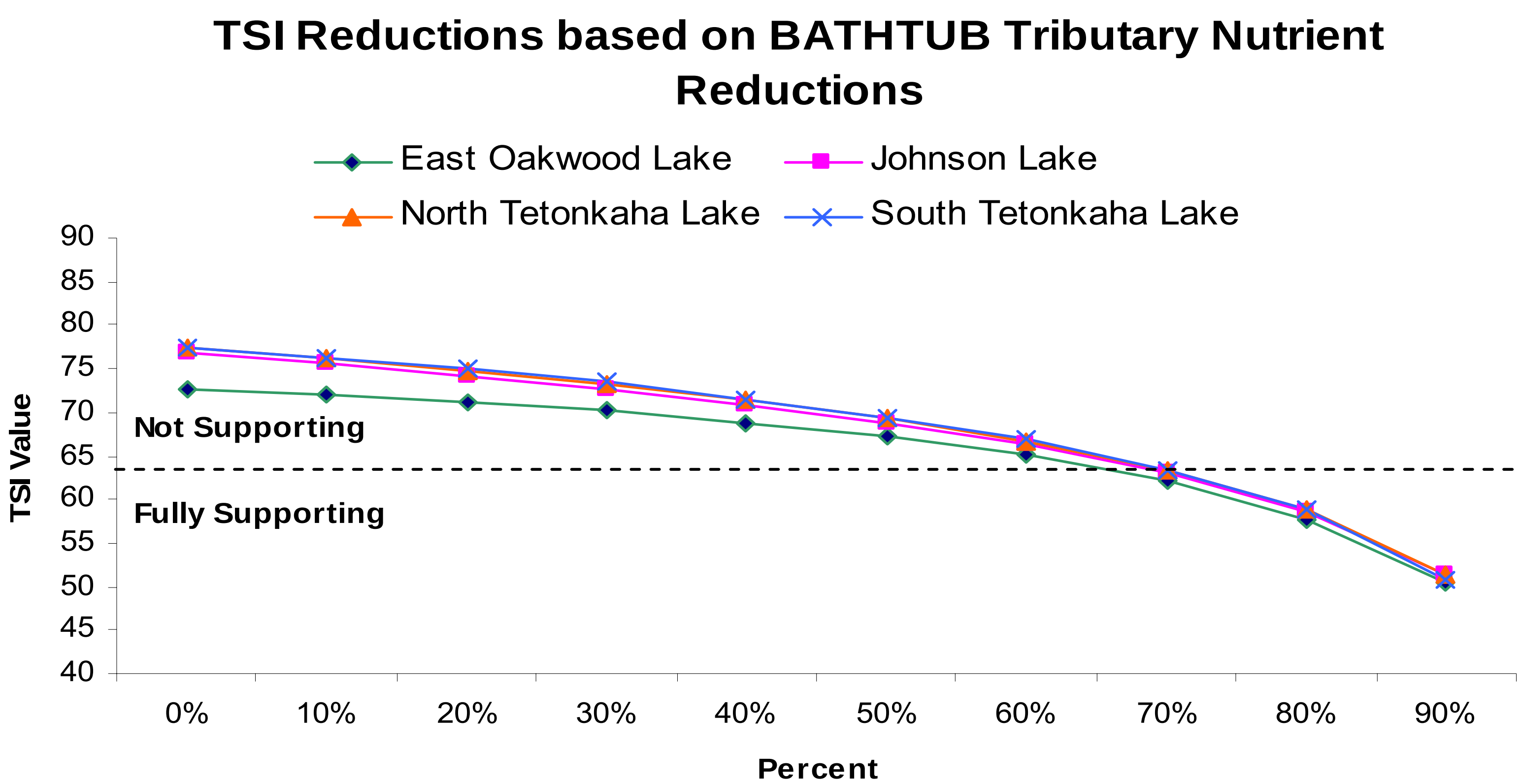


Figure 23. BATHTUB Predicted Mean TSI Reductions and Use Support of East Oakwood Lake and West Oakwood Lake

AGNPS Feedlot Model

The Brookings County Conservation District evaluated 51 feedlots within the East Oakwood Lake watershed. Seventeen of the 51 operations were rated 50 or greater (Table 72). The AGNPS feedlot model ranks the feedlots on a scale from 0 to 100 with larger numbers indicating a greater release of pollutants.

Table 72. Oakwood Lakes Watershed AGNPS Ratings

Feedlot	Watershed	Rating
1005	East Oakwood	53
1062	East Oakwood	53
1013	West Oakwood	53
1075	West Oakwood	54
1021	West Oakwood	55
1067	West Oakwood	55
1074	West Oakwood	55
1068	West Oakwood	56
1069	West Oakwood	57
1073	West Oakwood	57
1004	East Oakwood	58
1014	West Oakwood	60
1045	East Oakwood	63
1017	West Oakwood	63
1070	West Oakwood	67
1057	West Oakwood	80
1012	West Oakwood	82

The AGNPS model simulated 25 year 24 hour rainstorm events which is a model of the current requirement for the general permitting of waste storage facility construction. The model calculated the loading potential of phosphorus and chemical oxygen demand of each animal feeding operation (Table 73). The AGNPS phosphorus loading potentials ranged from 0.0 lbs. to 176 lbs. in the East Oakwood Lake watershed and from 0.0 lbs. to 713 lbs in the West Oakwood Lake watershed, for any single animal feeding operation.

Table 73. AGNPS Model Outputs for Feedlots in the Oakwood Lakes Watershed

Site	Density	Mean PO4 (ppm)	Mean COD (ppm)	Mean PO4 (lbs)	Mean COD (lbs)	Sum Phos (ppm)	Sum COD (ppm)	Sum Phos (lbs)	Sum COD (lbs)
BSR	1	13	634	98	4864	13	634	98	4864
T43	11	24	1280	83	4345	268	14083	911	47790
T44	9	39	1920	134	6808	354	17277	1210	61269
T45	6	4	215	25	1209	23	1291	152	7253
T46	11	13	827	46	2936	142	9094	511	32291
T48	13	18	1305	66	4523	239	16964	852	58793

AnnAGNPS Modeling

The AnnAGNPS Model was used to compare sediment, nitrogen, and phosphorus loadings within the watershed during 1-year, 10-year, and 25-year simulated periods. Several landuse scenarios were modeled including 1) present watershed condition, 2) changing cropland (corn and soybeans) to grass, 3) removing the feedlots, 4) removing any impoundments, and 5) changing cropping practices to no-tillage.

Critical phosphorus cells (> 2 lbs/acre/year) and critical nitrogen cells (> 3 lbs/acre/year) during a 10-year simulated period were identified (Table 74). Best management practices (BMPs) were applied to determine the amount of reduction that would be possible. Appendix O lists the top five percent AnnAGNPS cells where BMPs were the most effective.

Table 74. Critical Phosphorus and Nitrogen Cells in the Oakwood Lake Watershed

Phosphorus - - Critical Cells			Nitrogen Critical Cells		
Cell	Watershed	lb/acre/yr	Cell	Watershed	lb/acre/yr
3333	WOL	28.469	3333	WOL	115.34
3332	WOL	6.928	2603	EOL	18.816
3842	WOL	6.298	5492	WOL	8.696
3793	WOL	6.098	2622	EOL	7.849
3323	EOL	6.037	3793	WOL	7.258
4413	WOL	5.519	3282	EOL	7.239
3233	EOL	5.205	4413	WOL	7.149
4032	WOL	5.131	3842	WOL	7.054
5633	WOL	5.103	5633	WOL	6.744
5391	WOL	5.084	5632	WOL	6.335
5632	WOL	5.014	5643	WOL	5.995
5643	WOL	4.882	**3053**	EOL	**5.479**
5032	WOL	4.782	3332	WOL	5.453
4912	WOL	4.629	5391	WOL	4.893
2603	EOL	4.591	2683	EOL	4.86
3223	EOL	4.427	4643	WOL	4.607
3592	WOL	4.397	5032	WOL	4.532
5663	WOL	4.361	4032	WOL	4.445
4992	WOL	4.327	2743	EOL	4.386
5362	WOL	4.309	4043	WOL	4.343
4043	WOL	4.291	3273	EOL	4.313
3843	WOL	4.286	5663	WOL	4.198
3992	WOL	4.257	2713	EOL	4.18
3802	WOL	4.25	3323	EOL	3.943
3832	WOL	4.25	6173	EOL	3.868
3803	WOL	4.218	5182	WOL	3.801
5182	WOL	3.424	3233	EOL	3.554
2792	EOL	3.237	4692	WOL	3.461
2782	EOL	3.234	4912	WOL	3.451
5492	WOL	2.802	5362	WOL	3.418
2743	EOL	2.536	4992	WOL	3.397
4431	WOL	2.197	4503	WOL	3.388
2523	EOL	2.081	3592	WOL	3.383
			2642	EOL	3.323
			2562	EOL	3.298
			3241	EOL	3.214
			2733	EOL	**3.211**
			3843	WOL	3.194
			5783	WOL	3.11
			3553	WOL	3.089
			3992	WOL	3.082
			3003	EOL	3.079
			3802	WOL	3.054
			3803	WOL	3.046
			3832	WOL	3.046

** Bolded Cells contain a Feedlot

Table 75 shows overall watershed results of sediment, nitrogen, and phosphorus for a 10-year simulation period. Feedlot removal and no-tillage application were scenarios applied watershed-wide. As indicated, feedlots in the watershed are not contributing as much to nutrient problems as compared to agricultural practices.

Table 75. Modeled Percent Reductions in Nutrients and Sediment After BMP Application

West Oakwood Lake Watershed - 10 Year Simulation Period

Scenerio	Sediment Load (tons/acre/year)	Nitrogen Load (mass) (lb/ac/year)	Attached Nitrogen Load (lb/ac/yr)	Dissolved Nitrogen Load (lb/ac/yr)	Total Phosphorus Load (mass) (lb/ac/yr)	Attached Phosphorus Load (lb/ac/yr)	Dissolved Phosphorus Load (lb/ac/yr)
Present Condition	0.0000	427	201	226	249	46	203
No Feedlots	0.0000	414	193	221	247	45	202
No Tillage	0.0000	344	106	263	233	36	197
Percent Difference from Present Condition							
No Feedlots	0	3 ↓	4 ↓	2 ↓	1 ↓	2 ↓	1 ↓
No Tillage	0	19 ↓	47 ↓	14 ↑	7 ↓	23 ↓	3 ↓

** based on 39,578 watershed acres

East Oakwood Lake Watershed - 10 Year Simulation Period

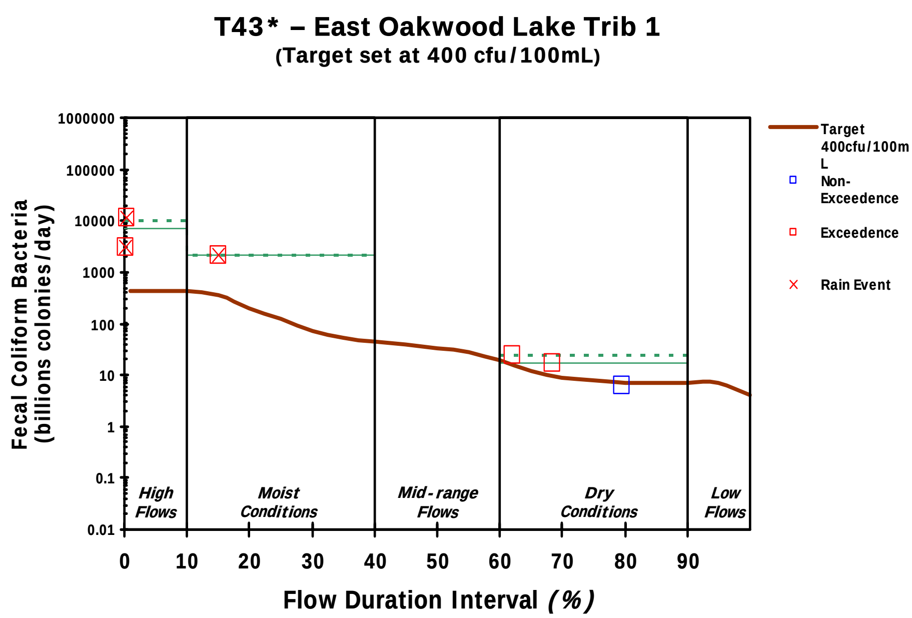
Scenerio	Sediment Load (tons/acre/year)	Nitrogen Load (mass) (lb/ac/year)	Attached Nitrogen Load (lb/ac/yr)	Dissolved Nitrogen Load (lb/ac/yr)	Total Phosphorus Load (mass) (lb/ac/yr)	Attached Phosphorus Load (lb/ac/yr)	Dissolved Phosphorus Load (lb/ac/yr)
Present Condition	0.0000	166	85	81	84	20	64
No Feedlots	0.0000	159	79	79	84	20	64
No Tillage	0.0000	179	78	91	72	13	58
Percent Difference from Present Condition							
No Feedlots	0	5 ↓	7 ↓	2 ↓	1 ↑	2 ↓	1 ↓
No Tillage	0	7 ↑	8 ↓	11 ↑	15 ↓	33 ↓	10 ↓

** based on 13,397 watershed acres

Flow Duration Intervals

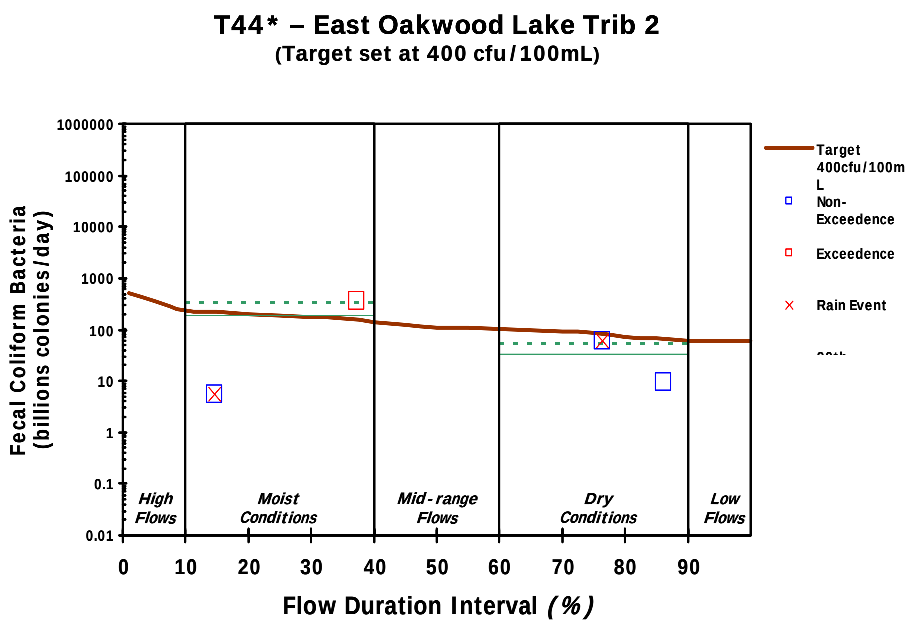
Flow duration intervals were constructed for each of the tributary sites to assess that status of fecal coliform bacteria and total suspended solids. However, none of the tributaries are assigned numeric standards for these parameters. But each lake is assigned beneficial uses which are associated with numeric standards for fecal coliform bacteria and total suspended solids. These flow duration intervals could be used to assess the amount of bacteria and sediment load the inlets and outlets are carrying in comparison to the numeric standard that is applicable for the lakes. Sample data collected during this project, as well as by the SD DENR were utilized in the calculation of the loadings.

Although none of the inlets are assigned water quality standards for fecal coliform bacteria or for total suspended solids, the target line is based on the numeric criteria related to the lakes or the Big Sioux River. The outlet of East Oakwood Lake (Sites T45 and T46) was graphed based on the numeric standard related to the Big Sioux River, because this stream eventually drains into the river. The target line on the fecal coliform bacteria graphs for the inlet sites T43, T44, and T48 reflect the 400 cfu/100mL numeric standard associated with beneficial uses (7) Immersion Recreation and (8) Limited Contact Recreation (Figures 24, 25, and 26). The target line on the fecal coliform bacteria graphs for sites T45 and T46 reflect the 2000 cfu/100mL numeric standard associated with beneficial use (8) Limited Contact Recreation assigned to the Big Sioux River (Figures 27 and 28). The target line on the total suspended solids graphs reflect the 158 mg/L numeric standard associated with beneficial use (5) Warmwater Semi-permanent Fish Life Propagation assigned to both the Big Sioux River and the lakes (Figures 29, 30, 31, 32, and 33).



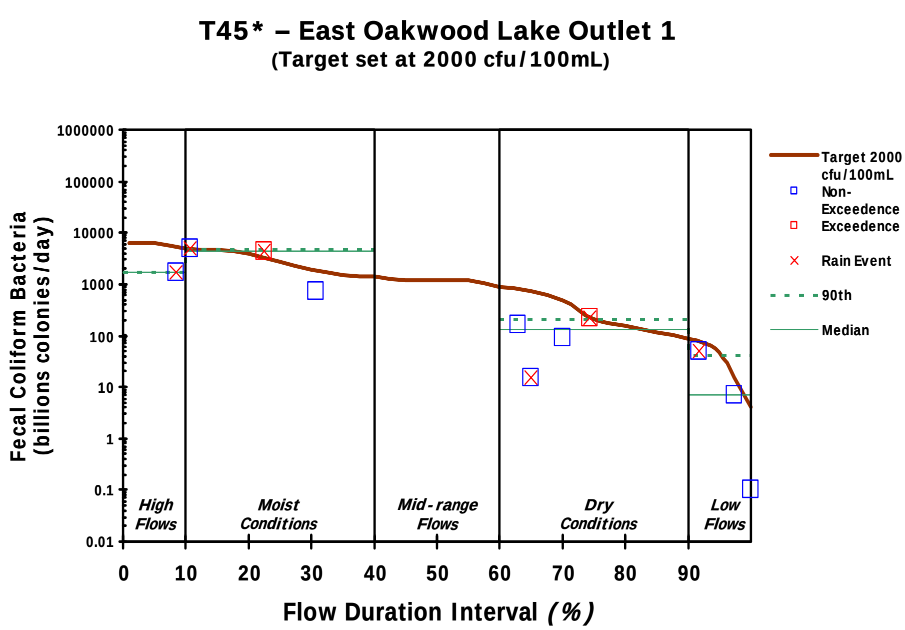
* numeric standard does not apply

Figure 24. Fecal Coliform Bacteria Flow Duration Interval of Inlet (T43)



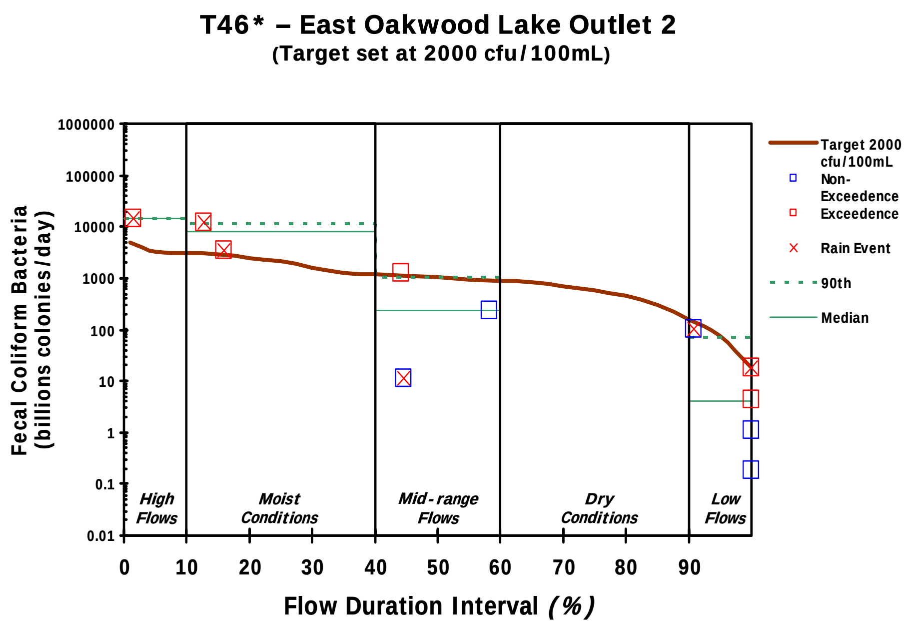
* numeric standard does not apply

Figure 25. Fecal Coliform Bacteria Flow Duration Interval of Inlet (T44)



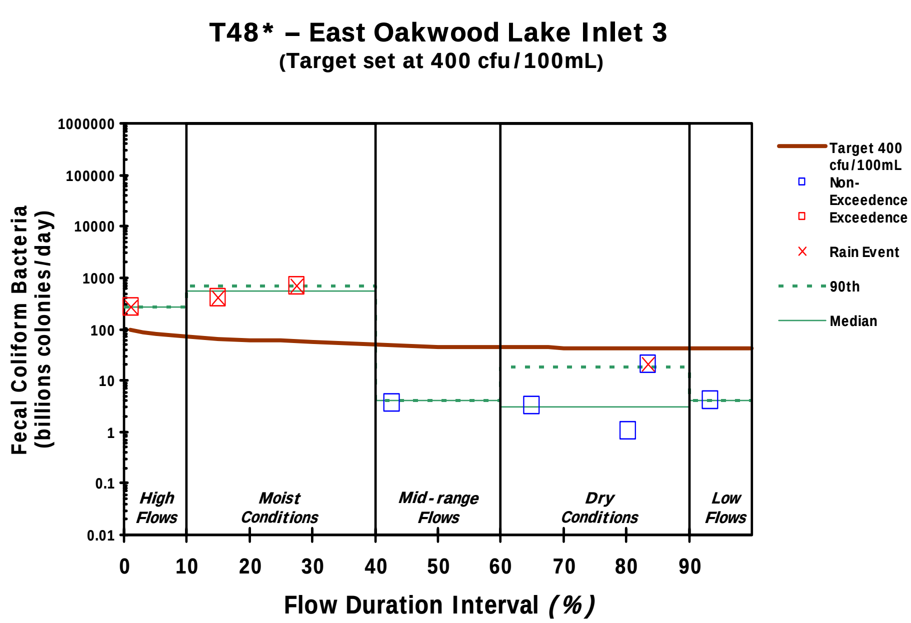
* numeric standard does not apply

Figure 26. Fecal Coliform Bacteria Flow Duration Interval of Outlet (T45)



* numeric standard does not apply

Figure 27. Fecal Coliform Bacteria Flow Duration Interval of Outlet (T46)



* numeric standard does not apply

Figure 28. Fecal Coliform Bacteria Flow Duration Interval of Inlet (T48)

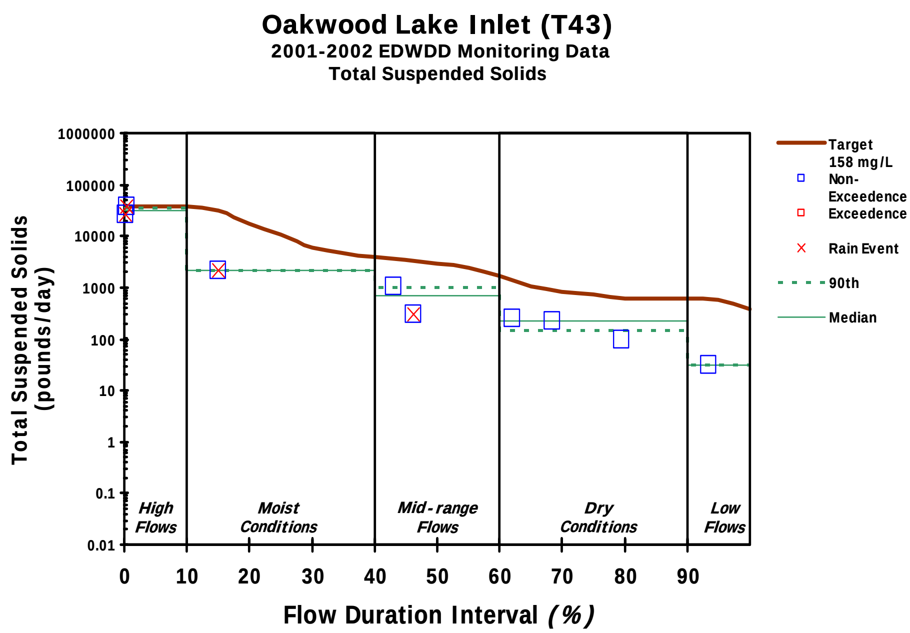


Figure 29. Total Suspended Solids Flow Duration Interval of Inlet (T43)

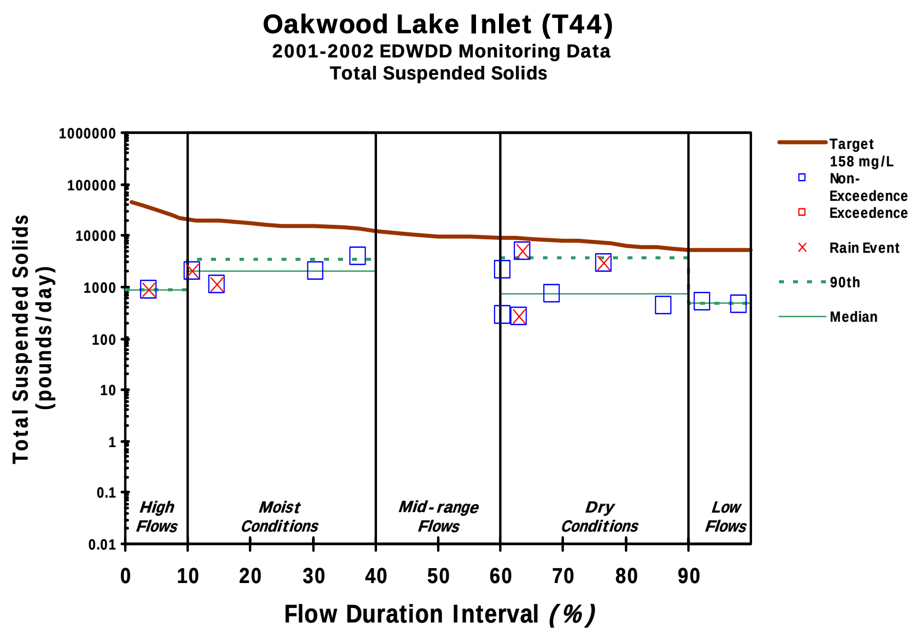


Figure 30. Total Suspended Solids Flow Duration Interval of Inlet (T44)

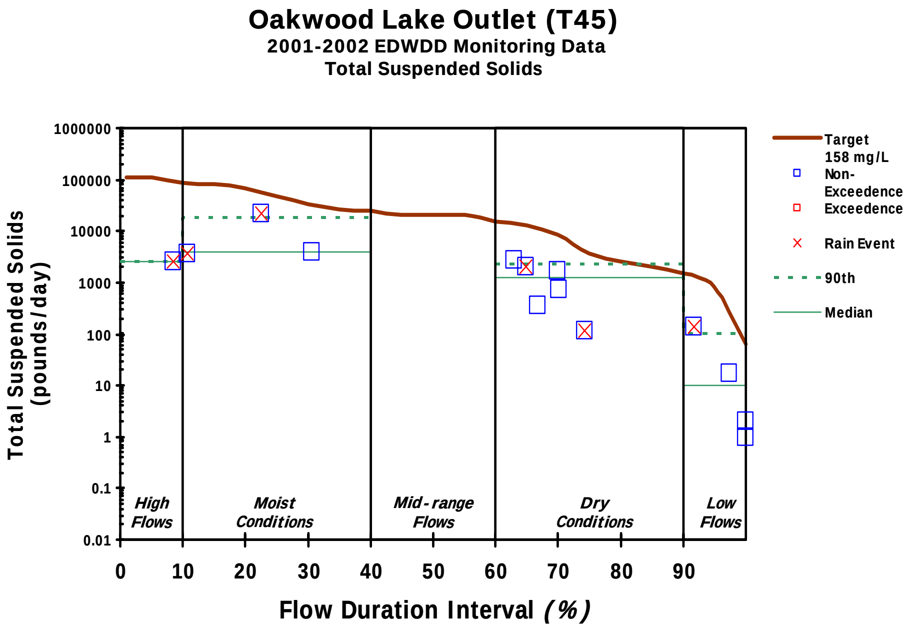


Figure 31. Total Suspended Solids Flow Duration Interval of Outlet (T45)

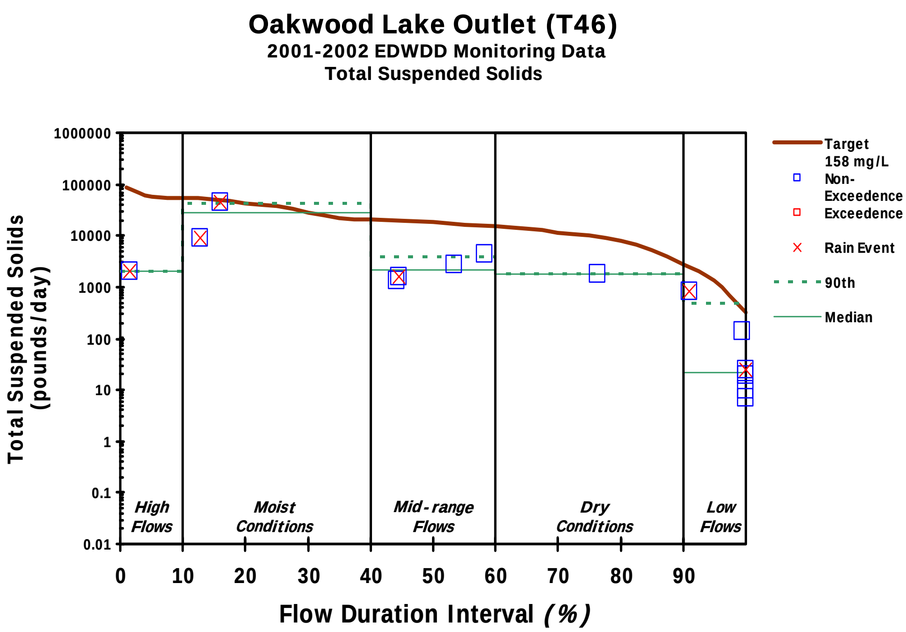


Figure 32. Total Suspended Solids Flow Duration Interval of Outlet (T46)

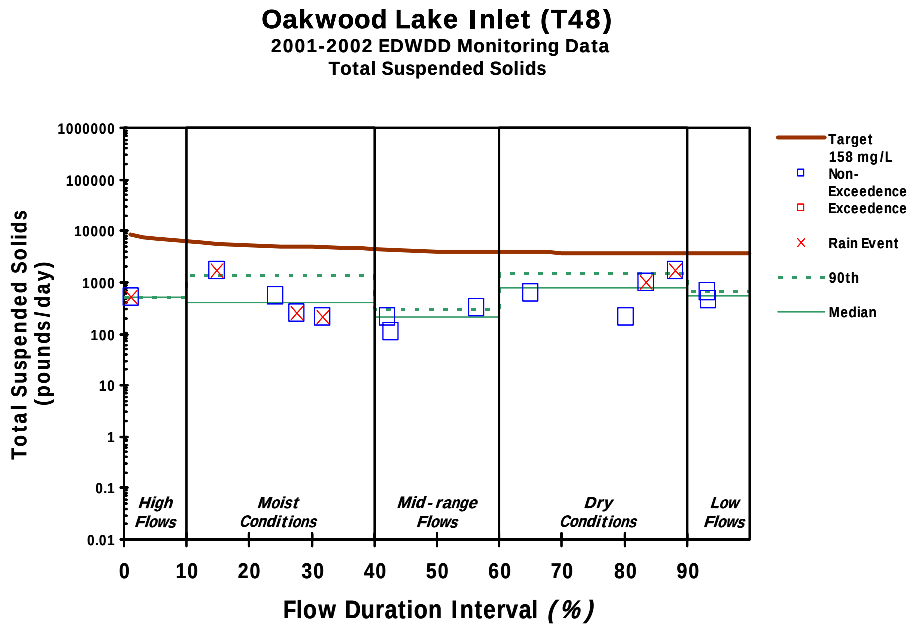


Figure 33. Total Suspended Solids Flow Duration Interval of Inlet (T48)

Site T43 and Site T48 are inlets to West Oakwood Lake. The fecal flow duration intervals for these two sites show they are receiving fecal matter during rain events. This could indicate feedlot runoff problems. There are also high fecal coliform amounts at Site T46 which is a site on the outlet of East Oakwood Lake near the Big Sioux River.

ANALYSIS AND SUMMARY

WEST OAKWOOD LAKE WATERSHED (Johnson Lake and Lake Tetonkaha)

This map (Figure 34) shows the location of the area designated as the West Oakwood Lake watershed. The watershed consists of the three connected lake segments Johnson Lake, North Lake Tetonkaha, and South Lake Tetonkaha. This area encompasses approximately 40,912 acres, with West Oakwood Lake itself covering approximately 702 surface acres.

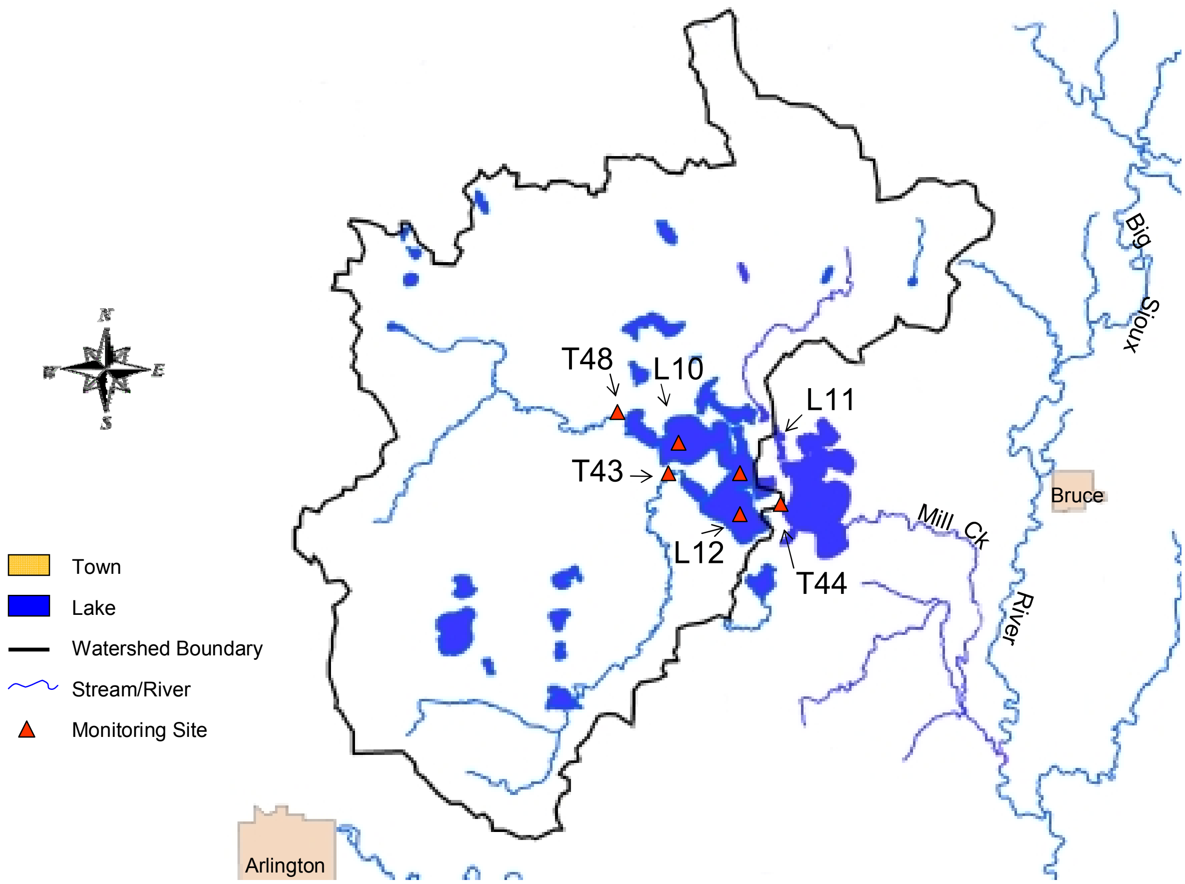


Figure 34. West Oakwood Lake Watershed Map

Landuse Summary

The West Oakwood Lake watershed is located within the Northern Glaciated Plains level III ecoregion and characterized by the level IV ecoregion of the Big Sioux Basin. This is an area of rolling terrain and an incised stream drainage network. The rolling areas are extensively tilled for small grains, corn, sunflowers, and soybeans. Most of the area is cropland, such as corn and soybeans, and some areas are grassland and pastureland. There were 34 animal feeding operations consisting of 4,336 animals assessed in the West Oakwood Lake watershed. The majority were cattle operations (94 percent) and the remaining were hog operations. Several seasonal homes are located around the southern end of Lake Tetonkaha.

Water Quality Summary

Beneficial uses assigned to the three in-lake sites (Site L10 -Johnson Lake and Sites L11 and L12 - Lake Tetonkaha) are 5, 7, 8, and 9.

(5) Warmwater Semi-permanent Fish Life Propagation
(7) Immersion Recreation
(8) Limited Contact Recreation
(9) Fish and Wildlife Propagation, Recreation and Stock Watering

Beneficial uses assigned to the two inlets and the one outlet of West Oakwood Lake are 9 and 10.

(9) Fish and Wildlife Propagation, Recreation and Stock Watering
(10) Irrigation

Based on the results from the water quality criteria established by the SD DENR as described in Results Section under Water Quality Monitoring, all the in-lake sites and the inlets/outlet are meeting the water quality criteria to support their beneficial uses.

Chlorophyll is the photosynthetic pigment in all green plants and can be a measure of the amount of algae present in a lake. Phosphorus is the primary nutrient algae use for growth. Phosphorus is usually the limiting nutrient in the growth of algae. Therefore, increases in phosphorus should yield increases in algae mass. In-lake monitoring indicates a correlation (R^2=0.4888 at Site L10, R^2=0.4967 at Site L11 and R^2=0.2716 at Site L12) between chlorophyll-*a* and total phosphorus at all three in-lake sites (Figures 35 and 36).

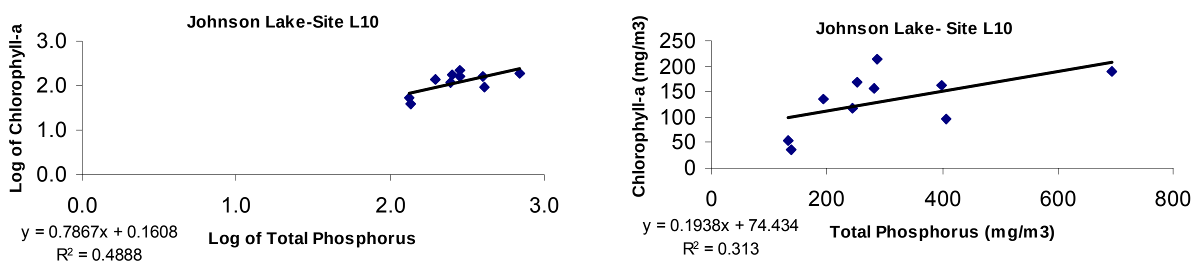


Figure 35. Johnson Lake Total Phosphorus to Chlorophyll-*a* Relationship

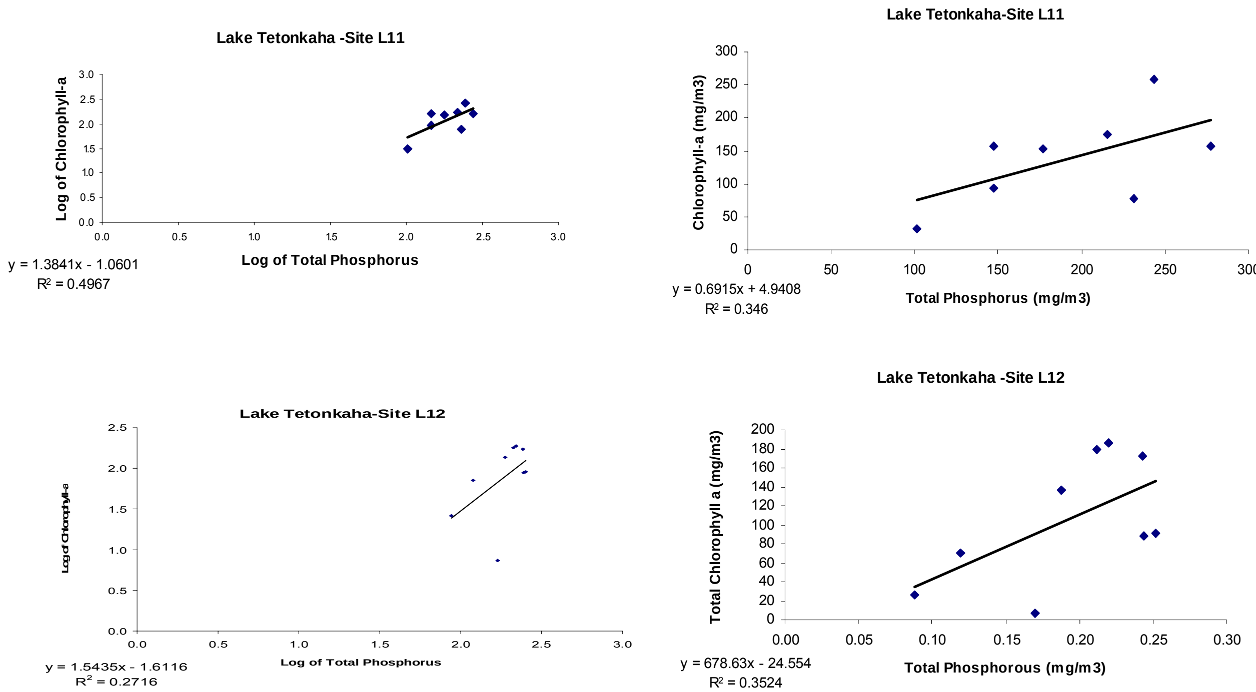


Figure 36. Lake Tetonkaha Total Phosphorus to Chlorophyll-*a* Relationship

The maximum in-lake chlorophyll-*a* concentration for Johnson Lake was 213.35 mg/m^3 collected at Site L10 on August 12, 2004 (Figure 37). The average chlorophyll-*a* concentration was 126.7 mg/m^3 and the median concentration was 135.88 mg/m^3. Lake Tetonkaha maximum in-lake chlorophyll-*a* concentration was 258.23 mg/m^3 collected at Site L11 on August 12, 2004 (Figure 38). The average chlorophyll-*a* concentration was 121.18 mg/m^3 and the median concentration was 136.33 mg/m^3.

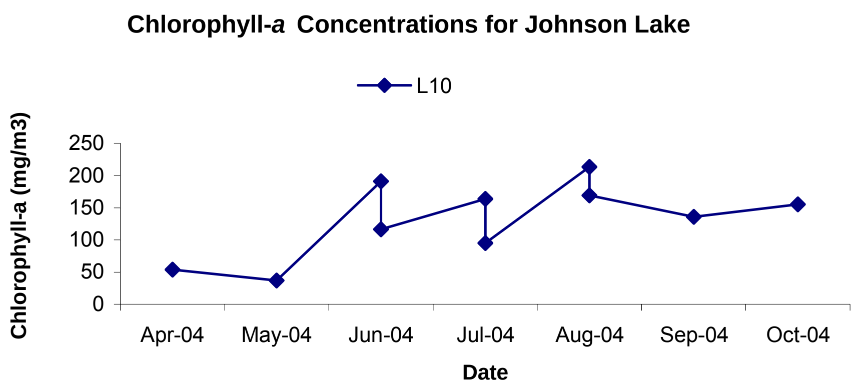


Figure 37. Johnson Lake Chlorophyll-*a* Concentrations (mg/m^3)

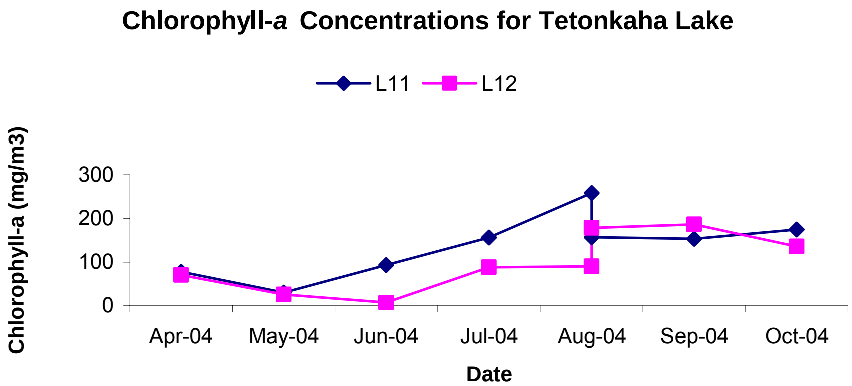


Figure 38. Lake Tetonkaha Chlorophyll-*a* Concentrations (mg/m³)

Water clarity is measured using a Secchi disk. The deeper the Secchi disk can be seen, the clearer the water. Indicatively, water clarity decreases as the amount of chlorophyll-*a* increases, as shown by Figures 39 and 40. Secchi depth in Johnson Lake ranged from 0.20 meters to 0.63 meters ($\bar{x}$ = 0.31 meters) and Secchi depth in Lake Tetonkaha ranged 0.20 meters to 0.57 meters ($\bar{x}$ = 0.32 meters).

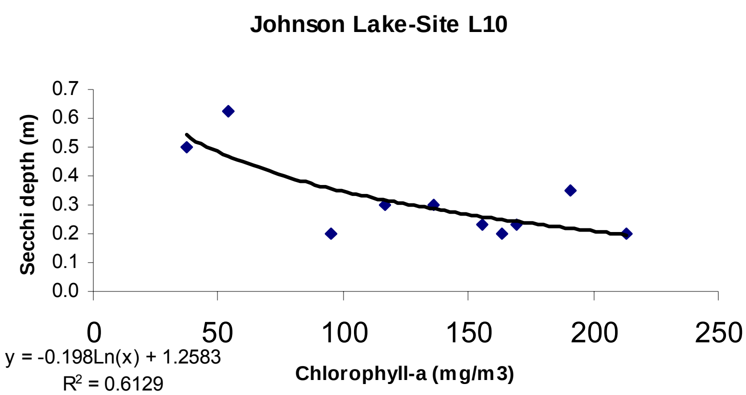


Figure 39. Johnson Lake Chlorophyll-*a* to Secchi Depth Relationship

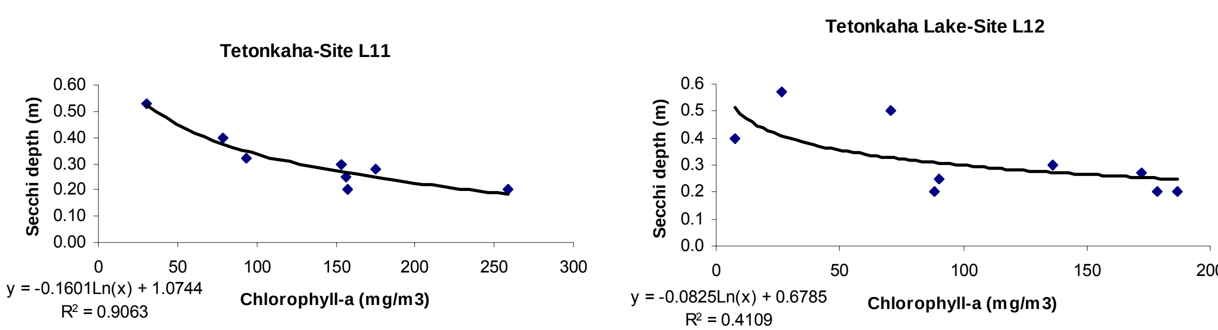


Figure 40. Lake Tetonkaha Chlorophyll-*a* to Secchi Depth Relationship

For an organism such as algae to survive in a given environment, it must have the necessary nutrients and environment to maintain life and successfully reproduce. If an essential life component approaches a critical minimum, this component will become the limiting factor (Odum 1959). Nutrients such as phosphorus and nitrogen are most often the limiting factors in highly eutrophic lakes. Typically, phosphorus is the limiting nutrient for algal growth. However, in many highly eutrophic lakes with an overabundance of phosphorus, nitrogen can become the limiting factor. Both Johnson Lake and Lake Tetonkaha are phosphorus-limited lakes as shown in Figures 41 and 42.

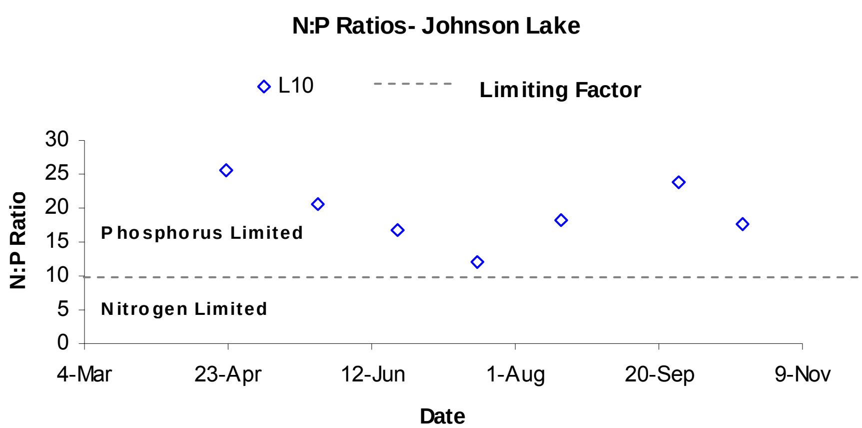


Figure 41. Johnson Lake Total Nitrogen to Total Phosphorus Ratio

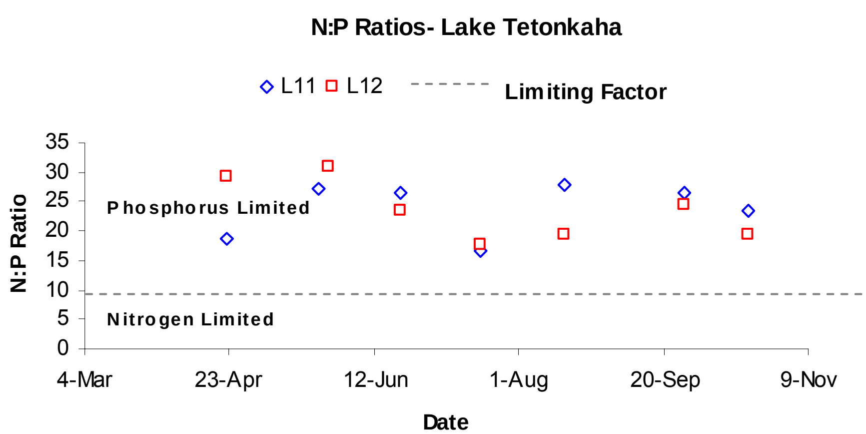


Figure 42. Lake Tetonkaha Total Nitrogen to Total Phosphorus Ratio

In 2003, lake levels in Lake Tetonkaha dropped approximately 1.1 ft between the months of May and October. In 2004, the lake levels between May and October rose approximately 0.75 ft (Figure 43). As shown by Figure 44, lake levels in Johnson Lake rose approximately 0.45 ft in 2004.

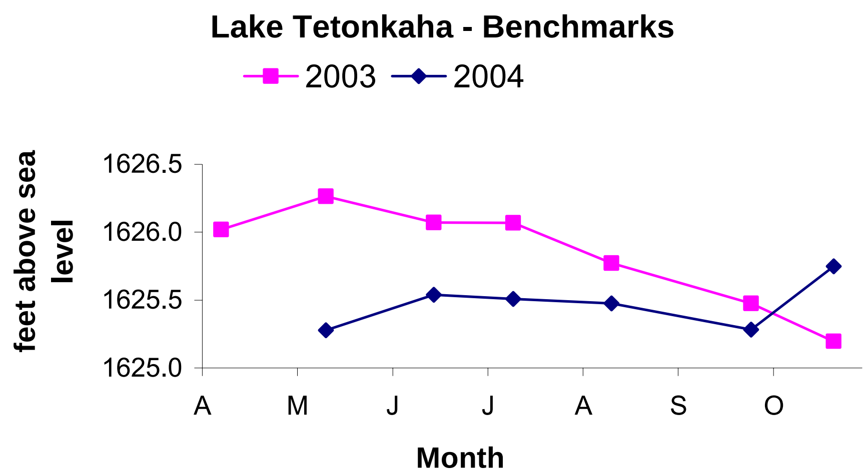


Figure 43. 2003 and 2004 Lake Level Readings of Lake Tetonkaha

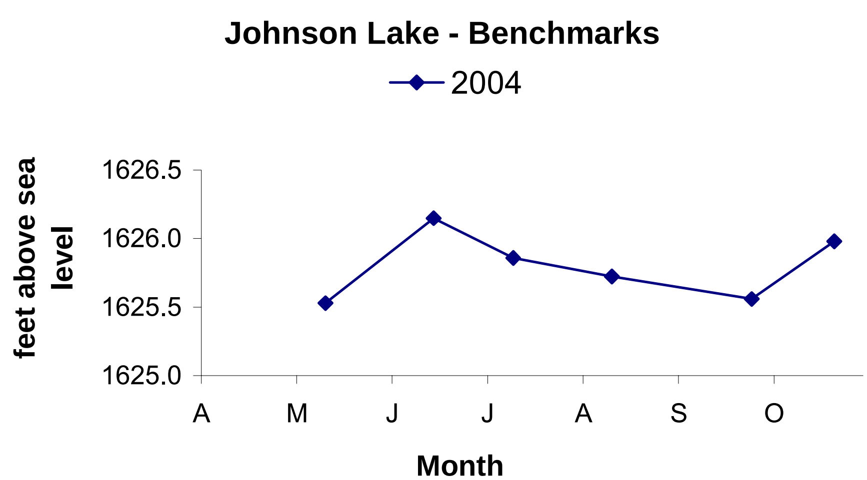


Figure 44. 2004 Lake Level Readings of Johnson Lake

Hydrologic Budget

Hydrologic Budget

A hydrologic budget explains the amount of water entering and leaving a lake. In theory, all inflow of water must equal all outflow during the course of the hydrologic cycle (Table 76). The inflow sources during our study period include precipitation, groundwater, and tributary flow. For the purpose of this study, groundwater was estimated to help balance this equation.

Table 76. Hydrologic Budget for West Oakwood Lake

Inflow Sources	Load (acre-ft)	Outflow Sources	Load (acre-ft)
Surface Area = 691.95 acres			
Precipitation	1,439.26	Evaporation	1,404.66
Tributaries (T43 and T48)	9,153.42	Tributary (T44)	10,746.15
Groundwater	1,755.34	Change in Storage	197.21
Totals	12,348.02		12,348.02

In order to calculate the precipitation inputs, 2003 rainfall data were taken from the weather station located in Brookings County. The amount of precipitation in inches was converted to feet and multiplied by the surface area of West Oakwood Lake (2.08 ft × 691.95 acres). The tributaries (T43 and T48) flows were estimated using the FLUX model from water quality data collected in 2001 and 2002.

The outflow of West Oakwood Lake included evaporation, tributary flow, and change in storage. West Oakwood Lake flows into East Oakwood Lake through a series of culverts. A Thalimedes OTT hydrometer was setup on a culvert at Site T44 where the majority of the outflow from West Oakwood Lake occurred. The phosphorus loading at Site T44 was estimated using the FLUX model. Land evaporation data was collected from a weather station located two miles northeast of Brookings (SDSU 2003). In order to change the land evaporation data into surface water evaporation, monthly evaporation amounts were multiplied by the Class A monthly land pan coefficient (0.8) for the Midwestern United States (Fetter 1998). The monthly evaporation amounts were added, converted to feet, and multiplied by the surface area of West Oakwood Lake.

After all of the hydrologic outflows were subtracted from the inputs, 1,755.34 acre-ft were unaccounted for. Since groundwater is difficult to estimate and was not yet included as a source, this amount was assumed to be from groundwater contribution.

Sediment and Nutrient Budgets

Suspended Solids Budget

The estimated total suspended solids loading from West Oakwood Lake watershed runoff was derived using the FLUX model. TSS runoff loading from West Oakwood Lake tributaries is estimated as 910,716 kg. After outflow was subtracted from inflows, total yearly load of sediment remaining in the lake was estimated at 637,911.7 kg.

Nitrogen Budget

The sources of total nitrogen entering West Oakwood Lake included tributaries and groundwater. Atmospheric nitrogen was not included in the inflow estimates. As atmospheric nitrogen enters a lake, it is utilized by different species of algae; therefore, making it impossible to calculate. Total nitrogen concentrations are derived from adding TKN concentrations to nitrate-nitrite concentrations. The amount of total nitrogen loading into West Oakwood Lake was 39,826.29 kg (Figure 45). Of the 39,826.29 kg, the tributaries contributed 94 percent. The contribution from each tributary was derived from the FLUX model. After the outflow was subtracted from the inflow, the remainder became the estimated total yearly nitrogen load (93.99 kg) retained within the lake.

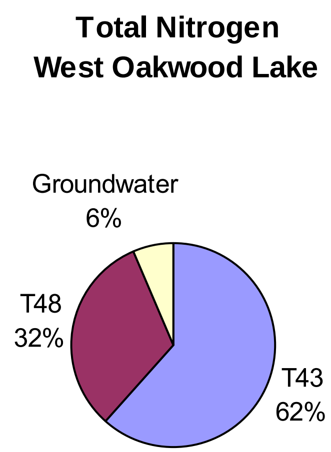


Figure 45. West Oakwood Lake Total Nitrogen Load

Since nitrogen is water soluble it is very difficult to estimate its contribution from groundwater. For the purpose of this study, a total nitrogen concentration of 1.18 mg/L was used for groundwater inflow. The concentration was averaged from South Dakota Geological Survey (SDGS) monitored wells. Groundwater contribution was estimated to be six percent of the nitrogen loading. The following calculations were used to find the groundwater contribution.

Hydrologic load converted to m^3:

$$1{,}755 \text{ acre-ft} \times 1{,}234 = 2{,}166{,}089.6 \text{ m}^3$$

Convert m^3 to liters:

$$2{,}166{,}089.6 \text{ m}^3 \times 1{,}000 = 2{,}166{,}089{,}560 \text{ L}$$

Groundwater nitrogen average concentration multiplied by hydrologic load (L):

$$1.18 \text{ mg/L} \times 2{,}166{,}089{,}560 \text{ L} = 2{,}555{,}985{,}680.8 \text{ mg}$$

Total groundwater nitrogen load converted to kg:

$$2{,}555{,}985{,}680.8 \text{ mg} \div 1{,}000{,}000 = 521.3 \text{ kg}$$

Phosphorus Loadings

Total phosphorus inflow to West Oakwood Lake during the sampling seasons was approximately 5,536.1 kg. Inflow to West Oakwood Lake included tributaries, precipitation, and groundwater (Figure 46). Of the 5,536.1 kg, tributaries contributed 98 percent of the total loading with 4,425 kg coming from Site T43 and 1,002 kg coming from Site T48. Tributary loadings were derived using the FLUX model. After the outflow was subtracted from the inflow, the remainder became the estimated total yearly phosphorus load (491 kg) retained within the lake.

Groundwater was responsible for less than one percent of the total phosphorus delivered to the lake. Groundwater contribution was estimated by multiplying the mean total phosphorus concentration (0.026 mg/L) from groundwater samples collected (from SDGS), by the amount of groundwater discharged into the lake (1,755.34 acre-ft). The following calculations were used to find the groundwater contribution:

Hydrologic load converted to m³:

$$1{,}755.34 \text{ acre-ft} \times 1{,}234 = 2{,}166{,}089.56 \text{ m}^3$$

Converted to m³ to liters:

$$2{,}166{,}089.56 \text{ m}^3 \times 1{,}000 = 2{,}166{,}089{,}560 \text{ L}$$

Groundwater phosphorus average concentration multiplied by hydrologic load (L):

$$0.026 \text{ mg/L} \times 2{,}166{,}089{,}560 \text{ L} = 56{,}318{,}328.56 \text{ mg}$$

Total groundwater phosphorus load converted to kg:

$$56{,}318{,}328.56 \text{ mg} \div 1{,}000{,}000 = 56.32 \text{ kg}$$

The phosphorus load from precipitation (1,439.3 acre-ft) was multiplied by 0.03 mg/L (the average phosphorus content often found in non-populated regions) to determine the phosphorus contribution from precipitation (Wetzel 1975). Estimated concentrations of phosphorus from precipitation were estimated to be less than one percent of the total phosphorus load. The following calculations were used to find total precipitation phosphorus load:

Hydrologic load converted to m³:

$$1{,}439.3 \text{ acre-ft} \times 1{,}234 = 1{,}776{,}046.84 \text{ m}^3$$

Converted m³ to liters:

$$1{,}776{,}046.84 \text{ m}^3 \times 1{,}000 = 1{,}776{,}046{,}840 \text{ L}$$

Precipitation phosphorus average concentration multiplied to hydrologic load (L):

$$0.03 \text{ mg/L} \times 1{,}776{,}046{,}840 \text{ L} = 53{,}281{,}405.2 \text{ mg}$$

Total precipitation phosphorus load converted to kg:

$$53{,}281{,}405.2 \text{ mg} \div 1{,}000{,}000 = 53.28 \text{ kg}$$

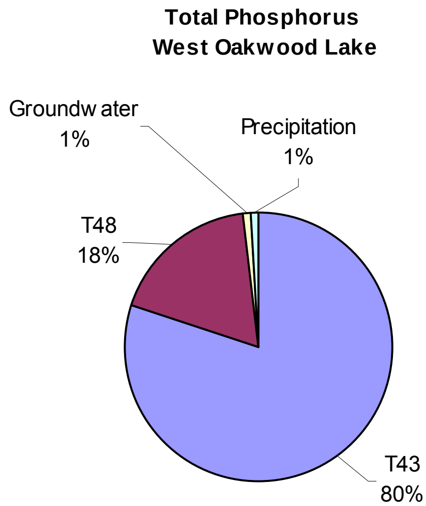


Figure 46. West Oakwood Lake Total Phosphorus Load

Total Dissolved Phosphorus

The estimated total dissolved phosphorus loading from West Oakwood Lake watershed runoff was derived using the FLUX model. The total dissolved phosphorus loading from both inlets is 3,975.3 kg. After all the inputs were subtracted from the output, the remainder became the estimated total yearly load of total dissolved phosphorus (2,887.6 kg) retained within the lake.

Biological and Physical Habitat Summary

Phytoplankton (Algae) Data Summary

Planktonic algae were collected once in June and once in August at both Johnson Lake and Lake Tetonkaha. Johnson Lake consisted of 52 species and 41 genera. Lake Tetonkaha consisted of 46 species and 39 genera. Algae were divided into four separate divisions – flagellated algae, blue-green algae, diatoms, and non-motile green algae. The most diverse group in both lakes was the non-motile green algae with 20 species in Johnson Lake and 15 species in Lake Tetonkaha. However, the blue-green algae exhibited the most abundance in both lakes, with *Oscillatoria agardhii* being the most dense (Figures 47 and 48). An oversupply of nutrients, especially phosphorus, will result in the excessive growth of these species. In June, three noxious species were identified in Johnson Lake and Lake Tetonkaha, *Oscillatoria agardhii, Anabaena subcylindrica, and Microcystis* sp, and in August these same noxious species were found, with the exception of *Microcystis* sp.

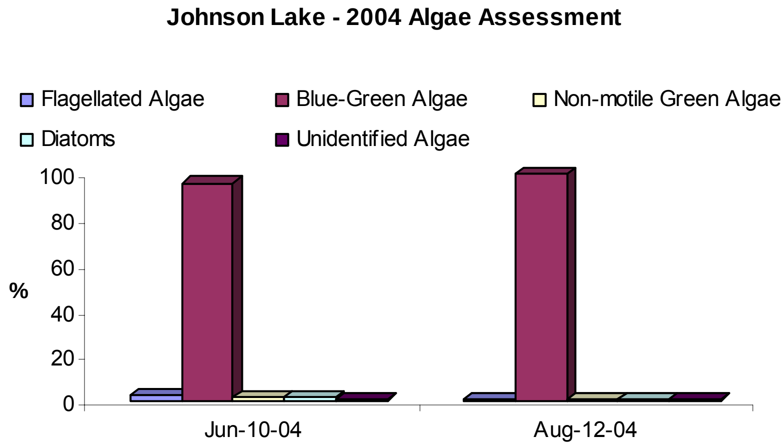


Figure 47. Percentage of Major Algae Groups Collected in Johnson Lake

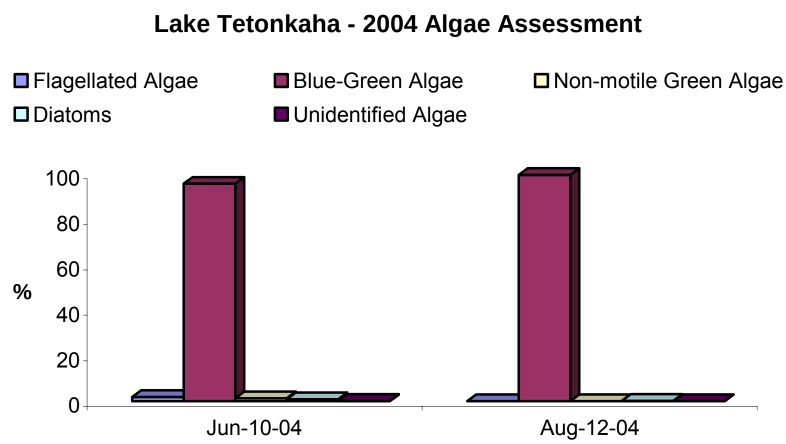


Figure 48. **Percentage of Major Algae Groups Collected in Lake Tetonkaha**

Aquatic Macrophyte (Plants) Survey

In August 2003, aquatic plants were surveyed in Johnson Lake along 20 transects at 63 sampling locations. Aquatic plants were also surveyed in Lake Tetonkaha in July and August 2004, along 29 transects at 92 sampling locations. Sago Pondweed, a submergent species, was the only species of aquatic macrophytes found during both surveys. Sago Pondweed was found at seven of the 20 transects in Johnson Lake, and at five of the 29 transects in Lake Tetonkaha (Figures 7 and 8 in the Methods Section of this report and Figures 19 and 20 in the Results Section).

Fish, Macroinvertebrate, and Physical Habitat Survey

Fish and physical habitat measurements were not completed at any of the tributaries. The South Dakota Game, Fish, and Parks completed a fisheries survey of West Oakwood Lake during August of 2004 (Appendices A and B). A visual survey of the shoreline habitat was completed at the time of the aquatic plant survey.

Macroinvertebrates were collected at each tributary site in this watershed, except for Site T43. The following table (Table 77) summarizes the scores for each sampling site based on the macroinvertebrate data and the scoring system setup for tributaries during the North-Central Big Sioux River Assessment Project. Score sheets for each site can be found in the Results Section. Tributary sites T44 and T48 had HBI scores of 9.6 and 8.8, respectively. T44 with a HBI of 9.6, had one Ephemeropteran and two Trichoptera found. Tolerant Chironomidae dominated this community, with 88 percent of the total assemblage being Chronomidae. Site T48 with a HBI of 8.8, was dominated by the amphipod *Hyalella* sp. and the highly tolerant Chironomidae *Glyptotendipes* sp. It should be noted that these streams serve as either an inlet or an outlet to a lake, therefore typical stream species are likely not present.

Table 77. Bug, Fish, and Habitat Index Values for the West Oakwood Lake Watershed

Site	Macroinverts	Fish	Habitat
T43	---	---	---
T44	25	---	---
T48	51	---	---

Trophic State Index (TSI) Summary

The trophic state of a lake is a numerical value that ranks it relative productivity. Developed by Carlson (1977), the Trophic State Index (TSI), allows a lake's productivity to be easily quantified and compared to other lakes. Low TSI values correlate with small nutrient concentrations, while higher TSI values correlate with higher levels of nutrient concentrations. TSI values range from 0 (oligotrophic) to 100 (hypereutrophic). Table 78 describes the TSI trophic levels and numeric ranges applicable to West Oakwood Lake. In this index, each increase of 10 units represents a doubling of algal biomass.

Table 78. Carlson Trophic Levels and Numeric Ranges

Trophic Level	Numeric Range
Oligotrophic	0-35
Mesotrophic	36-50
Eutrophic	51-65
Hypereutrophic	66-100

Trophic levels in West Oakwood Lake were calculated by segment (i.e. Johnson Lake, North Lake Tetonkaha, South Lake Tetonkaha). The median of chlorophyll-*a* and Secchi depth TSI values was calculated to provide a single index score for each lake. (Table 79). The calculated TSI value of West Oakwood Lake is 77.6 indicating a hypereutrophic condition (Figure 49). Each segment of West Oakwood Lake (Johnson Lake, North Lake Tetonkaha, and South Lake Tetonkaha) is individually described further in the following paragraphs.

Table 79. Observed Trophic State Index Values Collected in West Oakwood Lake

	Total Phosphorus	Secchi Depth	Chlorophyll-*a*	Median TSI (Secchi & chla)
Johnson	86.5	76.7	78.1	77.4
N. Tetonkaha	79.9	77.0	78.9	78.0
S. Tetonkaha	73.0	75.5	79.3	77.4
Overall W. Oakwood	79.8	76.4	78.8	77.6

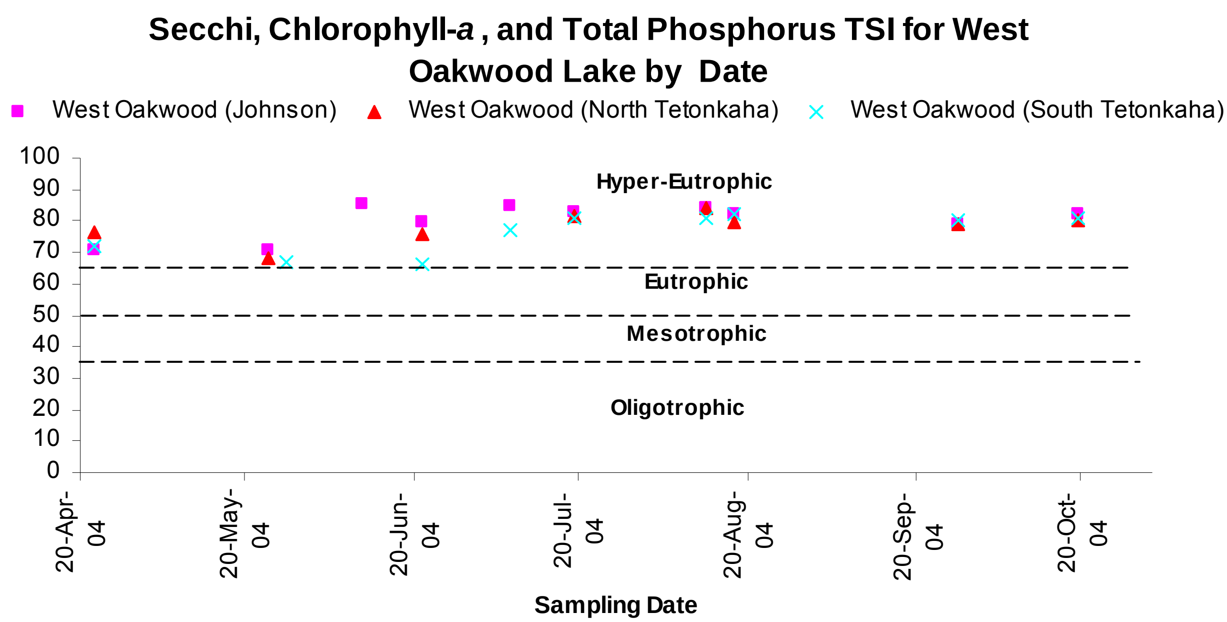


Figure 49. West Oakwood Lake Secchi, Chlorophyll-*a*, and Total Phosphorus TSI Values Plotted by Carlson Trophic Levels in

In order to determine impairment of a lake the SD DENR assesses the trophic status of a lake, using the median TSI value of chlorophyll-*a* concentrations and Secchi depth measurements. The SD DENR has developed an EPA approved protocol that establishes desired TSI levels of lakes based on their fishery classification. West Oakwood Lake is classified as a warmwater semi-permanent fishery and is currently not supporting the desired TSI level (SDDENR 2005). The full support target for lakes within the warmwater semi-permanent fishery classification is set at an overall median (of chlorophyll-*a* and Secchi depth TSI) TSI value ≤ 63.4.

Trophic State Index values are plotted using beneficial use support categories as shown in Figure 50. TSI values steadily increased from May through October. Results show all parameters are not supporting of the beneficial uses throughout the sampling season.

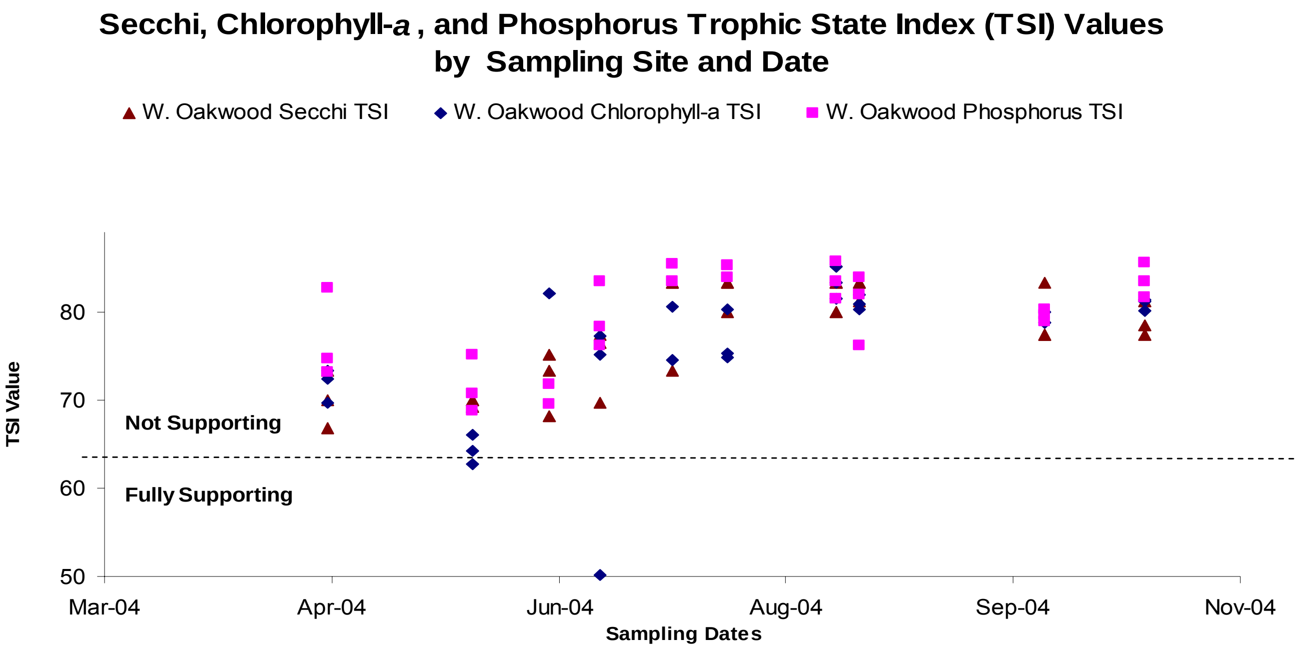


Figure 50. West Oakwood Lake Secchi and Chlorophyll-*a* TSI Values Plotted by Beneficial Uses Support

Johnson Lake Segment

Average values for the trophic levels in the Johnson Lake segment of West Oakwood Lake are shown in Table 80. The median of the chlorophyll-*a* TSI value and the Secchi depth TSI values was calculated to provide a single index score for Johnson Lake. A median overall observed TSI value of 77.4 indicates Johnson Lake is in a hypereutrophic condition (Figure 51).

Table 80. Observed Trophic State Index Values Collected in Johnson Lake

Parameter	Total Phosphorus	Secchi Depth	Chlorophyll-*a*	Median TSI (Secchi & chla)
Mean TSI	86.5	76.7	78.1	77.4

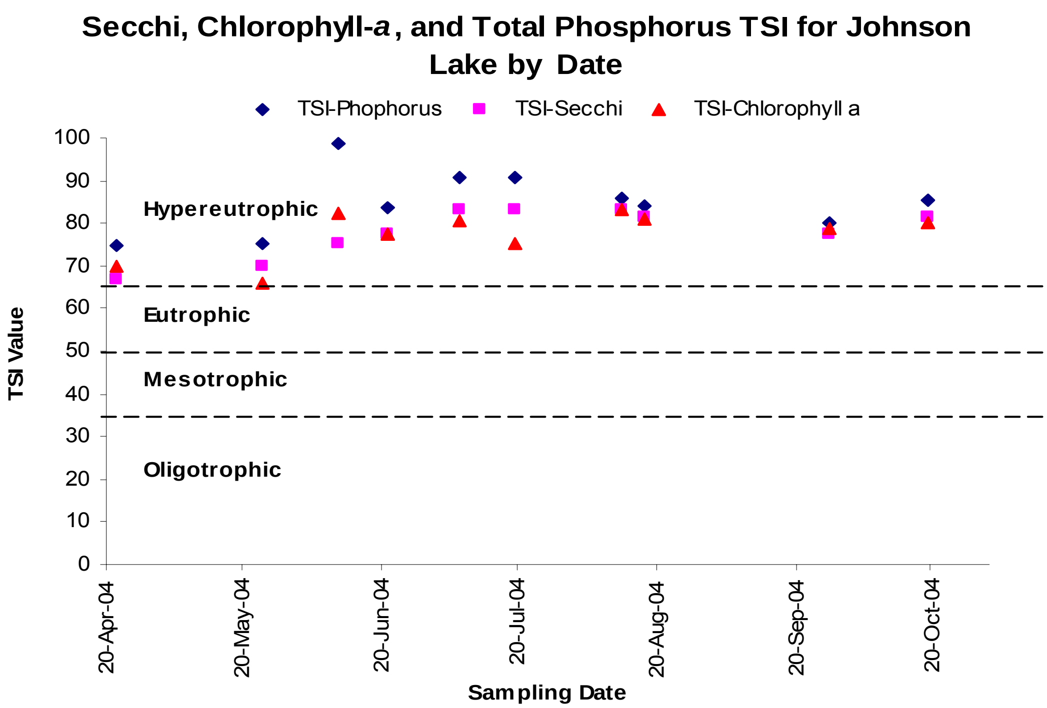


Figure 51. Johnson Lake Secchi, Chlorophyll-*a,* and Total Phosphorus TSI Values Plotted by Carlson Trophic Levels

Trophic State Index values are plotted using beneficial use support categories in Figure 52. Numeric ranges for these beneficial use categories are shown in Table 81. Using these numeric ranges, all parameters are not supporting the assigned beneficial uses from May through October.

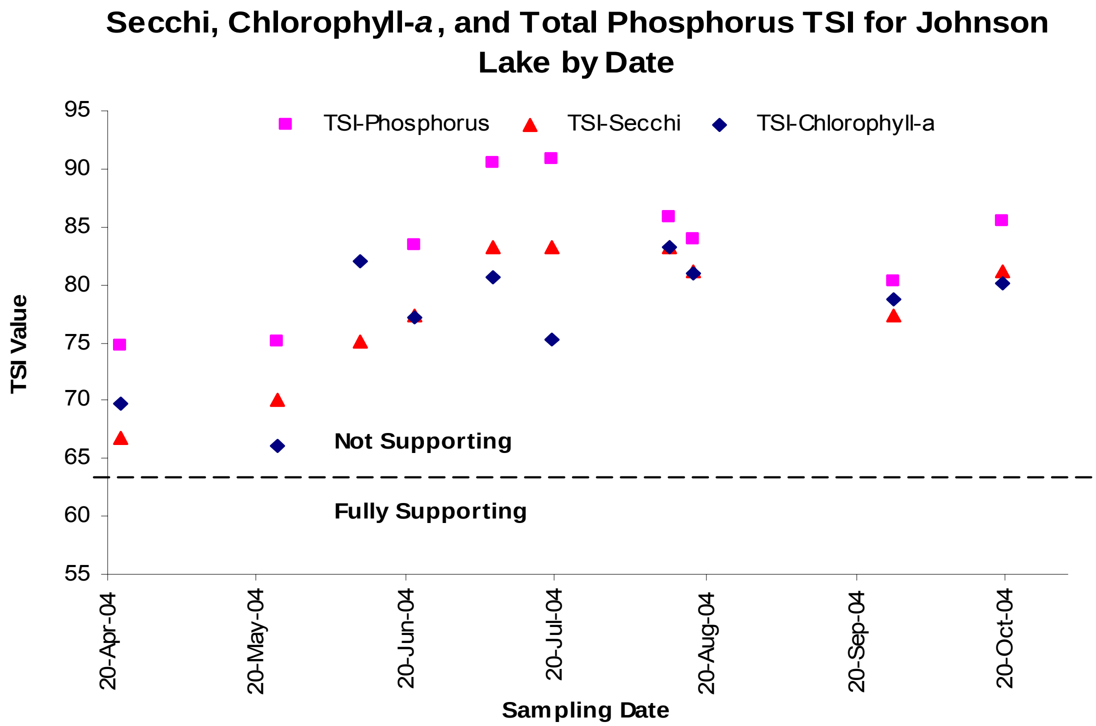


Figure 52. Johnson Lake Secchi and Chlorophyll-*a* TSI Values Plotted by Beneficial Use Support

Reduction Prediction based on BATHTUB Model

In-lake responses to watershed nutrient loading reductions were calculated for each segment of West Oakwood Lake using the BATHTUB Model. Each variable was modeled for each lake. The results for Johnson Lake are shown in Figure 53 and Table 81. See Appendix P for a description of each variable based on the BATHTUB calculations. The reduction of phosphorus from watershed contribution would improve Johnson Lake from a non-supporting TSI value of 76.8 to a supporting TSI value ≤ 63.4.

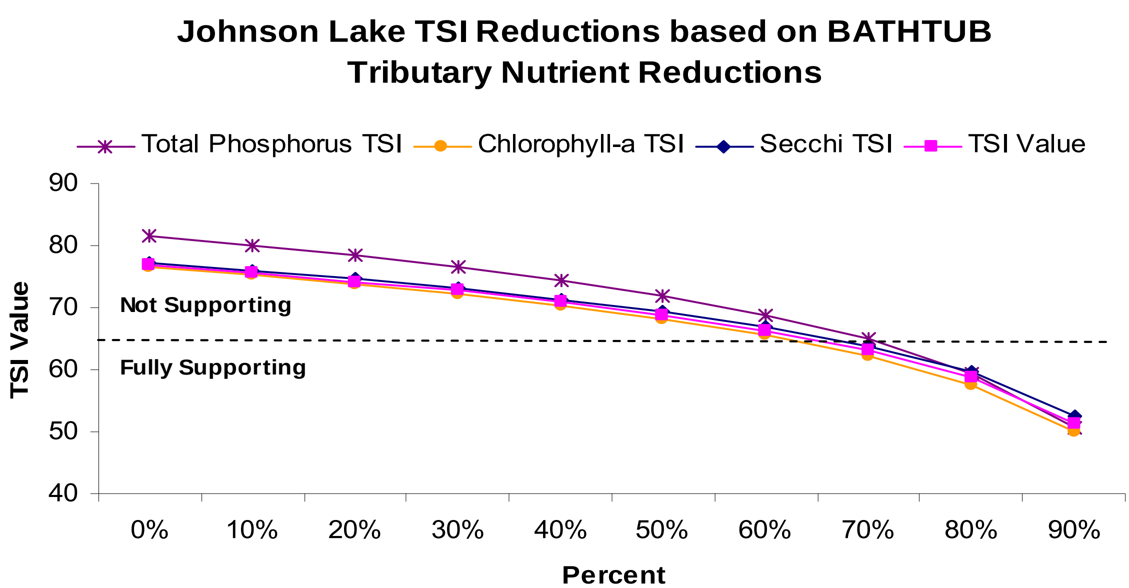


Figure 53. BATHTUB Predicted Mean TSI Reductions and Use Support of Johnson Lake

Table 81. Johnson Lake Observed and Predicted Watershed Reductions of Nitrogen and Phosphorus Concentrations and Predicted In-lake Mean TSI Values Using BATHTUB

Johnson Lake	Observed Values caluculated using BATHTUB	Condition of the Lake based on current loadings	Percent reductions for total lake load based on predicted model								
			10%	20%	30%	40%	50%	60%	70%	80%	90%
Variable	OBSERVED	PREDICTED	Est	Est	Est	Est	Est	Est	Est	Est	Est
Total P	302.8	215.1	194	172.8	151.8	130.7	109.6	88.5	67.4	46.3	25.2
Total N	4219	2751.1	2495.3	2239.5	1983.7	1727.9	1472.2	1216.2	960.4	704.6	448.7
CHL-A	126.7	107.3	94.3	81.6	69.4	57.5	46.1	35.3	25.1	15.6	7.3
SECCHI	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.8	1	1.7
ORGANIC N	4029	2605.2	2308.5	2019.7	1740	1469.5	1210	962.7	729.8	514.8	323.8
ANTILOG PC-1	11747.4	7393.2	5968.8	4703.2	3595.7	2642.1	1841.9	1191	686.9	325.2	100.1
ANTILOG PC-2	16.2	14.3	13.9	13.4	12.9	12.3	11.7	10.9	10.1	9.1	7.9
(N-150)/P	13.4	12.1	12.1	12.1	12.1	12.1	12.1	12	12	12	11.9
INORGANIC N/P	4.5	5.3	6.3	7	7.6	8.1	8.4	8.6	8.7	8.5	7.8
FREQ (CHL-a>10)%	100	100	100	99.9	99.8	99.4	98.4	95.8	88	66	20.5
FREQ (CHL-a>20)%	99.6	99.2	98.6	97.5	95.5	91.8	85	72.8	52.2	24	2.6
FREQ (CHL-a>30)%	97.8	96	93.8	90.4	85.1	77	65	48.1	27.4	8.7	0.5
FREQ (CHL-a>40)%	93.9	90	85.9	80	71.8	60.9	46.8	30.4	14.4	3.4	0.1
FREQ (CHL-a>50)%	88.3	82.2	76.2	68.5	58.6	46.6	33	19.2	7.7	1.4	0
FREQ (CHL-a>60)%	81.5	73.5	66.3	57.4	47	35.3	23.1	12.2	4.3	0.7	0
TSI-P	86.5	81.6	80.1	78.4	76.6	74.4	71.9	68.8	64.9	59.5	50.7
TSI-CHLA	78.1	76.5	75.2	73.8	72.2	70.4	68.2	65.6	62.2	57.6	50.1
TSI-SEC	76.7	77.1	75.9	74.6	73.1	71.4	69.4	67	63.9	59.6	52.6
Median TSI (chla & Secchi)	77.4	76.8	75.6	74.2	72.7	70.9	68.8	66.3	63.1	58.6	51.4

North Lake Tetonkaha Segment

Average values for the trophic levels in the North Lake Tetonkaha segment of West Oakwood Lake are shown in Table 82. The median of the chlorophyll-*a* TSI value and the Secchi depth TSI value was calculated to provide a single index score for North Lake Tetonkaha. An overall median observed TSI of 78.0 indicates North Lake Tetonkaha is in a hypereutrophic condition (Figure 54).

Table 82. Observed Trophic State Index Values Collected in North Lake Tetonkaha

Parameter	Total Phosphorus	Secchi Depth	Chlorophyll-*a*	Median TSI (Secchi & chla)
Mean TSI	79.9	77.0	78.9	78.0

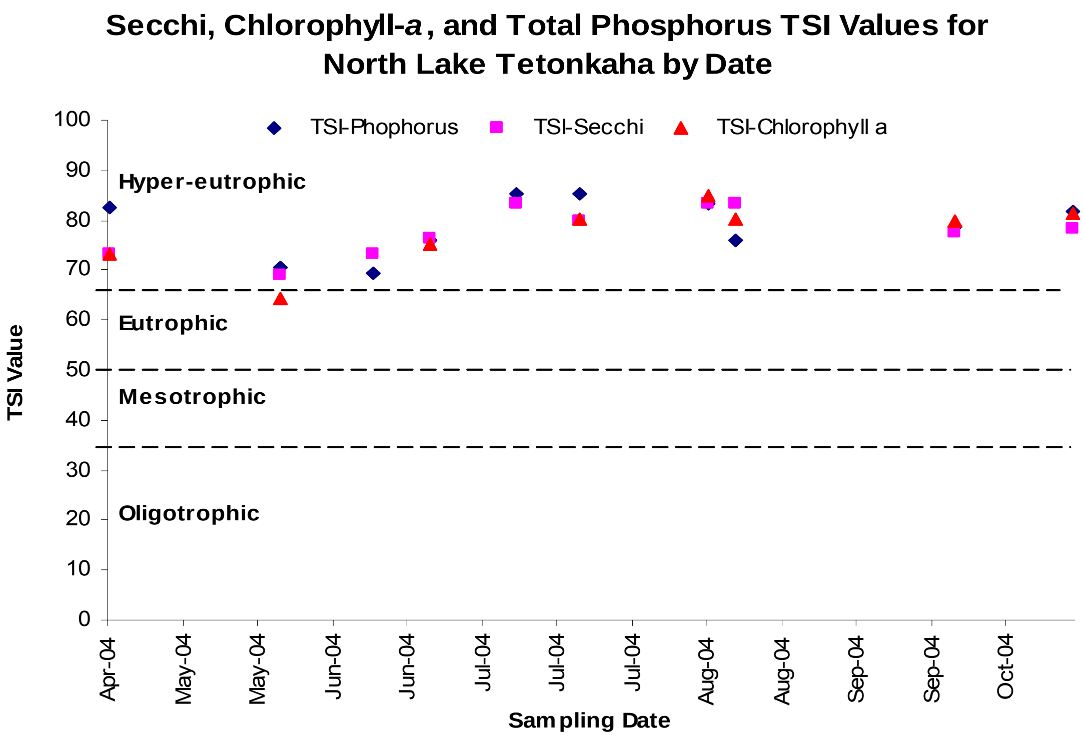


Figure 54. North Lake Tetonkaha Secchi, Chlorophyll-*a*, and Total Phosphorus TSI Values Plotted by Carlson Trophic Levels

Trophic State Index values are plotted using the beneficial use support category in Figure 55. Numeric ranges for beneficial use support are shown in Table 78. Using these numeric ranges, all parameters are not supporting the assigned beneficial uses from June through October.

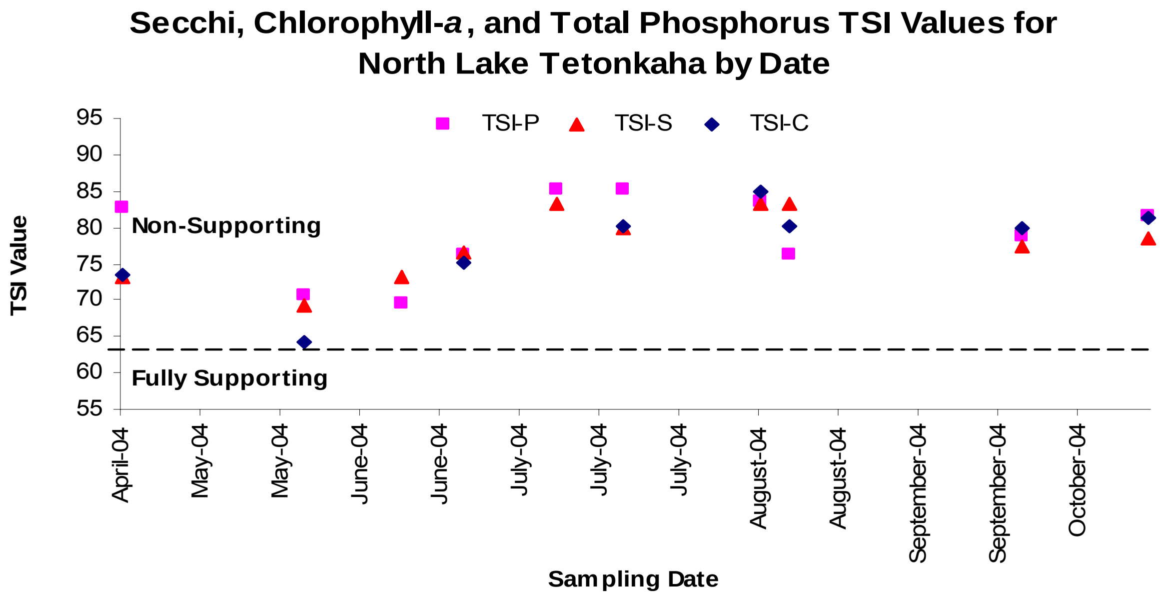


Figure 55. North Lake Tetonkaha Secchi and Chlorophyll-*a* TSI Values Plotted by Beneficial Use Support

Reduction Prediction based on BATHTUB Model

In-lake responses to watershed nutrient loading reductions were calculated for each segment of West Oakwood Lake using the BATHTUB Model. Each variable was modeled for each lake. The results for the North Lake Tetonkaha segment are shown in Figure 56 and Table 83. See Appendix P for a description of each variable based on the BATHTUB calculations. A reduction of phosphorus from the watershed would improve the North Lake Tetonkaha segment from a non-supporting TSI value of 77.3 to a supporting TSI value ≤ 63.4.

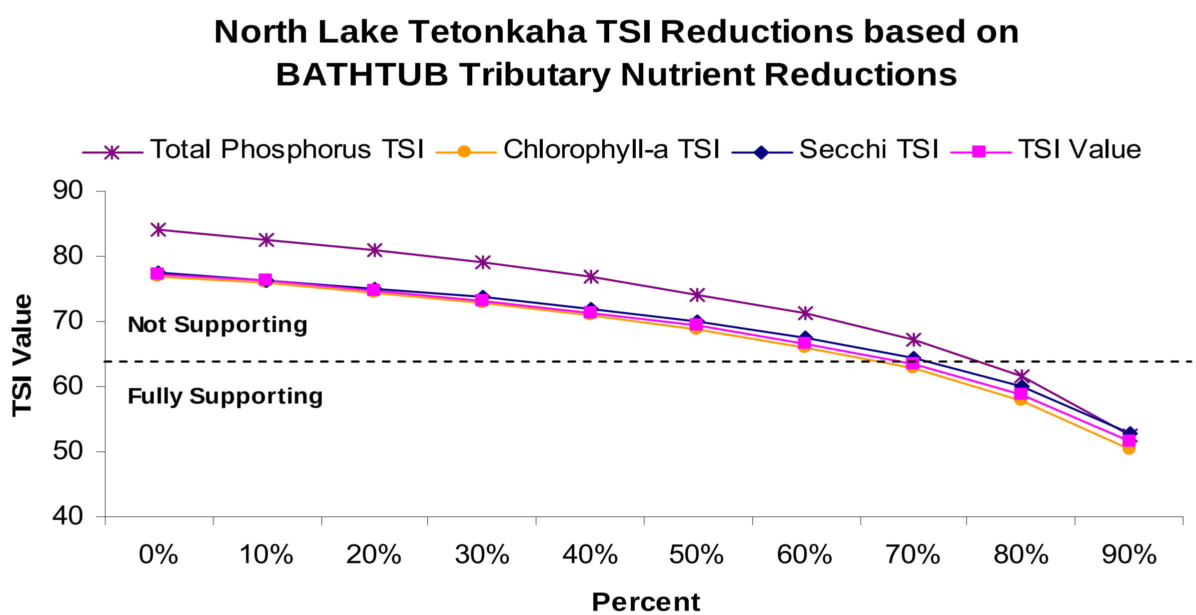


Figure 56. North Lake Tetonkaha BATHTUB Predicted Mean TSI Reductions and Use Support

Table 83. North Lake Tetonkaha Observed and Predicted Watershed Reductions in Nitrogen and Phosphorus Concentrations and Predicted In-lake Mean TSI Values Using the BATHTUB model

North Tetonkaha	Observed Values caluculated using BATHTUB	Condition of the Lake based on current loadings	Percent reductions for total lake load based on predicted model								
			10%	20%	30%	40%	50%	60%	70%	80%	90%
Variable	OBSERVED	PREDICTED	Est	Est	Est	Est	Est	Est	Est	Est	Est
Total P	191	254.1	229.1	204	179	154	129	104	78.9	53.9	28.9
Total N	2942	2616	2372.6	2129.1	1885.6	1642.1	1398.8	1155.2	911.7	668.2	424.7
CHL-A	137.9	113.6	99.8	86.3	73.3	60.7	48.6	37.1	26.2	16.2	7.4
SECCHI	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.6	0.7	1	1.7
ORGANIC N	3976	2753.6	2438.2	2131.3	1833.9	1546.5	1271	1008.2	761.2	533.3	331.4
ANTILOG PC-1	9651	8131.1	6558	5161	3939	2888.2	2007.7	1292.5	740.3	346	103
ANTILOG PC-2	18.5	14.5	14.1	13.6	13	12.5	11.8	11.1	10.2	9.2	7.9
(N-150)/P	14.6	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.6	9.5
INORGANIC N/P	0	0	0	0	1	2	2.9	3.7	4.4	5	5.2
FREQ (CHL-a>10)%	100	100	100	99.9	99.8	99.5	98.7	96.4	89.4	68.2	21.2
FREQ (CHL-a>20)%	99.7	99.4	98.9	98	96.3	93.1	86.9	75.3	55.1	25.9	2.8
FREQ (CHL-a>30)%	98.4	96.7	94.8	91.8	87.1	79.6	68	51.3	29.9	9.7	0.5
FREQ (CHL-a>40)%	95.4	91.5	87.8	82.4	74.8	64.1	50.2	33.3	16.1	3.9	0.1
FREQ (CHL-a>50)%	90.8	84.5	79	71.6	62.1	50.1	36.1	21.4	8.8	1.7	0
FREQ (CHL-a>60)%	84.9	76.4	69.5	60.9	50.5	38.5	25.8	13.9	5	0.8	0
TSI-P	79.9	84	82.5	80.8	79	76.8	74.2	71.1	67.1	61.6	52.6
TSI-CHLA	78.9	77	75.8	74.3	72.7	70.9	68.7	66	62.7	57.9	50.2
TSI-SEC	77	77.6	76.4	75.1	73.6	71.9	69.9	67.4	64.3	59.9	52.7
Median TSI (chla & Secchi)	78.0	77.3	76.1	74.7	73.2	71.4	69.3	66.7	63.5	58.9	51.5

South Lake Tetonkaha Segment

Average values for the trophic levels in the South Lake Tetonkaha segment of West Oakwood Lake are shown in Table 84. The median of the chlorophyll-*a* TSI value and the Secchi depth TSI value was calculated to provide a single index score for South Lake Tetonkaha. An overall median observed TSI of 77.4 indicates South Lake Tetonkaha is in a hypereutrophic condition (Figure 57).

Table 84. Observed Trophic State Index Values Collected in South Lake Tetonkaha

Parameter	Total Phosphorus	Secchi Depth	Chlorophyll-*a*	Median TSI (Secchi & chla)
Mean TSI	73.0	75.5	79.3	77.4

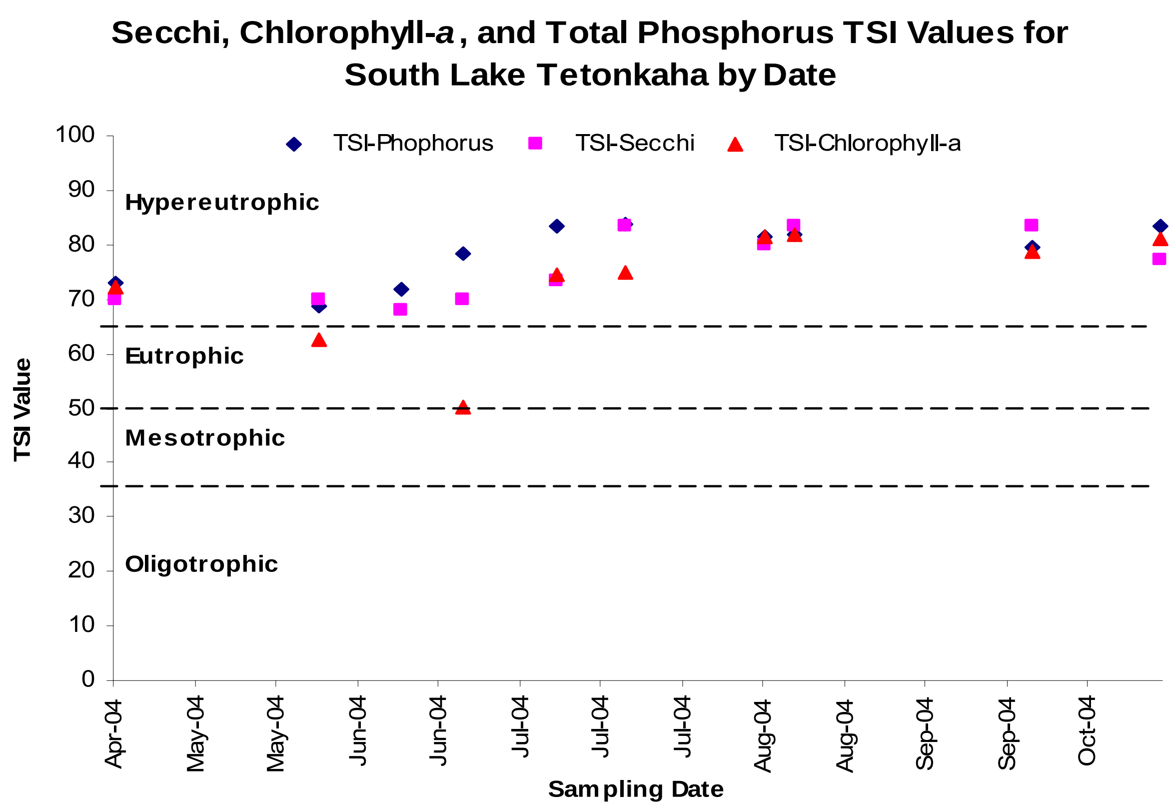


Figure 57. South Lake Tetonkaha Secchi, Chlorophyll-*a*, and Total Phosphorus TSI Values Plotted by Carlson Trophic Levels

Trophic State Index values are plotted based on beneficial use support categories in Figure 58. Numeric ranges for beneficial use support are shown in Table 78. Using these numeric ranges, all parameters are not supporting the assigned beneficial uses from June through October.

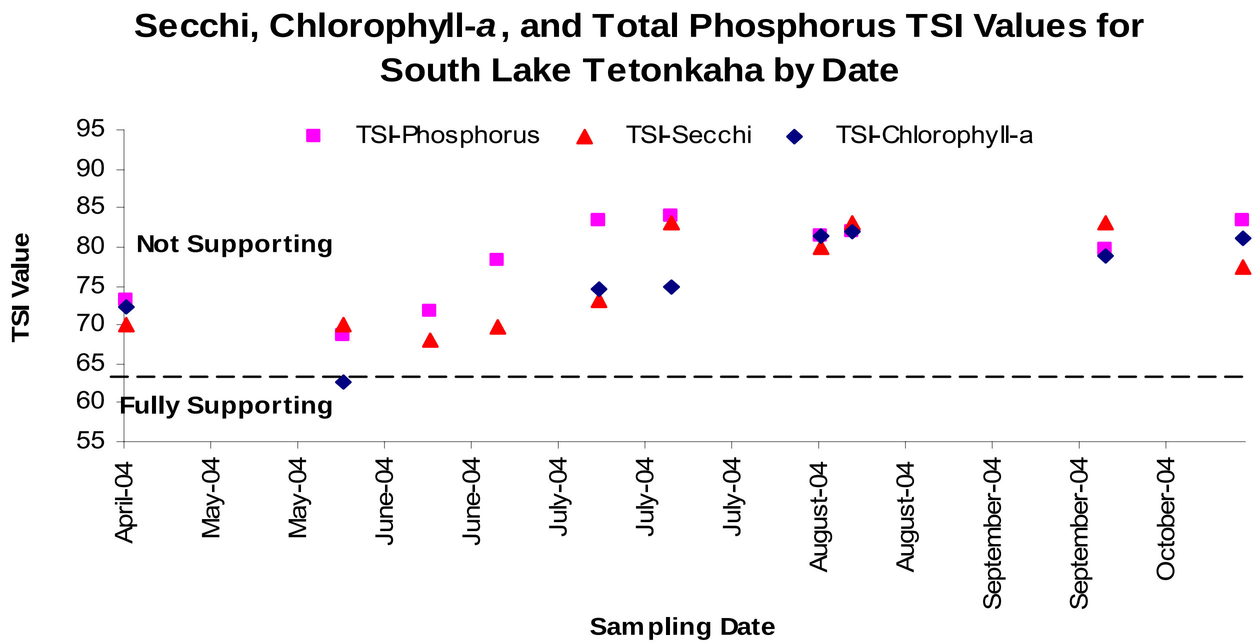


Figure 58. South Lake Tetonkaha Secchi and Chlorophyll-*a* TSI Values Plotted by Beneficial Use Support

Reduction Prediction based on BATHTUB Model

In-lake responses to watershed nutrient loading reductions were calculated for each segment of West Oakwood Lake using the BATHTUB Model. Each variable was modeled for each lake. The results for the South Lake Tetonkaha segment are shown in Figure 59 and Table 85. See Appendix P for a description of each variable based on the BATHTUB calculations. The reduction of phosphorus from watershed contribution would improve the South Lake Tetonkaha segment from a non-supporting TSI value of 76.5 to a supporting TSI value ≤ 63.4.

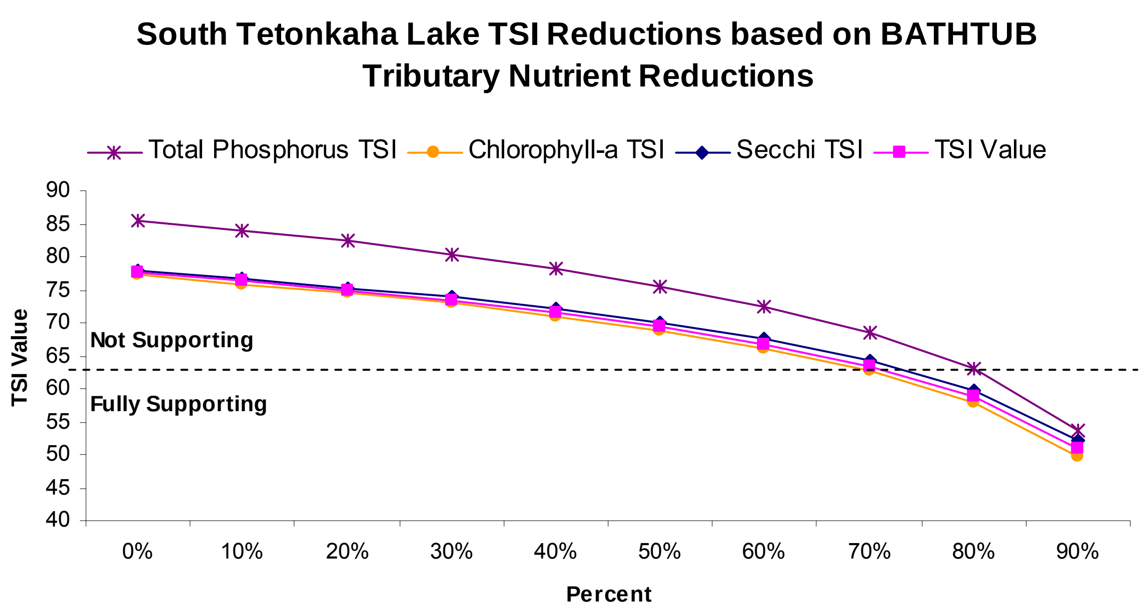


Figure 59. South Lake Tetonkaha BATHTUB Predicted Mean TSI Reductions and Use Support

Table 85. South Lake Tetonkaha Observed and Predicted Watershed Reductions in Nitrogen and Phosphorus Concentrations and Predicted In-lake Mean TSI Values Using the BATHTUB Model

South Tetonkaha	Observed Values caluculated using BATHTUB	Condition of the Lake based on current loadings	Percent reductions for total lake load based on predicted model								
			10%	20%	30%	40%	50%	60%	70%	80%	90%
Variable	OBSERVED	PREDICTED	Est	Est	Est	Est	Est	Est	Est	Est	Est
Total P	184	281.2	253.4	225.6	197.9	170	142.3	114.5	86.7	59	31.2
Total N	4039	2527	2290.2	2053.3	1816.5	1579.7	1343	1106	869.1	632.3	395.5
CHL-A	106.3	115.5	101.4	87.6	74.2	61.3	49	37.2	26.1	15.9	17.1
SECCHI	0.3	0.3	0.3	0.3	0.4	0.4	0.5	0.6	0.7	1	1.7
ORGANIC N	3780	2812.3	2489.3	2175.1	1870.6	1576.5	1294.7	1026.2	773.9	541.7	336.7
ANTILOG PC-1	8205.7	8375.2	6745.1	5298.7	4034.8	2949.5	2041.8	1306.4	740.8	339.5	95.8
ANTILOG PC-2	16.1	14.6	14.1	13.6	13.1	12.5	11.9	11.1	10.3	9.2	7.9
(N-150)/P	21.2	8.5	8.4	8.4	8.4	8.4	8.4	8.3	8.3	8.2	7.9
INORGANIC N/P	9.4	0	0	0	0	0.1	0.9	1.7	2.5	3.2	3.6
FREQ (CHL-a>10)%	100	100	100	99.9	99.8	99.6	98.8	96.5	89.2	67.1	18.5
FREQ (CHL-a>20)%	99.1	99.4	98.9	98.1	96.4	93.3	87.2	75.5	54.8	25	2.2
FREQ (CHL-a>30)%	95.8	96.9	95.1	92.2	87.5	80.1	68.5	51.5	29.7	9.2	0.4
FREQ (CHL-a>40)%	89.7	91.9	88.3	83	75.4	64.8	50.7	33.5	15.9	3.6	0.1
FREQ (CHL-a>50)%	81.8	85.1	79.7	72.4	62.8	50.8	36.6	21.6	8.7	1.6	0
FREQ (CHL-a>60)%	73	77.2	70.4	61.8	51.3	39.2	26.2	14	4.9	0.7	0
TSI-P	73	85.5	84	82.3	80.4	78.2	75.6	72.5	68.5	62.9	53.7
TSI-CHLA	79.3	77.2	75.9	74.5	72.9	71	68.8	66.1	62.6	57.8	49.6
TSI-SEC	75.5	77.8	76.6	75.3	73.8	72	70	67.5	64.2	59.7	52.2
Median TSI (chla & Secchi)	77.4	77.5	76.25	74.9	73.35	71.5	69.4	66.8	63.4	58.75	50.9

Point Sources

This watershed is predominately agricultural. There are no municipalities or known point sources located in this watershed.

Non-Point Sources

Non-point sources of concern are those that contribute TSS and nutrients. Since non-point sources can be difficult to pinpoint, the following are the possible sources of sediment and nutrients within this watershed. Possible sediment sources of pollution include agricultural runoff and eroding stream bed and banks. Possible sources of phosphorus include human and animal waste, soil erosion, fertilizer runoff, and detergents. Possible sources of nitrogen are fertilizers, animal wastes, and septic systems.

EAST OAKWOOD LAKE WATERSHED

This map (Figure 60) shows the area and location designated as the East Oakwood Lake watershed. This area encompasses approximately 14,128 acres, with the lake itself covering approximately 1,000 acres.

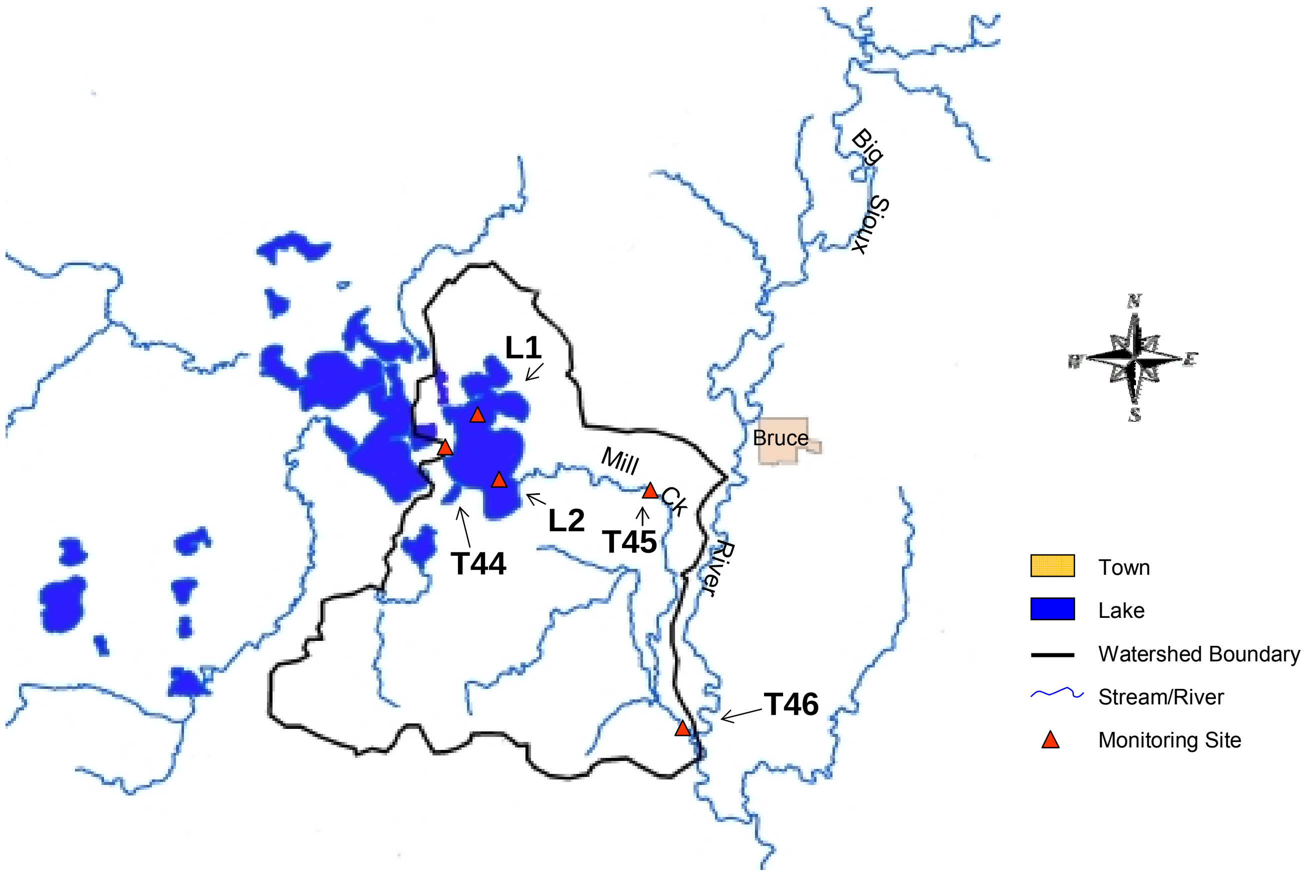


Figure 60. East Oakwood Lake Watershed Location Map

Landuse Summary

The East Oakwood Lake watershed area is located within the Northern Glaciated Plains level III ecoregion and characterized by the level IV ecoregion of the Big Sioux Basin. This is an area of rolling terrain and a drainage area consisting of incised streams. The rolling areas are extensively tilled for small grains, corn, sunflowers, and soybeans. Most of the area is cropland, such as corn and soybeans, with some areas in grassland and pastureland. Twenty-three feedlots comprised of 5,601 animals were assessed. Of this number, 70 percent were cows, 18 percent were sheep, and 12 percent were pigs.

Water Quality Summary

Beneficial uses for the two in-lake sites (L1 and L2) of East Oakwood Lake are 5, 7, 8, and 9.

(5) Warmwater Semi-permanent Fish Life Propagation
(7) Immersion Recreation
(8) Limited Contact Recreation
(9) Fish and Wildlife Propagation, Recreation and Stock Watering

Beneficial uses for the one inlet (T44) and two outlet sites (T45 and T46) for East Oakwood Lake are 9 and 10.

(9) Fish and Wildlife Propagation, Recreation and Stock Watering
(10) Irrigation

Based on the results from the water quality criteria established by the SD DENR as described in the Results Section under Water Quality Monitoring, the tributary sites are meeting the water quality criteria and supporting assigned beneficial uses. The two in-lake sites are meeting the water quality criteria for beneficial use (7) Immersion Recreation, (8) Limited Contact Recreation, and (9) Fish and Wildlife Propagation, Recreation and Stock Watering. In regards to beneficial use (5) Warm Water Semi-permanent Fish Life Propagation, the in-lake sites are meeting the criteria for water temperature, dissolved oxygen, total suspended solids, and ammonia nitrogen as N, but not pH. The combined surface and bottom sample from both in-lake monitoring sites show East Oakwood Lake is not meeting the water quality criteria for pH (Table 86 and Figure 61).

Table 86. East Oakwood Lake Water Quality Exceedences

Date	Site	Parameter	Standard	Sampled Value
9/28/2001	L1-S	pH	≥ 6.5 - ≤ 9.0	9.1
8/8/2002	L1-S	pH	≥ 6.5 - ≤ 9.0	9.2
9/12/2002	L1-S	pH	≥ 6.5 - ≤ 9.0	9.1
8/8/2002	L1-B	pH	≥ 6.5 - ≤ 9.0	9.2
8/8/2002	L2-S	pH	≥ 6.5 - ≤ 9.0	9.2
8/8/2002	L2-B	pH	≥ 6.5 - ≤ 9.0	9.2
4/23/2003	L1	pH	≥ 6.5 - ≤ 9.0	9.5
6/2/2003	L1	pH	≥ 6.5 - ≤ 9.0	9.1
4/23/2003	L2	pH	≥ 6.5 - ≤ 9.0	9.5
7/15/2003	L2	pH	≥ 6.5 - ≤ 9.0	9.1

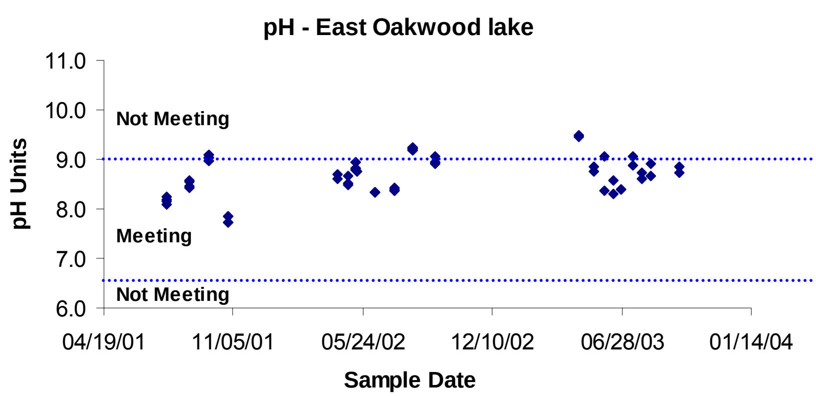


Figure 61. East Oakwood Lake pH Grab Samples based on Numeric Standard ≥ 6.5 to ≤ 9.0

Water temperatures and pH levels tend to increase in highly productive lakes. This higher productivity is likely caused by excessive nutrients. Thus, these higher pH levels may indicate elevated levels of nutrients in this lake, causing excessive algal and macrophyte growth. Figure 62 shows the pH levels in comparison to the water temperature in East Oakwood Lake.

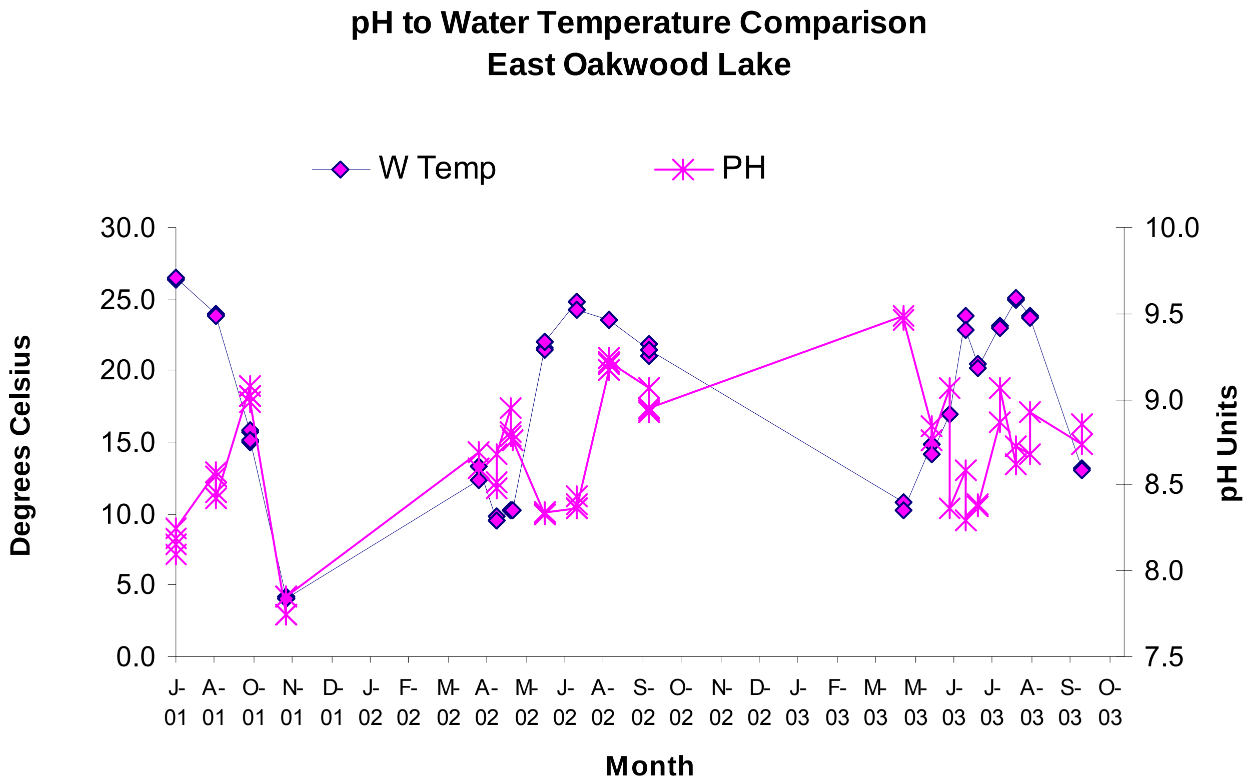


Figure 62. East Oakwood Lake pH to Water Temperature Comparison

Chlorophyll is the photosynthetic pigment in all green plants and can be a measure of the amount of algae present in a lake. Phosphorus is the primary nutrient algae use for growth. Plots of total phosphorus and chlorophyll-*a* were constructed (Figure 63) to show the relationship between the amount of phosphorus present versus the amount of algal growth. Phosphorus is usually the limiting nutrient in the growth of algae. Therefore, increases in phosphorus should yield increases in algae mass. Figure 63 indicates there is a correlation between chlorophyll-*a* and total phosphorus at Site L1 (R^2=0.89), as well as at Site L2 (R^2=0.84).

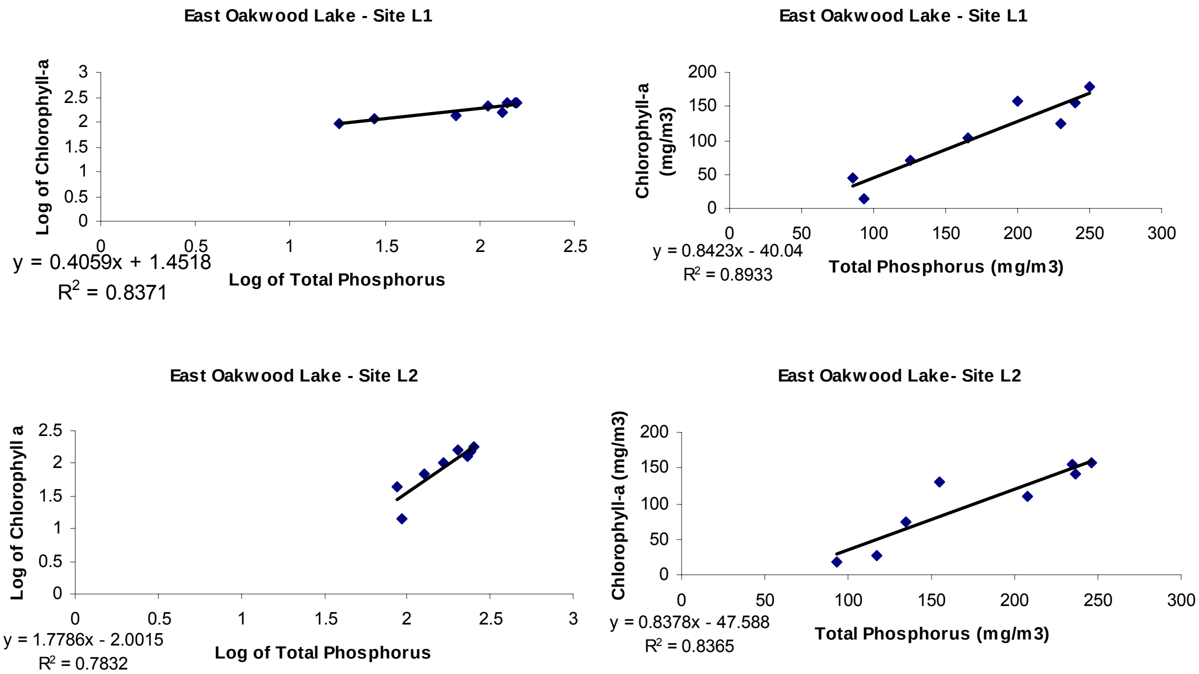


Figure 63. Sites L1 and L2 Phosphorus to Chlorophyll-*a* Relationship

The maximum in-lake chlorophyll-*a* concentration of 179.9 mg/m^3 was collected at Site L1 on August 11, 2003 (Figure 64). The average chlorophyll-*a* concentration was 104.1 mg/m^3 and the median concentration was 117.6 mg/m^3.

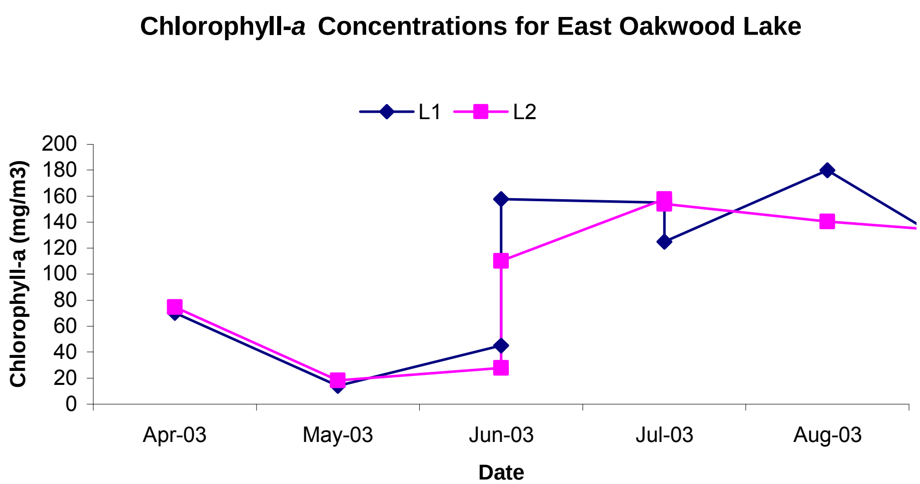


Figure 64. East Oakwood Lake Chlorophyll-*a* Concentrations (mg/m^3)

Water clarity is measured using a Secchi disk. The deeper the Secchi disk can be seen, the clearer the water. Indicatively, water clarity decreases as the amount of chlorophyll-*a* increases, as shown by Figure 65. Secchi depth ranged from 0.10 meters to 0.70 meters ($\bar{x}$ = 0.35 meters).

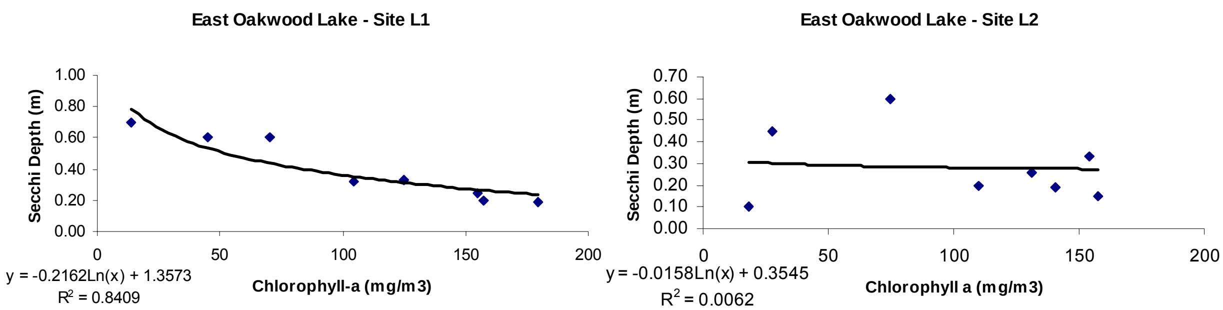


Figure 65. Sites L1 and L2 Chlorophyll-*a* to Secchi Depth Relationship

For an organism, such as algae, to survive in a given environment, it must have the necessary nutrients and environment to maintain life and successfully reproduce. If an essential life component approaches a critical minimum, this component will become the limiting factor (Odum 1959). Nutrients such as phosphorus and nitrogen are most often the limiting factors in highly eutrophic lakes. Typically, phosphorus is the limiting nutrient for algal growth. However, nitrogen can become the limiting factor in many highly eutrophic lakes with an overabundance of phosphorus. East Oakwood Lake is a phosphorus-limited lake as shown by Figure 66.

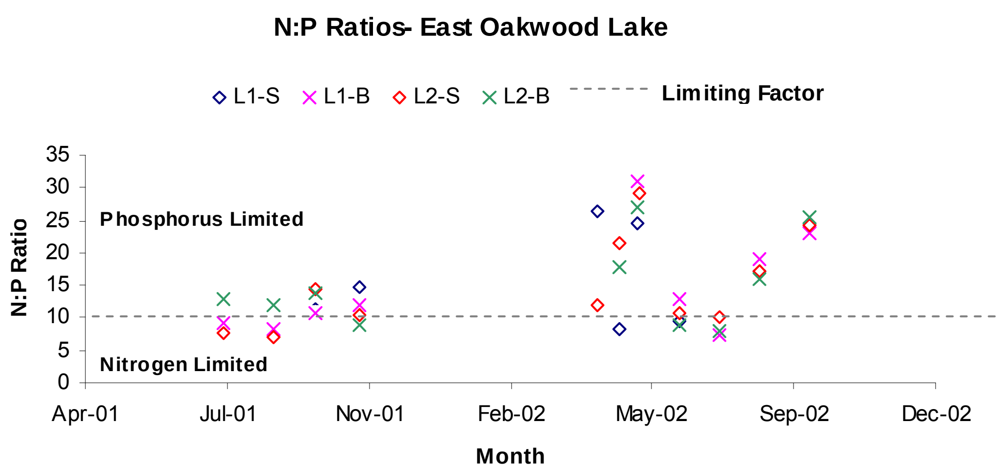


Figure 66. East Oakwood Lake Total Nitrogen to Total Phosphorus Ratio

In 2003, lake levels in East Oakwood Lake dropped approximately 0.7 ft between the months of April and October. In 2004 the difference in lake levels between May and October was an increase of approximately 0.36 ft. As shown by Figure 67, lake levels rose in June and October of 2004 due to heavy rains.

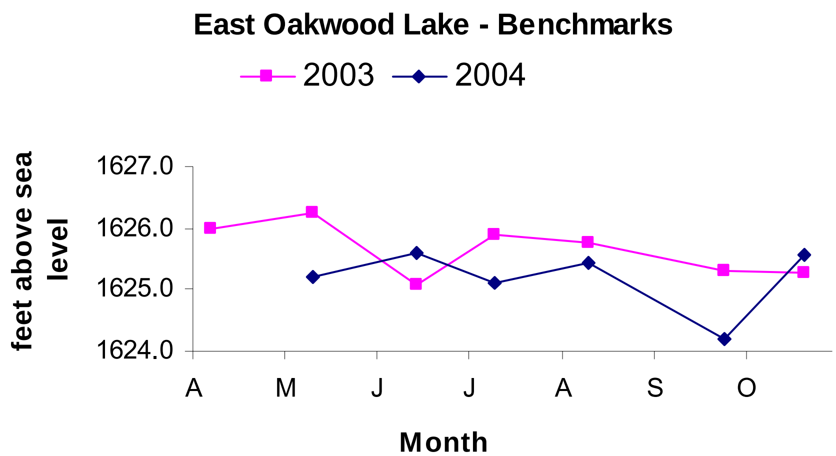


Figure 67. East Oakwood Lake 2003 and 2004 Lake Level Readings

Hydrologic Budget

Hydrologic Budget

A hydrologic budget explains the amount of water entering and leaving a lake. In theory, all inflows of water must equal all outflows during the course of the hydrologic cycle (Table 87). The inflow sources during the study period included precipitation, groundwater, and tributary flow. For the purpose of this study, groundwater was estimated to help balance the equation.

Table 87. Hydrologic Budget of East Oakwood Lake

Inflow Sources	Load (acre-ft)	Outflow Sources	Load (acre-ft)
Surface Area = 404.56 acres			
Precipitation	841.48	Evaporation	821.26
Tributary (T44)	10,746.44	Tributary (T45)	24,931.06
Groundwater	14,332.70	Change in Storage	168.30
Totals	25,920.62		25,920.62

In order to calculate the precipitation inflow, 2003 rainfall data were taken from the weather station located in Brookings County. The amount of precipitation in inches was converted to feet and multiplied by the surface area of East Oakwood Lake (2.08 ft × 404.56 acres). Inflow loading from Site T44 was estimated using the FLUX model and water quality data collected in 2001-2002.

The outflow of East Oakwood Lake included evaporation, tributary flow, and change in storage. Outflow was monitored at Sites T45 and T46. Outflow loading from these sites was estimated using the FLUX model and water quality data collected in 2001-2002. Land evaporation data was collected from the weather station located two miles northeast of Brookings (SDSU 2003). In order to change the land evaporation data into surface water evaporation, monthly evaporation amounts were multiplied by the Class A monthly land pan coefficient (0.8) for the Midwestern United States (Fetter 1998). The monthly evaporation amounts were added, converted to feet, and multiplied by the surface area of East Oakwood Lake.

After all of the hydrologic outflows were subtracted from the inflows, 14,332.7 acre-ft were unaccounted for. Groundwater was one of the possible sources of unaccounted inflow. However, this amount is much larger than what would be expected as groundwater contribution. Therefore, it was possible that part of the unaccounted 14,332.7 acre-ft was attributed to an inlet that was not monitored during the study period.

Sediment and Nutrient Budgets

Suspended Solids Budget

The estimated total suspended solids loading to East Oakwood Lake from watershed runoff was derived using the FLUX model. Loading from the inlet (Site T44) was estimated at 272,804.3 kg. Monitored outflow at Site T45 showed a total suspended solids load of 512,776.1 kg. After the outflow was subtracted from the inflow, an estimated 239,971.8 kg was unaccounted for and was presumed to be loading from un-monitored inflow.

Nitrogen Budget

Sources of total nitrogen load entering East Oakwood Lake are attributed to groundwater and the inlet. Atmospheric nitrogen was not included in the inflow estimates. As atmospheric nitrogen enters the lake, it is utilized by different species of algae making it is impossible to calculate. Total nitrogen concentrations are derived from adding TKN concentrations to nitrate-nitrite concentrations. Total nitrogen load into East Oakwood Lake was 60,602.4 kg, with 66 percent being attributed to inflow from the inlet (Figure 68). After outflow was subtracted from the inflow, an estimated 10,815.5 kg of nitrogen was retained within East Oakwood Lake.

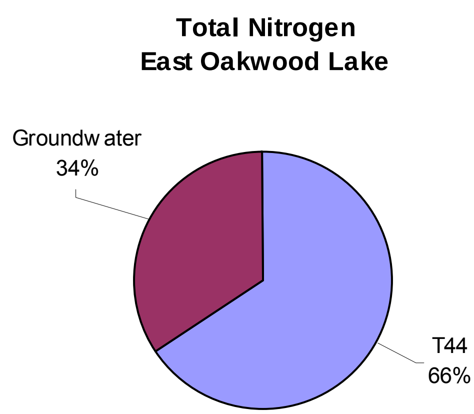


Figure 68. East Oakwood Lake Total Nitrogen Loads

Nitrogen contribution from groundwater is difficult to estimate because of its solubility in water. Therefore, a total nitrogen concentration of 1.18 mg/L was used to represent groundwater inflow. This concentration was derived by averaging samples from the SDGS monitored wells in the area. Results show groundwater contributed 34 percent of the nitrogen loading to East Oakwood Lake. The following calculations were used to find the groundwater contribution of nitrogen:

Hydrologic load converted to m^3:

$$14{,}332.7 \text{ acre-ft} \times 1{,}234 = 17{,}686{,}551.8 \text{ m}^3$$

Convert m³ to liters:

$$17{,}686{,}551.8 \text{ m}^3 \times 1{,}000 = 17{,}686{,}551{,}800 \text{ L}$$

Groundwater nitrogen average concentration multiplied by hydrologic load (L):

$$1.18 \text{ mg/L} \times 17{,}686{,}551{,}800 \text{ L} = 20{,}870{,}131{,}124 \text{ mg}$$

Total groundwater nitrogen load converted to kg:

$$20{,}870{,}131{,}124 \text{ mg} \div 1{,}000{,}000 = 20{,}870.1 \text{ kg}$$

Phosphorus Budget

Total phosphorus loading from inflow to East Oakwood Lake during the sampling period was estimated at 3,510.2 kg. Inflows to East Oakwood Lake included tributaries, precipitation, and groundwater (Figure 69). Site T44 contributed 86 percent of the 3,510.2 kg of total phosphorus. Tributary loading was derived using the FLUX model. Monitored outflow at Site T45 showed a phosphorus load of 6,897.6 kg. After the outflow was subtracted from the inflow, an estimated 3,387.4 kg of phosphorus was unaccounted for and was presumed to be loading from un-monitored inflow.

Groundwater was responsible for 13 percent of the total phosphorus delivered to the lake. Groundwater contribution of total phosphorus was estimated by multiplying the mean total phosphorus concentration (0.026 mg/L) from groundwater samples collected by the SDGS by the amount of groundwater discharged into the lake (459.85 acre-ft). The following calculations were used to find the phosphorus contribution from groundwater:

Hydrologic load converted to m³:

$$14{,}332.7 \text{ acre-ft} \times 1{,}234 = 17{,}686{,}551.8 \text{ m}^3$$

Converted to m³ to liters:

$$17{,}686{,}551.8 \text{ m}^3 \times 1{,}000 = 17{,}686{,}551{,}800 \text{ L}$$

Groundwater phosphorus average concentration multiplied by hydrologic load (L):

$$0.026 \text{ mg/L} \times 17{,}686{,}551{,}800 \text{ L} = 459{,}850{,}346.8 \text{ mg}$$

Total groundwater phosphorus load converted to kg:

$$459{,}850{,}346.8 \text{ mg} \div 1{,}000{,}000 = 459.85 \text{ kg}$$

Total phosphorus load from precipitation (841.48 acre-ft) was multiplied by 0.03 mg/L (an average phosphorus content often found in non-populated regions) to determine phosphorus load from precipitation (Wetzel 1975). It was estimated that total phosphorus concentration from precipitation was responsible for one percent of the total phosphorus load to the lake. The following calculations were used to find the phosphorus contribution from precipitation:

Hydrologic load converted to m³:

$$841.48 \text{ acre-ft} \times 1{,}234 = 1{,}038{,}386.32 \text{ m}^3$$

Converted to m³ to liters:

$$1{,}038{,}386.32 \text{ m}^3 \times 1{,}000 = 1{,}320{,}386{,}320 \text{ L}$$

Precipitation phosphorus average concentration multiplied to hydrologic load (L):

$$0.03 \text{ mg/L} \times 1{,}320{,}386{,}320 \text{ L} = 31{,}151{,}589.6 \text{ mg}$$

Total precipitation phosphorus load converted to kg:

$$31{,}151{,}589.6 \text{ mg} \div 1{,}000{,}000 = 31.15 \text{ kg}$$

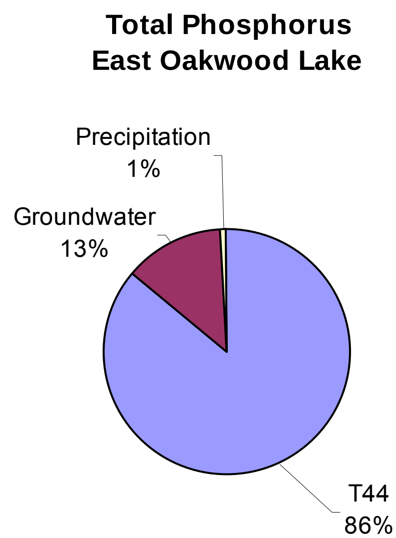


Figure 69. East Oakwood Lake Total Phosphorus Loads

Total Dissolved Phosphorus

The estimated total dissolved phosphorus loading from East Oakwood Lake watershed runoff was derived using the FLUX model. The total dissolved phosphorus loading from Site T44 is estimated at 1,087.7 kg. Monitored outflow at Site T45 showed a total dissolved phosphorus load of 5,593.1 kg. After the outflow was subtracted from the inflow, an estimated 4,505.4 kg of total dissolved phosphorus was unaccounted for and was presumed to be loading from un-monitored inflow.

Biological and Physical Habitat Summary

Phytoplankton (Algae) Data Summary

Planktonic algae were collected once in June and once in August in East Oakwood Lake and consisted of 57 species which represented 45 genera. They were divided into four separate algal divisions – flagellated algae, blue-green algae, diatoms, and non-motile green algae. The most diverse group was the non-motile green algae with 19 species. However, the blue-green algae exhibited the most abundance (Figure 70), with the *Oscillatoria agardhii* species being the most dense. Most noxious/nuisance conditions in lakes are produced by just three algae *Anabaena flos-aquae*, *Aphanizomenon flos-aquae*, and *Microcystis aeruginosa.* An oversupply of nutrients, especially phosphorus, will result in the excessive growth of these species. In June, four noxious species were identified in East Oakwood Lake, *Anabaena circinalis*, *Oscillatoria agardhii*, *Anabaena subcylindrica*, and *Microcystis aeruginosa*. In August, the same four species were present in addition to *Oscillatoria limnetica*, another noxious species.

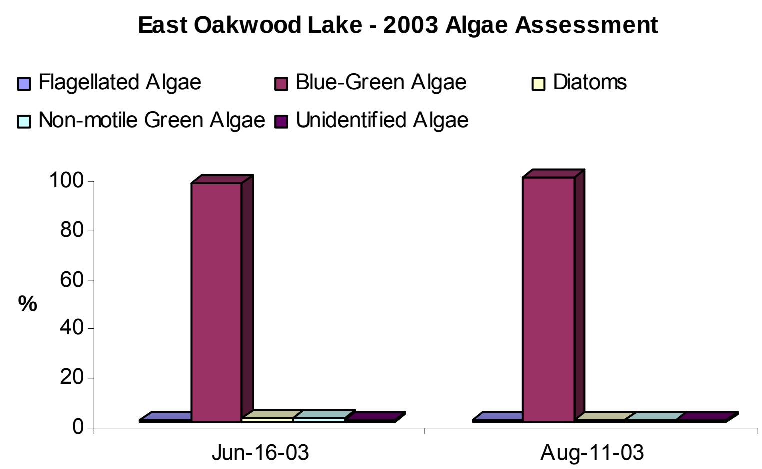


Figure 70. Percentage of Major Algae Groups Collected in East Oakwood Lake

Aquatic Macrophyte Survey (Aquatic Plants)

Between July 31st and August 11th, 2003, aquatic plants were surveyed in East Oakwood Lake along 32 transects at 130 sampling locations. Table 88 lists species identified during the survey. Sago Pondweed was the most abundant of the submergent macrophytes and cattail was the most abundant of the emergent species. Aquatic plants were absent at 19 of the 32 transects. See Figures 6, 7, and 8 in Methods Section for the number and location transects and see Figures 18, 19, and 20 in the Results Section for exact location of these species. Figure 71 shows the frequency of occurrence of each species using data from the 32 transects.

Table 88. East Oakwood Lake Aquatic Macrophytes

Common Name	Genus	Species	Habitat
Leafy Pondweed	*Potamogeton*	*foliosus*	Submergent
Claspingleaf Pondweed	*Potamogeton*	*richardsonii*	Submergent
Sago Pondweed	*Potamogeton*	*pectinatus*	Submergent
Cattails	*Typha*	*spp.*	Emergent

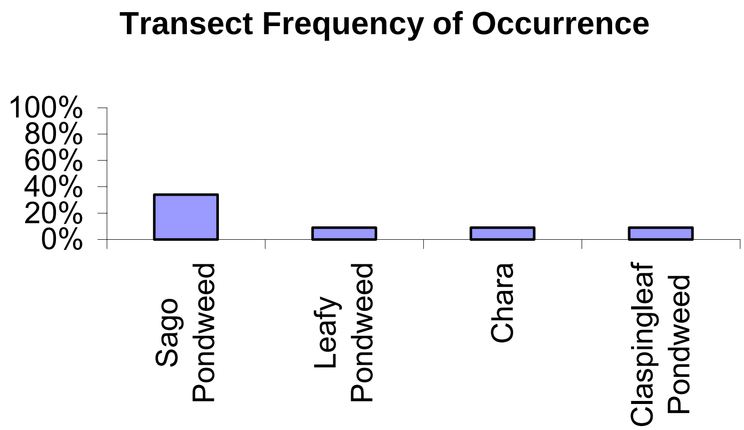


Figure 71. Type and Frequency of Aquatic Macrophytes at 32 Transects

Fish, Macroinvertebrate, and Habitat Summary

Fish and physical habitat measurements were not sampled on the outlet of East Oakwood Lake. However, the South Dakota Game, Fish, and Parks completed a fisheries survey of East Oakwood Lake during August and September of 2004 (Appendices A and B) and a visual shoreline habitat survey was completed during the aquatic plant survey.

Macroinvertebrates were collected at tributary Sites T44, T45, and T46. The following table (Table 89) summarizes the scores for each sampling site based on the macroinvertebrate data and the scoring system setup for tributaries during the North-Central Big Sioux River Assessment Project. Score sheets for each site can be found in the Results Section. HBI scores ranged from 9.0 to 9.6. Site T44 with a HBI of 9.6, had one Ephemeropteran and two Trichoptera found. Tolerant Chironomidae dominated this community, with 88 percent of the total assemblage being Chronomidae. T45 with a HBI of 9.0, was dominated by the amphipod *Hyalella* sp. and the highly tolerant Chironomidae *Glyptotendipes* sp. Site T46 with a HBI of 9.3, was dominated by the communities of Oligochaeta (Tubificidae) and Diptera (primarily Chironomidae). It should be noted that these streams serve as either an inlet or an outlet to a lake and the typical stream species are likely not present.

Table 89. Bug, Fish, and Habitat Index Values in the East Oakwood Lake Watershed

Site	Macroinverts	Fish	Habitat
T44	25	---	---
T45	46	---	---
T46	52	---	---

Trophic State Index (TSI) Summary

The trophic state of a lake is a numerical value that ranks it relative productivity. Developed by Carlson (1977), the Trophic State Index (TSI) allows a lake's productivity to be easily quantified and compared to other lakes. TSI values range from 0 (oligotrophic) to 100 (hypereutrophic). Low TSI values correlate with small nutrient concentrations, while higher TSI values correlate with higher levels of nutrient concentrations. Table 90 describes the TSI trophic levels and numeric ranges applicable to East Oakwood Lake.

Table 90. Carlson Trophic Levels and Numeric Ranges

Trophic Level	Numeric Range
Oligotrophic	0-35
Mesotrophic	36-50
Eutrophic	51-65
Hypereutrophic	66-100

The median of the chlorophyll-*a* TSI value and the Secchi depth TSI value was calculated to provide a single trophic state index score for East Oakwood Lake (Table 91). An overall median observed TSI of 67.4 indicates East Oakwood Lake is exhibiting a hypereutrophic condition (Figure 72).

Table 91. Observed Trophic State Index Values Collected in East Oakwood Lake

Parameter	Total Phosphorus	Secchi Depth	Chlorophyll-*a*	Median TSI (Secchi & chla)
Mean TSI	77.5	60.0	74.7	67.4

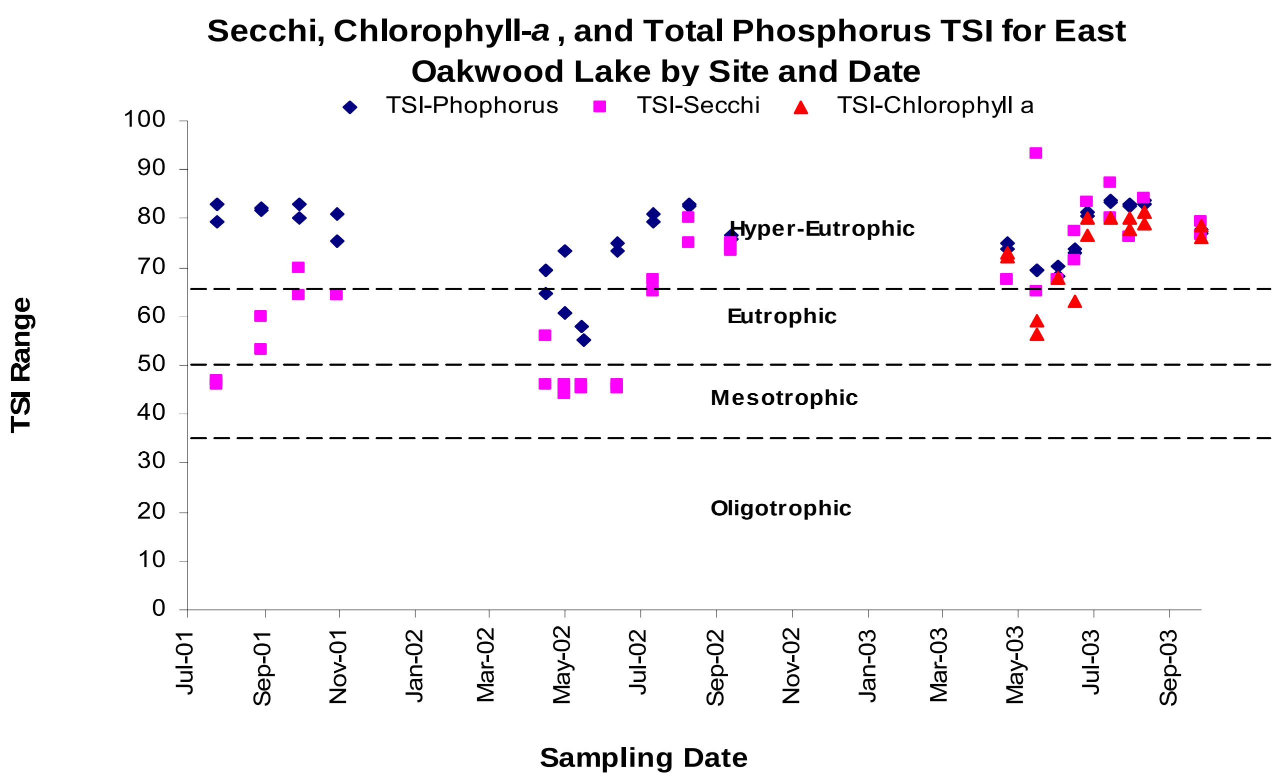


Figure 72. East Oakwood Lake Secchi and Chlorophyll-*a* TSI Plotted by Carlson Trophic Levels

In order to determine impairment of a lake the SD DENR assesses the trophic status of a lake, using the median TSI value of chlorophyll-*a* concentrations and Secchi depth measurements. The SD DENR has developed an EPA approved protocol that establishes desired TSI levels of lakes based on their fishery classification. East Oakwood Lake is classified as a warmwater semi-permanent fishery and is currently not supporting the desired TSI level (SDDENR 2005). The full support target for lakes within the warmwater semi-permanent fishery classification is set at an overall median (of chlorophyll-*a* and Secchi depth TSI) TSI value ≤ 63.4.

Trophic State Index values are plotted using beneficial use support categories as shown in Figure 73. TSI values steadily increased from May through October. All parameters are not supporting of the beneficial uses from July through October. Secchi depth was sampled in 2001 and 2002. Results show the TSI values of each are scattered throughout the sampling season. In 2003, both Secchi depth and chlorophyll-*a* were sample and TSI values of both increase throughout the season.

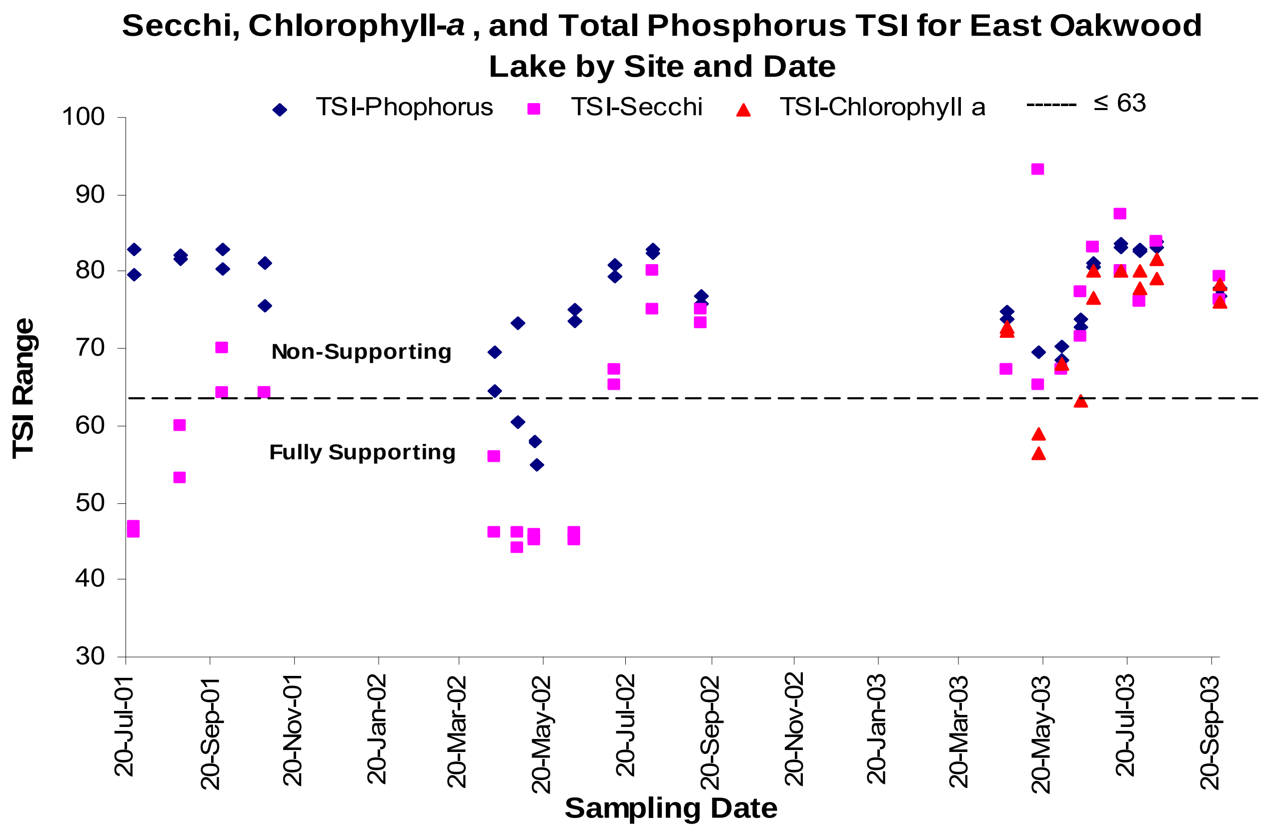


Figure 73. East Oakwood Lake Secchi Depth and Chlorophyll-*a* TSI Values Plotted by Beneficial Use Support

Reduction Prediction based on BATHTUB Model

In-lake responses to reductions in watershed nutrient loading were calculated using the BATHTUB model. Each sampled variable was modeled (Figure 74 and Table 92). See Appendix P for a description of each BATHTUB variable. The reduction of watershed phosphorus contribution would improve the lake from a non-supporting predicted TSI value of 72.5 to a supporting TSI value ≤ 63.4. The phosphorus loading can be attributed to watershed runoff and internal sediment loading from previous watershed runoff.

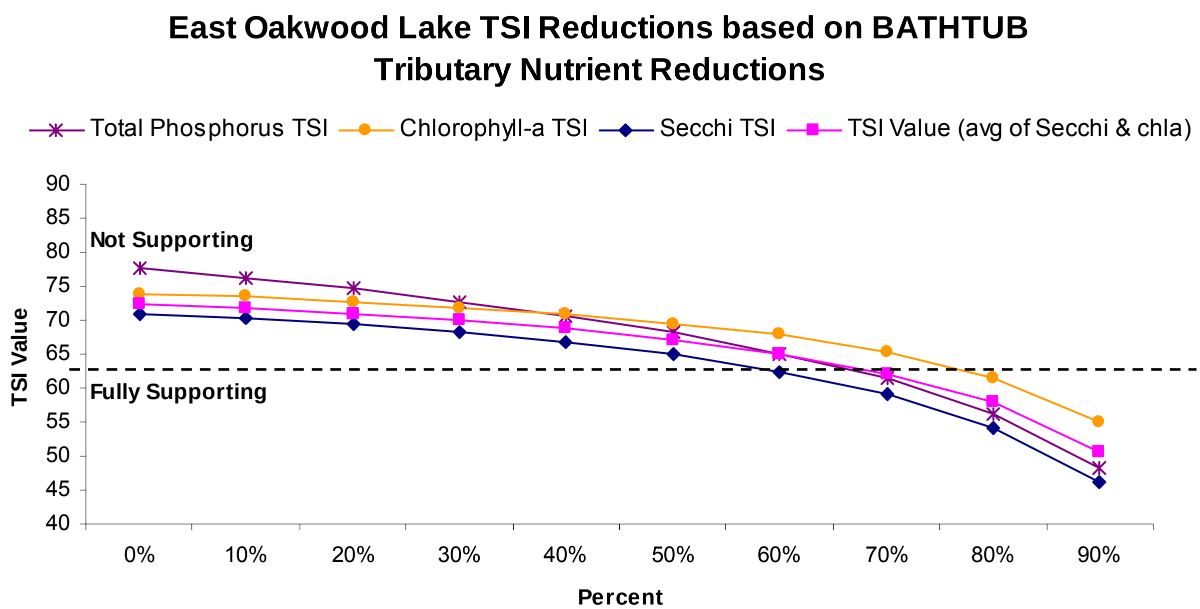


Figure 74. East Oakwood Lake BATHTUB Predicted Mean TSI Reductions and Use Support

Table 92. East Oakwood Lake Observed and Predicted Watershed Reductions in Nitrogen and Phosphorus Concentrations and Predicted In-lake Mean TSI Values Using the BATHTUB Model

East Oakwood Lake	Observed Values caluculated using BATHTUB	Condition of the Lake based on current loadings	Percent reductions for total lake load based on predicted model								
			10%	20%	30%	40%	50%	60%	70%	80%	90%
Variable	OBSERVED	PREDICTED	Est	Est	Est	Est	Est	Est	Est	Est	Est
Total P	162	163.5	147.7	131.9	116.1	100.3	84.6	68.7	52.9	37.1	21.3
Total N	2063.5	2454.9	2230	2005.2	1780.4	1555.5	1330.7	1105.8	881	656.2	431.3
CHL-A	89.3	82.8	78.3	73.2	67.3	60.6	53	44.2	34.3	23.4	12
SECCHI	1	0.5	0.5	0.5	0.6	0.6	0.7	0.8	1.1	1.5	2.6
ORGANIC N	1865	2050.5	1948.3	1831.7	1698.1	1545.1	1370.5	1170.1	944.4	696	437.7
ANTILOG PC-1	2839.3	4271.4	3735.3	3193.9	2651.7	2116.8	1601.6	1117.6	689.7	344.4	111.4
ANTILOG PC-2	28.3	16	16.2	16.3	16.5	16.7	16.8	16.9	17	16.9	16.2
(N-150)/P	11.8	14.1	14.1	14.1	14	14	14	13.9	13.8	13.6	13.2
INORGANIC N/P	3.3	22	26.7	44.9	82.3	10.5	1	1	1	1	0.5
FREQ (CHL-a>10)%	99.9	99.9	99.9	99.8	99.7	99.5	99.1	98.1	95.3	85.5	49.6
FREQ (CHL-a>20)%	98.2	97.6	97.1	96.3	95	93	89.6	83.3	71.2	47.7	13
FREQ (CHL-a>30)%	92.6	90.8	89.2	87	84	79.5	72.8	62.3	46.2	23.8	3.7
FREQ (CHL-a>40)%	83.8	80.6	78	74.7	70.2	64.1	55.7	44	28.8	12	1.2
FREQ (CHL-a>50)%	73.4	69.3	66	62	56.8	50	41.4	30.5	17.9	6.2	0.5
FREQ (CHL-a>60)%	63	58.3	54.8	50.4	45.1	38.4	30.5	21.1	11.2	3.4	0.2
TSI-P	77.5	77.6	76.2	74.6	72.7	70.6	68.1	65.1	61.4	56.3	48.3
TSI-CHLA	74.7	73.9	73.4	72.7	71.9	70.9	69.5	67.8	65.3	61.5	55
TSI-SEC	60	71	70.3	69.3	68.2	66.7	64.9	62.4	59.1	54.1	46.1
Median TSI (chla & Secchi)	67.4	72.5	71.9	71.0	70.1	68.8	67.2	65.1	62.2	57.8	50.6

Point Sources

This watershed is predominately agricultural. There are no municipalities or known point sources located in this watershed.

Non-Point Sources

Non-point sources of concern are those that contribute TSS and nutrients. Since non-point sources can be difficult to pinpoint, the following are the possible sources of sediment and nutrients within this watershed. Possible sediment sources of pollution include agricultural runoff, and eroding stream bed and banks. Possible sources of phosphorus include human and animal waste, soil erosion, fertilizer runoff, and detergents. Possible sources of nitrogen are fertilizers, animal wastes, and septic systems.

WATER QUALITY GOALS

Water quality goals are based on beneficial uses and standards to meet those uses. This assessment was initiated due to East Oakwood Lake being listed on the 303 (d) Waterbody List because of excessive nutrients, siltation, and noxious aquatic plants, all of which do not have applicable numeric water quality standards. However, lakes are also assessed based on Trophic State Index (TSI). TSI takes into account the water clarity, nutrient levels, and quality of water. Based on the monitoring results all lakes in the Oakwood chain of lakes are impaired and do not meet TSI requirements. Water quality results also show East Oakwood Lake is not supporting its beneficial uses based on the numeric standard for pH (Figure 75).

Goals were established to reduce nutrient loadings to acceptable levels in order to meet the beneficial uses of these lakes. Decreasing nutrient loads will improve TSI levels in these lakes as well as improve the pH levels. To meet the TSI criteria, all lakes must maintain at a mean TSI of $\leq$ 63.4. As for pH in East Oakwood Lake, pH levels must be maintained at greater than or equal to 6.5 and less than or equal to 9.0 to support the lake's beneficial uses.

Excessive Nutrients

Phosphorus is the main nutrient that contributes to excessive algae and weed growth in lakes. Each of the lakes showed high phosphorus TSI levels. Possible sources of phosphorus include human and animal waste, soil erosion, fertilizer runoff, and detergents. It is recommended that phosphorus levels be maintained below 0.3 mg/L to help prevent algal blooms. Algal blooms can also produce higher levels of pH, similar to what is being seen in East Oakwood Lake. Phosphorus levels will need to be reduced in order to improve pH to levels that will support the beneficial uses assigned to East Oakwood Lake.

Assessment results show that all three lakes are in a hypereutrophic condition. Characteristics of a hypereutrophic lake include very high levels of nutrients, excessive plant growth, and excessive algae growth. East Oakwood Lake and West Oakwood Lake are extremely biologically productive. This productivity will continue to increase, speeding up the natural lake processes and eventually becoming detrimental to aquatic life. Therefore, it is important to slow down productivity in order to improve water quality and fully support beneficial uses.

Siltation

Excessive siltation can cause an over abundance of phosphorus because during periods of anoxia the sediment can release phosphorus. Phosphorus can also be released after sediment is re-suspended due to wave action or foraging of fish such as carp.

Noxious Aquatic Plants

Noxious aquatic plants were documented in both East Oakwood Lake and West Oakwood Lake. West Oakwood Lake lacked diversity of aquatic plants. Chlorophyll-*a* levels were high, 40 ug/L to 93 ug/L, in each of the lakes. These levels are known to produce nuisance algae blooms. Concentrations in excess of 55 ug/L signify hypereutrophic conditions.

MANAGEMENT OPTIONS AND RECOMMENDATIONS

Before considering in-lake management options, sources of external loadings must be dealt with first. If external sources are not reduced before implementing in-lake alternatives, the management plan will likely fail. If it is determined that external sources are not contributing to the water body problems, then in-lake restoration would be the next step.

At this time two TMDLs are proposed due to TSI impairment (Appendix Q and R). These reports will address the impairments identified for East Oakwood Lake and West Oakwood Lake. Both lakes were identified for TMDL development in the 303 (d) list of impaired water and assessment results show that both are not currently supporting their beneficial uses. The TMDL reports can be found in Appendices Q and R.

BEST MANAGEMENT PRACTICES

External Management of Nutrient Sources

Best management practices (BMPs) proposed to control external nutrient transport from agricultural non-point sources are shown in Table 93. This table lists optional BMP practices that can be used to reduce or eliminate external sources of nutrients. As indicated by the AnnAGNPS model, agricultural practices are contributing to the nutrient load in this watershed (See Results Section).

Table 93. Best Management Practices for Nutrient Reductions

BMP	Potential Reduction
(1) Feedlot Runoff Containment	High
(2) Manure Management	High
(3) Grazing Management	Moderate
(4) Alternative Livestock Watering	Moderate
(5) Conservation Tillage (30% residue)	Moderate
(6) No Till	High
(7) Grassed Waterways	Moderate
(8) Buffer/Filter Strips	Moderate
(9) Commercial Fertilizer Management	Moderate
(10) Wetland Restoration or Creation	High
(11) Riparian Vegetation Restoration	High
(12) Conservation Easements	High
(13) Livestock Exclusion	High

Note: approximate range of reductions:
Low = 0-25% Moderate = 25-75% High = 75-100%

Agricultural animals need to be pastured at least 30 meters away from the shoreline of these lakes and excluded from directly accessing the lakes.

At a minimum, it is recommended the first 30 meters of bank along the shoreline of all the lakes should have vegetated buffers; although, > 30 meters is preferred. Establishing buffer zones greater than 30 meters around shallow agricultural lakes have shown to increase numbers of zooplankton (Dodson et. al 2004). Zooplankton has shown to suppress phytoplankton and increase macrophyte abundance.

Most of these BMPs are further explained in Table 94. An explanation of the benefits of using a particular BMP and the reduction that can be achieved when put to use. This table was adapted from MPCA (1990) sources.

Table 94. Percent Reduction Achievable by Best Management Practice

BMP	Benefits	Achievable Reduction
Manure Management	• Reduces Nutrient Runoff • Significant Source of Fertilizer	50-100% reduction of nutrient runoff
Buffer/Filter Strips	• Controls sediment, phosphorus, nitrogen, organic matter, and pathogens	50% sediment and nutrient delivery reduction
Conservation Tillage	• Reduces runoff • Reduces wind erosion • More efficient in use of labor, time, fuel, and equipment	30-70% pollutant reduction 50% nutrient loss reduction (depends on residue and direction of rows and contours)
Fencing	• Reduces erosion • Increases vegetation • Stabilized banks • Improves aquatic habitat	Up to 70% erosion reduction
Grassed Waterways	• Reduces gulleys and channel erosion • Reduces sediment associated nutrient runoff • Increases wildlife habitat	10-50% sediment delivery reduction (broad) 0-10% sediment deliver reduction (narrow)
Strip Cropping	• Reduces erosion and sediment loss • Reduces field loss of sediment associated nutrients	High quality sod strips filter out 75% of eroded soil from cultivated strips

Improved landuse practices can greatly reduce the amount of nutrients entering East Oakwood Lake and West Oakwood Lake. In addition to the affects of the watershed on water quality, there are also affects from shoreline development. Much of West Oakwood Lake's southwest shoreline is developed. Lakeshore homeowners can also help reduce lake pollution and protect water quality by preventing nutrients and sediment from entering the lake. The following lakeshore BMPs should be implemented by lakeshore owners:

- Maintaining appropriate landscaping
- Reducing the use of fertilizers on lawns/gardens
- Reduce the use of pesticides
- Use lawn fertilizers free of phosphorus
- Consider planting native vegetation near shoreline
- Use organic fertilizers and pesticides

Fertilizers and weed killers contribute greatly to nutrients in the lake as it runs off lakeshore property during heavy rains. Additionally, a septic survey of shoreline homes should be conducted to ensure these systems are not contributing to the excess nutrients in the lake. Currently, there is not a centralized sewer system in place for these developments.

Figure 75 is a priority management map showing the areas of the watershed that may be contributing the most to external nutrient loadings. The red shaded areas are the AnnAGNPS cells found to be contributing more than one pound per acre of phosphorus and more than three pounds per acre of nitrogen. These results are based on a 10-year simulation using the AnnAGNPS model. The complete listing of phosphorus and nitrogen loadings for each cell can be found in Appendix O.

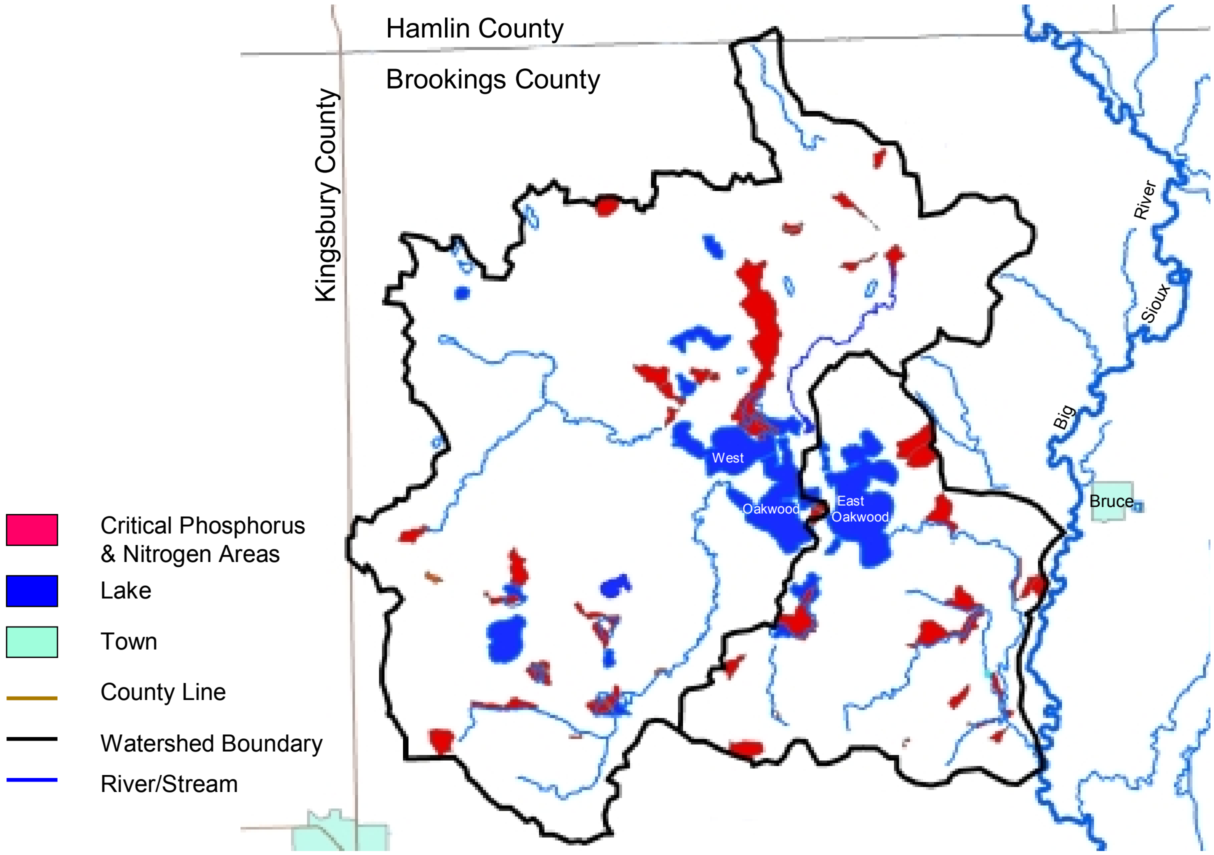


Figure 75. Critical Nutrient Areas Based on a 10-Year Simulation at Current Conditions

Internal (In-Lake) Management of Nutrients

West Oakwood Lake is currently outfitted with an in-lake aerator at the southeast end of Lake Tetonkaha. It is operational from late fall and into early spring. Although the aerator is present, this lake will still winter kill occasionally. It is situated near the southeast end of Tetonkaha Lake. During the study period several large carp were observed within this lake system. Carp can devastate aquatic vegetation, which reduces aquatic invertebrates, and ultimately reduces the necessary habitat to sustain a good population of game fish. Since the fish kill during the winter of 2000-2001, Game, Fish and Parks has restocked both lakes.

The following are five in-lake management alternatives to consider for improving water quality in Oakwood Lakes:

1) Effective fish barrier between Big Sioux River and East Oakwood Lake
2) Septic system survey of South Lake Tetonkaha
3) Aggressive removal of rough fish biomass in both East and West Oakwood Lakes
4) Dredge Mortimer Slough
5) Aquatic plant re-establishment in West Oakwood Lake

Sediment sealing and sediment removal are probably the most highly effective means of reducing nutrients and sediment in many lake systems. However, aluminum sulfate treatment would not work effectively with these shallow lakes and is not recommended. Wave action alone would likely break the seal this chemical makes with the bottom sediments. Dredging may be an option for the area known as Mortimer's Slough. This slough is presently being used as a walleye rearing pond by S.D. Game, Fish and Parks. Making this slough deeper would improve filtering of nutrients from agricultural runoff, as well as act as a settling pond for sediment before it enters West Oakwood Lake from the north. It would also enhance the current walleye rearing activities. An evaluation of the bottom sediments of this slough would need to be accomplished before considering dredging.

These lakes are frequently stocked with walleye fingerlings and adult yellow perch. Table 95 shows the most recent stocking efforts. According to the West Oakwood Lake Fisheries Survey (2004), this lake would be capable of sustaining a walleye population if it did not winterkill. It is unlikely that efforts to improve the water quality will prevent occasional winterkills. SD Game, Fish and Parks also recommended commercial fishing for common carp, bigmouth buffalo, and black bullhead. A severe algae bloom was documented during the survey and Secchi depth measured 0.28 meters. The fisheries survey of East Oakwood Lake (2004) also noted a "dense algae bloom" and a Secchi depth measurement of 0.23 meters. This report also recommended commercial fishing for common carp and black bullhead.

Table 95. Oakwood Lakes Recent Stocking Efforts

2001	Lake	# Stocked	Species	Size
	East Oakwood	100,000	Walleye	Fingerling
	East Oakwood	10,159	Yellow Perch	Adult
	West Oakwood	79,300	Walleye	Fingerling
	West Oakwood	12,221	Yellow Perch	Adult
2004				
	East Oakwood	100,700	Walleye	Fingerling
	West Oakwood	119,100	Walleye	Fingerling

It is recommended that rough fish be harvested from these lakes as they keep phosphorus recycled and re-suspended through their feeding activities. Commercial fishing has taken place in the past, but has not been as aggressive as it should be. According to the SD Game, Fish and Parks Department, the most recent commercial fishing activity has been on West Oakwood Lake. In the past year several thousand pounds of rough fish have been removed (Table 96). However, without an effective fish barrier in place to prevent these species from entering this lake system, commercial fishing will not make a significant impact on fish biomass removal.

Table 96. Recent Rough Fish Removal by Commercial Fishing

Lake	Date	Type	Pounds
West Oakwood	Feb 2003	Bullheads	2,100
West Oakwood	Oct 2005	Bullheads	6,600
West Oakwood	Apr-Jun 2006	Bullheads	19,700
West Oakwood	Apr-Jun 2006	Carp	9,000
West Oakwood	Apr-Jun 2006	Bigmouth Buffalo	3,000

Economics and monetary limitations have prevented a more aggressive approach to removing the rough fish biomass from these lakes. According to GFP (Todd St Sauver, Fisheries Manager, Southeast Region, pers. comm), after winterkills (which heavily reduces the rough fish biomass) they have seen stocking efforts of walleye flourish and water quality improve. It is believed water quality improvement could be seen after removing much of the rough fish biomass. In addition, it would be imperative to install an effective fish barrier at the outlet of East Oakwood Lake ***before*** removal of the rough fish biomass. As the area between the Big Sioux River and the outlet of East Oakwood Lake floods or receives high waters, rough fish (i.e. common carp) find their way from the Big Sioux River into the Oakwood Lakes system. These fish can have a devastating effect on a lake system, from rooting up vegetation, stirring up bottom sediments, to adding to the amount of nutrients from their waste and carcasses. Other methods to control nutrients may be ineffective due to the shallowness of the lakes and the findings from the Oakwood-Poinsett (1991) assessment indicating that these lakes are acting as nutrient sinks.

Due to the development of the southeast shoreline of Lake Tetonkaha, it is recommended septic systems be checked to ensure they are in compliance with regulations and ensure any pipes emitting discharge directly to the lake do not contain detergents or other harmful chemicals.

Increased nutrient levels have shown to decrease plant community diversity with an increase in dominance of species such has sago pondweed (Moss et. al 1996). Sago pondweed was the only species of aquatic plant found in West Oakwood Lake. The precence of rough fish as well as deteriorated water quality has limited the diversity of plant growth in this lake. The shoreline of this lake is varied with some sheltered bays. It is recommended that aquatic plants be re-established in these areas, but only ***after*** an effective fish barrier is in place to prevent any more rough fish from entering the lakes and ***after*** a large portion of the rough fish biomass has been removed. It will be imperative to work in conjunction with the South Dakota Game, Fish and Parks Department in determining the best approaches to these management alternatives. It is recommended data such as population estimates of the nuisance fish species (common carp, bigmouth buffalo, and black bullhead) be collected to determine the amount of biomass that should effectively be removed. The SD Game, Fish and Parks Department (Todd St Sauver, Fisheries Manager, Southeast Region, pers. comm) suggested fish composting as an alternative to disposing of the unwanted fish. This would be a viable alternative if commercial fishermen have no interest in them. Establishment of composting areas would require landowner cooperation. The land owner would benefit from the compost by using it to enrich their cropland soils.

The reduction of nutrients to these lakes will likely reduce noxious the blue-green algae problems and summer algae blooms. To facilitate the growth of macrophytes and prevent the blue-green algae from dominating, experimental fish free enclosures could be placed in vulnerable areas to try to re-colonize beneficial aquatic plants.

HISTORICAL COMPARISON

Water Quality Comparisons

The Oakwood chain of lakes was assessed over a ten year period during the South Dakota Oakwood Lakes-Poinsett Rural Clean Water Program project (USDA-ASCS 1991). This project was conducted between 1981 and 1991. Between the years of 1987 and 1989, water quality was collected from the Oakwood Lakes watershed. Several monitoring locations during that study coincide with the monitoring locations used for this assessment.

According to the 1991 report, surface water monitoring indicated that all tributaries to the Oakwood Lakes supply excess amounts of nitrogen and phosphorus to the system. The lakes can sustain large algal blooms even in low flow years because much of the bottom sediments are saturated with phosphorus. This report concluded that the Oakwood Lakes system is operating as phosphorus sink with a 70 to 100 percent trapping efficiency.

The report recommended any future goals to improve water quality in these lakes would need to include in-lake restoration measures due their nutrient saturated in-lake sediments.

Best Management Practices were applied to some areas of the watershed. However the report stated that during the project waste managements systems were not well accepted due to their high costs. Some producers were not eligible for cost-sharing because they were already using conservation measures. Not all BMPs were implemented because of economic reasons or landowner changes. Other federal programs prohibited this project's program to offer incentives in some cases. For these reasons, there is still room for improvement throughout this watershed. In fact, this assessment showed that there are seventeen feedlots that rated > 50 on their AGNPS ratings.

The lakes were found to be hypereutrophic in 1991. The tributaries were carrying nutrient levels high enough to keep the lake in its hypereutrophic condition. The report didn't feel that BMPs alone would result in noticeable water quality improvements to the lake, only that they could reduce sedimentation. Because the lakes occasionally winterkill, the chemical and biological components of the system become altered. The report also stated nutrients seem to be released from lake sediments in the late summer as indicated by chlorophyll-a numbers and Secchi depth measurements. It was recommended assessing internal nutrient loadings from sediment. It is believed improvements to water quality may not be seen with watershed BMPs, if internal loads are the problem.

A comparison of the historic TSI values for phosphorus, Secchi depth, and chlorophyll-*a* are compared with the most recent assessment TSI values for East Oakwood Lake (Figure 76) and West Oakwood Lake (Figure 77). Both graphs indicate little if any change in trophic state of these lakes.

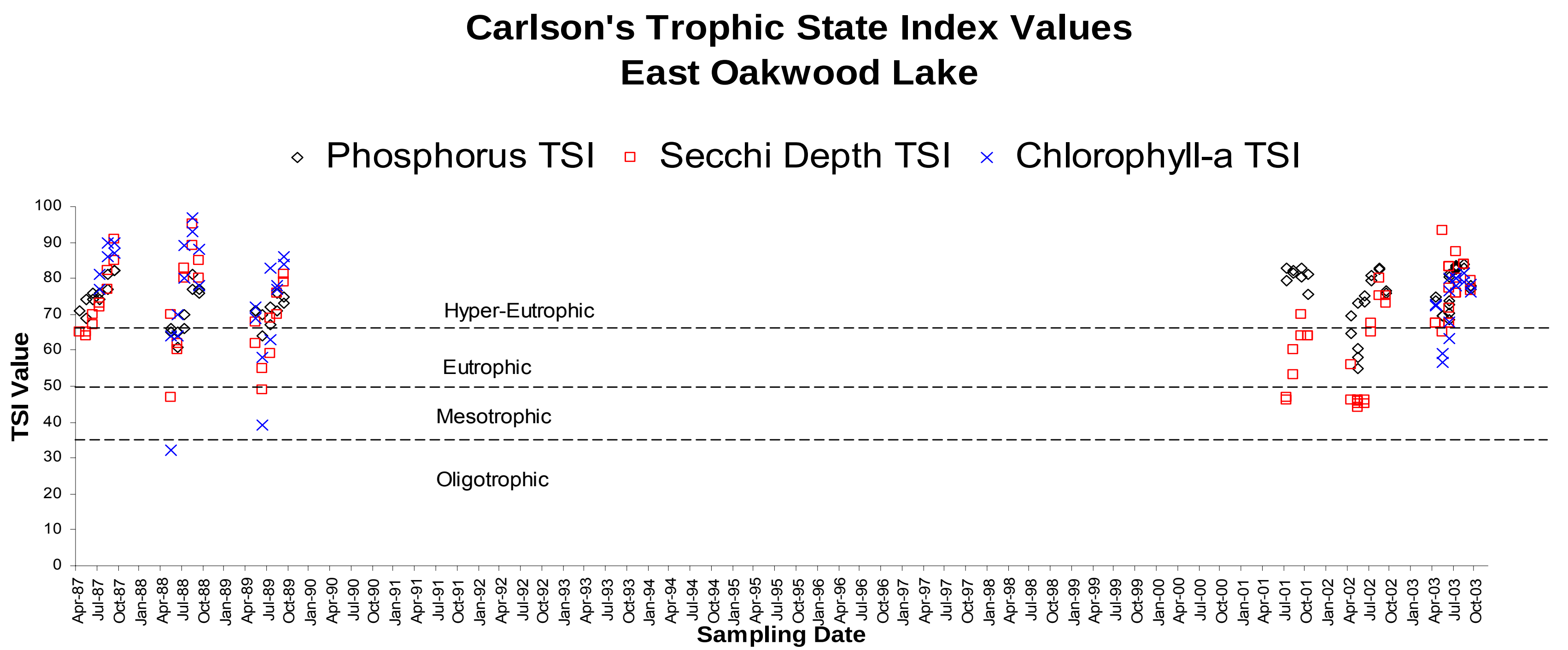


Figure 76. Comparison of Historical TSI Values with Current TSI Values of East Oakwood Lake

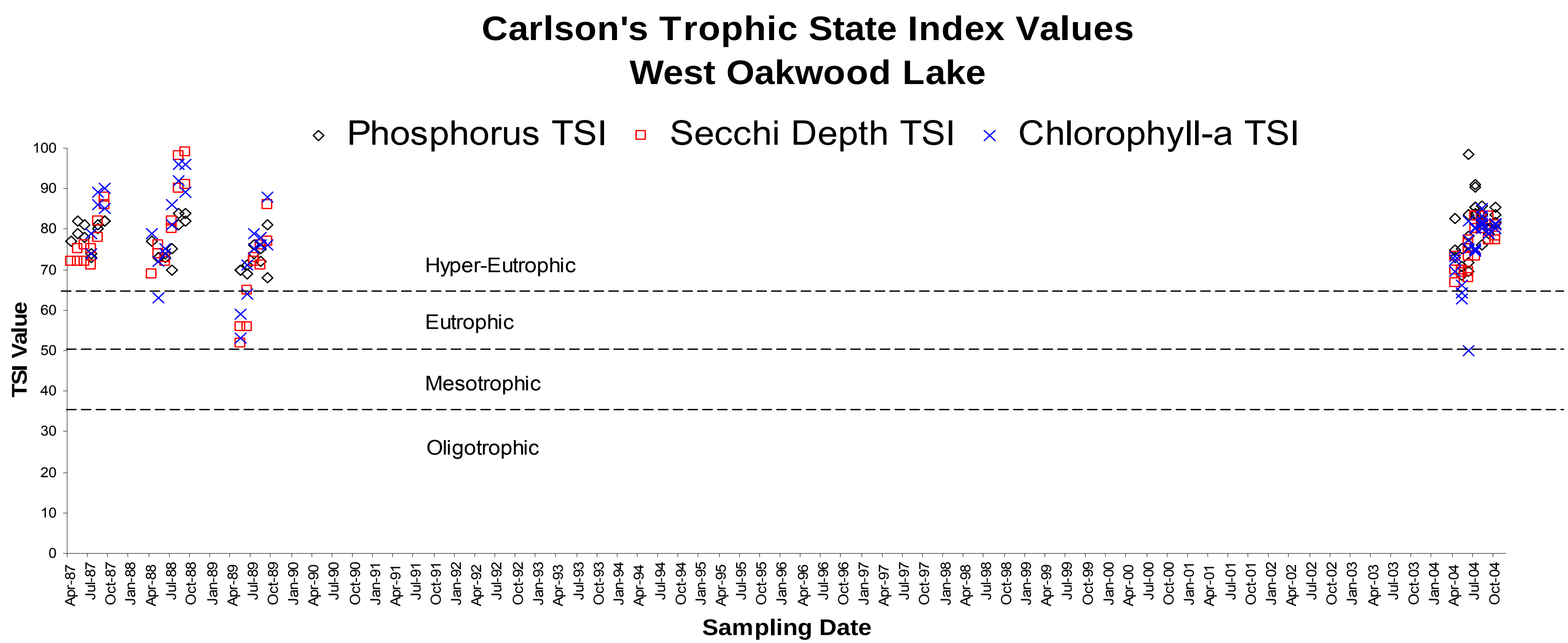


Figure 77. Comparison of Historical TSI Values with Current TSI Values of West Oakwood Lake

Overall, TSI value (combined average of Secchi depth measurement and chlorophyll-a) used to determine support or non-support of a lakes beneficial uses was plotted for both East Oakwood Lake and West Oakwood Lake. A historical comparison with current TSI measurements is shown in Figure 78. Both lakes are not currently supporting their beneficial uses based on TSI value.

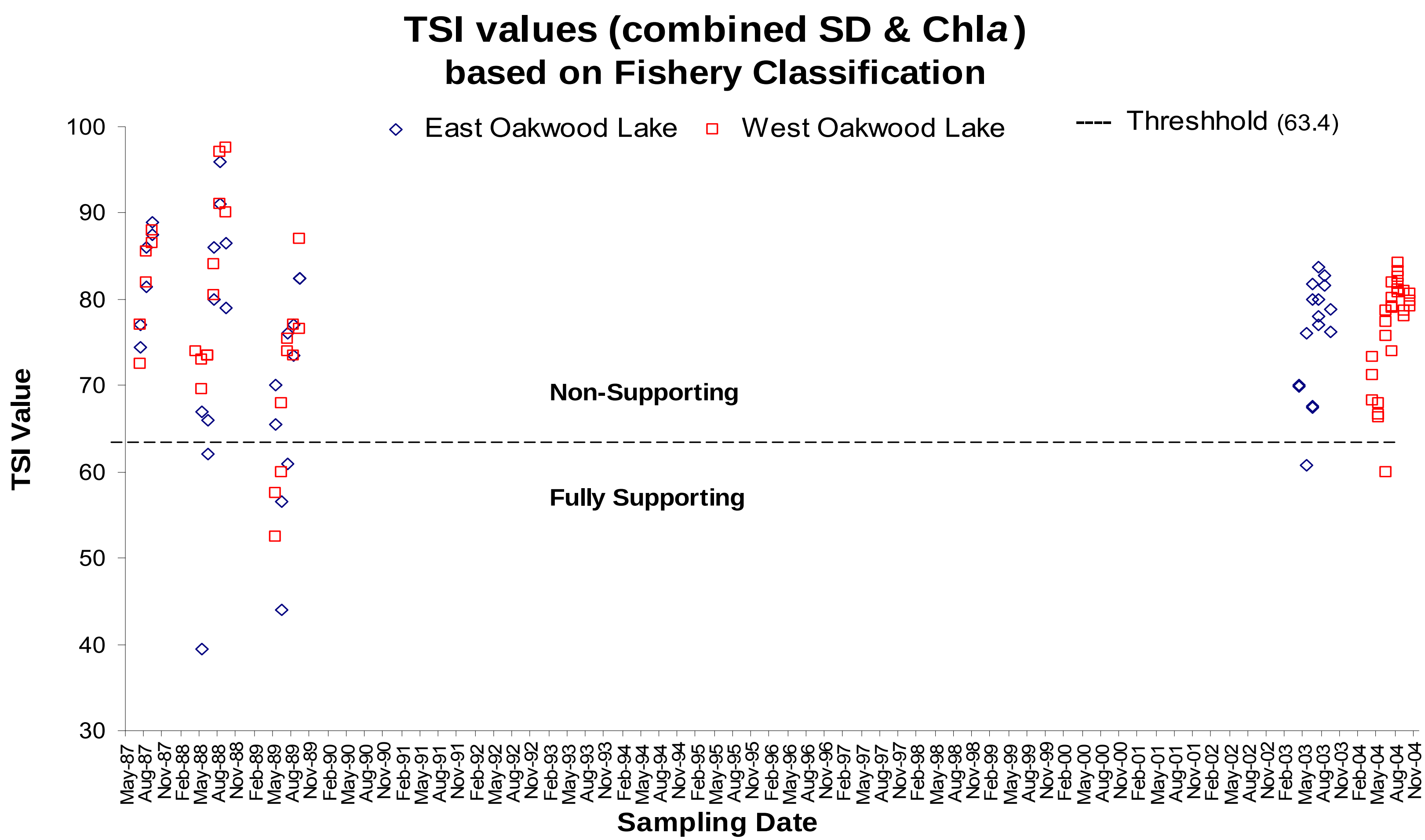


Figure 78. Comparison of Historical and Current Overall TSI Values used to Determine Beneficial Use Support of Oakwood Lakes

Historic monitoring sites and coinciding monitoring sites from the current assessment were used to compare water quality averages of total suspended solids, total nitrogen, and total phosphorus. Table 97 shows increased solids within West Oakwood Lake and at the inlet (Site T43) of West Oakwood Lake. Table 98 shows increases in total nitrogen in West Oakwood Lake and at the inlet (Site T48) of West Oakwood Lake. Phosphorus is showing to have increased in both lakes with a decrease at the inlet (Site T48) of West Oakwood Lake (Table 99).

Table 97. Historic Comparison of Total Suspended Solids

		Total Suspended Solids (mg/L)	1987-1989	2001-2002
Site (1987-1989)	Site (2001-2002)		Mean	Mean
T-1	T48	Inlet to Johnson Lake	29	22
L-2	L10	*Johnson Lake	32	41
L-3	L11	*North Lake Tetonkaha	32	42
T-2	T43	Inlet to South Lake Tetonkaha	20	47
L-4	L12	*South Lake Tetonkaha	27	35
IL-1	T44	Connection between South Tetonkaha and East Oakwood	22	26
L-7	L1	North East Oakwood Lake	27	13
T-0	T45	Outlet of East Oakwood Lake	18	20

* samples were collected from 1987-1989 and in 2004

Table 98. Historic Comparison of Total Nitrogen

		Total Nitrogen (mg/L)	1987-1989	2001-2002
Site (1987-1989)	Site (2001-2002)		Mean	Mean
T-1	T48	Inlet to Johnson Lake	2.45	2.69
L-2	L10	*Johnson Lake	2.93	4.22
L-3	L11	*North Lake Tetonkaha	3.09	2.94
T-2	T43	Inlet to South Lake Tetonkaha	2.45	2.05
L-4	L12	*South Lake Tetonkaha	3.01	4.04
IL-1	T44	Connection between South Tetonkaha and East Oakwood	2.62	3.04
L-7	L1	North East Oakwood Lake	2.71	2.06
T-0	T45	Outlet of East Oakwood Lake	1.62	1.56

* samples were collected from 1987-1989 and in 2004

Table 99. Historic Comparison of Total Phosphorus

		Total Phosphorus (mg/L)	1987-1989	2001-2002
Site (1987-1989)	Site (2001-2002)		Mean	Mean
T-1	T48	Inlet to Johnson Lake	0.393	0.193
L-2	L10	*Johnson Lake	0.153	0.303
L-3	L11	*North Lake Tetonkaha	0.146	0.191
T-2	T43	Inlet to South Lake Tetonkaha	0.490	0.420
L-4	L12	*South Lake Tetonkaha	0.136	0.184
IL-1	T44	Connection between South Tetonkaha and East Oakwood	0.213	0.241
L-7	L1	North East Oakwood Lake	0.121	0.162
T-0	T45	Outlet of East Oakwood Lake	0.112	0.176

* samples were collected from 1987-1989 and in 2004

PUBLIC INVOLVEMENT AND COORDINATION

STATE AGENCIES

The SD DENR was the primary state agency involved in the completion of this assessment. They provided equipment as well as technical assistance throughout the project. They also provided ambient water quality data for the lakes.

FEDERAL AGENCIES

The Environmental Protection Agency (EPA) provided the primary source of funds for the completion of the assessment of the Big Sioux River watershed.

LOCAL GOVERNMENTS, OTHER GROUPS, AND GENERAL PUBLIC

The EDWDD provided the sponsorship that made this project possible on a local basis. In addition to providing administrative sponsorship, EDWDD also provided local matching funds and personnel to complete the assessment.

Public involvement consisted of individual meetings with landowners that provided information on feedlots in the area. Other information about housing developments were collected from a local real estate agency.

OTHER SOURCES OF FUNDS

In addition to funds supplied by the East Dakota Water Development District (EDWDD) and the Environmental Protection Agency (EPA), additional financial support was provided by the Brookings County Conservation District (BCCD) and the South Dakota Conservation Commission (through a grant to BCCD). The inventory of the animal feeding operations and assessment of the potential environmental risk posed by each was work completed by BCCD using these funds in support of the overall project. The inventory and assessment of the AFOs was funded by EPA 319, EDWDD, and the SDCC grant.

ASPECTS OF THE PROJECT THAT DID NOT WORK WELL

Most of the objectives proposed for the project were met in an acceptable fashion and in a reasonable time frame. Due to delays in obtaining a properly working AnnAGNPS program and delays in receiving water quality results from the WRI lab, the related tasks of this project fell behind schedule. Additionally, another sizeable 319 funded watershed assessment project was being completed as the same time this project was beginning. Three years into this project, two additional lakes were added and needed to be sufficiently assessed.

The sampling of macroinvertebrates near or at a lake inlet and lake outlets may not have provided information sufficient enough to indicate the status of the overall stream. With the sampling locations so close to the lake, species may not have been typical to the small steam environment because of influence from macroinvertebrates from the lake. The use of rock baskets may have been misleading due to the types of macroinvertebrates inhabiting a stream at a particular site. It would only be valuable if the substrate of that stream also included rocks. A rock basket within a silt-bottom stream may collect bugs that are not typically seen or inhabit a particular area of the stream due to rocks not ordinarily being in the area. Another method of sampling macroinvertebrates in these heavily silted streams may have been more effective (i.e. D-net sampler).

This assessment should have included sediment sampling to determine the quantity of nutrients trapped in the sediment as well as the depth of accumulated sediment within these lakes.

Sampling and analysis methods could be improved in future projects by

- winter sampling the lakes for water quality through the ice
- require sediment samples of the lakes (especially if there is suspected phosphorus problem)
- yearly ambient water quality monitoring so future studies have a good base of data

Overall, data gathered during this project was sufficient enough to make a reasonable determination on the condition of these two lakes and to make realistic suggestions for management options. The ultimate goal is to reduce nutrient levels in the lakes and improve water quality.

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