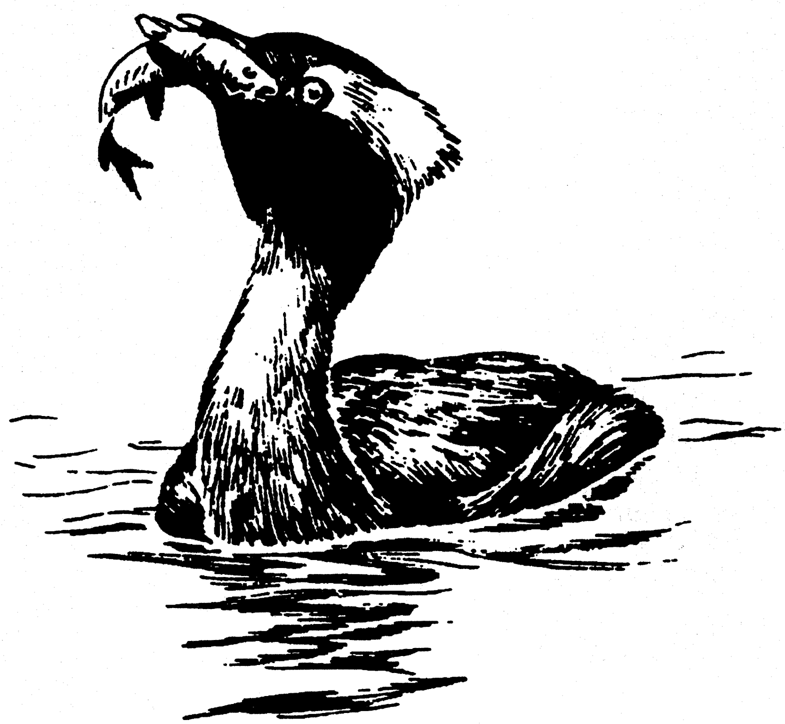
PHASE I
WATERSHED ASSESSMENT
FINAL REPORT

LAKE MADISON / BRANT LAKE
LAKE COUNTY SOUTH DAKOTA



South Dakota Watershed Protection Program
Division of Financial and Technical Assistance
South Dakota Department of Environment and Natural Resources
Nettie H. Myers, Secretary

October 1998

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Nettie H. Myers, Secretary

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State of South Dakota
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October 1998

Feedlots

EXECUTIVE SUMMARY

In 1994 a lake and watershed water quality assessment study was initiated for the watershed of Lake Madison and Brant Lake. Lake Madison and Brant Lake are located in eastern South Dakota in Lake County. The watershed size for both of these lakes totals 44,000 acres (17,806.8 ha). The watershed is defined by the drainage area from the headwaters of Memorial Creek (southeast of Ramona, S.D.) and the outlet of Lake Herman to the outlet of Brant Lake (see diagram on pg ii).

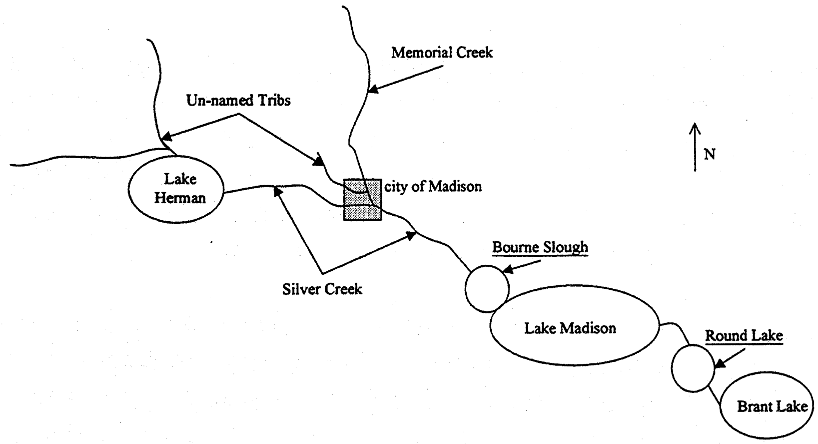
Main components of the assessment consisted of inlake water quality monitoring, algae sampling, tributary monitoring, storm sewer monitoring, groundwater monitoring, and landuse assessment. The assessment included 11 tributary monitoring sites, 6 inlake monitoring sites, and 3 storm sewer monitoring sites. In order to further evaluate the water quality of the Madison/Brant watershed, landuse and geo-technical information was compiled. This information was incorporated into the Agricultural Nonpoint Source computer model (AGNPS) to produce:

1. Nonpoint source yields from each subwatershed and the net loading at the outlet of Brant Lake;
2. Critical nonpoint source cells within each subwatershed (elevated sediment, nitrogen, phosphorus); and
3. A priority ranking of each animal feeding area and a quantification of nutrient loading.

Tributary water quality data collected during the project exhibited 9 exceedances of the pH standard and 3 exceedances of the tributary fecal coliform standard. In-lake samples collected from Lake Madison and Brant Lake exhibited a total of 19 unionized ammonia exceedances, 29 pH exceedances, and 19 observations were below the dissolved oxygen standard of 5.00 mg/L. The standard for fecal coliform was exceeded from one sample collected from Bourne Slough.

Silver Creek ran continuously during 1995 comprising over 75% of the hydrologic budget, 91% of the total sediment load, and 92% of the overall phosphorus budget for Lake Madison (see diagram). Groundwater constituted only 1.6% of hydrologic budget and 0.4% of the phosphorus budget. The two primary components of the hydrologic budget for Lake Madison were Silver Creek and precipitation (19.4%). The amount of phosphorus contributed by the city of Madison to Silver Creek constituted 13% of the total load delivered to Lake Madison in 1995.

The primary components of the hydrologic budget for Brant Lake were the discharge from Lake Madison (73%), groundwater (18.2%), and precipitation (5.9%). The discharge from Round Lake constituted 88% of the overall phosphorus load to Brant Lake. Round Lake actually discharged more phosphorus than it received from Lake Madison during 1995.



An estimate of the contribution of lawn fertilizers to Lake Madison and Brant indicated that this source contributed approximately 0.77% of the overall total phosphorus loadings to Lake Madison and 0.2% of the total phosphorus inputs to Brant Lake. Onsite wastewater disposal systems contributed anywhere from 1.5% to 4.5% of the total phosphorus load to Brant Lake. Lake Madison is serviced by a centralized sewer system which is why a similar onsite wastewater estimate was not calculated for this lake.

The AGNPS model indicated that sediment deliverability for 6 of the 23 identified subwatersheds exhibited excessive loadings to Lake Madison and Brant Lake. The suspected source of this sediment were relatively steep agricultural lands with slopes ranging from 7 – 18% that were being cropped or had poor vegetative cover. Six of the 19 subwatersheds analyzed appeared to have high nutrient deliverability rates. The high nutrient deliverability can be attributed to the high sediment yields from these subwatersheds as well.

Forty-one animal feeding areas were evaluated as part of the study. Of these, 24 were found to have an AGNPS rank of 30 or greater and 3 had an AGNPS rank of 50 or greater. Compared to other watersheds within eastern South Dakota, the density of potentially critical feeding areas found within the Madison/Brant watershed was high (24 with an AGNPS rank > 30).

Inlake monitoring of Lake Madison and Brant Lake indicated that these lakes were too shallow to undergo permanent stratification. The predominant algal species in both lakes was the blue green *Aphanizomenon flos-aquae* which favors high concentrations of phosphorus. Mean concentration of phosphorus in surface samples from Lake Madison and Brant Lake was 0.271 mg/L and 0.170 mg/L, respectively. This is considerably higher than the 0.02 mg/L requirement to initiate intense blue-green algal blooms.

The average total nitrogen to dissolved phosphorus ratios for both Lake Madison and Brant Lake indicated phosphorus limitation. The mean total phosphorus trophic status (TSI) was 84 for Lake Madison and 77 for Brant Lake, indicating that both lakes are hyper-eutrophic. The summer chlorophyll *a* concentrations for Lake Madison and Brant Lake also ranged well within the hypereutrophic range.

Reduction response models were developed for both lakes using the significant relationships between total phosphorus and chlorophyll *a*. A 50% reduction of tributary phosphorus loadings to Lake Madison and Brant Lake would result in a chlorophyll *a* concentration reduction of 88% and 90% for each lake, respectively. If the reduction could be reached, the TSI ranking for chlorophyll *a* would be reduced to a mesotrophic status for both lakes.

With BMP installation on areas with a rate of erosion greater than 7.0 tons per acre, and the containment of all nutrient sources from all of the livestock feeding areas, a 32.5% and 40% reduction in total phosphorus loadings to Lake Madison and Brant Lake can be expected, respectively. Another 10-13% reduction in phosphorus loadings can be realized if the storm sewers contributing nutrients to Silver Creek are reduced or eliminated. Additional reductions in phosphorus loadings can be obtained if phosphorus from lawn fertilization for both lakes, and failing onsite wastewater disposal systems for Brant Lake are reduced.

The contribution of internal phosphorus loading to the nutrient budget of Lake Madison and Brant Lake was not calculated. However, Bourne Slough continually receives phosphorus from Silver Creek. This phosphorus is then transported into the main basin of Lake Madison. The shallow nature of Bourne Slough has reduced its capacity to withhold phosphorus from the rest of Lake Madison. A small sediment removal project to increase the depth around the mouth of Bourne Slough may increase its ability to retain a greater amount of phosphorus. Round Lake is also releasing more sediment and phosphorus to Brant Lake than it received from Lake Madison. A sediment survey should also be completed on Round Lake to determine the volume and distribution of sediment for Round Lake.

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Ron Byrd
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TABLE OF CONTENTS

Executive Summary i

Acknowledgements iv

Table of Contents v

List of Equations ix

List of Tables ix

List of Figures x

Introduction 1

Historical Information 1

Lake Herman Executive Summary 4

Methods and Materials 6

Hydrological Data 6

Water Quality Sampling 6

Tributary Water Quality 10

South Dakota Water Quality Standards 10

Seasonal Water Quality 11

Concentrations 11

Loadings 11

Discussion of Water Quality by Tributary Site 12

Site LMT6 12

Site LMT5 15

Site LMT4 19

Site LMT3 20

Sites LMT1 and LMT2 22

Site-by-Site Comparisons (LMT1-LMT6) 25

Site LMT7 30

Site BLT8 and BLT9 32

Site BLT10 40

Site BLT11 42

Nutrient and Sediment Budget 45
Hydrologic Budget 45
Lake Madison 45
Round Lake 47
Brant Lake 48

Suspended Solids Budget 49
Lake Madison 49
Round Lake 50
Brant Lake 50

Nitrogen Budget 51
Lake Madison 51
Round Lake 52
Brant Lake 52

Phosphorus Budget 52
Lake Madison 52
Round Lake 53
Brant Lake 54

Urban Runoff 55
Stormwater Runoff Concentrations 57

Stormwater Runoff Loadings 60

Lake Madison Inlake Data
Methods and Materials 69

South Dakota Water Quality Standards 73

Lake Madison Inlake Water Quality 75

Water Temperature 75

Dissolved Oxygen 76

pH 78

Alkalinity 78

Solids 79

Ammonia 79

Nitrate-Nitrite 80

Total Kjeldahl Nitrogen 80

Total Nitrogen 80

Total Phosphorus 81

Total Dissolved Phosphorus 82

Limiting Nutrient – Lake Madison 82

Trophic State Index – Lake Madison 84

Long Term Trends 86

Chlorophyll *a* 86

Brant Lake Inlake Data

Brant Lake Inlake Water Quality 89

Water Temperature 89

Dissolved Oxygen 89

pH 89

Alkalinity 90

Fecal Coliform 90

Solids 92

Ammonia 92

Nitrate-Nitrite 92
Total Kjeldahl Nitrogen 93
Total Nitrogen 93
Total Phosphorus 93
Total Dissolved Phosphorus 94
Limiting Nutrient – Brant Lake 94
Trophic State Index – Brant Lake 95
Chlorophyll *a* 96
Reduction Response Model (Lake Madison).......................................100
Reduction Response Model (Brant Lake)..102
Lawn Fertilization and Shoreline Development 105
Onsite Wastewater Disposal Systems...107
Fisheries Data 110
Agricultural Nonpoint Source Model Conclusions....................................113
Conclusions 116
Restoration Alternatives..122
Recommended Targeted Reduction...123
Literature Cited 126
Appendix A. Agricultural Non-Point Source Model 130
Appendix B. 1996 Fisheries Annual Reports 159
Appendix C. Dissolved Oxygen Profiles 187
Appendix D. Inlake Water Quality and Algal Samples 196
Appendix E. Tributary Water Quality Samples.......................................211

Appendix F. QA/QC Water Quality Samples 216

Appendix G. Ground Water Quality Samples 218

Appendix H. Urban Water Quality Samples 220

Appendix I. Socioeconomic Information 223

LIST OF EQUATIONS

Equation 1. Equation for Urban Loading Calculations 63

Equation 2. Equation for the Urban Runoff Coefficient 64

Equation 3. Equation for the Phosphorus to Chlorophyll *a* Relationship, Madison ..88

Equation 4. Equation for the Phosphorus to Chlorophyll *a* Relationship, Brant........99

Equation 5. Equation for Vollenweider's Reduction Response Model 100

Equation 6. Equation for Calculating Residence Time of Phosphorus 100

LIST OF TABLES

Table 1. Silver Creek and Skunk Creek Beneficial Use Criteria 10

Table 2. 'Waters of the State' Beneficial Use Criteria 10

Table 3. Comparison of Seasonal Concentrations 12

Table 4. Loadings for Sites LMT2 – LMT5 16

Table 5. Loss of Water for Sites LMT2- LMT5, Spring 1995 18

Table 6. Total Loadings and Export Coefficients for Sites LMT1 – LMT6...............28

Table 7. Descriptive Statistics for All Parameters, Sites LMT1 – LMT6 29

Table 8. Total Loadings and Export Coefficients for Sites LMT7 – BLT11 35

Table 9. Descriptive Statistics for All Parameters, Sites LMT7 – BLT11 36

Table 10. Total Loadings and AGNPS Loadings for Site BLT10.............................41

Table 11. Total Loadings and AGNPS Loadings for Site BLT11.............................45

Table 12. Hydrologic Budget for Lake Madison 46

Table 13. Hydrologic Budget for Round Lake 48

Table 14. Hydrologic Budget for Brant Lake 48

Table 15. Descriptive Statistics for Stormwater Runoff Parameters from Madison .. 62

Table 16. Land use Categories for the city of Madison 63

Table 17. Land use Runoff Coefficient 64

Table 18. Estimated Annual Loads of Selected Constituents, 1995 66

Table 19. Estimated Annual Loads of Selected Constituents, 1997 67

Table 20. Total Loadings of Four Pollutants from the city of Madison 68

Table 21. Lake Madison/Brant Lake Beneficial Use Criteria 73

Table 22. Descriptive Statistics for Lake Madison Inlake Sampling 77

Table 23. Selected Parameter Concentrations from Winter Samples, Lake Madison 78

Table 24. Trophic State Index Levels 84

Table 25. Average Trophic State Index Levels for Lake Madison 84

Table 26. Lake Madison Chlorophyll *a* Concentrations 86

Table 27. Descriptive Statistics for 2 Brant Lake Monitoring Sites 91

Table 28. Average Trophic State Index Levels for Brant Lake 96

Table 29. Effects of Reducing Phosphorus to Lake Madison 101

Table 30. Effects of Reducing Phosphorus to Brant Lake 104

Table 31. Annual Loadings from Lawn Fertilization 106

Table 32. Copied from Table 2 (Rodiek 1978) 107

Table 33. AGNPS Reduction Response Results 123

LIST OF FIGURES

Figure 1. Location of the Lake Herman, Lake Madison, Brant Lake Watersheds 2

Figure 2. Location of the Lake Madison/Brant Lake Tributary Monitoring Sites........9

Figure 3. Location of Site LMT6 12

Figure 4. Seasonal Total Phosphorus Loadings for Site LMT6........14

Figure 5. Location of Site LMT5 15

Figure 6. Location of the North Skunk Creek Aquifer 17

Figure 7. North Skunk Creek Aquifer Recharge for the Spring of 1995........18

Figure 8. Location of Site LMT4 19

Figure 9. Seasonal Total Phosphorus Loadings for Site LMT4........20

Figure 10. Location of Site LMT3 20

Figure 11. Seasonal Hydrologic Loadings for Site LMT3 21

Figure 12. Location of Sites LMT1 and LMT2 22

Figure 13. Total Dissolved Phosphorus Concentrations for Sites LMT1 – LMT6 27

Figure 14. Total Phosphorus Concentrations for Sites LMT1 – LMT6 27

Figure 15. Location of Site LMT7 30

Figure 16. Location of Site BLT8........33

Figure 17. Seasonal Hydrologic Loadings for Site BLT8 37

Figure 18. Seasonal Total Phosphorus Loadings for Site BLT8 37

Figure 19. Location of Site BLT9........38

Figure 20. Seasonal Hydrologic Loadings for Site BLT9 39

Figure 21. Seasonal Total Phosphorus Loadings for Site BLT9 39

Figure 22. Location of Site BLT10........40

Figure 23. Seasonal Total Phosphorus Loadings for Site BLT10 42
Figure 24. Location of Site BLT11 43
Figure 25. Daily Discharge for Site BLT11 44
Figure 26. Total Suspended Solids Input, Lake Madison 49
Figure 27. Total Suspended Solids Input, Round Lake 49
Figure 28. Total Suspended Solids Input, Brant Lake 50
Figure 29. Total Nitrogen Inputs, Lake Madison 51
Figure 30. Total Nitrogen Inputs, Brant Lake 52
Figure 31. Total Phosphorus Inputs, Lake Madison 53
Figure 32. Total Phosphorus Inputs, Brant Lake 54
Figure 33. Locations of Urban Sampling Sites for the city of Madison 56
Figure 34. Locations of the Inlake Sampling Sites, Lake Madison/Brant Lake 72
Figure 35. pH Measurements for Lake Madison 78
Figure 36. Lake Madison Total Phosphorus Concentrations 81
Figure 37. Total Nitrogen to Total Phosphorus Ratio, Lake Madison 82
Figure 38. Inorganic Nitrogen to Dissolved Phosphorus Ratio, Lake Madison 83
Figure 39. Total Nitrogen to Dissolved Phosphorus Ratio, Lake Madison 83
Figure 40. Lake Madison Trophic State Index (TSI) 85
Figure 41. Long Term Trends for Lake Madison 85
Figure 42. Chlorophyll *a* concentrations for Lake Madison 86
Figure 43. Total Phosphorus to Chlorophyll *a* using all data, Lake Madison 87
Figure 44. Log of Total Phosphorus to Log of Chlorophyll *a* for Site LM2 88
Figure 45. Brant Lake Dissolved Oxygen 89

Figure 46. Brant Lake pH Measurements 90

Figure 47. Brant Lake Total Phosphorus Concentrations 93

Figure 48. Total Nitrogen to Total Phosphorus Ratio, Brant Lake 95

Figure 49. Inorganic Nitrogen to Dissolved Phosphorus Ratio, Brant Lake 95

Figure 50. Total Nitrogen to Dissolved Phosphorus Ratio, Brant Lake 95

Figure 51. Brant Lake Trophic Status Index 96

Figure 52. Brant Lake Summer Chlorophyll *a* Concentrations 97

Figure 53. Total Phosphorus to Chlorophyll *a* using All Data, Brant 97

Figure 54. Log of Total Phosphorus to Log of Chlorophyll *a* using All Data, Brant..98

Figure 55. Phosphorus to Chlorophyll Relationship using 1994-95 Data, Brant 98

Figure 56. Predicted Reduction of Chlorophyll *a* and Phosphorus for Lake Madison102

Figure 57. Predicted Reduction of Chlorophyll *a* and Phosphorus for Brant Lake...104

Figure 58. Lake Madison and Brant Lake Watersheds and the Locations of the Tributary Monitoring Sites 117

INTRODUCTION

Lake Madison and Brant Lake are located in Lake County, South Dakota. The purpose of this Phase I Diagnostic/Feasibility Study was to determine sources of impairments to these lakes and to examine the way the lakes function as hydrologic systems. Lake Madison, Brant Lake and Lake Herman form a chain of lakes connected by a single tributary. The tributary which joins the three lakes is Silver Creek (Figure 1).

This study was initiated in the fall of 1994, and proceeded until the fall of 1997 when the storm sewer water quality data had been collected. The main components of the assessment consisted of inlake water quality monitoring, algae sampling, tributary monitoring, storm sewer monitoring, groundwater monitoring, and land use assessment. In order to assess land use, the Agricultural Nonpoint Source (AGNPS) model was used. AGNPS is a comprehensive land use model which estimates soil loss and delivery and livestock impacts from the watershed. The model was used to identify critical areas of nonpoint source pollution and to predict the response of water quality following implementation of Best Management Practices (BMPs).

Lake Description (Lake Madison and Brant Lake)

Lake Madison is a hypereutrophic natural lake of glacial origin located approximately three miles southeast of the city of Madison, South Dakota. The lake has a surface area of 2,799 acres (1,132 ha) and mean depth of 9.7 ft. (3.0 m). The lake has a heavily developed shoreline with cabins and permanent homes. Public access to the lake is excellent and the lake has very high use. The population within a 65-mile radius is 270,159 according to 1990 census figures.

Lake Madison has been included in South Dakota Lake Water Quality Assessment (LWQA) sampling program since 1989. Mean Carlson trophic state index is 74.15 indicating hypereutrophy. There is an established sanitary district encompassing the entire shoreline. Sanitary treatment consists of a central collection facility and infiltration-percolation basins.

Brant lake is a 1,000 acre (405 ha) lake of glacial origin located 1.5 miles northwest of the town of Chester, South Dakota and 2 miles southeast of Lake Madison. Brant Lake has a highly developed shoreline with cabins and permanent homes. The mean depth of the lake is 11 ft. (3.4 m). Existing data from 1989 indicate that Brant Lake has a mean trophic state index of 70.73 which indicates hypereutrophy. Privately owned septic tanks and drain fields are the current sanitary treatment around the lakeshore.

Brant Lake and Lake Madison have experienced damage to shoreline and homes due to high water during the 1993 flood. Brant Lake had a catastrophic failure of a shoreline stabilization project due to high water and wind at that time.

Watershed Description (Lake Madison and Brant Lake)

The individual watersheds of Lake Madison and Brant Lake encompass 29,191 acres (11,813 ha) and 7,658 acres (3,099 ha), respectively. The size of the combined watershed is 36,849 acres

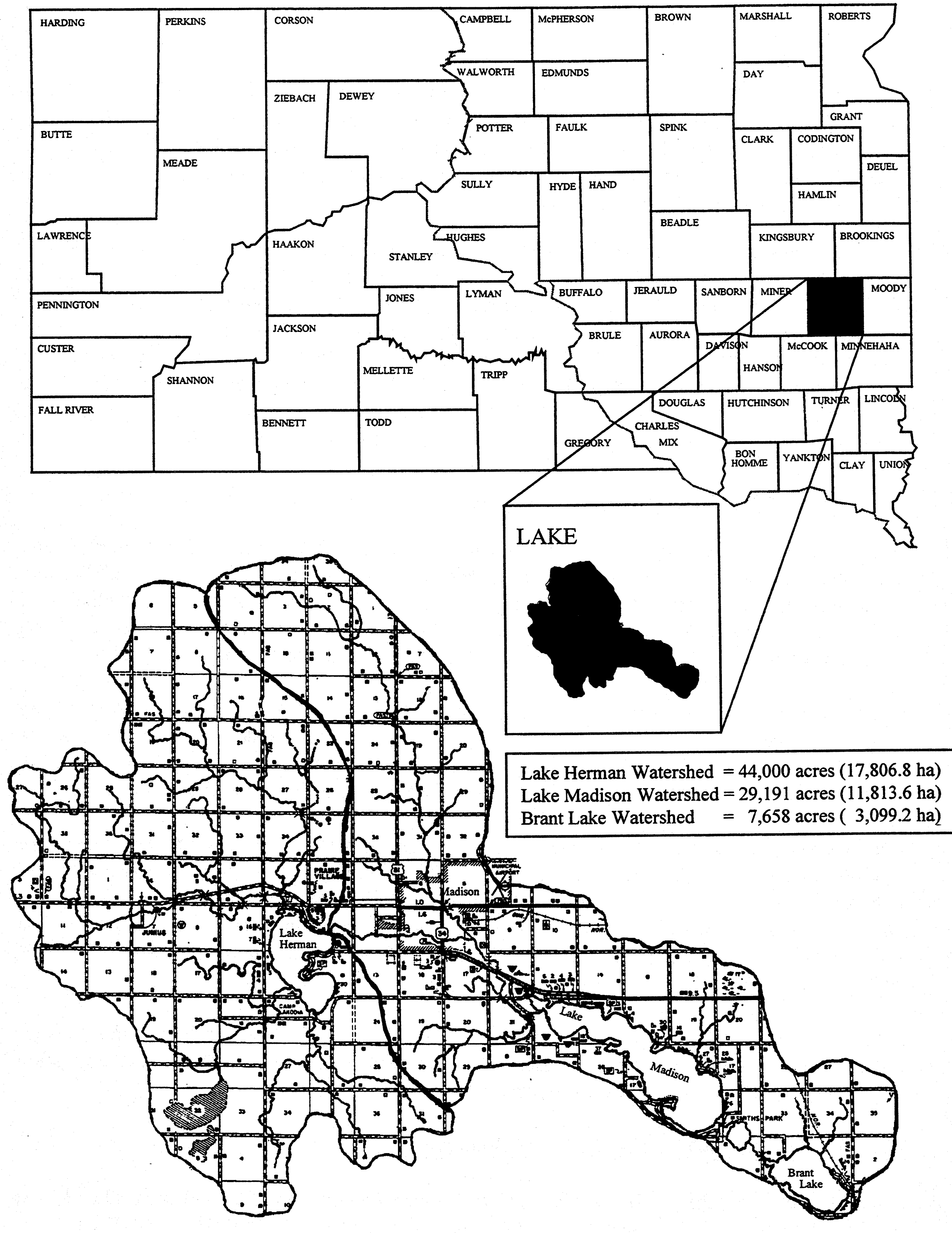


Figure 1. Lake Herman, Lake Madison, and Brant Lake Watershed in Lake County, South Dakota.

14,912 ha) and for the purposes of this study the two-lake drainage will be treated as a single system. The watershed of Lake Herman is not included in the study. The watershed area under investigation will be the area from the outlet of Lake Herman to the Skunk Creek outlet from Brant Lake (Figure 2).

Land use is primarily agricultural with a community of 6,257 people (Madison, SD) located in the watershed. Agricultural land use in the watershed is approximately 84% cropland and 15% grass or pasture. Animal feeding operations for beef, swine and poultry are scattered throughout the watershed. Major soil associations found in the watershed include Egan-Viborg, Egan-Wentworth, and Dempster.

The city of Madison has some light industry and storm sewers which drain directly to Silver Creek above Lake Madison. Agbusinesses concerned with sales and storage of fertilizers and pesticides are located in the city. Further socioeconomic information is located in Appendix G.

Public Access (Lake Madison and Brant Lake)

Brant Lake has three public access areas around the lake that offer boat ramps, shore fishing, and toilet facilities. Lake Madison has four state-owned public access areas offering camping, picnic areas, shore fishing, boat ramps, swimming areas and toilet facilities. Both lakes are located within convenient driving distance of the city of Sioux Falls, SD (population +100,000). As a result these lakes experience heavy recreational use during the spring, summer and fall months.

Lake Herman

Lake Herman has been the subject of intensive study and restoration efforts since the early 1970's. Lake Herman was not considered in this study project due to the abundance of recent information already available. However, the existing data on Lake Herman is used in this report on the three-lake chain.

Lake Herman is a 1,350 acre (546.3 ha) glacial lake located in Lake County, South Dakota. The lake is the first lake in the Lake Madison/Brant Lake Watershed. It is drained by Silver Creek which flows through the city of Madison before entering Lake Madison, Round Lake and, finally Brant Lake. Lake Herman and its 44,000 acre watershed are located in the Central Lowlands Province of the western section of the Prairie Coteau. A Phase III Post-Implementation investigation was completed for Lake Herman in 1993. The Executive Summary is included here for a summary of the water quality problems identified in the Lake Herman Watershed. These identified problems are causing degradation of the water quality of Lake Herman and other water bodies located downstream such as Silver Creek and Lake Madison. To review the conclusions of this report or obtain a copy please contact the South Dakota Department of Environment and Natural Resources in Pierre, SD (SDDENR, 1994).

EXECUTIVE SUMMARY

In September 1977 the U.S. Department of Agriculture (USDA) and the U.S. Environmental Protection Agency (EPA) initiated a joint water quality/land management effort, the Model Implementation Program. This program was devised in order to demonstrate the effectiveness of concentrating and coordinating the various soil conservation programs and water quality management programs of the USDA and the EPA.

After intensive analysis of historical and present data was completed it was determined that twelve Best Management Practices (BMPs) would have the greatest benefit on the water quality and overall health of the lake.

A monitoring program was put in place during the Model Implementation Program (MIP) to assess the progress these land treatment efforts would have made on the water quality, including the three sediment control structures. This monitoring program did not, however, determine the long-term effect that the BMPs and the sediment control structures would have on the water quality of the Lake Herman watershed.

In March 1992, the Lake Herman Phase III Post-Implementation study was initiated to determine the long-term effects of the MIP and reassess the three sediment control structures. Monitoring was conducted on 11 sites within the watershed and three in-lake sites. Water samples, stage and current velocity monitoring, and Agricultural Nonpoint Source data was collected by employees of the then Soil Conservation Service (SCS) located in the Lake County field office. Sampling was conducted March through October of 1992 and March through August of 1993 when equipment was finally removed. The South Dakota State Health Lab located in Pierre, SD analyzed water samples.

The Agricultural Nonpoint Source (AGNPS) computer model was also used to:

1. Evaluate and quantify the loadings from the four main tributaries.
2. Define critical cells within each subwatershed.
3. Quantify the nutrient loadings from each feedlot and priority rank each feedlot.
4. Estimate the effect of the sediment control structures on reducing sediment loadings to Lake Herman.

Problems identified from previous investigations have included periodic fish kills, heavy blue-green algae blooms, and high siltation problems. Most of the problems associated with Lake Herman are derived from excessive nutrient loadings and siltation due to nonpoint pollution sources and possibly untreated feedlots.

The sediment control structures, which are drawdown type dry structures, were monitored during a 72-hour operating procedure in 1992 and a 24-hour operating procedure in 1993. Results indicated that the 72-hour operating procedure on dam #1 was more effective than the 24-hour procedure in reducing suspended solid concentrations. Dam #2 and #3 did not have any consistent trends in defining any differences between the two operating procedures. The excessive amount of water during 1993 may have caused data to become slightly skewed due to the fact that all three dams became less efficient as the storm intensity increased (see AGNPS analysis of the Lake Herman watershed). AGNPS also revealed that the subwatershed of site 1 and 2 contained a higher percentage of clays than the other two subwatersheds (3A and 3B). It may require a longer retention time to increase the overall efficiency of the sediment control structures due to the nature of the soils. A sediment survey completed on dam #1 indicated that an average of 217 tons of material per year was retained. Due to weather a similar survey could not be completed on dam #2 and #3. Annual means for all parameters indicated that there has been an overall decrease in concentrations of suspended solids since the inception of the MIP. However, with flooding occurring in 1993, concentrations slightly increased.

Monitoring from all tributaries indicated that water quality in subwatersheds 3A and 3B declined primarily due to feedlots located in the northern part of the watershed. High fecal coliform counts accompanied high nitrates+nitrites and low dissolved oxygen concentrations. Thirteen feedlots were identified in the watershed of which 12 were located in the subwatershed of site 3B. AGNPS also ranked two feedlots much higher than the other eleven. It was also revealed that the erosion rate (tons/acre) for sediment, phosphorus and nitrogen was highest in the subwatershed of site 1 and 3B although site 3A and 3B delivered larger loads (tons/drainage area) to the lake. This correlates with the water quality field data. The higher erosion rate and the high percentage of clays in the subwatershed of site 1 have caused the lower efficiency of dam #3.

Inlake water sampling results indicated that Lake Herman remains a hypereutrophic lake. The phosphorus concentrations were slightly higher in 1993 whereas the suspended solids and chlorophyll *a* concentrations were slightly reduced in 1993. This phenomenon can be attributed to the flood that delivered over 52,000 acre-feet more water in 1993 than in 1992. The lake has been documented previously as being nitrogen limited and continued to exhibit this phenomenon during the Phase III study. An aquatic plant survey did not find any submerged aquatic weed beds within the lake proper although there were several large areas (100 meters X 50 meters) of emergent weed beds containing cattails and giant reed grass.

Based on the results given in the following report the recommendations listed below should be implemented to upgrade MIP treatment measures or improve existing conditions within the Lake Herman watershed.

1) Establish animal waste management systems for two feedlots
2) Continue to promote, reevaluate and/or increase the number and area of BMPs within the watershed.
3) Streambank stabilization and riparian vegetation management of areas along tributaries damaged by the flood.
4) Increase retention time of sediment control structures.
5) Continue to monitor and maintain riprapping installed during MIP for Lake Herman shoreline stabilization.

METHODS AND MATERIALS

Hydrologic Data

Eleven tributary locations were chosen for collecting hydrologic and nutrient information from the combined Lake Madison and Brant Lake Watersheds (Figure 2). These monitoring locations were placed at specific areas within the watershed that would best show DENR which sub-watersheds were contributing the largest nutrient and sediment loads. Gaging stations were installed where water quality samples were collected to record the daily stage of the tributary. The recorders were checked weekly and data was downloaded monthly. A Marsh-McBirney flow meter was used to take periodic flow measurements at different stage heights. The stage and flow measurements were used to develop a stage/discharge table that was used to calculate an average daily loading for each site. The loadings for each day were totaled to determine the annual loading rate.

In addition to the measurements above, Silver Creek water quality and quantity was monitored above and below the city of Madison. Sampling sites LMT1 through LMT4 were placed at certain locations above Madison to determine the water quality and quantity upstream of Madison's storm sewer network. Each one of these sites was monitored throughout 1995 and partly in 1996. A full year of data including loadings, water quality parameters in mg/L, and export coefficients (kg/year) were calculated.

Monitoring was conducted from March through November of 1995. Monitoring took place primarily during 1995 although one sample per tributary site was collected in March of 1996. At that time it was decided to continue to monitor the hydrologic loadings until August of 1996 when all the monitoring and gauging equipment was finally removed. Continuous base flow data was collected from each tributary monitoring site. Data that was collected included average daily stage, instantaneous discharge, and water quality samples. When possible, peak flow event data was also collected in order to determine the loadings delivered during these events. All tributary water quality samples collected during the project were collected with a model DH-47 suspended sediment sampler. When using the DH-47, a similar length of time is used to travel from the surface of the stream to the bottom of the stream and back to the surface (called a vertical). A series of verticals is spaced evenly across the stream. The sampler is designed in such a way as to collect water based on the discharge at each specific vertical, i.e. the faster the flow the more water will be collected at that vertical during the same time interval. This allows for a more representative sample to be collected at a specific cross-section of stream. See the South Dakota Dept. of Environment and Natural Resources *Watershed Protection Standard Operating Procedures* manual for further details.

Water Quality

All sites, (tributary and outlet) were sampled twice weekly during the first week of snowmelt runoff and once a week thereafter until the runoff stopped in April. Base flow monitoring also took place after the snowmelt runoff ceased. All nutrient and solids parameters were sampled using approved methods documented in South Dakota's EPA-approved *Standard Operating*

Procedures for Field Samplers. The South Dakota State Health Laboratory in Pierre, SD, analyzed all samples. The purpose of these samples was to develop nutrient and sediment loadings to determine critical areas in the watershed.

A standard water quality sample set analyzed by the State Health Laboratory consisted of the following parameters:

Total Alkalinity	Total Solids	Total Suspended Solids
Ammonia	Nitrate-Nitrite	Total Kjeldahl Nitrogen
Fecal Coliform	Total Phosphorus	Total Dissolved Phosphorus

Water quality parameters which were calculated from the measured parameters analyzed above were:

Unionized Ammonia	Organic Nitrogen
Total Dissolved Solids	Total Nitrogen

In addition to the chemical water quality data above, physical parameters and biological data were also collected. The following is a list of field parameters collected:

Water Temperature	Air Temperature	Dissolved Oxygen
Field pH		

Water Quality Parameters Defined:

A total phosphorus sample consists of two general forms of phosphorus. The first is dissolved phosphorus, which is a measure of the phosphorus dissolved in 1 liter of water, not bound to any particle and available for immediate uptake by plants. The second form of phosphorus is the particulate phosphorus which is attached to a sediment particle. The particulate form is calculated by subtracting the dissolved phosphorus from the total phosphorus.

Dissolved phosphorus is not attached to sediment particles and is the form of phosphorus most available for uptake by plants and algae. Sources can be fertilizer, animal waste runoff, and phosphorus detergents. The quantities of phosphorus entering streams through land runoff vary greatly and are dependent upon soils, vegetation, quantity of runoff and pollution (Wetzel, 1983).

Suspended solids are those solids transported in the water column to the downstream area of the receiving body of water. Suspended solids concentrations are an estimate of the sediment transported in the stream.

Fecal coliform is a bacteria that is an indicator of waste material from warm-blooded animals and usually indicates presence of livestock wastes.

Nitrogen is found in many forms in the environment, both inorganic and organic. Nitrates + nitrites (NO_{3+2}) and ammonia (NH_4^+) can be indicators of excessive inputs associated with fertilizer and animal wastes as well as the natural breakdown of vegetation. Ammonia is a breakdown product of the biodegradation of vegetation and other organic matter, such as animal wastes. Unionized ammonia is highly toxic to many organisms and is subject to South Dakota water quality standards. The concentration of unionized ammonia is dependent upon the temperature and pH of the water.

Total Nitrogen is calculated by summing total kjeldahl nitrogen and the nitrate+nitrite nitrogen.

Organic nitrogen is an estimate of the amount of nitrogen tied up in vegetation or animal biomass. To estimate organic nitrogen, ammonia is subtracted from total kjeldahl concentrations.

The buffering capacity of water is estimated by measuring the concentration of total alkalinity.

Quality Assurance/Quality Control samples were collected according to South Dakota's EPA approved *Clean Lakes Quality Assurance/Quality Control Plan.* This document can be obtained by contacting the South Dakota Department of Environment and Natural Resources at (605) 773-4254.

The subsequent discussion reviews the water quality and flow data from each site within the Silver Creek drainage upstream of Lake Madison (Sites LMT1 through LMT6). The discussion begins with Site LMT6, the site located closest to Lake Madison on Silver Creek, and moves progressively upstream discussing how each upstream monitoring site effects the downstream sites and Lake Madison.

The next discussion will compare Site LMT7, located on a small tributary from the northeast draining through Wentworth Park, and BLT8 which is the outlet of Lake Madison. The final discussion will include the water quality trends and loadings associated with Sites BLT9, BLT10, Brant Lake, and BLT11 (outlet of Brant Lake).

Sites on Silver Creek were numbered in consecutive order progressing downstream from the outlet of Lake Herman (Site LMT1) to the outlet of Brant Lake (Site LMT11). Sites LMT3, 4, 7, and 10 were installed to monitor various smaller tributaries contributing to Silver Creek, Lake Madison, and Brant Lake (Figure 2).

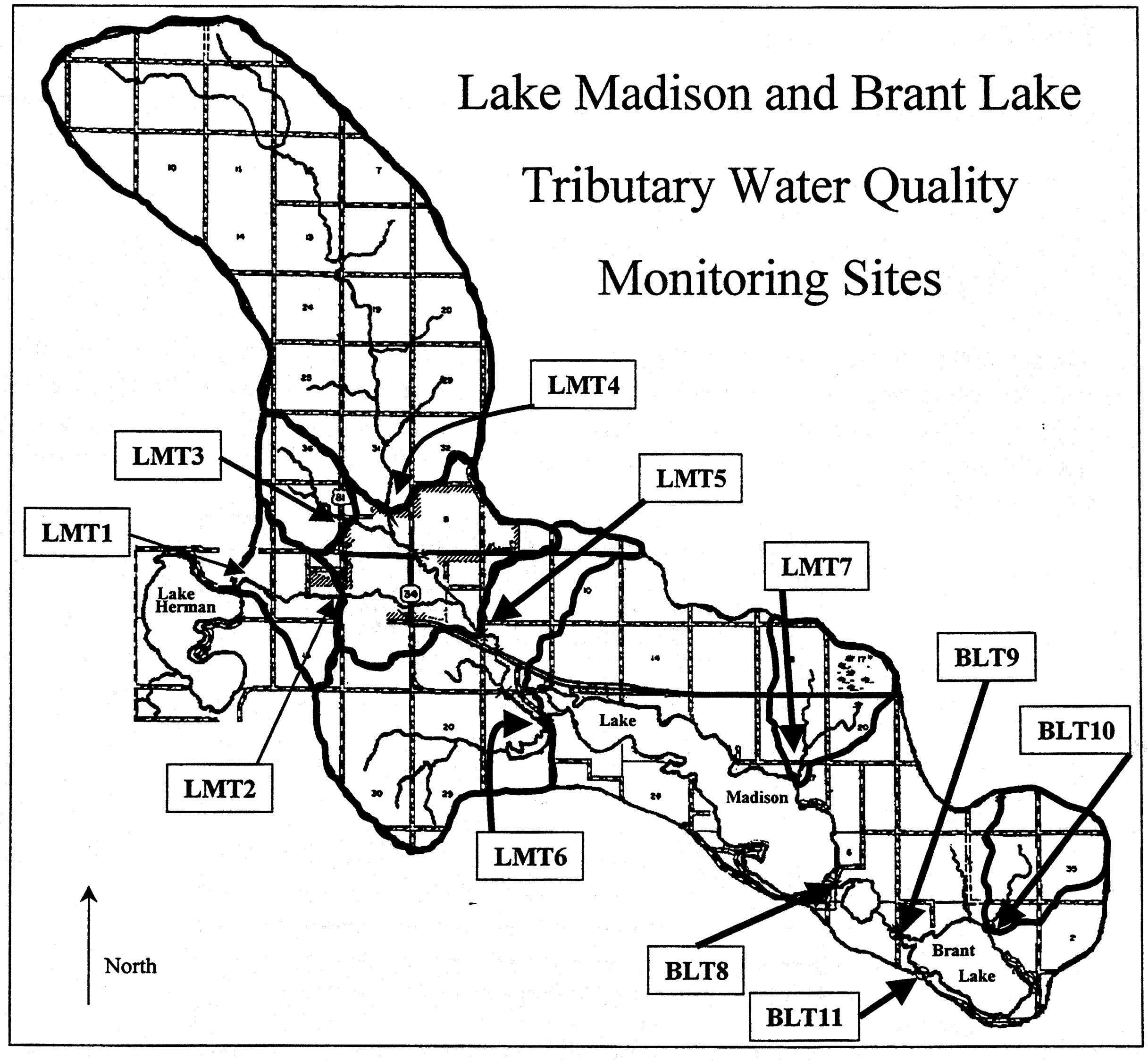

Lake Madison and Brant Lake
Tributary Water Quality
Monitoring Sites
LMT1
LMT2
LMT3
LMT4
LMT5
LMT6
LMT7
BLT8
BLT9
BLT10
BLT11
Lake Herman
Lake
Madison
Brant Lake
North

Figure 2.

WATER QUALITY DISCUSSION

South Dakota Water Quality Standards

Silver Creek and Skunk Creek have been assigned the following water quality beneficial uses:

- (6) Warmwater Marginal Fish Life Propagation
- (8) Limited Contact Recreation
- (9) Wildlife Propagation and Stock Watering
- (10) Irrigation Waters

The remaining streams have been assigned beneficial uses 9 and 10. In the case where the above uses have two or more standard limits for the same parameter, the most stringent standard is applied. Table 1 indicates the most stringent standard limits for Silver Creek to Bourne Slough and Skunk Creek to the Big Sioux River (Outlet of Brant Lake) for the parameters analyzed in this study (Figure 2).

Table 1. Silver Creek and Skunk Creek Beneficial Use Criteria

Parameter	Limits
Un-ionized Ammonia**	< 0.05 mg/L
Dissolved Oxygen*	> 5.0 mg/L
PH*	> 6.0 and < 9.0 su
Suspended Solids**	< 150 mg/L
Total Dissolved Solids**	< 2500 mg/L
Temperature*	< 32.22°C
Fecal Coliform***	< 2,000/100 ml (grab sample)
Alkalinity**	< 750 mg/L
Nitrates	< 50 mg/L

Table 2. Waters of the State Beneficial Use Criteria

Parameter	Limits
PH*	> 6.0 and < 9.5 su
Total Dissolved Solids**	< 2500 mg/L
Alkalinity**	< 750 mg/L
Nitrates	< 50 mg/L

* A variation allowed under subdivision 74:03:02:32(1) – The applicable criterion is to be maintained at all times.

** A variation allowed under subdivision 74:03:02:32(2) – The applicable criterion is to be maintained at all times based on the results of a 24-hour representative composite sample. The numerical value of a parameter found in any one grab sample collected during any 24-hr period may not exceed 1.75 times the applicable criterion.

*** Fecal Coliforms from May 1 to September 30 may not exceed a concentration of 1,000 per 100 ml as a geometric mean based on a minimum of 5 samples obtained during separate 24-hr periods for any 30-day period, and they may not exceed this value in more than 20 percent of the samples examined in the 30-day period. They may not exceed 2,000 per 100 ml in any one sample from May1 to September 30.

According to the water quality data collected during the 1994-96 sampling seasons there were only 14 exceedances of the standards located in Table 1. These standards are applicable to the stream monitoring sites located on Silver Creek (LMT1, LMT2, LMT5, and LMT6) and Skunk Creek which is the outlet of Brant Lake (BLT11). Of the 14 exceedances, 9 were associated with pH. The maximum exceedance of the pH standard >6.0 < 9.0 su was 9.39 su. This sample was observed on March 12, 1996 and also resulted in the only exceedance of the unionized ammonia standard of >0.05 mg/L. For this observation the pH and ammonia concentrations were relatively high resulting the unionized ammonia exceedance.

The remaining eight pH exceedances were slightly greater than the 9.0 su standard and may have been due to meter drift. However, these observations were consistently higher during the spring samples and occurred at Site LMT1 and BLT11 only, which are the outlets of Lake Herman and Brant Lake, respectively (Figure 2).

The other exceedances were associated with dissolved oxygen and fecal coliforms. On June 28, 1995, 3 sites exceeded the standard of 2,000 fecal coliforms per 100 ml. Site LMT2, LMT5, and LMT6 counts were significantly greater than the 2,000 fecal colonies per 100 ml standard, ranging from 2600 to 4200 per 100 ml. For Site LMT2 there was also an exceedance of the dissolved oxygen standard of 4.0 mg/L on June 28 in which the dissolved oxygen concentration dropped to 3.9 mg/L. The higher nitrates and suspended solids concentrations, although the standards for these parameters were not exceeded, contributed to the decrease in oxygen concentrations and increase in fecal coliforms.

For the remaining sites, which fall under the Wildlife Propagation and Stock Watering Irrigation Waters standards (Table 2), there were no observed exceedances.

TRIBUTARY WATER QUALITY AND LOADINGS

Seasonal Water Quality

Different seasons of the year can yield different water quality in a tributary due to the changes in precipitation and agricultural practices. Tributary samples were separated into spring (March 15 to May 31, 1995), summer (June 1 to August 31, 1995), and fall (September 1, to October 30, 1995). According to the water quality samples collected in 1995, the largest nutrient and sediment concentrations and loadings typically occurred during the spring (Table 3).

The smaller tributaries discharged most of their nutrient and sediment loadings during the spring. The majority of sediment and nutrient loading occurred during the spring runoff period. However, the outlet of Lake Madison and Brant Lake discharged a majority of nutrient loads (phosphorus) during the summer. The most likely causes for this are: as the loadings from tributaries enter the lake, a lag period (retention time) will take place until the nutrients that do not settle to the bottom are discharged from the lake. For Lake Madison and Brant Lake the phosphorus discharged during the summer was the majority but was still 50% or less of the total loadings.

Table 3. Average Chemical Concentrations for All Tributary Sites by Season*

Parameter	Spring		Summer		Fall	
	Count	Average	Count	Average	Count	Average
Flow	68	44.70	28	64.90	11	63.11
Dissolved Oxygen	88	11.35	28	6.71	11	9.25
Field pH	88	8.36	28	8.31	11	8.57
Fecal Coliform	80	52	28	796	11	152
Alkalinity	88	172	28	185	11	198
Total Solids	88	1,127	28	1,328	11	1,390
Suspended Solids	88	41	28	33	11	20
Ammonia-N	88	0.144	28	0.101	11	0.039
Nitrate-Nitrite - N	88	0.791	28	0.629	11	0.518
Total Kjeldahl - N	88	1.54	28	1.374	11	1.40
Total Phosphorus	88	0.293	28	0.258	11	0.282
Dissolved Phosphorus	88	0.151	28	0.154	11	0.198

* The shaded area is the highest seasonal concentration for that parameter.

The concentrations of phosphorus, nitrogen, and suspended solids are higher in the spring than at any other time of year. Applied fertilizer, decaying organic matter and accumulated animal waste that are carried by spring runoff and rain events are the most likely cause of these elevated concentrations. Nitrates are water soluble; meaning they can easily dissolve in water. In the spring the soil may be either frozen or saturated and most of the flow occurs overland into lakes and streams.

Site LMT6 Water Quality

Site LMT6 is the final monitoring site on Silver Creek as it passes underneath State Highway 19 just before the creek enters Bourne Slough (Figure 3). This site was monitored to determine how much difference there may be between Site LMT5, which was near the Madison's Wastewater Treatment Facility, and Bourne Slough. In addition, it was used to determine the magnitude of nutrient and sediment loadings entering Lake Madison from this major subwatershed. AGNPS indicated that the total surface area draining to this point (Site LMT6) is approximately 25,480 acres. Site LMT6 is influenced by all upstream sites (LMT1-LMT5)

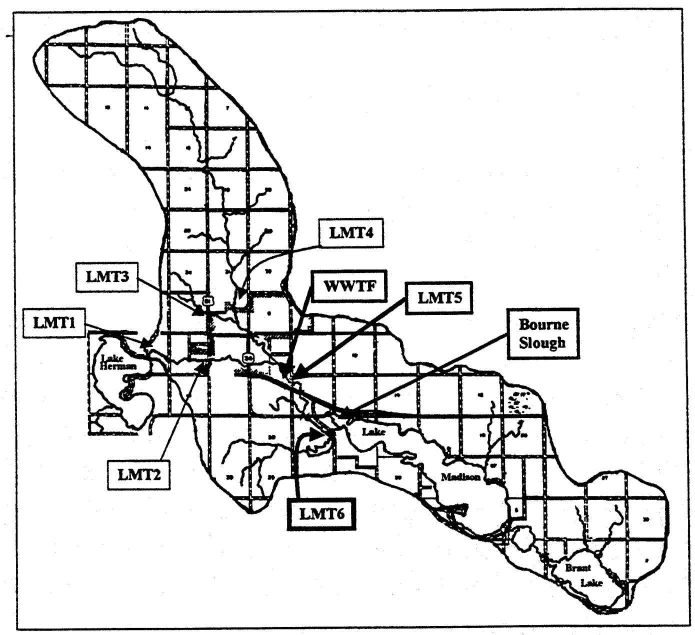


Figure 3. Location of Site LMT6.

(Figure 3).

The water quality at Site LMT6 is influenced by two different areas in the 25,480-acre drainage to this point. The first area is the subwatershed draining the 20,480 acres above Site LMT5 located near the Madison Wastewater Treatment Facility (WWTF). The second area is the acreage draining into Silver Creek between LMT5 and LMT6, which is approximately 5000 acres (Figure 3).

Although Site LMT6 did not have the highest median concentration of fecal coliform, which was exhibited by Site LMT4 (Memorial Creek), it did have the largest mean concentration (663 colonies/100ml). It also exhibited the largest maximum concentration of fecal coliform colonies (4200 colonies/100 ml) which occurred on June 28, 1995. The maximum concentrations for all Sites LMT1 through LMT6 occurred on this date.

Nutrient concentrations for this site were not significantly different from those collected at Site LMT5. Phosphorus concentrations ranged from 0.171 mg/L to 0.397 mg/L for Site LMT6 (mean = 0.309 mg/L) and the range for Site LMT5 phosphorus concentrations was 0.167 to 0.402 mg/L (mean = 0.310 mg/L). The maximum concentration at Site LMT6 of 0.397 mg/L occurred on April 17 whereas the maximum concentration at Site LMT5 of 0.402 mg/L occurred on August 7. As can be seen on Figure 14, total phosphorus at Site LMT6 was slightly lower than Site LMT5. The dissolved phosphorus concentrations were only slightly different between the two sites as well. In fact, the mean concentration at Site LMT6 was only slightly less than at Site LMT5, 0.134 mg/L vs. 0.150 mg/L. Site LMT6 dissolved phosphorus concentrations were not significantly different from any of the other sites previously discussed.

Total dissolved phosphorus was found to have only a slight relationship with total phosphorus (R^2 = 0.65) indicating that particulate phosphorus is more significant at this monitoring site. Total dissolved phosphorus constituted less than 50% of the total phosphorus (mean = 43%).

The mean suspended solids concentration for Site LMT6 was significantly higher than Site LMT5, 64 mg/L vs. 39 mg/L, respectively. This was in contrast to the phosphorus concentrations discussed above. The Site LMT6 suspended solids maximum of 106 mg/L occurred on April 3, 1995. Suspended solids were consistently higher in early spring samples compared to late spring and summer. Higher flows occurred during this time from spring rains and snowmelt runoff. However, statistically significant relationships were not exhibited between instantaneous discharge in cubic feet per second and total suspended solids concentrations (R^2 = 0.01). The correlation between discharge and total suspended solids may have been greater if more samples had been collected (n = 12). There was also no relationship indicated through regression analysis between total suspended solids and total phosphorus (R^2 = 0.14). This was found to be the case with all six sites, i.e. no relationship between total suspended solids and total phosphorus. Site LMT6 was receiving the majority of its phosphorus from other sources than suspended solids.

Nitrates ranged from 0.2 mg/L to 2.8 mg/L with low variability. Site LMT6 concentrations were not significantly different from those at Site LMT5 upstream. Nitrates, which can be an indicator of animal wastes as well as fertilizer runoff, were variable and did not exhibit any trends throughout 1995. However, the 2.8 mg/L maximum concentration occurred during snowmelt runoff with relatively high concentrations of total suspended solids, total phosphorus, and dissolved phosphorus. There were also observations of relatively high nitrate levels during the summer months. These observations (1.5 mg/L and 0.5 mg/L) were accompanied by high fecal coliform, suspended solids, and phosphorus concentrations. When high dissolved phosphorus and fecal coliform are present together, it this is usually an indication of animal waste material.

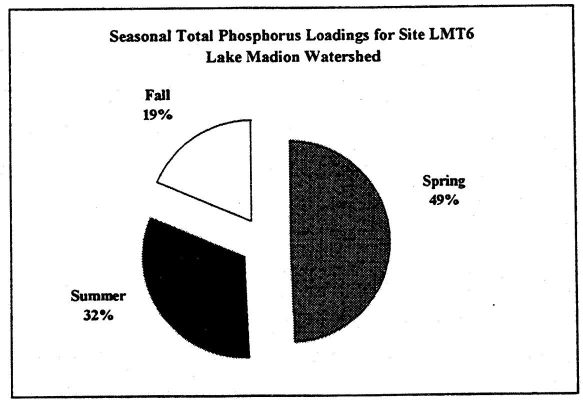


Figure 4.

Other concentrations of nitrogen species present in the water such as ammonia and un-ionized ammonia did not indicate any water quality problems (Table 7). Un-ionized ammonia, which is calculated through the use of water temperature, ammonia concentrations, and pH, did not attain any large concentrations during the 1995 sampling year.

Most of the nutrient and sediment loadings occurred during the spring months when snowmelt runoff and rainfall principally occurred (Figure 4). Subwatershed size at Site LMT6 was approximated by AGNPS at 25,480 acres. This excludes the Lake Herman subwatershed. In order to compare export coefficients to the other subwatersheds, Site LMT5 total loadings were subtracted from Site LMT6 total loadings. This difference in loadings was then divided by the 5,000 acres (25,480 – 20,480 acres) located between Site LMT5 and Site LMT6 for the individual export coefficient (Table 6).

A total of 23,351 lbs of phosphorus was transported to Lake Madison from the Silver and Memorial Creek subwatersheds. Dissolved phosphorus constituted 9,670.5 lbs of the total phosphorus load (41%) (Table 6). The total phosphorus load decreased by 603 lbs and the dissolved phosphorus load decreased by 1,665 lbs between Site LMT5 and LMT6. This loss of phosphorus resulted in negative export coefficients for both dissolved and total phosphorus (TP = -0.12, TDP = -0.33 lbs/acre). The reduction in phosphorus loadings was due to the slightly lower concentrations of dissolved and total phosphorus at Site LMT6 compared to Site LMT5.

A total of 2,518.8 tons of suspended solids was discharged into Lake Madison through Site LMT6 (Table 6). Although some of suspended solids were filtered out at Bourne Slough before the solids entered the main lake, the suspended solids value is still underestimating the extent of the bedload transported on the bottom of the stream. The suspended solids export coefficient for Site LMT6 was 275.9 lbs/acre-yr (Table 6). The export coefficient for the 5,000 acres between Site LMT5 and LMT6 was the highest suspended solids coefficient for Sites LMT1-LMT6 (Table 6). This is primarily due to the increase in suspended solids concentrations in the Silver

Creek Area south of the wastewater treatment facility. That area has stretches of cutbanks, erosion of which during high flows may have resulted in the higher suspended solids concentrations. The concentrations transported through Site LMT5 from the city storm sewers would be increased due to streambank erosion.

Site LMT5 Water Quality

Site LMT5 is located approximately 1.5 miles southeast of the city of Madison on Silver Creek. This monitoring site was placed downstream of the confluence of Silver Creek and Memorial Creek (Figure 5). It is also located approximately 2 miles upstream from Site LMT6. Near this monitoring station is the city of Madison's Wastewater Treatment Facility. The storm sewers from the city of Madison also discharge into the Silver and Memorial Creek at various points within the city limits. Between the confluence of Silver and Memorial Creek and Site LMT5 (Figure 5) there is a small area in which some agriculture production takes place and it is necessary to try and distinguish between these two influences on the water quality of Silver Creek. The urban contribution of phosphorus, sediment and nitrogen to Silver Creek and Lake Madison will be discussed in a separate section.

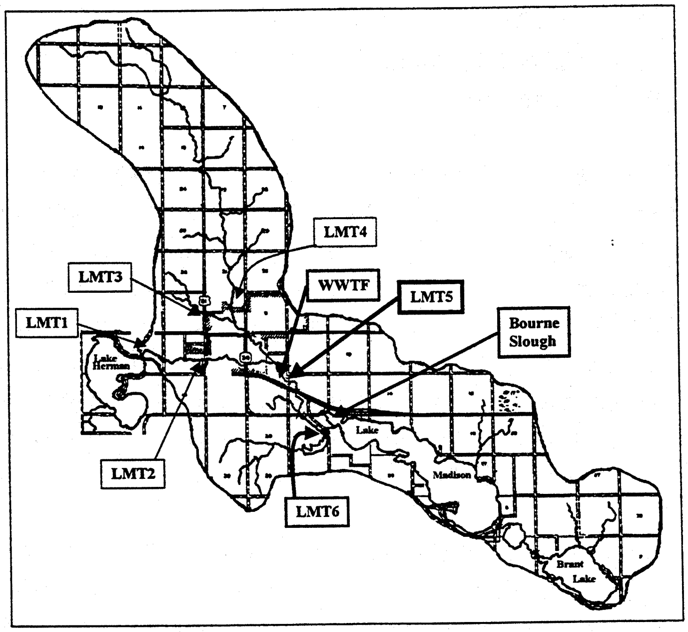


Figure 5. Location of Site LMT5.

The Site LMT5 (Silver Creek) subwatershed includes the monitoring sites LMT1-LMT4 (Figure 5). According to the data collected for the Agricultural Nonpoint Source computer program (AGNPS) the surface area of the entire subwatershed including LMT2, 3, and 4 is 20,480 acres. The subwatershed area that was included in the calculation of the export coefficients was only 3,480 acres. This number was calculated by adding the subwatersheds for LMT2, LMT3, and LMT4 (1,720 + 1,400 + 13,880 = 17,000 acres) and subtracting this from the total surface area of the Site LMT5 subwatershed (20,480 – 17,000 = 3,480 acres). This calculation method was also conducted for all of the sediment and nutrient loadings. For example, all the total phosphorus loadings from LMT2, LMT3, and LMT4 were added together equaling 21,002.9 lbs of TP. This number was then subtracted from the total phosphorus loadings from Site LMT5 (23,953.8 – 21,002.9 = 2,956 lbs of TP). The 2,956 lbs represents the gain in total phosphorus between the upstream sites (LMT2, 3 and 4) and the downstream Site LMT5. The total phosphorus export coefficient for the 3,480 acres was 0.85 lb/acre (2,956 lbs/3,480 acres) (Table 6). This 3,480 acres includes the city of Madison and the area between the City and the Wastewater Treatment Facility.

The water chemistry collected from Site LMT6 was very similar to Site LMT4. Site LMT5 exhibited relatively high nutrient levels and moderate levels of suspended solids (Site LMT5 TSS mean = 39 mg/L). Although exhibiting a lower mean total phosphorus concentration than Site LMT4, Site LMT5 had a higher median value (0.321 mg/L compared to 0.312 mg/L of TP). Site LMT5 fecal coliforms, an indicator of waste from warm blooded animals, exhibited higher mean concentrations than the upstream sites LMT2 and LMT3. Site LMT5 coliforms were still consistently lower than the concentrations from Site LMT4 (Table 7). A large increase in fecal coliforms (2600 colonies per 100 ml) was observed on June 28, 1995. A slight increase in suspended solids (60 mg/L), ammonia, nitrates, and phosphorus concentrations also accompanied this concentration.

The mean dissolved phosphorus concentration at Site LMT5 (0.150 mg/L) was significantly lower than at Site LMT4 (0.255 mg/L). The mean concentrations at the remaining upstream sites (LMT2 and LMT3) were not significantly different from Site LMT5 (Table 7). The volume of water from Sites LMT2 and LMT3 is significantly larger than at Site LMT4. Sites LMT2 and LMT3 may have had a larger effect on the water quality of Site LMT5 and essentially diluted the impact of LMT4 on LMT5. Mean dissolved phosphorus constituted 48% of the total phosphorus. Although concentrations of suspended solids were slightly higher at Site LMT5, resulting in a higher percentage of particulate phosphorus (52%), the concentrations of suspended solids and total phosphorus were not related ($R^2 = 0.02$).

Nitrogen concentrations were well within the range of concentrations from the other sites included in this discussion. The mean concentrations for nitrates and total nitrogen were lower than the upstream Site LMT2 (Silver Creek) and Site LMT4 (Memorial Creek) (Table 7). Ammonia concentrations were not significantly different and did not exhibit any trends. Dissolved oxygen, alkalinity, and pH values did not indicate any water quality problems either.

There was a 6.6% increase in the amount of water discharged at Site LMT5 compared to the 3 upstream sites (Table 4). However, there was an increase in the suspended solids (sediment) and phosphorus loadings by 25.6% and 14.7%, respectively. Total nitrogen loadings actually decreased by 8.6% between the 3 upstream sites and downstream Site LMT5. The mean concentration of total nitrogen was actually less at Site LMT5 compared to the two upstream sites which provided 99% of the nitrogen loadings (Table 4 and 7).

Table 4. Hydrologic, Sediment, and Nutrient Loadings for Sites LMT2, LMT3, LMT4 and LMT5.

Site	Area	Water	TSS	TN	TP
LMT2	1720	20610.5	1269.3	63.9	7.8
LMT3	1400	425.8	4.4	0.6	0.06
LMT4	15280	6610.1	182.3	19.1	2.6
LMT5	20480	29463.5	1829.0	76.4	12.0
(2+3+4) - 5	3480	1817.1	373	-7.2	1.5
Units	acres	acre-feet	tons	tons	tons

Most of the loadings occurred during the spring runoff period and dropped off substantially after the spring runoff ended. During the spring runoff period, a loss of water occurred between the three upstream tributary sites LMT2, 3, 4 and the Silver Creek downstream Site LMT5. As can be seen on Figure 6, the North Skunk Creek aquifer is located along Memorial and Silver Creek in a northwest to southeast direction to the outlet of Brant Lake which is the source for Skunk Creek. The North Skunk aquifer consists of poorly sorted sandy gravel located northwest of Lake Madison. The aquifer eventually grades into a well sorted sand and gravel southeast of Lake Madison. Recharge to the aquifer is by infiltration of precipitation and snowmelt. In a number of investigations it was observed that Lakes Madison, Herman, and Brant are connected to the aquifer. The direction of water movement in the aquifer is primarily to the southeast (USGS, 1986).

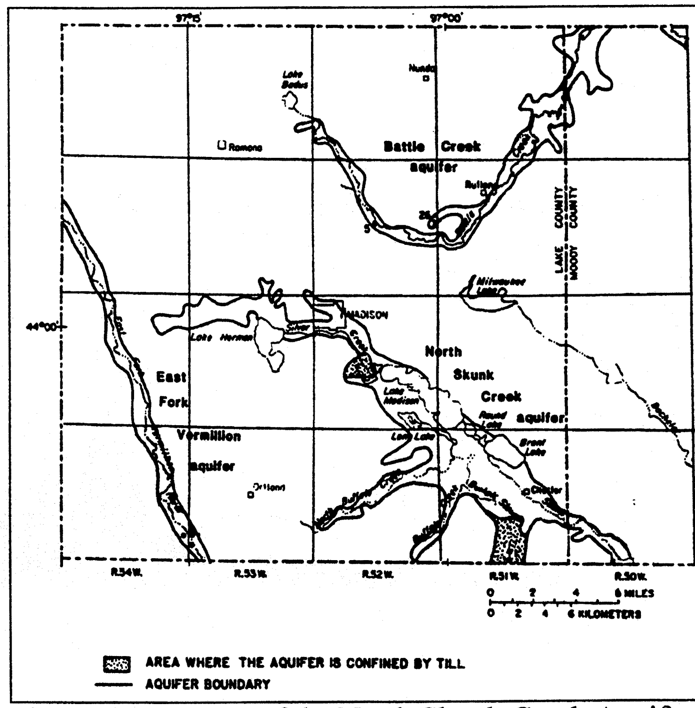


Figure 6. Location of the North Skunk Creek Aquifer.

After comparing the seasonal loadings between the upstream sites LMT2, 3, 4, and the downstream Site LMT5, it was determined that an estimated 6,410 acre-feet of water was lost over the course of the spring runoff period from March 16 to May 31, 1995. After review of the available information on the aquifer and consultation with hydrologists, it was determined that this surface water was lost to the aquifer during spring groundwater recharge (Figure 7).

The South Dakota DENR Water Rights Program has several monitoring wells in this aquifer. On March 16, 1995, Water Rights personnel took a measurement of Well LK-84B in which the depth from the top of the water to the top of the casing was 11.1 ft. On June 7, 1995, Water Rights personnel took another measurement on Well LK-84B. At this time the depth from the top of the casing was 4.8 ft indicating that over the course of the spring runoff monitoring period (March 16 – June 1, 1995) the water table had increased in depth by 6.3 ft.

The area in question where Sites LMT2, 3, 4, and 5 are located comprises approximately 6 square miles (3,480 acres). A storage coefficient ranging from 0.2 to 0.3 was used (USGS, 1965 and USGS, 1990). We would multiply the storage coefficient (specific yield) by the change in depth (6.3 ft) = 0.2 * 6.3 = 1.26 ft or 0.3 * 6.3 = 1.89 ft). Assuming then that the change in depth of the aquifer would range uniformly across the entire aquifer from 1.26 to 1.89 feet. The amount of recharge that occurred during the spring runoff of 1995 would range from 4,838.4 to

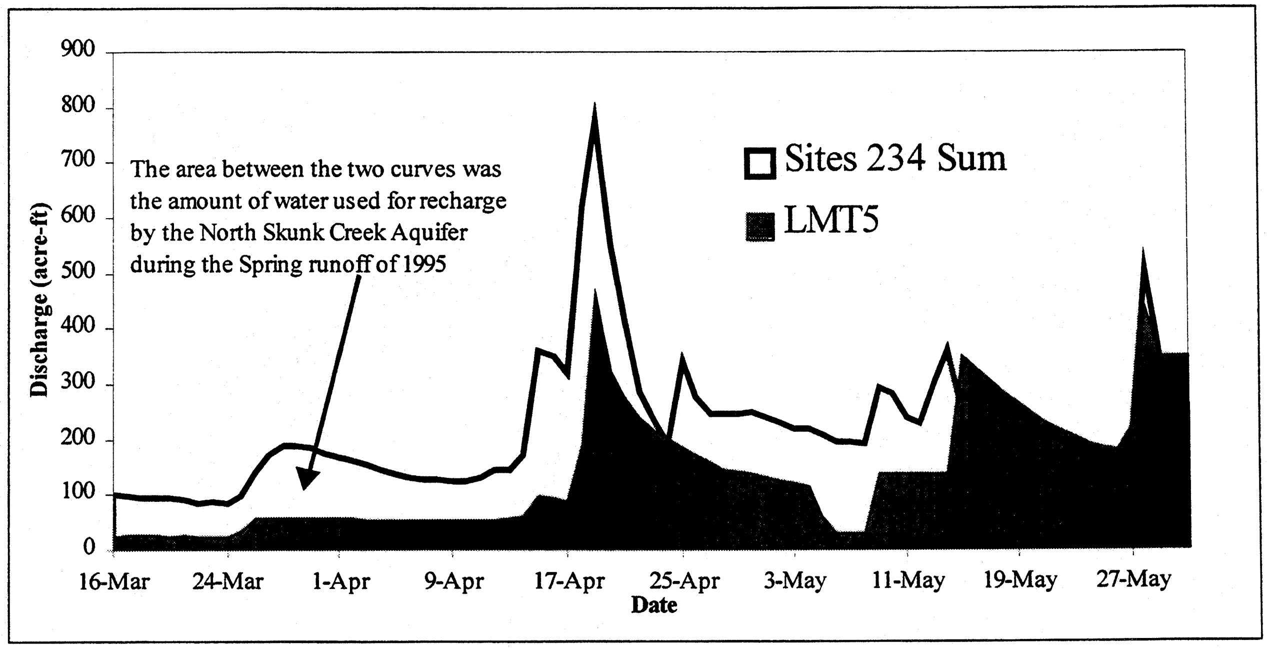


Figure 7. The North Skunk Creek Aquifer Recharge for the Spring of 1995.

7,257.6 acre-feet of recharge. This seems a logical explanation for the loss of 6,411 acre-feet of water during the spring runoff period of 1995, assuming the entire aquifer increased by 1.26 to 1.89 (Table 5).

Figure 7 shows the loss of water that occurred between the upstream and downstream sites. This substantial loss of water also resulted in a reduction in the nutrient and sediment loadings for the spring runoff period. However, over the course of the entire monitoring period the suspended solids increased by 373 tons between the upstream Sites LMT2, 3, and 4 and Site LMT5. There was also an increase in total phosphorus by 1.5 tons. Site LMT5 export coefficients for suspended solids and total phosphorus were larger than those for Sites LMT3 and LMT4 but was less than that of Site LMT2 (Table 6). The dissolved phosphorus export coefficient for Site LMT5 was 0.24 lb/acre. This was lower than Sites LMT2 and LMT4 but higher than LMT3. These differences in export coefficients may be partially explained by the storm sewer runoff from the city. The concentrations of suspended solids and total phosphorus from the storm sewer samples were extremely high but dissolved phosphorus concentrations were lower, resulting in

Table 5. Loss of Water Table Spring 1995 for Sites LMT2,3,4 compared to Site LMT5.

Site	Area	Water
LMT2	1720	12751.0
LMT3	1400	306.2
LMT4	15280	4033.8
LMT5	20480	10680.0
(2+3+4) - 5	2080	-6410.8
Units	acres	acre-feet

the differences in the relative export coefficients. The effect of storm sewers on Silver Creek and Lake Madison will be discussed later in the report.

Site LMT4 Water Quality

Site LMT4 (Memorial Creek) drains from the north. According to the data collected for the Agricultural Nonpoint Source computer program (AGNPS) the subwatershed size for Memorial Creek at the sampling site was 13,880 acres (Figure 8). Landuse is primarily agricultural in this subwatershed but some constant impairments were revealed.

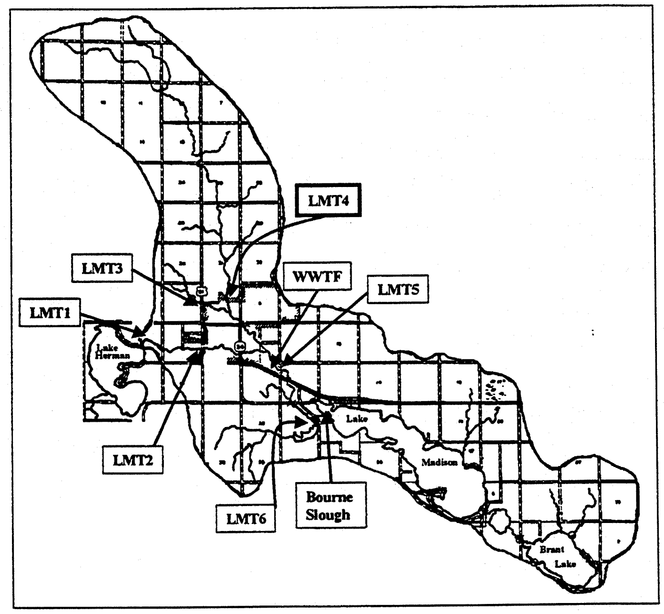


Figure 8. Location of Site LMT4.

Median fecal coliform counts for Site LMT4 were 165 colonies per 100 ml but the mean was 574 colonies per 100 ml primarily because of a single isolated maximum value of 3,900 coliform colonies per 100 ml. Of the six sites included in this section the Site LMT4 exhibited the second highest mean of 574 colonies per 100ml and the second highest maximum concentration of 3,900 fecal colonies per 100 ml. Here, again, the maximum concentration occurred on June 28. During 1995, there were other periodic spikes of fecal coliforms accompanied by higher concentrations of suspended solids, nitrates, and, total and dissolved phosphorus.

In addition to high fecal coliform counts during 1995, Site LMT4 consistently had high concentrations of nitrates+nitrites (mean = 1.15 mg/L, max = 2.80). There were also observations of high total phosphorus and total dissolved phosphorus. The maximum concentration of total phosphorus at Site LMT4 was 0.528 mg/L and the mean concentration was 0.322 mg/L. The mean fraction for dissolved phosphorus was 79%. The data suggests that livestock and fertilizers seem to be the problem in this upper subwatershed. The buffering capacity of this site was well maintained (alkalinity mean = 163 mg/L). The pH levels ranged from 7.7 to 8.2 su, and dissolved oxygen ranged from 5.1mg/L to 11.6 mg/L (Table 7).

The high nutrients (TP mean = 0.322 mg/L) at Site LMT4 are largely bioavailable and susceptible to immediate plant and algal uptake. Total and dissolved phosphorus were not correlated with the suspended solids loadings (R^2 = 0.003,df=11). Mean and median suspended solids concentrations (mean = 22 mg/L, median = 17 mg/L) were relatively low in comparison to the other six sites included in this discussion. The median suspended solids concentration (TSS = 17 mg/L) was only higher than Site LMT3 (TSS = 7 mg/L). This may be due to the higher velocities recorded from Memorial Creek (Site LMT4). The data collected at Site LMT4 indicates erosion is not a significant problem.

During 1995 this drainage contributed 6,610 acre-feet of water into Silver Creek. This water transported 2.60 tons of total phosphorus, 182.3 tons of suspended solids, 2.23 tons of dissolved phosphorus, and 19.1 tons of total nitrogen. The phosphorus export coefficient (lbs/acre) from Site LMT4 was significantly higher than Site LMT3 but significantly lower than the other monitoring sites on Silver Creek (Table 6). The dissolved phosphorus export coefficient of 0.32 lbs/acre was relatively high in comparison to the other sites (Table 6). Most of the loadings occurred during the spring snowmelt and rains, which is when the higher phosphorus concentrations were observed (Figure 9). There was a very significant relationship exhibited between total dissolved phosphorus and total phosphorus samples collected from Site LMT4 (R^2=0.87) which is indicative of the high percentage of dissolved phosphorus (79%). This was also confirmed by the lower suspended solids export coefficient calculated from the total loadings (26.26 lbs/acre).

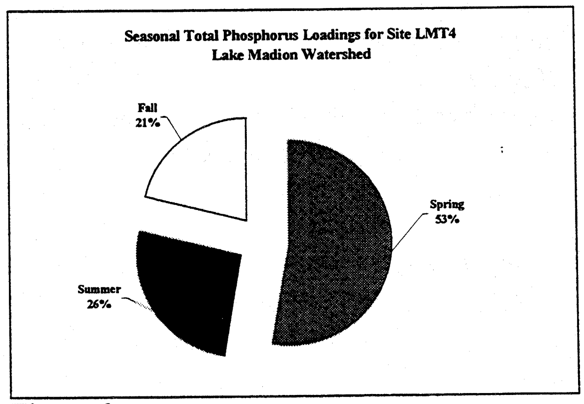


Figure 9

The different forms of nitrogen at Site LMT4 had higher export coefficients than at any of the other Silver Creek monitoring sites excluding Site LMT2 (Table 6). Site LMT4 nitrogen export coefficients were significantly larger than for Sites LMT3, 5, and 6. This essentially means that the Site LMT4 subwatershed has problems with nutrients but no existing problems with sediment.

Site LMT3 Water Quality

Site LMT3 is a small unnamed tributary that drains from the northwest of Madison, SD. Site LMT3 was located on Olive Street in the extreme northwest part of the city of Madison and was not influenced by any runoff from the city's storm sewers. This tributary also merges with Memorial Creek approximately ½ mile downstream from where Site LMT3 was located (Figure 10). The landuse characteristics of this subwatershed were primarily intensive small grain. There was a partial grassed waterway near the center of a field which served as the primary drainage area for this

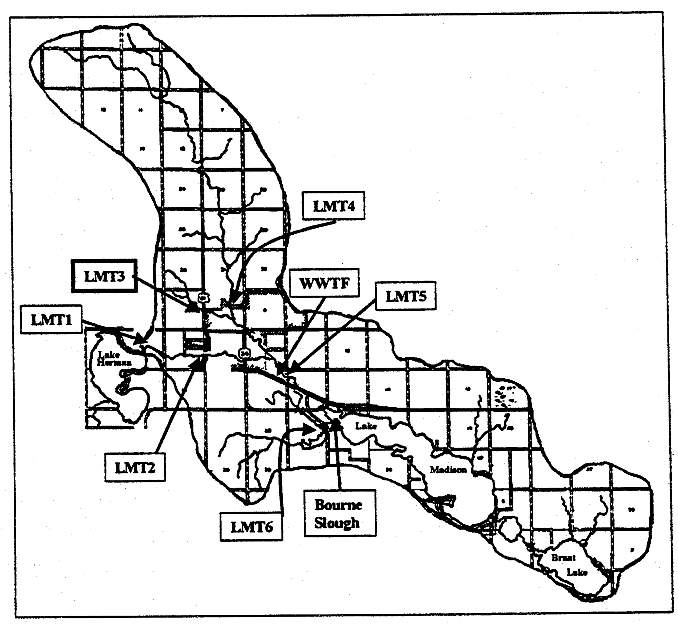


Figure 10. Location of Site LMT3.

small tributary. According to the Agricultural Nonpoint Source computer model, the drainage area above this monitoring site amounted to approximately 1400 acres. A total of 426 acre-feet of water were discharged through LMT3 during the course of 1995. However, some difficulty was experienced with the monitoring device and average daily stages were not calculated from March 15 through May 8. Daily discharge estimates were calculated by averaging the instantaneous discharge measurements that were collected during this period.

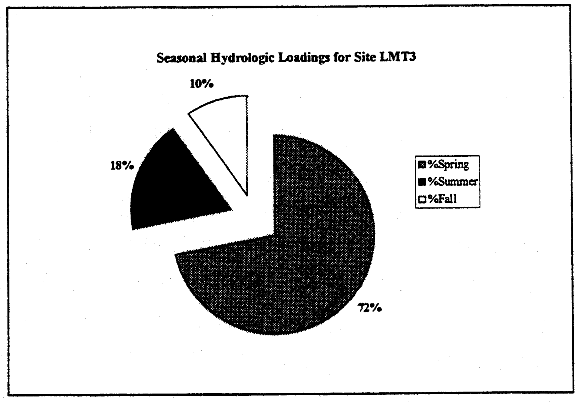


Figure 11.

As with the other sites, the majority of the hydrologic loadings occurred during spring. For Site LMT3, 72% of the total water discharged during 1995 occurred during the spring (Figure 11). The majority of the sediment and nutrient loadings were also discharged during the spring.

Site LMT3 exhibited relatively low concentrations of phosphorus, suspended solids, fecal coliform, and nitrogen compared to monitoring sites along Silver and Memorial Creek. The suspended solids (TSS) mean was significantly lower than the other sites at 9 mg/L. Also, after conducting a regression analysis on TP and TSS concentrations, there was no significant relationship between these two parameters. TSS ranged from a minimum of 2 mg/L to a maximum of 24 mg/L (Table 7). The mean concentration for TP at Site LMT3 was 0.164 mg/L and the mean for dissolved phosphorus (TDP) was 0.144 mg/L (Table 7). TP concentrations were significantly lower during the sampling year than at any of the other sites. However, the dissolved phosphorus concentrations were well within the middle of the range of the other sites (Table 7). When regression analysis was conducted, a strong relationship was shown to exist between TP and TDP (R^2 =0.96, df=11,n=12). The principal chemical species of total phosphorus was primarily dissolved phosphorus, which constituted 84% of the total phosphorus. The dissolved phosphorus was consistently present in higher amounts relative to the total phosphorus concentrations. With higher suspended solids concentrations higher particulate phosphorus concentrations do occur. Since suspended solids at Site LMT3 were so low, the dissolved phosphorus fraction became the predominate form.

The mean concentrations for the nitrogen forms were all consistently lower than at any of the other sites. Mean nitrate+nitrite concentrations for LMT3 were 0.473 mg/L although the median was 0.1 mg/L. Nitrates ranged from 0.1 to 1.4 mg/L, respectively. Nitrate+nitrites exceeded 1.0 mg/L on four occasions during 1995. However, three of these observations occurred early in the spring runoff. The remaining observation occurred on June 28 when a fecal coliform concentration of 2,000 coliform per ml was also recorded. High coliform levels also occurred at all other monitoring sites sampled on June 28. This was caused by a rainfall event that was large enough to have caused material previously retained on the surface of the land or within the streambed to have been transported downstream. The mean fecal coliform concentration was 243, but the median concentration was 15 colonies per 100 ml for Site LMT3.

Other parameters, such as alkalinity, dissolved oxygen, pH, and dissolved solids, did not indicate any other water quality problems in this small 1400-acre subwatershed (Table 7).

The 1995 phosphorus loading data exhibited an export coefficient of 0.09 lb/acre TP. This was minor in comparison to other sections of the watershed where 1.0 lb/acre TP was exceeded. A total of 121 pounds of phosphorus was discharged into Memorial Creek from Site LMT3 during the 1995 sampling year. Total dissolved phosphorus loadings totaled 112 pounds for a dissolved phosphorus coefficient of 0.08 lb/acre. This was very low in comparison to the other monitoring sites in Table 6. Suspended solids and total nitrogen export coefficients were 6.35 lb/acre and 0.82 lb/acre, respectively. These export coefficients were also low.

Sites LMT1 and LMT2 Water Quality

Site LMT1 and LMT2, the final two tributary sites, were located furthest upstream of Lake Madison (Figure 12). Site LMT1 is located on the outlet of Lake Herman which is the primary source of Silver Creek. The water for Lake Herman is derived from the 44,000-acre watershed previously identified in Figure 1. A stage monitor was placed in the outlet of Lake Herman to monitor the total discharge from the lake and derive pollutant loadings for Silver Creek. Please refer to the Phase III Final Report for any further details concerning the locations of possible nonpoint sources in the Lake Herman Watershed. Site LMT2 is located approximately 1 mile downstream of the Lake Herman outlet (LMT1) at a box culvert on Highway 34 just prior to Silver Creek entering the city limits of Madison, SD (Figure 12).

The mean total phosphorus concentration at LMT1 during 1995 was 0.265 mg/L whereas downstream Site LMT2 exhibited a higher mean of 0.312 mg/L. Figure 14 on page 27 shows the range of phosphorus concentrations for all of the Silver Creek Sites between Lake Herman and Lake Madison. As can be seen, Sites LMT2, 4, 5, and LMT6 were not significantly different during 1995. Site LMT1 exhibited higher phosphorus concentrations during spring whereas Site LMT2 did not show any particular seasonal trend. The maximum total phosphorus concentration for Site LMT1 was 0.321 mg/L and the minimum concentration was 0.059 mg/L. The maximum and minimum concentrations were observed from samples collected on

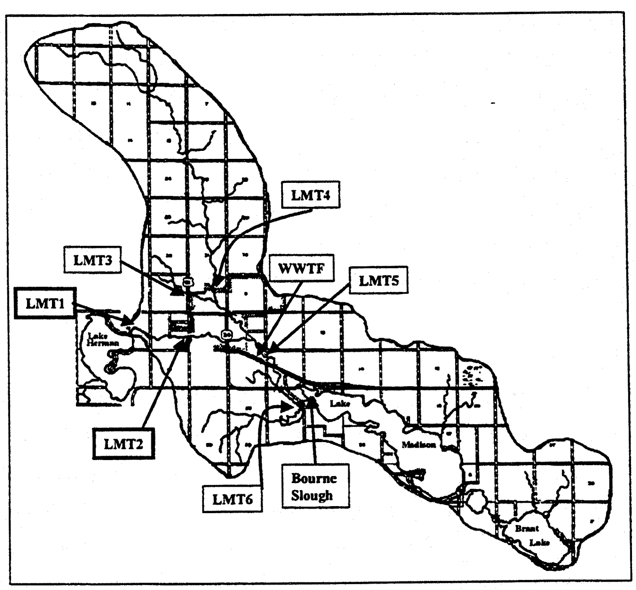


Figure 12. Location of Site LMT1 and LMT2

March 27 and April 3, respectively. A total of 4 samples of the first 5 samples collected during the spring runoff were greater than 0.3 mg/L. In comparison, Site LMT2 phosphorus concentrations ranged from a minimum concentration of 0.157 mg/L to a maximum concentration of 0.403 mg/L from samples collected on June 5 and March 14, 1995, respectively. The maximum concentrations for Site LMT2 may have been due to fertilizer application or improper manure management and heavy runoff.

The mean concentration for dissolved phosphorus was significantly higher at Site LMT2 (mean = 0.132 mg/L) in comparison to Site LMT1 (mean = 0.106 mg/L). In fact, the minimum concentration 0.040 mg/L for Site LMT1 occurred on March 14, 1995, which was the same date when the maximum concentration of 0.216 mg/L was observed from Site LMT2. Concentrations for both Site LMT1 and LMT2 declined during the spring due to dilution from the spring runoff. After the spring runoff in June concentrations increased to >0.100 mg/L for all of the remaining samples.

The average total phosphorus concentration from Site LMT1 consisted of 40% dissolved and 60% particulate. There was essentially no difference in the fraction of dissolved phosphorus between Sites LMT1 and LMT2.

Concentrations of suspended solids ranged from 2 mg/L to 70 mg/L for Site LMT1. Downstream, Site LMT2 ranged from 4 mg/L to 80 mg/L. The mean concentrations were 28 mg/L and 35 mg/L for Site LMT1 and LMT2, respectively (Table 7). Seasonally, the concentrations for both of these sites gradually increased through early spring and peaked during April. The maximum concentrations for both sites occurred on April 24, 1995. After this date the concentrations decreased. However, at Site LMT2 on June 28, 1995 the suspended solids concentrations increased to 72 mg/L. There was a decrease in dissolved oxygen to 3.9 mg/L and an increase in nutrient concentrations on this date as well. In addition, Site LMT2 fecal coliforms increased to 3,100 colonies per 100 ml, which is a large increase considering that before this date the mean fecal coliform count was 19 colonies per 100ml. This increase in solids, nutrients, and fecal coliform indicate an input of some type of animal waste into Silver Creek.

Total phosphorus and suspended solids concentrations can be related during periods when there is heavy runoff occurring. However, a regression analysis indicated an insignificant relationship between these two water quality parameters. The R^2 values in a regression analysis range from 0 to 1. An R^2 value of 1 would indicate that all of the variability within the total phosphorus concentrations is due to the suspended solids concentrations. The R^2 values were 0.02 and 0.002, respectively (d.f. = 11, n=12) for Site LMT1 and LMT2. During the spring of the year the total phosphorus concentrations increased with increasing concentrations of suspended solids. The concentrations were not related or a trend was not detected during the remaining part of the sampling year.

The mean concentration of fecal coliform bacteria was 25 colonies per 100ml. There was a slight increase in the number of fecal colonies to a maximum of 130 colonies per 100 ml during the summer but this was the only instance of an increase above the mean. In fact, the median concentration was 10 colonies per 100 ml (Table 7, page 29). In contrast, the Site LMT2 fecal coliform mean was 389 per 100 ml. The maximum value at LMT2 for fecal coliform colonies was 3100 per 100 ml. Site LMT2 exhibited lower fecal counts during the spring samples, ranging between 10 and 50 fecal colonies per 100 ml. Large increases occurred during the months of June and August (3100 per 100 ml).

The mean concentration of nitrates for Site LMT1 and LMT2 was 0.18 mg/L and 0.92 mg/L, respectively. Site LMT1 was consistently below 0.3 mg/L whereas Site LMT2 exhibited periodic spikes >0.90 mg/L throughout the sampling year. In fact, Site LMT2 exhibited the highest concentration for Sites LMT1-LMT6 at 3.4 mg/L (Table 7, page 29). During that sampling event, there was only a slight increase in the other parameters such as fecal coliforms, which increased to only 30 fecal colonies per 100 ml. That sample was collected during spring runoff on March 27, 1995 when nitrates+nitrites mixed with snow and residual vegetation left from the previous year were discharged into Silver Creek in addition to remnant manure from livestock operations.

Ammonia was slightly higher at Site LMT2 compared to Site LMT1. Site LMT1 ranged from 0.02 mg/L to 0.23 mg/L with a mean of 0.07 mg/L. Site LMT2 ranged from 0.02 mg/L to 1.22 mg/L with a mean of 0.18 mg/L (Table 7, page 29). The maximum concentration at Site LMT2 (1.22 mg/L) occurred on March 14, 1995 which was probably the result of a first flush. After this maximum concentration, the remaining samples collected in 1995 ranged from 0.02 mg/L to 0.3 mg/L. This same phenomenon occurred at Site LMT1 which exhibited a maximum concentration of 0.23 mg/L on March 14. This is probably an indication of a buildup of ammonia in the lake during late winter or prior to spring runoff before a major discharge event occurred.

Total nitrogen concentrations were significantly higher at Site LMT2 when compared to LMT1, 2.79 mg/L vs. 1.83 mg/L (Table 7, page 29). The larger nitrogen concentrations at Site LMT2 from the parameters described above were the primary reason for the higher mean concentration. Site LMT2 exhibited the second highest mean total nitrogen concentrations for all (11) of the tributary sites. The highest mean concentration was 3.51 mg/L observed at Site LMT7 which will be discussed later. This particular parameter was also significantly higher at Site LMT2 when compared to LMT1 (Table 7).

The remaining parameters did not exhibit any extreme values or significant differences between Site LMT1 and Site LMT2. Table 7 on page 29 shows the minimum, maximum, mean, median, and standard deviation for each parameter collected from Sites LMT1 through LMT6.

From March 15 to October 31, 1995, Lake Herman discharged 19,677 acre-feet of water into Silver Creek. That amount of water also transported 6.5 tons of total phosphorus and 1,063 tons of suspended solids. The spring runoff exhibited the highest rate of water discharge, which occurred during the months March - May 31. Suspended solids loadings increased from 1,063 tons at Site LMT1 to 1,269 tons of suspended solids loadings at Site LMT2. This represents an increase of 19%. Total phosphorus (TP) loadings increased from site LMT1 (6.5 tons – TP; 2.3 tons-TDP) to site LMT2 (7.8 tons – TP; 3.0 tons - TDP) (Table 6, page 28). The percentage increase in hydrologic loading was 5 % but the increase in nutrients (total phosphorus, total dissolved phosphorus, and total nitrogen) was 17%, 22%, and 53%, respectively. This represents a significantly large nutrient input between LMT1 and LMT2. The fecal coliform mean counts were also higher at LMT2 than at LMT1.

Export coefficients were calculated through the use of total loadings discharged from a site divided by the surface area (subwatershed) that this particular site drains. For example, Site LMT2 drains 1,720 acres in addition to the watershed area drained through the outlet of Lake Herman (44,000 acres). To determine the phosphorus export coefficient for the 1,720 acres, the total phosphorus loadings discharged from Site LMT2 was subtracted from Site LMT1 (**15,689 – 13,029 = 2,660** lbs) (Table 6). The increase of 2,660 lbs of phosphorus was then divided by the 1,720 acres located between Site LMT1 and LMT2. The phosphorus export coefficient for this 1,720 acre (Site LMT2) would be 1.55 lbs of total phosphorus/acre. All the nutrient export coefficients from Site LMT2 are significantly higher than the remaining 6 sites within the Silver Creek drainage (Table 6). The suspended solids export coefficients for Site LMT2 were also very high in comparison to Sites LMT2 - LMT6 at 240.5 lbs of TSS/acre.

SITE BY SITE COMPARISONS (LMT1-LMT6)

Sites LMT3 and LMT4 exhibited the highest percentages of dissolved phosphorus as part of total phosphorus at 84% and 79%, respectively (Table 7). The remaining four sites did not have their total dissolved phosphorus values exceed 50% of total phosphorus concentrations. In addition, no significant relationships were found to exist between total suspended solids and total phosphorus. This indicates that the total phosphorus concentrations are derived from sources other than sediment-based phosphorus.

Sites LMT2, LMT3, and LMT4 did not measure the contribution to the total nutrient and sediment loadings by the city storm sewers. However, in the data discussed later in this report, in the urban water quality sections, the nutrient, sediment and fecal coliform bacteria concentrations were very high. Total phosphorus concentrations exceeded 1.0 mg/L in many instances. Site LMT5, located approximately 1 mile southeast of the city of Madison, downstream of the wastewater treatment facility, did indicate significant increases in phosphorus and sediment export coefficients between the three upstream sites and Site LMT5.

The maximum concentration of TP (0.528 mg/L) was collected at Site LMT4 (Memorial Creek). The highest concentrations of total phosphorus occurred during the snowmelt runoff in March. Seasonal comparison of loadings also indicated that most of the loadings occurred during the spring months. However, this was primarily due to the larger amounts of water that were discharged during at this time period (March-May). Site LMT4 exhibited the highest mean concentration of total phosphorus although Figure 14 shows no significant differences between Sites LMT2, 4, 5, and 6. Site LMT6 exhibited the highest median concentration between the six sites (Figure 14 and Table 7). Although the highest percentage of total dissolved phosphorus was exhibited by Site LMT3 (84%), the concentration levels of total phosphorus were significantly lower than the other sites (Table 7). In contrast, the total dissolved phosphorus concentrations from Site LMT3 were not significantly different from any of the other sites except

Site LMT4 which was significantly higher than all of the sites. There was a significant increase in total dissolved phosphorus between Site LMT1 and LMT2 that also corresponds to the increase in nitrates-nitrites and fecal coliforms that occurred as well.

Total suspended solids were not a problem for the Site LMT4 subwatershed. Nutrient (nitrates and total dissolved phosphorus) and fecal coliform concentrations were significantly different from the remaining sites. Animal waste may only be part of the problem. AGNPS analysis will provide a better picture of the contents of the subwatershed. Nutrient or fertilizer management may also be a good idea for this watershed.

The largest phosphorus export coefficients were calculated from the data collected at Site LMT2 and LMT5 as described above. The large dissolved phosphorus export coefficients were calculated from the data collected at Site LMT2 and LMT4. Export coefficients for the rest of the investigated parameters can be found in Table 6.

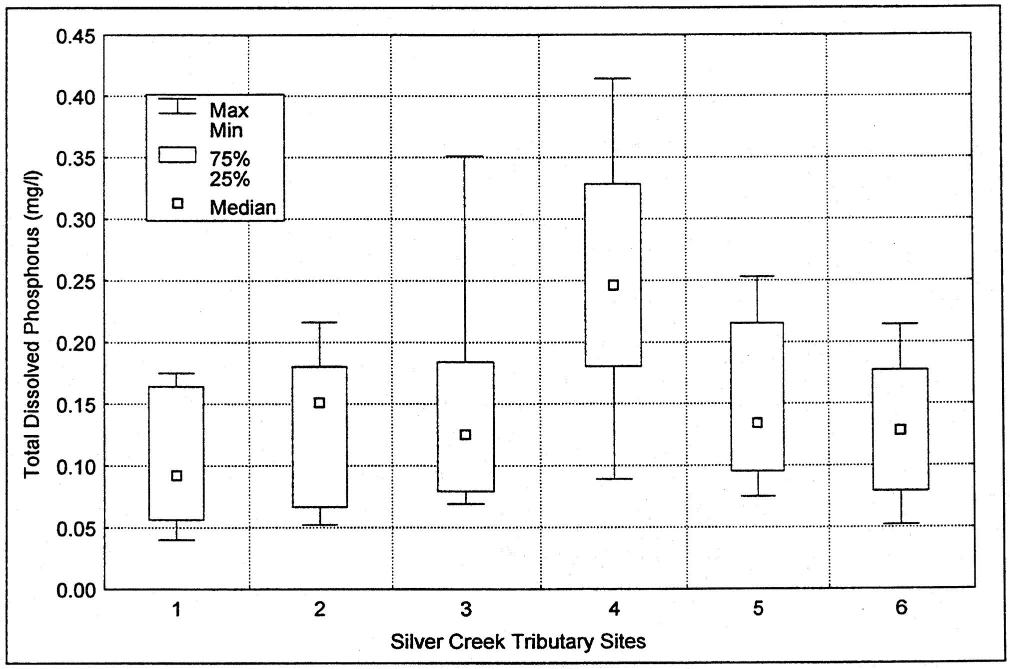


Figure 13

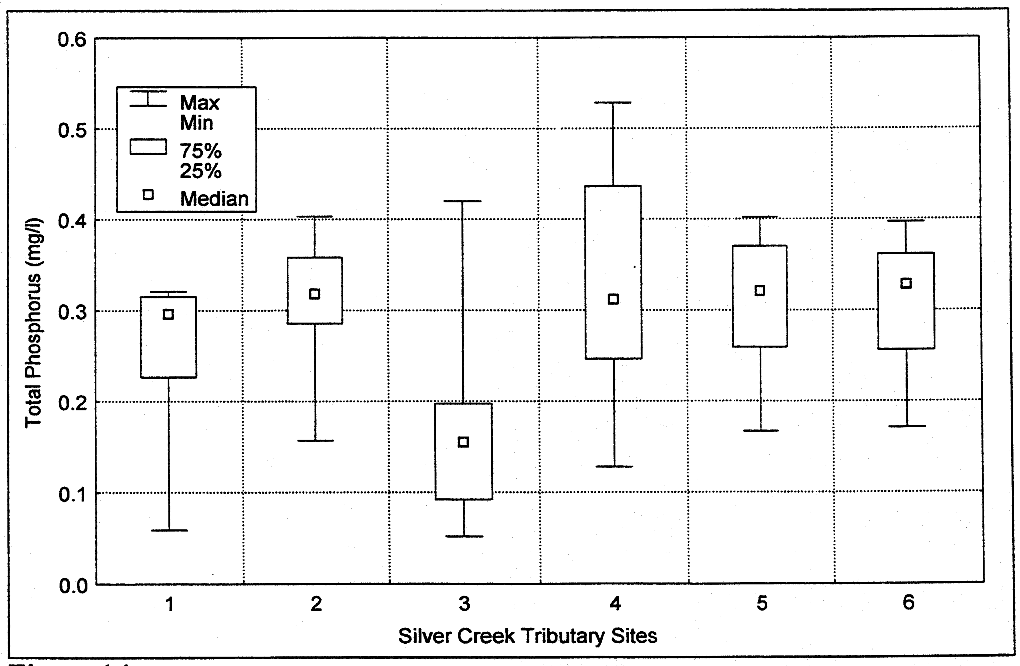


Figure 14

Table 6. TOTAL LOADINGS FOR ALL SITES BROKEN INTO SEASONAL AND TOTAL LOADINGS
LAKE MADISON/BRANT 314
1994-1996

SITE	Watershed acres	WATER acre-feet	TALKAL lbs/year	TSOL lbs/year	TDSOL lbs/year	TSSOL Lbs/year	AMMO lbs/year	UN-AMM lbs/year	NO3+2 lbs/year	TKN-N lbs/year	Org Nitro lbs/year	Tot Nitro lbs/year	TPO4P lbs/year	TDPO4P lbs/year
LMT1		19677.48	7927131.83	63902956.14	61790517.18	2125037.68	2667.68	420.20	11839.23	76748.77	70146.23	83472.82	13029.14	4599.70
LMT2	1720	20610.48	8685747.99	67866876.61	65347759.36	2538691.40	4281.30	291.46	38288.85	89202.17	84627.26	127719.39	15689.29	5909.85
LMT3	1400	425.85	227869.33	1796227.67	1787380.64	8891.58	23.17	0.78	321.63	822.12	798.95	1143.97	121.19	111.98
LMT4	15280	6610.07	3001371.17	21644417.60	21279893.25	364524.35	417.73	11.24	19483.68	18753.37	18335.63	38117.30	5192.37	4466.72
LMT5	20480	29463.54	12593249.49	98420054.46	94762080.13	3657974.33	4085.32	307.95	56000.89	96699.30	92613.98	152700.19	23953.83	11335.09
LMT6	25480	30334.96	12811513.27	99473779.82	94436132.55	5037647.27	3597.44	293.67	52735.78	107179.74	103520.22	160194.87	23350.93	9670.52

Export Coeffcients

Site	Watershed acres	WATER feet	TALKAL lbs/ac/yr	TSOL lbs/ac/yr	TDSOL lbs/ac/yr	TSSOL Lbs/ac/yr	AMMO lbs/ac/yr	UN-AMM lbs/ac/yr	NO3+2 lbs/ac/yr	TKN-N lbs/ac/yr	Org Nitro lbs/ac/yr	Tot Nitro lbs/ac/yr	TPO4P lbs/ac/yr	TDPO4P lbs/ac/yr
LMT2	1720	0.54	441.06	2304.60	2068.16	**240.50**	0.94	-0.07	**15.38**	7.24	8.42	**25.72**	**1.55**	**0.76**
LMT3	1400	0.30	162.76	1283.02	1276.70	6.35	0.02	0.00	0.23	0.59	0.57	0.82	0.09	0.08
LMT4	13880	0.48	216.24	1559.40	1533.13	26.26	0.03	0.00	1.40	1.35	1.32	**2.75**	0.37	**0.32**
LMT5	3480	0.52	194.90	2043.83	1823.86	**214.33**	-0.18	0.00	-0.60	-3.47	-3.20	-4.10	**0.85**	0.24
LMT6	5000	0.17	43.65	210.75	-65.19	**275.93**	-0.10	0.00	-0.65	2.10	2.18	1.50	-0.12	-0.33

Table 7. Descriptive statistics for selected physical and chemical parameters collected from six tributary monitoring sites on Silver Creek, 1995.

		WTEMP	ATEMP	DO	FPH	FECAL	TALK	TS	TDS	TSS	AMM	UN-AMM	NO3+2	TKN	Or-Nit	T-Nit	TPO4P	TDPO4P
	Units	°C	°F	mg/L	su	per100ml	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
LMT1	mean	10.3	56.9	10.6	8.86	25	140	1076	1048	28	0.07	0.0072	0.18	1.65	1.58	1.83	0.265	0.106
	median	6.0	52.0	10.4	8.90	10	150	1159	1136	28	0.02	0.0037	0.20	1.85	1.83	1.95	0.296	0.092
	maximum	25.0	82.0	15.8	9.16	130	163	1327	1291	70	0.23	0.0196	0.30	2.42	2.40	2.52	0.321	0.175
	minimum	1.5	32.0	5.9	8.40	10	25	142	140	2	0.02	0.0014	0.10	0.56	0.33	0.76	0.059	0.040
	StDev	8.4	16.6	3.1	0.28	37	39	324	315	17	0.07	0.0059	0.08	0.59	0.62	0.57	0.080	0.052
LMT2	mean	9.8	55.3	9.1	8.52	389	158	1166	1130	35	0.18	0.0047	0.92	1.87	1.69	2.79	0.312	0.132
	median	6.0	51.0	9.8	8.66	20	158	1198	1176	34	0.02	0.0034	0.50	1.84	1.64	2.48	0.318	0.151
	maximum	24.0	79.0	12.2	9.12	3100	171	1353	1281	80	1.22	0.0133	3.40	2.75	2.28	5.78	0.403	0.216
	minimum	1.0	36.0	3.9	7.91	10	139	826	817	4	0.02	0.0008	0.20	0.92	0.90	1.32	0.157	0.052
	StDev	8.2	16.7	2.5	0.43	972	11	153	142	26	0.35	0.0043	0.93	0.47	0.37	1.23	0.064	0.061
LMT3	mean	9.7	55.5	8.7	7.88	243	184	1536	1527	9	0.02	0.0004	0.47	0.87	0.85	1.34	0.164	0.144
	median	7.0	51.0	8.6	7.86	15	179	1682	1679	7	0.02	0.0002	0.10	0.85	0.83	0.97	0.155	0.125
	maximum	24.0	86.0	13.4	8.38	2000	264	2069	2067	24	0.02	0.0011	1.40	1.45	1.43	2.55	0.420	0.351
	minimum	2.0	34.0	4.4	7.47	10	109	994	977	2	0.02	0.0001	0.10	0.22	0.20	0.32	0.052	0.069
	StDev	7.9	17.3	2.8	0.25	623	56	340	342	7	0.00	0.0003	0.53	0.35	0.35	0.78	0.100	0.082
LMT4	mean	9.8	54.8	8.8	7.98	574	163	1181	1159	22	0.06	0.0007	1.15	1.35	1.30	2.50	0.322	0.255
	median	7.0	52.0	8.7	7.98	165	153	1150	1133	17	0.02	0.0004	0.80	1.35	1.33	1.94	0.312	0.246
	maximum	23.5	82.0	11.6	8.20	3900	232	1607	1531	76	0.39	0.0023	2.80	2.48	2.09	4.42	0.528	0.414
	minimum	1.0	33.0	5.1	7.70	10	90	693	686	6	0.02	0.0001	0.10	0.31	0.29	1.11	0.128	0.089
	StDev	7.7	16.4	2.0	0.15	1192	40	272	265	20	0.11	0.0007	0.90	0.54	0.47	1.14	0.115	0.099
LMT5	mean	10.6	55.9	9.7	8.37	452	154	1156	1117	39	0.10	0.0030	0.90	1.53	1.43	2.43	0.310	0.150
	median	8.5	56.0	10.4	8.34	15	156	1182	1147	35	0.03	0.0019	0.50	1.58	1.55	2.08	0.321	0.134
	maximum	23.5	85.0	12.2	8.95	2600	169	1379	1319	72	0.58	0.0075	2.80	2.45	2.04	4.50	0.402	0.253
	minimum	1.0	22.0	6.2	7.83	10	130	800	790	7	0.02	0.0007	0.20	0.59	0.57	0.99	0.167	0.075
	StDev	7.7	21.0	2.0	0.32	821	11	164	149	21	0.16	0.0027	0.76	0.50	0.41	1.00	0.074	0.060
LMT6	mean	10.6	59.0	10.1	8.38	663	164	1210	1146	64	0.09	0.0032	0.87	1.58	1.49	2.46	0.309	0.134
	median	8.5	62.0	10.9	8.37	120	164	1223	1155	68	0.04	0.0016	0.50	1.59	1.53	2.18	0.328	0.128
	maximum	24.0	88.0	12.8	8.84	4200	177	1449	1346	106	0.53	0.0099	2.80	2.25	1.93	4.39	0.397	0.214
	minimum	1.0	34.0	6.6	8.06	10	146	902	858	5	0.02	0.0008	0.20	1.01	0.99	1.41	0.171	0.052
	StDev	8.5	19.8	2.1	0.23	1345	8	166	144	33	0.15	0.0034	0.77	0.36	0.30	0.88	0.070	0.056

LMT7 Water Quality

LM7 is a smaller separate tributary, draining directly into Lake Madison and originating in the northeastern part of the Lake Madison watershed (Figure 15). The subwatershed is approximately 1,920 acres (777 ha) and the landuse comprised primarily of pasture and small grain.

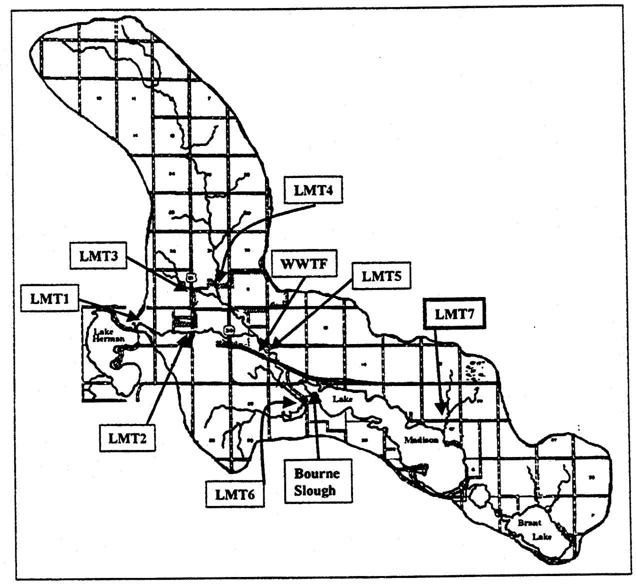


Figure 15. Location of Site LMT7.

This small unnamed tributary drains a relatively small subwatershed and drains rather quickly during thunderstorms. This tributary does not run for any great length of time and provides its loadings to the lake within a very short duration, as is evident in the wide range of concentrations observed from this site. However, the data from Site LMT7 is somewhat skewed due to a single sampling event that occurred on April 18, 1995. A flushing event apparently occurred shortly before sampling and the maximum concentration of 936 mg/L for suspended solids was collected. A high total phosphorus concentration (1.26 mg/L) was also observed for this date although the total phosphorus mean for Site LMT7 (Table 9) was not as large as most of the Silver Creek monitoring stations discussed previously.

On April 18, 1995, the maximum suspended solids concentration was collected from Site LMT7. Concentration reached a maximum of 936 mg/L which is far in excess of the limit allowed in the South Dakota water quality standards. Nitrates/nitrites (NO_{3+2}) and phosphates exhibited high concentrations on this date as well, indicating a possible rainfall event carrying a relatively large load of nutrients and sediment into Lake Madison. Only 14% of the total phosphorus was comprised of non-particulate or dissolved phosphorus. A major percentage of phosphorus sampled on 4/18/95 was attached to sediment particles and not immediately available for algal or plant uptake. There were extremely high nitrate-nitrite concentrations found at this site during the entire sampling period. AGNPS identified seven critical cells within this subwatershed with sediment nitrogen ≥ 9.8 lbs/acre. Heavy fertilization together with organic nitrogen found within a small wetland near this site may have contributed to the increased levels of nitrate+nitrite. Dissolved oxygen and pH values from all samples did not reflect problems associated with suspended solids or nitrate+nitrite concentrations. Ammonia was relatively low and only increased slightly on April 18 when the 936 mg/L of suspended solids was observed.

The total phosphorus (TP) mean of 0.255 mg/L was skewed due to the one sampling event in which the TP concentration reached 1.26 mg/L as discussed in the previous paragraph. The median, which is the middle value in a series of numbers, was significantly smaller at 0.141mg/L. The TP median value from LMT7 was the lowest observed for any of the tributary sites (LMT1-BLT11) (Table 9). A regression analysis was conducted between total phosphorus and total suspended solids revealing a very strong relationship (R^2 = 0.92, df=11). However, this relationship is skewed due to the one observation on April 18 that exhibited excessive concentrations of TSS and TP. Other observations were made during 1995 where TP concentrations exceeded 0.200 mg/L. However, 6 of the 12 samples collected during 1995 were <0.200 mg/L.

The total dissolved phosphorus (TDP) mean of 0.120 mg/L was little effected by the excessive concentration of TP. However, the TDP concentration of 0.174 mg/L for this date was the second highest value observed during the monitoring period. The median (0.104 mg/L) was only slightly less than the mean. A TDP maximum concentration of 0.259 mg/L was observed with a TP concentration of 0.295 mg/L and a maximum value for nitrates (3.6 mg/L). A regression analysis was also conducted between TDP and TP concentrations to determine if these two parameters were closely linked during a major runoff period in this small subwatershed. The analysis indicated only a slight relationship (R^2 = 0.20, df = 11). The average dissolved phosphorus fraction constituted 76% of the total phosphorus concentration.

Nitrates (NO_{3+2}) exceeded 2.0 mg/L in 8 of 12 samples collected at LMT7. The mean was 2.28 mg/L in comparison to the next highest mean at Site LMT4 which reached 1.15 mg/L. Although higher concentrations occurred during the months of March and April, nitrates were consistently higher here than at any other site during the sampling year. A source of nitrates could be the small wetland located near the sampling site. Fertilizers and feedlot wastes can also be major sources, the former depending on fertilizer application rates. Despite the high concentration of nitrates, ammonia (NH_4^+) levels were quite low (Table 9). In fact, out of the 11 tributary sites monitored, Site LMT7 had the third lowest concentrations observed during the project.

Dissolved oxygen concentrations for Site LMT7 exceeded 10 mg/L in all samples collected during March and April. As the season moved into June, increasing the water temperature, the dissolved oxygen concentration dropped, reaching a low of 4.3 mg/L on August 8. The water temperature during August sampling was 23.5°C. As water temperature increases, the ability of water to hold oxygen becomes less. The presence of decomposing organic material, reduced flow, and higher temperatures on August 8, contributed lower dissolved oxygen concentrations.

Other parameters such as alkalinity, pH, and dissolved solids did not exhibit any unusual values outside the expected range.

AGNPS data did not indicate that this subwatershed was a major contributor of nutrients to the lake. AGNPS did indicate that, due to the relatively steep slope (7-18%) and the generally sparse vegetative cover (C-factors = 0.09-0.35), this subwatershed and some acreage within an adjacent subwatershed should be converted to a high residue management system or to rangeland, due to the high sediment deliverability rate.

Fecal coliform concentrations did not indicate the presence of livestock until the last two samples of 1995. Counts of 590 and 1000 fecal coliform per 100 ml were obtained from those samples. Placement of cattle in a small pasture upstream of Site LMT7 for fall grazing may have been the cause of those higher values. The mean concentration of fecal coliforms at this site was 217 colonies per 100 ml. This mean concentration was significantly less than Sites LMT2-LMT6. However, the 217 colonies per 100 ml was larger than the individual mean concentrations recorded for Sites BLT8-BLT11 (Table 9).

Nutrient and sediment loadings were calculated based on the water quality samples collected during 1995. AGNPS calculated that the subwatershed for Site LMT7 constituted only 5.8% of the total watershed area (44,000 acres). However, it did comprise 8.4% of the total estimated sediment loading for a 25-year storm event. The nutrient and sediment export coefficients for LMT7 were 165.68 lbs/ac/yr for suspended solids, 3.82 lbs/ac/yr for total nitrogen, and 0.34 lbs/ac/yr for total phosphorus (Table 8). The suspended solids export coefficient was relatively high, although there were higher suspended solids coefficients observed from sites LMT2, 5, 6. LMT7 did have a higher export coefficient than sites BLT8 through BLT11. One item that must be considered when comparing suspended solids coefficients is that BLT8, BLT9, and BLT11 are monitoring sites located at the outlets of Lake Madison, Round Lake, and Brant Lake, respectively. These lakes can act as retention devices or sediment sinks, reducing the amount of sediment that is discharged into receiving waters downstream. Site BLT 10, which is a sampling station in a subwatershed of similar size draining into Brant Lake, had a significantly smaller suspended solids coefficient than LMT7.

Nutrient export coefficients for subwatershed LMT7 were comparable to BLT10, LMT3 and LMT4. LMT7 had a relatively high total nitrogen export coefficient of 3.82 lbs/ac/yr whereas BLT10, which is a watershed of similar size but drains into Brant Lake, had a significantly lower coefficient of 1.51 lbs/ac/yr. The high nitrogen export coefficient for LMT7 was due to the consistently high concentrations of nitrates that were observed at this site throughout the entire 1995 sampling year.

After calculating the overall discharge from the monitoring that took place during 1995-96, the total amount of water discharged into Lake Madison from this site was estimated at 842 acre-feet. This amount of water carried 644 lbs of phosphorus into Lake Madison. The total phosphorus export coefficient for LMT7 was not significantly different from a subwatershed of similar size, i.e. LMT7 = 0.34 lbs/acre/yr and BLT10 = 0.35 lbs/acre/yr were not significantly different. In comparison to other subwatersheds within the Lake Madison watershed, this is the lowest phosphorus export per unit area, excluding LMT3, for the project.

BLT8 - BLT9 Water Quality

These sites were located on the outlet of Lake Madison and Round Lake (Figure 16). They were used to determine the hydrologic, sediment and nutrient budget for each of the lakes. The subwatershed size for BLT8 includes all the subwatersheds previously described from the outlet of Lake Herman (Site LMT1) to the outlet of Lake Madison (BLT 8). The total area according to AGNPS computer programs is 36,120 acres (14,617.8 ha).

Site BLT8 should be different, comparatively speaking, due to the location on the outlet of Lake Madison. The water quality from the outlet of Lake Madison is not only determined by how much material was deposited in the lake but also by the amount of this material that was used in the biological processes within the lake. The same can be said of Site BLT9 due to its location on the outlet of Round Lake. The material discharged from Lake Madison (Site BLT8) was either deposited in Round Lake, used in biological process for growth, or transported into Brant Lake.

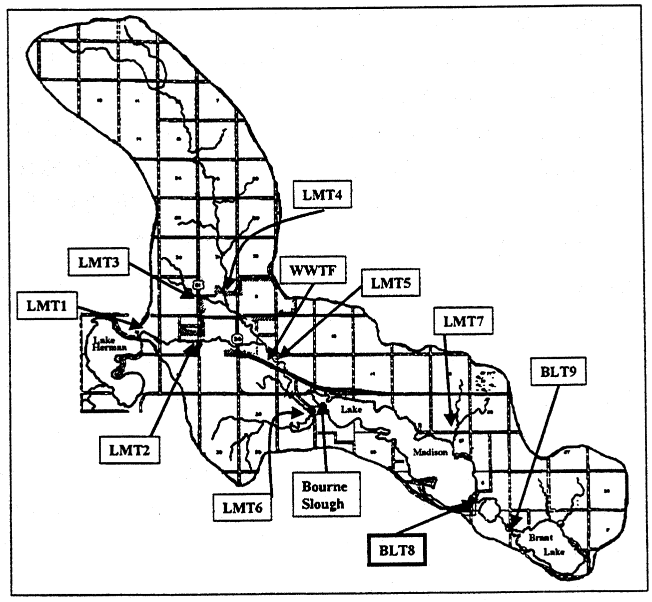


Figure 16. Location of Site BLT8.

Lake Madison acts as a sediment and nutrient sink retaining a high percentage of the nutrients and sediment discharged into its basin. The outlet water quality is a function of what has been discharged into the lake. BLT8 was monitored for the same period of time as the other sites previously discussed. No point sources are located within the area of the outlet that may have potentially affected the water quality or loading data. The regression analysis conducted between the instantaneous discharge and stage was very good ($R^2 = 0.97$, n=27, df=26).

As discussed above, the water quality data for the outlet of Lake Madison is a reflection of the water quality of the lake. Fecal coliform at the outlet did not exceed 50 colonies/100ml during the course of the investigation. However, there were several samples that exhibited concentrations ranging between 10 fecal colonies/100 ml to 50 fecal colonies/100ml which may have been due to the presence waterfowl. A comparison with the nearest inlake Site LM3 did not indicate any problems with fecal coliform. The mean coliform concentration for Site BLT8 of 20 colonies/100ml was lower than any other site (Tables 6-7).

The suspended solids (TSS) concentrations at Site BLT8, were relatively low as well (11 mg/L). The lowest mean TSS concentrations was exhibited by site LMT3 (9 mg/L). However, BLT8 exhibited the next lowest mean for this variable. The median was actually lower at 8 mg/L. There was an increase in the suspended solids concentrations during the month of April. These increased concentrations may have been due to the high rate of flows that occurred during the spring runoff that transported more material in the water. Some of the incoming solids remained suspended to be discharged from the lake. Site LMT6, which is the largest source of water, sediment, and nutrients to Lake Madison, exhibited much higher concentrations in April as well.

Ammonia concentrations were consistently higher at Site BLT8. The mean ammonia concentration was 0.27 mg/L which was the highest mean for all of the tributary sites. This was greatly influenced by the water quality from Lake Madison, as ammonia levels at all three inlake monitoring sites from Lake Madison ranged from 0.23 to 0.30 mg/L. Although ammonia was higher in concentration at this site, the higher levels occurred during the period of least runoff (March, June-Oct). During summer and late fall, algal blooms reach maximum densities and collapse. As algal cells decay, the breakdown products are released into the water column and settle to the bottom or are discharged out of the lake. This continues throughout the winter months and into March. When higher discharge rates occur, the ammonia is diluted and new growth begins to take up nitrogen. During the spring turnover when most of the discharge occurred, the concentrations dropped to 0.02 mg/L. The mean nitrate concentration was 0.18 mg/L. This was the smallest mean exhibited by any of the tributary monitoring sites. Nitrate samples did not exceed 0.4 mg/L (Table 9).

Concentrations of phosphorus found at Site LMT8 are greatly effected by the settling rate of inlake phosphorus and how much is used by for plant and animal biomass. The lake acts as a sediment and phosphorus sink retaining material that is transported from the upstream sites. Although the mean total phosphorus concentration decreased between Site LMT6 (0.309 mg/L) and Site LMT8 (0.202 mg/L), a similar reduction in dissolved phosphorus did not occur (LMT6 = 0.134 mg/L, BLT8 = 0.133 mg/L). In the early spring and fall, dissolved phosphorus concentrations are actually greater at the outlet site than at the inlet site. As the growing season intensifies, the increase in biomass requires more dissolved phosphorus, i.e. the dissolved phosphorus concentration becomes smaller at the outlet site than at the inlet site. During the late growing season the outlet concentrations are slightly higher which may indicate that an algal bloom had collapsed in the southeastern bay near the outlet of Lake Madison. As the algal bloom was decomposed by bacteria, dissolved phosphorus was released and discharged. There was also a slight drop in the dissolved oxygen level at this time. Through regression analysis, it was also indicated that there was a relatively strong relationship between total phosphorus and dissolved phosphorus concentrations during 1995 ($R^2 = 0.73$). In many cases during the early spring and summer sampling year, there was a very high fraction of dissolved phosphorus.

The nutrient and sediment loadings discharged from Site BLT8 are dependent upon how much of the nutrient and sediment material was retained by the lake. There was a substantial reduction in the amount of total phosphorus and total nitrogen but there was a large increase in ammonia loadings between LMT6 and BLT8. The lake is using some of the nitrates earlier in the season as biomass increases, Site BLT8 ammonia is released during the subsequent breakdown of algae and other vegetation and some of it then leaves the lake through the outlet.

Table 8. TOTAL LOADINGS AND EXPORT COEFFICIENTS FOR SITES 7-11
LAKE MADISON/BRANT 314 1994-1996

SITE	Water ac-ft	TALKAL lbs/yr	TSOL lbs/yr	TDSOL lbs/yr	TSSOL lbs/yr	AMMON lbs/yr	UN-AMM lbs/yr	NO3+2 lbs/yr	TKN-N lbs/yr	Org-N lbs/yr	Tot-N lbs/yr	TPO4P lbs/yr	TDPO4P lbs/yr
LMT7	842.31	584668.81	4298382.12	3978323.86	318108.83	94.08	2.05	4000.44	3329.62	3234.90	7326.97	643.46	251.15
BLT8	32748.53	14294688.32	90537698.88	89671033.15	858245.24	21892.01	1590.98	12847.09	125159.11	102879.75	138023.04	15358.34	10399.65
BLT9	34207.47	14971166.93	97073551.04	93063325.39	3926639.23	18869.99	1210.03	18105.33	140401.88	121752.68	158396.82	22040.89	7151.44
BLT10	709.90	510411.86	2593728.58	2481797.39	111921.07	41.02	1.36	1203.43	1527.95	1486.93	2726.11	630.77	454.47
BLT11	44282.67	19622076.69	119246010.01	115374508.82	3788739.05	15696.38	1339.99	22312.42	164055.63	148267.29	186735.88	21066.99	7349.88

Export Coefficients - lbs/ac/yr

SITE	Subwater-shed Acres	TALKAL	TSOL	TDSOL	TSSOL	AMMON	UN-AMM	NO3+2	TKN-N	Org-N	Tot-N	TPO4P	TDPO4P
LMT7	1920	304.52	2238.74	2072.04	165.68	0.05	0.00	2.08	1.73	1.68	3.82	0.34	0.13
BLT8	36120	395.76	2506.58	2482.59	23.76	0.61	0.04	0.36	3.47	2.85	3.82	0.43	0.29
BLT9	38760	386.25	2504.48	2401.01	101.31	0.49	0.03	0.47	3.62	3.14	4.09	0.57	0.18
BLT10	1800	283.56	1440.96	1378.78	62.18	0.02	0.00	0.67	0.85	0.83	1.51	0.35	0.25
BLT11	44000	445.96	2710.14	2622.15	86.11	0.36	0.03	0.51	3.73	3.37	4.24	0.48	0.17

Table 9. Descriptive Statistics for water quality parameters collected at sites LMT7-BLT11 for the Lake Madison/Brant diagnostic/feasibility study.

Site	Statistic	WTEMP	ATEMP	DO	FPH	FECAL	TALK	TS	TDS	TSS	AMM	UN-AMM	NO_{3+2}	TKN-N	Or-Nit	T-Nit	TPO4P	TDPO4P
	Units	°C	°F	mg/L	su	per100ml	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
LMT7	mean	7.9	54.3	10.5	8.01	217	254	2017	1914	103	0.05	0.0007	2.28	1.24	1.19	3.52	0.255	0.120
	median	4.0	51.0	11.0	8.00	30	286	2031	1914	9	0.02	0.0005	2.25	1.21	1.15	3.29	0.141	0.104
	maximum	23.5	84.0	13.5	8.25	1000	315	2569	2556	936	0.15	0.0016	3.60	2.08	2.06	4.79	1.260	0.259
	minimum	1.0	34.0	4.3	7.82	10	126	1433	1087	3	0.02	0.0001	0.70	0.63	0.61	2.22	0.052	0.052
	StDev	8.6	18.8	2.8	0.13	349	66	393	485	293	0.05	0.0005	0.92	0.50	0.49	0.86	0.363	0.069
BLT8	mean	9.1	51.1	9.2	8.51	20	178	973	962	11	0.27	0.0117	0.18	1.65	1.38	1.83	0.202	0.133
	median	5.3	46.5	10.1	8.63	10	169	936	925	8	0.17	0.0049	0.15	1.65	1.37	1.81	0.194	0.121
	maximum	25.0	82.0	14.3	9.09	50	221	1206	1198	29	0.80	0.0583	0.30	2.29	1.78	2.59	0.339	0.303
	minimum	2.0	32.0	3.6	7.77	10	151	860	856	4	0.02	0.0010	0.10	1.20	0.89	1.30	0.112	0.023
	StDev	7.4	17.0	3.2	0.46	14	25	113	117	8	0.30	0.0181	0.09	0.38	0.32	0.45	0.068	0.094
BLT9	mean	8.5	49.6	10.3	8.62	26	181	974	936	38	0.17	0.0085	0.29	1.78	1.61	2.07	0.241	0.081
	median	4.5	44.5	11.0	8.60	10	173	943	886	30	0.11	0.0052	0.20	1.80	1.76	1.96	0.216	0.073
	maximum	26.3	88.0	13.4	9.22	100	243	1208	1144	98	0.46	0.0295	0.70	2.24	2.05	2.94	0.402	0.214
	minimum	1.0	24.0	6.0	8.08	10	147	844	826	16	0.02	0.0008	0.10	1.03	1.01	1.13	0.171	0.043
	StDev	8.8	20.1	2.5	0.40	30	31	120	114	26	0.17	0.0098	0.23	0.35	0.36	0.52	0.074	0.051
BLT10	mean	7.9	53.5	10.5	8.16	96	256	1337	1293	44	0.03	0.0007	0.84	0.84	0.81	1.68	0.423	0.249
	median	3.8	50.0	10.9	8.19	75	254	1404	1388	16	0.02	0.0006	0.95	0.88	0.86	1.57	0.281	0.230
	maximum	24.5	91.0	13.2	8.39	320	340	1654	1646	296	0.09	0.0017	1.40	1.42	1.33	2.82	1.400	0.405
	minimum	1.0	24.0	6.7	7.91	10	140	691	680	7	0.02	0.0002	0.30	0.10	0.08	1.01	0.190	0.134
	StDev	8.5	22.6	2.0	0.15	101	69	283	318	89	0.02	0.0005	0.39	0.35	0.34	0.55	0.363	0.081
BLT11	mean	9.1	52.6	11.1	8.72	11	169	898	869	29	0.08	0.0055	0.21	1.33	1.26	1.54	0.171	0.059
	median	5.4	48.0	11.7	8.65	10	163	897	858	21	0.03	0.0030	0.15	1.35	1.31	1.58	0.150	0.064
	maximum	26.5	84.0	14.2	9.35	20	199	1153	1088	88	0.32	0.0238	0.40	2.06	2.04	2.16	0.350	0.117
	minimum	2.0	21.0	7.4	8.29	10	136	606	597	7	0.02	0.0011	0.10	0.69	0.61	0.79	0.105	0.023
	StDev	8.3	22.0	2.3	0.31	3	19	146	134	27	0.10	0.0068	0.13	0.41	0.44	0.38	0.071	0.030

Table 8 shows the amount of material discharged from Lake Madison (BLT8). Although this table shows the export coefficients from Site BLT8, coefficients for lake outlets such as Lakes Herman (LMT1), Madison (BLT8) and Brant (BLT11) should not be compared to coefficients calculated for tributaries sites such as LMT7 and BLT10 which have much smaller subwatersheds and no impoundment structure retaining water. Comparisons are invalid due to the nature of lakes acting as sediment and phosphorus sinks.

The total nitrogen and total phosphorus loadings discharged from Lake Madison totaled 69.0 tons and 7.7 tons, respectively. This is in comparison to 80.1 tons of total nitrogen and 11.7 tons of total phosphorus discharged into Lake Madison through LMT6. This is a 13.9% and 34.2% loss in nitrogen and phosphorus loadings leaving the lake.

The amount of ammonia discharged from Lake Madison was 506% larger than LMT6 (1.8 tons) to BLT8 (10.9 tons). The ammonia loadings increase can be attributed to the breakdown and decomposition of organic material in the lake. The concentrations were significantly greater at BLT8. The nitrate loadings for LMT6 and BLT8 decreased by 75.6% during the same time period (Table 8). Only Site LMT6 and BLT8 were included in comparisons as LMT6 is the largest contributor to Lake Madison. LMT7 loadings will be included in the overall budget calculations later in the report.

There was an 8.3% increase in total dissolved phosphorus loadings between LMT6 and LMT8 in contrast to the reduction in total phosphorus loadings. This may have been due to the algal blooms and other vegetation undergoing decomposition. An 83% reduction also occurred for the sediment loadings between LMT6 and BLT8 during 1995.

In contrast to the other sites, Site BLT8 discharged a greater amount of phosphorus during the summer even though a higher rate of water discharge occurred during the spring (Figure 17 and 18). This was due to the higher TP concentrations in the summer sampling period. Spring hydrologic loadings constituted 52% of the total discharge from BLT8 but only 39% of the total phosphorus loadings. Sixty-Seven percent of the sediment loadings and 54% of the total

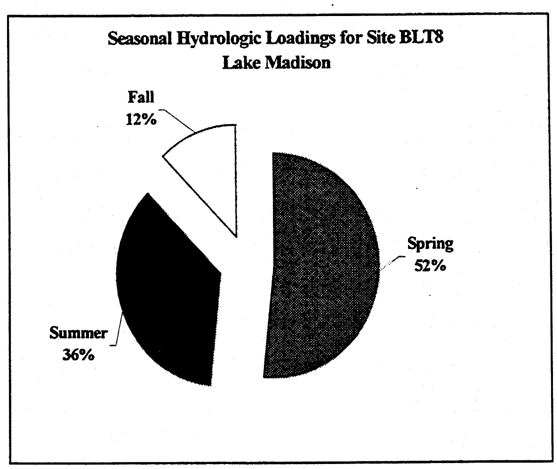


Figure 17

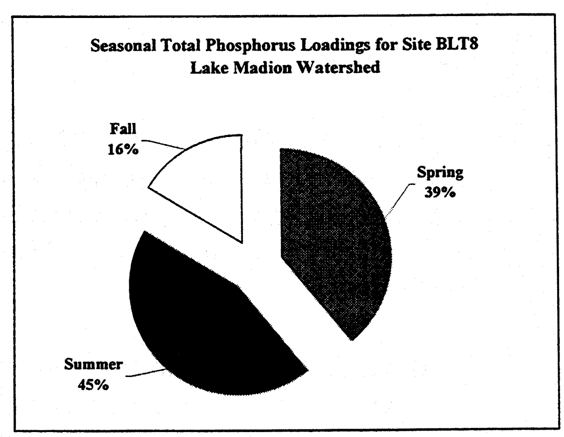


Figure 18

nitrogen loadings occurred during the spring as well.

Site BLT9

BLT9 monitored the water quality and discharge of Round Lake, which is a small 152 acre (61.5 ha) lake immediately downstream of Lake Madison (Figure 19). Excluding the ungauged runoff from the shoreline and 1-2 small but relatively insignificant tributaries, Round Lake receives its water primarily from Lake Madison. According to the AGNPS computer model, the subwatershed area is 38,760 acres (15,686.2 ha) which includes everything from the Lake Herman outlet to the outlet of Round Lake.

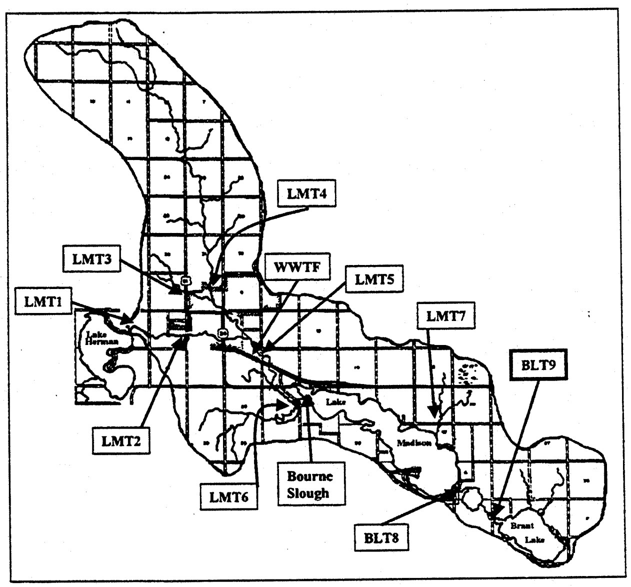


Figure 19. Location of Site BLT9.

The water quality of Round Lake is greatly affected by the discharge from Lake Madison. Although the mean ammonia (NH_3) concentration from Round Lake is less than the mean from the outlet of Lake Madison (BLT8) (0.168 mg/L vs. 0.27 mg/L) it is very similar in its trends. During the month of April, all of the concentrations dropped to 0.02 mg/L due to the high rate of water discharged into Lake Madison. This is the same type of trend that occurred for the Round Lake water quality data and discharge. Ammonia concentrations ranged from a maximum of 0.46 mg/L to a minimum of 0.02 mg/L (Table 9). The maximum concentration of un-ionized ammonia, which can be highly toxic to fish, never exceeded 0.03 mg/L (Table 9). Un-ionized ammonia concentrations are dependent upon pH and temperature. As these two parameters increase, un-ionized ammonia, as a percentage of total ammonia, generally increases as well.

The pH of Site BLT9 ranged from minimum of 8.08 su to a maximum of 9.22 su. The maximum pH occurred during the late summer when the maximum temperatures were also observed (Table 9). Incidentally, the minimum alkalinity concentration of 147 mg/L occurred on this date as well. Natural waters can range from 20 to 200 mg/L (Lind, 1985).

Fecal coliform ranged from 10 colonies per 100 ml to a maximum of 970 per 100 ml. This maximum concentration occurred on March 13, 1996 when the last sample was taken. There is a feeding area located along the shores of this lake and it was being used during the collection of the water quality data. However, as of 1998, all livestock have been removed and the land sold (Halpin, 1998).

Although ammonia concentrations were slightly lower in comparison to Site BLT8 (0.17 mg/L vs. 0.27 mg/L), the other nitrogen parameters were all slightly higher (Table 9). The concentrations at Site BLT9 are greatly effected by the water quality and discharge from Site BLT8. The ammonia discharged from BLT8 becomes slightly diluted or is used by plants and algae as it passes through Round Lake resulting in a decrease in concentration. The nitrates and other parameters increase slightly, possibly due to the feedlot and or the conversion of ammonia back to nitrates.

Total phosphorus was not significantly different between BLT8 and BLT9. The total phosphorus mean at Site BLT8 was 0.202 mg/L whereas the mean concentration for Site BLT9 was 0.241 mg/L (Table 9). The maximum value for Site BLT8 was 0.339 mg/L that occurred on August 8, 1995. The maximum value for Site BLT9 was 0.402 mg/L and occurred on the same date. The dissolved phosphorus mean for Site BLT9 of 0.081 mg/L was significantly lower than mean from Site BLT8 which was 0.133 mg/L. The dissolved fraction of total phosphorus was also lower at Site BLT9 (37%). Basically, the dissolved and particulate phosphorus reversed percentage values at Site BLT8 where they constituted 62% and 38% of total phosphorus, respectively. Site BLT9 phosphorus fractions exhibited an opposite distribution where dissolved and particulate phosphorus constituted 37% and 66%, respectively. This may have occurred owing to the higher suspended solids that were present at Site BLT9 and in Round Lake. Resuspension of the sediment in the small lake resulted in the attachment of some of the dissolved phosphorus onto the resuspended particles. A regression analysis indicated that there was a slight relationship between total phosphorus and suspended solids (R^2=0.31,df=11). The suspended solids concentrations at Site BLT9 ranged from 16 mg/L to 98 mg/L and the mean concentration was 38 mg/L. Site BLT8 ranged from 4 mg/L to 29 mg/L and the mean was 11 mg/L (Table 9).

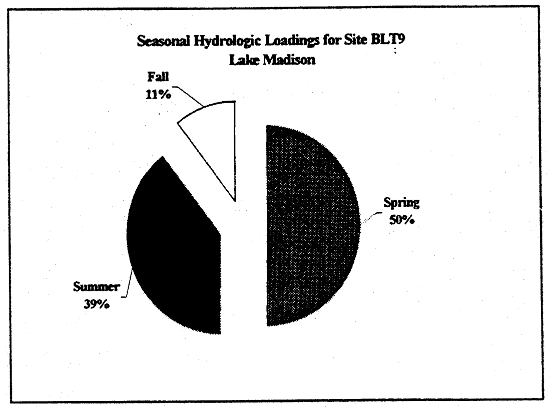


Figure 20

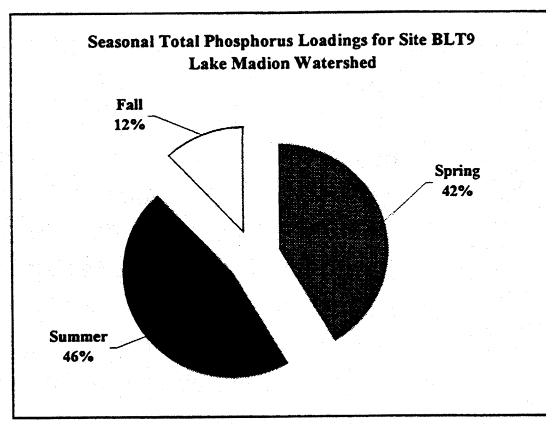


Figure 21

During 1995, 34,207.5 acre-feet of water was discharged from Site BLT9. This constituted a 4.5% increase from the 32,478.5 acre-feet calculated from Site BLT8. As is indicated from Figure 20, 50% of hydrologic loadings occurred during the spring. This is the same scenario that occurred at Site BLT8. Fifty percent of the loadings occurred during spring but over 45% of the total phosphorus loadings occurred during the summer. This indicates the effect that Lake Madison has on the water quality of Round Lake.

Total phosphorus loadings increased by 44% between BLT8 and BLT9 (Table 8). The suspended solids loadings increased by 358%. Lake Madison discharged 429.1 tons compared to 1,963.3 tons discharged from Brant Lake. This indicates that Round Lake has a significant internal loading problem. Sediment trapped in Round Lake in previous years is presently being resuspended and transported into Brant Lake.

Total nitrogen loadings increased to 79.2 tons at BLT9 from 69 tons discharged from Site BLT8. This constituted a 15% increase in overall total nitrogen loadings.

BLT10 Water Quality

BLT10 is a small 1,800 acre (728.5 ha) subwatershed that drains from the northeastern part of the Brant Lake watershed. Some steep banks with pasture and small corn and grain cropping practices characterize this watershed (Figure 22). This site can be compared to the smaller tributary sites already discussed such as LMT3, LMT4, and LMT7.

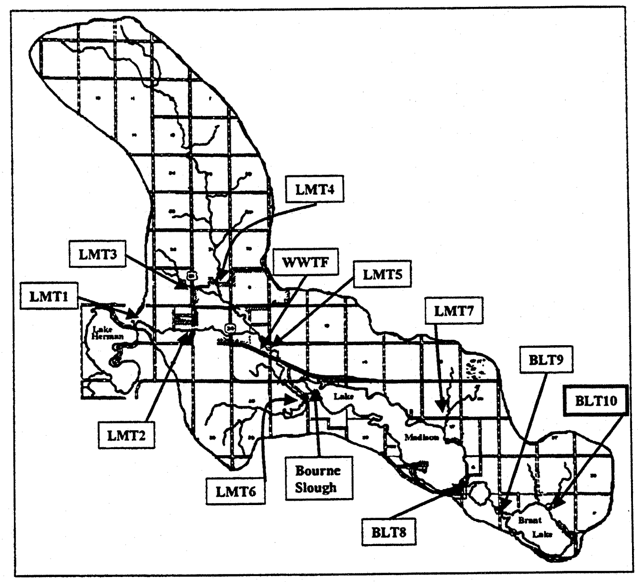


Figure 22. Location of Site BLT10.

BLT10 fecal coliform concentrations ranged from 10 to 320 coliforms/100ml. The mean and median were 96 and 75 colonies/100ml, respectively (Table 9). Concentrations were 200 coliform per 100 ml or less during the spring. The higher counts consistently occurred during the summer. AGNPS located a feedlot/feeding area in the upper reaches of this subwatershed. However, it received a relatively low rating (see AGNPS section). This feeding area, which may also be used as a summer pasture, may receive a small number of livestock during the summer months. The fecal coliform concentrations did not exceed 400 coliform per 100 ml in any of the samples.

Increases in total phosphorus concentrations can sometimes be linked to increases in fecal coliform counts. The mean and median concentrations of total phosphorus concentrations were 0.423 mg/L and 0.281 mg/L, respectively (Table 9). The highest TP concentration for the entire set of tributary samples was collected in a sample from BLT10; 1.4 mg/L observed on March 15. There were consistently high total phosphorus concentrations observed from this site. Although some of the other monitoring sites exhibited some degree of relationship between total phosphorus and suspended solids, regression analysis indicated no relationship for BLT10 (R^2 = 0.02, df = 10, n=11). Fertilizers or nutrient runoff from feedlots or grazing areas were likely primary sources of these higher phosphorus concentrations.

Dissolved phosphorus concentrations were consistently higher in this subwatershed as well. The mean dissolved fraction of total phosphorus comprised 73% of the total phosphorus. Although this is significant, other subwatersheds exhibited higher dissolved fractions such as the un-named tributary located in the northwestern part of the watershed (Site LMT3 = 84%). The dissolved phosphorus mean and median at BLT10 were 0.249 mg/L and 0.230 mg/L, respectively (Table 9). The maximum concentration was 0.412 mg/L (Table 9). Although this was not the largest concentration observed from the 11 tributary monitoring stations, it was still an excessive concentration for bioavailable phosphorus. The excessive concentrations occurred during the period of least runoff (March, June - October). During the period of high runoff (April) the concentrations were reduced to below 0.200 mg/L when dilution occurred.

Nitrate+nitrite mean and median concentrations were 0.84 mg/L and 0.95 mg/L. respectively (Table 9). Nitrates were consistently low during the month of April except for one observation. For the sample collected on April 18, 1995 the nitrate+nitrite concentration was 1.2 mg/L. In addition, there was an excessive total phosphorus concentration of 0.566 mg/L, a suspended solids concentration of 296 mg/L, 100 fecal coliform/100ml, in addition there was an increase in flow recorded on this date as well. The other increases in fecal bacteria, phosphorus and nitrate+nitrite concentrations can be attributed to nutrient runoff from grazing areas. Ammonia concentrations did not increase during the study period.

Total suspended solids levels were excessive during only one event (April 18, 1995). That TSS concentration of 296 mg/L occurred together with an increase in fecal coliform (100 coliform/100ml), nitrates+nitrites (1.2 mg/L), total phosphorus (0.566 mg/L), and total dissolved phosphorus (0.203 mg/L). After this event no other excessive concentrations were observed. A TSS concentration of 68 mg/L was observed in the following spring runoff (1996) but was not accompanied by an increase in fecal coliform or nitrate+nitrite. AGNPS indicated three critical cells within this 1800-acre subwatershed with an estimated sediment erosion rate of 8.0 tons/acre. A single critical

Table 10. Total Actual and AGNPS Loadings for Site BLT10 in Tons/year.

BLT10	Actual	AGNPS
TSS	56	479
TN	1.4	3.4
TP	0.3	1.3

cell with sediment nitrogen ≥ 9.8 lbs/acre and one critical cell with sediment phosphorus ≥ 4.9 lbs/acre were also identified. The only feedlot that was documented in this area was not rated very high for pollution potential by AGNPS (15 on a scale of 0-100). Summer grazing or a winter lot may have been in the area but was not being used when the AGNPS data was collected. This area should be field verified before any installation of BMPs takes place.

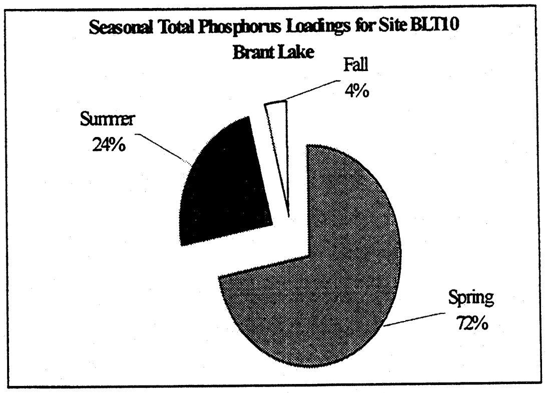


Figure 23.

Total loadings for 1995 were compared to annualized AGNPS loading data in Table 10. The results indicate that at least with the annualized version of AGNPS there is some agreement between the data determined through actual water quality data and AGNPS The units used are tons/year. This is the estimated tonnage of sediment (discounting the bedload) and nutrients delivered to Brant Lake from the 1800 acres above monitoring Site BLT10.

Over 70% of the loadings occurred during the spring. This occurred for all parameters including water and total phosphorus (Figure 23).

The export coefficients for Sites LMT7 –BLT11 can be found on Table 8. In comparison to the other subwatersheds (LMT3, 4, and 7), of similar size, the sediment export coefficient (lbs/acre/yr) for BLT10 is relatively high at 62.2 lbs/acre/yr primarily due to high land slopes (Figure 21). The nutrient export coefficients for both phosphorus and nitrogen (lbs/acre/yr) are similar excluding Site LMT3 (1400 acres). LMT3 has less phosphorus and nitrogen mass delivered from each acre than LMT4, 5, 7 and BLT10.

Site BLT11 Water Quality

The BLT11 monitoring station was placed at the outlet of Brant Lake to monitor the discharge from Brant Lake into Skunk Creek (Figure 24). The water quality of the outlet is a greatly affected by the in-lake water quality. In this particular situation, the water quality at the outlet of Brant Lake is also a reflection of all the contributions to Silver Creek. This includes the 44,000 acre (17,806.8 ha) watershed.

Table 8 shows the descriptive statistics for the water quality data collected from the outlet (BLT11). The mean concentration of fecal coliform for the outlet was 11 fecal coliform/100 ml and the median was 10 fecal coliform/100 ml. The discharge area from the lake was sampled approximately 300 meters downstream from the outfall of the lake.

There was a better access point at this location and the discharge could be readily collected due to its location near a county road.

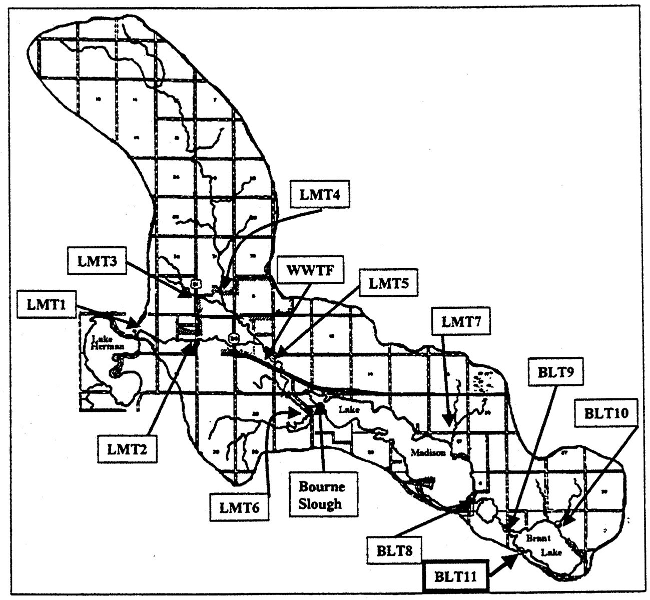


Figure 24. Location of Site BLT11.

The suspended solids mean was 29 mg/L and may have been lower if the gauging station had been placed on the immediate outfall of Brant Lake. The median was 20.5 mg/L and there was one observation at 88 mg/L. This was probably due to a large discharge from the lake during the month of April which was the month with the highest discharge. A regression analysis conducted between suspended solids and total phosphorus observations indicated that there was a definite relationship, although not extremely significant, between these two variables (R^2=0.58, d.f.=10, n=11). Another regression analysis was conducted between suspended solids and instantaneous discharge (cfs). Site BLT11 monitored the discharge from Brant Lake, but a high percentage of the suspended material is settled or trapped within the lake before the water is discharged. This was indicated by the regression analysis (R^2=0.10, d.f.=10, n=11).

The mean total phosphorus concentration for Site BLT11 was 0.171 mg/L (median=0.150 mg/L). The largest total phosphorus concentration of 0.236 mg/L and the largest suspended solids concentrations (88 mg/L) were collected on the same date. At the same time the total dissolved phosphorus concentration was comparatively low at 0.033 mg/L. An estimated 59% of the total phosphorus discharged from the lake on April 18, 1995 was attached to sediment particles. The mean fraction of dissolved phosphorus was 41.0%. This was one of the lowest percentages that was observed for all of the tributary sites. The mean concentration for dissolved phosphorus was the lowest documented for all of the tributary sites and the mean total phosphorus concentration was slightly more than the 0.164 mg/L at Site LMT3 which was the lowest mean concentration observed for all of the tributary sites.

Total nitrogen was less than 2.0 mg/L in all except 2 of the 11 samples. 2.16 mg/L and 2.17 mg/L were the only two observations >2.0 mg/L. Nitrate+nitrite and ammonia concentrations did not exhibit any excessive concentrations during the project. In fact, the maximum nitrate+nitrite concentrations did not exceed 0.4 mg/L. Ammonia did have increases during March and June of 1995 but these were very minor and can be related to the breakdown of organic matter.

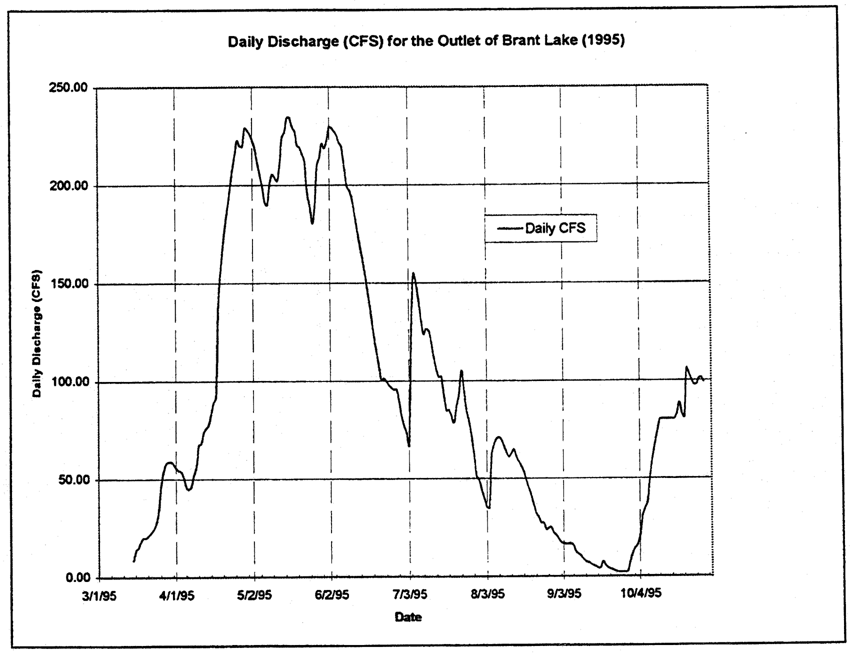


Figure 25

Nutrient and sediment loadings from Brant Lake were calculated for the water year March 16 to October 30, 1995. Lake Herman, Lake Madison, and Round Lake act as sediment and nutrient traps for Brant Lake. The outlet of Brant Lake is a reflection of the 44,000-acre watershed upstream. However, the water quality discharged from Round Lake has the greatest impact on Brant Lake.

The discharge relationship between the daily stages and instantaneous discharge was calculated through regression analysis. This analysis indicated a very strong relationship between those two variables (R^2=0.97,d.f.=23, n=26). After the relationship between stage and discharge had been determined and the daily discharge (liters/day) had been calculated, it was found that the period of highest discharge was April, May, and June of 1995 (Figure 25). The same pattern was exhibited by the other tributary monitoring sites.

The total amount of water discharged over the course of 1995 was 44,283 acre-feet. During the spring of that year (March 16 – May 31) the amount of discharge from Brant Lake was 21,344 acre-feet or 48% of the annual discharge.

As with other sites located on the outlets of the lakes within this watershed, it is hard to complete export coefficients for comparison purposes because each lake acts as a retention device trapping nutrients and sediment at different rates. The subwatersheds are also much larger than the smaller subwatersheds such as LMT3 and LMT7. Comparisons should be made between each of the monitoring stations located on lake outlets.

Seasonal loadings for TSS, TN, and TP were higher during summer (June 1 – Aug 31) than during spring or fall periods. The principal reason for higher loadings during summer were higher nutrient and sediment concentrations. The mean TSS concentrations for the spring months (March- May) was 26 mg/L whereas the summer months (June-

Table 11. Actual and AGNPS Loadings for Site BLT10 in Tons/year.

BLT11	Actual	AGNPS
TSS	1894	817
TN	93.4	88.0
TP	10.5	14.9

August) had a significantly higher mean concentration of 40.5 mg/L. This same phenomenon was exhibited by the total nitrogen (TN) and total phosphorus (TP) seasonal loadings.

The total loadings and the annual loadings calculated through the AGNPS computer program are listed in Table 11. These AGNPS loading numbers confirm with fair correspondence the loadings calculated through the water quality data. AGNPS identified 4 critical cells with an erosion rate of >8.0 tons/acre for sediment, 3 critical cells with a sediment-nitrogen erosion rate of >9.8 lbs/acre of sediment-nitrogen, and 3 critical cells with a sediment-phosphorus erosion rate of >4.9 lbs/acre within the immediate subwatershed of the outlet of Brant Lake. These cells are immediately contributing to the loadings at the outfall of Brant Lake. However, the greatest contributor of phosphorus is the discharge from Round Lake (BLT9).

Hydrologic Budgets

The hydrologic load explains how much water entered the lake and how much water left the lake. In theory, all inputs of water must equal all outputs during the course of hydrologic cycle. However, monitoring all the possible inputs to a lake is very difficult. In some cases, estimates of the water load to the lake are needed to help balance the equation. The hydrologic inputs to Lake Madison, Round Lake, and Brant Lake come from many sources; precipitation, tributary run-off, indirect runoff, and groundwater. The period of record used to develop the loadings was March 16 – October, 1995. In order to calculate the precipitation inputs, 1995 rainfall data was taken from the weather station 2 miles of east Madison. Evaporation, which is an output of water, was not collected at this weather station. The nearest weather station that collected evaporation data was 2 miles northeast of Brookings. This data set was then used for the three lakes. The amount of evaporation and precipitation in inches was converted to feet and multiplied by the individual surface area of each lake. In the case of the evaporation data, the monthly pan evaporation rates were multiplied by the Class A monthly land pan coefficients for the midwestern United States to derive a monthly evaporation rate for each lake (Roberts and Stall, 1967; in Fetter, 1988).

Lake Madison

The three main water source inputs into Lake Madison are LMT6 (input from Silver Creek), LMT7 (Wentworth Park), and precipitation. There are less significant tributaries contributing to Lake Madison which need to be considered in the overall water budget. These small tributaries were not monitored but their surface area (drainage area) was calculated using the AGNPS computer program (see AGNPS Report in the Appendix for a discussion of these individual tributaries).

Table 12. HYDROLOGIC BUDGET - Lake Madison

	Surface Area 2,799.3 acres	Volume 27,153 ac-ft	
Input Sources	**Load (ac-ft)**	**Output Sources**	**Load (ac-ft)**
Precipitation	7777.4	Evaporation	6260.4
LMT6	30335.0	Outlet (BLT8)	32748.5
LMT7	842.3	Change in Storage	1091.8
Groundwater	654.6		
Ungauged Runoff	491.4		
Totals	40,100.7		40,100.7

At the end of the monitoring period (Oct. 30, 1995) the level of Lake Madison was 0.77 foot above the spillway. The difference between the beginning (0.38 ft) and ending (0.77 ft) of the monitoring period is 0.39 foot which constitutes 1091.7 acre-feet (0.39 * 2799.3 acres) for a positive change in storage. Change in storage accounts for changes in surface elevation over the study period. A positive change occurs if the lake volume increases over the study period. In this case, the lake volume increased for all three lakes involved in this investigation. A positive increase of 1091.7 acre-ft occurred for Lake Madison during 1995 (Table 12). In addition to the 1091.7 ac-ft, there was also an additional 54.3 ac-ft that came from other undocumented sources. The changed in storage (1091.7 ac-ft) and the missing 54.3 ac-ft discharged from the outlet (total = 1,146 ac-ft) can be accounted for by assuming that the 1,146 ac-ft came from ungauged runoff or groundwater inputs.

These ungauged runoff amounts (ac-ft) were calculated by using the hydrologic export coefficients of the monitored tributaries (LMT7 and BLT10) of similar size. These individual drainage areas were 1,920 acres and 1,800 acres, respectively. The smaller subwatersheds that were not monitored during the study period were used in the ungauged runoff calculation (those tributaries which run directly into Lake Madison, Round Lake, or Brant Lake). AGNPS indicated that there were two small subwatersheds that run directly into Lake Madison from the northeast. These two were 880 acres and 240 acres in size and located directly next to the LMT7 subwatershed. Since these two were next to the LMT7 subwatershed the hydrologic export coefficient from LMT7 (842.3 ac-ft/1920 ac = 0.4387 ft/yr) was used to estimate the discharge from these 2 smaller subwatershed for a total of 491.3 ac-ft. It was assumed that any of the 40 acre cells south of Lake Madison that were not included in the ungauged runoff calculation had a minimal contribution to the overall hydrologic budget of Lake Madison. 0.4387 ft/yr was multiplied by 880 acres = 386.1 and 240 acres = 105.3 for a total of 491.3 ac-ft. The hydrologic export coefficient developed from LMT7 was also used on the ungauged 2040 acre subwatershed draining into Round Lake (0.4387 *2040 = 894.9 ac-ft) which constituted 894.9 ac-ft of ungauged runoff into Round Lake. The export coefficient derived from the BLT10 subwatershed was used for the two smaller subwatersheds located in the Brant Lake Subwatershed (729 acres and 1080 acres). Again the 40-acre cells that were not monitored and drained directly into the Lakes were assumed to have a negligible impact on the lake volume.

This methodology of using the LMT7 and BLT10 hydrologic export coefficients was also used with the nutrient and sediment loading calculations for the smaller ungauged tributaries. The total nitrogen export coefficient from LMT7 (TN in lbs/ac/yr) was multiplied by the surface area of the subwatershed (acres) to derive the total loadings for nitrogen (lbs/yr). The nutrient and sediment export coefficients from LMT7 were used to calculate the total loadings from the three ungauged tributaries on Lake Madison and Round Lake. The export coefficients from BLT10 were used to calculate the total loadings from the two smaller ungauged tributaries draining into Brant Lake.

After the estimates of ungauged runoff were added to the Lake Madison inputs, the water budget was still short 842.31 ac-ft. The only other input source not yet included in the budget was groundwater. Inputs from groundwater are generally very difficult to assess and the amount of water needed to balance the hydrologic budget seemed low. However, the regression equations used to calculate the daily discharge estimates were very good (LMT6 R^2 = 0.98, and BLT8 R^2 = 0.97). This area of South Dakota has been in a wet cycle and the water table has been above normal. Groundwater inputs to the lake may be more extensive during a dry cycle. There may be a large groundwater input to Lake Madison as the groundwater output is not taken into consideration when developing the budget.

Round Lake

To determine the hydrologic budget for Round Lake the surface area of Round Lake had to be determined from existing topography maps. After planimetering the area of Round Lake on the topography map, it was determined that the lake's surface area was approximately 152 acres. The contribution from ungauged runoff to Round Lake was calculated by using the export coefficients for Site LMT7. This ratio of 2.2795 ft/acre was then divided into 2040 acres which is the only ungauged tributary located within the immediate subwatershed of Round Lake. From this calculation, ungauged runoff was

Table 13. HYDROLOGIC BUDGET – Round Lake			
	Surface Area 152 acres	Volume N/A	
Input Sources	Load (ac-ft)	Output Sources	Load (ac-ft)
Precipitation	422.3	Evaporation	339.9
BLT8	32748.5	Outlet (BLT9)	34207.5
Groundwater	555.4	Change in Storage	73.7
Ungauged Runoff	894.9		
Totals	34621.1		34621.1

assumed to be 894.9 ac-ft (0.4387 ft/yr * 2040 acres). Again, the 40 acre cells used in the AGNPS program that were immediately adjacent to Brant Lake were assumed to have a negligible impact on the hydrologic budget of Round Lake.

Brant Lake

Brant Lake has a surface area of 1000 acres and is the primary source for Skunk Creek. Brant Lake is hydraulically connected to Lake Madison through Silver Creek and the North Skunk Creek Aquifer (Figure 9). The hydrologic budget for Brant Lake is very similar to the two previous lakes. The calculations for ungauged runoff were also calculated in the same manner except that the hydrologic coefficient from Site BLT10 was used on the two ungauged tributaries (720 and 1080 acres).

Table 14. HYDROLOGIC BUDGET – Brant Lake			
	Surface Area 1000 acres	Volume 11,000	
Input Sources	Load (ac-ft)	Output Sources	Load (ac-ft)
Precipitation	2778.3	Evaporation	2236.4
BLT9	34207.5	Outlet (BLT11)	44282.7
BLT10	709.9	Change in Storage	450
Groundwater	8563.5		
Ungauged Runoff	709.9		
Totals	46969.1		46969.1

The difference between Lake Madison, Round Lake, and Brant Lake is that there is a much larger groundwater component (8,563.5 ac-ft) for Brant Lake. For all surface water components that were monitored the regression analysis was relatively significant between the independent variables (stage) and the dependent variable (discharge). The R^2 values for the regression analysis from BLT9, 10, and 11 ranged from 0.87 to 0.97 indicating a significant relationship between these two variables. Brant Lake did gain a significant amount of water from other sources that were not monitored. This lake is hydraulically connected to the North Skunk Creek Aquifer which had a significantly larger impact on Brant Lake compared to Lake Madison. Also Brant Lake is the fourth and final lake located in this chain of lakes. This may have resulted in a low groundwater input to Lake Madison and Round Lake and a higher groundwater input into Brant Lake as Brant Lake is at the bottom of the chain (lower elevation).

Suspended Solids Budget

Lake Madison

Based on the suspended solids loading data collected during 1995 from Site LMT6, suspended solids (sediment) do not appear to be an impairment for Lake Madison. According to the data collected, including all of the inputs in Table 6, Lake Madison shows less than one acre-foot of sediment per year entering the lake from all documented sources. Assuming that the sediment is uniform silt, the suspended solids load was divided by the total pounds of sediment entering the lake (5,541,340 pounds) by a factor of 135 pounds per cubic feet (Uniform Silt = 135 lbs/ft^3) (Kuck, 1998). The cubic feet were then converted to acre-feet for a total of 0.94 ac-ft of sediment. There may be more sediment entering Lake Madison from the bedload of a stream. However, all tributary samples collected during this investigation were collected with a suspended sediment sampler (DENR SOP, 1998). This sampling method is much more accurate for calculating sediment loadings than using the simple grab sample method. If the amount of suspended solids entering

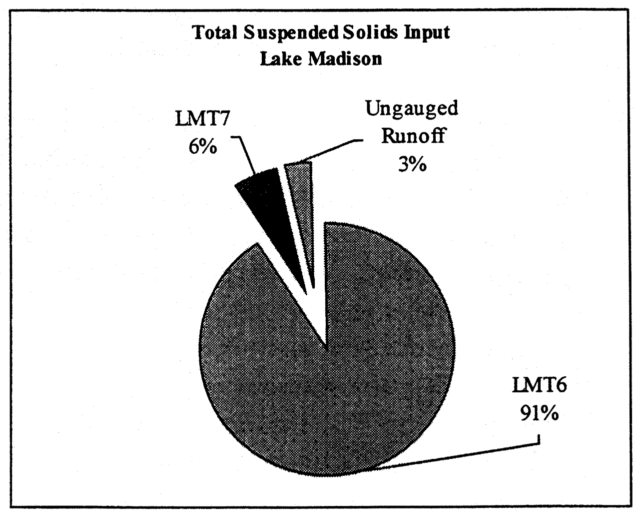


Figure 26

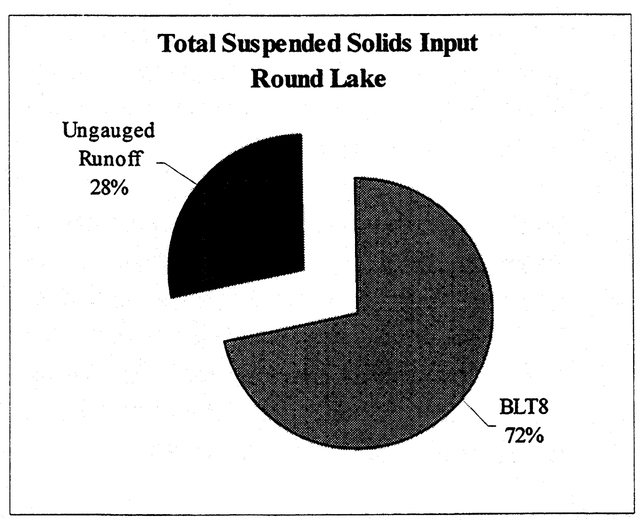


Figure 27

Lake Madison is doubled to include sediments that may have been missed, the rate of deposition of sediment for Lake Madison would still be less than 0.009 inches over the entire surface area of Lake Madison. It is not known how much of the suspended solids are actual inorganic sediment or organic matter (decaying plants and algae). Due to the amount of intensive agriculture, some of the suspended solids would be inorganic. However, during the course of the study, Lake Madison accumulated 2346.1 tons of sediment, which constitutes 0.0003 inches of sediment over the entire surface area of the lake.

Round Lake

The suspended solids loadings for Round Lake were similar to Lake Madison for the year 1995. The total load delivered to Round Lake was 598 tons but the total sediment load discharged from Round Lake was 1963 tons. The 1365 tons discharged from Round Lake indicate another input probably from internal loadings. Using the conversion of 135 pounds of uniform silt per cubic foot, the amount of sediment discharged into the lake constitutes < 1 acre-foot of sediment.

The outlet of Lake Madison (BLT8) had a mean TSS concentration of 11 mg/L compared to a mean of 38 mg/L at BLT9. The median concentrations were significantly different as well. The explanation for this difference may be the shallowness of Round Lake combined with current and wind wave action which may have resuspended surficial sediments and transported them out of Round Lake and into Brant Lake.

Brant Lake

The suspended solids budget for Brant Lake was very similar to that of Lake Madison as well. The total amount of suspended solids discharged into Brant Lake was 2075.3 tons which constituted 0.71 acre-foot of sediment. This 0.71 acre-foot of sediment constitutes only 0.008 inches of sediment over the entire surface area of Brant Lake.

During 1995, Brant Lake accumulated approximately 180.9 tons of sediment. As mentioned in the Lake Madison sediment budget discussion, suspended solids are not a significant impairment for Brant Lake. Figure 28 displays the contributors to the Brant Lake sediment budget.

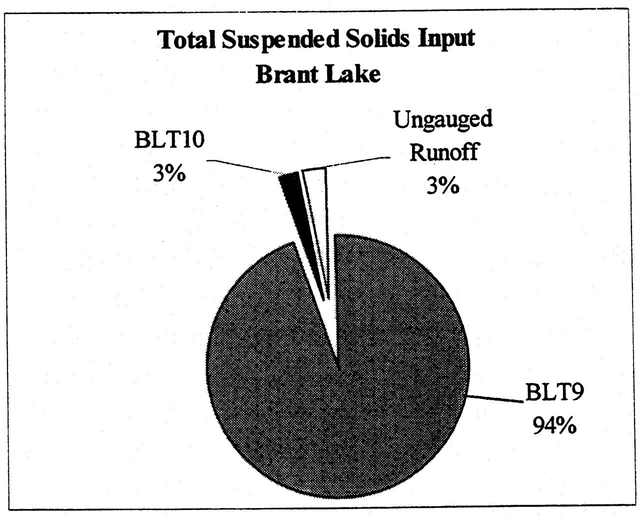


Figure 28

Nitrogen Budget

Lake Madison

Nitrogen is water soluble which makes it very difficult to estimate groundwater contributions. Depending on the time of year and the agricultural practices on the surface of the land, nitrogen concentrations can vary greatly. For the purpose of this study, a total nitrogen concentration of 3.83 mg/L was used for the groundwater input. Most of this was in an inorganic form (>90%), i.e. nitrate+nitrite (NO_{3+2}) or N_2. This concentration of nitrogen was estimated from groundwater samples collected from wells located northwest of the lake. The wells are used for monitoring the impact of the City of Madison and the Lake Madison Sanitary District infiltration/percolation basins on the ambient groundwater.

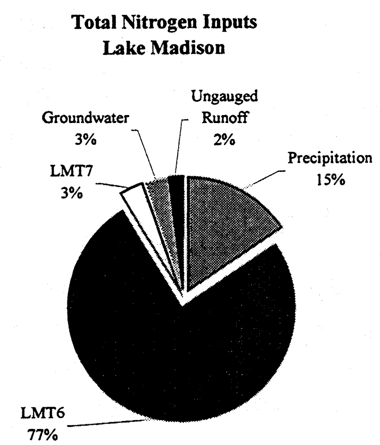


Figure 29

Groundwater nitrogen does not heavily impact Lake Madison since groundwater nitrogen comprises only 3% of the total nitrogen budget for the lake. Because it is difficult to remove nitrogen from the system, groundwater should not be a concern to the overall budget. The input from precipitation was estimated at 13.1 kg/ha/yr (11.685 lbs/ac/yr) and constituted 15% of the overall nitrogen budget (USEPA, 1990). Precipitation nitrogen was assumed to be in an inorganic form as well. A display of the nitrogen inputs is shown in Figure 29.

Based on the data collected during 1995, the inlake volume of total nitrogen in Lake Madison increased by 73, 310.4 lbs. Assuming that groundwater and precipitation inputs are primarily inorganic, the majority of this retained nitrogen was inorganic (>87%). However, the lake did discharge over 18,200 lbs of ammonia (NH_3). Most of the ammonia was discharged during the summer when algal blooms occur. As the algal blooms collapse, one of the primary byproducts of biodegradation is ammonia. Organic nitrogen was also retained in the lake but at a lesser amount than for inorganic. Algae cells consist of organic nitrogen and other materials and most of the organic nitrogen discharged through the outlet was contained within the algal cells. As some species of blue-green algae are able to convert unusable forms of nitrogen (N_2) into usable forms, nitrogen is very difficult to control. Phosphorus is more easily managed. Most of the nitrogen discharged into the lake was in inorganic forms (NO_{3+2}). Seventy-five percent of the nitrogen output from Lake Madison was in the organic form.

Round Lake

The inlake volume of total nitrogen for Round Lake actually decreased by 5,023.8 lbs. BLT8 constituted 90% of the total nitrogen budget for Round Lake. Since over 75% of the nitrogen discharged from Lake Madison was in the organic form then it only makes sense that the majority of the nitrogen inputs into Round Lake were in the form of organic nitrogen (>75%). Round Lake has a much smaller surface area (152 acres) which allows for a much lower residence time. This allows the material entering Round Lake to be transported quickly through the system into Brant Lake.

Brant Lake

As stated in the Round Lake discussion, organic nitrogen was the predominant species discharged into Brant Lake. For the total nitrogen budget of Brant Lake, BLT9 constituted 60% of the budget. However, groundwater was a significant portion of the overall budget for nitrogen (Figure 30). Groundwater and precipitation were assumed to be in an inorganic form and so were not included in the organic portion of the nitrogen budget.

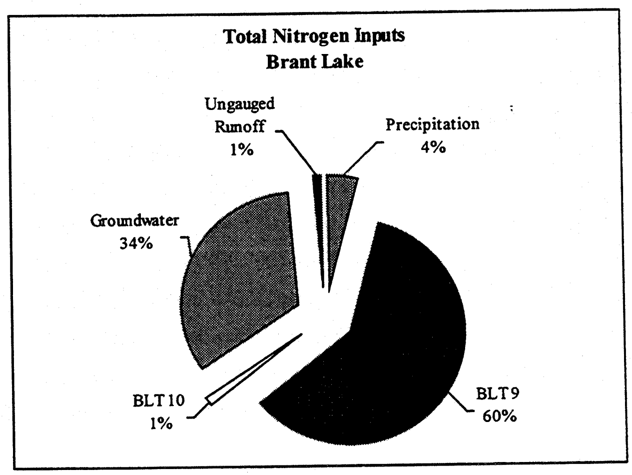


Figure 30

The inputs of nitrogen to Brant Lake totaled 264,740.6 lbs whereas the outputs totaled 186,740.0 lbs This increased the inlake volume of total nitrogen for Brant Lake by a total of 78,000.6 lbs of total nitrogen. This excessive amount of nitrogen was primarily organic nitrogen (algae and other aquatic vegetation). Approximately 80% of the total nitrogen that was discharged from the lake was in the organic form as well. Again, this large amount of organic material was primarily discharged during the summer (50%). Brant Lake actually lost 25,027.7 lbs of organic nitrogen during 1995 assuming that atmospheric and groundwater inputs were inorganic. Summer is the most productive period for aquatic vegetation and 50% of the nitrogen discharge that occurred during the summer was comprised of the organic nitrogen stored in algal and plant biomass.

Phosphorus Budget

Lake Madison

Phosphorus inputs to Lake Madison during the 1995 sampling season totaled 25,186.5 lbs (11,422.4 kg). Site LMT6 was responsible for 92.7% of the total phosphorus delivered to the lake (Figure 31) but constituted only 76% of the hydrologic input. Groundwater constituted less than 1% of the phosphorus budget.

Mean total phosphorus concentration from groundwater samples collected in 1995 was 0.063 mg/L. This concentration was then multiplied by the amount of groundwater discharged to each of the individual lakes.

Site LMT7, which monitors a small subwatershed northeast of Lake Madison, contributed 3% of the total phosphorus budget for Lake Madison. The ungauged runoff was assumed to provide an insignificant contribution to the lake as well.

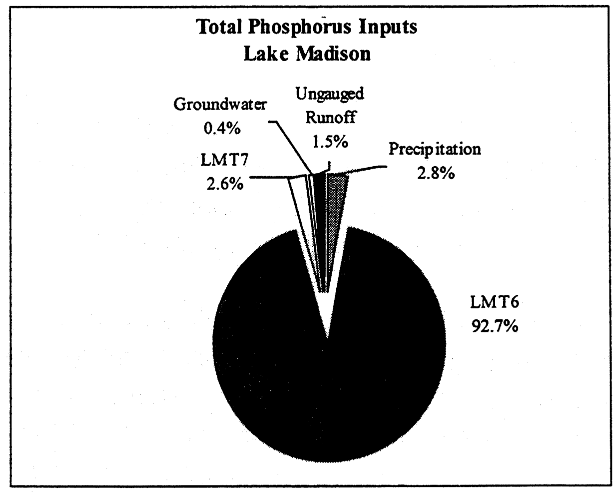


Figure 31

Lake Madison retained 9,828.2 lbs of total phosphorus during 1995. More phosphorus entered the lake than left the lake through external sources (BLT8). Fifty percent of the phosphorus discharged into Lake Madison through Bourne Slough was received during the spring season, which is when 54% of the hydrologic load occurred. The total phosphorus loading during the spring is then used primarily for algal production during the summer. There is a lag period for the phosphorus to work its way through the Lake Madison system allowing algae to use the bioavailable phosphorus. The material discharged into the lake during the spring would take some time to work its way to the outlet which is why the loading rate for the outlet is slightly higher during the summer. This also allows phosphorus attached to some of the sediment sufficient time to settle to the bottom of the lake.

Silver Creek (LMT6) delivered 38% of the total dissolved phosphorus load during the spring and 38% during the summer. However, Lake Madison discharged significantly more dissolved phosphorus during the summer (55%). Dissolved phosphorus may have been released from the sediments during the summer and discharged. However, another explanation is that during the summer, several algal blooms may have died off that resulted in a release of dissolved phosphorus.

Round Lake

Round Lake, which is only 152 acres in size, received 16,185.1 lbs of phosphorus from external sources. It discharged a total of 22,040.89 lbs. This additional phosphorus may have accumulated during low water years and from sediment discharged into Round Lake from Lake Madison or ungauged runoff. High flow periods allow accumulated sediment and phosphorus to be resuspended and discharged into Brant Lake. As mentioned previously, Lake Madison discharged a majority of phosphorus (44%-TP, 55%-DP) during the summer. Round Lake discharged a majority of phosphorus (46%-TP, 40%-DP) during the summer as well.

Brant Lake

The primary contributor of total phosphorus to Brant Lake was Round Lake (BLT9) (Figure 32). Groundwater and precipitation contributions were estimated using the same method described for Lake Madison. A mean concentration of 0.063 mg/L total phosphorus was used to calculate the groundwater contribution.

Although groundwater constituted 6% of the total phosphorus budget for Brant Lake, it is not a significant contribution in comparison to that of BLT9. When ungauged runoff and BLT10 were added, they contributed approximately 6% of the total phosphorus budget as well. BLT10 discharged over 70% of the total phosphorus load during the spring runoff period. Over 70% of the total discharge from this small subwatershed occurred during this time period as well.

Brant Lake accumulated 3,951.9 lbs of total phosphorus during 1995. 1,754.2 lbs of total dissolved phosphorus also accumulated in Brant Lake. During the summer, Brant Lake discharged over 50% of its phosphorus load. This is in comparison to Site LMT6 (Silver Creek inlet to Lake Madison) which discharged 50% of its TP load into Lake Madison during the spring. This correlates with the inlake TP concentrations as well. Significantly higher TP concentrations occurred during the summer.

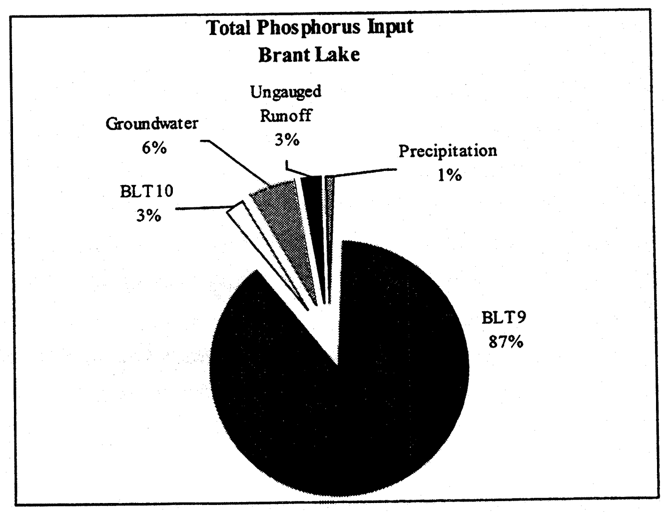


Figure 32

Urban Runoff

Urban stormwater runoff was, prior to 1980, considered to be an insignificant source of water quality degradation. However, the completion of the National Urban Runoff Program (NURP) indicated that significant detrimental effects on the water quality of the receiving water had occurred. In 1987, the Clean Water Act required municipalities with a population of 100,000 or more to apply for a permit under the National Pollutant Discharge Elimination System (NPDES). This permit emphasized the use of Best Management Practices (BMPs) to reduce pollutant loadings. Although cities smaller than 100,000 people were not required to obtain a NPDES permit, they could still have a significant impact on local receiving water bodies and should implement BMPs to improve the water quality of their urban runoff (USEPA, 1992(2)).

During 1995, three samples were collected between upstream Site LMT2 and downstream Site LMT5 on Silver Creek. Three samples were also collected on another sampling site located between Sites LMT3 and 4 and the downstream Site LMT5 on Memorial Creek (Figure 33). However, not enough information was gathered from these 6 samples. To determine the impact of storm sewers from the city of Madison on Silver Creek, the storm sewers were monitored during the spring and summer of 1997. Three ISCO, Model 6700, automatic samplers were installed at three individual sites within the city of Madison. These automatic samplers were to gather water quality data from three distinct areas of Madison.

Sampling sites within the city were selected by their runoff representativeness, landuse representativeness, and accessibility. The sampling sites were also selected in consultation with personnel of the city of Madison.

The first sampler was to be installed at the intersection of Union and 4th Street to sample the water quality from the small industrial section of the city (Site LMC-1). However, the manhole in which this sampler was to be placed was not deep enough for the sampler to be installed correctly. After investigating the storm sewers aligned along Union Street it was determined that the best possible site for accessibility and sampling capability was the intersection of Union and Center Streets (Figure 33). Although there was some industry within this drainage area, this section of the city is predominantly residential.

The second sampling site was placed north of Sixth Street between Chicago and Liberty Avenues (Site LMC-2). This section of the storm sewer system drains a small residential area in northwest Madison (Figure 33).

The third and final automatic sampler was placed next to a 72-inch pipe which drains much of main street and the downtown area of the city (Site LMC-3). This section of the city is a mixture of some light industry, commercial and agri-business as well as some residential areas. The pipe drains to the east, passes under a railroad track and discharges into Memorial Creek near the Railroad Bridge.

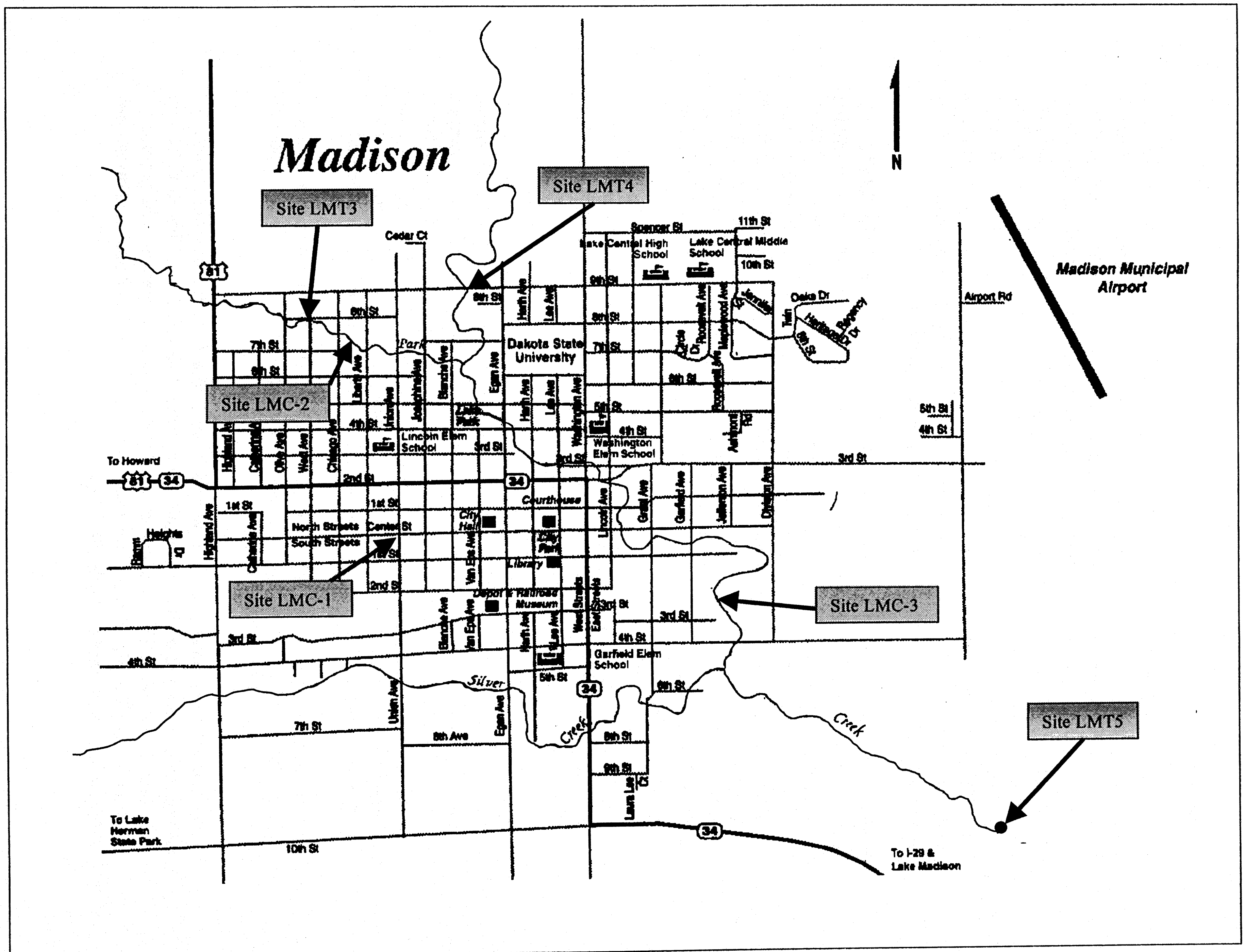


Figure 33. Location of urban sampling sites and nearest tributary monitoring sites within the city of Madison.

The first two automatic samplers were placed directly within the storm sewer manholes. Also installed with the samplers were Model 730 ISCO bubbler modules used to monitor and record the stage of the water. Once the stage reaches a designated depth called the setpoint the sampler turns on and begins collecting the sample. Each site was assigned a specific setpoint. The third sampler was placed in a field enclosure which was fastened to the 72-inch concrete culvert.

The automatic samplers were installed according to the following guidelines:

1. the intake hose was located above the channel bottom in an area of well-mixed flow.
2. the sampler was placed at the minimum height above the channel which would allow the sampler pump to work with minimum effort.
3. the sampler was programmed to collect 1000 ml after the set point had been reached and to collect 1000 ml every 5 minutes until a total volume of 5000 ml had been reached. The composite 5000 ml sample was collected in an ice cooled 9.4 L container where it remained until the sampler could be serviced, as soon as possible, by personnel from the Lake County Conservation District.

Once the composited sample had been removed from the automatic sampler, it was taken back to the NRCS office to be processed and sent to the South Dakota Health Laboratory to be analyzed.

The following parameters were chosen for laboratory analysis:

Fecal Coliform	TotalSuspended Solids	Ammonia
Total Phosphorus	Dissolved Phosphorus	Cadmium
Chromium	Lead	Mercury
	pH	

Concentrations of Parameters in Stormwater Runoff

All samples collected in 1997 were collected between May and August. The first samples for three sites were collected on May 5, 1997 and the last samples were collected on August 25, 1997. High levels of bacteria (fecal coliform) were found at all three sites (Table 15). The National Urban Runoff Program (NURP) reported that urban runoff typically contains coliform densities of 10,000 to 100,000 organisms per 100 ml.
The fecal coliform count per 100 ml ranged from 10 to 340,000, 10 to 15,000,000 (MPN), and 10 to 120,000 from Sites LMC-1, LMC-2, and LMC-3, respectively (Table 15). There are some potential health risks associated with primary (swimming) and secondary (boating) contact recreation that takes place in water bodies exhibiting high counts of these bacteria (USEPA, 1993). Urban samples typically contain higher

densities of coliform bacteria. Pet and bird wastes can be sources of the increased presence of bacteria. Organic wastes and sanitary sewer overflows can also be sources.

Total phosphorus concentrations ranged from a minimum value of 0.167 mg/L (Site LMC-1) to a maximum value of 2.070 mg/L (LMC-3). The mean total phosphorus concentrations from each of the city sites were significantly larger than any of the other tributary sites that were monitored during 1995. Site BLT10 located in the Brant Lake watershed exhibited the highest mean for the Lake Madison and Brant Lake tributary sites (0.423 mg/L). In comparison, the largest mean exhibited from the city's sites was 1.152 mg/L calculated from Site LMC-1 samples (Table 15). This scenario was not observed with the total dissolved phosphorus concentrations. The mean dissolved phosphorus concentrations for LMC-1, 2, and 3 were 0.176, 0.140, and 0.181 mg/L, respectively. The largest concentrations for 11 tributary sites sampled in 1995 was 0.255 mg/L calculated from Site LMT4. The dissolved phosphorus concentrations for the city sites ranged from a minimum concentration of 0.060 mg/L (Site LMC-2) to a maximum of 0.415 mg/L (LMC-3). Urban runoff typically contains high concentrations of nutrients. As explained earlier, nutrients encourage undesirable algal blooms. The sources of nutrients in urban runoff are chemical fertilizers used on lawns, parks, and golf courses as well as other chemicals from roads, sidewalks, parking lots, homes, and commercial sites (Terrene, 1994).

Total suspended solids exhibited very high concentrations for all but two of the samples collected during the summer of 1997. Concentrations ranged from a minimum of 12 mg/L (Site LMC-2) to a maximum of 1,636 mg/L collected from Site LMC-1 on June 30, 1997. Mean concentrations were 661, 463, and 538 mg/L for Site LMC-1, 2, and 3, respectively. Again, the mean concentrations of the city sites were significantly higher than any of the tributary sites sampled in 1995. Suspended solids or sediment (organic and inorganic) are derived from many areas. Sediment loading occurs from soil erosion and runoff from construction sites and other urban land. Urbanization increases the rate of storm water runoff by removing vegetation changing slopes and creating impermable surfaces (e.g. asphalt, cement, and pavement). The increased rate of runoff transports sediment from erosion, litter and road sanding. Other pollutants such as nutrients and metals attach to the sediment particles and are transported downstream as well (USEPA, 1993; Terrene, 1994).

To determine whether the high total phosphorus concentrations were sediment based, a regression analysis was conducted between total phosphorus and suspended solids concentrations. The analysis indicated that high concentrations of total phosphorus were significantly related to high concentrations of suspended solids (R^2=0.80,df=47). Another regression analysis indicated that there was not a significant relationship between suspended solids and the dissolved phosphorus concentrations (R^2=0.06,df=42).

City mean ammonia concentrations were significantly higher than the mean concentrations from tributary samples collected in 1995. The mean concentrations for city sites were 0.368, 0.359, and 0.443 mg/L at Sites LMC-1, 2, and 3, respectively. The highest mean observed from the tributary sites in 1995 was 0.27 mg/L from the outlet of Lake Madison (BLT8). The ammonia concentrations from the city ranged from a minimum concentration of 0.02 mg/L (LMC-1) to a maximum concentration of 1.170 mg/L (LMC-3). The ammonia concentrations were consistently high, in comparison to the tributary sites, throughout the summer of 1997 as evidenced by the high mean and median ammonia concentrations in Table 15. Urban sources of ammonia are similar to the sources for bacteria and nutrients.

Dissolved oxygen concentrations ranged from a minimum concentration of 1.20 mg/L (LMC-3) to a maximum of 11.80 (LMC-3) (Table 15). The mean concentrations for Sites LMC-1, 2, and 3 were 4.96, 6.49, and 6.53 mg/L, respectively. Oxygen demanding matter such as sediment (inorganic and organic), litter, and organic wastes, among others create low oxygen conditions in receiving water bodies especially during periods of warmer temperatures. In fact, a major urban runoff event into a stream can severely deplete the creek of oxygen. In addition, the water temperature of urban runoff is typically higher than in other forms of runoff due to the nature of the substrate, i.e. pavement and sidewalks, which tend to warm up more faster. Higher temperatures further reduce the ability of water to hold as much oxygen.

pH for urban samples collected in 1997 ranged from a minimum of 6.66 su (LMC-3) to a maximum of 8.23 su (LMC-3). These values were not significantly different from tributary samples collected in 1995.

Heavy metals analysis of all the urban samples included the following: cadmium, chromium, lead, and mercury.

Cadmium mean concentrations were not significantly different between sites, although site LMC-2 (predominantly residential) was slightly less. The mean concentrations for Sites LMC-1, 2, and 3 were 0.950, 0.656, and 1.24 micrograms per liter (µg/L), respectively. An assessment of urban Mid-Atlantic Coast runoff conducted by the Metropolitan Washington Council of Governments indicated that an average concentration for cadmium was 1.0 µg/L. The values collected from city of Madison sites fall close to this average concentration. The 1985 *Standard Methods* states that U.S. drinking waters reported a mean of 8.2 µg/L. Sources for cadmium can be metal electroplating, pigments in paints, and deterioration of galvanized pipe (Terrene Institute-Urbanization and Water Quality, 1994; Standard Methods, 1985). A cadmium concentration of 200 µg/L is toxic to certain fish (Standard Methods, 1995).

According to the 1995 "*Standard Methods for the Examination of Water and Wastewater*", the hexavalent chromium concentration of U.S. drinking waters has been reported to range between 3 and 40 µg/L with a mean of 3.2 µg/L. Hexavalent chromium concentrations ranged from a minimum of 1.00 µg/L to a maximum of 1.8 µg/L collected from Site LMC-3. The highest mean concentration of 1.12 µg/L was recorded from Site LMC-3 as well (Table 15). There were only two observations from the entire chromium data set (n=27) which were greater than 1.0µg/L. Hexavalent chromium can originate from industrial sources, as well as paint pigments and from the breakdown of galvanized and chrome-plated products (USEPA-1993 and Terrene, 1994).

Total recoverable lead concentrations ranged from a minimum concentration of 1.00 µg/L (LMC-2) to a maximum concentration of 109.00 µg/L (LMC-1). The mean concentrations for Sites LMC-1, 2, and 3 were 47.18, 16.22, and 46.62 µg/L, respectively. LMC-1 and LMC-3 monitored areas with at least some industrial and commercial properties. LMC-2 monitored an area of Madison dominated by a residential area. Traffic and business related activities would not be as prevalent in that area of the city. The data collected from the Mid –Atlantic Coast discussed previously reported average lead concentrations for urban areas at 389 µg/L and suburban areas at 18 µg/L (Terrene-Urbanization and Water Quality, 1994). The 1995 "*Standard Methods for the Examination of Water and Wastewater*" reported that lead in natural waters averaged 5 µg/l and but concentrations reaching 400 µg/L have been recorded. Sources of lead can be from scraping and painting bridges as well as from industrial areas and dissolution of old lead plumbing (Terrene Institute, 1994 and Standard Methods, 1985).

Total mercury was often non-detectable at all monitoring sites (<0.2µg/L). There were two samples with mercury higher than 0.2 µg/l. The concentration in these two samples was 0.3 and 0.4 µg/L. Approximately 2,700 to 6,000 tons of mercury are released annually into the atmosphere by natural degassing from the Earth's crust and oceans. Other sources of mercury are from the burning household and industrial wastes and coal (Foulke, 1994).

Other parameters that were not analyzed but are typically present in urban runoff are oil and grease, chlorides, trash and debris, all of which can produce varying degrees of degradation in the receiving water body. The impervious surfaces found in urban areas result in a complete change of hydrology. Paved surfaces absorb less rainfall and increase the velocity of stormwater runoff. This increase in velocity transports sediment and other pollutants more rapidly and with more force, which can result in streambank erosion. With the increased velocity, sediment and other pollutants are not allowed to settle out as they naturally would in a wetland and grassed waterway. The sediment load is completely discharged into the receiving water body which can severely degrade the aquatic habitat.

Loading Calculations to Silver and Memorial Creek

The estimated area of the city of Madison used to calculate sediment, nutrient, and heavy metal loadings to Silver and Memorial Creek was 2,215 acres. The entire city is larger but the urban area, which is primarily drained by the storm sewer network, is located on the eastern side of Highway 81/ Highland Avenue. The surface areas for twelve individual zones were estimated by planimetering each zone from a 1996 zoning map of the city of Madison (Table 16). These twelvezoned areas of the city were then placed into five general land use categories and their surface areas totaled (Table 17). All residential zones were placed into residential, all industrial zones were placed into industrial, etc.

The airport, which is located in the northeastern part of the city, was not included in this analysis as it is not serviced by the storm sewer system. In addition, the light manufacturing zone in the southeastern part of the city (south of Highway 34) was excluded for the same reason.

Table 15. Statistics for selected constituents from stormwater runoff at three sampling sites within the City of Madison collected during the summer of 1997.

SITE	Statistic	WT °C	DO mg/L	FPH su	FECAL** /100 mL	TSS mg/L	AMM mg/L	Un-Amm mg/L	TP mg/L	TDP mg/L	TOTAL RECOVERABLE CADMIUM µg/l*	HEXAVALENT CHROMIUM µg/l	TOTAL RECOVERABLE LEAD µg/l	TOTAL MERCURY µg/l	HARDNESS µg/l
LMC-1	**Mean**	**21.5**	**4.96**	**7.57**	**79,144**	**661**	**0.368**	**0.0076**	**1.152**	**0.176**	**0.950**	**1.00**	**47.18**	**0.200**	**124**
LMC-1	**Median**	**24.0**	**4.80**	**7.55**	**40,000**	**550**	**0.430**	**0.0058**	**1.035**	**0.170**	**0.750**	**1.00**	**29.25**	**0.200**	**128**
LMC-1	**Min**	**10.4**	**3.00**	**7.03**	**10**	**192**	**0.020**	**0.0001**	**0.718**	**0.067**	**0.500**	**1.00**	**21.20**	**0.200**	**85**
LMC-1	**Max**	**25.0**	**7.60**	**8.13**	**340,000**	**1636**	**0.960**	**0.0270**	**1.960**	**0.308**	**2.100**	**1.00**	**109.00**	**0.200**	**160**
LMC-1	**StDev**	**5.2**	**1.44**	**0.32**	**121,143**	**426**	**0.267**	**0.0073**	**0.407**	**0.059**	**0.562**	**0.00**	**41.42**	**0.000**	**23**
LMC-2	**Mean**	**19.3**	**6.49**	**7.67**	**2,555,780**	**463**	**0.359**	**0.0099**	**0.645**	**0.140**	**0.656**	**1.00**	**16.22**	**0.213**	**118**
LMC-2	**Median**	**21.0**	**5.40**	**7.80**	**47,000**	**304**	**0.300**	**0.0074**	**0.620**	**0.152**	**0.500**	**1.00**	**8.00**	**0.200**	**105**
LMC-2	**Min**	**9.0**	**4.40**	**6.71**	**10**	**12**	**0.120**	**0.0007**	**0.167**	**0.060**	**0.500**	**1.00**	**1.00**	**0.200**	**65**
LMC-2	**Max**	**25.0**	**10.40**	**8.09**	**15,000,000**	**1376**	**0.660**	**0.0266**	**1.340**	**0.209**	**1.500**	**1.00**	**59.20**	**0.300**	**170**
LMC-2	**StDev**	**5.2**	**2.15**	**0.45**	**6,097,051**	**466**	**0.200**	**0.0094**	**0.406**	**0.051**	**0.343**	**0.00**	**24.33**	**0.035**	**42**
LMC-3	**Mean**	**20.6**	**6.53**	**7.52**	**32,532**	**538**	**0.443**	**0.0077**	**1.001**	**0.181**	**1.240**	**1.12**	**46.62**	**0.220**	**99**
LMC-3	**Median**	**21.5**	**6.10**	**7.58**	**21,500**	**407**	**0.410**	**0.0061**	**0.907**	**0.162**	**0.950**	**1.00**	**55.00**	**0.200**	**95**
LMC-3	**Min**	**13.0**	**1.20**	**6.66**	**10**	**70**	**0.140**	**0.0005**	**0.338**	**0.082**	**0.500**	**1.00**	**22.80**	**0.200**	**80**
LMC-3	**Max**	**25.0**	**11.80**	**8.23**	**120,000**	**1512**	**1.170**	**0.0153**	**2.070**	**0.415**	**3.000**	**1.80**	**62.40**	**0.400**	**125**
LMC-3	**StDev**	**3.7**	**2.96**	**0.53**	**44,809**	**431**	**0.306**	**0.0052**	**0.628**	**0.107**	**0.853**	**0.27**	**17.12**	**0.063**	**12**

N = 12 for LMC-1, 9 for LMC-2, and 10 for LMC-3.

* = micrograms/liter = 10^{-3} milligrams/liter or 10^{-6} grams/liter.

** = most probable number (mpn).

Table 16.		
Map Designation	**Zone**	**Landuse Category**
RG 20	General Residence	Residential
RD 60	Duplex Residence	Residential
RS 90	Single Family Residence	Residential
MR	Manufactured Housing	Residential
HB	Highway Business	Commercial
BG	General Business	Commercial
NB	Neighborhood Business	Commercial
AP	Airport	N/A
ML	Light Manufacturing	Industrial
MH	Heavy Manufacturing	Industrial
AG	Agricultural	Parks*
* = Baughman Park was the only agricultural zone classified as a park. The remaining areas zoned as agricultural were classified as agricultural for a total 5 land used categories.		

The surface areas were required so that an estimate of the pollutant loadings from the storm sewers for each landuse could be calculated. The method used to calculate pollutant loadings is referred to as the "Simple Method" (Schueler, 1987 *in* USEPA, 1992(2)). The results obtained by this method provide some insight on potential problem areas for cities requiring a stormwater permit as well as for those not required having a permit. Due to the small size of Madison (2,215 acres) the entire city was assumed to be one drainage area. Using this method pollutant loads can be expressed for alternative time periods or on a system-wide or watershed basis.

The loadings (L) are calculated by using the following equation:

Equation 1: $$L_i = \left[\frac{(P)(CF)(Rv_i)}{12}\right](C_i)(A_i)(2.72)$$

Where:

- L_i = Annual pollutant load (lb/yr)
- P = Annual precipitation (in/yr)
- CF = Correction factor that adjusts for storms where no runoff occurs (a value of 0.9 is typically used)
- Rv_i = Weighted-average runoff coefficient for the landuse area
- C_i = Event-mean concentration of pollutant (mg/L)
- A_i = Catchment area (acres)

The numbers 12 and 2.72 are unit conversion factors.

Each of the parameters in Equation 1 are defined in the USEPA (1992). The annual precipitation in 1995 and 1997 recorded from the weather station two miles east of Madison was 33.34 and 20.19 inches, respectively.

The weighted-average runoff coefficient is a measure of the percentage of rainfall that becomes surface runoff (% imperviousness). To determine a runoff coefficient, Equation 2 in USEPA 1992(2) discussed below was used.

Equation 2: $Rv_i = 0.05 + 0.009 \times I$

Where: Rv_i = Weighted-average runoff coefficient
I = Percent imperviousness

The percent imperviousness for each of the five landuse categories was estimated by using literature values found in USEPA 1992(2) and Table 17.

Table 17				
Landuse	**Acres**	**% of Total Area**	**% Impervious**	**Runoff Coefficient***
Commercial	180.91	8.17	75	0.725
Industrial	223.82	10.11	55	0.545
Residential	1657.49	74.85	24	0.266
Agricultural	100.62	4.54	15	0.185
Parks	51.62	2.33	15	0.185
Total	**2214.46**	**100**		
* = Calculated using Equation 3.				

To calculate the event-mean concentration of an individual pollutant (*Ci*), three different event-mean values were used. The minimum, maximum, and mean concentrations for each of the parameters described previously were used to give a range of storm sewer loadings to Silver and Memorial Creek. The three concentrations were based on the concentrations from the samples collected in 1997.

The entire area of the city of Madison (2,215 acres) was used as the catchment area (*Ai*).

Estimated Loadings from the City of Madison

The loadings from the city of Madison were estimated using the method above. Two tables show the total loadings using two separate years of rainfall data. All of the urban samples collected in 1997 were used with the rainfall data in 1995 and 1997 to determine what kind of an effect the differences in rainfall would have on the total loadings. In addition, the mean, minimum, and maximum concentrations from all of the samples collected in 1997 were used to develop a minimum, maximum and mean loading for each pollutant in each landuse category (Tables 18 and 19).

Loadings from each landuse category were totaled in Tables 18 and 19. The total phosphorus loading rate, using the total phosphorus mean concentration of 0.995 mg/L, was 4,889 lbs using the 1995 rainfall data, versus 2,961lbs using the 1997 rainfall data (Tables 18 and19). This is why a range of loadings is given using the minimum and maximum concentrations. The loading rate from the city of Madison should fall within this range. The reason for using this range is the high variability in concentrations that can occur in urban runoff due to the variability in rainfall.

In Table 20 below, the 1995 loadings calculated from Sites LMT2, LMT3, and LMT4 were summed for four individual pollutants. Those sites monitored a small tributary northwest of the city, Memorial Creek north of Madison, and Silver Creek. The total loading rate at the above three sites was subtracted from the loadings at Site LMT5 which is located approximately one mile southwest of the city on Silver Creek. An increase of 2,951 lbs of total phosphorus was observed between the upstream sites and Site LMT5 during 1995 (23,954 – 21,003 = 2,951). This increase of 2,951lbs falls well within the range developed using the simple method described previously.

The only parameter which decreased in loadings between the upstream and downstream sites was ammonia. As discussed earlier in this report, nitrogen loadings decreased between the upstream sites and Site LMT5. This may be due to the effect of the Skunk Creek aquifer recharge that occurred during the spring of 1995. Nitrogen is very soluble and entered the aquifer during the spring of the year which resulted in the loading loss in surface water measurements.

In order to determine the effect of urban loadings on Lake Madison, the loadings described above (Site LMT5 minus Above City) were divided by the total 1995 loadings for Site LMT6 (inlet to Lake Madison). As is indicated on Table 20, the estimated contribution of the City to the load of Site LMT6 is 15% for suspended solids, 13% for total phosphorus, and 9% for dissolved phosphorus. This is significant when it is taken into consideration that Site LMT6 constitutes over 90% of the suspended solids and phosphorus budgets to Lake Madison. If rerouting of the storms sewers is implemented or other best management practices are installed to significantly reduce or eliminate the loadings from the city, to the lake this will help in reaching a 40-50% reduction in overall phosphorus loadings to Lake Madison.

Table 18. Estimated annual loads of selected constituents or properties

1995 Land Use	Method for Estimating Annual Loads	Surface Area	Suspended Solids Lbs	Ammonia lbs	Total Phosphorus Lbs	Dissolved Phosphorus lbs	Cadmium lbs	Chromium lbs	Lead lbs	Mercury lbs	Hardness lbs
Commercial	Simple: minimum	180.91	10705	18	149	54	446	892	892	178	57984
	Simple: maximum		1459418	1044	1891	624	2676	1606	97235	357	294381
	Simple: mean		522588	367	888	168	884	928	35744	187	111796
Industrial	Simple: minimum	223.82	9956	17	139	50	415	830	830	166	53927
	Simple: maximum		1357296	971	1759	581	2489	1493	90431	332	273782
	Simple: mean		486020	341	826	156	822	863	33243	174	103973
Residential	Simple: minimum	1657.49	35984	60	501	180	1499	2999	2999	600	194913
	Simple: maximum		4905820	3508	6357	2099	8996	5398	326855	1199	989560
	Simple: mean		1756674	1232	2985	565	2971	3121	120153	629	375801
Agricultural	Simple: minimum	100.62	1519	3	21	8	63	127	127	25	8229
	Simple: maximum		207126	148	268	89	380	228	13800	51	41780
	Simple: mean		74168	52	126	24	125	132	5073	27	15866
Parks & Recreation	Simple: minimum	51.62	779	1	11	4	32	65	65	13	4222
	Simple: maximum		106260	76	138	45	195	117	7080	26	21434
	Simple: mean		38049	27	65	12	64	68	2603	14	8140
Totals	**Simple: minimum**	**2214.46**	**58943**	**98**	**820**	**295**	**2456**	**4912**	**4912**	**982**	**319276**
	Simple: maximum		**8035920**	**5747**	**10413**	**3438**	**14736**	**8841**	**535401**	**1965**	**1620937**
	Simple: mean		**2877499**	**2018**	**4889**	**926**	**4867**	**5112**	**196815**	**1030**	**615576**

Table 19. Estimated annual loads of selected constitutents or properties

1997 Land Use	Method for Estimating Annual Loads	Surface Area	Suspended Solids lbs	Ammonia lbs	Total Phosphorus Lbs	Dissolved Phosphorus lbs	Cadmium lbs	Chromium lbs	Lead lbs	Mercury lbs	Hardness lbs
Commercial	Simple: minimum	180.91	6483	11	90	32	270	540	540	108	35114
	Simple: maximum		883793	632	1145	378	1621	972	58883	216	178271
	Simple: mean		316468	222	538	102	535	562	21646	113	67701
Industrial	Simple: minimum	223.82	6029	10	84	30	251	502	502	100	32657
	Simple: maximum		821950	588	1065	352	1507	904	54763	201	165797
	Simple: mean		294323	206	500	95	498	523	20131	105	62964
Residential	Simple: minimum	1657.49	21791	36	303	109	908	1816	1816	363	118035
	Simple: maximum		2970861	2125	3850	1271	5448	3269	197936	726	599257
	Simple: mean		1063805	746	1808	342	1799	1890	72762	381	227577
Agricultural	Simple: minimum	100.62	920	2	13	5	38	77	77	15	4984
	Simple: maximum		125431	90	163	54	230	138	8357	31	25301
	Simple: mean		44914	32	76	14	76	80	3072	16	9608
Parks & Recreation	Simple: minimum	51.62	472	1	7	2	20	39	39	8	2557
	Simple: maximum		64349	46	83	28	118	71	4287	16	12980
	Simple: mean		23042	16	39	7	39	41	1576	8	4929
Totals	**Simple: minimum**	**2214.46**	**35695**	**59**	**497**	**178**	**1487**	**2975**	**2975**	**595**	**193347**
	Simple: maximum		**4866383**	**3480**	**6306**	**2082**	**8924**	**5354**	**324227**	**1190**	**981605**
	Simple: mean		**1742552**	**1222**	**2961**	**561**	**2948**	**3096**	**119187**	**624**	**372780**

Table 20. Total Loadings for 4 pollutants from the City of Madison	**TSS lbs/yr**	**AMM lbs/yr**	**TP lbs/yr**	**TDP Lbs/yr**
Above City - Sum of LMT2, 3, &4	2912107	4722	21003	10489
CITY Load - 1995 Mean Conc	2877499	2018	4889	926
CITY Load - 1995 **Min Conc**	58943	98	820	295
CITY Load - 1995 **Max Conc**	8035920	5747	10413	3438
Site LMT5 (below the City)	3657974	4085	23954	11335
City = (Above City minus Site LMT5)	**745867**	**-637**	**2951**	**846**
Site LMT6	**5037647**	**3597**	**23351**	**9671**
% of Site LMT6 Load = (City/LMT6)*100	**15%**	**-18%**	**13%**	**9%**

INLAKE DATA

METHODS AND MATERIALS

Nutrient and other chemical/physical parameters were sampled at four inlake sites in Lake Madison and two inlake sites in Brant Lake (Figure 34). The South Dakota State Health Laboratory in Pierre, SD analyzed all samples. Samples were collected from the surface and bottom of the lakes on a bi-monthly schedule except during periods of unsafe ice cover. An exception to the above mentioned schedule was for site LM1A which was sampled from the surface only due to shallow water depth at a frequency of once a month. The purpose of these samples was to assess ambient nutrient concentrations in the lakes and identify trophic states. All samples were collected and analyzed using the methods described in the field manual entitled: *South Dakota Standard Operating Procedures for Field Sampler*.

A water quality sample set analyzed by the State Health Laboratory consisted of the following parameters:

Total Alkalinity	Total Solids	Total Suspended Solids
Ammonia	Nitrate-Nitrite	Total Kjeldahl Nitrogen
Fecal Coliform	Total Phosphorus	Total Dissolved Phosphorus
Chloride*		

* Chloride samples were collected at Site LM1A only and intended as a marker parameter for human waste.

Water quality samples which were calculated from the parameters analyzed above were:

Unionized Ammonia	Organic Nitrogen
Total Dissolved Solids	Total Nitrogen

In addition to the chemical water quality data above, inlake physical field parameters and biological data were also collected. The following is a list of field parameters collected:

Water Temperature	Air Temperature	Dissolved Oxygen
Field pH	Secchi Depth	

The biological parameters are listed below:

Chlorophyll *a*	Algal Samples

The chlorophyll *a* samples were used with the phosphorus and secchi disk data to evaluate eutrophic trends in the lakes. The hydrologic and nutrient budgets were used to estimate lake response to reduced phosphorus inputs. The model, taken from Wetzel 1983, is actually a model derived by Vollenweider and Kerekes, 1980.

Quality Assurance/Quality Control samples were collected in accordance to South Dakota's EPA approved *Clean Lakes Quality Assurance/Quality Control Plan.* This document can be obtained by contacting the South Dakota Department of Environment and Natural Resources at (605) 773-4254.

Description of Physical and Chemical Parmeters

pH is an index of how acidic or basic a solution is through the measurement of the hydrogen ion concentration. The pH of typical calcareous water is the result of the ratio of hydrogen ions (arising from the two dissociations of carbonic acid) to hydroxyl ions (provided by the hydrolysis of bicarbonate and carbonate). The importance of photosynthesis is obvious here, as plants and algae can successively absorb CO_2, and eliminate bicarbonates, precipitate carbonates, and form hydroxyl ions. All these events can account for rises in pH. Also extra hydrogen ions created from decomposition will tend to lower the pH in the hypolimnion. Decomposers (bacteria) will use oxygen to break down organic material into simpler inorganic forms. The lack of light in the hypolimnion prevents plant growth or photosynthesis, so no additional oxygen can be created. Typically, a high decomposition rate lowers oxygen concentrations and pH in the hypolimnion.

Dissolved oxygen (DO) is another important physical variable that is involved in two activities within an aquatic system. The first activity is respiration where oxygen is required to produce or maintain biomass for the entire aquatic community. The second activity is the biodegradation process where it used break down organic substances (Cole, 1983). Lack of oxygen can put great stress on the system sometimes resulting in the death of organisms such as fish (winterkill and summerkill). Oxygen is input into the system through the air-water interface by the process of diffusion and through photosynthesis conducted by algae and aquatic macrophytes.

Alkalinity refers to the buffering capacity of a solution, and is usually identified as mg/L of $CaCO_3$ (calcium carbonate). Carbonates and bicarbonates allow the water to adjust to the pH and never allow the pH to become to acidic. The formal definition of alkalinity is the capacity of water to accept protons (H^+). Alkalinity acts as a pH buffer and stores inorganic carbon which helps water support algal growth and other aquatic life (Manahan, 1990). The range of alkalinity values in natural environment is usually from 20 to 200 mg/L (Lind, 1985).

Total solids is the material left after evaporation of a sample subsequent to the sample drying in an oven. Total suspended solids is the portion that is retained by a filter and the dissolved solids is the fraction which passes through the filter (Standard Methods, 1985). Subtracting the suspended solids from the total solids yields the total dissolved solids concentration.

Ammonia is the initial product of the decay of organic wastes and is also the form in which plants can easily use (Manahan, 1990). High levels of ammonia could also indicate the presence of organic wastes or pollution.

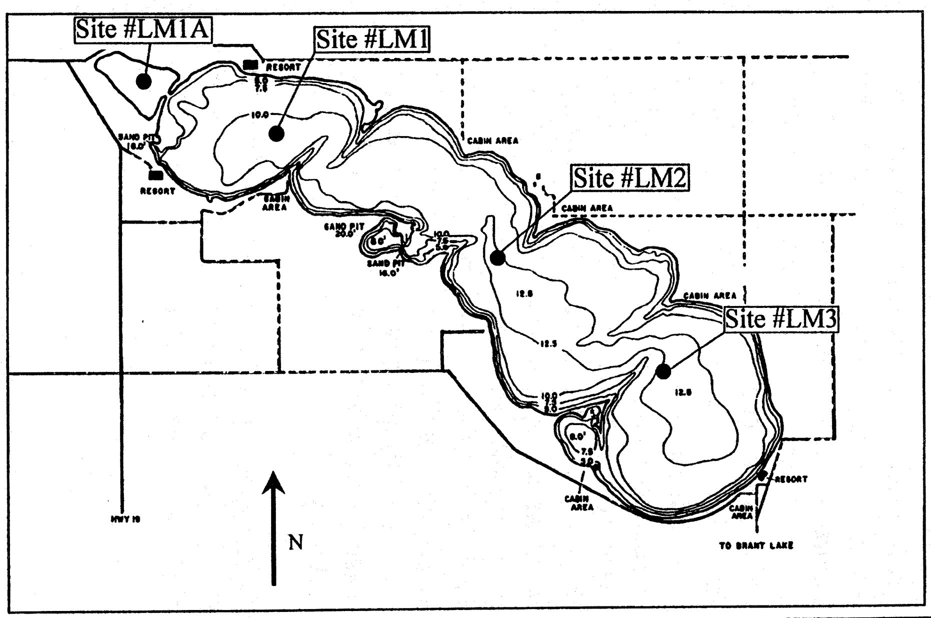
Un-ionized ammonia (NH_4OH) can be highly toxic to many organisms, especially fish (Wetzel, 1983). Un-ionized ammonia is calculated from the total ammonia concentrations (mg/L), pH (su) and water temperature (°C). Increases in temperature and pH usually result in an increase in the un-ionized ammonia concentrations. The concentration of total ammonia is variable, seasonal and spatially within each lake. The amount of total ammonia and un-ionized ammonia present also depends on how productive the lake is and how much organic material is present (Wetzel, 1983).

Nitrate and nitrite are inorganic forms of nitrogen. Both nitrate+nitrite and ammonia are the forms of nitrogen most easily assimilated by aquatic plants and algae (Wetzel, 1983). Sources of nitrate can include agricultural fertilization, loadings from septic tanks, sewage and industrial wastes, and the atmosphere. Ammonia (NH_3) can be biologically converted into nitrate (NO_3) through nitrifying bacteria (*Nitrosomonas*). Bacteria are also responsible for denitrification which takes place when nitrate and nitrite are converted to N_2, which is lost as nitrogen gas to the atmosphere (Manahan, 1990).

Total Kjeldahl nitrogen (TKN) is used to calculate both organic nitrogen and total nitrogen. Total Kjeldahl nitrogen minus ammonia equals organic nitrogen. Total Kjeldahl nitrogen plus nitrate and nitrite are equal to total nitrogen. Organic nitrogen can be released from decaying organic matter or it can enter the lake system from septic systems or agricultural waste. Organic nitrogen is broken down to usable ammonia and other inorganic forms of nitrogen.

Phosphorus concentrations greater than 0.02 mg/L indicate that a lake is eutrophic and may experience some algal blooms (Wetzel, 1983). The interest in phosphorus stems from its major role in biological production, which in this case means algal blooms. There are various chemical forms of phosphorus present in the lake environment. However, during the project only two forms were measured: total phosphorus and total dissolved phosphorus. The most important measure is the total phosphorus content of unfiltered water. It consists of phosphorus in the particulate form and in the dissolved form. Total phosphorus minus dissolved phosphorus equals the particulate form (Wetzel, 1983). Particulate phosphorus is sorbed to sediment or is found locked within vegetation which uses phosphorus to create more biomass. Phosphorus differs from nitrogen in that it is not as water-soluble and will sorb on to sediment and other substrates. Once phosphorus sorbs to any substrate it is not readily available for uptake by algae. Phosphorus sources can occur naturally in the geology and soil, and from decaying organic matter; or derived from waste septic tanks or agricultural runoff. When phosphorus enters a lake it is either consumed by the organic matter in bioproduction or it is lost to the sediments of the lake. The sediment layer of a lake will not give up the phosphorus unless an anoxic (complete loss of oxygen) condition prevails, resulting in the reduction of the redox potential of the microzone. The phosphorus is then released from the sediment into the water column to be used by algae and other aquatic and semi aquatic vegetation even though the lake does not stratify.

Total dissolved phosphorus is the fraction of total phosphorus that is readily available for use by algae. Dissolved phosphorus will sorb on to suspended material if they are present in the water column or it may be immediately taken up by algae and aquatic plants.



Lake Madison Inlake Sampling Sites

Brant Lake Inlake Sampling Sites

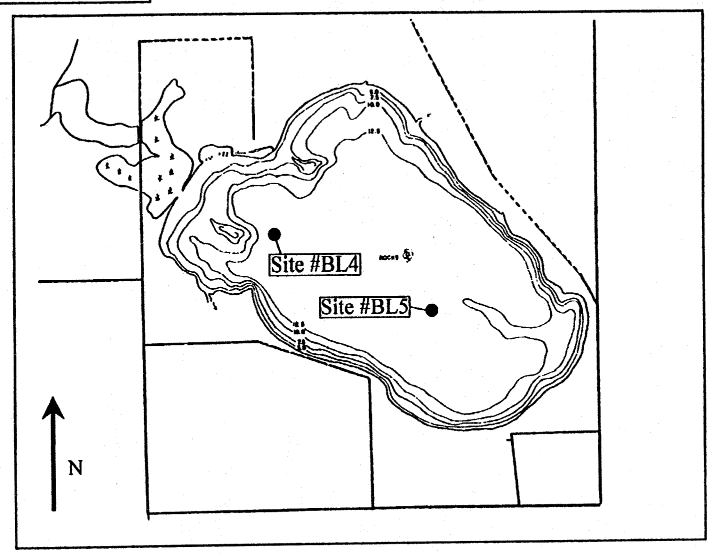


Figure 34. Lake Madison and Brant Lake Inlake Sampling Sites. (maps not to scale)

WATER QUALITY DISCUSSION

South Dakota Water Quality Standards

Lake Madison and Brant Lake have been assigned the following water quality beneficial uses:

- (4) Warmwater Permanent Fish Life Propagation
- (7) Immersion Recreation
- (8) Limited Contact Recreation
- (9) Wildlife Propagation and Stock Watering

In the case when the above uses have different standard limits for the same parameter, the most stringent standard is applied. Table 21 indicates the most stringent standard limits for Lake Madison and Brant Lake for the parameters analyzed in this study.

Table 21. Lake Madison and Brant Lake Beneficial Use Criteria

Parameter	Limits
Un-ionized Ammonia**	< 0.04 mg/L
Dissolved Oxygen*	> 5.0 mg/L
pH*	> 6.0 and < 9.0 su
Suspended Solids**	< 90 mg/L
Total Dissolved Solids**	< 2500 mg/L
Temperature*	< 26.67°C
Fecal Coliform***	< 400/100 ml (grab sample)
Alkalinity**	< 750 mg/L
Nitrates	< 50 mg/L
Sulfates	< 500 mg/L

* A variation allowed under subdivision 74:03:02:32(1) – The applicable criterion is to be maintained at all times.

** A variation allowed under subdivision 74:03:02:32(2) – The applicable criterion is to be maintained at all times based on the results of a 24-hour representative composite sample. The numerical value of a parameter found in any one grab sample collected during any 24-hr period may not exceed 1.75 times the applicable criterion.

*** Fecal Coliform from May 1 to September 30 may not exceed a concentration of 200 per 100 ml as a geometric mean based on a minimum of 5 samples obtained during separated 24-hr periods for any 30-day period, and they may not exceed this value in more than 20 percent of the samples examined in the 30-day period. They may not exceed 400 per 100 ml in any one sample from May1 to September 30.

Because of the excess nutrients entering the Lake Madison system, there were numerous exceedances for various parameters for both lakes during the course of the project. There were a total of 19 un-ionized ammonia exceedances documented in Lakes Madison and Brant, fourteen from Madison and five from Brant. The maximum exceedance exhibited for Lake Madison and Brant Lake was 0.137 mg/L and 0.088 mg/L, respectively. All of the un-ionized ammonia exceedances occurred during July and August, 1995, when higher water temperatures and pH values were observed. Temperature values ranged from 21.8 to 25.5°C and the pH values ranged from 8.28 to 8.99 for the samples that exhibited un-ionized ammonia exceedances. Un-ionized ammonia increases with increasing temperature and pH. Although the pH values were not the maximum values observed during the project they were relatively high as indicated by the range. But coupled with higher temperatures this resulted in the exceedances for un-ionized ammonia.

pH is another parameter subject to the water quality standards assigned to Lake Madison and Brant Lake (Table 21). Most of the pH exceedances during this study can be attributed to algal blooms. This was the case for the surface samples. This indicates that most of the pH exceedances can be attributed to increases in algal photosynthesis. There were 29 documented exceedances from Lake Madison and Brant Lake. A number of these exceedances were surface and bottom samples collected on the same date. Stratification does not occur in the two lakes. They are continually well-mixed and relatively shallow wind-swept prairie lakes. Photosynthesis can take place in most of the water column. Appendix 2 lists the exceedances for the parameters that are subject to water quality standards.

There were nineteen observations for dissolved oxygen that were below the standard of 5.00 mg/L. There were only two observations on Brant Lake which were lower than 5.0 mg/L. One sample from each site (Sites BL4 and BL5). These samples were collected from the bottom on separate dates during the summer sampling period, July 11 and Aug 22, respectively.

The seventeen observations that occurred in Lake Madison during 1995 were recorded from all sites. Eleven of the 17 occurred during January and February of 1995. This is a winterkill situation for fish in which snow covers over ice and prevents sunlight from penetrating. The limited amount of photosynthesis that takes place during the winter is reduced even more, resulting in anoxia. This is the same phenomenon that occurs during the summer. Summerkill occurs when there is not enough oxygen produced to maintain the high rate of biodegradation due to the tremendous amount of organic matter (algae blooms). Biodegradation uses oxygen in the chemical breakdown of organic matter and occurs year round in an area called the microzone. This microzone usually lacks oxygen because there is no replenishment of oxygen this close to the sediments. Due to this lack of replenishment, oxygen concentrations stratify in a narrow band immediately above the sediment in the summer during extremely stagnant periods. During periods of low oxygen, ammonia may increase since it is a product of the chemical reactions involved with biodegradation. At these times ammonia did increase but did not exceed 1.0 mg/L. Another phenomenon requiring oxygen is termed respiration. Plants and algae require some oxygen to maintain their biomass 24 hours a day (respiration). During the night aquatic vegetation and algae do not produce oxygen and this can result in reduced oxygen conditions.

There was one exceedance of the temperature standard for Brant Lake and no exceedances for Madison. A temperature of 27°C was recorded on July 11, 1995 at the surface of Site 5.

One fecal coliform sample was collected from site LM-1A (Bourne Slough) on June 26, 1995 that exceeded the fecal coliform standard. The concentration 550 colonies per 100 ml exceeded the grab sample standard of 400 coliforms/100ml. On June 28, 1995 a sample was collected from Site LMT6 located on Silver Creek just as it enters Bourne Slough. The fecal coliform concentration was 4,200/100ml. There was possibly some livestock located in the pasture to the west of Highway 19 at this time. There was also a high nitrate+nitrite concentration collected from LMT6 from this date (1.5 mg/L). All water quality exceedances are listed in Appendix 2.

Lake Madison Inlake Water Quality

During the study period, a total of 204 samples were collected from Lake Madison, Round Lake, and Brant Lake. This does not include the quality assurance and quality control (QA/QC) samples collected during the project. There were four sampling surface and three bottom sites on Lake Madison and two surface and bottom sampling sites on Brant Lake. One surface sample was collected from Round Lake.

In addition to the 204 samples collected during this project, there was also historic data available for Lake Madison and Brant Lake collected during the statewide lakes assessment during 1989, 1991, and 1992. The following sections will discuss each individual lake and individual parameters.

Lake Madison

Lake Madison is a 2,799.3 acre (1,132.9 ha) natural (glacial) lake located in Lake County, South Dakota. Estimated volume of the lake is 27,153 acre-ft (3.350×10^7 m^3).

The water temperature of Lake Madison is important to its biology and can be a factor in periodic algal blooms. Some blue-green algae are much more tolerant of higher temperatures than other algae (Wetzel, 1983). The range of temperatures from low winter to high summer temperatures results in changes in seasonal algal populations. Diatoms are usually found during lower water temperatures and blue-greens are often found during higher temperature periods (Wetzel, 1983).

The average summer surface water temperature for Lake Madison was 21.5°C and near the bottom was 21.1°C (Table 22). This is common for a shallow prairie windswept lake such as Lake Madison. At no time during the study period did Lake Madison stratify. Lake Madison has a mean depth of 9.7 ft (3.0 m), which is too shallow for enduring thermal stratification. Temperature and oxygen profiles are shown in Appendix A. The summer sampling period was June through September.

Average DO concentrations from all Lake Madison surface sites was 8.52 mg/L whereas the bottom concentrations were slightly less at 7.55 mg/L. The minimum concentration recorded during the monitoring of 1994 and 1995 was 2.90 mg/L. This low concentration was observed on 2/21/95, the late winter period. During winter, snow cover can prevent sunlight from penetrating ice, reducing or stopping photosynthesis. The metabolic rates of fish and other aquatic organisms are reduced during the winter; but these organisms still have to utilize some oxygen so that, when combined with the oxygen used by the biodegradation process, may result in depletion of water oxygen supplies. Near the microzone of the water and the surface of the sediments oxygen is reduced because this is the area in which most of the biodegradation occurs. The temperature and oxygen profiles shown in Appendix C illustrate the typical nature of both Lake Madison and Brant Lake. Anoxia (zero O_2) was not observed during the project but these conditions do exist and Lake Madison does have a history of becoming anoxic resulting in fish kills.

As in various other lakes within this ecoregion and in eastern South Dakota lakes in general, the predominant forms of algae within Lake Madison during the summer are blue-green algae. As discussed below, the predominant species in the samples collected from Lake Madison during June 26,1995, was *Aphanizomenon flos-aquae*. These blue-green blooms can create super-oxygenated conditions but can also undergo respiration, reducing oxygen levels even more during the evening and dark hours.

Blue-green algae dominated in Lake Madison and Brant Lake on two of three seasonal sampling dates (Appendix C). Much less common were flagellated (motile) algae from several phyla, diatoms, and non-motile green algae, in order of importance. This relationship biologically indicates that the two adjoining lakes are highly eutrophic. Of the bluegreen algae identified, the filamentous taxon *Aphanizomenon flos-aquae* was the dominant form present during the study period. *Aphanizomenon* are commonly identified as problem algae related to eutrophication, taste and odor problems, toxicity and aesthetic nuisance (Taylor, 1974).

Table 22. Descriptive Statistics for the Lake Madison Inlake Sampling Sites, 1995.

		Un-Chl-a* mg/m3	Cor-Chl-a* mg/m3	WT C	DO mg/L	FpH su	FEC /100 ml	TALK mg/L	TS mg/L	TDS mg/L	TSS mg/L	AMM mg/L	UN-AMM mg/L	NO3+2 mg/L	TKN mg/L	O-N mg/L	T-N mg/L	TP mg/L	TDP mg/L
LM1A Surface	Mean	148.85	146.13	13.4	8.02	8.22	72	205	1363	1321	42	0.16	0.0036	0.72	2.43	2.28	3.15	0.346	0.094
	Median	134.89	124.01	14.8	7.60	8.22	10	176	1261	1211	38	0.02	0.0020	0.10	2.44	2.42	3.02	0.328	0.047
	Minimum	12.40	10.84	1.0	3.20	6.07	10	154	1148	1080	3	0.02	0.0001	0.10	1.28	0.73	1.70	0.174	0.011
	Maximum	408.55	413.59	26.0	13.20	9.08	550	319	1881	1878	82	0.63	0.0113	3.70	4.00	3.98	5.00	0.523	0.366
	StDev	126.65	132.72	9.4	3.59	0.87	154	63	247	267	27	0.24	0.0035	1.23	0.85	1.03	0.97	0.132	0.107
LM1 Surface	Mean	62.13	59.23	14.0	8.73	8.27	25	168	1041	1025	16	0.30	0.0203	0.23	2.21	1.90	2.44	0.283	0.221
	Median	39.51	30.35	16.0	8.90	8.23	10	175	1045	1044	12	0.28	0.0086	0.10	1.96	1.51	2.26	0.276	0.210
	Minimum	0.33	0.72	0.0	4.60	6.39	10	0	880	840	1	0.02	0.0001	0.10	1.17	1.15	1.27	0.108	0.010
	Maximum	291.12	305.62	26.0	13.60	9.11	210	230	1364	1333	40	0.82	0.1207	0.80	4.57	4.29	4.67	0.540	0.701
	StDev	74.64	78.43	8.7	2.34	0.70	49	48	130	132	11	0.27	0.0315	0.19	0.92	0.94	0.87	0.127	0.167
LM1 Bottom	Mean			13.9	7.41	8.25	50	177	1050	1031	19	0.34	0.0216	0.25	1.94	1.60	2.19	0.273	0.199
	Median			14.0	7.20	8.26	10	172	1054	1050	15	0.31	0.0112	0.10	1.98	1.45	2.16	0.282	0.218
	Minimum			2.5	3.30	6.90	10	129	906	853	2	0.02	0.0005	0.10	1.02	1.00	1.12	0.118	0.010
	Maximum			25.3	13.60	9.13	340	237	1377	1365	60	0.88	0.1374	0.90	3.23	2.64	3.53	0.450	0.365
	StDev			8.1	2.63	0.56	104	28	133	139	16	0.30	0.0345	0.25	0.56	0.46	0.55	0.104	0.112
LM2 Surface	Mean	79.55	82.53	13.9	8.81	8.33	10	175	1020	1004	16	0.24	0.0152	0.17	2.12	1.88	2.28	0.257	0.169
	Median	44.56	46.97	15.0	8.20	8.48	10	169	1049	1044	13	0.13	0.0058	0.10	1.85	1.63	2.03	0.276	0.198
	Minimum	0.00	0.00	1.0	3.40	6.02	10	142	859	841	3	0.02	0.0000	0.10	0.72	0.70	0.82	0.079	0.020
	Maximum	470.68	454.45	25.2	14.40	9.42	10	231	1224	1219	54	0.74	0.1034	0.30	5.96	5.94	6.06	0.430	0.293
	StDev	113.19	112.46	8.6	2.53	0.82	0	27	109	108	12	0.25	0.0250	0.09	1.08	1.12	1.06	0.100	0.095
LM2 Bottom	Mean			13.9	7.64	8.29	10	173	1021	1005	16	0.28	0.0190	0.17	1.72	1.44	1.90	0.255	0.194
	Median			14.0	7.60	8.49	10	166	1027	1021	11	0.21	0.0068	0.10	1.75	1.39	1.95	0.286	0.223
	Minimum			3.0	2.90	6.44	10	104	888	849	2	0.02	0.0002	0.10	1.08	0.94	1.18	0.085	0.010
	Maximum			25.0	12.20	9.17	10	239	1226	1218	42	0.81	0.1003	0.30	2.46	2.21	2.66	0.413	0.325
	StDev			7.9	2.31	0.67	0	31	103	106	11	0.25	0.0264	0.09	0.40	0.34	0.43	0.091	0.102
LM3 Surface	Mean	45.26	46.36	13.8	8.38	8.32	17	166	1007	995	11	0.23	0.0139	0.16	1.83	1.59	1.99	0.223	0.165
	Median	22.11	20.95	16.0	8.00	8.45	10	167	1009	1003	12	0.05	0.0031	0.10	1.79	1.54	2.02	0.242	0.196
	Minimum	0.33	0.00	1.0	3.80	7.05	10	0	864	852	2	0.02	0.0005	0.10	1.07	1.05	1.17	0.085	0.013
	Maximum	222.44	225.42	25.0	14.20	9.27	90	230	1170	1163	24	0.74	0.0822	0.30	2.70	2.57	2.80	0.486	0.316
	StDev	56.63	57.94	8.5	2.42	0.71	19	48	90	91	6	0.26	0.0213	0.09	0.43	0.38	0.46	0.095	0.096
LM3 Bottom	Mean			13.9	7.61	8.33	16	177	1011	998	13	0.27	0.0159	0.15	1.76	1.49	1.91	0.236	0.173
	Median			14.0	7.50	8.45	10	170	1010	1002	10	0.11	0.0040	0.10	1.79	1.40	1.92	0.253	0.193
	Minimum			3.5	3.40	7.25	10	149	875	845	2	0.02	0.0006	0.01	1.18	0.99	1.28	0.089	0.010
	Maximum			25.0	14.60	9.25	110	235	1200	1191	40	0.84	0.1186	0.30	2.73	2.32	2.83	0.433	0.307
	StDev			7.8	2.66	0.58	24	26	94	98	10	0.29	0.0281	0.09	0.45	0.33	0.50	0.096	0.094

* Corrected and Uncorrected Chlorophyll *a* concentrations collected from the surface sites only.

pH

There were three observations in the months of January and February in which the pH decreased to 7.00 or below (Figure 35). In fact, the lowest observed pH was collected from site the surface at Site LM2 (pH = 6.02) (Table 22). During these periods the dissolved oxygen concentration was reduced and the lake began to go anoxic although the dissolved oxygen concentrations never dropped below 3.0 mg/L. The lack of light (snow cover) reduced the photosynthetic activity resulting in lower dissolved oxygen levels.

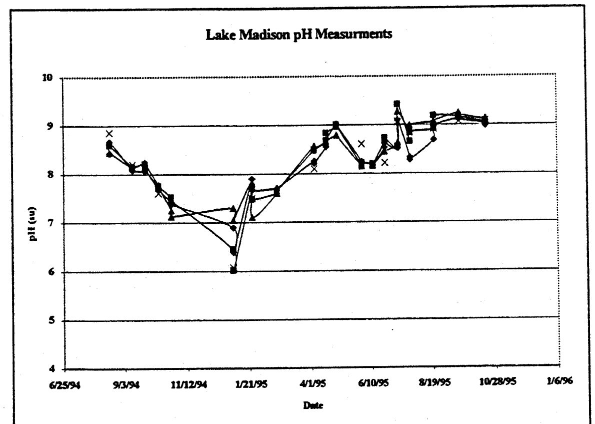


Figure 35. pH measurements from Lake Madison, 1994-95.

Most of the samples collected, exclusive of the January and February samples, exhibited an average pH of 8.49 which is typical of most eastern South Dakota lakes. The samples collected in January and February were collected at a particular time of year when anoxia frequently occurs which can create a more acidic environment.

Alkalinity

The mean concentration for bottom samples was 176 mg/L whereas the mean surface concentration was 180. There was no significant difference between the surface and bottom samples. The mean for Site LMT1A (Figure 34) was slightly higher than the rest of the sites (mean = 205.1 mg/L). The range for the bottom sites was 104 – 239 mg/L whereas the range for the surface sites including site LMT1A was 127-319 mg/L. Site LM1A exhibited the most variation where the range was 154 to 319 mg/L. The alkalinity in Lake Madison is relatively stable except for the instances that occurred during January when the alkalinity climbed to 319 mg/L (Table 23). The remaining sites (both bottom and surface) ranged from 104 to 239 mg/L (Table 22). There was some seasonality associated with the alkalinity, i.e. a gradual increase in concentrations during the late fall in winter. However, the concentrations gradually decreased during spring to the same point they were during the prior year.

Table 23. Dissolved oxygen and total alkalinity concentrations and pH measurements for all Lake Madison inlake sampling sites sampled on 1/03/95.

Site	D.O. (mg/L)	pH (su)	TALK(mg/L)
LM1A	3.4	6.07	319
LM1B	6.5	6.90	222
LM2B	7.8	6.44	216
LM3B	4.6	7.30	219
LM1S	8.9	6.39	219
LM2S	8.2	6.02	223
LM3S	7.6	7.05	217

Total Solids

Dissolved solids averaged 1,017.5 mg/L for bottom samples and 1,066.1 mg/L for surface samples. A significant difference was not observed between surface and bottom sites. Concentrations at Site LM1A were significantly larger than at the other inlake sites. Dissolved solids are typically made up of salts and compounds which keep the alkalinity high. A regression analysis was conducted between total dissolved solids and total alkalinity. Interestingly, a very strong relationship existed between these two variables only at Site LM1A (R^2 =0.86, DF=12). This may indicate that groundwater may be having an impact on the water quality of Bourne Slough and may be the reason why the pH dropped during the month of January due to the addition of more carbonates and dissolved material contributed by the groundwater. Another regression analysis was conducted on the remaining three surface and bottom sites and this regression analysis revealed an insignificant relationship (R^2=0.002, df=56).

Total suspended solids averages for surface and bottom sites were 19.6 mg/L and 15.6 mg/L, respectively. However, if Site LM1A is not included in the calculation for the surface mean, the mean concentration drops to 14.5 mg/L. The TSS average at Site LM1A is significantly larger than at the rest of the sites (Table 22). This is primarily caused by the shallow depth of Bourne Slough (≈4 ft). Bourne Slough is filled with fine sediment and organic matter that is easily suspended during windy days. Of the eleven samples collected on Bourne Slough only three samples were below 15 mg/L. These three samples were collected during the months of January and February when the slough was completely iced over. The suspended solids increased after the ice melted in late March. In fact a concentration of 68 mg/L was observed in the sample collected on April 5, 1995.

Ammonia

Ammonia levels were not significantly different between sites or between bottom and surface samples (Table 22). However, the bottom samples were slightly higher at 0.29 mg/L. The mean concentration for the surface sites was 0.24 mg/L. The decomposition rate of organic matter in bottom sediments of the lake is greater than the decomposition at the surface, and is probably responsible for the increased ammonia concentrations (Cole, 1983). The maximum concentrations occurred during two periods. One period was during January and February when biodegradation occurred under the ice and as a result the oxygen became substantially decreased. The decomposition resulted in higher levels of ammonia. The second period occurred during the summer when increased rates of algal and vegetation growth occur. Algal blooms die off creating lower levels of oxygen and increased levels of ammonia as the algae begin to decompose. The maximum concentration for all sites was 0.88 mg/L collected from the bottom of Site LM1 on January 24, 1995 (Table 22).

Un-Ionized Ammonia

There were several exceedances of the 0.04 mg/L standard as discussed previously. The maximum concentration observed from Lake Madison was 0.1374 mg/L (Table 22). This sample was collected from the bottom of Site LM1 on August 21, 1995. All sites (bottom and surface) exhibited their maximum concentrations during late July and August excluding Bourne Slough which exhibited its maximum concentration in June. The concentration of un-ionized ammonia increased with the higher temperatures and pH associated with the summer months. There were no significant differences exhibited between sites or between bottom and surface samples for this parameter (Table 22).

Nitrate and Nitrite

The concentrations of nitrate+nitrite in Lake Madison and/or Brant Lake ranged from 0.1 to 3.7 mg/L. There were no significant differences between surface and bottom sites. However, the mean nitrate+nitrite concentration from Site LM1A was significantly larger than the rest of Lake Madison's sites (0.715 mg/L) (Table 22). During the months of January and February there was a slight increase in concentrations (from 0.1 to 0.3 mg/L) for all of the inlake sites excluding Site LM1A. Site LM1A had a much larger increase in NO_{3+2} from 0.1 to 3.7 mg/L. With the increase of ammonia and reduction of oxygen concentrations nitrates+nitrites will also buildup as the reduced photosynthetic rates do not allow as much ammonia or nitrates to be taken up by algae (Wetzel, 1983).

The range of concentrations exhibited by the rest of the inlake sites, excluding Site LM1A, was from 0.1 to 0.9 mg/L. Nitrate concentrations can decrease sharply during late spring and summer because of algal uptake. But with reduced uptake by plants in the fall and continued biodegradation, an increase in ammonia and nitrates may take place.

Total Kjeldahl Nitrogen / Organic Nitrogen

In regard to organic nitrogen levels, Site LM1A was again significantly different from the main part of the lake. Because of the larger amounts of vegetation within Bourne Slough, organic nitrogen was higher. Organic nitrogen means ranged from a minimum of 0.94 mg/L at the bottom of Site LM2 to a maximum concentration of 5.94 mg/L at the surface of Site LM2 (Table 22). The highest concentration of organic nitrogen (5.94 mg/L) was sampled at the surface of LM2 on July 11, 1995. The surface samples had higher concentrations than the bottom samples due to the amount of organic matter (algae) near the surface. Near the bottom the organic matter was converted into other forms of nitrogen.

Total Nitrogen

Concentrations were quite varied between surface and bottom sites. Minimum concentrations were as low as 0.82 mg/L whereas the maximum concentrations ranged as high as 6.06 mg/L collected from the surface of Site LM2. The highest average concentration occurred from the surface samples collected from Site LM1 (2.44 mg/L). These concentrations followed very similar trends to those described in the organic nitrogen section. Due to the many sources of nitrogen; atmosphere, soil, fertilizer, and fecal matter, it is very difficult to prevent it from entering a water body such as Lake Madison or Brant, especially since it is water-soluble. Also, since blue green algae can convert atmospheric nitrogen (N_2) for their growth, the focus of nutrient reduction should be on phosphorus.

Total Phosphorus

Inlake phosphorus concentrations in Lake Madison averaged 0.254 mg/L (median 0.270 mg/L) in the surface samples, excluding Site LM1A, and averaged 0.271 mg/L (median 0.273 mg/L) for the surface samples when Site LM1A is included. The bottom samples averaged 0.254 mg/L (median 0.275 mg/L) without Site LM1A. As with some of the other nutrient parameters there was a significant difference exhibited between the three inlake sites and Bourne Slough. Site LM1A was significantly higher in TP than the remaining three surface and bottom sites (mean 0.346 mg/L) (Table 22). The total phosphorus concentrations ranged from 0.079 mg/L (Site LM2S) to 0.540 mg/L (Site LM1S). The concentrations peaked for all inlake sites during the summer and significantly dropped during the winter months except for Site LM1A (Figure 36). Bourne Slough started to become anoxic near the microzone (sediment-water interface). However, oxygen levels were not measured at this point and were only measured approximately one foot beneath the surface of the water. In addition, groundwater may have been begun to flow into the lake with the reduced rates of surface runoff and the water table still exhibiting high levels. To the northwest and north of Bourne Slough are the infiltration/percolation basins for the city of Madison and the Lake Madison Sanitary District. Although there is not a significant load to the lake from this source at this point there may be periodic pulses that occur when conditions are right. The concentrations during the next sampling date completely dropped below inlake Lake Madison levels. This sampling somewhat coincides with the low concentrations of dissolved oxygen.

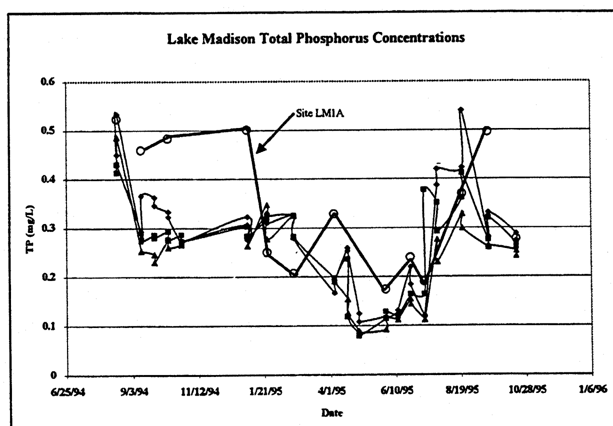


Figure 36. Lake Madison Total Phosphorus Concentrations.

The remaining sites all followed a very similar pattern as is indicated on Figure 36. Phosphorus concentrations drop during the winter and early spring and begin to increase during the early and late summer. This correlates with spring loadings (March 16 – May 31). Approximately 49% of the annual TP load occurs in spring. During the months of April and May there is a significant drop in inlake concentrations which is a result of the dilution of the spring runoff. After the spring runoff occurs and the hydrologic loadings cease or slow down, inlake phosphorus concentrations begin to increase. This also correlates with the chlorophyll-*a* concentrations that begin to increase in late June and July.

Total Dissolved Phosphorus

The dissolved phosphorus average from the bottom samples was slightly more (0.187 mg/L) than the surface samples (0.171 mg/L). The average concentration of Site LM1A was significantly less than any of the other inlake sites (mean 0.093 mg/L). Dissolved phosphorus may sorb on to suspended material that may be present in the water column. This seems to be the case in Bourne Slough where the shallow depth promotes resuspension of the sediment that comes into contact with dissolved phosphorus. A regression analysis indicated that total phosphorus and suspended solids from LM1A had a relatively strong relationship (R^2=0.70,df=9) when the observations from January and February were removed from the data set as outliers. There was no relationship indicated between dissolved phosphorus and suspended solids (R^2=0.001,df=9).

The dissolved phosphorus concentrations from the inlake sites, excluding Site LM1A, ranged from a minimum of 0.01 mg/L collected from various sites to a maximum of 0.365 mg/L collected from the bottom of Site LM1 on August 21, 1995. The bottom samples exhibited higher concentrations probably due to the release of phosphorus from the sediments. Also the surface samples have more algae present using some of the available dissolved phosphorus, effectively lowering the concentration.

The inlake total phosphorus concentrations were diluted as a result of the spring flows. This same phenomenon also occurred with the inlake dissolved phosphorus concentrations. However, there was a sharp increase in concentrations once the spring flows began to decrease. There was not a strong relationship between percent dissolved phosphorus and total suspended solids. In addition, there was no correlation between total phosphorus in the inlake suspended solids concentrations (bottom and surface analyzed separately).

The total average concentration of dissolved phosphorus from all surface and bottom samples (0.170 mg/L) available to algae is almost 9 times the amount necessary to stimulate algal growth.

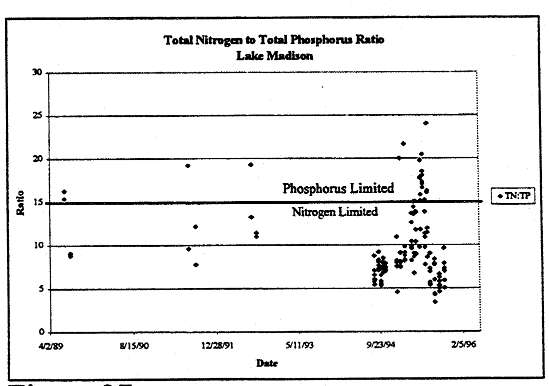


Figure 37

Limiting Nutrient

If an organism (algae) is to survive in a given environment, it must have the necessary nutrients and environment to maintain itself and be able to reproduce. If an essential material approaches a critical minimum, this material will be the limiting factor (Odum, 1959). Phosphorus is often the nutrient that is limiting in aquatic ecosystems. However, a number of highly eutrophic lakes in eastern South Dakota are known to develop nitrogen limitation. If the lake has very abundant phosphorus concentrations, the algal growth is considered to be limited by available nitrogen.

In order to determine which nutrient will tend to be limiting, EPA (1980) has suggested a total nitrogen to total phosphorus ratio of 15:1. They also suggest an inorganic nitrogen to dissolved phosphorus ratio of 7:1 (Figures 37 and 38). In this instance all the lake data available from Lake Madison was included. This includes all of the composite samples collected during the statewide lake assessment database from 1989 to 1995. EPA (1990) later suggested a 10:1 ratio for total nitrogen to total phosphorus, and no suggestion for the inorganic parameters. The mean total nitrogen to total phosphorus ratio was 9.8 (median 8.2) for Lake Madison. Regardless of which total nitrogen to total phosphorus ratio is used (10:1 or 15:1) Lake Madison is nitrogen limited when using either of these two ratios, i.e. if the ratio of nitrogen divided by phosphorus is less than 10:1 or 15:1, the lake is assumed to be nitrogen limited (Figure 37). The mean TN:TP ratio was 9.8 indicating that the lake is nitrogen limited most of the time. Minimum and maximum ratios ranged from 3.4 to 24. In addition, when using the inorganic nitrogen to dissolved phosphorus ratio of 7:1, any ratio less than 7 is nitrogen limited as well. The calculated mean inorganic ratio was 4.5 (median 3.1). These ratios indicate that Lake Madison is a nitrogen limited lake (Figure 37 and 38). However, blue green algae can assimilate usable nitrogen from the organic fraction of nitrogen (Wetzel, 1983). To see if the blue green algae were still limited by nitrogen, assuming they were using their own nitrogen, total nitrogen (organic and inorganic) was divided by dissolved phosphorus. Using the ratio limitation for the inorganic parameters, (7:1), the blue greens appear to be phosphorus limited (mean 29.3, median 12.2). Figure 39 clearly indicates that dissolved phosphorus appears to be the limiting nutrient. Although this indicates that algal growth in Lake Madison is limited by dissolved phosphorus, there are other environmental parameters which could be affecting the growth rates of blue green algal blooms such as photoperiod, temperature, and turbidity. Turbidity is certainly a limiting factor in Bourne

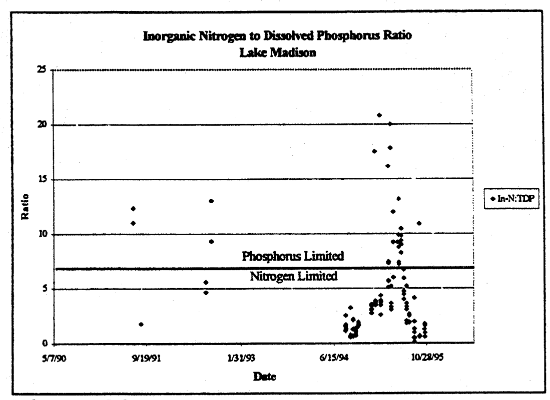


Figure 38

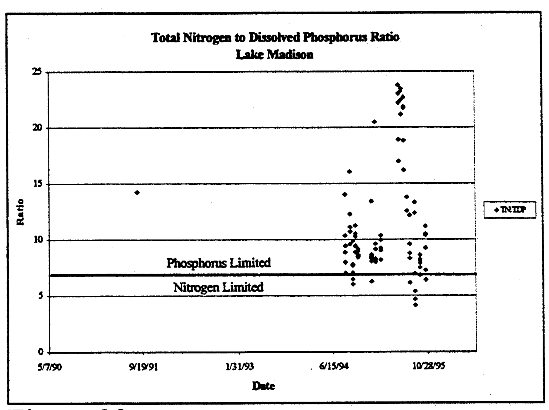


Figure 39

Slough where the shallow depth allows the resuspension of solids that limit light penetration into the water. Although this does not completely eliminate algal growth, it may be a limiting factor.

Trophic State Index – Lake Madison

Carlson's (1977) Trophic State Index (TSI) is an index that can be used to measure the relative eutrophic state of a waterbody. The eutrophic state is how much production occurs in the waterbody. The smaller the nutrient concentrations are in a waterbody, the lower the trophic level and as the nutrient levels increase the waterbody becomes more eutrophic or even hypereutrophic. Those lakes lacking nutrients such as in montane areas (Black Hills) are termed oligotrophic. The majority of lakes in South Dakota are in the eutrophic to hypereutrophic range as a result of excessive nutrient input. Table 24 describes the different numeric limits for the various levels of the Carlson Index.

Table 24. Trophic Index Levels.

Trophic Level	Numeric Range
Oligotrophic	0 -- 35
Mesotrophic	36 -- 50
Eutrophic	51 -- 64
Hyper-eutrophic	65 -- 100

Table 25. Average Trophic State Index Levels for Lake Madison.

Parameter→	TSI Secchi Disk	TSI Phosphorus	TSI Chlorophyll *a*
Average	63.46	84.89	70.52
Median	62.12	85.10	74.55
Minimum	42.56	69.39	33.44
Maximum	87.14	94.92	90.94
StDev	8.53	6.45	13.48

Three different parameters are used to determine the average trophic state of a waterbody: 1) total phosphorus, 2) secchi disk, and 3) chlorophyll *a*. TSI levels for all of the water quality data available for Lake Madison is indicated on Table 25 and Figure 40.

The mean and median of total phosphorus and chlorophyll *a* are far into the hyper-eutrophic level of the index. The secchi depth TSI is in the high end of the eutrophic scale. This is indicative of the excessive amounts of nutrients in Lake Madison. Over the years in which data was available for Lake Madison, the mean trophic status is 73, which is in the hyper-eutrophic range of the index.

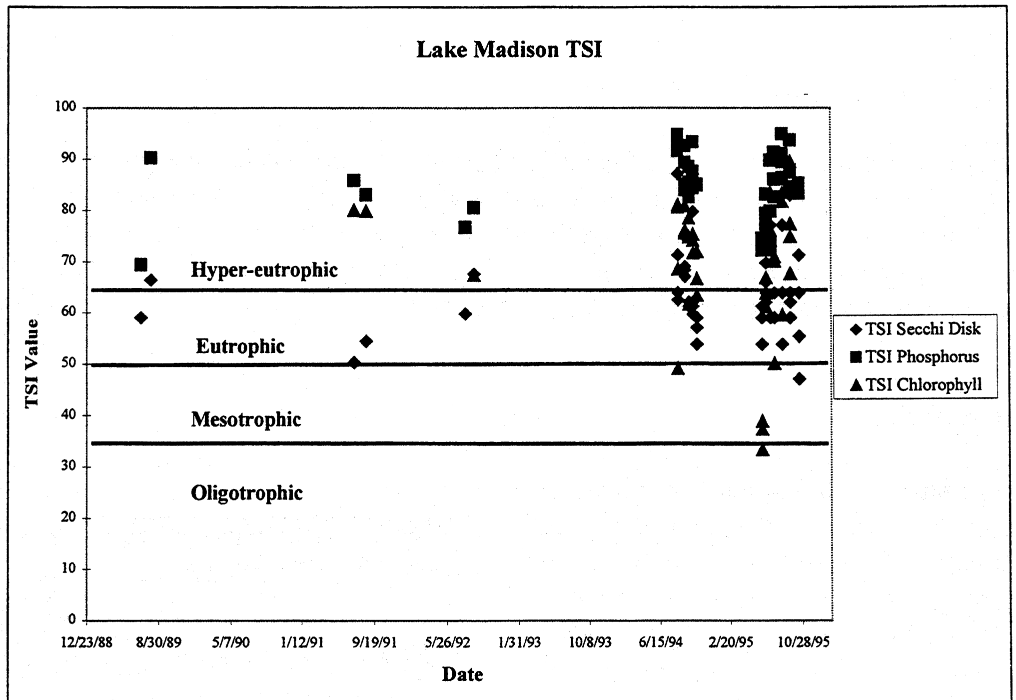


Figure 40

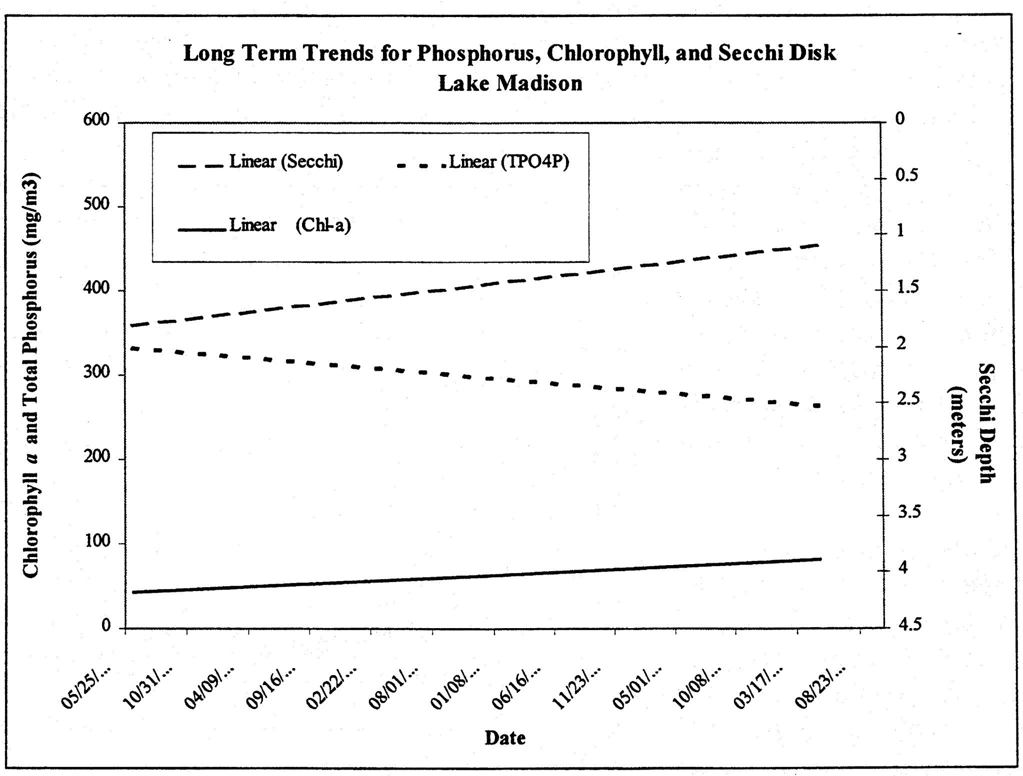


Figure 41

Long Term Trends (Lake Madison)

Long-term trends (1979-1995) for Lake Madison do not exhibit a significant change in water quality either an improvement or degradation. Figure 41 indicates that although there seems to be an increasing trend towards higher chlorophyll *a* concentrations and a slight decreasing trend for total phosphorus concentrations and secchi depth, there has been essentially no appreciable change in the water quality for Lake Madison from 1979 to 1995.

Chlorophyll *a*

Chlorophyll *a*, a pigment in plants and algae, is a common indicator of algal biomass. Chlorophyll *a* samples were collected each time a surface sample was collected during the project. In addition, the statewide lake assessment in 1991 and 1992 collected chlorophyll *a* and phosphorus samples. Due to light restrictions, chlorophyll *a* concentrations near the bottom of a lake are not representative of the nutrients in the waterbody. Summer concentrations were slightly higher in 1995 compared to 1994 for Lake Madison. During 1995, summer chlorophyll *a* peaked during early July and again in August for the three inlake sites (LM1, 2, and 3) (Figure 42). Site LM1A had less pronounced increases during this time period but exhibited a large increase later in September. Chlorophyll concentrations at Site LM1A were significantly larger than at the other three inlake sites. The mean concentration of 148.8 mg/m^3 from Bourne Slough is significantly higher than the next highest mean collected from Site LM2 (Table 26). Bourne Slough also exhibited slightly higher concentrations in the winter, primarily due to clear ice and the availability of bioavailable phosphorus (dissolved phosphorus).

Table 26. Lake Madison Chlorophyll a concentrations (mg/m^3).

Site→	LM1	LM2	LM3	LM1A
Mean	62.1	79.5	45.3	148.8
Median	39.5	44.6	22.1	134.9
Minimum	0.3	0.0	0.3	12.4
Maximum	291.1	470.7	222.4	408.6
StDev	74.6	113.2	56.6	126.7

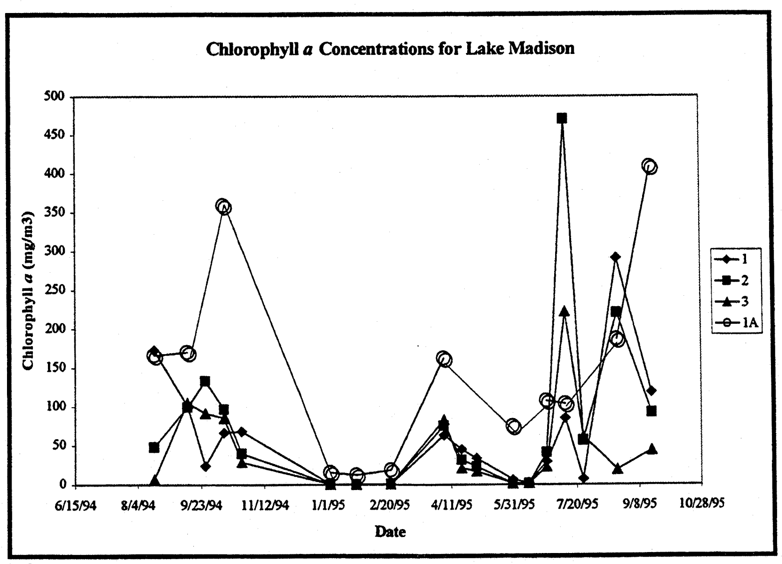


Figure 42

Typically, chlorophyll *a* increases with increasing phosphorus concentrations. However, other variables can play a role in how the distribution of algae and chlorophyll *a* may occur.

For instance, water turbidity may be an impairment in the lake, which results in the reduction of light available for photosynthesis by blue-green algae.

The predominant algae present in Lake Madison during summer sampling were blue-green algae. *Microcystis* spp., *Aphanizomenon* spp. and *Anabaena* spp. were all present in greater numbers than any other species of algae which included a number of different species of diatoms and green algae.

Chlorophyll concentrations ranged from 0 mg/m3 from Site LM2 on January 24,1995 to a maximum concentration of 470.7 mg/m3 collected from Site LM2 on July 11, 1995. Why Site LM2 exhibited such a large range of concentrations might be attributed to the center location in the lake.

Chlorophyll *a* and total phosphorus have a relationship in regard to increasing concentrations. Typically as total phosphorus increases so does chlorophyll *a*. As shown in Figures 43, the relationship between these two variables was not significant for Lake Madison (R^2=0.24,df=40). After completing regression analysis on various sites and data sets, no significant relationship was detected. However, after completing a logarithmic transformation of the phosphorus and chlorophyll *a* concentrations from the middle inlake Site LM2, a significant relationship was found (R^2=0.65,df=10) (Figure 44). There were only 10 samples collected from each inlake site and none of these samples were removed from the LM2 data set. All other data collected outside of Site LM2 was excluded from the analysis.

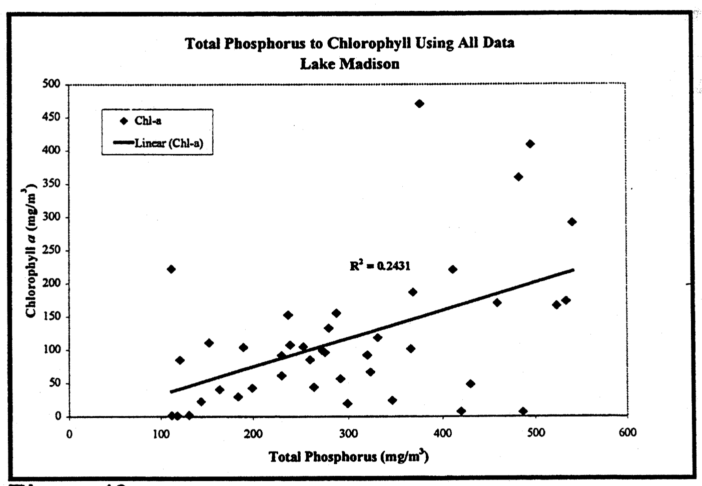


Figure 43

Site LM1A exhibited a significant relationship between chlorophyll *a* and total phosphorus. However, Site LM1A total phosphorus and chlorophyll *a* concentrations were both significantly different from the three inlake monitoring sites for Lake Madison. LM1A was not included in the regression analysis. Other factors that may have effected the relationship between total phosphorus and chlorophyll *a* at all lake sites may have been strong winds, which moved the algae into bays out of the vicinity of a monitoring site. Since Site LM2 was not significantly different between the other 2-inlake sites and it was located in the center of the lake, this site was chosen for the reduction/response analysis which will be discussed later in the report.

The relationships between phosphorus and chlorophyll *a* can be used to estimate the amount of reduction in lake chlorophyll *a* that can be expected by reducing inlake phosphorus concentrations. The prediction of chlorophyll *a* levels through the use of inlake phosphorus concentrations can best be explained by Equation 3:

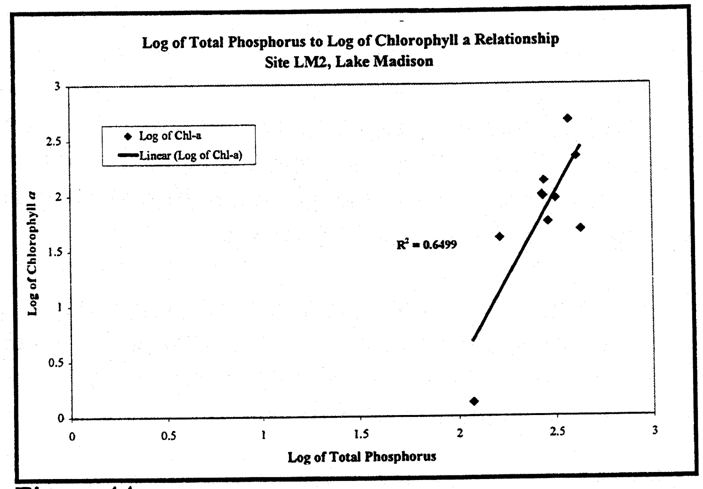


Figure 44

{Equation 3} $\text{Log}_{10}Y = -5.738 + 3.099(\text{Log}_{10}X)$

where Y = chlorophyll *a* concentration and X = total phosphorus concentration. The values of total phosphorus used in this analysis ranged from 0.118 mg/L to 0.430 mg/L. Chlorophyll *a* ranged from 1.34 mg/m^3 to 470.7 mg/m^3. Application of this equation in predicting chlorophyll *a* concentrations using total phosphorus values should be kept within the range of total phosphorus values available from actual lake samples.

Brant Lake Inlake Water Quality Discussion

As the beneficial uses for each lake and the standards pertaining to these uses were discussed previously, they will not be included here.

Water Temperature

This 1,000 acre (404.7 ha) lake is a very shallow windswept lake (Mean Depth = 11 ft) which does not allow thermal stratification to take place. Temperatures ranged between 1°C in the winter to a maximum temperature of 27°C in the summer. There was no significant difference between the surface (mean 14.0°C) and bottom samples (mean 13.6°C) although the surface samples were slightly higher. Temperature and oxygen profiles are located in the Appendix.

Dissolved Oxygen

There was no significant difference between sites nor between surface and bottom samples. The average concentrations for the surface and bottom samples were 9.83 and 8.91 mg/L, respectively. In contrast to the dissolved oxygen data for Lake Madison, there were no incidences of anoxia documented during the study. In fact, Brant Lake was supersaturated in oxygen during the winter months (D.O. = 15.8 mg/L). These increases during the winter months were due to winter algae blooms facilitated by lack of snow on the ice. With the lower temperatures water can hold more oxygen and algae underneath the ice can conduct photosynthesis producing oxygen. Near the bottom of both sites the oxygen levels resulted in some exceedances of the < 5.00 mg/L dissolved oxygen standard. However, these exceedances were only recorded from samples collected on the bottom. Both observations of the exceedances (4.8 mg/L and 3.1 mg/L) occurred during the summer.

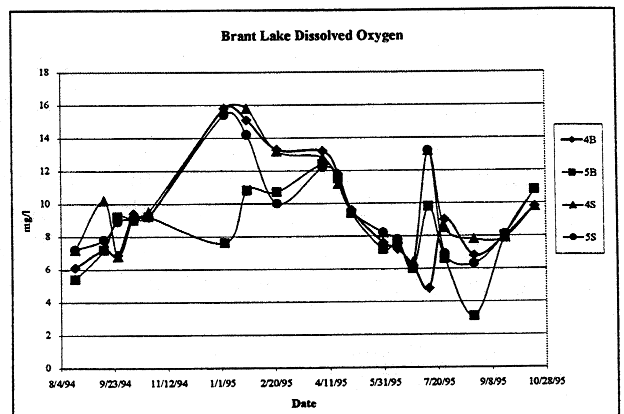


Figure 45

pH

Brant Lake exhibited no significant differences between sites or depths. The average pH measurements for the surface and bottom samples were 8.38 and 8.29, respectively (Table 27). The minimum value was 6.9 su sampled from the bottom of Site 4B on October 25,1994. The maximum value of 9.32 su was recorded as an exceedance of the water quality standards. This value was recorded from both bottom and surface samples of Site BL5 on October 18, 1995. The pH from Site BL4 surface and bottom was 9.21

and 9.14, respectively, on this same date. The only explanation for this instance is that a late algae bloom occurred driving the pH up. The predominant chemical species is (HCO_3^- and CO_3^{2-}) as a result of the uptake of CO_2 (Carbon Dioxide). After the algal growth occurs, the lake is allowed to equilibrate and pH shifts back down or below 9.00 to the 8.00 range where the predominant carbonate species is the bicarbonate ion (HCO_3^-). Brant Lake usually recovers quickly in these situations as a result of an adequate buffering capacity.

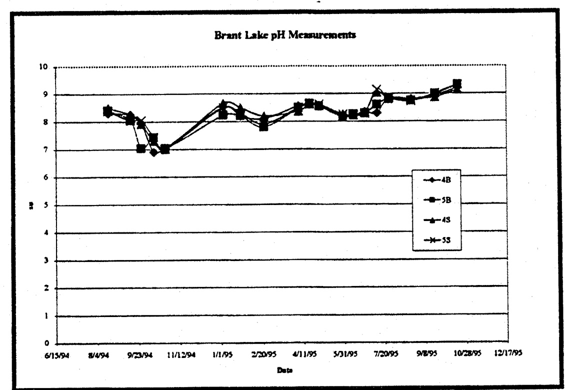


Figure 46

Alkalinity

Lakes within the State of South Dakota usually range from 150 to 200 mg/L. The minimum value for Brant Lake was 147 mg/L collected from the surface of Site BL5 and the maximum value of 236 mg/L was collected from the bottom of Site BL4. No significant differences were exhibited between sites or depths (bottom and surface). The trend towards increasing alkalinity during the winter months was almost exactly the same as that exhibited by Lake Madison. This may be an indication that during the winter months groundwater is more of an influence than during the rest of the year.

Fecal Coliform

Fecal coliform is used as an indicator of human or animal wastes. There were 76 fecal coliform samples collected during the project (8/17/94 – 10/18/95). Of the 76 samples only 5 samples exceeded 10 colonies per 100 ml. The maximum concentration exhibited was 70 per 100 ml. No exceedances occurred for this lake.

Table 27. Descriptive Statistics for 2 Brant Lake Inlake Monitoring Sites, 1995.

		Un-Chl-a mg/m3	Cor-Chl-a mg/m3	WT C	DO mg/L	FpH su	FEC /100 ml	TALK mg/L	TS mg/L	TDS mg/L	TSS mg/L	AMM mg/L	UN-AMM mg/L	NO3+2 mg/L	TKN mg/L	O-N mg/L	T-N mg/L	TP mg/L	TDP mg/L
BL4 Surface	Mean	43.2	43.2	14.0	10.04	8.39	11	181	918	904	14	0.15	0.0099	0.19	1.69	1.54	1.88	0.174	0.111
	Median	25.3	24.2	16.0	9.50	8.50	10	170	974	959	11	0.12	0.0057	0.10	1.56	1.34	1.86	0.180	0.124
	Minimum	2.3	1.4	1.0	6.40	7.01	10	152	0	0	0	0.02	0.0006	0.10	0.76	0.74	0.86	0.069	0.020
	Maximum	153.4	168.3	26.0	15.80	9.14	20	234	1221	1190	31	0.46	0.0322	0.40	2.93	2.78	3.23	0.296	0.223
	StDev	47.1	49.8	8.7	2.88	0.54	2	27	240	236	9	0.14	0.0105	0.11	0.58	0.58	0.59	0.071	0.058
BL4 Bottom	Mean			13.5	9.31	8.31	15	184	908	891	17	0.17	0.0121	0.20	1.59	1.42	1.79	0.181	0.143
	Median			15.0	9.00	8.31	10	172	952	946	15	0.14	0.0064	0.20	1.52	1.42	1.71	0.165	0.095
	Minimum			2.0	4.80	6.90	10	155	0	0	0	0.02	0.0005	0.10	0.98	0.92	1.08	0.092	0.008
	Maximum			24.0	15.80	9.21	50	236	1105	1091	41	0.46	0.0751	0.40	2.30	2.23	2.40	0.296	0.935
	StDev			7.7	3.16	0.57	12	25	233	229	10	0.14	0.0176	0.11	0.36	0.36	0.37	0.061	0.202
BL5 Surface	Mean	32.5	32.7	14.1	9.61	8.38	13	181	888	875	13	0.17	0.0134	0.19	1.61	1.44	1.80	0.165	0.115
	Median	13.4	13.0	16.5	9.10	8.39	10	166	959	942	15	0.21	0.0049	0.10	1.60	1.34	1.79	0.156	0.117
	Minimum	0.0	0.0	1.0	6.20	7.02	10	147	0	0	0	0.02	0.0006	0.10	0.78	0.76	0.88	0.052	0.020
	Maximum	218.1	223.3	27.0	15.40	9.32	70	232	1034	1027	28	0.45	0.0868	0.40	2.74	2.59	2.84	0.346	0.236
	StDev	52.9	54.6	8.7	2.66	0.56	14	27	226	223	8	0.14	0.0214	0.11	0.43	0.41	0.43	0.076	0.064
BL5 Bottom	Mean			13.6	8.50	8.26	10	173	893	879	14	0.19	0.0134	0.19	1.52	1.33	1.71	0.167	0.121
	Median			12.5	9.00	8.29	10	172	938	936	12	0.21	0.0047	0.10	1.54	1.37	1.72	0.173	0.146
	Minimum			3.0	3.10	7.04	10	0	0	0	0	0.02	0.0005	0.10	0.87	0.85	0.97	0.069	0.016
	Maximum			25.0	12.40	9.32	10	234	1054	1045	39	0.47	0.0882	0.40	2.29	2.10	2.39	0.283	0.226
	StDev			8.0	2.32	0.60	0	48	227	224	10	0.13	0.0218	0.12	0.30	0.29	0.34	0.057	0.060

Total Solids

The dissolved solids concentrations in Brant Lake averaged 937 mg/L with a median of 947 mg/L. The concentrations in Brant ranged from a minimum of 808 mg/L from the bottom of Site 4 and to a maximum concentration of 1190 mg/L collected from the surface of Site 4 (9/13/94). There was very little change in total dissolved concentrations from year to year. Significant differences were not exhibited between sites or between bottom and surface samples.

Total suspended solids in the surface samples of Brant Lake averaged 14 mg/L whereas the bottom samples averaged 16 mg/L. The maximum concentrations were 41 mg/L and 31 mg/L for the bottom and surface samples, respectively. The maximum concentrations occurred during the summer period. The concentrations also exhibited more variability during this time period as well. Algae, organic matter and fine particles suspended off the bottom increased the concentrations at this depth. Algae and small suspended particles within the water column were the primary reason the surface samples had increases in concentrations during the summer.

Ammonia (un-ionized ammonia)

Bacterial decomposition of organic matter is the primary source of ammonia in lakes and streams. High ammonia concentrations can be used to demonstrate organic pollution. The bottom samples averaged 0.18 mg/L (median 0.19 mg/L). The surface samples averaged 0.16 mg/L (median 0.14 mg/L). Again, the bottom samples were slightly higher than the surface samples which is related to the organic matter in the sediment which is constantly undergoing decomposition. Wide variability was exhibited for the Brant Lake ammonia concentrations where the standard deviation (0.14 mg/L) for all ammonia samples was greater than 50% of the overall mean of 0.17 mg/L. The concentrations ranged from 0.02 mg/L to a maximum of 0.47 mg/L sampled from the bottom of Site BL5 on October 25, 1994.

Un-ionized ammonia, which is subject to water quality standards based on the beneficial uses of Brant Lake, exhibited five exceedances of the 0.04 mg/L standard. All of the exceedances occurred during the summer of 1995 (Table 27). If concentrations of ammonia are high it does not necessarily mean that the concentration of un-ionized ammonia will be high. Concentrations of un-ionized ammonia increased during the summer when the pH increased as a result of photosynthesis and higher water temperatures. The range of concentrations was a maximum of 0.09 mg/L collected from Site BL5 on 7/26/95 and a minimum of 0.0005 mg/L calculated from samples collected during the winter at the bottom of Site BL4. The maximum concentrations for all four of the inlake sites occurred on 7/26/1995.

Nitrate and Nitrite

Nitrate+Nitrite are inorganic forms of nitrogen that are most easily assimilated by algae and other aquatic plants. The process that converts nitrate and nitrite into free nitrogen usually takes place in the lower strata of lakes. This process also increases with increasing temperature and decreasing pH. There were no significant differences exhibited between sites or sampling depths. The average concentration of nitrate/nitrite for the bottom was 0.20 mg/L whereas the surface concentrations averaged 0.19 mg/L. There was a slight increase in concentrations in winter and during the spring when concentrations increased to 0.40 mg/L, but this may have been the result of a buildup over the winter months when algal production and all biological activity, in general, slightly decreases.

Total Kjeldahl Nitrogen/Organic Nitrogen

Kjeldahl nitrogen is used to calculate both organic nitrogen and total nitrogen. The organic nitrogen concentration mean and median of the surface samples were 1.49 mg/L and 1.34 mg/L, respectively. Mean and median concentrations for the bottom samples were 1.38 mg/L and 1.37 mg/L, respectively. The highest concentration of organic nitrogen (2.78 mg/L) was sampled from the surface of Site 4 on January 25,1995. This may have been due to an algae bloom under the ice during the winter. In addition, the surface samples usually exhibited higher concentrations due to the amount of organic matter (algae) near the surface.

Total Nitrogen

The maximum total nitrogen concentration found in Brant Lake during the course of the study was 3.23 mg/L sampled on January 25,1995. There were no significant differences exhibited between sites or between depths (surface and bottom). The means for the surface and bottom samples were 1.84 mg/L and 1.75 mg/L, respectively.

Total Phosphorus

As with the nutrients and solids parameters discussed thus far, there have been no significant differences exhibited in phosphorus between sites or depths (Figure 47). Inlake phosphorus concentrations in Brant Lake averaged 0.170 mg/L (median 0.157 mg/L) in the surface samples and 0.174 mg/L (median 0.167 mg/L) in the bottom samples (Table 27). There was some variance between the samples. The samples ranged between a minimum of 0.052 mg/L from the surface of Site BL5 to a maximum value of 0.346 mg/L from the surface of the Site BL5 as well.

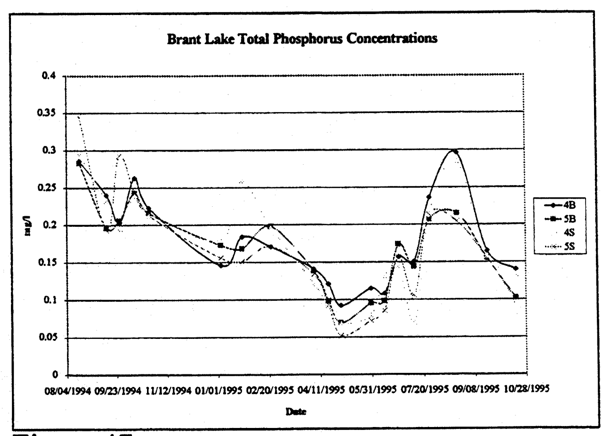


Figure 47

Trends for Brant inlake phosphorus concentrations were very similar to those of Lake Madison. There was a reduction in phosphorus concentrations when most of the hydrologic loadings occurred that diluted inlake phosphorus. Following the spring runoff, increases in concentrations occurred during the middle summer months, peaking in September, and then dropping back down to under 0.200 mg/L.

Total Dissolved Phosphorus

Dissolved phosphorus average concentrations were 0.110 mg/L and 0.113 mg/L for the bottom and surface samples, respectively. The minimum concentration was 0.008 mg/L sampled from the bottom of Site BL4. Concentrations followed the same general trend decreasing during the major runoff period for all of the sites and increasing once this runoff slowed. The maximum concentration reached 0.236 mg/L from the surface of Site BL5. A regression analysis was conducted to determine the relationship of dissolved phosphorus and suspended solids. No relationship (R^2=0.004,df=70) existed between these two variables from the data collected in 1995. In addition there was no relationship exhibited between total phosphorus and suspended solids (R^2=0.03,df=71). The average concentration of all the inlake dissolved phosphorus samples was 0.112 mg/L, which is almost six times the amount necessary to stimulate algal growth. Although the relationship between suspended solids and dissolved phosphorus was not significant, a slight inverse relationship was observed between suspended solids and dissolved phosphorus.

Limiting Nutrient for Brant Lake

Blue green algae require a certain amount of nitrogen and phosphorus to develop and maintain a bloom. Depending on how much of these nutrients is available for uptake these blooms can be intense and severe and restrict the attainment of some of the beneficial uses for Brant Lake. If either phosphorus or nitrogen is reduced to an amount which can significantly reduce the severity of these blooms, it is known as the limiting nutrient for Brant Lake. In cases where the amount of nitrogen is limiting, blue-green algae can fix atmospheric N_2 (nitrogen) provided there is enough phosphorus available to sustain their growth (Wetzel, 1983). This is why when nitrogen may be the limiting factor it is easier to control the severity of algal blooms through phosphorus management.

Brant Lake has relatively moderate dissolved phosphorus concentrations that are greatly affected by the amount surface water loadings delivered from Lake Madison. Also, during certain times of the year, the dissolved phosphorus concentrations are six times the concentration necessary to stimulate algal growth. Due to these high concentrations of dissolved phosphorus, the ratio of 15:1 was used to determine the limiting factor. If the ratio of nitrogen divided by phosphorus is greater than either 15:1 or 7:1 for In-N/Diss P, the lake is assumed to be phosphorus limited for the respective parameters. A ratio of less than the above-mentioned ratios, assumes the lake is nitrogen limited.

Both mean ratios and Figures 48 and 49 clearly indicated that Brant Lake was limited by nitrogen. For total nitrogen and total phosphorus, the average ratio was 12.1:1

(phosphorus limit is 15). The inorganic nitrogen and dissolved phosphorus ratios averaged 5.3:1 (phosphorus limit is 7).

The algal samples collected during the summer of 1995 contained blue-green algae as the predominant species of algae present, i.e. primarily *Aphanizomenon flos-aquae,* followed distantly by *Oscillatoria spp.,* and *Anabaena spp.* in order of importance (Appendix D). Blue greens can assimilate usable forms of nitrogen from the organic fraction of total nitrogen. Also, the blue-greens ability to convert atmospheric N_2 to usable forms is enhanced when the productivity of a lake is increased by the addition of large amounts of phosphorus. However, since blue-greens are only able to assimilate dissolved phosphorus and can assimilate or convert several kinds of nitrogen (inorganic and organic), total nitrogen was divided by dissolved phosphorus as being the most realistic ratio to be used for that reason. Using the numerical limit as the inorganic nitrogen to dissolved phosphorus ratio (7:1), Brant Lake seems to be, at least for blue greens, convincingly limited by phosphorus (mean TN:DP ratio = 24.9:1) as indicated on Figure 50.

Aphanizomenon populations (in terms of algal cells/ml) were much larger in Brant Lake than the remaining algal groups (flagellated algae and diatoms). However, non-motile green algae were particularly scarce in both lakes compared to the other algal components (Appendix C). This type of algal association is often reported, and may be characteristic for eutrophic hardwater lakes in the North Temperate Zone. That is, one dominated by blue-greens and diatoms with green algae (*Chlorophyta*) comprising a minor portion of the lake algal community (Prescott, 1992).

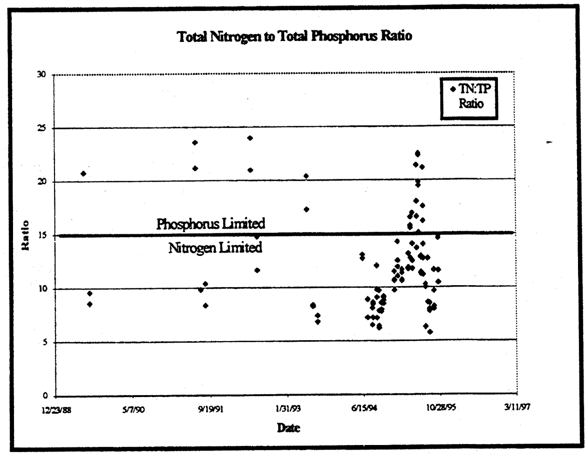


Figure 48

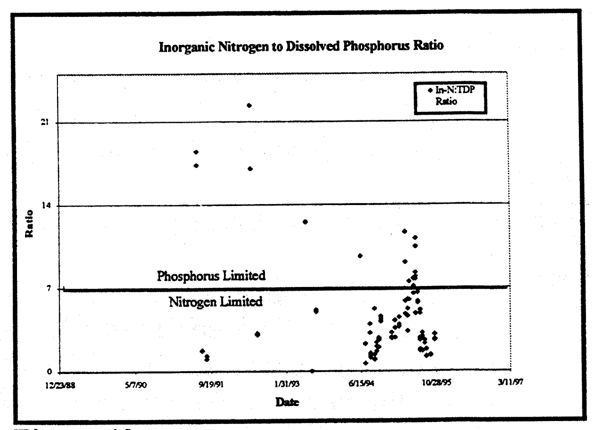


Figure 49

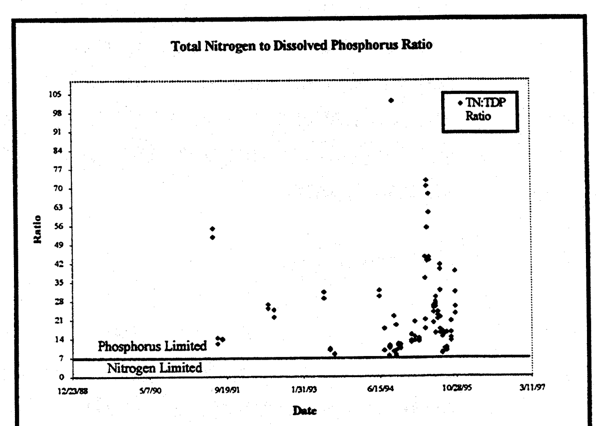


Figure 50

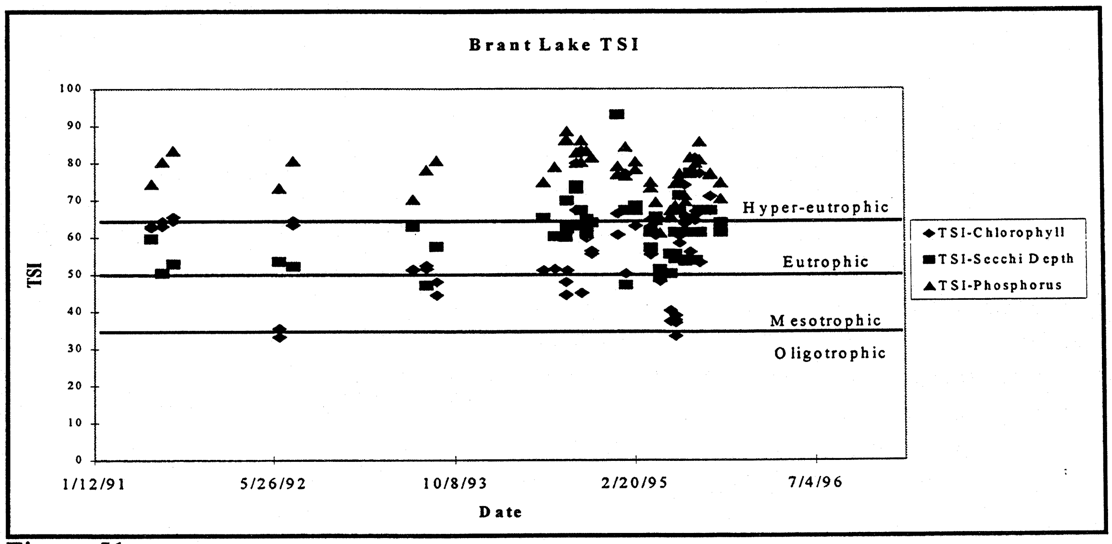


Figure 51

There are other factors also involved in the development of an algal bloom such as temperature, sunlight, and water clarity among others. However, nutrients are much more easily managed than any of these other factors.

Trophic State Index (Brant Lake)

Carlson's Trophic Status Index is one of the better indices available that can be used to measure the productivity of a lake (Carlson, 1977). The smaller nutrient concentrations in the waterbody, the lower the trophic level; and the larger the nutrient concentrations are, the more eutrophic the waterbody. Oligotrophic is the term used to describe the least productive (nutrient-poor) lakes and hypereutrophic is the term used to describe lakes with overabundant nutrients and excessive production. The numeric limits were provided in the Lake Madison discussion in Table 21.

The mean and median of total phosphorus are in the hyper-eutrophic range of the index. The secchi depth and chlorophyll *a* are in the far end of the eutrophic range of the index (Table 28 and Figure 51).

Table 28. Average Trophic State Index Levels for Brant Lake

Parameter	Secchi Depth	Chlorophyll *a*	Total Phosphorus
Mean	61.85	58.96	76.76
Median	61.29	60.94	77.63
Standard Deviation	9.26	12.79	6.65

Chlorophyll *a*

Statistical analysis was used to determine if there was a significant relationship between sites BL4 and BL5. No significant differences were found between the sites. However, the chlorophyll *a* concentrations were extremely variable throughout the course of the study. In fact, the standard deviation, which is a measure of the distribution of the observations around the mean, is greater than the means of Sites BL4 and BL5. The means were 43.2 mg/m^3 (stdev=47.1) and 32.5 mg/m3 (stdev=52.9) for Sites BL4 and BL5, respectively.

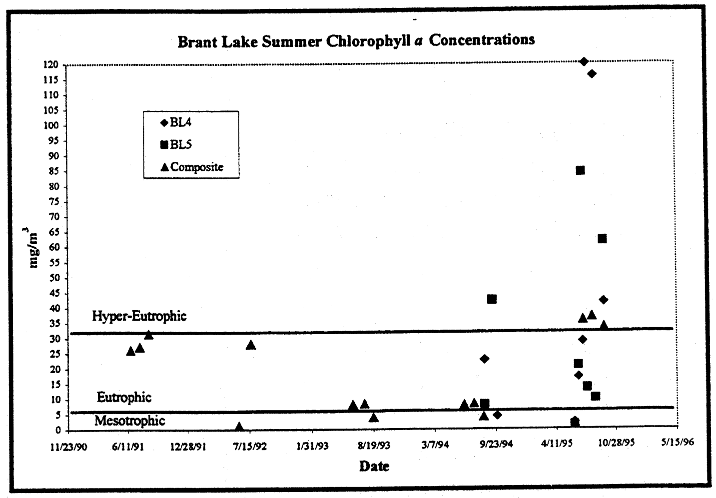


Figure 52

The chlorophyll *a* concentrations for Brant Lake ranged of a minimum of 0 mg/m^3 sampled on February 22, 1995 to a maximum of 218.1 mg/m3 sampled on September 26, 1995. As expected, chlorophyll *a* concentrations were higher during the late summer and early fall than at any other time period during the sampling year.

Surface chlorophyll *a* samples were also collected during the summers of 1991-1995 for the statewide Lake Water Quality Assessment. The chlorophyll *a* samples collected for the twice-yearly assessments were composite surface samples taken from two or three different locations on each lake. The chlorophyll summer samples collected between 1991 and 1995 from the statewide lakes assessments and this project ranged from 1.31 mg/m3 collected on June 11, 1992 (composite surface sample) to a maximum concentration of 218.1 mg/m3 collected on September 26, 1994 from BL5. The relative trophic status values for these concentrations are 33.2 to 83.4 which range all the way from Oligotrophic to Hypereutrophic. Samples collected later in the summer of 1992 (July) ranged into the upper eutrophic range (63.3 – TSI). However, during the summer of 1993 the chlorophyll *a* samples stayed in lower eutrophic-mesotrophic range due to the extensive flooding which may have flushed and/or diluted inlake algal populations (Figure 52). Although chlorophyll *a* is an important parameter for Brant Lake, the extent of algae blooms depends to a

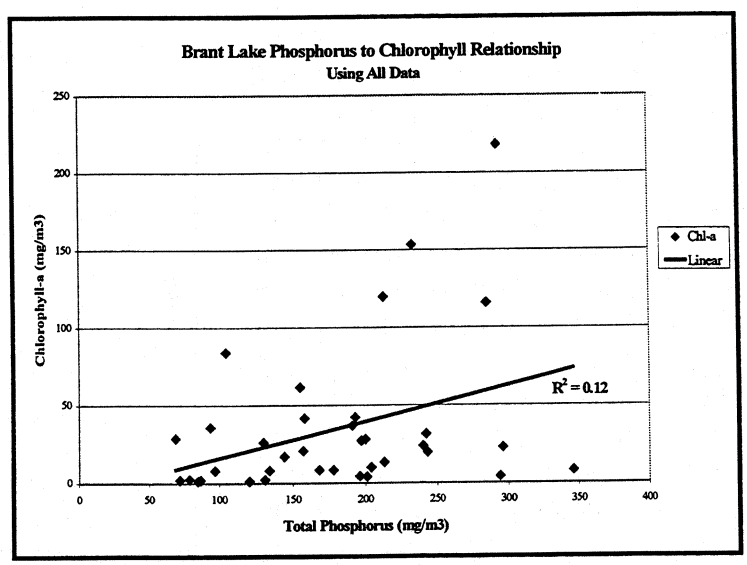


Figure 53

large degree on the nutrient content of the lake.

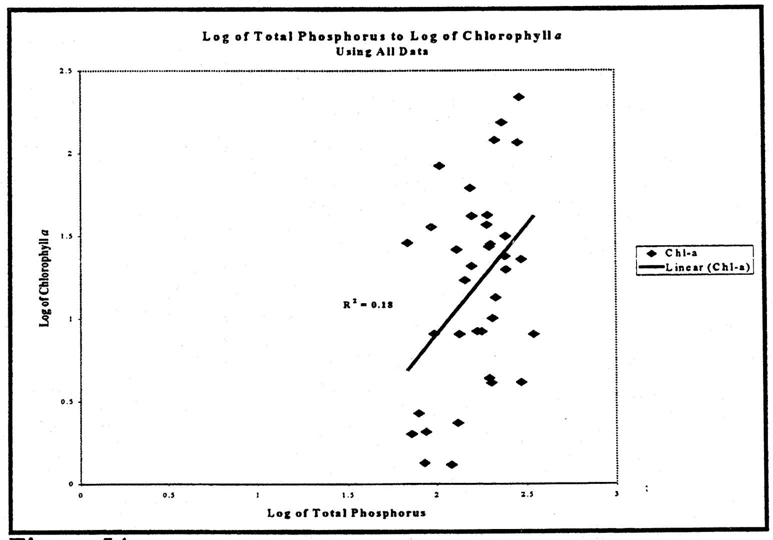


Figure 54

Chlorophyll *a* and total phosphorus may be expected to have a direct relationship in regard to increasing concentrations. Typically, as total phosphorus increases so does chlorophyll *a*. However, as shown in Figure 53, there seems to be little relationship between phosphorus and chlorophyll *a* in data from 1991 through 1995 (R^2 value of 0.12). The fact that the lake may not always be phosphorus limited; the fixation of nitrogen by blue-green algae; and the inclusion of the year 1993 in which flooding took place (flushing the lake out), may be some of the reasons for the lower R^2 value. Since 1993, the lake has been receiving and discharging very large amounts of water. This also has had an impact on the chlorophyll *a* and total phosphorus relationship. To normalize the distribution of the data, a log transformation of the total phosphorus and chlorophyll *a* concentrations was also conducted. However, this transformation had minimal impact on the distribution of the data (R^2 = 0.18) (Figure 54). The retention time of the water in Brant Lake may be affecting the amount of chlorophyll produced in the lake as phosphorus is not used extensively during periods when other conditions for algal growth are not optimum or even suitable.

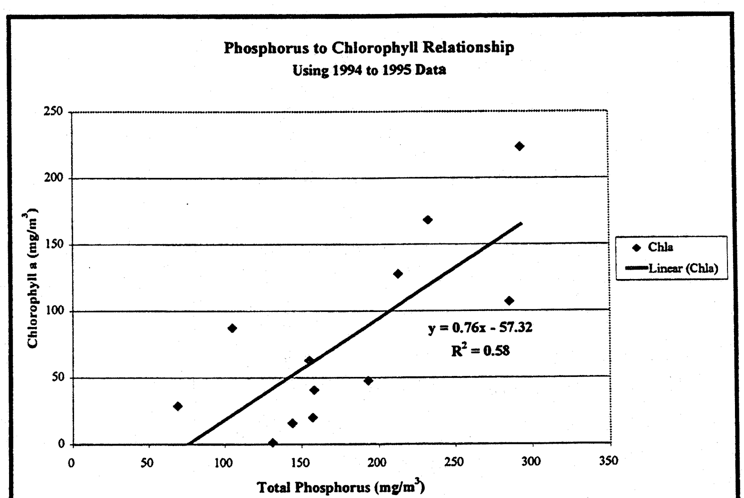


Figure 55

Data previous to the present project was excluded in the data analysis including the 1991 and 1992 years which were very dry. In addition, the data collected during 1993 was excluded as this was the year when extensive flooding occurred in eastern South Dakota. From the data set that was collected in 1994 and 1995, there were observations which were considered outliers. An example would be the two samples collected on August

17, 1994 (Sites BL4 and 5). These two samples had high phosphorus concentrations (0.296 mg/L and 0.346 mg/L) and low concentrations of chlorophyll a (23.1 mg/m3 and 5.78 mg/m3). These low concentrations may be due to the wind moving the algae into a bay resulting in the lower chlorophyll concentrations. These two samples plus an additional four more were removed from the data set. After these data points were removed, the regression analysis was completed on the remaining data. The R^2 was improved to a value of 0.58 (n=12). A log transformation on this data set did not improve the relationship between total phosphorus and chlorophyll *a*.

The relationships between phosphorus and chlorophyll *a* can be used to estimate the reduction in chlorophyll *a* that could be attained by reducing inlake phosphorus concentrations. The better the relationship the more confident lake managers can be in expected results. When applying the regression derived from the data previously discussed it is important to note that the predictions should be made within the range of data used in the analysis. It may skew the results if recommendations are made outside of this range of data. The total phosphorus concentrations applied to the regression analysis ranged from 0.069 mg/L to 0.293 mg/L. The chlorophyll *a* concentrations ranged from 1.45 mg/m3 to 223.25 mg/m3. This data set and the resulting regression analysis will be used in the next section for the reduction-response model. The equation for the line in Figure 54 will be used to predict chlorophyll *a* from inlake phosphorus concentrations. The line equation (Equation 4) is shown below:

{Equation 4} $$Y=0.75817x - 57.3156$$ (Brant Lake Data Only)

Y = predicted chlorophyll *a* concentration

x = phosphorus concentration

Reduction/Response Model (Lake Madison)

Inlake total phosphorus concentrations are a function of the total phosphorus load delivered to the lake by the watershed. Vollenweider and Kerekes (1980) developed a mathematical relationship for inflow of total phosphorus and the inlake total phosphorus concentration. They assumed that if you change the inflow of total phosphorus you change inlake phosphorus concentration a relative but steady amount over time. The variables used in the relationship are:

1) $[\overline{P}]_\lambda$ = Average inlake total phosphorus concentration
2) $[\overline{P}]_i$ = Average concentration of total phosphorus which flow into the lake
3) $\overline{T}_p$ = Average residence time of inlake total phosphorus
4) $\overline{T}_w$ = Average residence time of lake water

Data collected during the project (1994 and 1995) provided enough information to estimate $[\overline{P}]_\lambda$, $[\overline{P}]_i$, and $\overline{T}_w$. In order to estimate the residence time of total phosphorus ($\overline{T}_p$) it was necessary to back calculate Equation 5 below, and solve for $\overline{T}_p$ by forming Equation 6 (Wittmuss, 1996).

{Equation 5} $$[\overline{P}]_\lambda = \left[\frac{\overline{T}_p}{\overline{T}_w}\right][\overline{P}]_i$$

{Equation 6} $$(\overline{T}_p) = \frac{[\overline{P}]_\lambda}{[\overline{P}]_i}(\overline{T}_w)$$

Values for $[\overline{P}]_\lambda$, $[\overline{P}]_i$, $\overline{T}_w$ were determined in the following manner:

$[\overline{P}]_\lambda$ was determined by averaging all of the surface total phosphorus samples from 1994-95 collection period.

$[\overline{P}]_i$ was determined by adding all of the input loadings for total phosphorus in milligrams and dividing that number by the total number of liters that entered the lake. The values for both of these numbers came from tributaries, groundwater, and the atmosphere.

$\overline{T}_w$ was determined by averaging the total volume of Lake Madison (27,153 acre-feet) by the total inputs of water into the lake (40,101 acre-feet/days of discharge measurements).

$$\overline{T}_w = \frac{27{,}153\,acre - feet}{40{,}101\,acre - feet/234\,days} = 158.4 \text{ days} = 0.434 \text{ year}$$

The final values for $\left[\overline{P}\right]_\lambda$ and $\left[\overline{P}\right]_i$ are:

$$\left[\overline{P}\right]_\lambda = 0.254 \text{ mg/L} \qquad \left[\overline{P}\right]_i = 0.231 \text{ mg/L}$$

By placing the numbers in the proper places as discussed in Equation 3, $\overline{T_P}$ would be:

$$\left(\overline{T_P}\right) = \left[\frac{0.254}{0.231}\right](0.434) = 0.478 \text{ years} = 175 \text{ days}$$

Referring back to Equation 5, reducing the inputs of total phosphorus, the equation would estimate the reduction of inlake total phosphorus. This is assuming constant inputs of water. Theoretically the retention time for total phosphorus should also be reduced. With only one year of sampling, there is no way to estimate the reduction in the retention time of total phosphorus. The $\overline{T_P}$ constant (0.478) derived from the data will be used in Equation 5. After estimating the amount of reduction of inlake phosphorus after a reduction of input phosphorus, Equation 3 (page 87) can be used to see the reduction of chlorophyll *a*. As can be seen in Table 29, a 50% reduction in phosphorus inputs to Lake Madison will reduce the inlake chlorophyll *a* concentration by an estimated 88%. The 50% reduction would also lower the chlorophyll TSI value to the mesotrophic line (Figure 56). As stated above, this is considering no reduction in the retention time of total phosphorus. If the retention time is lowered, the lake should experience even lower inlake concentrations and lower chlorophyll *a* concentrations. As the input concentrations of phosphorus are lowered, the lake will see algal blooms that are less intense and of a shorter duration. These tables and graphs are predictive on the data collected during the study. Actual changes can be expected to be different depending on runoff values and the extent of change that occurs in the volume of water passing through Lake Madison.

Table 29. Effects of Reducing Phosphorus to Lake Madison

Reduction of Phosphorus Inputs	Input Phos Concentration	InLake Phos Concentration[1]	Chlorophyll *a*	Percent Chlorophyll *a*	Phosphorus TSI	Chlorophyll TSI
0%	0.231	0.254	52.08	0%	84.05	69.35
10%	0.208	0.229	37.57	28%	82.53	66.14
20%	0.185	0.203	26.08	50%	80.83	62.56
30%	0.162	0.178	17.24	67%	78.91	58.50
40%	0.139	0.153	10.69	79%	76.68	53.81
50%	0.115	0.127	6.08	88%	74.05	48.27
60%	0.092	0.102	3.04	94%	70.83	41.49
70%	0.069	0.076	1.25	98%	66.68	32.74
80%	0.046	0.051	0.36	99%	60.83	20.41
90%	0.023	0.025	0.04	100%	50.83	N/A

[1] Inlake phosphorus concentrations must be converted from mg/L to mg/m^3 before using Equation 1 to predict chlorophyll *a*.

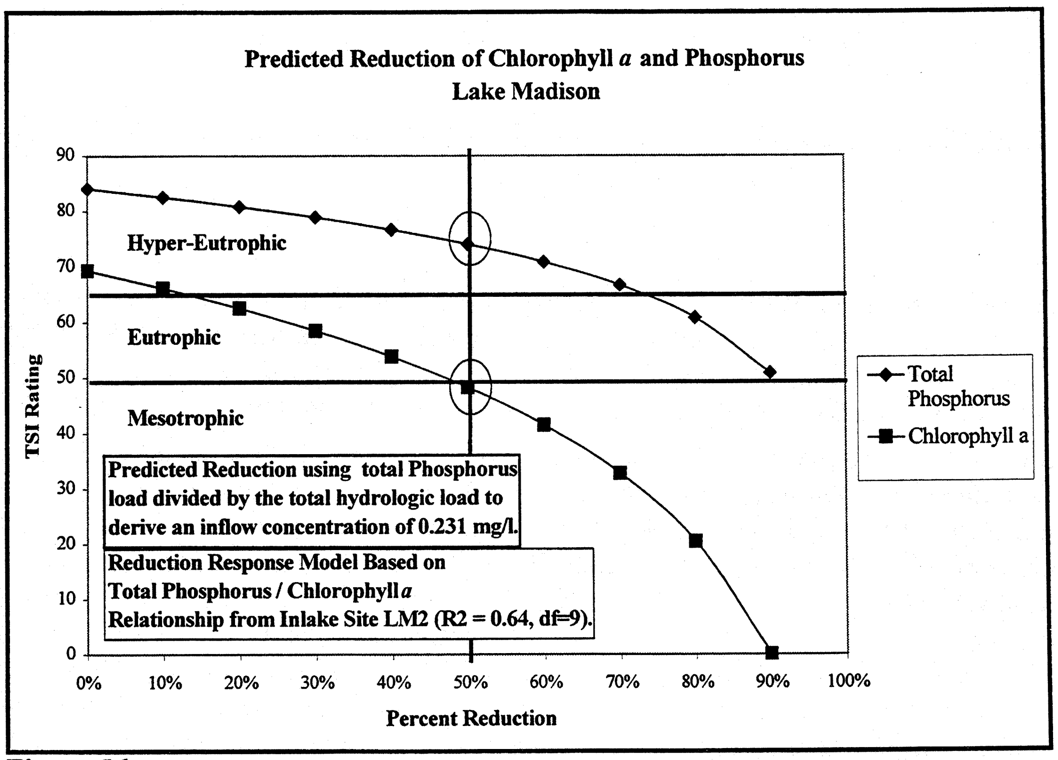


Figure 56

Reduction Response Model (Brant Lake)

Inlake total phosphorus concentrations are a function of the total phosphorus load delivered to the lake. If you change the inflow of total phosphorus you change inlake phosphorus concentration a relative but steady amount. The variables used in this process were the same variables as those used for Lake Madison.

The residence time of total phosphorus ($\overline{T_p}$) was calculated using the same manner described previously through the use of Equation 5 and 6.

$$\{\text{Equation 5}\} \quad [\overline{P}]\lambda = \left[\frac{\overline{T_p}}{\overline{T_w}}\right][\overline{P}]i$$

$$\{\text{Equation 6}\} \quad (\overline{T_p}) = \frac{[\overline{P}]\lambda}{[\overline{P}]i}(\overline{T_w})$$

Values for $[\overline{P}]\lambda$, $[\overline{P}]i$, $\overline{T_w}$ were:

$[\overline{P}]_\lambda$ was determined by averaging all of the surface total phosphorus samples from the 1994-95 collection period.

$[\overline{P}]_i$ was determined by adding all of the input loadings for total phosphorus in milligrams and dividing that number by the total number of liters of water that entered the lake. The values for both of these numbers came from tributaries, groundwater, and the atmosphere.

$\overline{T}_w$ was determined by averaging the total volume of Brant Lake (11,000 acre-feet) by the total inputs of water into the lake (46,969 acre-feet/days of discharge measurements).

$$\overline{T}_w = 11{,}000 acre - feet \Big/ 46{,}969 acre - feet / 234 days = 55 \text{ days} = 0.15 \text{ year}$$

The final values for $[\overline{P}]_\lambda$ and $[\overline{P}]_i$ are:

$[\overline{P}]_\lambda$ = 0.170 mg/L $\qquad$ $[\overline{P}]_i$ = 0.196 mg/L

By placing the numbers in the proper places as discussed in Equation 3, $\overline{T}_P$ would be:

$$(\overline{T}_P) = \left[\frac{0.170}{0.196}\right](0.150) = 0.13 \text{ year} = 47 \text{ days}$$

Referring back to Equation 5, reducing the inputs of total phosphorus, the equation would estimate the reduction of inlake total phosphorus. This is assuming constant inputs of water. Theoretically, the retention time for total phosphorus should also be reduced. With only one year of sampling, there is no way to estimate the reduction in the retention time of total phosphorus. The $\overline{T}_P$ constant (0.13) derived from the data will be used in Equation 5. After estimating the amount of reduction of inlake phosphorus after a reduction of input phosphorus, Equation 4 (page 99) can be used to determine the reduction of chlorophyll *a*. As can be seen in Table 29, a 50% reduction in phosphorus inputs to Brant Lake will reduce the inlake chlorophyll *a* concentration by an estimated 90%. The corresponding inlake total phosphorus concentration would be 0.085 mg/L. The 50% reduction would also lower the chlorophyll TSI value to the mesotrophic line (Figure 57). As stated previously, this reduction response model does not consider a reduction in the phosphorus retention time. Brant Lake should experience even lower inlake phosphorus and chlorophyll *a* concentrations if inflow phosphorus concentrations are reduced. As reductions in the phosphorus loadings to the lake are lowered, the lake will see algal blooms that are less intense and of shorter duration. The tables and graphs are predictive on the data collected during the study. As the parameters in this model change with the addition of more data, changes in the output will occur as well.

Table 30. Effects of Reducing Phosphorus to Brant Lake

Reduction of Phosphorus Inputs	Input Phos Concentration	InLake Phos Concentration	Chlorophyll *a*	Percent Chlorophyll *a*	Phosphorus TSI	Chlorophyll TSI
0%	0.196	0.170	71.19	0%	78.20	72.41
10%	0.176	0.153	58.34	18%	76.68	70.46
20%	0.157	0.136	45.49	36%	74.98	68.02
30%	0.137	0.119	32.64	54%	73.06	64.76
40%	0.118	0.102	19.79	72%	70.83	59.85
50%	0.098	0.085	6.94	90%	68.20	49.57
60%	0.078	0.068	N/A	N/A	64.98	N/A
70%	0.059	0.051	N/A	N/A	60.83	N/A
80%	0.039	0.034	N/A	N/A	54.98	N/A
90%	0.020	0.017	N/A	N/A	44.98	N/A

[1] Inlake phosphorus concentrations must be converted from mg/L to mg/m^3 before using Equation 1 to predict chlorophyll *a*.

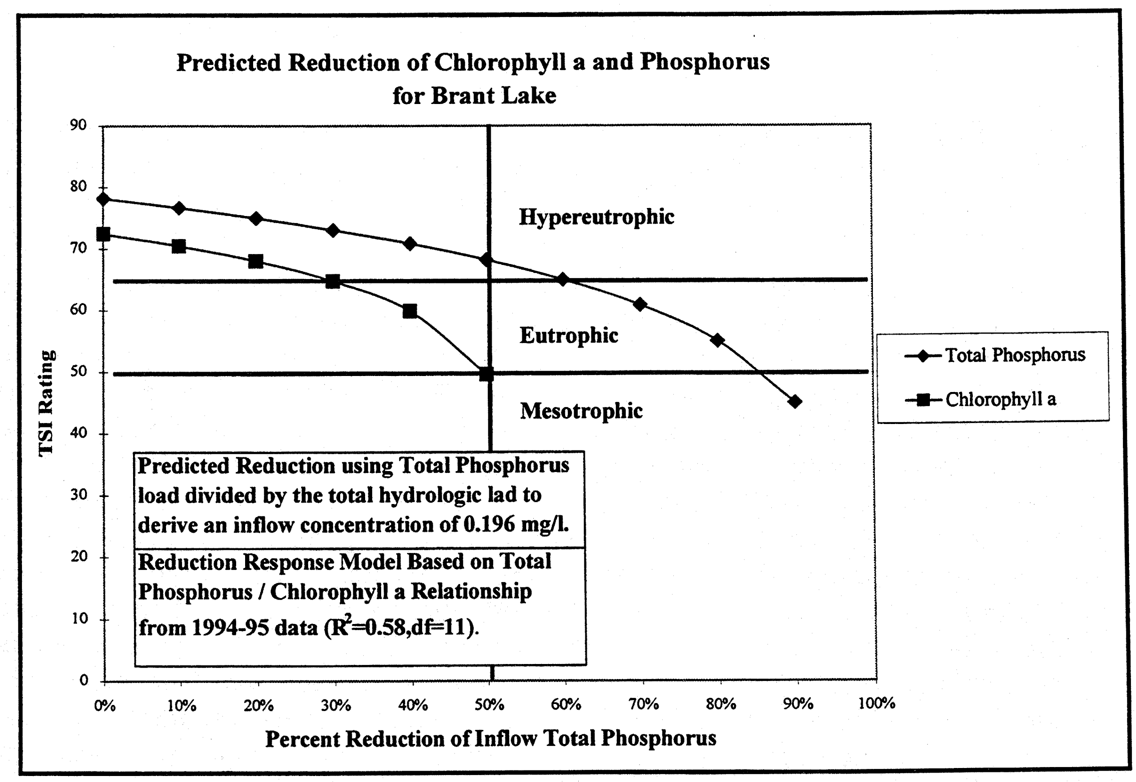


Figure 57

Lawn Fertilization and Shoreline Development

Lawn fertilization and shoreline development can have a significant impact on the water quality of a lake. As the natural vegetative buffer strips surrounding the lake are changed, their ability to reduce the amount of material such as nutrients and sediment entering the waterbody is severely limited. Contributions of nutrients and sediment from the surrounding shoreline areas can have a significant impact on the water quality of a lake. In addition, if the fertilizer amounts are applied on the surface of the lawn and it is not incorporated into the soil right away, a significant amount of this fertilizer can be washed off the lawn during a rainstorm.

To derive an estimate of total and dissolved phosphorus loadings from the lawns surrounding Lake Madison and Brant Lake the following calculations were conducted.

Annual pollutant loadings for phosphorus and nitrogen can be estimated using a method called the simple method (Schueler, 1987, in Tools for Watershed Management, 1996). This method was used to calculate an estimate for the export of phosphorus off the lawns from Lake Madison and Brant Lake. Using this method the annual loadings are estimated as follows:

$$L = (P)(Pj)(Rv)\{C\}(A)(0.227)$$

Where L represents the annual mass of pollutant export (in pounds per year);

P = annual precipitation (in inches per year) = 29.8 inches;
Pj = correction factor for smaller storms not producing runoff = 0.9;
Rv = runoff coefficient;
C = average concentration of pollutant;
A = site area (in acres)

The runoff coefficient (Rv) was calculated by using the formula "Rv = 0.05 + 0.009(I) where I is the impervious area for the site. The area surrounding Lake Madison and Brant Lake were assumed to be low-density residential. Literature values available for (I) estimate the impervious area for a residential area at 24% (USEPA (2), 1992). Rv was then calculated to be 0.266 = 0.05 + 0.009 (24).

The average concentration of the pollutant (phosphorus) was estimated by using the literatures values taken from *Tools for Watershed Management*. From Table 3.2 of that publication the average concentrations of runoff for total phosphorus and dissolved phosphorus were estimated as 0.52 mg/L and 0.27 mg/L, respectively (Terrene, 1996).

The site area was calculated for Lake Madison and Brant Lake by using the values taken from the lake survey forms that were returned. It was also estimated that there were 655 property owners on Lake Madison and 263 property owners on Brant Lake. An average lot size was calculated from the information in the survey forms. The average lot size for Lake Madison was 0.35 acre and for Brant Lake the average lot size was 0.26 acre.

Using these numbers, the L (export coefficient) for total phosphorus was calculated as 0.8421 lbs/yr/acre and dissolved phosphorus was calculated as 0.4373 lbs/yr/acre. These two numbers were then multiplied by the average lot size for each lake and multiplied again by the estimated number of lots. For example, 194.8 lbs = (0.8421 lbs/yr/acre)(0.35 lot size)(655 lots) for the total phosphorus loading for Lake Madison. Table 31 shows the loadings for total phosphorus and dissolved phosphorus for both lakes from lawn fertilization.

Table 31. Estimated Annual Loadings from Lawn Fertilization (lbs per year).

	Total Phosphorus	Dissolved Phosphorus
Lake Madison	194.8	101.2
Brant Lake	57.1	29.7

The total phosphorus inputs to Lake Madison equal 25,186.5 lbs. The estimated loadings from lawn fertilization potentially constitute 0.77% of the overall phosphorus loadings to Lake Madison. However, the parameter of concern is dissolved phosphorus. The total dissolved phosphorus loading to Lake Madison was 10,147.41 lbs. Lawn fertilization would constitute approximately 1% of the dissolved phosphorus loadings to Lake Madison.

The contribution of lawn fertilization would constitute 0.2% of the total phosphorus inputs and 0.3% of the dissolved phosphorus inputs to Brant Lake.

The contributions from lawn fertilization are relatively insignificant to the overall phosphorus budgets for both lakes. However, the amount of phosphorus applied to the lakes may be underestimated. In some cases, from the returned surveys, there were several individuals who indicated that they applied fertilizer to their lawn 2-3 times a year. The averaged lot size was calculated to be 0.35 acres for Lake Madison and 0.26 acres for Brant Lake. There were several areas on both lakes which had much larger lawns than these two average lot sizes. Therefore, contributions from the lawns may be much higher than was calculated through this method.

Lawn fertilization (N, P, K) is often applied at a much higher rate per unit area than is agricultural fertilization. Using grass as an example, a recommended application rate for an established lawn is approximately 1.5 lbs of P_2O_5 per 1000 sq. feet of lawn. Grass harvested as hay when looking for a yield goal of 4.0 tons of hay per acre requires an estimated 0.5969 lbs of P_2O_5 per 1000 sq. feet (Cooperative Extension Service, 1998). This is approximately 2.5 times as much fertilizer applied to the same amount of area (1,000 sq. feet).

Onsite Wastewater Disposal Systems

As the natural shoreline of a lake is altered, the natural movement of nutrients to the lake is typically accelerated. Changing the shoreline by reducing vegetative cover increases the loss of phosphorus to surface water by reducing the uptake by vegetation and increasing the potential for fertilizer runoff. Onsite wastewater disposal systems remove solids and bacteria from sewage. Ammonia is converted to nitrates and is subsequently dispersed to the groundwater with quantity and quality of the effluent depending on the design of the specific onsite system. Phosphorus removal from the effluent is incidental and is usually confined to the adsorption to soil particles (Hutchinson and Jowett, 1997).

The influence of the onsite wastewater disposal systems (septic systems) effluent on the nutrient load to a lake can be relatively important. Septic system effluent can contain about 1000 times the concentration of phosphorus in a lake. Some research has indicated that the potential nutrient input to a lake from groundwater containing septic system effluent may be significant. It is important to consider septic systems as a potentially significant source of nutrients to lakes. High water tables in areas containing failing septic systems can contaminate groundwater and increase the transport of phosphorus through soils to nearby surface waters. Sawhney and Starr (1977) reported that concentrations of 2.5 mg/L of TP were observed in soil solutions removed from a 30-cm depth below a trench used in an onsite septic system. They suggested that shallow soils located in high or perched water tables could potentially deliver high concentrations of phosphorus to groundwater. Although certain soils have a high affinity for phosphorus, long-term effects of constant inputs to the soil remain uncertain. The soils surrounding septic systems have a finite number of adsorption sites and should not be used as the only means of phosphorus removal in the long term (Hutchinson and Jowett, 1997).

An estimate of the possible influence of onsite waste disposal systems on phosphorus loadings to Brant Lake was determined by the following methods:

According to the property directory there were an estimated 263 residences around Brant Lake. A survey form was sent to each property owner, and from those that were returned approximately 24% (63) of the 263 were permanent residences and 76% (200) were seasonal. Also, from the information included in the returned property owner survey, the onsite wastewater disposal systems were of various ages and conditions. Rodiek (1978) used the following method to calculate phosphorus-loading potentials to Lobdell Lake in Michigan from septic systems. Various assumptions were made for the lake residences and loading rates of phosphorus to the septic systems which will be used to derive an estimate for Brant Lake.

Table 32. Copied from Table 2, Rodiek (1978).

		LakeResidences
Assumptions		Loading rates to septic systems
4 people per residence	without detergent	0.50 kg x capita^{-1} x yr^{-1}
50% occupancy of residences	detergent only	1.60 kg x capita^{-1} x yr^{-1}
50% use of phosphorus detergent	detergent only	1.10 kg x capita^{-1} x yr^{-1}

Phosphorus Export for **Permanent** Residence:

$$\left[\left(0.5\frac{\text{kg - P}}{\text{capita - yr}}\times\frac{\text{4 capita}}{\text{residence}}\right)+\left(1.1\frac{\text{kg - P}}{\text{capita - yr}}\times\frac{\text{4 capita}}{\text{residence}}\times 0.50\ \text{P detergent}\right)\right]=4.2\frac{\text{kg - P}}{\text{residence - yr}}$$

Phosphorus Export for **Temporary** Residence (assumed 50% of year occupancy):

$$\left[\left(0.5\frac{\text{kg-P}}{\text{capita-yr}}\times\frac{\text{4capita}}{\text{residence}}\right)+\left(1.1\frac{\text{kg-P}}{\text{capita-yr}}\times\frac{\text{4capita}}{\text{residence}}\times 0.50\text{P detergent}\right)\right]\times 0.5\text{occupancy}=2.1\frac{\text{kg-P}}{\text{residence-yr}}$$

Using these estimates for phosphorus contributions to the septic system from each permanent and temporary residence on Brant Lake, a total contribution can be calculated:

$$4.2\frac{\text{kg - P}}{\text{residence}}\times 63\,\text{residence}=264.6\,\text{kg - P}\ (583.4\,\text{lbs - P})$$

$$2.1\frac{\text{kg - P}}{\text{residence}}\times 200\,\text{residence}=420.0\,\text{kg - P}\ (926.1\,\text{lbs - P})$$

An estimated total of 684.6 kg of phosphorus could be delivered to the septic systems. This estimate, however, does not take into consideration the ability of the surrounding soil to immobilize the phosphorus contributions. Retention of phosphorus for certain soil types can range up to an estimated 95% (Gilliom and Patmont, 1983). Rodiek (1978) estimated the soil retention of phosphorus for the soils where the septic tanks were located on Lobdell Lake. These efficiency ratings ranged from very poor (25% of phosphorus retained by the soil) to good (75% of the phosphorus would be retained). Using these figures, an estimated **171.2-kg P (377.5 lbs) to 513.5-kg P (1,132.3 lbs)** could potentially be delivered to Brant Lake over a 1-year period. The total input of phosphorus was estimated at 25,018.9 lbs for 1995. Using the range of 377.5 lbs to 1,132.3 lbs of phosphorus delivered to Brant Lake from the septic systems, these two load numbers could potentially constitute 1.5% to 4.5% of the total phosphorus load to Brant Lake.

Many of the soils rated for use as septic tank absorption fields in the Lake County Soil Survey were given ratings ranging up to severe (percolates slowly). These soils are comprised of higher clay content which allows less water to percolate between the soil particles. This forces the water to follow preferential flow paths and can result in septage contamination of a nearby lake if the less restrictive pathway through the soils leads to the lake. This is especially true if the onsite septic system has been failing for a number of years. The septage may only come into contact with a small fraction of the available soil volume (Hutchinson and Jowett, 1997). In addition, high or perched water tables would greatly increase the movement of phosphorus through the soil particles. The adsorptive capacity of the soils would be severely impaired if the soils became saturated with phosphorus, which may be the case for those cabins used as permanent residences. Sawhney and Starr (1977) reported that the soil solution surrounding a trench in a septic system drainfield that was monitored for phosphorus exhibited similar concentrations of phosphorus as the original wastewater.

Continuing efforts should be made to secure funding for a centralized sanitary sewer system on Brant Lake. Every opportunity to limit the amount of phosphorus delivered to the lake should be pursued to reduce the inlake concentrations of phosphorus and, consequently, limit the growth of the algae. If funding cannot be secured for a centralized sanitary sewer system the homeowners surrounding Brant Lake should upgrade their individual septic systems with modern units and properly maintain them to reduce the potential of septage reaching the lake. Lake Poinsett has 153 residences served by a centralized sanitary sewer system. As these cabins were being hooked to the central sewer system it was discovered that 75 to 80% of the individual septic systems were failing, indicating how important it is to upgrade old and dilapidated systems (Englund, 1995).

Fisheries Data

The following discussion was taken from the South Dakota Statewide Fisheries Survey for Lake Herman, Lake Madison, and Brant Lake. The entire fisheries survey for each lake is included in the Appendix C.

Definitions:

Proportional Stock Density (PSD) is calculated by the following formula:

$$\text{PSD} = \frac{\textit{Number of Fish} > \textit{quality length}}{\textit{Number of Fish} > \textit{stock length}} \times 100$$

PSD is unitless and usually calculated to the nearest whole digit

Relative weight (Wr) is a condition index that quantifies fish condition i.e. how much a fish weighs compared to its length. When mean Wr values are well below 100 for a size group, problems may exist in food and feeding relationships. When mean Wr values are well above 100 for a size group, fish may not be making the best use of available prey.

<u>Lake Herman</u>

Walleye gill net catch-per-unit-effort (CPUE) was 26.3 in 1994, decreased to 17.0 in 1995, then increased to 71.3 in 1996. Proportional stock density (PSD) for the same time period was 35, 60, and 28, respectively. Age and growth analysis indicates that the walleyes are reaching 35.5 centimeters or 14 inches between Ages 3 and 4 which is nearly average for South Dakota waters. The length-frequency histogram (Appendix C) indicates that a large number of walleyes are 23-27 cm. (9.0-10.6 in.) long. Stocking records show that 135,000 walleye fingerlings were stocked in 1995 and 2,707,000 fry were stocked in 1996. Shoreline seining sampled 10 young-of-the-year (YOY) walleye.

Yellow perch gill net CPUE was 6.0 in 1994, increased to 14.5 in 1995, then decreased to 10.5 in 1996. PSD increased from 44 in 1994 to 89 in 1995 then decreased to 32 in 1996. The length frequency histogram shows a good size distribution for the perch in Lake Herman and 18 YOY were sampled by shoreline seining. The stocking record shows that 136,840 perch fingerlings were stocked in 1996.

Black crappie frame net CPUE increased from 0.5 in 1994 to 17.6 in 1995 then to 21.1 in 1996. The length frequency histogram shows most of the fish were between 21 and 26 cm. (8.3-10.2 in.) in length. Fifteen YOY crappies were sampled by shoreline seining.

Other species sampled during the survey included northern pike, carp, bigmouth buffalo, white sucker, black bullhead, bluegill, and fathead minnow.

Recommendations:

At the time this report is being written, Lake Herman oxygen levels were hovering around 1 mg/L and winterkill was a real possibility. SDGF&P are planning on stocking 2,700,000 walleye fry marked with oxytetracycline in 1997 as part of a study designed to establish walleye stocking criteria. Should winterkill occur, additional stockings of panfish will likely be made.

Develop a habitat improvement plan for the lake that will benefit panfish and walleye reproduction and survival of the young, reduce the number of rough fish and improve water quality.

Lake Madison

Walleye CPUE in the gill nets was 12.5 in 1994, increased to 36.0 in 1995, then decreased slightly to 32 in 1996. Growth rates are below average for South Dakota water with walleyes reaching 35.6 centimeters sometime between their fourth and fifth year. The length-frequency histogram for walleyes shows most walleyes ranging in size from 27 to 42 cm. (10.6-16.5 in.). Shoreline seining sampled eighty-two YOY walleye that may have come from a stocking of 561,800 fingerling in 1996.

Gill net CPUE for yellow perch was 4.8 in 1994, increased to 61.3 in 1995, then decreased slightly to 44.7 in 1996. The length-frequency histogram for yellow perch shows two main year classes, one ranging in size from 13 to 19 cm. (5.1-7.5 in.) and one from 20 to 25 cm. (7.9-9.8 in.). Ten YOY yellow perch were sampled by shoreline seining indicating some natural reproduction.

Carp, bullhead and other rough fish numbers are at fairly low numbers and are not a concern at this time. Other species sampled during the survey included white sucker, bigmouth buffalo, black crappie, bluegill, northern pike, fathead minnow and Johnny darter. Data concerning these species is presented in the Appendix 3.

Recommendations:

Stock 28,000 yellow perch adults in 1997 to increase and maintain gill net CPUE at 50 or above to meet Systematic Approach to Management (SAM) objectives. Madison needs supplemental stocking to compensate for a lack of natural habitat necessary for consistent recruitment.

Although no artificial habitat work will be done in 1997, continue to develop a habitat improvement plan for Lake Madison that incorporates artificial structures, fishing piers, rough fish removal and watershed management.

Brant Lake

Walleye gill net CPUE was 2.5 in 1994, increased to 14.2 in 1995, and increased again to 26.8 in 1996. PSD for the same time period increased from 0 to 42. Age and growth analysis shows that the walleyes in Brant are not attaining 35.5 cm or 14 in. until Age 4 and 5 which is slower than average for South Dakota. The length frequency histogram in Figure 1 illustrates an excellent size distribution of walleyes in the lake.

Smallmouth bass frame net CPUE decreased from 2.3 in 1994 to 1.2 in 1995 then jumped to 18.7 in 1996. Mean relative weight (Wr) was 99 and PSD was only 7. Age and growth analysis showed growth was only slightly below average for South Dakota waters. The length frequency histogram shows that most smallmouth sampled were between 14 and 23 cm (5.5-9.1 in.) long. Shoreline seining sampled only one young-of-the-year (YOY) smallmouth.

Yellow perch gill net CPUE was 3.3 in 1994, increased to 12.7 in 1995 and increased again to 16.5 in 1996 with a PSD of 62 and a mean Wr of 111. The length-frequency histogram shows the perch ranged in length from 14 to 27 cm. (5.5-10.6 in.) with a good distribution. The increase in perch CPUE may be attributed to the stocking of 5,763 adults in 1995 and 45,600 fingerlings with 7,026 adults in 1996 and the placement of artificial spawning structure in the west inlet.

Other species sampled during the survey included white sucker, northern pike, black bullhead, spottail shiner, carp, shorthead redhorse, bigmouth buffalo, bluegill, black crappie, channel catfish, Johnny darter and fathead minnow. Data concerning these species can be found in Appendix 3.

Recommendations:

1. Stock 1,974,000 walleye fry marked with oxytetracycline in 1997 as part of a study designed to establish walleye stocking criteria.

2. Stock 9,870 black crappie adults in 1997 to increase the brood stock population of the lake.

3. Stock 98,700 bluegill fingerlings in 1997 to increase the population.

4. Stock 9,870 yellow perch adults in 1997 to increase the adult population of the lake.

5. Develop a habitat improvement plan for the lake that includes Christmas trees for perch spawning and shoreline brush piles for crappie, bass and bluegill benefits.

6. Black bullhead CPUE has increased from 1995 to 1996 and the population should be monitored closely. Continued increase in the population would warrant contacting the assigned commercial fisherman for bullhead removal.

Agricultural Nonpoint Source Model Conclusions

This is the conclusion to the AGNPS report. The entire report can be found in Appendix A.

Sediment

The overall sediment loadings from the watershed to the outlet of Brant Lake is very low (.07 tons/acre $_{25\ \text{year event}}$). This rate is equivalent to 3015 tons of sediment. This rate (.07 tons/acre $_{25\ \text{year event}}$) is much lower than the calculated subwatershed mean value of 0.76 tons/acre $_{25\ \text{year event}}$. This difference can probably be attributed to the impact of the routing of sediment through the Madison/Round/Brant lakes. Due to the trapping efficiency of these three lakes, the net watershed sediment deliverability rate at the outlet of Brant Lake of .07 tons/acre $_{25\ \text{year event}}$ appears to be very low. However, this low rate under estimates the status of erosion and sediment deliverability rates throughout the watershed. When a detailed subwatershed analysis was performed, six of the 23 subwatersheds analyzed appeared to have very high sediment deliverability rates.

An analysis of individual cell sediment yields indicated that out of the 1100 cells found within the Madison/Brant watershed, 75 (6.8%) had sediment erosion yields greater than 8.0 tons/acre $_{25\ \text{year event}}$. The suspected primary source of elevated sedimentation within the critical cells is from agricultural lands which have land slopes of 7% or greater which are utilized as cropland (high C-factor), or rangeland areas located on land slopes of 12% or greater which are overgrazed and therefore in poor condition. In order to reduce sedimentation from these 75 critical cells, the appropriate best management practices should be installed.

Therefore, it is recommended that efforts to reduce sediment should be focused within the identified critical subwatersheds and individual critical erosion cells located throughout the watershed. It is recommended that any targeted cell should be field verified prior to the installation of any best management practices.

Nutrients

Overall, the nutrient loadings from the Madison/Brant watershed to the outlet of Brant Lake is .0011 tons/acre $_{25\ \text{year event}}$ for total nitrogen and .0003 tons/acre $_{25\ \text{year event}}$ for total phosphorus. The estimated total 25 year event load of nutrients delivered at the outlet of the Brant Lake is 50.2 tons of nitrogen and 12.3 tons of phosphorus. This is probably pessimistic due to the sediment trapping impact of the Madison/Round/Brant lakes. However, the average subwatershed nutrient deliverability rate within the Madison/Brant watershed was estimated to be .0022 tons/acre $_{25\ \text{year event}}$ for nitrogen and .0008 tons/acre $_{25\ \text{year event}}$ for phosphorus. When a detailed subwatershed analysis was performed, five of the nineteen subwatersheds analyzed appeared to have high nutrient deliverability rates. An analysis of individual cell nutrient yields indicated that out of the 1100 cells found within the watershed, 74 (6.7%) had sediment nitrogen yields greater than 9.8 lbs./acre and sediment phosphorus yields greater than 4.9 lbs./acre. The majority of the identified critical cells (approximately 85%) are primary cells.

Based upon a subwatershed area weighted to number of critical cells analysis, the most critical source of nutrients and deliverability are from five of 23 subwatersheds analyzed. The elevated nutrient levels found within three of these subwatersheds are associated with nutrients from agricultural lands which are utilized as cropland and where fertilizer is applied. This is verified by the fact that of the 15 critical nitrogen cells located within these three subwatersheds, 12 are associated with high sediment yields (> 8.0 tons/acre) and 9 are associated with high levels of fertilization with at least a 20% availability factor. The suspected source of the elevated nutrient levels found within the Madison/Brant watershed is probably from animal feeding operations and the application of fertilizers on cropland and on highly erodible soils and slopes. Therefore, it is recommended that efforts to reduce nutrients should be focused within the identified critical subwatersheds, individual critical nutrient cells and priority animal feeding areas located throughout the watershed.

Animal Feeding Areas

Upon an analysis of 41 animal feeding areas found within the watershed, it was determined that 24 animal feeding operations are contributing excessive nutrients to the watershed (AGNPS ranking > 30). A total of three animal feeding areas with an AGNPS rank > 50 were identified. An analysis to evaluate the impact of feeding areas was also performed. When the model was run with the feeding areas with an AGNPS rating > 30 taken out of the watershed, the total phosphorous load into Madison Lake was reduced from 37,285 lbs. to 26,952 lbs. (27.7% reduction) and the total nitrogen load into Madison Lake was reduced from 115,884 lbs. to 77,089 lbs. (33.5% reduction). When this scenario was applied to Brant Lake, the total phosphorous load into Brant Lake was reduced from 34,812 lbs. to 21,328 lbs. (38.7% reduction) and the total nitrogen load into Brant Lake was reduced from 118,900 lbs. to 73,115 lbs. (38.5% reduction).

It is recommended that the feeding areas with an AGNPS ranking > 20 should be evaluated for potential operational or structural modifications in order to minimize future nutrient releases. It is also recommended that all other potential feeding operations/practices within the Madison/Brant watershed be evaluated and that efforts to reduce nutrients be targeted to the installation of appropriate best management practices in order to minimize the impacts of animal feeding areas.

It is recommended that efforts to reduce sediment and nutrients be targeted to the installation of appropriate best management practices on cropland (≥ 4% slope), conversion of highly erodible cropland lands (≥ 7%) to rangeland or CRP, improvement of land surface cover (C-factor) on cropland and rangeland, fertilization practices, and measures initiated to reduce nutrient runoff from animal feeding areas.

The implementation of appropriate best management practices targeting identified critical cells, priority subwatersheds and priority feeding areas upon the completion of a field verification process should produce the most cost effective treatment plan in reducing sediment and nutrient yields from the Madison/Brant watershed.

If you have any questions concerning this study, please contact the Department of Environment and Natural Resources at 605-773-4254.

CONCLUSIONS

Water Quality Standards

During the project there were only 14 exceedances of the water quality standards for the tributary samples collected from Silver Creek (outlet of Lake Herman to Bourne Slough). Nine of these exceedances were associated with the pH standard of 9.0 su. In addition, at Site LMT2 there was one sample which exceeded the dissolved oxygen standard of 4.0 mg/L and one sample that exceeded the unionized ammonia standard of 0.05 mg/L. The remaining three tributary exceedances surpassed the standard of 2,000 fecal coliform per 100 ml for any one grab sample. These three samples all occurred on the same date of June 28, 1995. No other tributary samples exceeded any of the assigned tributary water quality standards.

The inlake water quality standards were exceeded many times by a variety of parameters in Lake Madison and Brant Lake. There were a total of 19 unionized ammonia exceedances of the standard of 0.04 mg/L. Fourteen of which were from Lake Madison and five from Brant Lake. There were 29 documented exceedances from Lake Madison and Brant Lake of the pH standard 9.0 su. Most of the pH exceedances can be attributed to algal blooms. There were 19 dissolved oxygen observations that exceeded the standard of 5.00 mg/L. Brant Lake only exhibited two of the dissolved oxygen exceedances, which were collected at both of the bottom sites (BL4 and BL5). Lake Madison exhibited 17 dissolved oxygen exceedances. Eleven of these 17 occurred during January and February of 1995 during snow cover and reduced photosynthesis. There was one exceedance of the temperature standard for Brant Lake. The fecal coliform standard was exceeded only once from a sample collected from Bourne Slough and reached a concentration 550 coliform per 100ml on June 28, 1995. All of the above exceedances of the water quality standards are associated with excessive nutrient inputs into the lake and the presence of livestock in the streams.

Seasonal Water Quality

Typically, many water quality parameters decrease in concentration as the volume of water increases. This occurred for the inlake sample concentrations. During the spring runoff (March – May) when in some cases 70% of the runoff occurred for some of the tributary sites, the inlake concentrations for nutrients and suspended solids concentrations decreased. As the runoff decreased the concentrations began to increase through the summer sampling period. Tributary sample concentrations exhibited a variety of seasonal trends. Site LMT1 (outlet of Lake Herman) exhibited the maximum concentrations during the spring and as the sampling year continued the samples decreased in concentrations. However, this was highly dependent upon the individual parameter. Nutrients were typically higher in the spring with periodic spikes occurring during the year, which may have been due to fertilizer and animal waste runoff.

Tributary Sampling

Site LMT1 is the outlet of Lake Herman and Site LMT2 is located approximately 2 miles downstream in Silver Creek (Figure 58). There were significantly larger nutrient and fecal coliform concentrations collected from Site LMT2 compared to Site LMT1. These higher concentrations at Site LMT2 resulted in very higher export coefficients per unit area (lbs/acre/yr) for nutrients and sediments.

Site LMT3 monitored a small tributary draining 1400 acres from the northwest part of the watershed (Figure 58). It is the least impacted subwatershed within the Lake Madison watershed. Although this monitoring station exhibited the lowest concentrations of nutrients and sediment, it did exhibit the highest fraction of dissolved phosphorus (84%).

Site LMT4 monitored the 13,880-acre subwatershed draining from the north by Memorial Creek (Figure 58). This site also exhibited a high fraction of dissolved phosphorus but also had excessive levels of total phosphorus and nitrogen. Compounded with the high levels of nutrients there were consistently higher levels of fecal coliform. These high

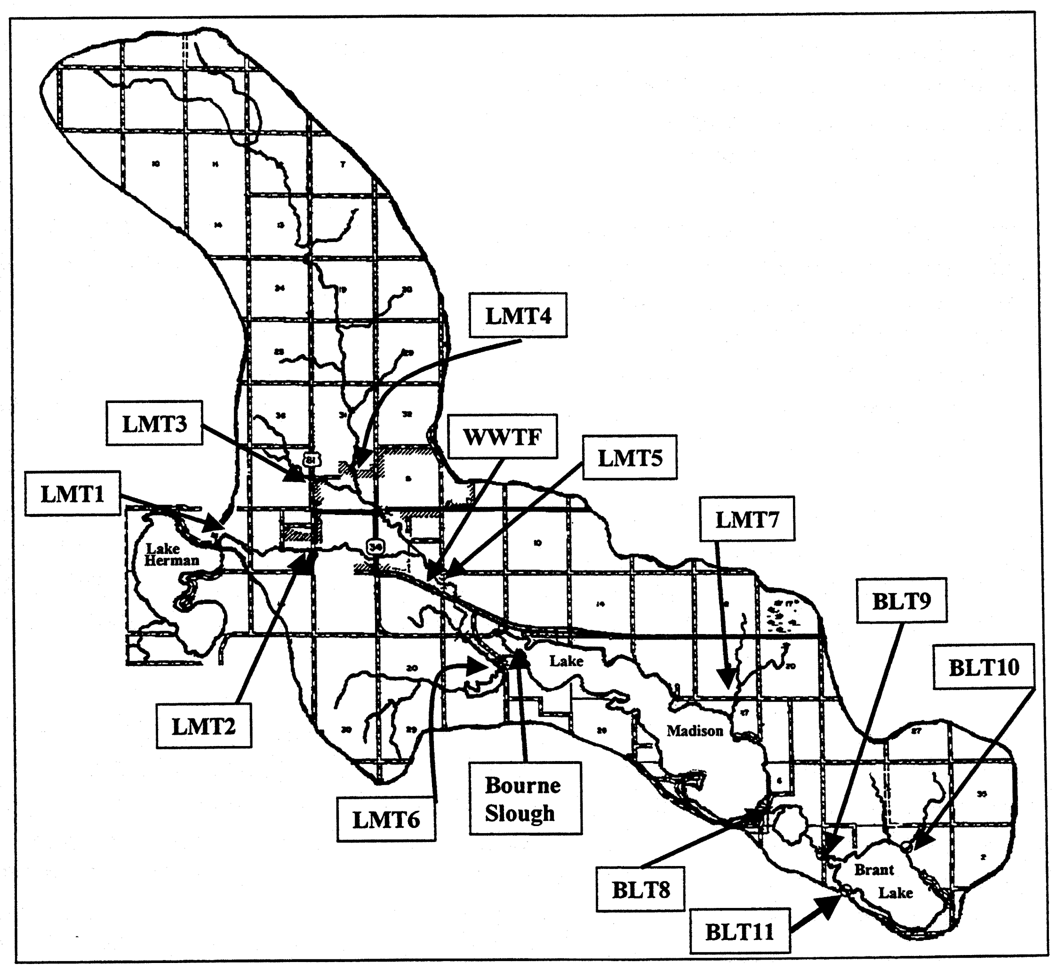


Figure 58. Lake Madison and Brant Lake Watersheds and Tributary Monitoring Sites.

concentrations resulted in moderately high nutrient export coefficients, which may be largely attributed to livestock grazing and feedlots. Fertilizer application may also play a role in the higher export coefficients.

Site LMT5 is located downstream from the city of Madison and Sites LMT1-LMT4 (Figure58). A 7.5-ton nitrogen loss in loadings occurred between the upstream sites and Site LMT5. This nitrogen loss was attributed to the recharge of the North Skunk Creek aquifer during the spring of 1995. Although total phosphorus concentrations were not significantly different from the upstream sites, the 3,480 acres exhibited the second highest export coefficient per acre. There was also a significant amount of sediment gained during the project at this site resulting in the third highest sediment export coefficient. This was attributed to runoff from the urban storm sewers.

Site LMT6 is located downstream of Site LMT5 and drains 5,000 acres excluding the area above Site LMT5 (Figure 58). It also drains a small tributary from the west before Silver Creek enters Bourne Slough. Site LM6 nutrient concentrations were not significantly different from Site LMT5 upstream. However, there was a large increase in the suspended solids concentrations. Fecal coliform also exhibited the highest mean concentration for all the sites monitored during the study. This indicates the presence of animal waste material and riparian degradation between Site LMT5 and Site LMT6. The phosphorus export coefficients were significantly lower than Site LMT5 but suspended sediment export coefficients increased.

Site LMT7 is a separate tributary draining 1,920 acres directly into Lake Madison from the northeastern part of the watershed (Figure 58). This site exhibited a relatively low phosphorus export coefficient but a higher sediment export coefficient. The water quality data indicated a relatively high fraction of dissolved phosphorus and the maximum concentration of suspended solids (936 mg/L) was also recorded from this site. This site also consistently exhibited very high nitrate-nitrite concentrations indicating agricultural runoff probably due to fertilizers.

Site BLT8 is the outlet of Lake Madison (Figure 58). Ammonia levels were higher here than from the other sites due to the breakdown of algae during summer. Phosphorus and suspended solids concentrations were lower here due to the trapping efficiency of Lake Madison. Fecal coliform concentrations were also considerably lower than the sites previously described.

Site BLT9 is the outlet of Round Lake (Figure 58). This lake acts a retention basin for the water and nutrient loadings discharged from Lake Madison. Concentrations of total phosphorus and suspended solids were higher at Site BLT9 when compared to the discharge from Lake Madison. In addition, the fraction of dissolved phosphorus was significantly lower when compared to the discharge from Lake Madison. The higher concentrations of TSS are primarily due to the resuspension of sediment in Round Lake. Round Lake is a small, shallow lake and during higher flow rates from Lake Madison when compounded with wind resuspension, result in higher concentrations of solids discharged from Round into Brant Lake.

Site BLT10 is a small tributary draining 1,800 acres from the northeastern part of the Brant Lake watershed (Figure 58). Due to the higher slopes in this area grazing areas and inadequate best management practices exacerbate existing nutrient and sediment runoff problems. Over 70% of the loadings occurred during the spring.

Site BLT11 is the outlet of Brant Lake (Figure 58). The second lowest mean total phosphorus concentration and the lowest mean dissolved phosphorus concentration was observed from this site. These observations are a result of the retention of nutrients and sediment by the lake before the water is discharged from Brant Lake.

Comparison of Water Quality Data and AGNPS Modeling

The AGNPS computer modeling conducted on the Lake Madison/Brant Lake watershed indicated high sediment and nutrient yield results from the same subwatersheds where water quality data indicated export coefficients for these same parameters. AGNPS indicated that subwatershed 6 (AGNPS report) delivered high amounts of sediment to Lake Madison. Subwatershed 6 was monitored by Site LMT7 in the lake assessment study. Site LMT7 had a very high sediment export coefficient at 165.68 lbs/acre/yr to Lake Madison. There were several smaller subwatersheds located in the 44,000 acre watershed which exhibited the potential for high sediment yield but were not monitored during the lake assessment study.

In addition to high sediment, high nutrient contribution was identified in other subwatersheds. These critical subwatersheds less than 2000 acres were located in areas adjacent to the Lake Herman outlet and northeast of Madison Lake, north of Round Lake and north and east of Brant Lake. They are contributing more than 5 lbs/ acre of nitrogen and more than 2 lbs/acre of phosphorus. Subwatershed 3 is included in these smaller subwatersheds less than 2000 acres. Subwatershed 3 was monitored above by the Site LMT1 and downstream through Site LMT2. The phosphorus and nitrogen export coefficients from Site LMT2 were higher than any of the other monitored tributary sites. Site LMT2 had a nitrogen export of 25.72 lbs/acre and a phosphorus export of 1.55 lbs/acre confirming that the water quality data and the AGNPS identified the same areas as providing larger amount of nutrients to Lake Madison and Brant Lake.

Possible sources for these areas of high nutrients and sediment were identified as high slopes and bank erosion due to lack of riparian vegetation as well as crop and lawn fertilization. Other sources which were identified as significant were confined and pastured livestock feeding areas.

Hydrologic and Nutrient Loadings

Silver Creek ran continuously during 1995 discharging 30,355 acre-feet of water into Lake Madison which constituted over 75% of the hydrologic load. Groundwater constituted only an estimated 1.6% of the overall hydrologic budget for Lake Madison.

The two primary components of the hydrologic budget of Lake Madison were Silver Creek and precipitation (19.4%).

The primary component of the hydrologic budget for Brant Lake was the discharge from Lake Madison (73%). Groundwater and precipitation comprised 18.2% and 5.9% of the Brant Lake hydrologic budget, respectively.

Silver Creek constituted 91% of the total amount of sediment discharged into Lake Madison. Lake Madison and Brant Lake accumulated 2,341.5 and 180.9 tons of sediment, respectively. These figures indicate that sedimentation from the watershed is not a problem for Lake Madison or Brant Lake.

Silver Creek constituted over 92% of the overall phosphorus budget for Lake Madison whereas groundwater only constituted 0.4% of the overall phosphorus budget to Lake Madison. Lake Madison accumulated 9,828.2 lbs of phosphorus during 1995. Brant Lake accumulated 3,951.9 lbs of phosphorus. The discharge from Round Lake constituted 88% of the overall phosphorus load to Brant Lake. Round Lake actually discharged more phosphorus than was delivered to it from Lake Madison during 1995.

Storm Sewers

The USEPA Simple Method for calculating pollutant loadings from urban areas was used to develop loadings from the city of Madison storm sewers. From this calculation method a minimum and maximum loading rate from the city of Madison's 2,214.5 acres was determined. The amount of phosphorus, which was calculated from the actual water quality data, estimated the city's contribution at approximately 2,951 lbs per year. This number derived from the actual water quality data fell within the range of loadings calculated using the USEPA Simple Method, which was 820 lbs to 10,413 lbs of phosphorus. The 2,915 lbs of phosphorus contributed by the city in 1995 constituted 13% of the total load delivered to Lake Madison from Silver Creek.

Inlake

Lake Madison and Brant Lake are too shallow to undergo stratification. The predominant algal species in both lakes was *Aphanizomenon flos-aquae.* This blue green algae favors high concentrations of phosphorus. Mean concentration of phosphorus in surface samples from Lake Madison and Brant Lake was 0.271 mg/L and 0.170 mg/L, respectively. This is considerably higher than the requirement to initiate intense blue-green algal blooms which is 0.02 mg/L. The fraction of dissolved phosphorus for both lakes averaged between 63% and 64%. During spring runoff, nutrient concentrations decreased but then increased during the summer months.

Limiting Nutrient and Trophic State Index (TSI)

Since blue-green algae are only able to assimilate dissolved phosphorus but can assimilate several kinds of nitrogen, a total nitrogen to dissolved phosphorus ratio was used to determine the limiting nutrient. When the total nitrogen to dissolved phosphorus ratio increases to 7:1, blue green algae appear to be phosphorus limited. The average total nitrogen to dissolved phosphorus ratio for Lake Madison was 29:1. Turbidity was a limiting factor in Bourne Slough where shallow depth allows resuspension of solids, reducing the amount of available light. Brant Lake exhibited the phosphorus limitation phenomenon. The average total nitrogen to dissolved phosphorus ratio for Brant Lake was 25:1. The mean total phosphorus trophic status was (TSI) 84 for Lake Madison and 77 for Brant Lake. The hypereutrophic range of Carlson's Trophic Index begins at 65 indicating that both Lake Madison and Brant Lake are in the hypereutrophic range.

Long-Term Trends

Data collected in 1979 and from 1991 to 1993 for the Statewide Water Quality Assessment and compared to data collected for this project, indicated that the overall water quality in Lake Madison and Brant Lake has not changed significantly in that period of time.

Chlorophyll *a* and Phytoplankton

The high surface concentrations of chlorophyll *a* indicated extensive blooms or algal increases that occurred during the summer in both lakes. Summer concentrations were higher in 1995. During 1995, summer chlorophyll *a* peaked during early July and August. The predominant algae present in Lake Madison during the summer samples were large populations of blue-green algae explaining the increase in chlorophyll. *Microcystis* spp., *Aphanizomenon* spp., *Oscillatoria* spp., and *Anabaena* spp. were all present in greater numbers than any other species. The summer chlorophyll *a* concentrations for Lake Madison ranged well within the hypereutrophic range, with TSIs in excess of 90.

Brant Lake typically followed the same trend in chlorophyll *a* concentrations although maximum values were not as large as Lake Madison. The maximum chlorophyll *a* concentration observed during the project resulted in a TSI of 83.4, falling well within the hypereutrophic range. The blue-green algae taxa *Aphanizomenon, Oscillatoria*, and *Anabaena*, dominated the algal community during the summer.

Relatively significant relationships were found between total phosphorus and chlorophyll *a* concentrations collected from both lakes. After analyzing all data available for Lake Madison only the data collected from Site LM2 in 1995 was found to exhibit a significant relationship between total phosphorus and chlorophyll *a* (R^2= 0.65). After analysis was completed on total phosphorus and chlorophyll *a* data collected from Brant Lake, outlying data points were removed from analysis. Only 1994 and 1995 data from Brant Lake were included in the regression analysis resulting in an R^2 of 0.58. Data collected prior to 1994 were not included in the analysis as these were atypical years (such as the flood in 1993) that diluted the concentrations of phosphorus and chlorophyll *a*. To make the reduction response model more accurate, data collected in 1994 and 1995, which reflected a more average year, were used.

Lawn Fertilization

An estimate of the contribution of lawn fertilizers to the phosphorus budgets for both Lake Madison and Brant Lake was calculated. The estimated loadings from lawn fertilization potentially contribute 0.77% of the overall total phosphorus loadings to Lake Madison and 0.2% of the total phosphorus inputs to Brant Lake. Higher contributions may occur from lawns with extremely steep slopes.

Onsite Wastewater Disposal Systems

Lake Madison is serviced by a central sewer system and was not included in this analysis. The amount of total phosphorus delivered to Brant Lake from onsite wastewater disposal systems could constitute anywhere from 1.5% to 4.5% of the total phosphorus load to Brant Lake.

Reduction Response Model

A model estimated the effects of reducing phosphorus in the watershed for both Lake Madison and Brant Lake. A 50% reduction of tributary loadings to Lake Madison and Brant Lake would result in a chlorophyll *a* concentration reduction of 88% and 90% for each lake, respectively. If the reduction could be reached, the TSI ranking for chlorophyll *a* would be reduced to mesotrophic for both lakes. However, a more realistic goal is a reduction of 40% for the tributary loadings. This would reduce the chlorophyll *a* concentrations for each lake by 79% and 72%, respectively. The TSI ranking for chlorophyll *a* would fall within the lower end of the eutrophic range which begins at 50.

RESTORATION ALTERNATIVES

Because of the soluble nature of nitrogen it is very difficult to remove it from a lake and watershed system. Phosphorus will not pass through groundwater as readily as nitrogen, as it sorbs on to soil and other substrates. Phosphorus is also considered the limiting nutrient when blue-green algae bloom. For these reasons the sponsors should concentrate on the removal of phosphorus from sources entering Lake Herman, Lake Madison, and Brant Lake.

There are a variety of sources of phosphorus that were identified within the Lake Madison and Brant Lake watersheds. In addition, the Phase III final report for Lake Herman identified sources of phosphorus within the Lake Herman watershed. Various treatments and best management practices will need to be implemented in order to accomplish a 50% reduction of phosphorus loadings.

In order to achieve this reduction a variety of best management practices (BMPs) need to be implemented in the watersheds. According to the AGNPS program, with BMP installation on those 40-acre cells with a rate of erosion greater than 7.0 tons per acre, and if all of the feeding areas that are contributing nutrients to the lakes are controlled, you can expect a reduction in total phosphorus loadings of 32.5% and 40.0% for Lake Madison and Brant Lake, respectively (Table 33).

A phased implementation project will be required to complete the treatments identified in the AGNPS analysis. A 2-year project focusing on the significantly worse areas should be attempted first, laying the groundwork for a long-term restoration project.

Another 10-13% reduction in phosphorus loadings can be realized if the storm sewers contributing nutrients to the Silver Creek are rerouted, reduced or eliminated. Lake Madison can then achieve and Brant Lake can exceed a 40% reduction in the phosphorus load. The storm sewers present a direct discharge from an urban area. Any hazardous spill in the drainage area of the storm sewers would result in damage to Lake Madison and Brant Lake. There are a variety of BMPs specifically tailored to urban areas that can help achieve a significant reduction of nutrient and sediment loadings.

These reductions do not take into consideration any reduction or BMP installation improving the water quality of Lake Madison and Brant Lake affected by lawn fertilization. Contributions of phosphorus from lawn fertilization can be reduced through the use of natural buffers or filter strips between the lake and the managed lawn, especially on lawns with high slopes. There are also available no-P fertilizers such as CENEX/Land O'Lakes "Clear Lake" fertilizer which is phosphate-free (26-0-7 = N-P-K). A second source of no-P fertilizer is Organic N soy-bean based fertilizer (6-0-6) from Renaissance Fertilizers, Edina, Minnesota. Another option is using straight ammonium nitrate fertilizer. These recommendations are for information only and do not imply endorsement by the SDDENR.

Table 33. Agricultural Nonpoint Source Computer Model Reduction Response Results.

			Percent Reduction in nutrients if:		
	Nutrient	Total Loadings	AGNPS Cells with Erosion > 8.0 tons/acre and 11 feeding areas	All feeding areas identified by AGNPS as contributing any nutrients	**AGNPS Cells with Erosion > 7.0 tons/acre and all feeding areas**
Lake Madison	Nitrogen (lbs)	115,884	15.2%	33.4%	**36.3%**
	Phosphorus (lbs)	37,285	15.1%	27.7%	**32.5%**
Brant Lake	Nitrogen (lbs)	118,900	20.7%	38.5%	**39.6%**
	Phosphorus (lbs)	34,812	24.1%	38.7%	**40.0%**

These fertilizer recommendations also apply to golf courses. The golf course, along the shore and main tributaries of Lake Herman should reconsider its management practices of fertilization and irrigation. Although no data was collected on the golf course specifically, in general, golf courses use large amounts of fertilizer and a great deal of water to maintain good conditions.

Lake Herman is a major phosphorus contributor to Silver Creek, Lake Madison, and Brant Lake. The reductions in phosphorus loadings described above do not consider the impact of water quality improvements within the Lake Herman watershed. If the water quality can be improved within the Lake Herman watershed, a further reduction in total phosphorus loadings will be realized for the lakes downstream. Please see the Phase III Post-Implementation Investigation of Lake Herman final report for restoration alternatives for the Lake Herman watershed. A copy of this report can be obtained from the SD DENR in Pierre, SD.

The installation of a centralized sewer system or continued upgrades to modern individual septic and holding tanks should be conducted for Brant Lake. Some type of modernized nutrient abatement procedure needs to be implemented for the failing onsite wastewater disposal systems of Brant Lake. The contribution of nutrients from these individual facilities will only become worse if improvements are not completed.

The Lake Madison Sanitary District and the city of Madison should add total phosphorus to their groundwater monitoring program for the wells surrounding these two wastewater treatment facilities. Although the nutrient mass balance calculations indicated that these facilities were contributing minor amounts of phosphorus to Lake Madison, the potential for major contributions of nutrients from the groundwater due to septage contamination is real. In addition, 2-3 piezometers (shallow wells) should be installed near the shoreline of Bourne Slough near the wastewater ponds of the Lake Madison Sanitary District. This should be completed at the beginning of the Phase II Implementation project. These piezometers will be used to monitor the nutrient contributions from the wastewater seepage to Lake Madison.

The city of Madison's Surface Water Discharge permit allows for emergency discharges from their wastewater facility. These discharges are due to excessive precipitation causing lift station failures. During these discharges the city is required by the permit to notify the SDDENR and sample the discharge. Water quality samples are collected above and below the discharge point to assess the water quality impact on Silver Creek (Woodmansey, 1998). Phosphorus should be added to the parameter list so that the total nutrient loading to Silver Creek and Lake Madison can be determined during these discharges. Nuisance algal blooms are a significant problem on Lake Madison and Brant Lake reducing their recreational value during the summer. All nutrient sources need to be reduced in order to achieve a 50% reduction and allow full beneficial use of these two lakes.

A final option to improve the water quality of Lake Madison and Brant Lake is dredging. The contribution of internal phosphorus loading to the nutrient budget of Lake Madison and Brant Lake was not calculated. Bourne Slough continually receives phosphorus from Silver Creek. Phosphorus is then transported into the main inlake area of Lake Madison. The shallow nature of Bourne Slough has reduced its capacity to withhold phosphorus from the rest of Lake Madison. A small sediment removal project to increase the depth around the mouth of Bourne Slough may increase its ability to retain a greater amount of phosphorus. A sediment survey should be conducted to determine the volume and distribution of sediment within Bourne Slough and the feasibility of a sediment removal project.

It was also identified that Round Lake was releasing more sediment and phosphorus to Brant Lake than it received from Lake Madison. A sediment survey should also be completed on this 152-acre lake to determine the volume and distribution of sediment. From this data a cost/benefit analysis of sediment removal can be completed.

Literature Cited

Administrative Rules of South Dakota, Department of Environment and Natural Resources, 1994. Water Pollution Control Program. Toxic Pollutant Criteria, Surface Water Quality Standards. Chapter 74:03:02.

Carlson, R.E., 1977. A Trophic State Index for Lakes. Limnology and Oceanography. 22:361-369.

Cole, G.A. 1987. Textbook of Limnology 3rd Edition. C.V. Mosby Co., St. Louis, Missouri.

Cooperative Extension Service, 1998. Fertilizer Recommendation Guide. SDSU.

Fetter, C.W. 1988. Applied Hydrogeology, 2nd Edition. Merrill Publishing Company.

Foulke, 1994. Mercury in Fish: Cause for Concern. FDA Consumer, Sept. 1994. V23, No.7. p5(4).

Gilliom, R.J., and Patmont, C.R. 1983. Lake Phosphorus Loading from Septic Systems by Seasonally Perched Groundwater. Journal of the Water Pollution Control Federation 55(10):1297-1305.

Halpin, J. 1998. Personal Communication.

Hutchinson, N.J. and E.C. Jowett. 1997. Nutrient Abatement in domestic septic systems: Research Initiatives of the Onatario Ministry of Environment and Energy. In.: Septic Odour, Commercial Wastewater and Phosphorus Removal. Conference Proceedings. University of Waterloo Centre for Groundwater Research. May 5, 1997.

Kuck, M. 1998. Personal Communication.

Lind, O.T. 1985. Handbook of Common Methods used in Limnology, 2nd Edition. Kendall/Hunt Publishing Company, Dubuque, Iowa.

Manahan, S.E. 1990. Environmental Chemistry. 4th Edition. Lewis Publishers, Inc. 612p.

Odum, E.P., 1959. Fundamentals of Ecology, 2nd Edition. W.B. Saunders Co., Philadelphia, Pennsylvania.

Prescott, G.W. 1962. Algae of the Western Great Lakes Area. Revised Edition. WM. C. Brown Co., Inc., Dubuque, Iowa.

Rodiek, R.K. 1979. Some Watershed Analysis Tools for Lake Management. in Lake Restoration: Proceedings of a National Conference. Environ. Protection Agency, 440/5-79-001. Washington D.C.

Sawhney, B.L. and J.L. Starr. 1977. Movement of Phosphorus from a Septic System Drainfield. Journal of Water Pollution Control Federation 49(11): 2238-2242.

South Dakota Dept. of Game, Fish, and Parks. 1996. Statewide Fisheries Survey 2102-F21-R-29 for Brant Lake.

South Dakota Dept. of Game, Fish, and Parks. 1996. Statewide Fisheries Survey 2102-F21-R-29 for Lake Herman.

South Dakota Dept. of Game, Fish, and Parks. 1996. Statewide Fisheries Survey 2102-F21-R-29 for Lake Madison.

South Dakota Dept. of Environment and Natural Resources. 1998. Watershed Protection Program Standard Operating Procedures Manual. Unpublished.

Stewart, W.C. and E. Stueven. 1996. 1995 South Dakota Lakes Assessment Final Report. South Dakota Department of Environment and Natural Resources, Watershed Protection Program. 760 pp.

Standard Methods for the Examination of Water and Wastewater. 1995. Joint Editorial Board, Am. Public Health Assoc., American Water Works Assoc., and Water Environment Federation, 19th Edition. Washington D.C.

Standard Methods for the Examination of Water and Wastewater. 1985. Joint Editorial Board, Am. Public Health Assoc., American Water Works Assoc., and Water Pollut. Control Fed., 16th Edition. Washington D.C.

Taylor, W. 1974. Phytoplankton Water Quality Relationships in U.S. Lakes, Part VIII: Algae Associated With or Responsible for Water Quality Problems. NTIS, Springfield Virginia.

Terrene Institute, 1996. A Watershed Approach to Urban Runoff. Washington, D.C.

Terrene Institute, 1994. Urbanization and Water Quality. Washington D.C.

U.S. Department of Agriculture – Soil Conservation Service, 1973. Soil Survey for Lake County South Dakota.

U.S. Environmental Protection Agency, 1993. Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters. EPA-840-B-92-002. Washington D.C.

U.S. Environmental Protection Agency, 1992. Guidance Manual for the Preparation of Part 2 of the NPDES Permit Applications for Discharges from Municipal Separate Storm Sewer Systems. EPA-833-B-92-002. Washington D.C.

U.S. Environmental Protection Agency, 1990. Clean Lakes Program Guidance Manual. EPA-440/4-90-006. Washington, D.C

U.S. Environmental Protection Agency, 1980. Clean Lakes Program Guidance Manual. EPA-440/5-81/003. Washington, D.C.

U.S. Geological Survey, 1990. Appraisal of the Water Resources of the Skunk Creek Aquifer in Minnehaha County, South Dakota. Water-Resources Investigation Report 87-4156.

U.S. Geological Survey, 1986. Water Resources of Lake and Moody Counties, South Dakota. Water Resource Investigation Report 84-4209.

U.S. Geological Survey, 1965. Hydrogeology of the Glacial Drift in the Skunk Creek-Lake Madison Drainage Basin Southeastern South Dakota. Hydrologic Investigations Atlas HA-195.

Vollenwieder, R.A. and J. Kerekes. 1980. The Loading Concept as a Basis for Controlling Eutrophication Philosophy and Preliminary Results of the OECD Programme on Eutrophication. Prog. Water Technol. 12:3-38.

Wittmuss, A.A., 1996. Phase I Diagnostic Feasibility Study Final Report for Lake Poinsett. South Dakota Department of Environment and Natural Resources. Watershed Protection Program. 77pp.

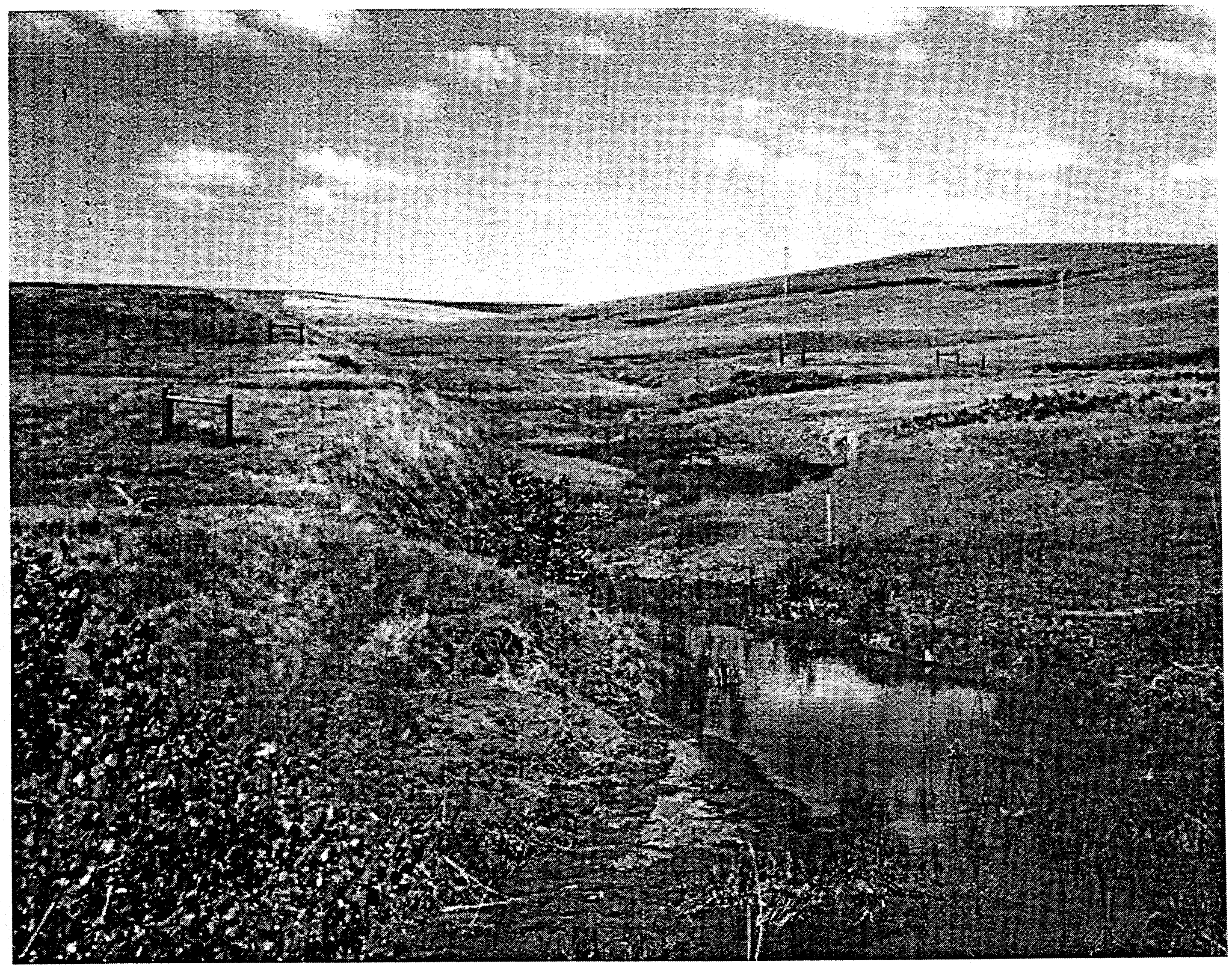
Wetzel, R.G., 1983. Limnology 3rd Edition. Saunders College Publishing, Philadelphia.

Woodmansey, K. 1998. Personal Communication.

Young, R.A., C.A. Onstad, D.D. Bosh, and W.P. Anderson. 1986. AGNPS, Agricultural Nonpoint Source Pollution Model. USDA-ARS-Conservation Research Report 35.

APPENDIX A

PRELIMINARY REPORT ON THE
AGRICULTURAL NONPOINT SOURCE (AGNPS) ANALYSIS
OF THE MADISON/BRANT WATERSHED
LAKE COUNTY, SOUTH DAKOTA



SOUTH DAKOTA WATERSHED PROTECTION PROGRAM
DIVISION OF FINANCIAL & TECHNICAL ASSISTANCE
SOUTH DAKOTA DEPARTMENT OF
ENVIRONMENT AND NATURAL RESOURCES

MAY 1998

TABLE OF CONTENTS

	Page #
Executive Summary	I-III
Summary of the Madison/Brant AGNPS analysis	1-3
Sediment Results	4
Nutrient Results	4-5
Discussion of Critical Cells	5-6
Ranking of Animal Feeding Areas	7
Conclusions	8-9
Feeding Area Analysis	10-13
Rainfall specs for the Madison/Brant watershed study	14
Overview of AGNPS model and data inputs	15-17
Location of Subwatersheds	18-19
Location of Animal Feeding	20
Location of Critical Erosion Cells	21
Subwatershed Nitrogen Yields	22
Subwatershed Phosphorous Yields	23

EXECUTIVE SUMMARY

The Madison/Brant watershed is located in eastern South Dakota and includes the city of Madison, South Dakota. The size of the Madison/Brant watershed and area modeled was 44,000 acres. This area is defined by the drainage area from the headwaters of Memorial Creek (southeast of Ramona, S.D.) and the outlet of Lake Herman to the outlet of Brant Lake.

In order to further evaluate the water quality status of the Madison/Brant watershed, landuse and geo-technical information was compiled. This information was then incorporated into a computer model. The primary objectives of utilizing a computer model on the Madison/Brant watershed was to:

1.) Evaluate and quantify Nonpoint Source (NPS) yields from each subwatershed and determine the net loading at the outlet of Brant Lake;
2.) Define critical NPS cells within each subwatershed (elevated sediment, nitrogen, phosphorus); and
3.) Priority rank each animal feeding area and quantify the nutrient loadings from each area.

Based on the results of the computer model, the following conclusions were formulated :

1. <u>Watershed/ Subwatershed Analysis</u>

   Sediment - Based upon a comparison of other watersheds in Eastern South Dakota, the AGNPS data indicates that the Madison/Brant watershed has a very low sediment deliverability rate at the outlet of Brant Lake (.07 tons/acre$_{25\ year\ event}$). This is equivalent to a load of 3015 tons of sediment. However, an analysis of the sediment transport and deliverability throughout the watershed indicated that during a 25 year storm event, approximately 15,130 tons of sediment enter Madison Lake and 2,419 tons of sediment leave the lake, and approximately 9,626 tons of sediment enter Brant Lake and 3,015 tons of sediment leave the lake. This correlates to a trapping efficiency of 84% for Madison Lake and 69% for Brant Lake. Due to the trapping efficiency of these two lakes, the net watershed sediment deliverability rate at the outlet of Brant Lake of .07 tons/acre $_{25\ year\ event}$ appears to be very low. However, this low rate under estimates the status of erosion and sediment deliverability rates throughout the watershed. The mean subwatershed sediment deliverability rate in the Madison/Brant watershed was estimated to be 0.74 tons/acre$_{25\ year\ event}$.

   When a detailed subwatershed analysis was performed, six of the 23 subwatersheds analyzed appeared to have very high sediment deliverability rates. Subwatersheds 6(#823), 16(#714), 20(#783), 22(#822), 23(#1047) and 25(#1090) were found to be delivering high amounts of sediment to the watershed. These six subwatersheds are located north-northeast of Madison Lake, north of Round Lake and north of Brant Lake. The suspected source of this sediment is from agricultural land which have slopes ranging from 7-18% and are currently cropped or have poor vegetative cover. The conversion of this acreage to a high residue management system or rangeland (landslopes > 7%) should reduce the volume of sediment delivered to watershed. *Overall, the total sediment delivered from the Madison/Brant watershed is high when adjusted for its watershed size and deliverability system.*

   Nutrients - The AGNPS data indicates that the Madison/Brant watershed (at the Brant Lake outlet) has a total nitrogen (soluble + sediment bound) deliverability rate of .0011 tons/acre$_{25\ year\ event}$, and a total phosphorus (soluble + sediment bound) deliverability rate of .0003 tons/acre$_{25\ year\ event}$. However, the mean subwatershed nutrient deliverability rate within the Madison/Brant watershed was estimated to be .0022 tons/acre $_{25\ year\ event}$ for nitrogen and .0008 tons/acre $_{25\ year\ event}$ for phosphorus. When a detailed subwatershed analysis was performed, six of the nineteen subwatersheds analyzed appeared to have high nutrient deliverability rates. Subwatershed 3(#477) high nutrient rate of .0084 tons/acre$_{25\ year\ event}$ (high water soluble) can be attributed to the high nutrient releases from Lake Herman for the model storm event.

Subwatersheds 16(#714), 19(#776), 20(#783), 22(#822) and 23(#1047) appear to be contributing elevated levels of total nutrients, however this can probably be attributed to nutrients which are associated with the high sediment yields from the subwatersheds. This is verified by the fact that of the six critical nutrient subwatersheds, five are subwatersheds that were listed inthe previous section as having high sediment yields, and all six are associated with high levels of fertilization with at least a 20% availability factor. The elevated nutrient levels found within subwatersheds 20(#783) and 23(#1047) are associated with nutrients from agricultural lands which are utilized as cropland and where fertilizer is applied. *Overall, the total nutrients delivered from the Madison/Brant watershed is high when adjusted for its watershed size and deliverability system* The most likely source of nutrients is probably from fertilization practices on cropland, sediment attached nutrients and from animal feeding operations within the watershed.

2. Critical NPS Cells

Sediment - An analysis of individual cell sediment yields indicated that out of the 1100 cells found within the Madison/Brant watershed, 75 had sediment erosion yield greater than 8.0 tons/acre$_{25 \text{ year event}}$. This is approximately 6.8% of the cells found within the entire watershed. The suspected primary source of elevated sedimentation within the critical cells is from agricultural lands which have landslopes of 7% or greater which are utilized as cropland (high C-factor), or rangeland areas located on landslopes of 12% or greater which are overgrazed and therefore in poor condition. Based upon a subwatershed area weighted to number of critical cells analysis, the most critical area for sediment erosion and deliverability was found to be from subwatersheds 6(#823), 9(#1048), 20(#783), 23(#1047), and 25(#1090). In order to reduce sedimentation from these 75 critical cells, the appropriate best management practices should be installed.

Nutrients - An analysis of individual cell nutrient yields indicated that out of the 1100 cells found within the watershed, 74 had sediment nitrogen yields greater than 9.8 lbs./acre and sediment phosphorus yield greater than 4.9 lbs./acre. This is approximately 6.7% of the cells within the watershed. The majority of the identified critical cells (approximately 85%) are primary cells. The suspected source of these elevated nutrient levels is probably from animal feeding operations and the application of fertilizers on cropland and on highly erodible soils and slopes. Based upon a subwatershed area weighted to number of critical cells analysis, the most critical source of nutrients and deliverability are from subwatersheds 16(#714), 22(#822) and to a much lesser degree from subwatersheds 6(#823), 19(#776), 20(#783), 23(#1047) and 25(#1090). Subwatershed 2(#399) contains over 50% (21 of 41) of the animal feeding areas found within the watershed while comprising only 32% of the watershed area. The identified critical subwatersheds and critical NPS cells should be given high priority when installing any future best management practices.

Feeding Area Evaluation- A total of 41 animal feeding areas were evaluated as part of the study. Of these, 24 were found to have an AGNPS rank of 30 or greater and 3 had an AGNPS rank of 50 or greater. The feeding areas located within cells #474, #982 and #984 (AGNPS rank > 50) appear to be contributing significant levels of nutrients to the watershed and feeding areas located in cells #11, #64, #65, #68, #89, #99, #155, #162, #188, #195, #458, #592, #638, #730, #806, #813, #836 and #1051 appear to be contributing elevated levels (AGNPS rank > 30) of nutrients to the watershed *Upon an analysis of other watersheds within eastern South Dakota , the density of potentially critical feeding areas found within the Madison/Brant watershed is high (24 with AGNPS rank > 30).* It is recommended that these 24 animal feeding areas be evaluated for potential operational or structural modifications in order to minimize future nutrient releases.

3. Conclusions - It is recommended that the implementation of appropriate best management practices be targeted to the critical subwatersheds, critical cells and priority animal feeding areas. However, due to the high rate of sediment erosion found within the critical subwatersheds and their high deliverability rate, initial efforts to reduce sediment should be targeted to these subwatersheds. Feeding areas with an AGNPS rank > 30 should be evaluated for potential operational or structural modifications in order to minimize future nutrient releases. The feeding areas located within cells #474, #982 and #984 appear to be contributing significant nutrients to the watershed and should be given a priority. It is recommended that any targeted cell should be field verified prior to the installation of any best management practices. This methodology should produce the most cost effective treatment plan in reducing sediment and nutrient yields from the Madison/Brant watershed.

Potential contributions of sediment from gully, riparian areas, wind and nutrients from septic systems within the Madison/Brant watershed were not evaluated as part of the computer modeling assessment phase.

MADISON/BRANT WATERSHED AGNPS ANALYSIS

Due to the lack of site specific water quality data, a computer model was selected in order to assess the Nonpoint Source (NPS) loadings throughout the Madison/Brant watershed. The model selected was the Agricultural Nonpoint Source Pollution Model (AGNPS), version 3.65. This model was developed by the USDA - Agricultural Research Service to analyze the water quality of runoff events from watersheds. The model predicts runoff volume and peak rate, eroded and delivered sediment, nitrogen, phosphorus, and chemical oxygen demand (COD) concentrations in the runoff and sediment for a single storm event for all points in the watershed. Proceeding from the headwaters to the outlet, the pollutants are routed in a step-wise fashion so the flow at any point may be examined. This model was developed to estimate subwatershed or tributary loadings to a waterbody. The AGNPS model is intended to be used as a tool to objectively compare different subwatersheds within a watershed and watersheds throughout a basin.

The Madison/Brant watershed is located in eastern South Dakota and includes the city of Madison, South Dakota (page 20). The size of the Madison/Brant watershed and area modeled was 44,000 acres. This area is defined by the drainage area from the headwaters of Memorial Creek (southeast of Ramona, S.D.) and the outlet of Lake Herman to the outlet of Brant Lake. Initially, the watershed was divided into cells each of which had an area of 40 acres with dimensions of 1320 feet by 1320 feet. The dominant fluid flow direction within each cell was then determined. Based upon the fluid flow directions and drainage patterns, 10 primary and 9 secondary subwatersheds were identified. The AGNPS analysis of the Madison/Brant watershed consisted of the collection of 21 field parameters for each cell, the calculation of nonpoint source pollution yields for each cell and subwatershed, impact and ranking of each animal feeding area, and an estimated hydrology runoff volume for each of the storm events modeled.

AGNPS GOALS

The primary objectives of running AGNPS model on the Madison/Brant watershed was to:

1.) Evaluate and quantify NPS loadings from each subwatershed;
2.) Define critical NPS cells within each subwatershed (elevated sediment, nitrogen, phosphorus); and
3.) Priority rank each animal feeding area and quantify the nutrient loadings from each area.

The following is a brief overview of each objective.

OBJECTIVE 1 - EVALUATE AND QUANTIFY SUBWATERSHED NPS LOADINGS

DELINEATION AND LOCATION OF SUBWATERSHEDS

Based upon monitoring sites and drainage patterns, eight (8) primary subwatersheds were delineated.

SUBWATERSHED	DRAINAGE AREA	OUTLET CELL #	DESCRIPTION (DF SITE)
1	1400	398	Park Creek N.W. Tributary (LMT 3)
2	15,280	399	Upper Park Creek (LMT 4)
3	1720	477	Silver Creek Tributary (LMT 2)
4	20,480	538	Confluence of Silver and Park Creeks (LMT 5)
5	25,480	737	Inlet to Madison Lake (LMT 6)
6	1920	823	N.E. Tributary to Madison Lake (LMT 7)
7	36,120	982	Outlet of Madison Lake (BLT 8)
8	38,760	1043	Inlet to Brant Lake (BLT 9)
9	1800	1048	N.E. Tributary to Brant Lake (BLT 10)
Brant Lake Outlet 10	44,000	1075	Outlet of Brant Lake (BLT 11)

Based upon fluid flow directions and drainage patterns, fifteen (15) secondary subwatersheds were delineated.

SUBWATERSHED	DRAINAGE AREA	OUTLET CELL #	DESCRIPTION
11	600	643	Tributary to Madison Lake
12	1520	646	Tributary to Madison Lake
13	240	674	Tributary to Madison Lake
14	280	680	Tributary to Madison Lake
15	120	713	Tributary to Madison Lake
16	280	714	Tributary to Madison Lake
17	25,520	738	Tributary to Madison Lake
18	240	775	Tributary to Madison Lake
19	160	776	Tributary to Madison Lake
20	880	783	Tributary to Madison Lake
21	320	817	Tributary to Madison Lake
22	240	822	Tributary to Madison Lake
23	760	1047	Tributary to Brant Lake
24	38,920	1059	Tributary to Brant Lake
25	1080	1090	Tributary to Brant Lake

Madison/Brant Subwatershed ***per acre*** loadings

SUBWATERSHED	DRAINAGE AREA (ACRES)	SEDIMENT TON/AC/YR. (ANNUAL)♣	SEDIMENT TON/AC/EVT. (25YR. EVT)	TOTAL NITRO. LBS/AC/YR. (ANNUAL)♣	TOTAL NITRO. LBS/AC/EVT. (25YR. EVT)	TOTAL PHOS. LBS/AC/YR. (ANNUAL)♣	TOTAL PHOS. LBS/AC/EVT. (25YR. EVT)
1 (#398)	1400	.469	.813	5.44	3.76	1.92	1.51
2 (#399)	15,280	.315	.488	5.52	3.27	1.67	1.16
3 (#477)	1720	.960	.644	41.23	16.89	9.97	4.28
4 (#538)	20,480	.196	.373	7.49	3.98	1.85	1.22
5 (#737)	25,480	.137	.349	6.47	3.67	1.60	1.13
6 (#823)	1920	.387	1.13	5.60	4.77	1.69	1.96
7 (#982)	36,120	.013	.067	4.64	2.31	0.89	0.55
8 (#1043)	38,760	.078	.155	5.19	2.66	1.20	0.73
9 (#1048)	1800	.266	.877	4.29	3.96	1.41	1.61
10 (#1075)	44,000	.018	.069	4.55	2.28	0.85	0.56
11 (#643)	600	.223	.658	3.62	3.46	1.19	1.35
12 (#646)	1520	.254	.742	4.70	3.71	1.39	1.45
13 (#674)	240	.158	.328	5.52	2.84	1.34	0.93
14 (#680)	280	.191	.528	4.20	3.51	1.22	1.28
15 (#713)	120	.051	.162	2.94	1.80	0.60	0.52
16 (#714)	280	.932	1.96	7.04	6.44	2.88	2.87
17 (#738)	25,520	.132	.331	6.20	3.41	1.54	1.00
18 (#775)	240	.138	.463	1.65	2.22	0.62	0.90
19 (#776)	160	.141	.571	5.67	5.56	1.77	1.91
20 (#783)	880	.405	1.65	4.05	5.57	1.52	2.48
21 (#817)	320	.060	.148	1.13	1.07	0.30	0.33
22 (#822)	240	1.05	2.09	7.94	6.82	3.12	3.04
23 (#1047)	760	.923	1.36	8.55	5.38	2.99	2.25
24 (#1059)	38,920	.062	.015	5.03	2.63	1.09	0.72
25 (#1090)	1080	.331	1.11	4.61	4.93	1.56	2.02
MEAN		.104	.267	3.47	4.34	1.02	1.33
MEDIAN		.076	.189	2.26	2.32	0.67	0.77
STDS		.066	.262	3.03	4.55	0.88	1.34

Madison/Brant Subwatershed ***total*** loadings

SUBWATERSHED	DRAINAGE AREA (ACRES)	SEDIMENT TON/YR. (ANNUAL)♣	SEDIMENT TON/EVT. (25YR. EVT)	TOTAL NITRO. TON/YR. (ANNUAL)♣	TOTAL NITRO. LBS/EVT. (25YR. EVT)	TOTAL PHOS. TON/YR. (ANNUAL)♣	TOTAL PHOS. LBS/EVT. (25YR. EVT)
1 (#398)	1400	657	1138	4	3	1	1
2 (#399)	15,280	4810	7459	42	25	13	9
3 (#477)	1720	1650	1108	35	15	9	4
4 (#538)	20,480	4018	7648	77	41	19	12
5 (#737)	25,480	3487	8895	82	47	20	14
6 (#823)	1920	742	2170	5	5	2	2
7 (#982)	36,120	479	2419	84	42	16	10
8 (#1043)	38,760	3033	5997	101	52	23	14
9 (#1048)	1800	479	1579	4	4	1	1
10 (#1075)	44,000	782	3015	100	50	19	12
11 (#643)	600	134	395	1	1	0	0
12 (#646)	1520	386	1128	4	3	1	1
13 (#674)	240	38	79	1	0	0	0
14 (#680)	280	54	148	1	0	0	0
15 (#713)	120	6	19	0	0	0	0
16 (#714)	280	261	548	1	1	0	0
17 (#738)	25,520	3371	8442	44	44	20	13
18 (#775)	240	33	111	0	0	0	0
19 (#776)	160	23	91	0	0	0	0
20 (#783)	880	356	1450	2	2	1	1
21 (#817)	320	19	47	0	0	0	0
22 (#822)	240	252	502	1	1	0	0
23 (#1047)	760	1030	1030	2	2	1	1
24 (#1059)	38,920	5819	5819	51	51	21	14
25 (#1090)	1080	1198	1198	3	3	1	1

♣- Annual loadings were estimated by calculating the NPS loadings for the cumulation of rainfall events during a average year. This includes a 1 year 24 hour event of 2.2" (E.I. = 26.8), 3 annual rainfall events of 1.6" (E.I. = 13.4) and a series of 11 small rainfall events of .9" (E.I. = 3.9) for a total "R" factor of 109.9. Rainfall events of less than .9" were modeled and found to produce insignificant amounts of sediment and nutrient yields.

SEDIMENT YIELD RESULTS

The AGNPS data indicates that the Madison/Brant watershed has a very low sediment deliverability rate at the outlet of Brant Lake (.07 tons/acre $_{25\ year\ event}$). This is equivalent to a load of 3015 tons of sediment. However, there are a number of individual subwatersheds which have elevated sediment deliverability rates. The mean subwatershed sediment deliverability rate within the Madison/Brant watershed was estimated to be 0.76 tons/acre $_{25\ year\ event}$. Subwatersheds with elevated sediment deliverability are 6(#823), 16(#714), 20(#783), 22(#822), 23(#1047) and 25(#1090). These subwatersheds are located in an area northeast of Madison Lake, north of Round Lake and north and east of Brant Lake. A comparison of the subwatershed total sediment yield to its aerial size for a 25 year storm event is:

SUBWATERSHED	EST. % TOTAL SEDIMENT LOADING	% OF WATERSHED AREA	# OF CRITICAL CELLS
6 (#823)	8.7%	5.9%	5
16 (#714)	2.2%	0.9%	1
20 (#783)	5.9%	2.7%	4
22 (#822)	2.0%	0.7%	0
23 (#1047)	4.2%	1.8%	3
25 (#1090)	4.8%	2.5%	5
Totals	27.8%	14.5%	18 of 75 (24%)

SEDIMENT ANALYSIS

Subwatersheds 6(#823), 16(#714), 20(#783), 22(#822), 23(#1047) and 25(#1090) are delivering high amounts of sediment to the watershed. These subwatersheds were found to contribute 27.8% of the total sediment, contain 24% of the critical erosion cells while occupying only 14.5% of the watershed area. The high sediment yields can be attributed to landuse, amount of surface residue and landslope. The suspected source of this sediment is from 1280 acres of cropland with slopes ranging from 7-18% which are currently cropped or have poor vegetative cover (C-factors .09-.35). The conversion of this acreage to a high residue management system or rangeland (landslopes > 7%) should reduce the amount of sediment delivered to the watershed. Subwatersheds 16(#714), 20(#783) and 22(#822) have very high sediment deliverability rates of 1.96, 1.65, and 2.09 tons/acre, respectively. This high deliverability rate can probably be attributed to the small size of the subwatersheds, their proximity to Madison Lake and their resulting short sediment travel length. Efforts should be taken to assure that high residue practices are promoted within these subwatersheds.

An analysis of the sediment transport and deliverability throughout the watershed indicated during a 25 year storm event, approximately 15,130 tons of sediment enter Madison Lake and 2,419 tons of sediment leave the lake and approximately 9,626 tons of sediment enter Brant Lake and 3,015 tons of sediment leave the lake. This correlates to a trapping efficiency of 84% for Madison Lake and 69% for Brant Lake. Due to the trapping efficiency of these two lakes, the net watershed sediment deliverability rate at the outlet of Brant Lake of .07 tons/acre $_{\text{25 year event}}$ appears to be very low. However, this low rate under estimates the status of erosion and sediment deliverability rates throughout the watershed.

The impact of sediment erosion derived from gully erosion, riparian areas, wind and their deliverability to the watershed was not modeled. Efforts should be made to target appropriate best management practices (BMP's) to the identified six critical subwatersheds and the 75 critical erosion cells identified on page 5 and 6.

NUTRIENT YIELD RESULTS

The AGNPS data indicates that the Madison/Brant watershed (at Brant Lake outlet) has a total nitrogen (soluble + sediment bound) deliverability rate of .0011 tons/acre $_{\text{25 year event}}$, and a total phosphorus (soluble + sediment bound) deliverability rate of .0003 tons/acre $_{\text{25 year event}}$. The total amount of nutrients delivered from the Madison/Brant watershed for a 25 year event is estimated to be 50.2 tons of nitrogen and 12.3 tons of phosphorus. However, the mean subwatershed nutrient deliverability rate within the Madison/Brant watershed was estimated to be .0022 tons/acre $_{\text{25 year event}}$ for nitrogen and .0008 tons/acre $_{\text{25 year event}}$ for phosphorus. Subwatersheds 3(#477), 16(#714), 19(#776), 20(#783), 22(#822) and 23(#1047) are contributing more than 5 lbs/acre of nitrogen and more than 2 lbs/acre of phosphorous. These critical subwatersheds are all less than 2000 acres and are located in areas adjacent to the Lake Herman outlet and northeast of Madison Lake, north of Round Lake and north and east of Brant Lake.

TOTAL NUTRIENT ANALYSIS

Subwatersheds 16(#714), 19(#776), 20(#783), 22(#822) and 23(#1047) appear to be contributing elevated levels of total nutrients, however this can probably be attributed to the nutrients which are associated with the high sediment yields from these subwatersheds. This is verified by the fact that of the five critical nutrient subwatersheds four of these subwatersheds were identified as critical erosion subwatersheds. Subwatershed 3(#477) elevated nutrient rate of .0069 tons/acre $_{\text{25 year event}}$ (high water soluble) can be attributed to the high nutrient concentration releases from Lake Herman for the model storm event. The elevated nutrient levels found within subwatersheds 20(#783), 23(#1047) and 18(#1030) are associated with nutrients from agricultural lands which are utilized as cropland and where fertilizer is applied.

Overall, the total nutrients delivered from the Madison/Brant watershed is high when adjusted for its watershed size and deliverability system (mean of .0022 tons/acre $_{25\ year\ event}$ for nitrogen and .0008 tons/acre $_{25\ year\ event}$ for phosphorus). The most likely source of nutrients is probably from fertilization practices on cropland, sediment attached nutrients and from animal feeding operations within the watershed.

OBJECTIVE 2 - IDENTIFICATION OF CRITICAL NPS CELLS (25 YEAR EVENT)

Priority Erosion Cells (erosion >8.0 tons/acre)	Priority Feeding Areas (AGNPS ranking >30)	Priority Nitrogen Cells (Sed.Nit. > 9.8 lbs/acre)	Priority Phosphorus Cells (Sed.Phos. > 4.9 lbs/acre)
37 10.06 tons/acre	984 (52)	* 88 10.32 lbs/ac.	* 88 5.16 lbs/ac.
182 8.66 "	982 (50)	* 113 10.79 "	* 113 5.39 "
*222 15.77 "	11 (49)	* 149 10.27 "	* 149 5.13 "
*233 15.75 "	89 (45)	* 151 11.31 "	* 151 5.65 "
*264 13.43 "	836 (43)	* 193 11.31 "	* 193 5.65 "
*282 9.53 "	592 (44)	* 222 19.50 "	* 222 9.75 "
298 15.16 "	188 (42)	* 233 18.99 "	* 233 9.49 "
*322 9.57 "	1051 (39)	* 264 17.19 "	* 264 8.59 "
*324 10.83 "	806 (39)	* 282 12.81 "	* 282 6.40 "
*341 9.53 "	162 (39)	* 310 10.35 "	* 310 5.18 "
*352 11.26 "	195 (39)	* 322 12.72 "	* 322 6.36 "
*370 13.86 "	68 (38)	* 333 10.24 "	* 333 5.12 "
*487 13.86 "	64 (37)	* 337 10.27 "	* 337 5.14 "
494 10.83 "	99 (37)	* 341 12.72 "	* 341 6.36 "
*528 10.94 "	155 (36)	* 352 14.64 "	* 352 7.32 "
562 11.69 "	458 (35)	* 369 11.31 "	* 369 5.65 "
581 10.83 "	730 (35)	* 370 17.67 "	* 370 8.84 "
602 10.40 "	666 (34)	* 378 10.35 "	* 378 5.18 "
636 13.86 "	813 (34)	* 394 10.00 "	* 394 5.00 "
648 9.53 "	638 (34)	* 486 10.32 "	* 486 5.16 "
700 9.53 "	846 (31)	* 487 17.49 "	* 487 8.75 "
714 18.90 "	65 (31)	* 488 10.18 "	* 488 5.09 "
*715 11.26 "	8 (30)	* 516 10.28 "	* 516 5.14 "
716 8.66 "		* 528 14.93 "	* 528 7.47 "
747 66.48 "		* 554 10.20 "	* 554 5.10 "
*748 10.40 "		* 612 10.16 "	* 612 5.08 "
749 32.80 "		* 620 11.31 "	* 620 5.65 "
752 9.10 "		* 628 11.31 "	* 628 5.65 "
*759 9.53 "		636 11.14 "	636 5.57 "
767 18.90 "		* 655 10.47 "	* 655 5.24 "
784 32.80 "		* 657 11.05 "	* 657 5.52 "
788 8.66 "		* 668 10.18 "	* 668 5.09 "
802 14.70 "		* 671 10.88 "	* 671 5.44 "
824 12.13 "		* 715 14.79 "	* 715 7.40 "
825 9.53 "		* 719 10.53 "	* 719 5.26 "
*826 9.53 "		747 29.50 "	747 14.75 "
*830 11.26 "		* 748 13.45 "	* 748 6.73 "
*835 15.16 "		* 759 12.82 "	* 759 6.41 "
*840 13.86 "		* 791 10.08 "	* 791 5.04 "
857 27.01 "		* 809 10.07 "	* 809 5.03 "
858 15.16 "		824 9.90 "	824 4.95 "
*860 9.96 "		825 9.98 "	825 4.99 "
861 33.76 "		* 826 12.81 "	* 826 6.40 "
*862 15.16 "		* 830 14.75 "	* 830 7.37 "
*867 11.69 "		* 835 19.42 "	* 835 9.71 "
874 13.86 "		* 840 17.62 "	* 840 8.81 "
*886 9.53 "		* 842 10.79 "	* 842 5.39 "
889 9.53 "		857 15.29 "	857 7.65 "
892 13.86 "		858 12.77 "	858 6.03 "
*901 9.53 "		* 860 13.27 "	* 860 6.63 "
903 8.66 "		* 862 19.37 "	* 862 9.69 "

Priority Erosion Cells

(erosion >8.0 tons/acre)

*904 9.53 "
913 9.53 "
*914 15.16 "
915 15.16 "
917 9.53 "
*941 9.10 "
*942 9.96 "
*961 14.73 "
963 25.08 "
964 12.99 "
974 32.80 "
993 9.96 "
*1005 14.73 "
1009 29.07 "
*1013 9.53 "
1028 11.26 "
*1029 18.33 "
*1033 10.83 "
*1034 8.66 "
*1035 9.10 "
1037 9.53 "
*1049 13.86 "
1065 15.34 "
1082 8.68 "
* - Primary Cell

Priority Nitrogen Cells

(Sed.Nit. > 9.8 lbs/acre)

* 867 15.43 "
874 10.02 "
* 885 9.90 "
* 886 12.81 "
* 891 10.56 "
892 9.82 "
* 900 11.31 "
* 901 12.85 "
* 904 12.81 "
913 11.93 "
* 914 19.37 "
* 941 12.34 "
* 942 13.11 "
* 961 18.83 "
* 1005 18.79 "
* 1013 12.89 "
* 1029 21.34 "
* 1033 14.51 "
* 1034 11.97 "
* 1035 12.55 "
* 1049 18.03 "
1050 10.26 "
1065 15.11 "

Priority Phosphorus Cells

(Sed.Phos. > 4.9 lbs/acre)

*867 7.71 "
874 5.01 "
*885 4.95 "
*886 6.40 "
*891 5.28 "
892 4.91 "
*900 5.65 "
*901 6.43 "
*904 6.40 "
913 5.97 "
*914 9.69 "
*941 6.17 "
*942 6.56 "
*961 9.42 "
* 1005 9.40 "
* 1013 6.44 "
* 1029 10.67 "
* 1033 7.26 "
* 1034 5.99 "
* 1035 6.27 "
* 1049 9.02 "
1050 5.13 "
1065 7.56 "

Based upon an evaluation of NPS cell yield data, the following critical cell yield criteria was established:

sediment erosion rate ≥ 8.0 tons/ acre
sediment nitrogen cell yields ≥ 9.8 lbs/acre
sediment phosphorus cell yields ≥ 4.9 lbs/acre

An analysis of the Madison/Brant watershed indicates that there are approximately 75 cells which have a sediment yield greater than 8.0 tons/acre. This is approximately 6.8% of the cells found within the entire watershed. The yields for each of these cells are listed on pages 5 and 6, and their locations are documented on page 21. Based upon a subwatershed area weighted to number of critical cells analysis, the most critical area for sediment erosion and deliverability was found to be from subwatersheds 6(#823), 20(#783), 23(#1047) and 25(#1090).

The model estimated that there are 74 cells which have a total sediment nitrogen yield greater than 9.8 lbs./acre and a total sediment phosphorus yield greater than 4.9 lbs./acre. This is approximately 6.7% of the cells within the watershed. The yields for each of these cells are listed on pages 5 and 6, and their locations are documented on pages 22 and 23. Based upon a subwatershed area weighted to number of critical cells analysis, the most critical source of nutrients and deliverability are from subwatersheds 6(#823), 20(#783), and to a much lesser degree from subwatersheds 23(#1047) and 25(#1090). Subwatershed 2(#399) contains over 50% (21 of 41) of the animal feeding areas found within the watershed while comprising only 32% of the watershed area. These two critical subwatersheds, the critical animal feeding areas and identified critical NPS cells should be given high priority when installing any future best management practices. Cells which are primary cells (cells which do not receive flow from other cells), may appear to have elevated nutrient concentrations due to low flow rates. Therefore, cells which are primary cells may not warrant the installation of best management practices. It is recommended that any targeted cells, subwatersheds, or feeding areas should be field verified prior to the installation of any best management practices.

OBJECTIVE 3 - PRIORITY RANKING OF ANIMAL FEEDING AREAS (25 YEAR EVENT)

A total of 41 animal feeding areas were identified as potential NPS sources during the AGNPS data acquisition phase of the project. On pages 10 -13 is a listing of the AGNPS analysis of each feeding area. Of these, 24 were found to have an AGNPS ranking of 30 or greater and three had an AGNPS ranking of 50 or greater. AGNPS ranks feeding areas from 0 to 100 with a 0 ranked feeding area yielding very little nutrients and 100 ranking yielding large amounts of nutrients.

AGNPS cells #474, #982 and #984 appear to be contributing significant levels (AGNPS ranking > 50) of nutrients to the watershed and feeding areas located in cells #11, #64, #65, #68, #89, #99, #155, #162, #188, #195, #458, #592, #638, #730, #806, #813, #836 and #1051 appear to be contributing elevated levels (AGNPS ranking > 30) of nutrients to the watershed. An analysis to evaluate the impact of feeding areas was also performed. When the model was run with the feeding areas with an AGNPS rating > 30 taken out of the watershed, the total phosphorous load into Madison Lake was reduced from 37,285 lbs. to 26,952 lbs. (27.7% reduction) and the total nitrogen load into Madison Lake was reduced from 115,884 lbs. to 77,089 lbs. (33.5% reduction). When this was applied to Brant Lake, the total phosphorous load into Brant Lake was reduced from 34,812 lbs. to 21,328 lbs. (38.7% reduction) and the total nitrogen load into Brant Lake was reduced from 118,900 lbs. to 73,115 lbs. (38.5% reduction).

It is recommended that these animal feeding areas be evaluated for potential operational or structural modifications in order to minimize future nutrient releases. It is also recommended that all other potential feeding areas within the watershed be evaluated. Other possible sources of nutrient loadings not modeled through this study were those from septic systems and from livestock depositing fecal material directly into the lakes or adjacent streams. Overall, based upon the accuracy of the watershed information gathered as part of this study, the total nutrients contributed from animal feeding areas within the Madison/Brant watershed is high.

CONCLUSIONS

Sediment

The overall sediment loadings from the watershed to the outlet of Brant Lake is very low (.07 tons/acre$_{25\ year\ event}$). This rate is equivalent to 3015 tons of sediment. This rate (.07 tons/acre$_{25\ year\ event}$) is much lower than the calculated subwatershed mean value of 0.76 tons/acre$_{25\ year\ event}$. This difference can probably be attributed to the impact of the routing of sediment through the Madison/Round/Brant lakes. Due to the trapping efficiency of these three lakes, the net watershed sediment deliverability rate at the outlet of Brant Lake of .07 tons/acre $_{25\ year\ event}$ appears to be very low. However, this low rate under estimates the status of erosion and sediment deliverability rates throughout the watershed.

When a detailed subwatershed analysis was performed, six of the 23 subwatersheds analyzed appeared to have very high sediment deliverability rates. Subwatersheds 6(#823), 16(#714), 20(#783), 22(#822), 23(#1047) and 25(#1090) were found to be contributing elevated levels of sediment.

An analysis of individual cell sediment yields indicated that out of the 1100 cells found within the Madison/Brant watershed, 75 (6.8%) had sediment erosion yields greater than 8.0 tons/acre $_{25\ year\ event}$. The suspected primary source of elevated sedimentation within the critical cells is from agricultural lands which have land slopes of 7% or greater which are utilized as cropland (high C-factor), or rangeland areas located on land slopes of 12% or greater which are overgrazed and therefore in poor condition. In order to reduce sedimentation from these 75 critical cells, the appropriate best management practices should be installed.

Therefore, it is recommended that efforts to reduce sediment should be focused within the identified critical subwatersheds and individual critical erosion cells located throughout the watershed. Based upon a subwatershed area weighted to number of critical cells analysis, the most critical area for sediment erosion and deliverability was found to be from subwatersheds 6(#823), 20(#783), 22(#822), and 25(#1090). It is recommended that any targeted cell should be field verified prior to the installation of any best management practices.

Nutrients

Overall, the nutrient loadings from the Madison/Brant watershed to the outlet of Brant Lake is .0011 tons/acre $_{25\ year\ event}$ for total nitrogen and .0003 tons/acre $_{25\ year\ event}$ for total phosphorus. The estimated total 25 year event load of nutrients delivered at the outlet of the Brant Lake is 50.2 tons of nitrogen and 12.3 tons of phosphorus. This is probably pessimistic due to the sediment trapping impact of the Madison/Round/Brant lakes. However, the average subwatershed nutrient deliverability rate within the Madison/Brant watershed was estimated to be .0022 tons/acre$_{25\ year\ event}$ for nitrogen and .0008 tons/acre$_{25\ year\ event}$ for phosphorus. When a detailed subwatershed analysis was performed, five of the nineteen subwatersheds analyzed appeared to have high nutrient deliverability rates. An analysis of individual cell nutrient yields indicated that out of the 1100 cells found within the watershed, 74 (6.7%) had sediment nitrogen yields greater than 9.8 lbs./acre and sediment phosphorus yields greater than 4.9 lbs./acre. The majority of the identified critical cells (approximately 85%) are primary cells.

Based upon a subwatershed area weighted to number of critical cells analysis, the most critical source of nutrients and deliverability are from subwatersheds 16(#714), 19(#776), 20(#783), 22(#822) and 23(#1047). The elevated nutrient levels found within subwatersheds 20(#783), 23(#1047) and 18(#1030) are associated with nutrients from agricultural lands which are utilized as cropland and where fertilizer is applied. This is verified by the fact that of the 15 critical nitrogen cells located within these three subwatersheds, 12 are associated with high sediment yields (> 8.0 tons/acre) and 9 are associated with high levels of fertilization with at least a 20% availability factor. The suspected source of the elevated nutrient levels found within the Madison/Brant watershed is probably from animal feeding operations and the application of fertilizers on cropland and on highly erodible soils and slopes. Therefore, it is recommended that efforts to reduce nutrients should be focused within the identified critical subwatersheds, individual critical nutrient cells and priority animal feeding areas located throughout the watershed.

Animal Feeding Areas

Upon an analysis of 41 animal feeding areas found within the watershed, it was determined that 24 animal feeding operations may be contributing excessive nutrients to the watershed (AGNPS ranking > 30). A total of three animal feeding areas with an AGNPS rank > 50 were identified. An analysis to evaluate the impact of feeding areas was also performed. When the model was run with the feeding areas with an AGNPS rating > 30 taken out of the watershed, the total phosphorous load into Madison Lake was reduced from 37,285 lbs. to 26,952 lbs. (27.7% reduction) and the total nitrogen load into Madison Lake was reduced from 115,884 lbs. to 77,089 lbs. (33.5% reduction). When this scenario was applied to Brant Lake, the total phosphorous load into Brant Lake was reduced from 34,812 lbs. to 21,328 lbs. (38.7% reduction) and the total nitrogen load into Brant Lake was reduced from 118,900 lbs. to 73,115 lbs. (38.5% reduction).

It is recommended that the feeding areas with an AGNPS ranking > 20 should be evaluated for potential operational or structural modifications in order to minimize future nutrient releases. It is also recommended that all other potential feeding operations/practices within the Madison/Brant watershed be evaluated and that efforts to reduce nutrients be targeted to the installation of appropriate best management practices in order to minimize the impacts of animal feeding areas.

It is recommended that efforts to reduce sediment and nutrients be targeted to the installation of appropriate best management practices on cropland (≥ 4% slope), conversion of highly erodible cropland lands (≥ 7%) to rangeland or CRP, improvement of land surface cover (C-factor) on cropland and rangeland, fertilization practices, and measures initiated to reduce nutrient runoff from animal feeding areas.

The implementation of appropriate best management practices targeting identified critical cells, priority subwatersheds and priority feeding areas upon the completion of a field verification process should produce the most cost effective treatment plan in reducing sediment and nutrient yields from the Madison/Brant watershed.

If you have any questions concerning this study, please contact the Department of Environment and Natural Resources at 605-773-4254.

FEEDING AREA ANALYSIS

Cell #	8
Nitrogen Concentration (ppm)	11.61
Phosphorus Concentration (ppm)	6.593
COD concentration (ppm)	313.07
Nitrogen mass (lbs)	36.938
Phosphorus mass (lbs)	20.976
COD mass (lbs)	996.12
Animal feedlot rating number	**30**

Cell #	19
Nitrogen Concentration (ppm)	11.167
Phosphorus Concentration (ppm)	3.503
COD concentration (ppm)	148.22
Nitrogen mass (lbs)	63.903
Phosphorus mass (lbs)	20.047
COD mass (lbs)	848.24
Animal feedlot rating number	**24**

Cell #	64
Nitrogen Concentration (ppm)	11.924
Phosphorus Concentration (ppm)	4.347
COD concentration (ppm)	192.95
Nitrogen mass (lbs)	101.26
Phosphorus mass (lbs)	36.919
COD mass (lbs)	1638.5
Animal feedlot rating number	**37**

Cell #	68
Nitrogen Concentration (ppm)	62.4
Phosphorus Concentration (ppm)	8.16
COD concentration (ppm)	1296
Nitrogen mass (lbs)	100.65
Phosphorus mass (lbs)	13.162
COD mass (lbs)	2090.5
Animal feedlot rating number	**38**

Cell #	99
Nitrogen Concentration (ppm)	29.378
Phosphorus Concentration (ppm)	10.961
COD concentration (ppm)	485.4
Nitrogen mass (lbs)	109.94
Phosphorus mass (lbs)	41.02
COD mass (lbs)	1816.6
Animal feedlot rating number	**37**

Cell #	161
Nitrogen Concentration (ppm)	6.226
Phosphorus Concentration (ppm)	2.146
COD concentration (ppm)	94.862
Nitrogen mass (lbs)	43.199
Phosphorus mass (lbs)	14.888
COD mass (lbs)	658.16
Animal feedlot rating number	**23**

Cell #	11
Nitrogen Concentration (ppm)	44.456
Phosphorus Concentration (ppm)	9.363
COD concentration (ppm)	872.08
Nitrogen mass (lbs)	209.22
Phosphorus mass (lbs)	44.066
COD mass (lbs)	4104.2
Animal feedlot rating number	**49**

Cell #	38
Nitrogen Concentration (ppm)	8.266
Phosphorus Concentration (ppm)	2.805
COD concentration (ppm)	121.32
Nitrogen mass (lbs)	54.211
Phosphorus mass (lbs)	18.397
COD mass (lbs)	795.69
Animal feedlot rating number	**26**

Cell #	65
Nitrogen Concentration (ppm)	17.03
Phosphorus Concentration (ppm)	5.26
COD concentration (ppm)	361.95
Nitrogen mass (lbs)	53.866
Phosphorus mass (lbs)	16.637
COD mass (lbs)	1144.9
Animal feedlot rating number	**31**

Cell #	89
Nitrogen Concentration (ppm)	30.36
Phosphorus Concentration (ppm)	11.623
COD concentration (ppm)	528.45
Nitrogen mass (lbs)	168.21
Phosphorus mass (lbs)	64.402
COD mass (lbs)	2928
Animal feedlot rating number	**45**

Cell #	155
Nitrogen Concentration (ppm)	21.753
Phosphorus Concentration (ppm)	4.813
COD concentration (ppm)	420.56
Nitrogen mass (lbs)	85.42
Phosphorus mass (lbs)	18.899
COD mass (lbs)	1651.4
Animal feedlot rating number	**36**

Cell #	162
Nitrogen Concentration (ppm)	18.988
Phosphorus Concentration (ppm)	6.027
COD concentration (ppm)	258.65
Nitrogen mass (lbs)	152.56
Phosphorus mass (lbs)	48.423
COD mass (lbs)	2078.2
Animal feedlot rating number	**39**

Cell #	188
Nitrogen Concentration (ppm)	100
Phosphorus Concentration (ppm)	28.333
COD concentration (ppm)	1500
Nitrogen mass (lbs)	181.22
Phosphorus mass (lbs)	51.346
COD mass (lbs)	2718.3
Animal feedlot rating number	**42**

Cell #	218
Nitrogen Concentration (ppm)	11.772
Phosphorus Concentration (ppm)	2.201
COD concentration (ppm)	225.28
Nitrogen mass (lbs)	10.781
Phosphorus mass (lbs)	2.015
COD mass (lbs)	206.31
Animal feedlot rating number	**7**

Cell #	241
Nitrogen Concentration (ppm)	19.184
Phosphorus Concentration (ppm)	5.379
COD concentration (ppm)	481.36
Nitrogen mass (lbs)	26.315
Phosphorus mass (lbs)	7.378
COD mass (lbs)	660.3
Animal feedlot rating number	**23**

Cell #	273
Nitrogen Concentration (ppm)	12.127
Phosphorus Concentration (ppm)	6.225
COD concentration (ppm)	291.04
Nitrogen mass (lbs)	32.92
Phosphorus mass (lbs)	16.898
COD mass (lbs)	790.07
Animal feedlot rating number	**26**

Cell #	332
Nitrogen Concentration (ppm)	10.436
Phosphorus Concentration (ppm)	1.826
COD concentration (ppm)	64.088
Nitrogen mass (lbs)	122.69
Phosphorus mass (lbs)	21.471
COD mass (lbs)	753.45
Animal feedlot rating number	**4**

Cell #	474
Nitrogen Concentration (ppm)	3.873
Phosphorus Concentration (ppm)	4.632
COD concentration (ppm)	239.84
Nitrogen mass (lbs)	56.077
Phosphorus mass (lbs)	67.074
COD mass (lbs)	3472.7
Animal feedlot rating number	**49**

Cell #	195
Nitrogen Concentration (ppm)	44.719
Phosphorus Concentration (ppm)	16.359
COD concentration (ppm)	733.02
Nitrogen mass (lbs)	128.63
Phosphorus mass (lbs)	47.056
COD mass (lbs)	2108.5
Animal feedlot rating number	**39**

Cell #	240
Nitrogen Concentration (ppm)	8.831
Phosphorus Concentration (ppm)	1.97
COD concentration (ppm)	222.96
Nitrogen mass (lbs)	12.392
Phosphorus mass (lbs)	2.764
COD mass (lbs)	312.86
Animal feedlot rating number	**13**

Cell #	247
Nitrogen Concentration (ppm)	14.462
Phosphorus Concentration (ppm)	6.114
COD concentration (ppm)	277.28
Nitrogen mass (lbs)	28.13
Phosphorus mass (lbs)	11.892
COD mass (lbs)	539.35
Animal feedlot rating number	**20**

Cell #	287
Nitrogen Concentration (ppm)	34.596
Phosphorus Concentration (ppm)	13.767
COD concentration (ppm)	630.65
Nitrogen mass (lbs)	34.918
Phosphorus mass (lbs)	13.896
COD mass (lbs)	636.53
Animal feedlot rating number	**22**

Cell #	458
Nitrogen Concentration (ppm)	2.607
Phosphorus Concentration (ppm)	5.055
COD concentration (ppm)	263.47
Nitrogen mass (lbs)	14.543
Phosphorus mass (lbs)	28.2
COD mass (lbs)	1469.9
Animal feedlot rating number	**35**

Cell #	573
Nitrogen Concentration (ppm)	19.174
Phosphorus Concentration (ppm)	7.248
COD concentration (ppm)	322.77
Nitrogen mass (lbs)	54.286
Phosphorus mass (lbs)	20.522
COD mass (lbs)	913.86
Animal feedlot rating number	**27**

Cell #	592
Nitrogen Concentration (ppm)	31.121
Phosphorus Concentration (ppm)	13.968
COD concentration (ppm)	647.13
Nitrogen mass (lbs)	387.15
Phosphorus mass (lbs)	173.77
COD mass (lbs)	8050.4
Animal feedlot rating number	**61**

Cell #	615
Nitrogen Concentration (ppm)	17.071
Phosphorus Concentration (ppm)	7.175
COD concentration (ppm)	327.98
Nitrogen mass (lbs)	47.3
Phosphorus mass (lbs)	19.88
COD mass (lbs)	908.76
Animal feedlot rating number	**28**

Cell #	638
Nitrogen Concentration (ppm)	18.355
Phosphorus Concentration (ppm)	7.482
COD concentration (ppm)	340.81
Nitrogen mass (lbs)	72.503
Phosphorus mass (lbs)	29.553
COD mass (lbs)	1346.2
Animal feedlot rating number	**34**

Cell #	666
Nitrogen Concentration (ppm)	15.585
Phosphorus Concentration (ppm)	5.772
COD concentration (ppm)	257.27
Nitrogen mass (lbs)	84.415
Phosphorus mass (lbs)	31.266
COD mass (lbs)	1393.5
Animal feedlot rating number	**34**

Cell #	672
Nitrogen Concentration (ppm)	10.527
Phosphorus Concentration (ppm)	2.053
COD concentration (ppm)	212.29
Nitrogen mass (lbs)	26.139
Phosphorus mass (lbs)	5.098
COD mass (lbs)	527.13
Animal feedlot rating number	**20**

Cell #	730
Nitrogen Concentration (ppm)	42.637
Phosphorus Concentration (ppm)	16.009
COD concentration (ppm)	727.27
Nitrogen mass (lbs)	89.051
Phosphorus mass (lbs)	33.436
COD mass (lbs)	1519
Animal feedlot rating number	**35**

Cell #	806
Nitrogen Concentration (ppm)	58.212
Phosphorus Concentration (ppm)	24.655
COD concentration (ppm)	1137.8
Nitrogen mass (lbs)	107.81
Phosphorus mass (lbs)	45.663
COD mass (lbs)	2107.3
Animal feedlot rating number	**39**

Cell #	813
Nitrogen Concentration (ppm)	88.068
Phosphorus Concentration (ppm)	35.065
COD concentration (ppm)	1609.2
Nitrogen mass (lbs)	88.321
Phosphorus mass (lbs)	35.166
COD mass (lbs)	1613.9
Animal feedlot rating number	**34**

Cell #	836
Nitrogen Concentration (ppm)	21.599
Phosphorus Concentration (ppm)	9.375
COD concentration (ppm)	434.41
Nitrogen mass (lbs)	126.27
Phosphorus mass (lbs)	54.811
COD mass (lbs)	2539.7
Animal feedlot rating number	**43**

Cell #	846
Nitrogen Concentration (ppm)	41.198
Phosphorus Concentration (ppm)	18.33
COD concentration (ppm)	849.06
Nitrogen mass (lbs)	60.398
Phosphorus mass (lbs)	26.872
COD mass (lbs)	1244.7
Animal feedlot rating number	**31**

Cell #	949
Nitrogen Concentration (ppm)	12.557
Phosphorus Concentration (ppm)	4.861
COD concentration (ppm)	217.4
Nitrogen mass (lbs)	20.88
Phosphorus mass (lbs)	8.083
COD mass (lbs)	361.48
Animal feedlot rating number	**15**

Cell #	982
Nitrogen Concentration (ppm)	30.764
Phosphorus Concentration (ppm)	14.187
COD concentration (ppm)	662.59
Nitrogen mass (lbs)	184.54
Phosphorus mass (lbs)	85.098
COD mass (lbs)	3974.5
Animal feedlot rating number	**50**

Cell #	983
Nitrogen Concentration (ppm)	17.474
Phosphorus Concentration (ppm)	7.385
COD concentration (ppm)	412.53
Nitrogen mass (lbs)	252.73
Phosphorus mass (lbs)	106.81
COD mass (lbs)	5966.5
Animal feedlot rating number	**0**

Cell #	984
Nitrogen Concentration (ppm)	13.574
Phosphorus Concentration (ppm)	5.885
COD concentration (ppm)	272.13
Nitrogen mass (lbs)	201.41
Phosphorus mass (lbs)	87.323
COD mass (lbs)	4037.7
Animal feedlot rating number	**52**

Cell #	1045
Nitrogen Concentration (ppm)	33.309
Phosphorus Concentration (ppm)	13.033
COD concentration (ppm)	595.85
Nitrogen mass (lbs)	49.274
Phosphorus mass (lbs)	19.28
COD mass (lbs)	881.43
Animal feedlot rating number	**27**

Cell #	1051
Nitrogen Concentration (ppm)	17.064
Phosphorus Concentration (ppm)	8.459
COD concentration (ppm)	396.07
Nitrogen mass (lbs)	80.984
Phosphorus mass (lbs)	40.144
COD mass (lbs)	1879.7
Animal feedlot rating number	**39**

Cell #	1070
Nitrogen Concentration (ppm)	6.596
Phosphorus Concentration (ppm)	3.557
COD concentration (ppm)	164.19
Nitrogen mass (lbs)	14.247
Phosphorus mass (lbs)	7.682
COD mass (lbs)	354.63
Animal feedlot rating number	**14**

RAINFALL SPECS FOR THE MADISON/BRANT WATERSHED STUDY

EVENT	RAINFALL	ENERGY INTENSITY
Monthly	.9	3.9
Semi-annual	1.6	13.4
1 year	2.2	26.8
5 year	3.4	69.1
10 year	3.9	93.3
25 year	4.6	133.5
50 year	5.2	174.4
100 year	5.7	213.0

NRCS R_{factor} for the Madison/Brant watershed = 110

Annual Loadings Calculations

monthly events = 11 events x 3.9 = 42.9

4 month event = 3 event x 13.4 = 40.2

1 year event = 1 event x 26.8 = 26.8

Modeled Cumm. R_{factor} = 109.9

POINT SOURCE LOADINGS FROM THE LAKE HERMAN WATERSHEDS

EVENT	FLOW RATE	NITROGEN	PHOSPHORUS	COD
25 year	10262 cfs	3.93 ppm 3.78 lbs./acre	.78 ppm 1.23 lbs./acre	136.6 ppm 76.84 lbs./acre
1 year	2907 cfs	8.17 ppm 1.63 lbs./acre	1.59 ppm .43 lbs./acre	132.7 ppm 20.72 lbs./acre
4-6 month	1503 cfs	10.93 ppm 1.07 lbs./acre	2.12 ppm .27 lbs./acre	127.7 ppm 10.21 lbs./acre
monthly	358 cfs	14.87 ppm .35 lbs./acre	2.85 ppm .09 lbs./acre	101.0 ppm 1.88 lbs./acre

OVERVIEW OF AGNPS DATA INPUTS

OVERVIEW

Agricultural Nonpoint Source Pollution Model (AGNPS) is a computer simulation model developed to analyze the water quality of runoff from watersheds. The model predicts runoff volume and peak rate, eroded and delivered sediment, nitrogen, phosphorus, and chemical oxygen demand concentrations in the runoff and the sediment for a **single** storm event for all points in the watershed. Proceeding from the headwaters to the outlet, the pollutants are routed in a step-wise fashion so the flow at any point may be examined. AGNPS is intended to be used as a tool to objectively evaluate the water quality of the runoff from agricultural watersheds and to present a means of objectively comparing different watersheds throughout the state. The model is intended for watersheds up to about 320,000 acres (8000 cells @ 40 acres/cell).

The model works on a cell basis. These cells are uniform square areas which divide up the watershed (figure 1). This division makes it possible to analyze any area, down to 1.0 acres, in the watershed. The basic components of the model are hydrology, erosion, sediment transport, nitrogen (N), phosphorus (P), and chemical oxygen demand (COD) transport. In the hydrology portion of the model, calculations are made for runoff volume and peak concentration flow. Total upland erosion, total channel erosion, and a breakdown of these two sources into five particle size classes (clay, silt, small aggregates, large aggregates, and sand) for each of the cells are calculated in the erosion portion. Sediment transport is also calculated for each of the cells in the five particle classes as well as the total. The pollutant transport portion is subdivided into one part handling soluble pollutants and another part handling sediment attached pollutants (figure 2).

PRELIMINARY EXAMINATION

A preliminary investigation of the watershed is necessary before the input file can be established. The steps to this preliminary examination are:

1) Detailed topographic map of the watershed (USGS map 1:24,000) (figure 3).
2) Establish the drainage boundaries (figure 4).
3) Divide watershed up into cells (40 acre, 1320 X 1320). Only those cells with greater than 50% of their area within the watershed boundary should be included (figure 5).
4) Number the cells consecutively from one to the number of cells (begin at NW corner of watershed and precede west to east then north to south (figure 5).
5) Establish the watershed drainage pattern from the cells (figure 5).

DATA FILE

Once the preliminary examination is completed, the input data file can be established. The data file is composed of the following 21 inputs per cell (table 1):

Data input for watershed (attachment 1)

1) a) Area of each cell (acres)
   b) Total number of cells in watershed
   c) Precipitation for a ___ year, 24 hour rainfall
   d) Energy intensity value for storm event previously selected

Data input for each cell

1) **Cell number** (figure 6)
2) **Receiving cell number** (figure 6)
3) **SCS number**: runoff curve number (tables 2-4), (use antecedent moisture condition II)
4) **Land slope** (topographic maps) (figure 7), average slope if irregular, water or marsh = 0
5) **Slope shape factor** (figure 8), water or marsh = 1 (uniform)
6) **Field slope length** (figure 9), water or marsh = 0, for S.D. assume slope length area 1
7) **Channel slope** (average), topo maps, if no definable channel, channel slope = 1/2 land slope, water or marsh = 0
8) **Channel sideslope**, the average sideslope (%), assume 10% if unknown, water or marsh=0 9)
9) **Manning roughness coefficient for the channel** (table 5), If no channel exists within the cell, select a roughness coefficient appropriate for the predominant surface condition within the cell
10) **Soil erodibility factor** (attachment 2),water or marsh = 0
11) **Cropping factor** (table 6), assume conditions at storm or worst case condition (fallow or seedbed periods), water or marsh = .00, urban or residential = .01
12) **Practice factor** (table 7), worst case = 1.0, water or marsh = 0 ,urban or residential = 1.0
13) **Surface condition constant** (table 8), a value based on land use at the time of the storm to make adjustments for the time it takes overland runoff to channelize.
14) **Aspect** (figure 10), a single digit indicating the principal direction of drainage from the cell (if no drainage = 0)
15) **Soil texture**, major soil texture and number to indicate each are:

Texture	Input Parameter
Water	0
Sand	1
Silt	2
Clay	3
Peat	4

16) **Fertilization level**, indication of the level of fertilization on the field.

Level	Assume Fertilization (lb./acre) N	P	Input
No fertilization	0	0	0
Low Fertilization	50	20	1
Average Fertilization	100	40	2
High Fertilization	200	80	3

avg. manure - low fertilization
high manure - avg.fertilization
water or marsh = 0
urban or residential = 0 (for average practices)

17) **Availability factor**, (table 9) the percent of fertilizer left in the top half inch of soil at the time of the storm. Worst case 100%, water or marsh = 0, urban or residential = 100%.
18) **Point source indicator**: indicator of feedlot within the cell (0 = no feedlot, 1 = feedlot) (attachment 3).

19) **Gully source level**: tons of gully erosion occurring in the cell or input from a sub-watershed (attachment 4).
20) **Chemical oxygen demand (COD) demand**, (table 10) a value of COD for the land use in the cell.
21) **Impoundment factor**: number of impoundment's in the cell (max. 13) (attachment 5)
   a) Area of drainage into the impoundment
   b) Outlet pipe (inches)
22) **Channel indicator**: number which designates the type of channel found in the cell (Table 11)

DATA OUTPUT AT THE OUTLET OF EACH CELL

Hydrology
Runoff volume
Peak runoff rate
Fraction of runoff generated within the cell

Sediment Output
Sediment yield
Sediment concentration
Sediment particle size distribution
Upland erosion
Amount of deposition
Sediment generated within the cell
Enrichment ratios by particle size
Delivery ratios by particle size

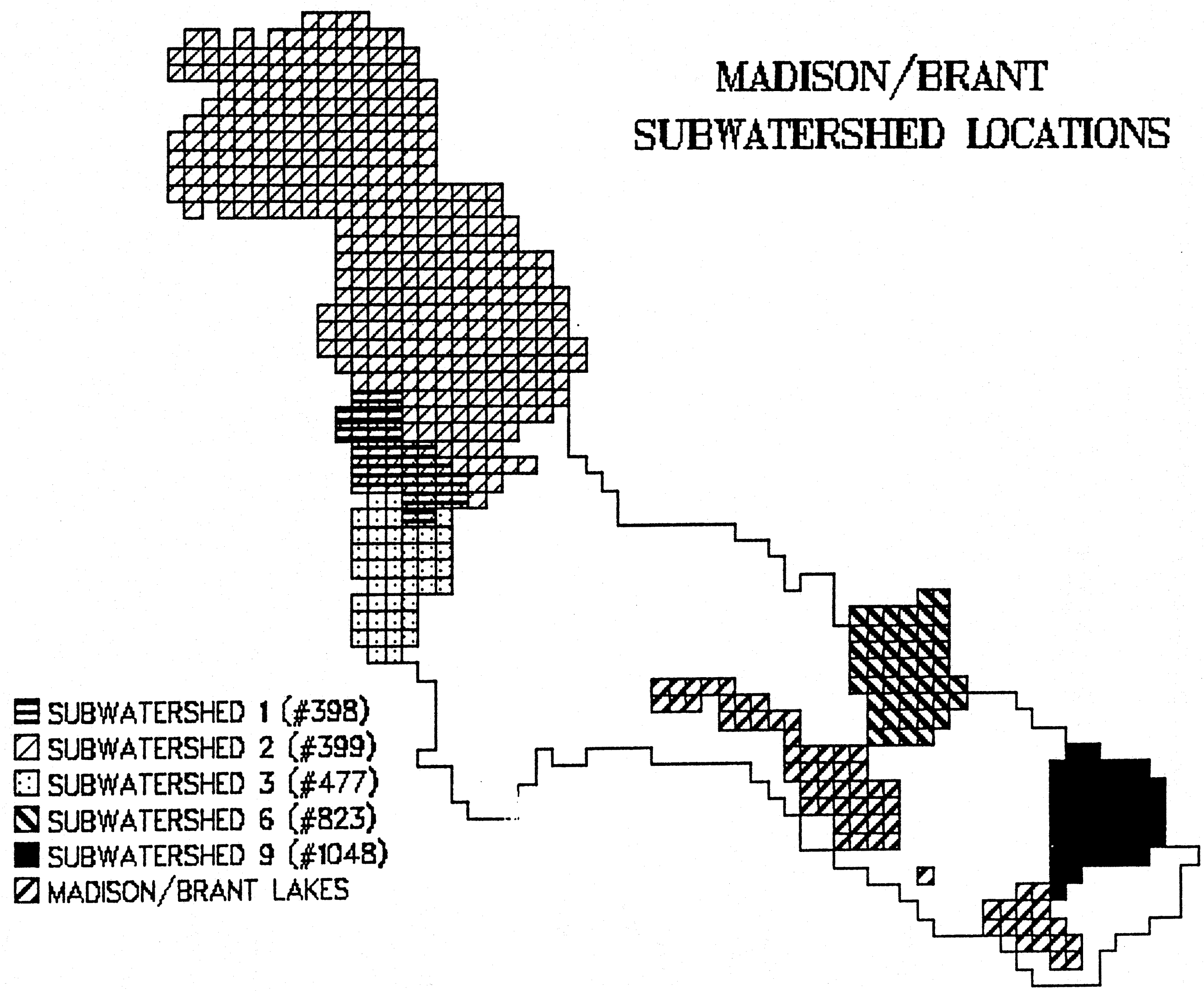
Chemical Output
Nitrogen
Sediment associated mass
Concentration of soluble material
Mass of soluble material

Phosphorus
Sediment associated mass
Concentration of soluble material
Mass of soluble material

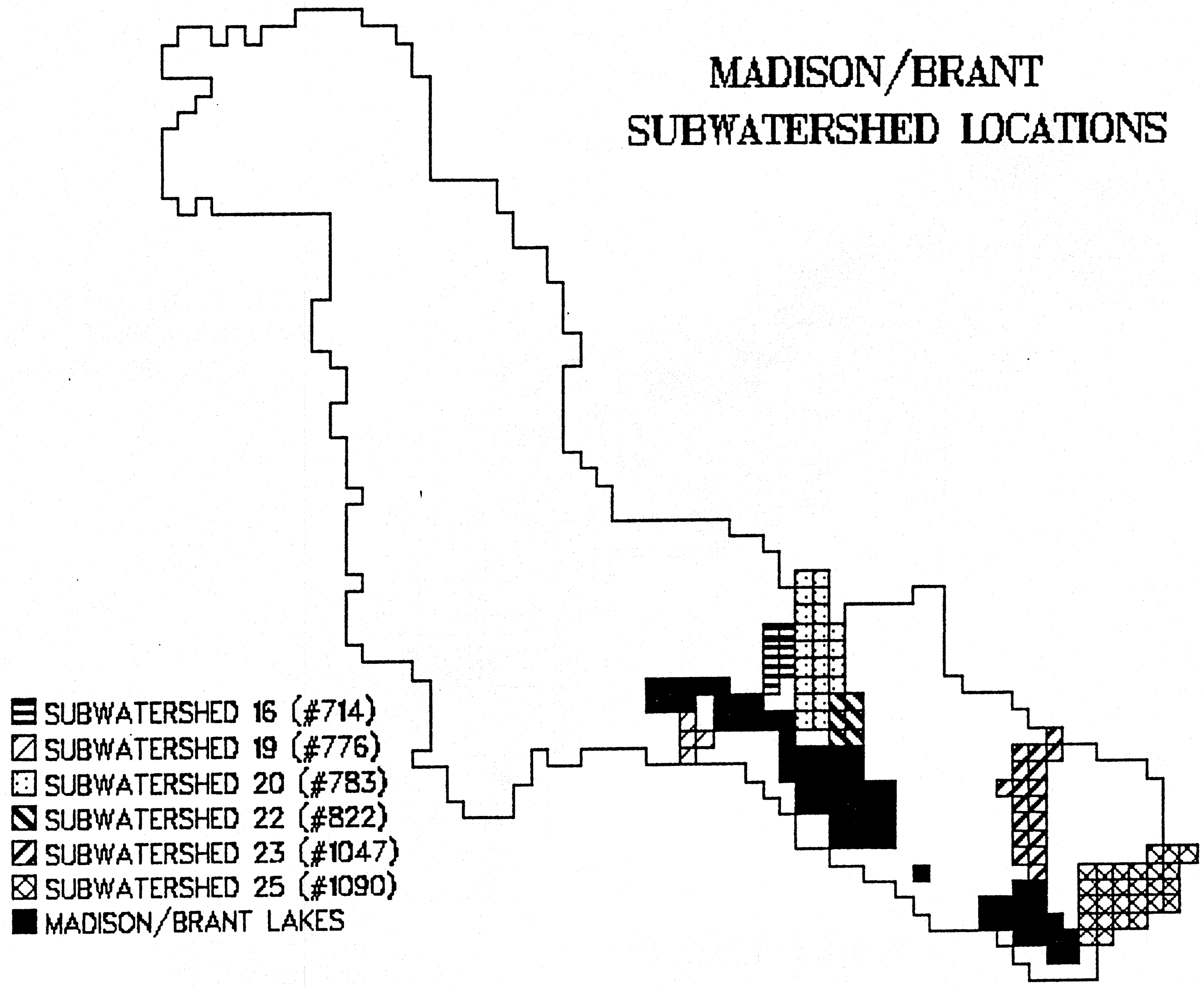
Chemical Oxygen Demand
Concentration
Mass

PARAMETER SENSITIVITY ANALYSIS
The most sensitive parameters affecting sediment and chemical yields are:
Land slope (LS)
Soil erodibility (K)
Cover-management factor (C)
Curve number (CN)
Practice factor (P)

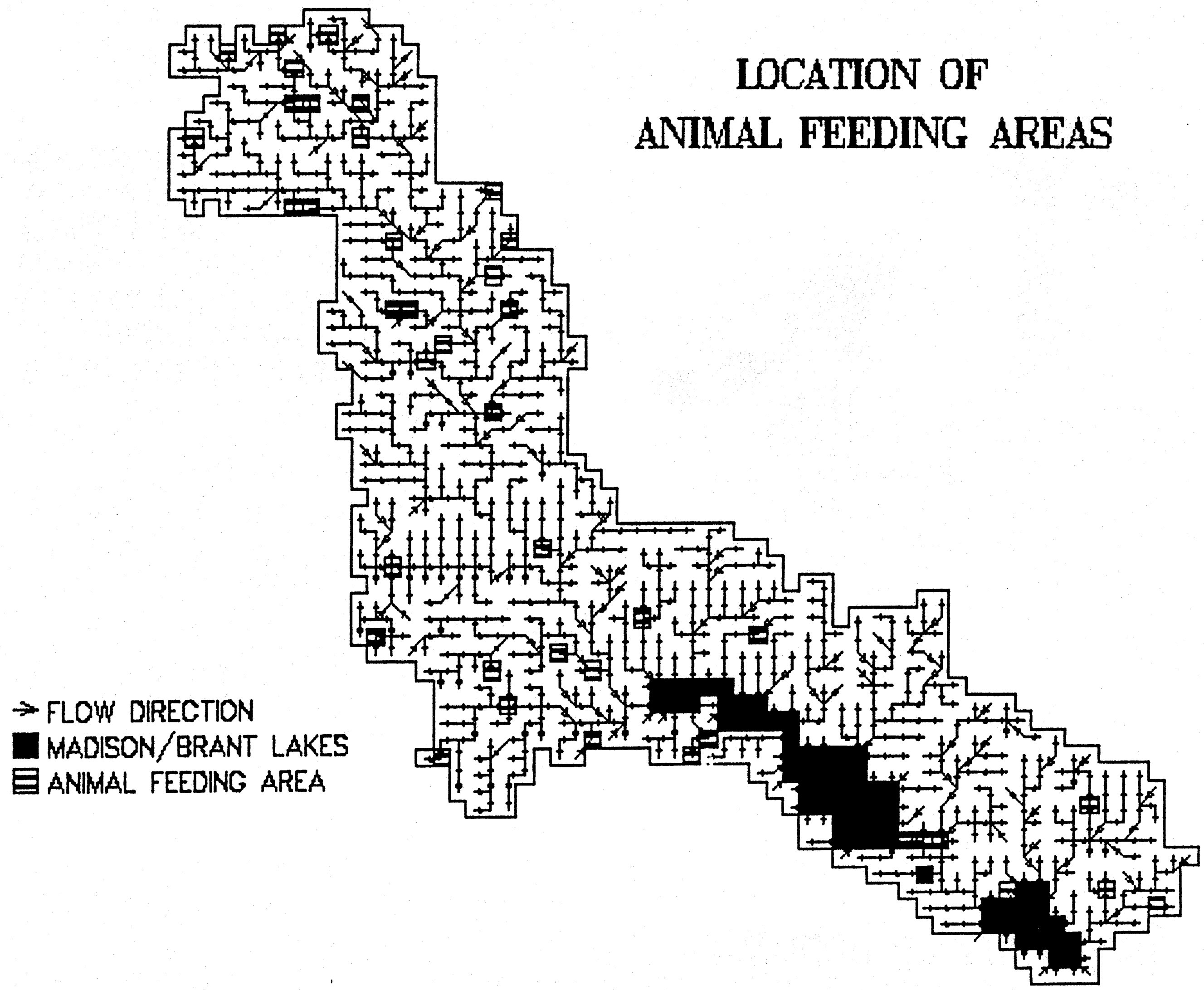
MADISON/BRANT SUBWATERSHED LOCATIONS



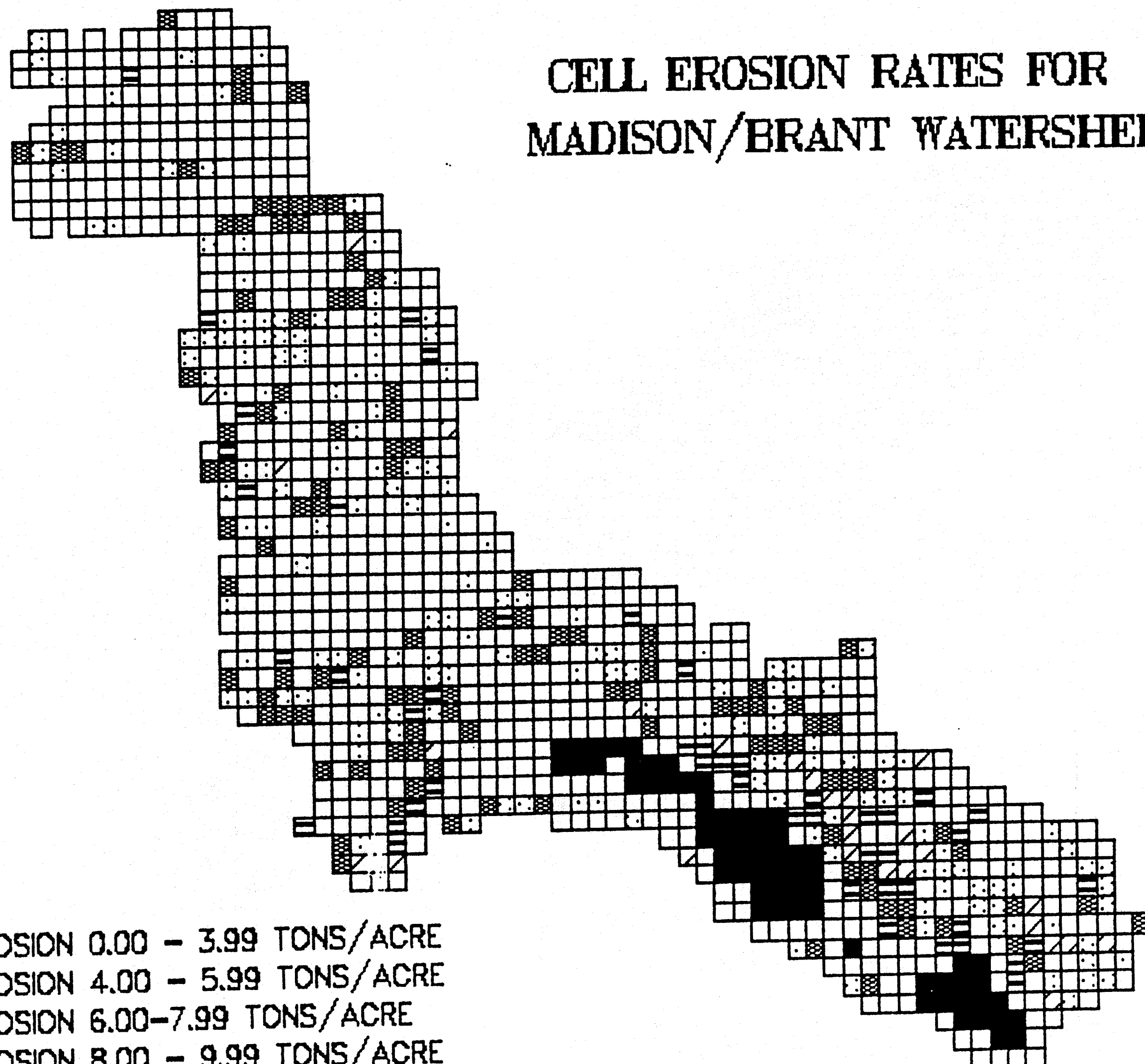
MADISON/BRANT SUBWATERSHED LOCATIONS



LOCATION OF ANIMAL FEEDING AREAS

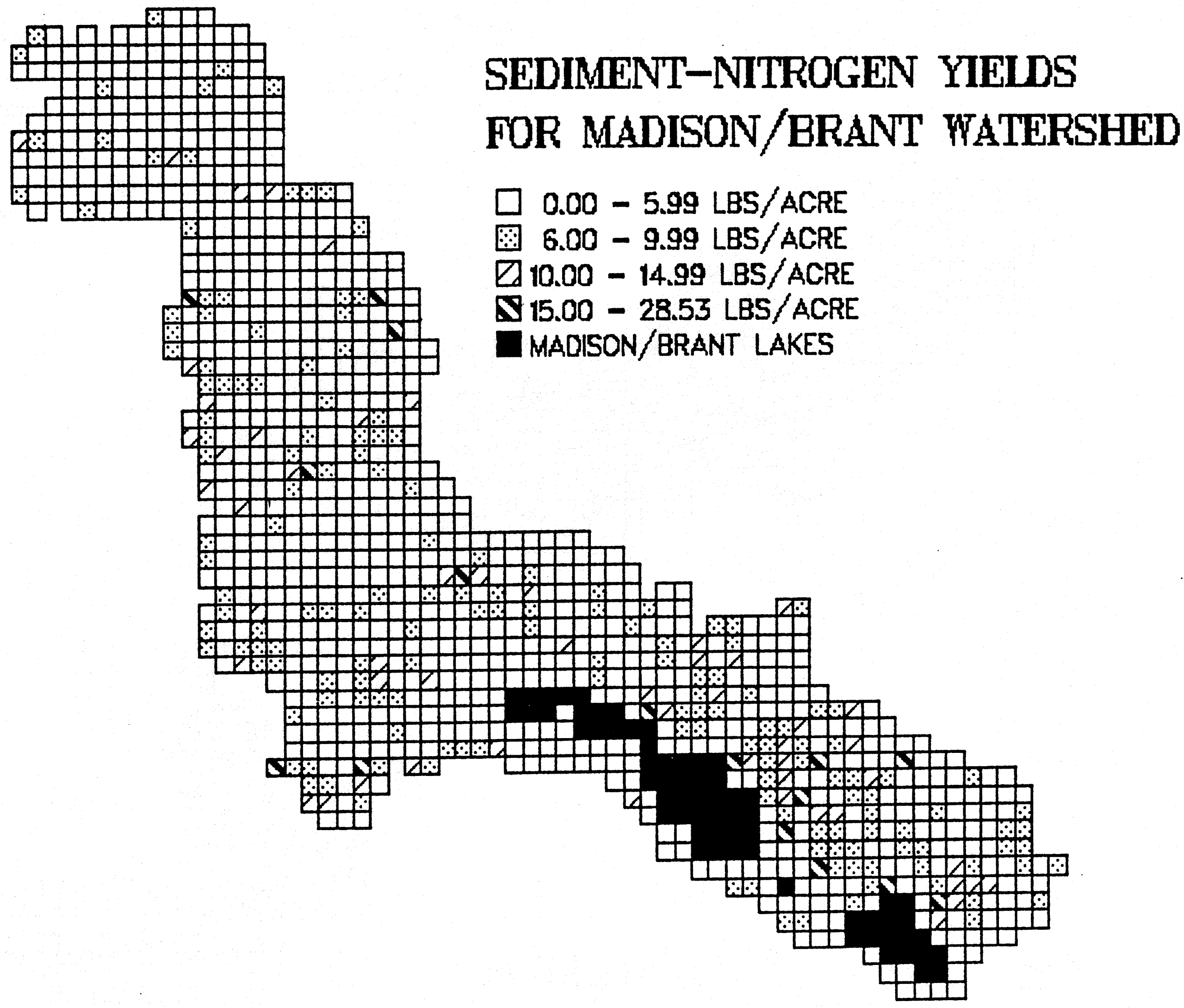


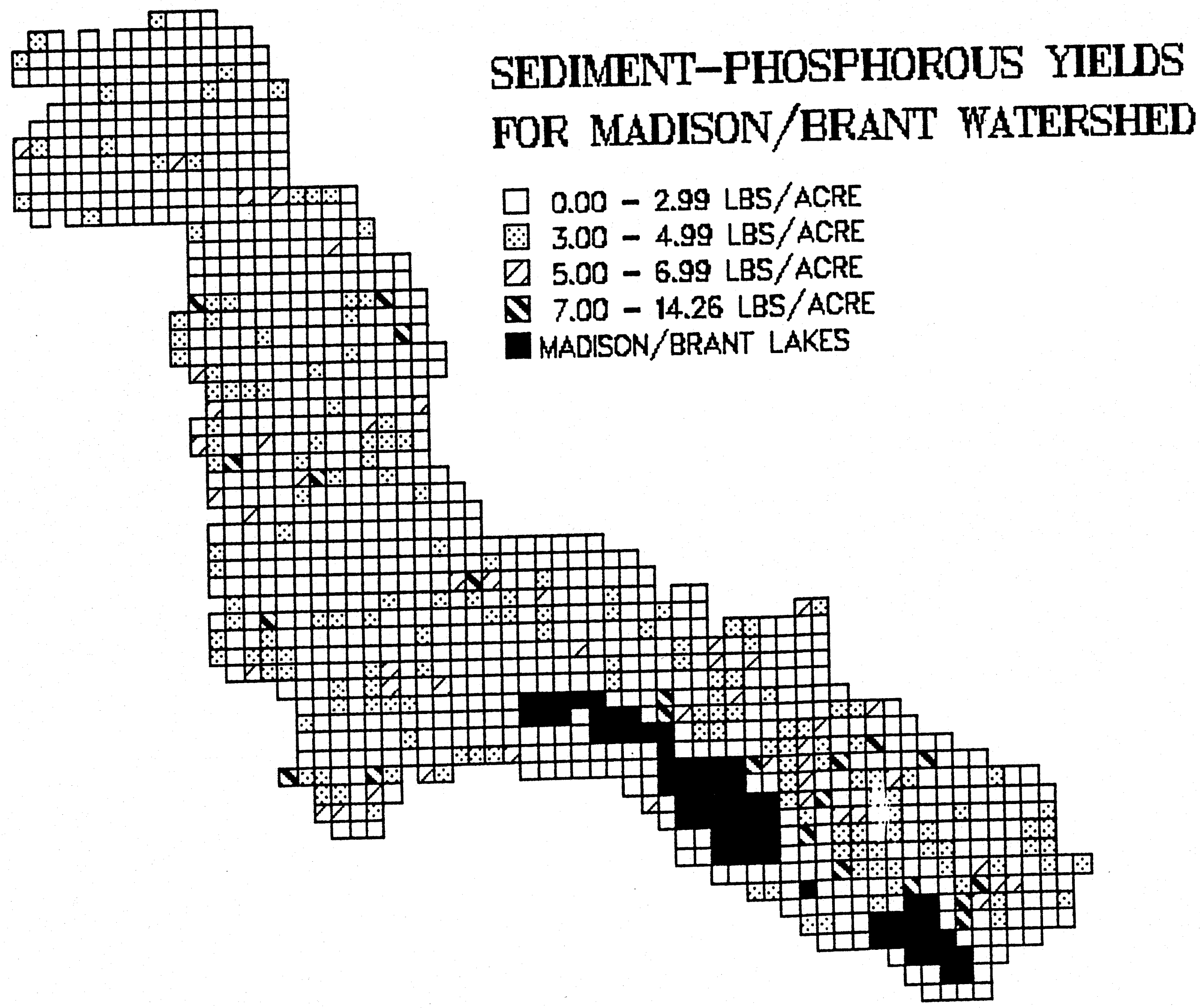
CELL EROSION RATES FOR MADISON/BRANT WATERSHED



CELL EROSION 0.00 - 3.99 TONS/ACRE
CELL EROSION 4.00 - 5.99 TONS/ACRE
CELL EROSION 6.00-7.99 TONS/ACRE
CELL EROSION 8.00 - 9.99 TONS/ACRE
CELL EROSION 10.00 - 66.48 TONS/ACRE
MADISON/BRANT LAKES

SEDIMENT-NITROGEN YIELDS FOR MADISON/BRANT WATERSHED




SEDIMENT-PHOSPHOROUS YIELDS
FOR MADISON/BRANT WATERSHED
0.00 - 2.99 LBS/ACRE
3.00 - 4.99 LBS/ACRE
5.00 - 6.99 LBS/ACRE
7.00 - 14.26 LBS/ACRE
MADISON/BRANT LAKES

APPENDIX B

SOUTH DAKOTA STATEWIDE FISHERIES SURVEY

2102-F21-R-29

Name: Brant Lake **County(ies)**: Lake
Legal Description: Sections 3, 4, 9, 10, Range 51W, Township 105N
Location from nearest town: 2 miles north of Chester, SD

Dates of present survey: August 1-2, 1996
Date last surveyed: July 24-26, 1995
Most recent lake management plan: F21-R-28 Date: 1995
Management classification: Warmwater Permanent
Contour mapped: 1964

Primary Game and Forage Species	Secondary and Other Species
1. Walleye	1. Northern Pike
2. Smallmouth Bass	2. Largemouth Bass
3. Black Crappie	3. Bluegill
4. Yellow Perch	4. Channel Catfish
5. Black Bullhead	5. Bigmouth Buffalo
6.	6. Carp
7.	7. White Sucker
8.	8. Spottail Shiner

PHYSICAL CHARACTERISTICS

Surface Area: 987 acres **Watershed**: 7,658 acres
Maximum depth: 14 feet **Mean depth**: 11 feet
Lake elevation at time of survey (from known benchmark): Full

1. Describe ownership of lake and adjacent lakeshore property:

   Brant Lake is listed as a meandered lake and the fishery is managed by the South Dakota Department of Game, Fish and Parks.

2. Describe watershed condition and percentages of land use:

   The watershed consists of 93 percent cropland and 7 percent pastureland.

3. Describe aquatic vegetative condition:

   Very little vegetation was present during the survey.

4. Describe pollution problems:

No problems were identified during the survey.

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

All structures were in good condition.

CHEMICAL DATA

1. Describe general water quality characteristics:

Water quality was fairly good during the survey with a Secchi disk measurement of 18 inches and only a small amount of algae present.

BIOLOGICAL DATA

Methods:

1. Describe fish collection methods and show sampling locations by gear type (electrofishing, gill netting, frame nets, etc.) on the lake map.

Brant Lake was sampled on August 1-2, 1996 with four, 3/4 inch, overnight frame net sets and four, 150 foot, overnight gill net sets. On August 28, 1996, seven quarter-arc pulls with a 6x100 foot, 1/4 inch bag seine were made. Netting results are listed in Tables 1-3, length frequencies in Figure 1 and sampling locations in Figure 2.

Results and Discussion:

Table 1. Total catch of four, 24 hour, 150 foot experimental gill net sets at Brant Lake, Lake County, August 1-2, 1996.

Species	Number	Percent	CPUE	80% C.I.	3 Year CPUE Avg.	PSD	Mean Wr
Walleye	107	43.7	26.8	±12.3	17.8	42	83
Yellow Perch	66	26.9	16.5	±10.9	10.8	62	111
White Sucker	40	16.3	10.0	±6.7	10.7	--	--
Black Bullhead	11	4.5	2.8	±2.1	1.9	--	--
Northern Pike	7	2.9	1.8	±0.8	1.1	--	--
Smallmouth Bass	6	2.4	1.5	±1.4	0.6	--	--
Carp	3	1.2	0.8	±0.8	0.8	--	--
Spottail Shiner	2	0.8	0.5	±0.8	0.8	--	--
Bigmouth Buffalo	2	0.8	0.5	±0.5	0.2	--	--
Shorthead Redhorse	1	0.4	0.3	±0.4	0.1	--	--

Table 2. Total catch of four, 24 hour, 3/4 inch mesh frame net sets at Brant Lake, Lake County, August 1-2, 1996.

Species	Number	Percent	CPUE	80% C.I.	3 Year CPUE Avg.	PSD	Mean Wr
Smallmouth Bass	75	32.2	18.7	±14.0	7.4	7	99
Black Bullhead	42	18.0	10.5	±12.6	4.3	--	--
Carp	29	12.4	7.2	±11.3	7.7	--	--
Yellow Perch	25	10.7	6.2	±3.4	2.5	--	--
Walleye	23	9.9	5.7	±5.2	3.5	--	--
White Sucker	16	6.9	4.0	±3.3	2.7	--	--
Northern Pike	9	3.9	2.2	±2.7	1.6	--	--
Black Crappie	6	2.6	1.5	±1.6	2.0	--	--
Bigmouth Buffalo	5	2.1	1.2	±0.8	2.0	--	--
Bluegill	1	0.4	0.2	±0.4	0.2	--	--
Channel Catfish	1	0.4	0.2	±0.4	0.1	--	--
Shorthead Redhorse	1	0.4	0.2	±0.4	0.1	--	--

Table 3. Total catch of seven quarter-arc seine pulls at Brant Lake, Lake County, August 28, 1996.

Species	Number	Percent	CPUE	80% C.I.	3 Year CPUE Avg.
Johnny Darter	10	50.0	1.2	±0.7	0.7
Fathead Minnow	4	20.0	0.5	±0.5	10.8
Spottail Shiner	3	15.0	0.4	±0.5	0.3
Smallmouth Bass	1	5.0	0.1	±0.2	2.9
Yellow Perch	1	5.0	0.1	±0.2	0.3
Walleye	1	5.0	0.1	±0.2	0.3

2. Brief narrative describing status of fish sampled, make references to the tables. See Appendix A for explanations of PSD, Wr and their normal values.

Walleye gill net catch-per-unit-effort (CPUE) was 12.5 in 1994, increased to 14.2 in 1995 and increased again to 26.8 in 1996 (Table 1). Proportional stock density (PSD) for the same time period increased from 0 to 42. Age and growth analysis shows that the walleyes in Brant are not attaining 35.5 centimeters (cm.) or 14 inches (in.) until Age 4 or 5 which is slower than average for South Dakota (Table 4). The length frequency histogram in Figure 1 illustrates an excellent size distribution of walleyes in the lake.

Smallmouth bass frame net CPUE decreased from 2.3 in 1994 to 1.2 in 1995 then jumped to 18.7 in 1996 (Table 2). Mean relative weight (Wr) was 99 and PSD was only 7. Age and growth analysis showed growth was only slightly below average for South Dakota waters (Table 5). The length frequency histogram shows that most smallmouth sampled were between 14-23 cm. (5.5-9.1 in.) long. Shoreline seining only sampled one young-of-the-year (YOY) smallmouth (Table 3).

Yellow perch gill net CPUE was 3.3 in 1994, increased to 12.7 in 1995 and increased again to 16.5 in 1996 with a PSD of 62 and a mean Wr of 111. The length frequency histogram shows the perch ranged in length from 14-27 cm. (5.5-10.6 in.) with a good distribution. The increase in perch CPUE may be attributed to the stocking of 5,763 adults in 1995 and 45,600 fingerlings and 7,026 adults in 1996 (Table 6) and the placement of artificial spawning structure in the west inlet.

Other species sampled during the survey included white sucker, northern pike, black bullhead, spottail shiners, carp, shorthead redhorse, bigmouth buffalo, bluegill, black crappie, channel catfish, Johnny darter and fathead minnows. Data concerning these species can be found in Tables 1-3.

Table 4. Average back-calculated lengths, in mms., for each age class of walleye in Brant Lake, Lake County, 1996.

			Back-calculation Age				
Year Class	Age	N	1	2	3	4	5
1995	1	0	0.00				
1994	2	13	162.77	204.53			
1993	3	16	156.21	227.60	282.53		
1992	4	17	138.76	225.54	282.20	339.37	
1991	5	10	142.27	249.29	312.22	357.84	394.28
All Classes			149.95	225.49	289.31	346.21	394.28
SD Average			163	289	389	450	508

Table 5. Average back-calculated lengths, in mms., for each age class of smallmouth bass in Brant Lake, Lake County, 1996.

			Back-calculation Age				
Year Class	Age	N	1	2	3	4	5
1995	1	11	99.71				
1994	2	30	123.23	168.72			
1993	3	7	96.14	180.14	232.33		
1992	4	4	107.22	184.70	236.27	273.23	
1991	5	2	101.15	175.02	256.76	321.05	350.95
All Classes			112.92	172.36	237.30	289.17	350.95
SD Average			105	196	259	297	

RECOMMENDATIONS

1. Stock 1,974,000 walleye fry marked with oxytetracycline in 1997 as part of a study designed to establish walleye stocking criteria.

2. Stock 9,870 black crappie adults in 1997 to increase the brood stock population of the lake.

3. Stock 98,700 bluegill fingerlings in 1997 to increase the population.

4. Stock 9,870 yellow perch adults in 1997 to increase the adult population of the lake.

5. Develop a habitat improvement plan for the lake that includes Christmas trees for perch spawning and shoreline brush piles for crappie, bass and bluegill benefits.

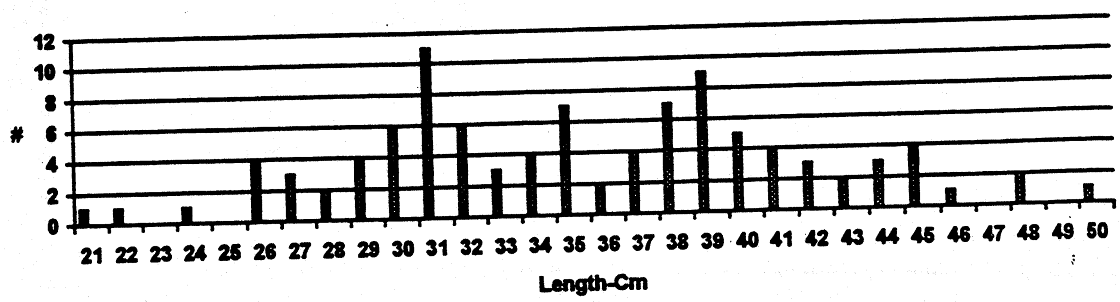
6. Black bullhead CPUE has increased from 1995 to 1996 and the population should be monitored closely. Continued increase in the population would warrant contacting the assigned commercial fisherman for removal.

Table 6. Stocking record for Brant Lake, Lake County, 1986-1996.

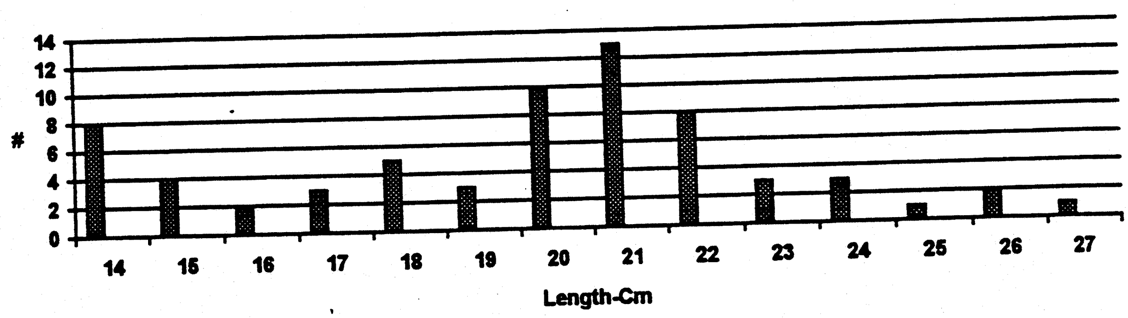
Year	Number	Species	Size
1986	50,000	Walleye	Fingerling
	25,000	Walleye	Fry
1987	14,029	Smallmouth Bass	Fingerling
	25,000	Walleye	Fry
1988	30,845	Walleye	Lrg. Fingerling
	50,000	Channel Catfish	Fingerling
1989	2,000,000	Walleye	Fry
	100,000	Walleye	Sml. Fingerling
	37,145	Walleye	Lrg. Fingerling
1990	25,000	Channel Catfish	Fingerling
	24,984	Walleye	Lrg. Fingerling
1991	2,000,000	Walleye	Fry
	100,000	Walleye	Sml. Fingerling
	10,000	Largemouth Bass	Med. Fingerling
1992	60,000	Fathead Minnow	Adult
	60,000	Smallmouth Bass	Fry
	100,000	Walleye	Sml. Fingerling
	50,500	Yellow Perch	Fingerling
1993	66,300	Black Crappie	Fingerling
	157	Black Crappie	Adult
	2,000,000	Walleye	Fry
	100,000	Walleye	Sml. Fingerling
	448	Walleye	Lrg. Fingerling
1995	50,000	Channel Catfish	Fingerling
	56,200	Fathead Minnow	Adult
	5,763	Yellow Perch	Adult
1996	11,662	Bluegill	Juvenile
	1,980,000	Walleye	Fry
	45,600	Yellow Perch	Fingerling
	7,026	Yellow Perch	Adult

Figure 1. Length frequency graphs of selected species from Brant Lake, Lake County, 1996.

Walleye-Gill Nets



Yellow Perch-Gill Nets



Smallmouth Bass-Frame Nets

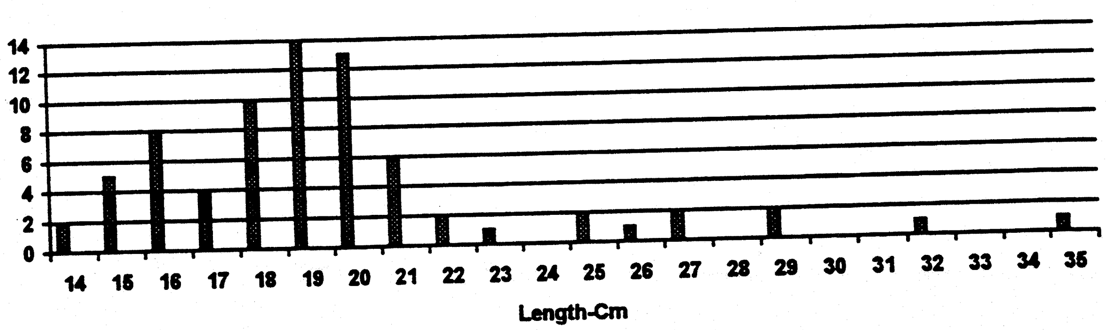
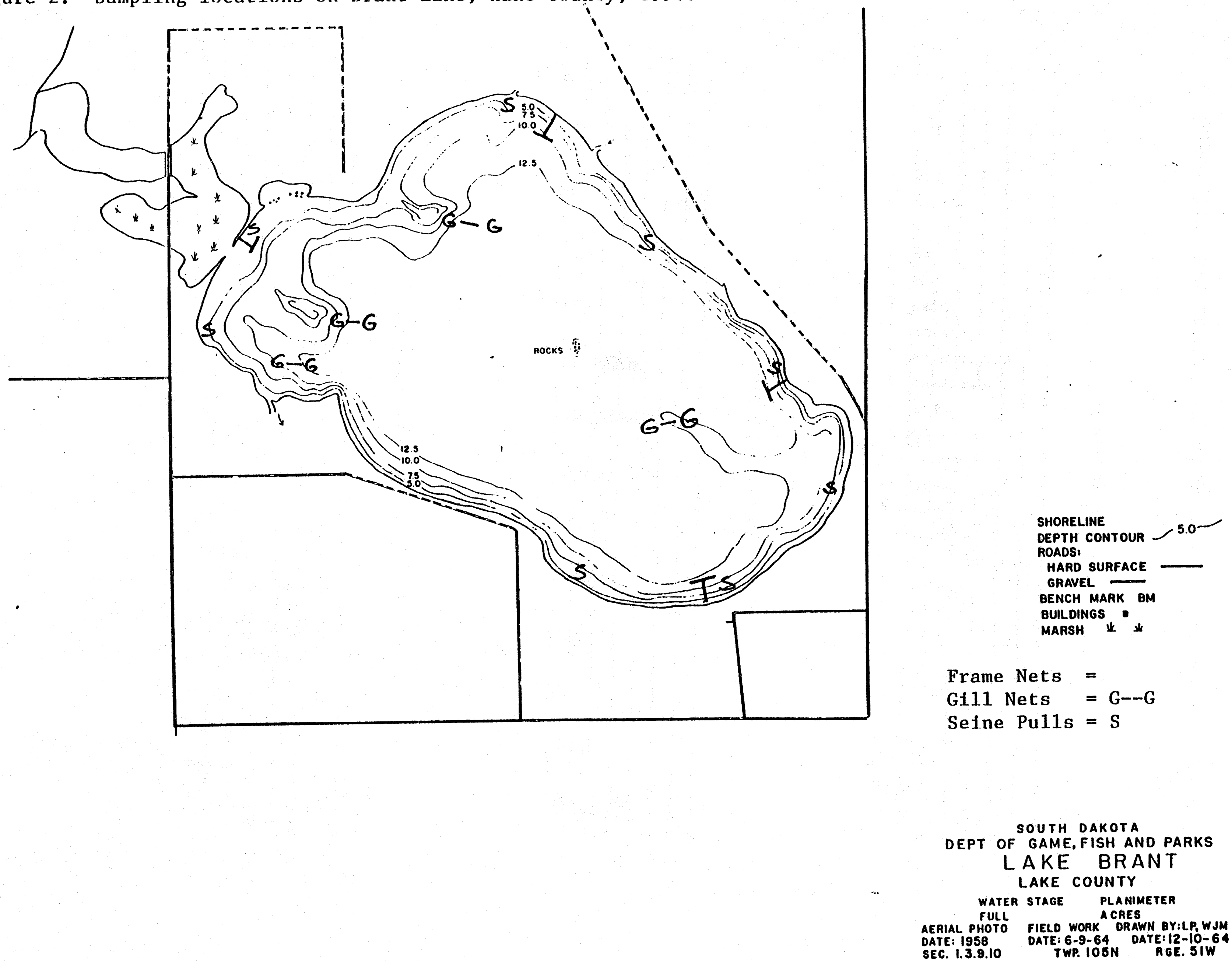


Figure 2. Sampling locations on Brant Lake, Lake County, 1996.



Appendix A. A brief explanation of PSD and Wr.

Proportional Stock Density (PSD) is calculated by the following formula:

PSD = <u>Number of Fish > quality length</u> x 100
Number of Fish > stock length

PSD is unitless and usually calculated to the mearest whole digit.

Size categories for selected species used in Region 3 lake surveys, in centimeters.

Species	Stock	Quality	Preferred	Memorable	Trophy
Walleye	25	38	51	63	76
Sauger	20	30	38	51	63
Northern Pike	35	53	71	86	112
Yellow Perch	13	20	25	30	38
Largemouth Bass	20	30	38	51	63
Smallmouth Bass	18	28	35	43	51
White Crappie	13	20	25	30	38
Black Crappie	13	20	25	30	38
Bluegill	8	15	20	25	30
Channel Catfish	28	41	61	71	91
Black Bullhead	15	23	30	38	46
Carp	28	41	53	66	84

PSD vallues in the 40-70 range indicate the population is balanced. Values less than 40 indicate a population dominated by small fish and values greater than 70 indicate a population comprised mainly of large fish.

Relative weight (Wr) is a condition indice that quantifies fish condition (ie. how much a fish weighs compared to its length). When mean Wr values are well below 100 for a size group, problems may exist in food and feeding relationships. When mean Wr values are well above 100 for a size group, fish may not be making the best use of available prey.

SOUTH DAKOTA STATEWIDE FISHERIES SURVEY

2102-F21-R-29

Name: Lake Herman **County(ies)**: Lake
Legal Description: Sec. 10-11,14-15, 22, R53, T106
Location from nearest town: 2 miles west of Madison, SD.

Dates of present survey: July 22-24, 1996
Date last surveyed: July 18-20, 1995
Most recent lake management plan: F21-R-28 Date: 1995
Management classification: Warmwater Marginal
Contour mapped: 1967

Primary Game and Forage Species	Secondary and Other Species
1. Walleye	1. Northern Pike
2. Black Crappie	2. Carp
3. Yellow Perch	3. Bluegill
4. Black Bullhead	4. White Sucker

PHYSICAL CHARACTERISTICS

Surface Area: 1,350 Acres **Watershed**: 36,275 acres
Maximum depth: 15 feet **Mean depth**: 5.5 feet
Lake elevation at time of survey (from known benchmark): Full

1. Describe ownership of lake and adjacent lakeshore property:

   Lake Herman is listed as a meandered lake and the fishery is managed by the South Dakota Department of Game, Fish and Parks.

2. Describe watershed condition and percentages of land use:

   The watershed contains 75 percent cropland and 25 percent pastureland.

3. Describe aquatic vegetative condition:

   Very little submerged vegetation was present in the lake. Some emergent cattail can be found in the bay in the northwest corner.

4. Describe pollution problems:

   No specific problems were identified.

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

The public boat ramp in Lake Herman State Park and the ramp located on the Fishing Access Area on the west side of the lake were in good condition.

CHEMICAL DATA

1. Describe general water quality characteristics:

The Secchi disk measurement was only 6 inches due to high turbidity and a fairly significant algae bloom.

BIOLOGICAL DATA

Methods:

1. Describe fish collection methods and show sampling locations by gear type (electrofishing, gill netting, frame nets, etc.) on the lake map.

Lake Herman was sampled on July 22-24, 1996, with ten, 3/4 inch, overnight frame net sets and four, 150 foot, overnight gill net sets. On August 28, 1996, eight quarter-arc pulls with a 6x100 foot, 1/4 inch mesh bag seine were made. Netting results are listed in Tables 1-3, length frequencies in Figure 1 and sampling locations in Figure 2.

Results and Discussion:

Table 1. Total catch of four, 24 hour, 150 foot experimental gill net sets from Lake Herman, Lake County, July 22-24, 1996.

Species	Number	Percent	CPUE	80% C.I.	3 Year CPUE Avg.	PSD	Mean Wr
Walleye	285	53.4	71.3	±16.6	38.2	28	88
Black Bullhead	128	24.0	32.0	±14.2	13.4	--	--
Yellow Perch	42	7.9	10.5	±5.7	10.3	32	103
Carp	33	6.2	8.3	±4.6	7.8	--	--
White Sucker	21	3.9	5.3	±1.0	6.6	--	--
Northern Pike	13	2.4	3.3	±0.8	1.4	6	--
Bigmouth Buffalo	9	1.7	2.3	±2.2	0.8	--	--
Black Crappie	3	0.6	0.8	±1.2	1.1	--	--

Table 2. Total catch of ten, 24 hour, 3/4 inch mesh frame net sets at Lake Herman, Lake County, July 22-24, 1996.

Species	Number	Percent	CPUE	80% C.I.	3 Year CPUE Avg.	PSD	Mean Wr
Black Bullhead	2232	78.6	223.2	±73.9	114.0	--	--
Black Crappie	211	7.4	21.1	±6.9	13.1	96	116
Walleye	209	7.3	20.9	±6.8	7.6	1	89
Yellow Perch	57	2.0	5.7	±3.0	2.7	--	--
Northern Pike	54	1.9	5.4	±1.4	2.3	--	91
Carp	28	1.0	2.8	±0.8	7.4	--	--
Bigmouth Buffalo	27	1.0	2.7	±1.9	0.9	--	--
White Sucker	19	0.7	1.9	±1.0	7.0	--	--
Bluegill	4	0.1	0.4	±0.4	0.2	--	--

Table 3. Total catch of eight, quarter-arc seine pulls at Lake Herman, Lake County, August 28, 1996.

Species	Number	Percent	CPUE	80% C.I.	3 Year CPUE Avg.
Fathead Minnow	101	70.1	12.6	±17.7	36.0
Yellow Perch	18	12.5	2.3	±1.4	2.6
Black Crappie	15	10.4	1.9	±1.5	1.0
Walleye	10	6.9	1.3	±0.5	0.6

2. Brief narrative describing status of fish sampled, make references to the tables. See Appendix A for explanations of PSD, Wr and their normal values.

Walleye gill net catch-per-unit-effort (CPUE) was 26.3 in 1994, decreased to 17.0 in 1995, then increased to 71.3 in 1996 (Table 1). Proportional stock density (PSD) for the same time period was 35, 60 and 28 respectively. Age and growth analysis indicates that the walleyes are reaching 35.5 centimeters (cm.) or 14 inches (in.) between Age 3 and 4 which is nearly average for South Dakota waters (Table 4). The length frequency histogram in Figure 1 shows a large number of walleyes 23-27 cm. (9.0-10.6 in.) long. Stocking records show that 135,000 walleye fingerlings were stocked in 1995 and 2,707,000 fry were stocked in 1996 (Table 5). Shoreline seining sampled 10 young-of-the-year walleye (Table 3).

Yellow perch gill net CPUE was 6.0 in 1994, increased to 14.5 in 1995, then decreased to 10.5 in 1996. PSD increased from 44 in 1994 to 89 in 1995 then decreased to 32 in 1996. The length frequency histogram shows a good size distribution for the perch in Lake Herman and 18 YOY were sampled by shoreline seining. The stocking record shows that 136,840 perch fingerlings were stocked in 1996.

Black crappie frame net CPUE increased from 0.5 in 1994 to 17.6 in 1995 then to 21.1 in 1996 (Table 2). The length frequency histogram shows most of the fish were between 21-26 cm. (8.3-10.2 in.) in length. Fifteen YOY crappies were sampled by shoreline seining.

Other species sampled during the survey included northern pike, carp, bigmouth buffalo, white sucker, black bullhead, bluegill, and fathead minnow. Data concerning these species can be viewed in Tables 1-3 and in Figure 1.

Table 4. Average back-calculated lengths, in mms., for each age class of walleye in Lake Herman, Lake County, 1996.

			Back-calculation Age						
Year Class	Age	N	1	2	3	4	5	6	7
1995	1	2	209.28						
1994	2	31	143.59	222.20					
1993	3	4	161.47	247.72	279.84				
1992	4	3	179.40	266.34	328.16	371.48			
1991	5	9	197.24	287.02	345.60	387.36	419.25		
1990	6	0	0.00	0.00	0.00	0.00	0.00	0.00	
1989	7	2	167.59	226.92	319.87	374.88	429.42	463.98	481.58
All Classes			160.08	239.09	325.22	382.17	421.10	463.98	481.58
SD Average			163	289	389	450	508	547	587

RECOMMENDATIONS

1. At the time this report is being written, Lake Herman oxygen levels are hovering around 1 mg/l and winterkill is a real possibility. At this time, we are planning on stocking 2,700,000 walleye fry marked with oxytetracycline in 1997 as part of a study designed to establish walleye stocking criteria. Should winterkill occur, additional stockings of panfish will likely be made.

2. Develop a habitat improvement plan for the lake that will benefit panfish and walleye reproduction and survival of the young, reduce the number of rough fish and improve water quality.

Table 5. Stocking record for Lake Herman, Lake County, 1986-1996.

Year	Number	Species	Size
1986	600,000	Walleye	Fry
	675,000	Northern Pike	Fry
	5,000	Black Crappie	Adult
	5,250	Yellow Perch	Yearling
	200	Yellow Perch	Adult
1988	2,000,000	Walleye	Fry
	1,000	Yellow Perch	Adult
1991	41,640	Yellow Perch	Fingerling
	17,800	Walleye	Lrg. Fingerling
	6,421	Walleye	Med. Fingerling
1992	170,000	Saugeye	Sml. Fingerling
	145	Walleye	Lrg. Fingerling
	162,500	Yellow Perch	Fingerling
1993	67,500	Saugeye	Sml. Fingerling
	67,500	Walleye	Sml. Fingerling
1995	41,000	Fathead Minnow	Adult
	135,000	Walleye	Fingerling
1996	2,707,000	Walleye	Fry
	136,840	Yellow Perch	Fingerling

Figure 1. Length frequency histograms of selected species from Lake Herman, Lake County, 1996.

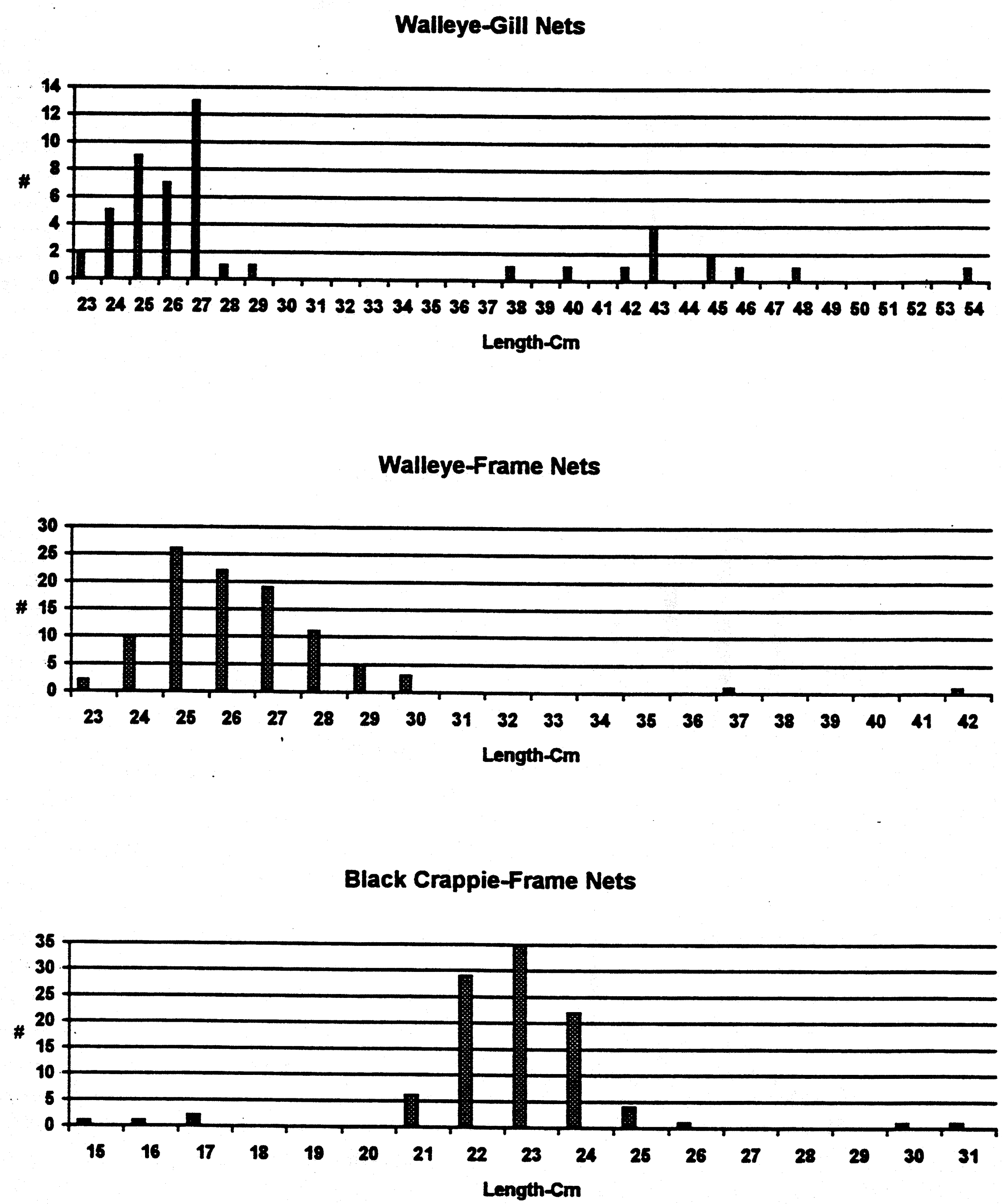
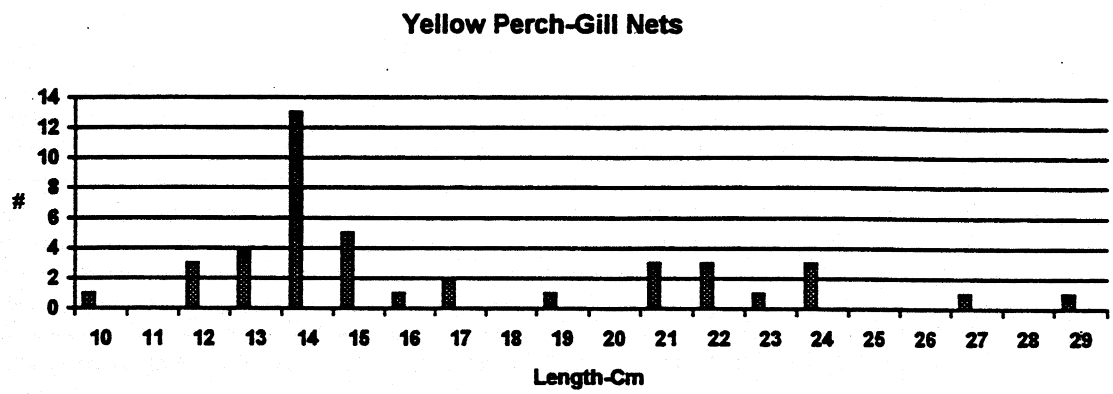
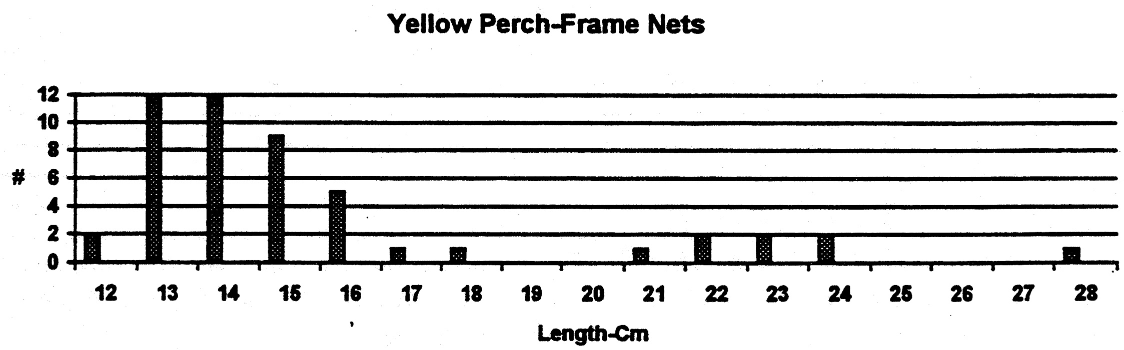


Figure 1 continued. Length frequency histograms of selected species from Lake Herman, Lake County, 1996.





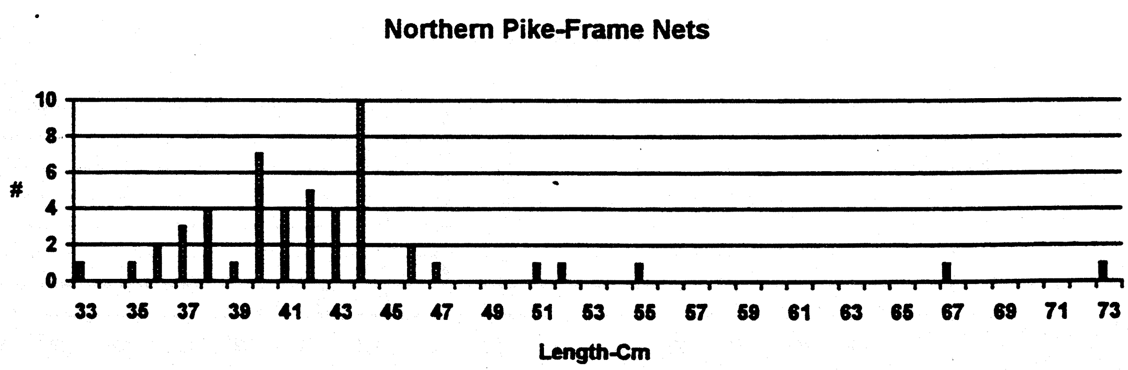
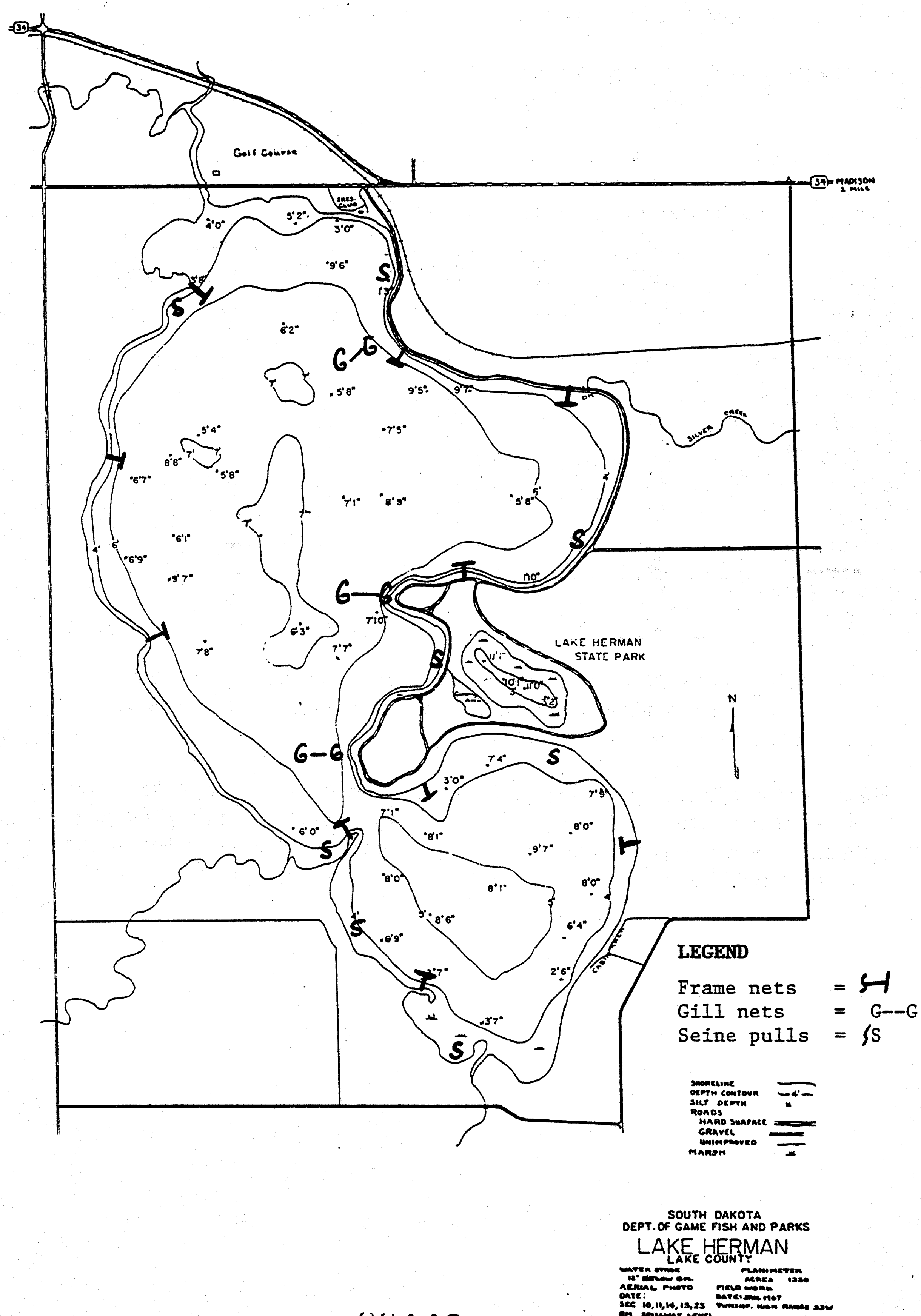


Figure 2. Sampling Locations at Lake Herman, Lake County, 1996.



Appendix A. A brief explanation of PSD and Wr.

Proportional Stock Density (PSD) is calculated by the following formula:

$$PSD = \frac{\text{Number of Fish} > \text{quality length}}{\text{Number of Fish} > \text{stock length}} \times 100$$

PSD is unitless and usually calculated to the mearest whole digit.

Size categories for selected species used in Region 3 lake surveys, in centimeters.

Species	Stock	Quality	Preferred	Memorable	Trophy
Walleye	25	38	51	63	76
Sauger	20	30	38	51	63
Northern Pike	35	53	71	86	112
Yellow Perch	13	20	25	30	38
Largemouth Bass	20	30	38	51	63
Smallmouth Bass	18	28	35	43	51
White Crappie	13	20	25	30	38
Black Crappie	13	20	25	30	38
Bluegill	8	15	20	25	30
Channel Catfish	28	41	61	71	91
Black Bullhead	15	23	30	38	46
Carp	28	41	53	66	84

PSD vallues in the 40-70 range indicate the population is balanced. Values less than 40 indicate a population dominated by small fish and values greater than 70 indicate a population comprised mainly of large fish.

Relative weight (Wr) is a condition indice that quantifies fish condition (ie. how much a fish weighs compared to its length). When mean Wr values are well below 100 for a size group, problems may exist in food and feeding relationships. When mean Wr values are well above 100 for a size group, fish may not be making the best use of available prey.

SOUTH DAKOTA STATEWIDE FISHERIES SURVEY

2102-F21-R-29

Name: Lake Madison **County (ies)**: Lake
Legal Description: S21-23, 25-27, 36, R52, T106; S29-32, R51, T106
Location from nearest town: 5 miles southeast of Madison, SD

Dates of present survey: July 31-August 2, 1996
Date last surveyed: July 24-26, 1995
Most recent lake management plan: F21-R-24 Date: 1990
Management classification: Warmwater Semi-Permanent
Contour mapped: 1964

Primary Game and Forage Species	Secondary and Other Species
1. Walleye	1. Northern Pike
2. Yellow Perch	2. Black Bullhead
3. Bluegill	3. White Sucker
4. Black Crappie	4. Common Carp
5. Largemouth Bass	5. Saugeye
6.	6. Bigmouth Buffalo

PHYSICAL CHARACTERISTICS

Surface Area: 2,799 acres **Watershed**: 29,191 acres
Maximum depth: 16 feet **Mean depth**: 9.7 feet
Lake elevation at time of survey (from known benchmark): Full

1. Describe ownership of lake and adjacent lakeshore property:

   Lake Madison is listed as a meandered lake and is managed by the South Dakota Department of Game, Fish, and Parks. The lakeshore is 95 percent privately owned with the remaining 5 percent state owned.

2. Describe watershed condition and percentages of land use:

   The watershed consists of 78 percent cropland and 22 percent grassland.

3. Describe aquatic vegetative condition:

   Small, scattered clumps of common coontail could be found around the lake and cattail was common in Peninsula Bay and Bourne Slough.

4. Describe pollution problems:

Residential and agricultural runoff causes problems with water quality at times in the form of increased turbidity and algae blooms.

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

All boat ramps and structures were in good condition.

CHEMICAL DATA

1. Describe general water quality characteristics:

Water conditions were fairly good during the survey although algae was concentrating on the windy side of the lake. The Secchi disk reading was 20 inches where algae wasn't a problem.

BIOLOGICAL DATA

Methods:

1. Describe fish collection methods and show sampling locations by gear type (electrofishing, gill netting, frame nets, etc.) on the lake map.

Lake Madison was sampled with ten, 3/4 inch, overnight frame net sets and three, 150 foot, overnight gill net sets on July 31-August 2, 1996. One frame net did not fish and was eliminated from the statistical analysis. Thirteen quarter arc pulls with a 6x100 foot, 1/4 inch mesh bag seine were made on August 28, 1996. Netting results are listed in Tables 1-3, length frequencies in Figure 1 and sampling locations in Figure 2.

Results and Discussion:

Table 1. Total catch of three, 24 hour, 150 foot overnight gill net sets at Lake Madison, Lake County, July 31-August 2, 1996.

Species	Number	Percent	CPUE	80% C.I.	3 Year CPUE Avg.	PSD	Mean Wr
Yellow Perch	134	52.3	44.7	±27.4	36.9	0	114
Walleye	96	37.5	32	±8.2	26.8	15	91
White Sucker	12	4.7	4.0	±2.9	2.8	--	--
Carp	6	2.3	2.0	±0.0	3.5	--	--
Black Bullhead	6	2.3	2.0	±1.1	0.8	--	--
Bigmouth Buffalo	1	0.4	0.3	±0.6	0.1	--	--
Black Crappie	1	0.4	0.3	±0.6	0.1	--	--

Table 2. Total catch of nine*, 24 hour, 3/4 inch mesh overnight frame net sets at Lake Madison, Lake County, July 31-August 2, 1996.

Species	Number	Percent	CPUE	80% C.I.	3 Year CPUE Avg.	PSD	Mean Wr
Carp	187	33.1	20.8	±6.4	27.4	96	--
Black Bullhead	132	23.4	14.7	±12.5	6.1	59	--
Walleye	105	18.6	11.7	±5.7	6.8	19	92
Yellow Perch	60	10.6	6.7	±2.5	10.9	16	--
White Sucker	30	5.3	3.3	±1.6	2.4	--	--
Bigmouth Buffalo	22	3.9	2.4	±0.9	2.3	--	--
Black Crappie	21	3.7	2.3	±1.2	1.7	--	121
Bluegill	4	0.7	0.4	±0.3	0.2	--	--
Northern Pike	4	0.7	0.4	±0.3	0.8	--	--

*=ten nets were set but one did not fish.

Table 3. Total catch of thirteen quarter-arc seine pulls at Lake Madison, Lake County, August 28, 1996.

Species	Number	Percent	CPUE	80% C.I.	3 Year CPUE Avg.
Walleye	82	62.6	6.3	±4.4	3.5
Fathead Minnow	25	19.1	1.9	±1.4	67.5
Yellow Perch	10	7.6	0.8	±0.7	7.9
Crappie spp.	8	6.1	0.6	±0.6	2.0
Bluegill	2	1.5	0.2	±0.2	0.1
White Sucker	2	1.5	0.2	±0.2	1.3
Johnny Darter	1	0.8	0.1	±0.1	0.1
Black Bullhead	1	0.8	0.1	±0.1	0.03

2. Brief narrative describing status of fish sampled, make references to the tables. See Appendix A for explanations of PSD, Wr and their normal values.

Walleye catch-per-unit-effort (CPUE) in the gill nets was 12.5 in 1994, increased to 36.0 in 1995, then decreased slightly to 32 in 1996 (Table 1). Growth rates are below average for South Dakota water with walleyes reaching 35.6 centimeters (cm.) sometime between their fourth and fifth year (Table 4). The length frequency histogram for walleyes in Figure 1 shows most walleyes ranging in size from 27-42 cm. (10.6-16.5 in.). Shoreline seining sampled eighty-two young-of-the-year (YOY) walleye that may have come from a stocking of 561,800 fingerlings in 1996 (Table 5).

Gill net CPUE for yellow perch was 4.8 in 1994, increased to 61.3 in 1995, then decreased slightly to 44.7 in 1996. The length frequency histogram for yellow perch in Figure 1 shows two main year classes, one ranging in size from 13-19 cm. (5.1-7.5 in.) and one from 20-25 cm. (7.9-9.8 in.). Ten YOY yellow perch were sampled by shoreline seining indicating some natural reproduction.

Carp, bullhead and other rough fish numbers are at fairly low numbers and are not a concern at this time. Other species sampled during the survey included white sucker, bigmouth buffalo, black crappie, bluegill, northern pike, fathead minnow and Johnny darter. Data concerning these species can be viewed in Tables 1-3.

Table 4. Average back-calculated lengths, in mms., for each age class of walleye in Lake Madison, Lake County, 1996.

			Back-calculation Age							
Year Class	Age	N	1	2	3	4	5	6	7	8
1995	1	0	0.00							
1994	2	3	124.14	210.38						
1993	3	22	141.34	216.83	256.79					
1992	4	13	146.85	230.35	270.77	309.83				
1991	5	20	156.70	228.21	276.51	313.36	342.28			
1990	6	13	155.45	227.25	294.80	334.24	362.77	384.64		
1989	7	7	146.96	216.42	284.39	327.56	357.37	386.33	407.10	
1988	8	3	179.27	250.40	296.89	348.88	388.52	421.53	444.70	463.35
1987	9	2	151.37	227.86	287.84	371.99	429.19	474.68	499.07	511.91
1986	10	1	185.27	273.39	376.84	449.63	499.44	545.42	602.89	637.37
All Classes			150.00	225.12	276.12	324.97	360.58	402.46	444.99	508.54
SD Average			163	289	389	450	508	547	587	

RECOMMENDATIONS

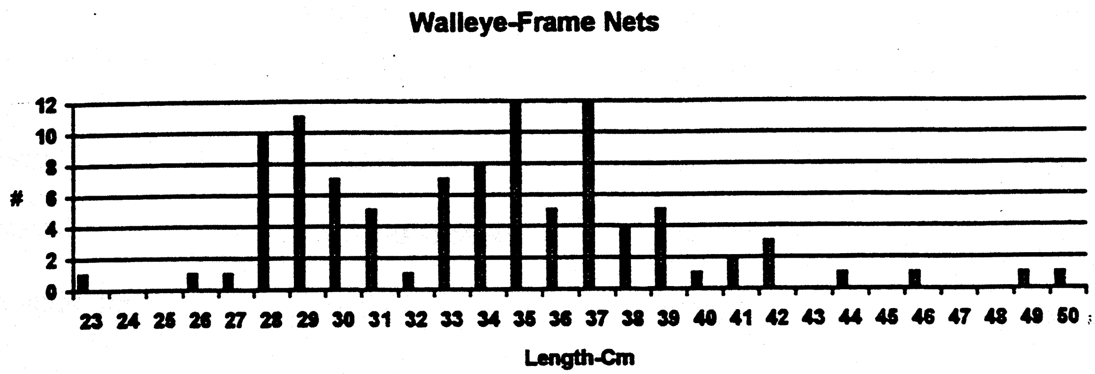
1. Stock 28,000 yellow perch adults in 1997 to increase and maintain gill net CPUE at 50 or above to meet Systematic Approach to Management (SAM) objectives. Madison needs supplemental stocking to compensate for a lack of natural habitat necessary for consistent recruitment.

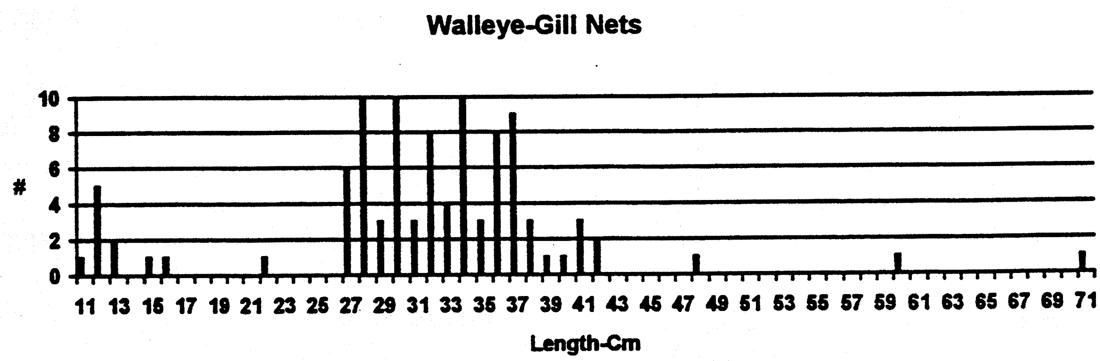
2. Although no artificial habitat work will be done in 1997, continue to develop a habitat improvement plan for Lake Madison that incorporates artificial structures, fishing piers, rough fish removals and watershed management.

Table 5. Stocking record for Lake Madison, Lake County, 1986-1996.

Year	Number	Species	Size
1986	700,000	Walleye	Fry
1987	138,000	Walleye	Sml. Fingerling
1988	35,000	Largemouth Bass	Fingerling
1989	160,000	Walleye	Sml. Fingerling
1991	4,200,000	Walleye	Fry
	150,000	Walleye	Sml. Fingerling
	60	Walleye	Adult
	75,341	Yellow Perch	Fingerling
1992	300,000	Walleye	Sml. Fingerling
	34	Walleye	Adult
	19,625	Yellow Perch	Fingerling
1993	283,766	Yellow Perch	Fingerling
1994	101,400	Fathead Minnow	Adult
	300,000	Walleye	Fry
	354,000	Walleye	Sml. Fingerling
1995	192,700	Fathead Minnow	Adult
	11	Walleye	Adult
	501	Walleye	Lrg. Fingerling
	42,537	Yellow Perch	Adult
	141,725	Yellow Perch	Fingerling
1996	189,400	Bluegill	Fingerling
	561,800	Walleye	Sml. Fingerling

Figure 1. Length frequency histograms of selected species sampled in Lake Madison, Lake County, 1996.





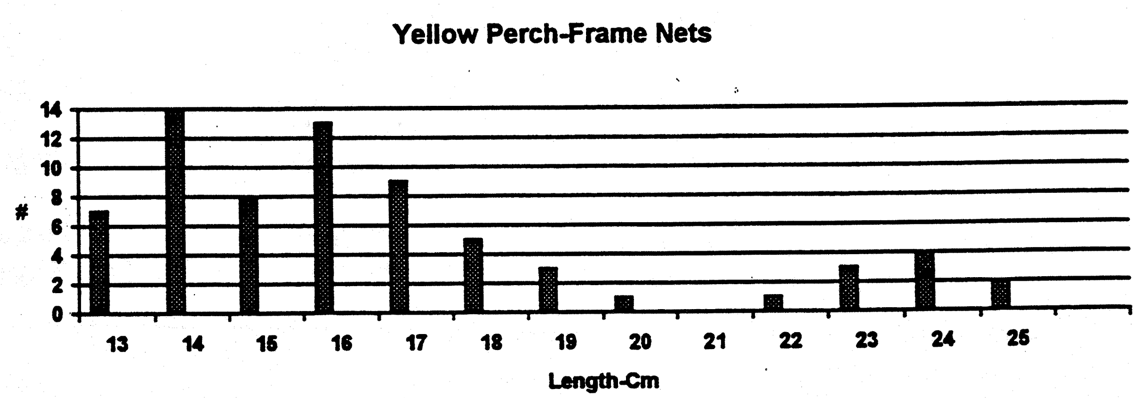
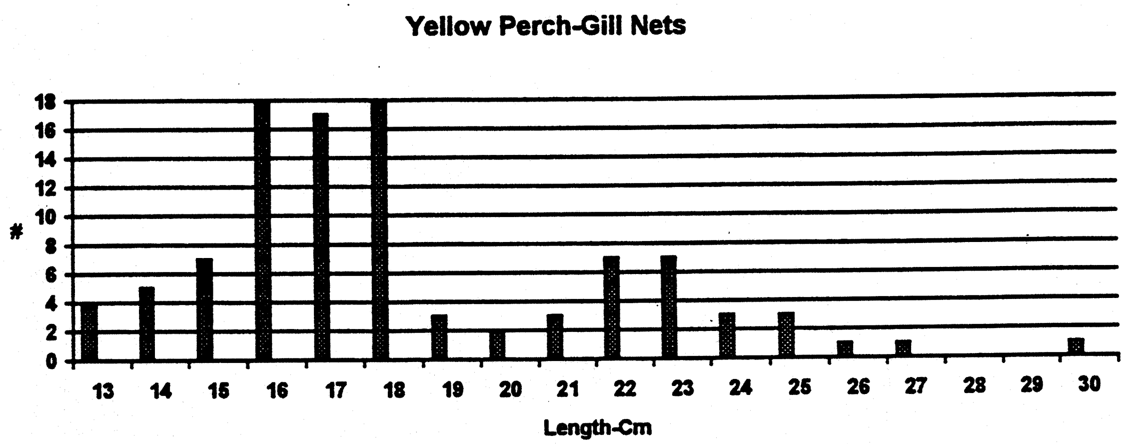
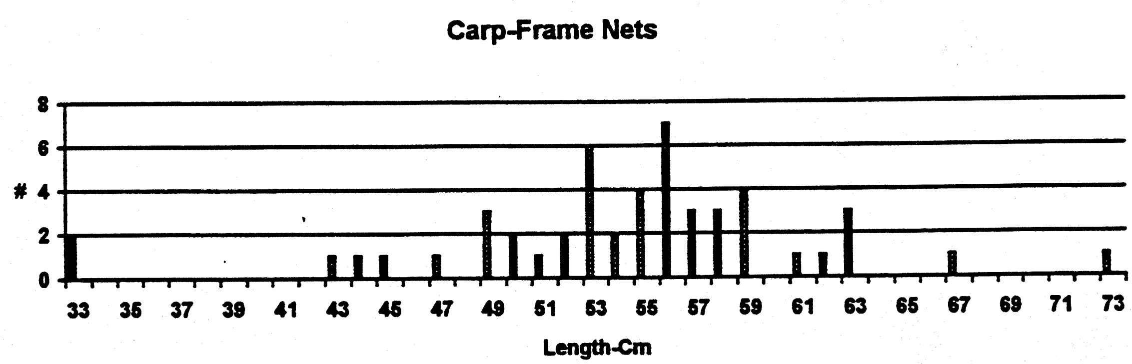
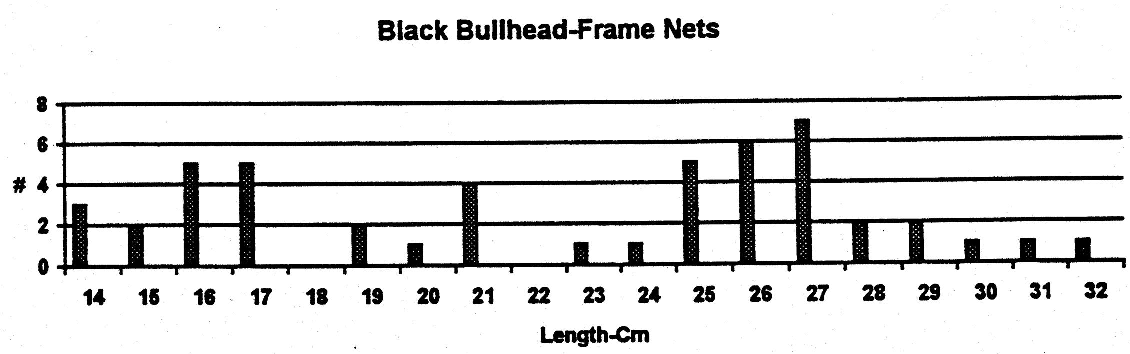
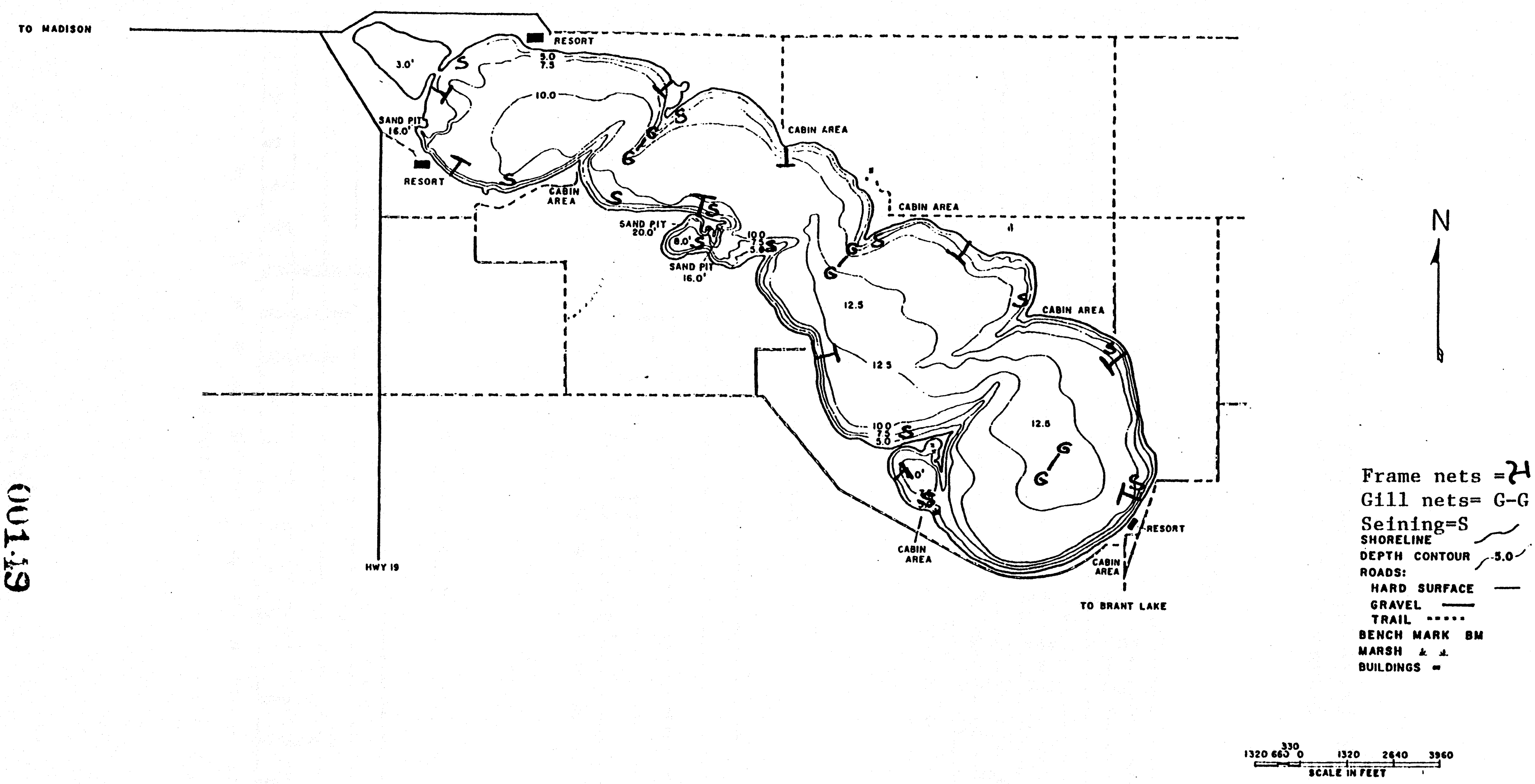


Figure 1 continued. Length frequency histograms of selected species sampled in Lake Madison, Lake County, 1996.









CONTOUR	ACRES	AVE. DEPTH	ACRE FEET
0-5.0	246.9	2.5	617.3
5.0-7.5	276.5	6.25	1728.1
7.5-10.0	580.2	8.75	5076.8
10.0-12.5	1270.1	11.25	14288.6
12.5-15.0	425.6	12.5	5320.0
TOTALS	2799.3	9.7	27030.8

SOUTH DAKOTA
DEPT OF GAME, FISH AND PARKS
LAKE MADISON
LAKE COUNTY
WATER STAGE PLANIMETER
ACRES 2799.3

AERIAL PHOTO DATE: 1956 FIELD WORK DATE: 6-11-64 DRAWN BY: LP, W DATE: 7-22-
SEC. 22.23.24.25. 26.30.31.32.36 TWP. 106N RGE. 51W. 52
BM. 3.6'

Figure 2. Sampling locations on Lake Madison, Lake County, 1996.

00119

Appendix A. A brief explanation of PSD and Wr.

Proportional Stock Density (PSD) is calculated by the following formula:

$$\text{PSD} = \frac{\text{Number of Fish} > \text{quality length}}{\text{Number of Fish} > \text{stock length}} \times 100$$

PSD is unitless and usually calculated to the mearest whole digit.

Size categories for selected species used in Region 3 lake surveys, in centimeters.

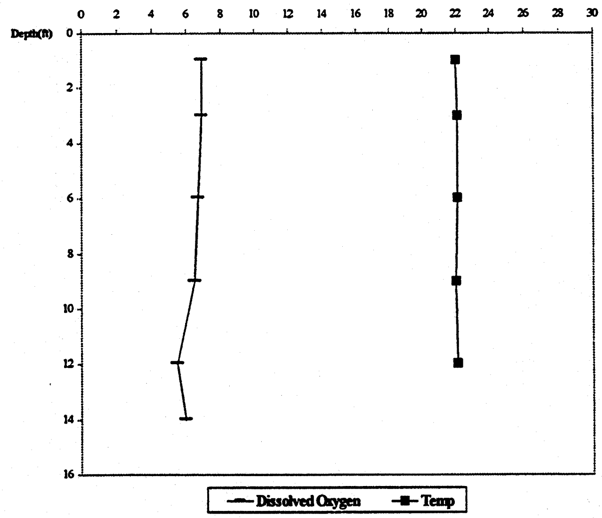
Species	Stock	Quality	Preferred	Memorable	Trophy
Walleye	25	38	51	63	76
Sauger	20	30	38	51	63
Northern Pike	35	53	71	86	112
Yellow Perch	13	20	25	30	38
Largemouth Bass	20	30	38	51	63
Smallmouth Bass	18	28	35	43	51
White Crappie	13	20	25	30	38
Black Crappie	13	20	25	30	38
Bluegill	8	15	20	25	30
Channel Catfish	28	41	61	71	91
Black Bullhead	15	23	30	38	46
Carp	28	41	53	66	84

PSD vallues in the 40-70 range indicate the population is balanced. Values less than 40 indicate a population dominated by small fish and values greater than 70 indicate a population comprised mainly of large fish.

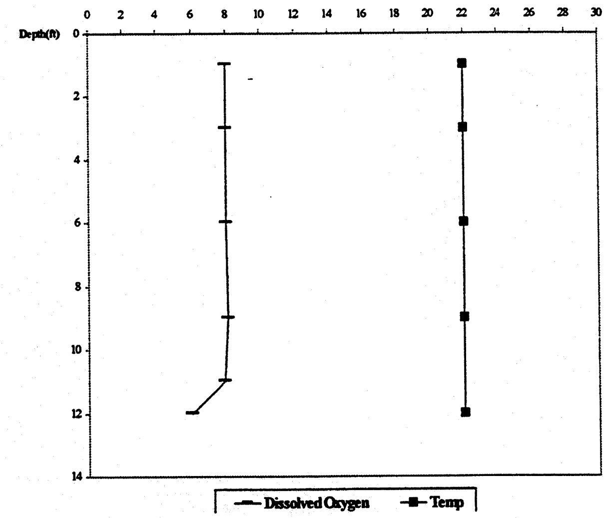
Relative weight (Wr) is a condition indice that quantifies fish condition (ie. how much a fish weighs compared to its length). When mean Wr values are well below 100 for a size group, problems may exist in food and feeding relationships. When mean Wr values are well above 100 for a size group, fish may not be making the best use of available prey.

APPENDIX C

Lake Madison
Dissolved Oxygen (mg/L) and Temperature (C) Profile
Site LM2 Date: 8/17/94



Lake Madison
Dissolved Oxygen (mg/L) and Temperature (C) Profile
Site LM2 Date: 9/12/94



Lake Madison
Dissolved Oxygen (mg/L) and Temperature (C) Profile
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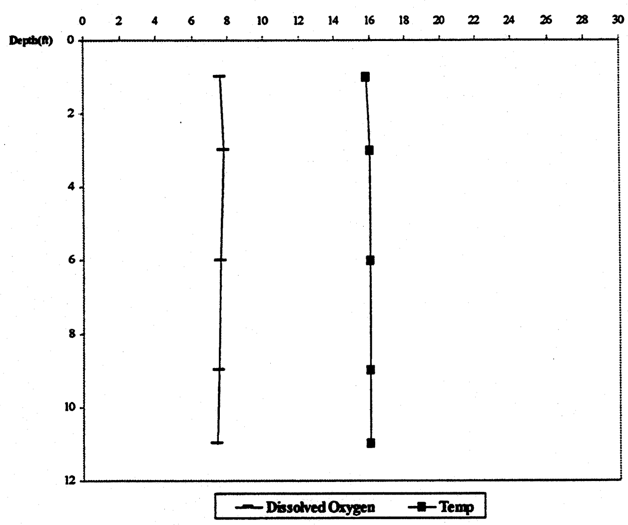
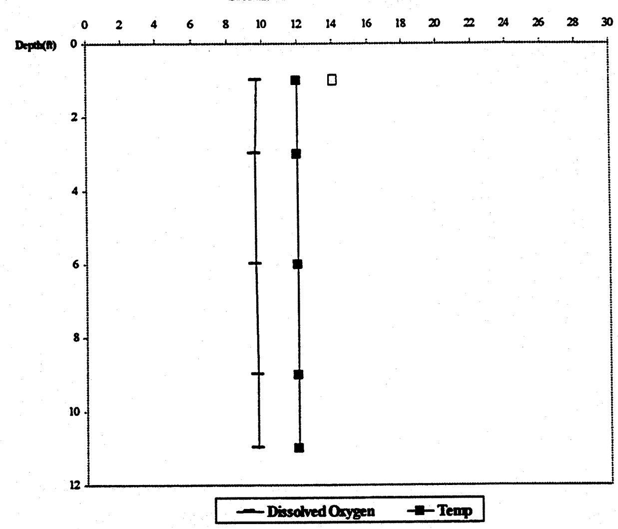


Lake Madison
Dissolved Oxygen (mg/L) and Temperature (C) Profile
Site LM2 Date: 10/11/94



Lake Madison
Dissolved Oxygen (mg/L) and Temperature (C) Profile
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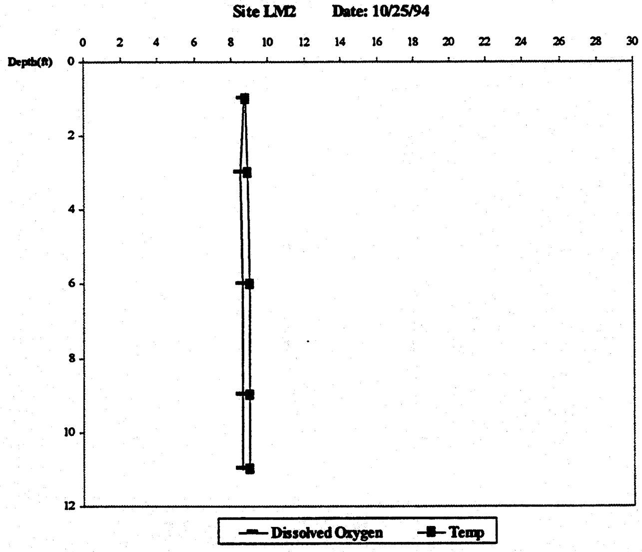
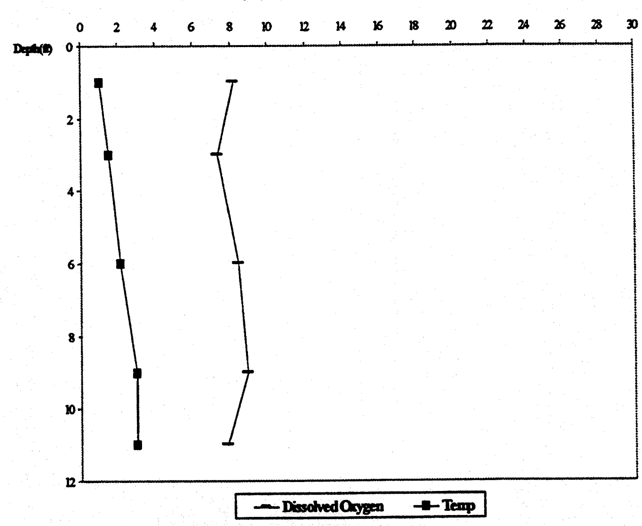
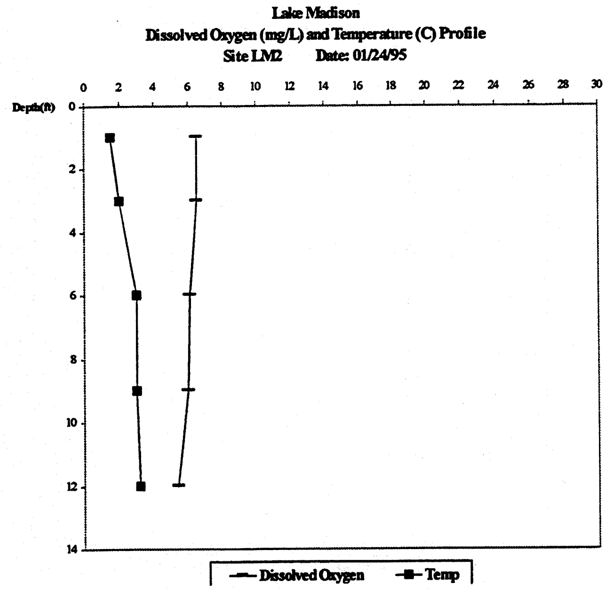


Lake Madison
Dissolved Oxygen (mg/L) and Temperature (C) Profile
Site LM2 Date: 01/3/95




Lake Madison
Dissolved Oxygen (mg/L) and Temperature (C) Profile
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Depth(ft)
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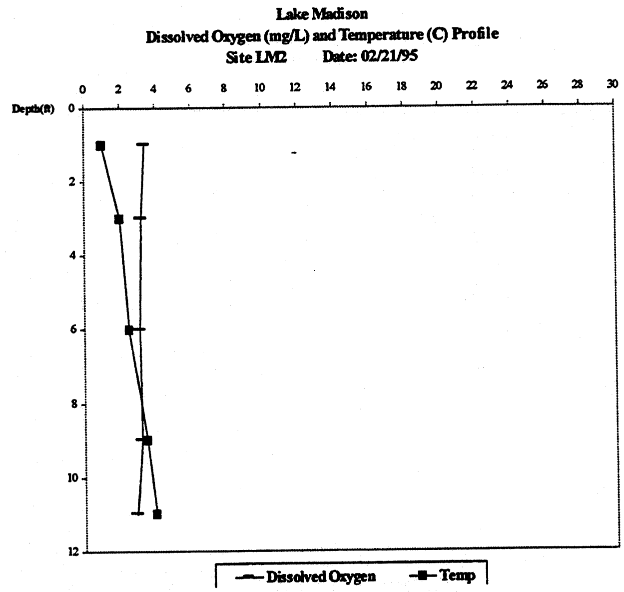
0 2 4 6 8 10 12 14
Dissolved Oxygen
Temp


Lake Madison
Dissolved Oxygen (mg/L) and Temperature (C) Profile
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Depth(ft)
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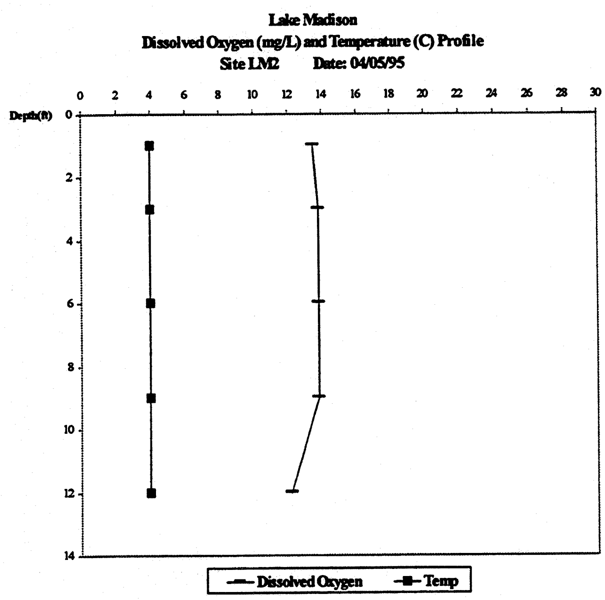
Dissolved Oxygen
Temp


Lake Madison
Dissolved Oxygen (mg/L) and Temperature (C) Profile
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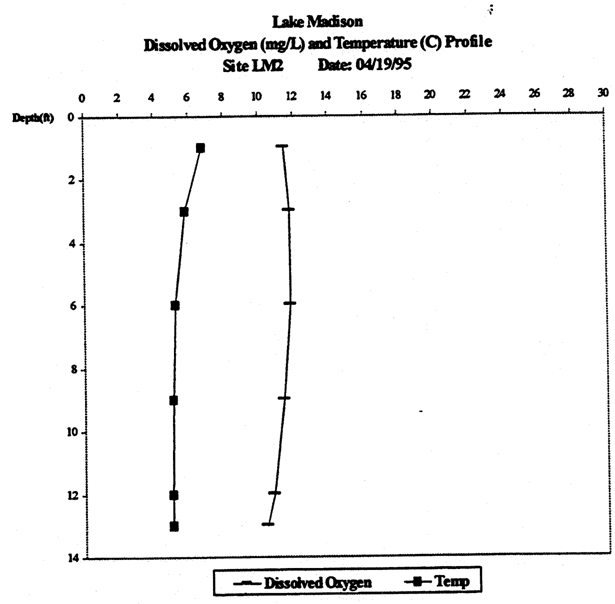
Dissolved Oxygen
Temp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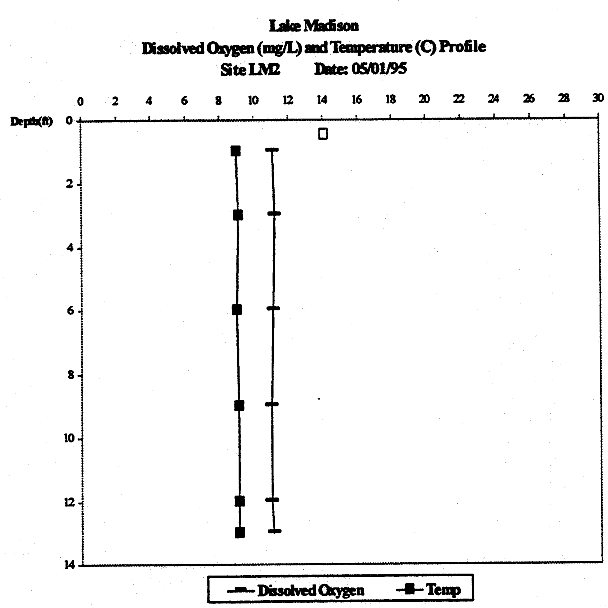
Temp


Lake Madison
Dissolved Oxygen (mg/L) and Temperature (C) Profile
Site LM2 Date: 05/01/95
Depth(ft)
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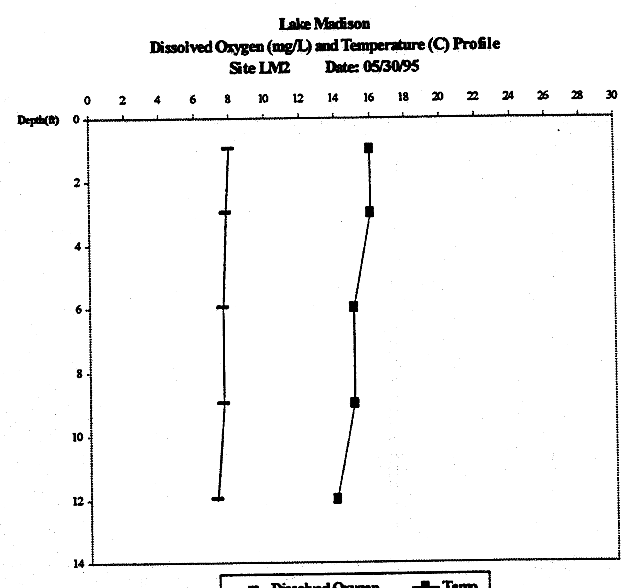
Dissolved Oxygen
Temp


Lake Madison
Dissolved Oxygen (mg/L) and Temperature (C) Profile
Site LM2 Date: 05/30/95
Depth(ft)
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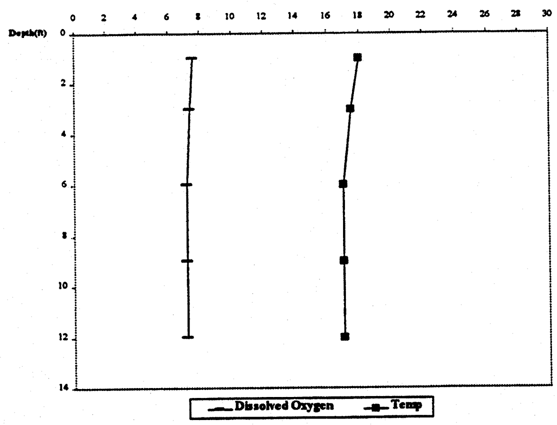
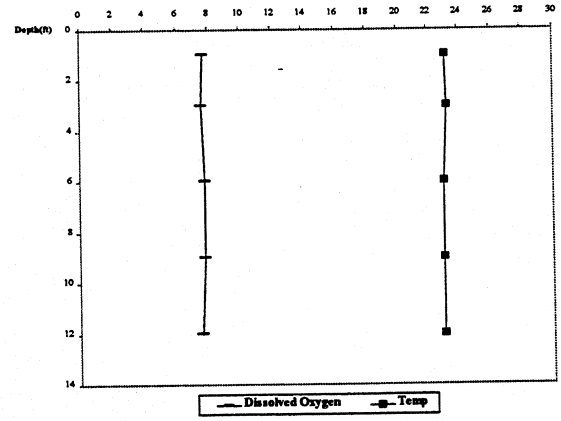
Dissolved Oxygen
Temp

Lake Madison
Dissolved Oxygen (mg/L) and Temperature (C) Profile
Site LM2 Date: 06/12/95



Lake Madison
Dissolved Oxygen (mg/L) and Temperature (C) Profile
Site LM2 Date: 06/26/95



Lake Madison
Dissolved Oxygen (mg/L) and Temperature (C) Profile
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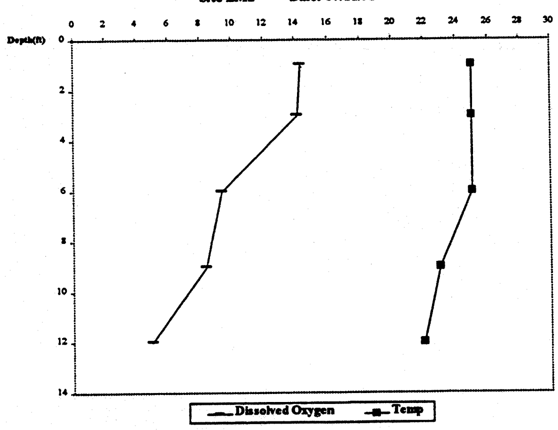
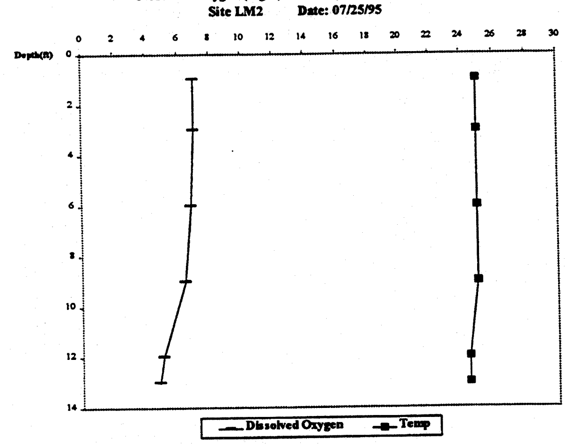


Lake Madison
Dissolved Oxygen (mg/L) and Temperature (C) Profile
Site LM2 Date: 07/25/95



Lake Madison
Dissolved Oxygen (mg/L) and Temperature (C) Profile
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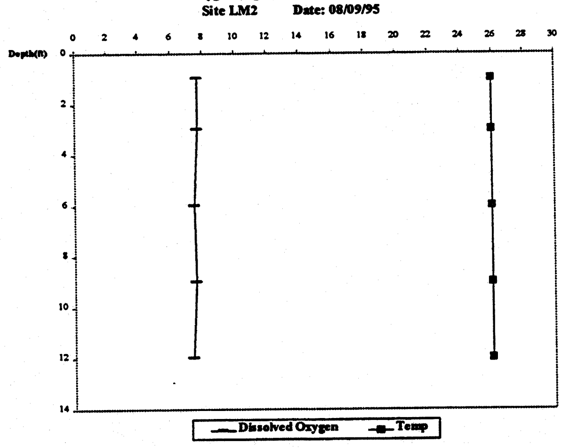

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Dissolved Oxygen (mg/L) and Temperature (C) Profile
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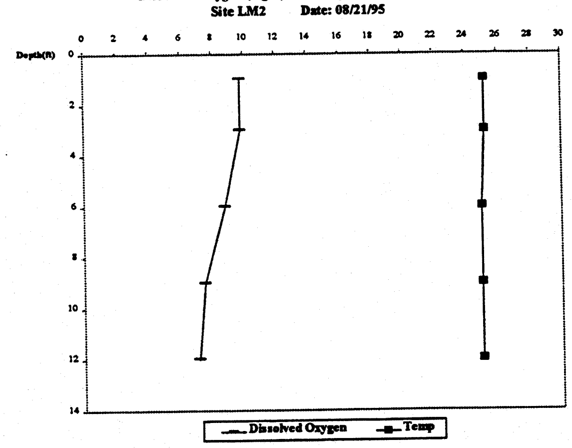

Lake Madison
Dissolved Oxygen (mg/L) and Temperature (C) Profile
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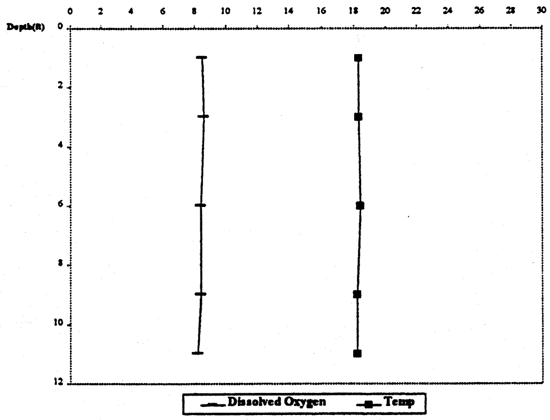
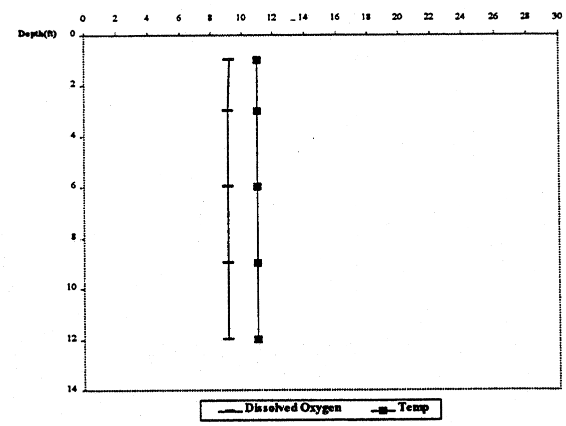


Lake Madison
Dissolved Oxygen (mg/L) and Temperature (C) Profile
Site LM2 Date: 10/18/95



Lake Madison
Dissolved Oxygen (mg/L) and Temperature (C) Profile
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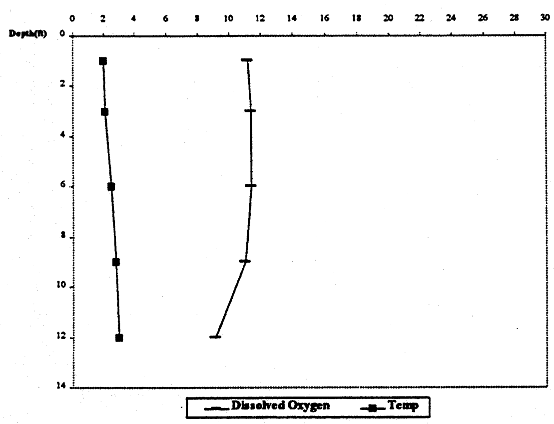

Lake Madison
Dissolved Oxygen (mg/L) and Temperature (C) Profile
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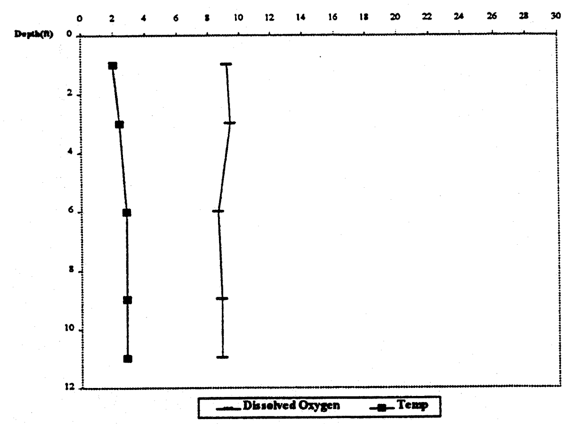
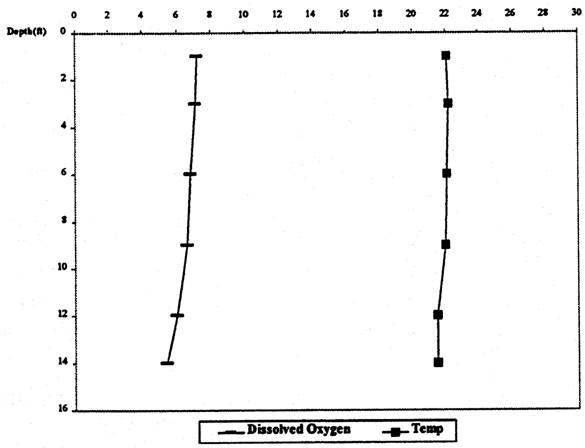


Brant Lake
Dissolved Oxygen (mg/L) and Temperature (C) Profile
Site BL5 Date: 8/17/94



Brant Lake
Dissolved Oxygen (mg/L) and Temperature (C) Profile
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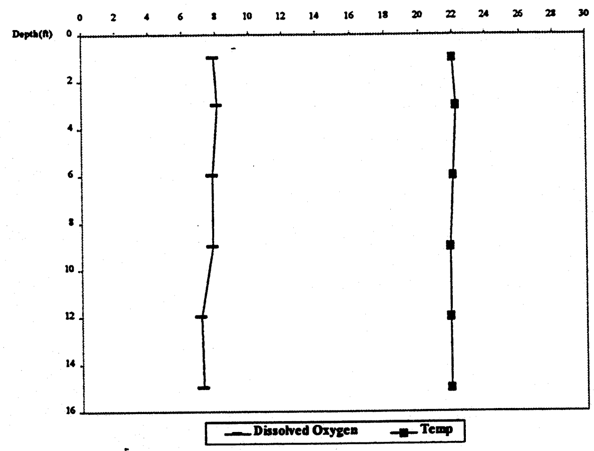

Brant Lake
Dissolved Oxygen (mg/L) and Temperature (C) Profile
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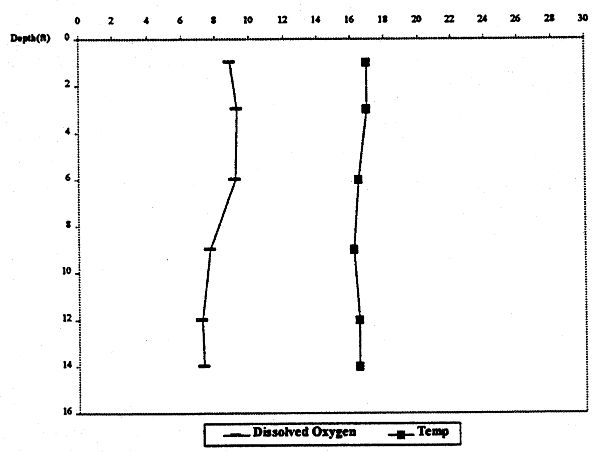

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Dissolved Oxygen (mg/L) and Temperature (C) Profile
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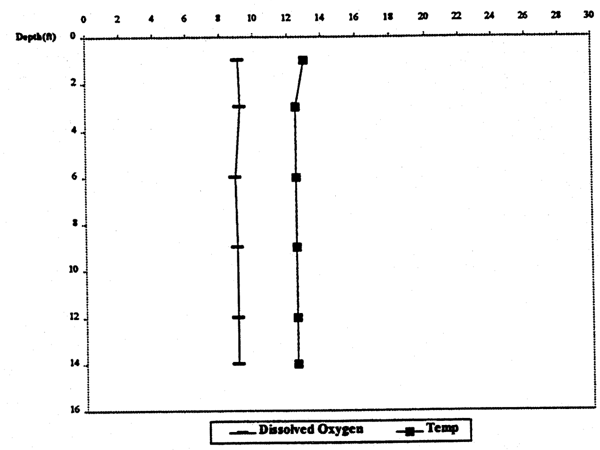

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Dissolved Oxygen (mg/L) and Temperature (C) Profile
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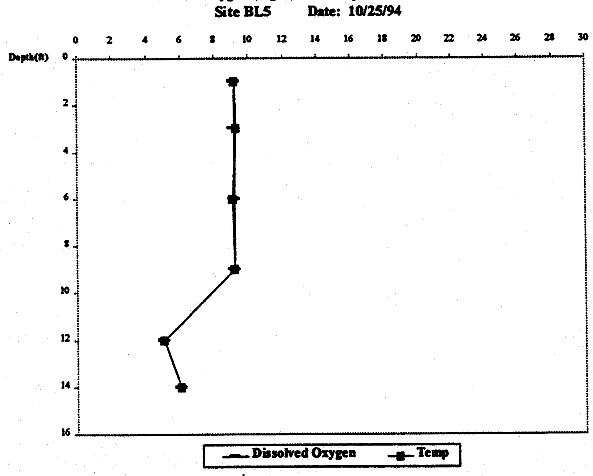

Brant Lake
Dissolved Oxygen (mg/L) and Temperature (C) Profile
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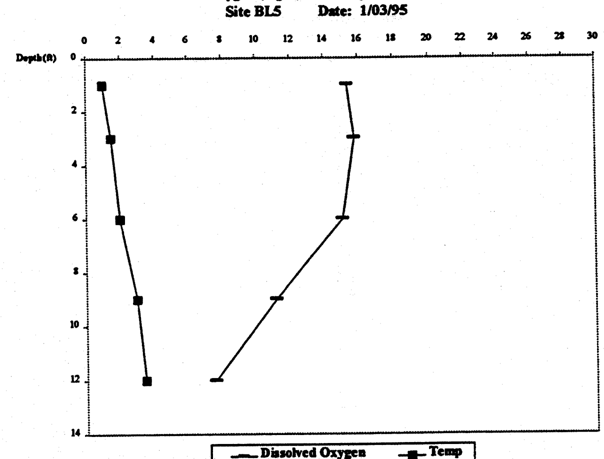

Brant Lake
Dissolved Oxygen (mg/L) and Temperature (C) Profile
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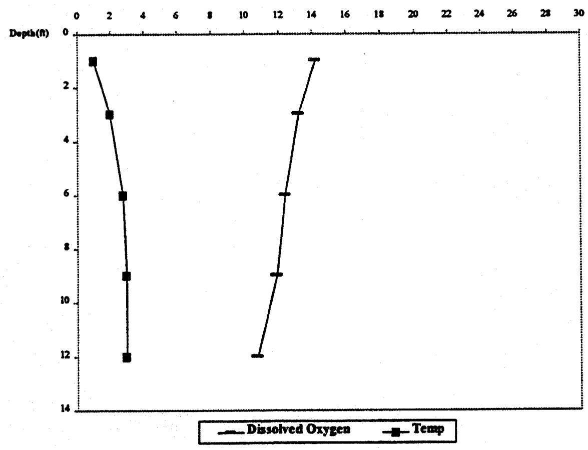
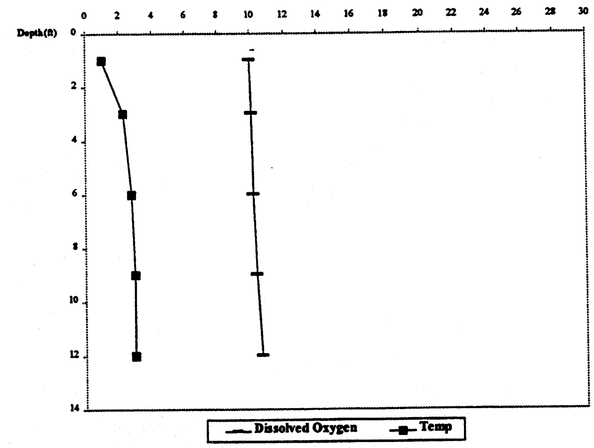
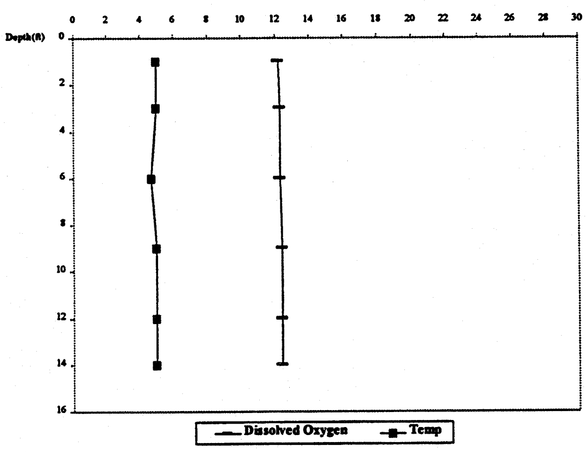


Brant Lake
Dissolved Oxygen (mg/L) and Temperature (C) Profile
Site BL5 Date: 2/22/95



Brant Lake
Dissolved Oxygen (mg/L) and Temperature (C) Profile
Site BL5 Date: 4/05/95



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Dissolved Oxygen (mg/L) and Temperature (C) Profile
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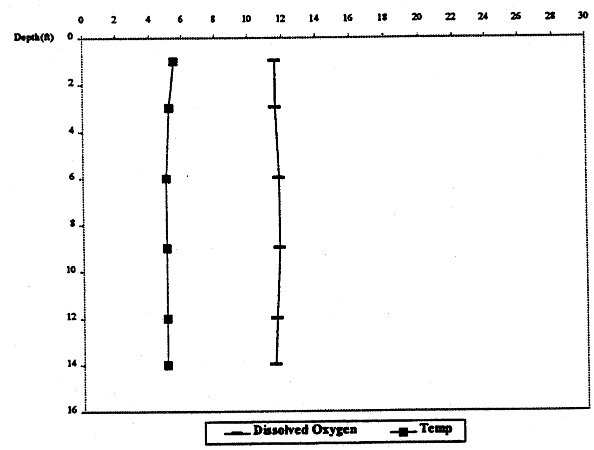
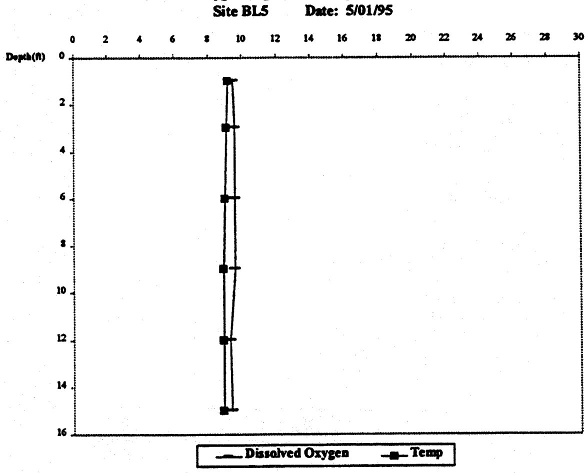
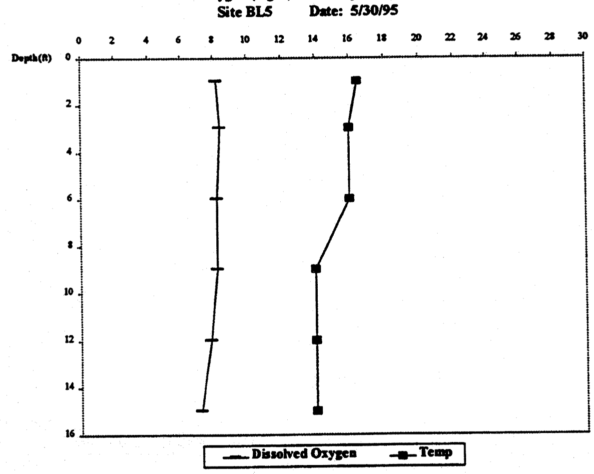


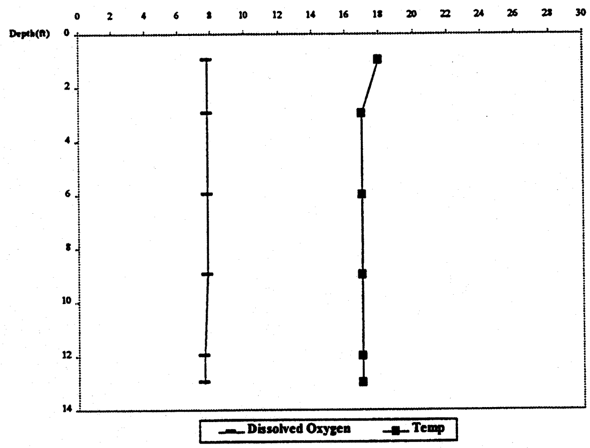
Brant Lake
Dissolved Oxygen (mg/L) and Temperature (C) Profile
Site BL5 Date: 5/01/95



Brant Lake
Dissolved Oxygen (mg/L) and Temperature (C) Profile
Site BL5 Date: 5/30/95



Brant Lake
Dissolved Oxygen (mg/L) and Temperature (C) Profile
Site BL5 Date: 6/12/95



Brant Lake
Dissolved Oxygen (mg/L) and Temperature (C) Profile
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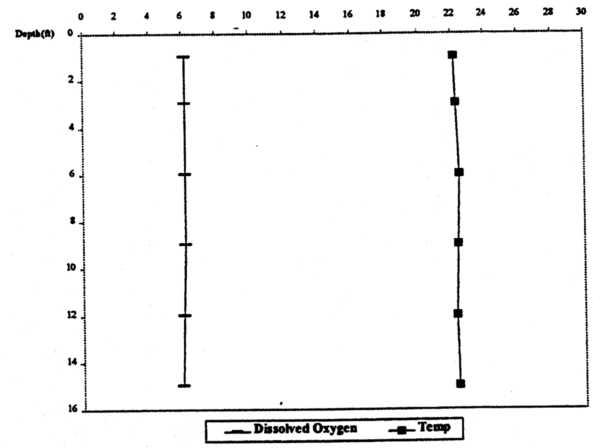
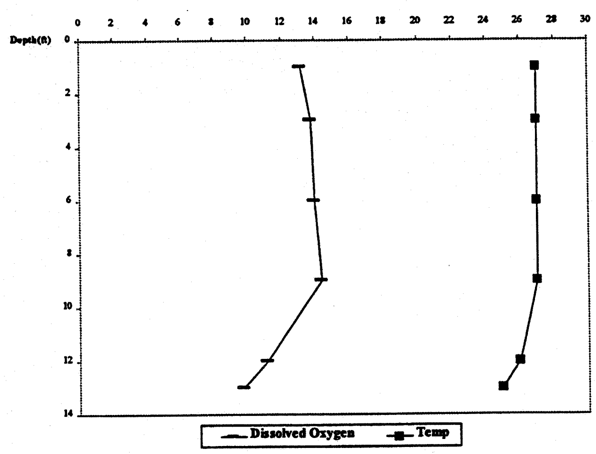
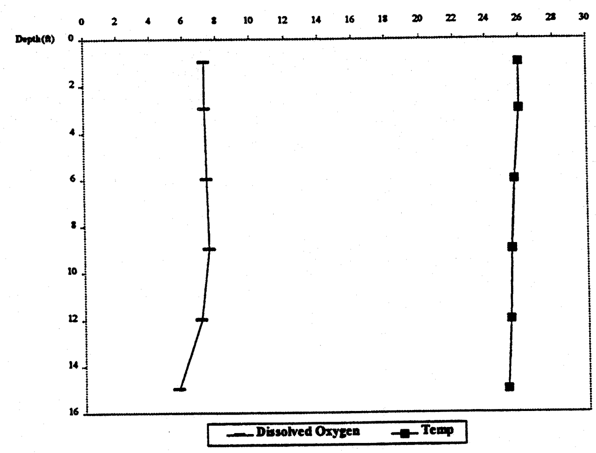


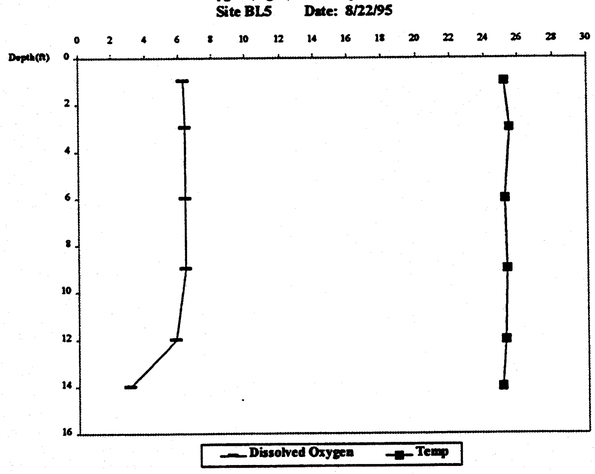
Brant Lake
Dissolved Oxygen (mg/L) and Temperature (C) Profile
Site BL5 Date: 7/11/95



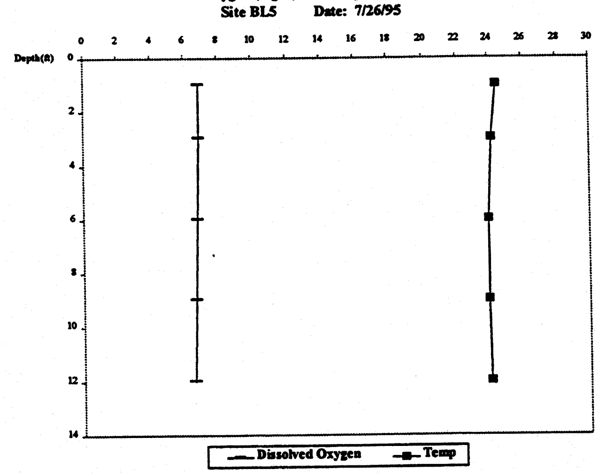
Brant Lake
Dissolved Oxygen (mg/L) and Temperature (C) Profile
Site BL5 Date: 8/09/95

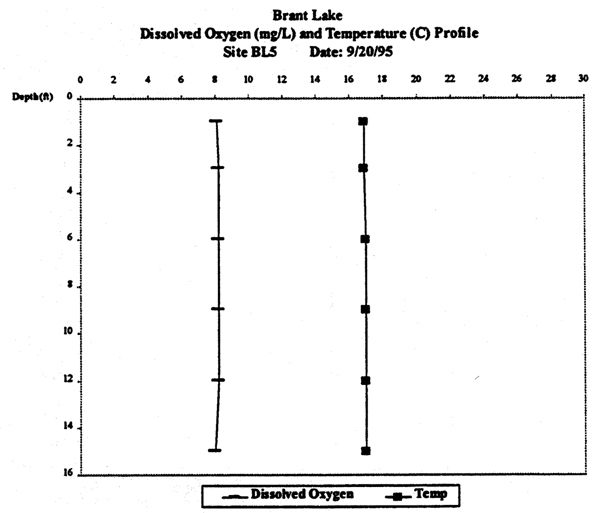


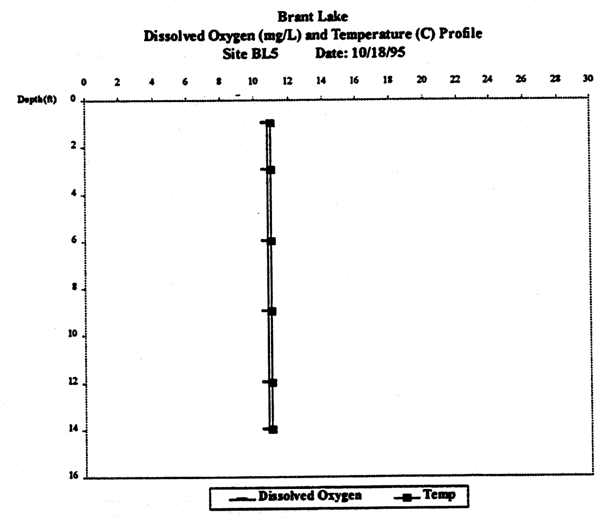
Brant Lake
Dissolved Oxygen (mg/L) and Temperature (C) Profile
Site BL5 Date: 8/22/95

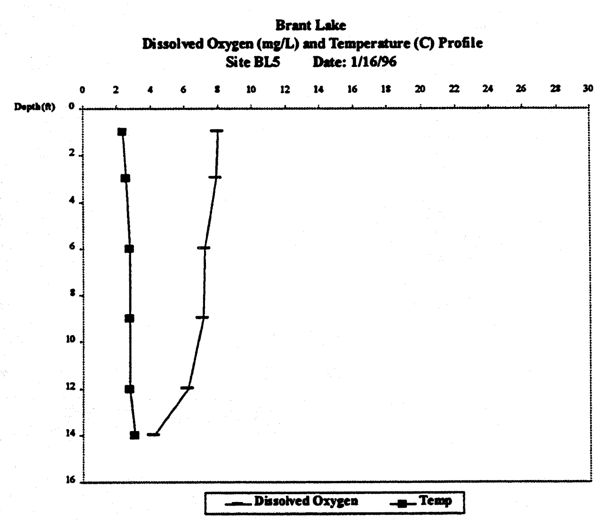


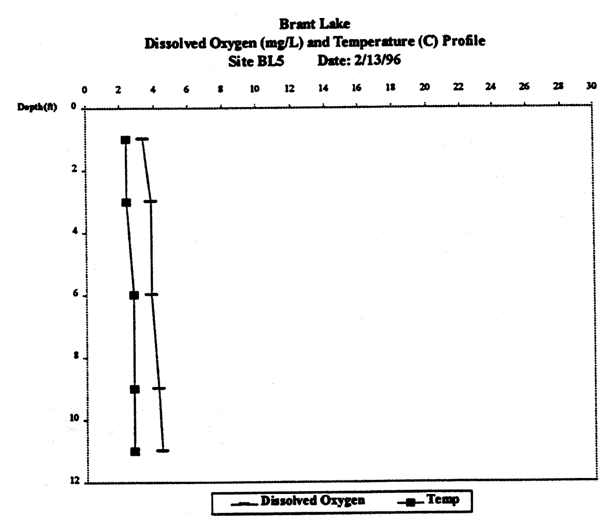
Brant Lake
Dissolved Oxygen (mg/L) and Temperature (C) Profile
Site BL5 Date: 7/26/95




Brant Lake
Dissolved Oxygen (mg/L) and Temperature (C) Profile
Site BL5 Date: 9/20/95
Depth(ft)
Dissolved Oxygen
Temp


Brant Lake
Dissolved Oxygen (mg/L) and Temperature (C) Profile
Site BL5 Date: 10/18/95
Depth(ft)
Dissolved Oxygen
Temp


Brant Lake
Dissolved Oxygen (mg/L) and Temperature (C) Profile
Site BL5 Date: 1/16/96
Depth(ft)
Dissolved Oxygen
Temp


Brant Lake
Dissolved Oxygen (mg/L) and Temperature (C) Profile
Site BL5 Date: 2/13/96
Depth(ft)
Dissolved Oxygen
Temp

APPENDIX D

1994-1995 314 LAKE MADISON/LAKE BRANT IN-LAKE SAMPLING DATA

DEPTH	Date	Site	UnCorr Chl-a	Corr Chl-a	WTEMP	ATEMP	DISOX	FPH	FECAL	TALKAL	TSOL	TDSOL	TSSOL	AMMON	UN-AMMON	NO3+2	TKN-N	O-Nitro	T-Nitro	TPO4P	TDPO4P	Secchi
	Units		mg/m3	mg/m3	C	F	mg/L	su	/100 mL	mg/L	mg/L	mg/L	mg/L	mg/L	mg/l	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	inches
Surface	08/17/1994	1	172.86	182.07	22.1	75.0	9.10	8.67	10	179	920	888	32	0.28	0.04981	0.10	4.57	4.29	4.67	0.533	0.333	18
Surface	09/12/1994	1	101.56	27.38	22.0	78.0	8.90	8.08	10	184	913	886	27	0.02	0.00105	0.10	3.27	3.25	3.37	0.366	0.210	21
Surface	09/26/1994	1	24.12	25.29	16.0	52.0	6.60	8.11	10	184	925	915	10	0.55	0.02016	0.10	1.74	1.19	1.84	0.346	0.306	34
Surface	10/11/1994	1	66.67	68.64	12.0	54.0	9.70	7.68	10	186	935	919	16	0.24	0.00248	0.10	2.47	2.23	2.57	0.323	0.250	34
Surface	10/25/1994	1	68.34	72.25	8.6	36.0	9.40	7.38	10	186	915	907	8	0.32	0.00128	0.10	2.02	1.70	2.12	0.270	0.426	42
Surface	01/03/1995	1	0.34	0.72	0.0	-6.0	8.90	6.39	10	219	1021	1010	11	0.45	0.00009	0.30	1.96	1.51	2.26	0.276	0.273	108
Surface	01/24/1995	1	0.33	0.72	1.0	25.0	6.80	7.67	10	227	1045	1044	1	0.73	0.00306	0.30	2.03	1.30	2.33	0.310	0.290	120
Surface	02/21/1995	1	0.67	0.72	2.0	34.0	5.00	7.70	10	230	1077	1075	2	0.77	0.00375	0.30	2.25	1.48	2.55	0.279	0.246	108
Surface	04/05/1995	1	63.32	57.08	4.0	36.0	13.60	8.21	10	176	917	909	8	0.03	0.00055	0.40	1.97	1.94	2.37	0.188	0.059	30
Surface	04/19/1995	1	45.18	38.81	6.8	50.0	11.40	8.69	210	0	880	840	40	0.02	0.00132	0.80	1.49	1.47	2.29	0.253	0.046	12
Surface	05/01/1995	1	33.84	30.35	9.9	51.0	11.60	9.02	10	127	986	961	25	0.02	0.00324	0.10	1.17	1.15	1.27	0.108	0.010	25
Surface	05/30/1995	1	6.37	5.78	16.0	70.0	8.00	8.23	100	157	1097	1092	5	0.38	0.01815	0.50	1.55	1.17	2.05	0.115	0.089	60
Surface	06/12/1995	1	2.35	1.45	17.0	72.0	7.40	8.16	10	162	1282	1273	9	0.47	0.02067	0.30	1.88	1.41	2.18	0.131	0.085	41
Surface	06/26/1995	1	29.82	30.35	23.0	70.0	7.10	8.62	10	166	1096	1071	25	0.11	0.01877	0.30	1.71	1.60	2.01	0.184	0.092	24
Surface	07/11/1995	1	85.43	86.70	26.0	84.0	12.40	9.09	10	142	1151	1139	12	0.02	0.00858	0.10	1.87	1.85	1.97	0.121	0.039	42
Surface	07/25/1995	1	7.37	7.23	25.0	81.0	4.60	8.28	10	158	1090	1081	9	0.82	0.08022	0.10	2.17	1.35	2.27	0.420	0.701	30
Surface	08/21/1995	1	291.12	305.62	25.5	83.0	8.30	8.97	10	170	1364	1333	31	0.34	0.12067	0.10	4.42	4.08	4.52	0.540	0.339	28
Surface	09/18/1995	1	118.59	124.99	18.3	66.0	8.10	9.11	10	169	1084	1062	22	0.03	0.00933	0.10	1.43	1.40	1.53	0.331	0.204	30
Surface	10/18/1995	1			11.0	52.0	8.90	8.98	10	175	1085	1070	15	0.14	0.02259	0.20	1.96	1.82	2.16	0.274	0.193	30
		LM1																				
		MEAN	62.13	59.23	14.0	55.9	8.73	8.27	25	168	1041	1025	16	0.30	0.02030	0.23	2.21	1.90	2.44	0.283	0.221	44
		MEDIAN	39.51	30.35	16.0	54.0	8.90	8.23	10	175	1045	1044	12	0.28	0.00858	0.10	1.96	1.51	2.26	0.276	0.210	30
		MAXIMUM	291.12	305.62	26.0	84.0	13.60	9.11	210	230	1364	1333	40	0.82	0.12067	0.80	4.57	4.29	4.67	0.540	0.701	120
		MINIMUM	0.33	0.72	0.0	-6.0	4.60	6.39	10	0	880	840	1	0.02	0.00009	0.10	1.17	1.15	1.27	0.108	0.010	12
		STDEV	74.64	78.43	8.7	23.5	2.34	0.70	49	48	130	132	11	0.27	0.03151	0.19	0.92	0.94	0.87	0.127	0.167	32
		RANGE	290.79	304.90	26.0	90.0	9.00	2.72	200	230	484	493	39	0.80	0.12058	0.70	3.40	3.14	3.40	0.432	0.691	108
Surface	08/17/1994	2	48.24	52.02	22.0	75.0	6.90	8.60	10	169	892	875	17	0.34	0.05277	0.10	2.93	2.59	3.03	0.430	0.293	30
Surface	09/12/1994	2	99.50	121.38	22.0	77.0	8.00	8.15	10	181	903	871	32	0.02	0.00122	0.10	2.10	2.08	2.20	0.273	0.198	22
Surface	09/26/1994	2	133.00	166.18	15.0	52.0	7.60	8.11	10	175	934	918	16	0.17	0.00579	0.10	1.93	1.76	2.03	0.280	0.206	34
Surface	10/11/1994	2	96.48	98.26	12.0	54.0	9.70	7.76	10	190	925	915	10	0.13	0.00161	0.10	2.07	1.94	2.17	0.276	0.206	36
Surface	10/25/1994	2	39.87	41.91	8.8	36.0	8.70	7.46	10	189	913	906	7	0.23	0.00112	0.10	1.85	1.62	1.95	0.273	0.213	60
Surface	01/03/1995	2	0.33	0.72	1.0	-8.0	8.20	6.02	10	223	1034	1028	6	0.47	0.00004	0.30	1.83	1.36	2.13	0.283	0.246	120
Surface	01/24/1995	2	0.00	0.72	1.5	23.0	6.50	7.48	10	231	1065	1062	3	0.71	0.00200	0.30	2.12	1.41	2.42	0.324	0.292	120
Surface	02/21/1995	2	0.67	0.00	1.0	41.0	3.40	7.65	10	229	1071	1065	6	0.74	0.00296	0.30	2.46	1.72	2.76	0.282	0.266	108
Surface	04/05/1995	2	75.38	71.53	4.0	36.0	13.50	8.48	10	183	924	912	12	0.02	0.00067	0.30	1.58	1.56	1.88	0.194	0.043	30
Surface	04/19/1995	2	31.83	27.46	6.8	68.0	11.50	8.83	10	146	859	841	18	0.02	0.00178	0.10	1.67	1.65	1.77	0.118	0.033	21
Surface	05/01/1995	2	23.12	19.51	9.0	51.0	11.10	9.00	10	144	916	895	21	0.02	0.00294	0.10	0.72	0.70	0.82	0.079	0.020	36
Surface	05/30/1995	2	1.01	0.72	16.0	66.0	8.00	8.22	10	153	1049	1044	5	0.44	0.02056	0.20	1.31	0.87	1.51	0.128	0.089	144
Surface	06/12/1995	2	1.34	0.72	18.0	72.0	7.60	8.17	10	158	1224	1219	5	0.59	0.02848	0.30	1.71	1.12	2.01	0.118	0.095	60
Surface	06/26/1995	2	40.87	41.91	23.2	71.0	7.70	8.73	10	163	1097	1078	19	0.09	0.01907	0.30	1.56	1.47	1.86	0.164	0.082	30
Surface	07/11/1995	2	470.68	454.45	25.0	82.0	14.40	9.42	10	142	1219	1165	54	0.02	0.01199	0.10	5.96	5.94	6.06	0.377	0.033	12
Surface	07/25/1995	2	56.62	57.80	25.0	78.0	7.00	8.85	10	152	1076	1065	11	0.36	0.10338	0.10	2.03	1.67	2.13	0.292	0.243	42
Surface	08/21/1995	2	220.77	231.20	25.2	81.0	9.80	9.18	10	161	1113	1086	27	0.02	0.00933	0.10	3.15	3.13	3.25	0.412	0.263	30
Surface	09/18/1995	2	92.13	98.98	18.3	63.0	8.50	9.16	10	166	1076	1057	19	0.02	0.00673	0.10	1.51	1.49	1.61	0.320	0.187	34
Surface	10/18/1995	2			11.0	52.0	9.20	9.02	10	175	1081	1068	13	0.09	0.01568	0.10	1.72	1.63	1.82	0.260	0.197	54
		LM2																				
		MEAN	79.55	82.53	13.9	56.3	8.81	8.33	10	175	1020	1004	16	0.24	0.01516	0.17	2.12	1.88	2.28	0.257	0.169	54
		MEDIAN	44.56	46.97	15.0	63.0	8.20	8.48	10	169	1049	1044	13	0.13	0.00579	0.10	1.85	1.63	2.03	0.276	0.198	36
		MAXIMUM	470.68	454.45	25.2	82.0	14.40	9.42	10	231	1224	1219	54	0.74	0.10338	0.30	5.96	5.94	6.06	0.430	0.293	144
		MINIMUM	0.00	0.00	1.0	-8.0	3.40	6.02	10	142	859	841	3	0.02	0.00004	0.10	0.72	0.70	0.82	0.079	0.020	12
		STDEV	113.19	112.46	8.6	23.1	2.53	0.82	0	27	109	108	12	0.25	0.02504	0.09	1.08	1.12	1.06	0.100	0.095	39
		RANGE	470.68	454.45	24.2	90.0	11.00	3.40	0	89	365	378	51	0.72	0.10334	0.20	5.24	5.24	5.24	0.351	0.273	132

DEPTH	Date	Site	UnCorr Chl-a	Corr Chl-a	WTEMP	ATEMP	DISOX	FPH	FECAL	TALKAL	TSOL	TDSOL	TSSOL	AMMON	UN-AMMON	NO3+2	TKN-N	O-Nitro	T-Nitro	TPO4P	TDPO4P	Secchi
	Units		mg/m3	mg/m3	C	F	mg/L	su	/100 mL	mg/L	mg/L	mg/L	mg/L	mg/L	mg/l	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	inches
Surface	08/17/1994	3	6.70	5.78	22.2	74.0	6.80	8.45	10	166	946	930	16	0.41	0.04760	0.10	2.70	2.29	2.80	0.486	0.316	33
Surface	09/13/1994	3	104.86	108.38	21.0	71.0	8.20	8.13	10	167	908	884	24	0.05	0.00272	0.10	2.00	1.95	2.10	0.253	0.196	24
Surface	09/26/1994	3	91.79	98.26	16.0	51.0	8.00	8.23	90	172	929	916	13	0.02	0.00096	0.10	1.40	1.38	1.50	0.230	0.193	36
Surface	10/11/1994	3	85.43	88.87	11.5	54.0	9.40	7.76	30	193	923	911	12	0.05	0.00060	0.10	1.79	1.74	1.89	0.260	0.213	42
Surface	10/25/1994	3	28.81	32.51	8.8	32.0	8.80	7.13	10	192	920	909	11	0.29	0.00066	0.10	1.92	1.63	2.02	0.273	0.240	42
Surface	01/03/1995	3	0.34	0.00	1.5	-2.0	7.60	7.05	10	217	1001	993	8	0.44	0.00046	0.30	1.79	1.35	2.09	0.263	0.246	120
Surface	01/24/1995	3	0.33	0.72	1.0	23.0	4.90	7.11	10	224	1014	1012	2	0.71	0.00082	0.30	2.22	1.51	2.52	0.277	0.262	120
Surface	02/21/1995	3	0.67	1.45	1.5	40.0	3.80	7.65	10	230	1051	1049	2	0.74	0.00309	0.20	2.28	1.54	2.48	0.282	0.249	108
Surface	04/05/1995	3	83.08	80.92	4.0	38.0	14.20	8.53	10	191	935	921	14	0.02	0.00075	0.20	1.78	1.76	1.98	0.190	0.039	30
Surface	04/19/1995	3	21.44	18.79	6.2	66.0	10.60	8.66	10	148	864	852	12	0.02	0.00118	0.10	1.70	1.68	1.80	0.125	0.023	27
Surface	05/01/1995	3	17.09	15.17	9.0	52.0	10.20	8.79	10	150	914	900	14	0.02	0.00192	0.10	1.07	1.05	1.17	0.085	0.013	40
Surface	05/30/1995	3	1.68	2.17	16.0	66.0	7.80	8.23	10	150	1009	1003	6	0.42	0.02006	0.30	1.52	1.10	1.82	0.115	0.082	156
Surface	06/12/1995	3	2.01	2.17	18.0	76.0	7.60	8.16	10	0	1170	1163	7	0.63	0.02975	0.30	1.99	1.36	2.29	0.112	0.089	42
Surface	06/26/1995	3	22.78	22.40	23.0	71.0	6.50	8.45	10	161	1084	1071	13	0.27	0.03297	0.30	1.89	1.62	2.19	0.144	0.085	34
Surface	07/11/1995	3	222.44	225.42	24.0	82.0	12.60	9.27	10	152	1159	1137	22	0.02	0.00994	0.10	2.59	2.57	2.69	0.112	0.036	42
Surface	07/25/1995	3	61.64	67.19	25.0	77.0	7.00	8.99	10	148	1056	1046	10	0.23	0.08220	0.10	1.98	1.75	2.08	0.230	0.171	42
Surface	08/21/1995	3	19.43	19.51	25.0	76.0	7.80	9.08	10	163	1087	1079	8	0.04	0.01625	0.10	1.18	1.14	1.28	0.299	0.274	60
Surface	09/18/1995	3	44.22	44.80	18.0	62.0	8.20	9.21	30	167	1079	1065	14	0.02	0.00715	0.10	1.56	1.54	1.66	0.264	0.204	42
Surface	10/18/1995	3			11.0	51.0	9.30	9.13	20	170	1082	1072	10	0.02	0.00427	0.10	1.33	1.31	1.43	0.242	0.197	96
		LM3																				
		MEAN	45.26	46.36	13.8	55.8	8.38	8.32	17	166	1007	995	11	0.23	0.01386	0.16	1.83	1.59	1.99	0.223	0.165	60
		MEDIAN	22.11	20.95	16.0	62.0	8.00	8.45	10	167	1009	1003	12	0.05	0.00309	0.10	1.79	1.54	2.02	0.242	0.196	42
		MAXIMUM	222.44	225.42	25.0	82.0	14.20	9.27	90	230	1170	1163	24	0.74	0.08220	0.30	2.70	2.57	2.80	0.486	0.316	156
		MINIMUM	0.33	0.00	1.0	-2.0	3.80	7.05	10	0	864	852	2	0.02	0.00046	0.10	1.07	1.05	1.17	0.085	0.013	24
		STDEV	56.63	57.94	8.5	21.9	2.42	0.71	19	48	90	91	6	0.26	0.02135	0.09	0.43	0.38	0.46	0.095	0.096	39
		RANGE	222.11	225.42	24.0	84.0	10.40	2.22	80	230	306	311	22	0.72	0.08173	0.20	1.63	1.52	1.63	0.401	0.303	132
Surface	08/17/1994	4	22.78	23.12	22.5	80.0	7.20	8.50	10	188	0	0	0	0.23	0.03010	0.10	2.44	2.21	2.54	0.296	0.223	20
Surface	09/12/1994	4	153.43	168.34	22.5	86.0	10.20	8.26	10	194	1221	1190	31	0.02	0.00159	0.10	2.70	2.68	2.80	0.233	0.126	15
Surface	09/26/1994	4	4.36	3.61	16.5	60.0	6.80	7.92	10	189	870	862	8	0.28	0.00696	0.10	1.43	1.15	1.53	0.196	0.160	32
Surface	10/11/1994	4	23.79	23.84	12.5	66.0	9.20	7.31	10	195	882	867	15	0.28	0.00129	0.20	1.86	1.58	2.06	0.240	0.180	36
Surface	10/25/1994	4	12.73	12.28	9.2	42.0	9.50	7.01	10	203	874	857	17	0.46	0.00082	0.30	1.65	1.19	1.95	0.213	0.166	30
Surface	01/04/1995	4	38.19	36.85	1.0	0.0	15.80	8.67	10	222	965	959	6	0.02	0.00081	0.30	1.45	1.43	1.75	0.180	0.113	4
Surface	01/25/1995	4	111.56	112.71	1.0	26.0	15.80	8.50	10	234	974	963	11	0.15	0.00415	0.30	2.93	2.78	3.23	0.259	0.160	24
Surface	02/22/1995	4	27.47	26.73	1.0	41.0	13.20	8.20	10	231	1033	1025	8	0.15	0.00211	0.40	1.69	1.54	2.09	0.197	0.148	24
Surface	04/05/1995	4	26.80	24.57	5.0	42.0	12.80	8.37	10	195	898	887	11	0.02	0.00057	0.40	1.19	1.17	1.59	0.121	0.036	36
Surface	04/19/1995	4	21.11	18.06	5.5	58.0	11.20	8.63	10	157	828	809	19	0.02	0.00105	0.10	1.33	1.31	1.43	0.092	0.026	29
Surface	05/01/1995	4	6.70	5.06	9.2	55.0	9.50	8.57	10	154	883	876	7	0.02	0.00122	0.10	0.76	0.74	0.86	0.069	0.020	72
Surface	05/30/1995	4	2.68	1.45	16.0	76.0	8.20	8.26	20	159	938	930	8	0.27	0.01377	0.20	1.11	0.84	1.31	0.079	0.066	54
Surface	06/12/1995	4	2.35	1.45	18.0	84.0	7.80	8.22	10	159	1046	1041	5	0.40	0.02153	0.20	1.78	1.38	1.98	0.131	0.124	36
Surface	06/26/1995	4	17.09	15.90	22.2	69.0	6.40	8.33	10	165	991	967	24	0.22	0.01993	0.30	1.56	1.34	1.86	0.144	0.079	24
Surface	07/11/1995	4	28.81	28.90	26.0	94.0	13.20	9.04	10	152	1033	1025	8	0.02	0.00802	0.10	1.36	1.34	1.46	0.069	0.046	60
Surface	07/26/1995	4	119.93	127.88	24.0	73.0	8.50	8.84	10	156	978	964	14	0.12	0.03220	0.10	2.09	1.97	2.19	0.213	0.131	36
Surface	08/22/1995	4	115.91	106.93	26.0	81.0	7.80	8.81	10	170	1048	1021	27	0.08	0.02262	0.10	2.33	2.25	2.43	0.285	0.150	24
Surface	09/20/1995	4	41.71	40.82	17.0	55.0	7.90	8.87	10	166	981	954	27	0.03	0.00573	0.10	1.16	1.13	1.26	0.158	0.095	24
Surface	10/18/1995	4			11.0	55.0	9.80	9.14	10	158	1007	983	24	0.06	0.01306	0.10	1.29	1.23	1.39	0.133	0.060	30
		LM4																				
		MEAN	43.19	43.25	14.0	60.2	10.04	8.39	11	181	918	904	14	0.15	0.00987	0.19	1.69	1.54	1.88	0.174	0.111	32
		MEDIAN	25.30	24.21	16.0	60.0	9.50	8.50	10	170	974	959	11	0.12	0.00573	0.10	1.56	1.34	1.86	0.180	0.124	30
		MAXIMUM	153.43	168.34	26.0	94.0	15.80	9.14	20	234	1221	1190	31	0.46	0.03220	0.40	2.93	2.78	3.23	0.296	0.223	72
		MINIMUM	2.35	1.45	1.0	0.0	6.40	7.01	10	152	0	0	0	0.02	0.00057	0.10	0.76	0.74	0.86	0.069	0.020	4
		STDEV	47.15	49.83	8.7	23.1	2.88	0.54	2	27	240	236	9	0.14	0.01054	0.11	0.58	0.58	0.59	0.071	0.058	16
		RANGE	151.09	166.90	25.0	94.0	9.40	2.13	10	82	1221	1190	31	0.44	0.03163	0.30	2.17	2.04	2.37	0.227	0.203	68

DEPTH	Date	Site	UnCorr Chl-a	Corr Chl-a	WTEMP	ATEMP	DISOX	FPH	FECAL	TALKAL	TSOL	TDSOL	TSSOL	AMMON	UN-AMMON	NO3+2	TKN-N	O-Nitro	T-Nitro	TPO4P	TDPO4P	Secchi
	Units		mg/m3	mg/m3	C	F	mg/L	su	/100 mL	mg/L	mg/L	mg/L	mg/L	mg/L	mg/l	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	inches
Surface	08/17/1994	5	8.04	5.78	22.1	80.0	7.20	8.39	10	190	0	0	0	0.23	0.02346	0.10	2.38	2.15	2.48	0.346	0.236	33
Surface	09/13/1994	5	42.21	47.69	22.0	85.0	7.80	8.05	10	189	852	835	17	0.09	0.00441	0.10	1.65	1.56	1.75	0.193	0.190	16
Surface	09/26/1994	5	218.09	223.25	17.0	62.0	8.90	8.06	10	192	838	823	15	0.15	0.00529	0.10	2.74	2.59	2.84	0.293	0.150	24
Surface	10/11/1994	5	19.77	19.51	13.0	67.0	9.10	7.45	70	194	876	859	17	0.28	0.00184	0.20	1.87	1.59	2.07	0.243	0.186	28
Surface	10/25/1994	5			9.2	43.0	9.20	7.02	10	202	863	847	16	0.45	0.00082	0.30	1.63	1.18	1.93	0.213	0.180	30
Surface	01/04/1995	5	21.44	21.68	1.0	10.0	15.40	8.51	10	226	965	957	8	0.02	0.00057	0.30	1.49	1.47	1.79	0.156	0.117	4
Surface	01/25/1995	5	7.37	7.23	1.0	25.0	14.20	8.30	10	232	959	953	6	0.23	0.00405	0.30	1.85	1.62	2.15	0.151	0.147	96
Surface	02/22/1995	5	0.00	0.00	1.0	46.0	10.00	7.90	10	231	1024	1022	2	0.25	0.00177	0.40	1.54	1.29	1.94	0.171	0.144	22
Surface	04/05/1995	5	12.73	10.84	5.0	45.0	12.20	8.50	10	194	887	881	6	0.04	0.00152	0.40	1.17	1.13	1.57	0.134	0.075	48
Surface	04/19/1995	5	22.78	19.51	5.5	66.0	11.60	8.62	10	164	833	815	18	0.02	0.00103	0.10	1.35	1.33	1.45	0.092	0.020	27
Surface	05/01/1995	5	6.03	5.06	9.2	55.0	9.50	8.62	10	160	875	864	11	0.02	0.00136	0.10	0.78	0.76	0.88	0.052	0.020	84
Surface	05/30/1995	5	2.01	1.45	16.5	74.0	8.20	8.25	10	160	926	922	4	0.26	0.01344	0.20	1.34	1.08	1.54	0.072	0.059	78
Surface	06/12/1995	5	1.34	0.00	18.0	82.0	7.80	8.23	10	161	1034	1027	7	0.37	0.02036	0.20	1.71	1.34	1.91	0.085	0.072	54
Surface	06/26/1995	5	20.77	20.23	22.2	68.0	6.20	8.29	10	165	993	965	28	0.21	0.01749	0.30	1.71	1.50	2.01	0.157	0.089	18
Surface	07/11/1995	5	84.09	87.42	27.0	92.0	13.20	9.15	10	147	1021	1005	16	0.02	0.00961	0.10	1.60	1.58	1.70	0.105	0.043	36
Surface	07/26/1995	5	13.40	13.01	24.5	73.0	6.90	8.85	10	156	970	950	20	0.31	0.08679	0.10	1.24	0.93	1.34	0.213	0.151	12
Surface	08/22/1995	5	10.05	10.84	25.2	76.0	6.30	8.73	10	165	1027	1019	8	0.21	0.04969	0.10	1.49	1.28	1.59	0.204	0.168	36
Surface	09/20/1995	5	61.64	62.86	16.9	51.0	8.10	9.01	10	166	963	942	21	0.02	0.00489	0.10	1.70	1.68	1.80	0.155	0.088	24
Surface	10/18/1995	5			11.0	54.0	10.80	9.32	10	151	968	947	21	0.02	0.00592	0.10	1.33	1.31	1.43	0.098	0.046	36
		LM5																				
		MEAN	32.46	32.73	14.1	60.7	9.61	8.38	13	181	888	875	13	0.17	0.01339	0.19	1.61	1.44	1.80	0.165	0.115	37
		MEDIAN	13.40	13.01	16.5	66.0	9.10	8.39	10	166	959	942	15	0.21	0.00489	0.10	1.60	1.34	1.79	0.156	0.117	30
		MAXIMUM	218.09	223.25	27.0	92.0	15.40	9.32	70	232	1034	1027	28	0.45	0.08679	0.40	2.74	2.59	2.84	0.346	0.236	96
		MINIMUM	0.00	0.00	1.0	10.0	6.20	7.02	10	147	0	0	0	0.02	0.00057	0.10	0.78	0.76	0.88	0.052	0.020	4
		STDEV	52.86	54.58	8.7	20.9	2.66	0.56	14	27	226	223	8	0.14	0.02144	0.11	0.43	0.41	0.43	0.076	0.064	25
		RANGE	218.09	223.25	26.0	82.0	9.20	2.30	60	85	1034	1027	28	0.43	0.08623	0.30	1.96	1.83	1.96	0.294	0.216	92
Surface	08/18/1994	1A	166.16	176.29	22.2	74.0	7.30	8.86	10	176	1221	1141	80	0.02	0.00505	0.10	3.07	3.05	3.17	0.523	0.047	6
Surface	09/12/1994	1A	170.18	159.91	21.0	71.0	4.50	8.20	10	185	1151	1101	50	0.02	0.00127	0.10	3.15	3.13	3.25	0.459	0.037	14
Surface	10/11/1994	1A	359.12	385.09	11.0	56.0	9.50	7.61	10	165	1261	1179	82	0.02	0.00016	0.10	4.00	3.98	4.10	0.483	0.087	10
Surface	01/03/1995	1A	15.75	12.28	1.0	6.0	3.40	6.07	10	319	1626	1612	14	0.63	0.00007	0.50	1.79	1.16	2.29	0.501	0.366	42
Surface	01/24/1995	1A	12.40	10.84	1.0	26.0	4.70	7.50	10	311	1806	1801	5	0.57	0.00162	3.70	1.30	0.73	5.00	0.250	0.244	41
Surface	02/21/1995	1A	18.76	17.34	1.0	41.0	3.20	7.60	10	314	1881	1878	3	0.48	0.00171	3.20	1.28	0.80	4.48	0.207	0.177	48
Surface	04/05/1995	1A	162.24	147.60	3.0	36.0	12.20	8.10	10	176	1276	1208	68	0.02	0.00026	0.40	2.30	2.28	2.70	0.328	0.026	12
Surface	05/23/1995	1A	75.04	67.92	14.8	49.0	7.60	8.61	30	168	1246	1216	30	0.02	0.00198	0.10	1.60	1.58	1.70	0.174	0.013	18
Surface	06/26/1995	1A	107.54	95.37	21.0	71.0	5.60	8.22	550	182	1243	1211	32	0.17	0.01126	0.70				0.239	0.066	20
Surface	07/11/1995	1A	103.85	100.43	26.0	80.0	11.60	9.06	220	158	1305	1267	38	0.02	0.00824	0.10	2.17	2.15	2.27	0.190	0.023	12
Surface	08/21/1995	1A	186.60	166.90	24.0	76.0	12.50	8.92	20	175	1377	1333	44	0.02	0.00612	0.10	2.76	2.74	2.86	0.369	0.029	12
Surface	09/18/1995	1A	408.55	413.59	17.0	62.0	8.90	9.07	30	154	1148	1080	68	0.02	0.00544	0.10	3.19	3.17	3.29	0.496	0.011	8
Surface	10/16/1995	1A			11.0	65.0	13.20	9.08	20	183	1174	1142	32	0.02	0.00390	0.10	2.57	2.55	2.67	0.277	0.095	18
		LM1A																				
		MEAN	148.85	146.13	13.4	54.8	8.02	8.22	72	205	1363	1321	42	0.16	0.00362	0.72	2.43	2.28	3.15	0.346	0.094	20
		MEDIAN	134.89	124.01	14.8	62.0	7.60	8.22	10	176	1261	1211	38	0.02	0.00198	0.10	2.44	2.42	3.02	0.328	0.047	14
		MAXIMUM	408.55	413.59	26.0	80.0	13.20	9.08	550	319	1881	1878	82	0.63	0.01126	3.70	4.00	3.98	5.00	0.523	0.366	48
		MINIMUM	12.40	10.84	1.0	6.0	3.20	6.07	10	154	1148	1080	3	0.02	0.00007	0.10	1.28	0.73	1.70	0.174	0.011	6
		STDEV	126.65	132.72	9.4	22.2	3.59	0.87	154	63	247	267	27	0.24	0.00345	1.23	0.85	1.03	0.97	0.132	0.107	14
		RANGE	396.15	402.75	25.0	74.0	10.00	3.01	540	165	733	798	79	0.61	0.01119	3.60	2.72	3.25	3.30	0.349	0.355	42

DEPTH	Date	Site	UnCorr Chl-a	Corr Chl-a	WTEMP	ATEMP	DISOX	FPH	FECAL	TALKAL	TSOL	TDSOL	TSSOL	AMMON	UN-AMMON	NO3+2	TKN-N	O-Nitro	T-Nitro	TPO4P	TDPO4P	Secchi
	Units		mg/m3	mg/m3	C	F	mg/L	su	/100 mL	mg/L	mg/L	mg/L	mg/L	mg/L	mg/l	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	inches
Surface	06/13/1995	RL6			19.0	76.0	7.20	8.14	10	153	1163	1135	28	0.55	0.02667	0.30	1.87	1.32	2.17	0.157	0.089	24
Bottom	08/18/1994	1			22.0	75.0	5.80	8.43	10	171	916	894	22	0.35	0.03851	0.10	2.58	2.23	2.68	0.450	0.336	18
Bottom	09/13/1994	1			22.0	78.0	8.20	8.08	10	184	912	880	32		0.00000	0.10	2.04	2.04	2.14	0.280	0.193	21
Bottom	09/26/1994	1			16.0	52.0	6.40	8.06	10	179	931	920	11	0.56	0.01836	0.10	2.01	1.45	2.11	0.363	0.300	34
Bottom	10/11/1994	1			12.0	54.0	9.00	7.70	10	183	939	920	19	0.22	0.00237	0.10	2.60	2.38	2.70	0.333	0.240	34
Bottom	10/25/1994	1			8.6	36.0	9.30	7.43	10	190	909	899	10	0.31	0.00139	0.10	1.88	1.57	1.98	0.266	0.230	42
Bottom	01/03/1995	1			3.0	-6.0	6.50	6.90	10	222	1031	1009	22	0.59	0.00050	0.30	3.23	2.64	3.53	0.323	0.263	108
Bottom	01/24/1995	1			2.5	25.0	5.40	7.90	10	231	1054	1050	4	0.88	0.00706	0.30	2.16	1.28	2.46	0.330	0.307	120
Bottom	02/21/1995	1			3.2	34.0	3.30	7.70		237	1110	1108	2	0.83	0.00447	0.20	2.46	1.63	2.66	0.325	0.295	108
Bottom	04/05/1995	1			4.0	36.0	13.60	8.26	10	179	906	890	16	0.06	0.00123	0.30	1.98	1.92	2.28	0.167	0.049	30
Bottom	04/19/1995	1			4.4	50.0	10.40	8.55	340	135	913	853	60	0.02	0.00081	0.90	1.34	1.32	2.24	0.259	0.046	12
Bottom	05/01/1995	1			9.8	51.0	11.50	9.02	60	129	1010	975	35	0.02	0.00322	0.10	1.02	1.00	1.12	0.125	0.010	25
Bottom	05/30/1995	1			14.0	70.0	7.60	8.24	330	156	1097	1091	6	0.39	0.01648	0.90	1.43	1.04	2.33	0.118	0.098	60
Bottom	06/12/1995	1			17.0	72.0	7.20	8.18	10	171	1298	1287	11	0.46	0.02114	0.30	1.86	1.40	2.16	0.125	0.092	36
Bottom	06/26/1995	1			23.0	70.0	5.60	8.53	10	170	1124	1068	56	0.12	0.01719	0.30	1.40	1.28	1.70	0.220	0.105	26
Bottom	07/11/1995	1			23.0	84.0	5.20	8.52	10	160	1151	1146	5	0.08	0.01124	0.10	1.25	1.17	1.35	0.118	0.098	42
Bottom	07/25/1995	1			24.8	81.0	4.30	8.33	30	156	1099	1086	13	0.81	0.08676	0.10	1.99	1.18	2.09	0.387	0.341	30
Bottom	08/21/1995	1			25.3	83.0	4.60	8.69	10	172	1377	1365	12	0.62	0.13739	0.10	2.44	1.82	2.54	0.423	0.365	30
Bottom	09/18/1995	1			18.4	66.0	7.90	9.13	10	169	1073	1056	17	0.05	0.01613	0.10	1.39	1.34	1.49	0.282	0.218	30
Bottom	10/18/1995	1			11.0	52.0	8.90	9.02	10	174	1098	1083	15	0.14	0.02439	0.20	1.84	1.70	2.04	0.288	0.197	30
	BOTTOM	LM1																				
		MEAN			13.9	55.9	7.41	8.25	50	177	1050	1031	19	0.36	0.02151	0.25	1.94	1.60	2.19	0.273	0.199	44
		MEDIAN			14.0	54.0	7.20	8.26	10	172	1054	1050	15	0.33	0.01124	0.10	1.98	1.45	2.16	0.282	0.218	30
		MAXIMUM			25.3	84.0	13.60	9.13	340	237	1377	1365	60	0.88	0.13739	0.90	3.23	2.64	3.53	0.450	0.365	120
		MINIMUM			2.5	-6.0	3.30	6.90	10	129	906	853	2	0.02	0.00000	0.10	1.02	1.00	1.12	0.118	0.010	12
		STDEV			8.1	23.5	2.63	0.56	104	28	133	139	16	0.30	0.03458	0.25	0.56	0.46	0.55	0.104	0.112	32
		RANGE			22.8	90.0	10.30	2.23	330	108	471	512	58	0.86	0.13739	0.80	2.21	1.64	2.41	0.332	0.355	108
Bottom	08/18/1994	2			22.1	75.0	5.50	8.60	10	170	912	891	21	0.31	0.04822	0.10	2.14	1.83	2.24	0.413	0.320	30
Bottom	09/12/1994	2			22.0	77.0	7.90	8.15	10	178	910	883	27	0.02	0.00122	0.10	2.23	2.21	2.33	0.290	0.190	22
Bottom	09/26/1994	2			16.0	52.0	7.40	8.21	10	173	935	924	11	0.21	0.00960	0.10	1.49	1.28	1.59	0.286	0.246	34
Bottom	10/11/1994	2			12.0	54.0	9.70	7.76	10	199	928	912	16	0.13	0.00161	0.10	2.12	1.99	2.22	0.293	0.236	36
Bottom	10/25/1994	2			9.0	36.0	8.60	7.52	10	189	911	903	8	0.23	0.00130	0.20	1.79	1.56	1.99	0.286	0.223	60
Bottom	01/03/1995	2			3.0	-8.0	7.80	6.44	10	216	1012	1003	9	0.59	0.00017	0.30	1.98	1.39	2.28	0.303	0.283	120
Bottom	01/24/1995	2			3.2	23.0	5.40	7.70	10	225	1058	1053	5	0.81	0.00436	0.30	2.23	1.42	2.53	0.318	0.308	120
Bottom	02/21/1995	2			4.0	41.0	2.90	7.60		239	1100	1098	2	0.65	0.00297	0.20	2.46	1.81	2.66	0.325	0.325	108
Bottom	04/05/1995	2			4.0	38.0	12.20	8.49	10	104	937	926	11	0.02	0.00069	0.30	1.59	1.57	1.89	0.197	0.056	30
Bottom	04/19/1995	2			5.0	68.0	10.40	8.68	10	148	888	849	39	0.02	0.00113	0.10	1.49	1.47	1.59	0.236	0.039	21
Bottom	05/01/1995	2			9.1	51.0	11.10	8.96	10	146	920	903	17	0.02	0.00273	0.10	1.08	1.06	1.18	0.085	0.010	36
Bottom	05/30/1995	2			14.0	66.0	7.20	8.16	10	153	1027	1021	6	0.48	0.01699	0.20	1.54	1.06	1.74	0.115	0.092	144
Bottom	06/12/1995	2			17.0	72.0	7.20	8.19	10	159	1226	1218	8	0.63	0.02960	0.30	1.83	1.20	2.13	0.118	0.095	60
Bottom	06/26/1995	2			23.1	71.0	7.60	8.66	10	164	1088	1062	26	0.10	0.01852	0.30	1.30	1.20	1.60	0.164	0.085	30
Bottom	07/11/1995	2			22.0	82.0	5.00	8.55	10	163	1194	1187	7	0.25	0.03503	0.10	1.31	1.06	1.41	0.164	0.262	12
Bottom	07/25/1995	2			24.5	78.0	4.80	8.66	10	160	1097	1055	42	0.50	0.10034	0.10	1.89	1.39	1.99	0.351	0.239	42
Bottom	08/21/1995	2			25.0	81.0	7.10	8.92	10	164	1108	1095	13	0.19	0.06104	0.10	1.13	0.94	1.23	0.361	0.296	30
Bottom	09/18/1995	2			18.2	63.0	8.20	9.17	10	166	1063	1047	16	0.02	0.00680	0.10	1.38	1.36	1.48	0.275	0.187	34
Bottom	10/18/1995	2			11.0	52.0	9.10	9.05	10	171	1081	1070	11	0.10	0.01844	0.20	1.75	1.65	1.95	0.267	0.186	54
	BOTTOM	LM2																				
		MEAN			13.9	56.4	7.64	8.29	10	173	1021	1005	16	0.28	0.01899	0.17	1.72	1.44	1.90	0.255	0.194	54
		MEDIAN			14.0	63.0	7.60	8.49	10	166	1027	1021	11	0.21	0.00680	0.10	1.75	1.39	1.95	0.286	0.223	36
		MAXIMUM			25.0	82.0	12.20	9.17	10	239	1226	1218	42	0.81	0.10034	0.30	2.46	2.21	2.66	0.413	0.325	144
		MINIMUM			3.0	-8.0	2.90	6.44	10	104	888	849	2	0.02	0.00017	0.10	1.08	0.94	1.18	0.085	0.010	12
		STDEV			7.9	23.0	2.31	0.67	0	31	103	106	11	0.25	0.02638	0.09	0.40	0.34	0.43	0.091	0.102	39
		RANGE			22.0	90.0	9.30	2.73	0	135	338	369	40	0.79	0.10017	0.20	1.38	1.27	1.48	0.328	0.315	132

DEPTH	Date	Site	UnCorr Chl-a	Corr Chl-a	WTEMP	ATEMP	DISOX	FPH	FECAL	TALKAL	TSOL	TDSOL	TSSOL	AMMON	UN-AMMON	NO3+2	TKN-N	O-Nitro	T-Nitro	TPO4P	TDPO4P	Secchi
	Units		mg/m3	mg/m3	C	F	mg/L	su	/100 mL	mg/L	mg/L	mg/L	mg/L	mg/L	mg/l	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	inches
Bottom	08/18/1994	3			21.8	74.0	5.90	8.45	20	170	977	937	40	0.41	0.04640	0.10	2.73	2.32	2.83	0.433	0.300	33
Bottom	09/12/1994	3			21.0	71.0	8.50	8.13	10	177	897	874	23	0.02	0.00109	0.10	1.75	1.73	1.85	0.253	0.193	24
Bottom	09/26/1994	3			16.0	51.0	8.20	8.24	10	173	921	912	9	0.02	0.00098	0.10	1.23	1.21	1.33	0.246	0.173	36
Bottom	10/11/1994	3			12.0	54.0	9.60	7.78	10	193	919	908	11	0.05	0.00065	0.10	1.79	1.74	1.89	0.276	0.200	40
Bottom	10/25/1994	3			8.7	32.0	8.80	7.25	10	188	913	904	9	0.30	0.00089	0.10	1.86	1.56	1.96	0.266	0.230	48
Bottom	01/03/1995	3			4.0	-2.0	4.60	7.30	10	219	992	987	5	0.68	0.00156	0.30	2.01	1.33	2.31	0.306	0.276	120
Bottom	01/24/1995	3			3.5	23.0	4.60	7.83	10	231	1044	1041	3	0.84	0.00624	0.30	2.51	1.67	2.81	0.347	0.307	120
Bottom	02/21/1995	3			3.5	40.0	3.40	7.60		235	1107	1102	5	0.78	0.00342	0.30	2.40	1.62	2.70	0.325	0.292	108
Bottom	04/05/1995	3			4.0	38.0	14.60	8.57	10	190	942	930	12	0.02	0.00082	0.20	1.75	1.73	1.95	0.197	0.043	20
Bottom	04/19/1995	3			5.0	66.0	10.40	8.62	10	150	875	845	30	0.02	0.00099	0.10	1.99	1.97	2.09	0.154	0.036	27
Bottom	05/01/1995	3			9.0	52.0	10.10	8.80	10	149	902	890	12	0.02	0.00196	0.10	1.24	1.22	1.34	0.089	0.010	40
Bottom	05/30/1995	3			14.0	66.0	6.80	8.15	10	151	1010	1002	8	0.44	0.01523	0.20	1.43	0.99	1.63	0.092	0.095	156
Bottom	06/12/1995	3			17.0	76.0	7.40	8.17	10	157	1200	1191	9	0.60	0.02698	0.20	1.87	1.27	2.07	0.112	0.089	42
Bottom	06/26/1995	3			23.0	71.0	6.40	8.45	10	165	1055	1038	17	0.28	0.03419	0.30	1.83	1.55	2.13	0.154	0.098	34
Bottom	07/11/1995	3			22.0	82.0	5.60	8.64	10	160	1137	1135	2	0.11	0.01837	0.10	1.18	1.07	1.28	0.112	0.102	42
Bottom	07/25/1995	3			25.0	77.0	4.50	8.84	10	153	1080	1062	18	0.42	0.11864	0.10	1.82	1.40	1.92	0.276	0.200	42
Bottom	08/21/1995	3			24.8	76.0	7.50	9.06	10	165	1072	1062	10	0.03	0.01175	0.01	1.42	1.39	1.43	0.328	0.266	60
Bottom	09/18/1995	3			18.3	62.0	8.30	9.25	110	167	1081	1067	14	0.02	0.00768	0.10	1.41	1.39	1.51	0.260	0.183	42
Bottom	10/18/1995	3			11.0	51.0	9.40	9.10	10	172	1079	1072	7	0.02	0.00405	0.10	1.18	1.16	1.28	0.253	0.200	96
	BOTTOM	LM3																				
		MEAN			13.9	55.8	7.61	8.33	16	177	1011	998	13	0.27	0.01589	0.15	1.76	1.49	1.91	0.236	0.173	59
		MEDIAN			14.0	62.0	7.50	8.45	10	170	1010	1002	10	0.11	0.00405	0.10	1.79	1.40	1.92	0.253	0.193	42
		MAXIMUM			25.0	82.0	14.60	9.25	110	235	1200	1191	40	0.84	0.11864	0.30	2.73	2.32	2.83	0.433	0.307	156
		MINIMUM			3.5	-2.0	3.40	7.25	10	149	875	845	2	0.02	0.00065	0.01	1.18	0.99	1.28	0.089	0.010	20
		STDEV			7.8	21.9	2.66	0.58	24	26	94	98	10	0.29	0.02806	0.09	0.45	0.33	0.50	0.096	0.094	40
		RANGE			21.5	84.0	11.20	2.00	100	86	325	346	38	0.82	0.11800	0.29	1.55	1.33	1.55	0.344	0.297	136
Bottom	08/17/1994	4			21.8	80.0	6.10	8.30	10	185	0	0	0	0.15	0.01243	0.10	2.30	2.15	2.40	0.286	0.220	20
Bottom	09/13/1994	4			22.0	86.0	7.20	8.26	10	191	860	833	27	0.02	0.00154	0.10	2.25	2.23	2.35	0.240	0.023	15
Bottom	09/27/1994	4			16.2	60.0	6.87	7.95	10	186	881	871	10	0.28	0.00729	0.10	1.20	0.92	1.30	0.203	0.160	32
Bottom	10/11/1994	4			12.2	66.0	9.40	6.90	40	199	880	865	15	0.27	0.00047	0.20	1.84	1.57	2.04	0.263	0.170	36
Bottom	10/25/1994	4			9.5	42.0	9.20	7.04	10	209	874	858	16	0.46	0.00090	0.30	1.59	1.13	1.89	0.223	0.183	30
Bottom	01/04/1995	4			2.0	0.0	15.80	8.53	10	223	952	946	6	0.02	0.00064	0.30	1.26	1.24	1.56	0.146	0.117	4
Bottom	01/25/1995	4			2.3	26.0	15.10	8.20	10	229	963	956	7	0.14	0.00219	0.30	1.73	1.59	2.03	0.184		24
Bottom	02/22/1995	4			3.0	41.0	13.30	8.10	10	236	1052	1046	6	0.13	0.00171	0.40	1.59	1.46	1.99	0.171	0.008	24
Bottom	04/05/1995	4			4.0	42.0	13.20	8.56	10	196	902	892	10	0.02	0.00080	0.40	1.27	1.25	1.67	0.141	0.046	36
Bottom	04/19/1995	4			5.0	58.0	11.80	8.62	50	165	831	808	23	0.02	0.00099	0.10	1.44	1.42	1.54	0.121	0.036	29
Bottom	05/01/1995	4			9.2	55.0	9.60	8.55	10	155	916	901	15	0.02	0.00117	0.10	0.98	0.96	1.08	0.092	0.016	72
Bottom	05/30/1995	4			15.0	76.0	7.60	8.21	10	163	937	919	18	0.28	0.01191	0.20	1.37	1.09	1.57	0.115	0.062	78
Bottom	06/12/1995	4			17.0	84.0	7.20	8.22	10	160	1105	1091	14	0.41	0.02057	0.20	1.94	1.53	2.14	0.108	0.079	36
Bottom	06/26/1995	4			22.5	69.0	6.20	8.34	30	166	991	965	26	0.21	0.01981	0.30	1.49	1.28	1.79	0.157	0.075	24
Bottom	07/11/1995	4			21.0	94.0	4.80	8.31	10	164	1029	1014	15	0.31	0.02487	0.20	1.49	1.18	1.69	0.151	0.105	60
Bottom	07/26/1995	4			24.0	73.0	9.00	8.84	10	159	990	973	17	0.28	0.07513	0.24	2.13	1.85	2.37	0.236	0.161	36
Bottom	08/22/1995	4			22.5	81.0	6.80	8.81	10	172	1082	1041	41	0.10	0.02351	0.10	1.61	1.51	1.71	0.296	0.161	24
Bottom	09/20/1995	4			17.0	55.0	8.00	8.93	10	169	995	969	26	0.03	0.00639	0.10	1.26	1.23	1.36	0.165	0.095	24
Bottom	10/18/1995	4			11.0	55.0	9.80	9.21	10	162	1006	982	24	0.07	0.01724	0.10	1.52	1.45	1.62	0.140	0.063	30
	BOTTOM	LM4																				
		MEAN			13.5	60.2	9.31	8.31	15	184	908	891	17	0.17	0.01208	0.20	1.59	1.42	1.79	0.181	0.099	33
		MEDIAN			15.0	60.0	9.00	8.31	10	172	952	946	15	0.14	0.00639	0.20	1.52	1.42	1.71	0.165	0.087	30
		MAXIMUM			24.0	94.0	15.80	9.21	50	236	1105	1091	41	0.46	0.07513	0.40	2.30	2.23	2.40	0.296	0.220	78
		MINIMUM			2.0	0.0	4.80	6.90	10	155	0	0	0	0.02	0.00047	0.10	0.98	0.92	1.08	0.092	0.008	4
		STDEV			7.7	23.1	3.16	0.57	12	25	233	229	10	0.14	0.01758	0.11	0.36	0.36	0.37	0.061	0.064	18
		RANGE			22.0	94.0	11.00	2.31	40	81	1105	1091	41	0.44	0.07466	0.30	1.32	1.31	1.32	0.204	0.212	74

DEPTH	Date	Site	UnCorr Chl-a	Corr Chl-a	WTEMP	ATEMP	DISOX	FPH	FECAL	TALKAL	TSOL	TDSOL	TSSOL	AMMON	UN-AMMON	NO3+2	TKN-N	O-Nitro	T-Nitro	TPO4P	TDPO4P	Secchi
	Units		mg/m3	mg/m3	C	F	mg/L	su	/100 mL	mg/L	mg/L	mg/L	mg/L	mg/L	mg/l	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	inches
Bottom	08/17/1994	5			21.5	80.0	5.40	8.40	10	181	0	0	0	0.19	0.01903	0.10	2.29	2.10	2.39	0.283	0.226	33
Bottom	09/13/1994	5			21.8	85.0	7.20	8.05	10	190	858	840	18	0.11	0.00532	0.10	1.30	1.19	1.40	0.196	0.153	16
Bottom	09/26/1994	5			9.2	42.0	9.20	7.04	10	195	863	851	12	0.25	0.00048	0.10	1.18	0.93	1.28	0.206	0.170	30
Bottom	10/11/1994	5			12.5	67.0	9.00	7.43	10	197	882	863	19	0.28	0.00169	0.10	1.83	1.55	1.93	0.243	0.190	28
Bottom	10/25/1994	5			9.5	43.0	9.20	7.04	10	203	869	853	16	0.47	0.00092	0.30	1.60	1.13	1.90	0.216	0.176	30
Bottom	01/04/1995	5			3.5	10.0	7.60	8.23	10	219	941	936	5	0.17	0.00313	0.30	1.54	1.37	1.84	0.173	0.146	4
Bottom	01/25/1995	5			3.0	25.0	10.80	8.20	10	223	938	937	1	0.24	0.00397	0.40	1.60	1.36	2.00	0.168	0.151	96
Bottom	02/22/1995	5			3.0	46.0	10.70	7.80	10	234	1030	1029	1	0.24	0.00160	0.40	1.72	1.48	2.12	0.198	0.164	22
Bottom	04/05/1995	5			5.0	45.0	12.40	8.48	10	193	890	881	9	0.04	0.00146	0.40	1.22	1.18	1.62	0.138	0.092	48
Bottom	04/19/1995	5			5.0	66.0	11.50	8.64	10	159	833	812	21	0.02	0.00104	0.10	1.52	1.50	1.62	0.098	0.023	27
Bottom	05/01/1995	5			8.9	55.0	9.40	8.55	10	164	872	865	7	0.02	0.00114	0.10	0.87	0.85	0.97	0.069	0.016	84
Bottom	05/30/1995	5			14.0	74.0	7.20	8.16	10	162	933	922	11	0.27	0.00956	0.20	1.51	1.24	1.71	0.095	0.072	78
Bottom	06/12/1995	5			17.0	82.0	7.60	8.26	10	0	1054	1045	9	0.37	0.02026	0.20	1.71	1.34	1.91	0.098	0.069	54
Bottom	06/26/1995	5			22.4	68.0	6.00	8.29	10	172	1011	972	39	0.24	0.02026	0.30	1.66	1.42	1.96	0.174	0.092	18
Bottom	07/11/1995	5			25.0	92.0	9.80	8.61	10	158	1041	1009	32	0.08	0.01506	0.10	1.73	1.65	1.83	0.144	0.105	36
Bottom	07/26/1995	5			24.1	73.0	6.60	8.80	10	160	966	946	20	0.35	0.08819	0.10	1.21	0.86	1.31	0.207	0.154	12
Bottom	08/22/1995	5			25.0	76.0	3.10	8.75	10	166	1030	1023	7	0.21	0.05091	0.10	1.62	1.41	1.72	0.215	0.172	36
Bottom	09/20/1995	5			17.0	51.0	8.00	8.98	10	166	978	958	20	0.02	0.00466	0.10	1.40	1.38	1.50	0.155	0.092	24
Bottom	10/18/1995	5			11.0	54.0	10.80	9.32	10	153	972	950	22	0.02	0.00592	0.10	1.41	1.39	1.51	0.102	0.039	36
	BOTTOM	LM5																				
		MEAN			13.6	59.7	8.50	8.26	10	173	893	879	14	0.19	0.01340	0.19	1.52	1.33	1.71	0.167	0.121	37
		MEDIAN			12.5	66.0	9.00	8.29	10	172	938	936	12	0.21	0.00466	0.10	1.54	1.37	1.72	0.173	0.146	30
		MAXIMUM			25.0	92.0	12.40	9.32	10	234	1054	1045	39	0.47	0.08819	0.40	2.29	2.10	2.39	0.283	0.226	96
		MINIMUM			3.0	10.0	3.10	7.04	10	0	0	0	0	0.02	0.00048	0.10	0.87	0.85	0.97	0.069	0.016	4
		STDEV			8.0	21.3	2.32	0.60	0	48	227	224	10	0.13	0.02183	0.12	0.30	0.29	0.34	0.057	0.060	25
		RANGE			22.0	82.0	9.30	2.28	0	234	1054	1045	39	0.45	0.08771	0.30	1.42	1.25	1.42	0.214	0.210	92

Table 1. Biological Monitoring in Lake Madison (1995-96).

Algae Type	26 June 1995		18 August 1995		12 February 1996	
	Site LM-1 Surface cells/ml	Site LM-3 Surface cells/ml	Site LM-1 Surface cells/ml	Site LM-3 Surface cells/ml	Site LM-1 Surface cells/ml	Site LM-3 Surface cells/ml
Blue-Green Algae						
Aphanizomenon flos-aquae	20195 (577 fils*/ml)	21350 (610 fils/ml)	94,000 (2350 fils/ml)	39,800 (995 fils/ml)	0	0
Microcystis aeruginosa	640	80	15,750	21,930	0	0
Oscillatoria spp.	0	0	6,000	2,200	0	0
Anabaena sp.	1560	920	0	0	0	0
Chroococcus sp.	0	0	0	83	0	0
unid entified small colonies	100	110	0	0	0	0
unidentified large cells	40	0	0	0	0	0
unidentified small filaments	0	0	0	0	0	10
Total Blue-Green Algae	22535	22460	115,750	64,013	0	10
Flagellated Algae						
Cryptomonas spp.	1	20	27	27	0	1
Chroomonas spp.	170	410	0	0	120	2
Carteria spp.	0	0	0	0	0	20
Trachelomonas spp.	4		0	0	0	0
unidentified small flagellates and			0	0	1,580	1,340
misc. small single cells?	0		0	0	0	0
Total Flagellated Algae	175	430	27	27	1,700	1,363

*fils = filaments

Table 1. **Biological Monitoring in Lake Madison (1995-96) Cont.**

Algae Type	26 June 1995		18 August 1995		12 February 1996	
	Site LM-1 Surface cells/ml	Site LM-3 Surface cells/ml	Site LM-1 Surface cells/ml	Site LM-3 Surface cells/ml	Site LM-1 Surface cells/ml	Site LM-3 Surface cells/ml
Diatoms						
Melosira granulata	20	30	0	0	0	0
Stephanodiscus hantzschii?	680	300	0	0	0	0
Stephanodiscus niagarae	4	0	0	0	0	0
Stephanodiscus spp.	0	0	0	0	0	0
Cyclotella meneghiniana?	20	30	0	0	0	0
Gyrosigma sp.	0	1	0	0	0	0
Nitzschia sp.	2	0	0	0	3	0
Nitzschia acicularis	0	0	0	0	0	0
unidentified pennate diatoms	2	3	0	0	0	0
Navicula sp.	0	1	0	0	1	1
unid. small centric diatoms	0	0	0	0	1	100
Total Diatoms	728	365	0	0	5	101

Table 1. Biological Monitoring in Lake Madison (1995-96) Cont.

Algae Type	26 June 1995		18 August 1995		12 February 1996	
	Site LM-1 Surface cells/ml	Site LM-3 Surface cells/ml	Site LM-1 Surface cells/ml	Site LM-3 Surface cells/ml	Site LM-1 Surface cells/ml	Site LM-3 Surface cells/ml
Green Algae						
Scenedesmus spp.	120	0	0	0	0	0
Characium sp.	10	0	0	0	0	0
Oocystis sp	4	6	0	0	0	0
unidentified small green cells	0	0	0	0	0	0
Total Green Algae	134	6	0	0	0	0

Table 1. Biological Monitoring in Lake Madison (1995-96) Cont.

Algae Type	26 June 1995		18 August 1995		12 February 1996	
	Site LM-1 Surface cells/ml	Site LM-3 Surface cells/ml	Site LM-1 Surface cells/ml	Site LM-3 Surface cells/ml	Site LM-1 Surface cells/ml	Site LM-3 Surface cells/ml
unidentified single small round cells:						
green/greenish/blue-green cells	180	400	0	0	2	0
brown cells	0	0	0	0	0	0
blue-green cells	0	0	0	0	0	0
Grand Total Algae	23,752	23,661	115,777	64,040	1,707	1,464

Table 2. **Biological Monitoring in Brant Lake (1995-96).**

Algae Type	26 June 1995		20 August 1995		13 February 1996	
	Site BL-4 Surface cells/ml	Site BL-5 Surface cells/ml	Site BL-4 Surface cells/ml	Site BL-5 Surface cells/ml	Site BL-4 Surface cells/ml	Site BL-5 Surface cells/ml
Blue-Green Algae						
Aphanizomenon flos-aquae	22,074 (566 fils*/ml)	15,327 (393 fils/ml)	96,800 (2,420 fils/ml)	162,400 (4,060 fils/ml)	0	0
Microcystis aeruginosa	0	0	0	0	0	0
Oscillatoria spp.	0	0	4,200	7,300	0	0
Anabaena sp.	2,080	2,520	0	0	0	0
Chroococcus sp.	0	0	0	0	0	0
unid entified small colonies	120	140	0	0	0	0
unidentified small cells	40	0	0	0	0	0
unidentified small filaments	0	0	0	0	0	0
Total Blue-Green Algae	24,314	17,987	101,000	169,700	0	0
Flagellated Algae						
Cryptomonas spp.	4	8	10	13	3	5
Chroomonas spp.	200	540	0	0	360	80
Carteria spp.	0	0	0	0	0	0
Trachelomonas spp.	2	0	0	0	0	0
unidentified small flagellates (and misc. small single cells?)	0	0	0	0	1,780	5,420
Total Flagellated Algae	206	548	10	13	2,143	5,505

*fils = filaments

Table 2. Biological Monitoring in Brant Lake (1995-96) Cont.

Algae Type	26 June 1995		20 August 1995		13 February 1996	
	Site BL-4 Surface cells/ml	Site BL-5 Surface cells/ml	Site BL-4 Surface cells/ml	Site BL-5 Surface cells/ml	Site BL-4 Surface cells/ml	Site BL-5 Surface cells/ml
Diatoms						
Melosira granulata	30	3	0	20	0	0
Melosira varians	0	0	0	0	45	10
Surirella sp.	2	0	0	0	4	4
Fragilaria sp.	0	10	0	0	0	0
Stephanodiscus hantzschii?	480	980	0	0	0	0
Stephanodiscus niagarae	21	15	100	80	0	0
Synedra sp.	0	0	0	0	36	7
Cyclotella meneghiniana?	20	60	0	0	0	0
Gyrosigma sp.	1	0	0	0	0	0
Nitzschia sp.	10	4	0	0	1	0
Nitzschia acicularis	0	10	0	0	0	0
Fragilaria capucina	0	0	0	0	60	115
Gomphonema sp.	0	0	0	0	6	0
uniddentified small and medium centric diatoms	0	0	0	0	2	43
Total Diatoms	564	1082	100	100	154	179

*fils = filaments
**col = colonies

Table 2. Biological Monitoring in Brant Lake (1995-96) Cont.

Algae Type	26 June 1995		20 August 1995		13 February 1996	
	Site BL-4 Surface cells/ml	Site BL-5 Surface cells/ml	Site BL-4 Surface cells/ml	Site BL-5 Surface cells/ml	Site BL-4 Surface cells/ml	Site BL-5 Surface cells/ml
Green Algae						
Scenedesmus spp.	0	20	0	0	0	0
Schroederia setigera	3	1	0	0	0	0
Characium sp.	0	0	0	0	0	0
Oocystis sp	40	6	0	0	0	0
Quadrigula sp.	0	9	0	0	0	0
Micractinium sp.	0	1	0	0	0	0
Stigeoclonium sp.	0	0	0	0	0	46
unidentified small green cells and/or colonies	10	0	0	0	0	0
Total Green Algae	53	37	0	0	0	46

Table 2. Biological Monitoring in Brant Lake (1995-96) Cont.

Algae Type	26 June 1995		20 August 1995		13 February 1996	
	Site BL-4 Surface cells/ml	Site BL-5 Surface cells/ml	Site BL-4 Surface cells/ml	Site BL-5 Surface cells/ml	Site BL-4 Surface cells/ml	Site BL-5 Surface cells/ml
<u>unidentified single small round cells:</u>						
green/greenish/blue-green cells	520	582	0	0	0	0
brown cells	0	0	0	0	0	0
blue-green cells	0	0	0	0	0	0
Grand Total Algae	25,137	19,654	101,110	169,813	2,297	5,730

APPENDIX E

SAMPLE DATA FOR LAKE MADISON 1994-1996																						
	LAKE MADISON TRIBUTARY SITES																					
PROJECT	DATE	TIME	SITE	DEPTH	FLOW	WTEMP	ATEMP	DISOX	FPH	FECAL	TALKAL	TSOL	TDSOL	TSSOL	AMMON	UN-AMMON	NO3+	TKN-N	O-Nit	T-Nit	TPO4P	TDPO4P
					CFS	C	F	mg/L	su	/100 m	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Lake Madison	14-Mar-95	125	LMT1	Surface		3.5	69.0	9.70	8.56	10	25	142	140	2	0.23	0.00888	0.20	0.56	0.33	0.76	0.059	0.040
Lake Madison	20-Mar-95	1130	LMT1	Surface	5.04	6.0	44.0	15.80	9.03	10	132	958	946	12	0.11	0.01395	0.20	2.07	1.96	2.27	0.315	0.161
Lake Madison	27-Mar-95	930	LMT1	Surface	11.95	5.0	42.0	10.50	8.45	10	162	1159	1136	23	0.09	0.00306	0.20	2.27	2.18	2.47	0.321	0.164
Lake Madison	03-Apr-95	900	LMT1	Surface	14.24	5.0	44.0	15.10	9.09	10	153	1155	1126	29	0.02	0.00267	0.10	2.42	2.40	2.52	0.321	0.092
Lake Madison	11-Apr-95	800	LMT1	Surface	13.20	1.5	32.0	11.60	8.90		158	1176	1144	32	0.02	0.00139	0.10	1.85	1.83	1.95	0.305	0 052
Lake Madison	17-Apr-95	905	LMT1	Surface	63.31	5.5	49.0	10.40	9.13	20	150	1205	1175	30	0.02	0.00299	0.10	1.91	1.89	2.01	0.298	0.085
Lake Madison	24-Apr-95	930	LMT1	Surface	203.45	8.0	52.0	13.20	9.16	10	136	1128	1058	70	0.02	0.00374	0.20	0.89	0.87	1.09	0.289	0.062
Lake Madison	05-Jun-95	1020	LMT1	Surface	117.00	19.0	74.0	7.90	8.75	20	150	1247	1219	28	0.07	0.01203	0.30	1.56	1.49	1.86	0.190	0.056
Lake Madison	28-Jun-95	1255	LMT1	Surface	42.09	23.7	82.0	5.90	8.40	20	163	1327	1291	36	0.17	0.01960	0.30	1.33	1.16	1.63	0.226	0.118
Lake Madison	07-Aug-95	910	LMT1	Surface	14.90	25.0	77.0	7.20	9.13	130	161	1243	1215	28	0.02	0.00869	0.10	1.28	1.26	1.38	0.296	0.175
Lake Madison	10-Oct-95	830	LMT1	Surface	100.68	11.5	61.0	9.60	8.83	10	148	1100	1082	18	0.02	0.00248	0.20	2.04	2.02	2.24	0.292	0.165
Lake Madison	12-Mar-96	830	LMT1	Surface		4.5	38.0	20.00	9.55	10	154	1120	1106	14	0.06	0.01792	0.10	2.04	1.98	2.14	0.462	0.265
				Mean	58.59	9.9	55.3	11.41	8.92	24	141	1080	1053	27	0.07	0.00812	0.18	1.69	1.61	1.86	0.28	0.120
				Maximum	203.45	25.0	82.0	20.00	9.55	130	163	1327	1291	70	0.23	0.01960	0.30	2.42	2.40	2.52	0.46	0.265
				Minimum	5.04	1.5	32.0	5.90	8.40	10	25	142	140	2	0.02	0.00139	0.10	0.56	0.33	0.76	0.06	0.040
				StDev	64.50	8.2	16.7	4.03	0.34	36	38	309	301	17	0.07	0.00644	0.08	0.57	0.61	0.55	0.09	0.068
Lake Madison	14-Mar-95	1400	LMT2	Surface		6.0	71.0	8.20	7.91	10	159	826	817	9	1.22	0.01330	1.40	2.75	1.53	4.15	0.403	0.216
Lake Madison	20-Mar-95	1020	LMT2	Surface	5.92	3.5	39.0	10.80	8.19	10	139	956	952	4	0.20	0.00337	0.70	1.84	1.64	2.54	0.279	0.151
Lake Madison	27-Mar-95	1000	LMT2	Surface	16.88	4.0	37.0	9.80	7.97	30	171	1270	1257	13	0.10	0.00106	3.40	2.38	2.28	5.78	0.328	0.197
Lake Madison	03-Apr-95	920	LMT2	Surface	17.72	4.5	48.0	12.20	8.87	10	168	1198	1176	22	0.02	0.00163	0.30	2.08	2.06	2.38	0.285	0.095
Lake Madison	11-Apr-95	1000	LMT2	Surface	21.11	1.0	36.0	11.20	8.66		158	1192	1158	34	0.02	0.00079	0.40	2.08	2.06	2.48	0.298	0.052
Lake Madison	17-Apr-95	925	LMT2	Surface	58.80	5.0	43.0	10.30	8.99	10	155	1257	1199	58	0.02	0.00218	0.90	1.89	1.87	2.79	0.318	0.082
Lake Madison	24-Apr-95	1000	LMT2	Surface	165.30	7.5	51.0	11.60	9.12	10	141	1148	1068	80	0.02	0.00336	0.40	0.92	0.90	1.32	0.295	0.062
Lake Madison	05-Jun-95	1110	LMT2	Surface	125.74	20.0	74.0	6.40	8.35	50	155	1244	1224	20	0.11	0.00898	0.50	1.71	1.60	2.21	0.157	0.066
Lake Madison	28-Jun-95	1050	LMT2	Surface	61.45	21.8	76.0	3.90	8.11	3100	165	1353	1281	72	0.19	0.01047	1.50	1.62	1.43	3.12	0.361	0.180
Lake Madison	07-Aug-95	950	LMT2	Surface	17.27	24.0	79.0	7.10	8.76	630	171	1261	1227	34	0.02	0.00467	0.20	1.58	1.56	1.78	0.358	0.168
Lake Madison	10-Oct-95	920	LMT2	Surface	84.34	10.8	54.0	8.80	8.75	30	153	1119	1075	44	0.02	0.00201	0.40	1.70	1.68	2.10	0.352	0.179
Lake Madison	12-Mar-96	900	LMT2	Surface		3.0	45.0	17.40	9.39	10	154	1047	1034	13	0.30	0.06202	0.40	2.17	1.87	2.57	0.482	0.315
				Mean	57.45	9.3	54.4	9.81	8.59	355	157	1156	1122	34	0.19	0.00949	0.88	1.89	1.71	2.77	0.33	0.147
				Maximum	165.30	24.0	79.0	17.40	9.39	3100	171	1353	1281	80	1.22	0.06202	3.40	2.75	2.28	5.78	0.48	0.315
				Minimum	5.92	1.0	36.0	3.90	7.91	10	139	826	817	4	0.02	0.00079	0.20	0.92	0.90	1.32	0.16	0.052
				StDev	53.59	8.1	16.2	3.40	0.48	929	10	150	138	25	0.34	0.01703	0.90	0.46	0.36	1.18	0.08	0.079
Lake Madison	14-Mar-95	1055	LMT3	Surface		7.0	64.0	8.00	7.76	10	109	994	977	17	0.02	0.00017	1.10	1.45	1.43	2.55	0.420	0.351
Lake Madison	20-Mar-95	1050	LMT3	Surface		3.2	36.0	10.70	8.03	10	225	1682	1679	3	0.02	0.00023	0.10	0.52	0.50	0.62	0.190	0.184
Lake Madison	27-Mar-95	1020	LMT3	Surface	1.49	3.0	37.0	10.80	7.84	20	152	1717	1715	2	0.02	0.00015	1.00	1.10	1.08	2.10	0.220	0.203
Lake Madison	03-Apr-95	945	LMT3	Surface	0.01	6.0	50.0	9.60	7.98	10	212	1744	1720	24	0.02	0.00026	0.10	0.72	0.70	0.82	0.100	0.069
Lake Madison	11-Apr-95	1020	LMT3	Surface		2.0	34.0	6.50	7.47		263	1788	1780	8	0.02	0.00006	0.10	0.87	0.85	0.97	0.089	0.085
Lake Madison	17-Apr-95	940	LMT3	Surface	2.40	4.0	47.0	11.20	7.99	10	136	1337	1334	3	0.02	0.00022	1.40	0.73	0.71	2.13	0.131	0.125
Lake Madison	24-Apr-95	1025	LMT3	Surface	0.71	8.5	51.0	13.40	8.38	10	179	1509	1501	8	0.02	0.00076	0.10	0.22	0.20	0.32	0.052	0.079
Lake Madison	05-Jun-95	1135	LMT3	Surface	0.44	24.0	86.0	8.60	8.04	36	264	1777	1771	6	0.02	0.00110	0.10	0.92	0.90	1.02	0.092	0.069
Lake Madison	28-Jun-95	835	LMT3	Surface	8.80	18.0	72.0	4.60	7.54	2000	111	1114	1098	16	0.02	0.00023	1.00	1.37	1.35	2.37	0.197	0.125
Lake Madison	07-Aug-95	840	LMT3	Surface	2.29	22.0	76.0	4.40	7.86	290	153	1163	1156	7	0.02	0.00064	0.10	0.85	0.83	0.95	0.157	0.139
Lake Madison	10-Oct-95	950	LMT3	Surface	2.62	8.8	57.0	8.30	7.81	30	218	2069	2067	2	0.02	0.00022	0.10	0.83	0.81	0.93	0.155	0.158
Lake Madison	12-Mar-96	930	LMT3	Surface		1.0	45.0	11.20	7.36	10	50	265	258	7	0.46	0.00095	0.80	1.89	1.43	2.69	0.439	0.358
				Mean	2.34	9.0	54.6	8.94	7.84	221	173	1430	1421	9	0.06	0.00042	0.50	0.96	0.90	1.46	0.19	0.162
				Maximum	8.80	24.0	86.0	13.40	8.38	2000	264	2069	2067	24	0.46	0.00110	1.40	1.89	1.43	2.69	0.44	0.358
				Minimum	0.01	1.0	34.0	4.40	7.36	10	50	265	258	2	0.02	0.00006	0.10	0.22	0.20	0.32	0.05	0.069
				StDev	2.78	8.0	16.8	2.76	0.28	596	66	489	491	7	0.13	0.00035	0.51	0.45	0.37	0.84	0.12	0.100

PROJECT	DATE	TIME	SITE	DEPTH	FLOW	WTEMP	ATEMP	DISOX	FPH	FECAL	TALKAL	TSOL	TDSOL	TSSOL	AMMON	UN-AMMON	NO3+	TKN-N	O-Nit	T-Nit	TPO4P	TDPO4P
					CFS	C	F	mg/L	su	/100 m	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Lake Madison	14-Mar-95	1030	LMT4	Surface		4.5	56.0	8.30	7.70	10	90	693	686	7	0.39	0.00233	1.30	2.48	2.09	3.78	0.528	0.384
Lake Madison	20-Mar-95	1115	LMT4	Surface	3.41	5.0	36.0	10.80	8.03	20	159	841	805	36	0.02	0.00026	0.30	1.57	1.55	1.87	0.436	0.305
Lake Madison	27-Mar-95	1040	LMT4	Surface	14.23	4.0	37.0	9.90	7.85	460	152	1465	1446	19	0.02	0.00016	2.80	1.62	1.60	4.42	0.358	0.279
Lake Madison	03-Apr-95	1000	LMT4	Surface	5.77	7.0	52.0	10.40	8.15	10	178	1084	1069	15	0.02	0.00041	0.10	1.48	1.46	1.58	0.246	0.154
Lake Madison	11-Apr-95	1030	LMT4	Surface	1.15	1.0	33.0	11.60	7.90		232	1431	1419	12	0.02	0.00014	0.90	1.04	1.02	1.94	0.128	0.089
Lake Madison	17-Apr-95	955	LMT4	Surface	27.33	4.5	47.0	9.90	7.91	260	142	1150	1133	17	0.02	0.00019	2.50	1.10	1.08	3.60	0.285	0.246
Lake Madison	24-Apr-95	1035	LMT4	Surface	26.74	9.0	52.0	8.70	7.92	10	143	1038	1019	19	0.02	0.00028	0.80	0.31	0.29	1.11	0.207	0.180
Lake Madison	05-Jun-95	1155	LMT4	Surface	12.24	21.0	74.0	8.20	8.15	180	227	1333	1327	6	0.02	0.00114	0.70	1.35	1.33	2.05	0.272	0.233
Lake Madison	28-Jun-95	905	LMT4	Surface	19.80	19.1	73.0	5.70	7.98	3900	140	1607	1531	76	0.04	0.00137	2.00	1.70	1.66	3.70	0.312	0.197
Lake Madison	07-Aug-95	1050	LMT4	Surface	23.60	23.5	82.0	5.10	8.01	740	153	1109	1085	24	0.02	0.00099	0.50	1.08	1.06	1.58	0.328	0.328
Lake Madison	10-Oct-95	1010	LMT4	Surface	47.04	9.2	61.0	8.50	8.20	150	180	1236	1226	10	0.02	0.00054	0.70	1.13	1.11	1.83	0.440	0.414
Lake Madison	12-Mar-96	1000	LMT4	Surface		1.0	51.0	11.50	7.61	80	77	379	366	13	0.72	0.00263	0.80	2.68	1.96	3.48	0.536	0.459
				Mean	18.13	9.1	54.5	9.05	7.95	529	156	1114	1093	21	0.11	0.00087	1.12	1.46	1.35	2.58	0.34	0.272
				Maximum	47.04	23.5	82.0	11.60	8.20	3900	232	1607	1531	76	0.72	0.00263	2.80	2.68	2.09	4.42	0.54	0.459
				Minimum	1.15	1.0	33.0	5.10	7.61	10	77	379	366	6	0.02	0.00014	0.10	0.31	0.29	1.11	0.13	0.089
				StDev	13.88	7.8	15.7	2.08	0.18	1141	46	348	341	19	0.22	0.00086	0.87	0.64	0.48	1.12	0.13	0.111
Lake Madison	14-Mar-95	1430	LMT5	Surface		10.5	65.0	9.00	7.83	10	130	800	790	10	0.58	0.00750	1.20	2.45	1.87	3.65	0.397	0.253
Lake Madison	20-Mar-95	1255	LMT5	Surface	9.38	5.0	33.0	11.30	8.18	10	149	908	901	7	0.10	0.00186	0.50	1.58	1.48	2.08	0.259	0.134
Lake Madison	27-Mar-95	1110	LMT5	Surface	48.64	4.5	34.0	10.40	7.99	660	148	1233	1174	59	0.10	0.00116	2.80	1.70	1.60	4.50	0.364	0.177
Lake Madison	03-Apr-95	1040	LMT5	Surface	20.01	6.0	56.0	12.20	8.61	10	169	1169	1144	25	0.02	0.00105	0.20	2.06	2.04	2.26	0.230	0.102
Lake Madison	11-Apr-95	1100	LMT5	Surface	13.65	1.0	22.0	11.80	8.40		163	1182	1147	35	0.03	0.00066	0.40	1.58	1.55	1.98	0.276	0.095
Lake Madison	17-Apr-95	1030	LMT5	Surface	103.67	5.0	46.0	10.80	8.64	20	150	1250	1190	60	0.02	0.00104	1.30	1.44	1.42	2.74	0.334	0.128
Lake Madison	24-Apr-95	1100	LMT5	Surface	201.41	8.5	52.0	10.90	8.95	10	144	1162	1090	72	0.02	0.00257	0.40	0.59	0.57	0.99	0.289	0.075
Lake Madison	05-Jun-95	1315	LMT5	Surface	151.34	21.0	83.0	7.60	8.34	270	164	1273	1243	30	0.08	0.00684	0.50	1.22	1.14	1.72	0.167	0.095
Lake Madison	28-Jun-95	1120	LMT5	Surface	112.07	21.0	77.0	6.20	8.18	2600	156	1379	1319	60	0.12	0.00729	1.50	1.67	1.55	3.17	0.321	0.151
Lake Madison	07-Aug-95	1050	LMT5	Surface	63.03	23.5	85.0	6.90	8.33	920	161	1186	1154	32	0.02	0.00197	0.70	0.99	0.97	1.69	0.402	0.215
Lake Madison	10-Oct-95	1040	LMT5	Surface	90.44	11.0	62.0	9.20	8.58	10	163	1176	1138	38	0.02	0.00142	0.40	1.59	1.57	1.99	0.370	0.224
Lake Madison	12-Mar-96	1030	LMT5	Surface		2.5	54.0	12.40	8.84	30	118	689	663	26	0.55	0.03621	0.60	2.41	1.86	3.01	0.506	0.369
				Mean	81.36	10.0	55.8	9.89	8.41	414	151	1117	1079	38	0.14	0.00580	0.88	1.61	1.47	2.48	0.33	0.168
				Maximum	201.41	23.5	85.0	12.40	8.95	2600	169	1379	1319	72	0.58	0.03621	2.80	2.45	2.04	4.50	0.51	0.369
				Minimum	9.38	1.0	22.0	6.20	7.83	10	118	689	663	7	0.02	0.00066	0.20	0.59	0.57	0.99	0.17	0.075
				StDev	63.04	7.8	20.0	2.10	0.33	790	15	206	194	21	0.20	0.00993	0.73	0.54	0.41	0.97	0.09	0.085
Lake Madison	15-Mar-95	1145	LMT6	Surface		8.5	67.0	10.40	8.06	10	157	902	858	44	0.53	0.00989	1.00	2.25	1.72	3.25	0.354	0.177
Lake Madison	20-Mar-95	1325	LMT6	Surface	7.81	2.0	35.0	12.40	8.39	10	164	961	956	5	0.07	0.00164	0.50	1.35	1.28	1.85	0.213	0.118
Lake Madison	27-Mar-95	1140	LMT6	Surface	38.14	4.5	36.0	11.20	8.06	190	171	1449	1346	103	0.06	0.00082	2.80	1.59	1.53	4.39	0.361	0.177
Lake Madison	03-Apr-95	1100	LMT6	Surface	20.31	7.0	62.0	12.80	8.59	10	177	1264	1158	106	0.02	0.00108	0.20	1.95	1.93	2.15	0.256	0.092
Lake Madison	11-Apr-95	1130	LMT6	Surface	25.12	1.0	34.0	11.50	8.37		167	1223	1155	68	0.04	0.00083	0.40	1.78	1.74	2.18	0.285	0.052
Lake Madison	17-Apr-95	1100	LMT6	Surface	85.20	5.0	46.0	11.20	8.56	50	155	1300	1208	92	0.02	0.00087	1.40	1.69	1.67	3.09	0.397	0.128
Lake Madison	24-Apr-95	1130	LMT6	Surface	188.48	8.7	54.0	10.90	8.84	10	146	1188	1100	88	0.02	0.00208	0.40	1.01	0.99	1.41	0.321	0.079
Lake Madison	05-Jun-95	1400	LMT6	Surface	127.83	22.0	73.0	7.90	8.31	230	169	1277	1241	36	0.07	0.00600	0.50	1.31	1.24	1.81	0.171	0.079
Lake Madison	28-Jun-95	1345	LMT6	Surface	93.80	23.0	88.0	6.60	8.29	4200	166	1416	1328	88	0.10	0.00878	1.50	1.48	1.38	2.98	0.338	0.148
Lake Madison	07-Aug-95	1130	LMT6	Surface	55.41	24.0	88.0	6.90	8.33	1700	163	1154	1118	36	0.02	0.00204	0.50	1.18	1.16	1.68	0.328	0.212
Lake Madison	10-Oct-95	1120	LMT6	Surface	96.40	11.1	66.0	9.10	8.43	220	163	1178	1136	42	0.02	0.00104	0.40	1.82	1.80	2.22	0.373	0.214
Lake Madison	13-Mar-96	1310	LMT6	Surface		5.0	63.0	11.80	8.61	20	131	830	748	82	0.43	0.02084	0.40	2.05	1.62	2.45	0.606	0.310
				Mean	73.85	10.2	59.3	10.23	8.40	605	161	1179	1113	66	0.12	0.00466	0.83	1.62	1.51	2.46	0.33	0.149
				Maximum	188.48	24.0	88.0	12.80	8.84	4200	177	1449	1346	106	0.53	0.02084	2.80	2.25	1.93	4.39	0.61	0.310
				Minimum	7.81	1.0	34.0	6.60	8.06	10	131	830	748	5	0.02	0.00082	0,20	1.01	0.99	1.41	0.17	0.052
				StDev	56.08	8.2	18.9	2.10	0.23	1290	12	193	179	32	0.17	0.00603	0.75	0.37	0.29	0.84	0.11	0.074

PROJECT	DATE	TIME	SITE	DEPTH	FLOW	WTEMP	ATEMP	DISOX	FPH	FECAL	TALKAL	TSOL	TDSOL	TSSOL	AMMON	UN-AMMON	NO3+	TKN-N	O-Nit	T-Nit	TPO4P	TDPO4P
					CFS	C	F	mg/L	su	/100 m	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Lake Madison	14-Mar-95	910	LMT7	Surface	0.92	1.0	51.0	10.00	7.82	30	187	1433	1430	3	0.15	0.00089	2.90	1.23	1.08	4.13	0.220	0.164
Lake Madison	21-Mar-95	1130	LMT7	Surface	0.04	4.0	51.0	10.20	7.96	10	310	1800	1795	5	0.02	0.00021	2.20	0.63	0.61	2.83	0.052	0.052
Lake Madison	28-Mar-95	1330	LMT7	Surface	1.74	4.0	42.0	12.30	8.04	20	188	2459	2449	10	0.02	0.00025	3.60	1.19	1.17	4.79	0.295	0.259
Lake Madison	04-Apr-95	1145	LMT7	Surface	0.30	1.5	36.0	13.50	8.01	10	282	2242	2234	8	0.02	0.00019	2.30	0.82	0.80	3.12	0.069	0.056
Lake Madison	11-Apr-95	1345	LMT7	Surface	0.14	1.0	34.0	12.10	7.88		290	2038	2033	5	0.02	0.00014	3.30	0.66	0.64	3.96	0.052	0.052
Lake Madison	18-Apr-95	1125	LMT7	Surface	39.75	1.5	34.0	11.80	7.99	200	126	2023	1087	936	0.12	0.00109	2.70	2.05	1.93	4.75	1.260	0.174
Lake Madison	25-Apr-95	1125	LMT7	Surface	3.07	10.0	70.0	13.20	8.25	10	238	1537	1529	8	0.02	0.00064	0.70	2.08	2.06	2.78	0.121	0.105
Lake Madison	06-Jun-95	1150	LMT7	Surface	1.47	22.0	84.0	9.20	8.15	80	299	1701	1691	10	0.02	0.00122	1.00	1.22	1.20	2.22	0.092	0.072
Lake Madison	08-Aug-95	845	LMT7	Surface	0.45	23.5	80.0	4.30	7.92	590	315	2367	2331	36	0.04	0.00163	2.10	1.32	1.28	3.42	0.161	0.102
Lake Madison	11-Oct-95	840	LMT7	Surface	0.51	10.0	61.0	8.20	8.03	1000	308	2569	2556	13	0.02	0.00039	2.00	1.15	1.13	3.15	0.232	0.168
Lake Madison	12-Mar-96	1130	LMT7	Surface		1.0	55.0	11.90	8.10	50	105	612	590	22	0.33	0.00369	1.00	1.32	0.99	2.32	0.365	0.275
				Mean	4.84	7.2	54.4	10.61	8.01	200	241	1889	1793	96	0.07	0.00094	2.16	1.24	1.17	3.41	0.27	0.134
				Maximum	39.75	23.5	84.0	13.50	8.25	1000	315	2569	2556	936	0.33	0.00369	3.60	2.08	2.06	4.79	1.26	0.275
				Minimum	0.04	1.0	34.0	4.30	7.82	10	105	612	590	3	0.02	0.00014	0.70	0.63	0.61	2.22	0.05	0.052
				StDev	12.30	8.4	17.8	2.67	0.12	333	77	564	609	279	0.10	0.00104	0.95	0.48	0.46	0.89	0.35	0.080
Brant Lake	15-Mar-95	1115	BLT8	Surface	22.32	5.5	61.0	3.60	7.77	10	211	999	992	7	0.80	0.00609	0.30	2.29	1.49	2.59	0.266	0.236
Brant Lake	21-Mar-95	905	BLT8	Surface	23.58	4.5	42.0	6.80	7.86	30	190	860	856	4	0.64	0.00552	0.20	1.81	1.17	2.01	0.177	0.171
Brant Lake	28-Mar-95	920	BLT8	Surface	52.62	5.0	46.0	10.20	8.30	30	194	928	920	8	0.38	0.00925	0.30	2.15	1.77	2.45	0.216	0.157
Brant Lake	04-Apr-95	1110	BLT8	Surface	38.06	5.0	32.0	14.30	8.87	10	221	943	930	13	0.02	0.00170	0.30	1.71	1.69	2.01	0.194	0.059
Brant Lake	11-Apr-95	1420	BLT8	Surface	42.24	2.0	34.0	12.20	9.07		169	891	862	29	0.02	0.00206	0.10	1.80	1.78	1.90	0.194	0.046
Brant Lake	18-Apr-95	915	BLT8	Surface	98.77	5.0	35.0	10.80	8.64	10	151	882	862	20	0.02	0.00104	0.10	1.59	1.57	1.69	0.171	0.052
Brant Lake	25-Apr-95	905	BLT8	Surface	192.11	8.0	47.0	10.80	8.66	10	153	879	863	16	0.02	0.00136	0.10	1.27	1.25	1.37	0.115	0.023
Brant Lake	06-Jun-95	850	BLT8	Surface	167.53	19.0	72.0	7.20	8.21	20	159	1054	1049	5	0.48	0.02711	0.20	1.51	1.03	1.71	0.112	0.085
Brant Lake	08-Aug-95	910	BLT8	Surface	55.44	25.0	82.0	6.60	8.61	50	158	1206	1198	8	0.31	0.05834	0.10	1.20	0.89	1.30	0.339	0.303
Brant Lake	11-Oct-95	910	BLT8	Surface	102.47	12.0	60.0	9.90	9.09	10	169	1089	1085	4	0.02	0.00423	0.10	1.21	1.19	1.31	0.232	0.193
Brant Lake	13-Mar-96	830	BLT8	Surface		4.0	53.0	13.60	8.37	10	215	1291	1289	2	0.17	0.00447	0.40	1.33	1.16	1.73	0.218	0.159
				Mean	79.51	8.6	51.3	9.64	8.50	19	181	1002	991	11	0.26	0.01101	0.20	1.62	1.36	1.82	0.20	0.135
				Maximum	192.11	25.0	82.0	14.30	9.09	50	221	1291	1289	29	0.80	0.05834	0.40	2.29	1.78	2.59	0.34	0.303
				Minimum	22.32	2.0	32.0	3.60	7.77	10	151	860	856	2	0.02	0.00104	0.10	1.20	0.89	1.30	0.11	0.023
				StDev	59.75	7.2	16.2	3.27	0.44	14	26	144	148	8	0.28	0.01734	0.11	0.37	0.31	0.43	0.06	0.089
Brant Lake	15-Mar-95	925	BLT9	Surface	19.67	2.0	52.0	12.80	8.12	10	215	844	826	18	0.33	0.00420	0.70	2.24	1.91	2.94	0.239	0.092
Brant Lake	21-Mar-95	935	BLT9	Surface	11.15	2.8	39.0	11.20	8.27	10	197	857	839	18	0.37	0.00706	0.50	1.76	1.39	2.26	0.197	0.088
Brant Lake	28-Mar-95	1005	BLT9	Surface	53.09	4.0	39.0	11.30	8.46	100	192	919	899	20	0.19	0.00611	0.60	2.24	2.05	2.84	0.208	0.085
Brant Lake	04-Apr-95	1000	BLT9	Surface	23.73	2.0	24.0	12.50	9.01	10	243	966	940	26	0.02	0.00182	0.20	1.83	1.81	2.03	0.223	0.046
Brant Lake	12-Apr-95	1140	BLT9	Surface	65.02	1.0	34.0	13.40	9.04	10	156	888	842	46	0.02	0.00180	0.10	1.88	1.86	1.98	0.171	0.052
Brant Lake	18-Apr-95	945	BLT9	Surface	91.88	5.0	34.0	10.40	8.51	60	156	971	873	98	0.02	0.00078	0.10	1.73	1.71	1.83	0.328	0.046
Brant Lake	25-Apr-95	935	BLT9	Surface	197.43	8.8	50.0	10.70	8.68	10	160	903	869	34	0.02	0.00150	0.10	1.03	1.01	1.13	0.180	0.043
Brant Lake	06-Jun-95	930	BLT9	Surface	158.35	21.0	76.0	6.00	8.08	20	158	1093	1053	40	0.46	0.02247	0.30	1.54	1.08	1.84	0.187	0.085
Brant Lake	08-Aug-95	1015	BLT9	Surface	61.66	26.3	88.0	7.70	9.22	20	147	1208	1144	64	0.02	0.01017	0.10	1.84	1.82	1.94	0.402	0.060
Brant Lake	11-Oct-95	1000	BLT9	Surface	75.14	12.0	60.0	7.40	8.83	10	185	1093	1077	16	0.23	0.02951	0.20	1.66	1.43	1.86	0.271	0.214
Brant Lake	13-Mar-96	910	BLT9	Surface		3.0	46.0	13.80	8.45	970	206	1263	1235	28	0.32	0.00930	0.30	2.66	2.34	2.96	0.268	0.147
				Mean	75.71	8.0	49.3	10.65	8.61	112	183	1000	963	37	0.18	0.00861	0.29	1.86	1.67	2.15	0.24	0.087
				Maximum	197.43	26.3	88.0	13.80	9.22	970	243	1263	1235	98	0.46	0.02951	0.70	2.66	2.34	2.96	0.40	0.214
				Minimum	11.15	1.0	24.0	6.00	8.08	10	147	844	826	16	0.02	0.00078	0.10	1.03	1.01	1.13	0.17	0.043
				StDev	60.32	8.5	19.1	2.59	0.38	286	31	143	141	25	0.17	0.00930	0.22	0.42	0.41	0.56	0.07	0.052

PROJECT	DATE	TIME	SITE	DEPTH	FLOW	WTEMP	ATEMP	DISOX	FPH	FECAL	TALKAL	TSOL	TDSOL	TSSOL	AMMON	UN-AMMON	NO3+	TKN-N	O-Nit	T-Nit	TPO4P	TDPO4P
					CFS	C	F	mg/L	su	/100 m	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Brant Lake	15-Mar-95	945	BLT10	Surface	0.12	2.5	54.0	10.40	7.91	100	140	691	680	11	0.09	0.00074	1.40	1.42	1.33	2.82	1.400	0.367
Brant Lake	21-Mar-95	1100	BLT10	Surface		4.5	46.0	11.90	8.23	10	255	1358	1351	7	0.04	0.00080	1.10	0.92	0.88	2.02	0.282	0.253
Brant Lake	28-Mar-95	1150	BLT10	Surface	2.16	3.0	39.0	12.10	8.14	20	227	1489	1469	20	0.02	0.00029	1.10	0.10	0.08	1.20	0.279	0.230
Brant Lake	04-Apr-95	1045	BLT10	Surface	0.55	1.0	24.0	13.20	8.32	50	253	1348	1339	9	0.02	0.00037	0.30	0.84	0.82	1.14	0.266	0.230
Brant Lake	12-Apr-95	1300	BLT10	Sirface	0.69	1.0	35.0	11.30	7.95	10	301	1589	1565	24	0.02	0.00016	0.80	0.70	0.68	1.50	0.190	0.134
Brant Lake	18-Apr-95	1100	BLT10	Surface	24.15	2.0	33.0	11.80	8.06	100	153	1098	802	296	0.02	0.00022	1.20	0.87	0.85	2.07	0.566	0.203
Brant Lake	25-Apr-95	1055	BLT10	Surface	3.29	7.5	57.0	10.30	8.13	10	248	1195	1186	9	0.02	0.00040	0.50	0.51	0.49	1.01	0.220	0.190
Brant Lake	06-Jun-95	1115	BLT10	Surface	2.18	21.0	84.0	8.20	8.24	320	315	1450	1425	25	0.02	0.00138	0.30	1.09	1.07	1.39	0.312	0.259
Brant Lake	08-Aug-95	1145	BLT10	Surface	0.96	24.5	91.0	6.70	8.24	150	325	1497	1469	28	0.02	0.00174	0.60	1.04	1.02	1.64	0.478	0.405
Brant Lake	11-Oct-95	1120	BLT10	Surface	0.44	11.5	72.0	9.50	8.39	190	340	1654	1646	8	0.02	0.00098	1.10	0.89	0.87	1.99	0.236	0.218
Brant Lake	13-Mar-96	1100	BLT10	Surface		1.0	51.0	11.50	7.96	10	125	422	354	68	0.86	0.00700	0.50	3.39	2.53	3.89	0.626	0.412
				Mean	3.84	7.2	53.3	10.63	8.14	88	244	1254	1208	46	0.10	0.00128	0.81	1.07	0.97	1.88	0.44	0.264
				Maximum	24.15	24.5	91.0	13.20	8.39	320	340	1654	1646	296	0.86	0.00700	1.40	3.39	2.53	3.89	1.40	0.412
				Minimum	0.12	1.0	24.0	6.70	7.91	10	125	422	354	7	0.02	0.00016	0.30	0.10	0.08	1.01	0.19	0.134
				StDev	7.69	8.4	21.4	1.89	0.16	99	76	385	414	85	0.25	0.00196	0.39	0.84	0.61	0.85	0.35	0.091
Brant Lake	15-Mar-95	1325	BLT11	Surface	8.80	3.5	69.0	9.70	8.56	10	136	606	597	9	0.08	0.00309	0.20	1.53	1.45	1.73	0.151	0.066
Brant Lake	21-Mar-95	1005	BLT11	Surface	16.96	5.8	41.0	14.24	8.57	10	177	775	768	7	0.06	0.00283	0.30	1.09	1.03	1.39	0.125	0.079
Brant Lake	28-Mar-95	1035	BLT11	Surface	58.50	5.0	41.0	11.60	8.46	10	196	863	849	14	0.16	0.00557	0.40	0.77	0.61	1.17	0.164	0.082
Brant Lake	04-Apr-95	905	BLT11	Surface	50.71	3.0	21.0	11.70	8.63	10	199	901	888	13	0.03	0.00130	0.40	1.31	1.28	1.71	0.148	0.066
Brant Lake	12-Apr-95	1200	BLT11	Surface	74.73	2.0	34.0	13.20	9.01	10	180	866	840	26	0.02	0.00182	0.10	1.74	1.72	1.84	0.138	0.023
Brant Lake	18-Apr-95	1015	BLT11	Surface	142.95	4.0	33.0	11.80	8.72	10	161	916	828	88	0.02	0.00114	0.10	1.35	1.33	1.45	0.236	0.033
Brant Lake	25-Apr-95	1000	BLT11	Surface	236.14	8.8	55.0	10.90	8.66	10	162	892	867	25	0.02	0.00144	0.10	0.69	0.67	0.79	0.151	0.030
Brant Lake	06-Jun-95	1005	BLT11	Surface	213.45	20.5	84.0	7.60	8.29	20	161	1005	989	16	0.32	0.02379	0.30	1.44	1.12	1.74	0.105	0.062
Brant Lake	08-Aug-95	1100	BLT11	Surface	106.75	26.5	83.0	7.40	8.98	10	163	1153	1088	65	0.02	0.00751	0.10	2.06	2.04	2.16	0.350	0.117
Brant Lake	11-Oct-95	1030	BLT11	Surface	94.16	12.0	65.0	13.20	9.35	10	155	1007	979	28	0.02	0.00655	0.10	1.35	1.33	1.45	0.144	0.028
Brant Lake	13-Mar-96	1000	BLT11	Surface		6.0	51.0	8.70	8.25	10	193	1157	1133	24	0.25	0.00589	0.20	1.97	1.72	2.17	0.201	0.171
				Mean	100.32	8.8	52.5	10.91	8.68	11	171	922	893	29	0.09	0.00554	0.21	1.39	1.30	1.60	0.17	0.069
				Maximum	236.14	26.5	84.0	14.24	9.35	20	199	1157	1133	88	0.32	0.02379	0.40	2.06	2.04	2.17	0.35	0.171
				Minimum	8.80	2.0	21.0	7.40	8.25	10	136	606	597	7	0.02	0.00114	0.10	0.69	0.61	0.79	0.11	0.023
				StDev	76.98	7.9	20.8	2.30	0.33	3	20	159	150	25	0.11	0.00648	0.12	0.44	0.44	0.41	0.07	0.044

APPENDIX F

1994-1995 314 Lake Madison/Brant Lake Quality Assurance/Quality Control Data

PROJECT	TIME	SAMP	DEPTH	DATE Units	SITE	WATER TEMP C	AIR TEMP F	DISSOLVED OXYGEN mg/L	FIELD pH su	FECAL COLIFORM /100 mL	TOTAL ALKALINITY mg/L	TOTAL SOLIDS mg/L	TOTAL DISSOLVE SOLIDS mg/L	TOTAL SUSPENDED SOLIDS mg/L	AMMON mg/L	UNIONIZED AMMON mg/L	NO3+2 mg/L	TKN-N mg/L	TPO4P mg/L	TDPO4P mg/L
BRANT LAKE	1220	Grab	Surface	25-Oct-94	LM5	9.2	43.0	9.20	7.02	10	202	863	847	16	0.45	0.00082	0.30	1.63	0.213	0.180
Duplicate	1230	Grab	Surface	25-Oct-94	LM5	9.2	43.0	9.20	7.02	10	206	875	860	15	0.45	0.00082	0.20	1.54	0.243	0.623
PERCENT DIFFERENCE						0.0	0.0	0.00	0.00	0	2	1	2	6	0.00	0.00000	33.33	5.52	12.346	71.108
LAKE MADSION	1145	Grab	Surface	21-Feb-95	1A	1.0	41.0	3.20	7.60	10	314	1881	1878	3	0.48	0.00171	3.20	1.28	0.207	0.177
Duplicate	1145	Grab	Surface	21-Feb-95	1AD	1.0	41.0	3.20	7.60	10	305	1862	1856	6	0.44	0.00157	3.30	1.09	0.190	0.177
PERCENT DIFFERENCE						0.0	0.0	0.00	0.00	0	3	1	1	50	8.33	8.33333	3.03	14.84	8.213	0.000
Lake Madison	1430	Grab	Surface	14-Mar-95	LMT5	10.5	65.0	9.00	7.83	10	130	800	790	10	0.58	0.00750	1.20	2.45	0.397	0.253
Duplicate	1430	Grab	Surface	14-Mar-95	LMT5	10.5	65.0	9.00	7.83	10	133	785	777	8	0.58	0.00750	1.20	2.24	0.377	0.256
PERCENT DIFFERENCE						0.0	0.0	0.00	0.00	0	2	2	2	20	0.00	0.00000	0.00	8.57	5.038	1.172
Brant Lake	1035	Grab	Surface	28-Mar-95	BLT11	5.0	41.0	11.60	8.46	10	196	863	849	14	0.16	0.00557	0.40	0.77	0.164	0.082
Duplicate		Grab	Surface	28-Mar-95	BLT11D					50	198	865	855	10	0.16	0.00000	0.40	1.51	0.177	0.085
PERCENT DIFFERENCE						0.0	0.0	0.00	0.00	80	1	0	1	29	0.00	100.00000	0.00	49.01	7.345	3.529
Brant Lake	1015	Grab	Surface	18-Apr-95	BLT11	4.0	33.0	11.80	8.72	10	161	916	828	88	0.02	0.00114	0.10	1.35	0.236	0.033
Duplicate	1030	Grab	Surface	18-Apr-95	BLT11D	4.0	33.0	11.80	8.72	10	162	934	850	84	0.02	0.00114	0.10	1.45	0.210	0.026
PERCENT DIFFERENCE						0.0	0.0	0.00	0.00	0	1	2	3	5	0.00	0.00000	0.00	6.90	11.017	21.212
Brant Lake	1055	Grab	Surface	25-Apr-95	BLT10	7.5	57.0	10.30	8.13	10	248	1195	1186	9	0.02	0.00040	0.50	0.51	0.220	0.190
Duplicate		Grab	Surface	25-Apr-95	BLT10D					10	247	1217	1205	12	0.02	0.00000	0.40	0.41	0.220	0.187
PERCENT DIFFERENCE						0.0	0.0	0.00	0.00	0	0	2	2	25	0.00	100.00000	20.00	19.61	0.000	1.579
LAKE MADSION	940	Grab	Surface	23-May-95	1A	14.8	49.0	7.60	8.61	30	168	1246	1216	30	0.02	0.00198	0.10	1.60	0.174	0.013
Duplicate	940	Grab	Surface	23-May-95	1AD	14.8	49.0	7.60	8.61	20	168	1242	1213	29	0.02	0.00000	0.10	1.47	0.171	0.010
PERCENT DIFFERENCE						0.0	0.0	0.00	0.00	33	0	0	0	3	0.00	100.00000	0.00	8.13	1.724	23.077
Round Lake	1020	Grab	Surface	13-Jun-95	RL6	19.0	76.0	7.20	8.14	10	153	1163	1135	28	0.55	0.02667	0.30	1.87	0.157	0.089
Duplicate	1020	Grab	Surface	13-Jun-95	RL6	19.0	76.0	7.20	8.14	10	141	1196	1172	24	0.55	0.00000	0.30	1.84	0.161	0.092
PERCENT DIFFERENCE						0.0	0.0	0.00	0.00	0	8	3	3	14	0.00	100.00000	0.00	1.60	2.484	3.261
LAKE MADSION	845	Grab	Surface	11-Jul-95	1A	26.0	80.0	11.60	9.06	220	158	1305	1267	38	0.02	0.00824	0.10	2.17	0.190	0.023
Duplicate		Grab	Surface	11-Jul-95	1AD	26.0	80.0	11.60	9.06	110	158	1324	1284	40	0.02	0.00824	0.10	2.06	0.187	0.023
PERCENT DIFFERENCE						0.0	0.0	0.00	0.00	50	0	1	1	5	0.00	0.00000	0.00	5.07	1.579	0.000
Brant Lake	910	Grab	Surface	08-Aug-95	BLT8	25.0	82.0	6.60	8.61	50	158	1206	1198	8	0.31	0.05834	0.10	1.20	0.339	0.303
Duplicate		Grab	Surface	08-Aug-95	BLT8					30	158	1201	1195	6	0.29	0.00000	0.10	1.16	0.310	0.299
PERCENT DIFFERENCE						0.0	0.0	0.00	0.00	40	0	0	0	25	6.45	100.00000	0.00	3.33	8.555	1.320
LAKE MADSION	900	Grab	Surface	18-Sep-95	1A	17.0	62.0	8.90	9.07	30	154	1148	1080	68	0.02	0.00544	0.10	3.19	0.496	0.011
Duplicate	900	Grab	Surface	18-Sep-95	1AD	17.0	62.0	8.90	9.07	70	153	1156	1092	64	0.02	0.00544	0.10	3.70	0.479	0.011
PERCENT DIFFERENCE						0.0	0.0	0.00	0.00	57	1	1	1	6	0.00	0.00000	0.00	13.78	3.427	0.000
LAKE MADSION	1350	Grab	Surface	16-Oct-95	1A	11.0	65.0	13.20	9.08	20	183	1174	1142	32	0.02	0.00390	0.10	2.57	0.277	0.095
Duplicate	1350	Grab	Surface	16-Oct-95	1AD	11.0	65.0	13.20	9.08	20	181	1171	1137	34	0.02	0.00000	0.10	2.59	0.253	0.084
PERCENT DIFFERENCE						0.0	0.0	0.00	0.00	0	1	0	0	6	0.00	100.00000	0.00	0.77	8.664	11.579
Blank	1300			25-Oct-94						10	5	3	2	1	0.02	0.00000	0.10	0.10	0.008	0.008
Blank	855	Grab	Bottom	25-Oct-94	LM3	8.7	32.0	8.80	7.25	10	5	3	2	1	0.02	0.00006	0.10	0.10	0.008	0.008
Blank	1300			04-Apr-95					7.15	10	4	22	21	1	0.02	0.00002	0.10	0.10	0.008	0.008
Blank				19-Apr-95				11.50	8.63	10	4	7	6	1	0.02	0.00068	0.10	0.10	0.000	0.000
Blank				26-Jun-95	1AB					10	6	22	20	2	0.02	0.00000	0.10	0.10	0.008	0.008
Blank				21-Aug-95	1AB					10	7	22	21	1	0.02	0.00000	0.10	0.10	0.008	0.008
Blank				11-Oct-95	BLT11B					10	4	27	26	1	0.02	0.00000	0.10	0.10	0.008	0.008
Blank										10	4	22	21	1	0.02	0.00000	0.10	0.10	0.008	0.008

APPENDIX G

1994-1995 314 Lake Madison/Brant Lake Groundwater Data

PROJECT	DATE	TIME	SITE	SAMP	DEPTH	WTEMP C	ATEMP F	DISOX mg/L	FPH su	FECAL /100 mL	TALKAL mg/L	TSOL mg/L	TDSOL mg/L	TSSOL mg/L	AMMON mg/L	UN-AMMON mg/L	NO3+2 mg/L	TKN-N mg/L	TPO4P mg/L	T.DISS. PO4P mg/L
Madison City Wells	19-Oct-94	950	A	Grab	26.5	11			7.46	10	230	326	324	2	ND	0.00000	ND	0.1		0.02
Madison City Wells	19-Oct-94	1025	C	Grab						10	225	980	977	3		0.00000		0.81		0.183
Madison City Wells	19-Oct-94	1025	D	Grab						10	285	1685	1682	3		0.00000		0.71		0.02
Madison City Wells	19-Oct-94	950	E	Grab						10	330	2068	2064	4		0.00000		0.92		0.017
Madison City Wells	19-Oct-94	950	F	Grab						10	325	1246	1244	2		0.00000		0.1		0.033
Lake Madison Sanitary D	02-Nov-94	1100	5	Grab	14				7.28	10	253	2046	1986	60	0.02	0.00003	12.2	0.54	0.1	0.02
Lake Madison Sanitary D	02-Nov-94	1030	6	Grab	15				7.36	10	302	1850	1438	412	0.02	0.00004	3	0.89	0.416	0.616
Madison City Wells	02-May-95	1040	A	Grab	25.1	11		3.5	7.57	10	207	405	404	1	0.15	0.00111	3.1	0.1		0.008
Madison City Wells	02-May-95	940	C	Grab	5.15	5		3.1	7.43	10	209	1179	1176	3	0.045	0.00015	0.46	0.3		0.171
Madison City Wells	02-May-95	1000	D	Grab		10.5		3.2	7.19	10	259	2252	2251	1	0.045	0.00013	7.2	0.1		0.036
Madison City Wells	02-May-95	1010	E	Grab		8		10.2	7.29	10	246	2392	2390	2	0.045	0.00014	4.9	0.1		0.008
Madison City Wells	02-May-95	1020	F	Grab		10		8.2	7.37	10	194	1247	1245	2	0.045	0.00020	0.25	0.1		0.016
Lake Madison Sanitary D	21-Jun-95	1548	5	Grab						10			0		0.02	0.00000	3.1			
Lake Madison Sanitary D	21-Jun-95	1605	6	Grab						10		1360	1360		0.02	0.00000	5.5			
Madison City Wells	11-Jul-95	115	B			12	91		7.28				0			0.00000			0.059	
Inlake Madison	11-Jul-95	215	BS-E						7.41				0			0.00000			0.02	
Inlake Madison	11-Jul-95	145	BS-W						7.41				0			0.00000			0.01	
Madison City Wells	21-Aug-95	215	B						7.41				0			0.00000			0.062	
Inlake Madison	21-Aug-95	115	BS-E						7.45				0			0.00000			0.029	
Inlake Madison	21-Aug-95	140	BS-W						7.43				0			0.00000			0.008	
Madison City Wells	18-Sep-95	130	B			9.9	63	4.2	7.6				0			0.00000			0.07	
Inlake Madison	18-Sep-95	210	BS-E			12.5	62	6	7.48				0			0.00000			0.025	
Inlake Madison	18-Sep-95	200	BS-W			12.5	62	0.9	7.43				0			0.00000			0.008	
Madison City Wells	16-Oct-95	300	B			9.8	65	9.6	7.6				0		0.02	0.00014	0.8	0.42	0.046	
Inlake Madison	16-Oct-95	340	BS-E			13	65	6.3					0		0.02	0.00000	2.5	0.26	0.008	
Inlake Madison	16-Oct-95	320	BS-W			12	65	3.1	7.3				0		0.02	0.00009	7.5	0.41	0.021	

APPENDIX H

1994-1997 314 Lake Madison/Brant Lake Urban Samples
Collected from the City of Madison Storm Sewers

DATE	TIME	SITE	SAMP	DEPTH	WTEMP	ATEMP	DISOX	FPH	FECAL	TSSOL	AMM	Un-Amm	TPO4P	TOTAL DISS. PO4	Cadmium	Hexavalent Chromium	Total Recoverable Chromium	Lead	Mercury	Hardness	OrthoPO4	Zinc	TALKAL	TSOL	TDSOL	NO3+2	TKN-N
					C	F	mg/L	su	/100 mL	mg/L	mg/L	mg/L	mg/L	mg/L	microg/l	microg/l	microg/l	microg/l	microg/l	mg/l	mg/L	microg/	mg/L	mg/L	mg/L	mg/L	mg/L
06/19/1996	1610	SE 3rd	Grab	Surface				8.50	6000	884	0.46		1.090	0.214	1.40		14.80	58.40	0.20	260	0.115						
06/19/1996	1600	Union	Grab	Surface				8.13	8300	972	1.03		2.120	0.700	1.60		16.20	79.80	0.20	330	0.586						
08/07/1995	1515	PAM	Grab	Surface																700					0		
03/27/1995	1400	PAM	Grab	Surface	4.0	36.0	10.90	8.13	60	38	0.11	0.00168	0.338	0.167	1.10		1.60	3.30	0.20				166	1248	1210	3.00	2.09
04/13/1995	1325	PAM	Grab	Surface	6.0	56.0	12.30	8.81	90	56	0.02	0.00161	0.354	0.069	0.50		1.60	9.00	0.20				145	1136	1080	0.40	1.74
04/17/1995	1300	PAM	Grab	Surface	5.5	47.0	11.60	8.94	20	62	0.02	0.00204	0.344	0.118	0.50		1.60	2.60	0.20						-62		
				Avg	5.2	46.3	11.60	8.63	57	52	0.05	0.00178	0.345	0.118									156	1192	743	1.70	1.92
03/27/1995	1000	LMT2	Grab	Surface	4.0	37.0	9.80	7.97	30	13	0.10	0.00106	0.328	0.197									171	1270	1257	3.40	2.38
04/11/1995	1000	LMT2	Grab	Surface	1.0	36.0	11.20	8.66	NA	34	0.02	0.00079	0.298	0.052									158	1192	1158	0.40	2.08
04/17/1995	925	LMT2	Grab	Surface	5.0	43.0	10.30	8.99	10	58	0.02	0.00218	0.318	0.082									155	1257	1199	0.90	1.89
				Avg	3.3	38.7	10.43	8.54	20	35	0.05	0.00134	0.315	0.110									161	1240	1205	1.57	2.12
08/07/1995	1520	WTP	Grab	Surface																620					0		
03/27/1995	1040	LMT4	Grab	Surface	4.0	37.0	9.90	7.85	460	19	0.02	0.00016	0.358	0.279									152	1465	1446	2.80	1.62
04/11/1995	1030	LMT4	Grab	Surface	1.0	33.0	11.60	7.90	NA	12	0.02	0.00014	0.128	0.089									232	1431	1419	0.90	1.04
04/17/1995	955	LMT4	Grab	Surface	4.5	47.0	9.90	7.91	260	17	0.02	0.00019	0.285	0.246									142	1150	1133	2.50	1.10
				Avg	3.2	39.0	10.47	7.89	360	16	0.02	0.00017	0.257	0.205									175	1349	1333	2.07	1.25
03/27/1995	1345	WTP	Grab	Surface	4.0	36.0	11.30	8.02	330	28	0.02	0.00024	0.341	0.246	0.60		1.70	2.70	0.62				142	1373	1345	2.30	1.49
04/13/1995	1350	WTP	Grab	Surface	5.5	56.0	13.70	8.41	100	82	0.07	0.00227	0.243	0.102	0.50		2.20	5.10	0.20				170	1015	933	0.50	0.98
04/17/1995	1140	WTP	Grab	Surface	5.0		11.00	8.07	180	14	0.02	0.00029	0.262	0.216	2.40		1.60	1.70	0.02						-14		
				Avg	4.8	46.0	12.00	8.17	203	41	0.04	0.00093	0.282	0.188									156	1194	755	1.40	1.24
03/27/1995	1110	LMT5	Grab	Surface	4.5	34.0	10.40	7.99	660	59	0.10	0.00116	0.364	0.177									148	1233	1174	2.80	1.70
04/11/1995	1100	LMT5	Grab	Surface	1.0	22.0	11.80	8.40	NA	35	0.03	0.00066	0.276	0.095									163	1182	1147	0.40	1.58
04/17/1995	1030	LMT5	Grab	Surface	5.0	46.0	10.80	8.64	20	60	0.02	0.00104	0.334	0.128									150	1250	1190	1.30	1.44
				Avg	3.5	34.0	11.00	8.34	340	51	0.05	0.00095	0.325	0.133									154	1222	1170	1.50	1.57

1994-1997 314 Lake Madison/Brant Lake Urban Samples
Collected from the City of Madison Storm Sewers

DATE	TIME	SITE	SAMP	DEPTH	WTEMP C	ATEMP F	DISOX mg/L	FPH su	FECAL /100 mL	TSSOL mg/L	AMM mg/L	Un-Amm mg/L	TPO4P mg/L	TOTAL DISS. PO4 mg/L	Cadmium microg/l	Hexavalent Chromium microg/l	Total Recoverable Chromium microg/l	Lead microg/l	Mercury microg/l	Hardness mg/l	OrthoPO4 mg/L	Zinc microg	TALKAL mg/L	TSOL mg/L	TDSOL mg/L	NO3+2 mg/L	TKN-N mg/L
05/05/1997	1550	72"	Compos	Surface	22.0		7.80			70	0.14		0.338		0.50	1.80		22.80	0.20	95							
05/07/1997	1030	72"	Compos	Surface	13.0	22.0		6.66	180	234	0.49	0.00053	0.413	0.101	0.60	1.30		34.50	0.20	90							
05/28/1997	1445	72"	Compos	Surface	16.0	50.0	11.80	8.23	32000	352	0.26	0.01242	0.654	0.101	0.80	1.00		58.40	0.20	90							
06/12/1997	1030	72"	Compos	Surface	20.0	70.0		7.04		260	0.41	0.00178	1.040	0.230	0.90	1.00		55.00	0.20	95							
06/19/1997	1115	72"	Compos	Surface	20.0	80.0	1.20	7.01		968	1.17	0.00474	2.050	0.415	2.50	1.00			0.20	125							
06/20/1997	915	72"	Compos	Surface	22.0	70.0	6.20	7.52		462	0.41	0.00614	0.915	0.193	1.00				0.20	80							
06/30/1997	1430	72"	Compos	Surface	24.0	85.0	5.80	7.70	26000	1512	0.59	0.01527	2.070	0.170	3.00	1.00			0.40	95							
07/17/1997	930	72"	Compos	Surface	25.0	75.0	5.60	7.58	120000	720	0.60	0.01271	1.210	0.154	1.50	1.00			0.20	100							
07/31/1997	1600	72"	Compos	Surface	21.0	65.0	7.80	8.12	10	532	0.19	0.01013	0.899		1.00	1.00			0.20	110							
08/25/1997	1345	72"	Compos	Surface	23.0	85.0	6.00	7.81	17000	268	0.17	0.00525	0.420	0.082	0.60	1.00		62.40	0.20	105							
					10.0																						
			LMC-3	Mean	20.6	66.9	6.53	7.52	32532	538	0.44	0.00766	1.001	0.181	1.24	1.12		46.62	0.22	99							
			LMC-3	Median	21.5	70.0	6.10	7.58	21500	407	0.41	0.00614	0.907	0.162	0.95	1.00		55.00	0.20	95							
			LMC-3	Min	13.0	22.0	1.20	6.66	10	70	0.14	0.00053	0.338	0.082	0.50	1.00		22.80	0.20	80							
			LMC-3	Max	25.0	85.0	11.80	8.23	120000	1512	1.17	0.01527	2.070	0.415	3.00	1.80		62.40	0.40	125							
			LMC-3	StDev	3.7	20.1	2.96	0.53	44809	431	0.31	0.00517	0.628	0.107	0.85	0.27		17.12	0.06	12							
05/28/1997	1400	Cen&Un	Compos	Surface	10.4	50.0		7.68	40000	292	0.43	0.00392	1.030	0.308	0.50	1.00		27.50	0.20	160							
06/12/1997	1330	Cen&Un	Compos	Surface	21.0	70.0		7.69		192	0.45	0.00922	0.718	0.170	0.50	1.00		21.20	0.20	130							
06/19/1997	1145	Cen&Un	Compos	Surface	24.0	80.0	3.00	7.19		1272	0.96	0.00782	1.930	0.227	2.10	1.00			0.20	130							
06/20/1997	1000	Cen&Un	Compos	Surface	22.0	70.0	6.00	7.75		490	0.43	0.01083	0.887	0.190	0.70				0.20	125							
06/30/1997	1400	Cen&Un	Compos	Surface	25.0	85.0	5.60	7.59	110000	1636	0.61	0.01321	1.960	0.190	2.10	1.00			0.20	120							
07/14/1997	1330	Cen&Un	Compos	Surface	25.0		3.00	7.38	8000	564	0.17	0.00229	0.970	0.152	0.90	1.00	18.20	109.00	0.20	155			101	813		0.50	2.39
07/17/1997	915	Cen&Un	Compos	Surface	25.0	75.0		7.43	6000	644	0.45	0.00679	1.100	0.151	0.90	1.00			0.20	130							
07/24/1997	900	Cen&Un	Compos	Surface	24.0	70.0	4.80	8.06	50000	382	0.47	0.02696	1.390	0.170	0.50	1.00				140		107					
07/26/1997	1400	Cen&Un	Compos	Surface	11.0	90.0	5.40	7.45		760	0.06	0.00034	1.040	0.067	0.70				0.20	120							
07/31/1997	1530	Cen&Un	Compos	Surface	21.0	65.0	7.60	8.13	10	536	0.09	0.00490	0.784		0.70	1.00			0.20	85							
08/15/1997	1330	Cen&Un	Compos	Surface	24.0	70.0	4.80	7.03		296	0.02	0.00011	0.938	0.166	0.80	1.00			0.20	100							
08/25/1997	1330	Cen&Un	Compos	Surface	25.0	85.0	4.40	7.50	340000	864	0.27	0.00477	1.080	0.146	1.00	1.00		31.00	0.20	90							
					12.0																						
			LMC-1	Mean	21.5	73.6	4.96	7.57	79144	661	0.37	0.00760	1.152	0.176	0.95	1.00		47.18	0.20	124							
			LMC-1	Median	24.0	70.0	4.80	7.55	40000	550	0.43	0.00585	1.035	0.170	0.75	1.00	18.20	29.25	0.20	128							
			LMC-1	Min	10.4	50.0	3.00	7.03	10	192	0.02	0.00011	0.718	0.067	0.50	1.00		21.20	0.20	85							
			LMC-1	Max	25.0	90.0	7.60	8.13	340000	1636	0.96	0.02696	1.960	0.308	2.10	1.00		109.00	0.20	160							
			LMC-1	StDev	5.2	11.2	1.44	0.32	121143	426	0.27	0.00730	0.407	0.059	0.56	0.00	#DIV/0!	41.42	0.00	23							
05/05/1997	1550	Strang	Compos	Surface	22.0		7.60			140	0.12		0.179		0.50	1.00		10.40	0.20	150							
05/07/1997	1030	Strang	Compos	Surface	13.5	71.6		6.71	670	304	0.58	0.00073	0.620	0.175	0.50	1.00		1.00		170							
05/28/1997	1430	Strang	Compos	Surface	18.0	50.0	10.40	7.94	57000	110	0.27	0.00783	0.307	0.096	0.50	1.00		8.00	0.20	85							
06/12/1997	1430	Strang	Compos	Surface	19.0	70.0		7.75		12	0.27	0.00549	0.167	0.123	0.50	1.00		2.50	0.20	160							
06/30/1997	1330	Strang	Compos	Surface	25.0	85.0	5.40	7.78	37000	142	0.66	0.02188	0.448	0.209	0.50	1.00			0.20	65							
07/24/1997	930	Strang	Compos	Surface	24.0	70.0	4.40	7.95	240000	506	0.59	0.02662	0.856	0.152	0.50	1.00			0.20								
07/26/1997	1330	Strang	Compos	Surface	9.0	90.0	5.00	7.31		1044	0.30	0.00105	1.020	0.060	0.90				0.20						122		
07/31/1997	1545	Strang	Compos	Surface	21.0	65.0	7.60	8.09	10	536	0.14	0.00699	0.866		0.50	1.00			0.20	105							
08/25/1997	1315	Strang	Compos	Surface	22.0	85.0	5.00	7.82	15000000	1376	0.30	0.00884	1.340	0.167	1.50	1.00		59.20	0.30	90							
					9.0																						
			LMC-2	Avg	19.3	73.3	6.49	7.67	2555780	463	0.36	0.00993	0.645	0.140	0.66	1.00		16.22	0.21	118							
			LMC-2	Median	21.0	70.8	5.40	7.80	47000	304	0.30	0.00741	0.620	0.152	0.50	1.00		8.00	0.20	105							
			LMC-2	Min	9.0	50.0	4.40	6.71	10	12	0.12	0.00073	0.167	0.060	0.50	1.00		1.00	0.20	65							
			LMC-2	Max	25.0	90.0	10.40	8.09	15000000	1376	0.66	0.02662	1.340	0.209	1.50	1.00		59.20	0.30	170							
			LMC-2	StDev	5.2	13.0	2.15	0.45	6097051	466	0.20	0.00940	0.406	0.051	0.34	0.00		24.33	0.04	42							

APPENDIX I

Office of Equalization
Lake County Courthouse
Madison, South Dakota 57042
(605) 256-7605

Michelle Goodale

Please find the enclosed facts that you requested recently.

Brant Lake	Non-Ag Structures	-	5,992,000
	Non-Ag Land	-	3,489,900
	Non-Ag Totals	-	9,481,900
Lake Madison	Non-Ag Structures	-	25,643,443
	Non-Ag Land	-	8,496,550
	Non-Ag Totals	-	34,139,993
Madison City	Non-Ag Structures	-	102,579,178
	Non-Ag Land	-	24,986,997
	Non-Ag Totals	-	127,566,175
Lake County	Non-Ag Structures	-	177,833,231
	Non-Ag Land	-	43,441,838
	Non-Ag Totals	-	221,275,069
Lake County	Ag Structures	-	6,099,500
	Ag Land	-	181,366,284
	Ag Totals	-	187,465,784
Lake County Total Value		-	408,740,853

These values are all subject to change in the next few months due to any action taken by the boards of equalization.

Joyce Dragseth (signature)
Joyce Dragseth
Deputy Director

LAKE MADISON

SOCIO-ECONOMIC CHARACTERISTICS

OF THE

USER POPULATION

SOUTH DAKOTA STATE UNIVERSITY

CENSUS DATA CENTER

APRIL 1996

Dr. Jim Satterlee - Director

TABLE OF CONTENTS

A. INTRODUCTION 1

B. POPULATION PROFILE 3

C. EMPLOYMENT PROFILE 6

APPENDIX A 11

APPENDIX B 16

APPENDIX C 21

APPENDIX D 33

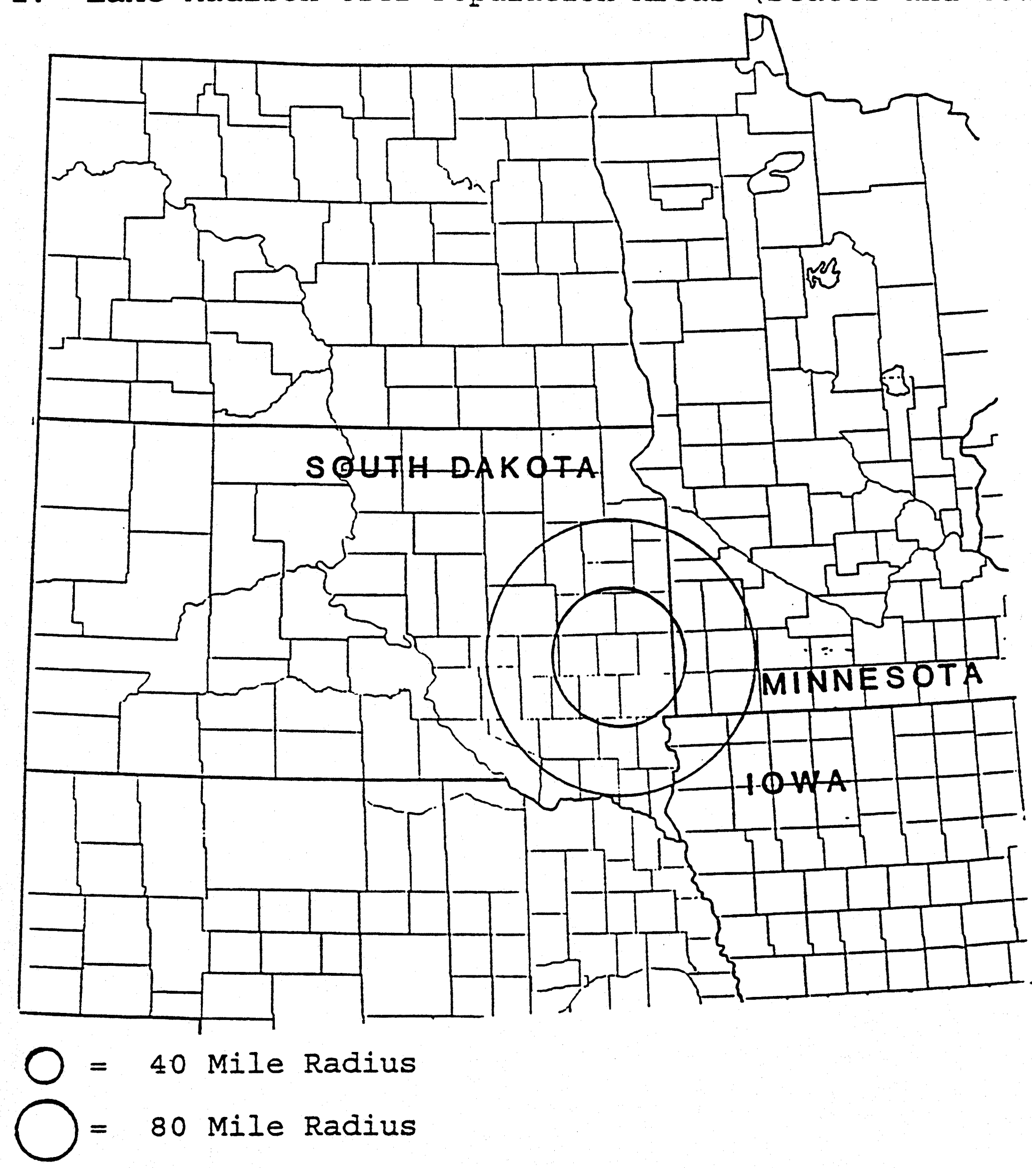
LAKE MADISON

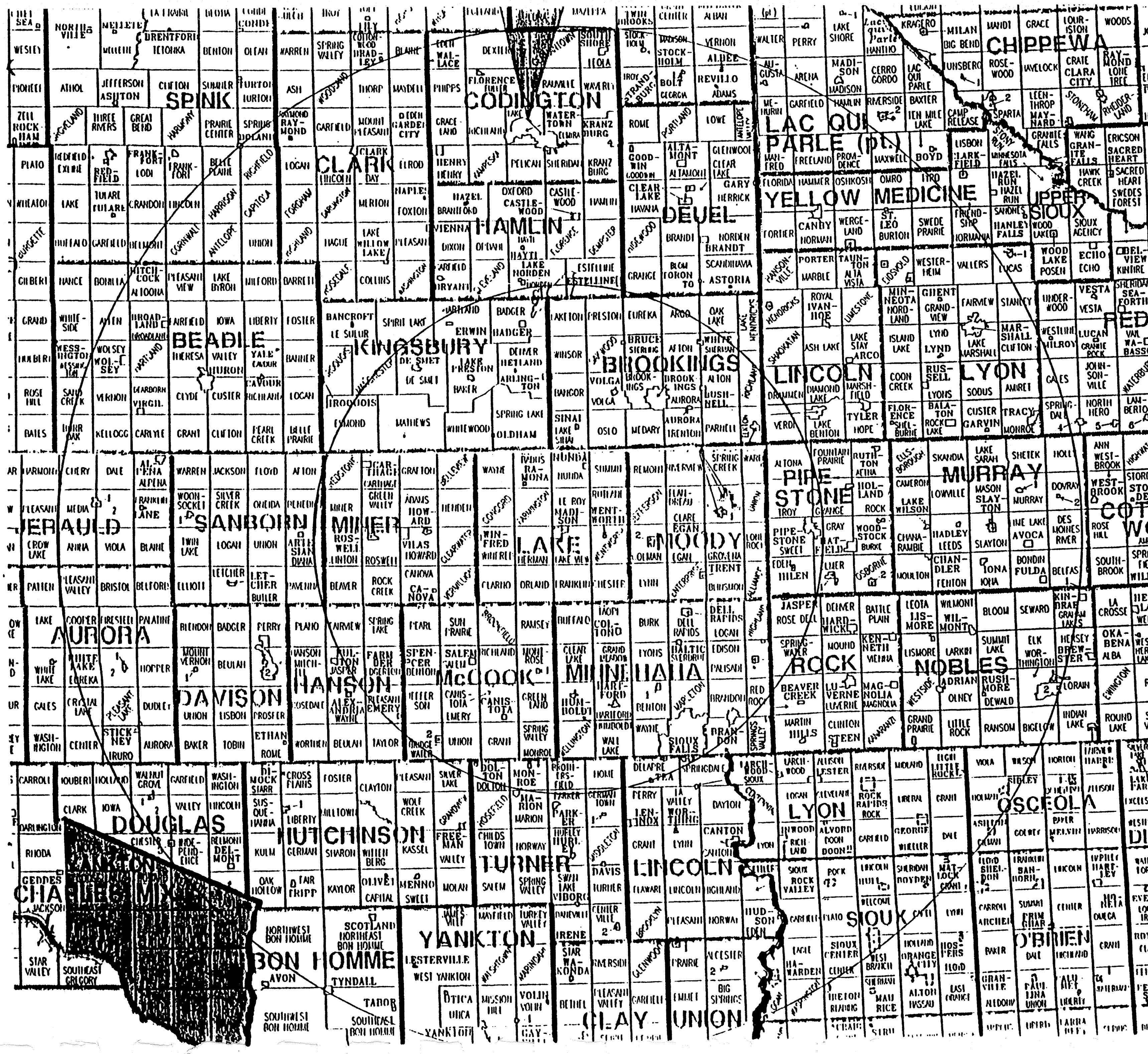
Description of Size and Economic Structure of Potential User Population: Lake Madison.

A. Introduction

The description of socio-economic characteristics of the potential user population will follow using two foci for analysis. First will be an examination of an area within an 80 mile radius surrounding Lake Madison. Secondly, will be a somewhat more focused analysis examining the same characteristics, but for those rural areas and communities within 40 miles of the lake (see Maps 1 and 2).

Map 1. Lake Madison User Population Areas (States and Counties)





Map 2. Lake Madison User Population Areas (States, Counties, and Townships)

B. Population Profile

Lake Madison, located 2 miles south and 1.5 miles east of Madison, received its name from the city of Madison. Lake Madison covers an area of 4.37 mi^2 with a maximum depth of 20 feet and an average depth of 10 feet. The northwestern part of Lake Madison is a State Recreation Area and is managed by the Parks Division of Game, Fish and Parks. It is used for picnicking, fishing, snowmobiling, swimming, boating, water skiing, bird watching, hunting and trapping. This area is used primarily by people within 40 miles, but is also used by tourists and hunters.

The number of potential users to be found within 80 miles of Lake Madison requires an examination of census data from twenty-nine South Dakota counties, nine Minnesota counties and three Iowa counties (see Map 1.). These 41 counties represent a total of 584 townships and 198 communities (see Map 2.). In order to most accurately portray the characteristics of the population around the Lake Madison user area, data from these townships and communities will be used. The 1990 U.S. Census of Population serves as the source of population numbers, 1989 data will be used for per capita and median family income information.

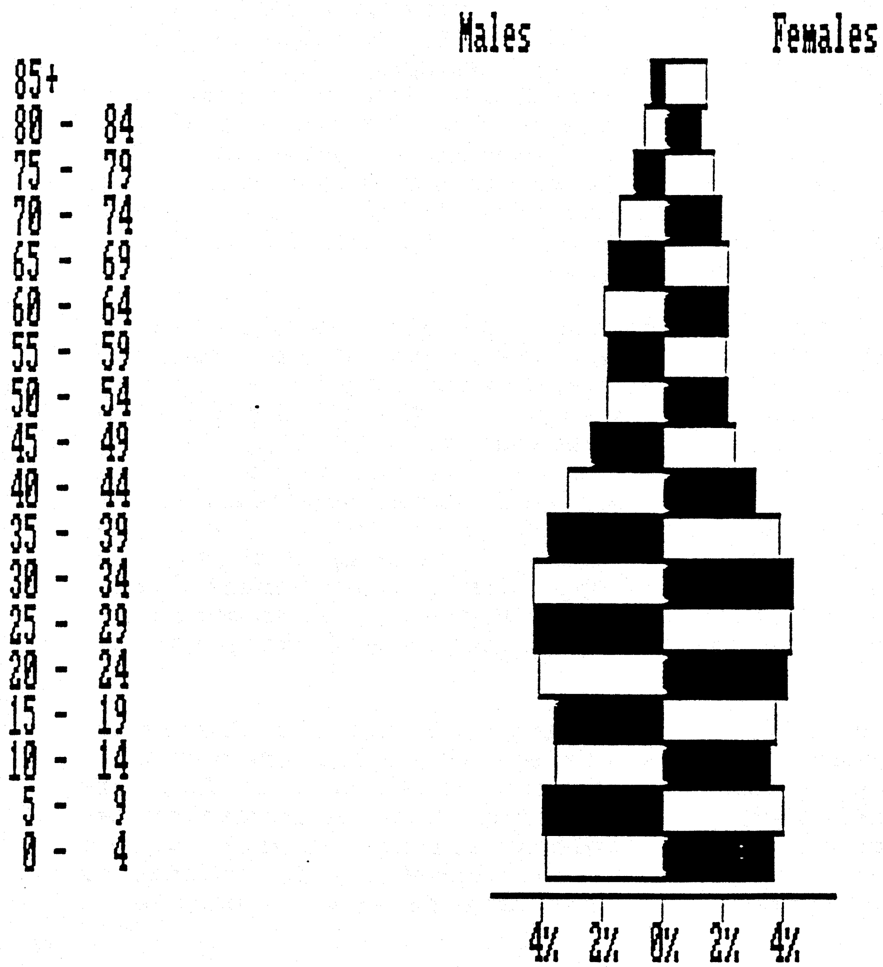
The total population represented within the 80 mile radius of Lake Madison is 461,077 persons. Seventy-three percent (335,781) of these residents reside in South Dakota, 19% (87,271) reside in Minnesota with the remaining 9% (38,025) residing in Iowa. Sixty-five percent (301,831) of these residents live in communities ranging in size from less than 50 persons to a metropolitan area of over 100,000 people. The remaining 35% (159,246 persons) of the population live in open-country farms or acreages outside of incorporated city boundaries (see Appendix C: User Population 80 Mile Radius). Figure 2 provides a profile of the 80 mile user population by age and sex distribution.

A more focused examination of the user area (40 mile radius) incorporates 13 South Dakota counties (comprised of 140 townships and 52 communities, see map 2), and 3 Minnesota counties (comprised of 11 townships and 4 communities, see map 2). The total population represented in this area is 195,381 persons of which 155,478 (80%) reside in communities ranging from 6 persons (Arlington) to the largest community (Sioux Falls), located 32 miles southeast of the Lake, with 100,814 persons. Twenty percent (39,903) of the user population live on open-country farms or acreages outside of incorporated city boundaries (see Appendix A: User Population 40 Mile Radius). The population pyramid (Figure 1) represents the distribution of persons by age and sex within the 40 mile radius.

The population pyramids representing both foci of analysis are indicative of the overall age and sex structure for the state of South Dakota. The pyramids for both the 40 and 80 mile foci are indicative of the **stationary** pyramid pattern that is characterized by roughly equal proportions of people at all age cohorts, with a tapering off at the older ages. In South Dakota, this pattern is associated with urban populations that have diverse economies.

Figure 1. Age Sex Structure for 40 Mile Radius

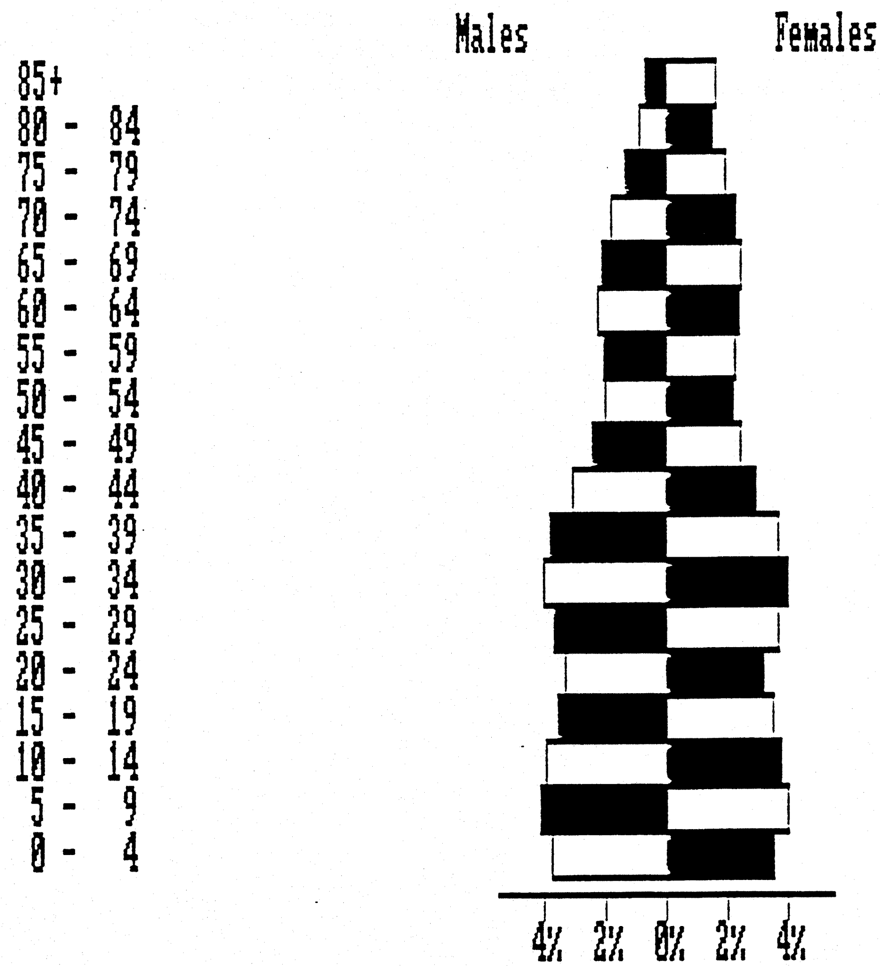
Age Group	Total	Males	% Males	Females	% Females
0 - 4	14,692	7,540	3.86	7,152	3.66
5 - 9	15,541	7,776	3.98	7,765	3.97
10 - 14	13,962	6,942	3.55	7,020	3.59
15 - 19	14,327	7,057	3.61	7,270	3.72
20 - 24	16,237	8,118	4.15	8,119	4.16
25 - 29	16,771	8,431	4.32	8,340	4.27
30 - 34	16,751	8,385	4.29	8,366	4.28
35 - 39	15,157	7,530	3.85	7,627	3.90
40 - 44	12,215	6,211	3.18	6,004	3.07
45 - 49	9,321	4,718	2.41	4,603	2.36
50 - 54	7,768	3,673	1.88	4,095	2.10
55 - 59	7,683	3,685	1.89	3,998	2.05
60 - 64	8,003	3,858	1.97	4,145	2.12
65 - 69	7,745	3,624	1.85	4,121	2.11
70 - 74	6,677	2,965	1.52	3,712	1.90
75 - 79	5,203	2,058	1.05	3,145	1.61
80 - 84	3,681	1,316	0.67	2,365	1.21
85+	3,647	1,005	0.51	2,642	1.35
Total:	195,381	94,892	48.57	100,489	51.43



Total Population: 195,381 Age Sex Structure for 40 Mile Radius

Figure 2. Age Sex Structure for 80 Mile Radius

Age Group	Total	Males	% Males	Females	% Females
0 - 4	33,371	17,165	3.72	16,206	3.51
5 - 9	37,482	19,114	4.15	18,368	3.98
10 - 14	35,489	18,265	3.96	17,224	3.74
15 - 19	32,414	16,405	3.56	16,009	3.47
20 - 24	29,886	15,258	3.31	14,628	3.17
25 - 29	34,073	17,117	3.71	16,956	3.68
30 - 34	36,824	18,488	4.01	18,336	3.98
35 - 39	34,537	17,572	3.81	16,965	3.68
40 - 44	27,857	14,180	3.08	13,677	2.97
45 - 49	22,277	11,099	2.41	11,178	2.42
50 - 54	19,394	9,353	2.03	10,041	2.18
55 - 59	19,682	9,413	2.04	10,269	2.23
60 - 64	21,243	10,242	2.22	11,001	2.39
65 - 69	21,067	9,912	2.15	11,155	2.42
70 - 74	18,679	8,399	1.82	10,280	2.23
75 - 79	15,167	6,215	1.35	8,952	1.94
80 - 84	10,912	4,026	0.87	6,886	1.49
85+	10,723	3,159	0.69	7,564	1.64
Total:	461,077	225,382	48.88	235,695	51.12



Total Population: 461,077 Age Sex Structure for 80 Mile Radius

C. Employment Profile

80 Mile Radius

Residents of the larger user area are for the most part employed in non-manufacturing type occupations (86.5%) (see Table 2). These occupations are represented by agriculture, ag business, education and service industries. Unemployment rates for both the larger user area (80 mile radius = 3.2%) and more local area (40 mile radius = 2.9%) are below the State average of 4.2% and substantially below the National average of 6.3%.

Per capita income for the larger user area was that of $11,425 and for the more central area $12,194. As can be seen from table 2, both are below the National average of $14,420 and slightly above the State average of $10,661. (See Appendices B and D for detailed township and community per capita income data.)

A more recognizable comparison of economic status would be that of median family income. Table 1 reflects the variation among counties and states. One will note the substantial differences between the South Dakota state average and that of the United States.

Table 1. REAL MEDIAN FAMILY INCOME 1989

SOUTH DAKOTA COUNTIES	REAL MEDIAN FAMILY INCOME 1989
Aurora, SD	19583
Beadle, SD	27354
Bon Homme, SD	21324
Brookings, SD	29457
Charles Mix, SD	20512
Clark, SD	23381
Clay, SD	28005
Codington, SD	28127
Davison, SD	27249
Day, SD	22906
Deuel, SD	21372
Douglas, SD	20953
Grant, SD	28471
Hamlin, SD	25362
Hanson, SD	28232
Hutchinson, SD	23573
Jerauld, SD	22784
Kingsbury, SD	25800
Lake, SD	28494
Lincoln, SD	32490
McCook, SD	25109
Miner, SD	23714
Minnehaha, SD	34286
Moody, SD	28478
Sanborn, SD	23929

Compiled by the SDSU Census Data Center - Brookings, SD 57007

Table 1. REAL MEDIAN FAMILY INCOME 1989

SOUTH DAKOTA COUNTIES	REAL MEDIAN FAMILY INCOME 1989
Spink, SD	24507
Turner, SD	24802
Union, SD	26683
Yankton, SD	28102
Lac Qui Parle, MN	25987
Lincoln, MN	24286
Lyon, MN	30582
Murray, MN	26889
Nobles, MN	28427
Pipestone, MN	26995
Redwood, MN	27182
Rock, MN	28811
Yellow Medicine, MN	27079
Lyon, IA	26142
Osceola, IA	28599
Sioux, IA	29356
South Dakota	27602
Minnesota	31838
Iowa	31659
United States	35225

Compiled by the SDSU Census Data Center - Brookings, SD 57007

Table 2. Socio-Economic Characteristics of User Population - Lake Madison

User Area Counties	Civilian Labor Force	Percent Unemployed	Employment Manufacturing	Employment Non-Manufacturing	Per Capita* Income
Aurora, SD	1267	1.1%	99	1154	8129
Beadle, SD	8918	4.1%	1228	7325	10373
Bon Homme, SD	2889	0.8%	378	2488	8208
Brookings, SD	13158	3.4%	2045	10660	9926
Charles Mix, SD	3738	5.5%	189	3343	7475
Clark, SD	1880	2.0%	133	1710	9280
Clay, SD	6769	5.7%	252	6132	9160
Codington, SD	11615	4.6%	2345	8734	10508
Davison, SD	8731	4.2%	1235	7132	10105
Day, SD	2886	4.3%	280	2481	9191
Deuel, SD	2040	2.6%	185	1801	9117
Douglas, SD	1494	1.5%	84	1388	7869
Grant, SD	3985	4.1%	388	3433	10394
Hamlin, SD	2052	2.0%	232	1778	9068
Hanson, SD	1486	2.4%	86	1365	9846
Hutchinson, SD	3753	2.1%	375	3300	9514
Jerauld, SD	1068	2.2%	46	999	9867
Kingsbury, SD	2609	2.3%	288	2261	9857
Lake, SD	5217	2.4%	592	4499	11388
Lincoln, SD	8070	2.0%	1201	6708	12246
McCook, SD	2601	1.8%	286	2269	9542
Miner, SD	1477	3.0%	103	1330	9711
Minnehaha, SD	68273	2.9%	8496	57814	13345
Moody, SD	3113	3.5%	397	2606	10169
Sanborn, SD	1221	2.8%	97	1090	8956

Compiled by the SDSU Census Data Center - Brookings, SD 57007

Table 2. Socio-Economic Characteristics of User Population - Lake Madison

User Area Counties	Civilian Labor Force	Percent Unemployed	Employment Manufacturing	Employment Non-Manufacturing	Per Capita* Income
Spink, SD	3476	1.8%	106	3306	9674
Turner, SD	3890	2.1%	263	3547	9355
Union, SD	4893	3.5%	861	3863	9997
Yankton, SD	9671	1.9%	1806	7682	10305
Lac Qui Parle, MN	3873	3.9%	389	3334	10368
Lincoln, MN	3003	2.8%	183	2736	9616
Lyon, MN	12513	4.6%	1784	10156	11121
Murray, MN	4318	3.9%	305	3844	10871
Nobles, MN	9627	4.2%	1751	7468	10860
Pipestone, MN	4731	5.1%	634	3857	10050
Redwood, MN	7807	3.0%	1218	6355	10489
Rock, MN	4667	3.8%	662	3826	11383
Yellow Medicine, MN	5147	4.7%	624	4280	10513
Lyon, IA	5435	1.5%	843	4513	9871
Osceola, IA	3429	3.0%	635	2692	10842
Sioux, IA	14897	1.5%	2434	12234	10411
	271687	3.2% (AVG.)	35538 (13.5%)	227493 (86.5%)	
South Dakota	335874	4.2%	34114	287777	10661
Minnesota	2311336	5.1%	399592	1792825	14389
Iowa	1403883	4.5%	234461	1105781	12422
United States	123473450	6.3%	20462078	95219124	14420

* See Appendices B and D for Per Capita Income by Township and Community

Compiled by the SDSU Census Data Center - Brookings, SD 57007

APPENDIX A

SOUTH DAKOTA TOWNSHIPS - 40 MILE RADIUS
LAKE MADISON

BROOKINGS COUNTY		HAMLIN COUNTY		HANSON COUNTY		HUTCHINSON COUNTY	
TOWNSHIPS	POPULATION	TOWNSHIPS	POPULATION	TOWNSHIPS	POPULATION	TOWNSHIPS	POPULATION
Afton	185	Estelline	245	Edgerton	129	Silver Lake	114
Alton	284	Norden	314	Fairview	132		
Argo	153		------------	Jasper	147		
Aurora	300		559	Plano	130		
Bangor	176			Pleasant	153		
Brookings	430			Spring Lake	130		
Elkton	104			Taylor	146		
Eureka	154			Wayne	192		
Lake Sinai	176				------------		
Laketon	120				1159		
Medary	950						
Oak Lake	108						
Oakwood	190						
Oslo	229						
Parnell	147						
Preston	189						
Richland	160						
Sherman	145						
Sterling	326						
Trenton	333						
Volga	299						
Winsor	176						

	5334						

CITIES & TOWNS	POPULATION	CITIES & TOWNS	POPULATION	CITIES & TOWNS	POPULATION	CITIES & TOWNS	POPULATION
Arlington	6	Lake Norden	427	Emery	417		
Aurora	619			Farmer	23		
Brookings	16270				------------		
Bruce	235				440		
Bushnell	81						
Elkton	602						
Sinai	120						
Volga	1263						
White	536						

	19732						

Compiled by the SDSU Census Data Center - Brookings, SD 57007

SOUTH DAKOTA TOWNSHIPS - 40 MILE RADIUS
LAKE MADISON

KINGSBURY		LAKE COUNTY		LINCOLN COUNTY		McCOOK COUNTY	
TOWNSHIPS	POPULATION	TOWNSHIPS	POPULATION	TOWNSHIPS	POPULATION	TOWNSHIPS	POPULATION
Badger	240	Badus	146	Delapre	1419	Benton	111
Baker	280	Chester	571	Springdale	1061	Bridgewater	173
Denver	245	Clarno	190			Brookfield	141
De Smet	328	Concord	125		2480	Canistota	132
Esmond	57	Farmington	188			Emery	108
Hartland	183	Franklin	228			Grant	175
Manchester	136	Herman	556			Greenland	183
Mathews	153	Lake View	468			Jefferson	132
Spirit Lake	167	Le Roy	239			Montrose	219
Spring Lake	327	Nunda	103			Pearl	100
Whitewood	139	Orland	135			Ramsey	136
		Rutland	213			Richland	199
	2255	Summit	186			Salem	182
		Wayne	124			Spring Valley	232
		Wentworth	213			Sun Prairie	152
		Winfred	134			Union	146
			3819				2521

CITIES & TOWNS	POPULATION	CITIES & TOWNS	POPULATION	CITIES & TOWNS	POPULATION	CITIES & TOWNS	POPULATION
Arlington	902	Madison	6257	Sioux Falls	1409	Bridgewater	533
Badger	114	Nunda	45			Canistota	608
De Smet	1172	Ramona	194			Montrose	420
Erwin	42	Wentworth	181			Salem	1289
Hetland	53	Winfred	54			Spencer	317
Lake Preston	663		6731				3167
Oldham	189						
	3135						

Compiled by the SDSU Census Data Center - Brookings, SD 57007

SOUTH DAKOTA TOWNSHIPS - 40 MILE RADIUS
LAKE MADISON

MINER COUNTY		MINNEHAHA COUNTY		MOODY COUNTY		SANBORN COUNTY	
TOWNSHIPS	POPULATION	TOWNSHIPS	POPULATION	TOWNSHIPS	POPULATION	TOWNSHIPS	POPULATION
Adams	143	Benton	630	Alliance	114	Afton	55
Beaver	78	Brandon	612	Blinsmon	258	Benedict	49
Belleview	100	Buffalo	238	Clare	179	Diana	49
Canova	102	Burk	306	Colman	235	Ravenna	61
Carthage	52	Clear Lake	175	Egan	211		
Clearwater	186	Dell Rapids	338	Enterprise	282		214
Clinton	132	Edison	346	Flandreau	367		
Grafton	114	Grand Meadow	268	Fremont	243		
Green Valley	62	Hartford	542	Grovena	239		
Henden	159	Highland	164	Jefferson	153		
Howard	129	Humboldt	318	Lone Rock	99		
Miner	78	Logan	277	Lynn	296		
Redstone	45	Lyons	559	Riverview	190		
Rock Creek	127	Mapleton	1686	Spring Creek	146		
Roswell	64	Palisade	276	Union	163		
Vermillion	105	Red Rock	342	Ward	85		
		Split Rock	2137				
	1676	Sverdup	614		3260		
		Taopi	347				
		Wall Lake	863				
		Wayne	1307				
		Wellington	304				
			12649				

CITIES & TOWNS	POPULATION	CITIES & TOWNS	POPULATION	CITIES & TOWNS	POPULATION	CITIES & TOWNS	POPULATION
Canova	172	Baltic	666	Colman	482		
Carthage	221	Brandon	3543	Egan	208		
Howard	1156	Colton	657	Flandreau	2311		
Roswell	19	Crooks	671	Trent	211		
Vilas	28	Dell Rapids	2484	Ward	35		
		Garretson	924				
	1596	Hartford	1262		3247		
		Humboldt	468				
		Sherman	66				
		Sioux Falls	99405				
			110146				

Compiled by the SDSU Census Data Center - Brookings, SD 57007

SOUTH DAKOTA TOWNSHIPS - 40 MILE RADIUS
LAKE MADISON

TURNER COUNTY

TOWNSHIPS	POPULATION
Brothersfield	148
Dolton	169
Home	279
Monroe	157
	753

TOTAL	TOWNSHIP	POPULATION	=	36793
TOTAL	CITY	POPULATION	=	150224
	TOTAL	POPULATION		187017

CITIES & TOWNS	POPULATION
Dolton	43
Monroe	151
	194

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MINNESOTA TOWNSHIPS - 40 MILE RADIUS
LAKE MADISON

LINCOLN COUNTY		PIPESTONE COUNTY		ROCK COUNTY	
TOWNSHIPS	POPULATION	TOWNSHIPS	POPULATION	TOWNSHIPS	POPULATION
Drammen	180	Altona	210	Beaver Creek	445
Verdi	234	Eden	279	Rose Dell	241
		Grange	259	Springwater	303
	414	Gray	258		
		Sweet	376		989
		Troy	325		
			1707		

TOTAL TOWNSHIP POPULATION	=	3110
TOTAL CITY POPULATION	=	5254
TOTAL POPULATION		8364

CITIES & TOWNS	POPULATION	CITIES & TOWNS	POPULATION	CITIES & TOWNS	POPULATION
		Ihlen	101	Jasper	75
		Jasper	524		
		Piestone	4554		
			5179		

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APPENDIX B

SOUTH DAKOTA TOWNSHIPS - 40 MILE RADIUS
LAKE MADISON

BROOKINGS COUNTY		HAMLIN COUNTY		HANSON COUNTY		HUTCHINSON COUNTY	
TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME
Afton	13865	Estelline	8780	Edgerton	7825	Silver Lake	10845
Alton	9068	Norden	9207	Fairview	8818		
Argo	8264			Jasper	9874		
Aurora	13746			Plano	9036		
Bangor	8101			Pleasant	6351		
Brookings	12743			Spring Lake	12510		
Elkton	10724			Taylor	8830		
Eureka	10058			Wayne	6135		
Lake Sinai	8297						
Laketon	12680						
Medary	11493						
Oak Lake	9964						
Oakwood	9312						
Oslo	10126						
Parnell	10762						
Preston	13502						
Richland	7225						
Sherman	8911						
Sterling	12428						
Trenton	12614						
Volga	11319						
Winsor	11243						

CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME
Arlington	8000	Lake Norden	9585	Emery	8211		
Aurora	8845			Farmer	10699		
Brookings	9723						
Bruce	9435						
Bushnell	7775						
Elkton	9487						
Sinai	9847						
Volga	9719						
White	7528						

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SOUTH DAKOTA TOWNSHIPS - 40 MILE RADIUS
LAKE MADISON

KINGSBURY

TOWNSHIPS	PC INCOME
Badger	7933
Baker	9176
Denver	9078
De Smet	12709
Esmond	16767
Hartland	12456
Manchester	5870
Mathews	12160
Spirit Lake	17174
Spring Lake	8635
Whitewood	11921

LAKE COUNTY

TOWNSHIPS	PC INCOME
Badus	13199
Chester	9345
Clarno	9401
Concord	7432
Farmington	12592
Franklin	11774
Herman	9459
Lake View	27709
Le Roy	21190
Nunda	7803
Orland	6679
Rutland	9337
Summit	8849
Wayne	6342
Wentworth	11038
Winfred	8300

LINCOLN COUNTY

TOWNSHIPS	PC INCOME
Delapre	13821
Springdale	13988

McCOOK COUNTY

TOWNSHIPS	PC INCOME
Benton	7284
Bridgewater	8664
Brookfield	16704
Canistota	11389
Emery	10217
Grant	8703
Greenland	12263
Jefferson	8997
Montrose	9310
Pearl	9726
Ramsey	10840
Richland	8376
Salem	10585
Spring Valley	6659
Sun Prairie	8491
Union	7544

CITIES & TOWNS	PC INCOME
Arlington	9557
Badger	8398
De Smet	10161
Erwin	10324
Hetland	8200
Lake Preston	9034
Oldham	9617

CITIES & TOWNS	PC INCOME
Madison	10824
Nunda	9410
Ramona	9608
Wentworth	9232
Winfred	7905

CITIES & TOWNS	PC INCOME
Sioux Falls	20919

CITIES & TOWNS	PC INCOME
Bridgewater	10196
Canistota	8816
Montrose	8638
Salem	10377
Spencer	9235

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SOUTH DAKOTA TOWNSHIPS - 40 MILE RADIUS
LAKE MADISON

MINER COUNTY		MINNEHAHA COUNTY		MOODY COUNTY		SANBORN COUNTY	
TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME
Adams	16483	Benton	10528	Alliance	9277	Afton	9588
Beaver	2564	Brandon	16751	Blinsmon	8084	Benedict	6903
Belleview	8066	Buffalo	8489	Clare	10753	Diana	12143
Canova	18189	Burk	14248	Colman	10813	Ravenna	7755
Carthage	6711	Clear Lake	7316	Egan	7321		
Clearwater	9071	Dell Rapids	14407	Enterprise	11819		
Clinton	11002	Edison	10989	Flandreau	9893		
Grafton	19867	Grand Meadow	7850	Fremont	10983		
Green Valley	13732	Hartford	13124	Grovena	9083		
Henden	7213	Highland	13619	Jefferson	17389		
Howard	12313	Humboldt	9647	Lone Rock	15766		
Miner	10124	Logan	8844	Lynn	9013		
Redstone	4597	Lyons	11445	Riverview	8297		
Rock Creek	8609	Mapleton	17558	Spring Creek	11036		
Roswell	10183	Palisade	10961	Union	11133		
Vermillion	9010	Red Rock	12047	Ward	8240		
		Split Rock	18563				
		Sverdup	10064				
		Taopi	11120				
		Wall Lake	11640				
		Wayne	13446				
		Wellington	11947				

CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME
Canova	7192	Baltic	10557	Colman	12248		
Carthage	8986	Brandon	12069	Egan	10474		
Howard	9529	Colton	9755	Flandreau	9630		
Roswell	3600	Crooks	9085	Trent	9467		
Vilas	5674	Dell Rapids	10397	Ward	12340		
		Garretson	10179				
		Hartford	9878				
		Humboldt	10052				
		Sherman	10899				
		Sioux Falls	13574				

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SOUTH DAKOTA TOWNSHIPS - 40 MILE RADIUS
LAKE MADISON

TURNER COUNTY

TOWNSHIPS	PC INCOME
Brothersfield	12447
Dolton	9135
Home	12663
Monroe	11513

CITIES & TOWNS	PC INCOME
Dolton	5717
Monroe	6954

MINNESOTA TOWNSHIPS - 40 MILE RADIUS
LAKE MADISON

LINCOLN COUNTY		PIPESTONE COUNTY		ROCK COUNTY	
TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME
Drammen	8746	Altona	8155	Beaver Creek	10010
Verdi	8706	Eden	11330	Rose Dell	9956
		Grange	10016	Springwater	11203
		Gray	13027		
		Sweet	11166		
		Troy	9593		

CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME
		Ihlen	10576	Jasper	6854
		Jasper	10381		
		Piestone	10317		

APPENDIX C

SOUTH DAKOTA TOWNSHIPS - 80 MILE RADIUS
LAKE MADISON

AURORA COUNTY

TOWNSHIPS	POPULATION
Aurora	130
Belford	190
Bristol	62
Center	116
Cooper	20
Crystal Lake	57
Dudley	111
Eureka	38
Firesteel	70
Hopper	83
Lake	57
Palatine	71
Patten	53
Plankinton	239
Pleasant Lake	97
Pleasant Valley	44
Truro	100
White Lake	86
	1624

BEADLE COUNTY

TOWNSHIPS	POPULATION
Allen	95
Altoona	135
Banner	49
Barrett	33
Belle Prairie	50
Bonila	80
Broadland	86
Burr Oak	43
Carlyle	94
Cavour	124
Clifton	131
Clyde	627
Custer	397
Dearborn	134
Fairfield	104
Foster	75
Grant	149
Hartland	106
Iowa	206
Kellogg	80
Lake Byron	237
Liberty	81
Logan	127
Milford	92
Pearl Creek	110
Pleasant View	56
Richland	158
Sand Creek	57
Theresa	266
Valley	257
Vernon	106
Wessington	61
Whiteside	60
Wolsey	97
	4563

BON HOMME COUNTY

TOWNSHIPS	POPULATION
NE Bon Homme	695
NW Bon Homme	592
SE Bon Homme	547
	1834

BROOKINGS COUNTY

TOWNSHIPS	POPULATION
Afton	185
Alton	284
Argo	153
Aurora	300
Bangor	176
Brookings	430
Elkton	104
Eureka	154
Lake Hendricks	141
Lake Sinai	176
Laketon	120
Medary	950
Oak Lake	108
Oakwood	190
Oslo	229
Parnell	147
Preston	189
Richland	160
Sherman	145
Sterling	326
Trenton	333
Volga	299
Winsor	176
	5475

CITIES & TOWNS	POPULATION
Plankinton	604
Stickney	323
	927

CITIES & TOWNS	POPULATION
Broadland	40
Cavour	166
Hitchcock	95
Huron	12448
Iroquois	57
Virgil	33
Wessington	241
Wolsey	442
Yale	128
	13650

CITIES & TOWNS	POPULATION
Scotland	968
Tabor	403
Tyndall	1201
	2572

CITIES & TOWNS	POPULATION
Arlington	6
Aurora	619
Brookings	16270
Bruce	235
Bushnell	81
Elkton	602
Sinai	120
Volga	1263
White	536
	19732

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SOUTH DAKOTA TOWNSHIPS - 80 MILE RADIUS
LAKE MADISON

CHARLES MIX

TOWNSHIPS	POPULATION
Choteau Creek	221
Kennedy	85
	306

CLARK COUNTY

TOWNSHIPS	POPULATION
Ash	47
Blaine	58
Collins	100
Cottonwood	109
Darlington	91
Day	87
Eden	82
Elrod	96
Fordham	151
Foxton	70
Garfield	91
Hague	51
Lake	110
Lincoln	95
Logan	50
Maydell	49
Merton	73
Mount Pleasant	177
Pleasant	167
Raymond	71
Richland	101
Rosedale	83
Thorp	66
Washington	89
Woodland	60
	2224

CLAY COUNTY

TOWNSHIPS	POPULATION
Bethel	213
Garfield	255
Glenwood	187
Meckling	228
Pleasant Valley	182
Prairie Center	210
Riverside	162
Spirit Mound	192
Star	188
	1817

CODINGTON COUNTY

TOWNSHIPS	POPULATION
Dexter	188
Eden	116
Elmira	311
Fuller	284
Germantown	164
Graceland	108
Henry	112
Kampeska	226
Kranzburg	340
Lake	690
Leola	63
Pelican	547
Phipps	77
Rauville	272
Richland	156
Sheridan	407
Waverly	163
	4224

CHARLES MIX

CITIES & TOWNS	POPULATION

CLARK COUNTY

CITIES & TOWNS	POPULATION
Bradley	117
Clark	1292
Garden City	93
Naples	35
Raymond	96
Vienna	93
Willow Lake	317
	2043

CLAY COUNTY

CITIES & TOWNS	POPULATION
Wakonda	329

CODINGTON COUNTY

CITIES & TOWNS	POPULATION
Florence	192
Henry	215
Kranzburg	132
South Shore	260
Wallace	83
Watertown	17592
	18474

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SOUTH DAKOTA TOWNSHIPS - 80 MILE RADIUS
LAKE MADISON

DAVISON COUNTY		DAY COUNTY		DEUEL COUNTY		DOUGLAS COUNTY	
TOWNSHIPS	POPULATION	TOWNSHIPS	POPULATION	TOWNSHIPS	POPULATION	TOWNSHIPS	POPULATION
Badger	170	Egeland	109	Altamont	109	Belmont	82
Baker	171			Antelope Valley	45	Chester	89
Beulah	369			Blom	140	East Choteau	151
Blendon	111			Brandt	159	Garfield	97
Lisbon	124			Clear Lake	188	Grandview	116
Mitchell	759			Glenwood	102	Holland	233
Mount Vernon	179			Goodwin	188	Independence	175
Perry	174			Grange	128	Iowa	144
Prosper	500			Havana	194	Lincoln	144
Rome	238			Herrick	171	Valley	148
Tobin	157			Hidewood	110	Walnut Grove	152
Union	73			Lowe	141	Washington	149
	3025			Norden	263		1680
				Portland	93		
				Rome	102		
				Scandinavia	215		
					2348		

CITIES & TOWNS	POPULATION	CITIES & TOWNS	POPULATION	CITIES & TOWNS	POPULATION	CITIES & TOWNS	POPULATION
Ethan	312			Altamont	48	Armour	854
Mitchell	13798			Astoria	155	Corsica	619
Mount Vernon	368			Brandt	123	Delmont	235
	14478			Clear Lake	1247		1708
				Gary	274		
				Goodwin	126		
				Toronto	201		
					2174		

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SOUTH DAKOTA TOWNSHIPS - 80 MILE RADIUS
LAKE MADISON

GRANT COUNTY

TOWNSHIPS	POPULATION
Adams	190
Georgia	97
Lura	89
Madison	147
Mazeppa	96
Stockholm	124
Troy	59
Twin Brooks	122
Vernon	289
	1213

HAMLIN COUNTY

TOWNSHIPS	POPULATION
Brandtford	158
Castlewood	171
Cleveland	159
Dempster	245
Dixon	89
Estelline	245
Florence	124
Garfield	164
Hamlin	239
Hayti	146
Norden	314
Opdahl	202
Oxford	235
	2491

HANSON COUNTY

TOWNSHIPS	POPULATION
Beulah	224
Edgerton	129
Fairview	132
Hanson	193
Jasper	147
Plano	130
Pleasant	153
Rosedale	293
Spring Lake	130
Taylor	146
Wayne	192
Worthen	97
	1966

HUTCHINSON COUNTY

TOWNSHIPS	POPULATION
Capital	103
Clayton	172
Cross Plains	118
Fair	146
Foster	144
German	142
Grandview	253
Kassel	131
Kaylor	223
Kulm	108
Liberty	162
Milltown	146
Molan	180
Oak Hollow	68
Pleasant	62
Sharon	111
Silver Lake	114
Starr	151
Susquehanna	207
Sweet	258
Valley	220
Wittenberg	267
Wolf Creek	248
	3734

CITIES & TOWNS	POPULATION
Albee	15
La bolt	91
Revillo	152
Stockholm	89
Strandburg	74
	421

CITIES & TOWNS	POPULATION
Bryant	374
Castlewood	549
Estelline	658
Hayti	372
Hazel	103
Lake Norden	427
	2483

CITIES & TOWNS	POPULATION
Alexandria	518
Emery	417
Farmer	23
Fulton	70
	1028

CITIES & TOWNS	POPULATION
Dimock	157
Freeman	1293
Menno	768
Olivet	74
Parkston	1572
Tripp	664
	4528

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SOUTH DAKOTA TOWNSHIPS - 80 MILE RADIUS
LAKE MADISON

JERAULD COUNTY		KINGSBURY COUNTY		LAKE COUNTY		LINCOLN COUNTY	
TOWNSHIPS	POPULATION	TOWNSHIPS	POPULATION	TOWNSHIPS	POPULATION	TOWNSHIPS	POPULATION
Alpena	108	Badger	240	Badus	146	Brooklyn	234
Anina	55	Baker	280	Chester	571	Canton	423
Blaine	86	Denver	245	Clarno	190	Dayton	460
Chery	67	De Smet	328	Concord	125	Delapre	1419
Crow Lake	61	Esmond	57	Farmington	188	Delaware	194
Dale	50	Hartland	183	Franklin	228	Eden	165
Franklin	81	Iroquois	64	Herman	556	Fairview	145
Harmony	50	Le Sueur	170	Lake View	468	Grant	337
Media	63	Manchester	136	Le Roy	239	Highland	254
Pleasant	78	Mathews	153	Nunda	103	La Valley	410
Viola	52	Spirit Lake	167	Orland	135	Lincoln	221
Wessington Springs	83	Spring lake	327	Rutland	213	Lynn	290
	834	Whitewood	139	Summit	186	Norway	277
			2489	Wayne	124	Perry	554
				Wentworth	213	Pleasant	382
				Winfred	134	Springdale	1061
					3819		6826

CITIES & TOWNS	POPULATION	CITIES & TOWNS	POPULATION	CITIES & TOWNS	POPULATION	CITIES & TOWNS	POPULATION
Alpena	251	Arlington	902	Madison	6257	Beresford	349
Lane	71	Badger	114	Nunda	45	Canton	2787
Wessiongton Springs	1083	Bancroft	30	Ramona	194	Fairview	73
	1405	De Smet	1172	Wentworth	181	Harrisburg	727
		Erwin	42	Winfred	54	Hudson	332
		Hetland	53		6731	Lennox	1767
		Iroquois	271			Sioux Falls	1409
		Lake Preston	663			Tea	786
		Oldham	189			Worthing	371
			3436				8601

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SOUTH DAKOTA TOWNSHIPS - 80 MILE RADIUS
LAKE MADISON

McCOOK COUNTY		MINER COUNTY		MINNEHAHA COUNTY		MOODY COUNTY	
TOWNSHIPS	POPULATION	TOWNSHIPS	POPULATION	TOWNSHIPS	POPULATION	TOWNSHIPS	POPULATION
Benton	111	Adams	143	Benton	630	Alliance	114
Bridgewater	173	Beaver	78	Brandon	612	Blinsmon	258
Brookfield	141	Belleview	100	Buffalo	238	Clare	179
Canistota	132	Canova	102	Burk	306	Colman	235
Emery	108	Carthage	52	Clear Lake	175	Egan	211
Grant	175	Clearwater	186	Dell Rapids	338	Enterprise	282
Greenland	183	Clinton	132	Edison	346	Flandreau	367
Jefferson	132	Grafton	114	Grand Meadow	268	Fremont	243
Montrose	219	Green Valley	62	Hartford	542	Grovena	239
Pearl	100	Henden	159	Highland	164	Jefferson	153
Ramsey	136	Howard	129	Humbolt	318	Lone Rock	99
Richland	199	Miner	78	Logan	277	Lynn	296
Salem	182	Redstone	45	Lyons	559	Riverview	190
Spring Valley	232	Rock Creek	127	Mapleton	1686	Spring Creek	146
Sun Prairie	152	Roswell	64	Palisade	276	Union	163
Union	146	Vermillion	105	Red Rock	342	Ward	85
				Split Rock	2137		
	2521		1676	Sverdup	614		3260
				Taopi	347		
				Valley Springs	275		
				Wall Lake	863		
				Wayne	1307		
				Wellington	304		
					12924		

CITIES & TOWNS	POPULATION	CITIES & TOWNS	POPULATION	CITIES & TOWNS	POPULATION	CITIES & TOWNS	POPULATION
Bridgewater	533	Canova	172	Baltic	666	Colman	482
Canistota	608	Carthage	221	Brandon	3543	Egan	208
Montrose	420	Howard	1156	Colton	657	Flandreau	2311
Salem	1289	Roswell	19	Crooks	671	Trent	211
Spencer	317	Vilas	28	Dell Rapids	2484	Ward	35
				Garretson	924		
	3167		1596	Hartford	1262		3247
				Humboldt	468		
				Sherman	66		
				Sioux Falls	99405		
				Valley Springs	739		
					110885		

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SOUTH DAKOTA TOWNSHIPS - 80 MILE RADIUS
LAKE MADISON

SANBORN COUNTY

TOWNSHIPS	POPULATION
Afton	55
Benedict	49
Butler	252
Diana	49
Elliott	121
Floyd	95
Jackson	101
Letcher	185
Logan	134
Oneida	49
Ravena	61
Silver Creek	108
Twin Lake	117
Union	65
Warren	75
Woonsocket	170
	1686

SPINK COUNTY

TOWNSHIPS	POPULATION
Antelope	96
Belle Plaine	118
Belmont	68
Capitola	227
Cornwall	61
Crandon	103
Frankfort	64
Harrison	59
Lincoln	216
Prairie Center	2770
Richfield	35
Spring	31
Union	78
	3926

TURNER COUNTY

TOWNSHIPS	POPULATION
Brothersfield	148
Centerville	211
Childstown	283
Daneville	213
Dolton	169
Germantown	326
Home	279
Hurley	152
Marion	237
Middleton	248
Monroe	157
Norway	208
Parker	249
Rosefield	218
Salem	213
Spring Valley	205
Swan Lake	208
Turner	205
	3929

UNION COUNTY

TOWNSHIPS	POPULATION
Alcestor	339
Big Springs	302
Emmet	278
Prairie	218
Sioux Valley	275
Spink	278
Virginia	258
	1948

CITIES & TOWNS	POPULATION
Artesian	217
Letcher	164
Woonsocket	766
	1147

CITIES & TOWNS	POPULATION
Doland	306

CITIES & TOWNS	POPULATION
Centerville	887
Chancellor	276
Davis	87
Dolton	43
Hurley	372
Irene	253
Marion	831
Monroe	151
Parker	984
Viborg	763
	4647

CITIES & TOWNS	POPULATION
Alcestor	843
Beresford	1500
	2343

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SOUTH DAKOTA TOWNSHIPS - 80 MILE RADIUS
LAKE MADISON

YANKTON COUNTY

TOWNSHIPS	POPULATION
Gayville	171
Jamesville	275
Marindahl	187
Mayfield	229
Mission Hill	332
Southeast Yankton	694
Turkey Valley	218
Utica	846
Volin	240
Walshton	214
West yankton	2102
	5508

TOTAL TOWNSHIP POPULATION	=	89,979
TOTAL CITY POPULATION	=	245,802
TOTAL POPULATION		335,781

CITIES & TOWNS	POPULATION
Gayville	401
Irene	2
Lesterville	168
Mission Hill	180
Utica	115
Volin	175
Yankton	12703
	13744

MINNESOTA TOWNSHIPS - 80 MILE RADIUS
LAKE MADISON

LAC QUI PARLE COUNTY

TOWNSHIPS	POPULATION
Arena	182
Augusta	141
Freeland	153
Garfield	196
Hamlin	215
Manfred	132
Maxwell	212
Mehurin	104
Providence	214
Ten Mile Lake	205
	1754

LINCOLN COUNTY

TOWNSHIPS	POPULATION
Alta Vista	252
Ash Lake	224
Diamond Lake	216
Drammen	180
Hansonville	150
Hendricks	255
Hope	331
Lake Benton	234
Lake Stay	187
Limestone	195
Marble	214
Marshfield	242
Royal	271
Shaokatan	216
Verdi	234
	3401

LYON COUNTY

TOWNSHIPS	POPULATION
Amiret	285
Clifton	291
Coon Creek	286
Custer	279
Eidsvold	229
Fairview	513
Grandview	345
Island Lake	250
Lake Marshall	511
Lucas	281
Lynd	468
Lyons	211
Monroe	259
Nordland	267
Rock Lake	324
Shelburne	227
Sodus	271
Stanley	294
Vallers	289
Westerheim	317
	6197

MURRAY COUNTY

TOWNSHIPS	POPULATION
Belfast	214
Bondin	366
Cameron	194
Chanarambie	238
Des Moines River	213
Dovray	217
Ellsborough	189
Fenton	241
Holly	186
Iona	276
Lake Sarah	289
Leeds	239
Lime Lake	209
Lowville	212
Mason	297
Moulton	261
Murray	221
Shetek	259
Skandia	192
Slayton	388
	4901

CITIES & TOWNS	POPULTION
Boyd	251
Marietta	211
	462

CITIES & TOWNS	POPULATION
Arco	104
Hendricks	684
Ivanhoe	751
Lake Benton	693
Tyler	1257
	3489

CITIES & TOWNS	POPULATION
Balaton	737
Florence	53
Garvin	149
Ghent	316
Lynd	287
Marshall	12023
Minneota	1417
Russell	394
Taunton	175
Tracy	2059
	17610

CITIES & TOWNS	POPULATION
Avoca	150
Chandler	316
Dovray	60
Fulda	1212
Hadley	94
Iona	158
Lake Wilson	319
Slayton	2147
	4456

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MINNESOTA TOWNSHIPS - 80 MILE RADIUS
LAKE MADISON

NOBLES COUNTY

TOWNSHIPS	POPULATION
Bigelow	401
Bloom	242
Dewald	345
Elk	308
Graham Lakes	262
Grand Prairie	272
Hersey	268
Larkin	245
Leota	504
Lismore	246
Little Rock	261
Lorain	333
Olney	205
Ransom	332
Seward	275
Summit Lake	400
Westside	292
Wilmont	263
Worthington	331
	5785

PIPE STONE COUNTY

TOWNSHIPS	POPULATION
Aetna	220
Altona	210
Burke	292
Eden	279
Elmer	297
Fountain Prairie	200
Grange	259
Gray	258
Osborne	394
Rock	207
Sweet	376
Troy	325
	3317

REDWOOD COUNTY

TOWNSHIPS	POPULATION
Gales	162
Springdale	243
Westline	241
	646

ROCK COUNTY

TOWNSHIPS	POPULATION
Battle Plain	229
Beaver Creek	445
Clinton	350
Denver	227
Kanaranzi	320
Luverne	477
Magnolia	303
Martin	465
Mound	274
Rose Dell	241
Springwater	303
Vienna	213
	3847

CITIES & TOWNS	POPULATION
Adrian	1141
Bigelow	232
Dundee	107
Ellsworth	580
Lismore	248
Round Lake	463
Rushmore	381
Wilmont	351
Worthington	9977
	13480

CITIES & TOWNS	POPULATION
Edgerton	1106
Hatfield	66
Holland	216
Ihlen	101
Jasper	524
Pipestone	4554
Ruthton	328
Trosky	120
Woodstock	159
	7174

CITIES & TOWNS	POPULATION

CITIES & TOWNS	POPULATION
Beaver Creek	249
Hardwick	234
Hills	607
Jasper	75
Kenneth	81
Luverne	4382
Magnolia	155
Steen	176
	5959

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MINNESOTA TOWNSHIPS - 80 MILE RADIUS
LAKE MADISON

YELLOW MEDICINE COUNTY

TOWNSHIPS	POPULATION
Burton	206
Florida	177
Fortier	117
Friendship	233
Hammer	374
Norman	300
Normania	190
Omro	166
Oshkosh	249
Swede Prairie	193
Tyro	226
Wergeland	215
	2646

TOTAL TOWNSHIP POPUALTION	=	32494
TOTAL CITY POPULATION	=	54777
TOTAL POPULATION		87271

CITIES & TOWNS	POPULATION
Canby	1826
Porter	210
St. Leo	111
	2147

IOWA TOWNSHIPS - 80 MILE RADIUS
LAKE MADISON

LYON COUNTY		OSCEOLA COUNTY		SIOUX COUNTY	
TOWNSHIPS	POPULATION	TOWNSHIPS	POPULATION	TOWNSHIPS	POPULATION
Allison	242	Gilman	797	Buncombe	1956
Centennial	224	Holman	3494	Capel	529
Cleveland	362	Viola	167	Center	399
Dale	290	Wilson	192	Eagle	345
Doon	1096			Garfield	229
Elgin	688		4650	Lincoln	2288
Garfield	355			Logan	826
Grant	327			Lynn	392
Larchwood	1224			Plato	618
Liberal	490			Reading	902
Logan	364			Rock	3346
Lyon	268			Settlers	125
Midland	204			Sheridan	1106
Richland	1166			Sioux	334
Riverside	408			Washington	252
Rock	2740			Welcome	1294
Sioux	285			West Branch	5230
Wheeler	1219				
					20171
	11952				

TOTAL TOWNSHIP POPULATION	=	36773
TOTAL CITY POPULATION	=	1252
TOTAL POPULATION		38025

CITIES & TOWNS	POPULATION	CITIES & TOWNS	POPULATION	CITIES & TOWNS	POPULATION
		Ashton	462	Boyden	640
		Sibley	2815	Chetsworth	103
				Hawarden	1850
			3277	Hull	1724
				Matlock	92
				Rockvalley	2492
				Sioux Center	5074
					11975

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APPENDIX D

SOUTH DAKOTA TOWNSHIPS - 80 MILE RADIUS
LAKE MADISON

AURORA COUNTY		BEADLE COUNTY		BON HOMME COUNTY		BROOKINGS COUNTY	
TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME
Aurora	8700	Allen	11042	NE Bon Homme	8350	Afton	13865
Belford	5768	Altoona	9524	NW Bon Homme	9031	Alton	9068
Bristol	3813	Banner	12783	SE Bon Homme	8266	Argo	8264
Center	4838	Barrett	7679			Aurora	13746
Cooper	-	Belle Prairie	11917			Bangor	8101
Crystal Lake	4692	Bonilla	2457			Brookings	12743
Dudley	7042	Broadland	5988			Elkton	10724
Eureka	29981	Burr Oak	8176			Eureka	10058
Firesteel	7487	Carlyle	6317			Lake Hendricks	8758
Hopper	11332	Cavour	9915			Lake Sinai	8297
Lake	5916	Clifton	7142			Laketon	12680
Palatine	5041	Clyde	11278			Medary	11493
Patten	2773	Custer	6792			Oak Lake	9964
Plankinton	6594	Dearborn	7771			Oakwood	9312
Pleasant Lake	5893	Fairfield	9820			Oslo	10126
Pleasant Valley	38079	Foster	8170			Parnell	10762
Truro	6724	Grant	14230			Preston	13502
White Lake	8271	Hartland	10770			Richland	7225
		Iowa	4368			Sherman	8911
		Kellogg	8843			Sterling	12428
		Lake Byron	12792			Trenton	12614
		Liberty	11234			Volga	11319
		Logan	889			Winsor	11243
		Milford	4845				
		Pearl Creek	5446				
		Pleasant View	6662				
		Richland	10499				
		Sand Creek	5593				
		Theresa	11864				
		Valley	10207				
		Vernon	11506				
		Wessington	6848				
		Whiteside	8251				
		Wolsey	9809				

CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME
Plankinton	10024	Broadland	9877	Scotland	8607	Arlington	8000
Stickney	7630	Cavour	7731	Tabor	8252	Aurora	8845
		Hitchcock	8487	Tyndall	8886	Brookings	9723
		Huron	11091			Bruce	9435
		Iroquois	8644			Bushnell	7775
		Virgil	7167			Elkton	9487
		Wessington	9358			Sinai	9847
		Wolsey	9809			Volga	9719
		Yale	9967			White	7528

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SOUTH DAKOTA TOWNSHIPS - 80 MILE RADIUS
LAKE MADISON

CHARLES MIX		CLARK COUNTY		CLAY COUNTY		CODINGTON COUNTY	
TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME
Choteau Creek	7333	Ash	15557	Bethel	9599	Dexter	11560
Kennedy	9359	Blaine	12981	Garfield	12667	Eden	7253
		Collins	11249	Glenwood	9337	Elmira	11034
		Cottonwood	5388	Meckling	15311	Fuller	9731
		Darlington	18752	Pleasant Valley	15863	Germantown	14172
		Day	9967	Prairie Center	13420	Graceland	11714
		Eden	6657	Riverside	10758	Henry	5780
		Elrod	9153	Spirit Mound	8771	Kampeska	12190
		Fordham	3647	Star	10714	Kranzburg	7768
		Foxton	6359			Lake	12801
		Garfield	7957			Leola	11557
		Hague	7123			Pelican	8617
		Lake	8977			Phipps	12845
		Lincoln	8561			Rauville	12989
		Logan	13765			Richland	11216
		Maydell	13064			Sheridan	9116
		Merton	10652			Waverly	7755
		Mount Pleasant	7907				
		Pleasant	10621				
		Raymond	9155				
		Richland	12449				
		Rosedale	4564				
		Thorp	8881				
		Washington	9219				
		Woodland	17038				

CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME
		Bradley	6765	Wakonda	7973	Florence	8131
		Clark	8999			Henry	8216
		Garden City	12975			Kranzburg	8507
		Naples	5248			South Shore	6836
		Raymond	7259			Wallace	11411
		Vienna	6165			Watertown	10660
		Willow Lake	10105				

SOUTH DAKOTA TOWNSHIPS - 80 MILE RADIUS
LAKE MADISON

DAVISON COUNTY		DAY COUNTY		DEUEL COUNTY		DOUGLAS COUNTY	
TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME
Badger	6652	Egeland	10190	Altamont	8962	Belmont	14668
Baker	4404			Antelope Valley	8892	Chester	8232
Beulah	8430			Blom	11432	East Choteau	4027
Blendon	4723			Brandt	8669	Garfield	8024
Lisbon	2889			Clear Lake	8674	Grandview	7552
Mitchell	12901			Glenwood	8250	Holland	7672
Mount Vernon	8862			Goodwin	9628	Independence	6595
Perry	10501			Grange	9898	Iowa	4563
Prosper	11445			Havana	11106	Lincoln	8464
Rome	8807			Herrick	8254	Valley	10116
Tobin	8586			Hidewood	10473	Walnut Grove	9633
Union	12886			Lowe	8653	Washington	4732
				Norden	7606		
				Portland	4161		
				Rome	18775		
				Scandinavia	8251		

CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME
Ethan	5638			Altamont	8568	Armour	8842
Mitchell	10272			Astoria	7751	Corsica	7951
Mount Vernon	9051			Brandt	6074	Delmont	7492
				Clear Lake	9472		
				Gary	7495		
				Goodwin	10557		
				Toronto	7852		

SOUTH DAKOTA TOWNSHIPS - 80 MILE RADIUS
LAKE MADISON

GRANT COUNTY TOWNSHIPS	PC INCOME	HAMLIN COUNTY TOWNSHIPS	PC INCOME	HANSON COUNTY TOWNSHIPS	PC INCOME	HUTCHINSON COUNTY TOWNSHIPS	PC INCOME
Adams	8721	Brandtford	10786	Beulah	9451	Capital	8202
Georgia	9947	Castlewood	10701	Edgerton	7825	Clayton	9170
Lura	7788	Cleveland	12374	Fairview	8818	Cross Plains	5230
Madison	14975	Dempster	3392	Hanson	14157	Fair	7425
Mazeppa	9297	Dixon	21150	Jasper	9874	Foster	2789
Stockholm	8751	Estelline	8780	Plano	9036	German	2793
Troy	10509	Florence	9060	Pleasant	6351	Grandview	7636
Twin Brooks	9940	Garfield	6345	Rosedale	12411	Kassel	7954
Vernon	16738	Hamlin	9239	Spring Lake	12510	Kaylor	18560
		Hayti	9283	Taylor	8830	Kulm	6065
		Norden	9207	Wayne	6135	Liberty	6994
		Opdahl	7193	Worthen	15550	Milltown	5296
		Oxford	10662			Molan	13397
						Oak Hollow	14679
						Pleasant	7149
						Sharon	6795
						Silver Lake	10845
						Starr	4989
						Susquehanna	5009
						Sweet	8331
						Valley	8516
						Wittenberg	23156
						Wolf Creek	8530

CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME
Albee	8884	Bryant	7799	Alexandria	9442	Dimock	6279
La Bolt	6606	Castlewood	8258	Emery	8211	Freeman	11082
Revillo	7544	Estelline	8487	Farmer	10699	Menno	9222
Stockholm	8751	Hayti	11673	Fulton	13124	Olivet	11065
Strandburg	8947	Hazel	9621			Parkston	9532
		Lake Norden	9585			Tripp	9804

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SOUTH DAKOTA TOWNSHIPS - 80 MILE RADIUS
LAKE MADISON

JERAULD COUNTY		KINGSBURY COUNTY		LAKE COUNTY		LINCOLN COUNTY	
TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME
Alpena	10354	Badger	7933	Badus	13199	Brooklyn	12025
Anina	27706	Baker	9176	Chester	9345	Canton	10955
Blaine	11865	Denver	9078	Clarno	9401	Dayton	12329
Chery	11897	De Smet	12709	Concord	7432	Delapre	13821
Crow Lake	11464	Esmond	16767	Farmington	12592	Delaware	10474
Dale	3982	Hartland	12456	Franklin	11774	Eden	11218
Franklin	8842	Iroquois	9048	Herman	9459	Fairview	9225
Harmony	8045	Le Sueur	7779	Lake View	27709	Grant	10317
Media	6841	Manchester	5870	Le Roy	21190	Highland	17471
Pleasant	8637	Mathews	12160	Nunda	7803	La Valley	13184
Viola	8070	Spirit Lake	17174	Orland	6679	Lincoln	10295
Wessington Springs	9350	Spring lake	8635	Rutland	9337	Lynn	9834
		Whitewood	11921	Summit	8849	Norway	12481
				Wayne	6342	Perry	10760
				Wentworth	11038	Pleasant	8593
				Winfred	8300	Springdale	13988

CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME
Alpena	10336	Arlington	9557	Madison	10824	Beresford	9259
Lane	5772	Badger	8398	Nunda	9410	Canton	11636
Wessiongton Springs	10241	Bancroft	7892	Ramona	9608	Fairview	11473
		De Smet	10161	Wentworth	9232	Harrisburg	9873
		Erwin	10324	Winfred	7905	Hudson	9585
		Hetland	8200			Lennox	9945
		Iroquois	7931			Sioux Falls	20919
		Lake Preston	9034			Tea	9882
		Oldham	9617			Worthing	8571

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SOUTH DAKOTA TOWNSHIPS - 80 MILE RADIUS
LAKE MADISON

McCOOK COUNTY		MINER COUNTY		MINNEHAHA COUNTY		MOODY COUNTY	
TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME
Benton	7284	Adams	16483	Benton	10528	Alliance	9277
Bridgewater	8664	Beaver	2564	Brandon	16751	Blinsmon	8084
Brookfield	16704	Belleview	8066	Buffalo	8489	Clare	10753
Canistota	11389	Canova	18189	Burk	14248	Colman	10813
Emery	10217	Carthage	6711	Clear Lake	7316	Egan	7321
Grant	8703	Clearwater	9071	Dell Rapids	14407	Enterprise	11819
Greenland	12263	Clinton	11002	Edison	10989	Flandreau	9893
Jefferson	8997	Grafton	19867	Grand Meadow	7850	Fremont	10983
Montrose	9310	Green Valley	13732	Hartford	13124	Grovena	9083
Pearl	9726	Henden	7213	Highland	13619	Jefferson	17389
Ramsey	10840	Howard	12313	Humbolt	9647	Lone Rock	15766
Richland	8376	Miner	10124	Logan	8844	Lynn	9013
Salem	10585	Redstone	4597	Lyons	11445	Riverview	8297
Spring Valley	6659	Rock Creek	8609	Mapleton	17588	Spring Creek	11036
Sun Prairie	8491	Roswell	10183	Palisade	10961	Union	11133
Union	7544	Vermillion	9010	Red Rock	12047	Ward	8240
				Split Rock	18563		
				Sverdup	10064		
				Taopi	11120		
				Valley Springs	21924		
				Wall Lake	11640		
				Wayne	13446		
				Wellington	11947		

CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME
Bridgewater	10196	Canova	7192	Baltic	10557	Colman	12248
Canistota	8816	Carthage	8986	Brandon	12069	Egan	10474
Montrose	8638	Howard	9529	Colton	9755	Flandreau	9630
Salem	10377	Roswell	3600	Crooks	9085	Trent	9467
Spencer	9235	Vilas	5674	Dell Rapids	10397	Ward	12340
				Garretson	10179		
				Hartford	9878		
				Humboldt	10052		
				Sherman	10899		
				Sioux Falls	13574		
				Valley Springs	10171		

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SOUTH DAKOTA TOWNSHIPS - 80 MILE RADIUS
LAKE MADISON

SANBORN COUNTY		SPINK COUNTY		TURNER COUNTY		UNION COUNTY	
TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME
Afton	9588	Antelope	5678	Brothersfield	12447	Alcestor	8781
Benedict	6903	Belle Plaine	10411	Centerville	10820	Big Springs	6668
Butler	6173	Belmont	8280	Childstown	8386	Emmet	3850
Diana	12143	Capitola	12206	Daneville	9917	Prairie	9773
Elliott	8972	Cornwall	13565	Dolton	9135	Sioux Valley	7944
Floyd	15025	Crandon	18691	Germantown	13007	Spink	13246
Jackson	8240	Frankfort	3247	Home	12663	Virginia	8093
Letcher	7386	Harrison	15782	Hurley	9019		
Logan	8608	Lincoln	666	Marion	8159		
Oneida	9758	Prairie Center	7610	Middleton	11423		
Ravena	7755	Richfield	28117	Monroe	11513		
Silver Creek	16659	Spring	5229	Norway	8277		
Twin Lake	9169	Union	6257	Parker	9392		
Union	10363			Rosefield	10649		
Warren	9901			Salem	9379		
Woonsocket	14767			Spring Valley	7031		
				Swan Lake	7489		
				Turner	8568		

CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC ICNOME	CITIES & TOWNS	PC INCOME
Artesian	8493	Doland	9162	Centerville	9384	Alcestor	9665
Letcher	7321			Chancellor	9722	Beresford	10544
Woonsocket	7567			Davis	12350		
				Dolton	5717		
				Hurley	9192		
				Irene	9129		
				Marion	9052		
				Monroe	6954		
				Parker	8629		
				Viborg	8452		

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SOUTH DAKOTA TOWNSHIPS - 80 MILE RADIUS
LAKE MADISON

YANKTON COUNTY

TOWNSHIPS	PC INCOME
Gayville	10631
Jamesville	5163
Marindahl	8459
Mayfield	7765
Mission Hill	10389
Southeast Yankton	9182
Turkey Valley	7291
Utica	7023
Volin	8874
Walshton	7675
West yankton	10430

CITIES & TOWNS	PC INCOME
Gayville	9885
Irene	13292
Lesterville	8145
Mission Hill	8514
Utica	7918
Volin	7816
Yankton	10964

MINNESOTA TOWNSHIPS - 80 MILE RADIUS
LAKE MADISON

LAC QUI PARLE COUNTY

TOWNSHIPS	PC INCOME
Arena	17130
Augusta	30628
Freeland	9069
Garfield	9066
Hamlin	9862
Manfred	4929
Maxwell	10755
Mehurin	9459
Providence	9940
Ten Mile Lake	10864

LINCOLN COUNTY

TOWNSHIPS	PC INCOME
Alta Vista	10298
Ash Lake	7717
Diamond Lake	9454
Drammen	8746
Hansonville	8024
Hendricks	8714
Hope	9830
Lake Benton	9998
Lake Stay	6659
Limestone	7822
Marble	8689
Marshfield	10748
Royal	9220
Shaokatan	11414
Verdi	8706

LYON COUNTY

TOWNSHIPS	PC INCOME
Amiret	9932
Clifton	11394
Coon Creek	9913
Custer	10588
Eidsvold	9450
Fairview	10298
Grandview	11312
Island Lake	9091
Lake Marshall	14365
Lucas	10412
Lynd	13257
Lyons	9143
Monroe	10498
Nordland	8892
Rock Lake	8790
Shelburne	11298
Sodus	9131
Stanley	10237
Vallers	9925
Westerheim	11198

MURRAY COUNTY

TOWNSHIPS	PC INCOME
Belfast	9349
Bondin	9354
Cameron	11096
Chanarambie	12744
Des Moines River	11112
Dovray	12867
Ellsborough	10244
Fenton	9322
Holly	10791
Iona	10611
Lake Sarah	11839
Leeds	10277
Lime Lake	11486
Lowville	9269
Mason	14447
Moulton	8050
Murray	8843
Shetek	11136
Skandia	10389
Slayton	10920

LAC QUI PARLE COUNTY

CITIES & TOWNS	PC INCOME
Boyd	7441
Marietta	9002

LINCOLN COUNTY

CITIES & TOWNS	PC INCOME
Arco	7923
Hendricks	10497
Ivanhoe	9596
Lake Benton	10020
Tyler	10323

LYON COUNTY

CITIES & TOWNS	PC INCOME
Balaton	9081
Florence	6803
Garvin	7598
Ghent	10115
Lynd	9529
Marshall	11851
Minneota	9630
Russell	9482
Taunton	8782
Tracy	10908

MURRAY COUNTY

CITIES & TOWNS	PC INCOME
Avoca	9516
Chandler	13819
Dovray	14200
Fulda	11408
Hadley	8530
Iona	6920
Lake Wilson	11503
Slayton	10806

MINNESOTA TOWNSHIPS - 80 MILE RADIUS
LAKE MADISON

NOBLES COUNTY		PIPE STONE COUNTY		REDWOOD COUNTY		ROCK COUNTY	
TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME
Bigelow	10439	Aetna	8030	Gales	10476	Battle Plain	17588
Bloom	7183	Altona	8155	Springdale	12748	Beaver Creek	10010
Dewald	11334	Burke	8863	Westline	8250	Clinton	8724
Elk	11176	Eden	11330			Denver	10472
Graham Lakes	13374	Elmer	7665			Kanaranzi	13406
Grand Prairie	9733	Fountain Prairie	13609			Luverne	11135
Hersey	9499	Grange	10016			Magnolia	10124
Larkin	9631	Gray	13027			Martin	10391
Leota	8857	Osborne	8181			Mound	10395
Lismore	11925	Rock	10064			Rose Dell	9956
Little Rock	10100	Sweet	11166			Springwater	11203
Lorain	13098	Troy	9593			Vienna	10487
Olney	9692						
Ransom	8836						
Seward	11397						
Summit Lake	10449						
Westside	9186						
Wilmont	9393						
Worthington	13824						

CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME
Adrian	10747	Edgerton	10487			Beaver Creek	9993
Bigelow	8738	Hatfield	10879			Hardwick	8269
Dundee	11065	Holland	7745			Hills	10245
Ellsworth	8826	Ihlen	10576			Jasper	6854
Lismore	9523	Jasper	10381			Kenneth	14041
Round Lake	10884	Pipestone	10317			Luverne	12388
Rushmore	9186	Ruthton	7339			Magnolia	8181
Wilmont	9163	Trosky	11540			Steen	9237
Worthington	11477	Woodstock	8778				

MINNESOTA TOWNSHIPS - 80 MILE RADIUS
LAKE MADISON

YELLOW MEDICINE COUNTY

TOWNSHIPS	PC INCOME
Burton	8920
Florida	9109
Fortier	9759
Friendship	9872
Hammer	7630
Norman	9793
Normania	13116
Omro	8739
Oshkosh	11210
Swede Prairie	17859
Tyro	10298
Wergeland	8482

CITIES & TOWNS	PC INCOME
Canby	10527
Porter	8720
St. Leo	10000

IOWA TOWNSHIPS - 80 MILE RADIUS
LAKE MADISON

LYON COUNTY		OSCEOLA COUNTY		SIOUX COUNTY	
TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME	TOWNSHIPS	PC INCOME
Allison	6091	Holman	13013	Buncombe	11133
Centennial	13705	Viola	10354	Eagle	6329
Cleveland	10448			Garfield	15872
Dale	6380			Lincoln	10362
Doon	8319			Plato	9492
Elgin	9271			Rock	11050
Garfield	8202			Sheridan	9595
Grant	5678			Sioux	8140
Larchwood	10052			Welcome	10118
Liberal	9043				
Logan	8396				
Lyon	7647				
Midland	9509				
Richland	11095				
Riverside	10439				
Rock	11636				
Sioux	12060				
Wheeler	9640				

CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME	CITIES & TOWNS	PC INCOME
				Hawarden	8509
				Hull	10537
				Rockvalley	11399

Compiled by the SDSU Census Data Center - Brookings, SD 57007

End of Lake Madison-Brant Lake Final Report

SD Department of Environment & Natural Resources
Watershed Protection Program
Total Maximum Daily Load

Lake Madison / Brant Lake Watershed,
Lake County South Dakota
January, 1999

These TMDLs were developed in accordance with Section 303(d) of the federal Clean Water Act and guidance developed by the US Environmental Protection Agency. The 1998 303(d) Waterbody List identified Lake Madison and Brant Lake as impaired by a measure of Trophic State Index (TSI) which serves as an indicator of the trophic condition of the lake. TMDLs for total phosphorus have been developed and are supported below.

TMDL Summary

Waterbody Name	**Lake Madison**
Hydrologic Unit Code (HUC)	10170203
TMDL Pollutant	**Total phosphorus**
Water Quality Target	Chlorophyll *a* Trophic State Index (TSI) of 50
TMDL Goal	50% reduction in total phosphorus
303(d) Status	1998 303(d) Waterbody List; Priority 1, Page 20, 29, 32
Impaired Beneficial Uses	Warmwater permanent fish life propagation; immersion recreation; limited contact recreation
Reference Document	Phase I Watershed Assessment Final Report - Madison Lake/Brant Lake, Lake County SD (SDDENR, 1998)

TMDL Summary

Waterbody Name	**Brant Lake**
Hydrologic Unit Code (HUC)	10170203
TMDL Pollutant	**Total phosphorus**
Water Quality Target	Chlorophyll *a* Trophic State Index (TSI) of 50
TMDL Goal	50% reduction in total phosphorus
303(d) Status	1998 303(d) Waterbody List; Priority 1, Page 20, 29, 32
Impaired Beneficial Uses	Warmwater permanent fish life propagation; immersion recreation; limited contact recreation
Reference Document	Phase I Watershed Assessment Final Report - Madison Lake/Brant Lake, Lake County SD (SDDENR, 1998)

I. *Executive Summary:*

- ***Waterbody Description and Impairments***

Lake Madison and Brant Lake are located in Lake County, South Dakota. Lake Madison, Brant Lake and Lake Herman form a chain of lakes connected by a single tributary. The tributary joining the three lakes is Silver Creek (Figure 2).

Lake Madison is a hypereutrophic natural lake of glacial origin located approximately three miles southeast of the city of Madison, South Dakota. The lake has a surface area of 2,799 acres (1,132 ha) and mean depth of 9.7 ft. (3.0 m). The lake has a heavily developed shoreline with cabins and permanent homes. Public access to the lake is excellent and the lake experiences very high use. According to 1990 census figures, the population within a 65-mile radius is 270,159.

Lake Madison has been included in South Dakota's Statewide Lakes Assessment sampling since 1989. The mean Carlson Trophic State Index (TSI) is 74.15, which is typical of hypereutrophic conditions. There is an established sanitary district encompassing the entire shoreline. Sanitary treatment consists of a central collection facility and infiltration-percolation basins.

Brant lake is a 1,000 acre (405 ha) lake of glacial origin located 1.5 miles northwest of the town of Chester, South Dakota and 2 miles southeast of Lake Madison. Brant Lake has a highly developed shoreline with cabins and permanent homes. The mean depth of the lake is 11 ft. (3.4 m). Data from 1989 indicates that Brant Lake has a mean TSI of 70.73 which is indicative of hypereutrophic conditions. Sanitary treatment around the lakeshore currently consists of privately owned septic tanks and drain fields.

During the 1993 flood event, Brant Lake and Lake Madison experienced damage to shorelines and homes due to high water. Brant Lake had a catastrophic failure of a shoreline stabilization project due to the high water and wind erosion.

- ***Stakeholder Description***

The Lake Conservation District was the local sponsor of the water quality assessment project. Both lakes were listed as a priority of the Section 319 Nonpoint Source Pollution Control Program for South Dakota. Funds for the project were obtained from Section 314 Clean Lakes funds ($100,000) administered by the Environmental Protection Agency (EPA) and granted to the State of South Dakota. The 30 % local match ($42,857) needed for the project was provided by the conservation district and the two lake associations. Figure 1 lists the participants and stakeholders during the assessment project.

Figure 1. List of stakeholders

Ron Byrd, Local Coordinator	City of Madison
Lake County Conservation District	Lake County
Natural Resource Conservation Service - Lake County	SD Dept GF&P
	SD DENR - Water Rights
Lake Madison Association	SD DENR - Environmental Services
Lake Madison Sanitary District	SD DENR - Watershed Protection
Brant Lake Association	US EPA - Clean Lakes Program

- ***Intent to Submit as a Clean Water Act Section 303(d) TMDL***

In accordance with Section 303(d) of the Clean Water Act, the South Dakota Department of Environment and Natural Resources submits for EPA, Region VIII review and approval, the total maximum daily load (TMDL) for total phosphorus for Lake Madison and the TMDL for total phosphorus for Brant Lake as provided in this summary and attached document. These TMDLs have been established at a level necessary to meet the applicable water quality standards for nutrients with consideration of seasonal variation and a margin of safety. The following designated use classifications will be protected through implementation of these TMDLs: warmwater permanent fish life propagation, immersion recreation and limited contact recreation.

II. Problem Characterization:

- ***Maps*** **(See Figure 2 below)**
- ***Waters Covered by TMDL***

Lake Madison
Brant Lake

- ***Rationale for Geographic Coverage***

The individual watersheds of Lake Madison and Brant Lake encompass 29,191 acres (11,813 ha) and 7,658 acres (3,099 ha), respectively. The size of the combined watershed is 36,849 acres (14,912 ha). For the purpose of this study, the two-lake drainage were treated as a single system. The watershed of Lake Herman was not included in this study as a previous assessment had already been done for Lake Herman. The watershed area under investigation was from the Lake Herman outlet to the Skunk Creek outlet of Brant Lake.

Land use is primarily agricultural with a community of 6,257 people (Madison, SD) within the watershed. Agricultural land use is approximately 84% cropland and 15% grass or pasture. Animal feeding operations for beef, swine and poultry are scattered throughout the watershed. Major soil associations include Egan-Viborg, Egan-Wentworth, and Dempster.

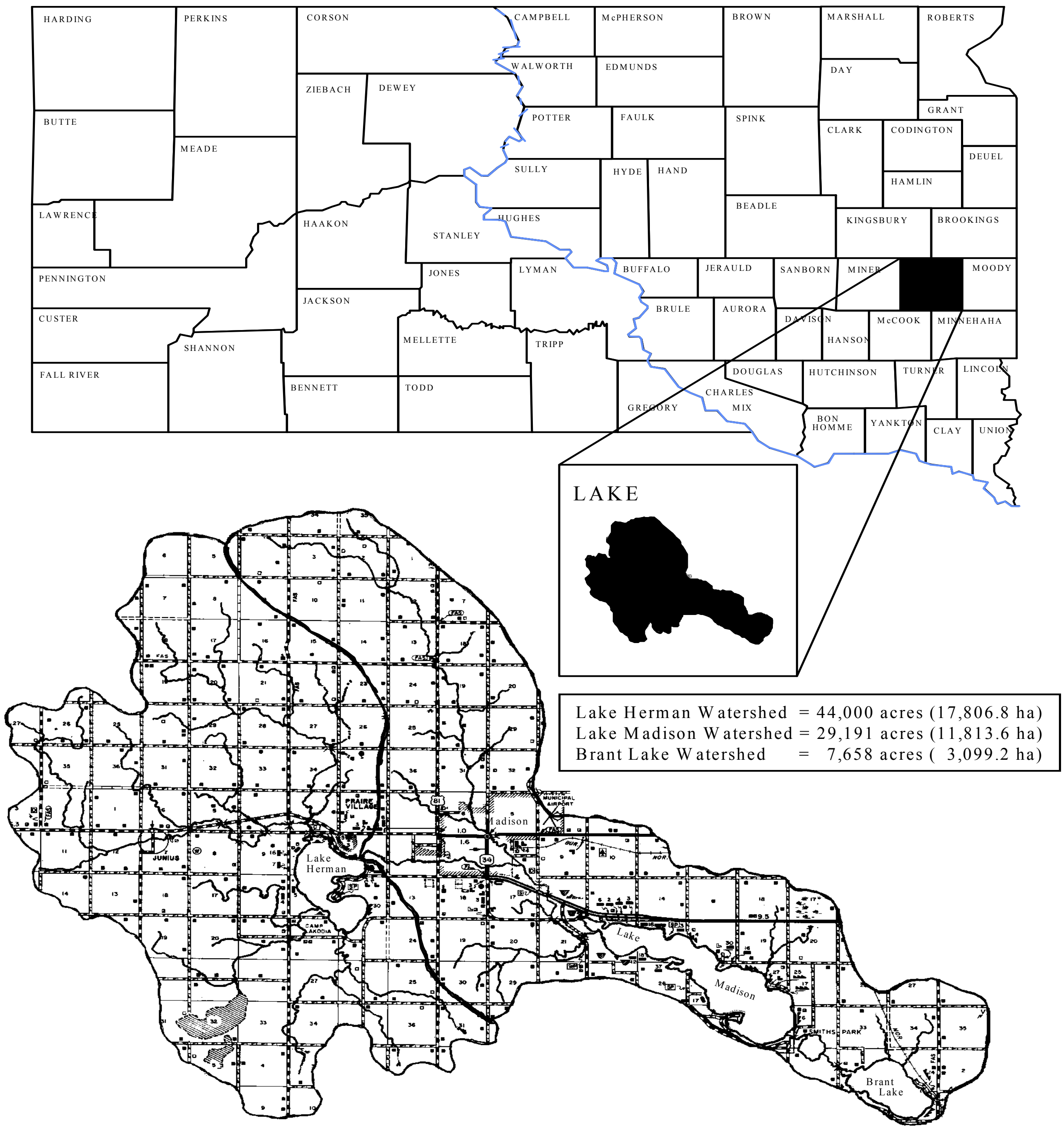


Figure 2. Lake Herman, Lake Madison, and Brant Lake Watershed in Lake County, South Dakota.

The city of Madison has some light industrial business and storm sewers which drain directly to Silver Creek above Lake Madison. Agbusinesses pertaining to sales and storage of fertilizers and pesticides are located within the city.

Brant Lake has three public access areas that offer boat ramps, shore fishing, and toilet facilities. Lake Madison has four state-owned public access areas offering camping, picnic areas, shore fishing, boat ramps, swimming areas and toilet facilities. Both lakes are located within convenient driving distance of the city of Sioux Falls, SD (population +100,000). As a result, these lakes experience heavy recreational use during the spring, summer and fall.

- ***Pollutant(s) of Concern***

Total phosphorus

- ***Use Impairments or Threats***

Since blue-green algae are not only able to assimilate phosphorus but can assimilate several kinds of nitrogen, a total nitrogen to phosphorus ratio was used to determine the limiting nutrient. When the total nitrogen to phosphorus ratio increases to 7:1, blue-green algae appear to be phosphorus limited. The average total nitrogen to phosphorus ratio for Lake Madison was 29:1. Brant Lake exhibited the phosphorus limitation phenomenon. The average total nitrogen to phosphorus ratio for Brant Lake was 25:1. The mean total phosphorus TSI was 84 for Lake Madison and 77 for Brant Lake. The hypereutrophic range of the TSI begins at 65. The TSI's from Lake Madison and Brant Lake indicate that both lakes are in the hypereutrophic range.

Lake Madison and Brant Lake are assigned the following water quality beneficial uses:

(4) Warmwater Permanent Fish Life Propagation
(7) Immersion Recreation
(8) Limited Contact Recreation
(9) Wildlife Propagation and Stock Watering

Both lakes experience winter kills due to snow cover and decreased photosynthesis, resulting in anoxia. This phenomenon also occurs over the summer when there is not enough oxygen produced to maintain the high rate of biodegradation due to the tremendous amount of organic matter (algae blooms). The predominant forms of algae during the summer are blue-green. These blue-green blooms can create super-oxygenated conditions but can also undergo respiration, reducing oxygen levels even more during the evening and dark hours. The filamentous taxon *Aphanizomenon flos-aquae* was the dominant form identified during the study period. *Aphanizomenon* species are commonly identified as problem algae related to eutrophication, taste and odor problems, toxicity and aesthetic nuisance (Taylor, 1974).

- ***Probable Sources***

Possible sources of high nutrient and sediment loads were identified as high slopes and bank erosion due to lack of riparian vegetation as well as crop and lawn fertilization. Confined and pastured livestock feeding areas were also identified as significant sources.

III. TMDL Endpoint:

- ***Description***

A model (Vollenweider and Kerekes, 1980) was used to estimate the effects of reducing phosphorus in the watershed for both Lake Madison and Brant Lake. The model predicts a 50% reduction of tributary loadings to Lake Madison and Brant Lake results in a reduction in chlorophyll *a* concentration by 88% and 90%, respectively. If this reduction is reached, the TSI ranking for chlorophyll *a* will be reduced to mesotrophic for both lakes. However, a more realistic goal, based on best professional judgement, is a reduction of 40% for the tributary loadings. This would substantially reduce the chlorophyll *a* concentrations for each lake by 79% and 72%, respectively. The TSI ranking for chlorophyll *a* would fall within the lower end of the eutrophic range which begins at 50.

Reduction/Response Model

Inlake total phosphorus concentrations are a function of the total phosphorus load delivered to the lake by the watershed. Vollenweider and Kerekes (1980) developed a mathematical relationship for inflow of total phosphorus and the inlake total phosphorus concentration. They assumed that if you change the inflow of total phosphorus you change inlake phosphorus concentration a relative but steady amount over time. The variables used in the relationship are:

1) $\left[\overline{P}\right]\lambda$ = Average inlake total phosphorus concentration
2) $\left[\overline{P}\right]i$ = Average concentration of total phosphorus which flow into the lake
3) $\overline{T}_p$ = Average residence time of inlake total phosphorus
4) $\overline{T}_w$ = Average residence time of lake water

Reduction/Response Model (Lake Madison)

Data collected during the project (1994 and 1995) provided enough information to estimate $\left[\overline{P}\right]\lambda$, $\left[\overline{P}\right]i$, and $\overline{T}_w$. In order to estimate the residence time of total phosphorus ($\overline{T}_p$) it was necessary to back calculate Equation 5 below, and solve for $\overline{T}_p$ by forming Equation 6 (Wittmuss, 1996).

{Equation 5} $$\left[\overline{P}\right]\lambda = \left[\frac{\overline{T}_p}{\overline{T}_w}\right]\left[\overline{P}\right]i$$

{Equation 6} $$\left(\overline{T}_p\right) = \frac{\left[\overline{P}\right]\lambda}{\left[\overline{P}\right]i}\left(\overline{T}_w\right)$$

Values for $\left[\overline{P}\right]\lambda$, $\left[\overline{P}\right]i$, $\overline{T}_w$ were determined in the following manner:

$\left[\overline{P}\right]\lambda$ was determined by averaging all of the surface total phosphorus samples from 1994-95 collection period.

$\left[\overline{P}\right]i$ was determined by adding all of the input loadings for total phosphorus in milligrams and dividing that number by the total number of liters that entered the lake. The values for both of these numbers came from tributaries, groundwater, and the atmosphere.

$\overline{T}_w$ was determined by averaging the total volume of Lake Madison (27,153 acre-feet) by the total inputs of water into the lake (40,101 acre-feet/days of discharge measurements).

$$\overline{T}_w = {}^{27{,}153 acre-feet}\!\Big/_{40{,}101 acre-feet/234 days} = 158.4 \text{ days} = 0.434 \text{ year}$$

The final values for $\left[\overline{P}\right]\lambda$ and $\left[\overline{P}\right]i$ are:

$\left[\overline{P}\right]\lambda = 0.254$ mg/L $\qquad$ $\left[\overline{P}\right]i = 0.231$ mg/L

By placing the numbers in the proper places as discussed in Equation 3, $\overline{T}_p$ would be:

$$\left(\overline{T}_p\right) = \left[\frac{0.254}{0.231}\right](0.434) = 0.478 \text{ years} = 175 \text{ days}$$

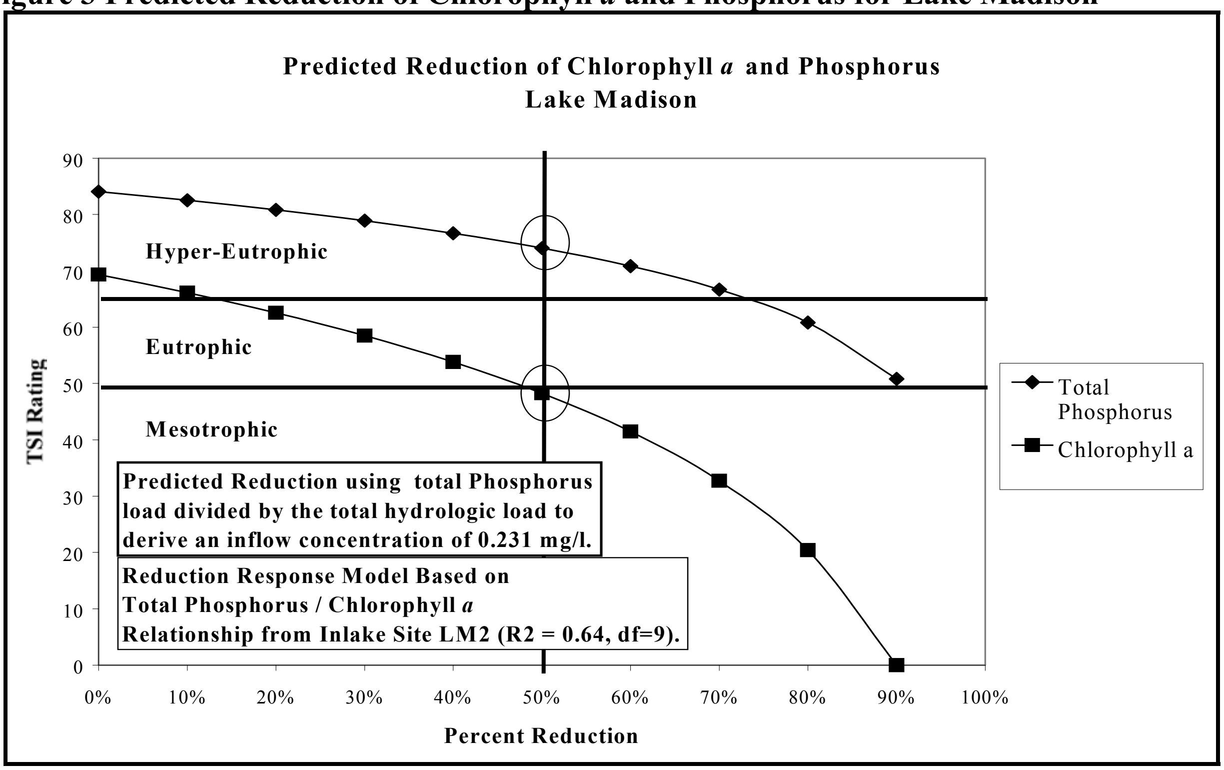
Referring back to Equation 5, reducing the inputs of total phosphorus, the equation estimates the reduction of inlake total phosphorus. This is assuming constant inputs of water. Theoretically the retention time for total phosphorus should also be reduced. With only one year of sampling, there is no way to estimate the reduction in the retention time of total phosphorus. The $\overline{T}_p$ constant (0.478) derived from the data was used in Equation 5. After estimating the amount of reduction of inlake phosphorus after a reduction of input phosphorus, Equation 3 (page 87) can be used to see the reduction of chlorophyll *a*. As can be seen in Table 1, a 50% reduction in phosphorus inputs to Lake Madison will reduce the inlake chlorophyll *a* concentration by an estimated 88%. The 50% reduction would also lower the chlorophyll TSI value to the mesotrophic line (Figure 3). As stated above, this is considering no reduction in the retention time of total phosphorus. If the retention time is lowered, the lake should experience even lower inlake concentrations and lower chlorophyll *a* concentrations. As the input concentrations of phosphorus are lowered, the lake will see algal blooms that are less intense and of a shorter duration. These tables and graphs are predictive on the data collected during the study. Actual changes can be expected to be different depending on runoff values and the extent of change that occurs in the volume of water passing through Lake Madison.

Table 1. Effects of Reducing Phosphorus to Lake Madison

Reduction of Phosphorus Inputs	Input Phos Concentration	InLake Phos Concentration[1]	Chlorophyll *a*	Percent Reduction Chlorophyll *a*	Phosphorus TSI	Chlorophyll TSI
0%	0.231	0.254	52.08	0%	84.05	69.35
10%	0.208	0.229	37.57	28%	82.53	66.14
20%	0.185	0.203	26.08	50%	80.83	62.56
30%	0.162	0.178	17.24	67%	78.91	58.50
40%	0.139	0.153	10.69	79%	76.68	53.81
50%	0.115	0.127	6.08	88%	74.05	48.27
60%	0.092	0.102	3.04	94%	70.83	41.49
70%	0.069	0.076	1.25	98%	66.68	32.74
80%	0.046	0.051	0.36	99%	60.83	20.41
90%	0.023	0.025	0.04	100%	50.83	N/A

[1] Inlake phosphorus concentrations must be converted from mg/L to mg/m^3 before using Equation 1 to predict chlorophyll *a*.

Figure 3 Predicted Reduction of Chlorophyll *a* and Phosphorus for Lake Madison



Reduction Response Model (Brant Lake)

The variables used in this process were the same variables as those used for Lake Madison.

The residence time of total phosphorus ($\overline{T_p}$) was calculated using the same manner described previously through the use of Equation 5 and 6.

$$\{\text{Equation 5}\}\quad [\overline{P}]\lambda = \left[\frac{\overline{T}_p}{\overline{T}_w}\right][\overline{P}]i$$

$$\{\text{Equation 6}\}\quad (\overline{T}_p) = \frac{[\overline{P}]\lambda}{[\overline{P}]i}(\overline{T}_w)$$

1. Values for $[\overline{P}]\lambda$, $[\overline{P}]i$, $\overline{T}_w$ were:
2. $[\overline{P}]\lambda$ was determined by averaging all of the surface total phosphorus samples from the 1994-95 collection period.
3. $[\overline{P}]i$ was determined by adding all of the input loadings for total phosphorus in milligrams and dividing that number by the total number of liters of water that entered the lake. The values for both of these numbers came from tributaries, groundwater, and the atmosphere.
4. $\overline{T}_w$ was determined by averaging the total volume of Brant Lake (11,000 acre-feet) by the total inputs of water into the lake (46,969 acre-feet/days of discharge measurements).
5. $\overline{T}_w = \frac{11{,}000 acre-feet}{46{,}969 acre-feet/234 days}$ = 55 days = 0.15 year

6. The final values for $[\overline{P}]\lambda$ and $[\overline{P}]i$ are:
   $[\overline{P}]\lambda$ = 0.170 mg/L $[\overline{P}]i$ = 0.196 mg/L

   By placing the numbers in the proper places as discussed in Equation 3, $\overline{T}_p$ would be:

$$(\overline{T}_p) = \left[\frac{0.170}{0.196}\right](0.150) = 0.13 \text{ year} = 47 \text{ days}$$

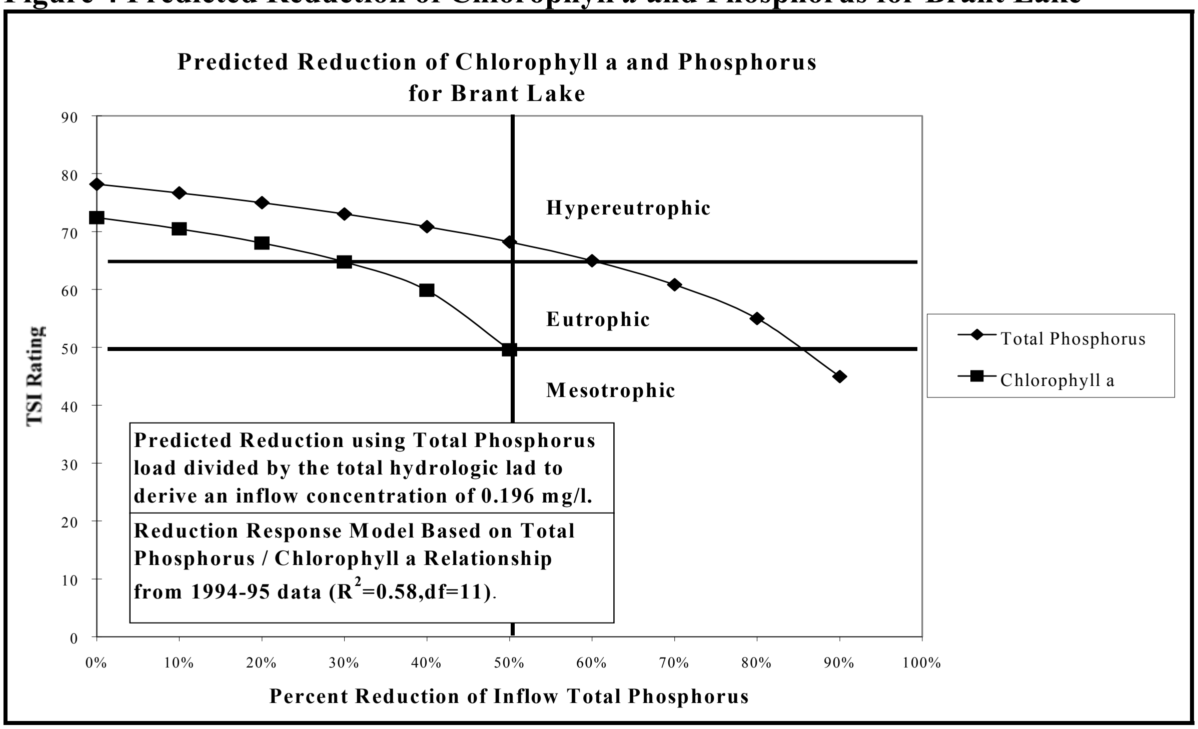
Referring back to Equation 5, reducing the inputs of total phosphorus, the equation would estimate the reduction of inlake total phosphorus. This is assuming constant inputs of water. Theoretically, the retention time for total phosphorus should also be reduced. With only one year of sampling, there is no way to estimate the reduction in the retention time of total phosphorus. The $\overline{T}_p$ constant (0.13) derived from the data will be used in Equation 5. After estimating the amount of reduction of inlake phosphorus after a reduction of input phosphorus, Equation 4 (page 99) can be used to determine the reduction of chlorophyll *a*. As can be seen in Table 2, a 50% reduction in phosphorus inputs to Brant Lake will reduce the inlake chlorophyll *a* concentration by an estimated 90%. The corresponding inlake total phosphorus concentration would be 0.085 mg/L. The 50% reduction would also lower the chlorophyll TSI value to the mesotrophic line (Figure 3). As stated previously, this reduction response model does not consider a reduction in the phosphorus retention time. Brant Lake should experience even lower inlake phosphorus and chlorophyll *a* concentrations if inflow phosphorus concentrations are reduced. As reductions in the phosphorus loadings to the lake are lowered, the lake will see algal blooms that are less intense and of shorter duration. The tables and graphs are predictive of the data collected during the study. As the parameters in this model change with the addition of more data, changes in the output will occur as well.

Table 2 . Effects of Reducing Phosphorus to Brant Lake

Reduction of Phosphorus Inputs	Input Phos Concentration	InLake Phos Concentration	Chlorophyll *a*	Percent Reduction Chlorophyll *a*	Phosphorus TSI	Chlorophyll TSI
0%	0.196	0.170	71.19	0%	78.20	72.41
10%	0.176	0.153	58.34	18%	76.68	70.46
20%	0.157	0.136	45.49	36%	74.98	68.02
30%	0.137	0.119	32.64	54%	73.06	64.76
40%	0.118	0.102	19.79	72%	70.83	59.85
50%	0.098	0.085	6.94	90%	68.20	49.57
60%	0.078	0.068	N/A	N/A	64.98	N/A
70%	0.059	0.051	N/A	N/A	60.83	N/A
80%	0.039	0.034	N/A	N/A	54.98	N/A
90%	0.020	0.017	N/A	N/A	44.98	N/A

[1] Inlake phosphorus concentrations must be converted from mg/L to mg/m^3 before using Equation 1 to predict chlorophyll *a*.

Figure 4 Predicted Reduction of Chlorophyll *a* and Phosphorus for Brant Lake



- ***Endpoint Link to Surface Water Quality Standards***

The water quality goal for each lake is a 50% reduction in phosphorus. The water quality standards target is a chlorophyll *a* TSI of 50.

The goal will greatly diminish productivity in the lake which in turn will lead to greater support of assigned beneficial uses. This improvement in water quality will assure the following:

a. visible pollutants are controlled;
b. more pollutants will not form in the lake;
c. growth of nuisance aquatic life will eventually diminish; and
d. improve recreation on the lake by:
    1. increasing aesthetics for swimming and fishing; and
    2. reduce possible bacterial contamination originating from animal feeding areas.

IV. TMDL Analysis and Development:

- ***Data Sources***

Data was collected by the department and the Lake Conservation District beginning in 1994 and ending in 1996 sampling seasons.

- ***Analysis Techniques or Models***

Eleven tributary locations were chosen for collecting hydrologic and nutrient information from the Lake Madison and Brant Lake Watershed. These monitoring locations were placed at specific areas within the watershed that would best show DENR which sub-watersheds were contributing the largest nutrient and sediment loads. Gauging stations were installed where water quality samples would be collected to record the daily stage of the tributary. The recorders were checked weekly and data was downloaded monthly. A Marsh-McBirney flow meter was used to take periodic flow measurements at different stage heights. The stage and flow measurements were used to develop a stage/discharge table for each site. The stage/discharge table was used to calculate an average daily loading for each site. The loadings for each day were totaled for annual loading rate.

In addition to the measurements above, Silver Creek water quality and quantity was monitored above and below the city of Madison. Sampling sites LMT1 through LMT4 were placed at certain locations above the city of Madison to determine the water quality and quantity prior to the city of Madison's storm sewer network. Each one of these sites was monitored through 1995 and partially through 1996. A full year of data including loadings, water quality concentrations (mg/L) and export coefficients (kg/year) were calculated.

All sites, (tributary and outlet) were sampled twice weekly during the first week of snowmelt runoff and once a week thereafter until the runoff stopped in April. Base flow monitoring also took place after the snowmelt runoff ceased. All nutrient and solids parameters were sampled using approved methods documented in the South Dakota's EPA approved *Standard Operating Procedures for Field Samplers*. The South Dakota State

Health Laboratory in Pierre, SD analyzed all samples. The purpose of these samples was to develop nutrient and sediment loadings to determine critical areas in the watershed.

In addition to water quality monitoring, information was collected to complete a comprehensive watershed landuse model. The AGNPS model was developed by the United States Department of Agriculture (Young et al, 1986) to give comparative values for every forty acre cell in a given watershed. Twenty-one parameters were collected for every 40 acre cell in the watershed.

- ***Seasonality***

Different seasons in the year can yield different water quality in a tributary due to the changes in precipitation and agricultural practices. To determine seasonal differences, tributary samples were separated into spring (March 15, to May 31, 1995), summer (June 1, to August 31, 1995), and fall (September 1, to October 30, 1995). According to the water quality samples collected in 1995, the largest nutrient and sediment concentrations and loadings typically occurred during the spring.

The outlet of Lake Madison and Brant Lake discharged the majority of nutrient loadings (phosphorus) during the summer. As the loadings from the tributaries enter the lake, a lag period (retention time) occurs until the nutrients that do not settle to the bottom of the lake, are discharged. For Lake Madison and Brant Lake, the greatest level of phosphorus loss was during the summer when the lake discharged; however, this accounted for only 50% or less of the total phosphorus loads. The smaller tributaries discharged most of their nutrient and sediment loads during the spring.

The concentrations of phosphorus, nitrogen, and suspended solids are higher in the spring than any other time of year. The most likely sources of these elevated concentrations include applied fertilizer, decaying organic matter and a buildup of animal waste are carried by spring run-off and rain events . Nitrate is water-soluble; meaning it can easily dissolve in water. In the spring, the soil may be either frozen or saturated and most of the flow occurs overland into lakes and streams.

- ***Margin of Safety***

The margin of safety is addressed through the final TMDL recommendation for each lake as a 50% reduction in phosphorus target to achieve meostrophy rather than a 40% reduction in phosphorus that resulted by the reduction response modeling efforts.

Another means to insure that this TMDL will be attained is the SD DENR requirement of the city of Madison to collect water quality samples above and below the discharge point to assess water quality impact on Silver Creek if an emergency discharge from the total retention wastewater facility occurs. This scenario is most likely to occur during a large spring precipitation event. It is recommended that total phosphorus be added to the parameter monitoring list so total nutrient loadings to Silver Creek and Lake Madison can be determined during any discharge.

The Lake Madison Sanitary District and the city of Madison have been requested to add total phosphorus to their groundwater monitoring program for the wells surrounding the two wastewater treatment facilities. Although the nutrient mass balance calculations indicated that these facilities were contributing insignificant levels of phosphorus to Lake Madison, the potential for major contributions of nutrients from the groundwater due to infiltration/percolation is possible. In addition, it is recommended that 2-3 piezometers (shallow wells) be installed near the shoreline of Bourne Slough near the wastewater ponds of the Lake Madison Sanitary District. This should be completed during the Phase II Implementation project. The seepage from the wastewater ponds along the shoreline of Bourne Slough should be monitored to determine if total phosphorus concentrations are increasing.

Another recommendation that will provide for a margin of safety is the installation of a centralized sewer system or continued upgrades to modern individual septic and holding tanks for homes and businesses located at Brant Lake. Some type of modernized nutrient abatement procedure needs to be implemented for the failing onsite wastewater disposal systems. The contribution of nutrients from these individual facilities will only become worse if modernization does not take place.

Finally, Lake Herman is a major phosphorus contributor to Silver Creek, Lake Madison, and Brant Lake. The reductions in phosphorus loadings described in these TMDLs do not consider the impact of water quality improvements within the Lake Herman watershed. If the water quality can be improved within the Lake Herman watershed, a further reduction in total phosphorus loadings will be realized for the lakes downstream. Please see the Phase III Post-Implementation Investigation of Lake Herman final report for restoration alternatives for the Lake Herman watershed.

V. Allocation of TMDL Loads or Responsibilities:

- ***Wasteload Allocation***

There are no point sources of pollutants of concern in this watershed with the exception of potential emergency discharges from the city of Madison's total retention wastewater facility. Therefore, the "wasteload allocation" component of these TMDLs is considered a zero value. The TMDLs are considered wholly included in the "load allocation" component.

- ***Load Allocation***

The load allocation is the 50% reduction in phosphorus loads. In order to achieve this reduction a variety of best management practices (BMPs) need to be implemented in the watershed. According to the AGNPS program, with BMP installation on those 40-acre cells with a rate of erosion greater than 7.0 tons per acre, and with proper management of feeding areas contributing nutrients to the lakes, a reduction in total phosphorus loadings of 32.5% for Lake Madison and 40.0% for Brant Lake can be realized.

Another 10-13% reduction in phosphorus loadings can be realized if the storm sewers contributing nutrients to the Silver Creek are rerouted, reduced or eliminated. Lake Madison can achieve and Brant Lake can exceed a 40% reduction in the phosphorus load. The storm sewers present a direct discharge from an urban area. Any hazardous spill in the drainage area of the storm sewers would result in damage to Lake Madison and Brant Lake. There are a variety of BMPs specifically tailored to urban areas that can help achieve a significant reduction of nutrient and sediment loadings when implemented.

As mentioned as part of the margin of safety section, Lake Herman is a major phosphorus contributor to Silver Creek, Lake Madison, and Brant Lake. The reductions in phosphorus loadings described above do not consider the impact of water quality improvements within the Lake Herman watershed. If the water quality can be improved within the Lake Herman watershed, a further reduction in total phosphorus loadings will be realized for the lakes downstream. Please see the Phase III Post-Implementation Investigation of Lake Herman final report for restoration alternatives for the Lake Herman watershed.

Nuisance algal blooms are a significant problem on Lake Madison and Brant Lake reducing their recreational value during the summer. All nutrient sources need to be reduced in order to achieve a 50% reduction and allow full beneficial use of these two lakes.

A final option to improve the water quality of Lake Madison and Brant Lake is dredging. The contribution of internal phosphorus loading to the nutrient budget of Lake Madison and Brant Lake was not calculated. Bourne Slough continually receives phosphorus from Silver Creek. Phosphorus is then transported into the main inlake area of Lake Madison. The shallow nature of Bourne Slough has reduced its capacity to withhold phosphorus from the rest of Lake Madison. A small sediment removal project to increase the depth around the mouth of Bourne Slough may increase its ability to retain a greater amount of phosphorus. A sediment survey should be conducted to determine the volume and distribution of sediment within Bourne Slough and the feasibility of a sediment removal project.

It was also identified that Round Lake was releasing more sediment and phosphorus to Brant Lake than it received from Lake Madison. A sediment survey should also be completed on this 152-acre lake to determine the volume and distribution of sediment. From this data a cost/benefit analysis of sediment removal can be completed.

VI. Schedule of Implementation:

The department is working with potential sponsors to initiate an implementation project on Lake Madison that would begin in the spring of 2000. It is expected that the sponsors will request project assistance during the fall 1999 funding round.

VII. Post-Implementation Monitoring:

Once the implementation project is completed, post-implementation monitoring will be required to assure that the TMDL has been reached and improvements to the beneficial uses occur. The department will continue to monitoring Swan Lake every two to four years as part of the Statewide Lakes Assessment Program.

VIII. Public Participation:

- *Summary of Public Review*

Public Meetings/ Personal Contact	*Articles/ Fact Sheets*	*Document Distribution*
Pre-project meetings May 11, 1993 **Funding meeting** **Mid-project meeting** August 4, 1996 **Near-end project meeting** **Final Report meeting** December 8, 1998 **Pre-Implementation meeting** January 25, 1999	**Madison Daily Leader** November 30, 1998	**October 1998** Ron Byrd Lake Conservation District NRCS - Lake County Lake Madison Association Lake Madison Sanitary District Brant Lake Association City of Madison Lake County SD GF&P SD DENR - Water Rights SD DENR - Environmental Services SD DENR - Watershed Protection US EPA - Clean Lakes Program **January 1999** US EPA TMDL Program
Electronic media	*Mailings*	*Public Comments Received*
December, 1998 Project Summary added to department website **January, 1999** TMDL Summary advertised on department website		Comments received during project meetings and review of the draft report and findings were considered

IX. Supporting Development Document(s) (attached):

Wittmuss, A. and McIntire, M., October 1998. PHASE I WATERSHED ASSSESSMENT FINAL REPORT - LAKE MADISON/BRANT LAKE - LAKE COUNTY SOUTH DAKOTA. South Dakota Watershed Protection Program, Division of Financial and Technical Assistance, South Dakota Department of Environment and Natural Resources, Pierre, South Dakota.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 8
999 18TH STREET - SUITE 500
DENVER, CO 80202-2466

APR 13 1999

RECEIVED

Ref: Ref: 8EPR-EP

Nettie Myers, Secretary
Department of Environment and Natural Resources
Joe Foss Building
523 East Capitol
Pierre, South Dakota 57501-3181

Re: TMDL Approvals
Lake Bryon
Elm Lake
Lake Faulkton
Lake Hendricks
Lake Hiddenwood
Lake Madison/Brant
McCook Lake
Ravine Lake
Redfield Lake
Swan Lake

Dear Ms. Myers:

We have completed our review of the total maximum daily loads (TMDLs) as submitted by your office for the subject waterbodies. In accordance with the Clean Water Act (33 U.S.C. 1251 et. seq.), we approve all aspects of the TMDLs as developed for these water quality limited waterbodies as described in Section 303(d)(1). We acknowledge that these particular TMDLs for the various lakes are based primarily on a voluntary and incentive-based approach to implementation.

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

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 clean up. 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 -- particularly 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 lake depth and its relationship to the impaired uses. Further, we feel it is reasonable to use factors such as lake depth 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 Bruce Zander of my staff at 303/312-6846.

Sincerely,

Max H. Dodson

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

Enclosures

Enclosure

APPROVED TMDLS

Waterbody Name*	TMDL Parameter / Pollutant	Water Quality Goal/Endpoint	TMDL	Section 303(d)1 or (d)3 TMDL	Supporting Documentation
Lake Bryon*	phosphorus	TSI < 70	50% reduction in phosphorus loads	§303(d)(1)	Lake Assessment Project Report, (Lake Byron excerpt) (SD DENR, August 1996) Lake Assessment Project Report, Lake Byron, Beadle County, SD (SD DENR, December 1992) Section 319 Nonpoint Source Control Program Watershed Project Final Report, Lake Byron Watershed Project (Beadle CD, December 31, 1997) Lake Byron Watershed Project Section 319 Project Implementation Plan (SD DENR, July 1993)
	sediment	Decrease annual inlake sediment accumulation by 1200 tons/year	50% reduction in sediment loads	§303(d)(1)	
Elm Lake*	phosphorus	N:TDP ratio > 7.5 averaged over growing season	60% reduction in phosphorus loads	§303(d)(1)	Phase I Watershed Assessment Final Report, Elm Lake, Brown Country, South Dakota (SDDENR, September1998)
Lake Faulkton*	phosphorus	TSI < 90	35% reduction in phosphorus loads	§303(d)(1)	Lake Assessment Project, Lake Faulkton, Faulk County, South Dakota (SD DENR, 1996)
	sediment	Increased average lake depth by 6 feet over 15.5 acres	Remove 150,000 cubic yards of lake sediment	§303(d)(1)	
Lake Hendricks*	phosphorus	TSI < 65	50% reduction in phosphorus loads	§303(d)(1)	Diagnostic/Feasibility Study Report, Lake Hendricks/Deer Creek Watershed, Brookings County, South Dakota; Lincoln County, Minnesota (SD DENR, February 1993)
	sediment	Increased average lake depth by 6 feet over 100 acres	Remove 1 million cubic yards of lake sediment	§303(d)(1)	

Waterbody Name*	TMDL Parameter / Pollutant	Water Quality Goal/Endpoint	TMDL	Section 303(d)1 or (d)3 TMDL	Supporting Documentation
Lake Hiddenwood*	phosphorus	Decreased winter fish kills and increased visitor days	Maintenance of increased depth regime plus 2% decrease in phosphorus loads	§303(d)(1)	Lake Hiddenwood Restoration and Protection Project Preproposal (North Central RC&D; August 1993) Lake Hiddenwood Restoration and Protection Project Implementation Plan for FY 94 (1994) Preliminary Report; Hiddenwood Recreation Damsite and Reservoir, North Central RC&D (RC-050-WA), Walworth County, SD (USDA, SCS; August 1978)
	sediment	Increased depth corresponding to increasing volume by 53 acre-feet	Maintenance of increased depth regime plus 5% decrease in sediment loads	§303(d)(1)	
Lake Madison*	phosphorus	TSI < 50	50% reduction in phosphorus loads	§303(d)(1)	Phase I Watershed Assessment Final Report - Madison Lake/Brant Lake, Lake County South Dakota (SD DENR, October 1998)
Lake Brant*	phosphorus	TSI < 50	50% reduction in phosphorus loads	§303(d)(1)	
McCook Lake*	sediment	Increased average lake depth by 4.5 feet over 183 acres	Remove 1.7 million cubic yards of lake sediment	§303(d)(1)	Diagnostic/Feasibility Study Report McCook Lake, Union County, South Dakota (SD DENR, March 1990)
Ravine Lake*	phosphorus	TSI of <84	70% reduction in phosphorus loads	§303(d)(1)	Diagnostic\Feasibility Study Report, Ravine Lake, Beadle County, SD (SD DENR, July 1990) AGNPS Modeling of the Ravine Lake Watershed, Huron, SD (SD DENR, July 1988)
	fecal coliform	< 400/100 mL fecal coliform counts	< 400/100 mL fecal coliform counts	§303(d)(1)	
Redfield Lake*	phosphorus	TSI < 90	45% reduction in total phosphorus load	§303(d)(1)	Lake Assessment Project Report, Lake Redfield, Spink County, SD (SD DENR, May 1993)
	sediment	Increased average lake depth by 5 feet over 31 acres	Remove 250,000 cubic yards of lake sediment	§303(d)(1)	

Waterbody Name*	TMDL Parameter / Pollutant	Water Quality Goal/Endpoint	TMDL	Section 303(d)1 or (d)3 TMDL	Supporting Documentation
Swan Lake*	phosphorus	TSI < 65	60% reduction in phosphorus loads	§303(d)(1)	Diagnostic/Feasibility Study Swan Lake; Turner County, South Dakota (SD DENR, January 1993)
	sediment	TSI (secchi depth) < 65	50% increase in secchi depth	§303(d)(1)	

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

■ TMDL Checklist ■

EPA Region VIII

State/Tribe: South Dakota
Waterbody Name: Lake Bryon
Point Source-control TMDL: Nonpoint Source-control TMDL: X (check one or both)
Date Received: March 30, 1999 Date Review completed: April 9, 1999 BAZ

Review Criteria (All criteria must be met for approval.)	Approved (check if yes)	Comments
■ TMDLs result in maintaining and attaining water quality standards	X	The waterbody classification uses which are addressed by this TMDL are aquatic life and recreation.
■ Water Quality Standards Target	X	Targets were established based on trophic status and sediment loading rate. These are reasonable indicators to use in expressing the TMDL targets since they are quantifiable and relate to the use impairments.
■ TMDL	X	The TMDLs are expressed in terms of annual phosphorus and sediment load reductions. This is a reasonable way to express the TMDL for lakes since it takes lakes a period of time to respond to pollutant reductions.
■ Significant sources identified	X	Significant sources were adequately identified in a categorical and/or individual source-by-source basis. All sources that need to be addressed through controls were identified (including the removal of lake bottom sediment, if needed.)
■ Technical analysis	X	Monitoring, empirical relationships, and best professional judgement were used in identifying pollutant sources and causes and in identifying acceptable levels of pollutant control, and in identifying appropriate levels of control. This level of technical analysis is reasonable and appropriate because of the character of the pollutants, the type of land use practices, and watershed type.
■ Margin of safety and Seasonality	X	An appropriate margin of safety is included by performing ongoing monitoring to assure water quality goals are achieved, by a high level of detailed monitoring and assessment, by further educational efforts throughout the watershed, by conservative assumptions regarding no-till or minimum till acreage, application of additional nutrient BMPs, and stabilization of more shoreline than recommended through the assessment Study. Seasonality was adequately considered by evaluating the cumulative impacts of the various seasons on water quality and by tailoring the BMPs to seasonal needs.
■ Allocation	X	All the allocation for the TMDL was a "load allocation" attributed to nonpoint sources. Allocation was attributed to such sources as animal feeding areas, shoreline areas, and croplands.
■ Public review	X	Public review and participation was conducted through meetings, electronic media, and mailings. The extent of public review is acceptable. Further, the review process sponsored by the State was adequate for purposes of developing a TMDL that will be implemented because of public acceptance.

■ TMDL Checklist ■

EPA Region VIII

State/Tribe: South Dakota Waterbody Name: Elm Lake Point Source-control TMDL: Date Received: March 30, 1999		Nonpoint Source-control TMDL: X (check one or both) Date Review completed: April 9, 1999 BAZ
Review Criteria (All criteria must be met for approval.)	**Approved** (check if yes)	**Comments**
■ **TMDLs result in maintaining and attaining water quality standards**	X	The waterbody classification uses which are addressed by this TMDL are drinking water and recreation.
■ **Water Quality Standards Target**	X	Targets were established based on nitrogen:phosphorus ratios. This is a reasonable approach since it relates to the trophic status of the waterbody which, in turn, relates to the uses of concern.
■ **TMDL**	X	The TMDL is expressed in terms of annual phosphorus load reduction. This is a reasonable way to express the TMDL for lakes since it takes lakes a period of time to respond to pollutant reductions.
■ **Significant sources identified**	X	Significant sources were adequately identified in a categorical and/or individual source-by-source basis. All sources that need to be addressed through controls were identified (including the removal of lake bottom sediment, if needed.)
■ **Technical analysis**	X	Monitoring, empirical relationships, AGNPS modeling, and best professional judgement were used in identifying pollutant sources and causes and in identifying acceptable levels of pollutant control, and in identifying appropriate levels of control. This level of technical analysis is reasonable and appropriate because of the character of the pollutants, the type of land use practices, and watershed type.
■ **Margin of safety and Seasonality**	X	An appropriate margin of safety is included by performing ongoing monitoring to assure water quality goals are achieved and by application of additional nonpoint source BMPs. Seasonality was adequately considered by evaluating the cumulative impacts of the various seasons on water quality and by tailoring the BMPs to seasonal needs.
■ **Allocation**	X	All the allocation for the TMDL was a "load allocation" attributed to nonpoint sources. Allocation was attributed to such sources as animal feeding areas, shoreline areas, and croplands.
■ **Public review**	X	Public review and participation was conducted through meetings, electronic media, and mailings. The extent of public review is acceptable. Since part of the Elm Lake watershed is in North Dakota, the state of North Dakota as well as local entities in that State have participated in the development of the TMDL and will be participating in the future through implementation of BMPks within the watershed. Further, the review process sponsored by the State was adequate for purposes of developing a TMDL that will be implemented because of public acceptance.

■ TMDL Checklist ■

EPA Region VIII

State/Tribe: South Dakota
Waterbody Name: Lake Faulkton
Point Source-control TMDL: Nonpoint Source-control TMDL: X (check one or both)
Date Received: March 30, 1999 Date Review completed: April 9, 1999 BAZ

Review Criteria (All criteria must be met for approval.)	**Approved** (check if yes)	**Comments**
■ **TMDLs result in maintaining and attaining water quality standards**	X	The waterbody classification uses which are addressed by this TMDL are aquatic life and recreation.
■ **Water Quality Standards Target**	X	Targets were established based on trophic status and lake depth. This is a reasonable approach since it relates to the trophic status of the waterbody as well as the physical nature of the lake which, in turn, relates to the uses of concern.
■ **TMDL**	X	The TMDL is expressed in terms of annual phosphorus load reduction and removal of lake sediment. This is a reasonable way to express the TMDL for this lake since it provides an effective surrogate reflective of both the aquatic life and recreational needs.
■ **Significant sources identified**	X	Significant sources were adequately identified in a categorical and/or individual source-by-source basis. All sources that need to be addressed through controls were identified (including the removal of lake bottom sediment, if needed.)
■ **Technical analysis**	X	Monitoring, empirical relationships, AGNPS modeling, and best professional judgement were used in identifying pollutant sources and causes and in identifying acceptable levels of pollutant control, and in identifying appropriate levels of control. This level of technical analysis is reasonable and appropriate because of the character of the pollutants, the type of land use practices, and watershed type.
■ **Margin of safety and Seasonality**	X	An appropriate margin of safety is included by performing ongoing monitoring to assure water quality goals are achieved and by application of additional nonpoint source BMPs. Seasonality was adequately considered by evaluating the cumulative impacts of the various seasons on water quality and by tailoring the BMPs to seasonal needs.
■ **Allocation**	X	All the allocation for the TMDL was a "load allocation" attributed to nonpoint sources. Allocation was attributed to such sources as animal feeding areas and croplands.
■ **Public review**	X	Public review and participation was conducted through meetings, electronic media, and mailings. The extent of public review is acceptable. Further, the review process sponsored by the State was adequate for purposes of developing a TMDL that will be implemented because of public acceptance.

■ TMDL Checklist ■

EPA Region VIII

State/Tribe: South Dakota
Waterbody Name: Lake Hendricks
Point Source-control TMDL: Nonpoint Source-control TMDL: X (check one or both)
Date Received: March 30, 1999 Date Review completed: April 9, 1999 BAZ

Review Criteria (All criteria must be met for approval.)	Approved (check if yes)	Comments
■ **TMDLs result in maintaining and attaining water quality standards**	X	The waterbody classification uses which are addressed by this TMDL are aquatic life and recreation.
■ **Water Quality Standards Target**	X	Targets were established based on trophic status and lake depth. This is a reasonable approach since it relates to the trophic status of the waterbody as well as the physical nature of the lake which, in turn, relates to the uses of concern.
■ **TMDL**	X	The TMDL is expressed in terms of annual phosphorus load reduction and removal of lake sediment. This is a reasonable way to express the TMDL for this lake since it provides an effective surrogate reflective of both the aquatic life and recreational needs.
■ **Significant sources identified**	X	Significant sources were adequately identified in a categorical and/or individual source-by-source basis. All sources that need to be addressed through controls were identified (including the removal of lake bottom sediment, if needed.)
■ **Technical analysis**	X	Monitoring, empirical relationships, and best professional judgement were used in identifying pollutant sources and causes and in identifying acceptable levels of pollutant control, and in identifying appropriate levels of control. This level of technical analysis is reasonable and appropriate because of the character of the pollutants, the type of land use practices, and watershed type.
■ **Margin of safety and Seasonality**	X	An appropriate margin of safety is included by augmenting the watershed land use controls with in-lake dredging. The in-lake dredging will further reduce the amount of available nutrients into the lake because of increased depth as well as provide further aquatic life habitat. Additional margin of safety could be provided through addressing the failing wastewater on-site systems near the lake. Seasonality was adequately considered by evaluating the cumulative impacts of the various seasons on water quality and by tailoring the BMPs to seasonal needs.
■ **Allocation**	X	All the allocation for the TMDL was a "load allocation" attributed to nonpoint sources. Allocation was attributed to such sources as animal feeding areas and croplands.
■ **Public review**	X	Public review and participation was conducted through meetings, electronic media, and mailings. The extent of public review is acceptable. Further, the review process sponsored by the State was adequate for purposes of developing a TMDL that will be implemented because of public acceptance. This TMDL involved cooperation between South Dakota and Minnesota since the watershed is in both states. Lincoln County, Minnesota participated in the process as a stakeholder.

■ TMDL Checklist ■

EPA Region VIII

State/Tribe: South Dakota
Waterbody Name: Lake Hiddenwood
Point Source-control TMDL: Nonpoint Source-control TMDL: X (check one or both)
Date Received: March 30, 1999 Date Review completed: April 9, 1999 BAZ

Review Criteria (All criteria must be met for approval.)	Approved (check if yes)	Comments
■ TMDLs result in maintaining and attaining water quality standards	X	The waterbody classification uses which are addressed by this TMDL are aquatic life and recreation.
■ Water Quality Standards Target	X	Targets were established based on lake depth, fish kill frequency, and visitor-days. These are reasonable targets for the TMDL since they relate to the impaired uses of concern.
■ TMDL	X	The TMDL are expressed in terms of annual phosphorus load reduction and removal of lake sediment. Also, the TMDL relates to the depth and volume of the Lake. Lake depth has a particularly important factor related to both the recreational use and fisheries use of the Lake. The emphasis at this point in time is to protect the improvements already made in the Lake as well as adding more controls on pollutant sources as a margin of safety.
■ Significant sources identified	X	Significant sources were adequately identified in a categorical and/or individual source-by-source basis. All sources that need to be addressed through controls were identified (including the removal of lake bottom sediment, if needed.)
■ Technical analysis	X	Monitoring, empirical relationships, AGNPS modeling, and best professional judgement were used in identifying pollutant sources and causes and in identifying acceptable levels of pollutant control, and in identifying appropriate levels of control. This level of technical analysis is reasonable and appropriate because of the character of the pollutants, the type of land use practices, and watershed type.
■ Margin of safety and Seasonality	X	An appropriate margin of safety is included by performing ongoing monitoring to assure water quality goals are achieved and by application of additional nonpoint source BMPs. Additional BMPs include entrapment dams, construction of four agricultural waste systems, and cropland BMPs. Seasonality was adequately considered by evaluating the cumulative impacts of the various seasons on water quality and by tailoring the BMPs to seasonal needs.
■ Allocation	X	All the allocation for the TMDL was a "load allocation" attributed to nonpoint sources. Allocation was attributed to such sources as animal feeding areas and croplands as well as to the bottom lake sediment.
■ Public review	X	Public review and participation was conducted through meetings, electronic media, and mailings. The extent of public review is acceptable. Further, the review process sponsored by the State was adequate for purposes of developing a TMDL that will be implemented because of public acceptance.

■ TMDL Checklist ■

EPA Region VIII

State/Tribe: South Dakota
Waterbody Name: Lake Madison/Lake Brant
Point Source-control TMDL: Nonpoint Source-control TMDL: X (check one or both)
Date Received: March 30, 1999 Date Review completed: April 9, 1999 BAZ

Review Criteria (All criteria must be met for approval.)	Approved (check if yes)	Comments
■ TMDLs result in maintaining and attaining water quality standards	X	The waterbody classification uses which are addressed by this TMDL are aquatic life and recreation.
■ Water Quality Standards Target	X	Targets were established based on trophic status. This is a reasonable approach since trophic status of the waterbody relates to the uses of concern.
■ TMDL	X	The TMDLs for each lake are expressed in terms of annual phosphorus load reduction. This is a reasonable way to express the TMDL for this lake since it takes a long period of time for a lake to respond to water quality controls, rather than on a daily basis.
■ Significant sources identified	X	Significant sources were adequately identified in a categorical and/or individual source-by-source basis. All sources that need to be addressed through controls were identified (including the removal of lake bottom sediment, if needed.)
■ Technical analysis	X	Monitoring, empirical relationships, AGNPS modeling, and best professional judgement were used in identifying pollutant sources and causes and in identifying acceptable levels of pollutant control, and in identifying appropriate levels of control. This level of technical analysis is reasonable and appropriate because of the character of the pollutants, the type of land use practices, and watershed type.
■ Margin of safety and Seasonality	X	An appropriate margin of safety is included by performing ongoing monitoring to assure water quality goals are achieved, by increasing the target phosphorus reduction from 40% to 50%, and possibly by application of additional nonpoint source BMPs. Seasonality was adequately considered by evaluating the cumulative impacts of the various seasons on water quality and by tailoring the BMPs to seasonal needs.
■ Allocation	X	All the allocation for the TMDL was a "load allocation" attributed to nonpoint sources. Allocation was attributed to such sources as animal feeding areas and croplands.
■ Public review	X	Public review and participation was conducted through meetings, electronic media, and mailings. The extent of public review is acceptable. Further, the review process sponsored by the State was adequate for purposes of developing a TMDL that will be implemented because of public acceptance.

■ TMDL Checklist ■

EPA Region VIII

State/Tribe: South Dakota
Waterbody Name: McCook Lake
Point Source-control TMDL: Nonpoint Source-control TMDL: X (check one or both)
Date Received: March 30, 1999 Date Review completed: April 9, 1999 BAZ

Review Criteria (All criteria must be met for approval.)	Approved (check if yes)	Comments
■ **TMDLs result in maintaining and attaining water quality standards**	X	The waterbody classification uses which are addressed by this TMDL are aquatic life and recreation.
■ **Water Quality Standards Target**	X	Targets were established based on lake depth. This is a reasonable approach since it relates to the trophic status of the waterbody as well as the physical nature of the lake which, in turn, relates to the uses of concern.
■ **TMDL**	X	The TMDL is expressed in terms of removal of lake sediment. This is a reasonable way to express the TMDL for this lake since it provides an effective surrogate reflective of both the aquatic life and recreational needs.
■ **Significant sources identified**	X	There are no contemporary sources of sediment (the pollutant of concern). Rather, the current lake sediment that has been deposited over the years is the primary cause of impairment within the lake.
■ **Technical analysis**	X	Monitoring, empirical relationships, and best professional judgement were used in identifying acceptable levels of sediment removal from the Lake. This level of technical analysis is reasonable and appropriate because of the character of the pollutants, the type of land use practices, and watershed type.
■ **Margin of safety and Seasonality**	X	An appropriate margin of safety is included by performing ongoing monitoring to assure water quality goals are achieved and by removal of more sediment than calculated to support inlake uses. Seasonality was adequately considered by evaluating the changes in lake conditions over the year, but seasonality has proven to be of very little concern related to the development of the TMDL and application of appropriate water quality controls.
■ **Allocation**	X	All the allocation for the TMDL was a "load allocation" attributed to nonpoint sources. Allocation was attributed to lake bottom sediments.
■ **Public review**	X	Public review and participation was conducted through meetings, electronic media, and mailings. The extent of public review is acceptable. Further, the review process sponsored by the State was adequate for purposes of developing a TMDL that will be implemented because of public acceptance.

■ TMDL Checklist ■

EPA Region VIII

State/Tribe: South Dakota
Waterbody Name: Ravine Lake
Point Source-control TMDL: Nonpoint Source-control TMDL: X (check one or both)
Date Received: March 30, 1999 Date Review completed: April 9, 1999 BAZ

Review Criteria (All criteria must be met for approval.)	Approved (check if yes)	Comments
■ TMDLs result in maintaining and attaining water quality standards	X	The waterbody classification uses which are addressed by this TMDL are aquatic life and recreation.
■ Water Quality Standards Target	X	Targets were established based on trophic status and fecal coliform concentration. This is a reasonable approach since these factors relate to the uses of concern.
■ TMDL	X	The TMDL is expressed in terms of annual phosphorus load reduction and fecal coliform concentration. This is a reasonable way to express the TMDLs for this lake since it provides an effective surrogate reflective of both the aquatic life and recreational needs and reflects the long response time of lakes of this type to pollutant controls within the watershed.
■ Significant sources identified	X	Significant sources were adequately identified in a categorical and/or individual source-by-source basis. All sources that need to be addressed through controls were identified (including the removal of lake bottom sediment, if needed.)
■ Technical analysis	X	Monitoring, empirical relationships, AGNPS modeling, and best professional judgement were used in identifying pollutant sources and causes and in identifying acceptable levels of pollutant control, and in identifying appropriate levels of control. This level of technical analysis is reasonable and appropriate because of the character of the pollutants, the type of land use practices, and watershed type.
■ Margin of safety and Seasonality	X	An appropriate margin of safety is included by performing ongoing monitoring to assure water quality goals are achieved and by application of additional nonpoint source BMPs including the stabilization of more shoreline than calculated and removal of more lake sediments than calculated. Seasonality was adequately considered by evaluating the cumulative impacts of the various seasons on water quality and by tailoring the BMPs to seasonal needs.
■ Allocation	X	All the allocation for the TMDL was a "load allocation" attributed to nonpoint sources. Allocation was attributed to such sources as animal feeding areas and croplands.
■ Public review	X	Public review and participation was conducted through meetings, electronic media, and mailings. The extent of public review is acceptable. Further, the review process sponsored by the State was adequate for purposes of developing a TMDL that will be implemented because of public acceptance.

■ TMDL Checklist ■

EPA Region VIII

State/Tribe: South Dakota
Waterbody Name: Redfield Lake
Point Source-control TMDL: Nonpoint Source-control TMDL: X (check one or both)
Date Received: March 30, 1999 Date Review completed: April 9, 1999 BAZ

Review Criteria (All criteria must be met for approval.)	Approved (check if yes)	Comments
■ TMDLs result in maintaining and attaining water quality standards	X	The waterbody classification uses which are addressed by this TMDL are aquatic life and recreation.
■ Water Quality Standards Target	X	Targets were established based on trophic status and lake depth. This is a reasonable approach since it relates to the trophic status of the waterbody as well as the physical nature of the lake which, in turn, relates to the uses of concern.
■ TMDL	X	The TMDL is expressed in terms of annual phosphorus load reduction and removal of lake sediment. This is a reasonable way to express the TMDL for this lake since it provides an effective surrogate reflective of both the aquatic life and recreational needs.
■ Significant sources identified	X	Significant sources were adequately identified in a categorical and/or individual source-by-source basis. All sources that need to be addressed through controls were identified (including the removal of lake bottom sediment, if needed.)
■ Technical analysis	X	Monitoring, empirical relationships, and best professional judgement were used in identifying pollutant sources and causes and in identifying acceptable levels of pollutant control, and in identifying appropriate levels of control. This level of technical analysis is reasonable and appropriate because of the character of the pollutants, the type of land use practices, and watershed type.
■ Margin of safety and Seasonality	X	An appropriate margin of safety is included by performing ongoing monitoring to assure water quality goals are achieved, by application of additional nonpoint source BMPs, and by dredging more lake sediments than calculated. Seasonality was adequately considered by evaluating the cumulative impacts of the various seasons on water quality and by tailoring the BMPs to seasonal needs.
■ Allocation	X	All the allocation for the TMDL was a "load allocation" attributed to nonpoint sources. Allocation was attributed to such sources as animal feeding areas and bottom sediments.
■ Public review	X	Public review and participation was conducted through meetings, electronic media, and mailings. The extent of public review is acceptable. Further, the review process sponsored by the State was adequate for purposes of developing a TMDL that will be implemented because of public acceptance.

■ TMDL Checklist ■

EPA Region VIII

State/Tribe: South Dakota
Waterbody Name: Swan Lake
Point Source-control TMDL: Nonpoint Source-control TMDL: X (check one or both)
Date Received: March 30, 1999 Date Review completed: April 9, 1999 BAZ

Review Criteria (All criteria must be met for approval.)	Approved (check if yes)	Comments
■ TMDLs result in maintaining and attaining water quality standards	X	The waterbody classification uses which are addressed by this TMDL are aquatic life and recreation.
■ Water Quality Standards Target	X	Targets were established based on trophic status and secchi depth. This is a reasonable approach since it relates to the trophic status of the waterbody as well as the physical nature of the lake which is, in turn, related to the uses of concern.
■ TMDL	X	The TMDL is expressed in terms of annual phosphorus load reduction and increase in clarity (e.g., secchi depth). This is a reasonable way to express the TMDL for this lake since it provides an effective surrogate reflective of both the aquatic life and recreational needs.
■ Significant sources identified	X	Significant sources were adequately identified in a categorical and/or individual source-by-source basis. All sources that need to be addressed through controls were identified (including the removal of lake bottom sediment, if needed.)
■ Technical analysis	X	Monitoring, empirical relationships, and best professional judgement were used in identifying pollutant sources and causes and in identifying acceptable levels of pollutant control, and in identifying appropriate levels of control. This level of technical analysis is reasonable and appropriate because of the character of the pollutants, the type of land use practices, and watershed type.
■ Margin of safety and Seasonality	X	An appropriate margin of safety is included by performing ongoing monitoring to assure water quality goals are achieved and by application of additional nonpoint source BMPs including selective dredging, bank stabilization, and elimination of inflow from Turkey Ridge Creek. Seasonality was adequately considered by evaluating the cumulative impacts of the various seasons on water quality and by tailoring the BMPs to seasonal needs.
■ Allocation	X	All the allocation for the TMDL was a "load allocation" attributed to nonpoint sources. Allocation was attributed to such sources as land uses in the Turkey Ridge Creek sub-watershed and in-lake sediments.
■ Public review	X	Public review and participation was conducted through meetings, electronic media, and mailings. The extent of public review is acceptable. Further, the review process sponsored by the State was adequate for purposes of developing a TMDL that will be implemented because of public acceptance.