MARSHALL COUNTY LAKES ASSESSMENT PROJECT

FINAL REPORT
FOR
SOUTH RED IRON LAKE
MARSHALL COUNTY, SOUTH DAKOTA

South Dakota Watershed Protection Program
Division of Financial and Technical Assistance
South Dakota Department of Environment and Natural Resources
Steven M. Pirner, Secretary

November 2008

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

MARSHALL COUNTY LAKES ASSESSMENT PROJECT

FINAL REPORT FOR

SOUTH RED IRON LAKE

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Sponsor

Marshall Conservation District

11/6/08

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

Marshall Conservation District

South Dakota Department of Environment and Natural Resources

South Dakota Department of Game, Fish & Parks

USDA Natural Resource Conservation Service

Prairie Agricultural Research, Inc.

Credit is also given to Sol Brich for creating the water and sediment depth map.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

.

EXECUTIVE SUMMARY

PROJECT TITLE: Marshall County Lakes Assessment Project (South Red Iron Lake)

PROJECT START DATE: 4/1/02	PROJECT COMPLETION DATE: 4/1/07
FUNDING:	TOTAL BUDGET: $192,000.00
TOTAL EPA GRANT:	$165,000.00 amended to $120,000.00
TOTAL EXPENDITURE OF EPA FUNDS:	$79,981.22
NONFEDERAL MATCH	
State Natural Resources Fee Funds	$25,000.00
Marshall Con. District	1,003.50
BUDGET REVISIONS:	Decrease $165,000 EPA funds to $120,000
TOTAL EXPENDITURES:	$105,984.72

SUMMARY ACCOMPLISHMENTS

The Marshall County Lakes Assessment Project was conducted because a number of lakes in the County were placed on the 303(d) list for an increasing TSI trend, sediment and nutrient loading, and accumulated sediment problems. The primary goal for the project was to determine sources of impairment to South Red Iron Lake, Nine Mile Lake, and North and South Buffalo Lakes, and provide sufficient background data to drive a Section 319 Implementation Project. This report concerns South Red Iron Lake.

An EPA section 319 grant provided a majority of the funding for this project. The State of South Dakota provided non-federal matching funds/in-kind services for the project.

Water quality monitoring indicated a trophic state relatively similar to other lakes in the region but slightly greater than the target TSI. The lake did not exhibit thermal stratification and dissolved oxygen concentrations were usually above the water quality standard. The standards criteria for nitrate, unionized ammonia, conductivity, and fecal coliform bacteria were not exceeded. Seasonality was indicated by typical temperature changes throughout the year and by seasonal changes in some parameter concentrations. Aquatic macrophyte and sediment surveys were completed for the lake. Aquatic macrophytes were not considered a major problem in the lake. Sediment amounts in the lake were considered slightly greater than was indicated by most other lake sediment surveys and removing those sediments could increase the lake volume, extend the life of the lake, and possibly alleviate internal nutrient loading.

The results from the BATHTUB model run were used to establish a total phosphorus load of 863.4 kg/year, which is a 5% reduction of the measured annual phosphorus load. Achievement of this load should ensure acceptable lake water quality and support the lake's beneficial uses.

The Annualized Agricultural Non-point Source computer model (AnnAGNPS) was not used during the study because the lake was very close to meeting its TSI target and any AnnAGNPS runs should be run during the implementation phase to direct BMP implementation.

INTRODUCTION

Purpose

The purpose of this assessment is to determine the sources of impairment to South Red Iron Lake and its tributaries, determine a total phosphorus load that will maintain full support of the lake's beneficial uses, and, if necessary, recommend strategies to restore the lake.

General Lake Description

South Red Iron Lake is a 610-acre natural lake located in Marshall County, South Dakota (Figure 1). The lake receives water from two small tributaries that receive drainage from primarily grazing lands and some cropland. The tributaries carry sediment loads and nutrient loads, which are thought to degrade water quality in the lake and cause eutrophication. The lake is primarily used for fishing. The average depth of the lake is 2.5 meters (8.3 feet) and it has a maximum depth of 4.6 meters (15 feet). The lake is connected to North Red Iron Lake and water can flow back and forth between them if water conditions allow (they are the same elevation). North Red Iron Lake drains to Clear Lake.

Lake Identification and Location

Lake Name: South Red Iron Lake	State: South Dakota
County: Marshall	Township: 126N
Range: 53W	Sections: 20, 29, 32
Nearest Municipality: Lake City	Latitude: 45.670000
Longitude: -97.318333	EPA Region: VIII
Primary Tributary: Unnamed	Receiving Water: North Red Iron Lake
HUC Code: 10160010	HUC Name: North Big Sioux Coteau

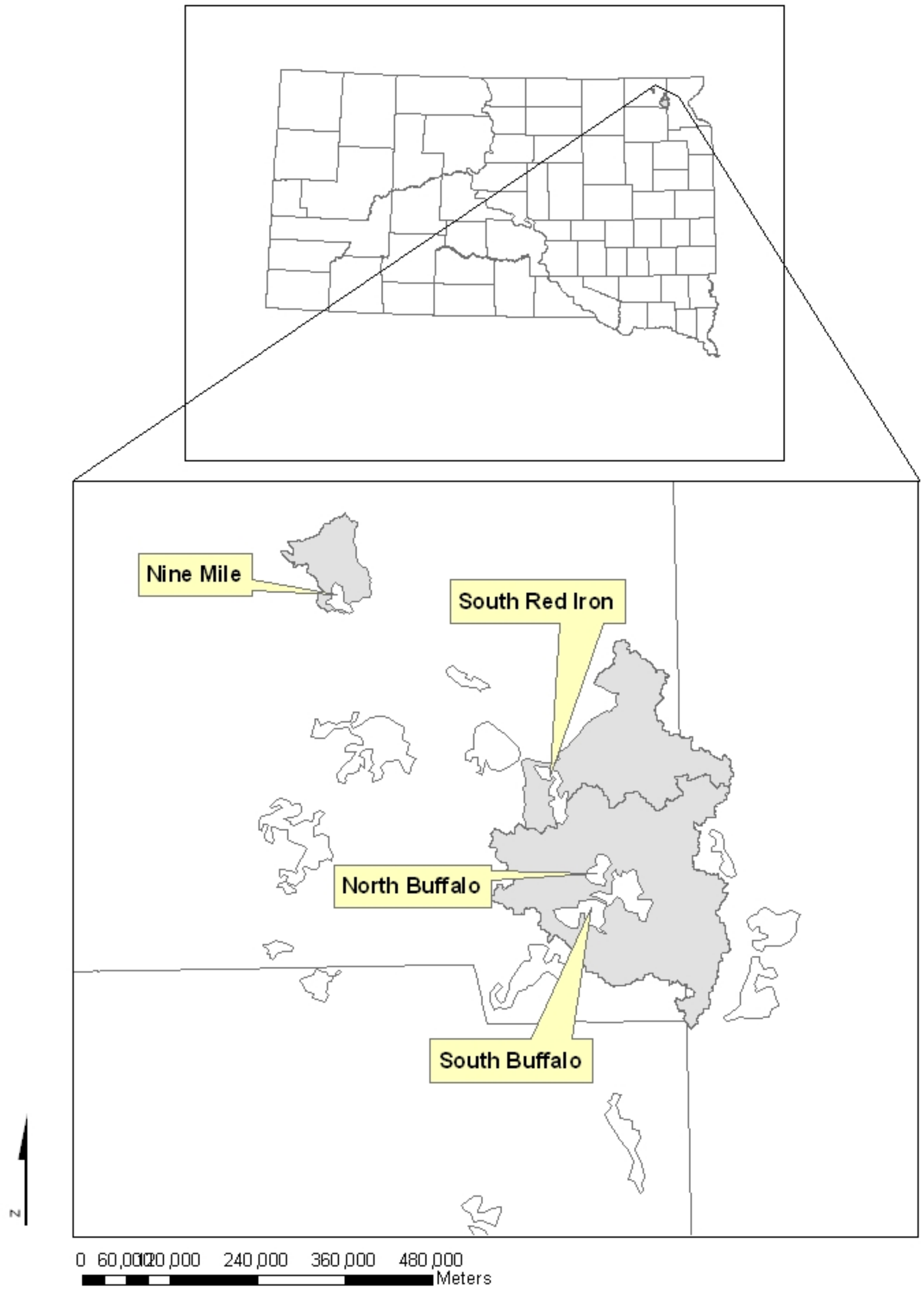

Figure 1. Lakes and their watersheds in the Marshall County Lakes Assessment Project.

Trophic Status Comparison

Developed by Carlson (1977), the Trophic State Index, or TSI, is a numerical value from 0 to 100 that allows a lake's productivity to be easily quantified and compared to other lakes. Higher TSI values correlate with higher levels of primary productivity. A comparison of the growing-season TSI for South Red Iron Lake to other lakes in the area (Table 1) shows that South Red Iron Lake had relatively better water quality than other lakes in the area and that a moderate to high rate of productivity is common for the region.

Table 1. TSI comparison of South Red Iron Lake and other area lakes*.

Lake	1989 Avg. TSI	1991 Avg. TSI	1993 Avg. TSI	Mean Trophic State
White Lake	69.05	71.74	69.59	Eutrophic
Roy	62.95	65.01	60.88	Eutrophic
Nine Mile Lake	60.08	66.11	63.87	Eutrophic
S. Buffalo	54.17	70.09	64.24	Eutrophic
Average	**61.56**	**68.24**	**64.65**	**Eutrophic**
S. Red Iron	**51.28**	**62.02**	**59.07**	**Eutrophic**

* TSI values taken from Stueven and Stewart, 1996.

Beneficial Uses and Water Quality Standards

The State of South Dakota has assigned all of the water bodies that are within its borders a set of beneficial uses. With these assigned uses are sets of standards for various physical and chemical properties. These standards must be maintained for the waterbody to satisfy its assigned beneficial uses. All bodies of water in the state receive the beneficial uses of fish and wildlife propagation, recreation, and stock watering. Following is the list of beneficial uses assigned to South Red Iron Lake.

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

With each of these uses are sets of water quality standards that must not be exceeded in order to maintain these uses. The following tables list those parameters measured during this study that must be considered when maintaining the beneficial uses as well as the concentrations for each parameter. When multiple standards for a parameter exist, the most restrictive standard is used. Additional "narrative" standards that may apply can be found in the "Administrative Rules of South Dakota: Articles 74:51:01:05; 06; 08; and 09". These contain language that generally prohibits the presence of materials causing pollutants to form, visible pollutants, and nuisance aquatic life. Carlson's (1977) trophic state indices were originally used during this study as a measure of beneficial use support. The indices are based on total phosphorus, Secchi disc transparency and chlorophyll *a*. The target values were derived from a SDDENR study of South Dakota lakes and from regionality of various lake attributes (Lorenzen, 2005). South Red Iron Lake is listed in the state's 2006 303(d) list and was identified as not supporting its fish life propagation use due to an elevated TSI and pH.

During 2008, refinement of the 303(d) listing criteria eliminated the use of TSI values as a means to measure beneficial use attainment. However, the TSIs are still used as a general means of judging overall lake quality and setting annual phosphorus loads.

Table 2. State beneficial use standards for South Red Iron Lake, Marshall County, South Dakota.

Parameters	mg/l (except where noted)	Beneficial Use Requiring this Standard
Alkalinity *($CaCO_3$)*	≤ 750 *(mean),* ≤ 1,313 *(single sample)*	Wildlife Propagation and Stock Watering
Coliform, fecal *(per 100 ml)* May 1 to Sept 30	≤ 200 *(Geo.mean),* ≤ 400 *(single sample)*	Immersion Recreation
Conductivity *(µmhos/cm @ 25 °C)*	≤ 4,000 *(mean,)* ≤ 7,000 *(single sample)*	Wildlife Propagation and Stock Watering
Nitrogen, Total ammonia as N	$(0.411/(1+10^{7.204-pH}))+(58.4/(1+10^{pH-7.204}))$ *(single sample)*	Warmwater Permanent Fish Propagation
Nitrogen, nitrates as N	≤ 50 *(mean),* ≤ *88 (single sample)*	Wildlife Propagation and Stock Watering
Oxygen, dissolved	≥ 5.0	Immersion and Limited Contact Recreation
pH (standard units)	≥ 6.5 - ≤ 9.0	Warmwater Permanent Fish Propagation
Solids, suspended	≤ 90 *(mean),* ≤ 158 *(single sample)*	Warmwater Permanent Fish Propagation
Temperature	≤ 26.67 C	Warmwater Permanent Fish Propagation

The tributaries of South Red Iron Lake have the beneficial uses of:

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

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

Table 3. State water quality standards for the unnamed tributaries of South Red Iron Lake.

Parameters	Criterion, mg/l (except where noted)
Nitrate	≤ 50 (mean), ≤ 88 (single sample)
Alkalinity	≤ 750 (mean), ≤ 1,313 (single sample)
pH	≥ 6.5 and ≤ 9.5
Conductivity	≤ 4,000 (mean), ≤ 7,000 (single sample)

Recreational Uses

The South Dakota Department of Game, Fish, and Parks provide a list of public facilities that are maintained at area lakes (Table 4). Most of the larger and more frequently used lakes in the area have adequate facilities. This includes South Red Iron Lake.

Table 4. Comparison of recreational uses on lakes near South Red Iron Lake.

Lake	State Parks	Ramps	Boating	Campground	Fishing	Picnic Tables	Swimming	Nearest Municipality
White Lake		X	X		X		X	Britton
South Buffalo		X	X		X		X	Lake City
Nine Mile Lake		X	X		X		X	Lake City
South Red Iron		**X**	**X**		**X**		**X**	**Lake City**
North Buffalo		X	X		X		X	Lake City
Roy Lake	X	X	X	X	X	X	X	Lake City

Watershed

South Red Iron Lake and its 26,477-acre watershed are located eight miles southeast of Lake City, South Dakota. The watershed is characterized by rolling mixed-grass prairie, pastureland with a small portion in cultivation. The major soil associations found in the watershed are of the Forman-Poinsett and Renshaw-Fordville-Sioux associations (USDA, 1975). The former consists of nearly level to rolling, well drained loamy and silty soils that formed in glacial drift. The latter consists of nearly level to steep, well-drained to excessively drained, loamy soils underlain by sand and gravel.

Land use in the watershed is primarily agricultural grazing with some cropland. Small grains and hay are the main crops on cultivated lands. The average annual precipitation in the watershed is 19.24 inches, of which most usually falls in April through September. Tornadoes and severe thunderstorms strike occasionally. These storms are local and of short duration and occasionally produce heavy rainfall events

History

South Red Iron Lake is a natural lake named after a famous Indian chief. The lake is used primarily for recreation such as fishing, swimming, water skiing, etc. Previous water quality data and anecdotal information indicated the lake experienced some algae problems in the past. Recently, users of South Red Iron Lake reported algae blooms in the lake. The 2000, 2002, and 2004 Integrated Report for Surface Water Quality Assessment documents described the water quality of South Red Iron Lake as fully supporting some beneficial uses and unknown for others. The 2006 Integrated Report reported non-support of its fish life propagation use due to TSI and pH problems caused by non-point source pollution. The Marshall Conservation District was concerned enough about the quality of the lakes in the area that they agreed to sponsor a four-lake assessment in Marshall County.

Threatened and Endangered Species

The only species on the federal list of threatened and endangered species likely to occur in the South Red Iron Lake watershed is the bald eagle (*Haliaeetus leucocephalis*), which is listed as threatened. No bald eagles were encountered during this study; however, care should be taken when conducting mitigation projects in the watershed.

Nesting bald eagles have not been documented in the project area but there could be eagles migrating through the area, especially during the fall waterfowl migration. Any mitigation processes that take place should avoid the destruction of large trees that may be used as eagle perches, particularly if an eagle is observed using the tree as a perch or roost.

PROJECT GOALS, OBJECTIVES, AND ACTIVITIES

Planned and Actual Milestones, Products, and Completion Dates

Objective 1. Lake Sampling and Sediment Survey

The lake water sampling commenced June, 2002 and continued through May 2003. Spring samples were collected during March, April, and May of 2003. Bimonthly samples were collected during June, July and August. The sediment survey was conducted during March, 2003.

Objective 2. Tributary Sampling

Immediately after the start of the project, the local coordinator began sampling the tributaries. Detailed cross-sectional and water velocity data were collected along with daily stage readings from stage recorders. These data were used to develop stage/discharge relationships so water flows could be calculated. The stage-discharge relationships for the in-coming tributaries were poor and did not warrant their use. In addition, monitoring at the outlet site was discontinued because of highway construction at that site (and flows did not occur). So the total inflow to the lake was estimated from the EDNA (Elevation Derivatives for National Application) Program (http://edna.usgs.gov). The annual inflow generated by EDNA was then used in the BATHTUB model to predict in-lake total phosphorus concentration and trophic state.

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

Duplicate and blank samples were collected during the course of the project to provide defendable proof that sample data were collected in a scientific and reproducible manner. QA/QC data collection began in June of 2002 and was completed as planned.

Objective 4. AnnAGNPS Modeling

Prairie Agricultural Research, Inc. toured the watershed and made initial determinations for the AnnAGNPS model. The NRCS office located in Britton made available information concerning land use information. AnnAGNPS modeling was not completed because the lake was nearly meeting its target TSI and it was felt that any AnnAGNPS runs should be done during the implementation phase to direct and assess BMP implementation.

Objective 5. Public Participation

The public was kept informed of the project through monthly meetings of the Marshall Conservation District.

Objectives 6 and 7. Restoration Alternatives and Final Report

The completion of the restoration alternatives and final report for South Red Iron Lake was delayed due to DENR personnel having other commitments.

Evaluation of Goal Achievements

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

Table 5. Proposed and actual objective completion dates for the Marshall County Lakes Assessment Project.

	6/02	7/02	8/02	9/02	10/02	11/02	12/02	1/03	2/03	3/03	4/03	503	6/03	7/03	8/03-12/06
Objective 1															
Lake Sampling															
Objective 2															
Tributary Sampling															
Objective 3															
QA/QC															
Objective 4															
Modeling															
Objective 5															
Public Participation															
Objective 6 & 7															
Final Report															

MONITORING METHODS AND RESULTS

OBJECTIVE 1 – Lake Sampling and Sediment Survey

In-lake Sampling Schedule, Methods, and Materials

Three sampling sites were chosen to monitor South Red Iron Lake (Figure 2). Sampling began in June 2002, and was conducted on a bimonthly basis at the in-lake sites during June, July, and August, and monthly during other months. Water samples were collected at both sites with a Van Dorn sampler from the lake surface and near the bottom of the lake. The samples were filtered, preserved, and packed in ice for shipping to the State Health Lab in Pierre, SD according to the "Standard Operating Procedures for Field Samplers" (Stueven, et al., 2000). The laboratory analyzed the samples for the following parameters:

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

Personnel conducting the sampling at each of the sites recorded the following observations.

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

Parameters measured in the field by sampling personnel were:

Water temperature	Air temperature
Specific conductance	Dissolved oxygen
Field pH	Secchi depth

Original data may be found in Appendix A.

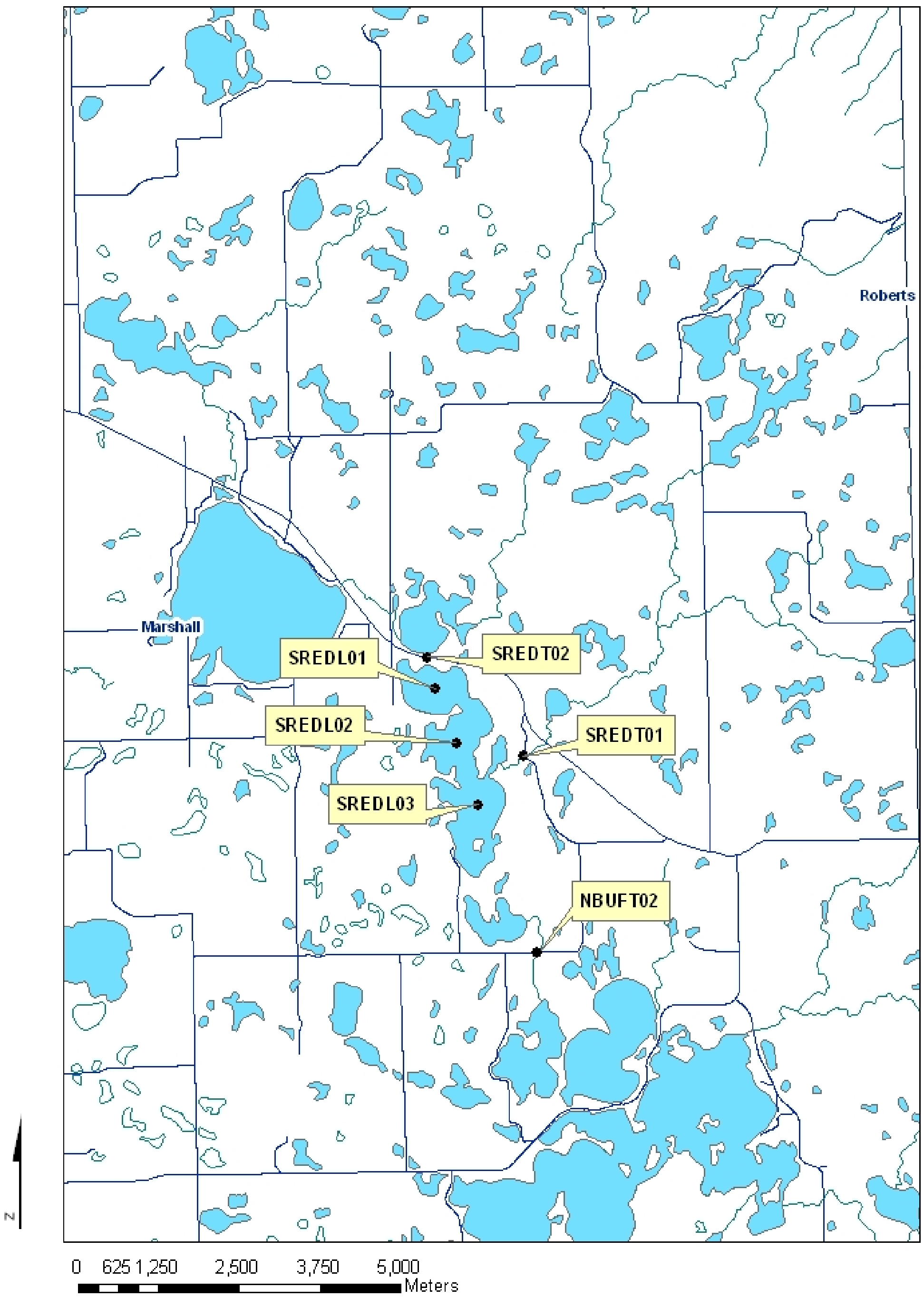

Figure 2. Sampling sites in South Red Iron Lake and its watershed.

In-lake Water Quality Results

Water Temperature

The water temperature in South Red Iron Lake exhibited little variation between the three sites. Temperatures showed seasonal variations that are consistent with its geographic location, steadily increasing in the spring and summer and consistently decreasing in the fall and winter (Figure 3). It can be reasonably expected that during most years temperatures would be within a few degrees of the project data at their respective dates.

The lowest water temperatures were recorded during the winter and the highest temperature was 23.53ºC, during August, 2002. This was lower than the state standard criterion that requires water temperature to be less than or equal to 32.22 ^{o}C (90ºF).

South Red Iron Lake showed no significant thermal stratification during the study and most temperature readings near the lake surface and bottom only differed by two degrees or less (Figure 3). The greatest difference between surface and bottom temperatures was 3.73 ºC and occurred on August 27, 2002 at Site SREDL01.

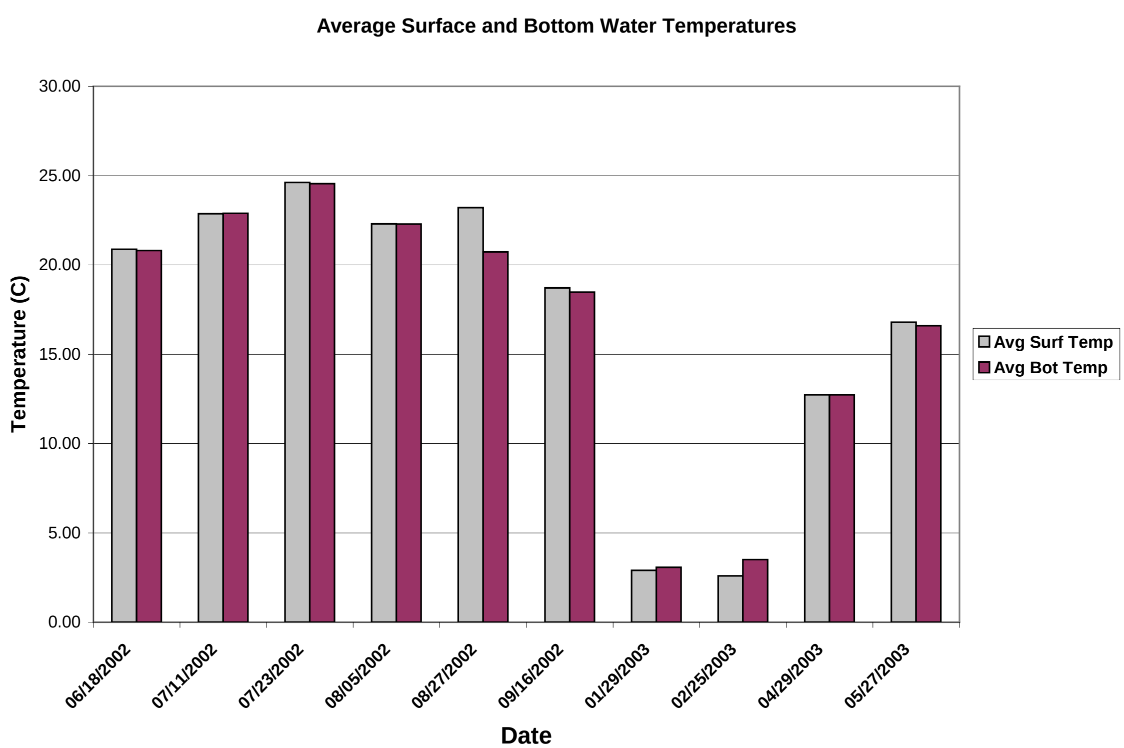

Figure 3. Average in-lake surface and bottom water temperatures for South Red Iron Lake, Marshall County, South Dakota, 2002/2003.

Dissolved Oxygen (DO)

Dissolved oxygen (DO) levels in South Red Iron Lake were usually sufficient to maintain the minimum requirement for the local managed fishery (Figure 4). DO depletion only occurred once during the project where two readings were below the 5.0 mg/l standard. This occurred at Site SREDL02 during 8/27/02 and the readings were 4.14 and 3.8 mg/l at 3.005 and 3.132 meter depths respectively. The other two readings (at 1.02 and 2.014 meters) were above 5.0 mg/l. Because there was adequate DO at the surface at this site and at the other two sampling sites, DO was not considered a problem and does not require a TMDL.

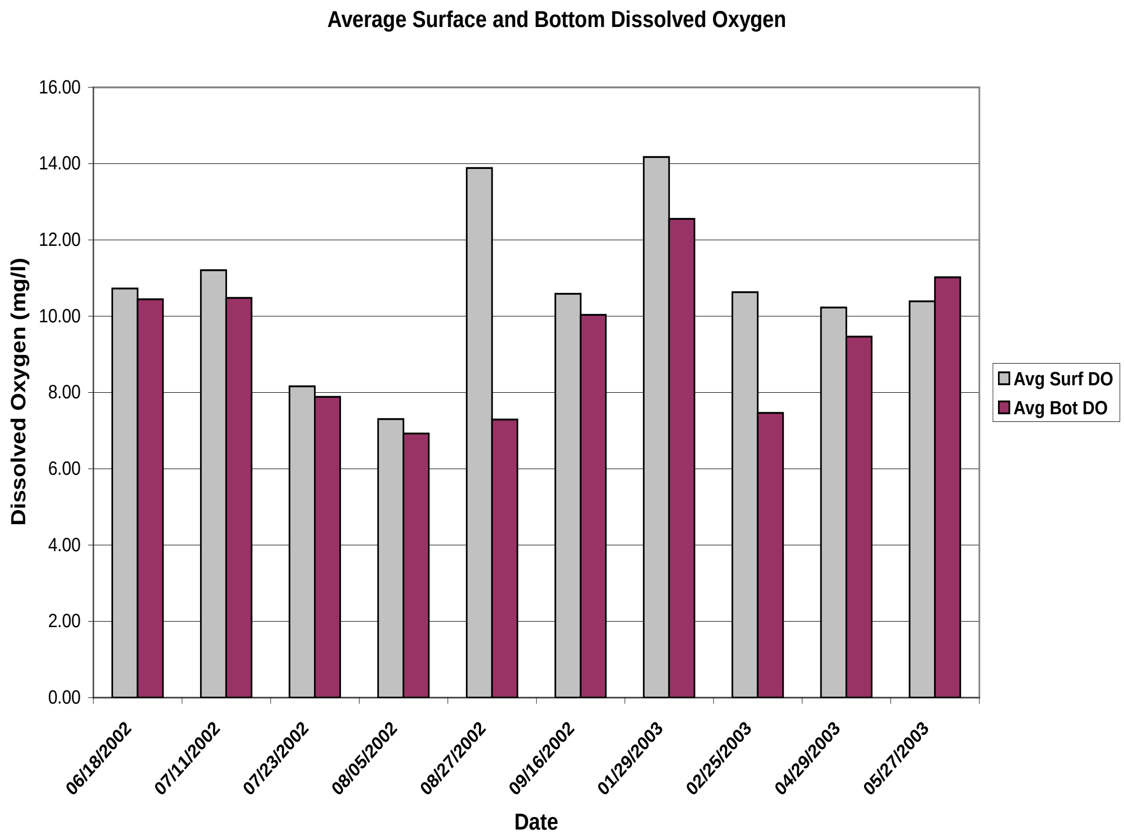

Figure 4. Average in-lake surface and bottom dissolved oxygen concentrations for South Red Iron Lake, Marshall County, South Dakota, 2002/2003.

pH

pH values in South Red Iron Lake ranged from 7.17 to 9.65 and averaged 8.68 (Table 6). However, the project coordinator indicated during the project that the YSI meter used to measure pH was operating abnormally. The YSI pH probe was eventually replaced but it was felt that much of the pH data were suspect. All four lakes monitored under the Marshall County Lakes Assessment Project exhibited a number of pH values greater than

9.0 and some as high as 10. This is not considered normal for lakes in this area of South Dakota. Algae are often implicated in causing higher pH values but none of these lakes had excessively high chlorophyll *a* concentrations. In addition, historical data show pH values in these lakes averaged 8.5-8.7 with only a couple of occurrences above 9.0 (Table 26 in Appendix A). Because of this it was decided not to use the pH data obtained during the project. It is also recommended that these data not be used in any other analysis, such as the South Dakota Integrated Report or 303(d) listings. Given the historical data, pH was not considered problematic in these lakes.

Table 6. In-lake pH values for South Red Iron Lake, Marshall County, South Dakota, 2002/2003.

Date	Depth	SREDL01	Depth	SREDL02	Depth	SREDL03
6/18/02	0.961	8.45	0.950	8.22	0.950	8.40
6/18/02	1.925	8.30	1.943	8.46	1.945	8.21
7/11/02	1.083	7.72	1.094	8.06	1.098	8.4
7/11/02	1.082	7.76	2.094	7.62	2.07	8.27
7/11/02	3.090	7.66	3.072	7.80	3.055	7.85
7/11/02			3.322	7.85	3.285	8.15
8/5/02	0.969	9.12	1.008	9.01	0.965	8.96
8/5/02	1.993	8.81	1.997	8.93	1.973	8.69
8/5/02	2.994	9.19	2.965	9.04	2.621	9.03
8/5/02	3.623	8.75	3.287	9.06		
8/27/02	1.000	9.38	1.020	9.59	1.021	9.65
8/27/02	1.996	9.38	2.014	9.53	1.802	9.58
8/27/02	2.990	9.23	3.005	9.32		
8/27/02	3.599	9.13	3.132	9.27		
9/16/02	1.0	8.75	1.0	8.84	1.0	8.83
9/16/02	2.0	8.81	2.0	8.88	2.0	8.86
9/16/02	3.0	8.90	3.0	8.92	3.0	8.92
9/16/02	3.4	8.88	3.1	8.95	3.1	8.95
1/29/03	1.1	7.34	1.0	7.55	1.0	7.51
1/29/03	2.0	7.41	2.1	7.50	2.0	7.52
1/29/03	3.0	7.17	3.0	7.37	3.0	7.53
1/29/03	2.8	7.17	3.1	7.53	3.2	7.61
2/25/03	0.9	8.94	0.9	9.01	0.9	9.24
2/25/03	1.9	8.94	1.9	9.01	1.9	9.18
2/25/03	2.9	8.93	2.9	8.97	2.9	9.13
2/25/03	3.3	8.89	2.9	8.96	3.1	9.05
4/29/03	0.977	8.99	0.940	9.04	0.983	9.03
4/29/03	1.961	8.99	1.941	9.04	1.937	9.03
4/29/03	2.963	8.99	2.965	9.04	2.947	9.03
4/29/03	3.679	8.81	3.026	9.03	3.156	9.03
5/27/03	1.048	9.06	1.091	9.03	1.174	9.02
5/27/03	2.102	9.06	2.071	9.03	2.096	9.03
5/27/03	3.078	9.06	3.057	9.03	3.096	9.02
5/27/03	3.666	9.03	3.170	9.03	3.242	9.02

Specific Conductance

Specific conductance ranged from 350 to 683 µS/cm. State standards for fish and wildlife propagation and stock watering require that conductivity should not equal or exceed 7,000 µS/cm on any single day. All specific conductance readings at South Red Iron Lake were less than the state standard and not considered a problem.

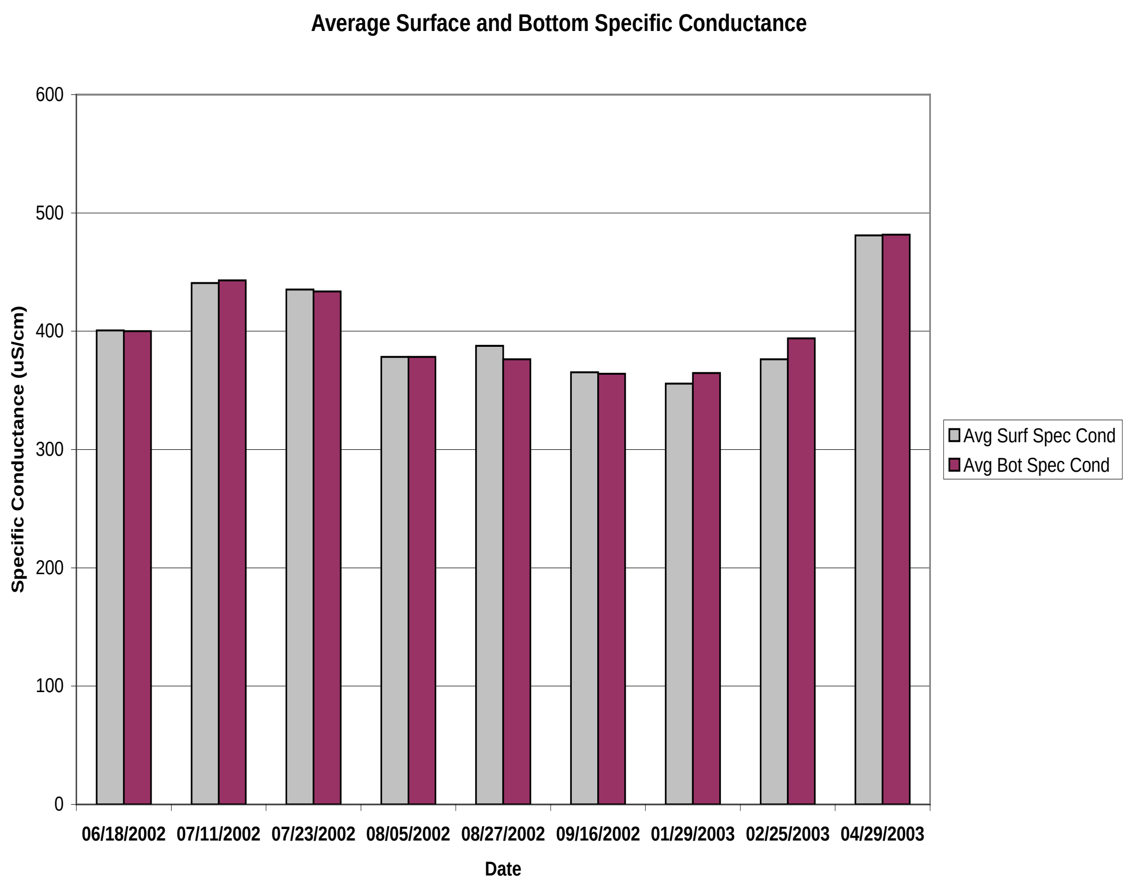

Figure 5. Average in-lake surface and bottom specific conductance values for South Red Iron Lake, Marshall County, South Dakota, 2002/2003.

Secchi Depth

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

Secchi transparency readings in South Red Iron Lake averaged 1.23 meters with the greatest readings found during January, 2003 (Figure 6). This was probably due to midwinter algae die-off and a settling of dead algae and other suspended matter to the bottom during ice cover. The mean Secchi transparency reading during the primary growing season (May 15 through September 15) was 0.92 meter, equivalent to a TSI value of 61.2. This indicates eutrophic conditions.

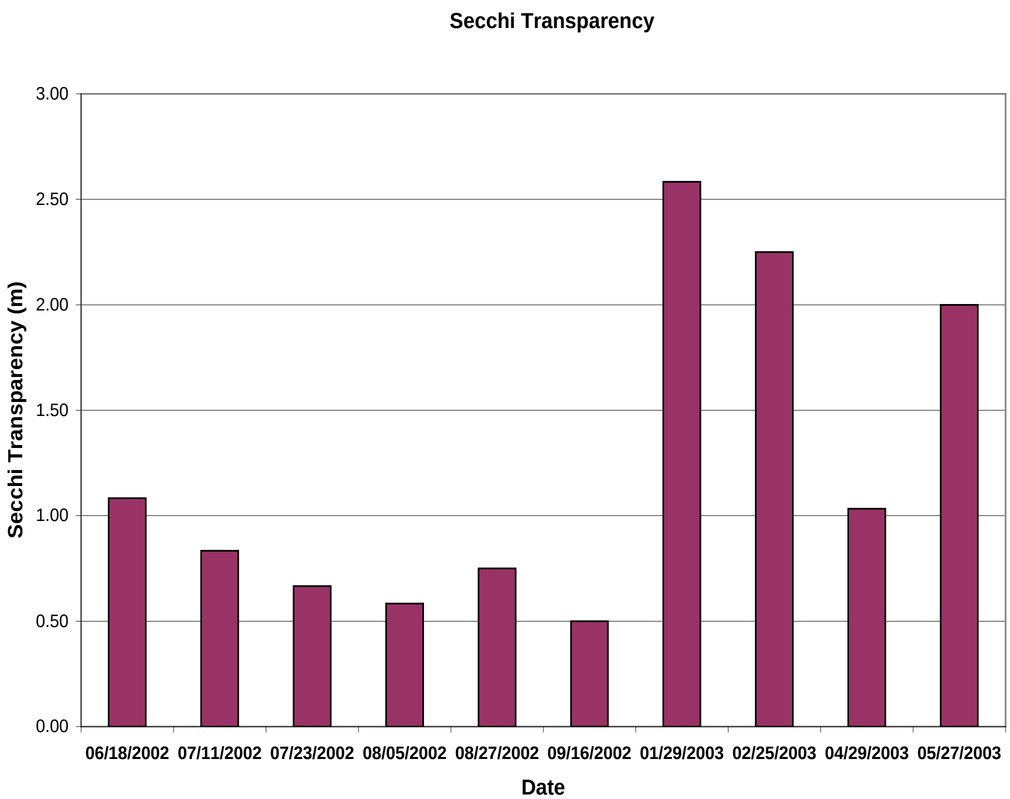

Figure 6. Average Secchi transparency depths for South Red Iron Lake, Marshall County, South Dakota, 2002/2003.

Alkalinity

The total alkalinity in South Red Iron Lake averaged around 244 mg/l (Figure 7) and varied from 227 mg/l to 299 mg/l. There was little difference in total alkalinity in samples collected from the surface or the bottom. The total alkalinity concentrations are typical for lakes in South Dakota. The alkalinity standard criterion was never exceeded.

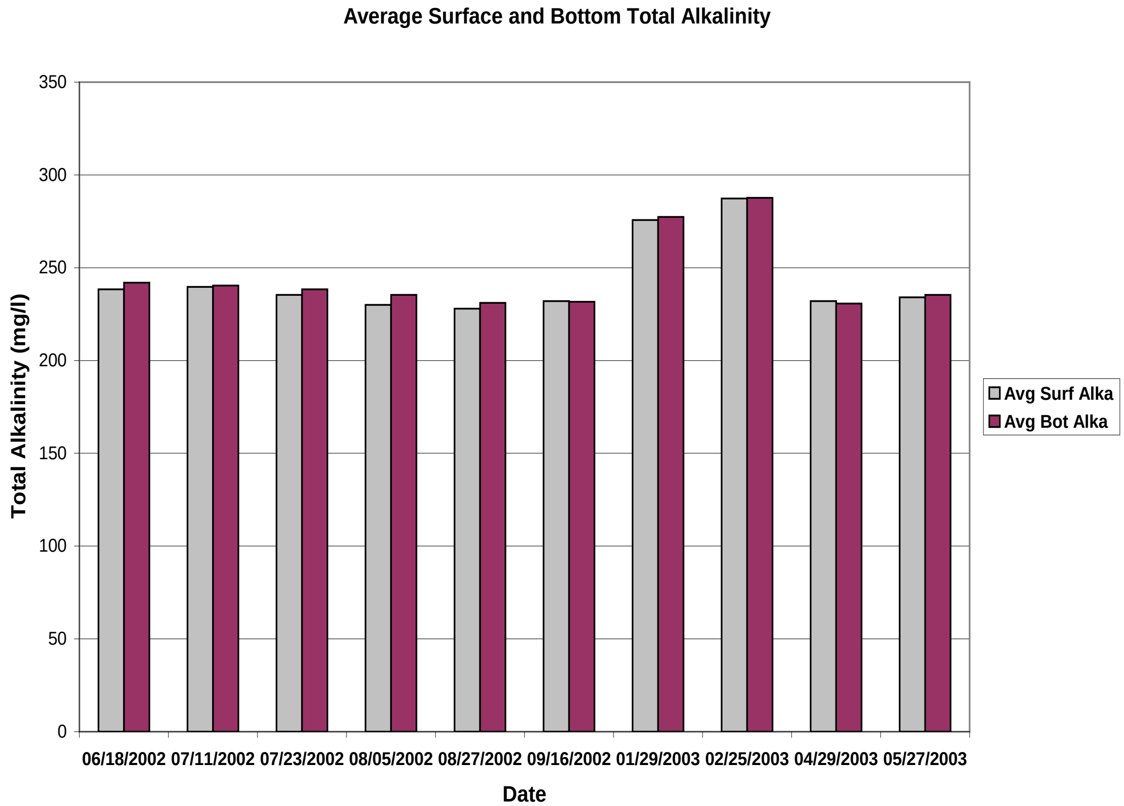

Figure 7. Average in-lake surface and bottom total alkalinity concentrations for South Red Iron Lake, Marshall County, South Dakota, 2002/2003.

Solids

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

South Red Iron Lake exhibited some seasonality in total solids concentrations with slightly higher values during the winter (Table 7). Total solids ranged from 360 mg/l to 478 mg/l and averaged 397 mg/l. Suspended solids concentrations in South Red Iron Lake exhibited slightly higher concentrations during the summer, probably a result of algae (Table 8). One value of 130 mg/l was thought to be due to the Van Dorn sampler hitting the lake bottom and was not used in calculating the average concentration. Suspended solids concentrations ranged from 3 mg/l to 60 mg/l (ignoring the 130 mg/l value) and averaged 19.1 mg/l.

Total volatile suspended solids comprised about 57% of the total suspended solids. Algae likely comprised the bulk of the organic matter in the lake.

Table 7. Total solids concentrations for South Red Iron Lake, Marshall County, South Dakota, 2002/2003.

DATE	SREDL01 Surface	SREDL01 Bottom	SREDL02 Surface	SREDL02 Bottom	SREDL03 Surface	SREDL03 Bottom
6/18/02	376	417	374	389	383	428
7/11/02	375	413	388	396	380	378
7/23/02	360	387	375	410	377	395
8/05/02	365	478	390	374	378	387
8/27/02	362		379	374	366	370
9/16/02	378	377	388	388	396	391
1/29/03	424	429	444	450	453	465
2/25/03	448	441	458	453	471	465
4/29/03	388	381	384	383	377	372
5/27/03	360	388	368	369	360	361

Table 8. Total suspended solids concentrations for South Red Iron Lake, Marshall County, South Dakota, 2002/2003.

DATE	SREDL01 Surface	SREDL01 Bottom	SREDL02 Surface	SREDL02 Bottom	SREDL03 Surface	SREDL03 Bottom
6/18/02	7	51	13	18	9	49
7/11/02	14	48	25	24	17	17
7/23/02	15	29	23	60	23	32
8/05/02	25	130	31	35	31	32
8/27/02	12		13	20	10	13
9/16/02	18	18	19	19	19	21
1/29/03	3	5	4	10	3	3
2/25/03	4	6	4	3	3	5
4/29/03	8	8	13	13	9	10
5/27/03	7	36	7	7	8	8

Nitrogen

All sixty of the samples collected from South Red Iron Lake and analyzed for nitrates had concentrations at or below the 0.1 mg/l detection limit (see Appendix A). Ammonia concentrations were at or below the 0.02 mg/l detection limit forty-two out of sixty samples (70% of the samples). Ammonia concentrations averaged 0.080 mg/l and ranged from below the 0.02 mg/l detection limit to 0.37 mg/l (Table 9). The median concentration was 0.02 mg/l. The water quality standard criterion for total ammonia was not exceeded in any of the samples

Total nitrogen in South Red Iron Lake averaged 1.23 mg/l and ranged from 0.75 mg/l to 1.89 mg/l (Appendix A); which is relatively low for lakes in South Dakota. Organic nitrogen comprised about 85.6% of the total nitrogen. This was likely due to algae and other organic matter in the lake.

Table 9. Total ammonia concentrations (mg/l) for South Red Iron Lake, Marshall County, South Dakota during 2002/2003.

DATE	SREDL01 Surface	SREDL01 Bottom	SREDL02 Surface	SREDL02 Bottom	SREDL03 Surface	SREDL03 Bottom
6/18/02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
7/11/02	0.1	0.1	0.1	0.1	0.12	0.13
7/23/02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
8/05/02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
8/27/02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
9/16/02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
1/29/03	0.24	0.24	0.22	0.23	0.18	0.16
2/25/03	0.36	0.37	0.32	0.35	0.31	0.33
4/29/03	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
5/27/03	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02

Phosphorus

The average in-lake total phosphorus concentration during the assessment was 0.055 mg/l. Total phosphorus concentrations greater than 0.02 mg/l are generally regarded as indicative of eutrophic conditions (USEPA, 1974) so South Red Iron Lake could be considered eutrophic. Total phosphorus concentrations were generally highest during the summer (Table 10).

Total dissolved phosphorus (TDP) in South Red Iron Lake averaged .016 mg/l and ranged from .008 to .039 mg/l (Table 11). TDP comprised about 33% of the total phosphorus. The total dissolved phosphorus concentrations were higher during the winter.

Table 10. Total phosphorus concentrations (mg/l) for South Red Iron Lake, Marshall County, South Dakota during 2002/2003.

DATE	SREDL01 Surface	SREDL01 Bottom	SREDL02 Surface	SREDL02 Bottom	SREDL03 Surface	SREDL03 Bottom
6/18/02	0.043	0.072	0.054	0.060	0.043	0.056
7/11/02	0.056	0.060	0.079	0.076	0.064	0.065
7/23/02	0.045	0.064	0.069	0.077	0.065	0.087
8/05/02	0.057	0.078	0.085	0.085	0.080	0.085
8/27/02	0.041	0.058	0.042	0.066	0.040	0.039
9/16/02	0.067	0.060	0.067	0.066	0.073	0.064
1/29/03	0.040	0.042	0.037	0.034	0.030	0.035
2/25/03	0.044	0.046	0.041	0.038	0.037	0.038
4/29/03	0.034	0.042	0.050	0.060	0.080	0.065
5/27/03	0.028	0.044	0.026	0.028	0.036	0.033

Table 11. Total dissolved phosphorus concentrations (mg/l) for South Red Iron Lake, Marshall County, South Dakota during 2002/2003.

DATE	SREDL01 Surface	SREDL01 Bottom	SREDL02 Surface	SREDL02 Bottom	SREDL03 Surface	SREDL03 Bottom
6/18/02	0.011	0.014	0.012	0.014	0.010	0.012
7/11/02	0.009	0.009	0.015	0.014	0.010	0.009
7/23/02	0.012	0.011	0.012	0.012	0.012	0.016
8/05/02	0.022	0.010	0.011	0.013	0.015	0.016
8/27/02	0.012	0.012	0.012	0.013	0.014	0.013
9/16/02	0.011	0.012	0.014	0.012	0.013	0.012
1/29/03	0.032	0.033	0.026	0.022	0.022	0.021
2/25/03	0.036	0.037	0.039	0.028	0.031	0.029
4/29/03	.0008	0.009	0.013	0.014	0.008	0.008
5/27/03	0.011	0.010	0.010	0.011	0.011	0.011

Fecal Coliform Bacteria

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

South Red Iron Lake is listed for the beneficial use of immersion recreation which requires that no single sample exceed 400 colonies/100ml or the 30-day geometric mean (consisting of at least 5 samples) is no more then 200 colonies/100ml. No exceedences of the state standard criterion were observed during the project. Samples collected and analyzed for fecal coliform were consistently below the detection limit of 10 colonies per 100 ml (see Appendix A).

Limiting Nutrients

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

The average total nitrogen (TN) to total phosphorus (TP) ratio for the water samples collected from South Red Iron Lake was 25.24 with a range of 9.63 to 67.5 (Appendix A). Sixty-seven out of sixty-eight TN:TP ratios calculated for the lake were greater than 10 and indicated phosphorus limitation. There was little seasonality to the TN:TP ratios.

Chlorophyll *a*

The data indicated relatively low concentrations throughout the project. (Table 12). The average "growing season" chlorophyll *a* concentration in South Red Iron Lake was 14.04 µg/l and indicated eutrophic conditions. The growing season chlorophyll *a* concentrations did not correlate well with in-lake total phosphorus concentrations (Figure 8).

Table 12. Chlorophyll *a* concentrations (µg/l) for South Red Iron Lake, Marshall County, South Dakota during 2002/2003.

DATE	SREDL01 (µg/l)	SREDL02 (µg/l)	SREDL03 (µg/l)
6/18/02	4.41	6.61	3.3
7/11/02	17.42	11.91	18.12
7/23/02	26.13	30.84	15.62
8/05/02	21.03	13.62	24.73
8/27/02	11.41	10.61	8.61
9/16/02	23.33	11.41	18.22
1/29/03			
2/25/03	2.2	3.8	2.5
4/29/03	5.71	9.11	6.51
5/27/03		1.5	1.9

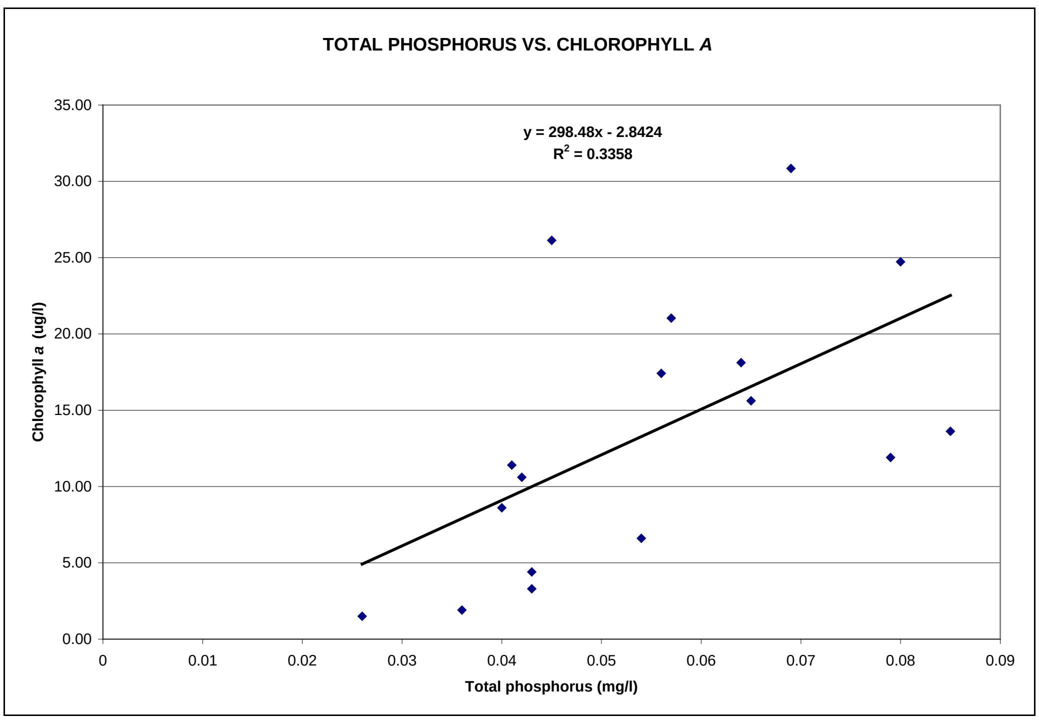

Figure 8. Regression between growing-season total phosphorus and chlorophyll *a* in South Red Iron Lake, 2002/2003.

Trophic State

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

Lakes with TSI values less than 35 are generally considered to be oligotrophic and contain very small amounts of nutrients, little plant life, and are generally very clear. Lakes that have a score of 35 to 50 are considered mesotrophic and have more nutrients and primary production than oligotrophic lakes (Table 13). Eutrophic lakes have a score between 50 and 65 and are subject to algal blooms and have large amounts of primary production. Hyper-eutrophic lakes receive scores greater than 65 and are subject to frequent and massive blooms of algae that severely impair their beneficial use and aesthetic beauty.

During the study the average growing season trophic state numerical value for South Red Iron Lake was 59.48, placing it in the eutrophic category. This TSI was based on total phosphorus, Secchi transparency, and chlorophyll *a*.

Table 13. Trophic state and TSI values.

TROPHIC STATE	TSI NUMERIC RANGE
OLIGOTROPHIC	0-35
MESOTROPHIC	36-50
EUTROPHIC	51-65
HYPER-EUTROPHIC	66-100

Lorenzen (2005) recognized the problems with using total phosphorus in TSIs and developed targets based on the fish life classification of a lake. During 2008, refinement of the 303(d) listing criteria eliminated the use of TSI values as a means to measure beneficial use attainment. However, the TSIs are still used as a general means of judging overall lake quality and setting annual phosphorus loads.

For a lake with a permanent fish life propagation use, full support of the use is obtained at a median growing-season Secchi-chlorophyll *a* TSI of <58.4. The median growing-season Secchi-chlorophyll *a* TSI for South Red Iron Lake was 60.0 and indicated the lake was not meeting its target TSI value.

Sediment Survey

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

A cursory sediment survey was conducted on South Red Iron Lake during March, 2003. A total of 17 holes were drilled through the ice. At each hole, the water depth was recorded and a piece of rebar was pushed into the sediment as far as possible and the length of rebar from the end back to the surface ice was noted. The difference between that measurement and the water depth equals the sediment depth.

Figure 11 provides the water and sediment depths at each test hole. Water depth averaged 10.9 feet (3.32 meters) with a maximum depth of 13.0 feet (3.96 meters). The sediment depths ranged from 0 to 11.5 feet (3.51 meters) and averaged 7.8 feet (2.38 meters). The average sediment was considered slightly higher than what is expected in a South Dakota Lake, where three to six foot of sediment is more common. Lake depth could be increased, possibly up to 42%, if this sediment was removed which would extend the usable life of the lake. This might also remove sediment that could otherwise release nutrients into the water column.

Elutriate Testing

Elutriate tests were run on composite sediment and water samples collected from the two in-lake sites during 5/18/2004. Sediment was collected with a Petite Ponar sampler and water was collected with a Van Dorn sampler. The samples were shipped to the State Health Lab for analysis. The sediment was mixed with lake water and the resultant elutriate was analyzed for the same parameters as the receiving water.

The elutriate and receiving water tests indicated many of the parameters were below their respective detection limits and none of the results indicated problematic conditions concerning these parameters (Table 14).

Macrophyte Survey

A macrophyte/shoreline condition survey was conducted during August 2003. Thirteen locations were established approximately equidistant from each other around the perimeter of the lake. At each location, the bank stability, vegetative cover, and vegetative zone width were rated from 0 to 10 (10 being the optimal condition). Three macrophyte survey points were also established at each location with the nearest point being approximately ten feet from the shoreline and the farthest point 30-40 feet away from the shoreline. At each point, a weighted garden rake (tined portion with one foot of handle) was thrown in four directions. The relative percent recovery of plant species on the rake was noted and the relative plant density at each point was judged from the four rake pulls.

The shoreline of South Red Iron Lake was rated as suboptimal to optimal condition. The rating scores for bank stability, vegetative cover, and vegetative zone

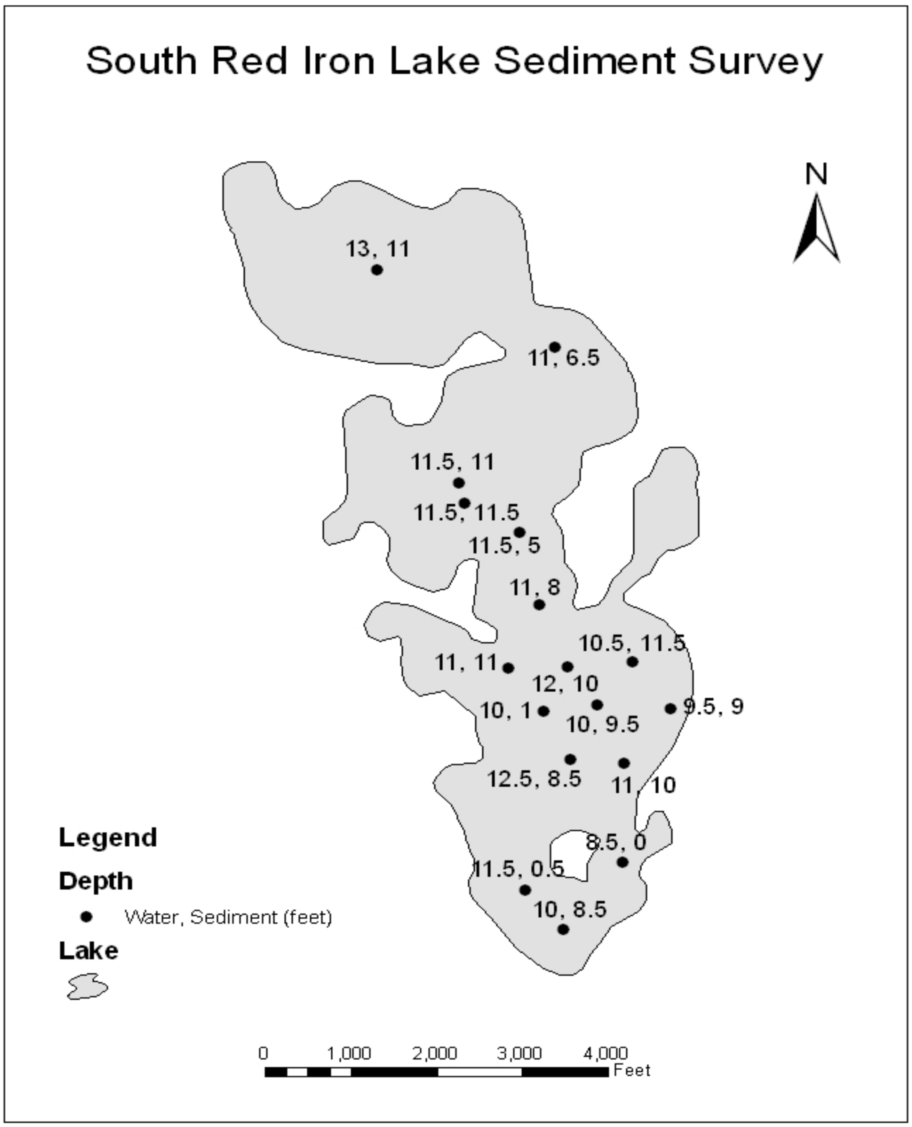

Figure 9. Water and sediment depths for South Red Iron Lake, Marshall County, South Dakota, 2004.

Table 14. Elutriate test results for South Red Iron Lake, Marshall County, South Dakota, during 5/18/2004.

Parameter	Receiving Water South Red Iron Lake	Elutriate Sample South Red Iron Lake	Unit
COD	28.2	44.4	mg/l
Phosphorus, total	0.010	0.019	mg/l
TKN	0.96	2.31	mg/l
Hardness	620	640	mg/l
Nitrate	<0.1	0.1	mg/l
Nitrite	<0.02	<0.02	mg/l
Ammonia	<0.02	0.49	mg/l
Aluminum	3.2	19.3	µg/l
Zinc	43.2	9.6	µg/l
Silver	<0.2	0.4	µg/l
Selenium	1.3	1.3	µg/l
Nickel	1.5	1.5	µg/l
Mercury, total	<0.1	<0.1	µg/l
Lead	<0.1	<0.1	µg/l
Copper	13.0	<0.4	µg/l
Cadmium	<0.2	<0.2	µg/l
Arsenic	0.004	0.004	µg/l
Alachlor	< 0.100	< 0.100	µg/l
Chlordane	< 0.500	< 0.500	µg/l
Endosulfan II	< 0.500	< 0.500	µg/l
Atrazine	< 0.100	< 0.100	µg/l
Endrin	< 0.500	< 0.500	µg/l
Heptachlor	< 0.400	< 0.400	µg/l
Heptachlor Epoxide	< 0.500	< 0.500	µg/l
Methoxychlor	< 0.500	< 0.500	µg/l
Toxaphene	< 0.100	< 0.100	µg/l
Aldrin	< 0.500	< 0.500	µg/l
Dieldrin	< 0.500	< 0.500	µg/l
Aroclor 1016	< 0.100	< 0.100	µg/l
Aroclor 1221	< 0.100	< 0.100	µg/l
Aroclor 1232	< 0.100	< 0.100	µg/l
Aroclor 1242	< 0.100	< 0.100	µg/l
Aroclor 1248	< 0.100	< 0.100	µg/l
Aroclor 1254	< 0.100	< 0.100	µg/l
Aroclor 1260	< 0.100	< 0.100	µg/l
Diazinon	< 0.500	< 0.500	µg/l
DDD	< 0.500	< 0.500	µg/l
DDT	< 0.500	< 0.500	µg/l
DDE	< 0.800	< 0.800	µg/l
BETA BHC	< 0.500	< 0.500	µg/l
GAMMA BHC	< 0.500	< 0.500	µg/l
ALPHA BHC	< 0.500	< 0.500	µg/l

width averaged scores of 9.3, 8.0, and 6.5 respectively (with scores of 9-10 being optimal, 6-8 as suboptimal, 3-5 as marginal, and 0-2 as poor). Most of the low scores for vegetative cover and vegetative zone, however, were due to some areas having rock banks (either natural or older rip-rap) and this doesn't necessarily mean that the rock is detracting from the quality of the shoreline.

The macrophyte survey indicated light density of emergent vegetation, cattails (*Typha* spp.) and bulrush (*Scirpus* spp.) along the lake's shoreline. The emergent vegetation was not considered a problem for the lake users. Submergent vegetation consisted of a light to moderate density mix of coontail (*Ceratophyllum demersum*) and sago pondweed (*Potamogeton pectinatus* L.) and was not considered a problem.

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Long-Term Trends

Data from this report are included in Figure 12 as well as TSI values calculated during previous sampling efforts. The trend of the TSI values is towards a decrease in TSI value and hence an improvement in lake quality. The median growing season Secchi-chlorophyll *a* TSI values showed an improvement in water quality.

Lorenzen's (2005) TSI target for full support was a median growing season Secchi-chlorophyll *a* TSI of $\leq$ 58.4. The TSI data obtained during this assessment show a median growing-season Secchi-chlorophyll *a* TSI that is only a point or two greater than the 58.4 target value and will improve to full support status if the trend continues.

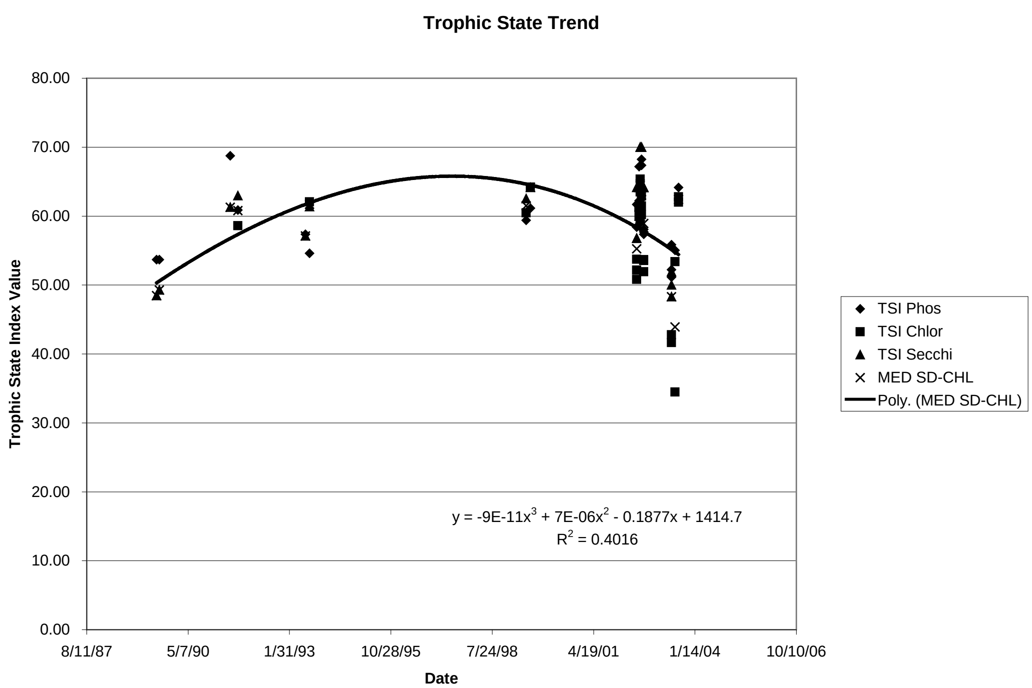

Figure 10. Trends in growing-season total phosphorus, Secchi transparency and chlorophyll *a* trophic state indices in South Red Iron Lake, South Dakota; with trend line for median Secchi-chlorophyll *a* TSI.

OBJECTIVE 2 – Tributary Sampling

Tributary Sampling Schedule, Methods, and Materials

Three stream monitoring sites were selected for South Red Iron Lake (two tributaries and one outlet) (Figure 2). The sites were selected to determine which portions of the watershed were contributing the greatest amount of nutrient and sediment load to the lake. Tributary sites NBUFT02 and SREDT01 used ISCO Model 4230 stage recorders. The outlet site (SREDT02) was equipped with an OTT Thalimedes type stage recorder. Water stages were monitored and recorded for each of the sites. A Marsh-McBirney Model 210D flow meter was used to determine flows at various stages during spring run-off.

Sampling at the tributary sites began June 18, 2002 and continued until flows stopped. Water samples were collected with the "grab" method by holding the sample bottle under the water until filled. The water samples were then filtered, preserved, and packed in ice for shipping to the State Health Lab in Pierre, SD according to the "Standard Operating Procedures for Field Samplers" (Stueven, et al., 2000).

The laboratory analyzed the samples for the following parameters:

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

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

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

Parameters measured in the field by sampling personnel included: water temperature; air temperature; specific conductance; dissolved oxygen; and field pH.

Tributary Sampling Results

Fecal Coliform Bacteria

Approximately 41% of the samples had fecal coliform bacteria concentrations at or below 10 colonies/100 ml (Appendix A). Although no fecal coliform standard exists for the tributaries, three of the twenty-two samples had a concentration above the 400 colonies/100 ml criterion for immersion recreation. No samples were greater than the 2000 colonies/100 ml criterion for limited contact recreation.

Alkalinity

Alkalinity concentrations in South Red Iron Lakes tributaries varied from as high as 285 mg/l to as low as 177 mg/l (Appendix A). The state standard for alkalinity is a maximum of 750 mg/l as a geometric mean or 1,313 mg/l in a single sample, which the tributary sites did not exceed in any of their samples. The mean concentrations from the sampling sites were 226 mg/l and 253 mg/l. These concentrations are generally typical of waterbodies in South Dakota.

Solids

Appendix A lists the total solids and suspended solids concentrations found in the South Red Iron Lake tributaries. The mean total solids concentrations for the tributaries were 401 and 382 mg/l with the inflowing tributary having a slightly greatest mean than the outflow site. The data obtained are not unusual for streams in South Dakota.

Total suspended solids concentrations ranged from 1 to 30 mg/l and usually comprised only about 4% or less of the total solids. There is no state standard for total suspended solids that applies to the tributaries.

Nitrogen

Nitrogen is analyzed in four forms: nitrate/nitrite, ammonia, and total Kjeldahl nitrogen (TKN). From these four forms, total, organic, and inorganic nitrogen may be calculated.

Inorganic nitrogen is the form of nitrogen most readily available for plant growth. The total inorganic nitrogen concentrations were usually 0.012 mg/l to 0.013 mg/l throughout the project (Table 15). Total organic nitrogen concentrations averaged 90% of the total nitrogen concentration.

Table 15. Total inorganic and organic nitrogen concentrations (mg/l) for South Red Iron Lake tributaries, Marshall County, South Dakota during 2002/2003.

TOTAL INORGANIC NITROGEN				TOTAL ORGANIC NITROGEN			
DATE	**SREDT01 mg/l**	**DATE**	**NBUFT02 mg/l**	**DATE**	**SREDT01 mg/l**	**DATE**	**NBUFT02 mg/l**
6/17/02	<0.012	6/17/02	0.130	6/17/02	1.39	6/17/02	1.30
7/15/02	<0.012	7/15/02	0.120	7/15/02	1.25	7/15/02	1.11
4/03/03	<0.012	8/13/02	0.130	4/03/03	1.46	8/13/02	0.65
4/16/03	<0.012	10/1/02	0.130	4/16/03	0.92	10/1/02	1.34
4/24/03	<0.012	4/3/03	0.350	4/24/03	1.03	4/3/03	1.16
4/30/03	0.15	4/16/03	0.120	4/30/03	1.22	4/16/03	0.92

Table 15. Continued.

TOTAL INORGANIC NITROGEN				TOTAL ORGANIC NITROGEN			
DATE	**SREDT01 mg/l**	**DATE**	**NBUFT02 mg/l**	**DATE**	**SREDT01 mg/l**	**DATE**	**NBUFT02 mg/l**
5/06/03	<0.012	4/24/03	0.120	5/06/03	1.03	4/24/03	0.90
5/13/03	<0.012	4/30/03	0.120	5/13/03	1.14	4/30/03	1.60
5/21/03	<0.012	5/6/03	0.160	5/21/03	0.99	5/6/03	1.40
5/29/03	0.15	5/13/03	0.120	5/29/03	1.42	5/13/03	1.20
		5/21/03	0.120			5/21/03	1.25
		5/29/03	0.150			5/29/03	0.90
Mean	0.040		0.148		0.99		1.14

Phosphorus

The total phosphorus concentrations in the tributaries ranged from 0.008 to 0.235 mg/l and averaged 0.090 and 0.083 mg/l (Table 16). Total dissolved phosphorus averaged 50% of the total phosphorus in the tributary and 30% in the outlet site.

Table 16. Total and total dissolved phosphorus concentrations (mg/l) for South Red Iron Lake tributaries, Marshall County, South Dakota during 2002/2003.

TOTAL PHOSPHORUS				TOTAL DISSOLVED PHOSPHORUS			
DATE	**SREDT01 mg/l**	**DATE**	**NBUFT02 mg/l**	**DATE**	**SREDT01 mg/l**	**DATE**	**NBUFT02 mg/l**
6/17/02	0.098	6/17/02	0.104	6/17/02	0.052	6/17/02	0.045
7/15/02	0.068	7/15/02	0.061	7/15/02	0.028	7/15/02	0.017
4/03/03	0.144	8/13/02	0.061	4/03/03	0.048	8/13/02	0.017
4/16/03	0.008	10/1/02	0.059	4/16/03	0.044	10/1/02	0.033
4/24/03	0.082	4/3/03	0.088	4/24/03	0.036	4/3/03	0.015
4/30/03	0.077	4/16/03	0.06	4/30/03	0.042	4/16/03	0.016
5/06/03	0.096	4/24/03	0.06	5/06/03	0.060	4/24/03	0.013
5/13/03	0.073	4/30/03	0.072	5/13/03	0.034	4/30/03	0.017
5/21/03	0.062	5/6/03	0.235	5/21/03	0.051	5/6/03	0.022
5/29/03	0.196	5/13/03	0.071	5/29/03	0.053	5/13/03	0.016
		5/21/03	0.038			5/21/03	0.018
		5/29/03	0.089			5/29/03	0.021
Mean	0.090		0.083		0.045		0.021

Tributary flows and phosphorus loading using the BATHTUB model

Because the outlet site did not flow due to highway construction and because the stage-discharge relationships of the two tributary sites were poor, EDNA was used to estimate the total inflow to the lake. EDNA (Elevation Derivatives for National Application)

Program (http://edna.usgs.gov) is a multi-layered database derived from a version of the National Elevation Dataset (NED), which has been hydrologically conditioned for improved hydrologic flow representation.

Atmospheric data came from a South Dakota State University database (http://climate.sdstate.edu/climate_site/climate.htn) where the precipitation data were collected from Britton, South Dakota. The Britton evaporation data were not available and so evaporation was based on the Brookings evaporation:precipitation ratio.

The data obtained from EDNA (total watershed inflow of 10.09 Hm^3/yr) was used in the Army Corps of Engineers BATHTUB model (Walker, 1999). BATHTUB provides numerous models for the calculation of in-lake concentrations of phosphorus, nitrogen, chlorophyll *a*, and Secchi depth. Models are selected that most closely predict current in-lake conditions from the loading data provided. These estimates are used in determining an annual total phosphorus load for the lake. Reductions in the phosphorus concentration of the tributaries were also modeled to predict changes in trophic state.

The BATHTUB model produced excellent agreement between the observed and predicted phosphorus, chlorophyll *a*, and Secchi TSIs (Table 20). The in-lake total phosphorus predicted by the model was 41.4 mg/m^3. This resulted in total phosphorus, chlorophyll *a*, and Secchi based TSI values of 57.8, 59.6, and 57.9 respectively.

The target TSI for South Red Iron Lake is 58.4 and is based on a median growing season Secchi-chlorophyll *a* TSI. The BATHTUB model, however, predicts average TSI values rather than median values. A comparison of the predicted average Secchi-chlorophyll *a* TSI to the observed median Secchi-chlorophyll TSI was 58.75 versus 60.00 respectively. The difference between the two (1.25 TSI units) was not considered large enough to justify resetting the target TSI and so the predicted average Secchi-chlorophyll *a* TSI values from the model can be compared to the target TSI value of 58.4.

Modeling the progressive decrease in total phosphorus loads in the tributaries produced TSI values that also progressively decreased (Figure 11). The target Secchi-chlorophyll *a* TSI of 58.4 was reached when the initial phosphorus load in the tributaries were decreased by approximately 5%.

Table 17. Results from BATHTUB, South Red Iron Lake, Marshall County, South Dakota.

Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	**1**	**Near Dam**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	41.4	0.39	43.5%	55.2	0.31	56.3%
TOTAL N MG/M3	1220.9	0.23	62.1%	1220.9	0.23	62.1%
C.NUTRIENT MG/M3	37.5	0.32	52.5%	47.0	0.28	63.4%
CHL-A MG/M3	19.2	0.62	82.4%	14.0	0.60	69.9%
SECCHI M	1.2	0.39	53.8%	0.9	0.55	41.6%
ORGANIC N MG/M3	674.1	0.42	75.5%	1088.6	0.26	94.8%
TP-ORTHO-P MG/M3	55.0	0.45	73.8%	42.9	0.39	64.7%
ANTILOG PC-1	411.0	0.85	65.4%	522.0	0.46	71.8%
ANTILOG PC-2	11.6	0.25	86.8%	8.2	0.56	68.0%
(N - 150) / P	25.9	0.46	73.2%	19.4	0.40	57.7%
INORGANIC N / P	546.8	0.73	99.8%	10.7	3.59	15.3%
TURBIDITY 1/M	1.0	0.40	73.2%	1.0	0.40	73.2%
ZMIX * TURBIDITY	2.1	0.40	30.1%	2.1	0.40	30.1%
ZMIX / SECCHI	1.7	0.40	4.0%	2.2	0.53	8.8%
CHL-A * SECCHI	22.3	0.33	86.5%	12.9	0.81	63.1%
CHL-A / TOTAL P	0.5	0.31	91.3%	0.3	0.67	65.9%
FREQ(CHL-a>10) %	77.1	0.38	82.4%	59.4	0.62	69.9%
FREQ(CHL-a>20) %	35.4	1.05	82.4%	18.9	1.39	69.9%
FREQ(CHL-a>30) %	15.2	1.56	82.4%	6.2	1.95	69.9%
FREQ(CHL-a>40) %	6.8	1.96	82.4%	2.3	2.37	69.9%
FREQ(CHL-a>50) %	3.2	2.29	82.4%	0.9	2.72	69.9%
FREQ(CHL-a>60) %	1.6	2.57	82.4%	0.4	3.01	69.9%
CARLSON TSI-P	57.8	0.10	43.5%	62.0	0.07	56.3%
CARLSON TSI-CHLA	59.6	0.10	82.4%	56.5	0.10	69.9%
CARLSON TSI-SEC	57.9	0.10	46.2%	61.2	0.13	58.4%

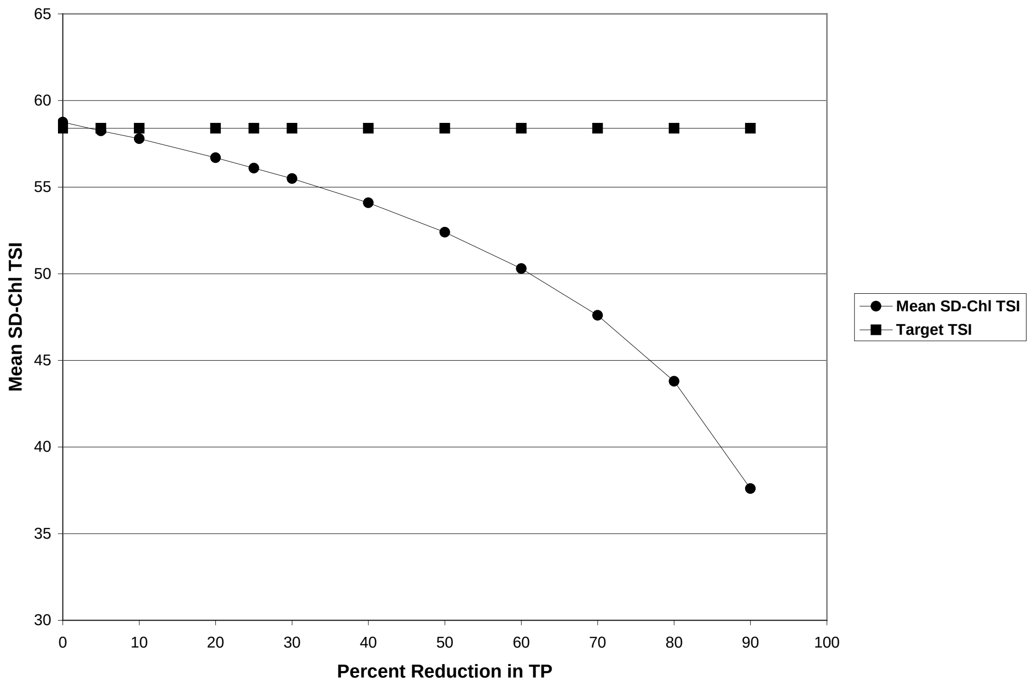

Figure 11. Graphical presentation of trophic state values in response to incremental percent reductions in total phosphorus loads from SREDT01 and NBUFT02.

The total phosphorus (TP) load and resultant TSIs before and after a 5% reduction in tributary TP load are given in Table 21. At the target TSI of 58.4, the annual total phosphorus load from all external sources should be at least 863.4 kg/yr. Given an original tributary load of 872.8 kg/yr, approximately 9.4 kg/yr of phosphorus needs to be removed from the tributary loads to reach a TMDL load of 863.4 kg/yr.

Table 18. BATHTUB predicted total phosphorus loads for South Red Iron Lake, Marshall County, South Dakota, during 2002/2003 and after a 5% TP load reduction.

Load Component	Original Predicted Load (kg/yr)	Load After 5% Reduction (kg/yr)
Tributaries(+lakeside)	872.8	829.2
Precipitation	34.2	34.2
Total Inflow	907.0	863.4
Outflow	417.3	404.2
Advective outflow	2.0	2.0
Total Outflow	419.4	406.1
Retention	487.6	457.3
TP TSI	57.8	57.4
CHL *a* TSI	59.6	59.1
SD TSI	57.9	57.4

OBJECTIVE 3 - Quality Assurance Reporting

Quality Assurance/ Quality Control (QA/QC) samples were collected for at least 10% of the total number of samples taken. Sixty samples were taken from South Red Iron Lake and its tributaries. Six sets of blanks and duplicates samples were collected during the project for QA/QC purposes (Table 19). The industrial statistic "%I" was used to assess the data precision; where precision (%I) = difference between duplicate analytical values divided by the sum of the values, multiplied by 100. Values greater than 10% were considered problematic and further investigation may be needed to correct the problem.

The field blanks were consistently at or below the detection limits of the parameters tested. The duplicate samples were generally satisfactory except for total dissolved phosphorus and total suspended solids, which had average %I values greater than 10% There are no obvious reasons for these results so further investigation may be needed to resolve this issue. These data should not be used or at least used with caution.

Table 19. Field blanks and duplicates for the South Red Iron Lake assessment .

StationID	SampleDate	Relative Depth	Type	Alka, mg/l	Fecal Col., #/100ml	E. Coli, #/100ml	NH3, mg/l	TKN, mg/l	NO3, mg/l	Diss P, mg/l	Total P, mg/l	TS, mg/l	TSS, mg/l	VSS, mg/l
MARSHALSREDL01	07/23/2002	Bottom	Blank	<6			<0.02	<.32	<0.1	<0.002	<0.002	<7	<1	<1
MARSHALSREDL01	07/23/2002	Bottom	Sample	234			<0.02	1.06	<0.1	0.011	0.064	387	29	13
MARSHALSREDL01	07/23/2002	Bottom	Replicate	231			<0.02	1.15	<0.1	0.028	0.044	366	15	7
%I				0.65			0.00	4.07	0.00	43.59	18.52	2.79	31.82	30.00
MARSHALSREDL01	07/23/2002	Surface	Blank	<6	<10	<1	<0.02	<.32	<0.1	<0.002	<0.002	<7	<1	<1
MARSHALSREDL01	07/23/2002	Surface	Sample	231	<10	<1	<0.02	0.93	<0.1	0.012	0.045	360	15	8
MARSHALSREDL01	07/23/2002	Surface	Replicate	232	<10	<1	<0.02	1.09	<0.1	0.012	0.045	374	14	9
%I				0.22	0.00	0.00	0.00	7.92	0.00	0.00	0.00	1.91	3.45	5.88
MARSHALSREDL02	05/27/2003	Surface	Blank	<6	<10	<1	<0.02	0.12	<0.1	<0.002	<0.002	<7	<1	<1
MARSHALSREDL02	05/27/2003	Surface	Sample	234	<10	<1	<0.02	0.96	<0.1	0.01	0.026	368	7	6
MARSHALSREDL02	05/27/2003	Surface	Replicate	232	<10	<1	<0.02	0.89	<0.1	0.008	0.024	358	5	4
%I				0.43	0.00	0.00	0.00	3.78	0.00	11.11	4.00	1.38	16.67	20.00
MARSHALSREDL02	05/27/2003	Bottom	Blank	<6	<10	<1	<0.02		<0.1	<0.002	<0.002	<7	<1	<1
MARSHALSREDL02	05/27/2003	Bottom	Sample	232			<0.02	1.1	<0.1	0.011	0.028	369	7	6
MARSHALSREDL02	05/27/2003	Bottom	Replicate	235			<0.02	0.9	<0.1	0.009	0.027	357	7	6
%I				0.64			0.00	10.00	0.00	10.00	1.82	1.65	0.00	0.00
MARSHALSREDL03	02/25/2003	Surface	Blank	<6	<2	<1	<0.02	<0.10	<0.1	0.004	0.002	<7	<1	<1
MARSHALSREDL03	02/25/2003	Surface	Sample	299	<10	<1	0.31	1.57	<0.1	0.031	0.037	471	3	<1
MARSHALSREDL03	02/25/2003	Surface	Replicate	298	<2	<1	0.32	1.31	<0.1	0.017	0.036	475	4	<1
%I				0.17	0.00	0.00	1.59	9.03	0.00	29.17	1.37	0.42	14.29	0.00
MARSHALSREDL03	02/25/2003	Bottom	Blank	<6			<0.02	<0.1	<0.1	0.004	<0.002	<7	<1	<1
MARSHALSREDL03	02/25/2003	Bottom	Sample	298			0.33	1.29	<0.1	0.029	0.038	465	5	<1
MARSHALSREDL03	02/25/2003	Bottom	Replicate	299			0.33	1.33	<0.1	0.032	0.037	470	4	1
%I				0.17			0.00	1.53	0.00	4.92	1.33	0.53	11.11	0.00
MARSHALSREDT01	05/13/2003		Blank	<6	<10	<1	<0.02	<0.11	<0.1	<0.002	<0.002	<7	<1	<1
MARSHALSREDT01	05/13/2003		Sample	234	<10	12.2	<0.02	1.16	<0.1	0.034	0.073	457	12	4
MARSHALSREDT01	05/13/2003		Replicate	233	20	9.8	<0.02	1.08	<0.1	0.04	0.075	447	12	5
%I				0.21		10.91	0.00	3.57	0.00	8.11	1.35	1.11	0.00	11.11
Average %I				0.35	8.33	2.73	0.23	5.70	0.00	15.27	4.06	1.40	11.05	9.57

OBJECTIVE 4- Annualized Agricultural Non-Point Source Model (AnnAGNPS)

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

The AnnAGNPS model was not used because the lake was nearly meeting its target TSI and it was felt that any AnnAGNPS runs should be done during the implementation phase to direct and assess BMP implementation.

OBJECTIVE 5 - Public Participation

State Agencies

The South Dakota Department of Environment and Natural Resources (SDDENR) was the primary state agency involved in the completion of this assessment. SDDENR provided equipment as well as technical assistance throughout the project.

The South Dakota Department of Game, Fish and Parks provided information about threatened and endangered species and a copy of the latest Fishery Report on South Red Iron Lake.

Federal Agencies

The Environmental Protection Agency (EPA) provided the primary source of funds for the completion of the assessment on South Red Iron Lake. The Natural Resource Conservation Service (NRCS) provided technical assistance. The Farm Service Agency allowed access to historical records to obtain data for this project report.

Local Governments; Industry, Environmental, and other Groups; and General Public

The Marshall Conservation District sponsored the project, provided project accounting, and hired a consulting firm, Prairie Agricultural Research, to do the field work. Public involvement primarily consisted of monthly meetings of the Marshall Conservation District.

Table 20 shows the funding sources, the budgeted amounts from each of these sources, total expenditures, and the percentage that was utilized. In-kind match came primarily from the Marshall Conservation District for utilizing their time to manage and direct the project. The project was completed using only about 72% of the proposed budget. This was probably due to fewer samples being collected than what was proposed and a general overestimation of project costs.

Table 20. Funding sources and funds utilization for the Marshall County Lakes Assessment Project.

Organization	Amount in Budget	Amount Spent	In-Kind	% utilized
EPA 319	165,000.00 amended to 120,000.00	79,981.22	0	67%
SDDENR	25,000.00	25,000.000	0	100%
Marshall CD	2,000.00	0	1,003.50	50%

RECOMMENDATIONS

There are a limited number of lake restoration techniques available to lake managers and the bulk of these are summarized by Cooke, et al. (1986). Several techniques were reviewed for their applicability to the South Red Iron Lake situation and each one is discussed below.

Lake Restoration Techniques Rejected for South Red Iron Lake

Dilution/flushing

Dilution/flushing is a technique to reduce algal biomass by introducing water of lower nutrient concentration while concurrently increasing water exchange (flushing) in the lake. This category was not considered a viable option for South Red Iron Lake because there is no source of dilution water nearby

Lake Drawdown

Lake drawdown is sometimes used to control aquatic macrophytes. Because South Red Iron Lake is a natural lake with no controllable outlet, this technique is not recommended at this time. Macrophytes were not considered a problem in this lake.

Biological Controls

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

Surface/Sediment Covers

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

Hypolimnetic Withdrawal

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

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

Aeration/Circulation

Aeration and circulation are well known techniques for preventing oxygen depletion in a lake. The dissolved oxygen concentrations were not low enough throughout the water column to warrant this technique.

Sediment Removal for Organics Control

This technique is usually recommended for the removal of material that would otherwise decompose and consequently result in oxygen depletion. Because dissolved oxygen concentrations were considered adequate, this technique is not recommended. The cost of dredging also precludes this technique.

Sediment Removal for Nutrient Control

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

There is some evidence that internal loading of phosphorus has occurred in South Red Iron Lake. The concentrations of phosphorus in samples collected from the lake bottom during the summer were usually greater than the phosphorus concentrations in samples collected from the surface. This was likely due to either internal loading from the sediments or recycling of phosphorus from dead algae and leaf litter. What isn't known is how much of a problem internal loading is. The monitoring data and the BATHTUB model runs indicated the lake was a phosphorus sink rather than a source. Therefore, sediment removal for nutrient control is not recommended until further evidence is gathered to quantify internal phosphorus loading and indicate it is a problem. The relatively high cost of dredging also precludes this technique from consideration.

Sediment Removal for Lake Longevity

One process of lake aging is the gradual sedimentation and filling of a lake. This could eventually lead to shallower depths, increased fish kills due to oxygen depletion, and other negative impacts to the lakes beneficial uses. This study determined that approximately nearly 42% of the lake volume is occupied by sediment. However, dredging is expensive and there does not appear to be a local financial base to support dredging at this time. This strategy should be reconsidered if a financial package can be developed to support dredging.

Algicides/Herbicides

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

The use of algicides or herbicides in South Red Iron Lake is not recommended for consideration because the lake is nearly at its target TSI and can reach the target by other means.

Phosphorus Inactivation and Bottom Sealing with Aluminum Sulfate

This technique was not considered viable because it's simply too expensive.

Techniques Recommended for Consideration

Watershed conservation practices/animal waste management

The lake was nearly meeting its TSI target and BMP implementation should help the lake meet its target TSI. The watershed appears to be in good shape and implementation of watershed BMPs could result in the necessary five percent reduction of total phosphorus loading. Current efforts by the local Conservation District and the Natural Resource Conservation Service (NRCS) should continue and be supplemented with other programs that promote BMP implementation.

ASPECTS OF THE PROJECT THAT DID NOT WORK WELL

All of the objectives proposed for the project were met in an acceptable fashion and in a reasonable time frame except for the preparation of the final report. This was due to DENR personnel having other commitments.

The decision not to use the pH data would have been easier if all of the calibration information was documented. E-mails and/or written notes about telephone conversations between the project officer and the project coordinator that clearly describe the calibration information and any problems with the pH probe would provide documentation and help trace when the problems arose. Project coordinators may not know what readings might be considered abnormal so it is imperative that the project officer have access to the data (and calibration information) as soon as possible so corrective measures can be initiated.

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APPENDIX A

Water Quality Data for the South Red Iron Lake Assessment Project

Table 21. Water quality data for South Red Iron Lake, Marshall County, South Dakota.

StationID	SampleDate	Relative Depth	Air Temp. °C	Water Temp. °C	DO, mg/l	pH	Secchi, m	Spec. Cond.	Chloro.*a* ug/l	Alka, mg/l	Fec. Col., #/100ml	E. Coli, #/100ml	NH3, mg/l	TKN, mg/l	NO3, mg/l	TN, mg/l	Diss P, mg/l	Total P, mg/l	TS, mg/l	TDS, mg/l	TSS, mg/l	VSS, mg/l	TN:TP	CHL TSI	SEC TSI
MARSHALSREDL01	06/18/2002	Surface	22.22	20.84	10.52	8.53	1.25	397	4.41	236	<10	1	<0.02	0.79	<0.1	0.89	0.011	0.043	376	369	7	7	20.70	45.13	56.78
MARSHALSREDL01	06/18/2002	Bottom	22.22	20.7	10.22	8.33		396		255			<0.02	0.9	<0.1	1	0.014	0.072	417	366	51	18	13.89		
MARSHALSREDL01	07/11/2002	Surface	15.55	23.28	10.38	7.72	1.00	435	17.42	236	<10	<1	0.1	1.23	<0.1	1.33	0.009	0.056	375	361	14	4	23.75	58.60	60.00
MARSHALSREDL01	07/11/2002	Bottom	15.55	23.3	10.21	7.66		441		237			0.1	1.18	<0.1	1.28	0.009	0.06	413	365	48	14	21.33		
MARSHALSREDL01	07/23/2002	Surface	19.44	24.96	8.21	9.29	1.00	436	26.13	231	<10	<1	<0.02	0.93	<0.1	1.03	0.012	0.045	360	345	15	8	22.89	62.58	60.00
MARSHALSREDL01	07/23/2002	Bottom	19.44	24.8	8.08	9.11		434		234			<0.02	1.06	<0.1	1.16	0.011	0.064	387	366	29	13	18.13		
MARSHALSREDL01	08/05/2002	Surface	17.22	22.73	7.41	9.52	0.75	382	21.03	229	<10	<1	<0.02	1.32	<0.1	1.42	0.022	0.057	365	340	25	14	24.91	60.45	64.15
MARSHALSREDL01	08/05/2002	Bottom	17.22	22.73	7.12	9.14		382		246			<0.02	1.23	<0.1	1.33	0.01	0.078	478	348	130	50	17.05		
MARSHALSREDL01	08/27/2002	Surface	20	23.53	17.19	9.36	0.75	389	11.41	227	<10	<1	<0.02	0.65	0.1	0.75	0.012	0.041	362	350	12	5	18.29	54.45	64.15
MARSHALSREDL01	08/27/2002	Bottom	20	19.82	8.33	9.13		373					<0.02	0.79	<0.1	0.89	0.012	0.058					15.34		
MARSHALSREDL01	09/16/2002	Surface	19.44	19.19	10.93	8.72	0.50	366	23.33	230	<10	2	<0.02	1.27	<0.1	1.37	0.011	0.067	378	360	18	12	20.45	61.47	70.00
MARSHALSREDL01	09/16/2002	Bottom	19.44	18.8	10.36	8.91		364		229			<0.02	1.4	<0.1	1.5	0.012	0.06	377	359	18	14	25.00		
MARSHALSREDL01	01/29/2003	Surface	-17.77	3.07	15.84	7.27	2.50	350		263	<10	<1	0.24	1.33	<0.1	1.43	0.032	0.04	424	421	3	2	35.75		46.78
MARSHALSREDL01	01/29/2003	Bottom	-17.77	3.88	9.7	7.35		359		267			0.24	1.45	<0.1	1.55	0.033	0.042	429	424	5	2	36.90		
MARSHALSREDL01	02/25/2003	Surface	-9.44	3.29	8.2	8.96	2.25	375	2.20	280	<10	<1	0.36	1.41	<0.1	1.51	0.036	0.044	448	444	4	3	34.32	38.30	48.30
MARSHALSREDL01	02/25/2003	Bottom	-9.44	4.09	6.17	8.9		390		280			0.37	1.24	<0.1	1.34	0.037	0.046	441	435	6	5	29.13		
MARSHALSREDL01	04/29/2003	Surface	7.22	12.55	10.16	8.99	1.10	487	5.71	234	<10	<1	<0.02	0.74	<0.1	0.84	0.008	0.034	388	380	8	6	24.71	47.66	58.62
MARSHALSREDL01	04/29/2003	Bottom	7.22	12.56	8.17	8.81		488		233			<0.02	0.73	<0.1	0.83	0.009	0.042	381	373	8	6	19.76		
MARSHALSREDL01	05/27/2003	Surface	20	16.89	10.2	9.06	2.25	613		232	<10	<1	<0.02	1.79	<0.1	1.89	0.011	0.028	360	353	7	7	67.50		48.30
MARSHALSREDL01	05/27/2003	Bottom	20	16.52	10.52	9.04		614		238			<0.02	0.93	<0.1	1.03	0.01	0.044	388	352	36	22	23.41		
MARSHALSREDL02	06/18/2002	Surface	22.22	20.88	10.67	8.58	0.75	402	6.61	242	<10	<1	<0.02	1.21	<0.1	1.31	0.012	0.054	374	361	13	10	24.26	49.10	64.15
MARSHALSREDL02	06/18/2002	Bottom	22.22	20.83	10.29	8.39		401		236			<0.02	1.22	0.1	1.32	0.014	0.06	389	371	18	11	22.00		
MARSHALSREDL02	07/11/2002	Surface	18.33	22.66	11.13	8.06	0.75	443	11.91	242	<10	<1	0.1	0.85	<0.1	0.95	0.015	0.079	388	363	25	10	12.03	54.87	64.15
MARSHALSREDL02	07/11/2002	Bottom	18.33	22.69	9.99	7.85		443		243			0.1	0.91	<0.1	1.01	0.014	0.076	396	372	24	4	13.29		
MARSHALSREDL02	07/23/2002	Surface	16.66	24.46	8.34	9.32	0.50	433	30.84	238	<10	1	<0.02	1.08	<0.1	1.18	0.012	0.069	375	352	23	12	17.10	64.21	70.00
MARSHALSREDL02	07/23/2002	Bottom	16.66	24.44	7.64	9.18		433		243			<0.02	1.28	<0.1	1.38	0.012	0.077	410	350	60	20	17.92		
MARSHALSREDL02	08/05/2002	Surface	17.22	22.14	7.11	9.13	0.50	376	13.62	231	<10	<1	<0.02	1.37	<0.1	1.47	0.011	0.085	390	359	31	15	17.29	56.19	70.00
MARSHALSREDL02	08/05/2002	Bottom	17.22	22.13	6.62	9.26		377		231			<0.02	1.28	<0.1	1.38	0.013	0.085	374	339	35	15	16.24		
MARSHALSREDL02	08/27/2002	Surface	20	23.27	13.08	9.63	0.75	388	10.61	228	<10	1	<0.02	0.96	<0.1	1.06	0.012	0.042	379	366	13	8	25.24	53.74	64.15
MARSHALSREDL02	08/27/2002	Bottom	20	19.95	3.8	9.28		372		233			<0.02	1.04	<0.1	1.14	0.013	0.066	374	354	20	12	17.27		
MARSHALSREDL02	09/16/2002	Surface	21.11	18.48	9.44	8.84	0.50	364	11.41	232	<10	<1	<0.02	1.43	<0.1	1.53	0.014	0.067	388	369	19	12	22.84	54.45	70.00
MARSHALSREDL02	09/16/2002	Bottom	21.11	18.26	9.16	8.95		363		234			<0.02	1.29	<0.1	1.39	0.012	0.066	388	369	19	15	21.06		
MARSHALSREDL02	01/29/2003	Surface	-17.22	3.44	10.51	7.55	2.75	366		280	<10	<1	0.22	1.4	<0.1	1.5	0.026	0.037	444	440	4	1	40.54		45.40
MARSHALSREDL02	01/29/2003	Bottom	-17.22	1.94	15.92	7.59		350		276			0.23	1.38	<0.1	1.48	0.022	0.034	450	440	10	3	43.53		
MARSHALSREDL02	02/25/2003	Surface	-5.55	2.7	11.68	9.03	2.25	373	3.80	283	<10	<1	0.32	1.35	<0.1	1.45	0.039	0.041	458	454	4	3	35.37	43.66	48.30
MARSHALSREDL02	02/25/2003	Bottom		2.9	7.28	8.95				285			0.35	1.3	<0.1	1.4	0.028	0.038	453	450	3	2	36.84		
MARSHALSREDL02	04/29/2003	Surface	7.22	12.84	10.14	9.03	1.00	479	9.11	233	<10	<1	<0.02	0.73	<0.1	0.83	0.013	0.05	384	371	13	9	16.60	52.24	60.00
MARSHALSREDL02	04/29/2003	Bottom	7.22	12.8	10.07	9.02		479		230			<0.02	0.77	<0.1	0.87	0.014	0.06	383	370	13	8	14.50		
MARSHALSREDL02	05/27/2003	Surface	20	16.82	10.58	9.03	2.00	614	1.50	234	<10	<1	<0.02	0.96	<0.1	1.06	0.01	0.026	368	361	7	6	40.77	34.55	50.00
MARSHALSREDL02	05/27/2003	Bottom	20	16.64	11.32	9.03		614		232			<0.02	1.1	<0.1	1.2	0.011	0.028	369	362	7	6	42.86		

Table 21. Continued.

StationID	SampleDate	Relative Depth	Air Temp. ºC	Water Temp. ºC	DO, mg/l	pH	Secchi, m	Spec. Cond.	Chloro.*a* ug/l	Alka, mg/l	Fec. Col., #/100ml	E. Coli, #/100ml	NH3, mg/l	TKN, mg/l	NO3, mg/l	TN, mg/l	Diss P, mg/l	Total P, mg/l	TS, mg/l	TDS, mg/l	TSS, mg/l	VSS, mg/l	TN:TP	CHL TSI	SEC TSI
MARSHALSREDL03	06/18/2002	Surface	23.88	20.9	10.99	8.41	1.25	403	3.30	237	<10	<1	<0.02	1.14	<0.1	1.24	0.01	0.043	383	374	9	8	28.84	42.28	56.78
MARSHALSREDL03	06/18/2002	Bottom	23.88	20.89	10.83	8.23		403		235			<0.02	1.28	<0.1	1.38	0.012	0.056	428	379	49	18	24.64		
MARSHALSREDL03	07/11/2002	Surface	15.55	22.65	12.12	8.32	0.75	444	18.12	241	<10	2	0.12	1.3	<0.1	1.4	0.01	0.064	380	363	17	5	21.88	58.99	64.15
MARSHALSREDL03	07/11/2002	Bottom	15.55	22.68	11.25	7.97		445		241			0.13	1.21	<0.1	1.31	0.009	0.065	378	361	17	6	20.15		
MARSHALSREDL03	07/23/2002	Surface	16.66	24.42	7.93	9.25	0.50	437	15.62	237	<10	<1	<0.02	1.04	<0.1	1.14	0.012	0.065	377	354	23	11	17.54	57.53	70.00
MARSHALSREDL03	07/23/2002	Bottom	16.66	24.41	7.94	9		434		238			<0.02	0.96	<0.1	1.06	0.016	0.087	395	363	32	12	12.18		
MARSHALSREDL03	08/05/2002	Surface	17.22	22.01	7.39	9.08	0.50	377	24.73	230	<10	<1	<0.02	1.14	<0.1	1.24	0.015	0.08	378	347	31	15	15.50	62.04	70.00
MARSHALSREDL03	08/05/2002	Bottom	17.22	22	7.03	9.23		376		229			<0.02	1.16	<0.1	1.26	0.016	0.085	387	355	32	18	14.82		
MARSHALSREDL03	08/27/2002	Surface	20	22.84	11.38	9.61	0.75	386	8.61	229	<10	<1	<0.02	0.83	<0.1	0.93	0.014	0.04	366	356	10	6	23.25	51.69	64.15
MARSHALSREDL03	08/27/2002	Bottom	20	22.41	9.74	9.56		384		228			<0.02	0.86	<0.1	0.96	0.013	0.039	370	357	13	8	24.62		
MARSHALSREDL03	09/16/2002	Surface	21.11	18.49	11.39	8.81	0.50	366	18.22	234	<10	<1	<0.02	1.47	<0.1	1.57	0.013	0.073	396	377	19	14	21.51	59.04	70.00
MARSHALSREDL03	09/16/2002	Bottom	21.11	18.38	10.58	8.92		365		232			<0.02	1.44	<0.1	1.54	0.012	0.064	391	370	21	12	24.06		
MARSHALSREDL03	01/29/2003	Surface	-16.11	2.2	16.18	7.56	2.50	351		284	<10	<1	0.18	1.31	<0.1	1.41	0.022	0.03	453	450	3	<1	47.00		46.78
MARSHALSREDL03	01/29/2003	Bottom	-16.11	3.38	12.04	7.69		385		289			0.16	1.4	<0.1	1.5	0.021	0.035	465	462	3	1	42.86		
MARSHALSREDL03	02/25/2003	Surface	-11.11	1.8	12.01	9.26	2.25	381	2.50	299	<10	<1	0.31	1.57	<0.1	1.67	0.031	0.037	471	468	3	<1	45.14	39.56	48.30
MARSHALSREDL03	02/25/2003	Bottom	-11.11	3.51	8.94	9.06		397		298			0.33	1.29	<0.1	1.39	0.029	0.038	465	460	5	<1	36.58		
MARSHALSREDL03	04/29/2003	Surface	7.22	12.8	10.38	9.03	1.00	477	6.51	229	<10	<1	<0.02	0.67	<0.1	0.77	0.008	0.08	377	368	9	6	9.63	48.95	60.00
MARSHALSREDL03	04/29/2003	Bottom	7.22	12.83	10.15	9.03		478		229			<0.02	0.98	<0.1	1.08	0.008	0.065	372	362	10	6	16.62		
MARSHALSREDL03	05/27/2003	Surface	20	16.65		9.02	1.75	617	1.90	236	<10	<1	<0.02	0.78	<0.1	0.88	0.011	0.036	360	352	8	7	24.44	36.86	51.93
MARSHALSREDL03	05/27/2003	Bottom	20	16.62	11.22	9.02		615		236			<0.02	0.97	<0.1	1.07	0.011	0.033	361	353	8	7	32.42		

Table 22. Water quality data for South Red Iron Lake's tributaries, Marshall County, South Dakota.

StationID	SampleDate	Air Temp. ºC	Water Temp. ºC	DO, mg/l	pH	Spec. Cond.	Alka, mg/l	Fecal Col., #/100ml	E. Coli, #/100ml	NH3, mg/l	TKN, mg/l	NO3, mg/l	TN, mg/l	Diss P, mg/l	Total P, mg/l	TS, mg/l	TDS, mg/l	TSS, mg/l	VSS, mg/l	TN:TP
SREDT01	06/17/2002	22.77	21.13	8.34	8.35	364	177	420	517	<0.02	1.41	<0.1	1.51	0.052	0.098	324	314	10	8	15.41
SREDT01	07/15/2002	23.88	22.9	8.08	8.28	439	221	20	35.9	<0.02	1.27	<0.1	1.37	0.028	0.068	363	355	8	4	20.15
SREDT01	04/03/2003	-2.77	0.89	24.48		4.8	189	<10	2	<0.02	1.48	<0.1	1.58	0.048	0.144	327	321	6	3	10.97
SREDT01	04/16/2003	1.66	8.34	12.78	7.98	500	252	100	>2420	<0.02	0.94	<0.1	1.04	0.044	0.008	379	374	5	4	130.00
SREDT01	04/24/2003	9.99	10.18	8.51	7.85	476	200	20	26.9	<0.02	1.05	<0.1	1.15	0.036	0.082	367	366	1	<1	14.02
SREDT01	04/30/2003	9.44	10.24	9.79	7.8	676	238	10	39.3	0.05	1.27	<0.1	1.37	0.042	0.077	413	411	2	1	17.79
SREDT01	05/06/2003	9.44	8.97	9.13	7.78	657	221	20	32.7	<0.02	1.05	<0.1	1.15	0.06	0.096	404	397	7	3	11.98
SREDT01	05/13/2003	15	10.05	8.4		7.13	234	<10	12.2	<0.02	1.16	<0.1	1.26	0.034	0.073	457	445	12	4	17.26
SREDT01	05/21/2003	12.77	12.1	6.14	7.84	744	244	<10	13.5	<0.02	1.01	<0.1	1.11	0.051	0.062	466	460	6	2	17.90
SREDT01	05/29/2004	21.11	19.48	3.2	7.61	776	285	670	37.8	0.05	1.47	<0.1	1.57	0.053	0.196	508	486	22	8	8.01
NBUFT02	06/17/2002	25.5	23.14	11.13	8.56	437	255	100	82.3	0.03	1.33	0.1	1.43	0.045	0.104	411	381	30	14	13.75
NBUFT02	07/15/2002	23.88					229	50	36.9	<0.02	1.13	<0.1	1.23	0.017	0.061	348	341	7	5	20.16
NBUFT02	08/13/2002	20	20.19	6.78	9.29	350	226	860	1120	0.03	0.68	<0.1	0.78	0.017	0.061	361	353	8	5	12.79
NBUFT02	10/01/2002	11.66	12.65	5.12	9.53	337	250	60	55.4	<0.02	1.36	0.1	1.46	0.033	0.059	394	385	9	3	24.75
NBUFT02	04/03/2003	-2.77	0.77	23.98	8.53	429	196	<2	<1	0.25	1.41	<0.1	1.51	0.015	0.088	267	254	13	4	17.16
NBUFT02	04/16/2003	2.22	7.69	11.8	8.32	482	245	20	34.1	<0.02	0.94	<0.1	1.04	0.016	0.06	358	354	4	3	17.33
NBUFT02	04/24/2003	11.66	10.86	10.22	8.48	507	256	<10	2	<0.02	0.92	<0.1	1.02	0.013	0.06	379	373	6	1	17.00
NBUFT02	04/30/2003	9.44	10.38	8.37	8.06	685	271	40	11	<0.02	1.62	<0.1	1.72	0.017	0.072	407	393	14	6	23.89
NBUFT02	05/06/2003	8.88	9.44	10.91	8.36	682	271	<10	4.1	0.06	1.46	<0.1	1.56	0.022	0.235	415	402	13	7	6.64
NBUFT02	05/13/2003	15		10.81		679	272	<10	<1	<0.02	1.22	<0.1	1.32	0.016	0.071	414	401	13	6	18.59
NBUFT02	05/21/2003	14.44	12.31	10.02	8.57	691	276	60	28.5	<0.02	1.27	<0.1	1.37	0.018	0.038	410	399	11	3	36.05
NBUFT02	05/29/2003	21.66	18.84	5.7	8.02	700	284	10	16.9	0.05	1.4	<0.1	1.5	0.021	0.089	425	405	20	8	16.85

Table 23. Profile data for Site SREDL01 in South Red Iron Lake, Marshall County, South Dakota.

Date	Temp	SpCond	DO%	DO Conc	Depth	pH
6/18/02	20.84	0.4310	118.1	10.55	0.961	8.45
6/18/02	20.70	0.4330	114.5	10.25	1.925	8.30
7/11/02	23.28	0.4350	121.7	10.38	1.083	7.72
7/11/02	23.29	0.4380	121.8	10.38	1.082	7.76
7/11/02	23.29	0.4410	119.8	10.21	3.090	7.66
8/5/02	22.74	0.3990	85.5	7.36	0.969	9.12
8/5/02	22.73	0.3990	84.8	7.30	1.993	8.81
8/5/02	22.73	0.3990	84.5	7.28	2.994	9.19
8/5/02	22.73	0.3990	82.7	7.12	3.623	8.75
8/27/02	23.53	0.4000	171.2	14.53	1.000	9.38
8/27/02	22.55	0.4020	177.6	15.35	1.996	9.38
8/27/02	20.15	0.4100	127.5	11.54	2.990	9.23
8/27/02	19.80	0.4140	91.4	8.33	3.599	9.13
9/16/02	19.18	0.4120	118.80	10.970	1.0	8.75
9/16/02	19.02	0.4120	117.70	10.900	2.0	8.81
9/16/02	18.83	0.4130	112.60	10.470	3.0	8.90
9/16/02	18.80	0.4130	111.00	10.330	3.4	8.88
1/29/03	3.14	0.5970	113.50	15.200	1.1	7.34
1/29/03	3.24	0.6020	96.90	12.930	2.0	7.41
1/29/03	3.54	0.6000	87.10	11.540	3.0	7.17
1/29/03	3.77	0.5970	69.40	9.140	2.8	7.17
2/25/03	3.26	0.6410	60.90	8.13	0.9	8.94
2/25/03	3.37	0.6410	56.60	7.53	1.9	8.94
2/25/03	3.62	0.6410	52.50	6.94	2.9	8.93
2/25/03	4.09	0.6490	47.30	6.17	3.3	8.89
4/29/03	13	0.3700	95.60	10.2	0.977	8.99
4/29/03	13	0.3700	95.10	10.1	1.961	8.99
4/29/03	13	0.3700	94.70	10.1	2.963	8.99
4/29/03	13	0.3700	74.90	8.0	3.679	8.81
5/27/03	17	0.5200	105.50	10.2	1.048	9.06
5/27/03	17	0.5200	106.40	10.3	2.102	9.06
5/27/03	17	0.5200	107.50	10.4	3.078	9.06
5/27/03	17	0.5200	107.90	10.5	3.666	9.03

Table 24. Profile data for Site SREDL02 in South Red Iron Lake, Marshall County, South Dakota.

Date	Temp	SpCond	DO%	DO Conc	Depth	pH
6/18/02	20.88	0.4360	117.2	10.46	0.950	8.22
6/18/02	20.81	0.4370	114.2	10.21	1.943	8.46
7/11/02	22.66	0.4430	129.0	11.13	1.094	8.06
7/11/02	22.70	0.4420	118.6	10.23	2.094	7.62
7/11/02	22.70	0.4420	117.9	10.16	3.072	7.80
7/11/02	22.69	0.4430	115.9	9.99	3.322	7.85
8/5/02	22.14	0.3980	81.0	7.05	1.008	9.01
8/5/02	22.14	0.3980	80.2	6.98	1.997	8.93
8/5/02	22.13	0.3990	78.1	6.81	2.965	9.04
8/5/02	22.14	0.3990	72.8	6.34	3.287	9.06
8/27/02	23.26	0.4010	130.3	11.11	1.020	9.59
8/27/02	21.50	0.4040	116.3	10.26	2.014	9.53
8/27/02	20.01	0.4110	45.6	4.14	3.005	9.32
8/27/02	19.97	0.4120	41.8	3.80	3.132	9.27
9/16/02	18.46	0.4160	100.40	9.410	1.0	8.84
9/16/02	18.32	0.4160	100.20	9.410	2.0	8.88
9/16/02	18.26	0.4170	101.20	9.520	3.0	8.92
9/16/02	18.26	0.4170	97.00	9.130	3.1	8.95
1/29/03	1.92	0.6260	112.40	15.550	1.0	7.55
1/29/03	2.71	0.6230	102.90	13.930	2.1	7.50
1/29/03	3.26	0.6220	96.00	12.800	3.0	7.37
1/29/03	3.40	0.6230	76.80	10.210	3.1	7.53
2/25/03	2.72	0.6510	82.60	11.18	0.9	9.01
2/25/03	3.14	0.6490	67.30	9.01	1.9	9.01
2/25/03	3.63	0.6520	59.10	7.80	2.9	8.97
2/25/03	3.69	0.6540	53.10	7.00	2.9	8.96
4/29/03	13	0.3700	96.00	10.1	0.940	9.04
4/29/03	13	0.3700	95.70	10.1	1.941	9.04
4/29/03	13	0.3700	95.70	10.1	2.965	9.04
4/29/03	13	0.3700	95.20	10.1	3.026	9.03
5/27/03	17	0.5200	109.20	10.6	1.091	9.03
5/27/03	17	0.5200	107.20	10.4	2.071	9.03
5/27/03	17	0.5200	115.70	11.2	3.057	9.03
5/27/03	17	0.5200	116.40	11.3	3.170	9.03

Table 25. Profile data for Site SREDL03 in South Red Iron Lake, Marshall County, South Dakota.

Date	Temp	SpCond	DO%	DO Conc	Depth	pH
6/18/02	20.91	0.4370	121.5	10.84	0.950	8.40
6/18/02	20.90	0.4370	121.0	10.79	1.945	8.21
7/11/02	22.63	0.4380	133.8	11.55	1.098	8.4
7/11/02	22.66	0.4390	128	11.04	2.07	8.27
7/11/02	22.66	0.4390	127.1	10.96	3.055	7.85
7/11/02	22.67	0.4390	123.2	10.62	3.285	8.15
8/05/02	22.01	0.3990	84.3	7.36	0.965	8.96
8/05/02	22.01	0.4000	83.9	7.33	1.973	8.69
8/05/02	22.00	0.3990	83.4	7.28	2.621	9.03
8/27/02	22.84	0.4030	113.4	9.74	1.021	9.65
8/27/02	22.18	0.4050	97.4	8.48	1.802	9.58
9/16/02	18.51	0.4180	122.10	11.430	1.0	8.83
9/16/02	18.42	0.4170	121.00	11.350	2.0	8.86
9/16/02	18.37	0.4180	117.20	11.000	3.0	8.92
9/16/02	18.37	0.4180	112.60	10.560	3.1	8.95
1/29/03	2.35	0.6200	114.20	15.620	1.0	7.51
1/29/03	3.02	0.6260	108.30	14.550	2.0	7.52
1/29/03	3.05	0.6420	103.30	13.850	3.0	7.53
1/29/03	3.33	0.6550	89.40	11.910	3.2	7.61
2/25/03	1.87	0.6830	83.70	11.59	0.9	9.24
2/25/03	2.83	0.6680	76.20	10.29	1.9	9.18
2/25/03	3.32	0.6660	72.40	9.64	2.9	9.13
2/25/03	3.54	0.6740	64.80	8.58	3.1	9.05
4/29/03	13	0.3700	98.30	10.4	0.983	9.03
4/29/03	13	0.3700	97.80	10.3	1.937	9.03
4/29/03	13	0.3700	97.40	10.3	2.947	9.03
4/29/03	13	0.3700	96.10	10.1	3.156	9.03
5/27/03	17	0.5200	103.70	10.1	1.174	9.02
5/27/03	17	0.5200	107.30	10.4	2.096	9.03
5/27/03	17	0.5200	112.70	11.0	3.096	9.02
5/27/03	17	0.5200	115.30	11.2	3.242	9.02

Table 26. Historical pH data and averages for South Red Iron Lake, Nine Mile Lake, and North and South Buffalo Lakes, Marshall County, South Dakota.

Nine Mile			N. Buffalo			S. Buffalo			S. Red Iron		
Date	**pH**	**Ref.**	**Date**	**pH**	**Ref.**	**Date**	**pH**	**Ref.**	**Date**	**pH**	**Ref.**
8/25/69	8	2	7/30/65	8.5	2	10/21/64	8.3	1	10/21/64	8.6	1
6/25/70	8.3	2	7/30/65	8.6	2	2/12/65	7.4	1	2/12/65	8.2	1
1989	8.96	4	7/30/65	8.6	2	5/21/65	8.3	1	5/21/65	7.6	1
6/28/91	8.8	5	11/26/65	8.7	2	9/10/65	8.7	1	9/10/65	8.7	1
6/28/91	8.85	5	11/26/65	8.7	2	8/25/69	8.5	2	8/25/69	8.7	2
9/10/91	8.08	5	2/11/66	8.2	2	6/25/70	8.6	2	4/29/74	8.5	2
9/10/91	7.83	5	2/11/66	8	2	8/13/79	8.6	3	4/29/74	8.4	2
7/7/93	8.8	5	2/11/66	7.9	2	8/13/79	8.6	3	7/10/74	8.9	2
7/7/93	8.76	5	4/24/66	8.4	2	1989	8.89	4	7/10/74	8.8	2
8/17/93	8.3	5	4/24/66	8.4	2	6/26/91	9.2	5	9/18/74	8.9	2
8/17/93	8.23	5	4/24/66	8.4	2	6/26/91	9.25	5	9/18/74	8.9	2
6/27/00	8.65	5	8/25/69	8.5	2	9/11/91	8.7	5	4/29/74	8.5	2
6/27/00	8.65	5	6/30/98	8.6	5	9/11/91	6.5	5	4/29/74	8.4	2
6/27/00	8.63	5	6/30/98	8.67	5	8/4/92	8.74	5	7/10/74	8.8	2
6/27/00	8.66	5	6/30/98	8.68	5	8/4/92	8.74	5	7/10/74	8.7	2
6/27/00	8.63	5	6/30/98	8.64	5	9/2/92	9.02	5	9/18/74	8.9	2
6/27/00	8.64	5	6/30/98	8.59	5	9/2/92	9.01	5	9/18/74	8.9	2
6/27/00	8.64	5	6/30/98	8.63	5	6/23/99	8.77	5	8/10/79	8.6	3
6/27/00	8.63	5	6/30/98	8.65	5	6/23/99	8.78	5	8/10/79	8.6	3
6/27/00	8.63	5	6/30/98	8.68	5	6/23/99	8.78	5	1989	9.37	4
6/27/00	8.62	5	6/30/98	8.66	5	6/23/99	8.74	5	6/26/91	9.11	5
5/27/03	8.86	5	6/30/98	8.66	5	6/23/99	8.76	5	6/26/91	9.08	5
5/27/03	8.92	5	6/30/98	8.67	5	6/23/99	8.74	5	9/10/91	8.61	5
6/16/04	8.7	5	8/11/98	8.53	5	6/23/99	8.75	5	9/10/91	8.65	5
6/16/04	8.7	5	8/11/98	8.97	5	6/23/99	8.75	5	7/7/93	8.62	5
7/20/04	8.7	5	8/11/98	9.01	5	6/23/99	8.76	5	7/7/93	8.65	5
	8.58		8/11/98	8.99	5	6/23/99	8.76	5	8/17/93	8.14	5
			8/11/98	8.74	5	7/1/03	8.41	5	8/17/93	7.85	5
			8/11/98	8.33	5	7/1/03	8.41	5	6/23/99	8.75	5
			8/11/98	9	5	7/1/03	8.44	5	6/23/99	8.71	5
			8/11/98	9	5	7/1/03	8.45	5	6/23/99	8.76	5
			8/11/98	9	5	7/1/03	8.51	5	6/23/99	8.73	5
			8/11/98	8.37	5	7/1/03	8.51	5	6/23/99	8.64	5
			8/11/98	8.79	5	7/1/03	8.53	5	6/23/99	8.75	5
			8/11/98	8.98	5	7/1/03	8.54	5	6/23/99	8.79	5
			8/11/98	8.99	5	7/1/03	8.68	5	6/23/99	8.79	5
			7/2/02	8.65	5	7/1/03	8.68	5	6/23/99	8.78	5
			7/2/02	8.64	5	7/1/03	8.68	5	6/23/99	8.78	5
			7/2/02	8.63	5	7/1/03	8.63	5	6/23/99	8.78	5
			7/2/02	8.63	5	8/5/03	8.49	5	6/23/99	8.78	5
			7/2/02	8.63	5	8/5/03	8.5	5	6/23/99	8.78	5
			7/2/02	8.62	5	8/5/03	8.49	5	8/4/99	8.65	5
			7/2/02	8.62	5	8/5/03	8.47	5	8/4/99	8.64	5
			7/2/02	8.61	5	8/5/03	8.45	5	8/4/99	8.56	5
			7/2/02	8.63	5	8/5/03	8.47	5	8/4/99	8.66	5
			7/2/02	8.64	5	8/5/03	8.46	5	8/4/99	8.67	5
			7/2/02	8.63	5	8/5/03	8.44	5	8/4/99	8.66	5
			7/2/02	8.62	5	8/5/03	8.57	5	8/4/99	8.62	5
			7/2/02	8.63	5	8/5/03	8.56	5	8/4/99	8.6	5
			8/5/02	8.85	5	8/5/03	8.56	5	8/4/99	8.52	5
			8/5/02	8.86	5	8/5/03	8.53	5	8/4/99	8.61	5
			8/5/02	8.86	5	8/5/03	8.52	5	8/4/99	8.62	5
			8/5/02	8.82	5		**8.57**		8/4/99	8.63	5
			8/5/02	8.82	5				8/4/99	8.6	5
			8/5/02	8.86	5				8/4/99	8.58	5
			8/5/02	8.87	5				8/4/99	8.65	5
			8/5/02	8.86	5				8/4/99	8.65	5
			8/5/02	8.8	5				8/4/99	8.64	5
			8/5/02	8.86	5				8/4/99	8.65	5
			8/5/02	8.87	5				7/1/03	8.43	5
			8/5/02	8.87	5				7/1/03	8.41	5
			8/5/02	8.81	5				7/1/03	8.4	5
				8.68					7/1/03	8.35	5

Table 26. Continued.

Nine Mile			N. Buffalo			S. Buffalo			S. Red Iron		
Date	pH	Ref.	Date	pH	Ref.	Date	pH	Ref.	Date	pH	Ref.
									7/1/03	8.3	5
									7/1/03	8.24	5
									7/1/03	8.22	5
									7/1/03	8.19	5
									7/1/03	8.18	5
									7/1/03	8.16	5
									7/1/03	8.2	5
									7/1/03	8.41	5
									7/1/03	8.37	5
									7/1/03	8.34	5
									7/1/03	8.35	5
									8/5/03	8.46	5
									8/5/03	8.44	5
									8/5/03	8.44	5
									8/5/03	8.42	5
									8/5/03	8.41	5
									8/5/03	8.47	5
									8/5/03	8.47	5
									8/5/03	8.46	5
									8/5/03	8.44	5
									8/5/03	8.5	5
									8/5/03	8.51	5
									8/5/03	8.51	5
									8/5/03	8.49	5
										8.57	

References: 1 – Petri, L.R. and L. R. Larson, no date. 2 – State Lakes Preservation Committee, 1977. 3 – Koth, 1981. 4 – Stueven and Stewart, 1996. 5 – SDDENR, 1991-2003, unpublished data.

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