PHASE I
WATERSHED ASSESSMENT
FINAL REPORT

ROY 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

March 2009

SECTION 319 TMDL

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

ROY LAKE WATERSHED ASSESSMENT FINAL REPORT

By

Dennis R. Skadsen, Project Coordinator Day County Conservation District
&
Barry A. McLaury, Environmental Program Scientist SD DENR

Sponsor

Day County Conservation District

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US EPA Region 8

Day County Conservation District

Roberts County Conservation District

Marshall County Conservation District

USDA Natural Resources Conservation Service

SD Department of Environment and Natural Resources

South Dakota Department of Game, Fish, and Parks – Roy Lake State Park

Table of Contents

LIST OF TABLES

LIST OF FIGURES

Executive Summary

PROJECT TITLE: Roy Lake Watershed Assessment Project

PROJECT START DATE: 12/1/2007

PROJECT COMPLETION DATE: 03/01/2009

FUNDING:	INITIAL BUDGET:	$51,710.00
	TOTAL BUDGET:	$51,710.00

TOTAL EPA GRANT:	$31,026.00
TOTAL EXPENDITURES OF EPA FUNDS	$19,544.65
TOTAL SECTION 319 MATCH ACCRUED:	$12,959.04
BUDGET AMENDMENTS:	N/A
TOTAL EXPENDITURES:	$32,503.69

SUMMARY OF ACCOMPLISHMENTS

The goal of this project was too locate and document sources of non-point source pollutants in the watershed that may be impacting Roy Lake's water quality. The assessment project was funded because Roy Lake was listed in the ***2006 South Dakota Integrated Report for Surface Water Quality Assessment*** as impaired. The lake was listed due to non-support of one of the lake's beneficial uses; *(4) Warmwater Permanent Fish Life Propagation* based on its trophic state index or TSI. In 2008, changes in the 303(d) listing eliminated the use of TSI values as means of measuring whether a waterbody was meeting its designated beneficial uses. Due to this change, Roy Lake is currently supporting all of its designated uses and will not require a supporting Total Maximum Daily Load (TMDL) document. An Environmental Protection Agency (EPA) Section 319 Clean Water Act grant provided a majority of the funding for this project. The State of South Dakota provided non-federal matching funds and in-kind services for the project. Total project expenditures did not exceed the initial budget.

All in-lake field and chemical parameters measured during the assessment were within state fishery standards for a warmwater permanent fishlife propagation waterbody. The lakes current TSI based on chlorophyll *a* and Secchi disk shows little change in the lakes trophic state since 1988 with slight increases and decreases observed in TSI based on chlorophyll *a* and Secchi disk. Trophic state results based on these two parameters are on track with other lakes in northeast South Dakota.

Tributary field and chemical parameters measured during the assessment were within state standards. However, it was noted that high e-coli and fecal coliform counts during rainstorm events indicate the need for future nutrient management along the two main tributaries entering Roy Lake.

Aquatic macrophyte and phytoplankton surveys were conducted during the assessment. No nuisance aquatic plants were observed. Roy Lake was found to have a very diverse population of algal species. Undesirable algae species that include Anabaena flos-aquae and Microcystis species were present but did not dominate the algal flora. Extensive algae blooms were not observed during the assessment.

All of the objectives and tasks set in the original project implementation plan were completed as scheduled except for the AnnAGNPS modeling. The model was not run due to the lake supporting its designated uses.

Watershed protection and improvement activities recommended by this study could be implemented as part of the Northeast Glacial Lakes Watershed Improvement and Protection Project, a three county state and federally funded watershed implementation project that is completing Segment 1, and recently received funding for a three year second segment scheduled to begin in 2009.

1.0 Introduction

Purpose

The purpose of this assessment is to determine the sources of water quality impairments to Roy Lake, located in Marshall County, South Dakota. Roy Lake was listed in the ***2006 South Dakota Integrated Report for Surface Water Quality Assessment*** as non-supportive of one of the lake's beneficial uses; *(4) Warmwater Permanent Fish Life Propagation.*

General Lake Description

Roy Lake is an important water-based recreational destination. Boating, swimming, and fishing are the main recreational activities. There are two resorts and a state park located on the lake that provides the public access to the lake. There are approximately 137 homes and cabins located along the lakes shoreline. These homes and cabins currently utilize on-site septic systems. The vast majority of undeveloped shoreline is owned by the State of South Dakota utilized for wildlife purposes.

Physical attributes of Roy Lake are listed below.

Watershed Area (acres):	9,614
Watershed to Lake Ratio:	6/1
Maximum Depth (feet):	20.6
Mean Depth (feet):	10
Surface Area (acres):	2,054
Shoreline Length (miles):	14.5

Roy Lake has several small unnamed tributaries, primarily outlets of nearby lakes, namely the outlet tributary of Cottonwood Lake located to the north, and the outlet tributary of Clear Lake located to the east of Roy Lake (Figure 1). Bullhead Lake, located on Roy Lake's southwest corner, also has a short tributary outlet to Roy Lake.

Lake Identification and Location

Lake Name: Roy Lake
County: Marshall
Nearest Municipality: Lake City
EPA Region: VIII
Primary Tributaries: Unnamed
Receiving Body of Water: Lost Lake
HUC #: 10160010
HUC Name: North Big Sioux Couteau

State: South Dakota
Township: 126 N
Range: 55 W
Sections: 19, 20, 21, 27, 28, 29, 33, 34
Longitude/Latitude: 45°42'06"N
97°26'06"W

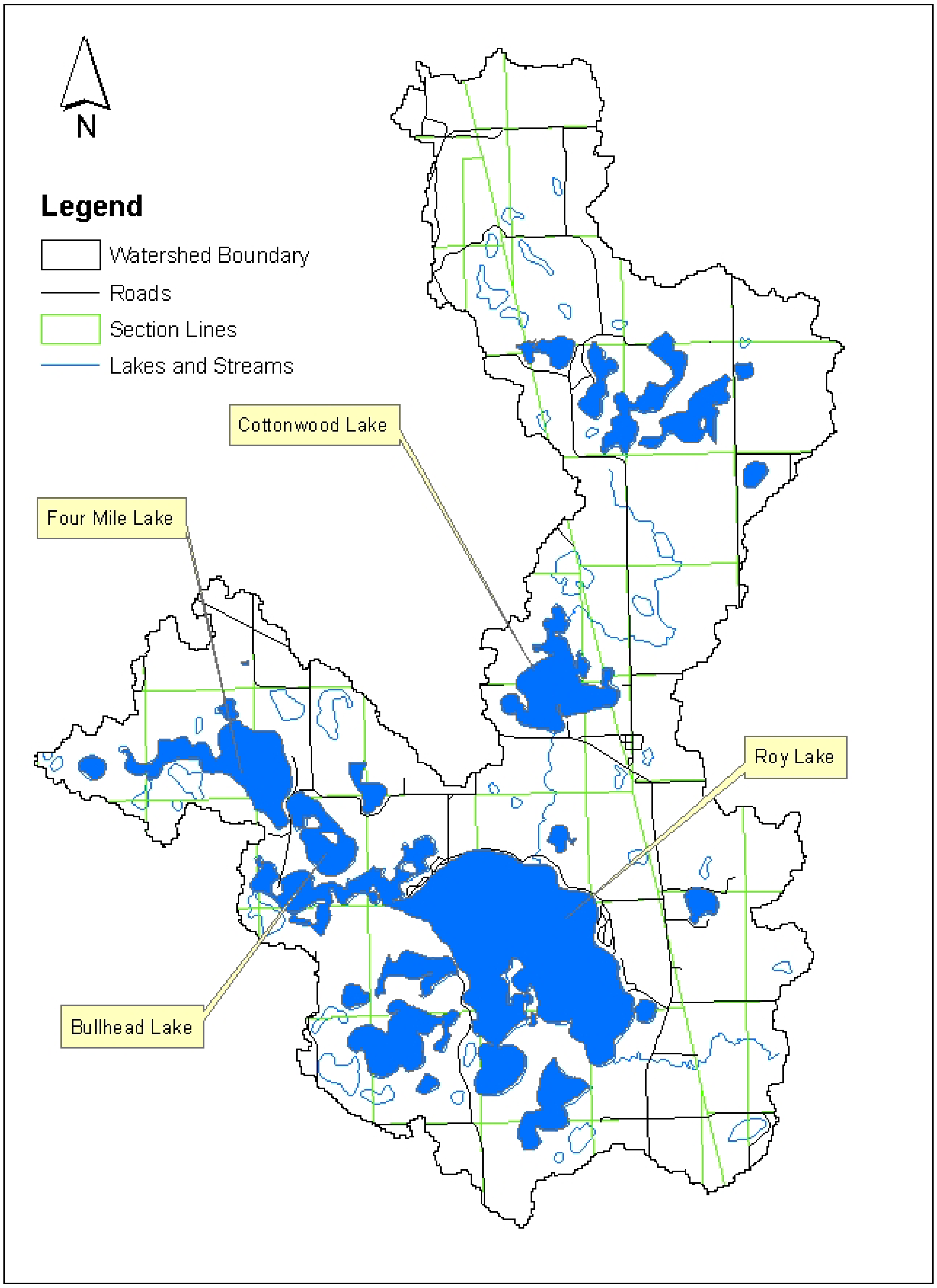

Figure 1. Roy Lake Watershed

Beneficial Uses and Water Quality Standards

Each water body within South Dakota is assigned beneficial uses. All waters (both lakes and streams) are designated with the use of fish and wildlife propagation, recreation, and stock watering. Additional uses are assigned by the state based on a beneficial use analysis of each water body. Water quality standards have been defined in South Dakota state statutes in support of these uses. These standards consist of a set of criteria that provide physical and chemical benchmarks from which management decisions can be developed (Table 1).

Roy Lake has been assigned the following beneficial uses:

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

With each beneficial use comes a set of water quality standards that provide a measurable means to determine if each beneficial use is being met. Table 1 lists each water quality parameter used and the standards for each parameter. The most restrictive criterion is used when multiple standards for a parameter exist. Additional water quality information can be found in the "Administrative Rules of South Dakota: Articles 74:51:01:05; 06; 08; and 09". These rules contain language that prohibits the presence of materials that cause pollutants to form, visible pollutants, and nuisance aquatic life in South Dakota water bodies.

Recreational Uses

A state park located on the lake provides camping facilities, swimming beach, fishing access, and three boat ramps for public use. There are two privately operated resorts providing cabins and boat rentals. The lake supports a warmwater fishery primarily managed as a black bass, walleye, and yellow perch fishery (SD GFP, 2007).

Table 1 State surface water quality standards for Roy Lake

Parameter	Standard	Use Requiring Standard
Alkalinity	< 750 mg/L[1] < 1313 mg/L[2]	(9) Fish, wildlife propagation, recreation and stock watering
Fecal coliform bacteria	400 colonies/100 ml 2,000 colonies/100 ml	(7) Immersion recreation (8) Limited contact recreation
Conductivity	< 4,000 umhos/cm[1] < 7,000 umhos/cm[2]	(9) Fish, wildlife propagation, recreation and stock watering
Undissociated Hydrogen Sulfide	< 0.002 mg/L	(4) Warmwater permanent fish life propagation
Nitrogen, Total Ammonia as N	formula available in integrated report	(4) Warmwater permanent fish life propagation
Nitrate as N	< 50 mg/L[1] or < 88 mg/L[2]	(9) Fish, wildlife propagation, recreation and stock watering
Dissolved Oxygen	$\geq$ 5.0	(4) Warmwater permanent fish life propagation (7) Immersion recreation (8) Limited contact recreation
pH (standard units)	6.0 - 9.5 6.5 - 9.0	(9) Fish, wildlife propagation, recreation and stock watering (4) Warmwater permanent fish life propagation
Suspended Solids	< 90 mg/L[1] <158 mg/L[2]	(4) Warmwater permanent fish life propagation
Total Dissolved Solids	< 2,500 mg/L[1] <4,375 mg/L[2]	(9) Fish, wildlife propagation, recreation and stock watering
Temperature (°F)	< 80°F	(4) Warmwater permanent fish life propagation

[1] 30-day average, [2] daily maximum

Geology, Climate, and Land Use

The majority of waterbodies located in Marshall County lie on top of a high tableland that early French explorers named the Coteau Des Prairie or Hill of the Prairies. The topography of the Coteau was formed by the stagnation of glacial ice during the late Wisconsin Glaciations that occurred approximately 12,000 years ago. As the glacier stagnated and began to fragment and melt, large blocks of ice were buried in melt water outwash. Melting of the ice blocks left depressions in the outwash of various size and depth. These depressions are the thousands of potholes, sloughs, and lakes characteristic of the modern day topography of the Coteau Des Prairie.

Roy Lake is positioned in the lower reaches of the Couteau Lake Outwash Deposit. This outwash deposit was formed during the late Wisconsin Glaciations and was a tributary of the Big Sioux River drainage during the glaciers retreat. Roy Lake is connected to several other lakes through subsurface aquifers and surface drainages that lie in this deposit include Bullhead Lake, Four Mile Lake, Clear Lake, and Cottonwood Lake (Figure 1). All of these lakes drain to Roy Lake through short intermittent tributaries between each lake following spring snowmelts or heavy rains. Roy Lake discharges through a surface outlet to Lost Lake that eventually drains into Cattail Lake, then to the Kettle Lakes system.

The major soil associations found in the project area include:

- Maddock-Serden, Embden-Hecla-Ulen, Beotia-Great Bend, and Harmony-Aberdeen-Exline - excessively drained to somewhat poorly drained soils formed in lacustrine materials on glacial lake plains
- Kranzburg, Forman-Poinsett, and Sinai-Poinsett - well-drained soils formed in loess on upland

- Forman-Aastad Buse, and Peever-Forman-Tonka - well-drained to poorly drained soils formed in glacial till on uplands
- Renshaw-Fordville-Sioux - well-drained to excessively drained soils formed in glacial outwash on uplands
- Dovray-Ludden-Lamoure - somewhat poorly drained to poorly drained soils formed in alluvium on bottom lands

Agriculture is the major land-use. Ownership and agricultural data for Marshall County are given in Table 2.

The climate of the project area is classified as Sub-humid Continental. Mean climatic conditions of the area are:

- Winter Average Daily Minimum Temperature - 4 degrees F
- Summer Average Daily Maximum Temperature - 82 degrees F
- Total Annual Precipitation - 21 inches
- Average Seasonal Snowfall - 31 inches

Approximately 75 percent (=16 inches) of the annual precipitation falls between the months of April to September. Tornadoes and severe thunderstorms occasionally strike. These storms, usually local and of short duration, occasionally produce heavy rainfall (data from Webster, SD reporting station).

Table 2. Land Ownership and Agricultural Data

*Data from South Dakota Agricultural 2006 Bulletin No. 66	**Marshall**
Population (2002 census)*	4,576
Land Area* (Acres)	536,888
Land Ownership	
Private (Acres)	483,944
Tribal (Acres)	26,363
Federal (Acres)	11,180
State (Acres)	15,401
Agricultural Data	
Number of Farms*	529
Total Cropland* (Acres)	339,758
Corn/Soybeans* (Acres)	176,000
Small Grain* (Acres)	27,500
CRP (Acres)	55,629
Hay* (Acres)	39,000
Range/Pasture (Acres)	170,000
Livestock Numbers* (2002 census)	
Cattle	88,141
Swine	10,810
Sheep	3,644

History

According to the SD Dept. of Game, Fish and Parks website;

http://www.sdgfp.info/Parks/Regions/GlacialLakes/RoyLake.htm;

the earliest know inhabitants of Roy Lake were Native Americans of the Woodland Culture. Artifacts dating between 900 and 1300 A.D. from these inhabitants have been found near Roy Lake. The lake was named after the first white settlement was established by the Roy (or Roi) family along the lakes shoreline.

2.0 Project Goals, Objectives, and Activities

Planned and Actual Milestones, Products, and Completion Dates

Objective 1: Determine the probable sources and types of non-point source pollutants impairing the beneficial uses of Roy Lake.

Task 1: Collect in-lake water quality and biological data to identify the current trophic state of Roy Lake.

Product: 1. In-Lake Water Quality Sampling

Monthly water quality samples will be collected at two in-lake sites on Roy Lake (Figure 2) except during periods of unsafe ice conditions, and during the months of June, July, and August when bi-weekly samples will be collected. Discrete surface and bottom samples will be collected from both sites. Approximately 56 in-lake samples will be collected.

Site	Location	
RL01	Lat. 45.703900	Long. -97.443900
RL02	Lat. 45.691800	Long. -97.424000

The collection of all field water quality data will be accomplished in accordance with the "STANDARD OPERATING PROCEDURES FOR FIELD SAMPLERS" (SOP), SD DENR, June, 2003.

Milestones:	**Planned**	**Total Completed**
Site RL01 Surface Samples	14	13
Site RL01 Bottom Samples	14	13
Site RL02 Surface Samples	14	13
Site RL02 Bottom Samples	14	13

Monthly in-lake samples were collected during December 2007 through May 2008 except for April 2008 when ice conditions and weather were unfavorable for sampling. Bi-weekly samples were collected during the months of June, July, and August, and one sample was collected in October of 2008. There were no changes or amendments to this task.

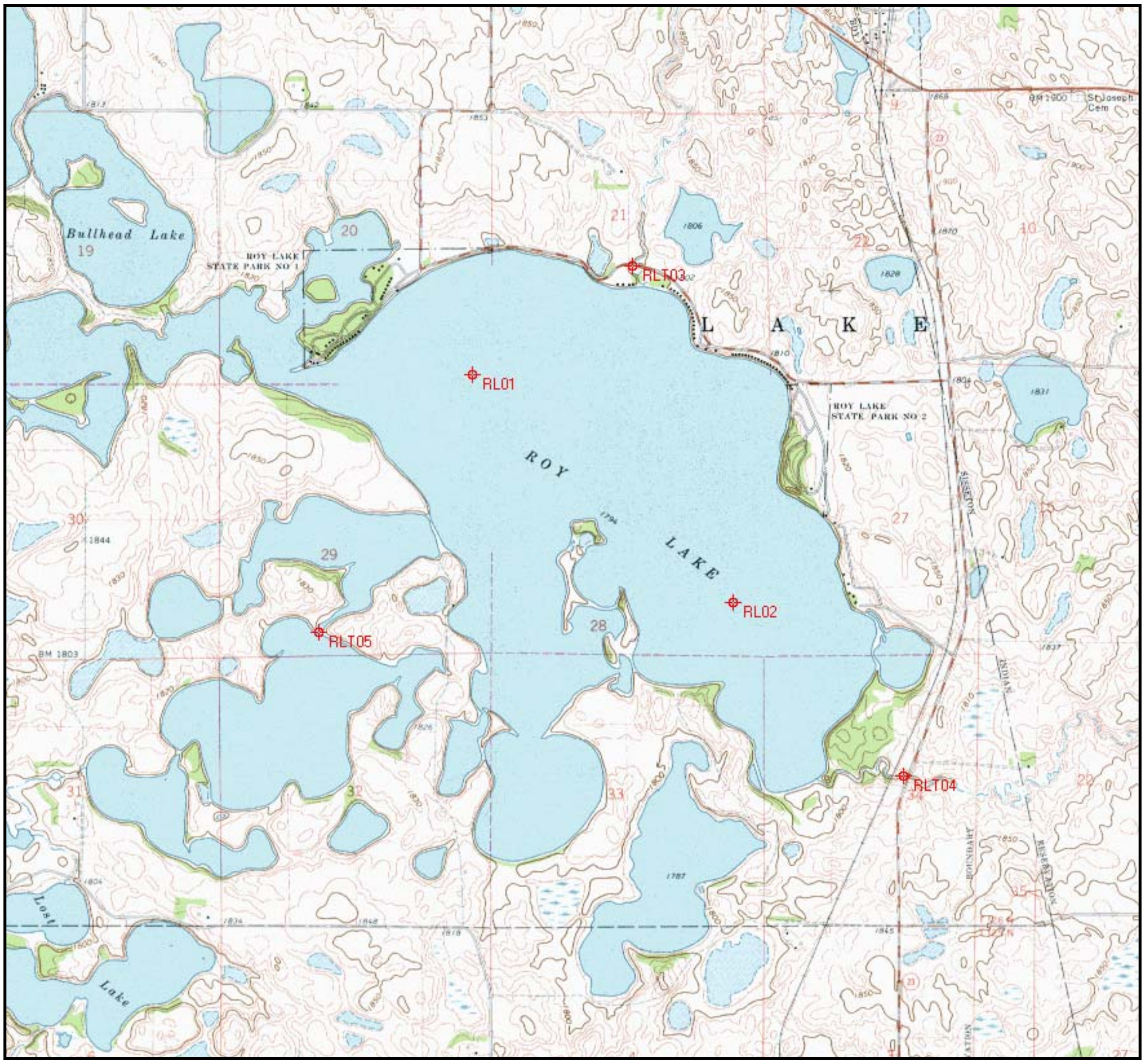

Figure 2. Roy Lake Tributary and In-Lake Sampling Sites

Product: **2. Macrophyte/Shoreline Survey**

A macrophyte/shoreline survey will be completed to determine the species and coverage of macrophytes in Roy Lake, and the condition of the lakes shoreline habitat. The local coordinator will conduct the survey with assistance from the project officer. The procedures for the macrophyte survey can be found in the "STANDARD OPERATING PROCEDURES FOR FIELD SAMPLERS" (SOP), SD DENR, June, 2003. Based on Roy Lakes surface area, 40 shoreline transects will be needed.

Milestones:	Planned	Total Completed
Shoreline Habitat Assessment	40 sites	36

Due to Roy Lake's size and the time needed to complete a comprehensive survey only 36 of the planned 40 sites were surveyed. Samples were only collected at 20 meters from the shoreline. A total of seven species of submergent aquatic macrophytes were collected. No exotic species were observed.

Task 2: **Determine nutrient and sediment loadings to Roy Lake from the watershed through tributary water quality sampling data, stage and flow measurements.**

Product: **3. Tributary stage and flow**

Install stage recorders at two tributary sites. Tributary flows will be measured weekly beginning with ice-out and during rainstorm events using a hand-held current velocity meter. Flow measurements and tributary stage measurements will be used to calculate a hydrologic budget for each tributary.

Site	Location	
RLT1	Lat. 45.709678	Long. -97.431659
RLT2	Lat. 45.682540	Long. -97.411112

Milestones:	Planned	Total Completed
Stage Recorder Installation RL03	1	1
Stage Recorder Installation RL04	1	1
Stage Recorder Installation In-Lake	0	1
Stage & Flow Measurements RL03	38	20
Stage & Flow Measurements RL04	38	22
Stage & Flow Measurements RL05	0	8

OTT Thalimedes stage recorders were installed on March 25, 2008 at two tributary sites (Figure 2) and one in-lake site to record tributary and lake level stages. Flow measurements were taken during storm events and weekly thereafter as flows occurred. Some problems were encountered with ponding at both tributary sites due to activity by beavers. All stage recorders were removed on October 29, 2008.

Product: 4. Tributary Water Quality Sampling

Collect water quality samples from two tributary monitoring sites (Figure 2). Samples will be collected during spring runoff, storm events, and monthly base flows. Samples will be collected twice weekly during the first week of spring snowmelt and once a week thereafter until runoff ceases. Base flows will be sampled monthly, and storm events will be sampled throughout the project period as they occur. Approximately 15 samples will be collected at each site for an estimated total number of 30 samples.

Milestones:	Planned	Total Completed
Tributary RL03 Monthly	7	3
Tributary RL03 Spring Runoff	4	4
Tributary RL03 Storm Event	4	2
Tributary RL04 Monthly	7	4
Tributary RL04 Spring Runoff	4	4
Tributary RL04 Storm Event	4	2
Tributary RL05	0	5

An additional sampling site was added at the lakes outlet (Figure 2). Several late spring snowstorms in April and early May provided spring runoff. Rainstorm events occurred in June and September. Due to a dry period in mid-summer, some of the planned monthly samples were not taken due to lack of flow.

Task 3: Provide quality controls and assurances for all in-lake and tributary water quality data collected during the project.

Product: 5. Quality Assurance and Quality Control

All QA/QC samples will be collected using the methods described in the “SOUTH DAKOTA NONPOINT SOURCE PROGRAM QUALITY ASSURANCE PROJECT PLAN” (QAPP), and the “STANDARD OPERATING PROCEDURES FOR FIELD SAMPLERS” (SOP), SD DENR, June, 2003. The activities involved with QA/QC procedures and the results of QA/QC monitoring will be compiled and reported in a section of the final project report.
The number of QA/QC samples is based on a minimum of 10 percent of all samples collected. For example, if the proposed number of in-lake

samples (42) is collected for the project, approximately 4 blank and 4 field replicate QA/QC samples will be needed during the project.

Milestones:	Planned	Total Completed
In-Lake Replicate Samples	5	5
In-Lake Blank Samples	5	5
Tributary Replicate Samples	3	3
Tributary Blank Samples	3	4

A total of 48 discrete in-lake surface and bottom samples were collected requiring 5 replicate and 5 blank QA/QC samples to meet the required 10% of in-lake samples collected. A total of 27 tributary samples were collected requiring 3 replicated and 3 blank QA/QC samples to meet the required 10% for tributary QA/QC. There were no amendments or changes to this task.

Task 4: Evaluate Roy Lake's watershed to determine agricultural impacts to water quality through the use of the Annualized Agricultural Nonpoint Source (ANNAGNPS) model.

Product: 6. ANNAGNPS Land-use Model

The Roy Lake watershed will be modeled using the ANNAGNPS model. ANNAGNPS is a comprehensive land use model that estimates sediment and nutrient loss and delivery, and evaluates the impacts of animal feeding operations (AFOs). The watershed will be divided into cells. Each cell will be analyzed after collecting several parameters for each cell with additional information collected for animal feeding operations.

The model will be used to identify critical areas of non-point source pollution to the surface waters in the watershed. If critical areas are found, the model will be used to determine attainable targets and goals for the TMDL. SD DENR will be responsible for completing this task and publishing the results in the final report.

The AnnAGNPS model was not run due to the lake meeting its fishery beneficial uses.

Objective 2: Implement a public outreach program to inform project area stakeholders about the opportunities for involvement in, and progress of the project.

Task 5: Develop and implement a multimedia outreach program to promote the project, offer opportunities for involvement, and inform the public of project progress.

Product: **7. Direct personal contact with and involvement in project opportunities**

Displays, public meetings, forums, and workshops will provide area residents a direct personal contact with the project and project involvement opportunities. Print material will be developed and distributed at these public events. The project or project partners will sponsor the following public meetings:

An informational meeting will be held for the general publics prior to the assessments start to provide information on the objectives and goals of the assessment and provide an avenue for input from area residents.

Project information will be on display at the Britton Winter Festival Farm Show

A final meeting will be held while the watershed assessment final draft is nearing completion to get any last public input and comment into the report.

Milestones:	**Planned**	**Total Completed**
Pre-Assessment Meeting	1	2
Britton Winter Show	1	1
Post Assessment Meeting	1	0

On July 12th and 13th, the Project Coordinator and Technician met with both Roy Lake Associations to discuss with lake property owners the purpose of the assessment and assessment activities. Questions posed by the public were answered and the future of Roy Lake was discussed including the possible formation of a sanitary sewer district. The Project Coordinator attended the Britton Winter Show on March 7, 2008 providing project information to the public. There were no amendments or changes to this task. A post assessment meeting will be held in conjunction with the Northeast Glacial Lakes Watershed Improvement and Protection Project summer 2009 after completion of the final report.

Product: **8. Project web site**

A web site will be developed and funded by an EPA 319 grant for the Northeast Glacial Lakes Watershed Protection and Improvement Project. The web site will be maintained through a cooperative agreement with SDACD. Progress reports and information about the Roy Lake Watershed Assessment Project will be added to this web site.

Web development software was purchased through a Watershed Information and Education Grant for the Northeast Glacial Lakes Watershed Improvement and Protection Project, design of a project website has begun but at the time of this report had not been completed. The Roy Lake Final Assessment Report will be posted on this site once approved by EPA and SD DENR.

Product: **9. News Releases**

Print media will be used to inform the public about assessment activities.

Milestones:	Planned	Total Completed
News Articles	2	1

One news article was written and published in area newspapers and Conservation District newsletter explaining the purpose and objectives of the Roy Lake Watershed Assessment Project.

Objective 3: **Project Evaluation, Reporting, and Grant Administration**

Task 5: **Project Sponsor's Reporting Duties**

Product: **10. GRTS Reports**

Submitted electronically to SD DENR to meet reporting requirements for 319 funds. Reports will include information on project milestones completed and planned.

Product: **11. Monthly and Semi-Monthly Progress and Financial Reports**

Reports to be submitted to the project sponsor and co-sponsor. These reports will be submitted electronically or by attendance of the Project Coordinator at monthly board meetings.

Product: **12. Final Report**

Report will follow EPA format requirements and include the final status of all project milestones, final project budgets, and water quality analysis.

Milestones:	Planned	Total Completed
GRTS Annual Report	1	1
Progress Reports	28	12
Final Report	1	1

Product: **13. Payment Vouchers**

Payment vouchers will be submitted not more than once per month utilizing the SD NPS Project Management System.

Milestones:	Planned	Total Completed
Payment Vouchers	16	9

2.1 Planned and Actual Milestones, Products and Completion Dates

All project milestones for in-lake and tributary sampling were completed within the time allotted by the project implementation plan. All but one of the monthly lake samples was collected. The April sample was not collected due to unsafe ice conditions, a result of a late spring thaw. The number of tributary samples collected was below the milestone expectation due to a dry period in July and August that resulted in little to know tributary flow. Stage and flow measurements were also lower than expected, again due to dry conditions during the late summer. All required QA/QC replicate and blank samples were completed. Milestones for each product are listed in Section 2.0.

2.2 Evaluation of Goal Achievements

The goal of the Roy Lake Assessment Project was to locate and document probable sources of nonpoint pollutants in the watershed. Since the 2006 listing as non-supportive, it has been determined that Roy Lake is in compliance with current state water quality standards and assigned fishery beneficial uses. Therefore, this assessment should be used as a benchmark for future water quality measurements and as a basis to develop protection strategies to maintain or improve the lakes water quality as changes in lakeshore development and watershed land-use occur as suggested in Section 6.0 of this report.

3.0 MONITORING RESULTS

Water quality field data, in-lake, tributary, QA/QC samples; stream velocity measurements, and stream stage recordings were collected by Day and Roberts County Conservation District personnel. Water samples were sent to the SD State Health Laboratory for analysis. Lab analysis was sent electronically to the SD DENR and hard copies were sent to the Day County Conservation District, the project sponsor. The project coordinator will be responsible for compiling water quality and other data collected during the assessment, and submitting this data to DENR for the final assessment report.

3.1 In-Lake Water Quality Results

Sampling Schedule

In-lake sampling of Roy Lake began in December 2007 and continued through October 2008. Samples were collected during the morning hours, typically from 9 to 11 A.M. There were two pre-selected in-lake surface and bottom sampling sites (Figure 2). Water samples were collected once monthly during the months of September through May, and bi-monthly June through August. Water samples were filtered, preserved, and packed in ice for shipping to the State Health Lab in Pierre, SD. In-lake laboratory and field parameter water quality data for Roy Lake are given in Appendix A.

The laboratory analyzed the following parameters:

Fecal Coliform Bacteria	Alkalinity
Total Solids	Total Suspended Solids
Ammonia	Nitrate
Total Kjeldahl Nitrogen (TKN)	Total Phosphorus
Total Volatile Suspended Solids	Total Dissolved Phosphorus
E coli/Enterococci	

Personnel conducting the sampling at each in-lake site recorded visual observations of the following weather and lake characteristics.

Precipitation	Wind Speed
Odor	Dead Fish
Film	Water Color
Ice Cover	Temperature

Parameters measured in the field by sampling personnel were:

Water Temperature
Dissolved Oxygen
Field pH
Secchi Depth
Air Temperature
Sample Depth
Total Water Depth

Water Temperature

Water temperature is of great importance to any aquatic ecosystem as it can affect chemical and biological processes. Many organisms are temperature sensitive; blue-green algae tend to dominate the warmer waters of summer while green algae and diatoms are more prevalent in the cooler waters of spring and fall. Water temperature also affects physical/chemical processes. Cooler water has the capacity to hold more dissolved oxygen than warm water. Warm water can also increase the un-ionized fraction of ammonia that, if high enough, can cause fish kills.

Surface water temperatures in Roy Lake indicated seasonal variations that are consistent with its geographic location in the northern Great Plains. Water temperatures steadily increased during the spring and summer and consistently decreased through the fall and winter months (Figure 3). It can be expected that during most years surface water temperatures will be within a few degrees of those observed during the project on their respective dates. Surface temperatures did not exceed the water quality standard of 27° C. during this study.

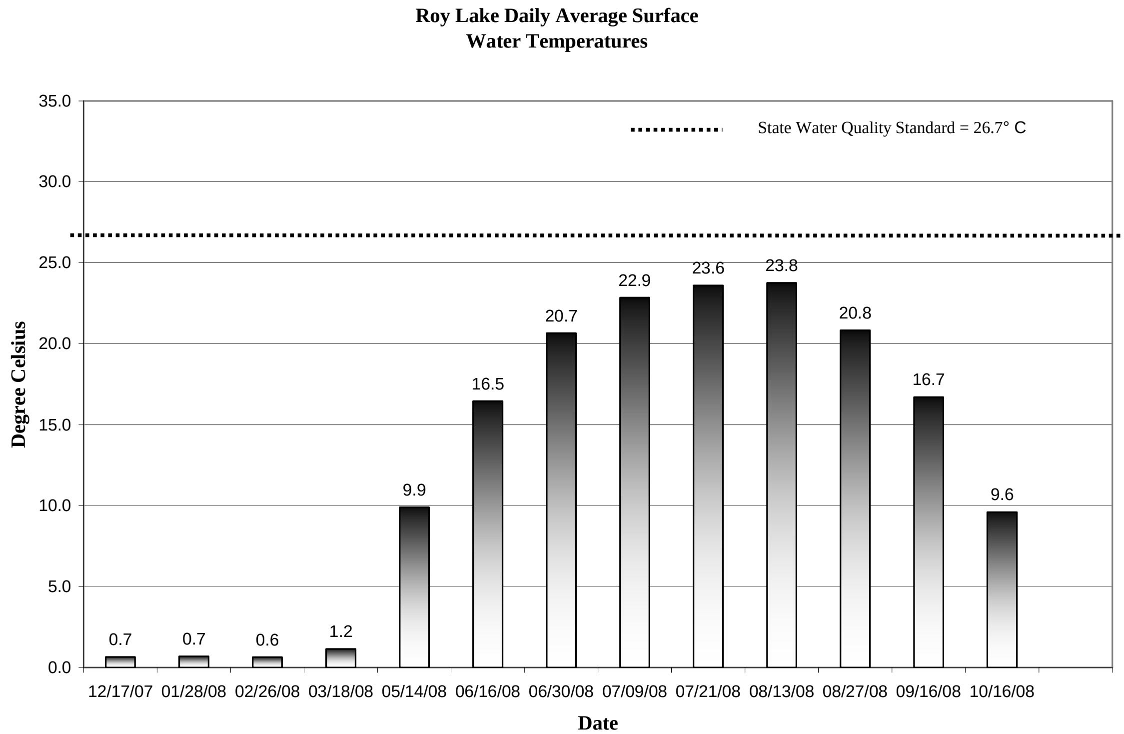

Figure 3. Average Surface Water Temperatures

Roy Lake is deep enough to stratify thermally, however summer oxygen and temperature profiles taken during the project did not show any strong stratification events. A weak stratification event did occur on August 13, 2008 (Figure 4) that was strong enough to affect other water quality parameters.

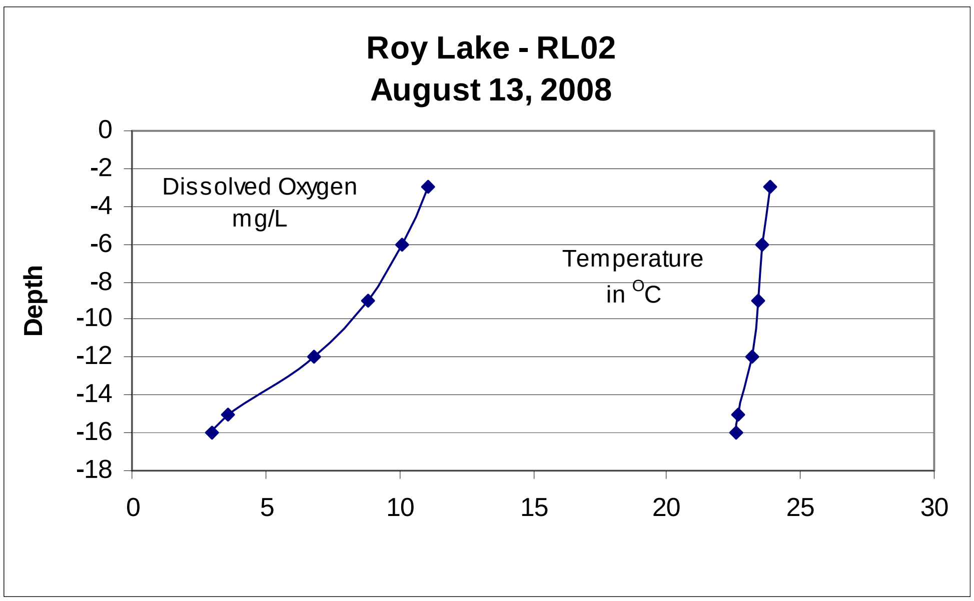

Figure 4. Weak Stratification Event on August 13, 2008.

Dissolved Oxygen

Dissolved oxygen (DO) is one of the more important water quality parameters in regards to the health and diversity of aquatic organisms in a lake. Lakes with good oxygen concentrations throughout the year are more likely to have a diverse population of aquatic organisms like fish than lakes with low oxygen concentrations. Lakes with poor DO usually lack diversity and stability, and are dominated by a few hardy species like carp and bullheads.

Many factors can influence DO concentrations in a water body. Temperature is one of the major determining factors as previously described. Daily and seasonal fluctuations in DO may occur in response to algal and bacterial action (Bowler, 1998). As algae photosynthesize during daylight hours, they produce oxygen that raises the concentration in the epilimnion. As photosynthesis ceases at night, respiration utilizes available oxygen causing a decrease in DO concentration. During winters when heavy snow covers ice, light penetration in a lake may be reduced to the point that photosynthesis ceases and algae and aquatic macrophytes cannot produce enough oxygen to keep up with consumption (respiration) rates. This can result in oxygen depletion that may lead to a winter fish kill.

Dissolved oxygen concentrations can also affect chemical parameters in a lake. When anoxic conditions form in a lake's benthic zone due to the lack of DO; dissolved phosphorus, ammonia, hydrogen sulfide and other undesirable parameters are released from lake sediments into the water column. Dissolved phosphorus can contribute to algal growth when stratified lakes turn over or shallow non-stratified lakes are mixed by wind. Ammonia and hydrogen sulfide can be toxic to aquatic organisms if present in sufficient concentrations.

During this study, forty-two percent (42%) of the bottom DO readings were below the state water quality standard of 5.0 mg/l, the criterion for warmwater permanent fish life. However, DO levels elsewhere in the water column were sufficient enough for fish survival (Figures 5 & 6). As stated above, anoxic conditions will release phosphorus from a lake's sediment. Elevated levels of total dissolved phosphorus (Figure 10) were recorded from bottom samples taken at RL02 on February 26, and March 18, 2008 when DO levels were low (Figure 6). The low oxygen levels recorded near the lakes bottom may indicate a build-up of organic material in the benthos that has not completely oxidized and is creating a biological oxygen demand (BOD) under certain conditions. If stronger periods of stratification begin to occur during the summer months, the release of phosphorus from this sediment could result in severe algal blooms that could begin to favor the dominance of nuisance blue-green algae, like *Anabaena flos-aquae*.

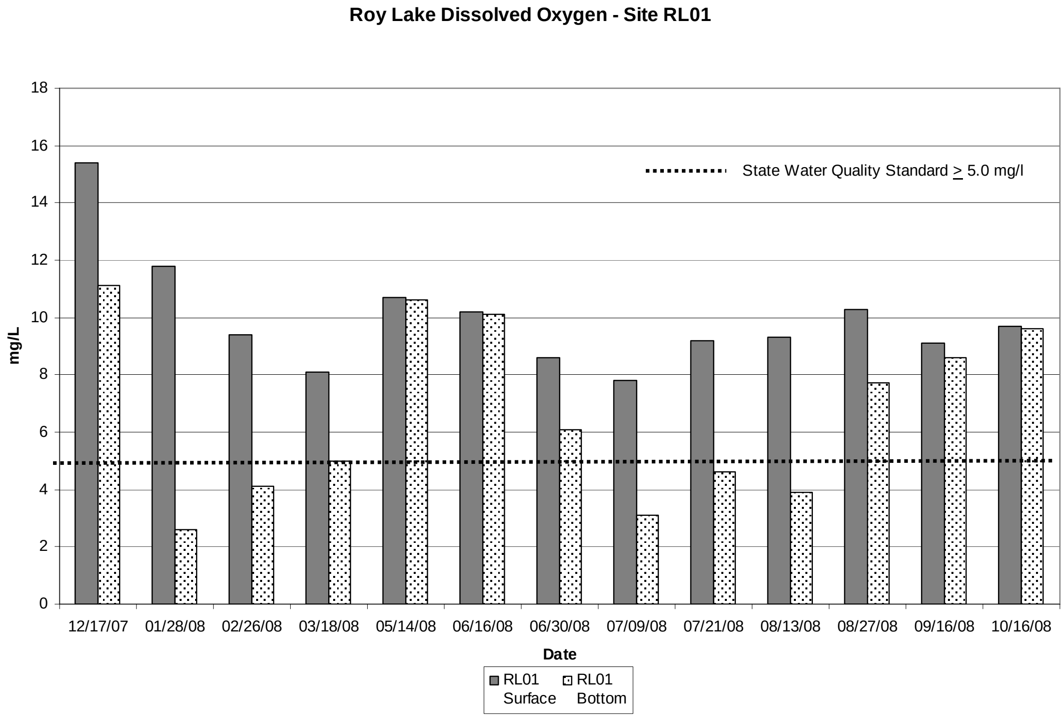

Figure 5. Dissolved Oxygen Site RL01

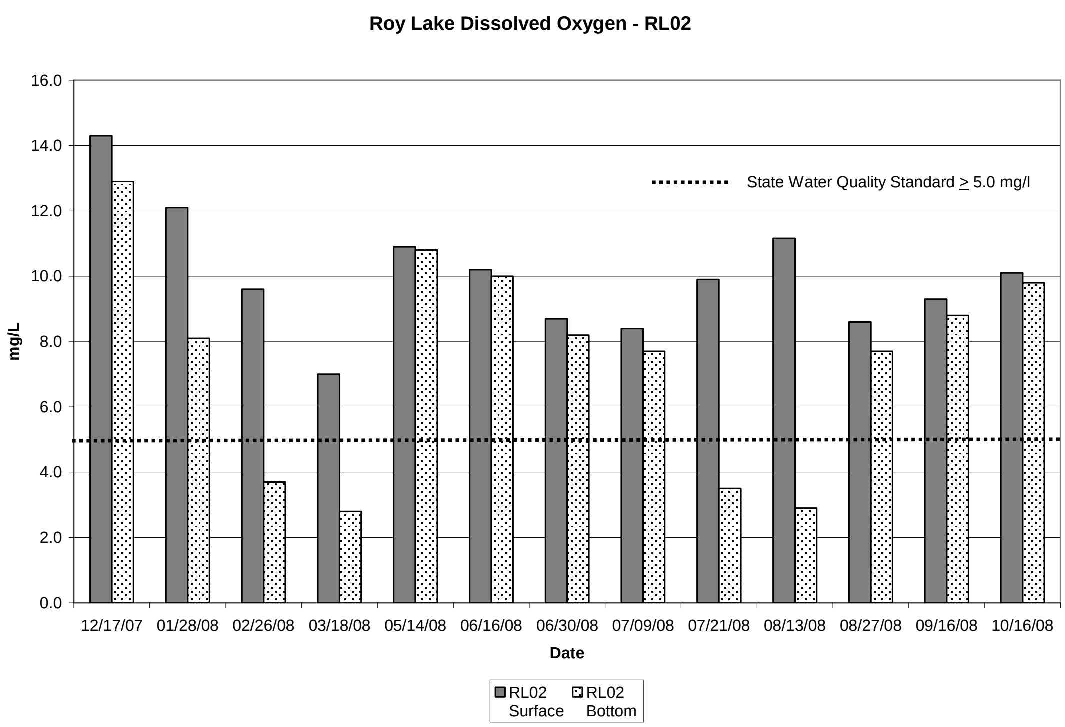

Figure 6. Dissolved Oxygen Site RL02

pH

pH is a measure of free hydrogen ions (H+) or potential hydrogen. Simply stated, it indicates the balance between acids and bases in a water body. pH is measured on a logarithmic scale between 0 and 14 and is recorded as standard units (su). Each pH point represents a 10-fold increase or decrease in hydrogen ion concentration. At neutrality (pH of 7) acid ions (H+) equal the base ions (OH-). Values less than 7 are considered acidic (more H+ ions) and greater than 7 are basic (more OH- ions).

Biological and chemical processes in a lake or reservoir can decrease pH. The decomposition of organic matter in a lake's benthos releases carbon dioxide into the water column. This carbon dioxide reacts with the water and is converted to carbonic acid, decreasing a lake's pH. The extent to which this process affects pH is determined by a lake's alkalinity. High alkalinity (>200 mg/L.) in a water body represents a considerable buffering capacity that will reduce any large fluctuations in pH caused by decomposition. Most aquatic plants and organisms (especially fish) are sensitive to acidity and will not survive at a pH below 6.0 su.

The pH of surface water collected from Roy Lake ranged from 8.01 to 8.87 su with an average pH of 8.59 su. The pH of bottom water samples ranged from 7.71 to 8.82 with an average pH of 8.44. All pH recorded during the study fell within the State water quality standard of 6.0 to 9.0 su set for the fishery beneficial uses assigned to Roy Lake.

Specific Conductance

Specific conductance ranged from 479 to 725 µS/cm with little difference between surface and bottom measurements. The average specific conductance for surface measurements was 613µS/cm and the average specific conductance for the bottom was 609 µS/cm. All specific conductance measurements taken from Roy Lake were below the state standard set for this parameter.

Secchi Depth

Secchi depth is a measure of lake transparency or clarity. Secchi depth is measured using a Secchi disk, a 20 cm (8 in) or larger diameter metal or plastic disk with alternating black and white colored quadrants. The disk is lowered into the water until it is no longer visible. The point where the disk disappears below the water surface is called the Secchi depth. Secchi depth is measured in meters or feet, usually by attaching a measuring tape to the disk. Secchi depth is one of the parameters used to determine the Trophic State Index (TSI) of a water body. The TSI of a lake indicates whether the body is nutrient-rich or nutrient-poor. Low Secchi depth measurements are typically due to algal blooms or high suspended sediments and may indicate a eutrophic or hyper-eutrophic TSI.

In mesotrophic to hypereutrophic lakes Secchi depths are typically deeper during the winter months when algae are dormant, and become shallower from the spring through summer months when diatom and algae species bloom. Roy Lake Secchi depths shown in Figure 7 indicate a typical winter to fall progression of Secchi depths. The deepest Secchi depths in Roy Lake were recorded on March 18, 2008. On this date the Secchi depth for Site RLO1 was 5.1 meters (16 ft.), just 0.08 meters from the lakes bottom. The lowest Secchi depth recorded was 0.56 meters on August 27, 2008 which correlated with the highest chlorophyll *a* concentrations (Figure 13) and the highest total suspended solid concentrations (Figures 9 & 10). The average Secchi depth for Roy Lake during the study was 1.85 meters or 6 feet. Field observations and water quality analysis indicate water clarity on Roy Lake is reduced by algae blooms and not suspended sediments (Figure 7).

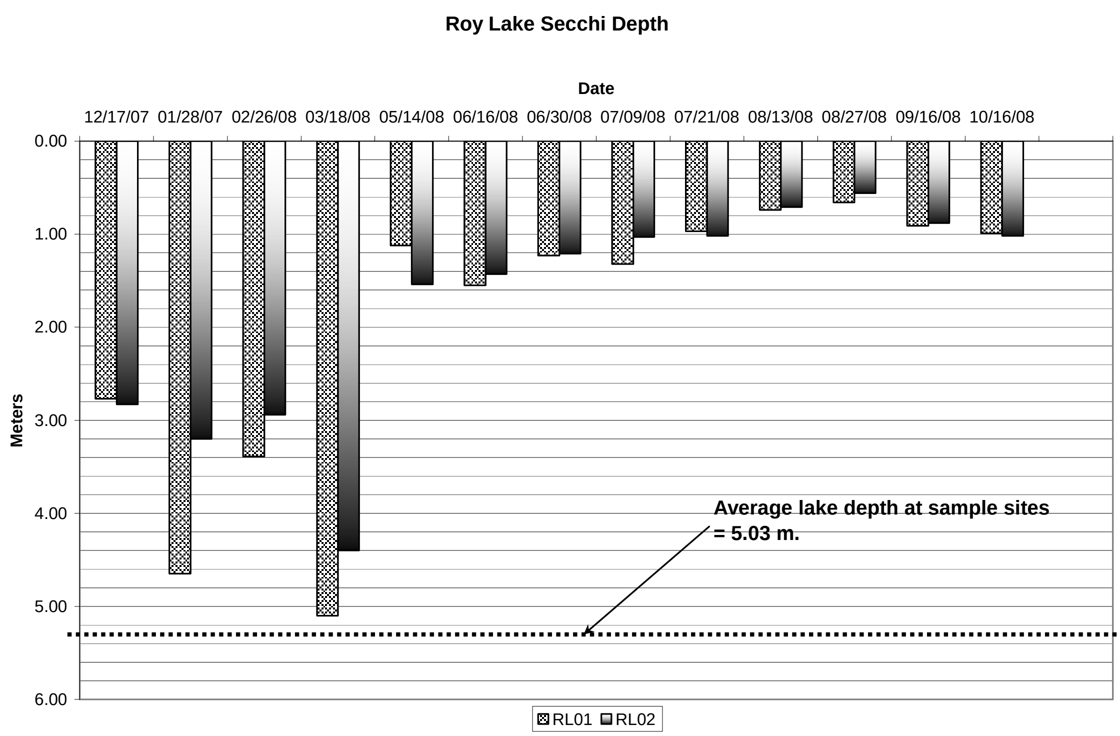

Figure 7. Secchi Depths

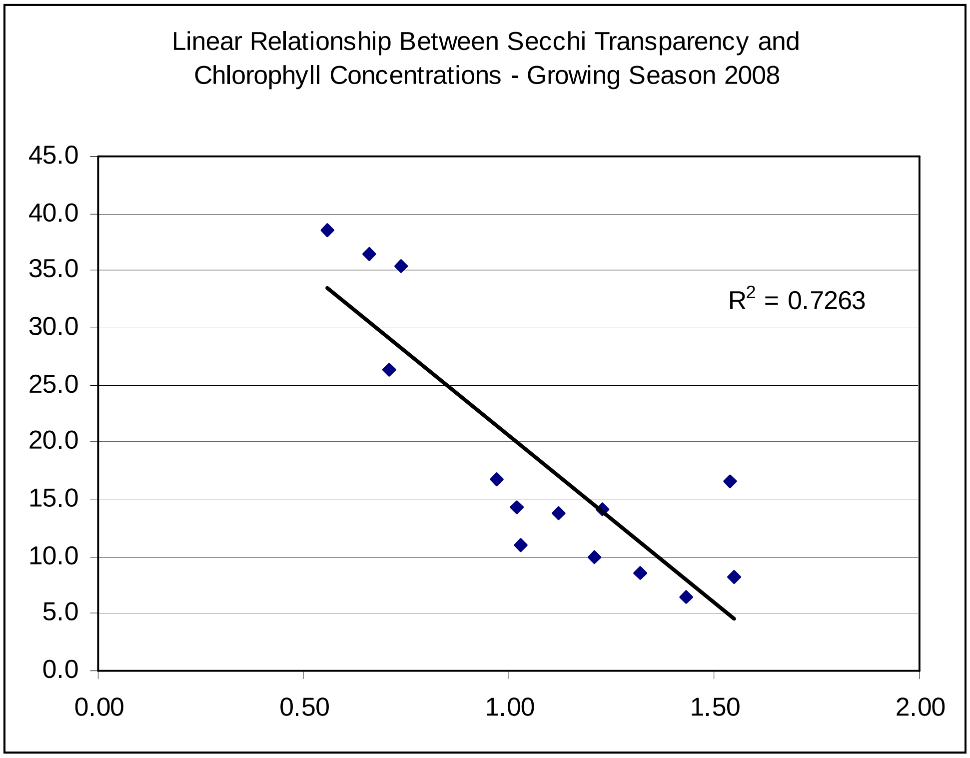

Figure 8. Relationships Between Secchi and Chlorophyll – Growing Season 2008

Alkalinity

Alkalinity measures the water's capacity to neutralize acids. Alkalinity exists due to the complex interaction of several compounds in water that include bicarbonates, carbonates, and hydroxides. In natural environments alkalinity usually ranges from 20 to 200 mg/L (Lind,1985) and is dependant on local soils. An alkalinity of >200 mg/L will buffer changes in a lake's pH caused by precipitation.

The alkalinity of Roy Lake surface samples ranged from 209 to 266 mg/l with an average alkalinity of 228 mg/l. Bottom samples ranged from 210 to 282 mg/l with an average alkalinity of 232 mg/l. The alkalinity measured in Roy Lake surface and bottom samples did not exceed the state standard set for this parameter.

Solids

Solids are represented by four parameters; total solids, total dissolved solids, suspended solids, and volatile suspended solids. Total solids are the materials, suspended and dissolved, present in a given volume of water. Suspended and dissolved solids are made up of organic and inorganic materials. Total dissolved solids are the material in a water sample that will pass though a 1 mm filter. Suspended solids are comprised of larger material like soil, algae, and other organic matter that will not pass through a filter. Total dissolved solid concentrations are derived by subtracting the suspended solid value from the total solid value. Suspended volatile solids (VTSS) are a measurement of organic matter in a sample that burns in a 500° C furnace.

Suspended solids are deposited on the bottoms of stream channels and lakes in the form of silt. Excessive silt deposition can destroy aquatic habitats and reduce the diversity of organisms inhabiting a lake or stream. Siltation can also fill a lake basin leading to reduced water depth, increased turbidity and water temperature, and an increase in the growth of aquatic macrophytes and nuisance algae.

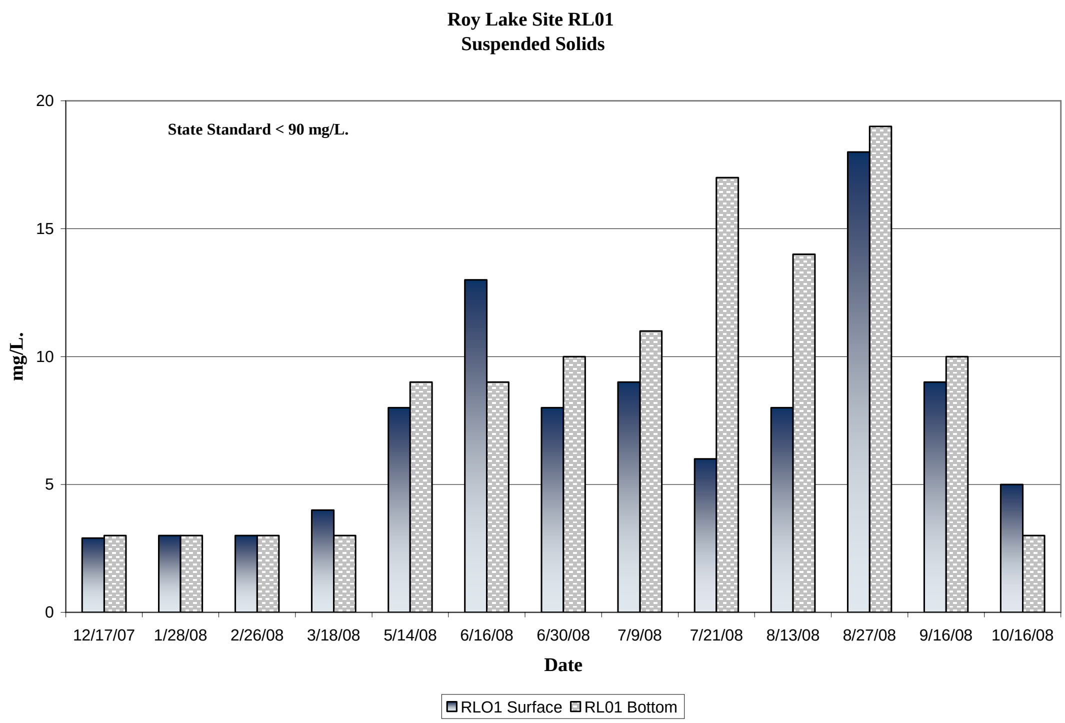

Figure 9. Suspended Solids Site RL01

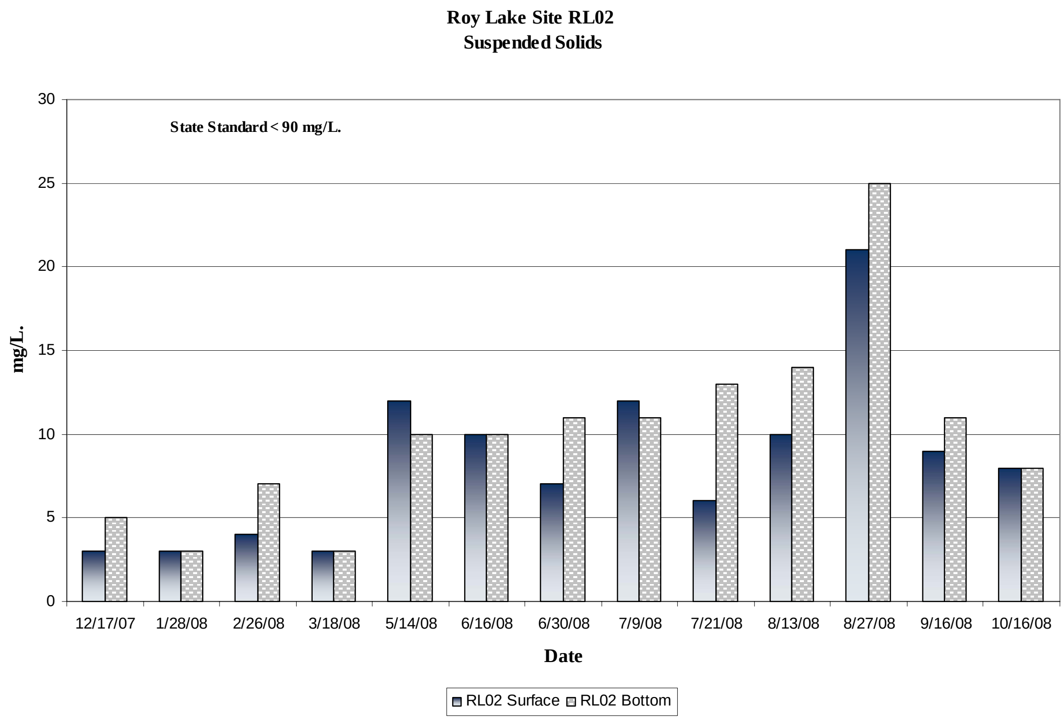

Figure 10. Suspended Solids Site RL02

Total solids concentrations for Roy Lake ranged from 437 to 788 mg/l and averaged 500 mg/l for surface samples, and from 443 to 648 mg/l with an average of 505 mg/l for bottom samples. Total suspended solids concentrations ranged from 4 to 21 mg/l and averaged 9 mg/l for surface samples, and ranged from 3 to 25 mg/l with an average of 10 mg/l for bottom samples. Both total solids and total suspended solids concentrations were below state standards for these parameters. Total suspended solids showed typical seasonal variations with the lowest concentration during the winter months when ice covers the lake and algae die-off and the lack of mixing by wind allows suspended particles to settle. Figures 9 and 10 show suspended solid concentrations from surface and bottom samples by date and sample site. Suspended solid concentrations agree with Secchi disk (Figure 7) and chlorophyll *a* (Figure 13) data collected for each sample date. No visual observations of suspended sediments were noted, the decrease in secchi depth readings beginning in May were due to an increase in algal production.

Nitrogen

Nitrogen was analyzed in three forms: nitrate/nitrite, ammonia, and Total Kjeldahl Nitrogen (TKN). From these three forms, total, organic, and inorganic nitrogen may be calculated. Nitrogen compounds are major cellular components of organisms. Because its availability may be less than the biological demand, environmental sources may limit productivity in freshwater ecosystems. Nitrogen is difficult to manage because it is highly soluble and very mobile. In addition, some blue-green algae fix atmospheric nitrogen, adding it to the nutrient supply in the lake.

Ammonia is a form of nitrogen produced by bacterial decomposition. This nutrient is readily available for plant growth, especially algae. Ammonia is produced by decaying organic matter in a lake's benthos and by bacterial conversion of other nitrogen compounds found in the lake. Decomposing bacteria in a lake's sediment and some blue-green algae species in the water column are able to convert free nitrogen (N^2) to ammonia. Algae can assimilate several forms of nitrogen; however their growth rate will greatly increase when ammonia is available (Wetzel, 1983). Animal feeding operations and anhydrous fertilizer applied on cropland are two possible sources of ammonia from watershed runoff. The South Dakota State Health Laboratory cannot detect ammonia levels below 0.02 mg/L.

All surface and bottom samples collected from Roy Lake were at or below 0.2 mg/l. Ammonia concentrations ranged from 0.02 to 0.59 mg/l with an average of 0.23 mg/l for surface samples, and from 0.06 to 1.02 mg/l with an average of 0.36 mg/l for bottom samples. The average ammonia concentration for both surface and bottom samples is 0.29 mg/l. Ammonia concentrations were at or below the 0.02 mg/l detection limit thirty-eight of the fifty-two (73%) surface and bottom samples collected.

Total nitrogen concentrations in Roy Lake's surface samples ranged from 1.16 to 1.91 mg/l with an average of 1.39 mg/l, and bottom samples ranged from 1.08 to 2.59 mg/l with an average concentration of 1.48 mg/l. Organic nitrogen comprised about seventy-eight percent (78%) of the total nitrogen found in the lake with plant material (macrophytes and algae) the most likely source.

Phosphorus

Phosphorus is one of the macronutrients required for primary production. When compared with carbon, nitrogen, and oxygen, it is typically the least abundant (Wetzel, 2001). Total phosphorus is the sum of all particulate and dissolved phosphorus in the lake. The attached phosphorus is directly related to the amount of total suspended solids present. An increase in the amount of suspended solids increases the fraction of attached phosphorus. Phosphorus loading to lakes can be of an internal or external nature. External loading refers to surface runoff over land, dust, and precipitation. Total phosphorus is one parameter used to calculate trophic state index (TSI) values.

Internal loadings of phosphorus can occur when oxygen concentrations near the sediment surface approach zero (anoxia). Phosphorus, ammonia and other compounds are released from the sediment under anoxic conditions. If a lake is stratified, phosphorus can accumulate in the deeper waters of stratified lakes and can suddenly become available to support algae growth after the water column is mixed by wind or fall turnover. Roy Lake remained un-stratified throughout most of the assessment study; however there was some weak stratification observed in July and August, especially on August 13, 2008 (Figure 4). The lake was well mixed on August 27 and on this date the lowest Secchi depths were recorded and the highest chlorophyll *a* concentrations were sampled indicating algae had probably utilized the phosphorus released by the weak stratification events.

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

The average in-lake total phosphorus concentration during the assessment was 0.06 mg/l for surface and bottom samples. Total phosphorus concentrations greater than 0.02 mg/l are indicative of eutrophic lakes (US EPA, 1974). This agrees with the median TSI calculated for Secchi disk readings and Chlorophyll *a* concentrations taken during the assessment that show Roy Lake has a eutrophic TSI. Total dissolved phosphorus concentrations for surface and bottom samples ranged from 0.006 to 0.047 mg/l with an average of 0.026 mg/l. Total dissolved phosphorus comprised forty-three percent (43%) of the total phosphorus from in-lake surface and bottom samples.

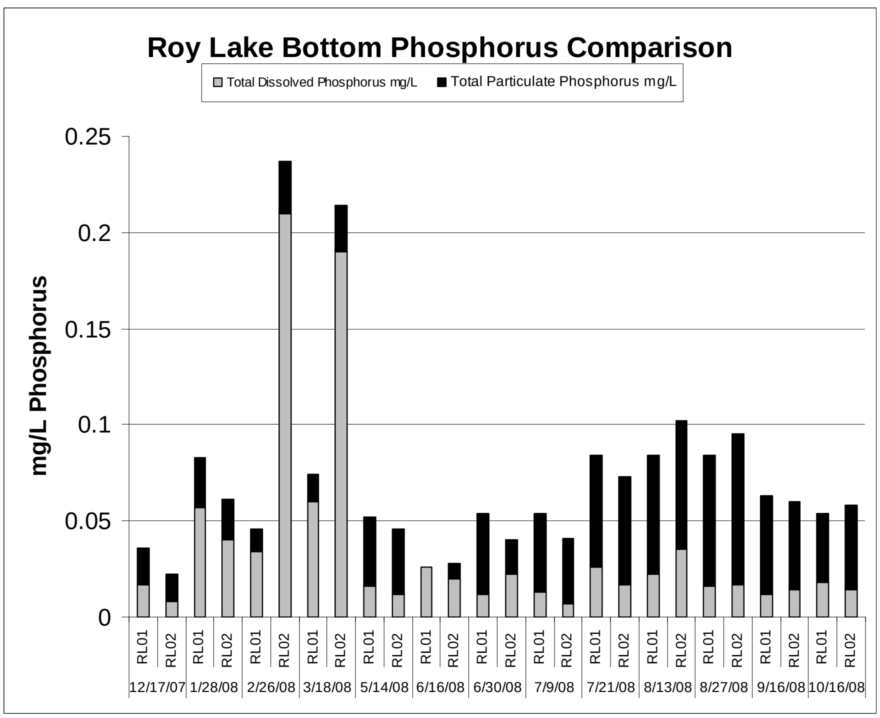

Figure 11. TDP to TP Comparisons Bottom Samples

The high total dissolved phosphorus concentrations seen in bottom samples collected from January through March 2008 (Figure 11), are probably due to the weak anoxic conditions that were recorded on these dates (Figures 5 & 6) which caused the release of phosphorus from the lakes sediment. Due to the fact that the timing of these releases was during the winter months, when heavy ice and snow cover allow very little sunlight for algae growth, this phosphorus was not utilized and had returned to the sediment by the May sample date.

The high total particulate phosphorus seen in July and August of 2008 are probably due to algae blooms. This data correspond to high chlorophyll *a* concentrations (Figure 12) and low Secchi disk readings (Figure 7) taken on these dates.

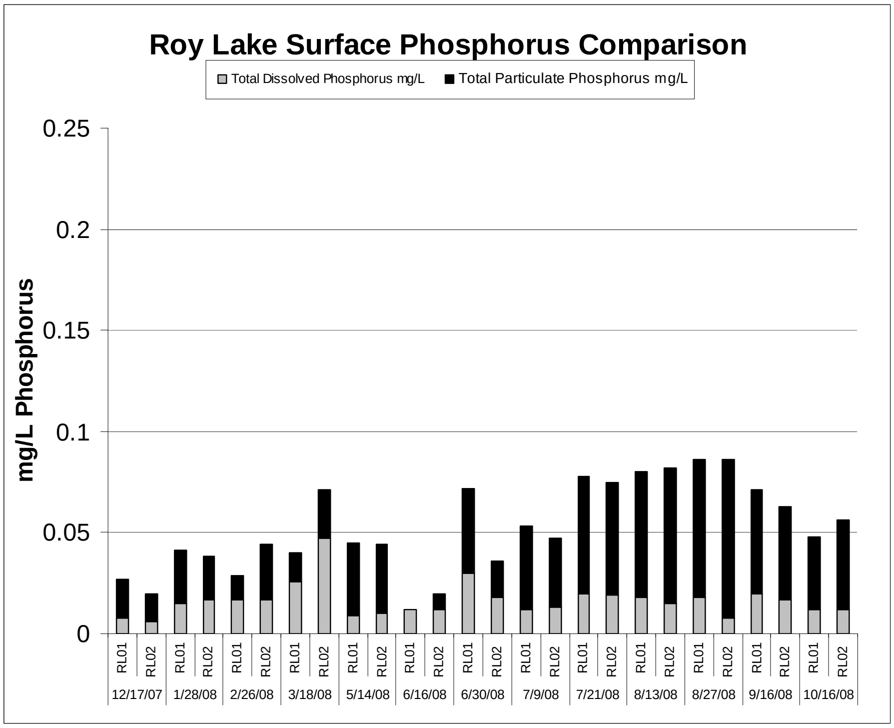

Figure 12. TDP to TP Comparisons Surface Samples

Fecal Coliform Bacteria

Fecal coliform bacteria are found in the intestinal tracts of warm-blooded animals. Fecal coliform bacteria are used to indicate the presence of animal waste and pathogens in a water body. Some common types of bacteria are *E. coli*, S*almonella,* and *Streptococcus,* which are associated with livestock, wildlife, and human waste (Novotny, 1994). In-lake concentrations of fecal coliform bacteria are typically low because exposure to sunlight kills the bacteria, however the nutrients associated with animal waste may remain in high concentrations. High fecal counts are typically found in tributary samples taken during storm events and snowmelt runoff, especially samples taken downstream of animal feeding operations.

Roy Lake is listed for the beneficial use of (7) Immersion Recreation which requires that no single fecal coliform bacteria sample exceed 400 colonies/100 ml. During the study, no samples exceeded the State standard and the majority of the samples were below the detection limit of 10 colonies/100 ml. for fecal coliform; and were at or below the detection limit of 2 colonies/100 ml. for E.coli. The highest fecal coliform sample was collected on September 16. On this date the fecal coliform sample was at 31.6 colonies/100 ml. and was probably due to the large number of migrating gulls observed on the lake that morning. The highest E.coli sample was 10.2 colonies/100 ml. on August 13, a day after a heavy rainfall event.

Chlorophyll *a*

Chlorophyll *a* is the green pigment in plants (including algae) that allows them to capture sunlight and produce food using nutrients in the water. Other pigments are also used by different types of algae, but chlorophyll *a* is the most abundant. Measuring chlorophyll levels in a lake provides a means to assess algal abundance, since almost all chlorophyll that occurs in open water is due to phytoplankton growing within the lake. It does have limitations, however, since chlorophyll content of phytoplankton cells can vary seasonally (Nicholls and Dillon, 1978). It is best used as an indicator rather than a direct measure of algal biomass. Chlorophyll *a* is also used to calculate TSI values.

Roy Lake chlorophyll *a* concentrations ranged from 0.64 to 38.49 µg/l and followed the typical seasonal trend with low concentrations during the winter months and increasing concentrations into the growing-season usually peaking in late summer (Figure 13). The average growing-season chlorophyll *a* was 18.83 µg/l. The growing-season chlorophyll *a* concentrations correlated well with in-lake surface total phosphorus concentrations as shown in Figure 14.

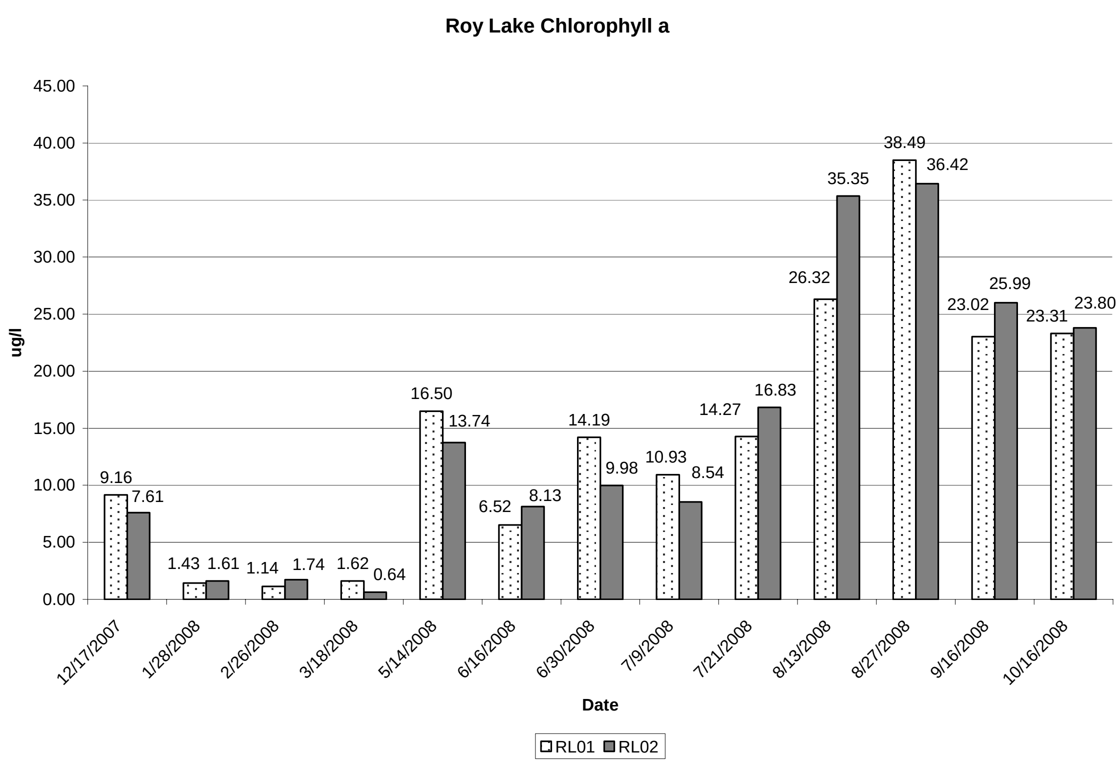

Figure 13. Chlorophyll *a* Concentrations

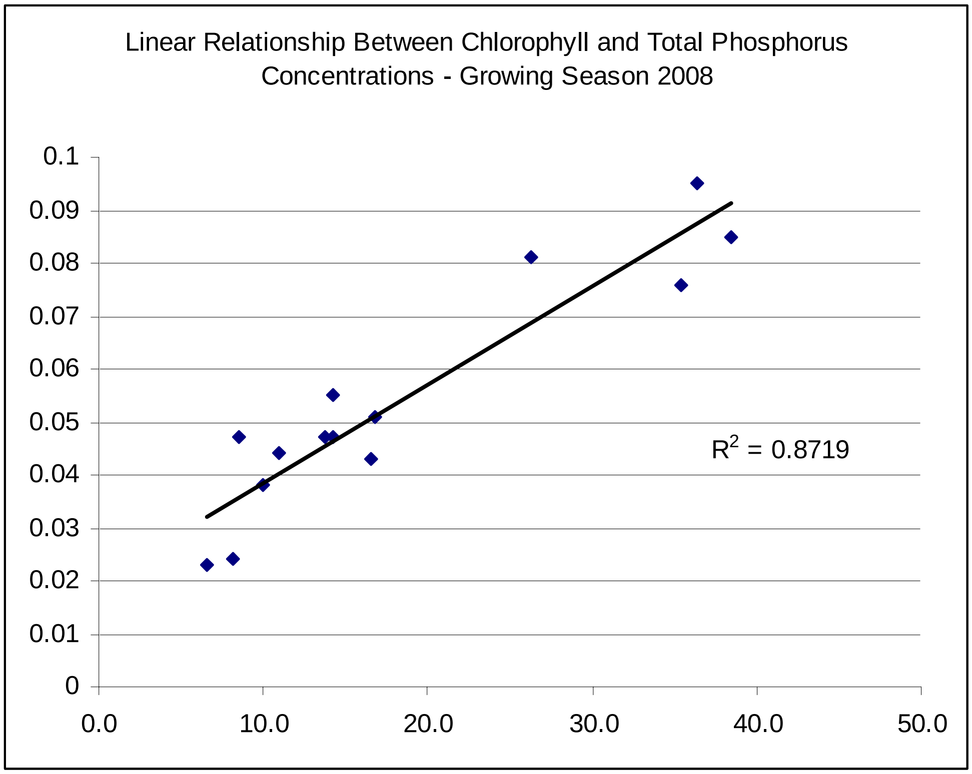

Figure 14. Regression between growing-season total phosphorus and chlorophyll *a* in Roy Lake.

Limiting Nutrients

Four primary nutrients are required for cellular growth in organisms. Two of these nutrients are phosphorus and nitrogen. Nitrogen is difficult to limit in aquatic environments due to its highly soluble nature. Phosphorus is easier to control making it the primary nutrient targeted for reduction when attempting to control a lakes eutrophication. The ideal ratio of nitrogen to phosphorus (N:P) for aquatic plant growth is 10:1 (EPA, 1994). Ratios higher than 10 indicate a lake is more likely to be a phosphorus-limited system, ratios less than 10 indicate the lake is likely to be a nitrogen-limited system.

The N:P ratios for water samples analyzed from Roy Lake are shown in Figure 15. This data and the make-up of the phytoplankton community indicate Roy Lake is not nitrogen limited. The average N:P ratio for Roy Lake is 30:1, indicating Roy Lake is a phosphorus limited waterbody.

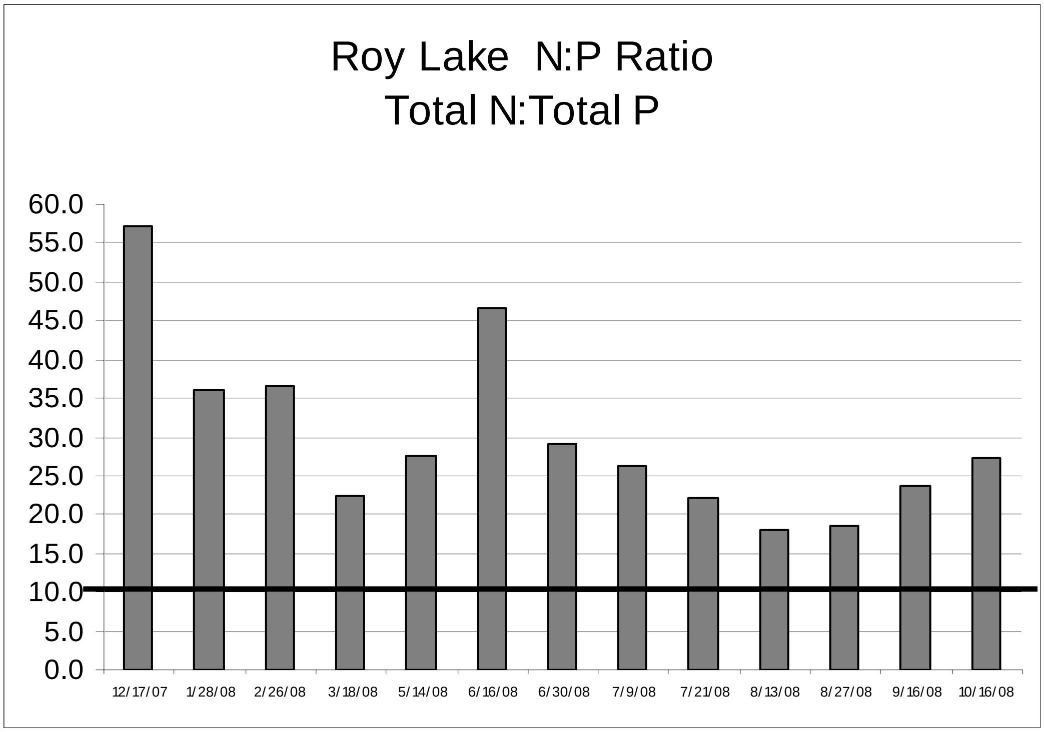

Figure 15. Roy Lake N:P Ratio

Trophic State

Trophic state refers to the degree of primary production within a lake and its relation to nutrient enrichment and water clarity. The Trophic State Index (TSI) developed by Carlson (1977) is a commonly used and widely accepted method for quantifying the trophic state of lakes. The TSI transforms measures of total phosphorus (nutrient), chlorophyll-*a* (algal biomass), and Secchi depth (water clarity) using linear regression models and logarithmic transformation to produce unitless index scores typically ranging from 0-100. The greater the index score, the more primary production, phosphorus and correspondingly lower water clarity waterbodies are expected to exhibit. Carlson (1977) assigned numeric ranges to classify the trophic state of a waterbody (Table 3).

Lakes with TSI values less than 35 are considered to be oligotrophic and contain very small amounts of nutrients, low primary production and are very clear. Lakes that obtain a score of 36 to 50 are considered to be mesotrophic and have more nutrients and primary production than oligotrophic lakes. Eutrophic lakes have a score between 50 and 65 and have moderately high nutrients and are susceptible to algae blooms and reduced water clarity. Hyper-eutrophic lakes have scores greater than 65 and contain excessive nutrients, sustainable nuisance algae blooms and poor water clarity.
The three TSI indices are expected to be interrelated as a function of the regression models. Therefore, it is assumed that any one of the three indices could be used to classify the trophic state of a waterbody. When the TSI is presented as an average or median value it is imperative that the indices are interrelated. Carlson (1991) suggests that if any TSI parameter deviates significantly ($\pm$ 5 TSI points) from the chlorophyll TSI

(main measure of primary production) then that parameter is contributing to the misclassification of the trophic state.

The South Dakota DENR, Water Resource Assistance Program (WRAP) uses the median of Secchi depth transparency and chlorophyll-*a* TSI to measure the trophic state of lakes and reservoirs. Many lakes in South Dakota are considered non phosphorus limited and have sufficient phosphorus (>0.02 mg/L) to support excessive algae growth (Downing et al. 2001). As a result, the phosphorus TSI was eliminated from the median index calculation to avoid misclassification (Carlson 1991).

Table 3. Trophic state categories established by Carlson (1977).

Trophic State Classification	TSI Numeric Range
Oligotrophic	0-35
Mesotrophic	36-50
Eutrophic	51-65
Hyper-eutrophic	66-100

To characterize the trophic state of Roy Lake it is necessary to examine differences between the trophic state indices. All three trophic state parameters appear to be relatively inter-related throughout the growing season (Table 4).

Table 4. Roy Lake growing season TSI values for all parameters.

Site	Month	Phosphorus TSI	Secchi TSI	Chlorophyll TSI
RL01	May	59.70	58.37	56.27
RL02	May	58.41	53.77	58.07
RL01	June	50.00	53.68	51.12
RL02	June	49.39	54.84	48.96
RL01	June	59.70	57.01	56.59
RL02	June	56.63	57.25	53.14
RL01	July	59.70	55.99	51.61
RL02	July	58.74	59.57	54.03
RL01	July	60.87	60.44	58.27
RL02	July	61.96	59.71	56.65
RL01	August	66.63	64.34	65.55
RL02	August	67.55	64.94	62.65
RL01	August	69.85	65.99	65.84
RL02	August	68.24	68.37	66.38

Chlorophyll is the best indicator of primary production (algae biomass) while Secchi provides a measure of water clarity. The trophic state dynamics of Roy Lake are such that primary production is significantly related to water clarity. Therefore, it was determined that the cumulative median (middle value) of Secchi-chlorophyll TSI would provide the best descriptor of trophic state for Roy Lake. The median Secchi-chlorophyll TSI for Roy Lake is 57.7, which classifies the lake as eutrophic. This is also consistent with the individual median calculations of both parameters (Table 5). The median phosphorus TSI value is also similar to the median Secchi and chlorophyll TSI. Based on the linear relationships between phosphorus–chlorophyll (r^2=0.87) and Secchi–chlorophyll (r^2=0.73), any reduction in phosphorus would likely decrease algae bio-mass and increase water clarity in Roy Lake.

Table 5. Roy Lake median growing season TSI by parameter 2008.

Parameter	2008
Median Growing Season TSI Secchi-Chlorophyll	57.7
Median Growing Season TSI Secchi	59.0
Median Growing Season TSI Chlorophyll	56.6
Median Growing Season TSI Phosphorus	59.7

The median Secchi-chlorophyll TSI target for a warmwater permanent fishery is 58.4 based on the TSI target targeting document (WRAP, 2005). Roy Lake's growing season TSI was calculated at 57.7 which is below this recommended target. Some potential areas of concern in the watershed have been identified for potential phosphorus reductions. If those reductions occurred, proper BMPs should help protect or improve the current trophic state of the lake. At this time Roy Lake is fully supporting its beneficial uses based on numeric standards and any BMPs that focus on nutrient reduction would benefit the maintenance of this support status.

Based on the limited historical data available, Roy Lake's TSI has a fairly consistent TSI ranging from its lowest TSI of 47.6 in 1995 to the highest 62.9 recorded in 1989 (Figure 16). There appears to be some year to year variability in TSI but over time the slope of the line suggests that TSI has been stable over the past 20 years. Roy Lake's TSI is comparable with other lakes in northeast South Dakota that includes nearby Clear Lake, and Enemy Swim and Pickerel Lakes.

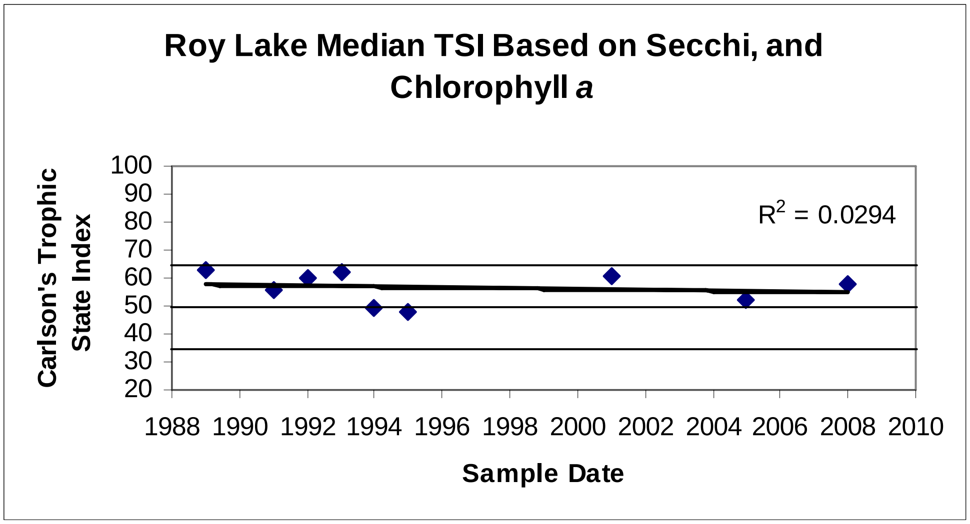

Figure 16.

3.2 In-Lake Biological Monitoring

Fisheries

One of Roy Lake's beneficial uses is (4) warmwater permanent fish life propagation. According to the most recent fisheries report, thirteen species of fish are found in the Lake, which is currently being managed as a black bass and walleye fishery. There is currently no fish consumption advisories listed for the lake. The Common carp is the only known exotic species inhabiting the lake. The South Dakota Dept. of Game, Fish, and Parks conduct annual fisheries surveys of all northeast SD lakes. A copy of the most current fisheries report can be found at:

http://www.sdgfp.info/Wildlife/fishing/NELakes/NELakesIndexII.htm

Macrophyte Survey

A macrophyte survey was conducted on September 2 and 3, 2008. Survey protocol was in accordance to the Standard Operating Procedures for Field Sampling, Vol. II, Biological and Habitat Sampling (SD DENR, 2005). Given the lakes size and shoreline length it was decided to sample one point located 20 meters from the shoreline for each transect instead of the usual four points. Four of the forty transects were not sampled due to their proximity to another transect located on an opposite shoreline (4) or due to the fact that they could not be reached because of shallow water (13, 36 & 37). Transect locations are shown in Figure 19.

Submergent aquatic macrophytes were collected at each transect. A total of eight species were observed; *Ceratophyllum demersum* (Hornwort-Coontail), *Chara sp*. (Stonewort-Muskgrass), *Myriophyllum exalbescens* (Water milfoil), *Potamogeton pectinatus* (Sago pondweed), *Potamogeton richardsonii* (Clasping-leaf pondweed), *Ruppia maritime* (Ditch-grass,Widgeon-grass), *Urticularia vulgaris* (Common bladderwort), *Zosterella* *dubia* (Water stargrass). Coontail was the most common submergent plant species encountered. Coontail was collected at all but one transect and had an average density score of 3.5. Common bladderwort was the rarest species collected from only one transect. The fact this species may have gone senescent by the time of the survey may account for its rarity. Emergent macrophytes observed include *Typha latifolia* (Common cattail) and *Scirpus acutus* (Hardstem bulrush). No introduced exotic plant species were observed during the survey. Common and scientific plant names used in this report follow Larson (1993). Table 4 lists all the density scores for aquatic macrophytes for each transect.

Shoreline Habitat Assessment

A shoreline habitat assessment was conducted during the macrophyte survey. The shoreline assessment consisted of scoring three habitat parameters with a numerical value; bank stability, vegetative protection, and riparian vegetative zone width. Numerical values ranged from 10, denoting the optimal condition, to 0 being the poorest condition. For Roy Lake, bank stability had an average score of 8.8, an optimal condition rating. Vegetative protection had an average score of 8.5, an optimal/suboptimal condition rating, and the riparian vegetative zone width had an average score of 8.3, a suboptimal condition rating. The maximum shoreline score of the three habitat parameters was 30. Roy Lake had an average shoreline score of 25.6. The high ratings are due to the fact that a majority of Roy Lake's shoreline is undeveloped land owned by the SD Dept. of Game, Fish, and Parks for game production with little degradation of the riparian zone from shoreline development or livestock grazing. The trend on many northeast South Dakota lakes has been to completely remove all existing shoreline vegetation and replace critical shoreline habitat with landscaping practices unsuitable for providing habitat for wildlife and protecting shorelines from erosion (Figure 17). The landscaping shown below on Roy Lake failed the spring of 2009. Developed shorelines along Roy Lake had the lowest habitat assessment with an average score of 16. Table 4 lists all the shoreline assessment habitat parameter scores for each transect along the lake.


Figure 17. Shoreline development along Roy Lake

Shoreline Soils and On-site Septic Systems

Since Roy Lake's water levels returned to normal in the late 1990's, shoreline development has increased on par with other large lakes in northeast South Dakota. Many of the smaller cabins and trailers found along the lake prior to the 1990s are being replaced with large year-round homes. With the advent of these larger homes (most with multiple baths, washing machines, dishwashers, and even hot tubs) the increase in effluent from on-site septic systems has greatly increased. There is evidence from other lakes in the region that an increase in effluent may negatively affect water quality. Most soils surrounding lakeshores are unsuitable for drain fields. Many are shallow soils overlying gravels and sands that allow rapid permeability resulting in untreated effluent flowing directly to ground and surface waters, or soils that have slow permeability that cause systems to back-up during high use or cause effluent to surface and flow above ground into the lake.   Since most lakeshore lots in northeast South Dakota are located on high ground sloping toward the lake, effluent in both soil types can reach surface waters.

The majority of Roy Lake's shoreline soils are rated as "very limited" for septic tank absorption fields, these include Aastad (AaA), Forman-Buse (FsE), and Forman-Poinsett (FxD) soils.

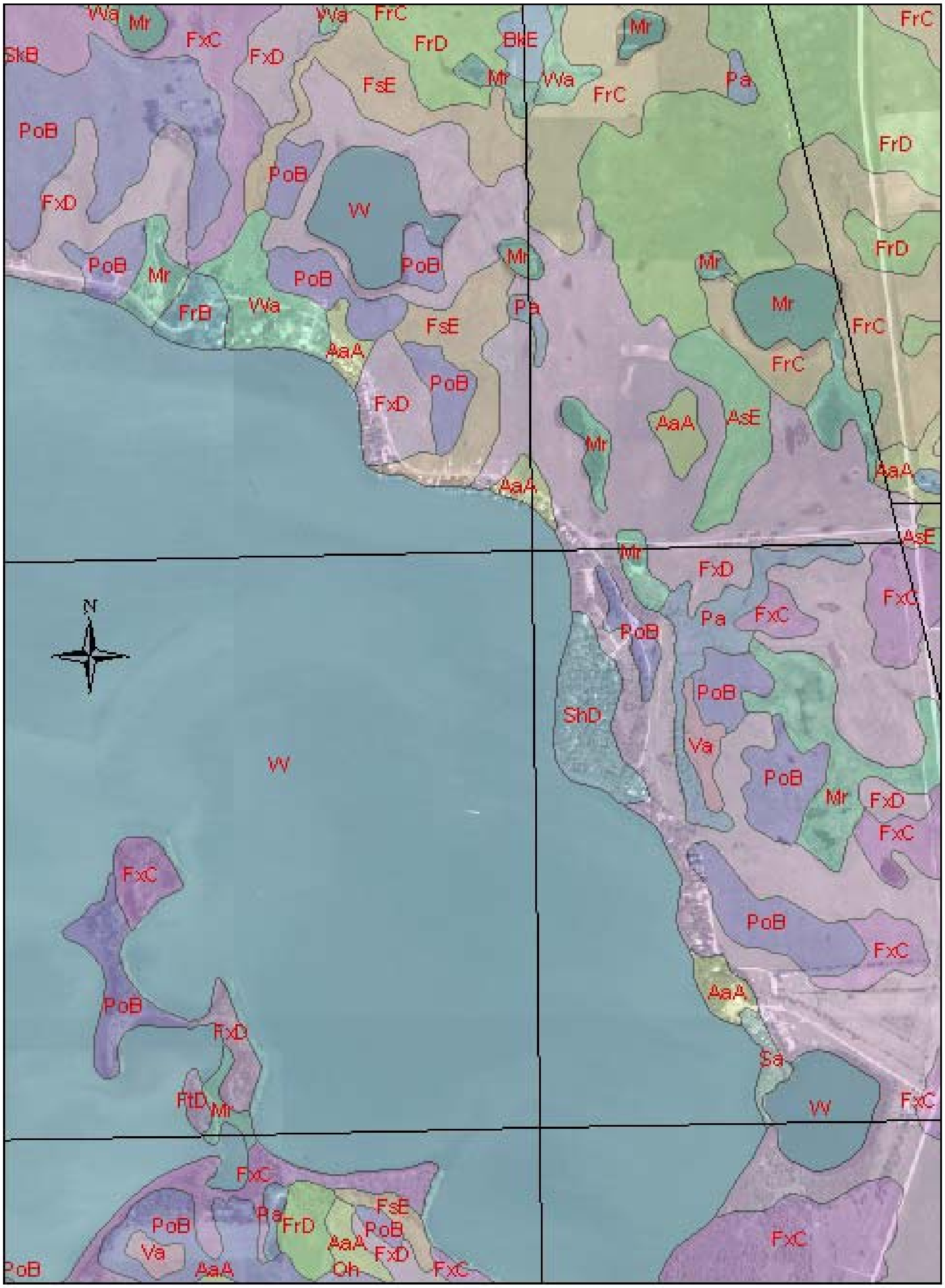

Figure 18. Roy Lake Shoreline Soils Map

Table 6. Macrophyte and Shoreline Assessment Survey Results

	Macrophyte Survey Results								Shoreline Habitat Assessment Results				
Transect #	Coontail	Stonewort	Water Milfoil	Sago Pondweed	Clasping-Leaf Pondweed	Widgeon-grass	Common Bladderwort	Water Stargrass	Bank Stability	Vegetative Protection	Riparian Zone Width	Total Shoreline Score	Land Use
1	4	0	4	0	0	0	0	3	8	10	10	28	wildlife
2	4	0	0	4	2	0	0	4	10	10	10	30	wildlife
3	3	0	4	1	0	1	1	0	10	10	10	30	wildlife
5	4	0	3	4	1	0	0	1	10	10	10	30	wildlife
6	1	4	2	3	1	0	0	0	10	10	10	30	wildlife
7	4	0	2	4	0	4	0	1	10	10	10	30	wildlife
8	2	4	0	3	2	0	0	0	8	8	7	23	developed
9	3	3	1	4	0	2	0	0	10	10	10	30	wildlife
10	5	0	1	3	0	1	0	1	10	10	10	30	wildlife
11	2	5	0	3	1	2	0	0	9	7	7	23	cropland
12	2	5	0	0	0	0	0	0	9	10	10	29	wildlife
14	5	0	1	0	0	0	0	0	10	10	10	30	wildlife
15	3	0	0	4	0	1	0	0	10	10	10	30	wildlife
16	4	0	4	3	0	3	0	0	8	10	10	28	wildlife
17	3	1	2	3	0	1	0	0	10	10	10	30	wildlife
18	1	0	3	3	0	0	0	0	9	9	7	25	wildlife
19	4	0	4	4	4	0	0	1	7	10	10	27	wildlife
20	0	5	0	4	0	0	0	0	10	10	10	30	wildlife
21	5	0	4	4	0	0	0	1	3	1	0	4	developed
22	1	2	2	2	0	0	0	0	5	4	3	12	developed
23	2	0	2	4	1	0	0	0	2	1	1	4	developed
24	2	3	0	4	2	0	0	0	9	9	7	25	developed
25	3	0	2	4	0	0	0	0	10	10	6	26	wildlife
26	1	0	2	4	4	0	0	0	7	8	5	20	developed
27	5	0	3	3	0	0	0	0	10	4	5	19	developed
28	5	0	0	0	0	0	0	0	7	4	4	15	wildlife
29	5	0	0	0	0	0	0	0	10	6	10	26	wildlife
30	5	0	4	2	0	1	0	0	10	10	10	30	wildlife
31	5	0	4	4	0	0	0	0	10	10	10	30	wildlife
32	3	0	2	0	0	0	0	1	7	10	10	27	wildlife
33	5	0	2	1	0	1	0	0	9	7	6	22	developed
34	5	0	0	0	0	0	0	0	8	10	10	28	wildlife
35	4	0	2	3	0	0	0	0	10	10	10	30	wildlife
38	5	0	4	4	0	0	0	0	10	9	10	29	wildlife
29	5	0	4	5	0	0	0	0	10	10	10	30	wildlife
40	5	0	4	3	0	0	0	1	10	10	10	30	wildlife
Average Plant Density Scores	3.5	0.9	2.0	2.7	0.5	0.5	0.0	0.4	8.8	8.5	8.3	25.6	Average Habitat Score
% Stations Present	97%	25%	72%	80%	25%	28%	3%	25%					

Average Score by Land Use	
Wildlife	28
Developed	16
Cropland	23

Figure 19. Aquatic Macrophytes and Shoreline Habitat Assessment Transect Locations.

Phytoplankton Survey

Planktonic algae were collected in surface samples monthly and semimonthly at two widely-separated water quality sites from December 2007 to November 2008, with the exception of April 2008. A total of 161 algal taxa were identified from the 25 samples taken during this survey which included three “unidentified algae“ categories (Table 6).

Nonmotile green algae (Chlorophyta) represented the most diverse algal group with 60 species followed by 46 taxa of flagellated (motile) algae belonging to 5 phyla. The remaining two algal groups were less varied. Blue-green algae (cyanobacteria) contributed 28 species and diatoms (Bacillariophyceae), 22 taxa.

Overall algal diversities in Roy Lake were some of the highest encountered over the course of past surveys of some 100 state water bodies. Only a handful (6 or 7) of lakes had this level of diversity, Lake Enemy Swim being one with 127 taxa. Sixteen smaller state lakes for which sufficient data was available averaged less than 75 taxa. A partial explanation for the large number of algal species in Roy Lake may lie in the nature of local zooplankton and fish populations. An examination of a dozen brown bottle algae samples (5 with 1L capacity) taken in spring and summer indicated a scarcity of zooplankton, particularly *Daphnia sp.* during 2008. Fish predation on large-sized zooplankton such as *Daphnia*, which graze mostly on the smaller algae, is a strong determinant of the biomass and size distribution of algae populations (Mazumder et al., 1990). In eutrophic lakes *Daphnia* tend to be the most important planktonic herbivores rather than the copepods which are often more numerous (Reynolds, C.S., 1998). At the same time they are also a preferred food item for the smaller fish (e.g. < 12 inches) due to their large size relative to most other zooplankton. It is suggested that a large population of planktivorous fish such as yellow perch, bluegill, crappie, and young-of- the- year, may have cropped down the local *Daphnia* population in Roy Lake to the extent that it allowed a highly diverse algae community to develop and maintain itself through spring and summer. The opposite of this situation may have occurred in Lake Mitchell during 2003 where a large recorded summer population of *Daphnia pulex* may have produced an algal community of low diversity with the number of algae species only about a quarter of those in Roy Lake.

The phytoplankton community in Roy Lake during summer 2008 was dominated by small-sized (approx.1u dia.) non-nitrogen-fixing blue-green algae (*Lyngbya limnetica, Aphanocapsa, Merismopedia*) which comprised 55% of average annual algae density (Table 6). Larger major blue-greens in this category *Oscillatoria agardhii* added nearly 11% to the total and several others *Microcystis*, *Coelosphaerium*, *Gomphosphaeria* nearly 3%.

Nitrogen-fixing blue-greens are able to fix (utilize) atmospheric or dissolved molecular N2 via heterocysts when more usable forms of nitrogen as ammonia, NO3, and NO2 are reduced or depleted. Nitrogen-fixers, such as *Ahanizomenon* and *Anabaena*, were of comparatively lesser importance in Roy Lake and comprised only a little more than 1% of average annual algae density. These results seem to suggest that nitrogen supplies were not limiting in Roy Lake during the summer of 2008, since non-N2-fixing blue-greens are as highly dependent on a sufficient supply of usable nitrogen being available as are green algae or diatoms.

Annual algae densities in Roy Lake displayed a single extended summer maximum from mid-July through August due to the abundance of blue-green algae (Table 5). Moreover, a considerable population of blue-greens persisted into mid-October due mainly to an autumn bloom of *Oscillatoria agardhii* which succeeded summer blooms of *Lyngbya limnetica* and secondarily, *Aphanocapsa*.

Maximum populations of flagellated algae were encountered during May and June owing mainly to the abundance of *Chrysochromulina parva* and secondarily, *Dinobryon*. Literature indicates the water temperature optimum for the former species is below 20C. Populations of *C. parva* as large as 600,000 cells/ml have been reported from one water body at 14C. Highest numbers of *C. parva* are found in eutrophic waters or after lake fertilization (Wehr and Sheath, 2003).

Diatoms were variously common in December (*Fragilaria crotonensis*), May (*Asterionella formosa* and *Stephanodiscus minutus*), mid-August (*S. minutus*), October and early November (*S. minutus*). It is not unusual for different species of diatoms to become abundant during any part of the growing season and into late autumn. Diatoms benefit from the mixing action of the water column in relatively shallow lakes in summer where their only limitation to growth may be a depletion of silicate (SiO2) levels. Under ice cover (January- March) the Roy Lake diatom population fell sharply to 1-12 cells/ml. (Table 5).

Non-motile green algae (Chlorophyta) were the least abundant algal group in Roy Lake during this survey. They accounted for less than 2% of annual algae density. The algae communities of typical alkaline eutrophic lakes in the Midwest are usually dominated by blue-greens and diatoms with green algae comprising a small percentage of the total population (Prescott, 1962). Alkaline lakes (pH > 8) tend to favor the growth of blue-greens over green algae probably due to the low levels of free CO2 dissolved in those waters. Blue-green algae appear to be more efficient in utilizing free CO2 at low concentrations than green algae (Shapiro, 1973).

Table 7. Roy Lake Average Algae Density(cells/ml) and Percent Composition

Date	Algae Group		cells / ml	%
17-Dec-07	Flagellated Algae		2,652	28.1
	Blue-Green Algae		2,743	29.1
	Diatoms		3,843	40.7
	Non-Motile Green Algae		126	1.3
	Unidentified Algae		70	0.7
		Total	**9,434**	
28-Jan-08	Flagellated Algae		1,670	41.3
	Blue-Green Algae		2,193	54.2
	Diatoms		5	0.1
	Non-Motile Green Algae		38	0.9
	Unidentified Algae		138	3.4
		Total	**4,044**	
26-Feb-08	Flagellated Algae		1,634	53.3
	Blue-Green Algae		1,304	42.5
	Diatoms		1	0.0
	Non-Motile Green Algae		2	0.1
	Unidentified Algae		125	4.1
		Total	**3,066**	
18-Mar-08	Flagellated Algae		1,700	43.3
	Blue-Green Algae		1,830	46.6
	Diatoms		12	0.3
	Non-Motile Green Algae		22	0.6
	Unidentified Algae		360	9.2
		Total	**3,924**	
14-May-08	Flagellated Algae		19,701	34.0
	Blue-Green Algae		30,955	53.4
	Diatoms		4,675	8.1
	Non-Motile Green Algae		1,427	2.5
	Unidentified Algae		1,205	2.1
		Total	**57,963**	
30-Jun-08	Flagellated Algae		14,278	22.0
	Blue-Green Algae		48,347	74.4
	Diatoms		1,180	1.8
	Non-Motile Green Algae		842	1.3
	Unidentified Algae		345	0.5
		Total	**64,992**	

Table 7. Roy Lake (continued)

Date	Algae Group	cells / ml	%
9-Jul-08	Flagellated Algae	7,134	2.3
	Blue-Green Algae	301,398	96.0
	Diatoms	2,042	0.6
	Non-Motile Green Algae	1,762	0.6
	Unidentified Algae	1,540	0.5
	Total	**313,876**	
21-Jul-08	Flagellated Algae	8,096	1.6
	Blue-Green Algae	479,082	95.8
	Diatoms	2,602	0.5
	Non-Motile Green Algae	6,475	1.3
	Unidentified Algae	4,021	0.8
	Total	**500,276**	
13-Aug-08	Flagellated Algae	9,239	1.8
	Blue-Green Algae	469,504	93.8
	Diatoms	7,595	1.5
	Non-Motile Green Algae	8,347	1.7
	Unidentified Algae	6,088	1.2
	Total	**500,773**	
27-Aug-08	Flagellated Algae	6,530	1.1
	Blue-Green Algae	556,334	96.8
	Diatoms	1,586	0.3
	Non-Motile Green Algae	7,582	1.3
	Unidentified Algae	2,850	0.5
	Total	**574,882**	
16-Sep-08	Flagellated Algae	4,637	2.6
	Blue-Green Algae	170,163	94.8
	Diatoms	1,176	0.7
	Non-Motile Green Algae	2,555	1.4
	Unidentified Algae	980	0.6
	Total	**179,511**	
10/16/2008	Flagellated Algae	3,240	1.9
	Blue-Green Algae	161,462	93.2
	Diatoms	4,322	2.5
	Non-Motile Green Algae	2,956	1.7
	Unidentified Algae	1,195	0.7
	Total	**173,175**	

Table 7. Roy Lake (continued)

Date	Algae Group	cells / ml	%
11/5/2008	Flagellated Algae	7,776	17.0
	Blue-Green Algae	21,198	46.4
	Diatoms	11,670	25.5
	Non-Motile Green Algae	3,708	8.1
	Unidentified Algae	1,380	3.0
	Total	**45,732**	

Table 8. Algae Species and Densities for Roy Lake

Roy Lake:Dec.2007-Nov 2008 25 samples total 2 inlake sites

#	Algae Species	Average Density cells/ml	Avg. % Density	Number samples	Algae Type
1	Aphanocapsa sp.	81757	39.4	25	Blue-Green (colonial)
2	Lyngbya limnetica	51646	10.4	13	Blue-Green (filament)
3	Oscillatoria agardhii	19783	10.8	11	Blue-Green (filament)
4	Merismopedia tenuissima	5222	1.3	14	Blue-Green (colonial)
5	Aphanothece sp.	3644	1.4	13	Blue-Green (colonial)
6	Chrysochromulina parva	3365	9.2	25	Flagellated algae
7	Pseudanabaena sp.	2744	2.2	23	Blue-Green (filament)
8	Aphanizomenon flos-aquae	2664	0.6	14	Blue-Green (filament)
9	Stephanodiscus minutus	1908	2.4	21	Diatom (centric)
10	unidentified algae	1561	2.1	25	unidentified
11	Merismopedia sp.	1344	0.4	11	Blue-Green (colonial)
12	Rhodomonas minuta	1281	5.3	25	Flagellated algae
13	unidentified flagellated algae	1030	2.5	25	unidentified
14	Microcystis sp.	879	1.3	12	Blue-Green (colonial)
15	Coelosphaerium naegelianum	752	0.8	19	Blue-Green (colonial)
16	Gomphosphaeria sp.	650	0.7	16	Blue-Green (colonial)
17	Lyngbya contorta	620	0.1	6	Blue-Green (filament)
18	Selenastrum minutum	559	0.6	24	Green
19	Dictyosphaerium pulchellum	471	0.1	14	Green (colonial)
20	Fragilaria crotonensis	363	3.2	11	Diatom (pennate)
21	Oocystis sp.	320	0.1	18	Green (colonial)
22	Ankistrodesmus sp.	308	0.3	23	Green (colonial)
23	Microcystis aeruginosa	292	0.1	8	Blue-Green (colonial)
24	Cryptomonas sp.	290	0.3	25	Flagellated algae
25	Nitzschia sp.	277	0.2	22	Diatom (pennate)

Table 8. continued

#	Algae Species	Average Density cells/ml	Avg. % Density	Number samples	Algae Type
26	Scenedesmus sp.	274	0.2	17	Green (colonial)
27	Chlamydomonas sp.	203	0.1	20	Flagellated algae
28	Dinobryon divergens	195	0.3	4	Flagellated algae
29	Kirchneriella sp.	188	0.1	18	Green
30	Melosira granulata	180	0.2	15	Diatom (centric)
31	Anabaena flos-aquae	174	0.3	6	Blue-Green (filament)
32	Anabaena circinalis	171	0.2	10	Blue-Green (filament)
33	Marssoniella elegans	154	0.1	2	Blue-Green (colonial)
34	Platymonas elliptica	150	0.0	13	Flagellated algae
35	Asterionella formosa	148	0.3	8	Diatom (pennate)
36	Anabaena spiroides crassa	148	0.1	4	Blue-Green (filament)
37	Micractinium sp.	133	0.0	2	Green (colonial)
38	Rhizosolenia eriensis	120	0.0	11	Diatom (centric)
39	Kephyrion sp.	106	1.3	19	Flagellated algae
40	Dactylococcopsis sp. ?	66	0.0	2	Blue-Green (filament)
41	Crucigenia quadrata	62	0.0	7	Green (colonial)
42	Nitzschia paleacea	48	0.0	6	Diatom (pennate)
43	Scenedesmus abundans	45	0.0	8	Green (colonial)
44	Anabaena sp.	43	0.0	5	Blue-Green (filament)
45	Pediastrum duplex	41	0.0	14	Green (colonial)
46	Chrysosphaerella brevispina	35	0.0	15	Flagellated algae
47	Actinastrum hantzschii	32	0.0	9	Green (colonial)
48	Tetrastrum staurogeniaeforme	31		12	Green (colonial)
49	Mougeotia sp.	31		9	Green (filament)
50	Nephrocytium sp.	29		10	Green (colonial)
51	Lagerheimia sp.	23		7	Green
52	Microcystis incerta	21		2	Blue-Green (colonial)
53	Dinobryon sp.	20		5	Flagellated algae
54	Fragilaria capucina	19		3	Diatom (pennate)
55	Botryococcus braunii	19		6	Green (colonial)
56	Mallomonas pseudocoronata	19		9	Flagellated algae
57	Elakatothrix viridis	18		10	Green (colonial)
58	Cosmarium phaseolus	15		8	Green
59	Sphaerocystis schroeteri	15		9	Green (colonial)
60	Pandorina morum	15		6	Flagellated algae
61	Coelastrum sp.	14		8	Green (colonial)
62	Treubaria sp.	14		7	Green
63	Chlorogonium sp.	13		5	Flagellated algae
64	Synedra acus	12		18	Diatom (pennate)
65	Pediastrum boryanum	12		9	Green (colonial)

Table 8. continued

#	Algae Species	Average Density cells/ml	Avg. % Density	Number samples	Algae Type
66	Scenedesmus acuminatus	12		6	Green (colonial)
67	Nitzschia acicularis	11		4	Diatom (pennate)
68	Cyclotella meneghiniana	10		6	Diatom (centric)
69	Staurastrum tetracerum	10		10	Green
70	Trachelomonas sp.	10		17	Flagellated algae
71	Oscillatoria chalybea	8		1	Blue-Green (filament)
72	Chrysolykos planktonicus	8		3	Flagellated algae
73	Pseudokephyrion sp.	7		2	Flagellated algae
74	Scenedesmus quadricauda	7		4	Green (colonial)
75	Mallomonas sp.	6		6	Flagellated algae
76	Glenodinium sp.	6		14	Flagellated algae
77	Melosira sp.	6		4	Diatom (centric)
78	Scenedesmus bijuga	6		7	Green (colonial)
79	Crucigenia tetrapedia	6		1	Green (colonial)
80	Elakatothrix gelatinosa	5		1	Green (colonial)
81	Elakatothrix sp.	5		2	Green (colonial)
82	Tetraedron minimum	5		5	Green
83	Crucigenia sp.	5		1	Green (colonial)
84	Lyngbya birgei	5		3	Blue-Green (filament)
85	Scenedesmus opoliensis	5		1	Green (colonial)
86	unidentified green algae	5		2	Green
87	Glenodinium gymnodinium	4		9	Flagellated algae
88	Chrysococcus sp.	4		3	Flagellated algae
89	Ceratium hirundinella	4		11	Flagellated algae
90	Nephroselmis olivacea	4		4	Flagellated algae
91	Tetraedron caudata	4		7	Green
92	Mallomonas tonsurata	3		13	Flagellated algae
93	Mallomonas acaroides	3		2	Flagellated algae
94	Mallomonas caudata	3		1	Flagellated algae
95	Gymnodinium sp. ?	3		4	Flagellated algae
96	Closteriopsis longissima	3		7	Green
97	Golenkinia radiata	3		1	Green
98	Coelastrum cambricum	3		1	Green (colonial)
99	Phormidium mucicola	3		1	Blue-Green (filament)
100	Stephanodiscus niagarae	3		13	Diatom (centric)
101	Dinobryon sertularia	3		5	Flagellated algae
102	Errerella sp.	3		1	Green (colonial)
103	Oscillatoria sp.	2		2	Blue-Green (filament)
104	Cryptoglena pigra ?	2		2	Flagellated algae
105	Pteromonas sp. ?	2		2	Flagellated algae

Table 8. continued

#	Algae Species	Average Density cells/ml	Avg. % Density	Number samples	Algae Type
106	Phacus pseudonordstedtii	2		6	Flagellated algae
107	Euglena sp.	2		8	Flagellated algae
108	Schroederia judayi	2		3	Green
109	Golenkinia sp.	2		2	Green
110	Ankistrodesmus falcatus	2		3	Green (colonial)
111	Franceia ovalis	2		4	Green
112	Scenedesmus dimorphus	2		1	Green (colonial)
113	Stephanodiscus hantzschii	1		1	Diatom (centric)
114	Anabaenopsis sp.	1		1	Blue-Green (filament)
115	Cylindrospermopsis raciborskii	1		1	Blue-Green (filament)
116	Chroococcus dipersus	1		1	Blue-Green (colonial)
117	Phacus acuminatus	1		6	Flagellated algae
118	Euglena polymorpha	1		11	Flagellated algae
119	Eudorina elegans	1		2	Flagellated algae
120	Entzia acuta	1		9	Flagellated algae
121	Selenastrum gracile	1		2	Green (colonial)
122	Coelastrum microporum	1		1	Green (colonial)
123	Tetraedron sp.	1		7	Green
124	Polyedriopsis spinulosa	1		3	Green
125	Staurastrum cingulum	1		7	Green
126	Closteriopsis longissima tropica	1		4	Green
127	Scenedesmus arcuatus	1		1	Green (colonial)
128	Quadrigula closterioides	1		1	Green (colonial)
129	Pediastrum simplex	1		1	Green (colonial)
130	Tetraedron regulare	1		1	Green
131	Anabaena sphaerica	1		1	Blue-Green (filament)
132	Navicula capitata	< 1		1	Diatom (pennate)
133	Navicula cryptocephala	< 1		4	Diatom (pennate)
134	Cymbella sp.	< 1		1	Diatom (pennate)
135	Cymatopleura solea	< 1		4	Diatom (pennate)
136	Rhizosolenia longispina	< 1		1	Diatom (centric)
137	Synedra ulna	< 1		2	Diatom (pennate)
138	Synedra cyclopum	< 1		1	Diatom (pennate)
139	Nitzschia vermicularis	< 1		1	Diatom (pennate)
140	Phacus pleuronectes	< 1		1	Flagellated algae
141	Euglena oxyuris	< 1		5	Flagellated algae
142	Euglena tripteris	< 1		4	Flagellated algae
143	Mesostigma viridis	< 1		1	Flagellated algae
144	Peridinium sp.	< 1		1	Flagellated algae
145	Trachelomonas volvocina	< 1		2	Flagellated algae
146	Glenodinium penardiforme	< 1		1	Flagellated algae

Table 8. continued

#	Algae Species	Average Density cells/ml	Avg. % Density	Number samples	Algae Type
147	Phacus nordstedtii	< 1		1	Flagellated algae
148	Phacus tortus	< 1		4	Flagellated algae
149	Euglena ehrenbergii	< 1		1	Flagellated algae
150	Phacus sp.	< 1		2	Flagellated algae
151	Closterium sp.	< 1		1	Green
152	Tetrastrum elegans	< 1		1	Green (colonial)
153	Tetraedron limneticum	< 1		4	Green
154	Cosmarium subcrenatum	< 1		3	Green
155	Tetraedron planktonicum	< 1		2	Green
156	Closteriopsis sp.	< 1		2	Green
157	Cosmarium sp.	< 1		2	Green
158	Staurastrum sp.	< 1		3	Green
159	Selenastrum sp.	< 1		1	Green
160	Ophiocytium sp.	< 1		1	Chrysophyte
161	Rhizochrysis limnetica	< 1		2	Chrysophyte

3.3 Tributary Water Quality Results

Two tributary sites and Roy Lake's outlet were selected for water quality sampling and monitoring (Figure 2). The two main tributaries for Roy Lake are of short duration, both less than three miles in length, and are outflows of Cottonwood Lake located north of Roy and Clear Lake located to the east. Both sites were equipped with OTT Thalimedes stage recorders. A Marsh-McBirney flow meter was used to measure flows at different stages during base flow, spring runoff, and summer rainstorm events.

Sampling Schedule

Sampling of Roy Lake's tributaries began in March 2008 and continued through October 2008. Samples were collected using the "grab" method by holding the sample bottle under the surface until filled. Water samples were filtered, preserved, and packed in ice for shipping to the State Health Lab in Pierre, SD. All field and sampling procedures followed the standard operating procedures mandated by the SD DENR (SD DENR, 2005). Tributary laboratory and field parameter water quality data for Roy Lake are given in Appendix A, page 68.

The laboratory analyzed the following parameters:

Fecal Coliform Bacteria
Total Solids
Ammonia
Total Kjeldahl Nitrogen (TKN)
Total Volatile Suspended Solids
E coli/Enterococci

Alkalinity
Total Suspended Solids
Nitrate
Total Phosphorus
Total Dissolved Phosphorus

Personnel conducting the sampling at each tributary site recorded visual observations of the following weather and lake characteristics.

Precipitation
Odor
Film
Ice Cover

Wind Speed
Dead Fish
Water Color

Parameters measured in the field by sampling personnel were:

Water Temperature
Dissolved Oxygen
Field pH
Stage and Flow

Air Temperature
Sample Depth
Total Water Depth

Water Temperature

Tributary temperatures ranged from a high of 26° C (79° F) on August 19 to a low of 0.7° C on March 25. The August 19 reading came within two degrees of exceeding the state standard of <80° F though DO and pH readings were within normal parameters. Water temperatures showed the expected seasonal variations from spring through fall.

Dissolved Oxygen

Dissolved oxygen (DO) measurements ranged from 14 mg/L to 8.4 mg/L. with an average of 10.5 mg/L. None of the DO measurements taken during the assessment fell below the state standard of ≥5.0 mg/L.

pH

The pH of surface water collected from Roy Lake tributaries ranged from 7.48 to 8.68 su with an average pH of 8.22 su. All pH recorded during the study fell within the State water quality standard of 6.0 to 9.0 su.

Specific Conductance

Specific conductance ranged from 351 to 744 µS/cm with the average specific conductance for Roy Lake’s tributaries at 514 µS/cm. All specific conductance measurements taken from Roy Lake’s tributaries were below the state standard set for this parameter.

Alkalinity

The alkalinity of samples taken from Roy Lake’s tributaries ranged from 180 to 281 mg/l with an average alkalinity of 231 mg/l. Tributary alkalinity did not exceed the state standard set for this parameter.

Solids

Total solids ranged from 387 to 622 mg/l with an average of 471 mg/l. Total suspended solid concentrations ranged from 4 to 92 mg/l with an average of 23 mg/l. Total suspended solids on average comprised 5% of the total solids per sample.

Nitrogen

Total inorganic nitrogen concentrations for Roy Lake’s tributaries ranged from 0.22 to 0.66 mg/l, and total organic nitrogen concentrations for Roy Lake’s tributaries ranged from 0.86 to 1.48 mg/l (Table 9).

Table 9. Total Inorganic and Organic Nitrogen Concentrations (mg/l) for Roy Lake Tributaries

	Total Inorganic Nitrogen (mg/l)			Total Organic Nitrogen (mg/l)		
Sample Date	**RLT03**	**RLT04**	**RLT05**	**RLT03**	**RLT04**	**RLT05**
3/25/08	0.65	0.28	-	1.20	1.12	-
4/2/08	0.25	0.26	-	1.28	1.18	-
4/8/08	0.22	0.23	-	1.36	1.45	-
4/15/08	0.22	0.22	-	1.20	1.24	-
5/7/08	0.22	0.53	0.47	1.00	0.86	0.85
6/12/08	0.22	0.22	-	0.95	0.98	-
6/16/08	-	-	0.22	-	-	1.03
7/22/08	-	0.22	0.22	-	1.24	1.28
8/19/08	0.22	0.22	0.22	1.10	1.14	1.18
9/2/08	0.40	0.22	-	1.09	1.48	-
10/7/08	0.22	0.66	-	1.35	1.17	-
10/20/08	-	-	0.22	-	-	1.34
Mean	0.29	0.31	0.27	1.17	1.19	1.14

Phosphorus

Total phosphorus from all tributary and outlet samples ranged from 0.004 to 0.068 mg/l with an average of 0.025 mg/l. Total phosphorus concentrations from RLT04 were on average the highest, while concentrations from RLT05 (the lakes outlet) were the lowest (Table 10). Total dissolved phosphorus concentrations averaged 30% of the total phosphorus for Roy Lake's tributaries.

Table 10. Total Phosphorus and Total Dissolved Phosphorus Concentrations (mg/l) for Roy Lake Tributaries and Outlet.

	Total Phosphorus (mg/l)			Total Dissolved Phosphorus (mg/l)		
Sample Date	**RLT03**	**RLT04**	**RLT05**	**RLT03**	**RLT04**	**RLT05**
3/25/08	0.088	0.068	-	0.042	0.022	-
4/2/08	0.095	0.099	-	0.015	0.020	-
4/8/08	0.142	0.158	-	0.017	0.020	-
4/15/08	0.108	0.099	-	0.010	0.012	-
5/7/08	0.050	0.078	0.059	0.013	0.016	0.004
6/12/08	0.071	0.109	-	0.025	0.039	-
6/16/08	-	-	0.036	-	-	0.012
7/22/08	-	0.077	0.048	-	0.048	0.015
8/19/08	0.062	0.082	0.051	0.028	0.028	0.021
9/2/08	0.126	0.138	-	0.068	0.057	-
10/7/08	0.069	0.102	-	0.031	0.023	-
10/20/08	-	-	0.049	-	-	0.009
Mean	0.090	0.101	0.049	0.028	0.029	0.012

Fecal Coliform Bacteria

Fifty-eight percent (58%) of the tributary samples had fecal coliform bacteria concentrations at or below 10 colonies/100 ml. On September 2, 2008 tributary samples had bacteria concentrations of 2500 and 1100 colonies/100 ml, and on June 12, 2008 bacteria concentrations of 290 and 340 colonies/100 ml were observed. Both samples were taken after rainstorm events of 3 inches of precipitation on June 12, and 2.5 inches of precipitation on September 2, 2008. High bacteria counts may indicate the need for nutrient management and riparian buffers upstream of both tributary sites.

3.4 Quality Assurance Reporting For In-Lake and Tributary Sampling

The project PIP called for one QA/QC set to be prepared for every 10 in-lake and 10 tributary samples collected in the field during the project. A QA/QC sample set consists of a field replicate and a blank sample of analyte-free de-ionized water. Field replicates are taken in the field with the same equipment, methods and within as close in time as possible to the previous sample to which the replicate is matched for comparison.

The industrial statistic “%I” was used to assess data precision; where precision (%I) = difference between replicate analytical values divided by the sum of the analytical values for both replicate and standard samples, multiplied by 100. Values greater than 10% are considered problematic and may indicate deviations in testing procedures.

In-Lake Sampling QA/QC

Five QA/QC sample sets were collected from Roy Lake on February 26, May 14, June 30, August 13, and September 16, 2008. This represented 10% of the 48 discrete surface and bottom in-lake samples collected from the lake.

Table 11 shows variations in chemical parameters between the sample and replicate set, and the chemical parameters detected in the blank sample.

Table 11. In-Lake Replicates and Blanks														
Date Sampled	Sample Location	Depth	Type	Alkalinity M mg/L.	Suspended Solids mg/L.	Total Dissolved Solids mg/L.	VTSS mg/L.	Ammonia mg/L	Nitrate mg/L	TKN mg/L	Total Phosphorus mg/L.	Total Dissolved Phosphorus mg/L.	Fecal Coliform /100mL	E.Coli /100mL
02/26/2008	RL02	Surface	Blank	<6.0	<3.0	ND	<3.0	<0.02	<0.2	<0.50	<0.002	<0.002	<1.0	<2.0
		Surface	Replicate	261	5.0	ND	<3.0	0.06	<0.2	1.28	0.033	0.015	<1.0	<2.0
		Surface	Sample	261	4.0	ND	<3.0	0.07	<0.2	1.24	0.034	0.017	<1.0	<2.0
			% I	0.0	11.1	ND	0.0	7.70	0.0	1.59	1.490	6.250	0.0	0.0
05/14/2008	RL01	Surface	Blank	<6	<3.0	<7	<3.0	<0.02	<0.2	<0.50	<0.002	0.006	<10	<1.0
		Surface	Replicate	220	8.0	459	4.0	0.34	<0.2	1.11	0.046	0.016	<10	<1.0
		Surface	Sample	221	8.0	457	6.0	0.59	<0.2	1.20	0.047	0.009	<10	<1.0
			% I	0.22	0.00	0.21	20.00	26.90	0.00	3.90	1.070	28.000	0.0	0.0
06/30/2008	RL01	Bottom	Blank	<6	<3	17.0	<3	<0.02	<0.2	<0.50	<0.002	0.003	<10	<2.0
		Bottom	Replicate	224	15.0	440	7.0	<0.02	<0.2	1.04	0.048	0.012	ND	ND
		Bottom	Sample	222	10.0	433	4.0	<0.02	<0.2	0.97	0.054	0.012	ND	ND
			% I	0.45	20.00	0.80	27.27	0.00	0.00	3.48	5.88	0.00	ND	ND
08/13/2008	RL01	Surface	Blank	<6	<3.0	<7	<3.0	<0.02	<0.2	<0.50	0.004	<0.002	<10	<2.0
		Surface	Replicate	216	4.0	447	3.0	<0.02	<0.2	1.17	0.070	0.015	<10	2.0
		Surface	Sample	216	8.0	452	5.0	<0.02	<0.2	1.37	0.076	0.018	<10	2.0
			% I	0.00	33.33	0.56	25.00	0.00	0.00	7.87	4.10	9.10	0.00	0.00
09/16/2008	RL02	Surface	Blank	<6.0	<3.0	<7.0	<3.0	<0.02	<0.2	<0.50	<0.002	<0.002	<1.0	<2.0
		Surface	Replicate	210	8.0	447	4.0	<0.02	<0.2	1.46	0.058	0.016	2.0	6.2
		Surface	Sample	210	9.0	451	5.0	<0.02	<0.2	1.33	0.062	0.017	2.0	8.2
			% I	0.00	5.90	0.45	11.10	0.00	0.00	4.66	3.33	3.03	0.00	13.89
	Average Percent Difference:			0.13	14.07	0.51	16.67	6.92	0.00	4.30	3.17	9.28	0.00	3.47

Tributary Sampling QA/QC

Three complete QA/QC sample sets were collected from Roy Lake tributaries and outlet on May 7, June 16, July 22, and October 7, 2008. This represented 10% of the 27 sample sets collected from tributary sites.

Table 12 shows variations in chemical parameters between the sample and replicate set, and the chemical parameters detected in the blank sample.

Table 12. Tributary Replicates and Blanks														
Date Sampled	Sample Location	Depth	Type	Alkalinity M mg/L.	Suspended Solids mg/L.	Total Dissolved Solids mg/L.	VTSS mg/L.	Ammonia mg/L	Nitrate mg/L	TKN mg/L	Total Phosphorus mg/L.	Total Dissolved Phosphorus mg/L.	Fecal Coliform /100mL	E.Coli /100mL
05/07/2008	RLT05	Surface	Blank	<6.0	<3.0	<7.0	<3.0	<0.02	<0.20	<0.50	<0.002	<0.002	<10	<1.0
06/16/2008	RLT05	Surface	Blank	<6.0	<3.0	<7.0	<3.0	<0.02	<0.2	<0.50	<0.002	<0.002	<10.0	<1.0
		Surface	Replicate	223	19	447	6	<0.02	<0.2	1.01	0.036	0.012	<10.0	ND
		Surface	Sample	223	17	449	6	<0.02	<0.2	1.05	0.036	0.012	<10.0	8.5
			% I	0.0	5.56	0.22	0.0	0.0	0.0	1.94	0.0	0.0	0.0	ND
07/22/2008	RLT04	Surface	Blank	<6.0	<3.0	<7.0	<3.0	<0.02	<0.2	<0.50	<0.002	<0.002	<10.0	<2.0
		Surface	Replicate	221	32	375	9	<0.02	0.2	1.56	0.08	0.021	50	208
		Surface	Sample	222	34	366	9	<0.02	0.2	1.26	0.077	0.048	40	275
			% I	0.23	3.03	1.21	0.0	0.0	0.0	10.63	1.91	39.13	11.11	13.87
10/07/2008	RLT03	Surface	Blank	<6.0	<3.0	<7.0	<3.0	<0.02	<0.2	<0.50	0.003	<0.002	<10.0	<2.0
		Surface	Replicate	200	3	449	<3.0	<0.02	0.2	1.12	0.069	0.028	70	922
		Surface	Sample	200	<3.0	449	<3.0	<0.02	0.2	1.37	0.069	0.031	60	870
			% I	0.0	0.0	0.0	0.0	0.0	0.0	10.04	0.0	5.08	7.69	2.90
	Average Percent Difference:			0.08	2.86	0.48	0.00	0.00	0.00	7.54	0.64	14.74	6.27	8.39

The variations between sample and replicate sets do not indicate any significant problems with field collection techniques or laboratory procedures or errors. Sample contamination, contamination of distilled water, poorly-rinsed sample bottles, and poorly-rinsed filters can account for differences, however natural sample variation, and the fact these QA/QC samples were replicate not duplicate, may be reasons for variations between replicate and sample sets.

The levels of a majority of the chemical parameters in the blank samples were below the SD State Health Laboratory's minimum detectable limits except for a few of the total phosphorus and dissolved phosphorus samples. The source of the total phosphorus detected in these samples is likely from over-the-counter distilled water used for the blank samples and for rinsing sampling equipment.

4.0 Public Involvement and Coordination

The assessment project, while funded separately, was coordinated with the Northeast Glacial Lakes Watershed Protection and Improvement Project, a multi-county multi-watershed implementation project sponsored by the Day County Conservation District. Due to the fact Roy Lake is located in Marshall County; the Marshall County Conservation District was an active partner in this assessment project. Both Day and Marshall County Conservation Districts have regularly scheduled monthly board meetings open to the general public. During these meetings the project coordinator updated District Boards, project partners, and other participants as to the status of the project. Project personnel met with two Roy Lake associations the summer of 2008 to present project goals and activities, and take public comment on the lakes water quality issues.

4.1 State Agencies

The South Dakota Department of Environment and Natural Resources administered the 319 funds for the project and provided state "fee" funds as match for the 319 funds. SD DENR also provided technical assistance with the installation of tributary monitoring stations, training, boat, and water quality testing equipment. The SD Department of Game, Fish and Parks provided information about threatened and endangered species, and Roy Lake's fisheries.

The following organizations have been apprised of or involved with this watershed assessment and the larger Northeast Glacial Lakes Watershed Improvement and Protection Project. Any future implementation efforts to protect or improve the water quality of Roy Lake will involve these state agencies.

- **South Dakota Game, Fish, and Parks (GFP) –** Technical advice and cost-share funds through the Department's "Private Lands Programs" for grazing improvements, wetland restoration, and grass seeding.

- **South Dakota Department of Agriculture –** Funding through the South Dakota Coordinated Soil and Water Conservation Commission Grant for technical assistance and conservation practice implementation.

4.2 Federal Agencies

The US Environmental Protection Agency made available $31,026.0 of 319 program funds for the project. The USDA Natural Resource Conservation Service provided technical assistance through the use of internet services and computer software, office space for the project coordinator and other District personnel, and ARC GIS layers for watershed mapping.

The following organizations have been apprised of or involved with this watershed assessment and the larger Northeast Glacial Lakes Watershed Improvement and Protection Project. Any future implementation efforts to protect or improve the water quality of Roy Lake will involve these federal agencies.

- **Natural Resources Conservation Service (NRCS) –** Provide technical assistance for BMPs through District Conservationists, Soil and Range Conservationists, and Tribal Liaison. Provide program funds for Environmental Quality Incentive Program (EQIP).

- **Farm Service Agency (FSA) –** Provide program funds for Conservation Reserve Program (CRP) and Continuous Conservation Reserve Program (CCRP).

- **U.S. Fish and Wildlife Service (FWS) –** Technical advice and cost-share funds through the "Partners for Fish and Wildlife" program for grazing improvements, small dams, wetland restoration, and grass seeding.

4.3 Local Governments, other Groups, Public-at-Large

The following organizations have been apprised of or involved with this watershed assessment and the larger Northeast Glacial Lakes Watershed Improvement and Protection Project. Any future implementation efforts to protect or improve the water quality of Roy Lake will involve these local groups.

- **Marshall County Conservation District –** Northeast Glacial Lake project partner/co-sponsor by MOU, local support and funding.

- **Roberts County Conservation District –** Northeast Glacial Lake project partner/co-sponsor by MOU, local support and funding.

- **South Dakota State University, Water Resources Institute (WRI) –** Technical advice, water quality analysis.

- **James River Water Development District (JRWDD) –** Local support and funding for Marshall County watershed activities.

- **Clear Lake Betterment Association –** Local support and funding for water quality testing of Clear Lake, efforts to form local sanitary sewer district that may include Roy Lake.

- **Roy Lake East, and Roy Lake West Lake Associations –** Local support of project activities, possible formation of partnership with Clear Lake Association.

The public-at-large were informed of the project through news releases in local newspapers, Conservation District newsletters, and radio interviews.

4.4 Other Sources of Funds

The State of South Dakota made available $20,684.00 in state fee funds. No other funds were required to complete the project.

5.0 Aspects of the Project That Did Not Work Well

Project personnel needed to replace three OTT data loggers, one flow meter, and one YSI multi-meter that all functioned improperly during the assessment.

6.0 Future Activity Recommendations

Roy Lake is currently meeting all of its beneficial uses based on this assessment. However, any changes is land-use that would increase the amount of non-point source pollutants reaching the lake could increase the biological oxygen demand, and cause higher internal loadings that would lead to frequent nuisance algal blooms. Therefore, resource agencies should work to improve land-use conditions along Roy Lake's shoreline and its watershed.

If an implementation project is funded for Roy Lake, the development of a central sewer collection system for the lake should be supported. The majority of soils found along Roy Lake's shoreline are unsuitable for septic system absorption fields.

In addition to protecting lakes from septic leachate, state and local governments need to implement stronger laws concerning how shoreline development is undertaken. In recent years shoreline development has accelerated along several northeast South Dakota lakes (including Roy Lake, figure 17) and in several cases have caused water quality problems (Figure 19). One northeast South Dakota County is currently working to develop "lake zone" ordinances to better protect water quality from shoreline erosion and construction site runoff. Implementation efforts should include efforts to educate the public and local governments on the negative effects improper shoreline development can have on water quality and lakeshore wildlife habitat.

Tributary sampling did show the presence of high bacteria counts indicating the need for nutrient management in the watershed. A combination of BMPs may be required to solve this problem including feedlot containment or alternatives, and riparian buffers along lake shores and tributaries located in pastures.

Much of Roy Lake's watershed is currently utilized as range and pasture, however in the last few years agricultural prices have led to more grassland conversion to crops. If this trend continues, water quality in Roy Lake may be negatively affected. Implementation of riparian buffers may be needed in the near future along Roy Lake's shoreline and tributaries.

Figure 20. Shoreline development along Pickerel Lake (note failure of hay bales to stop runoff from site)

Many lake associations in recent years have funded yearly water quality monitoring, whether in conjunction with ongoing 319 implementation projects like the Northeast Glacial Lakes Watershed Improvement and Protection Project, or participation in East Dakota Water Development District's "Dakota Water Watch", a volunteer lake monitoring program. Current water quality monitoring of lakes similar to Roy in northeast South Dakota show these lakes may be very sensitive to changes in watershed and shoreline land-use. Future watershed implementation projects should support these types of continuous water quality monitoring efforts that provide long term water quality trends, and a better understanding of the influence of watershed and shoreline best management practices.

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APPENDIX A

Roy In-Lake Field Parameters												
Date Sampled	**Sample Location**	**Depth**	**Air Temp °C**	**Water Temp °C**	**Secchi Disk (meters)**	**DO (mg/L)**	**Cond. (µS/cm)**	**pH (su)**	**Sample Depth (meters)**	**Stage Total Depth (m)**	**Wind (mph)**	**Snow Depth (meters)**
12/17/07	RL01	Surface	-8.89	0.70	2.77	15.40	ND	8.87	0.91	5.49	0 to 5	0.15
		Bottom		2.90		11.10	ND	8.54	5.33			
	RL02	Surface	-6.11	0.60	2.83	14.30	ND	8.86	0.91	4.42	0 to 5	0.3
		Bottom		1.90		12.90	ND	8.77	4.11			
1/28/08	RL01	Surface	-15.67	0.50	4.65	11.80	ND	8.49	0.91	5.42	10 to 20	0.15
		Bottom		4.20		2.60	ND	7.88	4.57			
	RL02	Surface	-15.67	0.84	3.20	12.10	ND	8.50	0.91	4.72	0 to 5	0.15
		Bottom		3.40		8.10	ND	8.35	3.96			
2/26/08	RL01	Surface	-8.89	0.75	3.39	9.40	ND	8.19	0.91	5.79	10 to 20	0.18
		Bottom		4.80		4.10	ND	7.71	5.49			
	RL02	Surface	-8.89	0.51	2.94	9.60	ND	8.30	0.91	5.18	20 to 30	0.19
		Bottom		4.80		3.70	ND	7.83	4.88			
3/18/08	RL01	Surface	-17.78	0.60	5.10	8.10	ND	8.20	0.91	5.18	5 to 10	0
		Bottom		4.10		5.00	ND	7.89	5.20			
	RL02	Surface	-16.83	1.70	4.40	7.00	ND	8.01	0.91	5.20	5 to 10	0
		Bottom		4.50		2.80	ND	7.87	4.90			
5/14/08	RL01	Surface	10.00	9.80	1.12	10.70	ND	8.57	0.91	5.79	5 to 10	0
		Bottom		9.50		10.60	ND	8.63	5.49			
	RL02	Surface	10.00	10.00	1.54	10.90	ND	8.65	0.91	5.46	5 to 10	0
		Bottom		9.60		10.80	ND	8.63	4.88			
6/16/08	RL01	Surface	16.67	16.23	1.55	10.25	556	8.73	0.91	5.85	5 to 10	0
		Bottom		16.04		10.13	553	8.73	5.49			
	RL02	Surface	18.33	16.70	1.43	10.23	557	8.74	0.91	5.46	5 to 10	0
		Bottom		16.10		10.00	552	8.74	4.88			
6/30/08	RL01	Surface	20.00	20.50	1.23	8.60	619	8.46	0.91	5.70	0 to 5	0
		Bottom		19.80		6.10	613	8.40	5.18			
	RL02	Surface	21.11	20.80	1.21	8.70	617	8.56	0.91	5.39	0 to 5	0
		Bottom		20.10		8.20	608	8.55	4.88			
7/9/08	RL01	Surface	23.89	22.80	1.32	7.82	646	8.44	0.91	5.52	5 to 10	0
		Bottom		22.20		3.09	644	8.17	5.18			
	RL02	Surface	23.89	22.90	1.03	8.40	644	8.43	0.91	5.39	5 to 10	0
		Bottom		22.70		7.74	642	8.46	4.88			

Roy In-Lake Field Parameters continued

Date Sampled	Sample Location	Depth	Air Temp °C	Water Temp °C	Secchi Disk (meters)	DO (mg/L)	Cond. (µs/cm)	pH (su)	Sample Depth (meters)	Stage Total Depth	Wind (mph)	Snow Depth (meters)
7/21/08	RL01	Surface	25.00	23.60	0.97	9.20	658	8.61	0.91	5.76	10 to 20	0
		Bottom		22.50		4.60	654	8.32	5.18			
	RL02	Surface	25.00	23.60	1.02	9.90	655	8.63	0.91	5.24	10 to 20	0
		Bottom		22.40		3.50	647	8.28	4.88			
8/13/08	RL01	Surface	26.67	23.53	0.74	9.35	725	8.76	0.91	5.64	5 to 10	0
		Bottom		22.89		3.95	723	8.47	5.18			
	RL02	Surface	26.67	23.99	0.71	11.16	699	8.78	0.91	5.36	5 to 10	0
		Bottom		22.62		2.98	696	8.50	4.88			
8/27/08	RL01	Surface	18.33	20.97	0.66	10.35	626	8.82	0.91	5.61	10 to 20	0
		Bottom		20.98		7.76	624	8.81	5.18			
	RL02	Surface	18.33	20.68	0.56	8.63	620	8.83	0.91	5.21	10 to 20	0
		Bottom		20.69		7.75	619	8.82	4.88			
9/16/08	RL01	Surface	21.11	16.70	0.91	9.16	662	8.79	0.91	5.55	5 to 10	0
		Bottom		16.50		8.6	663	8.79	5.18			
	RL02	Surface	21.11	16.70	0.88	9.3	552	8.85	0.91	5.21	5 to 10	0
		Bottom		16.30		8.8	549	8.81	4.88			
10/16/08	RL01	Surface	7.22	9.70	0.99	9.7	486	8.64	0.91	5.70	0 to 5	0
		Bottom		9.50		9.6	485	8.64	5.18			
	RL02	Surface	10.00	9.50	1.02	10.1	487	8.72	0.91	5.30	0 to 5	0
		Bottom		9.30		9.8	479	8.68	4.88			

Roy In-Lake Chemical Parameters

Date Sampled	Sample Location	Depth	Alkalinity M mg/L.	Total Dissolved Solids mg/L.	Suspended Solids mg/L.	Total Solids mg/L.	VTSS mg/L.	Ammonia mg/L	Nitrate mg/L	TKN mg/L	Total Phosphorus mg/L.	Total Dissolved Phosphorus mg/L.	Fecal Coliform /100mL	E.Coli /100mL
12/17/07	RL01	Surface	234	ND	<3.0	528	<3.0	<0.02	<0.2	1.19	0.027	0.008	<10	<1
		Bottom	240	ND	<3.0	542	<3.0	<0.02	<0.2	1.11	0.036	0.017		
	RL02	Surface	234	ND	<3.0	527	<3.0	<0.02	<0.2	1.23	0.02	0.006	<10	<1
		Bottom	232	521	5	526	<3.0	<0.02	<0.2	1.19	0.022	0.008		
1/28/08	RL01	Surface	250	ND	<3.0	557	<3.0	<0.02	<0.2	0.97	0.027	0.015	<10	<1
		Bottom	257	ND	<3.0	594	<3.0	0.35	<0.2	1.36	0.083	0.057		
	RL02	Surface	253	ND	<3.0	564	<3.0	0.03	<0.2	1.01	0.034	0.017	<10	<1
		Bottom	253	ND	<3.0	558	<3.0	0.17	<0.2	1.15	0.061	0.04		
2/26/08	RL01	Surface	263	ND	<3.0	600	<3.0	<0.02	<0.2	1.19	0.038	0.017	<2	<1
		Bottom	268	ND	<3.0	619	<3.0	0.24	<0.2	1.42	0.046	0.034		
	RL02	Surface	261	784	4	788	<3.0	0.07	<0.2	1.24	0.034	0.017	<1	<2
		Bottom	276	590	7	597	<3.0	1.02	<0.2	2.39	0.237	0.21		
3/18/08	RL01	Surface	258	588	4	592	<3.0	<0.02	<0.2	1.01	0.044	0.026	<2	<1
		Bottom	275	645	3	648	<3.0	0.29	<0.2	1.2	0.074	0.06		
	RL02	Surface	266	ND	<3.0	602	<3	0.14	<0.2	1.2	0.066	0.047	<2	<1
		Bottom	282	627	3	630	<3.0	0.86	<0.2	1.92	0.214	0.19		
5/14/08	RL01	Surface	221	457	8	465	6	0.59	<0.2	1.2	0.047	0.009	<10	<1
		Bottom	221	462	9	471	5	<0.02	<0.2	0.98	0.052	0.016		
	RL02	Surface	220	451	12	463	7	0.5	<0.2	1.08	0.043	0.01	<10	<1
		Bottom	221	455	10	465	5	0.17	<0.2	0.88	0.046	0.012		
6/16/08	RL01	Surface	222	453	13	466	4	<0.02	<0.2	1.03	0.024	0.012	<10	<1
		Bottom	222	453	9	462	<3.0	<0.02	<0.2	0.99	0.026	0.026		
	RL02	Surface	222	444	10	454	5	<0.02	<0.2	0.96	0.023	0.012	<10	2
		Bottom	223	445	10	455	3	<0.02	<0.2	0.95	0.028	0.02		
6/30/08	RL01	Surface	222	438	8	446	5	<0.02	<0.2	1.1	0.047	0.03	<10	<2
		Bottom	222	433	10	443	4	<0.02	<0.2	0.97	0.054	0.012		
	RL02	Surface	221	439	7	446	3	<0.02	<0.2	1.14	0.038	0.018	<10	<2
		Bottom	222	441	11	452	5	<0.02	<0.2	1.08	0.04	0.022		
7/9/08	RL01	Surface	222	446	9	455	6	<0.02	<0.2	1.01	0.047	0.012	<10	<2
		Bottom	226	451	11	462	6	<0.02	<0.2	1.12	0.054	0.013		
	RL02	Surface	223	449	12	461	5	<0.02	<0.2	1.18	0.044	0.013	<10	<2
		Bottom	223	444	11	455	5	<0.02	<0.2	1.15	0.041	0.007		

Roy In-Lake Chemical Parameters continued

Date Sampled	Sample Location	Depth	Alkalinity M mg/L.	Total Dissolved Solids mg/L.	Suspended Solids mg/L.	Total Solids mg/L.	VTSS mg/L.	Ammonia mg/L	Nitrate mg/L	TKN mg/L	Total Phosphorus mg/L.	Total Dissolved Phosphorus mg/L.	Fecal Coliform /100mL	E.Coli /100mL
7/21/08	RL01	Surface	221	450	6	456	<3	<0.02	<0.2	1.04	0.051	0.02	<10	2
		Bottom	228	559	17	576	5	0.06	<0.2	1.23	0.084	0.026		
	RL02	Surface	222	450	6	456	5	<0.02	<0.2	1.1	0.055	0.019	<10	<2
		Bottom	227	460	13	473	6	0.11	<0.2	1.21	0.073	0.017		
8/13/08	RL01	Surface	216	452	8	460	5	<0.02	<0.2	1.37	0.076	0.018	<10	2
		Bottom	219	449	14	463	6	<0.02	<0.2	1.28	0.084	0.022		
	RL02	Surface	217	445	10	455	7	<0.02	<0.2	1.27	0.081	0.015	<10	10.2
		Bottom	224	449	14	463	4	<0.02	<0.2	1.44	0.102	0.035		
8/27/08	RL01	Surface	214	443	18	461	6	<0.02	<0.2	1.41	0.095	0.018	<10	2
		Bottom	215	440	19	459	<3.0	<0.02	<0.2	1.32	0.084	0.016		
	RL02	Surface	217	445	21	466	6	<0.02	<0.2	1.71	0.085	0.008	<10	2
		Bottom	218	444	25	469	7	<0.02	<0.2	1.59	0.095	0.017		
9/16/08	RL01	Surface	209	428	9	437	5	<0.02	<0.2	1.21	0.054	0.02	31.6	2
		Bottom	211	444	10	454	4	<0.02	<0.2	1.41	0.063	0.012		
	RL02	Surface	210	451	9	460	5	<0.02	<0.2	1.33	0.062	0.017	2	8.2
		Bottom	210	450	11	461	6	<0.02	<0.2	1.18	0.06	0.014		
10/16/08	RL01	Surface	212	459	5	464	3	<0.02	0.2	1.28	0.061	0.012	<10	2
		Bottom	213	458	3	461	<3.0	<0.02	0.2	1.36	0.054	0.018		
	RL02	Surface	213	459	8	467	4	<0.02	0.2	1.4	0.053	0.012	<10	4.1
		Bottom	214	460	8	468	3	<0.02	0.2	1.37	0.058	0.014		

Roy Lake Tributary Field Parameters									
Date Sampled	Sample Location	Depth	Air Temp °C	Water Temp °C	Discharge (CFS)	Stage (feet)	DO (mg/L)	Cond. (µS/cm)	pH (su)
3/25/2008	RLT03	Surface	No Data	3.3	13.17	1.10	10.5	494	7.48
3/25/2008	RLT04	Surface	No Data	0.67	6.28	0.72	12.5	372	7.86
4/2/2008	RLT03	Surface	1.67	3.05	7.47	0.86	13.95	483	8.1
4/2/2008	RLT04	Surface	3.33	2.5	13.23	1.38	13.33	392	8.19
4/8/2008	RLT03	Surface	7.22	3.87	7.58	0.90	13.82	450	8.33
4/8/2008	RLT04	Surface	7.22	5.41	18.89	1.63	12.49	421	8.22
4/15/2008	RLT03	Surface	10.00	5.54	11.17	1.06	14.07	471	8.34
4/15/2008	RLT04	Surface	11.67	5.99	56.21	2.56	12.25	424	8.29
5/7/2008	RLT03	Surface	15.56	12.47	11.78	1.30	8.9	527	8.37
5/7/2008	RLT04	Surface	18.33	12.3	No Data	3.31	9.29	467	8.54
5/7/2008	RLT05	Surface	15.56	10.49	No Data	0.76	9.73	525	8.68
6/12/2008	RLT03	Surface	19.44	16.18	23.65	1.51	9.04	534	8.26
6/12/2008	RLT04	Surface	17.78	14.38	32.40	3.07	9.33	466	8.14
6/16/2008	RLT05	Surface	18.33	18.08	62.08	0.70	9.78	586	8.62
7/22/2008	RLT04	Surface	28.33	25.67	9.95	1.80	8.43	584	8.24
7/22/2008	RLT05	Surface	26.67	24.94	No Data	0.35	8.81	678	8.63
8/19/2008	RLT03	Surface	26.67	24.03	1.51	0.64	11.22	590	8.33
8/19/2008	RLT04	Surface	26.67	26.51	5.73	0.66	9.4	608	8.01
8/19/2008	RLT05	Surface	25.56	25.21	3.90	0.20	8.96	703	8.62
9/2/2008	RLT03	Surface	18.33	16.65	0.90	0.52	8.58	744	7.73
9/2/2008	RLT04	Surface	18.33	17.38	4.89	0.57	9.01	351	8.05
10/7/2008	RLT03	Surface	10	10.78	1.31	0.70	8.76	514	7.85
10/7/2008	RLT04	Surface	12.78	10.48	0.98	0.13	9.22	500	7.93
10/20/2008	RLT05	Surface	4.44	8.34	No Data	0.31	9.77	452	8.54

Roy Lake Tributary Chemical Parameters

Date Sampled	Sample Location	Depth	Alkalinity M mg/L.	Total Dissolved Solids mg/L	Total Suspended Solids mg/L.	Total Solids mg/L.	VTSS mg/L.	Ammonia mg/L	Nitrate mg/L	TKN mg/L	Total Phosphorus mg/L.	Total Dissolved Phosphorus mg/L.	Fecal Coliform /100mL	E.Coli /100mL
3/25/2008	RLT03	Surface	272	577	13	590	<3.0	0.45	0.2	1.65	0.088	0.042	<10	5
3/25/2008	RLT04	Surface	257	435	15	450	<3.0	0.08	0.2	1.20	0.068	0.022	<10	28.2
4/2/2008	RLT03	Surface	264	559	9	568	3	0.05	<0.2	1.33	0.095	0.015	10	21.3
4/2/2008	RLT04	Surface	255	430	41	471	4	0.06	<0.2	1.24	0.099	0.020	<10	14.6
4/8/2008	RLT03	Surface	234	504	30	534	6	<0.02	0.2	1.38	0.142	0.017	10	33.1
4/8/2008	RLT04	Surface	253	421	92	513	11	0.03	0.2	1.48	0.158	0.020	<10	69.7
4/15/2008	RLT03	Surface	235	489	4	493	<3.0	<0.02	0.2	1.22	0.108	0.010	<10	16.1
4/15/2008	RLT04	Surface	240	410	41	451	4	<0.02	0.2	1.26	0.099	0.012	10	140
5/7/2008	RLT05	Surface	220	465	10	475	<3.0	0.27	<0.2	1.12	0.059	0.004	<10	6.2
5/7/2008	RLT03	Surface	215	441	7	448	<3.0	<0.02	<0.2	1.02	0.050	0.013	<10	19.6
5/7/2008	RLT04	Surface	227	371	41	412	4	0.33	<0.2	1.19	0.078	0.016	10	59
6/12/2008	RLT03	Surface	216	457	17	474	5	<0.02	<0.2	0.97	0.071	0.025	290	1540
6/12/2008	RLT04	Surface	219	395	37	432	5	<0.02	0.2	1.00	0.109	0.039	340	1450
6/16/2008	RLT05	Surface	223	449	17	466	6	<0.02	<0.2	1.05	0.036	0.012	<10	8.5
7/22/2008	RLT05	Surface	222	463	11	474	6	<0.02	<0.2	1.30	0.048	0.015	10	4
7/22/2008	RLT04	Surface	222	366	34	400	9	<0.02	0.2	1.26	0.077	0.048	40	275
8/19/2008	RLT05	Surface	209	449	5	454	<3.0	<0.02	<0.2	1.20	0.051	0.021	<10	<2.0
8/19/2008	RLT03	Surface	180	383	4	387	3	<0.02	0.2	1.12	0.062	0.028	10	870
8/19/2008	RLT04	Surface	215	367	23	390	6	<0.02	0.2	1.16	0.082	0.028	20	403
9/2/2008	RLT03	Surface	233	614	8	622	<3.0	0.1	0.3	1.19	0.126	0.068	2500	4840
9/2/2008	RLT04	Surface	226	377	25	402	4	0.02	0.2	1.50	0.138	0.057	1100	4840
10/7/2008	RLT03	Surface	200	449	<3.0	452	<3.0	<0.02	0.2	1.37	0.069	0.031	60	870
10/7/2008	RLT04	Surface	281	455	29	484	<3.0	0.16	0.5	1.33	0.102	0.023	120	4840
10/20/2008	RLT05	Surface	216	451	10	461	3	<0.02	<0.2	1.36	0.049	0.009	<10	22.8