PHASE I
WATERSHED ASSESSMENT
AND TMDL
FINAL REPORT

GEDDES LAKE
CHARLES MIX 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

MARCH, 2007

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

GEDDES LAKE WATERSHED ASSESSMENT AND TMDL FINAL REPORT

Prepared By

Richard A. Hanson

Sponsor

South Central Water Development District

03/09/07

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

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South Central Water Development District

Charles Mix Conservation District

NRCS in Charles Mix County

SD DENR – Water Resource Assistance Program Staff

SD Department of Game, Fish and Parks

Additionally, Sean Kruger and Robert Smith provided assistance with the AnnAGNPS Modeling, and Andrew Repsys wrote the algae section. Sol Brich created the lake water and sediment depth maps.

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Abbreviations

AFOs	Animal Feeding Operations
AnnAGNPS	Annualized Agricultural Non-Point Source
BMPs	Best Management Practices
CV	Coefficient of Variance
DO	Dissolved Oxygen
NPS	Nonpoint Source
NRCS	Natural Resource Conservation Service
NTU	Nephelometric Turbidity Units
PSIAC	Pacific Southwest Interagency Committee
Q WTD C	Flow Weighted Concentration
SDDENR	South Dakota Department of Environment and Natural Resources
SD GF&P	South Dakota Department of Game, Fish & Parks
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TSI	Trophic State Index
µg/l	micrograms/liter
µmhos/cm	micromhos/centimeter
USGS	United States Geologic Survey

Executive Summary

PROJECT TITLE: South Central Lakes Watershed Assessment Project; Geddes Lake

PROJECT START DATE: 3/1/00 PROJECT COMPLETION DATE: 3/1/02

FUNDING: TOTAL BUDGET: $217,704

TOTAL EPA GRANT: $141,929

TOTAL EXPENDITURES OF EPA FUNDS: $126,857.14

TOTAL SECTION 319 MATCH ACCRUED: $ 77,510.11

BUDGET REVISIONS: $22,000 319 funds added 9/9/02 to original $113,663 319 funds. $6,266 319 funds added 9/16/03.

TOTAL EXPENDITURES: $204,367.25

SUMMARY ACCOMPLISHMENTS

The Geddes Lake assessment project began in April of 2000 and lasted through June of 2006. The project met nearly all of its milestones in a timely manner. The completion of the final report, however, was delayed until June of 2006 due to SDDENR having other commitments.

An EPA section 319 grant provided a majority of the funding for this project. The South Dakota State Fee Funds and the South Central Water Development District provided local matching funds for the project.

Water quality monitoring and watershed modeling resulted in the identification of several sources of impairment. These sources may be addressed through Best Management Practices and the implementation of several in-lake restoration strategies. Aquatic plant, algae, and sediment surveys were also completed for the lake.

The primary goal for the project was to determine sources of impairment to Geddes Lake and provide sufficient background data to drive a section 319 implementation project. Through identification of sources of impairment in the watershed, this goal was accomplished.

Introduction

Purpose

Geddes Lake had been experiencing beneficial use impairments because of algae blooms. The lake was placed on the 1998 303(d) list as being impaired due to excessively high trophic state indices (TSIs). The lake remained on the 303(d) list for having high TSIs in the 2000, 2002, 2004, and 2006 South Dakota Integrated Reports. Local concerns led to initiation of this assessment project with the South Central Water Development District as the project sponsor.

The purpose of this assessment was to determine the sources of impairment to Geddes Lake and its tributaries in Charles Mix County, South Dakota. The results from this study will be used to develop a Total Maximum Daily Load (TMDL) for the lake and tributaries. Pease Creek is the primary tributary to Geddes Lake and drains a mix of grazing lands and some cropland. Numerous winter feeding areas for livestock are present in the watershed. The stream carries sediment and nutrient loads that degrade water quality in the lake and cause increased eutrophication.

General Lake Description

Geddes Lake is a 28.3 hectare (70 acre) man-made impoundment located on Pease Creek in south-west Charles Mix County, South Dakota (Figure 1). The lake has an average depth of 0.98 meter (3.2 feet), a maximum depth of 3.66 meters (12 feet) and a capacity of approximately 86,353 cubic meters (70 acre-feet). Geddes Lake is generally well mixed with few, if any, periods of stratification during the summer. The outlet for the lake empties into Pease Creek, which eventually reaches the Missouri River in Charles Mix County, South Dakota. The 308.2 square kilometer (119 square mile) Geddes Lake watershed comprises a small portion of the 11,466 square kilometer (4,427 square mile) Fort Randall Reservoir hydrologic unit.

Lake Identification and Location

Lake Name: Geddes Lake	State: South Dakota
County: Charles Mix	Township: 97N
Range: 67W	Section(s): 25
Nearest Municipality: Geddes	Latitude: 44.1925
Longitude: -98.71638	EPA Region: VIII
Primary Tributary: Pease Creek	Receiving Body of Water: Pease Creek
HUC Code: 10140101	HUC Name: Fort Randall Reservoir

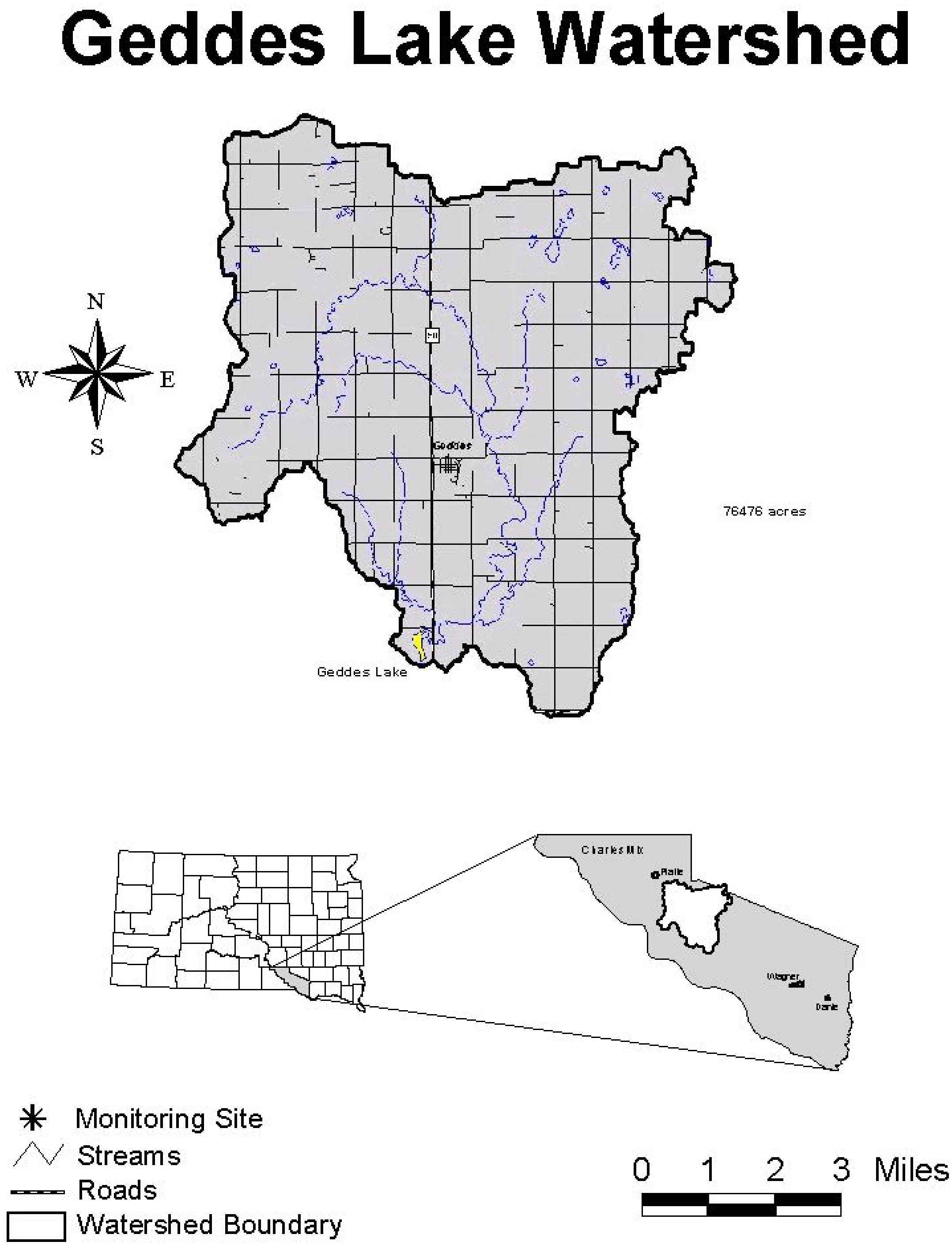

Figure 1. Location of Geddes Lake and its watershed.

Trophic Status Comparison

Developed by Carlson (1977), the Trophic State Index (TSI) allows a lake's productivity to be compared to other lakes. Higher TSI values correlate with higher levels of primary productivity. A comparison of Geddes Lake to other lakes in the Northwestern Glaciated Plains Ecoregion (Table 1) shows that a high level of productivity is common for the ecoregion. Geddes Lake had a slightly higher than average level of productivity compared to other lakes in the ecoregion, where the mean Secchi-chlorophyll *a* TSI value for the ecoregion was 76.06.

Table 1. TSIs Comparison of selected area lakes*.

Lake	County	TSI	Mean Trophic State
Academy	Charles Mix	81.69	Hyper-eutrophic
Corsica	Douglas	79.93	Hyper-eutrophic
Cottonwood	Sully	78.55	Hyper-eutrophic
Loyalton	Edmunds	66.65	Hyper-eutrophic
Rosette	Edmunds	78.45	Hyper-eutrophic
Geddes	**Charles Mix**	**77.60**	**Hyper-eutrophic**
Hiddenwood	Walworth	77.46	Hyper-eutrophic
Dante	Charles Mix	72.13	Hyper-eutrophic
Wilmarth	Aurora	72.09	Hyper-eutrophic

* The TSI values were taken from Stueven and Stewart (1996).

Beneficial Uses and Water Quality Standards

The State of South Dakota has assigned all water bodies that lie within its borders a set of beneficial uses. Along with these assigned uses are sets of standards for selected physical and chemical properties of the lake. These standards must be maintained for the lake to satisfy its assigned beneficial uses. All bodies of water in the state receive the beneficial uses of fish and wildlife propagation, recreation, and stock watering. The following beneficial uses are assigned to Geddes Lake.

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

The following table lists the parameters that must be considered when maintaining beneficial uses as well as the concentrations for each. When multiple standards for a parameter exist, the most restrictive standard is used.

Table 2. State beneficial use standards for Geddes Lake

Parameter	Criterion	Beneficial Use Requiring this Standard
Alkalinity *($CaCO_3$), mg/l*	< 750 *(mean)* < 1,313 *(single sample)*	Fish and Wildlife Propagation, Recreation, and Stock Watering
Coliform, fecal *(per 100 ml)* May 1 to Sept 30	< 200 *(mean)* < 400 *(single sample)*	Immersion Recreation
Conductivity (µmhos / cm @ 25^o *C)*	< 4,000 *(mean)* < 7,000 *(single sample)*	Fish and Wildlife Propagation, Recreation, and Stock Watering
Nitrogen, mg/l Total ammonia as N	$(0.411/(1+10^{7.204-pH}))+(58.4/(1+10^{pH-7.204}))$ *(single sample)*	Warmwater Semi-permanent Fish Propagation
Nitrogen, mg/l nitrates as N	< 50 *(mean)* < 88 *(single sample)*	Fish and Wildlife Propagation, Recreation, and Stock Watering
Oxygen, dissolved (mg/l)	> 5.0	Immersion and Limited Contact recreation
pH	6.5 - 9.0	Warmwater Semi-permanent Fish Propagation
Solids, suspended (mg/l)	< 90 *(mean)* < 158 *(single sample)*	Warmwater Semi-permanent Fish Propagation
Solids, total dissolved mg/l)	< 2,500 *(mean)* < 4,375 *(single sample)*	Fish and Wildlife Propagation, Recreation, and Stock Watering
Temperature	< 26.67 ºC	Warmwater Semi-permanent Fish Propagation

The State of South Dakota assigns the "fish and wildlife propagation, recreation and stock watering" and the "irrigation" beneficial uses to all streams and rivers in the state. The standards for that portion of Pease Creek located upstream of Geddes Lake and the unnamed minor tributary that enters Geddes Lake are given in Table 3.

Table 3. State water quality standards for Pease Creek upstream of Geddes Lake, and an unnamed tributary that enters Geddes Lake.

Parameter	Criterion
Nitrate	< 50 mg/l (mean): < 88 mg/l (single sample)
Alkalinity	< 750 mg/l (mean): < 1,313 mg/l (single sample)
pH	6.0 - 9.5
Total dissolved solids	< 2,500 mg/l for a 30-day geometric mean < 4,375 mg/l daily maximum for a drab sample
Conductivity	< 2,500 µmhos/cm (mean) < 4,375 µmhos/cm (single sample)

The portion of Pease Creek located downstream from Geddes Lake and extending to the confluence with the Missouri River is classified for the beneficial uses of “warm-water marginal fish life propagation”, “limited contact recreation”, “fish and wildlife propagation, recreation, and stock watering”, and “irrigation”. The parameters found in Tables 3 and 4 must be maintained.

Table 4. State beneficial use standards for Pease Creek downstream of Geddes Lake.

Parameters	**Criterion in mg/l (except where noted)**	**Beneficial Use Requiring this Standard**
Coliform, fecal *(per 100 ml)* May 1 to Sept 30	< 1000 *(mean)* < 2000 *(single sample)*	Limited Contact Recreation
Nitrogen, Total ammonia as N (mg/l)	$(0.411/(1+10^{7.204-pH}))+(58.4/(1+10^{pH-7.204}))$ *(single sample)*	Warmwater Marginal Fish Propagation
Oxygen, dissolved (mg/l)	> 5.0	Limited Contact Recreation
pH	6.0 – 9.0	Warmwater Marginal Fish Propagation
Solids, suspended (mg/l)	< 150 *(mean)* < 263 *(single sample)*	Warmwater Marginal Fish Propagation
Temperature	< 32.22 ^{o}C	Warmwater Marginal Fish Propagation

Recreational Uses

The South Dakota Department of Game, Fish, and Parks provides a list of existing public facilities that are maintained at area lakes (Table 5). Geddes Lake provides shore fishing and it has a boat ramp to provide access for fishing from boats.

Table 5. Recreational facilities at area lakes.

Lake	**State Parks**	**Ramps**	**Boating**	**Camping**	**Fishing**	**Public toilets**	**Picnic Tables**	**Swimming**
Academy Lake					X			X
Lake Andes					X			X
Dante Lake		1	X		X			X
Lake Francis Case	1	9	X	X	X	X	X	X
<u>Geddes Lake</u>		**<u>1</u>**	**<u>X</u>**		**<u>X</u>**			**<u>X</u>**
Lake Platte		1	X		X			X

Geology, Climate, Soils, and Land Use

Geddes Lake and its primary tributary, Pease Creek, are located in southwest Charles Mix County. The outlet of the lake discharges into Pease Creek, which eventually drains into the Missouri River. Located east of the Missouri River, the Geddes Lake watershed was subject to several periods of glaciation, which formed the parent material of the present day soils. The Late Wisconsin ice period of glaciation was the last to affect the area. The landscape of the watershed is level to slightly rolling. This is due in part to the past activity of the glaciers as well as ongoing water erosion.

The climate in Charles Mix County is continental with dry winters and wet springs. Annual precipitation can be expected to yield nearly 22 inches of which 80 percent can be expected to fall in the months of April through September.

Two soil associations best characterize the watershed (USDA, 1982). The dominant association is the Eakin-Highmore-Ethan association. It is characterized by well-drained, nearly level to gently rolling, silty and loamy soils on uplands. The second association is the Highmore-Eakin association. It is characterized by well-drained, nearly level to undulating, silty soils on uplands.

The watershed is primarily comprised of cropland (78.8%) and rangeland (20.8%). Forest (farmstead woodlots), urban areas, and water make up the remainder of the watershed. Approximately 47 feedlots are located in the watershed.

History

Charles Mix County has a diverse history. A few of the more outstanding events in the history of the area are covered here. The first permanent settlers, employees of the American Fur Company, arrived in 1830. In 1862 Charles Mix County was established and sporadic influxes of settlers occurred throughout the late 1800's. By 1878, farming within the flood plain of the Missouri River began. The first county seat was the town of Wheeler and was then transferred to the town of Lake Andes in 1916. Geddes Lake was named for the village of Geddes.

Threatened and Endangered Species

There are no threatened or endangered species documented in the Pease Creek watershed. The US Fish and Wildlife Service lists the pallid sturgeon (*Scaphirynchus albus*), whooping crane (*Grus americana*), bald eagle (*Haliaeetus leucocephalus*), least tern (*Sterna antillarum*), and piping plover (*Charadrius melodus*) as species that could potentially be found in Charles Mix County. The pallid sturgeon, piping plover, and least tern may be found in or along the Missouri River and are not located in the project area. None of these species were encountered during this study; however, care should be taken when conducting mitigation projects in the Pease Creek watershed.

Bald eagles typically prefer large trees for perching and roosting. As there are no confirmed documentation of bald eagles within the Pease Creek watershed, little impact to the species should occur. Any mitigation processes that take place should avoid the destruction of large trees that may be used as eagle perches, particularly if an eagle is observed using the tree as a perch or roost.

Whooping cranes are not and never have been documented in the Pease Creek watershed. Sightings in this area are likely only during fall and spring migration. When roosting, cranes prefer wide, shallow, open water areas such as flooded fields, marshes, artificial ponds, reservoirs, and rivers. Their preference for isolation and avoidance of areas that are surrounded by tall trees or other visual obstructions makes it highly unlikely that they will be present to be negatively impacted as a result of the implementation of BMPs.

Project Goals, Objectives, and Activities

Planned and Actual Milestones, Products, and Completion Dates

Objective 1. Lake Sampling Activities

Sampling of Geddes Lake began in May 2000 and continued at the two in-lake sites through May 2001. Insufficient ice cover prevented sampling through the ice during the winter months of 2000/2001.

Objective 2. Tributary Sampling Activities

At the onset of the project, the local coordinator and DENR staff installed ISCO Model 4230 flow meters at all of the monitoring sites except the outlet, which used a Stevens Type F stage recorder. This equipment was used to obtain a detailed picture of the daily discharge of water to the lake. Water samples were collected by GLS automatic samplers which were contained within the ISCO units at sites GLO-2, GLT-3, GLT-4, and GLT-5. The outlet (GLO-1) was sampled with a hand-held suspended sediment sampler. Calculations based on these discharge measurements and on nutrient and sediment concentrations from tributary sampling enabled estimates of the amount of nutrients and sediments entering the lake from the watershed to be made. Sampling of Pease Creek was limited primarily to the months of May through June/July of 2000 and 2001.

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

Duplicate and blank samples were collected during the course of the project to provide defendable proof that sample data were collected in a scientific and reproducible manner. QA/QC data collection began, and was completed, on schedule with the proposed timeline.

Objective 4. Watershed Modeling

Collection of the data required for completion of the Annualized Agricultural Non-point Source (AnnAGNPS) model was finished on schedule during the project. The local coordinator utilized public records as well as personal contact with landowners and operators in the watershed to gather the required data. Model runs were performed by SDDENR personnel.

Objective 5. Public Participation

All of the landowners were contacted individually to assess the condition of animal feeding operations and land management practices located within the watershed. Responses to letters, phone calls, and personal contact were excellent and generally provided the necessary information. Further information was provided to the community and stakeholders in the project at the Charles Mix County Conservation District and South Central Water Development District public meetings.

Objectives 6-8. Restoration Alternatives and Final Report

Completion of the restoration alternatives and final report for Geddes Lake was completed by January, 2007.

Evaluation of Goal Achievements

The goal of the watershed assessment completed on Geddes Lake was to determine and document sources of impairment to the lake and to develop feasible alternatives for restoration. This was accomplished through the collection of tributary and lake data and aided by the completion of the AnnAGNPS watershed modeling. Through data analysis and modeling, identification of impairment sources was possible. The identification of these impairment sources will aid the state's Non-point Source (NPS) Program by allowing strategic targeting of resources to portions of the watershed that will provide the greatest benefit per expenditure.

Table 6. Proposed and actual completion dates for the project objectives.

Month/Year	04/00	05/00	06/00	07/00	08/00	09/00	10/00	11/00	12/00	01/01	02/01	03/01	04/01	05/01	06/01
Objective 1															
Lake Sampling															
Objective 2															
Tributary Sampling															
Objective 3															
QA/QC															
Objective 4															
Modeling															
Objective 5															
Public Participation															
Objective 6,7															
Restoration Alternatives															
Objective 8															
Final Report															
Proposed completion															
Actual completion															

Table 6. Continued.

Month/Year	07/01	08/01	09/01	10/01	11/01	12/01	01/02	02/02	03/02	04/02	05/02	06/02	07/02	08/02	03/07
Objective 1															
Lake Sampling															
Objective 2															
Tributary Sampling															
Objective 3															
QA/QC															
Objective 4															
Modeling															
Objective 5															
Public Participation															
Objective 6,7															
Restoration Alternatives															
Objective 8															
Final Report															
Proposed completion															
Actual completion															

Monitoring, Methods, and Results

Objective 1. Lake Sampling Activities

Lake Sampling Schedule, Methods, and Materials

Sampling began in May 2000 and was conducted on a monthly basis until project completion in June 2001 at two sites (Figure 2). Dangerously thin ice cover prevented lake sampling through the ice during the winter months. Water samples were collected with a Van Dorn sampler according to the Standard Operating Procedures for Field Samplers (Stueven et al., 2000). The samples were filtered, preserved, and packed in ice for shipping to the State Health Lab in Pierre, SD. The Laboratory analyzed the samples for the following parameters:

Fecal coliform bacteria
Total solids
Total suspended solids
Nitrate
Total phosphorus
Total dissolved phosphorus
Alkalinity
Total dissolved solids
Ammonia
Total Kjeldahl Nitrogen (TKN)
Volatile total suspended solids

Additional water was sampled and filtered for chlorophyll *a* analysis. The filters were processed and the chlorophyll *a* analyzed by DENR personnel.

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

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

Parameters measured in the field by sampling personnel were:

Water temperature
Conductivity
Field pH
Secchi depth
Air temperature
Dissolved oxygen
Turbidity

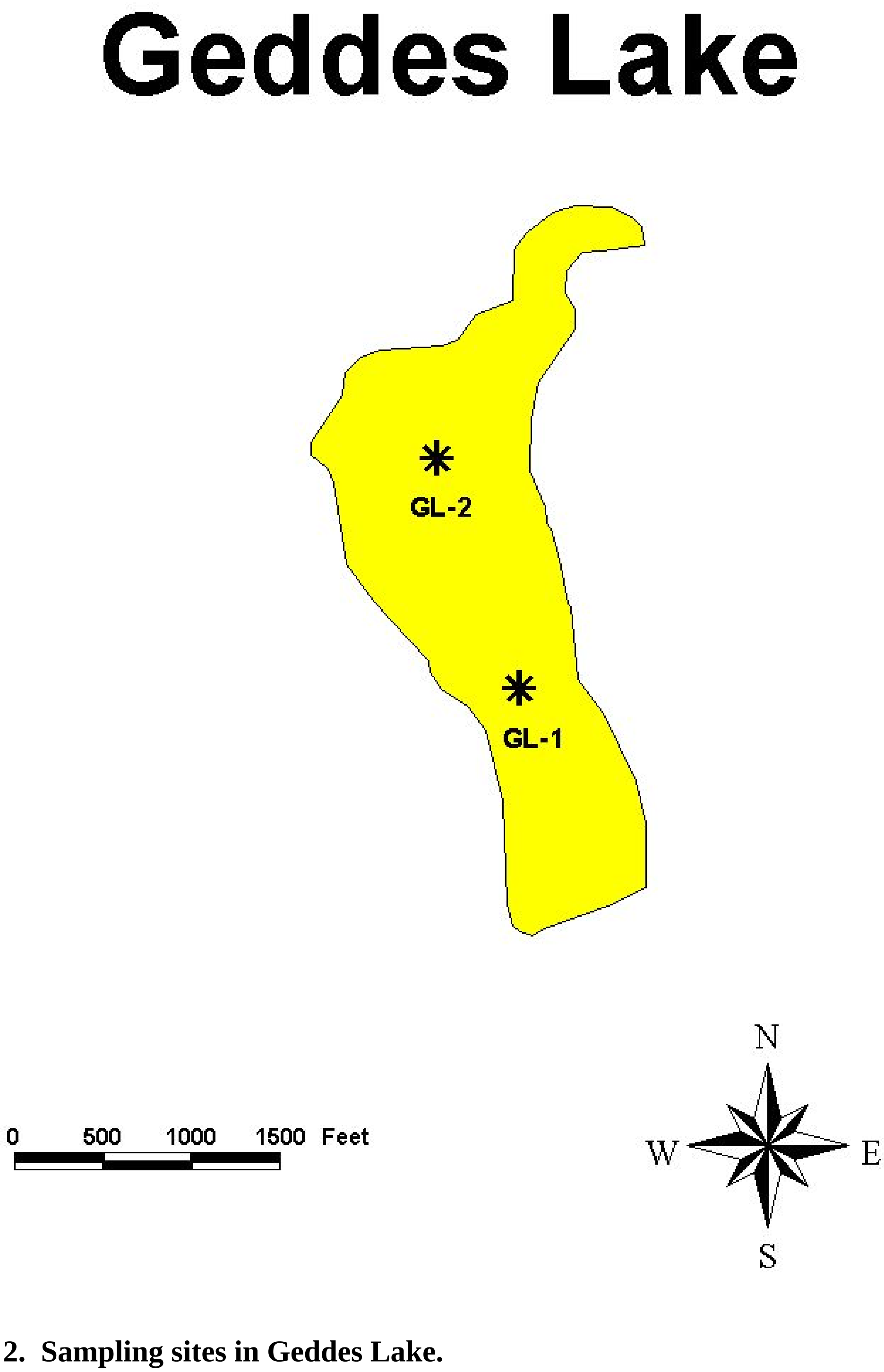

Figure 2. Sampling sites in Geddes Lake.

Lake Sampling Results

Original data can be found in Appendix A.

Water Temperature

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

Water temperatures in Geddes Lake ranged from 9.43^{o}C to 28.23^{o}C on the surface and 9.13^{o}C to 27.04^{o}C on the bottom. Temperature differences between surface and bottom samples were nearly always less than 1°C (Figure 3). All measured temperatures fell within the requirements for the designated beneficial uses of Geddes Lake.

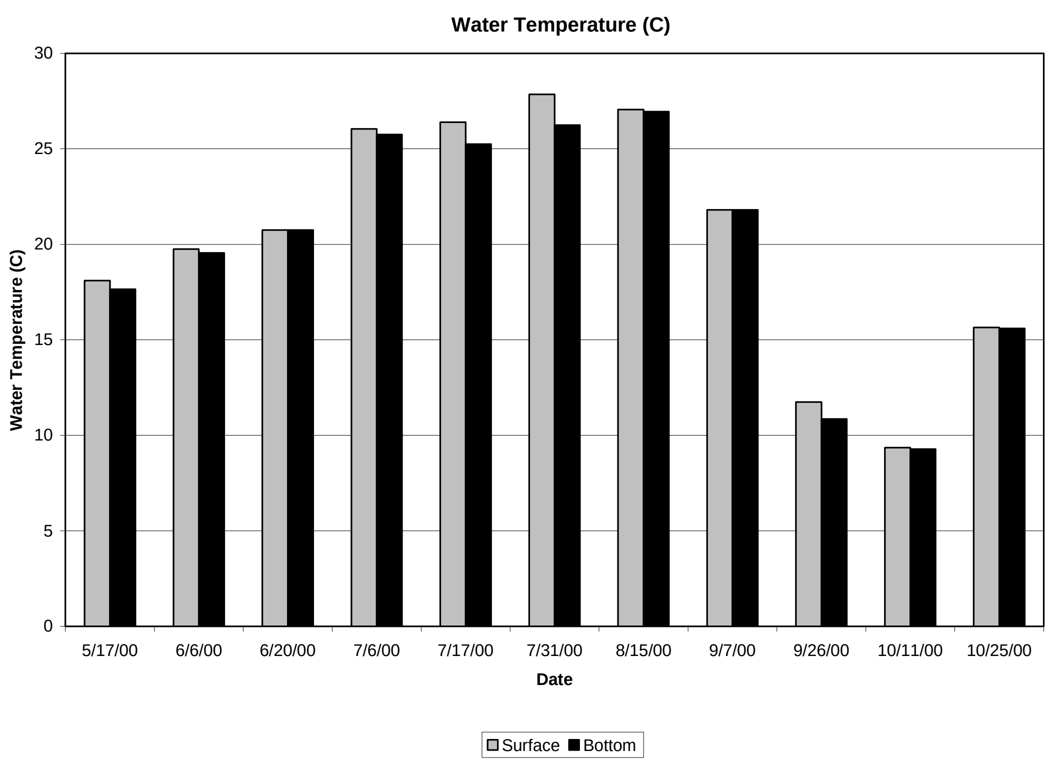

Figure 3. Average surface and bottom temperatures at Geddes Lake during 2000.

Dissolved Oxygen

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

Dissolved oxygen concentrations in Geddes Lake remained above the state standard (5 mg/l) during the spring and fall but a number of measurements (nearly 24%) taken during the summer and early fall months were less than 5 mg/l. There was usually at least one site with a measurement above 5.0 mg/l to provide a refuge for fish (see Figure 4) but during August and early September the lake DO readings did not reach 5.0 mg/l and so it was concluded that there was no refuge from low DO for fish. This means that a Total Maximum Daily Load (TMDL) should be established at 5.0 mg/l with the object of keeping lake DO levels high enough to maintain fish life propagation. The lake does not have significant thermal stratification and it is probable that bacteria decomposing organic matter depleted oxygen near the bottom of the lake.

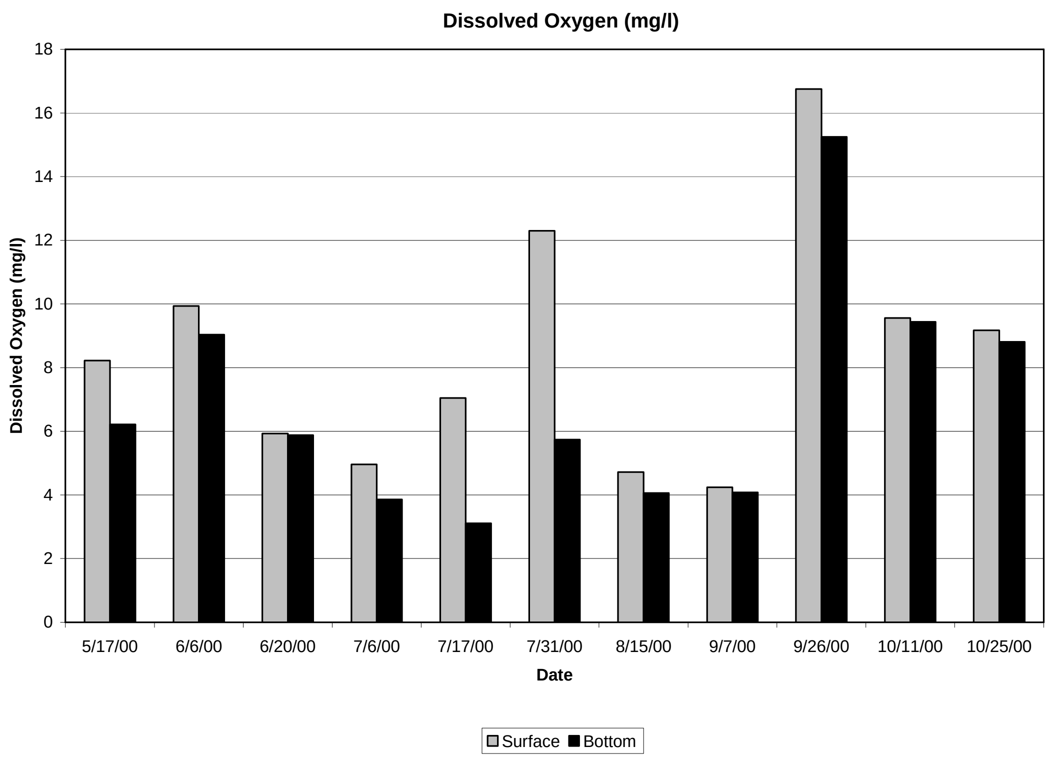

Figure 4. Average surface and bottom dissolved oxygen concentrations in Geddes Lake during 2000.

A whole lake oxygen deficit (WLOD) was calculated for Geddes Lake using a modification of equation 9.1 in Cooke et al. (1986):

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

Where: XDO_{t1} = mean DO at the beginning of summer or at late spring when lake was well oxygenated (6/6/2000, 9,490 mg/m^3).

XDOt2 = mean DO in-lake at the time when no refuge from low DO was available (all DO readings < 5.0 mg/l) (8/15/2000, 4,270 mg/m^3).

$t_2 - t_1$ = time elapsed in days (71 days).

Z_h = mean depth of lake (0.98 meters).

The whole lake DO deficit was calculated to be 72.01 mg m^{-2} day^{-1}. Wetzel (2000) suggested using oxygen deficit rates cautiously and therefore should be considered only a “ball park” estimate for Geddes Lake.

pH

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

The beneficial uses for Geddes Lake require that the pH values in the lake remain between the values of 6.5 and 9.0. The values recorded during the assessment remained within these limits except for surface and bottom samples taken at site GL-2 on September 26, 2000. On this day, the chlorophyll *a* concentration at site GL-2 was very high (159 µg/l) and the lake was supersaturated with dissolved oxygen (15.7 mg/l) and it is reasonable to assume that the algae influenced pH even though the relationship between growing-season chlorophyll *a* versus pH was weak (R^2 = 0.34). A composite algae sample taken September 26, 2000 indicated very high algae concentrations (851,110 cells/ml of mostly blue-green algae and diatoms). It is likely that any reduction in algae will result in a reduction in pH to a point where the WQ criteria are met. These two exceedences were only 3.5% of the total number of pH readings during the project and as such are not considered problematic or requiring of a TMDL.

Conductivity

Conductivity is a measure of water’s ability to conduct electricity, which is a function of the total number of ions present. Conductivity increases reflect an increase in the concentration of dissolved ions in the water body.

Conductivity values for samples taken from Geddes Lake ranged from a low of 893 µmhos/cm collected from site GL-2 during April 10, 2001 to a high of 3,985 µmhos/cm collected from site GL-2 on July 5, 2000. State standards require mean conductivity readings less than 4,000 µmhos/cm and single sample values less than 7,000 µmhos/cm. The levels recorded during the assessment were less than these criteria.

Secchi Transparency

Secchi transparency is the most commonly used measurement to determine water clarity. No regulatory standard for this parameter exists, however the Secchi reading is an important tool used for determining the trophic state of a lake. The two primary causes for low Secchi readings are suspended solids and algae. Greater Secchi readings are found in lakes that have clearer water, which is often associated with lower nutrient levels and "cleaner" water.

Secchi transparency ranged from 0.24 to 0.55 meter and averaged 0.29 meter (.95 foot) during the study. These values indicate hyper-eutrophic conditions. Secchi transparency readings changed seasonally with lowest readings during the summer (Figure 5). Secchi transparency related well with chlorophyll *a* (Figure 6) and so Secchi transparency may be an easy, indirect way to monitor algae in this lake.

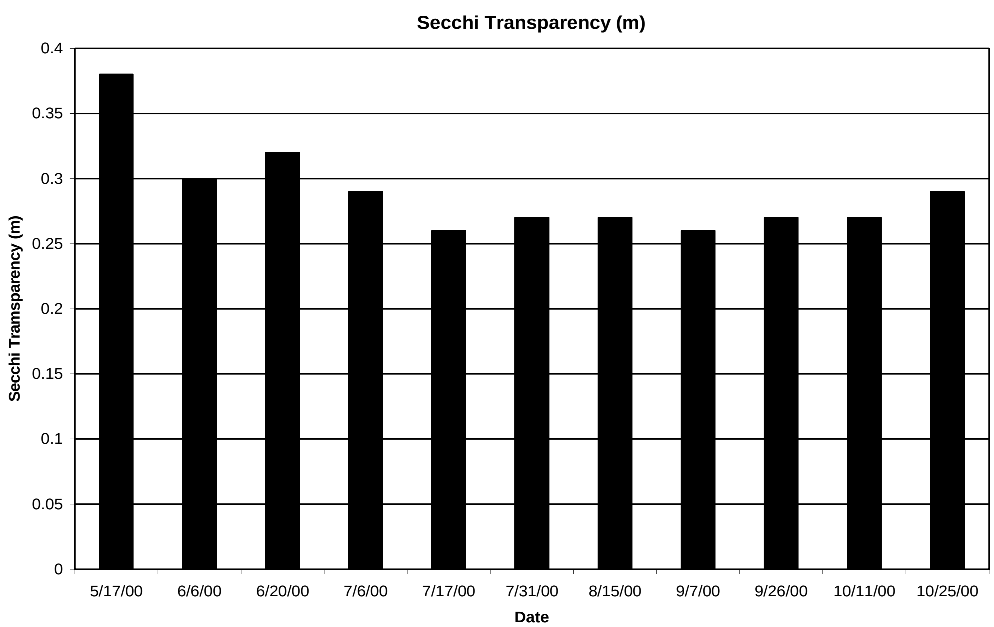

Figure 5. Average Secchi transparency in Geddes Lake during 2000.

Secchi transparency related well with chlorophyll *a* concentrations but abiotic influences on Secchi transparency are also thought to be present. Geddes Lake appears to have enough shoreline vegetation to protect its eastern shoreline from excessive erosion due to the predominant westerly winds. However, the western shore of the lake has a few spots where livestock go down to the lake and these areas may be introducing some sediment to the lake and impacting Secchi transparency.

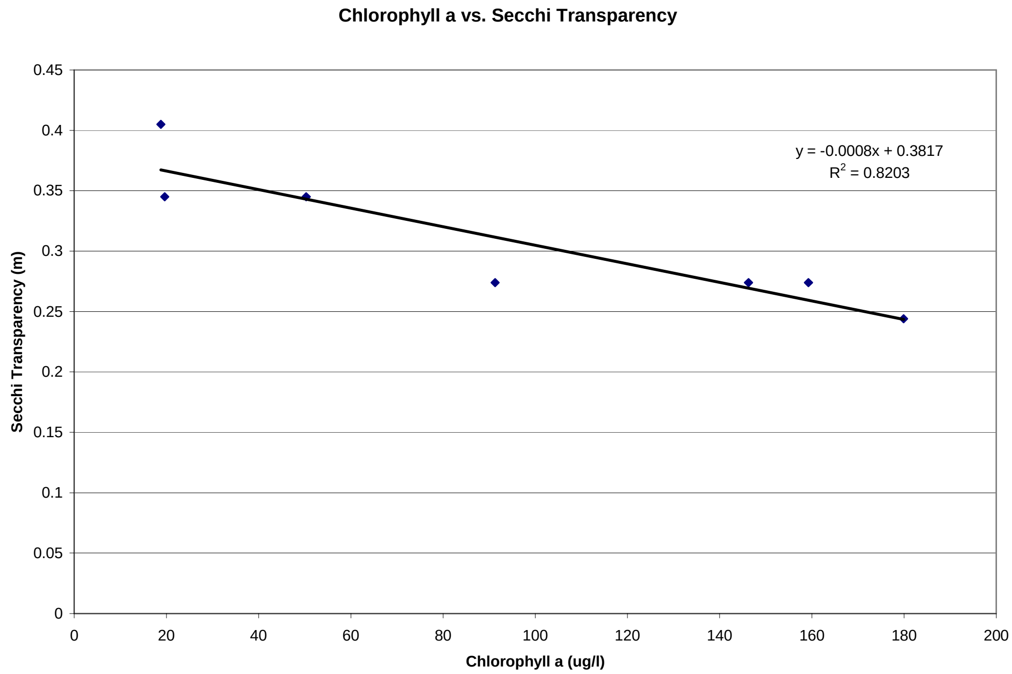

Figure 6. Chlorophyll *a* versus Secchi transparency in Geddes Lake during the growing season of 2000.

<u>Chlorophyll *a*</u>

Chlorophyll *a* is the primary photosynthetic pigment found in oxygen producing organisms (Wetzel, 1983). Chlorophyll *a* is a good indicator of a lake's productivity and state of eutrophication.

Chlorophyll *a* concentrations in Geddes Lake ranged from 8.44 to 179.91 µg/l and averaged 75.35 µg/l. The chlorophyll *a* levels increased from spring to summer with highest levels (>90 µg/l) occurring from July 6, 2000 through August 15, 2000. Chlorophyll *a* levels greater than or equal to 10 µg/l are generally indicative of eutrophication (USEPA, 1974), which makes Geddes Lake highly eutrophic, especially during the summer months.

Growing-season chlorophyll *a* concentrations correlated well with Secchi transparency and with total phosphorus concentrations (Figures 6 and 7). This means that control of phosphorus should result in a decrease in the growing-season chlorophyll *a* concentration.

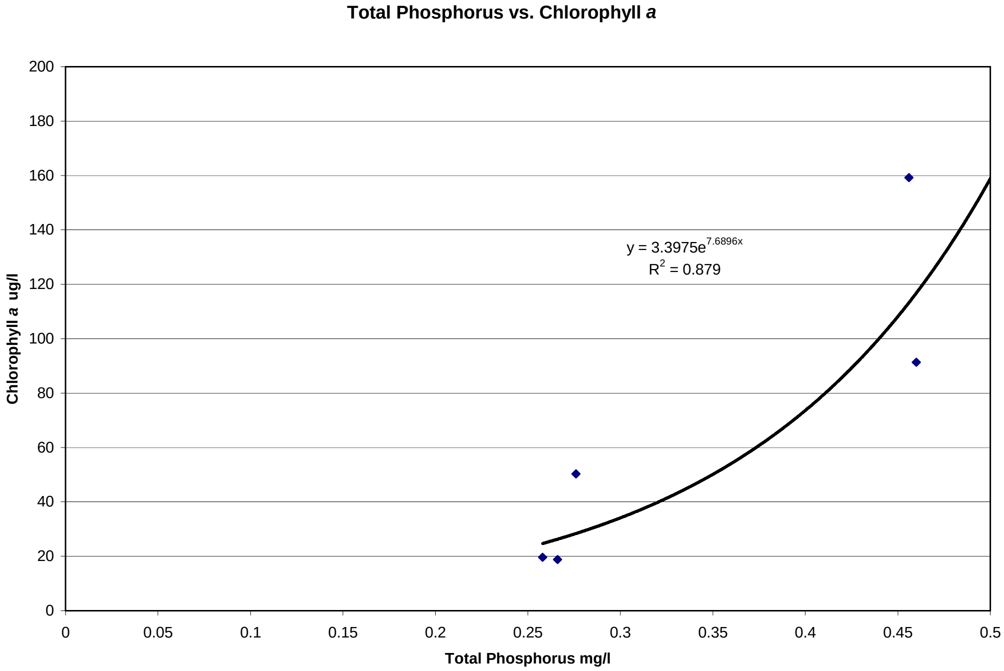

Figure 7. Total phosphorus versus chlorophyll *a* in Geddes Lake during the growing season of 2000.

Alkalinity

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

State standards for Geddes Lake require alkalinity concentrations to maintain a mean of less than 750 mg/l and never to exceed 1,313 mg/l in a single sample. Samples collected in Geddes Lake during this study ranged from a minimum of 96 mg/l to a maximum of 249 mg/l. The mean alkalinity concentration for surface samples taken from both sites was 150 mg/l, fairly typical for a South Dakota lake. The alkalinity concentrations in Geddes Lake did not impair its beneficial uses.

Solids

Solids are addressed as four separate parts in the assessment; total solids, dissolved solids, suspended solids, and volatile suspended solids. Total solids are the sum of all forms of material including suspended and dissolved as well as organic and inorganic materials that are found in a given volume of water.

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

Only four samples were analyzed for total dissolved solids but the results indicated that TDS makes up approximately 95% of the total solids concentrations. Total solids concentrations ranged from 1,072 to 4,047 mg/l and gradually increased during the spring and summer in the lake and peaked during November. The samples from sites GL-1 and GL-2 had total solids concentrations of 4,042 and 4,047 mg/l respectively. The lowest values recorded were during the spring of 2001 and averaged 1,075 mg/l.

Total suspended solids concentrations were found to contain anywhere from 3% to 70% volatile organic matter with an average of 51%. Total suspended solids concentrations varied from 19 mg/l to 76 mg/l and did not exceed the water quality standard criterion for single samples of 158 mg/l.

Nitrogen

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

Inorganic nitrogen is the most available form to plants, consisting of the sum of nitrate/nitrite and ammonia. Geddes Lake ammonia and nitrate nitrogen concentrations were below their respective detection limits for the entire project except during May 17, 2000 and April 10, 2001. Both dates fall within the runoff period and before algae populations increase in the lake.

Ammonia may be found in two forms, ionized and un-ionized. The latter form can be extremely toxic to fish. The un-ionized fraction of ammonia is dependent on pH and temperature. As these two parameters increase, so does the un-ionized fraction of ammonia. Ammonia tends to remain in its ionic form (NH^{4+}) except under higher alkaline conditions (pH>9.0) (Wetzel, 2000). Un-ionized levels in excess of 5% are lethal to fish and other aquatic life. Samples collected from Geddes Lake all remained below 1% un-ionized, resulting in no impairment of beneficial uses.

Total Kjedahl Nitrogen minus ammonia nitrogen equals the organic nitrogen fraction. Organic nitrogen concentrations in Geddes Lake ranged from 1.10 mg/l to 4.29 mg/l and averaged 2.36 mg/l. These values are typical for lakes in South Dakota and do not indicate any unusual phenomena occurring in the lake.

Total Phosphorus

Phosphorus is one of the macronutrients required for primary production. When compared with carbon, nitrogen, and oxygen, it is often the least abundant (Wetzel, 2000). Phosphorus loading to lakes can be of an internal or external nature. External loading refers to surface runoff, dust, and precipitation. Internal loading refers to the release of phosphorus from the bottom sediments to the water column of the lake. Total phosphorus is the sum of all attached and dissolved phosphorus in the lake.

Total phosphorus concentrations ranged from 0.26 mg/l to 0.81 mg/l and averaged 0.44 mg/l. Wetzel (1983) suggested that a total phosphorus concentration of 0.02 mg/l indicates a lake is eutrophic and may experience algae blooms. Based on this, Geddes Lake is highly eutrophic.

Dissolved Phosphorus

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

The dissolved fraction of phosphorus found in water samples taken from Geddes Lake ranged from .04 mg/l to .59 mg/l and averaged .18 mg/l. On average, the dissolved phosphorus fraction made up 37% of the total phosphorus concentration and so the majority of the phosphorus is in particulate (attached) form.

Fecal Coliform Bacteria

Fecal coliform are bacteria that are found in the waste of warm-blooded animals. Some common types of bacteria are *E. coli,* S*almonella,* and *Streptococcus,* which are associated with livestock, wildlife, and human waste. (Novotny and Olem, 1994).

Water samples collected from Geddes Lake exhibited fecal coliform concentrations that were below detection limits for the two sites except during April 10, 2001, when the concentration of fecal coliform bacteria at sites GL-1 and GL-2 were 530 and 450 colonies/100 ml respectively. These samples were collected during periods of runoff and probably reflect inputs from the watershed. These two exceedences only occurred on one day and did not occur on consecutive sampling dates. Listing in the South Dakota Integrated Report requires fecal coliform exceedences to be detected on consecutive sampling dates. Therefore, the results here were not considered problematic or requiring of a TMDL.

Limiting Nutrients

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

The total nitrogen to total phosphorus ratios for Geddes Lake ranged from 2.84:1 to 9.67:1 and averaged 6.44:1. These data indicate a nitrogen-limited system. In theory, one should try to limit the amount of the most limiting element (in this case nitrogen) in the system to get the greatest response (i.e. a decrease in algae). However, nitrogen is sometimes difficult to control and certain blue-green algae may obtain or "fix" nitrogen from the atmosphere. Phosphorus, which is in abundance, is often controlled instead. There was little seasonality with the TN:TP ratios, although the ratios calculated from samples obtained during the spring were generally the lowest.

Trophic State

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

Lakes with TSI values less than 35 are generally considered to be oligotrophic and contain very small amounts of nutrients, little plant life, and are generally very clear. Lakes that obtain a score of 36 to 50 are considered to be mesotrophic and have more nutrients and primary production than oligotrophic lakes (Table 7). Eutrophic lakes have a score between 51 and 64 and are subject to algal blooms and have large amounts of primary production. Hyper-eutrophic lakes receive scores greater than 65 and are subject to frequent and massive blooms of algae that severely impair their beneficial uses and aesthetic beauty.

Table 7. Trophic State Classifications.

TROPHIC STATE	COMBINED TSI NUMERIC RANGE
OLIGOTROPHIC	0-35
MESOTROPHIC	36-50
EUTROPHIC	51-64
HYPER-EUTROPHIC	65-100

Lorenzen (2005) proposed alternate TSI targets based on a growing-season median Secchi- chlorophyll *a* TSI. For Geddes Lake, a warm-water semi-permanent fishery, the target Secchi-chlorophyll *a* TSI value is 63.4 or less.

Geddes Lake did not meet the target value with a median growing-season Secchi-chlorophyll *a* TSI value of 77.13. The TSI values ranged from a 51.52 to 81.54. These values place Geddes Lake within the hyper-eutrophic category on Carlson's scale. It should be noted that use of Carlson's TSIs on nitrogen-limited lakes, such as Geddes Lake, may result in overestimated TSI values and so a degree of caution is needed when interpreting these TSIs.

Fishery Aspects

The most recently published fisheries survey was completed during the summer of 1998 (Meester, 1999). Previous surveys were completed during 1995. The 1998 survey revealed the primary species to be black crappie (*Pomoxis nigromaculatus*), bluegill (*Lepomis macrochirus*), largemouth bass (*Micropterus salmoides*), channel catfish (*Ictalurus punctatus*), and yellow perch (*Perca flavescens*). Secondary species were black bullhead (*Ictalurus melas*), common carp (*Cyprinus carpio*), green sunfish (*Lepomis cyanellus*), and orange-spotted sunfish (*Lepomis humilis*). The lake appears to have a stable population of large black crappie and an increasing population of small black bullheads.

Phytoplankton

Composite surface samples were collected twice monthly from the two in-lake sites June through October 2000 and monthly from April to May 2001 in Geddes Lake. A diverse algae community with a total of 84 algal taxa was identified over the course of the study (Appendix B). Green algae (Chlorophyta) were the most diverse group with 29 taxa (including 8 motile genera) closely followed by the diatoms (Bacillariophyceae) with 28 taxa. Blue-green algae (Cyanophyta) were less well represented with only 9 taxa. Twenty-six taxa of motile (flagellated) algae made up 31% of the total algae identified. Green flagellates were the most diverse of the motile algae with 8 genera whereas four other phyla of flagellates contained similar numbers of taxa, including dinoflagellates (Pyrrhophyta), cryptomonads (Cryptophyta), and euglenoids (Euglenophyta) with 4 taxa each, and yellow-brown flagellates (Chrysophyta) with 6 genera.

The seasonal pattern of algae abundance in Geddes Lake during this survey can be characterized by what was essentially a single annual maximum from August 15 to September 26, 2000, produced by a heavy bloom of blue-green algae, mainly *Oscillatoria (Planktothrix) agardhii* (Figure 8). Blue-greens comprised 64% of total algae density (abundance) and 52% of total algal biovolume (biomass) during this assessment (Figures 9 and 10).

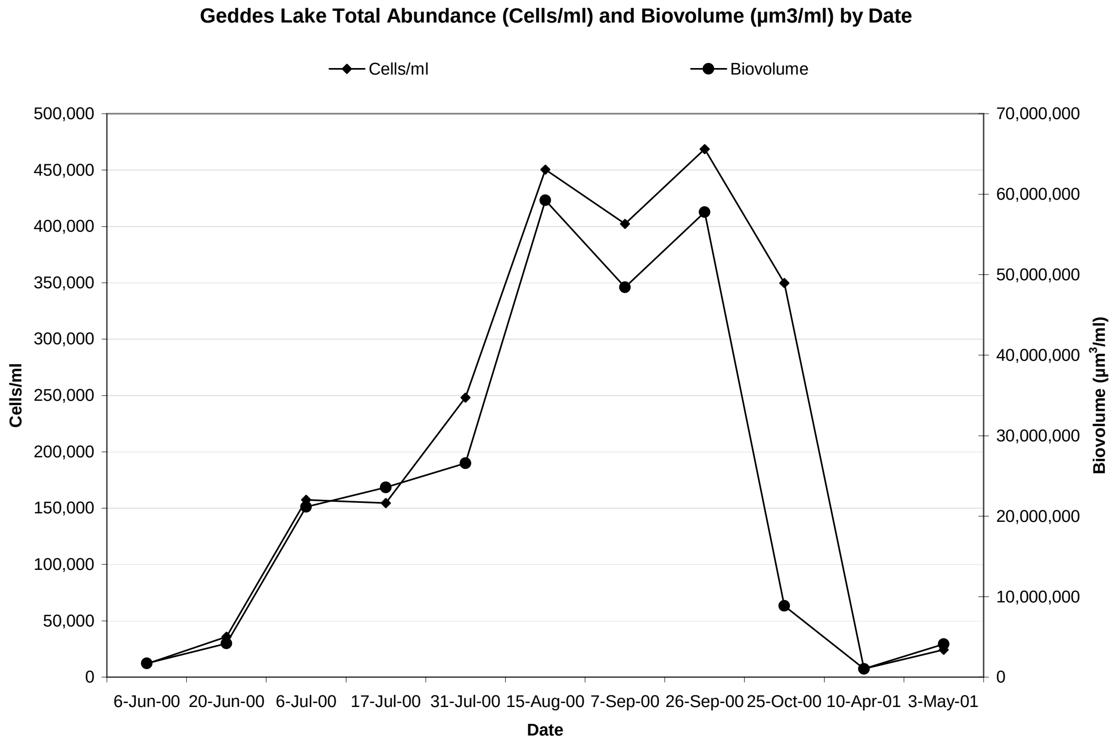

Figure 8. Total Abundance and biovolume of algae in Geddes Lake, 2000/2001.

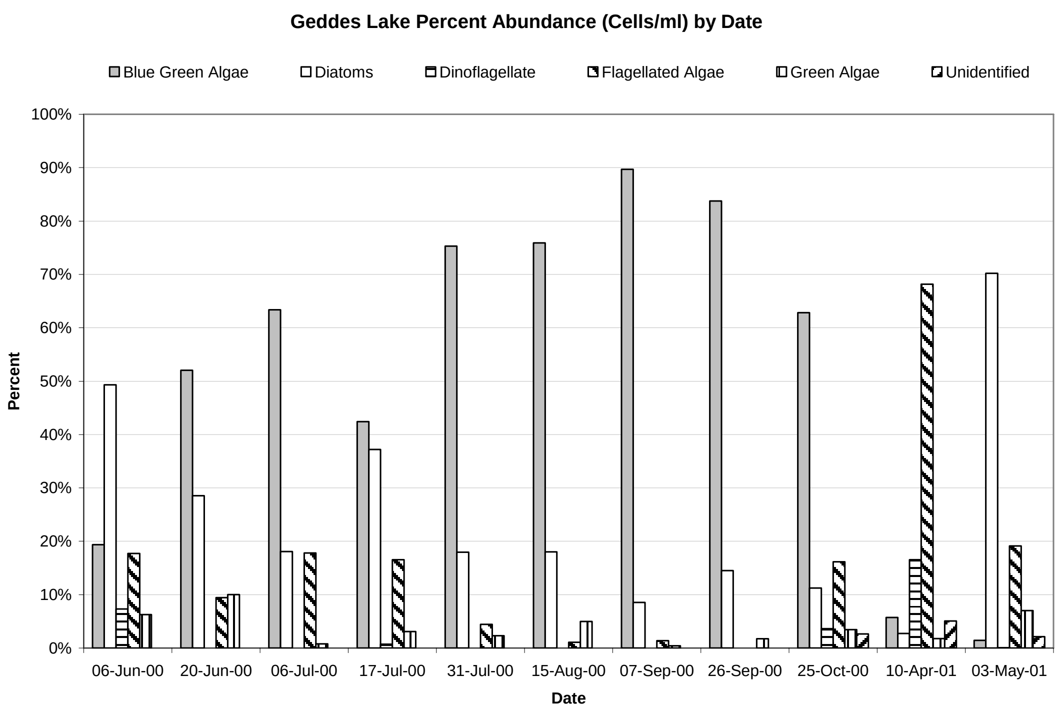

Figure 9. Percent cell abundance of algal types in Geddes Lake, 2000/2001.

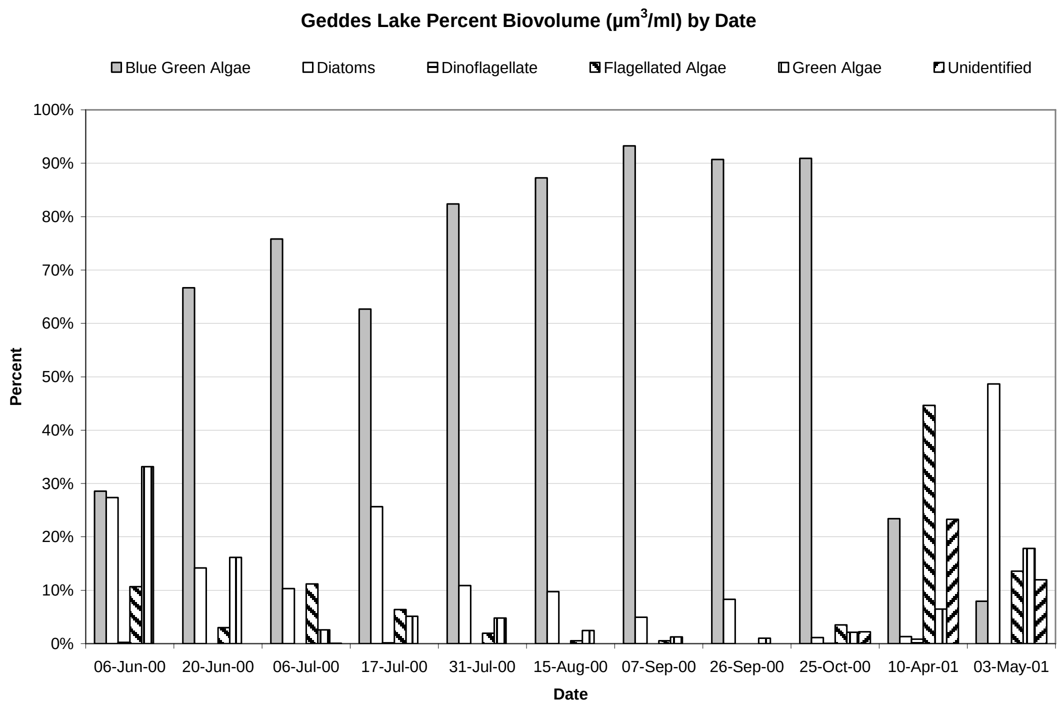

Figure 10. Percent biovolume of algal types in Geddes Lake, 2000/2001.

Aquatic Macrophyte Survey

The project coordinator and technician conducted an aquatic plant survey during the growing season of 2000. Seven transects were located across the lake and four sites per transect were sampled for aquatic macrophytes. In addition, the complete shoreline was inspected and the type and relative density of emergent plants noted.

No submerged aquatic vegetation was collected from Geddes Lake and the only emergent vegetation was cattails (*Typha* spp.). Approximately 95% of the shoreline was ringed with a five-foot (1.52 meter) wide band of cattails extending out from the shore. A few small areas were devoid of cattails and those areas were probably in that condition because of livestock wading into the lake and trampling the vegetation.

Sediment Survey

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

The sediment survey conducted on February 6, 2002 revealed an average water depth of 0.98 meter (3.2 feet) and an average sediment depth of 1.59 meters (5.2 feet) (Figures 11 and 12). In Geddes Lake the total sediment accumulation is approximately 383,963 m^3 of sediment.

Sediments were collected with a Petite Ponar sampler from the two in-lake sites during October 26, 2001 and mixed together for elutriate analysis at the State Health Laboratory. Lake water was also collected with a Van Dorn sampler, mixed together, and analyzed for the same constituents as the elutriate water. Selected results are listed in Table 8 and indicated low levels for those parameters that were detected. Most parameters were below detection limits and included; alachlor, chlordane, endrin, heptachlor, heptachlor epoxide, methoxychlor, toxaphene, aldrin, dieldrin, PCBs, diazinon, DDD, DDT, DDE, Beta BHC, Gamma BHC, Alpha BHC, nitrate, zinc, silver, total mercury, lead, cadmium, endosulfan II, and atrazine.

Table 8. Elutriate test toxins above detection limits in Geddes Lake.

Parameter	Water	Elutriate
Ammonia (mg/l)	0.07	6.46
COD (mg/l)	35.9	45.4
Hardness (mg/l)	1260	1320
TKN (mg/l)	1.20	8.28
Aluminum (mg/l)	< 0.5	1.8
Arsenic (µg/l)	6.8	39.0
Phosphorus (mg/l)	0.097	1.12
Selenium (µg/l)	5.0	2.7
Copper (µg/l)	4.4	2.5
Nickel (µg/l)	9.2	8.4

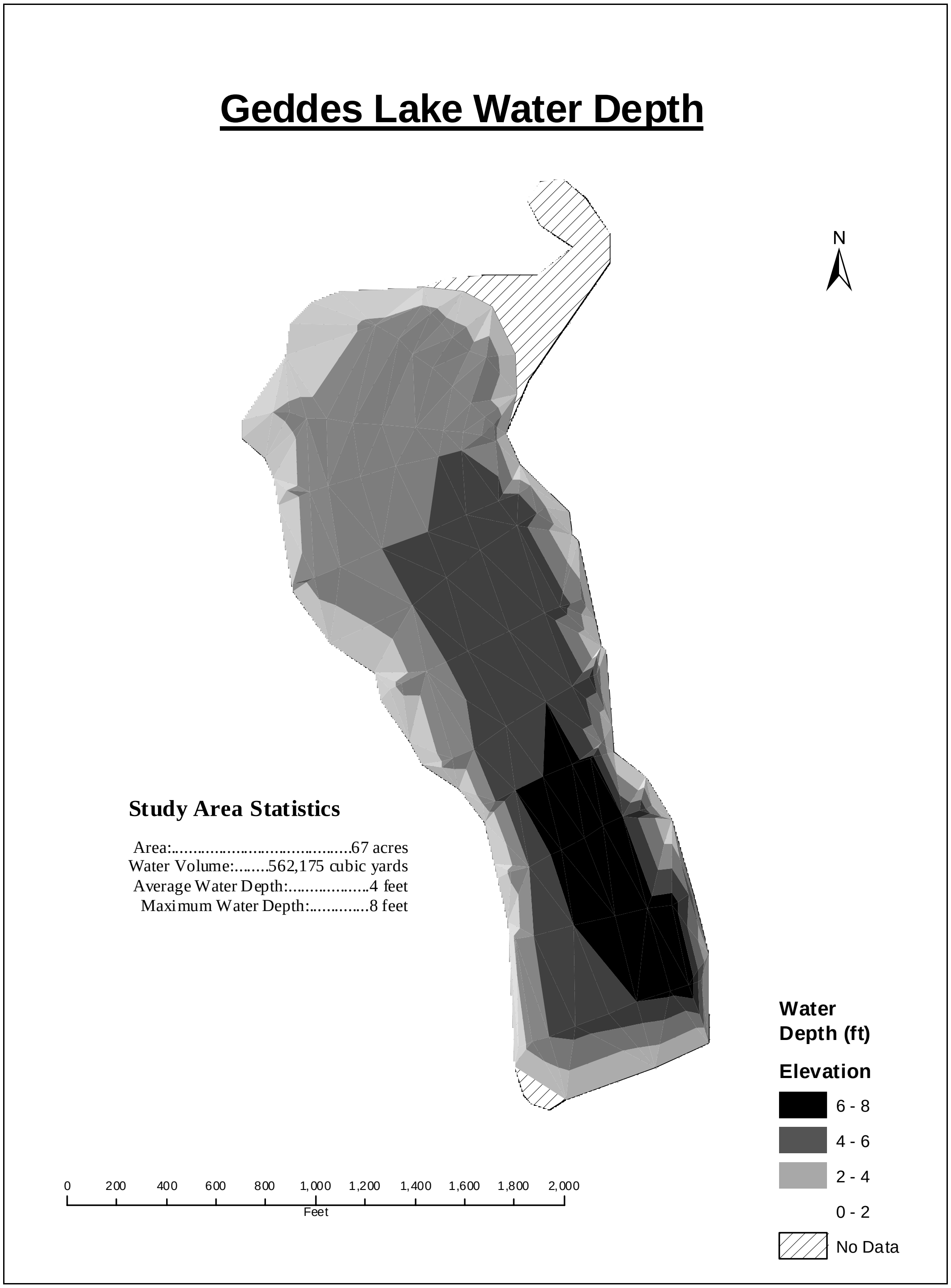

Figure 11. Water depths in Geddes Lake.

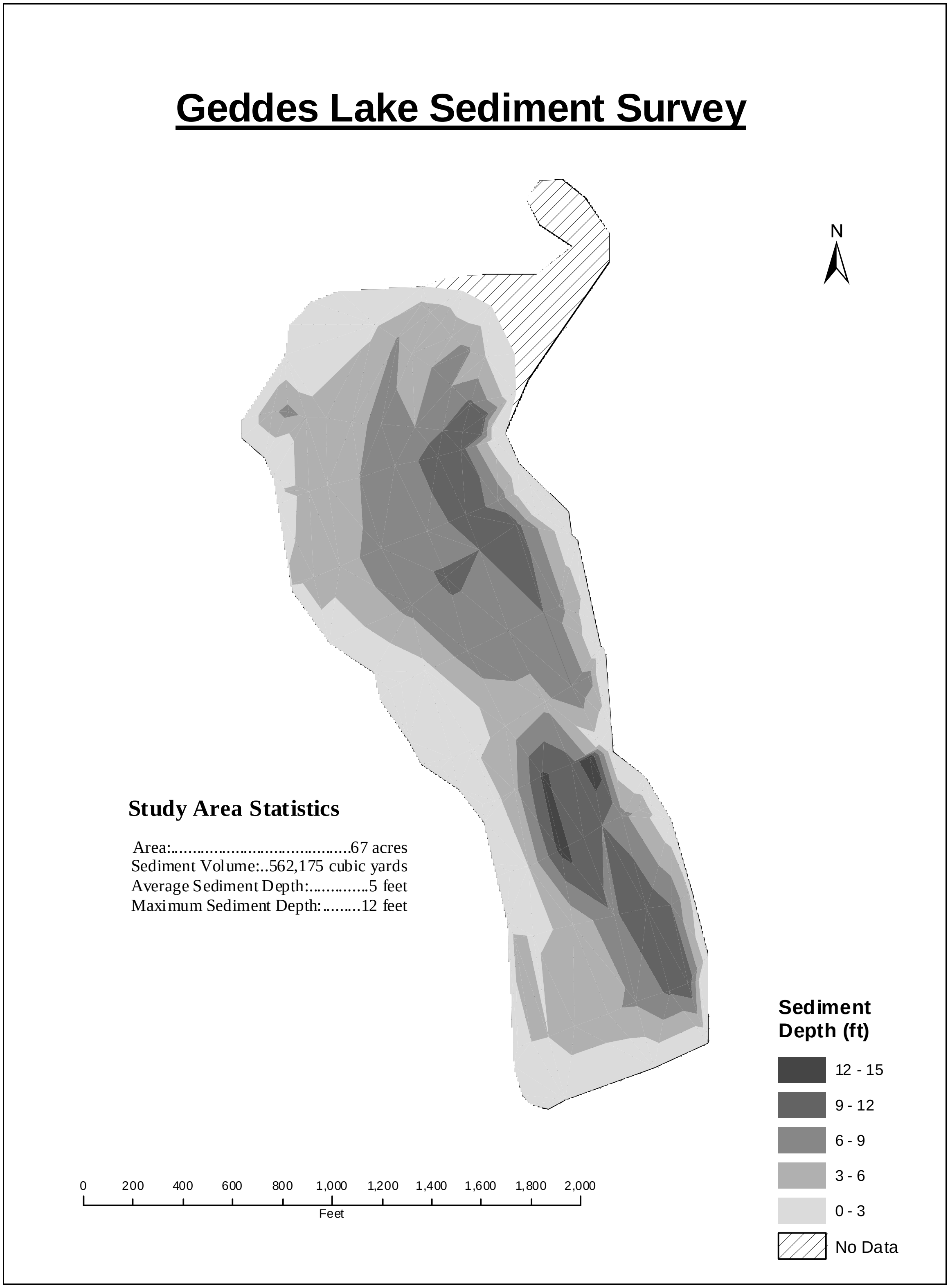

Figure 12. Sediment depths in Geddes Lake.

Long-Term Trends

Geddes Lake is listed on the state's 303(d) list as an impaired waterbody of poor water quality. Data collected during 1989, 1991, 1993, 1998, and 2000 indicate a lake that is hypereutrophic and deteriorating. This is due to excessive nutrients and algae growth. Reductions in nutrient and sediment loadings to Geddes Lake are needed to help improve the condition of the lake.

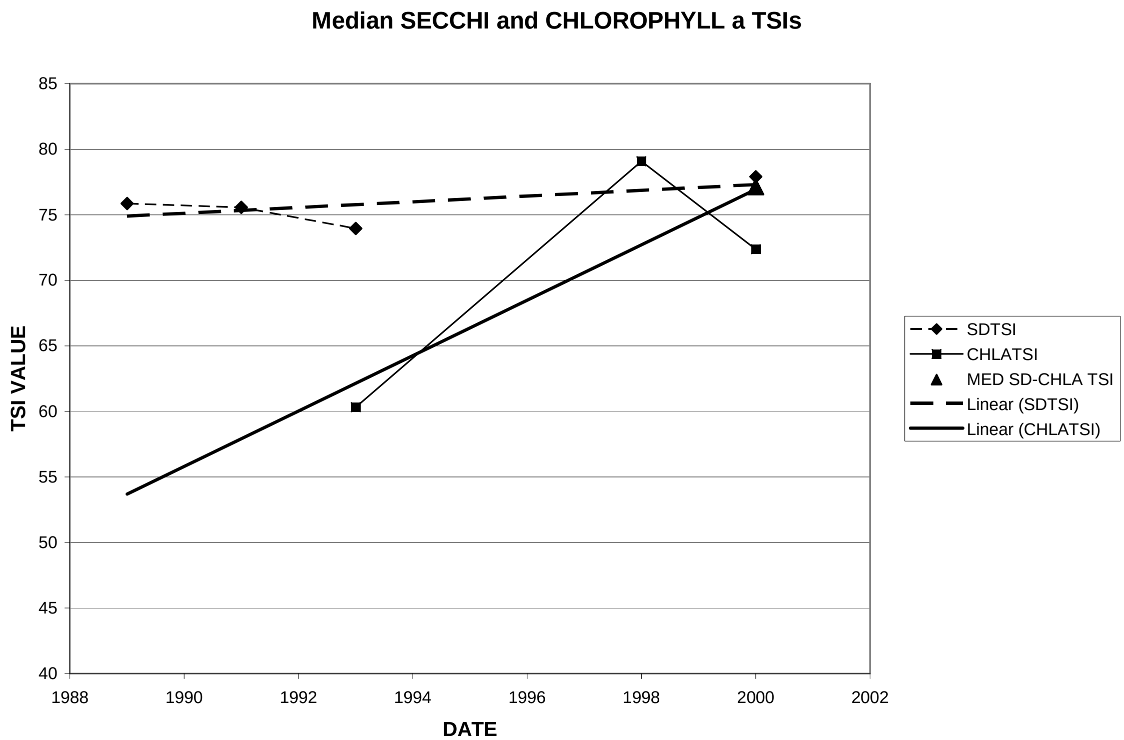

Figure 13. Long Term TSI Trend for Geddes Lake.

Objective 2. Tributary Sampling Activities

Tributary Sampling Schedule, Methods and Materials

Three sampling sites were used on Pease Creek to break up the main watershed into three areas; an upper area, a middle area, and a lower area (Figure 14). A gauging station was located at a site within each of the three areas, and also at a site on an unnamed tributary to Geddes Lake and at the outlet of Geddes Lake. All of the tributary sites were equipped with ISCO Model 4230 flow meters. The outlet used a Stevens Type F stage recorder. Water stages were monitored and recorded to the nearest 1/100th of a foot for each of the five sites. A Marsh-McBirney Model 210D flow meter was used to determine flows at various stages. The stages and flows were then used to create a stage/discharge table for each site.

Due to activities by beavers building a dam and the landowner subsequently destroying the dam, significant difficulties were experienced during attempts to collect meaningful data from site GLT-3. Figure 14 shows the locations of the sampling stations within the watershed.

Samples were collected at the sites during the spring of 2000 and the spring of 2001. All tributary samples were collected using GLS samplers housed within Model 4230 ISCO units except Site GLO-1, which was sampled with a suspended sediment sampler. Water samples were then filtered, preserved, and packed in ice for shipping to the State Health Lab in Pierre, SD. The laboratory then assessed the following parameters:

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

Personnel conducting the sampling at each of the sites recorded visual observations of weather and stream characteristics such as; precipitation, wind, odor/color, septic conditions, dead fish, film, turbidity, stream width, water depth, and ice cover.

Parameters measured in the field by sampling personnel were: water temperature, air temperature, conductivity, dissolved oxygen, and field pH.

Sample data from the tributaries may be found in Appendix C.

Tributary Sampling Results

<u>Fecal Coliform Bacteria</u>

Fecal coliform bacteria standards are not assigned for the listed beneficial uses for sites GLT-2, GLT-3, GLT-4, and GLT-5 in the Pease Creek watershed. However, these sites exhibited levels that were greater than 1,000 colonies/100ml in approximately 40 percent of the samples (Table 9). Site GLT-3 had the most frequent number of samples exceeding 1,000 colonies/100 ml (64%). This is most likely due to livestock operations in the watershed or possibly from beaver active along the creek.

Figure 14. Tributary monitoring sites for the Geddes Lake Assessment Project.

Site GLO-1, the outlet of Geddes Lake, must maintain fecal coliform bacteria concentrations of <1,000 colonies/ 100ml or a geometric mean of <2,000 colonies/ 100ml to maintain the beneficial use of limited contact recreation. Fecal coliform samples collected at this site did not exceed the criteria for limited contact recreational uses.

Table 9. Fecal coliform bacteria counts (#colonies/100ml) for the Geddes Lake tributary sites.

	GLT-5		GLT-4		GLT-3		GLT-2		GLO-1	
	Fecal	*E. coli*	Fecal	*E. coli*	Fecal	*E. coli*	Fecal	*E. coli*	Fecal	*E. coli*
18-May-00	13000		20000		3100		39000			
01-Jun-00	6400				2900					
19-Jun-00			10							
20-Jun-00									50	
21-Jun-00					3700		100			
28-Jun-00							1000			
05-Jul-00					28000					
10-Jul-00					16000					
08-Aug-00			4100							
01-Nov-00			1400		15000		1800			
05-Apr-01	20	80.1	160	326	10	24.6	40	26.2	10	11
10-Apr-01	40	71.2	70	114	30	50.4	60	194	610	816
19-Apr-01	20	8.5	650	1550	10	650	780	816	134	41.9
24-Apr-01	2600	2420					6000	2420		
01-May-01	60	69.1	380	727	290	380	170	178	154	33.6
07-May-01	410	1417	1700	2420	6289	1700	520	1900	166	770
Mean	2819	703	3136	1027	901	3136	4947	922	187	335

<u>Alkalinity</u>

Alkalinity varied considerably at the tributary sites (Table 10). The two sites closest to the lake (GLT-2 and GLT-3) had the highest concentrations of alkalinity, whereas the uppermost site (GLT-5) had the lowest alkalinity concentrations.

The state standard applied to Pease Creek and the unnamed tributary for alkalinity is <750 mg/l as a mean or <1,313 mg/l for a single sample. The highest single concentration was measured at site GLT-2 on June 21, 2000. At 315 mg/l, it is well within the state standard for alkalinity. Mean concentrations were also within the state standard for these waters.

Table 10. Alkalinity concentrations (mg/l) for the Geddes Lake tributary sites.

Date	GLT-5	GLT-4	GLT-3	GLT-2	GLO-1
18-May-00	136	156	205	245	
01-Jun-00	206		263		
19-Jun-00		188			
20-Jun-00					235
21-Jun-00			233	315	
28-Jun-00				306	
05-Jul-00			283		
10-Jul-00			278		
08-Aug-00		168			
01-Nov-00		272	208	285	
05-Apr-01	100	133	157	213	124
10-Apr-01	107	122	138	183	115
19-Apr-01	128	144	168	247	134
24-Apr-01	68			86	
01-May-01	143	161	176	238	154
07-May-01	127	127			166
Mean	127	163	211	235	155

Total and Suspended Solids

The total solids concentrations in the tributaries ranged from 205 mg/l to 4,333 mg/l (Table 11). Although only a limited number of samples (15) were analyzed for total dissolved solids, it appears that approximately 90% of the total solids concentration is composed of dissolved solids with suspended solids representing only a small fraction of the load. There is no state standard for total solids but those samples analyzed for total dissolved solids fell within the total dissolved solids state standard of a single sample value of less than 4,375 mg/l. The suspended solids concentrations collected from the tributary sites ranged from a low of 6 mg/l to 244 mg/l. The volatile portion composed approximately 25% of the total suspended solids load for all sites in the watershed.

When comparing mean concentrations for solids on Pease Creek it becomes apparent that the lowest concentrations of total solids were coming from the uppermost portion of the watershed (GLT-5) and the outlet of the lake (GLO-1). The remaining sites had relatively similar total solids concentrations ranging from 2,347 to 2,780 mg/l.

Total suspended solids concentrations were similar for all sites except for Site GLT-3 (Table 11). This site on Pease Creek was closest to Geddes Lake and also had high fecal coliform counts. A nearby livestock operation, along with some bank erosion, may contribute to the high total suspended solids concentrations at this site.

Table 11. Mean solids concentrations (mg/l) for the Geddes Lake tributary sites.

Station	Total Suspended	Total Volatile	Total Solids
GLT-5	31.3	8.0	1443
GLT-4	26.1	6.8	2426
GLT-3	73.2	10.1	2347
GLT-2	34.3	6.6	2780
GLO-1	32.5	7.8	1471

Nitrogen

The total inorganic nitrogen concentrations showed no particular trend or seasonality (Table 12). The concentrations ranged from 0.06 to 5.05 mg/l. Site GLT-2 on the unnamed tributary to the lake had the greatest mean concentration (2.57 mg/l).

Total organic nitrogen concentrations ranged from 0.47 to 3.19 mg/l (Table 13). Site GLT-3 had the greatest mean organic nitrogen concentration (1.84 mg/l). Total organic nitrogen averaged 61% of the total nitrogen concentration.

Table 12. Total inorganic nitrogen concentrations (mg/l) for Geddes Lake tributaries, Charles Mix County, South Dakota during 2000/2001.

Date	GLT-5	GLT-4	GLT-3	GLT-2	GLO-1
18-May-00	0.25	1.09	0.11	1.99	
01-Jun-00	0.06		0.06		
19-Jun-00		0.13			
20-Jun-00					0.40
21-Jun-00			0.14	0.41	
28-Jun-00				0.42	
05-Jul-00			1.36		
10-Jul-00			2.63		
08-Aug-00		0.23			
01-Nov-00		0.12	1.03	5.05	
05-Apr-01	2.08	2.46	2.00	3.70	2.15
10-Apr-01	0.85	1.55	1.53	3.55	2.30
19-Apr-01	0.12	0.53	0.63	3.02	1.12
24-Apr-01	0.78			2.76	
01-May-01	0.12	0.32	0.12	2.52	0.15
07-May-01	0.22	0.22	0.32	2.32	0.32
Mean	0.56	0.74	0.90	2.57	1.07

Table 13. Total organic nitrogen concentrations (mg/l) for Geddes Lake tributaries, Charles Mix County, South Dakota during 2000/2001.

Date	GLT-5	GLT-4	GLT-3	GLT-2	GLO-1
18-May-00	1.44	2.42	2.86	1.40	
01-Jun-00	3.19		2.19		
19-Jun-00		0.84			
20-Jun-00					1.34
21-Jun-00			1.62	0.71	
28-Jun-00				0.67	
05-Jul-00			2.69		
10-Jul-00			1.29		
08-Aug-00		1.29			
01-Nov-00		1.37	1.27	1.28	
05-Apr-01	1.19	0.88	0.85	0.69	0.98
10-Apr-01	1.17	1.43	1.22	0.89	1.10
19-Apr-01	1.38	1.08	0.74	0.47	1.03
24-Apr-01	1.21			0.58	
01-May-01	1.41	1.15	1.05	0.81	1.42
07-May-01	1.72	1.64	1.84	1.41	1.52
Mean	1.59	1.34	1.60	0.89	1.23

Phosphorus

The total phosphorus concentrations in the tributaries ranged from 0.102 to 0.978 mg/l and averaged .564 mg/l (Table 14). Nearly all of the flows occurred during the spring runoff period. Site GLT-5, the uppermost site on Pease Creek, had the greatest mean total phosphorus concentration. The mean total phosphorus concentration in Pease Creek progressively decreased in the sites nearer to the lake. Site GLT-2, the unnamed tributary of Geddes Lake, had the lowest mean total phosphorus concentration. This is interesting because Site GLT-2 had the greatest inorganic nitrogen concentrations. Perhaps the livestock operation adjacent to the creek or crop fields with commercial fertilizer are contributing large amounts of nitrogen to a creek that would otherwise carry low amounts of phosphorus and nitrogen.

Total dissolved phosphorus (TDP) (Table 15) averaged 68% of the total phosphorus in the incoming tributaries and the outlet. Like total phosphorus, the TDP concentrations in Pease Creek progressively decreased nearer to the lake. Site GLT-2 also had the lowest mean TDP concentration. The higher values during May of 2001 compared to 2000 was probably due to the larger flows during May of 2001 and the resultant erosion and run-off.

Table 14. Total phosphorus concentrations (mg/l) for Geddes Lake tributaries, Charles Mix County, South Dakota during 2000/2001.

Date	GLT-5	GLT-4	GLT-3	GLT-2	GLO-1
18-May-00	.452	.608	.391	.289	
01-Jun-00	.543		.497		
19-Jun-00		.681			
20-Jun-00					.392
21-Jun-00			.723	.109	
28-Jun-00				.137	
05-Jul-00			.813		
10-Jul-00			.609		
08-Aug-00		.426			
01-Nov-00		.298	.339	.264	
05-Apr-01	.880	.738	.598	.306	.587
10-Apr-01	.953	.753	.725	.387	.785
19-Apr-01	.874	.580	.485	.102	.558
24-Apr-01	.877			.796	
01-May-01	.978	.686	.493	.178	.568
07-May-01	.863	.764	.743	.434	.502
Mean	.803	.615	.583	.300	.565

Table 15. Total dissolved phosphorus concentrations (mg/l) for Geddes Lake tributaries, Charles Mix County, South Dakota during 2000/2001.

Date	GLT-5	GLT-4	GLT-3	GLT-2	GLO-1
18-May-00	.239	.380	.151	.059	
01-Jun-00	.157		.078		
19-Jun-00		.232			
20-Jun-00					.111
21-Jun-00			.075	.085	
28-Jun-00				.069	
05-Jul-00			.483		
10-Jul-00			.320		
08-Aug-00		.334			
01-Nov-00		.153	.232	.213	
05-Apr-01	.861	.638	.532	.268	.454
10-Apr-01	.937	.637	.581	.314	.618
19-Apr-01	.758	.430	.381	.061	.461
24-Apr-01	.681			.501	
01-May-01	.975	.586	.387	.127	.370
07-May-01	.784	.674	.633	.341	.375
Mean	.674	.452	.350	.204	.398

Hydrologic Budget

Table 16 depicts the total inflows and outflow calculated for Geddes Lake during the study. Atmospheric data came from a South Dakota State University database (http://climate.sdstate.edu/climate_site/climate.htn) where the precipitation and evaporation data were collected from Pickstown, South Dakota, approximately 15 miles southeast of Geddes Lake. These data indicated precipitation accumulations during the study were approximately 12% greater than the long-term average. Therefore, the measured phosphorus loads to the lake during the study may not represent the long-term average and may be a slight overestimation of long-term average phosphorus loads. This provides a small measure of safety when using these data to establish a TMDL for phosphorus. Detailed information on the calculation of flow data can be obtained from DENR upon request.

The months of April, May and June comprised the bulk of the total measured inflow. This is typical of South Dakota where water inflows (and nutrient and sediment loadings) peak during the spring and early summer. However, the total inflow was almost double the total outflow of the lake. This was probably due to underestimation of the outflow during the spring (April) of 2001. During the summer of 2000, the outlet structure underwent repair work and the stage recording equipment had to be removed. Only cross-sectional data and stream velocities were measured after August 2000 and the start of flow during the spring of 2001 was not noted. It is suspected that the outflows from August 2000 to the end of the project were underestimated.

Table 16. Hydrologic budget for Geddes Lake, May 2000 through April 2001.

Month	GLT-2 inflow	GLT-3 inflow	GL0-1 outflow	Avg. Ann. Precip.	Avg. Ann. Evap.
May 2000	164.19	383.45	76.74	23.97	35.93
June	42.60	206.86	16.50	7.53	45.32
July	0	421.97	0.02	5.60	48.07
August	0	0	0	9.74	44.80
September	0	0	0	2.68	40.37
October	3.04	0	0	9.86	18.84
November	23.42	0	0	19.83	0
December	0	0	0	2.04	0
January 2001	0	0	0	11.67	0
February	0	0	0	5.54	0
March	0	0	0	6.30	0
April	257.97	1495.45	1103.15	47.95	29.40
Total (Ac-ft)	**491.22**	**2507.73**	**1196.41**	**152.71**	**262.73**

Nutrient Loading

The phosphorus and nitrogen loads for the tributary sites were calculated with the Army Corps of Engineers loading program FLUX (Walker, 1999). FLUX uses individual sample data in correlation with daily discharges to develop loads for each parameter. The results from the FLUX program are given in Tables 17 and 18.

Table 17. Annual total nitrogen loads and loading coefficients for the Geddes Lake tributary sites.

Subwatershed	Acres Drained	TN Load (kg/yr)	TN Loading Coefficient (kg/acre)
GLT-5	19,000	4440.1	.2337
GLT-4	45,240	7919.3	.1751
GLT-3	59,640	7919.3	.1328
GLT-2	3,600	2100.1	.5834

Table 17 indicates the number of acres drained upstream of each monitoring station, the calculated total nitrogen load, and the loading coefficient for the portion of the watershed that is located upstream from that monitoring station. Loading coefficients were calculated by dividing the total load by the total number of acres drained resulting in load per unit area in kg/acre. Site GLT-5 is the uppermost site on Pease Creek, followed downstream by Site GLT-4, and by Site GLT-3. Site GLT-2 is on a separate small tributary draining to the lake. In Tables 17 and 18 the "acres drained" column and the "loading coefficient" column represent the land area between sites and not the cumulative acres or loads.

The total nitrogen loads from the Pease Creek watershed were highest at sites GLT-3 and GLT-4 but the loading coefficients decreased downstream in the Pease Creek watershed. Site GLT-2 had the greatest loading coefficient and this is not surprising given the fact that this is a relatively small watershed and a small livestock loafing/wintering area is located adjacent to this tributary. Reducing such sources of nitrogen in the watershed may reduce the intensity and frequency of blooms that occur during the summer.

The greatest portion of the total phosphorus load to Geddes Lake originates from the uppermost part of the Pease Creek watershed and the GLT-2 subwatershed. Phosphorus control measures should be targeted to these areas using the AnnAGNPS model and NRCS consultation.

Like total phosphorus, the greatest total dissolved phosphorus loads come from the Pease Creek watershed. Unlike for total nitrogen loading coefficients, site GLT-2 did not differ greatly from the sites in the lower and middle portions of the Pease Creek watershed. Site GLT-5, the uppermost site in the Pease Creek watershed, had the greatest TDP loading coefficient, although it is not known why.

Table 18. Annual total phosphorus and total dissolved phosphorus loads and loading coefficients for Geddes Lake tributary sites.

Subwatershed	Acres Drained	Load (kg/yr)		Loading Coeff. (kg/acre)	
		TP	TDP	TP	TDP
GLT-5	19,000	1376.5	1293.0	.0724	.0681
GLT-4	45,240	1868.8	1279.7	.0413	.0283
GLT-3	59,640	1868.8	1279.7	.0313	.0215
GLT-2	3,600	182.5	84.6	.0507	.0235

Seasonal loadings at Geddes Lake are heavily influenced by snowmelt and spring rain events. Table 19 depicts the monthly loads of phosphorus from the two inlet sites. The spring and early summer months of April, May, and June accounted for approximately 84% of the total discharge phosphorus load, which is typical of many South Dakota lakes. The results also show that site GLT-3 had by far the greatest total phosphorus loads (91.2% of the TP load), which is not surprising given that it is the major tributary to the lake.

Table 19. Seasonal loadings of total phosphorus from the two inlets to Geddes Lake.

Date	Site	Volume (hm3)	Mass (kg)	Percentage of TP Load
May-00	GLT-2	.195	58.2	2.86%
	GLT-3	.450	271.6	13.37%
Jun-00	GLT-2	.053	15.7	0.77%
	GLT-3	.255	154.0	7.58%
Jul-00	GLT-2	0	0	0%
	GLT-3	.521	314.1	15.46%
Aug-00	GLT-2	0	0	0%
	GLT-3	0	0	0%
Sep-00	GLT-2	0	0	0%
	GLT-3	0	0	0%
Oct-00	GLT-2	.004	1.1	0.05%
	GLT-3	0	0	0%
Nov-00	GLT-2	.029	8.6	0.42%
	GLT-3	0	0	0%
Dec-00 thru Mar-01	GLT-2	0	0	0%
	GLT-3	0	0	0%
Apr-01	GLT-2	.318	95.2	4.69%
	GLT-3	1.845	1113.1	54.79%

Reduction Response Modeling

In-lake response modeling was conducted with BATHTUB, an Army Corps of Engineers eutrophication response model (Walker, 1999). System responses were calculated using incremental reductions of ten percent in phosphorus loading from Pease Creek and the unnamed tributary. Loading data for the two tributaries were taken directly from the results obtained from the FLUX modeling (Table 20). Atmospheric loads were provided by SDDENR.

BATHTUB provides numerous models for the calculation of in-lake concentrations of phosphorus, nitrogen, chlorophyll *a*, and Secchi depth. Models are selected that most closely predict current in-lake conditions from the loading data provided. As reductions in the phosphorus load are predicted in the loading data, the selected models will closely mimic the response of the lake to these reductions.

Table 20. Annual loadings of selected parameters to Geddes Lake

Parameter	Site	Concentration (mg/l)	FLUX Load (kg/yr)	CV
Total Phosphorus	GLT-2	0.302	182.5	0.094
	GLT-3	0.600	1868.8	0.112
Total Dissolved Phosphorus	GLT-2	0.140	84.6	0.798
	GLT-3	0.411	1279.7	0.289
Total Suspended Solids	GLT-2	63.17	38203.1	0.660
	GLT-3	69.35	216153.9	0.518
Total Nitrogen	GLT-2	3.47	2100.1	0.073
	GLT-3	2.54	7919.3	0.091

Table 21 shows the response to reductions in the phosphorus load. The observed and predicted water quality data are listed in the first two columns. There appears to be good agreement between the observed and predicted mean TP concentrations, mean chlorophyll *a* concentrations, mean Secchi transparency, and their respective trophic state indices.

The difference between the actual median growing-season (May 15 – September 15) Secchi-chlorophyll a TSI (77.13) versus the median of the "estimated at 0% reduction" Secchi TSI and chlorophyll *a* TSI in Table 21 (76.88) was 0.25 TSI points. This was not considered a significant difference and so no adjustment factors were applied to the model.

The BATHTUB model was re-run a number of times following incremental 10% decreases in the total phosphorus concentration in the lake's two tributaries. The lake response exhibited a steady reduction of in-lake total phosphorus concentration and improvements in all of the TSIs. For Geddes Lake, the target TSI is a growing season median Secchi-chlorophyll *a* TSI of 63.4. A 92% reduction in tributary phosphorus

Table 21. BATHTUB model results: responses in Geddes Lake variables from reductions in tributary phosphorus loads.

		Phosphorus reduction responses in Geddes Lake.									
PERCENT TP REDUCTION		0%	10%	20%	30%	40%	50%	60%	70%	80%	90%
VARIABLE	OBSERVED	ESTIMATED	ESTIMATED	ESTIMATED	ESTIMATED	ESTIMATED	ESTIMATED	ESTIMATED	ESTIMATED	ESTIMATED	ESTIMATED
------------------	--------	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------
TOTAL P MG/M3	379.0	407.7	367.1	326.5	285.9	245.3	204.6	164.0	123.4	82.8	42.2
TOTAL N MG/M3	2759.0	2856.0	2580.6	2305.2	2029.8	1754.4	1479.0	1203.6	928.2	652.8	377.4
CHL-A MG/M3	86.7	106.7	103.8	100.3	95.9	90.4	83.2	73.8	61.1	44.1	20.9
SECCHI M	.3	.3	.3	.3	.3	.3	.3	.3	.4	.4	.6
ORGANIC N MG/M3	2586.0	2686.6	2620.7	2540.1	2440.1	2313.5	2150.3	1935.5	1647.6	1259.5	730.4
CARLSON TSI-P	89.81	90.87	89.35	87.66	85.75	83.54	80.92	77.73	73.62	67.87	58.14
CARLSON TSI-CHLA	74.35	76.38	76.11	75.78	75.34	74.76	73.94	72.77	70.92	67.72	60.39
CARLSON TSI-SEC	77.37	77.37	77.37	77.37	77.37	77.37	77.37	77.37	73.33	73.22	67.37
Mean TSI	80.51	81.54	80.94	80.27	79.49	78.56	77.41	75.96	72.59	69.64	61.97

Legend for Table 21.

TOTAL P MG/M3	Pool Mean Phosphorus Concentration
TOTAL N MG/M3	Pool Mean Nitrogen Concentration
CHL-A MG/M3	Pool Mean Chlorophyll *a* Concentration
SECCHI M	Pool Mean Secchi depth
ORGANIC N MG/M3	Pool Mean Organic Nitrogen Concentration
TSI	Trophic State Indices (Carlson 1977)

concentration is needed to reach the target Secchi-chlorophyll *a* TSI value of 63.4 (Figure 15). However, it is unlikely that a 92% reduction of tributary phosphorus concentrations can be attained without undue economic strain on the local landowners. A more realistic TSI target will need to be determined based on what lake/watershed measures are thought to be possible while still supporting the lakes beneficial uses. The AnnAGNPS model can also provide information about what watershed practices produce the greatest phosphorus reductions. The adjusted TSI target is presented in the AnnAGNPS section of this report.

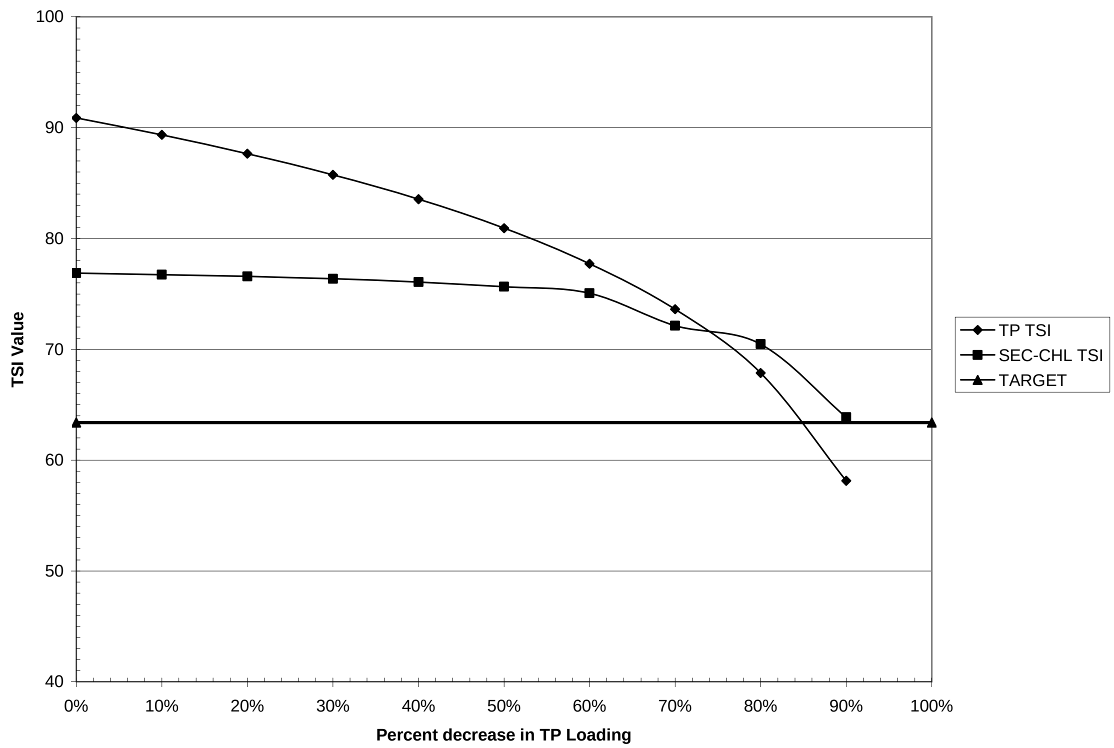

Figure 15. Graphical presentation of trophic state in response to incremental percent reductions in total phosphorus from the incoming tributaries.

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

A total of 44 tributary samples and 61 lake samples were collected along with seven sets of replicates and blanks for QA/QC purposes. All QA/QC samples may be found in Table 22.

Blank samples were very clean and did not indicate contamination of the samples by either the sampler or the laboratory. The precision values indicated acceptable precision values (<10%) for total alkalinity, total solids, nitrates, and total dissolved phosphorus. One total phosphorus QA/QC sample and one Total Kjeldahl Nitrogen QA/QC sample had a precision value greater than 10%. Of concern, however, are the fecal coliform bacteria and *E. coli* analyses. These parameters had average precision values greater than

10%. Natural variability, improper field technique, and/or laboratory error may have caused the poor precision.

Table 22. Quality assurance and quality control precision statements for samples taken as part of the Geddes Lake Assessment Project.

SITE	DATE	TYPE	Chl-A	T.ALKA	TSOL	TSSOL	AMMO	NIT	TKN	TPO4	TDPO4	VTSS	Fecal	E COLI
GLT-2	6/21/00	Grab		315	4189	23	0.11	0.3	0.82	0.109	0.085	<1	100	
GLT-2A	6/21/00	Replicate		313	4200	25	0.1	0.3	0.83	0.145	0.084	1	110	
GLT-2B	6/21/0001	Blank		<6	<7	<1	<0.02	0.1	<0.21	<0.002	<0.002	<1	<10	
		Precision		0.32	0.13	4.17	4.76	0	0.61	14.2	0.59	0	4.76	
GLT-3	5/14/01	Grab		168	1374	23	0.03	0.6	0.77	0.485	0.381	4	<10	17.3
GLT-3A	5/14/01	Replicate		166	1370	24	0.03	0.6	0.75	0.484	0.383	5	<10	22.8
GLT-3B	5/14/01	Blank		<6	14	<1	<0.02	0.1	<0.36	<0.002	<0.002	<1	<10	<1
		Precision		0.60	0.23	2.13	0	0	1.32	0.10	0.26	11.1	0	13.7
GLT-4	5/21/01	Grab		168	4333	21	0.13	<0.1	1.42	0.426	0.334	9	4100	
GLT-4A	5/21/01	Replicate		166	4400	21	0.14	<0.1	1.78	0.41	0.329	8	3100	
GLT-4B	5/21/01	Blank		<6	<7	<1	<0.02	0.1	<0.21	<0.002	<0.002	<1	<10	
		Precision		0.60	0.77	0	3.70	0	11.3	1.91	0.75	5.88	13.89	
GLT-5	5/24/01	Grab		100	753	7	0.38	1.7	1.57	0.88	0.861	4	20	80.1
GLT-5A	5/24/01	Replicate		101	751	9	0.37	1.7	1.77	0.916	0.867	5	60	108
GLT-5B	5/24/01	Blank		<6	8	<1	<0.02	0.1	<0.36	<0.002	<0.002	<1	<10	<1
		Precision		0.50	0.13	12.5	1.33	0	8.55	2.00	0.35	11.1	50.0	14.8
GLO-1	4/5/01	Grab		124	1089	20	1.05	1.1	2.03	0.587	0.454	4	10	11
GLO-1A	4/5/01	Replicate		125	1079	21	1.03	1.1	2.21	0.569	0.448	6	20	19.9
GLO-1B	4/5/01	Blank		<6	9	<1	<.02	<.1	<0.36	<.002	.005	<1	<10	<1
		Precision		0.40	0.46	2.44	0.96	0	4.25	1.56	0.67	.20	33.3	28.8
GLO-1	4/5/01	Grab		115	1026	38	0.5	1.8	1.6	0.785	0.618	4	610	816
GLO-1A	4/5/01	Replicate		116	1013	38	0.49	1.8	1.75	0.82	0.581	2	540	980
GLO-1B	4/5/01	Blank		<6	<7	<1	<.02	0.1	<0.36	<.002	<.002	<1	<10	<1
		Precision		0.43	0.64	0	1.01	0	4.62	2.18	3.09	33.3	6.09	9.13
GL-2	6/20/00	Grab	54.15	227	3188	60	<.02	<.1	1.64	0.306	0.075	20	<10	
GL-2A	6/20/00	Replicate	48.06	227	3197	62	<.02	<.1	1.44	0.302	0.073	22	<10	
GL-2B	6/20/00	Blank	-1.12	<6	<7	<1	<.02	0.1	<.21	<.002	<.002	<1	<10	
		Precision	5.96	0	0.14	1.64	0	0	6.49	0.66	1.35	0.05	0	
Average Precision (%|)			--	0.38	0.36	3.27	1.68	0	5.31	3.23	1.01	8.80	15.4	16.6

Where precision (%|) = Difference between duplicate analytical values divided by the sum of the values, multiplied by 100.

Objective 4. Annualized Agricultural Non-Point Source Model (AnnAGNPS)

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

In order to objectively assess the impact of watershed use by animal feeding operations, the AnnAGNPS feedlot assessment subroutine was employed. A complete evaluation was conducted on all animal feeding areas with a defined drainage to Geddes Lake. Animal lots with drainages confined to small areas and having no defined discharges were not rated during the assessment. Lots that were rated were assessed for a 25-year, 24-hour storm event in the drainage area. This is the largest event that waste systems in the area are designed to handle. The lots were given a score from a range of 0 to 100 and prioritized. DENR uses a score of 55 or greater to denote critical feedlots. The feedlot information and rating scores is presented in Table 28 in Appendix D.

AnnAGNPS Modeling Results

The results of AnnAGNPS model runs are summarized in Table 23. After the initial model run, cells were prioritized using phosphorus yield. Those cells having phosphorus yields equal to or greater than two standard deviations from the mean phosphorus yield were considered critical. Critical cells are shown in Figure 16.

Table 23. Percent change in the phosphorus and sediment total watershed yields for different land use scenarios in the Geddes Lake watershed, Charles Mix County, South Dakota.

	Att.. P	Diss. P	Total P	Sediment
Original condition	0	0	0	0
Change all non-water cells to good condition pasture	-95%	-51%	-44%	-93%
Change certain crops to no-till usage	-29%	-25%	-26%	-26%
Reduce fertilizer rates on certain crops	-3%	-34%	-31%	0%
Change all poor/fair condition pastures to good condition	0%	-0.5%	-0.5%	0%
Change only poor condition critical pastures to good condition	0%	-0.1%	-0.2%	0%
Eliminate feedlots having ratings of 55 or greater	0%	0%	0%	0%

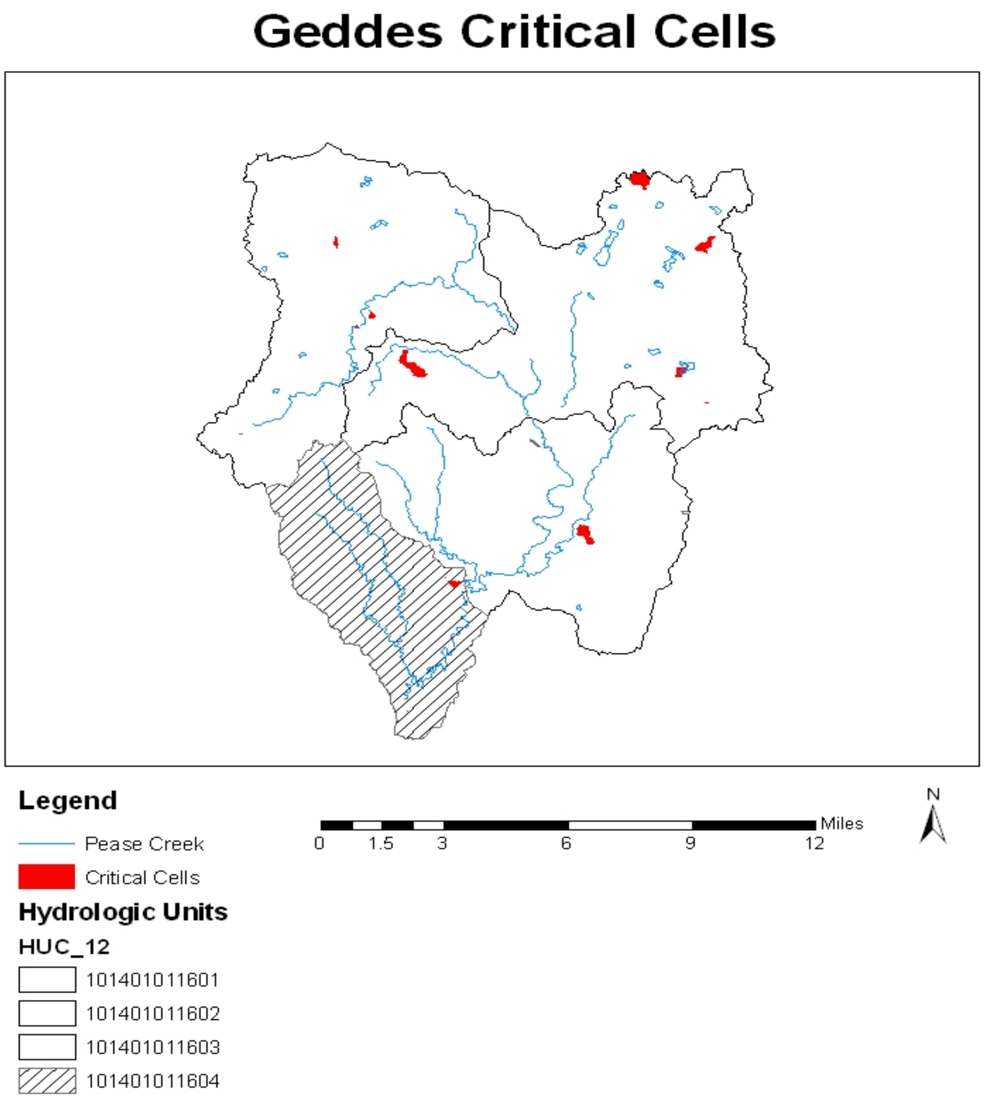

Figure 16. Critical cells in the Geddes Lake watershed.

The results in Table 23 show a number of valuable points:

1. Changing all of the non-water cells to good pasture resulted in a 51% reduction in dissolved phosphorus and a 95% reduction in attached phosphorus. Sediment yield was also reduced by 93%. This illustrates the maximum potential of how much the watershed

phosphorus yields can be reduced but it is doubtful that all or most of these cells would be changed to good pasture.

2. Adding no-till usage to certain crop cells produced a 25-29% reduction in phosphorus and sediment yields. This illustrates the importance of using no-till on crops and so no-till usage should be promoted in the watershed.

3. Reducing fertilizer application rates can reduce phosphorus yields from cells containing crops that are typically fertilized. Although operators tend to resist changing their fertilizer practices, fertilizer reduction should be stressed.

4. Improving the condition of existing pastures does not appear to significantly reduce phosphorus yields. However, converting crops to good condition pasture can reduce phosphorus yields and converting cropland to pasture should be discussed with the local operators, especially in areas not particularly conducive to crop production. Using the USDA Conservation Reserve Program (CRP) should also be discussed.

5. Only working on critical cells will not produce significant phosphorus reductions. This is not surprising given that there were less than 20 critical cells in a watershed containing over 6,000 cells. However, targeting critical cells is still a reasonable approach to maximizing phosphorus reductions per unit effort.

6. Taking out the 16 critical feedlots had a negligible effect on nutrient or sediment loads; again not surprising given the size of the watershed. Although this result may lead one to ignore feedlots, it is felt that any individual feedlot area may still contribute to the nutrient loads to the lake. The total mass of phosphorus coming from the critical feedlot cells was 1,416 pounds and reducing this may still be a significant part of an implementation project effort. In addition, the FLUX program results showed the part of the watershed containing Site GLT-2 had the highest nitrogen loading coefficient and a high total phosphorus loading coefficient and that there is a livestock operation adjacent to the creek. This area, as well as other operations near drainage ways should be visually inspected and assessed for their potential and need for erosion/nutrient controls.

Adjustment of TSI target based on AnnAGNPS Modeling

Incremental reductions in tributary phosphorus concentrations during the BATHTUB program model runs showed that a 92% reduction in phosphorus was needed to meet the median growing-season Secchi-chlorophyll *a* TSI target of 63.4. A 92% reduction in phosphorus through implementing watershed conservation practices was not deemed possible. Therefore, it is recommended that a target be established that reflects and recognizes the social and economical constraints within the watershed while still supporting the lakes beneficial uses.

It is thought that a 30% reduction in phosphorus may be the best attainable level of control while still supporting the lakes beneficial uses. It is estimated that a combination of feedlot improvement, use of no-till, converting crop to pasture or CRP, and decreasing fertilizer usage will result in a 30% reduction in phosphorus. Based on a 30% reduction in phosphorus from watershed improvements, the target Secchi-chlorophyll *a* TSI should be changed from 63.4 to 76.3 when watershed improvements are the only lake restoration strategy used (Figure 17). However, the original Secchi-chlorophyll *a* TSI target of 63.4 can still be used when in-lake restoration efforts such as phosphorus precipitation or algicides are used. It is felt that these in-lake strategies have a better chance of reaching the 63.4 target than the proposed watershed restoration practices.

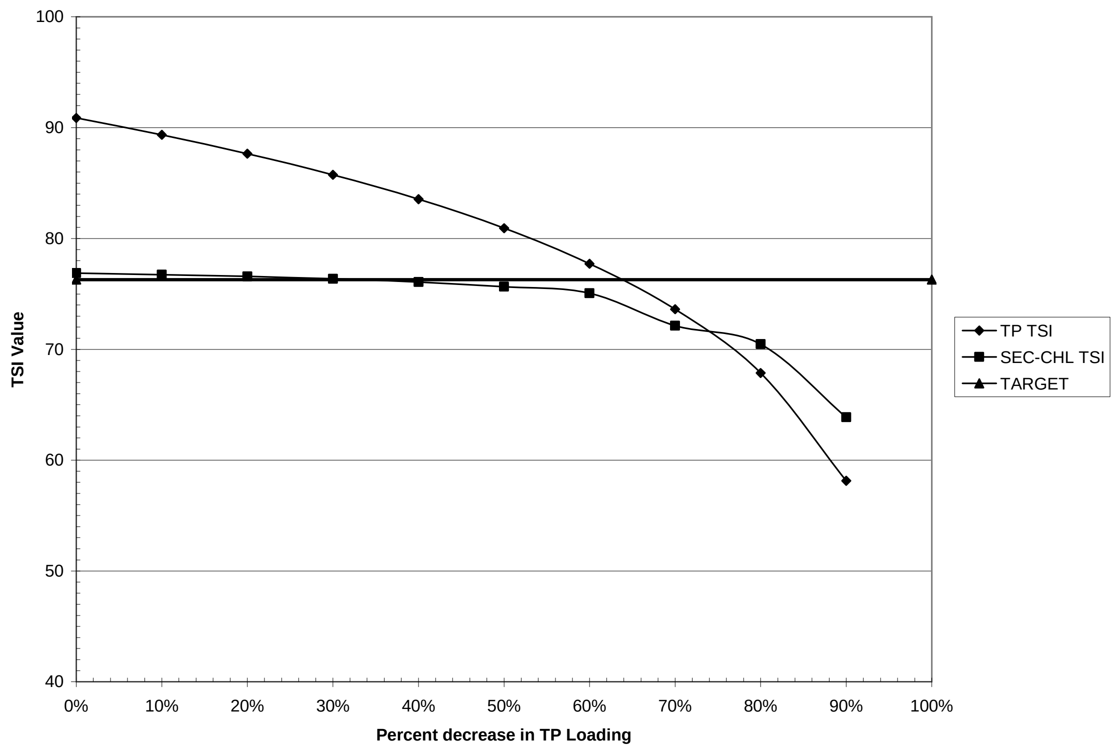

Figure 17. Graphical presentation of trophic state in response to incremental percent reductions in total phosphorus from the incoming tributaries and the adjusted Secchi-chlorophyll *a* TSI target of 76.3.

Objective 5. Public Participation

State Agencies

The South Dakota Department of Environment and Natural Resources (SDDENR) was the primary state agency involved in the completion of this assessment. SDDENR provided equipment as well as technical assistance throughout the course of the project. The South Dakota Department of Game, Fish, and Parks provided information about the fisheries in Geddes Lake.

Federal Agencies

The Environmental Protection Agency (EPA) provided the primary source of funds for the completion of the assessment on Geddes Lake.

The Natural Resource Conservation Service (NRCS) provided technical assistance, particularly in the collection of soil data for the AGNPS portion of the report.

The Farm Service Agency provided a great deal of information that was utilized in the completion of the AGNPS modeling portion of the assessment.

Local Governments, Special Interest Groups, and General Public

The South Central Water Development District (SCWDD) provided the local sponsorship that made this project possible. In addition to providing administrative sponsorship, SCWDD also provided local matching funds and personnel to complete the assessment.

The Charles Mix County Conservation District provided work space and in-kind services.

Public involvement consisted of some individual meetings with landowners that provided a great deal of historic perspective on the watershed. Additionally, landowners were contacted through mailings about land usages and most responded with the appropriate information.

Aspects of the Project That Did Not Work Well

All of the objectives proposed for the project were met in an acceptable fashion and in a reasonable time frame. The exception to this was the collection of stage (flow) data from site GLT-3 and the outlet (Site GLO-1). The presence of a beaver dam at Site GLT-3 created problems with accurately measuring the stage of the creek at the site. Better site evaluation prior to equipment installation should remedy this problem. The dam repairs at the outlet was not expected but regular communication with the SDGF&P might have provided some warning of repair activities and their impact on the outlet stage recorder.

Recommendations

There are a limited number of lake restoration techniques available to lake managers and the bulk of these are summarized by Cooke, et al. (1986). Eleven general categories were reviewed for their applicability to the Geddes Lake situation and each one is discussed below. Table 24 at the end of this section summarizes those techniques recommended for consideration for use in Geddes Lake.

Lake Restoration Techniques Rejected for Geddes Lake

Dilution/Flushing

Dilution/flushing is a technique to reduce algal biomass by introducing water of lower nutrient concentration while concurrently increasing water exchange (flushing) in the lake. This category was not considered a viable option for Geddes Lake because there is no source of dilution water nearby. Pumping water from the best dilution source, the Missouri River, was considered cost prohibitive.

Lake Drawdown/Plant Harvesting

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

Biological Controls

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

Surface/Sediment Covers

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

Hypolimnetic Withdrawal

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

Hypolimnetic withdrawal for Geddes Lake is not recommended because the lake does not stratify and because by midsummer the inflow of tributary water is diminished and there is little likelihood of keeping the lake full during the time when hypolimnetic withdrawal would be most effective. So the positive effects of hypolimnetic withdrawal may be offset by having a more shallow lake subject to wind mixing.

Techniques in Need of Further Investigation

Sediment Removal for Nutrient Control

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

It is likely that internal phosphorus loading can occur in the lake either through wind action in the shallow areas of the lake or through release of phosphorus from the sediments during periods of low dissolved oxygen. What isn't known is how much of a problem internal loading is. The monitoring data and the BATHTUB model runs indicated the lake sediment was a phosphorus sink rather than a source. Therefore, sediment removal for nutrient control is not recommended until further evidence is gathered to quantify internal phosphorus loading and indicate it is a problem.

Techniques Recommended for Consideration

Best Management Practices in the Watershed

The BATHTUB model indicated a 92% reduction in tributary phosphorus concentration was needed for Geddes Lake to meet its Sec-Chl TSI target of 63.4. This target was adjusted up to a median growing season Secchi-chlorophyll *a* TSI of 76.3 to reflect a more realistic view of what could be done in the watershed while still supporting the lakes beneficial uses. This means the phosphorus loading rate from the tributaries must be decreased from 2,051.3 kg/yr to 1,435.91 kg/yr, a difference of 615.39 kg/yr. Therefore, the TMDL for external TP loading is 1,435.91 kg/yr, or 3.93 kg/day.

In addition, control of incoming nutrients should also alleviate the low dissolved oxygen episodes in the lake. Nutrients, especially phosphorus, have been shown to increase eutrophication in lakes and reservoirs throughout the country, increasing oxygen depletion caused by decomposition of algae and aquatic plants (Carpenter et al., 1998). Carpenter et al. (1998) and Bertram (1993) also indicate that reductions in nutrients will eventually lead to the reversal of eutrophication and attainment of designated beneficial uses. Nurnberg (1995, 1995a, 1996, 1997), developed a model that quantified duration (days) and extent of lake oxygen depletion, referred to as an anoxic factor (AF). This model showed that AF is positively correlated with average annual local phosphorous

(TP) concentrations. The AF may also be used to quantify response to watershed restoration measures which makes it very useful for TMDL development. Nurnberg also developed several regression models that show nutrients (P and N) control all trophic state indicators related to oxygen and phytoplankton in lakes/reservoirs. Except for average lake depth, Geddes Lake morphological characteristics are within those Nurnberg used to develop regression models (Nurnberg ranges: $\bar{z}$ mean depth (m), 1.8 – 200; A_o lake surface area (hectares), 1.0 – 8.2*10^6 and $\bar{z} / A_o^{0.5}$ (m/km^2), 0.14 – 48.1; Geddes Lake values: $\bar{z}$ (m), 0.98; A_o (hectares), 28.3 and $\bar{z} / A_o^{0.5}$ (m/km^2), 0.28). Nevertheless, SDDENR believes that Nurnberg's work supports the conclusion that nutrients affect dissolved oxygen concentrations and algal populations in Geddes Lake. Thus reduction in nutrient (phosphorus) loads to the lake will improve dissolved oxygen concentrations and overall water quality in Geddes Lake. South Dakota's approach to treat the sources of nutrients and reduce/eliminate nutrient loads to impaired waters is consistent with accepted watershed strategies to treat sources rather than symptoms (low dissolved oxygen).

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

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

Phosphorus Inactivation and Bottom Sealing with Aluminum Sulfate

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

To reach the median growing-season Secchi-Chlorophyll *a* TSI target value of 63.4, the chlorophyll *a* concentration needs to be at least 9 mg/m^3 and the Secchi transparency needs to be at least 0.37 meter. And according to the relationship between total phosphorus and chlorophyll *a* in Figure 7, a growing-season total phosphorus concentration of 0.126 mg/l results in a chlorophyll *a* concentration of 8.95 mg/m^3. This means that the average in-lake growing-season total phosphorus concentration of .396 mg/l must be reduced by 68 percent to reach 0.126 mg/l. This reduction appears to be within the range of phosphorus reductions found in previous lake restoration efforts using alum precipitation (Cooke et al., 1986) and so the original TSI target of 63.4 can still be used rather than the adjusted target of 76.3.

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

This technique will be successful in the long-term only if the external loading of phosphorus is controlled. Otherwise repeated applications will be necessary to compensate for the annual influx of phosphorus from Pease Creek.

Aeration/Circulation

Aeration and circulation are well known techniques for preventing oxygen depletion in a lake. This study determined the whole lake oxygen deficit to be approximately 72.01 mg/m^2-day and any aeration/circulation of the lake should compensate for this deficit.

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

Algicides/Herbicides

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

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

To reach the median growing-season Secchi-Chlorophyll *a* TSI target of 63.4, the chlorophyll *a* concentration needs to be at least 9 mg/m^3. This concentration relates to a Secchi transparency value of 0.37 meter according to the relationship given in Figure 6. The median Secchi-Chlorophyll *a* TSI based on 9 mg/m^3 chlorophyll *a* and a Secchi transparency of 0.37 meter is 63.15, which provides a slight measure of safety from the target value of 63.4.

It is recommended that Secchi transparency be monitored in the lake at least once a week during the summer. If the Secchi transparency is less than 0.37 meter, then application of the algicide should be considered.

Sediment Removal for Lake Longevity

One process of lake aging is the gradual sedimentation and filling of a lake. This could eventually lead to shallower depths, increased fish kills due to oxygen depletion, and other negative impacts to the lake's beneficial uses. This study determined that nearly 56% of the total lake depth is occupied by sediment. Although stopping or slowing sedimentation through the use of watershed BMPs is an obvious strategy, it is clear that removing sediment from a lake is an option to extend the useful life of the lake and maintain lake conditions related to lake depth and volume. Secondary benefits of sediment removal might be the removal of phosphorus-rich sediment that may release nutrients to the lake, and improved dissolved oxygen through the removal of organics that decompose and create oxygen deficits.

Table 24. Summary of recommended lake restoration techniques for Geddes Lake.

Restoration Technique	Action	Targets	Comments
Best Management Practices in the watershed.	Reduce incoming TP by 615.39 kg/yr. to reach acceptable loading rate of 1,435.91 kg/yr. (3.93 kg/day).	TP load of 1,435.91 kg/yr (3.93 kg/day) results in meeting adjusted Sec-Chl TSI target of 76.3	Based on FLUX and BATHTUB modeling.
In-lake phosphorus precipitation and bottom sealing.	Decrease growing-season in-lake TP concentration by 0.254 mg/l Chemical amounts to be determined by titrations and existing water chemistry.	TP decrease to an in-lake TP concentration of 0.126 mg/l results in meeting Sec-Chl TSI target of 63.4.	Based on TP – chlorophyll *a* relationship. Based on chlorophyll *a* – Secchi relationship. Probable need for repeated applications if no external phosphorus controls.
Aeration/circulation.	Aerate lake to compensate for whole lake oxygen deficit rate of 72.01 mg/m^2-day.	Aerate until DO concentration is at least 5.0 mg/l.	Frequent monitoring of DO recommended for initiation and continuation of aeration.
Algicides.	Decrease chlorophyll *a* to concentration of 9 mg/m^3.	Decreasing chlorophyll *a* to 9 mg/m^3 results in Secchi of 0.37 meter and meeting Sec-Chl TSI target of 63.4.	Based on chlorophyll *a* – Secchi relationship. Monitor Secchi frequently. Use Secchi transparency target of 0.37 m to determine effectiveness or need for repeated treatment.
Sediment removal for lake longevity	Remove any amount of sediment to extend lake life.	Maintain minimal amount of sediment in the lake.	Success implied.

Literature Cited

Bertram, Paul. 1993. Total phosphorus and dissolved oxygen trends in the central basin of Lake Erie, 1970-1991. Journal of Great Lakes Research. 19(2):224-236

Carlson, R. E. 1977. A trophic state index for lakes. Limnology and Oceanography. 22:361-369.

Carpenter, S. R., N. F. Caraco, D. L. Correll, R. W. Howarth, A. N. Sharpley, and V. H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen**.** Ecological Applications, Vol. 8, No. 3: 559-568.

Cooke, G. Dennis, Eugene B. Welch, Spencer A. Peterson, and Peter R. Newroth. 1986. Lake and Reservoir Restoration. Butterworth Publishers, Stoneham, MA.

Lorenzen, Paul. 2005. Targeting impaired lakes in South Dakota. South Dakota Department of Environment and Natural Resources, Watershed Protection Program, Pierre, South Dakota.

Meester, Ronald J. 1996. Statewide fisheries surveys, 1995: surveys of public waters: part 1 lakes. South Dakota Department of Game, Fish and Parks, Pierre, SD.

Novotny, V. and H. Olem. 1994. Water quality, prevention, identification, and management of diffuse pollution. Van Nostrand Reinhold, New York.

Nürnberg, G.K. 1995. Quantifying anoxia in lakes. Limnol. Oceanogr. The American Society of Limnology and Oceanography, Inc. 406(6). 1100-1111.

Nürnberg, G.K. 1995a. The anoxic factor, a quantitative measure of anoxia and fish species richness in central Ontario lakes. Transactions of the American Fisheries Society. 124: 677-686.

Nürnberg, G.K. 1996. Trophic state of clear and colored , soft- and hardwater lakes with special consideration of nutrients, anoxia, phytoplankton and fish. Journal of Lakes and Reservoir Management. 12(4): 432-447.

Nürnberg, G.K. 1997. Coping with water quality problems due to hypolimnetic anoxia in Central Ontario Lakes. Wat. Qual. Res. J. Canada, 32: 432-447.

SDGF&P. 2004. South Dakota Statewide Fisheries Survey 2004. South Dakota Department of Game Fish and Parks. Pierre, South Dakota.

SDGF&P. 2005. South Dakota Statewide Fisheries Survey 2005. South Dakota Department of Game Fish and Parks. Pierre, South Dakota.

SDGF&P. 2005a. Angler Use and Harvest Surveys on Stockade Lake, South Dakota, 1999 and 2003With a Evaluation of the Aeration System Effectiveness. South Dakota Department of Game Fish and Parks. Pierre, South Dakota.

Stueven, E.H., and Stewart, W.C. 1996. 1995 South Dakota Lakes Assessment Final Report. South Dakota Department of Environment and Natural Resources, Watershed Protection Program. Pierre, SD.

Stueven, E.H., Wittmus, A., and Smith, R.L. 2000. Standard Operating Procedures for Field Samplers. South Dakota Department of Environment and Natural Resources, Pierre, SD.

U.S. Department of Agriculture. Soil Conservation Service. 1982. Soil survey of Charles Mix County, South Dakota.

U.S. Environmental Protection Agency. 1974. The relationships of phosphorus and nitrogen to the trophic state of northeast and northcentral lakes and reservoirs. National Eutrophication Survey Working Paper No. 23, Corvallis, Oregon.

U.S. Environmental Protection Agency. 1990. Clean lakes program guidance manual. EPA-44/4-90-0006. Washington D.C.

Walker, W. W. 1999. Simplified procedures for eutrophication assessment and prediction: user manual. U.S. Army Corps of Engineers.

Wetzel, R.G. 1983. Limnology 2nd Edition. Saunders Publishing Company, Philadelphia, Pennsylvania.

Wetzel, R.G. 2000. Limnological Analyses 3rd Edition. Springer-Verlag New York Inc., New York.

Appendix A

Lake Water Quality Data

Table 25. In-lake data for Geddes Lake.

SITE	DATE	TIME	Air Tem	Cond.	DO	pH	TEMP	DEPTH	TURB.	SECCHI	T Depth	Fecal C	Alk. M	TS	TSS	NH3	NO3	TKN	T. Phos.	TDP	VTSS	TDS	E-COL	Chla	SDTSI	TPTSI	CLTSI	TN	ON
GL-1	5/17/00	805	17.59		7.42	8.33	18.1	S	47.6	0.345	7.5	<5	246	3223	35	<0.01	<0.05	1.55	0.258	0.132	11	3069		19.64	75.35	84.26	59.81	1.6	1.54
GL-1	5/17/00	805	17.59		7.16	8.33	17.88	3	24																			0	0
GL-1	5/17/00	805	17.59		6.5	8.29	17.46	6	62.3																			0	0
GL-1	5/17/00	805	17.59		5.57	8.22	17.14	7	138.3																			0	0
GL-1	6/6/00	1538	24.25	3071	9.87	8.23	19.72	S	29.4	0.305	6.7													8.44	77.13		51.52	0	0
GL-1	6/6/00	1538	24.25	3067	9.55	8.24	19.61	3	30.2																			0	0
GL-1	6/6/00	1538	24.25	3054	8.94	8.23	19.31	6	33																			0	0
GL-1	6/20/00	930	22	3285	5.16	8.27	20.8	S	35.6	0.345	7.5	10	228	3168	48	<0.02	<0.1	1.73	0.276	0.071	20	3021		50.33	75.35	85.24	69.04	1.83	1.71
GL-1	6/20/00	930	22	3283	5.1	8.28	20.8	3	36.4																			0	0
GL-1	6/20/00	930	22	3282	5.07	8.28	20.8	6	39.5																			0	0
GL-1	7/6/00	815	22.2	3578	4.56	8.25	25.91	S	37.4	0.305	6.1													102.05	77.13		75.97	0	0
GL-1	7/6/00	815	22.2	3550	3.9	8.23	25.58	B	78.3																			0	0
GL-1	7/17/00	1245	22	3964	6.93	8.62	26.27	S	49.8	0.274	6.2	10	141	3352	50	0.02	<0.1	2.99	0.503	0.136	30			146.26	78.68	93.90	79.51	3.09	2.37
GL-1	7/17/00	1245	22	3868	2.32	8.16	24.9	B	51.2																			0	0
GL-1	7/31/00	1230	24	3875	12.4	8.93	27.47	S	44.8	0.274	6.7													115.02	78.68		77.15	0	0
GL-1	7/31/00	1230	24	3785	5.32	8.54	26.05	B	48.9																			0	0
GL-1	8/15/00	945	21	3548	4.63	8.39	26.95	S	51.4	0.274	5.8	<10	97	3574	60	<0.02	<0.1	4.31	0.456	0.06	30			159.24	78.68	92.48	80.34	4.41	4.29
GL-1	8/15/00	945	21	3544	3.88	8.42	26.9	B	54																			0	0
GL-1	9/7/00	825	20	3732	4.32	8.38	21.75	S	56.1	0.274	4.6													41.49	78.68		67.15	0	0
GL-1	9/7/00	825	20	3731	4.13	8.48	21.76	B	60.9																			0	0
GL-1	9/26/00	1205	18	3136	16.86	8.89	11.47	S	48.4	0.274	5.6	<10	96	3983	44	<0.02	<0.1	3.09	0.361	0.038	28			96.92	78.68	89.11	75.47	3.19	3.07
GL-1	9/26/00	1205	18	3066	15.75	8.91	10.61	B	49.1																			0	0
GL-1	10/11/00	1336	15.54		9.34	8.86	9.27	S	102.6	0.274	4.6														78.68			0	0
GL-1	10/11/00	1336	15.54		9.18	8.88	9.13	B	93.5																			0	0
GL-1	10/25/00	1500	15.75	3534	9.04	8.22	15.62	S	43.2	0.305	4.4	10	117	4042	36	0.13	<0.1	2.78	0.414	0.167	16				77.13	91.09		2.88	2.65
GL-1	10/25/00	1500	15.75	3521	8.38	8.15	15.46	B	47.1																			0	0
GL-1	4/10/01	930	8.5	919	9.46	7.81	9.79	S	42.3	0.259	6.3	530	122	1072	32	0.47	1.8	1.91	0.777	0.584	<1		1050	15.70	79.49	100.17	57.61	3.71	1.44
GL-1	4/10/01	930	8.5		9.4		9.79	3																				0	0
GL-1	4/10/01	930	8.5	922	8.7	7.74	7.6	B	33.6																			0	0
GL-1	5/3/01	831	12	1126	9.77	8.17	17	S	18.1	0.549	6	10	155	1109	19	<0.02	<0.1	1.42	0.451	0.295	3		8.6	42.45	68.65	92.32	67.37	1.52	1.4
GL-1	5/3/01	831	12		9.73		17.01	3																					
GL-1	5/3/01	831	12	1129	4.06	8.19	17.18	B	18.5																				
GL-2	5/17/00	830	17.59		7.5	8.39	18.12	S	45.6	0.405	4.75	20	249	3238	40	0.06	<0.05	1.72	0.266	0.066	14	3093		18.80	73.04	84.71	59.39	1.77	1.66
GL-2	5/17/00	830	17.59		6.95	8.38	18.13	3	56.5																				
GL-2	5/17/00	830	17.59		6.87	8.39	18.17	4.5	72																				
GL-2	6/6/00	1549	24.25	3081	10.04	8.25	19.84	S	33.4	0.3048	4.1													17.02	77.14		58.41		
GL-2	6/6/00	1549	24.25	3079	9.44	8.25	19.82	3	33.2																				
GL-2	6/6/00	1549	24.25	3079	9.14	8.25	19.83	4.4	34																				
GL-2	6/20/00	935	22	3280	6.69	8.29	20.69	S	43	0.3048	5.8	<10	227	3188	60	<0.02	<0.1	1.64	0.306	0.075	20	3003		54.15	77.14	86.73	69.76	1.74	1.62
GL-2	7/6/00	830	22.2	3597	5.36	8.31	26.23	S	48.2	0.274	5.7													152.83	78.68		79.94		
GL-2	7/6/00	830	22.2	3577	3.81	8.18	25.89	B	54.8																				
GL-2	7/17/00	1255	22	3985	7.17	8.64	26.53	S	51.2	0.244	5.5	20	141	3342	76	<0.02	<0.1	2.53	0.516	0.135	38			179.91	80.35	94.27	81.54	2.63	2.51
GL-2	7/17/00	1255	22		3.9		25.6	B																					
GL-2	7/31/00	1240	24	3935	12.16	8.91	28.23	S	48.4	0.274	5.2														78.68				
GL-2	7/31/00	1240	24	3805	6.15	8.58	26.36	B	49.6																				
GL-2	8/15/00	952	21	3556	4.81	8.58	27.07	S	50.2	0.274	4.6	<10	96	3567	56	<0.02	<0.1	3.96	0.46	0.063	30			91.31	78.68	92.61	74.88	4.06	3.94
GL-2	8/15/00	952	21	3553	4.24	8.59	27.04	B	52.7																				
GL-2	9/7/00	835	20	3734	4.15	8.59	21.76	S	58.1	0.244	4.5													97.40	80.35		75.52		
GL-2	9/7/00	835	20	3733	4.02	8.66	21.77	B	57.4																				
GL-2	9/26/00	1215	18	3164	16.61	9.07	11.95	S	50.7	0.274	4.1	10	101	3997	46	<0.02	<0.1	3.17	0.371	0.044	32			159.24	78.68	89.51	80.34	3.27	3.15
GL-2	9/26/00	1215	18	3096	14.69	9.01	11.1	B	51.7																				
GL-2	10/11/00	1345	15.54		9.78	8.96	9.43	S	42.6	0.274	4.1														78.68				
GL-2	10/11/00	1345	15.54		9.7	8.98	9.42	B	44.8																				
GL-2	10/25/00	1515	15.75	3537	9.29	8.2	15.73	S	52.5	0.274	4.1	<10	118	4047	48	0.1	<0.1	3.56	0.44		16				78.68	91.97		3.66	3.46
GL-2	10/25/00	1515	15.75	3536	9.24	8.18	15.73	B	57.8																				
GL-2	4/10/01	915	8.5	893	9.83	7.89	10.04	S	44.6	0.244	6.5	450	117	1017	40	0.51	1.7	1.79	0.813	0.594	6		1300	29.00	80.35	100.82	63.63	3.49	1.28
GL-2	4/10/01	915	8.5		9.7		9.95	3																					
GL-2	4/10/01	915	8.5	897	9.53	7.85	9.66	B	43.6																				
GL-2	5/3/01	817	12	1115	9.54	8.14	17.12	S	17.5	0.549	6.1	10	153	1100	19	<0.02	<0.1	1.12	0.429	0.296	6		11	33.32	68.65	91.60	65.00	1.22	1.1
GL-2	5/3/01	817	12		9.58		17.13	3																					
GL-2	5/3/01	817	12	1120	9.09	8.16	16.97	B	26.8																				
GL-2A	6/20/00	940	22	3280	6.96	8.29	20.69	S				10	227	3197	62	<0.02	<0.1	1.44	0.302	0.073	22	3051				86.5362286		1.54	1.42
GL-2B	6/20/00	945	22	3280	6.96	8.29	20.69					<10	<6	<7	<1	<0.02	<0.1	<0.21	<0.002	<0.002	<1	<7							

Appendix B

Phytoplankton Data

Table 26. Counts and biovolumes for algae collected from Geddes Lake, Charles Mix County, South Dakota, 2000-2001

SiteNumber	Date	Taxa	Cells/ml	Bio Volume
1	6/6/00	Peridinium cinctum	30	126000
1	6/6/00	Nitzschia acicularis	42	11760
1	6/6/00	Stephanodiscus hantzschii	61	12200
1	6/6/00	Nitzschia amphibia	42	4032
1	6/6/00	Melosira varians	84	54600
1	6/6/00	Cyclotella meneghiniana	2714	678500
1	6/6/00	Cyclotella pseudostelligera	103	16995
1	6/6/00	Stephanodiscus astraea minutula	30	10500
1	6/6/00	Scenedesmus quadricauda	122	19154
1	6/6/00	Chlamydomonas sp.	176	26400
1	6/6/00	Nephrocytium sp.	169	16055
1	6/6/00	Nitzschia palea	61	32025
1	6/6/00	Aphanizomenon flos-aquae	1680	196560
1	6/6/00	Cryptomonas erosa	42	21084
1	6/6/00	Ankistrodesmus falcatus	42	1050
1	6/6/00	Rhodomonas minuta	570	11400
1	6/6/00	Melosira granulata	42	23100
1	6/6/00	Selenastrum minutum	3600	72000
1	6/6/00	Nitzschia paleacea	30	2940
1	6/6/00	Euglena sp.	146	84680
1	6/6/00	Navicula minuscula	42	1890
1	6/6/00	Anabaena flos-aquae	1711	136880
1	6/6/00	Chrysococcus rufescens	260	22100
1	6/6/00	Trachelomonas volvocina	42	79170
1	6/6/00	Trachelomonas sp.	30	60000
1	6/20/00	Selenastrum minutum	895	17900
1	6/20/00	Euglena sp.	179	103820
1	6/20/00	Scenedesmus quadricauda	358	56206
1	6/20/00	Actinastrum hantzschii	537	128880
1	6/20/00	Cyclotella pseudostelligera	1342	221430
1	6/20/00	Cyclotella meneghiniana	895	223750
1	6/20/00	Rhodomonas minuta	537	10740
1	6/20/00	Oocystis pusilla	3579	193266
1	6/20/00	Nitzschia sp.	89	10680
1	6/20/00	Amphora perpusilla	89	14774
1	6/20/00	Anabaena flos-aquae	16823	1345840
1	6/20/00	Trachelomonas sp.	89	178000
1	6/20/00	Nitzschia acicularis	1700	476000
1	6/20/00	Nitzschia paleacea	626	61348
1	6/20/00	Aphanizomenon flos-aquae	7159	837603
1	6/20/00	Scenedesmus acuminatus	358	21480
1	6/20/00	Chlamydomonas sp.	89	13350
1	6/20/00	Nitzschia palea	358	187950
1	6/20/00	Cryptomonas erosa	179	89858
1	6/20/00	Ankistrodesmus falcatus	89	2225
1	7/6/00	Nitzschia acicularis	10252	2870560
1	7/6/00	Scenedesmus acuminatus	986	59160
1	7/6/00	Nitzschia fonticola	245	10290
1	7/6/00	Scenedesmus quadricauda	282	44274

Table 26. Continued

SiteNumber	Date	Taxa	Cells/ml	Bio Volume
1	7/6/00	Rhodomonas minuta	10895	217900
1	7/6/00	Nitzschia paleacea	1685	165130
1	7/6/00	Cyclotella meneghiniana	1404	351000
1	7/6/00	Ankistrodesmus falcatus	876	21900
1	7/6/00	Trachelomonas volvocina	490	923650
1	7/6/00	Chrysochromulina sp.	282	22560
1	7/6/00	Stephanodiscus hantzschii	141	28200
1	7/6/00	Aphanizomenon flos-aquae	103865	12152205
1	7/6/00	Cryptomonas erosa	4841	2430182
1	7/6/00	Chlamydomonas sp.	1122	168300
1	7/6/00	Navicula minuscula	141	6345
1	7/6/00	Cyclotella pseudostelligera	2353	388245
1	7/6/00	Selenastrum minutum	1966	39320
1	7/6/00	Unidentified misc. single ciliates and flagellates	141	141
1	7/6/00	Anabaena flos-aquae	15528	1242240
1	7/17/00	Actinastrum hantzschii	970	232800
1	7/17/00	Anabaena sp.	36203	2896240
1	7/17/00	Nitzschia sp.	289	34680
1	7/17/00	Ankistrodesmus falcatus	1352	33800
1	7/17/00	Nitzschia paleacea	1884	184632
1	7/17/00	Aphanizomenon flos-aquae	60665	7097805
1	7/17/00	Cyclotella pseudostelligera	1548	255420
1	7/17/00	Chromulina sp.	578	37570
1	7/17/00	Glenodinium sp.	242	169400
1	7/17/00	Cryptomonas erosa	3096	1554192
1	7/17/00	Nitzschia acicularis	22373	6264440
1	7/17/00	Cyclotella meneghiniana	6817	1704250
1	7/17/00	Cyclotella stelligera	242	37510
1	7/17/00	Navicula minuscula	6519	293355
1	7/17/00	Chlamydomonas sp.	1595	239250
1	7/17/00	Rhodomonas minuta	3526	70520
1	7/17/00	Tetraedron minimum	242	43560
1	7/17/00	Scenedesmus acuminatus	1156	69360
1	7/17/00	Selenastrum minutum	2276	45520
1	7/17/00	Trachelomonas volvocina	1063	2003755
1	7/17/00	Scenedesmus quadricauda	1940	304580
1	7/31/00	Anabaena sp.	103907	8312560
1	7/31/00	Scenedesmus acuminatus	2653	159180
1	7/31/00	Scenedesmus acuminatus	4864	291840
1	7/31/00	Nitzschia acicularis	14149	3961720
1	7/31/00	Anabaena flos-aquae	884	70720
1	7/31/00	Nitzschia paleacea	3095	303310
1	7/31/00	Navicula minuscula	6632	298440
1	7/31/00	Ankistrodesmus falcatus	2653	66325
1	7/31/00	Stephanodiscus hantzschii	442	88400
1	7/31/00	Cryptomonas erosa	1769	888038
1	7/31/00	Aphanizomenon flos-aquae	99485	11639745
1	7/31/00	Chlamydomonas sp.	1769	265350
1	7/31/00	Navicula minuscula	2653	119385

Table 26. Continued.

SiteNumber	Date	Taxa	Cells/ml	Bio Volume
1	7/31/00	Oocystis pusilla	1769	95526
1	7/31/00	Rhodomonas minuta	1326	26520
1	8/15/00	Nitzschia acicularis	10970	3071600
1	8/15/00	Scenedesmus quadricauda	1219	191383
1	8/15/00	Gloeocystis ampla	4876	2555024
1	8/15/00	Cryptomonas erosa	1219	611938
1	8/15/00	Ankistrodesmus falcatus	1828	45700
1	8/15/00	Aphanizomenon flos-aquae	365676	42784092
1	8/15/00	Anabaena sp.	27426	2194080
1	8/15/00	Selenastrum minutum	609	12180
1	8/15/00	Navicula cryptocephala v. veneta	609	57855
1	8/15/00	Cyclotella meneghiniana	26207	6551750
1	8/15/00	Chaetoceros sp.	609	57855
1	8/15/00	Rhodomonas minuta	1219	24380
1	8/15/00	Stephanodiscus hantzschii	2438	487600
1	8/15/00	Nitzschia paleacea	2438	238924
1	8/15/00	Stephanodiscus astraea minutula	609	213150
1	8/15/00	Scenedesmus acuminatus	2438	146280
1	9/7/00	Cyclotella meneghiniana	9742	2435500
1	9/7/00	Aphanizomenon flos-aquae	362604	42424668
1	9/7/00	Crucigenia quadrata	1443	122655
1	9/7/00	Chaetoceros sp.	4690	445550
1	9/7/00	Chlamydomonas sp.	722	108300
1	9/7/00	Anabaena flos-aquae	1804	144320
1	9/7/00	Cryptomonas erosa	1082	543164
1	9/7/00	Nitzschia acicularis	2526	707280
1	9/7/00	Nitzschia paleacea	2165	212170
1	9/7/00	Stephanodiscus hantzschii	361	72200
1	9/7/00	Selenastrum minutum	1804	36080
1	9/7/00	Rhodomonas minuta	361	7220
1	9/7/00	Ankistrodesmus falcatus	1804	45100
1	9/7/00	Anabaena	10824	865920
1	9/7/00	Eunotia pectinalis	361	259920
1	9/26/00	Anabaena sp.	10368	829440
1	9/26/00	Selenastrum minutum	518	10360
1	9/26/00	Cyclotella pseudostelligera	518	85470
1	9/26/00	Cyclotella meneghiniana	8294	2073500
1	9/26/00	Aphanizomenon flos-aquae	388793	45488781
1	9/26/00	Actinastrum hantzschii	4147	995280
1	9/26/00	Anabaena flos-aquae	25920	2073600
1	9/26/00	Chaetoceros sp.	8294	787930
1	9/26/00	Nitzschia paleacea	3629	355642
1	9/26/00	Nitzschia acicularis	18144	5080320
1	10/25/00	Microcystis sp.	1740	57420
1	10/25/00	Nitzschia sp.	60	7200
1	10/25/00	Chrysochromulina parva	5760	483840
1	10/25/00	Nitzschia acicularis	60	16800
1	10/25/00	Oscillatoria limnetica	37590	375900
1	10/25/00	Aphanocapsa sp.	187268	749072
1	10/25/00	Dactylococcopsis sp.	210	4200

Table 26. Continued.

SiteNumber	Date	Taxa	Cells/ml	Bio Volume
1	10/25/00	Scenedesmus acuminatus	360	21600
1	10/25/00	Chlamydomonas sp.	1920	288000
1	10/25/00	Chaetoceros elmorei	210	21000
1	10/25/00	Ankistrodesmus sp.	390	9750
1	10/25/00	Stephanodiscus astraea minutula	468	163800
1	10/25/00	Cyclotella atomus	173	3460
1	10/25/00	Unidentified flagellates	3360	100800
1	10/25/00	Nitzschia reversa	330	99000
1	10/25/00	Tetrastrum staurogeniaeforme	720	46800
1	10/25/00	Unidentified algae	4470	134100
1	10/25/00	Scenedesmus quadricauda	780	122460
1	10/25/00	Chroomonas sp.	3210	208650
1	10/25/00	Cryptomonas	1080	432000
1	10/25/00	Cyclotella meneghiniana	2749	687250
1	10/25/00	Gymnodinium sp.	120	324000
1	10/25/00	Kirchneriella sp.	5070	91260
1	10/25/00	Scenedesmus sp.	180	13500
1	10/25/00	Oscillatoria agardhii	91290	4381920
1	10/25/00	Chromulina sp.	300	19500
1	4/10/01	Synura uvella	146	190968
1	4/10/01	Tetrastrum staurogeniaeforme	2	130
1	4/10/01	Chromulina sp.	130	8450
1	4/10/01	Chromulina sp.	100	6500
1	4/10/01	Synedra delicatissima	1	660
1	4/10/01	Crucigenia sp.	6	510
1	4/10/01	Pandorina sp.	15	1875
1	4/10/01	Cryptomonas sp.	150	60000
1	4/10/01	Synedra sp.	1	280
1	4/10/01	Aphanocapsa sp.	250	1000
1	4/10/01	Chlamydomonas sp.	2490	373500
1	4/10/01	Pascheriella tetras	58	812
1	4/10/01	Stephanodiscus hantzschii	25	5000
1	4/10/01	Chlorogonium sp.	7	665
1	4/10/01	Surirella ovalis	2	2400
1	4/10/01	Ankistrodesmus sp.	90	2250
1	4/10/01	Scenedesmus opoliensis	2	564
1	4/10/01	Cyclotella meneghiniana	20	5000
1	4/10/01	Microcystis sp.	250	8250
1	4/10/01	Trachelomonas sp.	1	2000
1	4/10/01	Uroglenopsis americana	70	980
1	4/10/01	Amphiprora paludosa	1	4000
1	4/10/01	Navicula sp.	12	3000
1	4/10/01	Unidentified algae	640	19200
1	4/10/01	Nitzschia acicularis	9	2520
1	4/10/01	Micractinium sp.	350	11900
1	4/10/01	Pyramimonas sp.	2	452
1	4/10/01	Ochromonas sp.	30	2550
1	4/10/01	Scenedesmus acuminatus	8	480
1	4/10/01	Nitzschia sp.	10	1200

Table 26. Continued.

SiteNumber	Date	Taxa	Cells/ml	Bio Volume
1	5/3/01	Synura sp.	3	3927
1	5/3/01	Chlorogonium sp.	4	380
1	5/3/01	Chodatella sp.	5	300
1	5/3/01	Synedra sp.	13	3640
1	5/3/01	Chromulina sp.	185	12025
1	5/3/01	Chroomonas sp.	1230	79950
1	5/3/01	Chrysochromulina parva	50	4200
1	5/3/01	Gymnodinium sp.	1	2700
1	5/3/01	Coelastrum cambricum	6	300
1	5/3/01	Synura uvella	4	5232
1	5/3/01	Cryptomonas sp.	1510	604000
1	5/3/01	Cyclotella atomus	206	4120
1	5/3/01	Cyclotella meneghiniana	5968	1492000
1	5/3/01	Spermatozoopsis sp.	5	320
1	5/3/01	Phacus pseudonordstedtii	2	3618
1	5/3/01	Dactylococcopsis sp.	10	200
1	5/3/01	Dichotomococcus sp	760	5320
1	5/3/01	Dictyosphaerium pulchellum	680	10200
1	5/3/01	Surirella ovalis	2	2400

Appendix C

Tributary Water Quality Data

Table 27. Water quality data for the tributary sites, Geddes Lake watershed, Charles Mix County, 2000-2001.

SITE	DATE	TIME	Air Tem	Cond.	DO	pH	TYPE	W. Tem	TURB.	Fecal C	Alk. M	Alk. P	T. Solids	Sus. Sol	Ammoni	Nitrate	TKN	T. Phos.	T DIS P	VTSS	TDS	E-COLI
GLO-1	06/20/2000	915	22	3295	2.59	7.75	GRAB	20.15	37.5	50	235	0	3211	48	0.2	0.2	1.54	0.392	0.111	22	3015	
GLO-1	04/05/2001	1020	11	838	12.54	7.79	GRAB	5	30.2	<10	124	0	1089	20	1.05	1.1	2.03	0.587	0.454	4		11
GLO-1	04/05/2001	1025	11	838	12.54	7.79	GRAB	5	30.2	20	125	0	1079	21	1.03	1.1	2.21	0.569	0.448	6		19.9
GLO-1	04/05/2001	1030	11	838	12.54	7.79	GRAB	5	30.2	<10	<6	0	9	<1	<0.02	<0.1	<0.36	<0.002	0.005	<1		<1
GLO-1	04/10/2001	850	8.5	892	9.94	7.93	GRAB	9.95	43.9	610	115	0	1026	38	0.5	1.8	1.6	0.785	0.618	4		816
GLO-1	04/10/2001	855	8.5	892	9.94	7.93	GRAB	9.95	43.9	540	116	0	1013	38	0.49	1.8	1.75	0.82	0.581	2		980
GLO-1	04/10/2001	900	8.5	892	9.94	7.93	GRAB	9.95	43.9	<10	<6	0	<7	<1	<0.02	0.1	<0.36	<0.002	<0.002	<1		<1
GLO-1	04/19/2001	1200	17	926	9.54	8.14	GRAB	9.98	28.8	30	134	0	1030	27	0.32	0.8	1.35	0.558	0.461	4		41.9
GLO-1	05/01/2001	700	14	1129	3.09	7.69	GRAB	17.18	37.4	40	154	0	1099	42	0.05	0.1	1.47	0.568	0.37	6		33.6
GLO-1	05/07/2001	1420	16	1329	10.5	8.07	GRAB	15.23	16.6	760	166	0	1373	20	<0.02	0.3	1.54	0.502	0.375	7		770

SITE	DATE	TIME	Air Tem	Cond.	DO	pH	TYPE	W. Tem	TURB.	Fecal C	Alk. M	Alk. P	T. Solids	Sus. Sol	Ammoni	Nitrate	TKN	T. Phos.	T DIS P	VTSS	TDS	E-COLI
GLT-2	05/18/2000	1840	13.01	2962	8.1	8.27	COMP	14.54	41	39000	245	0	3548	94	0.29	1.7	1.69	0.289	0.059	20	3140	
GLT-2	06/21/2000	1210	29				GRAB			100	315	0	4189	23	0.11	0.3	0.82	0.109	0.085	<1	4021	
GLT-2	06/28/2000	1030	25	3839	7.7	7.75	GRAB	18.3	13.6	1000	306	0	4064	25	0.02	0.4	0.69	0.137	0.069	3	3912	
GLT-2	11/01/2000	1424	11	3348	7.54	7.71	GRAB	15.12	15.6	1800	285	0	3672	11	0.05	5	1.33	0.264	0.213	3		
GLT-2A	06/21/2000	1215	29				GRAB			110	313	0	4200	25	0.1	0.3	0.83	0.145	0.084	<1	4014	
GLT-2B	06/21/2000	1220	29				GRAB			<10	<6	0	<7	<1	<0.02	<0.1	<0.21	<0.002	0.002	<1	<7	
GLT-2	04/05/2001	1110	7	1554	13.5	7.43	GRAB	5.61	10.4	40	213	0	2199	9	0.5	3.2	1.19	0.306	0.268	3		26.2
GLT-2	04/10/2001	820	8.5	1432	10.4	8.2	GRAB	7.01	14.3	60	183	0	1923	10	0.45	3.1	1.34	0.387	0.314	4		194
GLT-2	04/19/2001	1115	16	2390	14	7.99	GRAB	10.55	13	780	247	0	3139	12	<0.02	3	0.49	0.102	0.061	4		816
GLT-2	04/24/2001	1211	26	720	10.67	7.94	GRAB	9.49	155.2	6000	86	0	895	126	0.36	2.4	0.94	0.796	0.501	20		>2420
GLT-2	05/01/2001	801	16	2148	9.7	7.6	GRAB	13.96	10.5	170	238	0	2643	13	<0.02	2.5	0.83	0.178	0.127	1		178
GLT-2	05/07/2001	1348	17	1509	14.28	8.44	GRAB	17.02	19.1	520	151	9	1529	20	<0.02	2.3	1.43	0.434	0.341	7		1900

SITE	DATE	TIME	Air Tem	Cond.	DO	pH	TYPE	W. Tem	TURB.	Fecal C	Alk. M	Alk. P	T. Solids	Sus. Sol	Ammoni	Nitrate	TKN	T. Phos.	T DIS P	VTSS	TDS	E-COLI
GLT-3	05/18/2000	1807	16.57	3533	8.77	8.36	COMP	15.29	52.9	3100	205	0	3643	104	0.01	0.1	2.87	0.391	0.151	18	3217	
GLT-3	06/01/2000	2900	24	3076	10.5	8.04	GRAB	21.06	133	2900	263	0	3286	180	0.01	0.05	2.2	0.497	0.078	16	3007	
GLT-3	06/21/2000	1250	29				GRAB			3700	233	0	3621	244	0.04	<0.1	1.66	0.723	0.075	32	3248	
GLT-3	07/05/2000	1130		3340	1.6	7.66	GRAB	23.6		28000	283	0	3399	42	1.26	<0.1	3.95	0.813	0.483	3	3233	
GLT-3	07/10/2000	1330					COMP			16000	278	0	3146	82	1.73	0.9	3.02	0.609	0.32	14	2905	
GLT-3	11/01/2000	1400	11	2966	9.8	8.03	GRAB	15.74	19.3	15000	208	0	3165	23	0.03	1	1.3	0.339	0.232	5		
GLT-3	04/05/2001	1134	7	1124	12.78	7.41	GRAB	6.01	12.7	10	157	0	1495	12	0.4	1.6	1.25	0.598	0.532	4		24.6
GLT-3	04/10/2001	1145	8.5	1033	9.55	7.88	GRAB	9.85	31.1	30	138	0	205	34	0.13	1.4	1.35	0.725	0.581	6		50.4
GLT-3	04/19/2001	900	10	1205	9.77	7.94	GRAB	10.64	18	<10	168	0	1374	23	0.03	0.6	0.77	0.485	0.381	4		17.3
GLT-3A	04/19/2001	905	10	1205	9.77	7.94	GRAB	10.64	18	<10	166	0	1370	24	0.03	0.6	0.75	0.484	0.383	5		22.8
GLT-3B	04/19/2001	910	10	1205	9.77	7.94	GRAB	10.64	18	<10	<6	0	14	<1	<0.02	0.1	<0.36	<0.002	0.004	<1		<1
GLT-3	05/01/2001	852	16	1348	9.75	7.89	GRAB	16.87	16.6	290	176	0	1380	26	<0.02	0.1	1.07	0.493	0.387	3		687
GLT-3	05/07/2001	1332	17	1080	10.8	7.86	GRAB	14.42	26.6	3500	136	0	1108	35	<0.02	0.3	1.86	0.743	0.633	6		1990

SITE	DATE	TIME	Air Tem	Cond.	DO	pH	TYPE	W. Tem	TURB.	Fecal C	Alk. M	Alk. P	T. Solids	Sus. Sol	Ammoni	Nitrate	TKN	T. Phos.	T DIS P	VTSS	TDS	E-COLI
GLT-4	05/18/2000	1720	16.01	3807	8.86	8.26	GRAB	15.43	49.1	20000	156	0	4070	55	0.19	0.9	2.61	0.608	0.38	15	3670	
GLT-4	06/19/2000	1400	29	4458	13.66	8.73	GRAB	25.23	1.5	10	188	26	4074	6	0.03	<0.1	0.87	0.681	0.232	4	3716	
GLT-4	08/08/2000	1230	22	4081	4.51	8.22	GRAB	25.36	18.5	4100	168	0	4333	21	0.13	<0.1	1.42	0.426	0.334	9		
GLT-4	11/01/2000	1330	11	3411	9.16	7.76	GRAB	15.47	20	1400	272	0	3779	21	<0.02	0.1	1.39	0.298	0.153	5		
GLT-4	08/08/2000	1235	22	4081	4.51	8.22	GRAB	25.36	18.5	3100	166	0	4400	21	0.14	<0.1	1.78	0.41	0.329	8		
GLT-4	08/08/2000	1240	22	4081	4.51	8.22	GRAB	25.36	18.5	<10	<6	0	<7	<1	<0.02	<0.1	<0.21	<0.002	<0.002	<1		
GLT-4	04/05/2001	1250	9	968	14.27	6.3	GRAB	6.24	16.6	160	133	0	1242	20	0.46	2	1.34	0.738	0.638	8		326
GLT-4	04/10/2001	1245	9	984	9.29	7.74	GRAB	9.51	26.7	70	122	0	1144	27	0.05	1.5	1.48	0.753	0.637	6		114
GLT-4	04/19/2001	1046	17	1017	9.67	7.91	GRAB	10.45	26.5	650	144	0	1148	43	0.03	0.5	1.11	0.58	0.43	7		1550
GLT-4	05/01/2001	1032	20	1146	12.1	7.84	GRAB	17.48	12.5	380	161	0	1127	22	<0.02	0.3	1.17	0.686	0.586	3		727
GLT-4	05/07/2001	1257	17	910	12.12	7.84	GRAB	14.18	22.4	1700	127	0	913	20	<0.02	0.2	1.66	0.764	0.674	4		2420

SITE	DATE	TIME	Air Tem	Cond.	DO	pH	TYPE	W. Tem	TURB.	Fecal C	Alk. M	Alk. P	T. Solids	Sus. Sol	Ammoni	Nitrate	TKN	T. Phos.	T DIS P	VTSS	TDS	E-COLI
GLT-5	05/18/2000	1640	14.39	3699	9.58	8.44	COMP	16.5	17.2	13000	136	0	3295	70	0.05	0.2	1.49	0.452	0.239	16	2974	
GLT-5	06/01/2000	1240	20.25	3240	10.95	8.1	GRAB		30.4	6400	206	0	3673	56	0.01	0.05	3.2	0.543	0.157	18	3496	
GLT-5	04/05/2001	1220	8	732	13.26	7.39	GRAB	6.01	10.2	20	100	0	753	7	0.38	1.7	1.57	0.88	0.861	4		80.1
GLT-5	04/05/2001	1225	8	732	13.26	7.39	GRAB	6.01	10.2	60	101	0	751	9	0.37	1.7	1.77	0.916	0.867	5		108
GLT-5	04/05/2001	1230	8	732	13.26	7.39	GRAB	6.01	10.2	<10	<6	0	8	<1	<0.02	0.1	<0.36	<0.002	<0.002	<1		<1
GLT-5	04/10/2001	1215	8.5	741	8.43	7.68	GRAB	9.6	13	40	107	0	773	8	0.05	0.8	1.22	0.953	0.937	1		71.2
GLT-5	04/19/2001	1005	16	839	9.64	7.98	INT	10.36	21.6	20	128	0	859	33	<0.02	0.1	1.4	0.874	0.758	7		8.5
GLT-5	04/24/2001	1302	23	368	8.04	7.61	INT	11.96	66.7	2600	68	0	464	47	0.08	0.7	1.29	0.877	0.681	11		>2420
GLT-5	05/01/2001	1003	19	874	9.21	7.74	GRAB	17.81	9.5	60	143	0	827	10	<0.02	<0.1	1.43	0.978	0.975	<1		69.1
GLT-5	05/07/2001	1231	17	897	11.71	7.77	INT	13.34	19.6	410	127	0	899	19	<0.02	0.2	1.74	0.863	0.784	6		1417

Appendix D

Feedlot Information and Rating Scores

Table 28. Feedlot information and rating scores for feedlots in the Geddes Lake watershed.

OBJECTID	Cell#	LotArea	LotCurveNu	Roofed_Are	Rainfall	Duration	Animal	Number_	SoilType	Cover2a	cellarea	lot/cell area	Rating Score
73	962	17.90	91	0.04	0.0	365.0	Sheep/Goat	100	B	Pasture Poor	93.18	0.1921013	38
50	1091	9.72	91	0.13	0.0	365.0	Beef Cow (Slaughter Steer)	120	B	Small Grains	78.28	0.1242274	54
46	1113	16.00	91	0.14	0.0	365.0	Beef Cow (Young beef)	30	B	Pasture Poor	53.6	0.2985075	36
43	1141	45.37	91	0.01	0.0	365.0	Beef Cow (Young beef)	10	C	Pasture Good	74.72	0.6071694	17
90	1343	1.29	91	0.02	0.0	365.0	Beef Cow (Slaughter Steer)	50	B	Pasture Poor	448.79	0.0028744	96
44	1372	13.00	91	0.01	0.0	365.0	Beef Cow (Young beef)	100	B	Pasture Good	228.62	0.0568629	44
60	1473	8.00	91	0.17	0.0	365.0	Beef Cow (Slaughter Steer)	100	B	Pasture Poor	15.12	0.5291005	55
72	1583	6.44	91	0.00	0.0	365.0	Beef Cattle (Mature)	10	C	Woodland	77.39	0.0832149	19
29	1732	2.88	91	0.06	0.0	365.0	Beef Cow (Young beef)	30	C	Small Grains	388.3	0.0074152	37
74	1781	11.81	91	0.00	0.0	365.0	Beef Cow (Slaughter Steer)	125	B	Pasture Poor	104.53	0.1129819	52
30	1832	28.15	91	0.05	0.0	365.0	Beef Cow (Young beef)	40	B	Pasture Poor	227.06	0.123954	29
77	1853	3.89	91	0.10	0.0	365.0	Beef Cattle (Mature)	10	B	Pasture Poor	36.25	0.1073103	21
78	1903	1.62	91	0.00	0.0	365.0	Beef Cow (Slaughter Steer)	20	C	Small Grains	48.48	0.0334158	65
25	2063	4.14	91	0.00	0.0	365.0	Beef Cow (Young beef)	100	C	Pasture Poor	18.24	0.227125	38
17	2202	8.00	91	0.16	0.0	365.0	Beef Cow (Young beef)	25	B	Pasture Poor	151.01	0.0529766	29
24	2252	10.30	91	0.04	0.0	365.0	Beef Cow (Young beef)	60	B	Pasture Good	83.62	0.1231906	35
23	2253	6.00	91	0.09	0.0	365.0	Beef Cow (Young beef)	80	B	Woodland	123.87	0.0484379	53
71	2303	3.69	91	0.18	0.0	365.0	Sheep/Goat	30	B	Farmstead	73.83	0.0499797	30
75	2362	6.52	91	0.60	0.0	365.0	Dairy Cattle (Mature)	100	B	Row Crop (Straight)	136.11	0.0479024	62
31	2432	3.44	91	0.05	0.0	365.0	Beef Cow (Young beef)	20	B	Pasture Good	52.93	0.0650828	16
41	2481	5.04	91	0.14	0.0	365.0	Beef Cow (Slaughter Steer)	80	C	Pasture Good	134.99	0.0373036	74
76	2522	7.26	91	0.08	0.0	365.0	Beef Cattle (Mature)	30	A	Pasture Poor	123.87	0.0586098	45
83	2642	7.57	91	0.07	0.0	365.0	Beef Cow (Slaughter Steer)	100	B	Pasture Poor	106.97	0.0707675	66
82	2691	4.26	91	0.08	0.0	365.0	Beef Cow (Slaughter Steer)	40	B	Pasture Poor	91.63	0.0464913	35
16	2782	3.80	91	0.07	0.0	365.0	Beef Cow (Young beef)	20	B	Farmstead	75.61	0.0502143	30
4	3093	6.22	91	0.00	0.0	365.0	Beef Cow (Young beef)	100	B	Pasture Poor	61.16	0.1016942	57
84	3142	16.71	91	0.08	0.0	365.0	Beef Cow (Slaughter Steer)	40	C	Pasture Poor	248.86	0.0671462	57
5	3143	18.00	91	0.26	0.0	365.0	Beef Cow (Young beef)	100	B	Small Grains	217.28	0.0828424	55
9	3272	3.64	91	0.06	0.0	365.0	Beef Cow (Slaughter Steer)	70	B	Woodland	42.03	0.0867109	46
10	3333	2.22	91	0.07	0.0	365.0	Beef Cow (Young beef)	30	B	Pasture Good	33.58	0.0660325	22
21	3592	18.14	91	0.04	0.0	365.0	Beef Cow (Young beef)	100	C	Woodland	139.66	0.1298561	40
81	3703	5.68	91	0.00	0.0	365.0	Beef Cattle (Mature)	80	B	Pasture Good	90.51	0.0627555	53
11	4011	8.43	91	0.00	0.0	365.0	Dairy Cattle (Mature)	30	B	Farmstead	74.06	0.1137696	58
12	4222	15.70	91	0.13	0.0	365.0	Dairy Cattle (Mature)	100	B	Farmstead	175.25	0.0896034	66
14	4452	2.08	91	0.02	0.0	365.0	Beef Cow (Slaughter Steer)	10	B	Pasture Poor	108.08	0.0192096	16
13	4731	1.06	91	0.05	0.0	365.0	Beef Cow (Young beef)	100	B	Pasture Good	96.3	0.0109649	56
26	4902	19.15	91	0.14	0.0	365.0	Beef Cow (Young beef)	40	C	Pasture Poor	40.48	0.4730336	31
36	5051	4.68	91	0.09	0.0	365.0	Beef Cow (Young beef)	80	B	Pasture Good	74.5	0.0628062	43
62	5252	17.30	91	0.02	0.0	365.0	Beef Cow (Slaughter Steer)	100	B	Woodland	216.39	0.0799482	54
37	5301	18.12	91	0.00	0.0	365.0	Beef Cow (Slaughter Steer)	100	B	Pasture Poor	74.95	0.2416985	56
87	5382	19.33	91	0.02	0.0	365.0	Beef Cow (Slaughter Steer)	280	B	Pasture Poor	223.06	0.0866583	72
85	5402	33.31	91	0.15	0.0	365.0	Beef Cow (Slaughter Steer)	100	C	Pasture Poor	21.79	1.5286829	55
88	5561	24.68	91	0.00	0.0	365.0	Beef Cow (Slaughter Steer)	40	C	Pasture Poor	74.06	0.3332433	38
89	5563	9.66	91	0.02	0.0	365.0	Beef Cow (Slaughter Steer)	70	C	Pasture Poor	119.2	0.0810403	57
45	5653	4.30	91	0.00	0.0	365.0	Beef Cow (Young beef)	20	B	Pasture Poor	174.58	0.0246204	26
65	5733	8.00	91	0.00	0.0	180.0	Beef Cow (Young beef)	160	B	Pasture Poor	108.75	0.0735632	37
70	5851	5.29	91	0.03	0.0	365.0	Beef Cattle (Mature)	15	B	Pasture Good	80.06	0.0660754	33

TOTAL MAXIMUM DAILY LOAD EVALUATION

For

GEDDES LAKE

PEASE CREEK WATERSHED

(HUC 10140101)

CHARLES MIX COUNTY, SOUTH DAKOTA

SOUTH DAKOTA DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES

March, 2007

Geddes Lake Total Maximum Daily Load

Waterbody Type:	Lake (Impounded)
State Waterbody (ADB) ID:	SD-MI-L-GEDDES_01
303(d) Listing Parameter:	TSI
Designated Uses:	Recreation, warm-water semi-permanent fish life
Size of Waterbody:	70 acres
Size of Watershed :	76,160 acres
Water Quality Standards:	Narrative and Numeric
Indicators:	Average Secchi-chlorophyll *a* TSI, pH, D.O.
Analytical Approach:	AnnAGNPS, BATHTUB, FLUX
Location:	HUC Code: 10140101
Goals:	30 % reduction in the phosphorus load, increase dissolved oxygen to 5.0 mg/l, decrease in-lake chlorophyll a concentration to 9.0 mg/m³, decrease in-lake total phosphorus concentration to 0.126 mg/l.
Targets:	Median growing season Secchi-chlorophyll *a* TSI value of 76.3, dissolved oxygen of 5.0 mg/l, 1,435.91 kg/yr (3.93 kg/day) external TP load.

Objective

The intent of this summary is to clearly present the components of the TMDL for Geddes Lake. The TMDL was developed in accordance with Section 303(d) of the federal Clean Water Act and guidance developed by EPA.

Introduction

Geddes Lake is a 70-acre man-made impoundment located in southwest Charles Mix County, South Dakota (Figure 1). The 1998, 2000, 2002, 2004, and 2006 South Dakota Integrated Reports identified Geddes Lake for TMDL development for trophic state index (TSI) and increasing eutrophication trend.

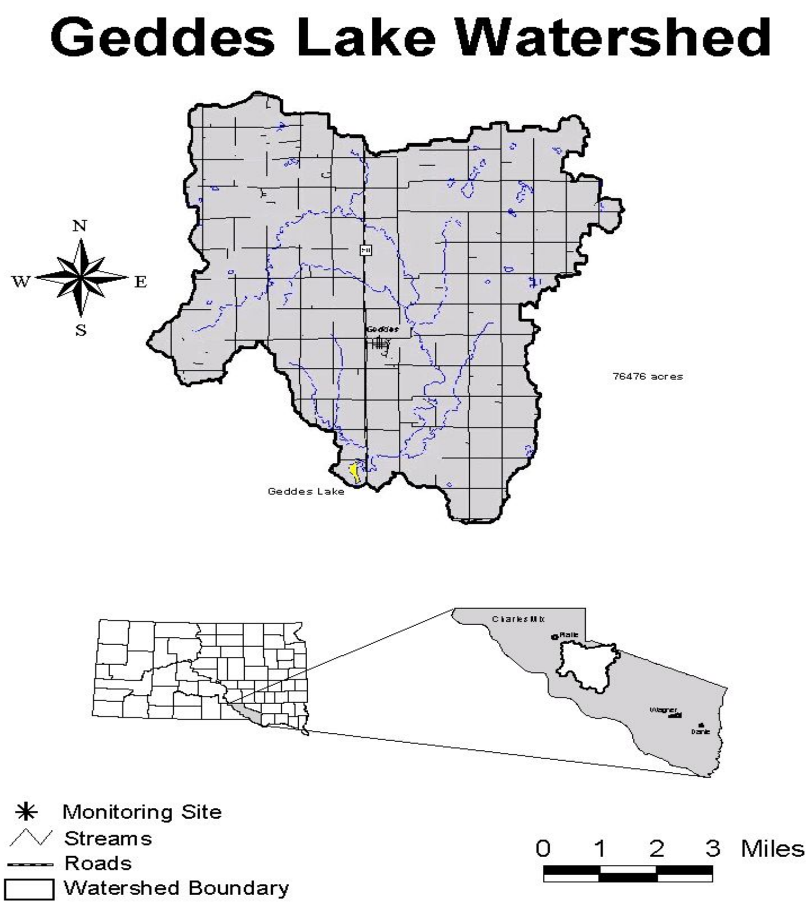

Figure 1. Location of Geddes Lake and its watershed.

The damming of Pease Creek 4 miles south of Geddes created the lake, which has an average depth of 3.2 feet (0.98 meters), a maximum depth of 12 feet (3.66 m), holds 70 acre-feet of water, and does not stratify during the summer. The outlet for the lake empties into Pease Creek, which eventually reaches the Missouri River.

Problem Identification

Pease Creek is the primary tributary to Geddes Lake and drains a mixture of grazing lands with cropland acres. The watershed is primarily comprised of cropland (78.8%) and rangeland (20.8%). Forest (farmstead woodlots), urban areas, and water make-up the remainder of the watershed. Approximately 47 livestock feedlots/winter feeding areas are present in the watershed. The stream carries nutrient loads, which degrade water quality in the lake and cause increased eutrophication.

Description of Applicable Water Quality Standards & Numeric Water Quality Targets

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

Individual parameters, including the lake's trophic state index (TSI) (Carlson 1977) value, determine the support of beneficial uses and compliance with standards. A gradual increase in fertility of the water due to nutrients washing into the lake from external sources is a sign of the eutrophication process. Geddes Lake was identified in the 1996, 1998, 2000, and 2002 South Dakota 305(b) Water Quality Assessment Reports as not supporting its beneficial uses due to algae, siltation, nutrients, turbidity, suspended solids, and dissolved oxygen. The 2004 and 2006 South Dakota Integrated reports listed the lake as not supporting its fish life propagation use due to an unacceptable trophic state index.

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

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

The numeric target, established to improve the trophic state of Geddes Lake, is a median growing season Secchi-chlorophyll *a* TSI of 76.3. This target may be achieved by a 30% reduction in phosphorus in the contributing tributaries through implementation of BMPs in the watershed.

This TMDL is based on phosphorus loading and is written to address the Secchi-chlorophyll *a* TSI impairment listing as well as the D.O. impairment discovered during the assessment. The TMDL is intended to ensure the narrative water quality standards and the D.O. standard is met in the lake.

Pollutant Assessment

Point Sources

There are no point sources of pollutants in this watershed.

Nonpoint Sources/ Background Sources

The FLUX modeling resulted in predicted total phosphorus loads of 182.5 kg/yr and 1868.8 kg/yr for the unnamed tributary to the lake and for Pease Creek respectively. This total load of 2,051.3 kg/yr is thought to come from a combination of non-point or natural sources. The sediment survey of the lake did not reveal any unusual sediment accumulation, although deepening the lake will extend the life of the lake and remove legacy phosphorus.

Linkage Analysis

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

In addition to water quality monitoring, data were collected to complete a watershed land use model. The Annualized Agriculture Nonpoint Pollution Source (AnnAGNPS) model was used to provide comparative values for each of the land uses and animal feeding operations located in the watershed.

The impacts of phosphorus reductions on the condition of Geddes Lake were calculated using BATHTUB, an Army Corps of Engineers model. The model predicted that by reducing phosphorus from the tributaries by 92% the TSI target value of 63.4 will be attained. This was not considered realistic and so the TSI target was changed to 76.3, which can be attained with a 30% reduction in tributary phosphorus loads.

TMDL and Allocations

TMDL (Annual)

0 kg/yr (WLA)
1,435.91 kg/yr (LA) nonpoint sources + natural
Implicit (MOS)
1,435.91 kg/yr (TMDL)

TMDL (Daily)

0 kg/day (WLA)
3.93 kg/day (LA) nonpoint sources + natural
Implicit (MOS)
3.93 kg/day (TMDL)

The South Dakota Department of Environment and Natural Resources believes that describing loadings as an annual load is more realistic and more protective of the waterbody. Most phosphorus based eutrophication models, such as those in the BATHTUB Program, use annual phosphorus loads. In addition, seasonality and uncontrollable precipitation make meeting a daily load unrealistic. Implementation plans will most likely be planned off of annual loads. The daily load is simply expressed as the annual load divided by 365.

Wasteload Allocations (WLAs)

There are no point source discharges of phosphorus in the watershed. Therefore, the "wasteload allocation" component of these TMDLs is considered a zero value. The TMDLs are considered wholly included within the "load allocation" component.

Load Allocations (LAs)

A 30% reduction in the phosphorus load to Geddes Lake may be obtained through fertilizer management, changing crops to pastureland or CRP, adopting no-till, and feedlot improvement. The annual phosphorus load from the tributaries should be reduced from 2,051.3 kg/yr to 1,435.91 kg/yr.

Critical Conditions

The impairments to Geddes Lake are most severe during the late summer. This is the result of warm water temperatures and peak algae growth.

Dissolved Oxygen

The proposed phosphorus TMDL should indirectly address the dissolved oxygen issue because nutrient loadings are likely the root cause of excess algae and the subsequent loss of dissolved oxygen through decomposition of dead algae and other organic matter. Addressing the phosphorus problem should also prevent or minimize dangerously low dissolved oxygen levels in the lake. Presumably phosphorus control will result in less algae and therefore less organic matter to decompose and less oxygen demand by bacteria. Aeration is recommended as a solution to the low DO levels. The TMDL for dissolved oxygen is set at the water quality standard criterion of 5.0 mg/l.

Follow-Up Monitoring

As part of the implementation, monitoring and evaluation efforts will target the effectiveness of implemented BMP's. Sample sites will be based on BMP site selection and parameters will be based on a product specific basis.

Monitoring during the implementation phase will begin prior to and continue after construction of the proposed BMP's. The lake will be sampled at appropriate intervals throughout the project. Samples will be collected both upstream and downstream of the proposed project area to measure impact of the specific site.

Once the implementation project is completed, long-term monitoring will continue every four years as part of the SDDENR Statewide Lakes Monitoring Program.

Public Participation

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

1. South Central Water Development District Board Meetings
2. Charles Mix County Conservation District Board Meetings
3. Articles in the local newspapers
4. Individual contact with residents in the watershed.

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

Implementation Plan

The South Dakota DENR is working with a regional RC&D (Resource Conservation and Development) to initiate an implementation project. It is expected that a local sponsor will request project assistance and seek 319 funding once the final report is accepted.

EPA REGION VIII TMDL REVIEW FORM

Document Name:	**Geddes Lake Watershed Assessment Final Report**
Submitted by:	**Gene Stueven, SD DENR**
Date Received:	**June 16, 2007**
Review Date:	**July 20, 2007**
Reviewer:	**Vern Berry, EPA**
Formal or Informal Review?	**Informal – Public notice**

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

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

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

1. Water Quality Impairment Status

Criterion Description – Water Quality Impairment Status

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

☐ Satisfies Criterion
☐ Satisfies Criterion. Questions or comments provided below should be considered.
☒ Partially satisfies criterion. Questions or comments provided below need to be addressed.
☐ Criterion not satisfied. Questions or comments provided below need to be addressed.
☐ Not a required element in this case. Comments or questions provided for informational purposes.

SUMMARY – Geddes Lake is a 70 acre man-made lake impoundment located on Pease Creek in southwest Charles Mix County, South Dakota. Pease Creek is within the Fort Randall Reservoir sub-basin of the Missouri River Basin. It is listed on South Dakota's 2006 303(d) list as impaired for trophic state index (TSI) due to nonpoint sources and is ranked as priority 1 (i.e., high priority) for TMDL development. The watershed is approximately 76,476 acres and drains predominantly cropland and pastureland. The mean Secchi – chlorophyll *a* TSI during the period of the project assessment was 73.04, and is not currently meeting its designated beneficial use for warmwater semi-permanent fish life propagation.

COMMENTS – The dissolved oxygen section on pages 14 -16 mention that a DO TMDL should be calculated; however the TMDL Summary (p. 72) only includes brief explanation of how the phosphorus TMDL "might indirectly address the dissolved oxygen issue." Although the larger assessment report contains many of the elements of a DO TMDL, the TMDL Summary does not a include a DO TMDL. Will a separate DO TMDL be developed? Or will the Geddes Lake DO impairment be include on the next Section 303(d) list of impaired waters?

In order for EPA to complete the TMDL approval with the correct linkage to the Section 303(d) waterbody listing, the TMDL needs to include the State waterbody ID on the first page of the TMDL Summary (p. 68). We would also like to see a clear linkage between the 303(d) listing cause(s) (e.g., TSI) and the TMDL goal(s) and target(s). E.g., this is a phosphorus TMDL written to address the TSI and DO impairment listing causes using the Secchi-chlorophyll *a* TSI as a target to ensure the narrative water quality standards are met in the lake.

DENR RESPONSE – A TMDL of 5 mg/l for dissolved oxygen has been added to the report and the TMDL summary.

Clear linkage between the 303(d) listing cause(s) and the TMDL goal(s) and target(s) has been added to the TMDL summary on the last paragraph of Section "Description of Applicable Water Quality Standards & Numeric Water Quality Targets:.

2. Water Quality Standards

Criterion Description – Water Quality Standards

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

☒ Satisfies Criterion
☐ Satisfies Criterion. Questions or comments provided below should be considered.
☐ Partially satisfies criterion. Questions or comments provided below need to be addressed.
☐ Criterion not satisfied. Questions or comments provided below need to be addressed.

☐ Not a required element in this case. Comments or questions provided for informational purposes.

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

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

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

Other applicable water quality standards are included on pages 3 - 5 of the assessment report.

3. Water Quality Targets

Criterion Description – Water Quality Targets

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

☐ Satisfies Criterion
☐ Satisfies Criterion. Questions or comments provided below should be considered.
☒ Partially satisfies criterion. Questions or comments provided below need to be addressed.
☐ Criterion not satisfied. Questions or comments provided below need to be addressed.
☐ Not a required element in this case. Comments or questions provided for informational purposes.

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

The actual Secchi-chlorophyll *a* TSI for Geddes Lake during the period of the assessment was 73.04. Nutrient reduction response modeling was conducted with BATHTUB, an Army Corps of Engineers eutrophication response model. The results of the modeling show that 92% or more reduction in the total phosphorus loading from the watershed would be necessary to meet the ecoregion-based beneficial use median Secchi-chlorophyll *a* TSI target of 63.4 or less. However, Geddes Lake does not appear to fit the recommended beneficial use-based target due to legacy phosphorus loading to the lake and the technical and financial inability to fully treat the internal and external loading to the lake. Therefore, a site specific Secchi-chlorophyll *a* TSI of $\leq$ 76.3 was chosen for Geddes Lake.

The proposed water quality target for this TMDL is: **maintain a growing season median Secchi -chlorophyll *a* TSI at or below 76.3.**

COMMENTS – The proposed Secchi-chlorophyll *a* TSI target of 76.3 includes an explanation that a 30% reduction in phosphorus loading is necessary to achieve the target. This implies that the current Secchi-chlorophyll *a* TSI is above 76.3, however the report says that the Geddes Lake value is 73.04 (p. 23). The Long-Term Trends section (p. 29) seems to indicate that the current TSI value is closer to 80: “A TSI decrease of approximately 17 points is needed to reach the target TSI of 63.4.” The mean TSI for Geddes Lake provided in Table 1 (p. 3) is 77.6. Please provide a clear statement of the current value for the Secchi-chlorophyll *a* TSI, and an explanation of how that value relates to the modeled TSI value and the target TSI value.

TMDL water quality targets must be set at a level that meets all applicable water quality standards. The Geddes Lake report seems to have set a water quality target that is based on what is “realistic” or “possible” rather than the WQS. Narrative water quality standards allow some flexibility in the determination of the appropriate target. If the recommended beneficial use-based TSI target does not fit, then an alternate target can be specified if ***it can be expected to meet the applicable water quality standards, which include the beneficial uses of the lake***. Either the TMDL target needs to be specified at a level which meets the applicable water quality standards (e.g., Secchi-chlorophyll *a* TSI of $\leq$ 63.4), or the TMDL needs to include an explanation and statement that the specified alternate target (i.e., TSI = 76.3) will meet the applicable water quality standard and will fully support the lake’s beneficial uses.

DENR RESPONSE – The chlorophyll *a* TSIs in the report were discovered to be based on an incorrect equation. The chlorophyll *a* TSIs were recalculated and these data were then used. Table 25 was updated with the new chlorophyll *a* TSI values and the actual median Secchi-chlorophyll *a* TSI was recalculated. The difference between the actual median growing-season (May 15 – September 15) Secchi-chlorophyll *a* TSI (77.13) versus the median of the “estimated at 0% reduction” Secchi TSI and chlorophyll *a* TSI in Table 21 (76.88) was 0.25 TSI points. This was not considered significant and so no adjustment was made to the BATHTUB Program model.

The actual median Secchi-chlorophyll a TSI value is only slightly greater than the proposed alternate TSI target of 76.3 reductions. Even so, such a minor shift in TSI will require a 30% decrease in phosphorus loading to the lake.

The long-term-TSI trend table contained some chlorophyll *a* TSI values that were incorrectly calculated. In addition, total phosphorus was originally included in the mean TSI values and this likely resulted in increased TSIs. These issues were remedied by recalculating the chlorophyll *a* TSI values and including the 2000 median Secchi-chlorophyll *a* TSIs instead of an average TSI based on Secchi, chlorophyll *a*, and total phosphorus. This is more in line with the current SDDENR approach of only using Secchi transparency and chlorophyll *a* TSIs..

Table 1 was presented as a comparison of TSI values from Geddes Lake to other lakes in the area. Conveniently, the average TSI values used in this table were previously reported in Stueven and Stewart (1996). However, the TSIs in Table 1 were average TSIs that were based on Secchi transparency, chlorophyll *a*, <u>and</u> total phosphorus. So it is not unexpected to see that these TSI values are greater than TSIs based solely on Secchi transparency and chlorophyll *a*. These are historical data used for rough comparison purposes only.

There are many lakes in South Dakota where the total phosphorus reductions necessary to meet the established TSI goal are not realistic due to economic and/or social constraints on the landowners. Consequently, it is necessary for SDDENR to choose an alternate TSI target and proposed reductions in total phosphorus loading for Geddes Lake that best fits the economic/social constraints on landowners while also ensuring the lake fully supports its beneficial uses. This was done for Geddes Lake.

4. Significant Sources

<u>Criterion Description – Significant Sources</u>

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

- ☐ Satisfies Criterion
- ☐ Satisfies Criterion. Questions or comments provided below should be considered.
- ☒ Partially satisfies criterion. Questions or comments provided below need to be addressed.
- ☐ Criterion not satisfied. Questions or comments provided below need to be addressed.
- ☐ Not a required element in this case. Comments or questions provided for informational purposes.

SUMMARY – The TMDL identifies the major sources of phosphorus as coming from nonpoint source agricultural landuses within the watershed. In particular, a loading analysis was done for nutrients and sediment considering various agricultural land use and land management factors. Cropland and grazing are the primary sources identified.

COMMENTS – The source assessment for other TMDLs developed by SD DENR typically include a breakdown of landuse types in the watershed by percentage as well as a listing of the AGNPS animal feedlot scores. Currently the assessment report only references landuse in a very general sense (e.g., p 70) “drains a mixture of grazing lands with cropland” and does not even mention the number of animal feeding areas in the watershed. The document needs to be revised to include these items.

The statement on page 77 says “There are no point sources of pollutants of concern in this watershed.” Does that mean there are point sources contributing phosphorous upstream of Geddes Lake (e.g., discharge from the Town of Geddes wastewater lagoons)? If so, what are the wasteload allocations from each facility? Why are they not concerns?

This TMDL and all future TMDLs should address point sources directly by: 1) listing all permitted point sources that cause or contribute to the impairment(s) addressed in the TMDL; 2) include the wasteload allocations from these point sources in the TMDL; and 3) include a more detailed explanation of how these loads will/will not be reduced as indicated in the TMDL (including why they are not significant sources if applicable). If there are no permitted point sources in the watershed we recommend a statement similar to “There are no point source discharges of [insert pollutant(s)] in the watershed.”

DENR RESPONSE – A breakdown of land use types in the watershed by percentage and the number of feedlots have been added to the “Geology, Soils, and Land Use” Section and the TMDL Summary. The listing of animal feedlots and their rating scores has been added (see Appendix D). Additional discussion of the feedlot rating scores was not added to the report because the AnnAGNPS model runs did not indicate the feedlots were a significant issue.

The statement on page 77 about there being no point discharges of concern to the lake has been corrected. The City of Geddes did have a discharge permit to allow the City to discharge to Pease Creek approximately 8 miles upstream of Geddes Lake. However, no discharges have ever occurred and the city has subsequently requested and received a “no discharge” permit from SDDENR. Therefore, the load allocation for point sources is zero.

5. Technical Analysis

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

☒ Satisfies Criterion
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☐ Criterion not satisfied. Questions or comments provided below need to be addressed.
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SUMMARY – The technical analysis addresses the needed phosphorus reduction to achieve the desired water quality. The TMDL recommends a 30% reduction in average annual total phosphorus loads to Geddes Lake. Based on the loads measured during the period of the assessment the total phosphorus load should be 1435.9 kg/yr to achieve the proposed TSI target. This reduction is based in large part on the BATHTUB mathematical modeling of the lake and its predicted response to nutrient load reductions.

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

The Annualized Agricultural Non-Point Source Model (AnnAGNPS) model was used to simulate alterations in land use practices and the resulting nutrient reduction response. The nutrient loading source analysis, that was used to identify necessary controls in the watershed, was based on the identification of critical cells. Critical cells were defined as those cells having phosphorus yields equal to or greater than two standard deviations above the mean phosphorus yield in the watershed. Implementing BMPs on the critical cells along with a combination of other BMPs such as working with farmers to convert to no-till on their cropland, reducing fertilizer application rates, and improving the condition of pasturelands. Also, eliminating runoff from the highest scoring animal feeding operations will further reduce phosphorus loading to the lake.

6. Margin of Safety and Seasonality

Criterion Description – Margin of Safety and Seasonality

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

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

☒ Satisfies Criterion
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SUMMARY – An appropriate margin of safety is included through conservative assumptions in the derivation of the target and in the modeling. Additionally, ongoing monitoring has been proposed to assure water quality goals are achieved. Seasonality was adequately considered by evaluating the cumulative impacts of the various seasons on water quality and by proposing BMPs that can be tailored to seasonal needs.

7. TMDL

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

☐ Satisfies Criterion
☐ Satisfies Criterion. Questions or comments provided below should be considered.
☒ Partially satisfies criterion. Questions or comments provided below need to be addressed.
☐ Criterion not satisfied. Questions or comments provided below need to be addressed.
☐ Not a required element in this case. Comments or questions provided for informational purposes.

SUMMARY – The TMDL established for Geddes Lake is a 1435.91 kg/yr total phosphorus load to the lake (30% reduction in annual total phosphorus load). This is the "measured load" which is based on the flow and concentration data collected during the period of the assessment. Since the annual loading varies from year-to-year, this TMDL is considered a long term average percent reduction in phosphorus loading.

COMMENTS – In November 2006 EPA issued the Memorandum "Establishing TMDL "Daily" Loads in Light of the Decision by the U.S. Court of Appeals for the D.C. Circuit in Friends of the Earth, Inc. v. EPA et. al., No. 05-5015 (April 25, 2006) and Implications for NPDES permits," which recommends that all TMDLs and associated load allocations and wasteload allocations include a daily time increment in conjunction with other appropriate temporal expressions that may be necessary to implement the relevant water quality standard. In June 2007 EPA made available a technical document "Options for the Expression of Daily Loads in TMDLs."

The Geddes Lake TMDL needs to be revised to include a "daily" expression of load consistent with the Friends of the Earth decision and the technical guidance. The technical guidance is available at: http://www.epa.gov/owow/tmdl/draft_daily_loads_tech.pdf.

DENR RESPONSE – The total phosphorus TMDL was originally presented as an annual TP load. This load was converted to a daily load and added to the report and TMDL Summary to satisfy USEPA requirements. However, SDDENR believes that describing loadings as an annual load is more realistic and more protective of the waterbody. Seasonality and uncontrollable precipitation make meeting a daily load unrealistic. Implementation plans will most likely be planned off of annual loads. The daily load is simply expressed as the annual load divided by 365.

8. Allocation

Criterion Description – Allocation
TMDLs apportion responsibility for taking actions or allocate the available assimilative capacity among the various point, nonpoint, and natural pollutant sources. Allocations may be expressed in a variety of ways such as by individual discharger, by tributary watershed, by source or land use category, by land parcel, or other appropriate scale or dividing of responsibility. A performance based allocation approach, where a detailed strategy is articulated for the application of BMPs, may also be appropriate for nonpoint sources. Every effort should be made to be as detailed as possible and also, to base all conclusions on the best available scientific principles. In cases where there is substantial uncertainty regarding the linkage between the proposed allocations and achievement of water quality standards, it may be necessary to employ a phased or adaptive management approach (e.g., establish a monitoring plan to determine if the proposed allocations are, in fact, leading to the desired water quality improvements).

☒ Satisfies Criterion
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☐ Criterion not satisfied. Questions or comments provided below need to be addressed.
☐ Not a required element in this case. Comments or questions provided for informational purposes.

SUMMARY – This TMDL addresses the need to achieve further reductions in nutrients to attain water quality goals in Geddes Lake. The allocation for the TMDL is a "load allocation" attributed to nonpoint sources. There are no significant point source contributions in this watershed. The source allocations for phosphorus are assigned to nonpoint source runoff from the watershed.

9. Public Participation

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

☒ Satisfies Criterion
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☐ Partially satisfies criterion. Questions or comments provided below need to be addressed.
☐ Criterion not satisfied. Questions or comments provided below need to be addressed.
☐ Not a required element in this case. Comments or questions provided for informational purposes.

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

10. Monitoring Strategy

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

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SUMMARY – Geddes Lake will continue to be monitored through the statewide lake assessment project. Post-implementation monitoring will be necessary to assure the TMDL has been reached and maintenance of the beneficial use occurs.

11. Restoration Strategy

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

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SUMMARY – The South Dakota DENR will work with a local Resource Conservation and Development group to initiate an implementation project for Geddes Lake. Implementation of various best management practices will be necessary to meet or exceed the WQ and TMDL targets/goals. This includes improvements to pasture grazing practices, implementation of no-till residue management on small grain and row crop lands, and reducing fertilizer application rates. Additional BMPs that could be implemented if necessary include construction of animal waste management systems, lake aeration and/or alum treatment.

12. Endangered Species Act Compliance

Criterion Description – Endangered Species Act Compliance

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

☐ Satisfies Criterion
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SUMMARY – EPA will request ESA Section 7 concurrence from the FWS for this TMDL.

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

MAY - 6 2008

Ref: 8EPR-EP

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

Re: TMDL Approvals
Geddes Lake; SD-MI-L-GEDDES_01

Dear Mr. Pirner:

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

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

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

Sincerely,

Carol L. Campbell

Carol L. Campbell
Acting Assistant Regional Administrator
Office of Ecosystems Protection
and Remediation

Enclosures

APPROVED TMDLs

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

Waterbody Name & AU ID	TMDL Parameter/ Pollutant (303(d) list cause)	Water Quality Goal/Endpoint	TMDL WLA / LA / MOS	Section 303(d)1 or 303(d)3 TMDL	Supporting Documentation (not an exhaustive list of supporting documents)
Geddes Lake* SD-MI-L-GEDDES_01	Phosphorus (TSI, dissolved oxygen**)	Maintain a mean annual Secchi disk-chlorophyll-a TSI at or below 76.3; dissolved oxygen ≥ 5.0	1435.91 kg/yr total phosphorous (3.93 kg/day; 88% reduction in average annual total phosphorous loads) LA = 1435.91 kg/yr WLA = 0 MOS = implicit	Section 303(d)(1)	■ Phase I Watershed Assessment and TMDL Final Report, Geddes Lake, Charles Mix County, South Dakota (SD DENR, March 2007)

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

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

Enclosure 2

EPA REGION VIII TMDL REVIEW FORM

Document Name:	**Geddes Lake Watershed Assessment Final Report**
Submitted by:	**Gene Stueven, SD DENR**
Date Received:	**November 23, 2007**
Review Date:	**November 28, 2007**
Reviewer:	**Vern Berry, EPA**
Formal or Informal Review?	**Formal – Final Approval**

This document provides a standard format for EPA Region 8 to provide comments to the South Dakota Department of Environment and Natural Resources on TMDL documents provided to the EPA for either official formal or informal review. All TMDL documents are measured against the following 11 review criteria:

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

Each of the 11 review criteria are described below to provide the rational for the review, followed by EPA's comments. This review is intended to ensure compliance with the Clean Water Act and also to ensure that the reviewed documents are technically sound and the conclusions are technically defensible.

1. Water Quality Impairment Status

Criterion Description – Water Quality Impairment Status

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

- ☒ Satisfies Criterion
- ☐ Satisfies Criterion. Questions or comments provided below should be considered.
- ☐ Partially satisfies criterion. Questions or comments provided below need to be addressed.
- ☐ Criterion not satisfied. Questions or comments provided below need to be addressed.
- ☐ Not a required element in this case. Comments or questions provided for informational purposes.

SUMMARY – Geddes Lake is a 70 acre man-made lake impoundment located on Pease Creek in southwest Charles Mix County, South Dakota. Pease Creek is within the Fort Randall Reservoir sub-basin of the Missouri River Basin. It is listed on South Dakota's 2006 303(d) list as impaired (SD-MI-L-GEDDES_01) for trophic state index (TSI) due to nonpoint sources and is ranked as priority 1 (i.e., high priority) for TMDL development. Data collected during the period of assessment show that Geddes Lake is also impaired for dissolved oxygen. The watershed is approximately 76,476 acres and drains predominantly cropland and rangeland (79% and 21% respectively). The mean Secchi – chlorophyll *a* TSI during the period of the project assessment was 77.13. Based on this data Geddes Lake is not currently meeting its designated beneficial use for warmwater semi-permanent fish life propagation.

2. Water Quality Standards

Criterion Description – Water Quality Standards

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

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

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

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

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

Other applicable water quality standards are included on pages 3 - 5 of the assessment report.

3. Water Quality Targets

Criterion Description – Water Quality Targets

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

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

The actual Secchi-chlorophyll *a* TSI for Geddes Lake during the period of the assessment was 77.13. Nutrient reduction response modeling was conducted with BATHTUB, an Army Corps of Engineers eutrophication response model. The results of the modeling show that 92% or more reduction in the total phosphorus loading from the watershed would be necessary to meet the ecoregion-based beneficial use median Secchi-chlorophyll *a* TSI target of 63.4 or less. However, Geddes Lake does not appear to fit the recommended beneficial use-based target due to legacy phosphorus loading to the lake and the technical and financial inability to fully treat the internal and external loading to the lake. Therefore, a site specific Secchi-chlorophyll *a* TSI of ≤ 76.3 was chosen for Geddes Lake which will fully support its beneficial uses and is achievable given the expected landowner participation in the watershed.

The proposed water quality targets for this water body are: **maintain a growing season median Secchi - chlorophyll *a* TSI at or below 76.3; dissolved oxygen $\geq$ 5.0 mg/L.**

4. Significant Sources

Criterion Description – Significant Sources

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

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☐ Not a required element in this case. Comments or questions provided for informational purposes.

SUMMARY – The TMDL identifies the major sources of phosphorus as coming from nonpoint source agricultural landuses within the watershed. In particular, a loading analysis was done for nutrients and sediment considering various agricultural land use and land management factors. Cropland and rangeland are the primary sources identified. Approximately 79% of the landuse is cropland and 21% is rangeland and pasture in the watershed.

5. Technical Analysis

Criterion Description – Technical Analysis

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

☒ Satisfies Criterion
☐ Satisfies Criterion. Questions or comments provided below should be considered.
☐ Partially satisfies criterion. Questions or comments provided below need to be addressed.
☐ Criterion not satisfied. Questions or comments provided below need to be addressed.
☐ Not a required element in this case. Comments or questions provided for informational purposes.

SUMMARY – The technical analysis addresses the needed phosphorus reduction to achieve the desired water quality. The TMDL recommends a 30% reduction in average annual total phosphorus loads to Geddes Lake. Based on the loads measured during the period of the assessment the total phosphorus load should be 1435.9 kg/yr to achieve the proposed TSI target. This reduction is based in large part on the BATHTUB mathematical modeling of the lake and its predicted response to nutrient load reductions.

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

The Annualized Agricultural Non-Point Source Model (AnnAGNPS) model was used to simulate alterations in land use practices and the resulting nutrient reduction response. The nutrient loading source analysis was used to identify necessary controls in the watershed. The analysis included the identification of critical nutrient loading cells, improving pasture conditions, changing tilling practices, reducing fertilizer rates and eliminating poor performing feedlots. Critical cells were defined as those cells having phosphorus yields equal to or greater than two standard deviations above the mean phosphorus yield in the watershed. Implementing a combination of feedlot improvements, converting to the use of no-till on cropland, converting cropland to pastureland or CRP and decreasing fertilizer application rates should achieve the proposed 30% reduction in phosphorus loading to the lake.

Improvements in the dissolved oxygen concentration of the lake can be achieved through reduction of organic loading to the lake as a result of proposed BMP implementation. The TMDL contains a linkage analysis between phosphorous loading and low dissolved oxygen in lakes and reservoirs. It is anticipated that meeting the phosphorous load reduction target in Geddes Lake will address the dissolved oxygen impairment.

6. Margin of Safety and Seasonality

Criterion Description – Margin of Safety and Seasonality

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

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

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

7. TMDL

Criterion Description – Total Maximum Daily Load

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

- ☒ Satisfies Criterion
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- ☐ Criterion not satisfied. Questions or comments provided below need to be addressed.
- ☐ Not a required element in this case. Comments or questions provided for informational purposes.

SUMMARY – The TMDL established for Geddes Lake is a 1435.91 kg/yr (3.93 kg/day) total phosphorus load to the lake (30% reduction in annual total phosphorus load). This is the "measured load" which is based on the flow and concentration data collected during the period of the assessment. Since the annual loading varies from year-to-year, this TMDL is considered a long term average phosphorus load. The SD DENR believes that describing the load as an annual load is more realistic and protective of the waterbody. Most phosphorus based eutrophication models use annual phosphorus loads, and seasonality and unpredictable precipitation patterns make a daily load unrealistic.

EPA recognizes that, under the specific circumstances, the state may deem the annual load the most appropriate timeframe (i.e., the TSI water quality target is based on an interpretation of narrative water quality standards which naturally does not include an averaging period). EPA notes that the Geddes Lake TMDL calculations for phosphorus include an approximated daily load derived through simple division of the annual load by the number of days in a year. This should be considered an "average" daily load that typically will not match the actual phosphorus load reaching the lake on a given day.

8. Allocation

Criterion Description – Allocation

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

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

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SUMMARY – This TMDL addresses the need to achieve further reductions in nutrients to attain water quality standards in Geddes Lake. The allocation for the TMDL is a "load allocation" attributed to nonpoint sources. There are no point source discharges of phosphorus in this watershed. The source allocations for phosphorus are assigned to runoff from cropland and range/pastureland.

9. Public Participation

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

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

10. Monitoring Strategy

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

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SUMMARY – Geddes Lake will continue to be monitored through the statewide lake assessment project. Post-implementation monitoring will be necessary to assure the TMDL has been reached and maintenance of the beneficial use occurs.

11. Restoration Strategy

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

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SUMMARY – The South Dakota DENR will work with a local Resource Conservation and Development group to initiate an implementation project for Geddes Lake. Implementation of various best management practices will be necessary to meet or exceed the WQ and TMDL targets/goals. This includes improvements to pasture grazing practices, implementation of no-till residue management on small grain and row crop lands, and reducing fertilizer application rates. Additional BMPs that could be implemented if necessary include construction of animal waste management systems, lake aeration and/or alum treatment.

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