WATERSHED ASSESSMENT
AND TMDL
FINAL REPORT

HAYES LAKE/FROZEN MAN CREEK
STANLEY 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 2004
SECTION 319 NONPOINT SOURCE POLLUTION CONTROL PROGRAM

ASSESSMENT/PLANNING PROJECT FINAL REPORT

HAYES LAKE AND FROZEN MAN CREEK WATERSHED ASSESSMENT AND TMDL
FINAL REPORT

By

Paul Lorenzen, Environmental Project Scientist

Sean Kruger, Environmental Program Scientist

Andrew Repsys, Environmental Project Scientist

Leonard P. Kuck, Project Consultant

Sponsor

Stanley County Conservation District

3/29/04

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

Grant # C 9998185-01

Acknowledgements

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

Lowell Noeske, District Conservationist (DC), NRCS, Hughes/Stanley County

Kevin Paulsen, Resource Conservation Technician, NRCS, Hughes/ Stanley County

Natural Resource Conservation Service (NRCS)

SD DENR – Watershed Resource Assistance Program

SD Department of Game, Fish and Parks

Sherri Donahey, Stanley County Conservation District

Stanley County Conservation District

West River Water Development District

Table of Contents

ACKNOWLEDGEMENTS I

TABLE OF CONTENTS II

LIST OF TABLES IV

LIST OF FIGURES V

LIST OF APPENDICES VI

EXECUTIVE SUMMARY VIII

INTRODUCTION 10

PURPOSE 10
GENERAL LAKE DESCRIPTION 10
LAKE IDENTIFICATION AND LOCATION 10
TROPHIC STATUS COMPARISON 12
HAYES LAKE BENEFICIAL USES 12
RECREATIONAL USE 13
GEOLOGY AND SOILS 13
HISTORY 14

PROJECT GOALS, OBJECTIVES, AND ACTIVITIES 15

PLANNED AND ACTUAL MILESTONES, PRODUCTS, AND COMPLETION DATES 15
Objective 1. Lake Sampling *15*
Objective 2. Tributary Sampling *15*
Objective 3. Quality Assurance/ Quality Control (QA/QC) *15*
Objective 4. Watershed Modeling *15*
Objective 5. Public Participation *15*
Objectives 6 and 7. Restoration Alternatives and Final Report *16*
EVALUATION OF GOAL ACHIEVEMENTS 16

MONITORING RESULTS 17

TRIBUTARY WATER QUALITY (FROZEN MAN CREEK) 17
Flow Calculations *17*
Load Calculations *17*
Tributary Sampling Schedule *17*
South Dakota Water Quality Standards for Frozen Man Creek Tributaries *18*
Watershed Overview *19*
Subwatersheds *19*
Hayes Lake Tributary Seasonal Water Quality *20*
Seasonal Loading *21*
Tributary Water Quality and Loadings *22*
Discharge 22
Fecal Coliform Bacteria 23
Alkalinity 23
Total Solids 24
Suspended Solids 24
Nitrogen 25
Phosphorus 27
Annual Loading Summary *28*
Water and Nutrient Budgets *28*
Tributary Site Summary 29
INLAKE WATER QUALITY (HAYES LAKE) 30
Inlake Sampling Schedule *30*
South Dakota Water Quality Standards for Hayes Lake *32*
Seasonal Inlake Water Quality *33*

Seasonal Inlake Concentrations ... 33
Inlake Water Quality Parameters ... *36*
Water Temperature ... 36
Dissolved Oxygen ... 36
pH ... 38
Secchi Depth ... 38
Chlorophyll a ... 40
Alkalinity ... 41
Solids ... 41
Nitrogen ... 43
Total Phosphorus ... 44
Dissolved Phosphorus ... 45
Fecal Coliform Bacteria ... 47
Limiting Nutrients ... *48*
TROPHIC STATE ... 49
REDUCTION RESPONSE MODELING ... 52
LONG TERM TRENDS ... 58
OTHER MONITORING ... 59
Agricultural Nonpoint Source Model (AGNPS) ... *59*
Sediment Survey ... *63*
BIOLOGICAL MONITORING ... 65
Fishery ... *65*
Hayes Lake Phytoplankton ... *65*
Aquatic Macrophyte Survey ... *69*
Threatened and Endangered Species ... *71*
QUALITY ASSURANCE REPORTING (QA/QC) ... 72
PUBLIC INVOLVEMENT AND COORDINATION ... 73
STATE AGENCIES ... 73
FEDERAL AGENCIES ... 73
LOCAL GOVERNMENTS; INDUSTRY, ENVIRONMENTAL, ... 73
OTHER GROUPS; AND PUBLIC AT LARGE ... 73
RECOMMENDATION AND CONCLUSIONS ... 74
ASPECTS OF THE PROJECT THAT DID NOT WORK WELL ... 75
FUTURE ACTIVITY RECOMMENDATIONS ... 75
LITERATURE CITED ... 77

List of Tables

Table 1. Historical TSI Comparison from Area Lakes (Stueven and Stewart, 1996) 12
Table 2. Comparison of Recreational Uses and Facilities for Area Lakes 13
Table 3. Proposed and Actual Objective Completion Dates... 16
Table 4. Frozen Man Creek, State Water Quality Standards. 18
Table 5. Seasonal Descriptive Statistics Hayes Lake Tributary Concentrations 20
Table 6. Seasonal Loadings of Phosphorus and Dissolved Phosphorus Hayes Lake 2001. 22
Table 7. Bacterial Counts for Frozen Man Creek 23
Table 8. Frozen Man Creek Alkalinity Concentrations mg/L 24
Table 9. Mean Solids Concentrations (mg/L) for Frozen Man Creek Watershed Sites ... 24
Table 10. Subwatershed Nitrogen Loads for Frozen Man Creek 26
Table 11. Subwatershed Phosphorus Loads for Frozen Man Creek Watershed.............. 27
Table 12. Subwatershed Dissolved Phosphorus Loads for Frozen Man Creek Watershed 28
Table 13. Summary of the Annual Lake Loadings for Hayes Lake 28
Table 14. Hayes Lake Nurtient, Sediment, and Water Budgets 28
Table 15. State Beneficial Use Standards for Hayes Lake 32
Table 16. Average seasonal surface water concentrations of measured parameters by site from Hayes Lake, Stanley County, South Dakota 2001 [2].. 34
Table 17. N:P ratios displayed as a function of percent reduction in phosphorus concentration based on 2001 data. 49
Table 18. Carlson Tropic State Index 50
Table 19. Output data generated by the BATHTUB model depicting percent phosphorus reductions from the Frozen Man Creek watershed to derive estimated shifts in mean growing season TSI.. 53
Table 20. Output data generated by the BATHTUB model depicting percent phosphorus reductions from internal lake loading and the Frozen Man Creek watershed to derive estimated shifts in mean TSI... 54
Table 21. Expected Nutrient Reductions in the Frozen Man Creek Watershed after BMP Implementation 60
Table 22. Priority Rated Cells to be targeted for BMP Implementation 61
Table 23. Elutriate Test Toxins for Hayes Lake 64
Table 24. Hayes Lake Algae Abundance (cells/ml) and Biovolume (um3/ml)............... 67
Table 25. Hayes Lake Algae Species List 68
Table 26. Aquatic Plant Species 71
Table 27. Quality Assurance and Quality Control Samples For Frozen Man Monitoring Stations.. 72

List of Figures

Figure 1. Map of Frozen Man Creek and Hayes Lake Watershed Stanley County, SD... 11
Figure 2. Map of Frozen Man Creek Monitoring Stations 19
Figure 3. Discharge measured from monitoring station HLT2..................................... 22
Figure 4. Map of Hayes Lake Inlake Monitoring Stations 31
Figure 5. Dissolved Oxygen/Depth Profile July 10, 2001 HL2.................................... 37
Figure 6. Hayes Lake Secchi Depth By Site and Month 2001. 39
Figure 7. Secchi vs. Total Suspended Solids for Hayes Lake HL2 39
Figure 8. Average Chlorophyll a concentrations for Hayes Lake. 40
Figure 9. Relationship between chlorophyll-a and Secchi depth Hayes Lake 2001........ 41
Figure 10. Average Total Suspended Solids vs Average Organic Solids for Hayes Lake 42
Figure 11. Inorganic Nitrogen in Hayes Lake. 43
Figure 12. Organic Nitrogen in Hayes Lake.. 44
Figure 13. Total Phosphorus Concentrations in Hayes Lake.. 45
Figure 14. Total Dissolved Phosphorus Concentrations in Hayes Lake.......................... 46
Figure 15. Total P vs Dissolved P (Surface) Hayes Lakes. 46
Figure 16. Total P vs Dissolved P (Bottom) Hayes Lake. 47
Figure 17. Fecal Coliform Counts Hayes Lake 2001. 47
Figure 18. Limiting Nutrients in Hayes Lake. 48
Figure 19. Phosphorus, Secchi depth, Chlorophyll *a* and mean Tropic State Values by Date for Hayes Lake 2001. 50
Figure 20. Growing season TSI by date for Hayes Lake 2001...................................... 51
Figure 21. Estimated TSI values for individual parameters based on percent phosphorus reductions from internal and external sources using the BATHTUB model........... 55
Figure 22. Estimated mean TSI values based on percent phosphorus reductions from the watershed and from a combination of the watershed and internal loading using the BATHTUB model... 56
Figure 24. Long Term TSI Trend for Hayes Lake... 58
Figure 25. Percent of Frozen Man Creek Watershed Treated with BMPs vs. Percent of Nutrient Load Reduced... 62
Figure 26. Map of Aquatic Macrophyte Survey Transects... 70

List of Appendices

Appendix A Fishery Data……………………………………………………………...78
Appendix B Sediment Survey…………………………………………………………...86
Appendix C Hayes Lake Tributary and Inlake Sample Data ……………………………100
Appendix D Dissolved Oxygen and Temperature Profile Data ………………………..104
Appendix E TMDL Summary……………………………………………………….113

Abbreviations

AFOs	**Animal Feeding Operations**
AGNPS	**Agricultural Non-Point Source**
BMPs	**Best Management Practices**
CPUE	**Catch per Unit Effort**
CV	**Coefficient of Variance**
DC	**District Conservationist**
DO	**Dissolved Oxygen**
FSA	**Farm Service Agency**
GPS	**Global Positioning System**
NPS	**Nonpoint Source**
NRCS	**Natural Resource Conservation Service**
NTU	**Nephelometric Turbidity Units**
Q WTD C	**Flow Weighted Concentration**
SD DENR	**SD Department of Environment and Natural Resources**
SD GF&P	**SD Department of Game, Fish & Parks**
SU	**Standard Units**
TKN	**Total Kjeldahl Nitrogen**
TSI	**Trophic State Index**
μmhos/cm	**micromhos/centimeter**
USGS	**United States Geologic Survey**

Executive Summary

PROJECT TITLE: Hayes Lake Dam and Watershed Assessment

PROJECT START DATE: 1/1/01 PROJECT COMPLETION DATE: 3/29/04

FUNDING: TOTAL BUDGET: $26,130

TOTAL EPA GRANT:	$19,080
TOTAL EXPENDITURES OF EPA FUNDS:	$9,981.46
TOTAL SECTION 319 MATCH ACCRUED:	$5,000.00
BUDGET REVISIONS:	none
TOTAL EXPENDITURES:	$14,981.46

SUMMARY ACCOMPLISHMENTS

The Hayes Lake and Frozen Man Creek watershed assessment project began on January 1, 2001 and was completed March of 2004 following data analysis and completion of the final report. All milestones were met in a timely manner.

An EPA Section 319 grant provided a majority of the funding for this project. The West River Water Development District, and Stanley County Conservation District provided local matching funds.

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 inlake treatment. An aquatic plant survey was completed for the lake. NRCS had completed a sediment survey on Hayes Lake in 1990 as part of its River Basin Study of the Lower Bad River. This was the third sediment survey on Hayes Lake since the dam was built.

The primary goal for the project was to develop a TMDL and determine sources of impairment to Hayes Lake. The project also provided sufficient background data to develop a Section 319-implementation project. Through identification of sources of impairment in the watershed, this goal was accomplished.

The AGNPS model identified several cropland cells within the watershed that were delivering nutrients and sediment to Hayes Lake. Through the implementation of best management practices and treatment of inlake phosphorus, a sufficient reduction in inlake nutrients will occur to improve the Trophic State Index (TSI) (Carlson, 1977) value of the lake and increase support of its beneficial uses. The implementation of best management practices will also reduce the delivery of nutrients and sediment to several large stock dams that exist in Frozen Man watershed above the Hayes Lake impoundment. These stock dams serve as a buffer to Hayes Lake catching sediment that would otherwise reach Hayes Lake causing a more rapid degradation of the impoundment.

The assessment also indicated that the inlake nutrients especially phosphorus are of concern. The model indicates that more than 50% of the loading affecting the mean TSI is due to internal phosphorus recycling. This is a common problem for man made impoundments where the watershed is very large in relationship to the impoundment storage volume. Hayes Lake has a surface area of 73.7 acres and watershed of 30,400 acres, which is a ratio of 412:1. Treatment of the internal phosphorus loads must be addressed to remove 25% or more of the existing inlake phosphorus.

The water quality goal for Hayes Lake is to stabilize or decrease the eutrophication process. Hayes Lake has a modeled mean growing season TSI value of 65.7, which suggests a hyper-eutrophic condition. Phosphorus reductions of >90% from both inlake and the watershed would need to be implemented in order to meet the current ecoregion (43) target for full support. This scenario is not attainable due to social and economic restraints posed within the watershed. An alternative site specific (watershed specific) evaluation criteria (full support, mean TSI <65.0) was proposed based on AGNPS modeling, BMPs and watershed specific phosphorus reduction attainability for Hayes Lake. Phosphorus reductions of 24% from the watershed and removal of 25% internal phosphorus load will result in a mean growing season TSI of <65.0 (eutrophic). Both the Secchi and chlorophyll *a* TSI would be maintained below the original ecoregion (43) target (TSI 55) for full support. The TMDL for this waterbody can be met by reducing 6,967 kg/yr from a combination of internal (4,257 kg TP) and external load (2,710 kg TP) sources. Phosphorus load estimates used for the TMDL were based on AGNPS modeled outputs. The recommended TMDL for Hayes Lake was estimated at 24,264 kg/yr.

Of the four beneficial uses designated to Hayes Lake the warm water semi-permanent fishery is the most common public use and emersion recreation is the most water quality sensitive. Hayes Lake is not used extensively for emersion recreation because of shoreline characteristics (clayey), location in respect to population and proximity to the Missouri River. The lake has large areas of shoreline that are lined with cattails and rushes. These plants restrict access to the open water in the lake and limit shoreline fishing. Despite this restriction littoral and basin macrophyte vegetation are considered important to nitrogen and phosphorus cycling within Hayes Lake.

Introduction

Purpose

The purpose of this pre-implementation assessment is to determine the sources of impairment to Hayes Lake in Stanley County, South Dakota, and the tributaries in its watershed. The creeks and small tributaries carry loadings of sediment and nutrients from snowmelt and spring rain events. The streams and tributaries, which are the headwaters of Frozen Man Creek, carry sediment and nutrient loads that degrade water quality in the lake and cause increased eutrophication. A Total Maximum Daily Load (TMDL) is required to correct the determined impairments. The discharge from this watershed ultimately reaches the Bad River.

Frozen Man Creek is the primary tributary to Hayes Lake and drains a mix of grazing lands, hayland, Conservation Reserve Program (CRP) acres and cropland acres. Winter feeding areas for livestock are present in the watershed.

General Lake Description

Hayes Lake is a 73.7 acre (29.8 ha) man-made impoundment located in west central Stanley County, South Dakota (Figure 1). Damming Frozen Man Creek 1/2 mile southeast of the town of Hayes created a lake in 1933. Currently the lake has an average depth of 6.1 feet (1.9 meters) and 3.6 miles (5.8 km) of shoreline. The lake has a maximum depth of 17 feet (6.7 m) and holds 450 acre-feet of water. Hayes Lake is subject to periods of stratification during the summer. The outlet for the lake empties into Frozen Man Creek, which joins with Plum Creek, which eventually reaches the Bad River about 27 miles (43.5 km) southwest of the town of Fort Pierre in Stanley County, South Dakota. The Hayes Lake watershed comprises a small portion of the Bad River hydrologic unit 10140102.

Lake Identification and Location

Lake Name: Hayes Lake	State: South Dakota
County: Stanley	Township: 5N
Range: 26W	Sections: W ½ of 29
Nearest Municipality: Hayes	Latitude: 44.36500
Longitude: -100.013333	EPA Region: VIII
Primary Tributary: Frozen Man Creek	Receiving Water: Frozen Man Creek
HUC Code: 10140102	HUC Name: Bad River
Surface Area: 73.7 Acres (29.8 ha)	Vol. at Spillway: 450 acre feet
Maximum Depth: 17 ft. (6.7 m)	Watershed Area: 30,406 acres (12,303 ha)

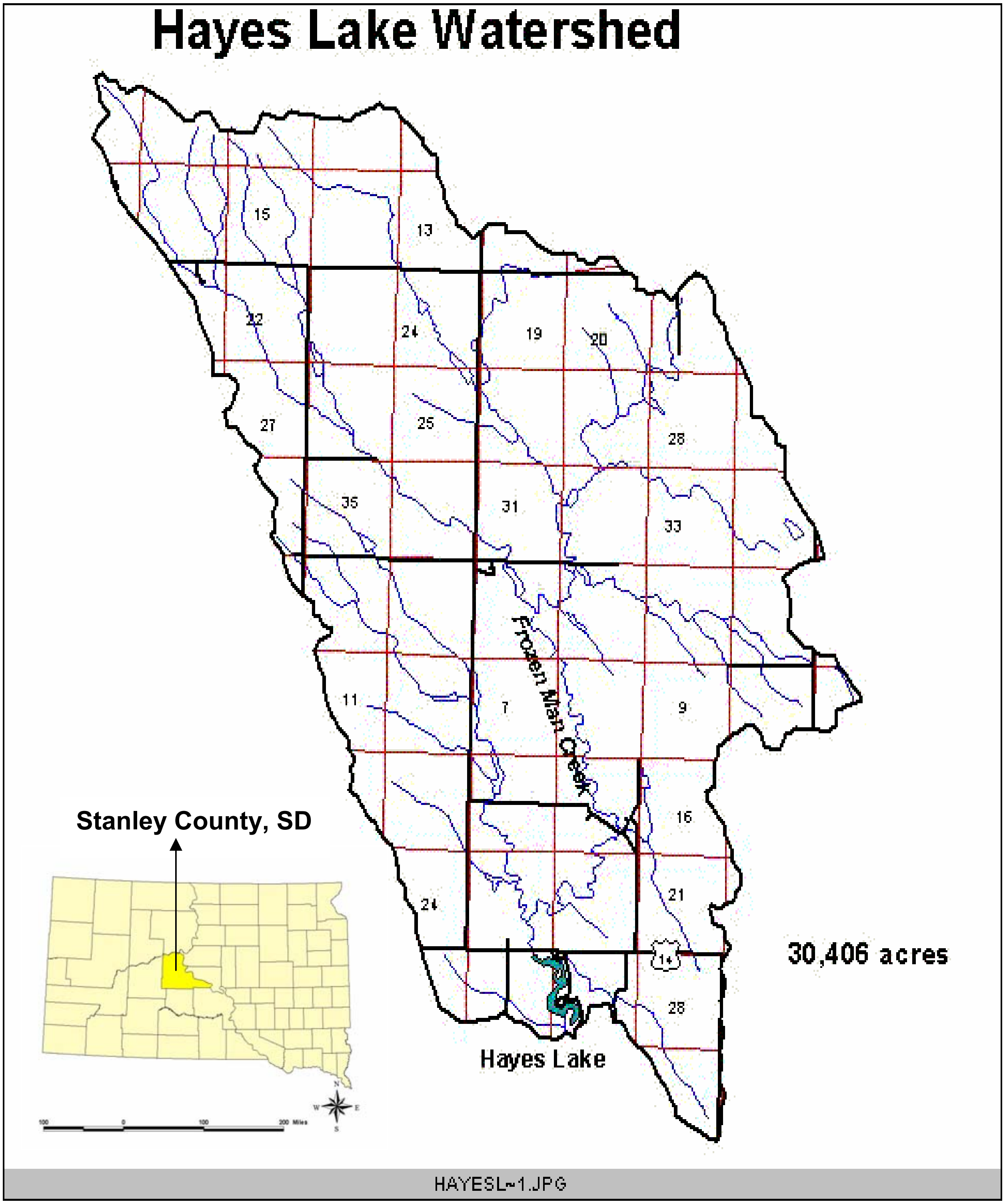


Figure 1. Map of Frozen Man Creek and Hayes Lake Watershed Stanley County, SD

Trophic Status Comparison

The trophic state of a lake is a numerical value that ranks its relative productivity. Developed by Carlson (1977), the Trophic State Index, or TSI, allows a lake's productivity to be easily quantified and compared to other lakes. Higher TSI values correlate with higher levels of primary productivity. A comparison of Hayes Lake to other lakes in the Northwestern Great Plains Ecoregion (Table 1) shows that a high level of productivity is common for the ecoregion. Hayes Lake has the second highest mean TSI value in the Northwest Great Plains Ecoregion of South Dakota. The values provided in Table 1 were generated from the most recent statewide lake assessment final report (Stueven and Stewart, 1996). The TSI for Hayes Lake will vary slightly in this report due to the use of additional new data gathered during this assessment.

Table 1. Historical TSI Comparison from Area Lakes (Stueven and Stewart, 1996)

Lake	County	Mean TSI	Trophic State Category
Angostura	Fall River	42.91	Mesotrophic
Orman Dam	Butte	45.18	Mesotrophic
Newell	Butte	50.96	Mesotrophic
Newell City Pond	Butte	51.74	Mesotrophic
Shadehill	Perkins	52.28	Mesotrophic
Murdo	Jones	52.35	Mesotrophic
Freeman	Jackson	61.80	Eutrophic
Fate	Lyman	63.90	Eutrophic
Isabel	Dewey	65.80	Hyper-eutrophic
Coal Spring	Perkins	66.60	Hyper-eutrophic
Brakke	Lyman	67.62	Hyper-eutrophic
Waggoner	Haakon	67.78	Hyper-eutrophic
New Wall	Pennington	68.06	Hyper-eutrophic
Hayes	**Stanley**	**69.08**	**Hyper-eutrophic**
Flat Creek	Perkins	69.28	Hyper-eutrophic

Hayes Lake Beneficial Uses

The State of South Dakota has assigned all of the water bodies a set of beneficial uses. Along with these assigned uses are sets of standards for the 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 list of beneficial uses are assigned to Hayes Lake.

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

Individual parameters as well as the lake's TSI value determine the support of these beneficial uses. Hayes Lake is identified in *Ecoregion Targeting for Impaired Lakes in South Dakota* (Stueven et al, 2000) as non-supporting its beneficial uses.

Recreational Use

The South Dakota Department of Game, Fish, and Parks provide a list of existing public facilities that are maintained at area lakes (Table 2). Hayes Lake Recreation Area is located along the east side and north end of the lake and has a number of facilities including a public toilet, picnic tables, shelter, boat ramp, and access to shore fishing. Camping is permitted in the area although no facilities are maintained.

Table 2. Comparison of Recreational Uses and Facilities for Area Lakes

Lake	Park	B. Ramp	Boating	Camping	Fishing	Picnicking	Swimming	Toilets	County
Brakke	No	Yes	Yes	No	Yes	No tables	No beach	Yes	Lyman
Fate	No	Yes	Yes	No	Yes	No tables	No beach	Yes	Lyman
Murdo	No	Yes	Yes	No	Yes	No tables	No beach	No	Jones
Freeman	No	No	No	commercial	Yes	No tables	No beach	No	Jackson
Hayes	**No**	**Yes**	**Yes**	**No**	**Yes**	**Yes**	**No beach**	**Yes**	**Stanley**
Waggoner	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Haakon
New Wall	No	Yes	Yes	No	Yes	No tables	No beach	No	Pennington

Geology and Soils

Hayes Lake and its primary tributary, Frozen Man Creek, are located within the Pierre Hills region in the Missouri Plateau section of the Great Plains Physiographic Province. The outlet to the lake discharges into Plum Creek and then into the Bad River. The Bad River flows into the Missouri River at Fort Pierre, South Dakota. Located west of the Missouri River, the Hayes Lake watershed is part of an ancient seabed, which formed the parent material of the present day soils. The landscape of the watershed is gently undulating to rolling with well developed drainage patterns. This is due to the ongoing water erosion.

The climate in Stanley County is continental with dry winters and wet springs. The weather is subject to frequent and extreme changes with fronts dropping temperatures by as much as 40 to 50^{o}F in 24 hours. Annual precipitation can be expected to yield 18 inches of which 80 percent can be expected to fall in the months of April through September.

The Promise-Opal association is the principal soil group for this watershed. The soils are deep or moderately deep, well drained, nearly level to moderately sloping, clayey soils on uplands. The association is about 50 percent Promise soil, 30 percent Opal soil and 20 percent other minor soils. The deep Promise soils occupy the smoother parts of the landscape. The Opal soils occupy the convex upper parts of the landscape and have parent shale material below about 30 inches. The minor soils in the association are the poorly drained Kolls soils in the depressions; the shallow Sansarc soils on the steeper, higher parts of the landscape and along drainage ways; the dense Swanboy soils in the drainage ways; and the moderately well drained Witten soils in the swales.

History

The area around Hayes Lake and Frozen Man Creek has a diverse history. A few of the more outstanding events in the history of the area are covered here.

Stanley County was founded in 1873 by an act of the legislature of Dakota Territory and was formally organized in 1889. It was named after General David S. Stanley, who was commander at Fort Sully. The original boundaries included the area that is now the counties of Haakon and Jackson, which were organized in 1914. The town of Fort Pierre is the county seat, the largest municipality in the county and the oldest continuous settlement in the state. Fort Pierre is located at the junction of highways 83, 14 and 34 on the west end of the bridge across the Missouri River (Lake Sharpe) to the sister city Pierre, the state Capitol.

An earthen embankment constructed in 1933 through the Works Progress Administration forms Hayes Lake. The lake gets its name from the community of Hayes located on Highways 14 and 34 at the upper end of the impoundment. The 670-foot rolled earth structure has a total depth of 27 feet and holds 17 feet of water at permanent pool elevation. The original structure had two earth spillways. The lower (principal) spillway was constructed with an earth approach section, a concrete chute spillway and no stilling basin. In 1946 a concrete approach and stilling basin were added. In 1963 a two foot concrete sill was added to the upper end of the approach section, which increased the permanent pool storage. The original spillway had deteriorated and was starting to wash out and was replaced by a new concrete spillway in 1998. Hayes Lake was, and still is, a popular fishing and picnicking area for area families.

The 30,400 acre (12,303 ha) watershed consists of the upper portion of Frozen Man Creek. The watershed is about 4 miles wide and is about 12 miles long. Land use is totally agricultural except for a few farmsteads, the community of Hayes (population 30) and a lightly developed road infrastructure. Agricultural use is a combination of cropland and grasslands.

Project Goals, Objectives, and Activities

Planned and Actual Milestones, Products, and Completion Dates

Objective 1. Lake Sampling

Sampling of Hayes Lake began in February 2001. Sampling of nutrient and solids parameters continued at the two selected sites through October 2001 as planned. Sufficient ice cover for foot travel occurred in February 2001 and samples were collected through the ice. Samples were collected by boat from April through October of 2001.

Objective 2. Tributary Sampling

At the onset of the project, the local coordinator and DENR staff installed OTT Thalamedes Stage recorders at pre-selected monitoring sites along the tributaries of Frozen Man Creek. This equipment was used to help obtain a detailed picture of the daily discharge of nutrients and sediments from the watershed into Hayes Lake. Sampling Frozen Man Creek was limited primarily to the months of March and April of 2001. Limited runoff occurred from snowmelt that started in mid-March. One small runoff event resulted from rainfall in the watershed on August 1, 2001.

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

Replicate 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 Agricultural Non Point Source (AGNPS) 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.

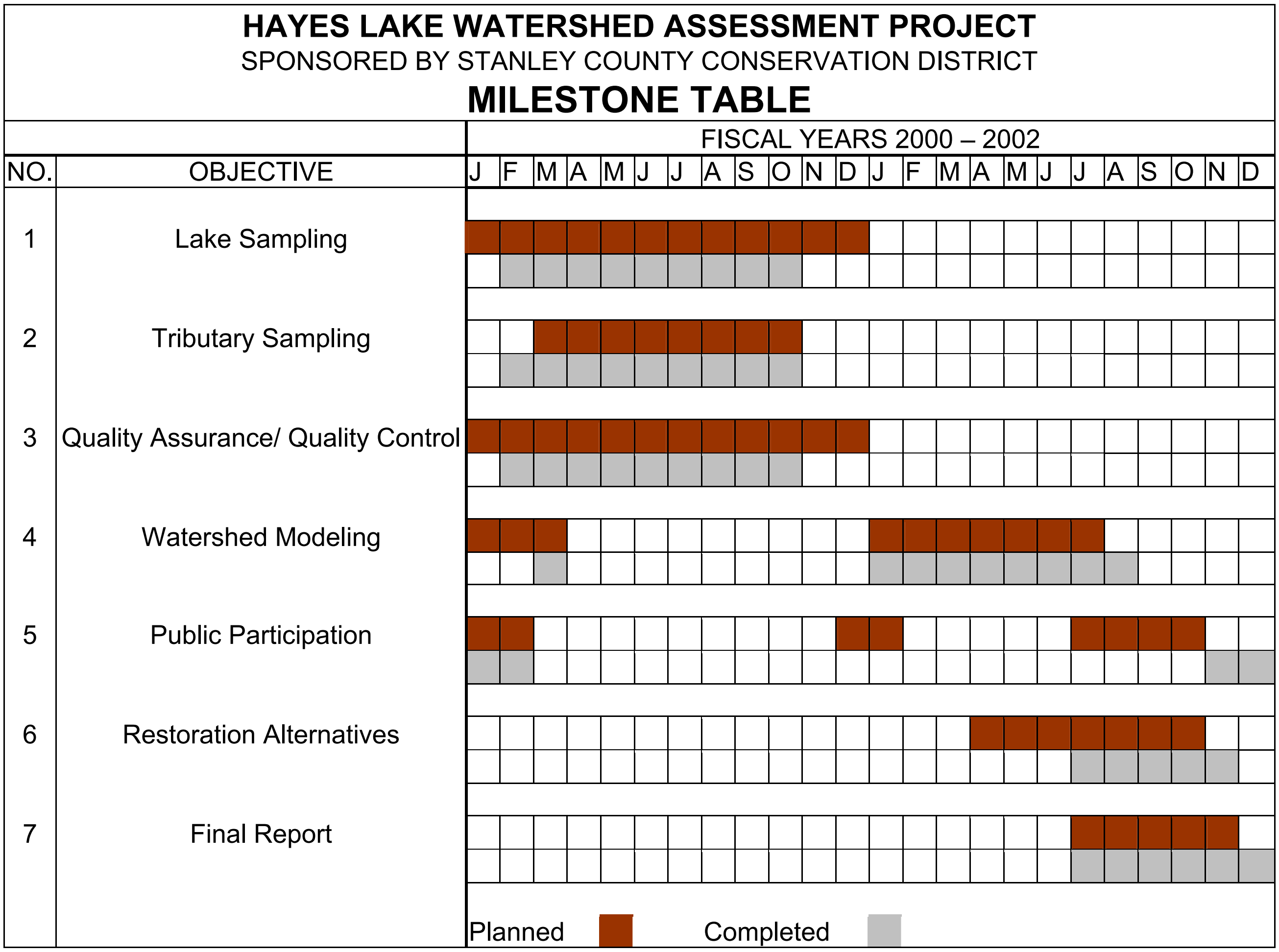
Objective 5. Public Participation

Some of the landowners were contacted to gather assessment information. The assessment project is located within the Bad River 319 Project Implementation area. Due to active participation of the operators in the implementation project, much of the information for the assessment was already available through the NRCS and FSA offices. Responses to letters, phone calls, and personal contact were excellent. The landowners cooperated to provide needed information. Further information was provided to the community and stakeholders in the project at the Stanley County Conservation District and West River Water Development District public board meetings.

Objectives 6 and 7. Restoration Alternatives and Final Report

Completion of the restoration alternatives and final report for Hayes Lake and Frozen Man Creek in Stanley County were completed in March of 2004.

Table 3. Proposed and Actual Objective Completion Dates



Evaluation of Goal Achievements

The goal of the watershed assessment completed on Hayes 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 AGNPS watershed modeling tool. Through data analysis and modeling, identification of impairment sources was possible. The identification of these impairment sources will aid the state's nonpoint source (NPS) program by allowing strategic targeting of resources to portions of the watershed that will provide the greatest benefit per expenditure.

Monitoring Results

Tributary Water Quality (Frozen Man Creek)

Flow Calculations

Two tributary and one outlet monitoring sites were selected along Frozen Man Creek, which is the primary tributary to Hayes Lake. The sites were selected to determine which portions of the watershed were contributing the greatest amount of nutrient and sediment load to the lake. All of the sites were equipped with Ott Thalamades stage recorders/data loggers. Water stages were monitored and recorded to the nearest $1/100^{th}$ of a foot for each of the three sites. A March-McBirney Model 210D flow meter was used to determine flows in cubic feet per second (cfs) at various stages. The stages and flows were then used to create a stage/discharge table for each site.

Load Calculations

Nutrient and sediment loads were calculated with the use of the Army Corps of Engineers Eutrophication Model known as FLUX. FLUX uses individual sample data in correlation with daily discharges to develop six loading calculations for each parameter. As recommended in the application sequence, a stratification scheme and method of calculation was determined using the total phosphorus load. This stratification scheme is then used for each of the additional parameters. Sample data collected on Frozen Man Creek may be found in Appendix A.

Tributary Sampling Schedule

Samples were collected at the sites during the spring and summer of 2001. Most samples were collected using 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 or calculated the following parameters:

Fecal Coliform Counts
Total Solids
Total Suspended Solids
Nitrate
Total Phosphorus
Total Dissolved Phosphorus
E. coli Bacteria Counts

Alkalinity
Total Dissolved Solids
Ammonia
Total Kjeldahl Nitrogen (TKN)
Volatile Total Suspended Solids
Un-ionized Ammonia

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

Precipitation	Wind	Odor
Septic Conditions	Dead Fish	Film
Turbidity	Width	Water Depth
Ice Cover	Water Color	

Parameters measured in the field by sampling personnel were:

Water Temperature	Air Temperature
Field pH	Dissolved Oxygen

South Dakota Water Quality Standards for Frozen Man Creek Tributaries

The state of South Dakota assigns at least two of the eleven beneficial uses to all bodies of water in the state:

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

(10) irrigation waters

are assigned to all streams and rivers.

All portions of Frozen Man Creek located upstream from section 30 in Township 5 North and Range 26 East in Stanley County, South Dakota including all of Frozen Man Creek north (upstream of Hayes Lake) from the bridge on Highways 14 and 34 at Hayes must maintain the criteria that support these uses. In order for the creek to maintain these uses, there are five parameters that must be maintained, these parameters, as well as the water quality values that must not be exceeded, are listed in Table 4.

Table 4. Frozen Man Creek, State Water Quality Standards.

Parameter	Limits
Nitrate (mg/L)	<50 (mean) <88 (single sample)
Alkalinity (mg/L)	<750 (mean) <1,313 (single sample)
pH (su)	> 6.5 and <9.5 su
Total Dissolved Solids (mg/L)	<2,500 mg/L for a 30-day geometric mean < 4,375 mg/L daily maximum for a grab sample
Conductivity (umhos/cm)	<2,500 (mean) <4,375 (single sample)

Watershed Overview

Discharges from Frozen Man Creek as well as precipitation are the primary sources of water entering Hayes Lake. Very little change was observed in the water chemistry, except for nitrates, during the 2001 sampling season. The 2001 sampling season was dry with limited discharges from Frozen Man Creek and very little rainfall entering the lake. Monitored lake levels and lack of base flow indicated that ground water was having a minimal impact on overall nutrient and sediment loadings. However, higher nitrate and dissolved solid concentrations suggested groundwater did contribute to base flows during the project period.

Subwatersheds

Frozen Man Creek was broken into two individual subwatersheds, each with a gauging station located at the outlet (Figure 2). Stage and discharge data was collected from each of these sites as well as water chemistry samples, which were combined to calculate the loadings from each of these subwatersheds. The amount of water discharged through the HLT1 gauging station was very small and had no appreciable effect on the water quality of the lake. The watershed above HLT1 drains 3,720 acres (12.2% of the total watershed). During the sampling period only two flows were detected. Both were 0.5 cfs or less. FLUX (Army Corps of Engineers Loading Model) calculations were not completed for HLT1, so all measured loads to the inlet of the lake are based on the data collected at HLT2. However, a conservative load estimate was incorporated into the BATHTUB (Army Corps of Engineers lake eutrophication model) model for site HLT1 and other ungaged portions of the watershed.

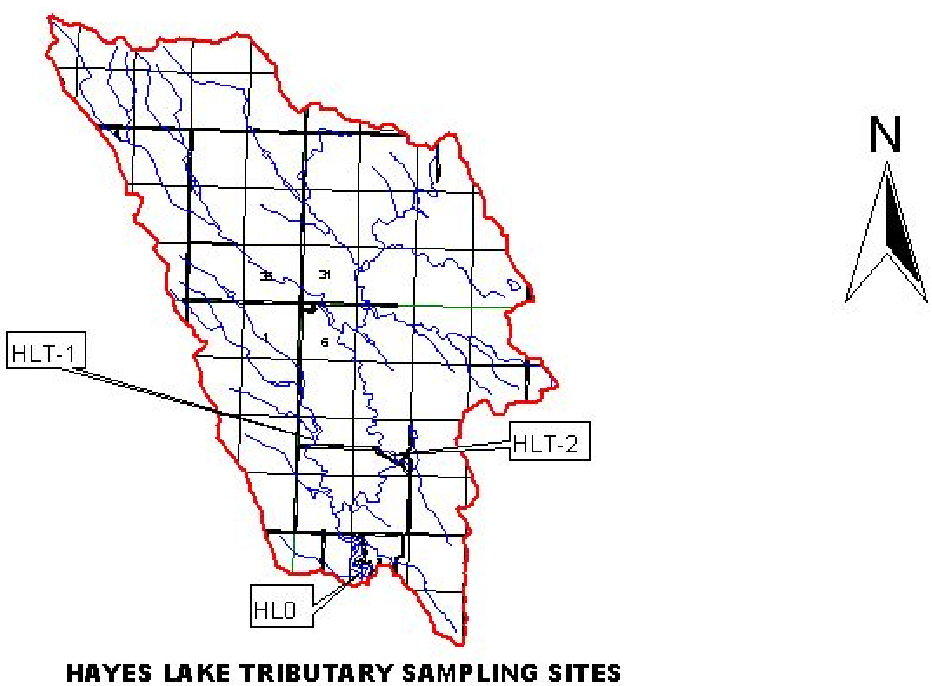


Figure 2. Map of Frozen Man Creek Monitoring Stations

Hayes Lake Tributary Seasonal Water Quality

Different seasons of the year can yield differences in water quality due to changes in precipitation and landuse practices. To discuss seasonal differences, tributary samples were separated into: spring (March –May 2001), summer (June – August 2001), and fall (September – November 2001). All tributary samples were collected during the spring (March – April) with the exception of one sample collected at HLT2 in the summer (August 1, 2001). During the entire project, two samples were collected at HLT1 and six samples were collected at HLT2. The lack of samples taken at HLT1 was attributed to a series of small stock dams located upstream from the monitoring station. A low water table in this small sub-watershed held back most available flow during the project period. In general, dry conditions and a lack of precipitation limited summer and fall sampling. During the 2001 assessment study, it was estimated that 83.6% of the total discharge to Hayes Lake occurred during the spring. Approximately 16.4% of the input occurred in the summer and 0% occurred during the fall. The average concentrations of all tributary samples by season are presented in the following table.

Table 5. Seasonal Descriptive Statistics Hayes Lake Tributary Concentrations

			Spring			Summer
Parameter	Count	Average	Maximum	Miniumum	Count	(not an average)
pH su	5	7.91	8.56	7.4	1	-
Water temp ^{0}C	8	6.64	16.5	2.3	1	-
DO mg/L	4	12.61	12.9	12.2	1	-
Alkalinity mg/L	8	101.14	203	40	1	133
Total Solids mg/L	8	787.14	1963	162	1	640
Suspended Solids mg/L	8	145.71	568	4	1	7
Dissolved Solids mg/L	8	641.6	1395	146	1	633
Volatile Suspended Solids mg/L	8	12.29	48	0.05	1	2
Ammonia mg/L	8	0.39	1.03	0.01	1	0.01
Nitrate mg/L	8	11.11	42.1	0.2	1	1.1
Total Kjeldahl-N mg/L	8	1.86	3.29	0.79	1	2.19
Total Phosphorus mg/L	8	0.56	0.922	0.063	1	0.183
Total Dissolved Phosphorus mg/L	8	0.25	0.67	0.049	1	0.098
E. Coli coloinies/100ml	8	87.49	380	0.5	1	53
Fecal Coliform Bacteria colonies/100ml	8	138.00	816	5	1	90

Dissolved oxygen concentrations were only collected in March during the spring. The presence of adequate flow and cooler water temperatures were likely responsible for the high dissolved oxygen. Flow aids to aerate water as it moves along the stream profile and cooler water temperatures allow for higher saturation capacity of the water. No dissolved oxygen measurements were collected during the summer (August 1, 2001) sampling due to equipment failure.

The average alkalinity value was 101 mg/L from both sites during the spring sampling period. The lowest alkalinity of 40 mg/L was experienced in March at HLT1 and the highest was 203 mg/L again at HLT1 in April. In general, alkalinity was low for all samples throughout the project though March concentrations were exceptionally low. Groundwater typically has higher alkalinity than rainwater because dissolved minerals are in constant contact with the soil. Low alkalinity in March may suggest that frozen conditions in the watershed limited surface water contact with the soil.

All solids parameters were low for both samples collected at HLT1 in the spring. Two samples collected in the spring (March 14, 2001 and April 24, 2001) at HLT2 indicated high total solids. The maximum total suspended solids (568 mg/L) and total dissolved solids (1,395 mg/L) were observed on April 24, 2001. The remaining solids samples from the spring and summer were several orders of magnitude lower than were observed on these sampling dates.

Like the solids parameters the maximum nitrate and TKN values were observed in the spring on April 24, 2001 at HLT2. Ammonia concentrations were highest early in the spring (March) and tapered down by April. Ammonia was below the laboratory detection limit in the single sample collected at HLT2 on August 1, 2001. Sources of nitrogen can derive from natural geology (soils), decomposition of organic material, run-off from animal feeding areas and land applied fertilizer and/or manure.

The average spring total phosphorus concentration was 0.56 mg/L (median 0.57 mg/L), this ranged from a high of 0.922 mg/L to a low of 0.063 mg/L. The single August (summer) sample collected at HLT2 yielded a total phosphorus concentration of 0.183 mg/L. In general, elevated total phosphorus concentrations corresponded with samples that also observed elevated solids and nitrogen concentrations. The average percent of dissolved phosphorus for spring samples was 50.4 % similar to the summer (August) sample collected at HLT2. The highest percentage of total dissolved phosphorus (77.8%-72.6%) was observed in the spring for both samples collected at HLT1.

Fecal coliform and E. coli counts (colonies/100ml) were relatively low in all tributary samples collected during the project. Once again elevated levels were observed from the two samples collected in the spring at HLT2 on March 14, 2001 and April 24, 2001. The single summer (August) sample yielded fecal coliform and E. coli counts < 100 colonies/100ml respectively.

Seasonal Loading

Seasonal loadings at Hayes Lake were heavily influenced by snowmelt and spring rain events. Table 6 depicts the loadings of phosphorus and total dissolved phosphorus as well as the concentrations and water discharge volumes that occurred each month. The spring months of March and April in 2001 accounted for over 82% of the total discharge that occurred during the project. Loadings that occurred during the remainder of the year had little impact on the condition of Hayes Lake. Flow only occurred during the months shown in Table 6.

Table 6. Seasonal Loadings of Phosphorus and Dissolved Phosphorus Hayes Lake 2001.

Season	Date	Measured Days	Sample Count	Volume (hm3)	TDP (kg)	T.Phos. (kg)	Percent of Discharge
Spring	Mar-01	24	4	0.476	126.6	417.4	71.0%
↓	Apr-01	30	1	0.073	5.9	64.1	10.9%
	May-01	31	0	0.012	0.9	9.9	1.7%
Summer	Jun-01	30	0	0.010	1.1	8.8	1.5%
↓	Jul-01	31	0	0.066	19.0	57.6	9.8%
	Aug-01	31	1	0.034	3.3	30.0	5.1%
Fall	Sept-01	30	0	0	0	0	0.0%
↓	Oct-01	23	0	0	0	0	0.0%

Tributary Water Quality and Loadings

Discharge

The amount of measurable flow can dictate the concentration and loading of nutrients and sediment delivered to a lake basin. During the project flow was minimal upstream from the monitoring station at HLT1. Only two discharge measurements, 0.5 cubic feet per second (cfs) collected March 14, 2001 and 0.03 cfs measured April 24, 2001 were taken during the project period. Because water samples were collected during these flow dates concentrations for sampled parameters will be discussed. However, the lack of discharge was such that loadings were not calculated for HLT1. Six discharge and sample combinations were taken at HLT2 over the course of the project. Discharge ranged from a high of 25.08 cfs measured March 14, 2001 to a low of 0.93 cfs measured April 24, 2001 (Figure 3).

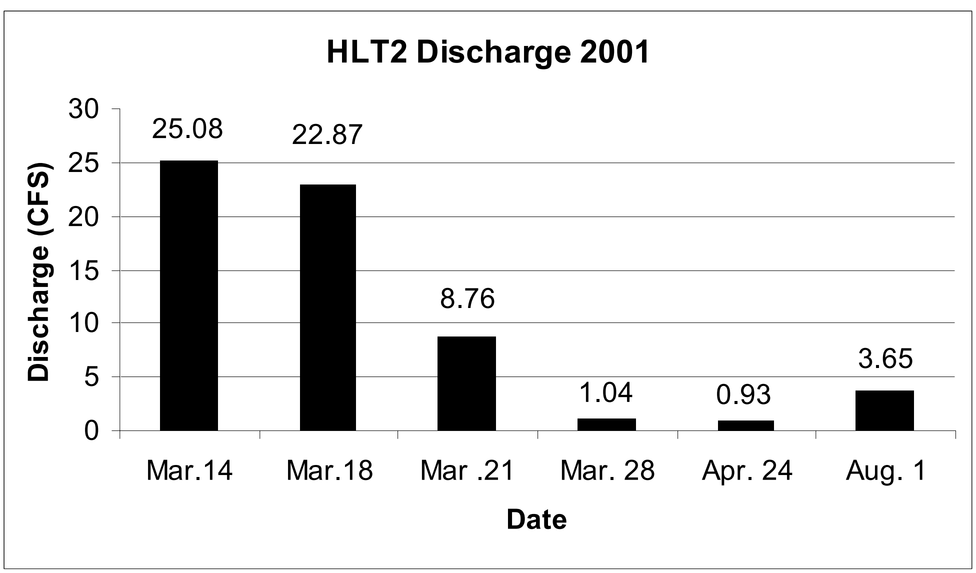


Figure 3. Discharge measured from monitoring station HLT2.

Fecal Coliform Bacteria

Fecal coliform bacteria 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, 1994). Some of our samples indicated the presence of *E. coli* at levels higher than the total fecal count. This is the result of standard lab testing procedures. Fecal coliform tests are conducted with an incubation temperature of 45°C while *E. coli* tests are conducted with an incubation temperature of 35°C. The higher incubation temperatures for the fecal test inhibit the growth of some bacteria, resulting in the lower counts for total fecal coliform.

Fecal coliform standards are not a concern for the listed beneficial uses for sites HLT1 and HLT2, in Frozen Man Creek watershed. Generally, these sites exhibited fecal levels that fell within state standards for all recreational uses. Site HLT2 had one sample on April 24 of 2001 with fecal counts that were significantly higher than were found in the rest of the watershed (Table 7). The source of the elevated bacterial counts is uncertain.

Fecal coliform samples collected at the outlet of Hayes Lake also fell within state standards for all recreational uses.

Table 7. Bacterial Counts for Frozen Man Creek

DATE	HLO-1		HLT1		HLT2	
	Fecal	*E. coli*	Fecal	*E. coli*	Fecal	*E. coli*
14-Mar-01			<10	16.1	90	179
18-Mar-01	<10	4.1			20	12.1
21-Mar-01	<10	<1			<10	<1
28-Mar-01	<10	<1			20	19.5
24-Apr-01	<10	<1	10	5.2	816	380
01-Aug-01					90	53
Mean	<10	<2	10	10.7	174.3	107.4

Alkalinity

Historically, the term alkalinity referred to the buffering capacity of the carbonate system in water. Today, alkalinity is used interchangeably with acid neutralizing capacity (ANC), which refers to the capacity to neutralize strong acids such as HCL, H_2SO_4 and HNO_3. Alkalinity in water is due to any dissolved species (usually weak acid anions) 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 its primary source of alkalinity. Alkalinity is commonly found in concentrations as high as 200 mg/L or more.

The state standard for Frozen Man Creek 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 HLT1 on April 24, 2001 (Table 8), and was well within the state standard for alkalinity. Due to minimal run-off during the project period, alkalinity concentrations for all the samples were relatively low and may have been higher had there been more run-off. The entire watershed is composed of shale-derived soils that are typically high in alkalinity. The watershed above HLT2 has a much larger drainage area and provided the only measurable loading of alkalinity.

Table 8. Frozen Man Creek Alkalinity Concentrations mg/L

Date	HLT1	HLT2
14-Mar-01	40	106
18-Mar-01		68
21-Mar-01		76
28-Mar-01		93
24-Apr-01	203	122
01-Aug-01		133

Total Solids

Total solids are the sum of all dissolved and suspended solids including all organic and inorganic materials. Dissolved solids are typically found at higher concentrations in ground water.

The total solids concentrations in Frozen Man Creek ranged from 162 mg/L collected from HLT1 on March 14, 2001 to a maximum value of 1,963 mg/L collected from HLT2 on April 24, 2001. The majority of the total solids concentration is composed of dissolved solids with suspended solids representing only a small fraction of the load. Whereas there are no state standards for total solids, the total solids concentrations for Frozen Man Creek fell well within the dissolved solids state standard of a 30 day geometric mean less than 2,500 mg/L and a single sample value of less than 4,375 mg/L.

When comparing mean concentrations for solids on Frozen Man Creek (Table 9) it becomes apparent that the majority of the dissolved solids (total solids minus suspended solids) are coming from the portion of the watershed located above site HLT2. This is the same portion of the watershed that was identified as the largest source of volatile solids, total solids, and alkalinity. The high dissolved solids may be related to the number of artesian wells that have been dug is this area. Most of them have an overflow and flow throughout the year. During the project HLT2 delivered an estimated 809,919 kg/yr of dissolved solids to Hayes Lake accounting for 84% of the total solids load.

Table 9. Mean Solids Concentrations (mg/L) for Frozen Man Creek Watershed Sites

Station	Total Solids	Total Dissolved	Total Suspended	Total Volatile
HLT1	286.0	276.0	10	8.0
HLT2	929.7	761.9	167.8	12.2

Suspended Solids

The median suspended solids concentrations were 10 mg/L and 70.5 mg/L for sites HLT1 and HLT2 respectively. Suspended solids ranged from a low of 4 mg/L collected from HLT1 on April 24, 2001, to a high of 568 mg/L collected from HLT2 on the same date. HLT1 has a small drainage area (17% of the entire watershed) and most flow during the project was stored by a stock dam just above the gauging station which reduced runoff and associated water velocity. Larger drainage area, higher water velocities and a poorly vegetated stream channel led to the significantly higher total suspended solids concentrations observed at HLT2.

The volatile portion composed approximately 10% of the total suspended solids for all sites in the watershed. Volatile solids are those that can be burned off at 500 ^{o}C. Material left after the "burn off" can be considered inorganic or sediment. Due to the small percent of volatile solids, it was determined that the majority of suspended solids are sediment. Sources of the inorganic sediment are from poorly managed row crop fields and/or channel deposition. The entire watershed is made up of shale soils that are very fine clay. These soils are subject to wind erosion and often move during winter snow events. Runoff from this snowmelt will carry more of this fine clay in suspension and may also account for the high amounts of suspended solids.

During the course of the project HLT2 delivered approximately 155,407 kg/yr (7 kg/acre) of suspended solids to Hayes Lake accounting for approximately 16% of the total solids load. This load equates to approximately 2.5 acre-feet of sediment per year at the current delivery rate. During this investigation drought conditions likely skewed the true impact of sedimentation from the watershed. Sedimentation would have been much higher had more runoff occurred. Future management efforts should consider the potential for sedimentation to Hayes Lake.

The runoff samples from station HLT1 were based on very low flow data. Dams above the sampling location for this watershed were influencing the amount of runoff during the sampling period. Data from HLT2 is more representative of the solids concentrations one might expect in the area without the benefit of sediment retention dams.

<u>Nitrogen</u>

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

The average total nitrogen concentration was 9.86 mg/L (median 4.95 mg/L) for all tributary samples collected during the project. This ranged from a high of 42.1 mg/L collected at HLT2 March 14, 2001 to a low of 0.2 mg/L collected at HLT1 April 24, 2001. In general, nitrogen at HLT1 was mostly organic in nature and nitrogen at HLT2 was mostly inorganic in nature. Inorganic nitrogen is more readily available to plant and algae growth in aquatic systems. Despite relatively high concentrations of total nitrogen, overall transport is dependant on the hydrologic load.

Table 10, indicates the number of acres drained by each monitoring station, the calculated total nitrogen load, and the discharge coefficient for the portion of the watershed that is located upstream from that monitoring station. Discharge coefficients were calculated by dividing the total load by the total number of acres drained resulting in load per unit area in kg/acre. Nitrogen loads from the Frozen Man Creek watershed were highest from subwatershed HLT2. Nitrate accounted for the greatest proportion of the load at 88% with TKN contributing 12% and ammonia contributing under1% of the total nitrogen load.

Table 10. Subwatershed Nitrogen Loads for Frozen Man Creek

Total Nitrogen			
Subwatershed	Acres Drained	Total Load (kg)	Discharge Coefficient kg/acre
HLT1	3,720	NC	NC
HLT2	22,206	21,062	0.948

NC – not calculated because of lack of flow data from HLT1

Reducing nitrogen loading may help reduce late summer algae blooms in the lake. As is identified in the limiting nutrient section of the report, phosphorus released from lake sediments shift the nitrogen to phosphorus ratio in the lake to a nitrogen-limited system. Reducing sources of nitrogen in the watershed may reduce the intensity and frequency of blooms that occur during the later part of summer.

The soils for this watershed are developed from Pierre shale. Layers have been identified in the bedded material that are high in nitrates and will yield nitrates to the ground water that seeps through these areas. Two samples from the HLT2 gauging site had high nitrate concentrations. One when the snowmelt started to run off and again about a month later when rain and snow caused a small runoff. There are three possible sources for increased nitrates to enter seepage waters in the watershed.

- Natural seeps that occur along the drainage ways may deliver nitrates to the draws and the nitrate is flushed downstream when runoff occurs.
- A water table that occurs below and down stream of impoundments (stock dams) may be intercepting some of these layers high in nitrate and cause it to flow to the surface downstream of the dam. Several dams have been constructed in the watershed for livestock water in the last 60 years and are still in existence.
- Or there may be seeps that have developed in cropland. The Pierre soils have a history of seeps developing and enlarging where native range has been converted to cropland. This is caused where the annual moisture exceeds the cropland needs and a water table develops and brings seep water to the ground surface.

Due to the natural occurrence of the high nitrate concentrations in the soils, it will be difficult to reduce nitrate loadings.

Phosphorus

Phosphorus is one of the macronutrients required for primary production. In comparison to carbon, nitrogen, and oxygen, it is often the least abundant in natural systems (Wetzel, 2001). Phosphorus loading to lakes can be of an internal or external nature. External loading refers to surface runoff, dust, and precipitation. Internal loading refers to the transfer of phosphorus from bottom sediments to the water column of the lake. Total phosphorus is the sum of all attached and dissolved phosphorus in the lake. The attached phosphorus is directly related to the amount of total suspended solids present (the ratio of total suspended solids to total dissolved phosphorus resulted in an inverse relationship with an R^2 of .63). An increase in the amount of suspended solids increases the fraction of attached phosphorus.

The average tributary total phosphorus concentration was 0.51 mg/L (median 0.48 mg/L). The highest and lowest concentrations (0.92 mg/L & 0.06 mg/L) were observed from both samples collected at HLT1. Total phosphorus collected at HLT2 ranged from a high of 0.88 mg/L to a low of 0.183 mg/L. In most occasions dissolved phosphorus accounted for approximately half of the total phosphorus concentration in HLT2 samples.

Table 11 and 12 indicate the number of acres drained by each monitoring station, the calculated total phosphorus and dissolved phosphorus load, and the discharge coefficient for the portion of the watershed that is located upstream from that monitoring station. Discharge coefficients were calculated by dividing the total load by the total number of acres drained resulting in load per unit area in kg/acre.

The largest portion of the total phosphorus load produced in the watershed originates from subwatershed HLT2. Subwatershed HLT2 accounts for 74 percent of the total drainage into Hayes Lake and delivered almost the entire phosphorus load. The AGNPS model identified priority cells in the drainage areas of the watersheds that drained into both HLT1 and HLT2 sampling locations. Due to the potential and relative chance of erosion priority loadings in each watershed should be treated equally.

Table 11. Subwatershed Phosphorus Loads for Frozen Man Creek Watershed

Phosphorus			
Subwatershed	Acres Drained	Total Load (kg)	Discharge Coefficient (kg/acre)
HLT2	22,206	587.8	0.026
HLT1	3,720	NC	NC

NC – not calculated because of lack of flow data from HLT1

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. Subwatershed HLT2 had the highest discharge coefficient and the highest percentage of dissolved phosphorus. Dissolved phosphorus accounted for 43% of the total phosphorus load delivered from HLT2.

Table 12. Subwatershed Dissolved Phosphorus Loads for Frozen Man Creek Watershed

Subwatershed	Acres Drained	Total Load (kg)	Discharge Coefficient (kg/acre)
HLT2	22,206	252.7	0.011
HLT1	3,720	NC	NC

NC – not calculated because of lack of flow data from HLT1

Annual Loading Summary

During the 2001 hydrologic period Frozen Man Creek (HLT2) delivered nutrient and sediment loads to Hayes Lake. These loadings are used to determine what influence the watershed had on the water quality of Hayes Lake. To calculate the current and future water quality in an impoundment, the BATHTUB model (Army Corps of Engineers Eutrophication Model) utilizes phosphorus and nitrogen loads entering the impoundment. Table 13, lists the annual loadings with standard errors (CV) calculated (FLUX) during the project at site HLT2.

Table 13. Summary of the Annual Lake Loadings for Hayes Lake

	Concentration (ppb)	FLUX Load (kg/yr)	CV
Total Phosphorus	550.7	587.8	0.187
Total Dissolved Phosphorus	236.8	252.7	0.057
Total Solids	904,509	965,326	0.361
Total Suspended Solids	145,616	155,407	0.493
Nitrate	17,360	18,527	0.693
TKN	2,375	2,535	0.187
Ammonia	518.9	553.8	0.384
Total Nitrogen	19,735	21,062	0.824

Water and Nutrient Budgets

As creeks flow through impoundments they often lose some nutrient and sediment loads. This is the case for Frozen Man Creek and Hayes Lake. Like Frozen Man Creek, the Hayes Lake outlet was also monitored during the project period. Sample data collected at the outlet of Hayes Lake is presented in Appendix C. This information was used to determine the amount of nutrient/sediment and hydrologic load retained by Hayes Lake during the project period (2001). Table 14 indicates that Frozen Man Creek decreased its nutrient and sediment load as it passed through the lake.

Table 14. Hayes Lake Nurtient, Sediment, and Water Budgets

Item	Units	Inlet	Outlet	Difference	% input
Total Phosphorus	Kg/yr	587.8	211.8	376.0	64
Total Dissolved Phosphorus	Kg/yr	252.7	120.4	132.3	52
Total Solids	Tons/yr	1064.27	257.53	806.74	76
Total Nitrogen	Kg/yr	21,062	3,679	17,383	83
Water	HM^3/yr	0.67	0.54	0.13	19

Tributary Site Summary

Nutrient loading to Hayes Lake occurs primarily during spring snowmelt and rainstorm events. No water quality standard violations were experienced on Frozen Man Creek during this assessment. HLT1 had little flow during the project although priority sediment and nutrient areas were identified in both subwatersheds. Strategies for grazing, cropland residue management and promotion of healthy riparian zones along the stream corridor would likely reduce the incidence of nutrient and solids loss during runoff events.

Concentrations

Two sampling events (March 14 & April 24) above HLT2 yielded high concentrations during the project. Elevated dissolved solids and nitrate concentrations were experienced on both these dates respectively. The high dissolved solids can be attributed to the flowing artesian wells that have been developed for stock water through the last century. Many of these wells flow throughout the year and often have a large build up of ice in the overflow area. The water from these wells is high in dissolved solids and can show up in the watershed runoff especially when the runoff volumes are reduced. Nitrates are likely a natural condition occurring in high concentrations in Pierre soils from the Upper Midwest. Spring seeps were likely contributing to the elevated concentrations on both accounts. Dissolved phosphorus accounted for approximately 50% of the total phosphorus concentration in samples collected at HLT2. Dissolved phosphorus derives from a variety of organic sources such as manure and septic systems.

Loadings

It was estimated that 83% of the nitrogen total load from HLT2 was stored in the lake. The majority of the nitrogen load was inorganic nitrate; the most readily available for uptake by aquatic macrophytes and algae. Phoshorus loads were relatively minor during the project period due to a lack of flow. Discharge coefficients were low in terms of kilograms per acre (0.026 and 0.011) for both total phosphorus and dissolved phosphorus respectively. However, it was estimated that 64% of the total phosphorus load from HLT2 remained in the lake over the project period. Phosphorus loads though relatively low can still contribute to the internal load stored within Hayes Lake. Dissolved solids contributed 84% of the total solids load to Hayes Lake. An estimated 76% of the total solids load from HLT2 was retained in the lake over the project period.

The drainage area of site HLT1 is a much smaller than site HLT2. HLT1 is approximately 12 per cent of the total area as compared to HLT2 that drained about 74 per cent of the total lake drainage. In addition HLT1 watershed has more large dams in relationship to its drainage area than the HLT2 subwatershed. This accounts for the low amount of flow that occurred during the sampling period and likely had an impact on the sampling data for total solids, suspended solids, volatile solids, organic nitrogen and total phosphorus.

Inlake Water Quality (Hayes Lake)

Inlake Sampling Schedule

Sampling began in February 2001 and was conducted on a monthly basis (except for March due to unsafe ice conditions) until October 2001 at the two pre-selected sites (Figure 4).

Water samples were filtered, preserved, and packed in ice for shipping to the State Health Lab in Pierre, SD. Sample data collected at Hayes Lake may be found in Appendix C. The laboratory then assessed the following parameters:

Fecal Coliform Counts	Total Kjeldahl Nitrogen (TKN)
E. coli Counts	Ammonia
Total Solids	Nitrate
Total Suspended Solids	Total Phosphorus
Total Volatile Solids	Total Dissolved Phosphorus
Alkalinity	

The calculated parameters included:

Total Dissolved Solids
Un-ionized Ammonia

Chlorophyll *a* was determined at the DENR laboratory.

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

Precipitation	Wind	Water Depth
Odor	Septic	Ice Cover
Dead Fish	Film	Water Color

Parameters measured in the field by sampling personnel were:

Water Temperature	Air Temperature
Secchi Depth	Dissolved Oxygen
Field pH	

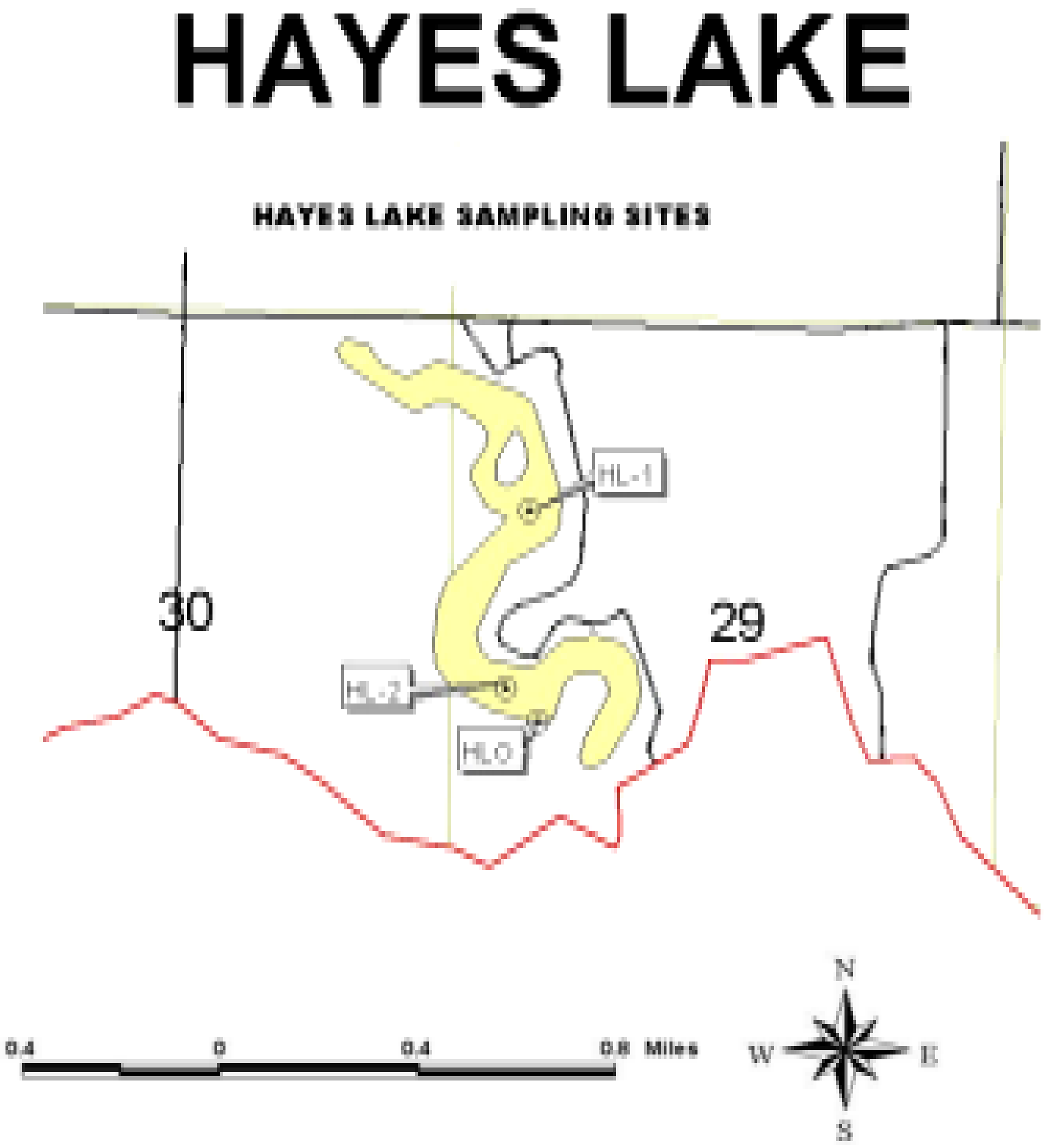


Figure 4. Map of Hayes Lake Inlake Monitoring Stations

South Dakota Water Quality Standards for Hayes Lake

All public waters within the State of South Dakota have been assigned beneficial uses. All public waters are assigned the beneficial use of fish and wildlife propagation, recreation and stock watering. Along with each of these uses are sets of water quality standards that must not be exceeded in order to support these uses. Hayes Lake has been assigned the following beneficial uses:

(5) 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 (Table 15) 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 stringent standard is used.

Table 15. State Beneficial Use Standards for Hayes Lake

Parameter	Standard		Beneficial Use Number
Total Dissolved Solids	<90 mg/L	30-day average*	9
	<158 mg/L	Daily maximum	9
Nitrates	<50 mg/L	30-day average*	9
	< 88 mg/L	Daily maximum	9
Suspended Solids	<90 mg/L	30-day average*	5
	158 mg/L	Daily maximum	5
Total Alkalinity as Calcium Carbonate	<750 mg/L	30-day average*	9
	1313 mg/L	Daily maximum	9
Conductivity at 25 deg. C	4,000 micromhos/cm	30-day average*	9
	7,000 micromhos/cm	Daily maximum	9
Fecal Coliform (counts)	<200/100mL	30-day average*	7 & 8
	<400/100mL	In any one sample	7 & 8
Un-ionized Ammonia Nitrogen	<0.04 mg/L	30-day average	5
	<1.75 times the criteria in App. A	Daily maximum	5
pH	>6.5 & <9.0 units		5 & 9
Dissolved Oxygen	> 5.0 mg/L		5, 7, & 8
Temperature	< 90 deg. F (26.67 C)		5

***30 day average:** Geometric mean of a minimum of 5 samples during separate 24-hour periods over 30 days.

<u>Seasonal Inlake Water Quality</u>

Typically, water quality parameters will vary with season due to changes in temperature, precipitation and agricultural practices. Thirty inlake water quality samples were collected during the project (16 surface and 14 bottom samples). These data were separated seasonally into winter (February) spring (April – May), summer (June – August), and fall (September – October). During the project, two discrete surface samples were collected in the winter, four samples in the spring, six samples in the summer and four samples in the fall of 2001.

Seasonal Inlake Concentrations

Sediment and nutrient concentrations in a lake basin can change dramatically with changes in season. Hydrologic loads to a lake in the spring may have small nutrient and sediment concentrations; however, more water during spring runoff usually results in higher loadings of nutrients and sediment. Inlake concentrations are also affected by internal loading, especially in lakes that seasonally stratify; Hayes Lake experienced minor thermal stratification throughout the project though summer anoxia was evident and persisted into fall. Average surface concentrations of inlake sampling sites and sampled parameters by season are listed in Table 16.

Dissolved oxygen concentrations were highest in the spring due to cooler water temperatures (cooler water can hold more dissolved oxygen in solution) and higher photosynthetic algal densities. Lower dissolved oxygen and even anoxia were evident in the lower six feet of depth during the winter, summer and fall sampling periods. The lower dissolved oxygen concentrations in the summer and fall were most likely due to oxygen demand by decomposing organic matter. Algae once abundant in the spring along with other organics some of which entered via Frozen Man Creek were likely decomposing in the summer creating an oxygen demand in the lower strata. Lower oxygen concentrations in the fall can also be attributed to the decomposition of organic matter especially macrophyte vegetation. Surface dissolved oxygen collected in the winter at both sites (HL1 and HL2) was also low (Table 15). This could be due to snow cover (prohibiting photosynthesis) and decomposition of organic matter under the ice. Persistent low dissolved oxygen (<5 mg/L) can be detrimental to fish and other aquatic life. The water quality standard for three of four beneficial uses designated to Hayes Lake is surface dissolved oxygen greater than 5 mg/L.

Table 16. Average seasonal surface water concentrations of measured parameters by site from Hayes Lake, Stanley County, South Dakota 2001 [2].

	Spring 2001		Summer 2001		Fall 2001		Winter 2001	
	HL1	HL2	HL1	HL2	HL1	HL2	HL1	HL2
PARAMETER	Average	Average	Average	Average	Average	Average	*	*
Field pH S.U	8.21	8.28	8.00	8.04	8.36	8.19		
Secchi m	1.09	1.16	1.54	1.41	1.05	1.05	0.57	0.85
Water temp (°C)	14.60	14.45	19.80	18.05	14.50	15.40	4.00	4.00
DO mg/L	10.90	10.90	7.14	7.22	7.90	8.00	5.90	5.00
Alkalinity mg/L	177.00	183.50	196.67	193.67	242.00	238.00	289.00	287.00
Total Solids mg/L	652.50	662.50	705.33	697.67	798.50	797.50	797.00	789.00
Total Dissolved Solids mg/L	643.50	654.00	699.17	692.67	785.00	781.00	790.00	782.00
Total Suspended Solids mg/L	9.00	8.50	6.17	5.00	13.50	16.50	7.00	7.00
Volatile Total Suspended Solids mg/L	5.00	7.00	5.17	3.67	9.00	14.00	2.00	2.00
Ammonia mg/L	0.10	0.12	0.01	0.04	<.02	<.02	0.22	0.25
Nitrate mg/L	1.80	1.85	<.1	0.07	<.1	<.1	0.20	0.10
TKN mg/L	1.67	1.63	1.36	1.37	1.53	1.40	2.03	1.84
Total Nitrogen mg/L	3.47	3.48	1.41	1.43	1.58	1.45	2.23	1.94
Total Phosphorus mg/L	0.14	0.14	0.27	0.27	0.31	0.32	0.11	0.12
Total Dissolved Phosphorus mg/L	0.05	0.05	0.22	0.23	0.20	0.22	0.05	0.06
E. Coli colonies/100ml	3.40	2.30	15.73	4.30	15.00	5.05	7.40	4.10
Fecal Coliform colonies/100ml	<10	7.50	16.67	10.00	22.50	7.50	<10	5.00
Chlorphyll-a mg/m3	26.59	38.20	4.77	5.74	30.09	30.59	2.80	11.51
N:P ratio	23.74	23.11	5.93	6.28	5.95	5.03	20.09	16.72
TSI (Secchi)	59.98	59.48	53.82	55.09	59.31	59.31	68.11	62.34
TSI (Phosphorus)	75.28	75.59	84.14	83.97	85.63	86.58	72.09	72.73
TSI (Chlorophyll-a)	50.42	73.11*	45.32	46.41	63.85	63.58	40.67	54.54
Mean TSI	61.89	72.54*	61.09	61.83	69.60	69.82	60.29	63.20

* = Only one sample was collected from inlake monitoring site, values not an average.

Highlighted areas are the seasons that recorded the highest average concentrations or values for a given parameter.

The pH of Hayes Lake remained within the range required to support the beneficial uses during all respective seasons. The highest fluctuation in pH occurred during the spring between April (8.67su) and May (7.74su). The highest pH (8.67su) was observed in the spring, while the lowest pH (7.72) was observed in the summer.

Average seasonal alkalinity concentrations were highest in the fall for HL1 and HL2. However, winter alkalinity was significantly higher than the average fall values.
The entire suite of solids parameters (total solids, total dissolved solids, total suspended solids and volatile total suspended solids) had the highest average seasonal concentrations in the fall for both sites. Lack of inlet discharge and evaporation over the late summer and fall likely contributed to the elevated concentration of solids. Winter samples showed slightly higher concentrations of dissolved solids perhaps due to ice cover though were fairly close to the fall average.

Average seasonal ammonia, nitrate and Total Kjeldahl Nitrogen (TKN) were highest during the spring for both sites. This is also when the highest tributary loadings occurred. All nitrogen parameters reduce significantly in the summer and fall. This may be attributed to the reduction in tributary loadings and/or assimilation by resident macrophytes and algae. Winter ammonia and TKN were elevated above the spring average perhaps due to release from the decaying macrophyte vegetation. Elevated nitrogen in the spring increased the average N: P ratio to suggest phosphorus limitation. Hayes Lake average N: P ratio shifted to nitrogen limitation in the summer and fall.

Average total phosphorus concentrations were highest in the fall for both sites. Total dissolved phosphorus concentrations were highest in the summer at both sites though concentrations were only slightly lower in the fall. Average Chlorophyll-*a* concentrations were highest in the fall at HL1 and highest in the spring at HL2. Both spring and summer average chlorophyll-a values were seasonally dominant. Algal density was found to be highest in the spring however, conditions may have been favorable for increase algal biomass in the fall. During the project no algae samples were collected past August 10th 2001.

During the study, fecal coliform and E. coli counts (colonies/100ml) were low and never exceeded the state water quality standard. The highest average seasonal concentrations of fecal coliform bacteria occurred at HL1 in the fall and HL2 in the summer. The highest average seasonal concentration of E. coli occurred in the summer at HL1 and in the fall at HL2.

Average Secchi Trophic State Index (TSI) values were highest in the spring for both sites though the spring and summer average values were fairly similar. Winter Secchi TSI values were significantly elevated perhaps due to ice cover and other internal mechanisms. Average phosphorus TSI values were highest in the fall for both sites. Average chlorophyll-a TSI values were also highest in the fall for both sites. Spring values were not an average due to missing chlorophyll-a data from HL1. The highest average combined TSI values were observed in the fall for both sites.

Inlake Water Quality Parameters

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 conditions. Oxygen dissolves in higher concentrations in cooler water. Higher toxicity of un-ionized ammonia is also related directly to warmer temperatures.

The average water temperature during the growing season (May-September) was 19.2 ^{0}C for surface samples and 17.6 ^{0}C for bottom samples. The lowest growing season temperature was 14 ^{0}C observed at the bottom of HL2 August 15, 2001. The highest inlake temperature was 21.6 ^{0}C recorded at the surface of HL1 June 13, 2001. No temperature data was available from the July sampling due to complications with sampling equipment. All measured water temperatures fell within the requirements for the designated beneficial uses of Hayes Lake. There was very little temperature stratification in Hayes Lake during the project period.

Dissolved Oxygen

There are many factors that influence the concentration of dissolved oxygen (DO) in a waterbody. Temperature is one of the most important of these factors. As the temperature of water increases, its ability to hold DO decreases. Daily and seasonal fluctuations in DO may also occur in response to algal and bacterial action (Bowler, 1998). As algae and aquatic plants photosynthesize during the day, they produce oxygen, which raises the concentration in the epilimnion. As photosynthesis ceases at night, respiration utilizes available oxygen causing a decrease in concentration. .

As algae bloom in the late spring and summer they create a shading effect. The shading condition blocks light penetration and reduces oxygen production by aquatic plants. The lack of oxygen production at lower depths coupled with oxygen consumption in the sediment can create anoxic conditions in the hypolimnion or deeper portion of the lake. The depleted oxygen levels near the sediments decrease the redox potential holding phosphorus to the sediments. Decreases in oxygen can lead to a release of phosphorus from the sediment resulting in an internal phosphorus load which is discussed later in the report.

Average DO concentration from all Hayes Lake surface sites was 8.1 mg/L differing significantly from the average bottom concentration of 5.9 mg/L. The maximum surface DO concentration of 11 mg/L was observed in April, while the minimum concentration (0.21 mg/L) was observed at the bottom in July. Oxygen stratification was evident in Hayes Lake during the project period

An oxygen-temperature profile measures the change in concentration of DO and corresponding temperature at different depths of the lake. The purpose of the profiles is to check for the extent of stratification, if any. Dissolved oxygen and temperature profiles were recorded at the sampling sites monthly beginning in February 2001. Dissolved oxygen and temperature measurements were recorded from the surface to the bottom at intervals of approximately two to three feet. There was very little variation in DO and temperature between sites. The February profile indicated low dissolved oxygen (< 5mg/L) near the lake bottom. Decomposition of organic material at the substrate-water interface was likely causing this band of lower DO. Profiles taken in April and May indicated uniform DO (11.0 mg/L) and temperature through the entire water column. By June, the lake began to experience oxygen stratification. Dissolved oxygen concentrations decreased from about 8.0 mg/L at the surface to about 3.0 mg/L from six feet of depth to the bottom.

The oxygen profile conducted at site HL2 on July 10 of 2001 indicated the lowest concentrations of DO during the entire sampling period. Dissolved oxygen concentrations on this date ranged from 5.3 mg/L at the surface to 0.24 mg/L near the bottom with a sharp decline between 5 and 6 feet of depth (Figure 5).

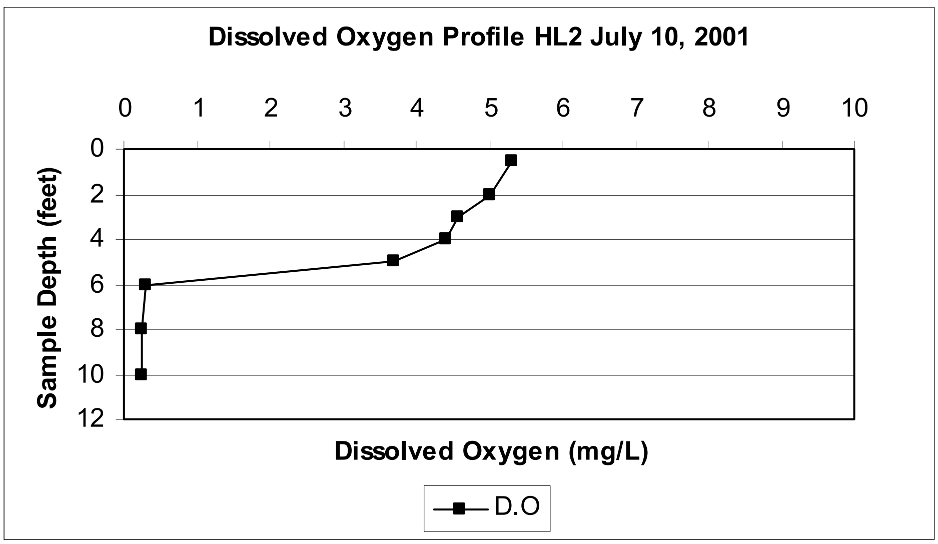


Figure 5. Dissolved Oxygen/Depth Profile July 10, 2001 HL2

Dissolved oxygen stratification was not evident in August though concentrations ranged from 5 to 6 mg/L throughout the water column. The lack of oxygen stratification in August can be attributed to observed windy conditions that likely mixed the water column and created a more homogenous profile. Stratification was observed again in September during calm wind conditions. The D.O at both sites was 8.6 mg/L at the surface and dropped 1 to 2 mg/L at every depth increment to1.6 mg/L at the bottom. It wasn't until October that DO levels improved and were observed as homogenous throughout the water column. Dissolved oxygen and temperature profiles for all sampling dates are graphically represented in Appendix D. Oxygen stratification in Hayes Lake may be attributed to the cyclic persistence of macrophyte vegetation and algae throughout the year. An aeration system may be beneficial in Hayes Lake to break oxygen stratification and reduce the incidence of phosphorus release into the water column.

pH

pH is a measure of free hydrogen ions (H^+) or potential hydrogen. More simply it indicates the balance between acids and bases in water. It is measured on a logarithmic scale between 0 and 14 and is recorded as standard units (su). At neutral (pH of 7) acid ions (H^+) equal the base ions (OH^-). Values less than 7 are considered acidic (more H^+ ions) and greater than 7 are basic (more OH^- ions). Algal and macrophyte photosynthesis act to increase a lake's pH. 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 Hayes Lake require that the pH values remain between 6.5 su and 9.0 su. The values recorded during the assessment remained within these limits at all times. The highest values recorded were during April on the surface of the lake at 8.67 su for both sites, respectively. The lowest pH value (7.72) observed on Hayes Lake was at HL1 on July 10, 2001. The algae and chlorophyll data indicate that the highest concentration of algal production correlated with the high pH concentrations.

Secchi Depth

Secchi depth transparency is the most commonly used measurement to determine water clarity. No regulatory standards for this parameter exist, 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. Deeper Secchi readings are found in lakes that have clearer water, which is often associated with lower nutrient levels and "cleaner" water.

Hayes Lake is a narrow lake and lies within a valley that provides minor wind protection, especially from the northwest. Large waves eroding the shoreline are not a serious problem for this lake at the present time, although the banks along the southern part of the lake show previous bank erosion. Cattails and reeds provide good shoreline protection in the upper one half of the lake. The soils around the lake are all clays. The amount of suspended solids does increase during windy periods even though the shoreline does not have serious bank erosion at the present time. Some of the solids come from the shoreline and some are picked up from the lake bottom in shallower areas.

Some of the lower Secchi depth readings occurred during the winter with ice cover and in early spring right after the ice went out and may have been due largely to the abundance of motile algae at those times (Figure 6). The dominance of pigmented flagellates in the algal community of Hayes Lake during this assessment can probably be related to lake morphology and local water quality. The stream-like characteristics of this small lake with a narrow, winding, wind-sheltered basin (short wind fetch distances), abundant macrophytes, and probable accumulation of organic matter derived from decayed local vegetation and/or imported from the drainage, may have created favorable conditions for those motile species especially during periods of minor wind/wave action and ice cover. Blue-green algae, including nuisance species, were of minor importance during this investigation.

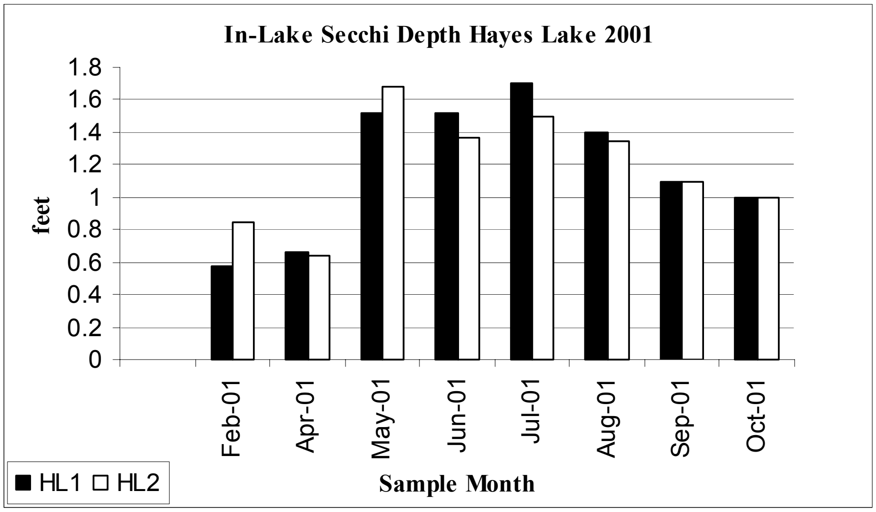


Figure 6. Hayes Lake Secchi Depth By Site and Month 2001.

Shoreline erosion will occur where the bank vegetation has been reduced or removed by domestic livestock. Banks that are void of vegetative cover are prone to erosion even by small waves. Livestock use of the riparian area also crushes portions of the bank into the lake. Part of the lake shoreline is grazed and the lake is used for livestock watering. Visual observations of the area where livestock were present did not indicate any significant destruction of riparian vegetation or the activation of bank erosion.

Suspended solids are generally related to the Secchi depth but it is not a strong relationship ($R^2 = 0.21$) in Hayes Lake (Figure 7). The majority of the suspended solids in Hayes Lake may be organic (such as algae and vegetative detritus) and not suspended soil particles. Suspended soil particles and other suspended matter increase turbidity and reduce Secchi depth.

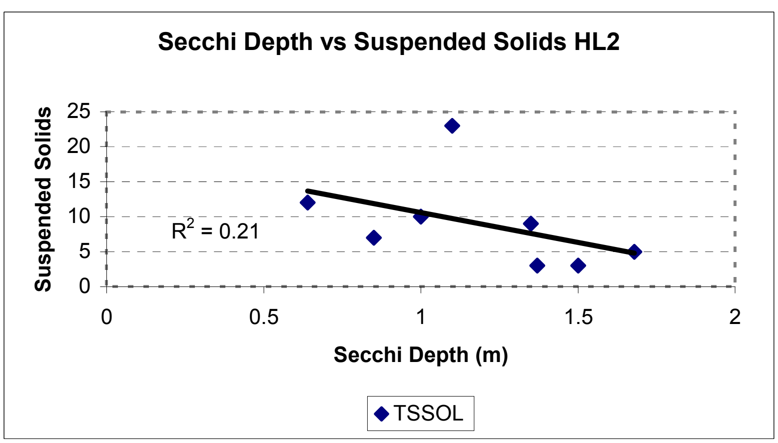


Figure 7. Secchi vs. Total Suspended Solids for Hayes Lake HL2

Chlorophyll a

Chlorophyll *a* is the primary photosynthetic pigment found in oxygen producing organisms (Wetzel, 1982). Chlorophyll *a* is a good indicator of a lake's productivity as well as its state of eutrophication. The total concentration of chlorophyll *a* is measured in mg/m^3 (ppb) and is used in Carlson's Trophic State Index to rank a lake's state of eutrophication.

Hayes Lake chlorophyll *a* levels were high right after the ice went out. This was due to a large amount of pigmented flagellates in the algal community. Chlorophyll *a* increased in the late summer and early fall (Figure 8) because of an increase in algae, but a nuisance bloom never occurred.

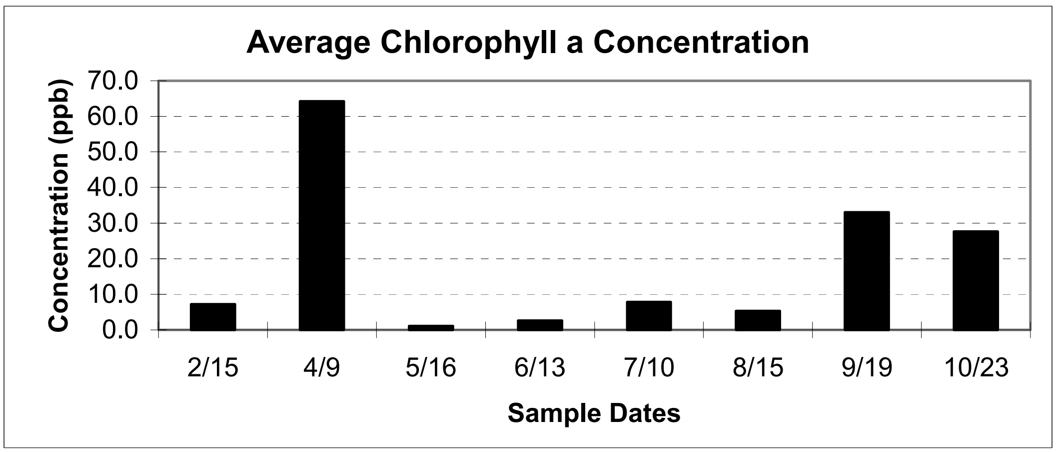


Figure 8. Average Chlorophyll a concentrations for Hayes Lake.

Hayes Lake has a significant amount of water surface area that is five feet or less in depth and produces abundant macrophyte communities. The macrophytes keep the available nitrogen at almost zero (nitrate and ammonia readings during the growing season months were below detectable levels). The lack of nitrogen (used up by the abundant plant growth) limits the amount of nuisance algae that can be produced.

There is some relationship (R^2=0.42) between Secchi readings and the chlorophyll *a* concentrations. Generally the larger the chlorophyll reading the shallower the Secchi depth recorded (Figure 9).

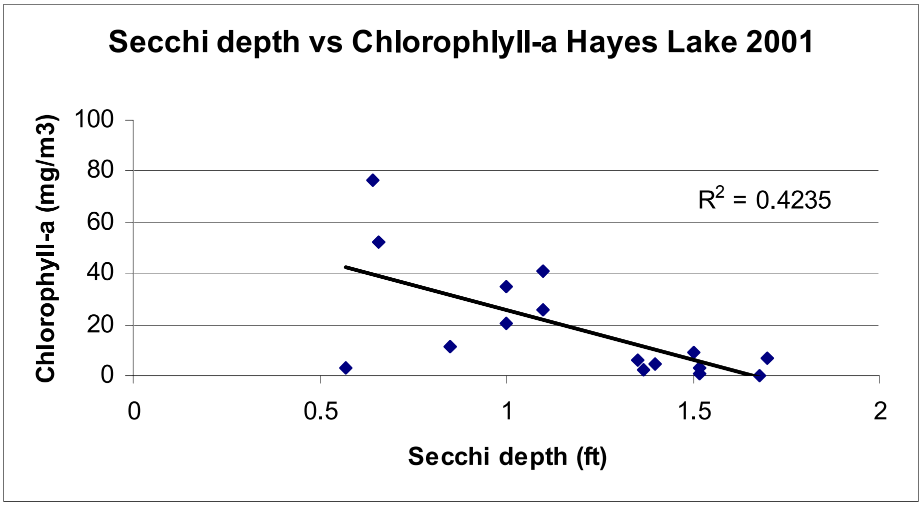


Figure 9. Relationship between chlorophyll-a and Secchi depth Hayes Lake 2001.

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 Hayes Lake require alkalinity concentrations to maintain a 30 day geometric mean of less than 750 mg/L and never to exceed 1,313 mg/L in a single sample. Samples collected in Hayes Lake during this study varied from a minimum of 169 mg/L collected April 9, 2001 at the surface at site HL-1, to a maximum of 289 mg/L collected on February 9, 2001 from the surface of the lake also at site HL-1. This sample was taken through the ice when the lake was at its lowest point before spring runoff occurred. The lake steadily increased in alkalinity during the sampling season with a reading for alkalinity at 248 mg/L in late October of 2001. Average alkalinity concentrations were slightly higher for the bottom samples at 206 mg/L versus an average of 204 mg/L on the surface. The alkalinity in Hayes Lake does not impair its beneficial uses. The continued increase during the summer may be the result of evaporation. The lower concentrations that occurred in the spring were likely a dilution effect from the spring runoff.

Solids

Solids are addressed in four separate categories 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.

The total and dissolved solids concentrations in Hayes Lake are nearly identical and will be addressed as one parameter. Peak values for total solids were recorded during the October 23, 2001 sampling. These samples contained total and dissolved solids concentrations in excess of 800 mg/L. The lowest values recorded were in the May 9, 2001 samples, which had values that ranged from 610 to 630 mg/L. The lower May concentrations were most likely the result of dilution by spring runoff.

The suspended solids found in Hayes Lake did not play a significant role through their effect on other parameters such as Secchi readings and turbidity. Suspended solids concentrations were found to contain anywhere from 11% to 100% volatile organic matter. The average organic concentration was approximately 37%. Total suspended solids concentrations varied from less than 1 mg/L collected on the surface of site HL-1 on July 10, 2001 to 23 mg/L collected at the surface at site HL-2 on September 19, 2001. From the chart below (Figure 10) it appears that algae were the main source of suspended solids in the early spring and late summer. This correlates to the algae information found in Biological Monitoring Hayes Lake Phytoplankton section.

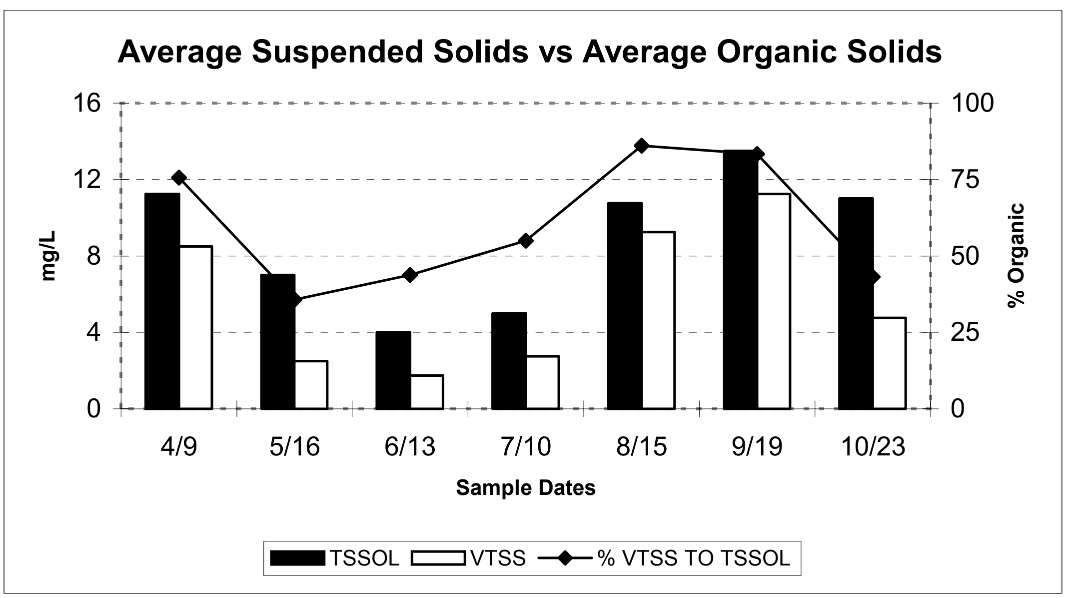


Figure 10. Average Total Suspended Solids vs Average Organic Solids for Hayes Lake

Nitrogen

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

Inorganic nitrogen is the most plant-available form, consisting of the sum of nitrate/nitrite and ammonia. Lake vegetation started to grow in late April and early May. Hayes Lake inorganic nitrogen concentrations were below the detection limit on the surface and the bottom for the entire growing season after May (Figure 11). The concentrations at the surface remained below detection limits because the excess amount of phosphorus in the water allowed for plant growth to use all the inorganic nitrogen as it became available. Hayes Lake supports a large amount of cattails, reeds, and macrophytes. The growth of these larger plants may also be using the available nitrogen.

Inorganic sources may be from the watershed through runoff, natural soil releases, the decay of organic matter, or chemical processes that occur in the lake from the exchange of N_2 from the atmosphere.

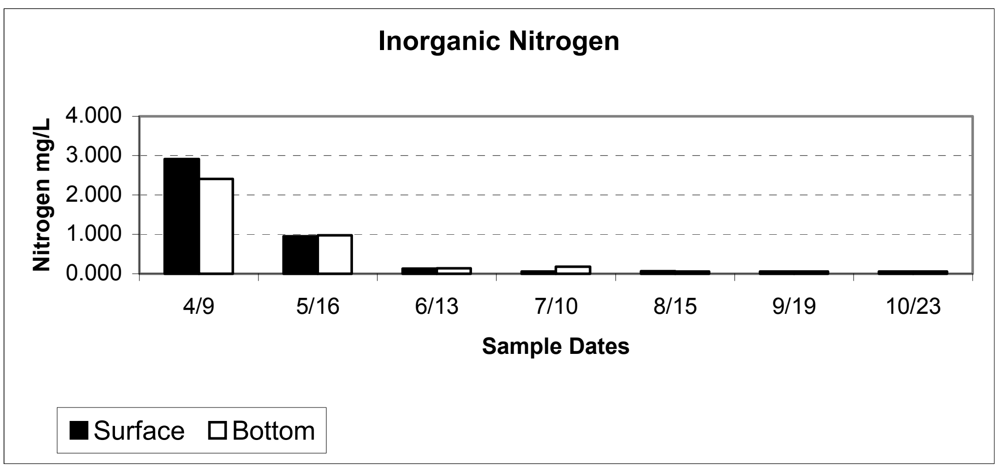


Figure 11. Inorganic Nitrogen in Hayes Lake.

Organic nitrogen is Total Keldahl Nitrogen minus the amount of ammonia. Organic nitrogen is not readily available to plants. There doesn't appear to be any significant trend for organic nitrogen in Hayes Lake (Figure 12). The highest concentration of organic nitrogen occurred along with the largest concentration of chlorophyll. The source of organic nitrogen may be organic inflow from the watershed and/or algae and macrophyte production within the lake.

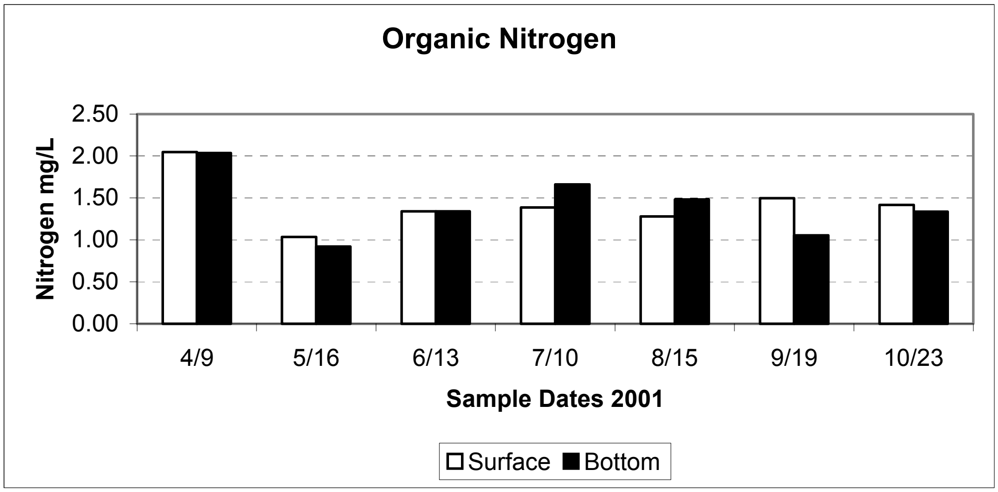


Figure 12. Organic Nitrogen in Hayes Lake.

Ammonia may be found in two forms, ionized and unionized. In higher concentrations the latter form can be toxic to fish. The unionized fraction of ammonia is dependent on pH and temperature. As these two parameters increase, so does the unionized fraction of ammonia. Ammonia tends to remain in its ionic form (NH^{4+}) except under higher alkaline conditions (pH>9.0) (Wetzel 2000). Unionized levels in excess of 0.05 mg/L can be lethal to fish and other aquatic life. Samples collected from Hayes Lake all remained below 0.01 mg/L unionized, resulting in no impairment of beneficial uses.

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. The attached phosphorus is directly related to the amount of total suspended solids present. An increase in the amount of suspended solids increases the fraction of attached phosphorus.

As a result of internal loading, total phosphorus concentrations were significantly different during the July, August and September samples (Figure 13). Nutrients released from the lake sediment impacted the bottom samples first. As the summer progressed into August, the concentration of phosphorus mixed throughout the water column, surface and bottom samples were nearly identical in value and remained this way throughout the remainder of the project. Winter samples indicated that a portion of the phosphorus had been adsorbed back into the sediments. Most likely algae settled to the bottom. This cycle of winter adsorption under aerobic conditions and summer release under anoxic conditions probably occurs on an annual basis.

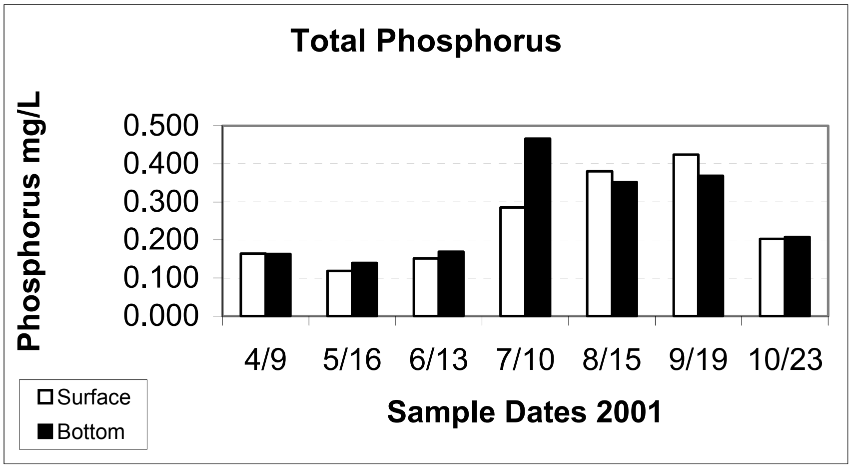


Figure 13. Total Phosphorus Concentrations in Hayes Lake.

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.

Samples collected from the surface and the bottom of Hayes Lake showed no correlation between the percentage of dissolved phosphorus and total suspended solids, organic suspended solids, inorganic suspended solids, or chlorophyll *a*. The strongest relationship observed compared the date of the sample with the portion of dissolved phosphorus. As the summer months progressed, anoxia at the bottom of the lake continued to release nutrients into the water column. The phosphorus was released slowly and dissolved throughout the water column, increasing the percentage at the surface. As this process occurs, a visible algal bloom would be expected. While moderately large summer algae populations developed, based on phosphorus levels, higher algae densities would have been likely if nitrogen supplies had been comparable to the high phosphorus concentrations present in Hayes Lake during the summer months. This was not the case due to the limited amount of nitrogen available for plant consumption. This large increase in dissolved phosphorus shifted the lake from a phosphorus-limited system to a nitrogen-limited system.

Due to less algal production and the release of phosphorus from the sediment, dissolved phosphorus was always slightly higher in the bottom samples than in the surface samples (Figure 14). The spread between the concentration of dissolved phosphorus at the surface and the bottom became greater in May, June and peaked in July when the lake stratification developed and the lake was most anoxic in the hypolimnion.

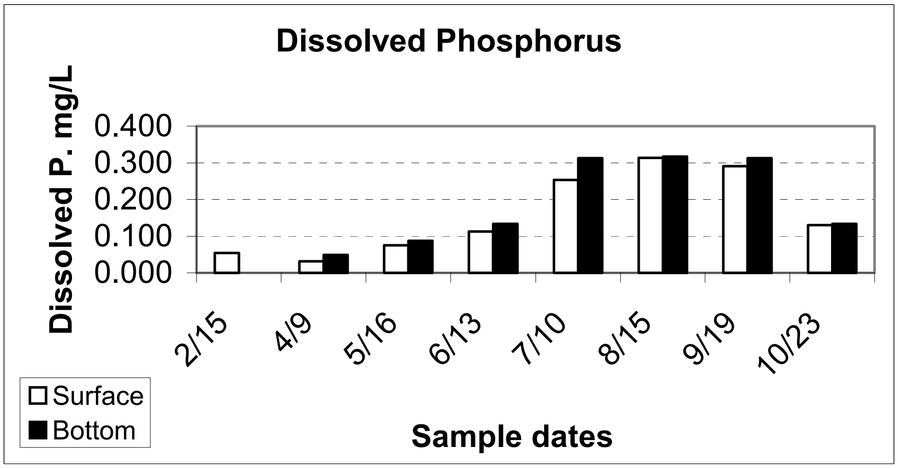


Figure 14. Total Dissolved Phosphorus Concentrations in Hayes Lake.

When comparing total phosphorus to dissolved phosphorus at the surface and the bottom the percentage of dissolved phosphorous at the surface (Figure 15) began to increase in the spring and peaked in July and then gradually began to return to the levels that occur during the winter months. This same pattern was not true of the bottom percentage of dissolved phosphorus (Figure 16) where the pattern started out the same in the spring and dipped significantly when the lake was most anoxic. After the July sample the surface and bottom samples followed the same pattern for the rest of the year.

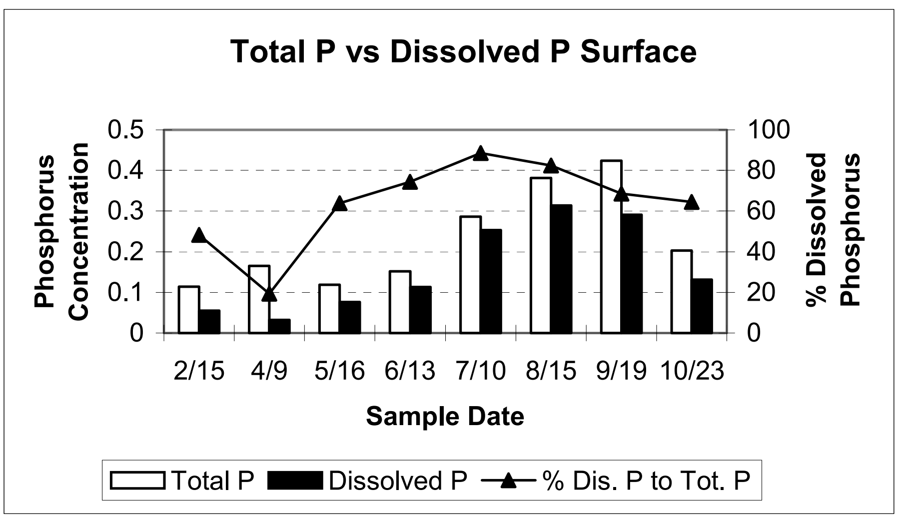


Figure 15. Total P vs Dissolved P (Surface) Hayes Lakes.

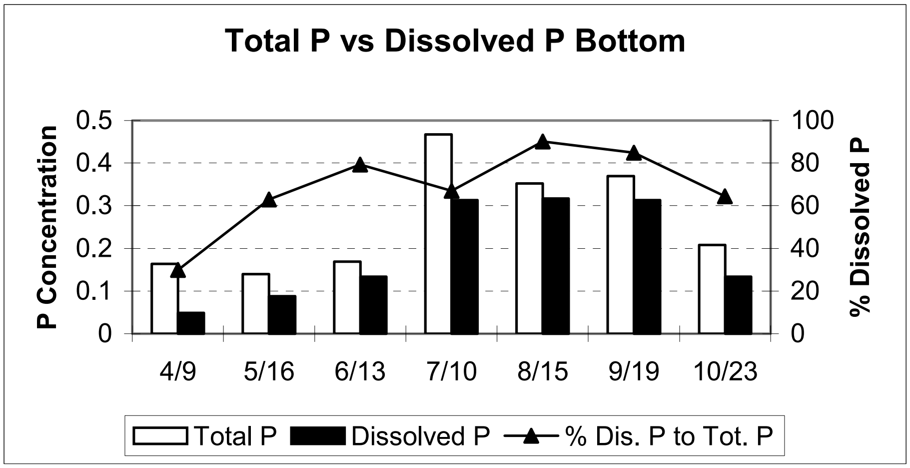


Figure 16. Total P vs Dissolved P (Bottom) Hayes Lake.

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, 1994). Fecal coliform bacteria are an indicator of the possibility of pathogens in the water.

Water samples collected from Hayes Lake exhibited a consistent pattern of fecal coliform concentrations that were below detection limits for sites HL1 and HL2. The exceptions to this were the samples collected during June, July and September (Figure 17) with concentrations as high as 40 colonies /100 mL. This concentration is still well below the state standard of 400-colonies/100 mL in any sample or 200-colonies/100 mL as an average of 5 samples over a 30-day period.

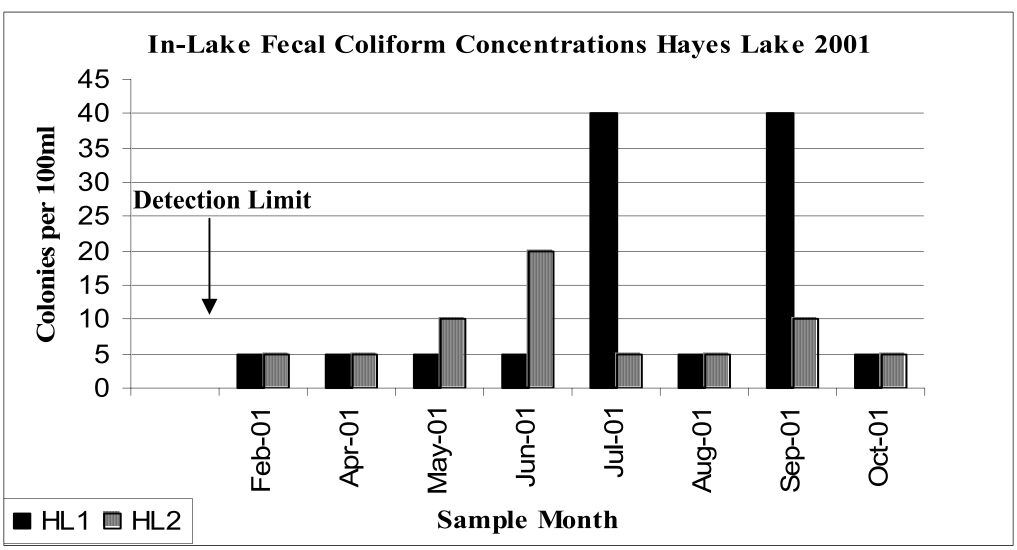


Figure 17. Fecal Coliform Counts Hayes Lake 2001.

Livestock were observed near the lake during the sampling periods of August, September and October. The only detectable fecal coliform concentration observed during these months was September. The presence of livestock in September renders them the likely sources of the bacteria. Bacteria levels observed in June and July may have also been due to livestock, although they were not observed during the sampling they may have been present prior to sample collection. Other potential sources of fecal coliform may be from wildlife and waterfowl species and not necessarily livestock. Due to the low concentrations observed during this study, fecal coliform contamination is not currently an issue in Hayes Lake.

Limiting Nutrients

Two of the primary nutrients required for cellular growth in organisms are 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 threshold ratio of nitrogen to phosphorus for aquatic plant growth is 10:1 (EPA, 1990). Ratios higher than 10:1 indicate a phosphorus-limited system. Those that are less than 10:1 represent nitrogen-limited systems.

The average surface nitrogen to phosphorus ratio for Hayes Lake during the entire project period was 10.8: 1. Samples collected after stratification had nearly identical N:P values for surface and bottom samples. Samples collected shortly after spring turnover and during the first few weeks of stratification showed a slight difference between surface and bottom ratios.

Samples taken in Hayes Lake were phosphorus limited during the spring and early summer and became nitrogen limited (mean growing season N:P 5.8:1) during the summer months (Figure18). The lake supports a large macrophyte growth as well as a large bulrush and cattail population. These plants use nitrogen from the water column, which may account for the long period of nitrogen-limited occurrence.

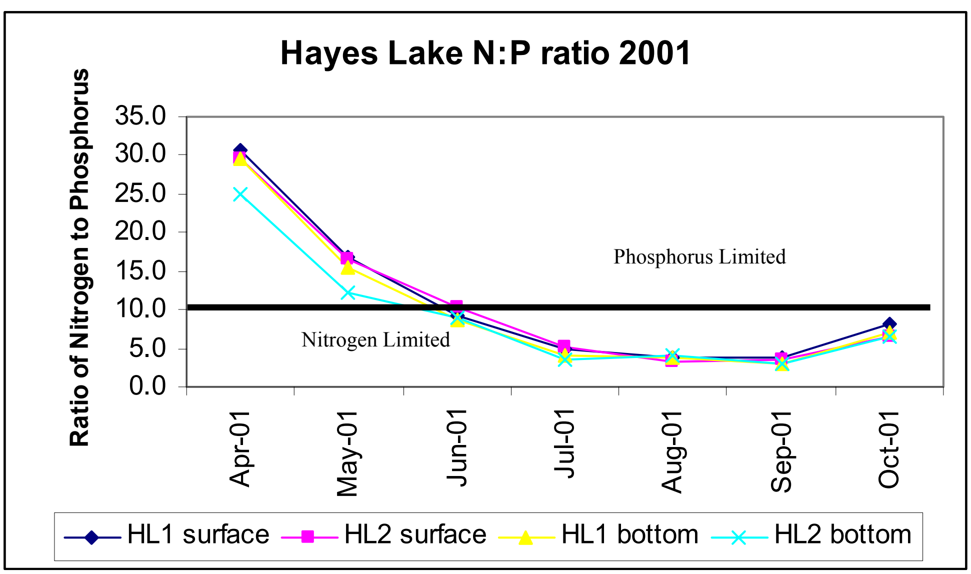


Figure 18. Limiting Nutrients in Hayes Lake.

Lake nitrogen concentrations were relatively low during the growing season and phosphorus concentrations were generally elevated. It was assumed that a considerable decrease in lake phosphorus concentration was needed to shift the growing season N:P ratio to suggest phosphorus limitation. Phosphorus concentrations were back calculated (reduced) in increments of 10% to predict the concentration needed to achieve phosphorus limitation based on current conditions (Table 17).

Table 17. N:P ratios displayed as a function of percent reduction in phosphorus concentration based on 2001 data.

Lake ID	Date	0%	10%	20%	30%	40%	50%	60%	70%
HL1	June	9.2	10.3	11.5	13.2	15.4	18.5	23.1	**30.8**
HL1	July	4.8	5.4	6.1	6.9	8.1	9.7	12.1	**16.1**
HL1	August	3.7	4.1	4.7	5.3	6.2	7.4	9.3	**12.4**
HL1	September	3.9	4.3	4.8	5.5	6.4	7.7	9.7	**12.9**
HL2	June	10.2	11.3	12.8	14.6	17.0	20.4	25.5	**34.0**
HL2	July	5.3	5.9	6.6	7.5	8.8	10.6	13.2	**17.6**
HL2	August	3.4	3.7	4.2	4.8	5.6	6.7	8.4	**11.2**
HL2	September	3.5	3.9	4.4	5.0	5.8	7.0	8.7	**11.6**

With the exception of June, the phosphorus concentration would have to be reduced by at least 60% to 70% before N:P ratios would exceed the EPA suggested 10:1 ratio for phosphorus limitation during the growing season. During the growing season surface total nitrogen was slightly variable ranging from 1.28 mg/L to 1.51 mg/L. Conversely, total phosphorus displayed considerable variation ranging from 0.148 mg/L in June to 0.431 mg/L in September. Anoxic conditions began near the lake bottom in June and continued throughout the summer months before improving in October. This suggests that the internal phosphorus stored in the sediment became available during the growing season contributing to the shift from spring phosphorus limitation. Though blue-green (nitrogen-fixers) algae were not abundant in Hayes Lake during the growing season, limited nitrogen and abundant phosphorus suggest favorable conditions. As mentioned earlier macrophyte population dynamics likely hinder the establishment of nuisance blue-greens during the growing season in Hayes Lake.

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. The values in a combined TSI number of the aforementioned parameters are averaged to give the lake's trophic state.

Lakes with TSI values less than 35 are generally considered to be oligotrophic and contain very small amounts of nutrients, little plant life, and are generally very clear. Lakes that obtain a score of 35 to 50 are considered to be mesotrophic and have more nutrients and primary production than oligotrophic lakes. Eutrophic lakes have a score between 50 and 65 and are subject to algal blooms and have large amounts of primary production. Hyper-eutrophic lakes receive scores greater than 65 and are subject to frequent and massive blooms of algae that severely impair their beneficial uses and aesthetic beauty (Table 18).

Table 18. Carlson Tropic State Index

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

Hayes Lake is located in the Northwestern Glaciated Plains (43) (a level III ecoregion). As determined in "Ecoregion Targeting for Impaired Lakes in South Dakota" (Stueven et al. 2000) reservoirs in this region should have a mean TSI value of 55 or less to fully support their beneficial uses. Partial support of these uses is reached at TSI values between 55 and 70. Lakes that do not support these uses have a mean TSI value of greater than 70. In this document Hayes Lake was listed as non-supporting with a TSI of >70.

A significant amount of deviation between phosphorus, Secchi depth and chlorophyll *a* TSI was evident in Hayes Lake over the study period. Phosphorus TSI values for both sites were generally higher during all sample periods in comparison to the respective TSI for Secchi and chlorophyll *a* (Figure 19). During the entire study period the mean TSI for Hayes Lake was 65. This varied from a mean of 53 recorded on May 16, 2001 to a 73 recorded on April 9, 2001. The values used when computing the TSI for a TMDL are taken during the growing season from May 15 to September 15. The Hayes Lake mean growing season TSI value during this time period was 63. This value places Hayes Lake within the eutrophic category on Carlson's scale. Dry conditions and limited nutrient loading from the watershed over the project is likely influencing the mean growing season TSI. Had Frozen Mann Creek experienced greater run-off volumes the mean growing season TSI would be expected to deviate from this value.

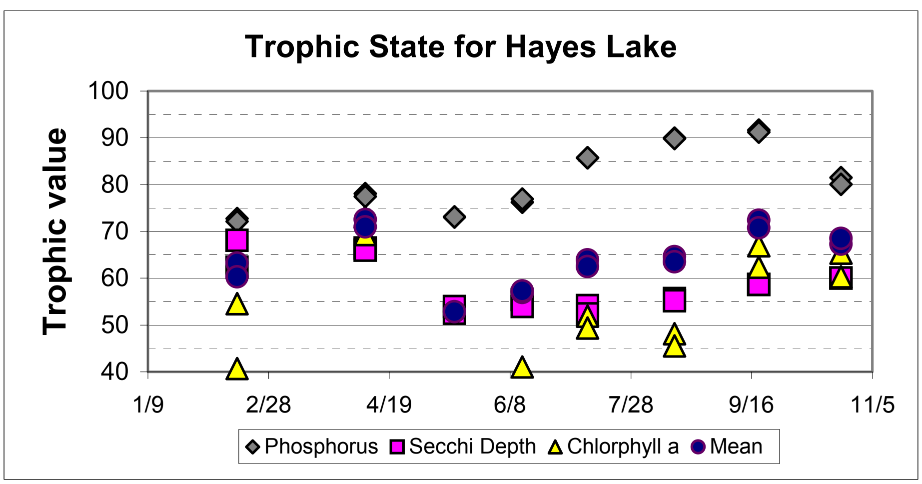


Figure 19. Phosphorus, Secchi depth, Chlorophyll *a* and mean Tropic State Values by Date for Hayes Lake 2001.

Mean Trophic State Index (TSI) values of individual parameters for Hayes Lake during the growing season were 85 (hyper-eutrophic) for total phosphorus, 55 (eutrophic) for Secchi depth, and 48 (mesotrophic) for chlorophyll *a*. It becomes apparent that the phosphorus TSI drives the overall mean TSI above the target for fully supporting (TSI of 55) by several orders of magnitude. The mean growing season chlorophyll *a* and Secchi TSI becomes 52 when the phosphorus TSI is not included. Because nitrogen is limiting primary production during the growing season; chlorophyll *a* and Secchi TSI respond only slightly to the apparent abundance of phosphorus in Hayes Lake (Figure 20). It is likely that macrophyte population dynamics in Hayes Lake is contributing to the lower Secchi and Chlorophyll *a* TSI. A significant reduction in internal and external phosphorus loading is needed to move the mean TSI to fully support its beneficial uses at the current target.

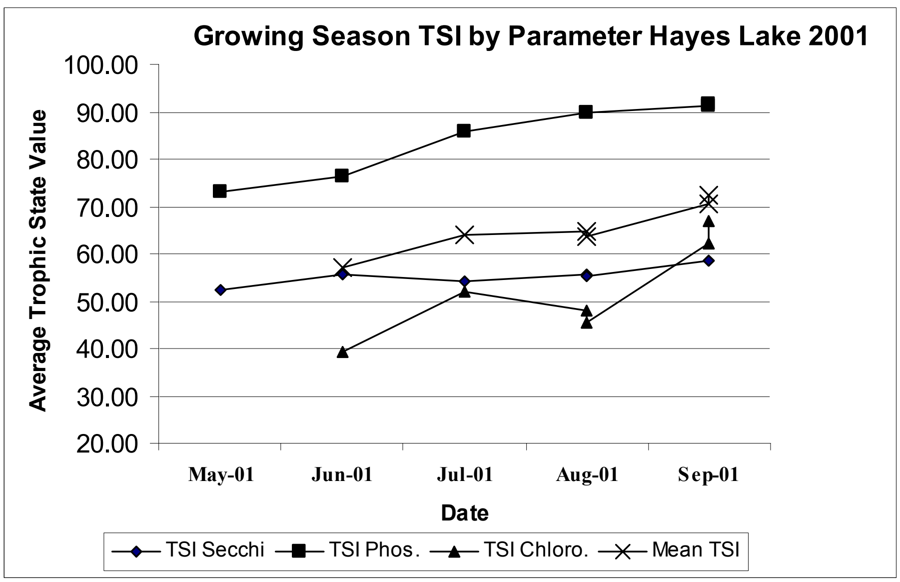


Figure 20. Growing season TSI by date for Hayes Lake 2001.

Reduction Response Modeling

Inlake reduction response modeling was conducted with BATHTUB, an Army Corps of Engineers Eutrophication Response Model (Walker, 1999). System responses were calculated using reductions in both the loading of phosphorus to the lake and from estimates of internal load. Loading data for Frozen Man Creek was taken directly from the results obtained from the FLUX modeling data calculated for the inlet to the lake. A conservative estimate based on HLT2 data was applied to the subwatershed of HLT1 and the other ungaged portions of the watershed to account for a total load from Frozen Man Creek. Atmospheric loads were provided by SDDENR.

BATHTUB provides numerous models for the calculation of inlake concentrations of phosphorus, nitrogen, chlorophyll *a*, and Secchi depth. Models are selected that most closely predict current inlake 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. BATHTUB not only predicts the inlake concentrations of nutrients; it also produces a number of diagnostic variables that help to explain the lake responses.

The BATHTUB model was ran for the present condition of the lake. The results indicate that 52% of the phosphorus load is internal, 44% is delivered from the monitored tributaries, 3% came from unmonitored watershed areas, and 1% from the atmosphere. TSI values calculated by the model were based on average growing season lake concentrations and tributary loading data collected and estimated over the course of the project. The model estimated a mean growing season TSI value of 65.7. This value exceeds the ecoregion (43) based beneficial use criterion for full support and indicates Hayes Lake as hyper-eutrophic.

Hayes Lake was nitrogen limited during most of the growing season so modeled inputs focused only on the reduction of phosphorus. Two reduction scenarios were executed; the first concentrated on phosphorus reductions from the Frozen Man Creek watershed. The second, was a reduction using a combination of internal phosphorus load and loads from the watershed. The second scenario was used because during the 2001 growing season internal phosphorus loads were strongly influencing in-lake condition and phosphorus loads from the watershed were relatively minor. Tables 19 and 20 show output data generated by the BATHTUB model for percent phosphorus reductions in increments of 10% for both scenarios.

Table 19. Output data generated by the BATHTUB model depicting percent phosphorus reductions from the Frozen Man Creek watershed to derive estimated shifts in mean growing season TSI.

	Percent External Phosphorus Reductions										
Parameter	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Total Phosphorus (mg/m^3)	323.13	314.76	306.21	297.4	288.38	279.05	269.43	259.53	249.22	238.56	228.53
Total Nitrogen (mg/m^3)	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550
Composite Nutrient (mg/m^3)	109.73	109.39	109.02	108.61	108.15	107.64	107.06	106.41	105.66	104.8	103.91
Chlorophyll-a (mg/m^3)	11.5	11.47	11.44	11.4	11.36	11.32	11.27	11.21	11.14	11.06	10.98
Secchi (meters)	1.41	1.41	1.42	1.42	1.42	1.42	1.43	1.43	1.43	1.44	1.44
Organic Nitrogen (mg/m^3)	450.88	450.2	449.45	448.62	447.69	446.65	445.48	444.16	442.63	440.88	439.05
Total Dissolved Phosphorus (mg/m^3)	26.33	26.27	26.22	26.15	26.08	26	25.91	25.8	25.68	25.55	25.4
Antilog PC-1 (principle Components)[2]	455.82	453.86	451.72	449.35	446.73	443.79	440.49	436.77	432.52	427.65	422.58
Antilog PC-2 (principle Components)[3]	6.98	6.98	6.97	6.97	6.96	6.95	6.95	6.94	6.92	6.91	6.9
(Total Nitrogen-150)/Total Phosphorus	4.33	4.45	4.57	4.71	4.85	5.02	5.2	5.39	5.62	5.87	6.13
Inorganic nitrogen/Phosphorus	3.7	3.81	3.93	4.06	4.2	4.36	4.54	4.73	4.95	5.21	5.47
Turbidity 1/M (1/Secchi-0.025* Chlorophyll-a)	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Mixed Layer Depth * Turbidity	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Mixed Layer Depth * Secchi	1.34	1.34	1.34	1.34	1.34	1.34	1.33	1.33	1.33	1.32	1.32
Chlorophyll-*a* * Secchi	16.26	16.23	16.2	16.17	16.14	16.1	16.06	16.01	15.95	15.88	15.81
Mean Chlorophyll-a / Total Phosphorus	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.05
Frequency (Chlorophyll-a > 10)%	46.64	46.47	46.28	46.08	45.85	45.59	45.3	44.97	44.59	44.15	43.69
Frequency (Chlorophyll-a > 20)%	11.46	11.38	11.29	11.19	11.08	10.96	10.82	10.67	10.49	10.29	10.08
Frequency (Chlorophyll-a > 30)%	3.17	3.14	3.11	3.07	3.03	2.99	2.94	2.88	2.82	2.75	2.68
Frequency (Chlorophyll-a > 40)%	1.02	1.01	0.99	0.98	0.97	0.95	0.93	0.91	0.89	0.86	0.83
Frequency (Chlorophyll-a > 50)%	0.37	0.36	0.36	0.35	0.35	0.34	0.33	0.33	0.32	0.31	0.29
Frequency (Chlorophyll-a > 60)%	0.15	0.15	0.14	0.14	0.14	0.14	0.13	0.13	0.12	0.12	0.12
Carlson TSI-(Phosphorus)	87.47	87.09	86.69	86.27	85.83	85.35	84.85	84.31	83.72	83.09	82.47
Carlson TSI-(Chlorophyll-a)	54.56	54.54	54.51	54.48	54.44	54.4	54.36	54.31	54.25	54.18	54.11
Carlson TSI-(Secchi)	55.01	55	54.98	54.96	54.94	54.92	54.89	54.86	54.83	54.79	54.75
Mean TSI	**65.68**	**65.54**	**65.39**	**65.24**	**65.07**	**64.89**	**64.70**	**64.49**	**64.27**	**64.02**	**63.78**

Table 20. Output data generated by the BATHTUB model depicting percent phosphorus reductions from internal lake loading and the Frozen Man Creek watershed to derive estimated shifts in mean TSI.

	Percent Internal and External Phosphorus Reductions											
Parameter	0%	10%	20%	**25%**	30%	40%	50%	60%	70%	80%	90%	99%
Total Phosphorus (mg/m^3)	323.13	305.68	287.29	278.04	266.55	245.77	222.65	197.45	169.05	133.51	90.87	26.16
Total Nitrogen (mg/m^3)	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550	1550
Composite Nutrient (mg/m^3)	109.73	109	108.09	107.58	106.88	105.39	103.34	100.44	96.02	87.85	71.69	25.52
Chlorophyll-a (mg/m^3)	11.5	11.44	11.36	11.31	11.25	11.12	10.93	10.67	10.26	9.49	7.9	2.75
Secchi (meters)	1.41	1.42	1.42	1.42	1.43	1.43	1.44	1.46	1.48	1.52	1.62	2.05
Organic Nitrogen (mg/m^3)	450.88	449.4	447.57	446.53	445.11	442.09	437.87	431.88	422.61	405.09	368.78	251.25
Total Dissolved Phosphorus (mg/m^3)	26.33	26.21	26.07	25.99	25.88	25.64	25.31	24.84	24.12	22.75	19.92	10.74
Antilog PC-1 (principle Components)[2]	455.82	451.58	446.39	443.45	439.44	431	419.37	403.12	378.65	334.55	251.94	59.92
Antilog PC-2 (principle Components)[3]	6.98	6.97	6.96	6.95	6.94	6.92	6.89	6.84	6.77	6.62	6.24	4.1
(Total Nitrogen-150)/Total Phosphorus	4.33	4.58	4.87	5.04	5.25	5.7	6.29	7.09	8.28	10.49	15.41	53.52
Inorganic nitrogen/Phosphorus	3.7	3.94	4.22	4.38	4.59	5.03	5.64	6.48	7.78	10.34	16.65	84.26
Turbidity 1/M (1/Secchi-0.025* Chlorophyll-a)	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Mixed Layer Depth * Turbidity	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Mixed Layer Depth * Secchi	1.34	1.34	1.34	1.34	1.33	1.33	1.32	1.3	1.29	1.25	1.17	0.93
Chlorophyll-*a* * Secchi	16.26	16.2	16.13	16.1	16.04	15.93	15.77	15.54	15.17	14.44	12.8	5.62
Mean Chlorophyll-a / Total Phosphorus	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.06	0.07	0.09	0.11
Frequency (Chlorophyll-a > 10)%	46.64	46.27	45.82	45.56	45.21	44.45	43.39	41.85	39.42	34.68	24.51	0.83
Frequency (Chlorophyll-a > 20)%	11.46	11.29	11.07	10.95	10.78	10.43	9.95	9.28	8.28	6.53	3.53	0.02
Frequency (Chlorophyll-a > 30)%	3.17	3.11	3.03	2.98	2.92	2.8	2.63	2.4	2.07	1.52	0.69	0
Frequency (Chlorophyll-a > 40)%	1.02	0.99	0.96	0.95	0.92	0.88	0.82	0.73	0.61	0.43	0.17	0
Frequency (Chlorophyll-a > 50)%	0.37	0.36	0.35	0.34	0.33	0.31	0.29	0.26	0.21	0.14	0.05	0
Frequency (Chlorophyll-a > 60)%	0.15	0.14	0.14	0.13	0.13	0.12	0.11	0.1	0.08	0.05	0.02	0
Carlson TSI-(Phosphorus)	87.47	86.67	85.77	85.3	84.69	83.52	82.1	80.37	78.13	74.72	69.18	51.22
Carlson TSI-(Chlorophyll-a)	54.56	54.51	54.44	54.4	54.34	54.23	54.06	53.82	53.44	52.68	50.88	40.51
Carlson TSI-(Secchi)	55.01	54.98	54.94	54.92	54.89	54.82	54.72	54.58	54.37	53.95	53.05	49.68
Mean TSI	**65.68**	**65.39**	**65.05**	**64.87**	**64.64**	**64.19**	**63.63**	**62.92**	**61.98**	**60.45**	**57.70**	**47.14**

To graphically depict how individual parameters of the TSI respond to reductions in phosphorus from both internal load and from the Frozen Man Creek watershed an in-lake reduction curve was generated. Phosphorus reductions in increments of 10% for individual parameters are displayed on Ecoregion (43) support criteria in Figure 21.

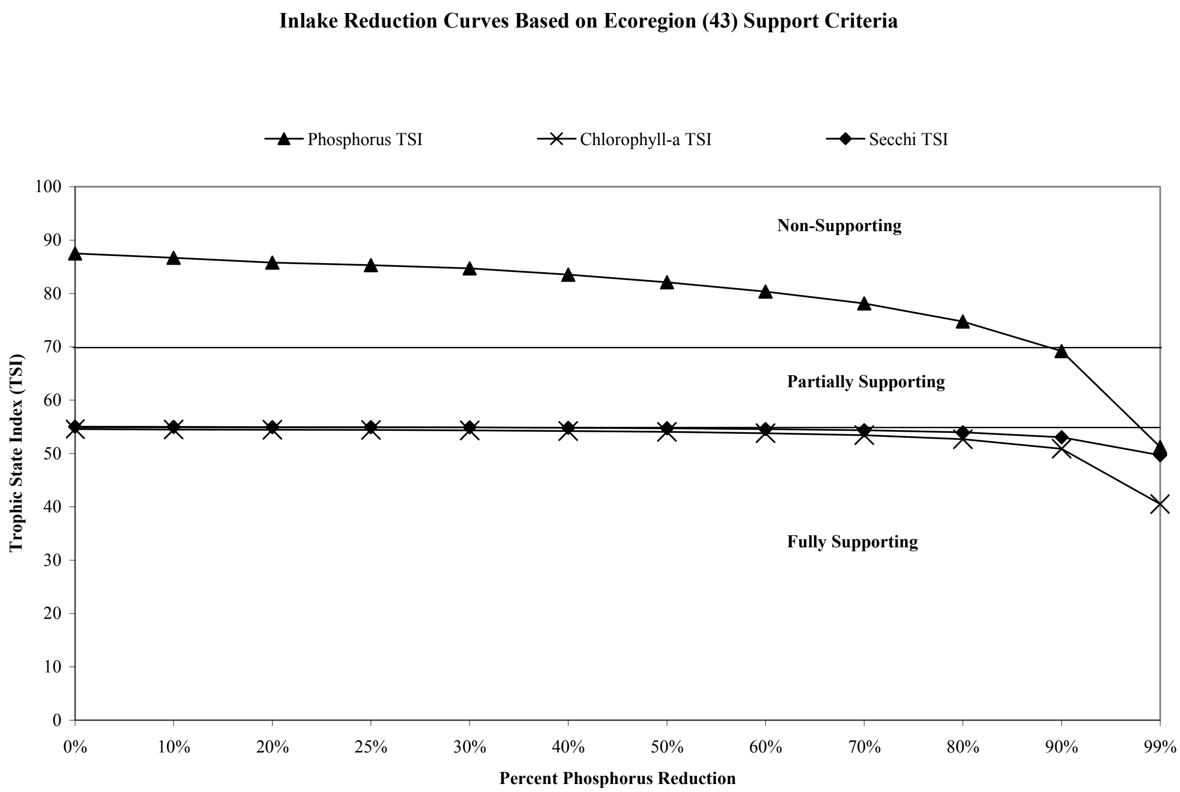


Figure 21. Estimated TSI values for individual parameters based on percent phosphorus reductions from internal and external sources using the BATHTUB model.

The model estimated little response in chlorophyll-*a* and Secchi TSI with considerable reductions in internal and external phosphorus. As individual parameters the modeled Secchi and chlorophyll-*a* TSI are in full support with no reduction in phosphorus from internal and external sources. The phosphorus component of the TSI is elevated and only reaches full support with over a 95% phosphorus reduction from both sources respectively. It is quite apparent that the phosphorus TSI drives the overall mean modeled TSI above the ecoregion (43) target for full support.

To graphically depict how the modeled mean growing season TSI respond to reductions in phosphorus from the Frozen Man Creek watershed an in-lake reduction curve was generated. A curve was also generated for phosphorus reductions from both internal load and from the watershed respectively. Phosphorus reductions in increments of 10% are displayed for both scenarios on Ecoregion (43) support criteria in Figure 22.

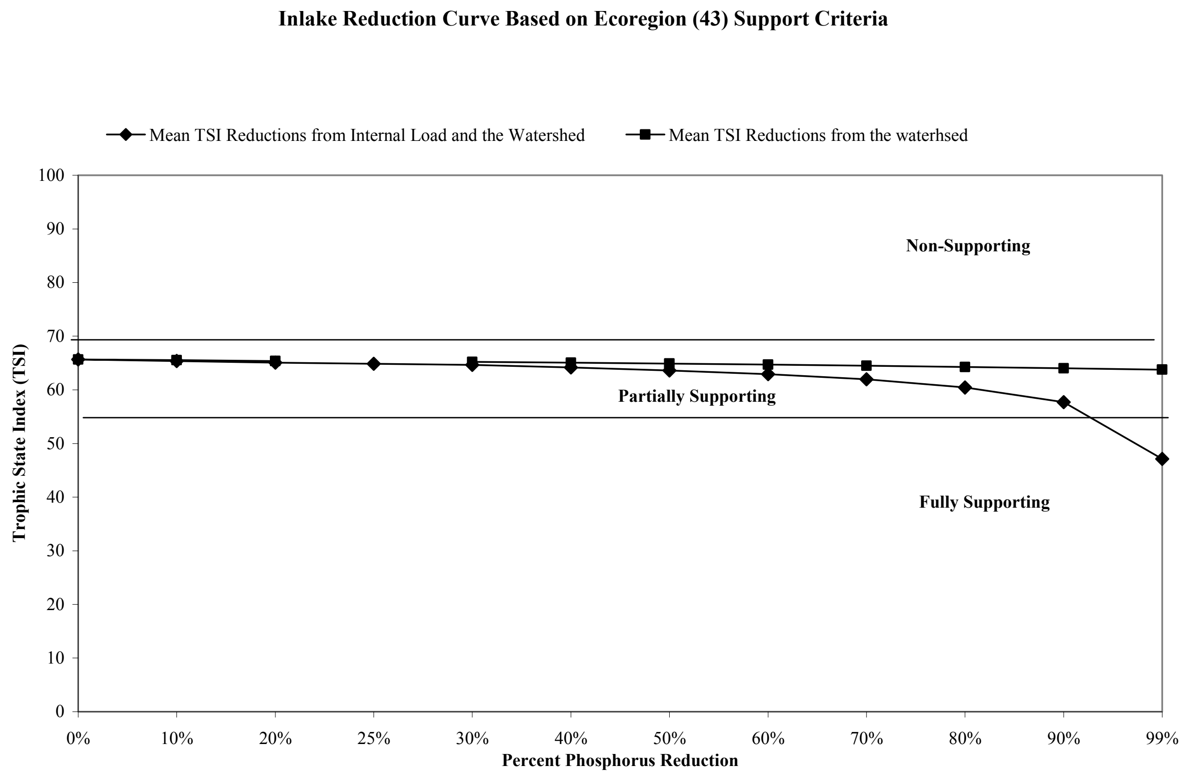


Figure 22. Estimated mean TSI values based on percent phosphorus reductions from the watershed and from a combination of the watershed and internal loading using the BATHTUB model.

According to the modeled reductions it is not possible to reduce phosphorus loads from the watershed to sufficiently bring the mean growing season TSI within full support by previously established ecoregion (43) criteria. The model estimates a phosphorus reduction in excess of 90% from both internal load and from the watershed to comply with current ecoregion (43) full support criteria. Based on social and economic restraints within the watershed a TMDL for full support would **not** be attainable under the current ecoregion (43) target for full support. Subsequent alternative site specific (watershed specific) evaluation criteria (fully supporting, mean TSI < 65.0) is proposed based on AGNPS modeling, BMPs and watershed specific phosphorus reduction attainability for Hayes Lake. Figure 23 shows an in-lake reduction curve for phosphorus reductions based on alternative site specific criteria (mean TSI < 65.0) for full support.

Inlake Reduction Curve Plotted on Alternative Support Criteria for Hayes Lake

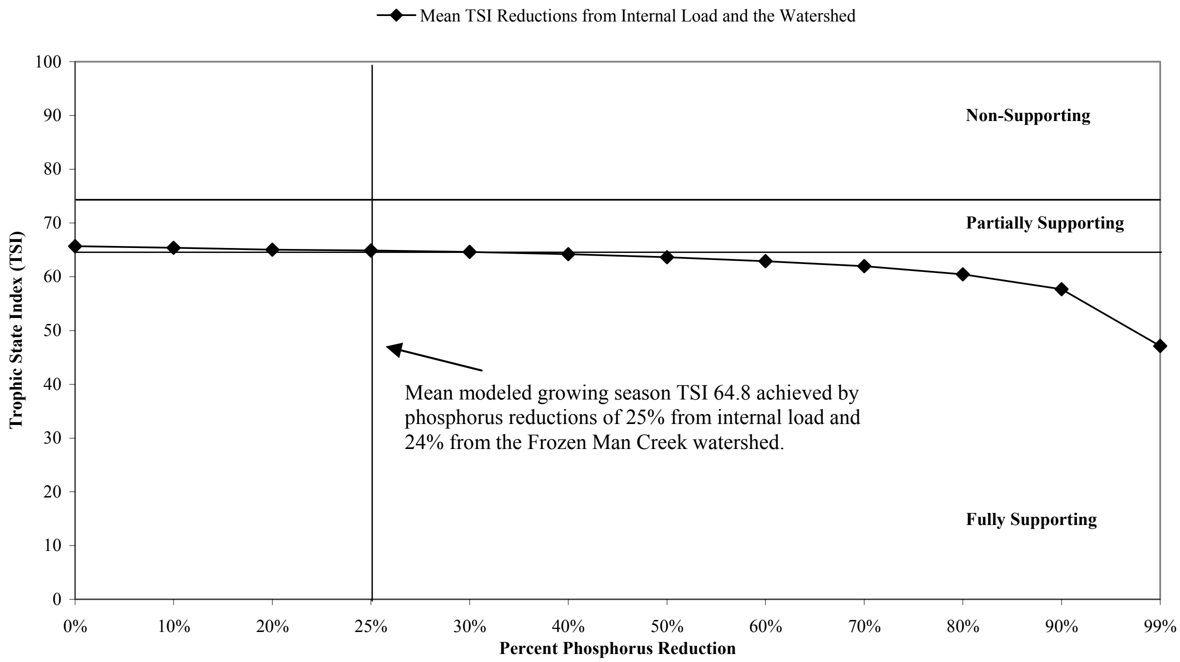


Figure 23. Mean TSI reductions based on phosphorus reductions from internal load and the watershed plotted on alternative site specific support criteria.

Upon careful consideration the best attainable reduction was modeled. To achieve a mean modeled TSI of < 65.0 (alternative full support) phosphorus reductions of 24% from the Frozen Man Creek watershed and 25% from internal loading would be required based on modeled outputs. According to the AGNPS model (page 61) a 24% reduction in phosphorus loading from the Frozen Creek watershed can be achieved by treating 50% of the priority cells with BMPs. A 25% reduction in inlake phosphorus loading would require such management options as an alum treatment or an aeration system. The suggested reductions are conservative and would achieve a mean modeled growing season TSI of 64.8.

Additional phosphorus reductions can improve the mean growing season TSI. Due to the significant impact of internal phosphorus loads on the trophic status of Hayes Lake, inlake treatment is necessary to achieve a TSI which falls below the alternative target for full support. The 25% suggested reduction is conservative and dependant on success of the particular management strategy applied. According to the AGNPS model, implementing BMPs on over 50% of the priority cells would not have an appreciable impact on reductions in phosphorus from the watershed. It is imperative that efforts be directed to the watershed prior to an inlake treatment to increase effectiveness. The TMDL for the conservative alternative TSI target (mean modeled growing season TSI of 64.8) is presented in Appendix E.

Long Term Trends

Hayes Lake is listed on the 2002 303(d) list as an impaired waterbody with a declining trend in water quality as a result of nutrients, sediment, and algal growth. This is also supported in the 1995 South Dakota Lakes Assessment Final Report. Data from the 1995 report is included in Figure 24 together with TSI values collected during the 2001 growing season. The 2001, TSI value for Hayes Lake is about the same as for samples collected in 1991. Dry conditions persisted in the watershed in both 1991 and 2001. It appears that TSI values improve during dry conditions with limited nutrient loads as apposed to wet years like 1993 when the TSI values were elevated near or at 70. Management options are needed for both inlake and from the watershed which benefit the mean growing season TSI of Hayes Lake especially during wet years when considerable run-off volumes occur. Nonetheless the growing season trophic state of Hayes Lake is stable and tends to improve during years of limited run-off.

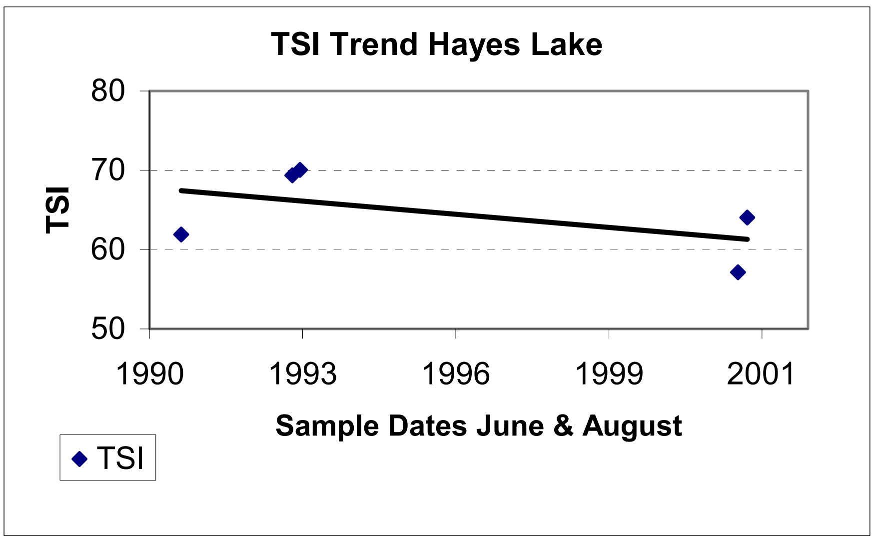


Figure 24. Long Term TSI Trend for Hayes Lake.

Other Monitoring

Agricultural Nonpoint Source Model (AGNPS)

AGNPS 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 equally sized portions, or cells of 40 acres. Each of these cells requires 26 parameters to be collected and entered into the program. The present land use in the 30,400 acres of the Frozen Man Creek watershed above Hayes Lake is 28% native range, 32% Conservation Reserve Program permanent vegetation, 33% cropland and 7% hay land, roads water and farmsteads. This data is based on cropping history of 1998 through 2000.

AGNPS allows input of the watershed data for different amounts of rainfall and to alter existing conditions to see what type of effect these alterations would have on the nutrient yield from the watershed. As an example the current conditions of the watershed using a 24-hour, 25-year storm which is 4.0 inches of rainfall for this area of Stanley County, results in the following nutrient and sediment yields delivered to the outlet:

Sediment	Upland 1.64 ton/ac.	Channel 0.15 ton/ac,	Total 6,102 tons
Nitrogen	Sediment 1.02 #/ac.	Soluble 2.82 #/ac.	Total 115,200 #'s
Phosphorus	Sediment 0.51 #/ac.	Soluble 0.60 #/ac.	Total 33,300 #'s
Runoff 2.31 in./ac, or 5,775 ac.ft. for the watershed			peak flow 6,321 cfs

For comparison the watershed data can be changed so that the entire watershed is in the same condition as those acres that are presently enrolled in CRP. This produces a modeled condition that reflects a grass ecosystem that probably exceeds the "pristine" condition that is thought to have occurred before the settlement of this area. This scenario is being used to show how the model reduces loading. It is unrealistic to expect these conditions in the Hayes Lake watershed. The nutrient and sediment yield for this condition is as follows:

Sediment	Upland 0.18 ton/ac.	Channel 0.01 ton/ac,	Total 694 tons
Nitrogen	Sediment 0.18 #/ac.	Soluble 0.74 #/ac.	Total 27,600 #'s
Phosphorus	Sediment 0.09 #/ac.	Soluble 0.11 #/ac.	Total 6,000 #'s
Runoff 1.87 in./ac or 4,675 ac.ft. for the watershed			peak flow 5,153 cfs

The results of the AGNPS model can help determine the targeted or critical cells in the watershed. The targeted or "critical" cells are identified by the amount of nutrients that they produce that ultimately reaches the outlet of the watershed.

The cells in the Frozen Man Creek watershed were broken into four levels of priority. Cell priority was assigned based on average nutrient loads produced by cells within the watershed. Cells that produced nitrogen **and** phosphorus loads greater than two standard deviations over the mean for the watershed were given a priority ranking of 1. Cells that produced nitrogen **or** phosphorus loads greater than two standard deviations over the mean were given a priority ranking of 2. Cells that produced nitrogen **and** phosphorus loads greater than one standard deviation over the mean were given a priority ranking of 3. Cells that produced nitrogen **or** phosphorus loads greater than one standard deviation over the mean were given a priority ranking of 4.

After the critical cells are determined, the land use in these cells is altered by simulating different Best Management Practices (BMPs) on individual cells of the computer model. The effects of the treated cells on the nitrogen, phosphorus, and sediment delivered at the outlet of the watershed may be found in Table 21. The average pounds per acre delivered by the watershed are compared before and after implementation of proposed Best Management Practices.

Table 21. Expected Nutrient Reductions in the Frozen Man Creek Watershed after BMP Implementation

	Lbs/ acre at outlet	Total N	Lbs/ acre at outlet	Total P	Sed. T/ac.	Total tons
Current	3.84	115,200	1.11	33,300	1.79	6,102
Priority 1 (600 ac. Treated, 2.0% of the Watershed)	3.57	107.100	1.03	30,900	1.62	5,672
% Reduction		7.0%		7.2%		7.0%
Priority 2 (1,300 ac. Treated 4.33% of the Watershed)	3.29	98,700	.95	28,500	1.55	5,423
% Reduction		14.3%		14.4%		11.1%
Priority 3 (2,300 ac Treated 7.7% of the Watershed)	2.95	88,500	.87	26,100	1.53	5,358
% Reduction		23.2%		21.6%		12.2%
Priority 4 (2,620 ac. Treated 8.7% of the Watershed)	2.85	85,500	.84	25,200	1.53	5,538
% Reduction		25.8%		24.3%		12.2%

Only three livestock operations were identified in the watershed that feed the livestock during the winter. There are no livestock feeding operations that feed year-around. All livestock are grazed during the growing season. The three operations that do feed during the winter months did not score high enough to be considered a nutrient factor.

The Frozen Man Creek watershed is composed of 750 cells resulting in a total acreage of 30,000. Of this, 1,200 acres or 4.0% of the watershed falls within the priority 1 category. Implementing Best Management Practices on 50 % of these cells by seeding 300 acres to permanent vegetation through the Conservation Reserve Program (CRP) and treating 300 acres of cropland with a four-year rotation of corn/sorghum, grain, sunflowers and grain, and reduced tillage, provides a reduction of 7.0 % in total nitrogen, 7.2 % in total phosphorus, and 7 % in sediment delivered to the outlet of the watershed.

An additional 1,400 acres fall within the priority 2 category. Implementing BMP’s on 50% of this area treating 350 acres with reduced tillage and seeding 350 acres to CRP brings the total treated acreage to 1,300 acres or 4.33% of the entire watershed. Treatment of these additional acres increases the reduction in total nitrogen to 14.3%, an 11.1 % reduction in total phosphorus, and an 11.1 % reduction in total sediment delivered to the outlet of the watershed.

A total of 50 cells (2,000 acres) fell within the priority 3 ranking. Best Management Practices for priority 3 cells include 500 acres of reduced tillage and 500 acres seeded to CRP, bringing the total treated acreage to 2,300 acres or 7.7 % of the watershed. Treating this additional area increases the total sediment reduction to 12.2 %, with a total nitrogen reduction of 23.2 % and the total phosphorus increases to 21.6 % reduction.

Priority 4 cells totaled 16 (640 acres). BMP treatment of 320 acres 50% reduced tillage and 50% in CRP, will reduce the total nitrogen by 25.8%, total phosphorus by 24.3% and total sediment reduction will remain the same at 12.2%. The total treated acres would be 2,620 acres or 8.7 % of the watershed. Table 22 displays the priority cells targeted for BMPs. The SD DENR has a topographic map (1:24000) with the delineated watershed boundary and the numbered cells. These maps can be available during an implementation phase to locate priority cells for implementaion.

Table 22. Priority Rated Cells to be targeted for BMP Implementation

Priority	Cell Number
1	36,305,310,311,328,329,332,333,334,335,352,356,357,358,359,366, 376,383,384,391,392,422,445,512,537,538,540,633,678
2	37,38,39,41,42,57,58,101,102,103,104,304,308,309,331,367,377,378,381, 382,421,423,424,444,446,513,539,575,632,648,649,650,662,677,691
3	40,51,52,53,54,55,56,66,67,68,69,70,71,72,73,76,77,84,85,86,87,88,89,90,94,95,96, 97,162,255,257,280,307,350,351,355,375,400,460,483,484,493,516,518,541,564, 567,568,569,570
4	23,24,91,126,127,128,129,281,425,511,535,545,546,563,712

The treatment of additional cropland acres in the watershed will result in little additional reductions in nutrient loading to the lake. Likewise the treatment of non-priority cells will have a minimal effect on nutrient load reductions.

Figure 25 represents the AGNPS predicted diminishing nutrient load reductions as additional cropland acres are treated with BMPs. Loading reductions begin to significantly decrease when BMP's are implemented and continue to decrease in significant amounts until 10% to 20% of the cropland acres in the watershed are implemented with BMPs. By treating all of the priority 1 through 4 cells (the scenario indicate above only treated 8.7% of the total watershed), 17.4% of the watershed cropland acres would receive some type of BMP. This falls within the range of treated cropland acres that is optimum for this watershed. It is interesting that treating all of the priority cells results in a total reduction of phosphorus of about 32% while treating half of the priority cells achieves a 24 % reduction.

The modeled improvements were based on implementing 26.5 % (2620 acres) of the 9,960 acres of cropland in the watershed. The AGNPS model indicated that 5,240 acres of cropland were in the priority 1 to 4 ranking which is 53% of the total cropland. This is not surprising as the soils of this watershed are very erosive both from wind and water if the surface is not protected by vegetation or crop residue.

The AGNPS program (version 3.65) is not designed to adequately assess range conditions. The Frozen Man Creek watershed is composed of 28.2% rangeland, 31.7% Conservation

Reserve Program (CRP), 33.2% cropland with the remaining 6.9% hayland, roads, water and farmsteads. There were no rangeland, hayland or CRP cells that occurred as priority cells. This does not mean that rangelands and water quality will not benefit from improved grazing management practices. Rotational grazing and management of riparian zones to improve the vegetative vigor and health by timing of livestock grazing will provide benefits that are difficult to simulate in this model.

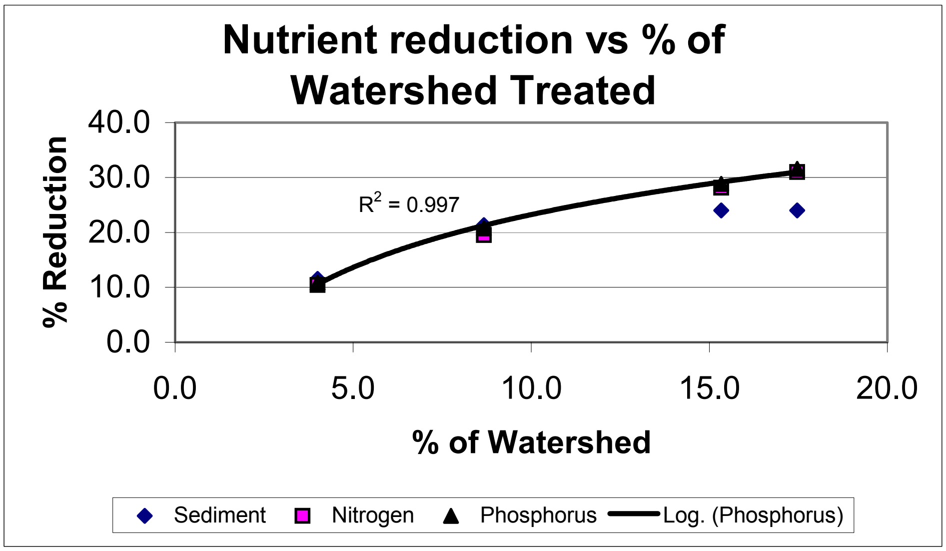


Figure 25. Percent of Frozen Man Creek Watershed Treated with BMPs vs. Percent of Nutrient Load Reduced.

The Natural Resource Conservation Service completed a River Basin Study in March of 1994 that included the Frozen Man Creek watershed. Most of this watershed exists in the area the study referred to as the tablelands. The study indicated that these tableland areas that still exist in native range are not a significant source of sediment to the Bad River and the same logic could be used for Hayes Lake. Small-plot rainfall simulators were used with this study and determined that steady state infiltration rates decreased by as much as 98% on heavily grazed areas dominated by buffalograss and blue gramma. The majority of the 8,440 acres native range in Frozen Man watershed has a significant under-story of buffalo and blue gramma grasses, so grazing management practices that encourage the increase of taller grasses would increase rainfall infiltration, benefit water quality, and help to reduce storm event runoff.

When using a model to simulate actual events that occur in the natural environment, a certain amount of error is expected. This error is dependent on the quality of the model, the quality of the data collected, and the quality of the actual measurements that are used to compare with the model data.

Total watershed reductions were calculated for the proposed AGNPS Best Management Practices. The model was set up to treat 50% of priority 1, 2, 3, and 4 areas with a 4 year rotation of grain, corn, grain and sunflowers using reduced tillage and to reseed 25% to permanent vegetation in the CRP. This treatment resulted in a 25.8% reduction in nitrogen, a 24.3% reduction in phosphorus and a 12.2% reduction in sediment entering the lake.

With the data available, it would not be possible to accurately estimate the reductions that are possible from grazing management practices. By changing the model to indicate improved grazing on 4,000 acres of rangeland only indicated a reduction in phosphorus of 150 kg/yr. The model does not compute the improvement in riparian conditions or the better infiltration rate. Visual observations of the watershed indicate that there is no significant channeling in the riparian areas that remain in native grass whether they are grazed or hayed. The areas in CRP have good and improving riparian zones. Most of the cropland exists in the upper portions of the watershed and several areas could use grassed waterways to protect the drainage ways that are farmed. Most of the acres closest to the lake and bordering the two major arms of Frozen Man Creek are not farmed. These areas have been left in native range and are left idle or cut for hay.

As a single event model, AGNPS doesn't accurately model the effects of large dams in the Frozen Man Creek watershed that have been built for stockwater. There are 5 or 6 dams in the watershed of 25 to 30 surface acres that collect sediment and reduce the peak flow of smaller storms. Some of these dams are located below areas of cropland with several of the priority-designated cells. These dams will soon fill with sediment and their value as a reservoir to hold sediment and nutrients will be lost. Treating the priority rated cells will prolong the life of these structures, which will benefit Hayes Lake down stream.

Conclusions from the AGNPS Model

- The grazing land, hayland and CRP land are not a nutrient or sediment problem in Frozen Man Creek watershed.
- There are areas of cropland that have significant erosion and are providing excess nutrients to Hayes Lake. These areas have been designated priority areas 1, 2, 3, and 4.
- Treatment of 50% of the priority areas as modeled would reduce the nitrogen load by 25%, the phosphorus load by 24% and the sediment load by 12%.
- The CRP land is presently providing good resource protection, but will eventually come out of this program. All of the area in CRP has a cropping history. CRP areas that are returned to cropland could cause similar problems as some of the priority cells.
- The grazing land is mostly used during the summer and the livestock are wintered in locations outside of the watershed. Grazing systems that keep the livestock moving over the grazing area have proven to be effective in maintaining good grass cover and encourage the increase in tall grass species. The result is better riparian areas and higher infiltration rates which results in better water quality.

Sediment Survey

The amount of soft sediment in the bottom of a lake may be used as an indicator of the volume of erosion occurring in its watershed and along its shoreline. The soft sediment on the bottom of lakes is often rich in phosphorus. When lakes turn over in the spring and fall, sediment and 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 invertebrate species. The end result may be a reduction in the diversity of aquatic insect, snail and crustacean species.

An analysis of the water and elutriate mix was conducted on samples collected on May 15, 2001. The results of this test may be found in Table 23. Elutriate samples are water samples that compare the toxins in the lake water to the toxins in the sediment from the bottom of the lake.

Elutriate test results indicated low to undetectable levels of all contaminants tested. The elutriate was tested for a multitude of chemicals commonly used in agricultural operations. The following chemicals were detected in the sediment but were below any level of concern: Alachlor, Chlordane, Endrin, Heptachlor, Heptachlor Epoxide, and Methoxychlor. The folloμwing chemicals were at undetectable levels: Aldrin, Dieldrin, PCB Aroclor 1016, 1221, 1232, 1242, 1248, 1254, and 1260, Diazinon, DDD, DDT, DDE, Beta BHC, Gamma BHC, Alpha BHC, Endosulfan II, and Toxaphene.

Table 23. Elutriate Test Toxins for Hayes Lake

Parameter	Water	Elutriate	Units
COD	42.7	44.7	mg/L
Phosphorus	0.102	0.124	mg/L
TKN	1.20	4.41	Mg/L
Hardness	310	240	Mg/L
Nitrate	0.6	0.1	mg/L
Aluminum	3.1	5.6	Ug/L
Zinc	8.0	4.4	Ug/L
Silver	<0.2	0.02	ug/L
Selenium	12.5	6.2	ug/L
Nickel	4.7	4.5	ug/L
Mercury	<0.2	<0.02	ug/L
Lead	<0.2	<0.02	ug/L
Copper	7.0	7.8	ug/L
Cadmium	<0.2	<0.02	ug/L
Arsenic	4.6	13.6	ug/L
Nitrite	0.08	0.06	mg/L
Atrazine	<0.5	<0.5	ug/L
Ammonia	0.23	3.72	mg/L

There have been three different sediment surveys conducted on Hayes Lake since it was constructed in 1933. The USDA Soil Conservation Service completed all of the surveys, which were conducted in 1937, 1978 and 1990. The data collected revealed an average sediment delivery of 180 tons per square mile of drainage area above the impoundment. The original dam structure was raised some time in the 1950's to a level with a surface area of 95.2 acres and total computed storage of 784 acre-feet. The 1990 survey estimated remaining storage at 696 acre-feet so the structure has lost about 88 acre-feet or 11% of storage in 57 years. The latest sediment survey (1990) report is available in Appendix B.

Biological Monitoring

Fishery

The most recently published fisheries survey for Hayes Lake was completed during the summer of 2000. A previous survey was completed during 1997. A copy of the South Dakota Game, Fish and Parks Fisheries Survey for Hayes Lake can be found in Appendix A.

The survey discusses in detail four of the eight fish species found in the lake. The species identified during the survey were bluegill, black bullhead, black crappie, largemouth bass, yellow perch, northern pike, saugeye and walleye. The lake has good populations of bluegill, black bullhead, black crappie, largemouth bass, and northern. The population of yellow perch is declining since black crappies have showed up in the species population. Black crappie had not been sampled in Hayes Lake before 1997.

From 1997 through 1999 walleye and saugeye have been introduced into the lake to increase predation on the panfish present. The 2000 survey found only one walleye/saugeye in the trap nets and two during fall electrofishing. Game Fish and Parks is not recommending future stocking of walleye or saugeye and feel that the present populations of largemouth bass and northern are adequate to control the panfish.

The lake has been managed primarily for quality-size largemouth bass and bluegill. The 2000 survey catch-per-unit effort (CPUE) for bluegill was 49.8 up from 45.1 in 1997. The CPUE for largemouth bass was 43.4 in 1997 and increased to 117.0 in the 2000 survey.

Quality-size black crappies are available in the lake. The CPUE for black crappie was 1.5 in 1997 and increased to 8.3 in 2000. Black bullheads were the second most common species collected during the 2000 survey with a CPUE for black bullheads of 41.8 compared 30.6 in 1997.

Hayes Lake Phytoplankton

Surface algae samples were collected monthly inlake or at the flowing outlet of Hayes Lake in June and August 2000 and twice a month in March and April 2001. A total of 66 taxa including two unidentified algae categories were identified for the period of this short survey (Table 24). Algae species richness (the number of algal taxa observed) in Hayes Lake during this study was rated as 'average' compared to other recently monitored small state lakes.

Flagellated (motile) algae belonging to five phyla were the most diverse group of planktonic algae in Hayes Lake with 29 taxa collected including an 'unidentified flagellates' category. Diatoms (Bacillariophyceae) and non-motile green algae (Chlorophyta) represented the second most diverse groups with 16 taxa each, distantly followed by blue-green algae (Cyanophyta) with only 5 taxa observed during this assessment (Table 25).

Yellow-brown (or, golden-brown) flagellates (Chrysophyta) were the most diverse phylum of motile algae with 11 taxa followed by green flagellates(Chlorophyta) with 8 taxa. Less diverse phyla of motile algae included dinoflagellates (Pyrrhophyta) with 4 taxa , cryptomonads (Cryptophyta) with 3 and euglenoids (Euglenophyta) with only two species observed.

Hayes Lake algal biovolume ranged from 1,421,913 μm^3/ml on August 10, 2000 to 13,406, 429 μm^3 / ml on April 9, 2001 (Table 21). Corresponding algal abundance (population density) for those dates amounted to 13,167 cells/ml and 47, 379 cells /ml,respectively. Average monthly algal abundance and biovolume for the study periodamounted to 38,988 cells/ml and 6,443,012 um3/ml, respectively.

The phytoplankton population during this survey consisted of mostly flagellated algae, which made up 73% of total algae abundance and 93% of total biovolume (Table 24). Blue-green algae made up 12% of algal numbers but only 1% of biovolume due to the presence of larger numbers of relatively small-sized cells of Aphanocapsa sp. in this group. Diatoms contributed 3% to total algae numbers and 5% of total biovolume. Major diatom species were Stephanodiscus minutus and S. hantzschii that were most common in late April, and Fragilaria capucina mesolepta which was collected only in mid June 2000. Non-motile green algae, represented mainly by Oocystis pusilla, Scenedesmus quadricauda, and Sphaerocystis schroeteri, made up 7% of total algae numbers and 2% of the biovolume and were most prevalent in June and August 2001. Unidentified algae species accounted for the remaining 5% of algal density and 1% of biovolume.

The seasonal distribution of algae populations in Hayes Lake consisted of relatively smaller algae populations in June and August 2000 with considerably higher population densities observed in late winter / early spring (late March-April 2001). Annual peaks in algal density and biovolume occurred during early spring (Table 25) and were due to the abundance of a number of flagellated algae species, primarily *Cryptomonas* sp., *Chlamydomonas* sp., *Chromulina* sp., *Rhodomonas minuta* and several other motile algal taxa (Table 22).

The dominance of pigmented flagellates in the algal community of Hayes Lake during this assessment can probably be related to lake morphology and local water quality. The stream-like characteristics of this small lake with a narrow, wind-sheltered basin (a small wind fetch), abundant macrophytes, and probably an accumulation of organic matter derived from decayed local vegetation and/or imported from the drainage, may have created favorable conditions for those motile species. Blue-green algae, including nuisance species, were of minor importance during this investigation. Small populations of *Anabaena circinalis* and *Anabaena flos-aquae* (2,524 cells/ml and 631 cells/ml, respectively) were present in the summer plankton of Hayes Lake on August 10, the last sampling date for the year 2001.

Table 24. Hayes Lake Algae Abundance (cells/ml) and Biovolume (um3/ml)

Date	Algae Group	cells / ml	%	μm^3 / ml	%
21-Mar-01	Flagellated Algae	50,883	93.1	5,962,041	87.6
	Dinoflagellates	280	0.5	756,000	11.1
	Blue-Green Algae	1,088	2.0	16,640	0.2
	Diatoms	5	0.0	920	0.0
	Non-Motile Green Algae	206	0.4	6048	0.1
	Unidentified Algae	2200	4.0	66,000	1.0
	Total	**54,662**		**6,807,649**	
28-Mar-01	Flagellated Algae	46,265	85.2	6,738,771	83.1
	Dinoflagellates	432	0.8	1,166,400	14.4
	Blue-Green Algae	2,400	4.4	48,000	0.6
	Diatoms	5	0.0	1,080	0.0
	Non-Motile Green Algae	600	1.1	15,000	0.2
	Unidentified Algae	4,600	8.5	138,000	1.7
	Total	**54,302**		**8,107,251**	
09-Apr-01	Flagellated Algae	42,550	89.8	12,470,823	93.1
	Dinoflagellates	280	0.6	756,000	5.6
	Blue-Green Algae	1,156	2.4	10,356	0.1
	Diatoms	273	0.6	79,250	0.6
	Non-Motile Green Algae	720	1.5	18,000	0.1
	Unidentified Algae	2,400	5.1	72,000	0.5
	Total	**47,379**		**13,406,429**	
24-Apr-01	Flagellated Algae	26,811	50.7	4,985,954	74.8
	Dinoflagellates	250	0.5	675,000	10.1
	Blue-Green Algae	19,965	37.8	84,465	1.3
	Diatoms	2,582	4.9	818,930	12.3
	Non-Motile Green Algae	232	0.4	9,770	0.1
	Unidentified Algae	3,040	5.7	91,200	1.4
	Total	**52,880**		**6,665,319**	
14-Jun-00	Flagellated Algae	1,804	15.7	944,431	42.0
	Dinoflagellates	0		0	
	Blue-Green Algae	0		0	
	Diatoms	3,647	31.6	974,460	43.4
	Non-Motile Green Algae	6,088	52.8	330,621	14.7
	Unidentified Algae	0		0	
	Total	**11,539**		**2,249,512**	
10-Aug-00	Flagellated Algae	2,272	17.3	340,984	24.0
	Dinoflagellates	84	0.6	441,745	31.1
	Blue-Green Algae	3,155	24.0	221,503	15.6
	Diatoms	168	1.2	56,376	4.0
	Non-Motile Green Algae	7,488	56.9	361,305	25.4
	Unidentified Algae	0		0	
	Total	**13,167**		**1,421,913**	

Table 25. Hayes Lake Algae Species List

March 18, 2001 to August 10, 2001	6 samples				
Algae Species (66 spp.)	Ave. Dens. cells / ml	Ave. Bio-vol. μm^3 / ml		Ave. Dens. cells / ml	Ave. Biovol. μm^3 / ml
Flagellated Algae :			**Diatoms :**		
Chroomonas sp.=			Asterionella Formosa	63	13,780
Rhodomonas minuta	3,936	165,312	Cyclotella meneghiniana	14	5,329
Cryptomonas erosa	2,429	1,262,482	Stephanodiscus minutus	240	84,000
Cryptomonas ovata	743	1,283,449	Stephanodiscus hantzschii	160	48,000
Glenodinium sp.	7	4,907	Nitzschia acicularis	25	7,000
Dinobryon sertularia	36	28,800	Nitzschia frustulum	7	842
Chlamydomonas sp.	3,227	1,051,893	Nitzschia vermicularis	1	667
Chrysochromulina parva	440	36,960	Nitzschia sp.	27	3,240
Ceratium hirundinella	7	68,712	Gomphonema sp.	2	400
Chromulina sp.	7,427	482,733	Synedra delicatissima	1	110
Kephyrion sp.	73	6,967	Fragilaria capucina mesolepta	501	127,783
Trachelomonas sp.	73	146,000	Fragilaria vaucheria	6	1,804
Euglena sp.	1	290	Melosira ambigua	31	18,447
Lobomonas rostrata	80	20,000	Melosira granulata angustissima	2	500
Spermatozoopsis sp.	73	4,672	Navicula cryptocephala veneta	6	595
Ochromonas sp.	67	5,667	Cocconeis placentula	7	3,226
Scourfieldia sp.	313	31,300	**Total** Diatoms	1,093	315,723
Pascheriella tetras	1706	255,875	*% Diatoms*	*3%*	*5%*
Synura uvella	4	5,232	**Non-Motile Green Algae :**		
Synura sp.	11	14,606	Oocystis pusilla	1,329	71,780
Chrysococcus rufescens	433	36,805	Oocystis sp.	2	300
Mallomonas akrokomos	169	254,007	Scenedesmus quadricauda	285	18,517
Mallomonas elongata	4	7,000	Scenedesmus bijuga	56	1,963
Mallomonas sp.	1	500	Scenedesmus sp.	1	75
Chlorogonium sp.	1	95	Coelastrum microporum	100	6,013
Gymnodinium palustre	52	140,400	Sphaerocystis schroeteri	384	13,429
Gymnodinium sp.	108	292,500	Crucigenia quadrata	51	1,124
Eudorina sp.	1	392	Crucigenia tetrapedia	28	701
Pandorina morum	1	175	Ankistrodesmus sp.	285	7,125
unidentified flagellated algae	7184	143,690	Ankistrodesmus falcatus	12	313
Total Flagellated Algae	28,607	5,751,421	Tetraedron regulare	14	435
% Flagellated Algae	*73*	*91*	Tetraedron minimum	7	1,262
Blue-Green Algae :			Tetrastrum staurogeniaeforme	1	65
Anabaena circinalis	421	29,870	Closterium aciculare	1	115
Anabaena flos-aquae	105	7,047	Selenastrum sp.	1	25
Aphanocapsa sp.	3,467	13,867	**Total** Non-Motile Green Algae	2,557	123,242
Oscillatoria sp.	14	284	*% Non-Motile Green Algae*	*7%*	*2%*
Dactylococcopsis sp.	621	12,427			
Total Blue-Green Algae	4,628	63,495	**Total** unidentified algae	2,040	61,200
% Blue-Green Algae	*12%*	*1%*	*% unidentified algae*	*5%*	*1%*

Aquatic Macrophyte Survey

The project coordinator and DENR staff conducted an aquatic plant survey on September 19, 2001. Submerged aquatic vegetation was located, sampled, identified, and recorded at fifteen predetermined sampling transects (Figure 26). Due to the dense amount of cattails and bulrushes around the shore an independent survey for emergent vegetation was conducted along the shoreline at a later date. In addition to vegetation sampling at each transect, the presence or absence of livestock was also recorded. Transects were located every 225 meters proceeding in a clockwise fashion around the lake beginning at the boat access. A range finder was used to select the 225 meter points along the lakeshore. GPS coordinates were not recorded during the survey, however, Figure 26 represents the approximate locations of transects around Hayes Lake.

Submergent vegetation in the lake was predominantly located within 1.5 meters of water depth from the shoreline although sites 4, 6, 7, 10, & 12 had abundant species of one or more plants at depths below 2.0 meters. Sampling with the plant grapple was conducted in all four directions at all sampling sites. At sites 2, 7, 8, & 9 the grapple was pulled in all four directions at two different depths to adequately sample the submergent vegetation present. The density rating found in the SOP was used to rate the density of plants at each transect.

Emergent species in the riparian zone were identified and recorded as present or absent within 5 meters of the transect flag. Species recorded were limited to those identified as aquatic or wetland species in “Aquatic and Wetlands Plants of South Dakota”, written by Gary E. Larson. The plant species identified in this survey and their habitat can be found in Table 26.

The submergent and emergent species were sampled using different methods, which restricts the comparisons that can be made between them. Table 26 lists both submergent and emergent species that were identified at the transects. Livestock have access to a portion of the shoreline during the summer. Transect #5 - #12 are located in an area where livestock were present from July to September. Emergent vegetation in the vicinity of transect #8 showed some damage from livestock on the shore and entering the lake to drink. The remaining transects identified as not having livestock showed little or no signs of their presence at the time of the survey.

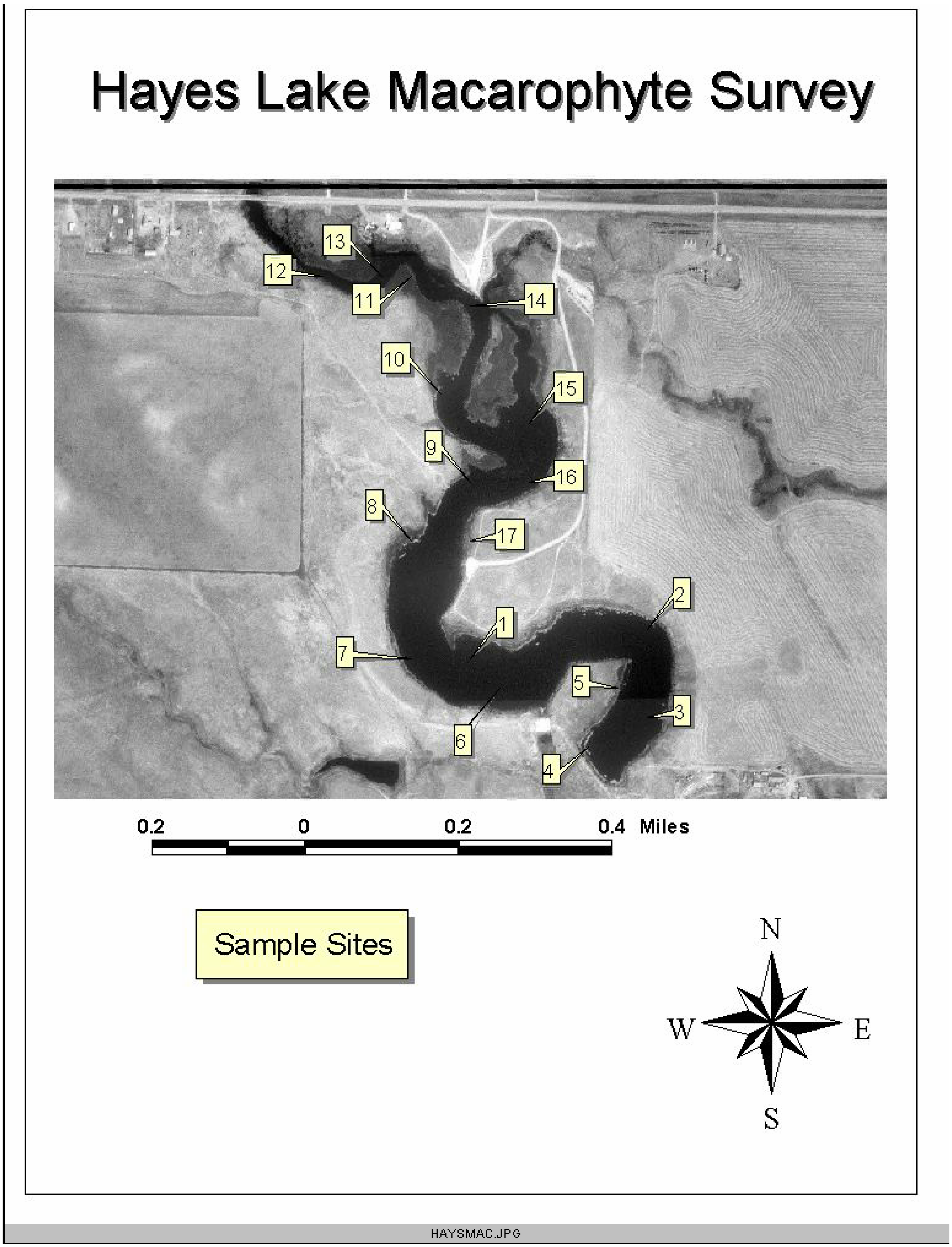


Figure 26. Map of Aquatic Macrophyte Survey Transects.

Table 26. Aquatic Plant Species

Common Name	Genus	Species	Habitat
Coontail	*Ceratophillum*	*demersum*	Submergent
Curly Leaf Pondweed	*Potamogeton*	*Crispus*	Submergent
Flat Stem Pondweed	*Potamogeton*	*zosteriformis*	Submergent
Floating Leaf Pondweed	*Potamogeton*	*Natans*	Submergent
Sago Pondweed	*Potamogeton*	*pectinatus*	Submergent
Common Cattail	*Typha*	*Latifolia*	Emergent
Curly Dock	*Rumex*	*Crispus*	Emergent
Hardstem Bulrush	*Scirpus*	*Acutus*	Emergent
Plantain	*Alisma*	Sp.	Emergent
Sedge	*Carex*	Spp.	Emergent
Water Smartweed	*Polygonum*	*punctatum*	Emergent
Sandbar Willow	*Salix*	*Exigua*	Emergent
Peachleaf Willow	*Salix*	*amygdaloides*	Emergent

No differences in submergent species between sites with and without livestock were observed. Species of submergent vegetation related more to the topography of the shoreline and related soils than from shoreline influences. Although livestock were present for an extended period of time they did not appear to make frequent use of the lake as a water source during the period of assessment.

The presence of livestock in the riparian area around Hayes Lake did not appear to reduce the diversity of submergent or emergent species. During the time the assessment was being conducted. The emergent and submergent vegetation did not show negative impacts from livestock. The intensity of use around a lake by livestock is often influenced by the timing of grazing, availability of other sources of water and availability of forgage. Many lakes and stock ponds experience strong negative influences from livestock use of the riparian zone, especially in the months of July through September.

Threatened and Endangered Species

There are no threatened or endangered species documented in the Frozen Man Creek watershed. The US Fish and Wildlife Service lists the whooping crane and bald eagle as species that could potentially be found in the area. None of these species were encountered during this study; however, care should be taken when conducting mitigation projects in the Frozen Man Creek Watershed.

Bald Eagles have not been documented in the project area due to a lack of habitat such as large trees for perching and roosting. There are few large trees in the Frozen Man Creek watershed making the likelihood of encountering and/or disturbing bald eagles minimal within the Frozen Man Creek watershed. However, 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 have never been documented in the Frozen Man 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.

Quality Assurance Reporting (QA/QC)

Quality assurance and quality control or QA/QC samples were collected for 10% of the inlake and tributary samples taken. A total of 12 tributary samples and 16 lake samples were collected along with three sets of replicates and blanks. All QA/QC samples may be found in Table 27, with blank samples that were above the detection limit highlighted.

Blank samples were very clean with the exception of nitrate concentrations. Even when the sample and the replicate were below the detection limit, the blank was recorded at the detection limit. It is unclear why there was a consistent hit of the same value for all of the nitrate tests. It is likely that the distilled water supply was contaminated. It is unlikely that the bottles or lab techniques were inadequate, as undetectable levels were measured in one of the replicates and nine of the samples. Due to the large number of samples in which nitrates were not detected, the fact that the distilled water supply had nitrate contamination will have little or no impact on the results of the assessment.

Replicate samples for alkalinity, total solids, nitrates, fecal coliform, *E. coli,* total phosphorus and dissolved phosphorus were all within 10% of the actual samples. Samples that posed the greatest differences were suspended solids, Total Kjeldahl Nitrogen (TKN), and volatile suspended solids.

Volatile solids may be considered the least reliable of the data with an average percent difference of 27%. The other parameters mentioned had 25% and 22% difference between the replicate and the sample. Due to algal production and natural variance the TKN is difficult to replicate. The small concentrations and the natural variance are the most likely reason for the discrepancies in the TSS and VTSS concentrations.

Table 27. Quality Assurance and Quality Control Samples For Frozen Man Monitoring Stations

SITE	DATE	TYPE	Talka	TSOL	TSSOL	AMMO	NIT	TKN	TP	TOP	VTSS	Fecal	ECOLI
HLT1	3/14/01	Grab	40	162	16	0.49	.060	2.56	0.922	0.670	13	<10	16.1
HLT10	3/14/01	Rep.	49	145	16	0.44	0.60	2.94	0.886	0.642	14	<10	14.6
HLT19	3/14/01	Blank	<6	<7	<1	<0.02	0.1	<0.36	<.002	<.002	<1	<10	<1
			20%	11%	0%	11%	0%	14%	4%	4%	7%	0%	10%
HL-1	5/16/01	Grab	185	697	8	0.18	0.7	1.30	0.119	0.074	3	<10	6.3
HL-10	5/16/01	Rep.	186	694	5	0.18	0.7	1.34	0.121	0.081	1	<10	6.1
HL-19	5/16/01	Blank	<6	<7	<1	<0.02	0.1	<0.36	<.002	<.002	<1	<10	<1
			1%	0%	46%	0%	0%	3%	2%	9%	50%	0%	3%
HL-2	9/19/01	Grab	231	787	23	<0.02	<0.1	1.45	0.431	0.299	23	10	9.6
HL-20	9/19/01	Rep.	230	793	31	<0.02	<0.1	2.40	0.514	0.302	29	<10	8.5
HL-29	9/19/01	Blank	<6	<7	<1	<0.02	0.1	<0.36	<.002	<.002	<1	<10	<1
			0%	1%	29%	0%	0%	49%	17%	1%	23%	0%	12%
Average Percent Difference			7%	4%	25%	4%	0%	22%	8%	5%	27%	0%	8%

Public involvement and coordination

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 also aided in the completion of the assessment by providing historical use information on the recreation area and a complete report on the condition of the fishery in Hayes Lake.

Federal Agencies

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

The Natural Resource Conservation Service (NRCS) provided technical assistance, particularly in the collection of soils 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; Industry, Environmental, Other Groups; and Public at Large

The West River Water Development District (WRWDD) provided the local sponsorship that made funding this project possible.

The Stanley County Conservation District (SCCD) aided in the development of watershed maps, determining the soil in the watershed and in the completion of the AGNPS report.

Public involvement consisted of some individual meetings with landowners that provided a great deal of historic perspective on the watershed.

Recommendation and Conclusions

Conclusions:

- The beneficial uses become more vulnerable as the mean Trophic State Index (TSI) increases. The mean growing season TSI modeled for current conditions of the lake was 65.7, which exceeds the upper limit of 55 for full support as listed in the 2000 Ecoregion Targeting document. Modeled phosphorus reductions exceeding 90% from both the watershed and inlake would have to be implemented to reach the suggested ecoregion target. This is unattainable due to social and economic restraints posed in the watershed. The mean TSI trend has remained stable to slightly improving for the past ten years though it tends to increase significantly in years with high run-off.
- Presently 30% of the land in the Frozen Man Creek watershed is enrolled in the CRP. Most of this land was placed in this program after 1990. When these contracts expire the land will be eligible to return to cropland use. Depending on the farming methods used, the return of this area to cropland could have a negative impact on the water quality of the lake.
- The existing large stock dams in the watershed above Hayes Lake play an important role in catching and storing nutrients and sediment. The effectiveness of these structures decreases as they fill with sediment or if they are not maintained in a functioning manner.
- The AGNPS model identified several priority cells that were producing moderate nutrient and sediment delivery down the watershed. This erosion and nutrient delivery is impacting the large stock dams and ultimately Hayes Lake.
- The present farm program has funding to implement BMP's on priority cells as well as develop grazing management systems, grassed waterways and buffer strips on CRP acres as contracts expire.
- Internal phosphorus loading to Hayes Lake occurs in the summer when oxygen levels are depleted at the substrate-water interface.
- The current macrophyte population in Hayes Lake provides a nutrient sink especially during the growing season. Macrophyte population dynamics contribute to the lower Secchi and chlorophyll *a* TSI and reduce the potential occurrence of nuisance algal blooms.

Recommendations:

- Technical assistance needs to be provided to the Frozen Man Creek watershed to plan and implement BMP's to treat the identified priority cells and expiring CRP contract acres. This assistance would aid the Natural Resource Conservation Service personnel that are assigned to Stanley County.
- The existing farm program should be used where eligible to implement practices however, there may be a need for some funding from sources such as EPA 319 funds to implement or add additional incentives to entice land owners to implement practices. For example, providing funding to replace a boundary fence to implement a grazing system may provide the additional incentive to keep an expired CRP contract in a grazing system instead of converting it back to cropland. These funds should be made available on an identified need bases.

- ❖ Possible solutions need to be explored to treat the inlake water to reduce the amount of available phosphorus. If a solution is available that provides long-term benefits to the lake, funding should be provided. Alum treatment and the use of aerations systems are potential examples. However, it is imperative that phosphorus loads be reduced prior to inlake treatment to allow an internal treatment to be successful.
- ❖ An alternative site specific (watershed specific) evaluation criteria (full support mean TSI <65.0) is recommended based on AGNPS modeling, BMPs and watershed specific phosphorus reduction attainability for Hayes Lake. Treatment of 50% of the watershed priority cells (24% reduction of phosphorus) along with a 25% reduction in inlake phosphorus will achieve this goal. The specified reductions would achieve a mean modeled growing season TSI of 64.8 and phosphorus TMDL of 25,264 kg/yr. This is a conservative estimate and attempts should be made to further reduce the mean TSI (lowering the TMDL) by; treating over 50% of the priority cells with BMPs, implementing grazing management strategies on rangeland and achieving over 25% reduction of internal phosphorus load. In addition, the individual Secchi and Chlorophyll-a TSI should be maintained under the original ecoregion (43) target of 55.
- ❖ Basin and littoral macrophytes in Hayes Lake should be maintained at the current status to provide a sink for available nitrogen and phosphorus.

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 number of tributary samples collected during the project was less than proposed due to the reduced number of runoff events during the project, but adequate for the completion of the report. The exception to this was the collection of data from site HLT1, which was the result of weather related runoff. However, conservative load estimates were incorporated into the BATHTUB model for HLT1 based on HLT2 data. This was done to better estimate the potential influence of this site on the trophic status of the lake.

Quality Assurance and Quality Control samples were not significantly impacted by the quality of distilled water used, however future projects in this area should attempt to locate a source of distilled water with no detectable nitrate concentration or the testing lab needs to change the way they record this entry.

Future Activity Recommendations

There are a number of concerns that need to be addressed in the Frozen Man Creek and Hayes Lake watershed. Best Management Practices in the watershed are expected to reduce phosphorus loads to the lake in excess of 24% and nitrogen loads by nearly 12%. These reductions are expected to only minimally reduce the mean trophic state of the lake. Through the use of improved grazing practices as a margin of safety, it is possible that larger reductions in the nutrient load may be achieved. Additional emphasis on controlling inlake phosphorus is needed to improve the mean growing season TSI. The benefits of this reduction may stabilize to improve Hayes Lake's long-term TSI trend, especially during periods of moderate to high run-off.

Mitigation procedures should include all of those listed in the AGNPS section of the report. These include reduced tillage practices, grass waterways or buffer strips where applicable, and between 4,500 and 9,000 acres of grazing management practices. Bank stabilization may be achieved through the use of riparian buffer strips and livestock exclusion in critical areas.

Inlake treatment such as alum will be needed to secure a portion of the internal load of phosphorus in the sediments. Similarly, an aeration system would decrease the potential for oxygen stratification and associated anoxia near the sediment-water interface allowing phosphorus to stay bound to the sediments lessoning availability in the water column. In addition to “on the ground” management practices, the use of informational meetings and materials will also aid in local understanding and involvement in the project. Continued monitoring as well as a post-implementation assessment should be completed if any or all of the discussed mitigation procedures are completed.

Literature Cited

Trophic State Index for Lakes. Limnology and Oceanography. 22:361-369

Fenneman, N. M., 1931, Physiography of Western United States: New York, McGraw Hill Book Co., 534 p.

Larson, G., Aquatic and Wetlands Plants of South Dakota

Minnesota, University of Web Site, 2001, Wackett, Dr. L., Atrazine Pathway Map. http://umbbd.ahc.umn.edu/index.html

Novotny and Olem, V. and H., 1994. Water Quality, Prevention, Identification, and Management of Diffuse Pollution, Van Nostrand Reinhold, New York

Prescott, G.W. 1962. Algae of the Western Great Lakes Area. Wm. C. Brown Publ., Dubuque, Iowa. 977 pp.

Stewart, W.C., Stueven, E. H., Smith, R. L., Repsys, A. J., 2000., Ecoregion Targeting For Impaired Lakes in South Dakota. South Dakota Department of Enviornment and Natural Resources, Division of Financial and Technical Assistance, Pierre, South Dakota.

U.S Department of Interior, Fish, and Wildlife Service and U.S. Department of Commerce, Bureau of Census 1997.

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 2rd Edition. Saunders Publishing Company, Philadelphia, Pennsylvania.

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

Wetzel, R.G. 2001. Limnology 3rd Edition. Saunders Publishing Company, Philadelphia, Pennsylvania.

APPENDIX A

FISHERY DATA

SOUTH DAKOTA STATEWIDE FISHERIES SURVEY

2102 – F-21-R-33

Name: Hayes Lake County: Stanley
Legal Description: Section 29-30, Township 5, Range 26
Location From Nearest Town: 1/2 mile East of Hayes

Date of Present Survey: 7/31/00
Date Last Surveyed: 7/8/97
Most Recent Lake Management Plan: F-21-R-29 Date: 1995
Management Classification: Warm water semi-permanent
Contour Mapped: yes Date: 1968

Primary Species:(game and forage)	Secondary and Other Species:
1. Largemouth Bass	1. Black Crappie
2. Bluegill	2. Yellow Perch
	3. Black Bullhead
	4. Saugeye
	5. Walleye

PHYSICAL CHARACTERISTICS

Surface Area: 64 acres Watershed: 10,000 acres
Maximum Depth: 15 feet Mean Depth: 6 feet
Lake Elevation at Survey (from known benchmark): -2 feet

1. Describe ownership of lake and adjacent lakeshore property:

The majority of Hayes Lake is within an 80-acre Game Production Area that is owned by the South Dakota Department of Game, Fish and Parks. The remainder of the lake, which is outside of Section 29, is privately owned.

2. Describe watershed condition and percentages of land use:

Topography in the Hayes Lake watershed is nearly level to rolling upland slopes. Land use in the watershed is 60% small grain farmland, 38% pasture and hayland, and 2% the town of Hayes.

3. Describe aquatic vegetative condition:

Hayes Lake is surrounded by emergent vegetation, consisting primarily of bulrush. Submergent vegetation, which is present to a depth of five feet during the summer months, is found throughout the lake.

4. Describe pollution problems:

No pollution problems were evident during the 2000 survey.

5. Describe condition of all structures, i.e. spillway, level regulators, boat ramps, etc.:

The dam grade, spillway and the boat ramp at Hayes Lake are in good condition. Public access is excellent with Highway 14 located along the north edge of the lake and good gravel roads providing access to the north and east shorelines.

CHEMICAL DATA

1. Describe general water quality characteristics:

Water quality characteristics for Hayes Lake were analyzed in the field on July 31, 2000, using a HACH water quality kit. Results are on Table 1.

2. Thermocline: no **Location from surface**

3. Secchi disc reading: 3.5 ft.

4. Stations for water chemistry located on attached map: yes

Table A1. Water chemistry results from Hayes Lake, Stanley County, July 31, 2000.

Station Number	Depth feet	Temp C	DO PPM	CO2 PPM	ALK MG\L	Hardness MG\L	pH
	surface	24.4	9.6	9.2	188	273	8
A	15	25.6	1.8	17.2	209	247	8

BIOLOGICAL DATA

Methods:

1. Describe fish collection methods and show sampling locations by gear type on the lake map.

Hayes Lake was surveyed using eight, 3/4 inch, frame net sets and two, 1/4 inch, baby frame net sets on July 31 through Aug. 8. On Sept.26, pulsed AC electrofishing was done for four, 10-minute transects. Conductivity was 600 Uhmos. Coefelt settings were 7.5 amps, 260 volts with a pulse width of 50 and a frequency of

100. All fish data was analyzed using the Winfin computer program.

Table A2. Total catch of four, 10-minute electrofishing transects on Hayes Lake, Stanley County, Sept. 26, 2000.

Spec	No.	Low 80% CI	Mean CPUE	Up 80% CI	Low 90% CI	PSD	Up 90% CI	Low 90% CI	Stock Mean Wr	Up 90% CI
LMB	78	75.2	117.0	158.8	57	67	76	98.9	99.5	100.2
SxW	2	0.2	3.0	5.8	Na	Na	na	76.7	99.9	123.0

Table A3. Total catch of eight, 24 hour, 3/4 inch frame nets at Hayes Lake, Stanley County, July 31, 2000.

Spec	No.	Low 80% CI	Mean CPUE	Up 80% CI	Low 90% CI	PSD	Up 90% CI	Low 90% CI	Stock Mean Wr	Up 90% CI
BLB	332	20.7	41.8	62.8	98	99	100	84.1	86.7	89.3
BLC	66	5.1	8.3	11.4	79	86	94	93.4	94.3	95.2
BLG	401	32.3	49.8	67.2	86	88	91	100.9	102.4	103.8
HYB	14	0.7	1.8	2.8	Na	Na	na	na	na	na
LMB	3	0.1	0.4	0.6	Na	Na	na	na	na	na
NOP	22	1.6	2.8	3.9	7	23	38	76.8	78.1	79.5
SxW	1	0.0	0.1	0.3	Na	Na	na	na	na	na
YEP	6	0.2	0.8	1.3	Na	Na	na	87.0	91.0	95.1

2. Brief narrative describing status of fish sampled.

Hayes Lake has an excellent panfish population. The most abundant species in the lake is bluegill with a CPUE of 49.8. PSD was 88 and RSD-P was 4. The last time the lake was surveyed in 1997, a CPUE of 45.1 with a PSD of 95 and a RSD of 2 was recorded. Condition was excellent with stock length and larger bluegill Wr of 102, up from 100 in 1997. Growth was slower than average requiring 5 years for bluegills to reach quality size.

Table A4. Average Back-Calculated Lengths for Each Age Class of Bluegill, Hayes Lake, Stanley County, 2000.

			Age							
Year Class	**Age**	**N**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1998	2	8	40	76						
1997	3	11	39	70	110					
1996	4	1	47	99	141	170				
1995	5	8	32	63	108	141	171			
1994	6	7	38	66	102	135	159	181		
1993	7	2	58	89	120	139	157	170	184	
1992	8	5	47	72	106	128	146	167	178	186

Sample Size	42							
Population Mean(mm)	43	76	114	142	158	173	181	186
Population Standard Error	3	5	6	7	5	4	3	0
Population Length **Increment**	34	38	28	16	14	9	5	

In 1997, saugeye and walleye fingerlings were introduced into the lake to increase predation on the panfish population, and help increase growth and the number of bluegill in the preferred or larger size categories. During the 2000 survey only one walleye/saugeye was sampled in trap nets and two during fall electrofishing. With a high-density bass population and good northern pike numbers it appears survival is poor. After three years of stocking and virtually no returns, future stockings of walleye/saugeye should be avoided.

The second most abundant species in Hayes Lake is black bullhead with a CPUE of 41.8 and a PSD of 99. This compares to a CPUE of 30.6 and a PSD of 99 in 1997. The average bullhead was over ten inches by age four.

Table A5. Average Back-Calculated Lengths for Each Age Class of Black Bullhead, Hayes Lake, Stanley County, 2000.

			Age						
Year Class	**Age**	**N**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1998	2	8	148	235					
1997	3	2	135	223	248				
1996	4	7	117	186	240	278			
1995	5	12	120	182	221	253	276		
1994	6	9	124	179	233	258	278	295	
1993	7	2	101	158	229	249	267	286	303

Sample Size 40

Population Mean(mm) 124 194 234 260 274 291 303

Population Standard Error 7 12 4 6 3 5 0

Population Length **Increment** 70 40 25 14 17 13

Yellow perch numbers have declined with a current CPUE of 0.8 compared to 9.1 in 1997. Wr for the six fish sampled was 91.

Black crappies continue to increase in numbers. They had not been sampled in the lake before 1997. During the last survey, a CPUE of 1.5 and a Wr of 95 were recorded. In 2000, CPUE jumped up to 8.3, PSD was 86, with an RSD-P of 16 and Wr was 94. Growth was above the state and regional average, with a three-year old crappie reaching quality length.

Table A6. Average Back-Calculated Lengths for Each Age Class of Black Crappie, Hayes Lake, Stanley County, 2000.

Age

Year Class	Age	N	1	2	3	4	5
1999	1	6	59				
1998	2	8	65	143			
1997	3	18	73	145	203		
1996	4	5	76	155	203	229	
1995	5	5	66	156	201	224	245

Sample Size 42

Population Mean (mm) 68 150 203 226 245

Population Standard Error 3 3 1 2 0

Population Length **Increment** 82 53 24 19

During the 1997 survey, electrofishing in mid-October yielded a CPUE of 43.4 LMB/hr. PSD was 32 and the Wr was 101. On 9/26/00, four, ten-minute electrofishing transects yielded a CPUE of 117.0. PSD was 67 with an RSD-P of 13. Condition was good with a Wr of 100. Bass growth is below the state average for fish under age four, but faster than average for fish over age four. The larger bass probably have more forage options than the younger fish.

Table A7. Average Back-Calculated Lengths for Each Age Class of Largemouth Bass, Hayes Lake, Stanley County, 2000.

			Age						
Year Class	**Age**	**N**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1999	1	3	66						
1998	2	3	70	144					
1997	3	26	74	164	242				
1996	4	27	84	166	237	290			
1995	5	12	96	173	241	297	343		
1994	7	1	70	164	251	306	357	406	434

Sample 72
Size

Population 77 162 243 298 350 406 434
Mean(mm)

Population 5 5 3 5 7 0 0
Standard
Error

Population 86 81 55 52 56 28
Length
Increment

RECOMMENDATIONS

Describe management approach.

1. **Discontinue walleye/saugeye stockings.**
2. **Resurvey in 2003 to check fish populations.**

Stocking record for Hayes Lake, Stanley County, 2000.

YEAR	SPECIES	NUMBER	SIZE
1997	SxW	1600	Lg.Fgl
1997	WAE	1600	Lg.Fgl
1998	WAE	1600	Lg.Fgl
1998	SxW	846	Lg.Fgl
1999	WAE	1600	Lg.Fgl

Appendix B Sediment Survey

HAYES LAKE SEDIMENTATION STUDY

Soil Conservation Service
U.S. Department of Agriculture
Huron, South Dakota

September 1990

Introduction and Acknowledgments

A detailed sediment survey of Hayes Lake, near the town of Hayes in Stanley County, South Dakota, was made by the Soil Conservation Service (SCS) during January 1990. See figure 1. The purpose of the survey was twofold:

1. Accumulate sedimentation data for planning and designing works of improvement for soil and water conservation.

2. Provide sediment yield information for use in the Bad River Water Quality Project.

Dave Konechne, Bob Strait, Carol Reed, Kevin Paulsen, and Kendel Newling of the U.S. Soil Conservation Service performed the sediment survey through the ice using the range lines located from the previous (1978) survey. Carol Reed, Geologist, SCS, analyzed the data and prepared this report.

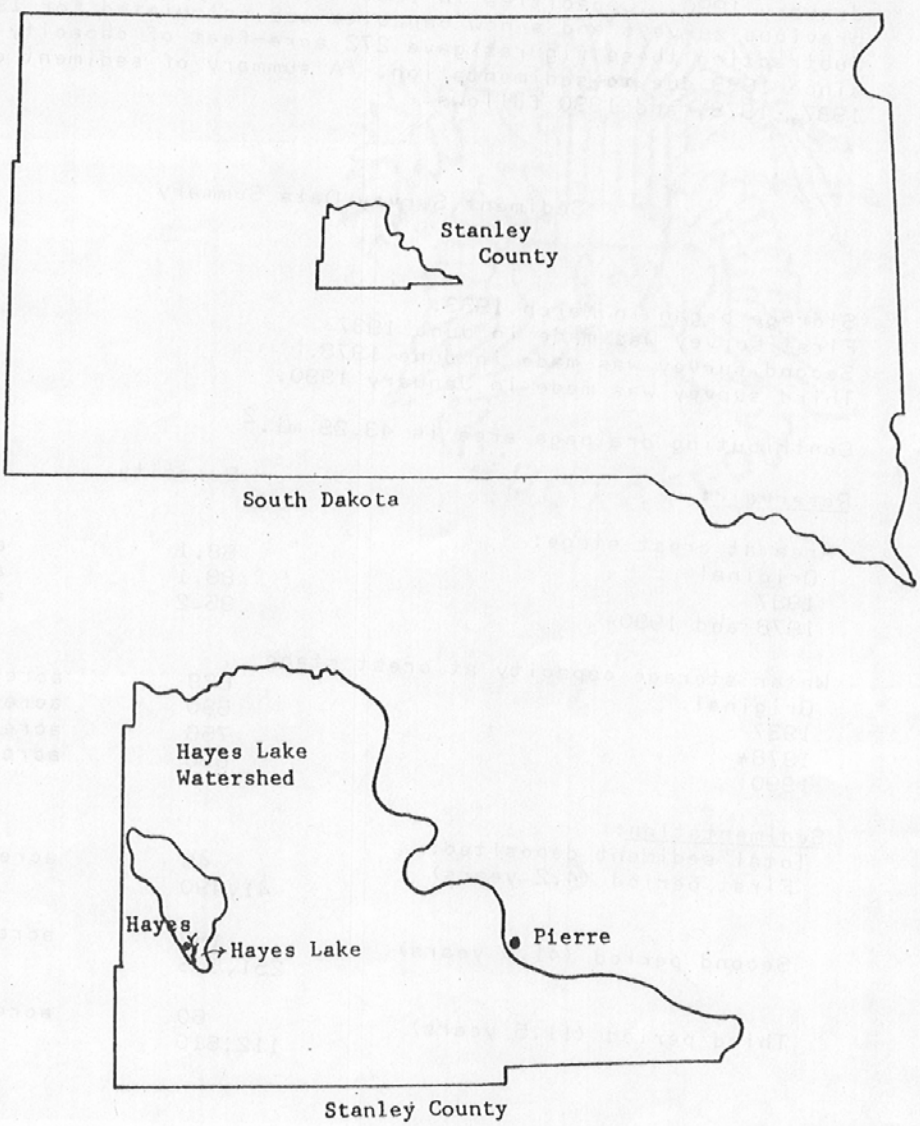


Figure 1 - Location Map of Hayes Lake and Hayes Lake Watershed

-8-

Summary

A detailed range sediment survey was made of Hayes Lake in January 1990. Capacities in 1937 and 1978 were obtained from previous surveys and a new capacity was calculated for 1990. Subtracting these figures gave 272 acre-feet of capacity loss since 1933 due to sedimentation. A summary of sediment data from 1937, 1978, and 1990 follows.

Sediment Survey Data Summary

Storage began in March 1933.
First survey was made in June 1937
Second survey was made in June 1978.
Third survey was made in January 1990.

Contributing drainage area is 43.29 $mi.^2$

Reservoir:	Quantity	Unit
Area at crest stage:		
Original	88.1	acres
1937	88.1	acres
1978 and 1990*	95.2	acres
Water storage capacity at crest stage		
Original	629	acre-feet
1937	580	acre-feet
1978*	756	acre-feet
1990	696	acre-feet
Sedimentation:		
Total sediment deposited:		
First period (4.2 years)	49	acre-feet
	41,490	tons
Second period (41.0 years)	163	acre-feet
	251,856	tons
Third period (11.5 years)	60	acre-feet
	112,610	tons

*Spillway was raised from 1,944.7 to 1,946.7 feet sometime in the 1950's.

Average annual accumulation per square mile of contributing drainage area:

First period (4.2 years)	0.27	acre-feet
	228	tons
Second period (41.0 years)	0.10	acre-feet
	142	tons
Third period (11.5 years)	0.12	acre-feet
	167	tons

Estimated average annual sediment yield to the mouth of the watershed in 1978 was 149 tons per square mile of contributing drainage area. No sediment estimates from gross erosion were made in 1990. Considering trap efficiency of Hayes Lake, along with the 1990 measured sediment volume, 180 tons per square mile of contributing drainage area currently is yielded to the mouth of the watershed annually.

Previous Surveys

Hayes Lake was first surveyed June 8 to 15, 1937, by Mark P. Connaughton, et al. 1/ This was a detailed range survey and iron pipes set in concrete permanently mark the range ends. 2/ Twenty-one ranges were established, sounded, and spudded; four sediment samples were collected and analyzed for volume weights. Data from that survey was recorded and compared to data from the survey done by SCS in 1978 in a comprehensive report by Lyle Steffen. 3/ Some data from the 1978 survey is included again in this report.

Location and Description

Hayes Lake watershed (28,237 acres) is in southeastern Stanley County, South Dakota. See figure 1. The watershed is longer than it is wide (12.2 miles by 3.6 miles) and is oriented along a northwest-southeast line. Hayes Lake (section 29, T. 5 N., R. 26 E.) is 1 mile southeast of Hayes which is 34 miles west of Pierre, South Dakota, on U.S. Highway 14.

1/ Connaughton, M.P., "Advance Report on the Sedimentation Survey of Hayes Lake,, Hayes, South Dakota, June 8-15, 1937", USDA-SCS, Sedimentation Studies, Division of Research, SCS-SS-20, 28 pages.

2/ Eakin, Henry M., "Silting of Reservoirs.", USDA Technical Bulletin 524, pages 129-135.

3/ Steffen, Lyle, "Hayes Lake Sedimentation Studies", USDA-SCS, November 1978, 16 pages.

The lake (see figure 2) is formed behind a gravity-type, earth-fill dam on Frozenman Creek, a tributary to the Bad River. The dam was built through the Works Progress Administration program in 1933, and it was 28 feet high. (Top of dam elevation was 1,947.7.) Its principal spillway, 20 feet wide, was excavated 6 feet below the top of the dam and was located on the dam's east abutment. An emergency spillway, 90 feet wide, was located about 200 feet west of the west abutment. It is assumed that this spillway was also excavated. It was 3 feet below the top of the dam.

The main spillway could not carry the occasional flood flows so sometime after construction (in the 1940's?) a concrete spillway, of the same dimensions as the original, replaced the emergency spillway. Later, (in the 1950's), the dam was raised 9 feet, the main spillway was essentially filled in, and a 2-feet high lip was added to the concrete spillway. Records are inaccurate on exact dates the changes were made. The top of the dam is now at elevation 1,956.7 feet and the concrete spillway elevation is 1,946.7 feet.

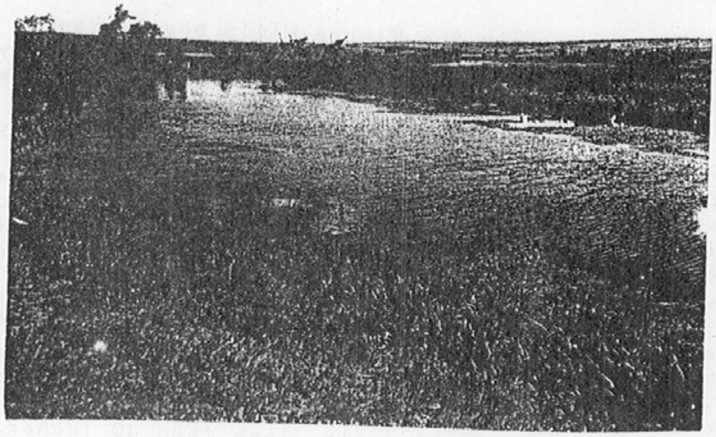
The lake was originally 88.1 surface acres in area and 629 acre-feet in volume. No new volume was recorded for the 2 feet higher spillway but the new surface area is 95.2 acres. A stage-storage water capacity curve was constructed after the 1937 sediment survey (contours were based on survey data). This curve was adjusted for compaction of the 49 acre-feet (at 38.8 pounds per cubic foot) of sediment deposited up to 1937, to 29 acre-feet (at 65.8 pounds per cubic foot) of sediment at the time the spillway was raised 2 feet. The adjusted curve was extended 2 feet and the new volume of water available after the spillway was raised was 756 acre-feet, or 784 acre-feet total volume. Some error is introduced here because it is known that sediment was deposited after 1937 but prior to the date the spillway was raised. The volume of this sediment is not accounted for in the above discussion so it is assumed that the water capacity of the lake in 1937 and at the time the spillway was raised (1950's) is the same - 756 acre-feet.

Climate, Physiography, Topography, Soils, and Geology

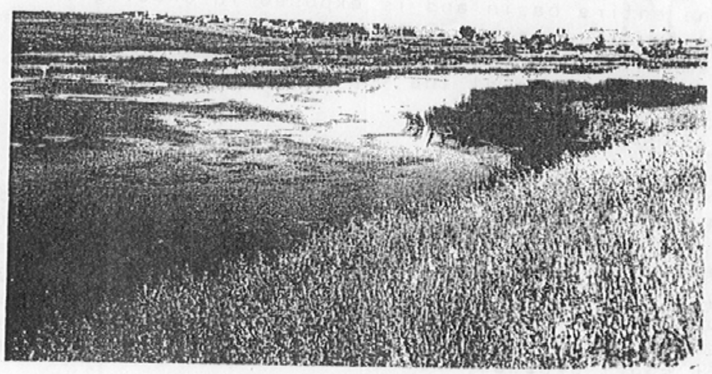
The climate of the Hayes Lake watershed is semiarid to subhumid based on the mixture of short and tall species of grasses found in the watershed. Average yearly precipitation in the Hayes Area is about 15 inches with a mean annual runoff of 0.45 inches.

Rain storms occur most frequently from April through July or August. These storms are of high intensity and short duration which contribute to flash-flooding.

The mean annual temperature in the area is about 47.5 degrees Fahrenheit; a maximum of 113 degrees and a low of -38 degrees Fahrenheit have been recorded.



Looking south, downstream, from near range marker R-16.



Looking northwest, upstream, from near range marker R-16. Town of Hayes is on hill in background.

Figure 2 - Hayes Lake at its widest point, segments 10 and 11. This wide, flat-bottomed portion of the lake acts as a sediment trap. Note the wide extent of marshy vegetation indicating significant sediment accumulations across the submerged flood plain.

The watershed lies within the Pierre Hills physiographic province in the Great Plains. Hayes Lake is just above the deeply dissected Bad River valley wall. The upper border of the watershed is the divide of the Cheyenne and Bad Rivers. This divide is about 2,200 feet above sea level and the lake elevation if 1,946.7 feet. the main branch of Frozenman Creek has a gradient of 0.0026 foot per foot. The landscape is characterized by long, smooth slopes on uplands with shorter, steeper slopes along well-defined drainageways. Local relief is generally about 30 feet, or less, and the drainage density is 1.9 miles of stream per square mile of drainage area.

Promise-Opal soils cover 86 percent of the watershed. These are deep and moderately deep, well drained, nearly level to moderately sloping, clayey soils formed in materials weathered from shale on uplands. Opal soils make up 25 percent of the unit and are underlain by shale at depths less than 40 inches. Promise soils are deeper to shale and both soils have medium fertility and low or moderate available water capacity. Permeability is very slow or slow and shrink-swell potential is high.

The Cretaceous Pierre Formation, primarily a silty shale, underlies the entire basin and is exposed in eroding streambanks, gullies, and the lakeshore. Some scattered Tertiary sands and gravels - remnants of ancient terraces or stream deposits - are found in the divide area at the top of the watershed.

<u>Land Use History</u>

The Hayes Lake watershed land use was estimated in 1937 (by the SCS sediment survey staff) to be 85 percent rangeland (including 15 percent abandoned homesteads) and 15 percent cropland (10 percent wheat, oats, and flax, and 5 percent corn and cane). Cover was generally thick weeds in June 1937, due to drought of the previous year. The weeds were primarily wild sunflowers, pepper grass, and alkali grass. In normal years the range consisted of short grasses (buffalo and grama) and the tall western wheatgrass.

Land use in May 1973, was compiled by the South Dakota State Planning Bureau, using computer processed LANDSAT imagery. 1/ Little change is noted since 1937 (36 years). There was 72 percent rangeland, 27 percent cropland (10 percent black fallow

1/ A map of Hayes Lake watershed land use, May 15, 1973, is published in Volume II of the "The South Dakota Statewide 208 Water Quality Management Plan," Office of Water Quality, South Dakota Department of Environmental Protection, Pierre, South Dakota, September 1978.

and 17 percent small grains), and 1 percent water in 1973. The range consisted of the tall western wheatgrass and green needlegrass species with an understory of short grasses, buffalo, and blue grama, along with some sedges.

Land use since 1975 showed a drastic increase in cropland acreage - probably due to high grain prices in 1974. From 1976 Agricultural Stabilization and Conservation Service (ASCS) photographs, field samples, and interviews, the watershed land use was found to be 30 percent rangeland, 68 percent cropland (23 percent winter wheat, 10 percent small grains, 10 percent rowcrops, 23 percent fallow - generally with more than 500 pounds residue, and 2 percent alfalfa), and 2 percent water. By 1990, land use was estimated to be about 71% cropland (mostly wheat and fallow), 27% rangeland, and 2% water.

Hayes is the only town in the watershed. There are 73 small dams and ponds throughout the watershed (1976 ASCS photographs).

Erosion

Sheet and rill erosion from cropland was estimated in 1978 to be 60 percent of the total water erosion in the watershed. Channelbank erosion from gullies and streambanks was and still is (in 1990) the second greatest contributor with about 27 percent of the total erosion. Based on aerial photos and sample studies in the field in 1978, there are about 150 active gullies and 50 miles of eroding streambanks in the watershed. The 1990 figures should be similar to 1978, based on similar land uses. Total tons of erosion per square mile of contributing drainage area per year is 1,350 or 2.1 tons per acre per year.

Based on field observations from 1978, sheet and rill erosion is most severe in the watershed on summer fallow fields with inadequate crop residue for cover. Erosion from rowcrop fields is secondary but probably is more severe than erosion from the small grain and alfalfa fields. The rangeland is only slightly eroding and reduces runoff considerably. Runoff from cropland may be aggravating the natural channelbank erosion in gullies and streams.

Lakeshore erosion may be more significant than estimated (1,200 feet, 15 feet high, recession rate of 0.2 foot per year). Connaughton's report mentions the fact that waves or ice constantly attack the lakeshores while other erosion only occurs during infrequent rainfall events.

Wind erosion is an important type of erosion that has not been quantitatively evaluated to date primarily because the mode of transport between the eroding areas and points of sediment yield are poorly understood. The lack of windbreaks and good vegetative cover on the cropland at critical periods of the year definitely contribute to severe wind erosion in the watershed.

Sediment Yields

Sediment Volume and Density

The volume of sediment in Hayes Lake was measured using the range method which is outlined in Chapter 7, Section 3, Sedimentation, of the Soil Conservation Service National Engineering Handbook, 1983. Soundings were made on 21 ranges and the sediment accumulation in the lake from 1978 to 1990 was calculated using Formula 7-4. This volume, 60 acre-feet, was subtracted from the water storage available in the lake in 1978, 756 acre-feet. Thus, 696 acre-feet of available water storage remains in the lake and a total of 272 acre-feet of sediment are stored in Hayes Lake today.

In order to convert volume or acre-feet of sediment to tons, the density or volume-weight of the sediment must be known. 1/ Fourteen sediment cores were collected in 1978 on seven ranges and the cores were divided into 33 samples to reflect the variable consolidation of the sediment. Volume weights for each of the 33 samples were determined in the SCS soils laboratory in Huron. For the 1990 study, the average density found for the 1978 samples was used because it was assumed that there would be little change.

A discussion of the study done on the 1978 sediment samples is included in the Appendix of this report.

Sediment Distribution

In 1990, a comparison of 1978 lake bottom elevations along each range and 1990 lake bottom elevations on the same ranges was made. The observations on sediment distribution made by Connaughton in the 1937 survey and Steffen in the 1978 survey appear to be generally true in the 1990 also. Following is a listing of Hayes Lake sediment characteristics.

1. Sediment thicknesses in the channel become greater downstream.

2. Sediment thicknesses on the flood plain become less downstream.

3. "New" sediment (since 1978) was found to be over 4 feet thick on the east half of R16-15.

4. "New" sediment on the flood plain on ranges near the dam averages 1.0 foot thick.

1/ Dry weight of sample divided by volume of wet sample = density. (pounds per cubic foot-pcf)

5. Bottom scouring occurs in the channel below lake surface during high flows even as close to the dam as R3-4. The channel has changed location and shifted 30 to 120 feet from its 1978 location at several ranges. (R3-4, R3-5, R6-7, R10-11)

6. Flood plain scour occurs above and below U.S. high 14 bridge. Several ranges showed little sediment accumulation from 1978 to 1990 due to scour in the channel.

7. Coarse particles of shale bedrock in the "new" sediment layer were found in the sample collected on the flood plain along R13-14.

8. Lakeshore erosion is continuing.

Lake bottom elevation comparisons between 1978 and 1990 provided information for most of the above observations.

As discussed in Connaughton's report, the 4 years following construction of the Hayes Lake dam were abnormally dry (10.98 inches average annual precipitation from 1933 to 1936). Any rain that fell in this period was particularly erosive because of the high runoff potential in the watershed (heavy clay soils and weedy cover). The sediment yield at the time of the first survey (June 1937) was 228 tons/mi^2/yr. This rate is much greater than the annual rate for the latter 41.0 years and it is considered to be abnormal for the above mentioned reasons.

Estimated Sediment Yield

Sediment yield to the mouth of Hayes Lake watershed was estimated to be 6,442 tons per year in 1978. This was based on the following relationship:

Gross Erosion x Sediment Delivery Ratio = Total Sediment Yield

Based on a contributing drainage area of 43.29 square miles, the sediment yield to the mouth of the watershed was estimated in 1978 to be 149 tons per square mile per year (tons/mi^2/yr). The measured sediment trapped in Hayes Lake (from 1937 to present) is 167 tons/mi^2/yr. Generally, not all the suspended sediment reaching the lake is trapped - some exits through the spillway during high flows. Using procedures outlined in USDA-SCS Technical Release 12 (1975), the trap efficiency of Hayes Lake is 93 percent. Based on this trap efficiency, and the 1990 sediment survey results, the actual sediment yield at the mouth of the watershed is currently about 180 tons/mi^2/yr.

See Appendix for more discussion on the Sediment Delivery Ratio and Sediment Yield Estimates.

APPENDIX

Sediment Volume and Density

Sediment deposits become denser in two ways - compaction due to weight of overlying sediment, and dessication, or drying. Density if also dependent on the texture of the sediment. A dry sandy clay may be 100 pounds per cubic foot (pcf) while the density of a dry silt may be 70 pcf.

In general, sediment shows a gradual increase in density with depth. However, an influx of sandy material over partially consolidated silts and clays may show a high density material grading to a lower density with depth. An abrupt increase in density with depth may indicate scouring of fence material during a rapid filling of a reservoir followed by deposition of new lighter weight sediment. The same density difference could be detected if a silt was deposited over sand, though.

When a lake dries, the uppermost sediments will become denser as they desiccate and may seal the surface so underlying deposits retain their water. Subsequent density measurements after the lake has filled, and more sediment deposited, may show low density sediment over high density sediments grading back to lighter sediments with depth. This particular situation may have occurred in samples S-24 and S-26 in Hayes Lake, since the lake was approximately 5 feet below spillway level in 1976.

The above paragraphs indicate that, generally, volume weights of sediment deposits vary laterally as well as vertically in a reservoir. The sediment samples collected in this survey corroborate that observation. The following section shows how sediment deposits are distributed in Hayes Lake and their volume converted to tons.

Sediment Description and Distribution (1978)

Sediment samples showed definite changes in consolidation of the sediment deposits vertically. The top layer, generally 0.2 foot thick, consisted of a suspended mixture of individually recognizable shale bedrock particles of various sizes. It is interesting to note that the grain sizes of the "new" sediment, "old" sediment, and Pierre shale samples were nearly identical.

The top layer of "new" sediment also had recognizable organic matter in it as well as Gastropod (snail) and Pelecypod (clam) shells. This layer had volume weights ranging from 8 to 60 pcf and was generally confined to segments above range R13-R14. Samples collected on range R3-R5 showed similar texture and density but this upper layer was thinner than that above R13-R14 and contained no recognizable shale particles.

Sediment Yield Estimates

Gully, streambank, lakeshore, road, and roadbank erosion were estimated in 1978 using direct volume methods (multiplying eroding areas by estimated erosion rates). These estimates were based on watershed samples (field and aerial photos) and other studies in the area made in the past (Western South Dakota River Basins and Sixth District Council of Local Governments Soil Erosion and Sediment Yield Study). The sample data and other information were expanded over the entire watershed using aerial photos and county highway maps.

Sediment Delivery Ratios

Sediment yield from sheet and rill erosion was estimated by multiplying the erosion by a sediment delivery ratio. From an SCS delivery ratio versus drainage area curve, a 12 percent delivery ratio could be used for Hayes Lake Watershed. An actual delivery ratio of 6 percent was used to account for the generally low slopes, rangeland along channels, and the 73 ponds and dams (many on the main creek) in the watershed. A 3 percent ratio was used for roadbank erosion because of the good grass condition in the road ditches. Weighted values of delivery ratios for gully and streambank erosion were used since erosion occurring near the lake had a much higher chance of actually becoming sediment yield to the lake. Ratios of 20 percent and 39 percent were used for gullies and streambanks, respectively. All lakeshore erosion reached the lake so a 100 percent delivery ratio was used.

Appendix C.

Hayes Lake Sample Data Inlake, Tributary and Outlet Data Collected 2001

Table C1. Inlake surface and bottom concentration data collected at site HL1 for all sampled dates 2001.

Lake ID	Date	Sample Depth	Field pH S.U	Secchi m	Water temp (°C)	DO mg/L	Alkalinity mg/L	Total Solids mg/L	Total Suspended Solids mg/L	Volatile Total Suspended Solids mg/L	Ammonia mg/L	Nitrate mg/L
HL1	15-Feb-01	Surface		0.57	4.0	5.9	289	797	7	2	0.22	0.2
HL1	9-Apr-01	Bottom			8.9	11	170	608	12	8	<.02	2.8
HL1	9-Apr-01	Surface	8.67	0.66	9.2	11.0	169	608	10	7	<.02	2.9
HL1	16-May-01	Bottom			19.2	10.4	186	699	6	2	0.17	0.7
HL1	16-May-01	Surface		1.52	20.0	10.8	185	697	8	3	0.18	0.7
HL1	13-Jun-01	Bottom	7.68		20.6	3.08	184	662	5	2	0.04	<.1
HL1	13-Jun-01	Surface	8.18	1.52	21.6	9.09	188	665	4	2	0.02	<.1
HL1	10-Jul-01	Bottom				0.24	209	734	10	6	0.24	<.1
HL1	10-Jul-01	Surface	7.72	1.7		5.32	195	709	<1	<1	<.02	<.1
HL1	15-Aug-01	Bottom			15.5	5.4	207	733	11	9	<.02	<.1
HL1	15-Aug-01	Surface	8.11	1.4	18.0	7.0	207	742	14	13	0.02	<.1
HL1	19-Sep-01	Bottom			17.0	8.18	238	777	7	3	<.02	<.1
HL1	19-Sep-01	Surface	8.18	1.1	19.0	8.6	236	790	19	15	<.02	<.1
HL1	23-Oct-01	Bottom			9.5	6.2	249	811	12	6	<.02	<.1
HL1	23-Oct-01	Surface	8.54	1.0	10.0	7.2	248	807	8	3	<.02	<.1

Table C1. (continued)

Lake ID	Date	Sample Depth	TKN mg/L	Total Nitrogen mg/L	Total Phosphorus mg/L	Total Dissolved Phos. mg/L	E. Coli colonies/ 100ml	Fecal Coliform colonies/ 100ml	Chlorphyll-*a* mg/m3	N:P ratio	Mean TSI
HL1	15-Feb-01	Surface	2.03	2.23	0.111	0.051	7.4	<10	2.80	20.1	60.3
HL1	9-Apr-01	Bottom	1.80	4.6	0.155	0.062				29.7	
HL1	9-Apr-01	Surface	2.04	4.94	0.161	0.031	<1	<10	52.07	30.7	70.9
HL1	16-May-01	Bottom	1.19	1.89	0.123	0.084				15.4	
HL1	16-May-01	Surface	1.3	2	0.119	0.074	6.3	<10	1.10	16.8	52.9
HL1	13-Jun-01	Bottom	1.36	1.41	0.163	0.120				8.7	
HL1	13-Jun-01	Surface	1.38	1.43	0.155	0.114	4.1	<10	2.90	9.2	57.3
HL1	10-Jul-01	Bottom	2.19	2.24	0.533	0.330				4.2	
HL1	10-Jul-01	Surface	1.33	1.38	0.285	0.250	41.1	40	6.81	4.8	62.5
HL1	15-Aug-01	Bottom	1.39	1.44	0.378	0.338				3.8	
HL1	15-Aug-01	Surface	1.36	1.41	0.379	0.306	2	<10	4.61	3.7	63.5
HL1	19-Sep-01	Bottom	1.08	1.13	0.378	0.305				3.0	
HL1	19-Sep-01	Surface	1.56	1.61	0.417	0.283	25.9	40	25.53	3.9	70.7
HL1	23-Oct-01	Bottom	1.29	1.34	0.192	0.123				7.0	
HL1	23-Oct-01	Surface	1.5	1.55	0.193	0.120	4.1	<10	34.64	8.0	68.5

Table C2. Inlake surface and bottom concentration data collected at site HL2 for all sampled dates 2001.

Lake ID	Date	Sample Depth	Field pH S.U	Secchi m	Water temp (oC)	DO mg/L	Alkalinity mg/L	Total Solids mg/L	Total Suspended Solids mg/L	Volatile Total Suspended Solids mg/L	Ammonia mg/L	Nitrate mg/L
HL2	15-Feb-01	Surface		0.85	4.0	5.0	287	789	7	2	0.25	0.1
HL2	9-Apr-01	Bottom			8.4	11.0	183	632	11	9	<.02	2.0
HL2	9-Apr-01	Surface	8.67	0.64	8.9	10.8	183	628	12	10	<.02	2.9
HL2	16-May-01	Bottom			19.0	10.8	186	699	9	1	0.38	0.7
HL2	16-May-01	Surface	7.88	1.68	20.0	11.0	184	697	5	4	0.23	0.8
HL2	13-Jun-01	Bottom			18.8	2.6	186	668	4	<1	0.14	<.1
HL2	13-Jun-01	Surface	8.17	1.37	21.1	8.5	181	666	3	2	0.09	0.1
HL2	10-Jul-01	Bottom				0.2	196	712	6	3	<.02	<.1
HL2	10-Jul-01	Surface	8.00	1.5		6.8	194	706	3	1	<.02	<.1
HL2	15-Aug-01	Bottom			14.0	5.6	209	723	9	7	<.02	<.1
HL2	15-Aug-01	Surface	7.94	1.35	15.0	6.4	206	721	9	8	<.02	<.1
HL2	19-Sep-01	Bottom			17.0	1.6	232	769	5	4	<.02	<.1
HL2	19-Sep-01	Surface	7.97	1.1	19.0	8.6	231	787	23	23	<.02	<.1
HL2	23-Oct-01	Bottom			11.8	6.2	247	810	14	5	<.02	<.1
HL2	23-Oct-01	Surface	8.40	1.0	11.8	7.4	245	808	10	5	<.02	<.1

Table C2. (continued)

Lake ID	Date	Sample Depth	TKN mg/L	Total Nitrogen mg/L	Total Phosphorus mg/L	Total Dissolved Phosphorus mg/L	E. Coli colonies/ 100ml	Fecal Coliform colonies/ 100ml	Chlorphyll-*a* mg/m3	N:P ratio	Mean TSI
HL2	15-Feb-01	Surface	1.84	1.94	0.116	0.058	4.1	<10	11.51	16.7	63.2
HL2	9-Apr-01	Bottom	2.29	4.29	0.172	0.036				24.9	
HL2	9-Apr-01	Surface	2.07	4.97	0.168	0.032	<1	<10	76.40	29.6	72.5
HL2	16-May-01	Bottom	1.20	1.9	0.157	0.091				12.1	
HL2	16-May-01	Surface	1.18	1.98	0.119	0.077	4.1	10	0.00	16.6	
HL2	13-Jun-01	Bottom	1.50	1.55	0.175	0.147				8.9	
HL2	13-Jun-01	Surface	1.41	1.51	0.148	0.112	6.2	20	2.40	10.2	57.0
HL2	10-Jul-01	Bottom	1.38	1.43	0.400	0.296				3.6	
HL2	10-Jul-01	Surface	1.46	1.51	0.286	0.256	6.2	<10	8.81	5.3	63.9
HL2	15-Aug-01	Bottom	1.59	1.64	0.398	0.296				4.1	
HL2	15-Aug-01	Surface	1.23	1.28	0.382	0.321	<1	<10	6.01	3.4	64.6
HL2	19-Sep-01	Bottom	1.05	1.1	0.359	0.321				3.1	
HL2	19-Sep-01	Surface	1.45	1.5	0.431	0.299	9.6	10	40.55	3.5	72.4
HL2	23-Oct-01	Bottom	1.40	1.45	0.223	0.145				6.5	
HL2	23-Oct-01	Surface	1.35	1.4	0.213	0.141	<1	<10	20.63	6.6	67.3

Table C3. Tributary and outlet concentration data collected for all sampled dates 2001.

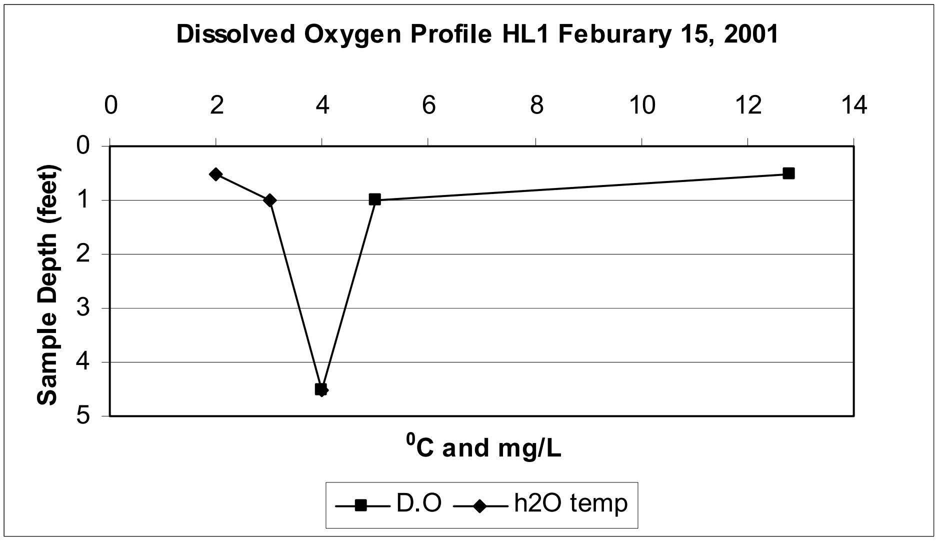
Lake ID	Date	Field pH S.U	Water temp (oC)	D.O mg/L	Alkalinity mg/L	Volatile Total Suspended Solids mg/L	Total Solids mg/L	Total Suspended Solids mg/L
HLT1	14-Mar-01	7.44	3.5	12.2	40	13	162	16
HLT1	24-Apr-01	8.18	16.5		203	3	410	4
HLT2	14-Mar-01	7.40	2.3	12.9	106	12	1448	264
HLT2	18-Mar-01		3.4	12.8	68	<1	495	94
HLT2	21-Mar-01	7.98	4.2		76	6	456	47
HLT2	28-Mar-01		3.7	12.6	93	4	576	27
HLT2	24-Apr-01	8.56	12.9		122	48	1963	568
HLT2	1-Aug-01				133	2	640	7
HLO	18-Mar-01	7.99	4.2	11.4	67	<1	460	42
HLO	21-Mar-01		4.8		73	3	449	26
HLO	28-Mar-01		7.3	12.7	75	4	394	10
HLO	24-Apr-01		13.4		171	9	614	11

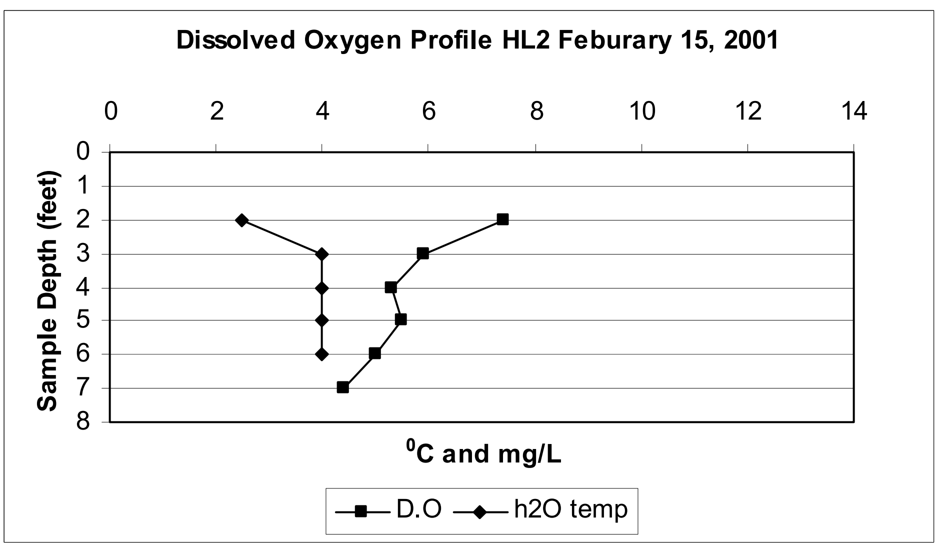
Table C3. (continued)

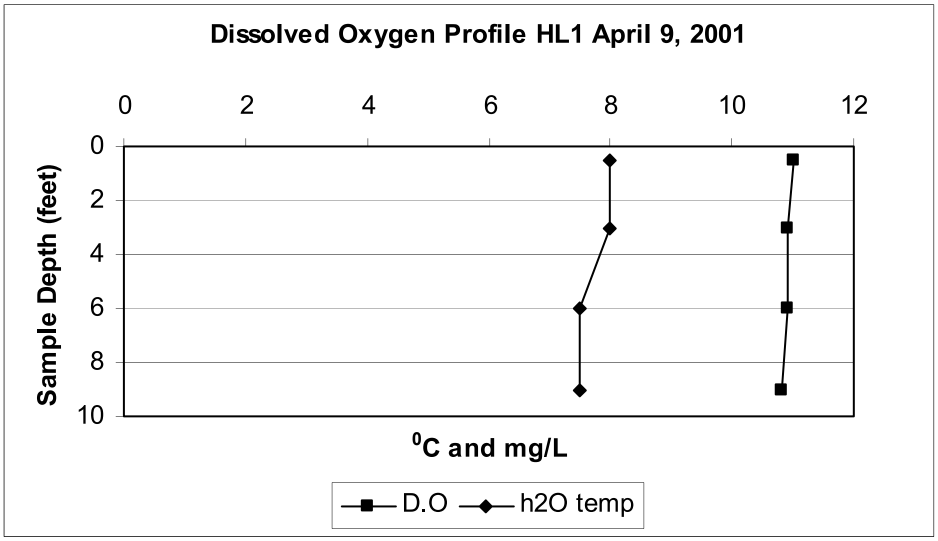
Lake ID	Date	Ammonia mg/L	Nitrate mg/L	TKN mg/L	Total Nitrogen mg/L	Total Phosphorus mg/L	Total Dissolved Phosphorus mg/L	E. Coli colonies/ 100ml	Fecal Coliform colonies/ 100ml
HLT1	14-Mar-01	0.49	0.60	2.56	3.16	0.922	0.670	16.1	<10
HLT1	24-Apr-01	<.02	0.2	0.79	0.99	0.063	0.049	5.2	10
HLT2	14-Mar-01	1.03	42.1	3.29	45.39	0.799	0.317	179	90
HLT2	18-Mar-01	0.43	5.8	2.06	7.86	0.571	0.292	12.1	20
HLT2	21-Mar-01	0.39	4.1	1.46	5.56	0.380	0.22	<1	<10
HLT2	28-Mar-01	0.22	6.0	1.22	7.22	0.299	0.143	19.5	20
HLT2	24-Apr-01	0.15	19.0	1.66	20.66	0.883	0.054	380	816
HLT2	1-Aug-01	<.02	1.1	2.19	3.29	0.183	0.098	53	90
HLO	18-Mar-01	0.38	5.6	2.36	7.96	0.508	0.307	4.1	<10
HLO	21-Mar-01	0.33	4.7	2.14	6.84	0.411	0.247	<1	<10
HLO	28-Mar-01	<.02	4.1	1.83	5.93	0.276	0.124	<1	<10
HLO	24-Apr-01	0.05	1.4	1.71	3.11	0.122	0.033	<1	<10

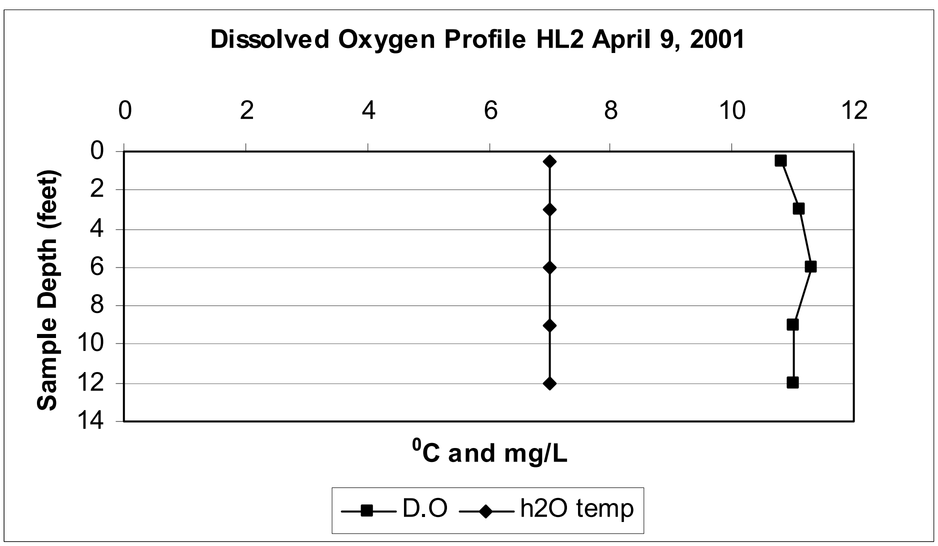
Appendix D.

Hayes Lake Dissolved Oxygen and Temperature Profiles Sampling Season 2001.

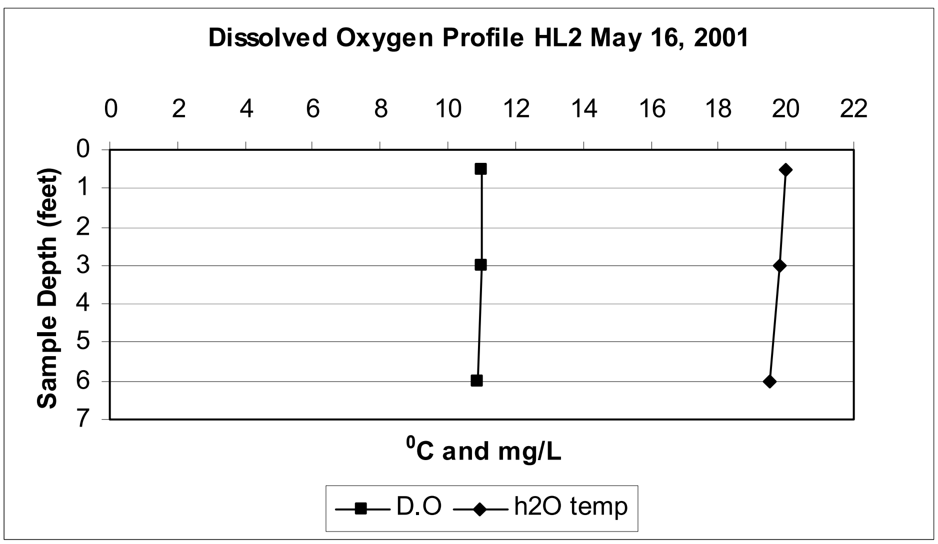

Dissolved Oxygen Profile HL1 Feburary 15, 2001
0
2
4
6
8
10
12
14
0
1
2
3
4
5
Sample Depth (feet)
0C and mg/L
D.O
h2O temp

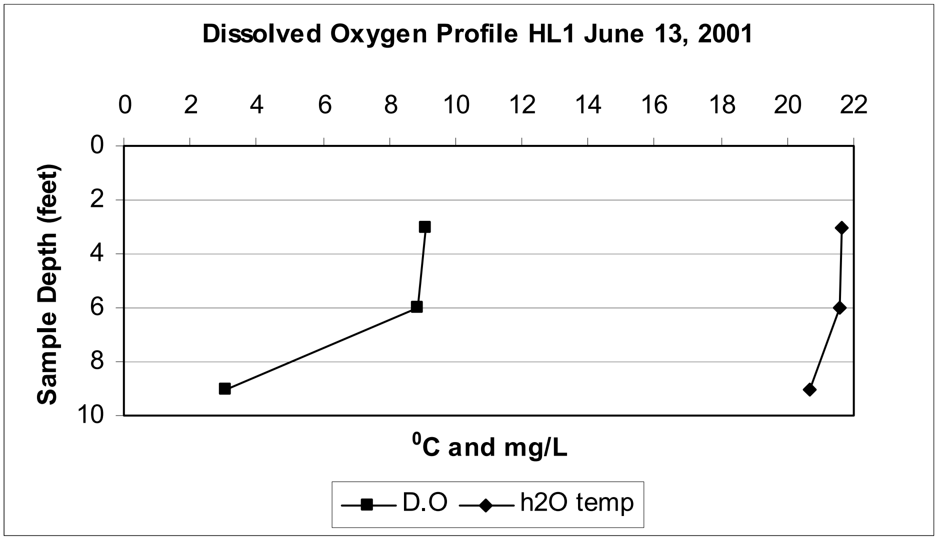

Dissolved Oxygen Profile HL2 Feburary 15, 2001
0
2
4
6
8
10
12
14
0
1
2
3
4
5
6
7
8
Sample Depth (feet)
0C and mg/L
D.O
h2O temp

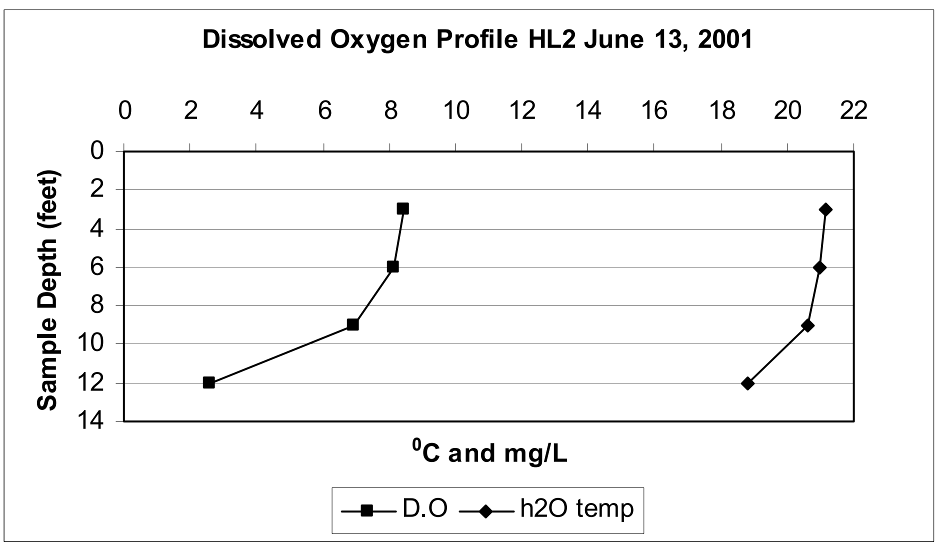

Dissolved Oxygen Profile HL1 April 9, 2001
0
2
4
6
8
10
12
Sample Depth (feet)
0
2
4
6
8
10
⁰C and mg/L
D.O
h2O temp

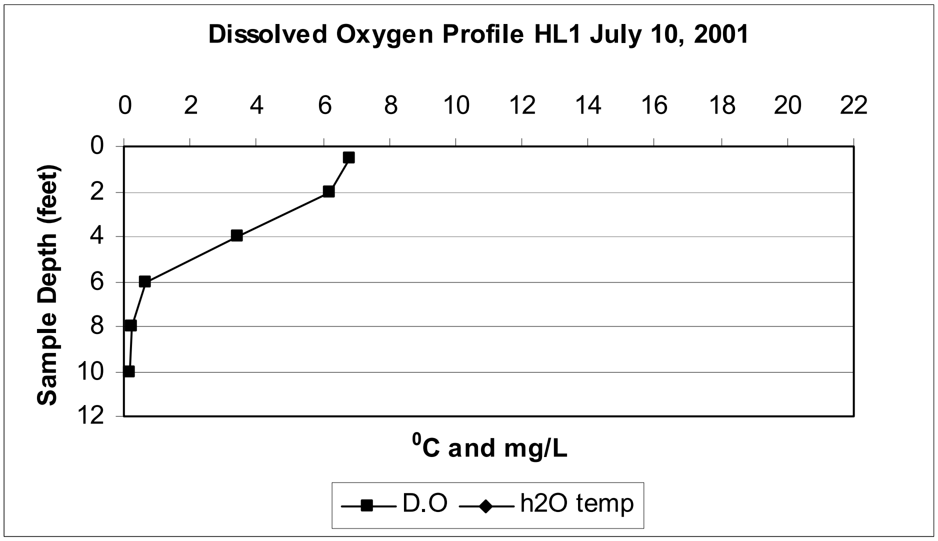

Dissolved Oxygen Profile HL2 April 9, 2001
0
2
4
6
8
10
12
Sample Depth (feet)
0
2
4
6
8
10
12
14
⁰C and mg/L
D.O
h2O temp

* Dissolved oxygen and water temperature profile data were not available from HL1 during the May 16, 2001 sampling period due to equipment failure.

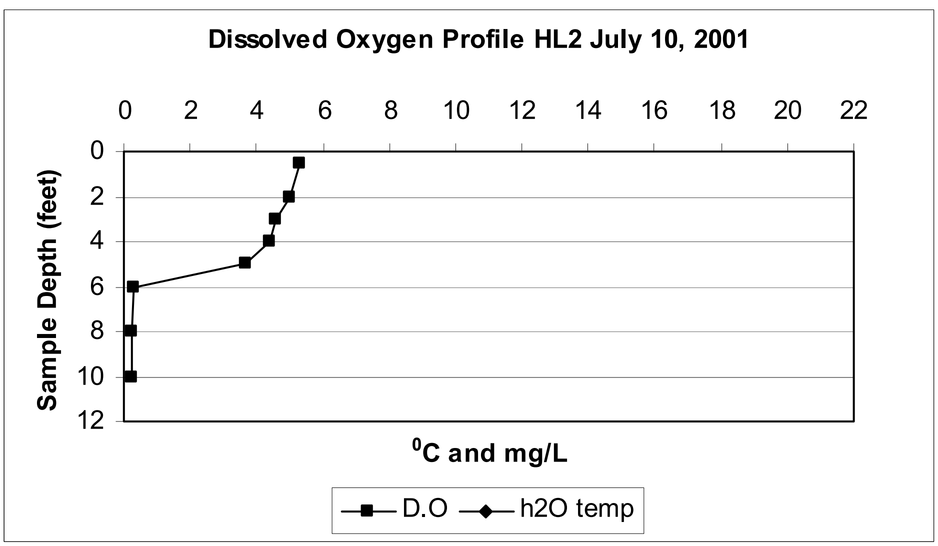



Dissolved Oxygen Profile HL1 June 13, 2001
0
2
4
6
8
10
12
14
16
18
20
22
Sample Depth (feet)
0C and mg/L
D.O
h2O temp

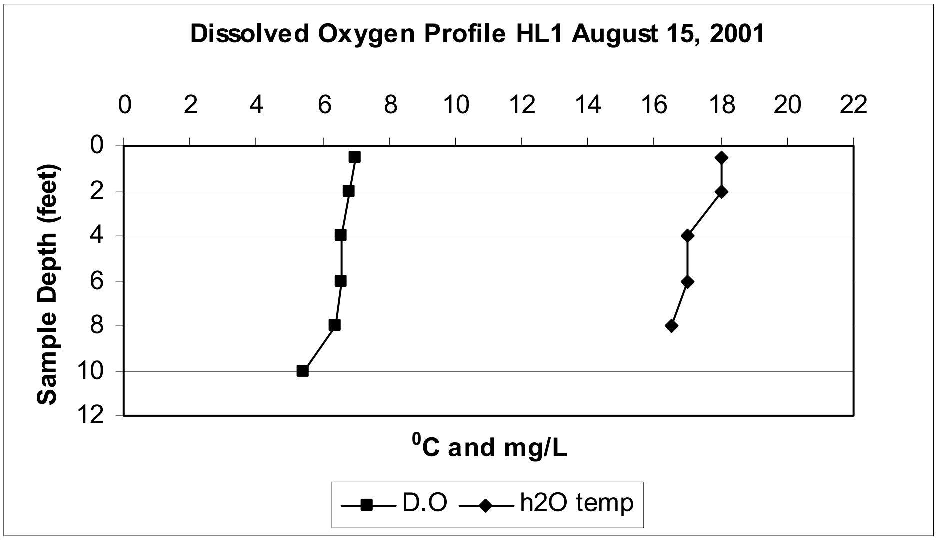

Dissolved Oxygen Profile HL2 June 13, 2001
0
2
4
6
8
10
12
14
16
18
20
22
Sample Depth (feet)
0C and mg/L
D.O
h2O temp

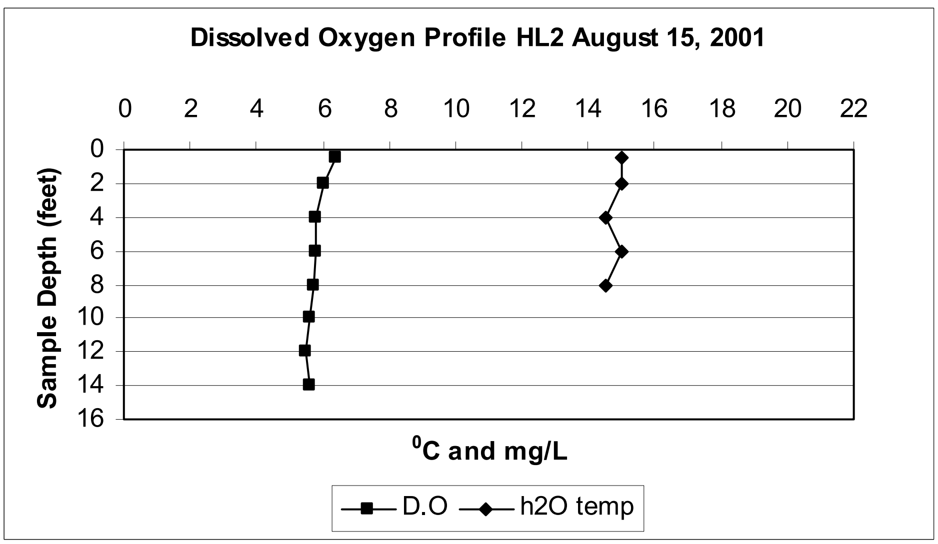


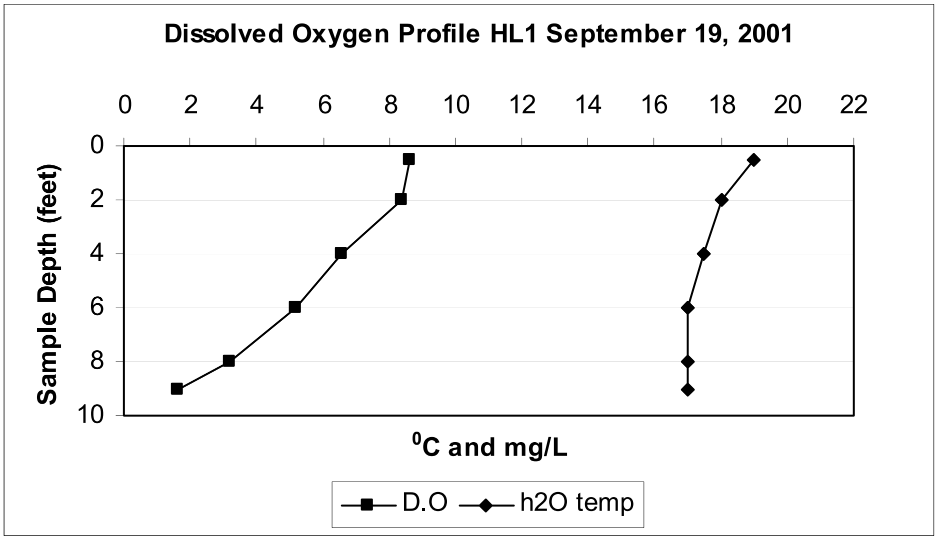
* Temperature data not available

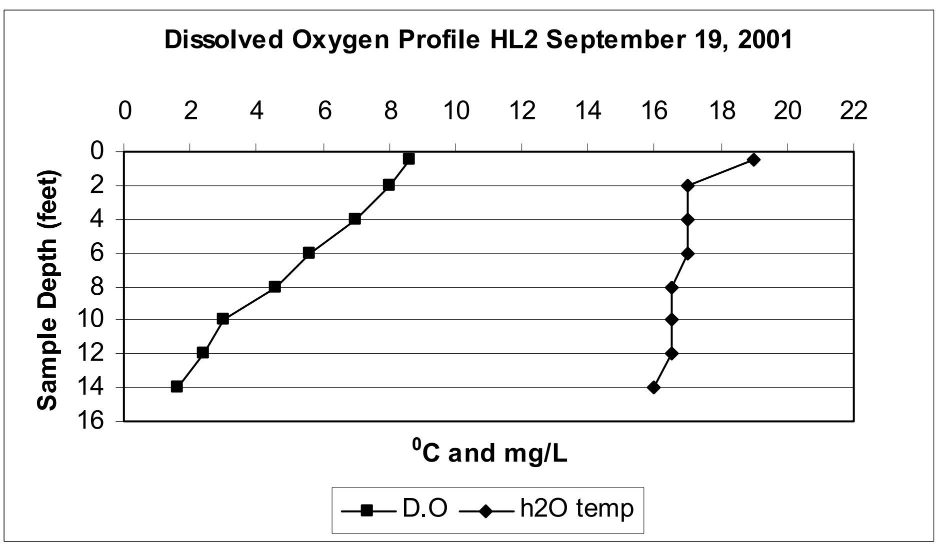


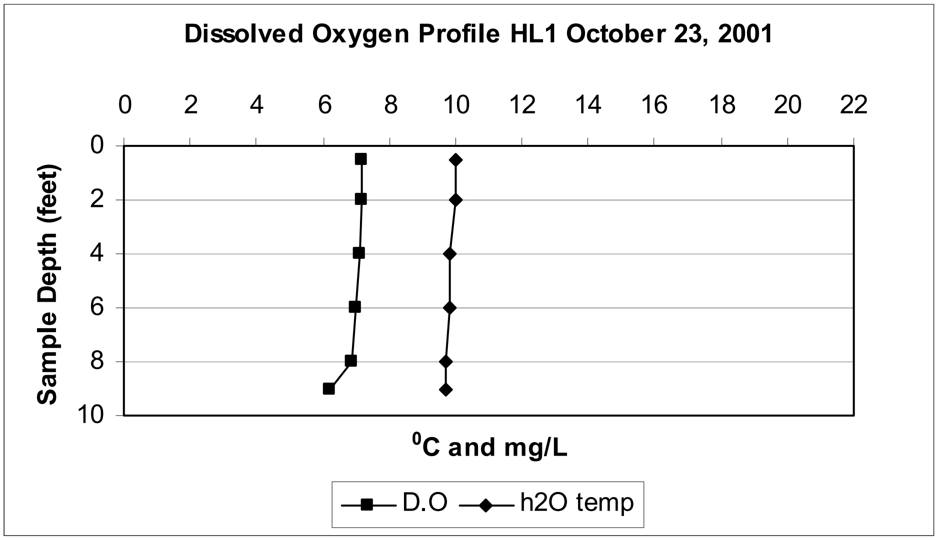
* Temperature data not available

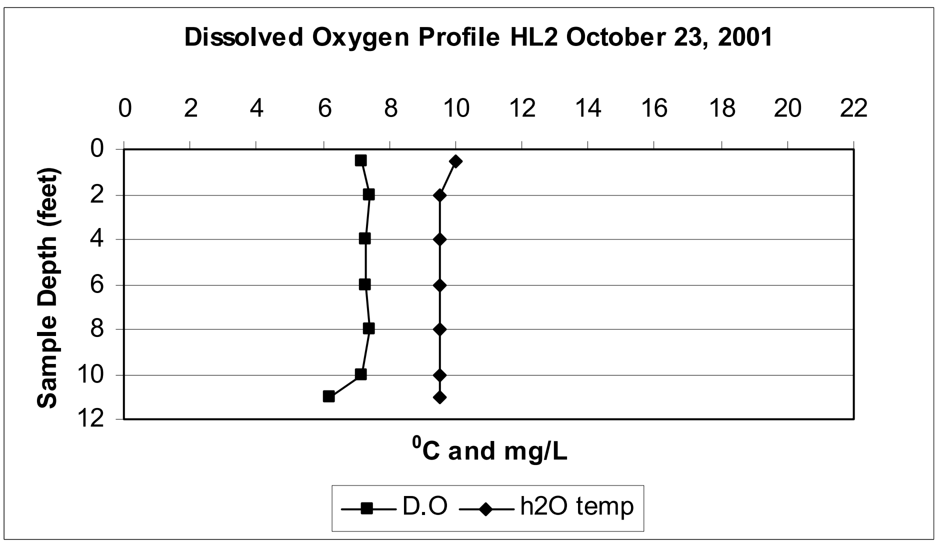

Dissolved Oxygen Profile HL1 August 15, 2001
0
2
4
6
8
10
12
14
16
18
20
22
Sample Depth (feet)
0
2
4
6
8
10
12
0C and mg/L
D.O
h2O temp


Dissolved Oxygen Profile HL2 August 15, 2001
0
2
4
6
8
10
12
14
16
18
20
22
Sample Depth (feet)
0
2
4
6
8
10
12
14
16
0C and mg/L
D.O
h2O temp


Dissolved Oxygen Profile HL1 September 19, 2001
0 2 4 6 8 10 12 14 16 18 20 22
0 2 4 6 8 10
Sample Depth (feet)
^{0}C and mg/L
D.O
h2O temp


Dissolved Oxygen Profile HL2 September 19, 2001
0 2 4 6 8 10 12 14 16 18 20 22
0 2 4 6 8 10 12 14 16
Sample Depth (feet)
^{0}C and mg/L
D.O
h2O temp


Dissolved Oxygen Profile HL1 October 23, 2001
0
2
4
6
8
10
12
14
16
18
20
22
0
2
4
6
8
10
Sample Depth (feet)
0C and mg/L
D.O
h2O temp


Dissolved Oxygen Profile HL2 October 23, 2001
0
2
4
6
8
10
12
14
16
18
20
22
0
2
4
6
8
10
12
Sample Depth (feet)
0C and mg/L
D.O
h2O temp

Appendix E.

TOTAL MAXIMUM DAILY LOAD (TMDL) EVALUATION

For

HAYES LAKE

FROZEN MAN CREEK WATERSHED

(HUC 10140102)

STANLEY COUNTY, SOUTH DAKOTA

SOUTH DAKOTA DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES

JANUARY 2003

Hayes Lake Total Maximum Daily Load

Waterbody Type:	**Lake (Impounded)**
303(d) Listing Parameter:	**TSI Trend,**
Designated Uses:	**Recreation, Warmwater semi-permanent aquatic life**
Size of Waterbody:	**73.7 acres**
Size of Watershed :	**30,400 acres**
Water Quality Standards:	**Narrative and Numeric**
Indicators:	**Average modeled TSI 65.7,**
Analytical Approach:	**AGNPS, BATHTUB, FLUX**
Location:	**HUC Code: 10140102**
Goal:	**Reduce phosphorus loads from the watershed by 24% and internal phosphorus load by 25%.**
Target:	**To meet alternative site specific (watershed specific) evaluation criteria (fully supporting, mean TSI < 65.0) based on AGNPS modeling, BMPs and watershed specific phosphorus reduction attainability. Target set conservatively at a mean modeled growing season TSI of 64.8.**

Objective:

The intent of this summary is to clearly identify the components of the TMDL submittal to support adequate public participation and facilitate the US Environmental Protection Agency (EPA) review and approval. The TMDL was developed in accordance with Section 303(d) of the federal Clean Water Act and guidance developed by EPA.

Introduction

Hayes Lake is a 73.7 acre man-made impoundment located in west central Stanley County, South Dakota. The 1998 and 2002 South Dakota 303(d) Waterbody

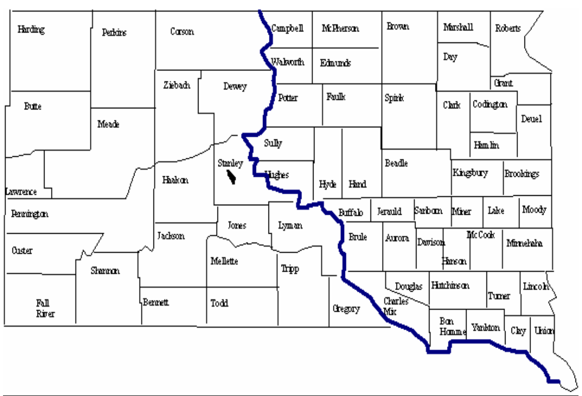


Figure E1. Watershed Location in South Dakota

List (pages 22 and 29 respectively) identified Hayes Lake for TMDL development for Trophic State Index (TSI) and increasing eutrophication trend.

In 1933, Frozen Man Creek was damned, approximately a quarter mile east and one half mile south of Hayes, South Dakota. The resulting lake has a current average depth of 6.1 feet (2 meters) a maximum depth of 17 feet (6.7 m) and over 3.6 miles (5.8 km) of shoreline. The lake holds approximately 450 acre-feet of water, and has an established elevation of 1946.7 ft at the spillway. The lake is subject to periods of stratification during the summer. The outlet of the lake empties into Frozen Man Creek, which eventually reaches the Bad River about 27 miles southwest of Fort Pierre, SD.

Problem Identification

Frozen Man Creek is the primary tributary to Hayes Lake and drains about 30,400 acres which is a mixture of grazing lands, cropland and has presently about 10,000 acres of Conservation Reserve. Winter feeding areas for livestock are present in the watershed but the AGNPS model indicates they have very little effect on the water quality of Hayes Lake. The stream carries nutrient loads, which are enhanced by runoff from eroding cropland, which degrade water quality in the lake, and cause increased eutrophication.

Description of Applicable Water Quality Standards & Numeric Water Quality Targets

Hayes 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, which are listed below:

- *Warm water semi-permanent 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. Through settling and chemical processes, the nutrients from the watershed eventually add to the internal phosphorus load. Hayes Lake is identified in the 2002 South Dakota Waterbody List and the

1998 "Ecoregion Targeting for Impaired Lakes in South Dakota" as partially supporting its aquatic life beneficial use.
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.

If adequate numeric criteria are not available, the South Dakota Department of Environment and Natural Resources (SD DENR) uses surrogate measures. To assess the trophic status of a lake, SD DENR uses the mean growing season TSI, which incorporates Secchi depth, chlorophyll *a* and phosphorus concentrations. SD DENR has developed a protocol that establishes desired TSI levels for lakes based on an ecoregion approach. This protocol was used to assess impairment and determine a numeric target for Hayes Lake.

Hayes Lake currently has a modeled mean growing season TSI of 65.7, which is indicative of high levels of primary productivity (hyper-eutrophic). Assessment monitoring indicates that the primary cause of the productivity is phosphorus loads from the watershed and the bottom sediments in the lake. Inlake phosphorus contributes about 52% of the phosphorus load while the watershed accounts for about 47%. This data was determined through inlake reduction response modeling using BATHTUB, an Army Corps of Engineers Euthrophication Response Model (Walker, 1999).

The numeric target, established to improve the trophic state of Hayes Lake, is a growing season average TSI of 55. In order to meet this ecoregion target phosphorus loads would have to be reduced in excess of 90% from inlake and the watershed respectively. This target is not attainable through recommendations in the Hayes Lake final report. The recommendations were based on alternative site specific (watershed specific) evaluation criteria (full support at a mean TSI <65.0) based on AGNPS modeling, BMPs and watershed specific phosphorus reduction attainability. The recommended target is set at a mean modeled growing season TSI of 64.8 while maintaining the Secchi and chlorophyll *a* TSI below the original ecoregion (43) target of 55. This can be achieved by reducing internal phosphorus loading by 25% and phosphorus loading from the from Frozen Man Creek watershed by 24%.

Pollutant Assessment

Point Sources

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

Nonpoint Sources Background Sources

The AGNPS model estimated that 15,202 kg/yr of phosphorus enter the lake on an average annual basis; resulting in an estimated internal phosphorus storage of 17,029 kg. Approximately 11,293 kg or 75% originate from the cropland acres in the watershed. The remaining 3,909 kg or 25% originate from other areas of the watershed, primarily hay and pasture lands. Nutrient loadings attributed to bank and channel erosion within the watershed are minimal and a phosphorus loading was not computed from this possible source. Of the estimated load, treatment of 8.73% (2,620 acres) of the most critical acres (page 44) of the watershed will result in phosphorus reductions of 2,710 kg/yr or 24%.

Linkage Analysis

Water quality data was collected from five monitoring sites within the Hayes Lake and Frozen Man Creek 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 Nonpoint Source Quality Assurance/Quality Control Plan. Details concerning water sampling techniques, analysis, and quality control are addressed on pages 8-43 of the assessment final report.

In addition to water quality monitoring, data was collected to complete a watershed landuse model. The Agriculture Nonpoint Pollution Source (AGNPS) model was used to provide comparative values and reductions for each of the land uses and animal feeding operations located in the watershed. See the AGNPS section of the final report, pages 44 - 48.

Phosphorus load estimates based on modeled input data from AGNPS were used for calculating the TMDL for Hayes Lake. Dry conditions in the watershed over the course of the project contributed to minimal measured phosphorus load estimates and would likely under estimate the TMDL. AGNPS simulations are based on long-term average hydrology and concentration inputs derived from current land-use practices.

TMDL and Allocations

Phosphorus to Hayes Lake (AGNPS):

	11,293	kg/yr from cropland
+	3,909	kg/yr from rangeland
+	17,029	kg/yr internal load (IL)
	32,231	kg/yr total

TMDL

+	3,909 kg/yr	(LA) Range
+	8,583 kg/yr	(LA) Crop
	12,772 kg/yr	(IL)
+	Implicit	(MOS Range)
	25,264 kg total	(TMDL)

Wasteload Allocations (WLAs)

There are no point sources of pollutants of concern in this watershed. Therefore, the "wasteload allocation" component of these TMDLs is considered a zero value. The TMDLs are considered wholly included within the "load allocation" component.

Load Allocations (LAs)

A 24% reduction in the phosphorus load to Hayes Lake may be obtained through the improvement of 50% of the critical cropland cells identified in the AGNPS section reducing the annual cropland load from 11,293 kg/yr to 8,583 kg/yr. A 25% reduction of inlake phosphorus load may be obtained by an inlake alum treatment or inlake aeration system reducing the internal load from 17,029 kg/yr to 12,772 kg/yr. The overall phosphorus reduction necessary to achieve a mean growing season TSI below the alternative target for full support (<65.0) is 6,967 kg/yr from both internal and external sources respectively. The suggested TMDL for Hayes Lake is 25,264 kg/yr.

Rangeland BMPs targeting 4,500 of the 9,000 acres of rangeland will result in additional reductions in phosphorus loads to the lake. This is addressed on page 48 of the final report and is addressed in the margin of safety.

Seasonal Variation

Different seasons of the year can yield differences in water quality due to changes in precipitation and agricultural practices. The majority of the tributary samples were collected in the spring (March –April) with one sample collected in the summer (August). To determine inlake seasonal differences, Hayes Lake samples were separated into spring (April-May), summer (June-August), fall (September-October), and winter (February) collection periods. Tributary and inlake seasonalized data may be found on page 11 and 25 respectively.

Margin of Safety

An implicit margin of safety was assigned to the TMDL calculation due to the difficulty of predicting additional phosphorus load reductions from implementation of BMPs on rangeland acres in the watershed. The model does not consider the sediment reduction which will result in phosphorus reduction that occurs because of the improved infiltration of rainfall and the improved health of the riparian zones.

Critical Conditions

The impairments to Hayes Lake are most severe during the late summer. This is the result of warm water temperatures, internal loadings, and peak algal growth. Historic data on Hayes Lake indicates that the TSI tends to improve during dry periods with minimal loading and increases in wetter years with appreciable loadings.

Follow-Up Monitoring

Hayes Lake will continue to be monitored every four years by the South Dakota Statewide Lakes Assessment Program.

Once the implementation project is completed, post-implementation monitoring will be necessary to assure that the TMDL has been reached and improvement to the beneficial uses occurs.

Public Participation

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

3. Stanley County Conservation District Board Meetings.
4. West River Water Development Board Meetings.
5. Articles in the local newspapers.
6. Individual contact residents in the watershed.

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

Implementation Plan

The South Dakota DENR will work with the Stanley County Conservation District and the West River Water Development District to initiate an implementation project in the future. It is expected that a local sponsor will request project assistance during a future EPA Section 319 funding round.

NOTICE OF
TOTAL MAXIMUM DAILY LOADS

The South Dakota Department of Environment and Natural Resources (DENR) announces the availability of the following Total Maximum Daily Loads (TMDLs) for review and comment.

Brakke Dam, Lyman County **Hayes Lake/Frozen Man Creek, Stanley County**

The TMDLs were developed in accordance with Section 303(d) of the federal Clean Water Act. These TMDLs were developed on a watershed basis that included public involvement.

TMDLs are an important tool for the management of water quality. The goal of a TMDL is to ensure that waters of the state attain water quality standards and provide designated beneficial uses. A TMDL is defined as "the sum of the individual waste load allocations for point sources and load allocations for both nonpoint source and natural background sources established at a level necessary to achieve compliance with applicable surface water quality standards." In other words, a TMDL identifies the total pollution load of any given water body can receive and still remain healthy. TMDLs are required on waters that do not attain water quality standards or assigned beneficial uses.

Any person interested in reviewing any TMDL document may request a copy by telephone or by mail. Also, each document has been uploaded to DENR's website under “NEW” at the Internet address

http://www.state.sd.us/denr/

Copies of the draft may also be obtained from Gene Stueven by writing to the address below, Gene Stueven at **denrinternet@state.sd.us** or by calling 1-800-438-3367.

Any person desiring to comment on the Brakke Dam or Hayes Lake TMDLs may submit comments to the address below. Persons are encouraged to comment electronically by sending the comments to Gene Stueven at the email address in the above paragraph. The department must receive the comments by August 16th[th] 2004.

Department of Environment and Natural Resources
Water Resources Assistance Program
523 East Capitol Avenue – Joe Foss Building
Pierre, South Dakota 57501-3181

Steven M. Pirner
Secretary
Department of Environment and Natural Resources

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 8
999 18TH STREET- SUITE 300
DENVER, CO 80202-2466
Phone 800-227-8917
http://www.epa.gov/region08

September 29, 2004

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
Brakke Dam
Fish Lake
Hayes Lake
Lake Herman

Dear Mr. Pirner:

We have completed our review, and have received Endangered Species Act Section 7 concurrence from the U.S. Fish and Wildlife Service, on the total maximum daily loads (TMDLs) as submitted by your office for the waterbodies listed in the enclosure to this letter. In accordance with the Clean Water Act (33 U.S.C. 1251 *et. seq.*), we approve all aspects of the TMDLs as developed for the water quality limited waterbodies as described in Section 303(d)(1).

Based on our review, we feel the separate TMDL elements listed in the enclosed review table adequately address the pollutants of concern, taking into consideration seasonal variation and a margin of safety. Please find enclosed a detailed review of these TMDLs.

For years, the State has sponsored an extensive clean lakes program. Through the lakes assessment and monitoring efforts associated with this program, priority waterbodies have been identified for cleanup. It is reasonable that these same priority waters have been a focus of the Section 319 nonpoint source projects as well as one of the priorities under the State's Section 303(d) TMDL efforts.

In the course of developing TMDLs for impaired waters, EPA has recognized that not all impairments are linked to water chemistry alone. Rather, EPA recognizes that *"Section 303(d) requires the States to identify all impaired waters regardless of whether the impairment is due to toxic pollutants, other chemical, heat, habitat, or other problems."* (see 57 Fed. Reg. 33040 for July 24, 1992). Further, EPA states that "*...in some situations water quality standards –*

particulary designated uses and biocriteria – can only be attained if nonchemical factors such as hydrology, channel morphology, and habitat are also addressed. EPA recognizes that it is appropriate to use the TMDL process to establish control measures for quantifiable non-chemical parameters that are preventing the attainment of water quality standards." (see Guidance for Water Quality-based Decisions: The TMDL Process; USEPA; EPA 440/4-91-001, April 1991; pg. 4). We feel the State has developed TMDLs that are consistent with this guidance, taking a comprehensive view of the sources and causes of water quality impairment within each of the watersheds. For example, in several of the TMDLs, the State considered nonchemical factors such as trophic state index (TSI) and its relationship to the impaired uses. Further, we feel it is reasonable to use factors such as TSI as surrogates to express the final endpoint of the TMDL.

Thank you for your submittal. If you have any questions concerning this approval, feel free to contact Vernon Berry of my staff at 303-312-6234.

Sincerely,

/s/ by Max H. Dodson

Max H. Dodson
Assistant Regional Administrator
Office of Ecosystems Protection and
Remediation

Enclosures

Enclosure 1

APPROVED TMDLS

Waterbody Name*	**TMDL Parameter/ Pollutant**	**Water Quality Goal/Endpoint**	**TMDL**	**Section 303(d)1 or 303(d)3 TMDL**	**Supporting Documentation** (not an exhaustive list of supporting documents)
Brakke Dam*	phosphorus	TSI mean < 64.51	501 kg/yr total phosphorous load to the lake (18.9% reduction in average annual total phosphorus load)	Section 303(d)(1)	# Phase I Watershed Assessment and TMDL Final Report, Brakke Dam, Lyman County, South Dakota (SD DENR, April 2004)
Fish Lake*	phosphorus	TSI mean ≤ 66.3	1,864 kg/yr total phosphorous load to the lake (25% reduction in average annual total phosphorus load)	Section 303(d)(1)	# Phase I Watershed Assessment Final Report and TMDL, Fish Lake, Deuel County, South Dakota (SD DENR, January 2004)
Hayes Lake*	phosphorus	TSI mean ≤ 64.8	25,264 kg/yr total phosphorous load to the lake (24% reduction of average annual watershed load, and 25% reduction of internal load)	Section 303(d)(1)	# Watershed Assessment and TMDL Final Report, Hayes Lake / Frozen Man Creek, Stanley County, South Dakota (SD DENR, March 2004)
Lake Herman*	phosphorus	TSI mean ≤ 73.93	3,417 kg/yr total phosphorous load to the lake (45% reduction in average annual total phosphorus load)	Section 303(d)(1)	# Total Maximum Daily Load for Total Phosphorous in Lake Herman, Lake County, South Dakota (SD DENR, September 2004)

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