PHASE I
WATERSHED ASSESSMENT
FINAL REPORT

RICHMOND LAKE
BROWN 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

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SECTION 319 TMDL
ASSESSMENT/PLANNING PROJECT FINAL REPORT

RICHMOND LAKE WATERSHED ASSESSMENT FINAL REPORT

By

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Sponsor

South Brown County Conservation District

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SD DENR - Water Resources Assistance Program

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ABBREVIATIONS

AFOs	Animal Feeding Operations
AGNPS	Agricultural Non-Point Source
BMP	Best Management Practice
CFS	Cubic Feet Per Second
CRP	Crop Rotation Practice
DEM	Digital Elevation Map
DO	Dissolved Oxygen
DOQ	Digital Ortho Quad
FSA	Farm Service Agency
NRCS	Natural Resources Conservation Service
NTU	Nephelometric Turbidity Units
PIP	Project Implementation Plan
SDDENR	South Dakota Department of Environment and Natural Resources
SDGF&P	South Dakota Department of Game, Fish & Parks
su	Standard Units
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TSI	Trophic State Index
umhos/cm	micromhos/centimeter
USGS	United States Geological Survey

Executive Summary

PROJECT TITLE: Richmond Lake Watershed Assessment

PROJECT START DATE: 2/1/2003 PROJECT COMPLETION DATE: 8/1/2004

FUNDING: INITIAL BUDGET: $92,050.00
TOTAL BUDGET: $92,050.00

TOTAL EPA GRANT:	$55,000
TOTAL EXPENDITURES OF EPA FUNDS	$45,716.40
TOTAL SECTION 319 MATCH ACCRUED:	$32,877.09
BUDGET AMENDMENTS:	N/A
TOTAL EXPENDITURES:	$78,593.49

SUMMARY OF ACCOMPLISHMENTS

The Richmond Lake Watershed Assessment Project began in February 2003 and ended in August 2004 up[on sample completion by the Richmond Lake project coordinator. The assessment was conducted as a result of Richmond Lake being placed on the most recent South Dakota 2006 303(d) waterbody list due to its trophic status. The Richmond Lake Watershed Assessment met most of its milestones in a timely manner except for tributary sampling which ran behind schedule due to a lack of rainfall. The project ran for more than one year but was not extended beyond the original deadline of December 31, 2004. Additional data was collected from the Richmond Lake tributaries during this time frame. The project came to a close when match money was no longer available to meet the required 40% match for 319 funds.

Initially, a section 319 grant ($55,000) provided 60% of the funding for the Richmond Lake project. The State of South Dakota was to provide 50% of the required match by awarding a $20,000 Natural Resources Fee Fund grant to the sponsor. Local matching funds were to be used to meet the remaining 48% of the required match funds ($17,050).

Water quality monitoring and watershed modeling resulted in the identification of sources of impairment to Richmond Lake. Water, algae, sediment, elutriate, and macrophyte surveys were also completed as part of the assessment.

Utilization of Best Management Practices through an implementation project and information and education should reduce fecal, sediment, and nutrient loadings to Richmond Lake which should result in a decrease in the lake's trophic status. The primary goal of the project was to determine sources of impairment to the lake and its watershed and provide sufficient background data to drive an implementation project. The goal was successfully achieved and interest has been shown for the development of an implementation project.

According to modeled reductions, it is not possible to reduce phosphorus loads from the watershed sufficiently to bring the median growing season Trophic State Index (TSI) to the targeted value. The beneficial use-based target does not appear to fit the recommended beneficial use-based target (Lorenzen 2006) due to legacy phosphorus loading to the lake and the technical and financial inability to fully treat the internal and external loading to the lake. The internal loading in Richmond Lake is so severe that realistic watershed reductions would have little effect on sufficiently lowering the TSI value three TSI points. The BATHTUB model estimates a phosphorus reduction in excess of 80% from external loads from the watershed would be needed to comply with the current fishery beneficial use classification targeting criteria. The AnnAGNPS model estimated that a 27% reduction in phosphorus can be achieved by transforming rangeland and crop land into grassland. Based on social and economic restrictions within the watershed, a Total Maximum Daily Load (TMDL) for full support would **not** be attainable under the current fishery beneficial use classification for full support. The site specific target for Richmond Lake will fully support its beneficial uses and is achievable given the expected landowner participation and possible reductions in the watershed. Subsequent alternative site-specific (watershed-specific) evaluation criteria (fully supporting, median TSI < 61.5) is proposed based on AnnAGNPS modeling, BMPs and watershed-specific phosphorus reduction attainability for Richmond Lake.

To achieve a median modeled TSI of < 61.5, phosphorus reductions of 10% may be attained by installing proper BMPs in feedlot areas. In addition to a 10% reduction in AFO contributions, a conservative 10% transformation of crop land/rangeland to grassland is also needed to reach the TSI site-specific reduction target.

Due to the significant impact of internal phosphorus loads on the trophic status of Richmond Lake, additional reductions to meet site specific standards could be achieved through inlake treatments. It is imperative that efforts be directed to watershed improvement prior to inlake treatment to increase effectiveness.

Introduction

Purpose

The purpose of this pre-implementation assessment is to determine the sources of impairment to Richmond Lake and its major tributary, Foot Creek, and associated tributaries draining to Foot Creek. Foot Creek, located in both McPherson and Brown

counties, is an intermittent stream with loadings of sediment and nutrients related to snow melt and rainfall events. There were seven tributary sites monitored during the Richmond Lake Assessment. The streams in the watershed drain predominantly agricultural land with both grazing and cropland acres. Feedlots and winter feeding areas for livestock are present in the watershed. The streams carry sediment and nutrient loads, which degrade water quality and cause increased eutrophication of Richmond Lake.

The Richmond Lake watershed is a sub-watershed within the Moccasin Creek watershed in Brown County, South Dakota (see Moccasin Creek report (McLaury, 2002)). The size of the area modeled for the Richmond Lake watershed was 103,000 acres. The inlets for Richmond Lake are located in the west arm of Richmond Lake (Foot Creek) and the north arm of Richmond Lake (unnamed). The outlet is located in the easternmost part of the lake and empties into Foot Creek which eventually spills into the James River.

General Lake Description

Richmond Lake is an 840 acre man-made water impoundment located in west central Brown County, South Dakota (Figure 1). Water entering Richmond Lake was sampled from two tributaries located in Brown, Edmunds and McPherson counties. The entire watershed consists of 103,000 acres of mainly agricultural land; crop and grazing and one small municipality in the far northwestern part of the watershed (Leola, SD). All homes and cabins around Richmond Lake are connected to a central sewer collection system. Richmond Lake is 840 acres in size, has an average water depth of 9.24 feet, a maximum depth of 24 feet, and holds approximately 12,435 acre-feet of water.

Lake Identification and Location

Lake Name: Richmond Lake
State: South Dakota
County: Brown
Township: 124N, 125N
Range: 64W, 65W
Sections: 1, 12-14, 23-25, 30, 31, 36
Nearest Municipality: Aberdeen, SD
Latitude: 45 deg. 32 min. 30 sec
Longitude: -97 deg. 38 min. 30 sec.
EPA Region: VIII
Primary Tributary: Foot Creek

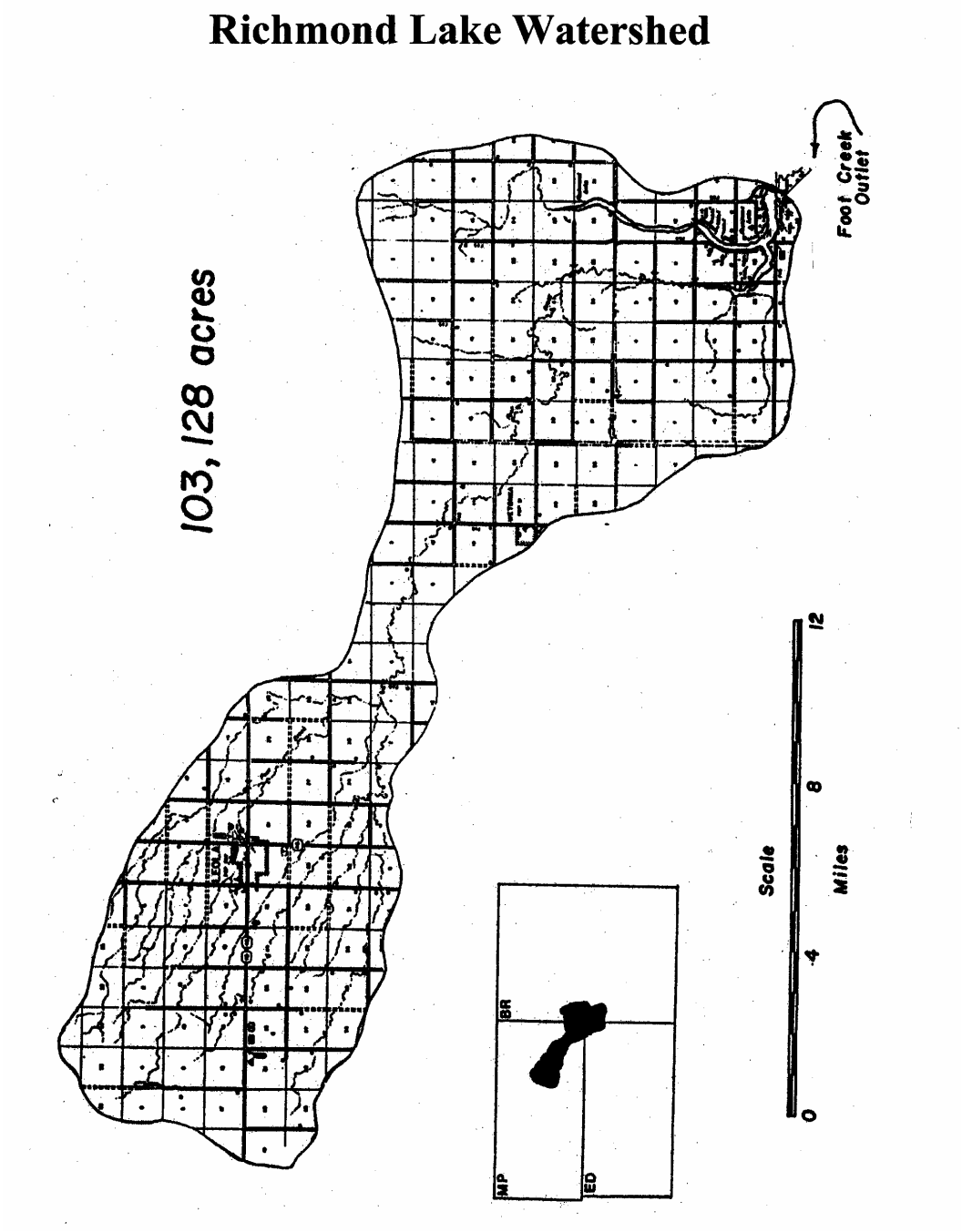

Figure 1. Richmond Lake Watershed

Trophic State Comparison

The trophic state of a lake is a numerical value that ranks its relative productivity. Developed by Carlson (1977), the Trophic State Index, or TSI, allows a lake's productivity to be easily quantified and compared to other lakes. Higher TSI values correlate with higher levels of primary productivity. A comparison of Richmond Lake to other lakes in the area (Table 1) shows that a high rate of productivity is common for the region. The values provided in Table 1 were generated from the most recent statewide lake assessment final report (Stueven and Stewart, 1996).

Table 1. TSI Comparison for Area Lakes

Lake	Nearest Municipality	TSI	Mean Trophic State
Elm	Leola	59.95	Eutrophic
Mina	Aberdeen	63.7	Eutrophic
Richmond	Aberdeen	67.4	Hypereutrophic
Wylie	Aberdeen	43.0	Mesotrophic

Beneficial Uses

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

(4) Warmwater permanent fish life propagation
(5) Immersion recreation
(6) Limited contact recreation
(7) Fish and wildlife propagation, recreation, and stock watering

Richmond Lake is identified in "Targeting For Impaired Lakes in South Dakota" and in the most recent 2006 South Dakota 303(d) Waterbody List as not supporting its beneficial uses due to its trophic status.

Table 2. State Beneficial Use Standards for Richmond Lake

Parameters	mg/L (except where noted)	Beneficial Use Requiring this Standard
Alkalinity *($CaCO_3$)*	≤750 *(mean)* ≤1,313 *(single sample)*	Wildlife Propagation and Stock Watering
Coliform, fecal *(per 100 mL)* May 1 to Sept 30	≤200 *(mean)* ≤400 *(single sample)*	Immersion Recreation
Conductivity *(umhos/cm@25 C)*	≤4,000 *(mean)* ≤7,000 *(single sample)*	Wildlife Propagation and Stock Watering
Nitrogen, unionized ammonia as N	≤.04 *(mean)* ≤1.75 times the applicable limit *(single sample)*	Warmwater Permanent Fish Life Propagation
Nitrogen, nitrates as N	≤50 *(mean)* ≤88 *(single sample)*	Wildlife Propagation and Stock Watering
Oxygen, dissolved	≥5.0	Warmwater Permanent Fish Life Propagation
pH *(standard units)*	≥6.0 - ≤9.0	Warmwater Permanent Fish Life Propagation
Solids, suspended	≤90 *(mean)* ≤158 *(single sample)*	Warmwater Permanent Fish Life Propagation
Solids, total dissolved	≤2,500 *(mean)* ≤4,375 *(single sample)*	Wildlife Propagation and Stock Watering
Temperature	≤26.66 degrees C	Warmwater Permanent Fish Life Propagation

NOTE: "Mean" is a 5-day sample geometric mean collected within 30 days.

Recreational Use

Richmond Lake is located northwest of Aberdeen, SD, in the west central portion of Brown County. Recreational activities such as wading and swimming occur mainly on the south side of the lake approximately ½ mile west of the Richmond Lake dam. Other recreational activities include fishing, water skiing, and jet skiing.

Geology

Richmond Lake and its tributaries lie in the region known as the James River Basin and the Lake Dakota Plain. The bed of ancient Lake Dakota is nearly flat with relief seldom exceeding ten feet except where stream valleys have been formed. Brown County is located between two coteaus. Directly west is the Coteau du Missouri and directly east is the Coteau des Prairies. Several streams flow down the slopes crossing tilled highlands and the two coteaus join the

James River in the lower portion of the depression. Most of the county is dotted with numerous depressions in the glacial drift with a few large enough to hold significant amounts of water. Some of the natural lakes in the area include Salt Lake, Alkali Lake, and Lord's Lake in the western portion of Brown County. These lakes have poor recreational value due to their shallow nature and high dissolved solids content. In times of drought, the evaporating water greatly increases the salt concentration. Numerous artificial lakes exist in Brown County, including Richmond, Willow Creek, Elm, Engle, Sand and Mud Lakes, which were created by damming of streams.

Brown County has a sub-humid continental climate with short, hot summers and long, cold winters. Below zero temperatures are very common in winter and temperatures of 100° F are normally experienced on a monthly basis during the summer. The average annual precipitation is just over 19 inches per year.

Ground water in the area is obtained from confined bedrock deposits and glacial till drift. Aquifers in the glacial drift zone contain about 3.6 million acre-feet of water storage and are recharged mainly by infiltration of precipitation. The bedrock aquifer contains approximately 61 million acre-feet of water storage and is recharged by subsurface inflow and underlying bedrock aquifers.

History

The origin and construction of Richmond Lake was a result of a period of dry, poor-growing seasons combined with the Depression and a high rate of unemployment in the surrounding communities. As a response, plans were made to dam water sources in close proximity to create impoundments that would provide a permanent water supply. The outcome of these projects would also provide habitat for waterfowl as well as recreational facilities for local people. This was all done in cooperation with the federal government's Works Program Administration (WPA), which was President Roosevelt's Emergency Re-Employment Campaign during the Depression in the 1930's.

The committee that administered the earlier Mina Lake project was nearly the same committee to administer the plans for the Richmond Lake project, with the exception of a few Edmunds County members. In a unique idea, the committee decided to seek financial support from manufacturers and distributors that local merchants had purchased goods from in the past. These out-of-state companies had a vested interest in the increase of resources in this region and made contributions totaling $8,000.00 (Kennedy,1940). Additional funding was provided by the city of Aberdeen, Brown County, and Richmond Township.

Ground was broken for construction of Richmond Dam on September 1, 1935. Work proceeded through the winter months and by the spring of 1937 the dam was near completion. That spring, the dam impounded Foot Creek and two other unnamed tributaries to flood nearly 1,000 acres of farmland. This water body is among the largest of the 657 WPA-built lakes in South Dakota. Richmond Lake gets its name from a freight station that was on the Aberdeen-Leola branch of the Minneapolis & St. Louis railroad.

Park development began in the summer of 1937 with the Brown County Commission acting as the local sponsor of the WPA project. More than 10,000 native trees and shrubs were transplanted to the south shore of the lake where the state campground exists today. In 1939, 18,000 trees were planted on the northeast side of the main body of the lake, an area that is now called Forest Drive. Richmond Lake today is a popular camping, boating, and fishing spot for people that live in the area.

Project Goals, Objectives, and Activities

Planned and Actual Milestones, Products, and Completion Dates

Objective 1. Lake Sampling

Sampling of Richmond Lake began in April 2003 and continued through February 2004. There were a total of 61 samples collected from the three sampling sites in Richmond Lake (Figure 2). It was intended that 65 lake samples be collected throughout the entire project, but there was a loss of one sample during the month of January in 2004 due to equipment failure.

A macrophyte survey was conducted on Richmond Lake in July 2003, with a total of 41 transects sampled. Filamentous green algae dominated the shallow substrate and outcompeted many other macrophytes. The second most predominant plant was *Potamogeton pectinatus* (sago pondweed). Other submergent species that were found in the lake (in relatively small numbers) were *Vallisneria americana* (eel grass) and *Zannichella palustris* (horned pond weed).

In August 2003, an elutriate sample was collected from Richmond Lake. A sediment survey of Richmond Lake was later conducted in February 2004 when ice conditions were favorable. Sediment and water depths were measured at 192 locations on the lake.

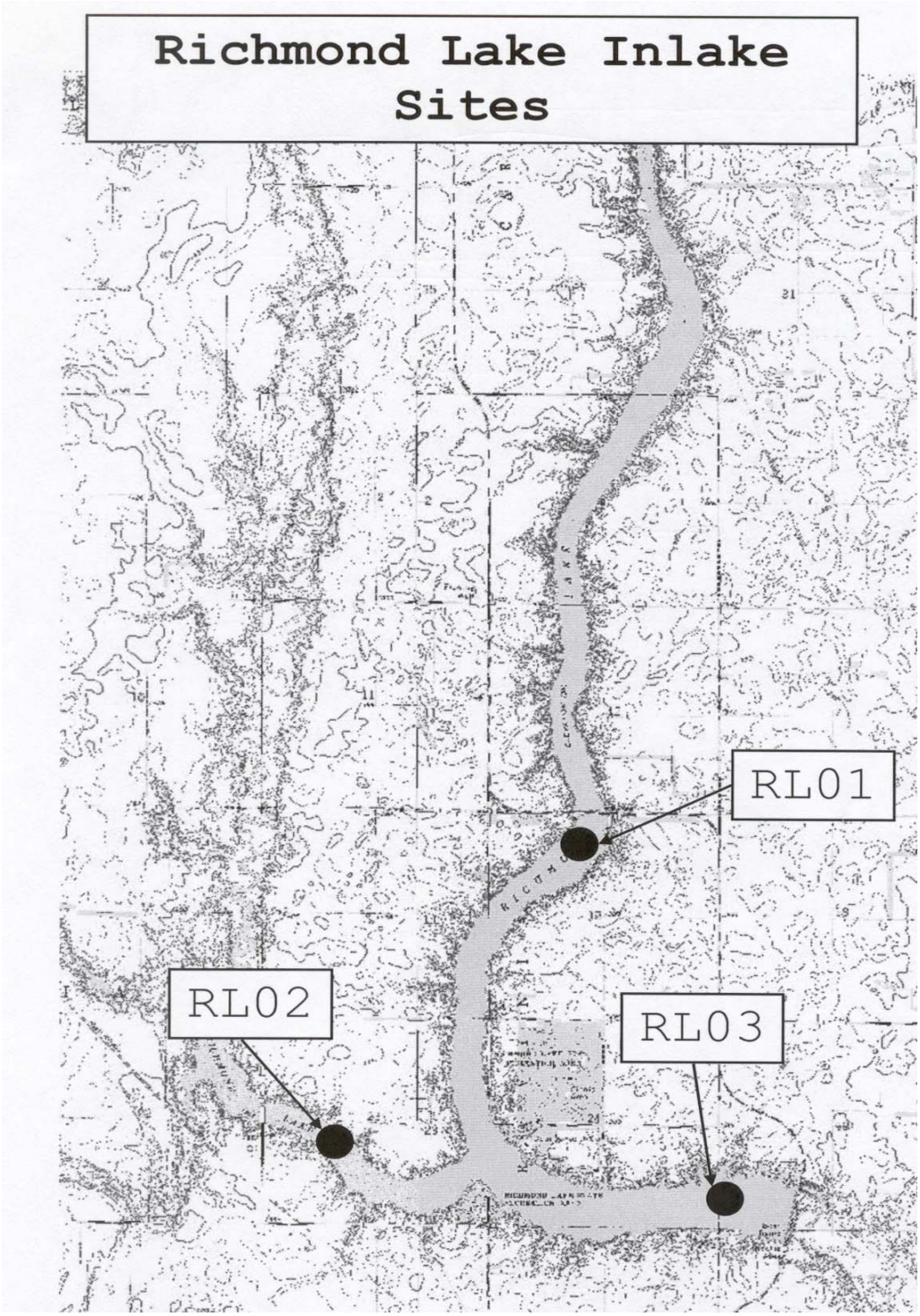

Figure 2. Richmond Lake Inlake Sites

Objective 2. Tributary Sampling

The tributaries of the Richmond Lake watershed were monitored for chemical and hydrologic parameters for 16 months of the project. Water quality samples and flow measurements were collected from 6 sampling sites. It was intended that the outlet of the lake be monitored as well, but due to low lake levels that site never flowed. Stage recorders were set up at all seven sites during March of 2003 to collect continuous stage data (Figure 3). There were a total of total of 31 samples taken between April 2003 and September of 2003. It was intended that 90 tributary samples be collected in all, but there were persisting dry conditions in 2003 and 2004. The project was extended the following spring in order to collect additional water quality samples. In June of 2004, an additional 14 samples were collected for a total of 45 samples. Of the 45 tributary samples analyzed, four samples were QAQC (1 blank and 1 duplicate). Equipment was removed from the tributary sites in July 2004.

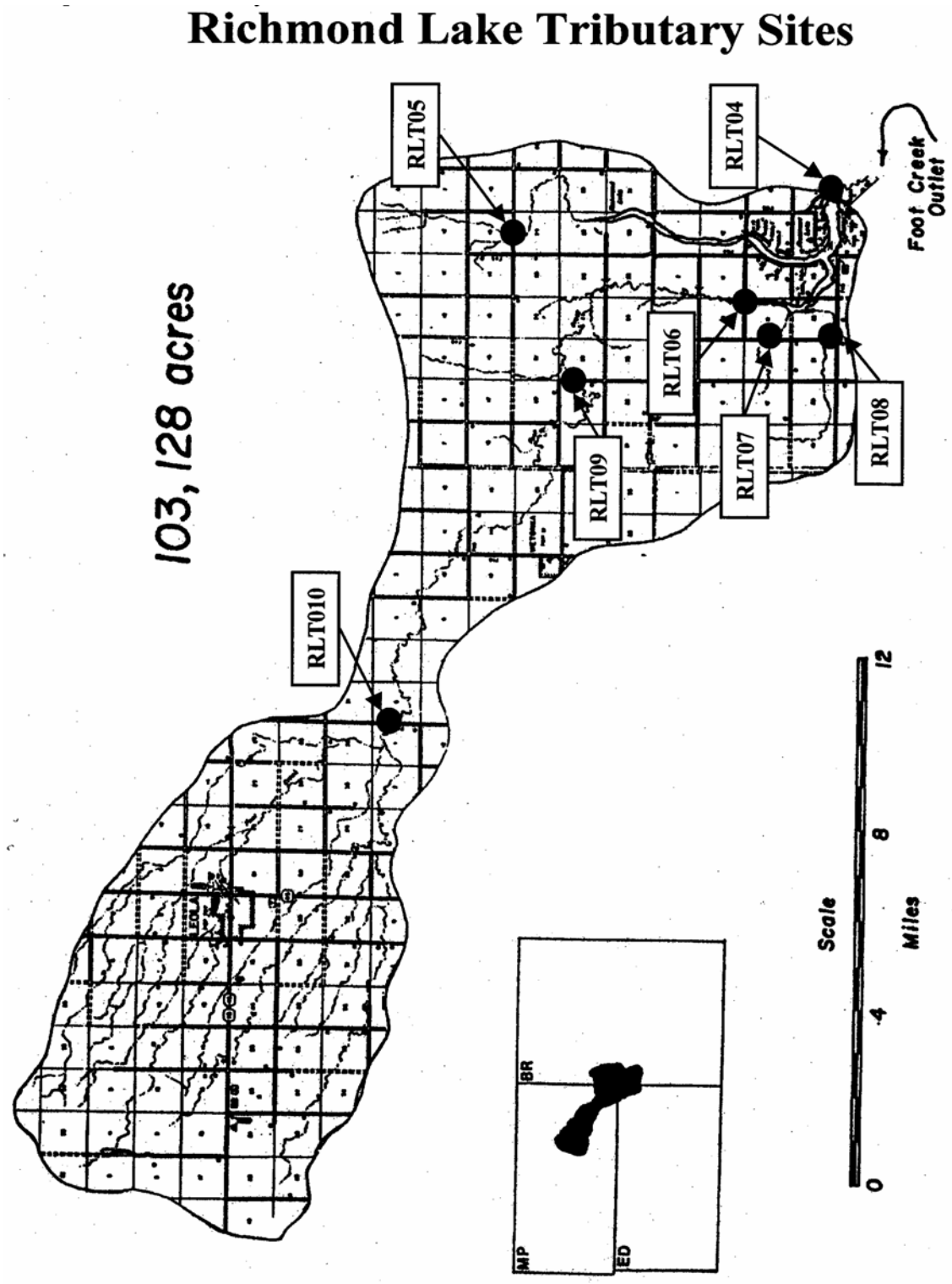

Figure 3. Richmond Lake Tributary Sites

Objective 3. QA/QC Sampling

Field water quality samples were collected in accordance with Standard Operating Procedures of the South Dakota Non-point Source Program. Duplicate and blank samples were collected during the course of the project to provide defendable proof that sample data were collected in a scientific and reproducible manner. A minimum of 10 percent of all water quality samples needed to be Quality Assurance/Quality Control (QA/QC). There were a total of 106 samples collected during the lake and tributary sampling. Of those samples, 14 were QA/QC.

QA/QC data collection began in May 2003 and was completed in February 2004. For the tributary sites, blank samples were collected on May 9, 2003, May 30, 2004, and June 11, 2004. Blank samples analyzed showed detections for three parameters. Suspended solids were detected in the May 9, 2003 blank sample (0.15 mg/L), ammonia and total dissolved phosphorus were detected in the May 30, 2004 and June 11, 2004 blank samples (ammonia 0.03 mg/L and total dissolved phosphorus 0.002 mg/L respectively for both samples). Detection limit for suspended solids is <1 mg/l, ammonia is <0.02 mg/L, and total dissolved phosphorus is <0.002 mg/L. Ammonia and total dissolved phosphorus were just over the detection limit. Reasons for increased ammonia and total dissolved phosphorus in blank samples could have been from a poorly rinsed sample bottle, sample contamination, contamination of distilled water, or laboratory error.

For the inlake sites, blank samples were collected on June 18, 2003, August 19, 2003, and February 18, 2004. Blank samples analyzed showed detections for two parameters. Ammonia and total dissolved phosphorus were detected in the June 18, 2003 and August 19, 2003 blank samples (ammonia 0.03 mg/L and total dissolved phosphorus 0.002 mg/L respectively for both samples). Detection limit for ammonia is <0.02 mg/L and total dissolved phosphorus is <0.002 mg/L. Ammonia and total dissolved phosphorus were just over the detection limits. Reasons for increased ammonia and total dissolved phosphorus in blank samples could have been from a poorly rinsed sample bottle, sample contamination, contamination of distilled water, or laboratory error.

The following are laboratory results of replicate samples taken from Richmond Lake on the dates described in the above paragraph:

Alkalinity: Numbers do not indicate any significant problems when compared to actual sample.

Total Solids: Numbers do not indicate significant problems when compared to actual sample.

Suspended Solids: Numbers do not indicate any significant problems when compared to actual sample.

Ammonia, Nitrates, TKN, and Total Phosphorus: Numbers do not indicate any significant problems when compared to actual sample.

Dissolved Phosphorus: Numbers do not indicate any significant problems when compared to actual sample.

E. coli/Enterococci: There is some sample variability between the actual sample and replicate sample. Natural variation is the most likely reason for the differences in samples.

Objective 4. AnnAGNPS Data Collection/Land Use Survey/Potential Pollution Sources

Many of the landowners in the watershed were contacted individually to assess the condition of animal feeding areas located within the project area. Investigations found that there were potential pollution sources in the Richmond Lake watershed. Contacts were made with landowners and feedlot operators regarding nutrient and sediment runoff.

Objective 5. Public Participation and Involvement

All landowners within the Richmond Lake watershed were contacted regarding information on land-use practices and/or animal feeding operations. There was a response rate of over 80% to the letters and surveys sent to landowners and/or operators.

Monthly updates were given at South Brown Conservation District board meetings, which are open to the public. There was also a project update presented at the Richmond Lake Association meeting in May of 2004. Additional information was made available through news releases printed in the quarterly South Brown Conservation District newsletters.

Objective 6. Development of Watershed Restoration Recommendations

Data was collected from tributary sites and analyzed through the use of the FLUX model, a watershed model from the Army Corps of Engineers. FLUX loadings, water and hydrologic budgets along with the AnnAGNPS watershed model were used to determine critical areas in the watershed.

Objective 7. Report Writing

This final report of the Richmond Lake Watershed Assessment is the end result of the investigation of impairments to Richmond Lake and its watershed. This final report will be used to generate a TMDL report.

EVALUATION OF GOAL ACHIEVEMENTS

The goal of the Richmond Lake Watershed Assessment Project was to determine and document sources of impairment to the lake and to develop feasible alternatives for restoration. This was accomplished through the collection of tributary and lake data aided by the completion of the AnnAGNPS watershed modeling tool. Through data analysis and modeling, identification of impairment sources was possible. Modeling and sampling found pollution sources in the Richmond Lake watershed. Through the use of properly installed BMP's in the Richmond Lake watershed driven by an implementation project, impairments found during the assessment can be resolved. The study was conducted because Richmond Lake was listed on the 2006 South Dakota 303 (d) waterbody list for its trophic status.

Table 3. Proposed and Actual Completion Dates

OBJECTIVE	PROPOSED COMPLETION DATE OF	ACTUAL COMPLETION DATE OF
1. Lake Sampling	March 2004	February 2004
2. Tributary Sampling	March 2004	July 2004
3. QA/QC Sampling	March 2004	February 2004
4. AnnAGNPS Data Collection	December 2003	December 2003
5. Public Participation	May 2004	May 2004
6. Watershed Recommendations	May 2004	May 2004
7. Report Writing	May 2004	May 2004

Monitoring Results

Surface Water Chemistry

Flow Calculations

A total of 10 monitoring sites were selected for Richmond Lake and its tributaries. Of the 10 monitoring sites, seven were stream sites and three were in-lake. The tributary sites were selected to determine which portions of the watershed were contributing the greatest amount of nutrient and sediment load to Richmond Lake. The stream sites were equipped with Stevens Type F stage recorders, Isco 4230 bubble-type stage recorders, and Ott Thalimedes stage recorders. Water stages were monitored and recorded to the nearest $1/100^{th}$ of a foot at each of the seven stream sites. A Marsh-McBirney Model 201D flow meter was used in conjunction with staff gage and stage recorder measurements at various water levels during runoff events in the Richmond Lake watershed. The stages and flows were then used to create a stage-to-discharge table for each monitoring site. Stage-to-discharge tables may be viewed in Appendix C of this report.

Load Calculations

Total nutrient and sediment loads were calculated with the use of the U.S. Army Corps of Engineers eutrophication model FLUX. FLUX uses individual sample data in correlation with daily average discharges to develop six loading calculations for each given water quality parameter. As recommended in the application sequence, a stratification scheme and method of calculation was determined using the total phosphorus load. This stratification scheme is then used for each of the additional parameters. The stratification scheme and calculation methods used for Richmond Lake are listed in the following table (Table 4). It should be noted that site RLT04 never flowed during the project so the FLUX model was not run on that tributary site. Sample data collected for Richmond Lake may be found in Appendix B of this report.

Table 4. Flux Calculation Methods

SITE	STRATIFICATION SCHEME	CALCULATION METHOD
RLT04	N/A	N/A
RLT05	1 strata - Flow	Q WTD C
RLT06	1 strata - Flow	Q WTD C
RLT07	1 strata - Flow	Q WTD C
RLT08	1 strata - Flow	Q WTD C
RLT09	1 strata - Flow	Q WTD C
RLT10	1 strata - Flow	Q WTD C

Tributary Sampling Schedule

Water samples were collected at six of the seven stream monitoring sites for Richmond Lake from the spring of 2003 through the summer of 2004. Samples were collected using a grab sample method. Water samples were then filtered, preserved, and packed in ice for shipping to the State Health Laboratory in Pierre, SD, for analysis. The laboratory assessed the following parameters:

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

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

Precipitation
Odor
Film
Water Depth
Water Color
Wind
Presence of Fish
Turbidity
Ice Cover

Parameters measured in the field by sampling personnel were:

Water Temperature
Dissolved Oxygen
Air Temperature
Field pH

Inlake Sampling Schedule

Sampling of Richmond Lake began in April 2003 and continued through February 2004 at three pre-selected sites on the lake. Water samples were filtered, preserved, and packed in ice for shipping to the State Health Lab in Pierre, SD. 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 of the sites recorded visual observations of the following weather and lake characteristics.

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

Parameters measured in the field by sampling personnel were:

Water Temperature
Conductivity
Field pH
Air Temperature
Dissolved Oxygen
Water Depth

South Dakota Water Quality Standards

The State of South Dakota assigns beneficial uses to all lakes in the state. The beneficial uses of fish and wildlife propagation, recreation, and stock watering are assigned to all lakes. All portions of Richmond Lake must maintain the criteria that support these uses. In order for the lake to maintain these uses, there are 13 standards that must be maintained. These standards, as well as the water quality values that must be met, are listed in Table 5 below.

Table 5. State Water Quality Standards

Parameter	Criteria
Nitrate	Average ≤50 mg/L for 3-samples in separate weeks within a 30-day period ≤88 mg/l (single sample)
Alkalinity	Average ≤750 mg/L for 3-samples in separate weeks within a 30-day period ≤1,313 mg/L (single sample)
Total Dissolved Solids	Average ≤2,500 mg/L for 3-samples in separate weeks within a 30-day period ≤ 4,375 mg/L daily maximum for a grab sample
Total Suspended Solids	≤158 mg/L Daily ≤90 mg/L 30-Day Average
Conductivity	≤4,000µmhos (mean) ≤7,000µmhos (single sample)
Total Petroleum Hydrocarbon Oil and Grease	≤10 mg/L ≤10 mg/L
pH	≥ 6.5 and ≤9.0 su
DO	≥ 5.0 mg/L
Fecal Coliform	geometric mean ≤200 colonies per 100 mg/ L for 5-samples in separate 24-hour periods for any 30-day period ≤400 mg/L daily maximum for a grab sample
Total Suspended Solids	Average ≤150 mg/L for 3-samples in separate weeks within a 30-day period ≤ 263 mg/L daily maximum for a grab sample
Temperature	≤80 degrees F
Un-ionized Ammonia	≤0.05 mg/L
Undisassociated Hydrogen Sulfide	≤0.002 mg/L (single grab)

Seasonal Loading

Due to unseasonably dry conditions during the project period, seasonal loadings to Richmond Lake were heavily influenced by spring and early summer runoff. Snowmelt and spring rainstorm events played a major role in loading. Table 6 depicts the percentage of discharge occurring in the watershed that entered the lake at different times of the sampling season. As shown in the Table below, in 2003 and 2004, almost all of the seasonal loading came during the spring and early summer. Runoff never occurred during the remainder of the year due to a lack of rainfall and subsoil moisture. BMPs implemented within the watershed should be

designed with maximum protection to the lake during the spring and early summer months. However, summer and fall should also be taken into consideration due to the year-to-year variability in the pattern of rainfall and snowfall.

Table 6. Estimated Seasonal Loading for Richmond Lake

Date (2003 and 2004)	Days	Total Phosphorus Average Monthly Total Discharge (kg)	Seasonal Percent of Total Discharge
Spring 2003	61	871.6	94%
Summer 2003	62	48.9	5%
Fall 2003	91	8.1	1%
Spring 2004	122	100.8	25%
Summer 2004	60	290.6	75%

Inlake Water Quality Parameters

Water Temperature

Water temperature is of great importance to any aquatic ecosystem. Many organisms and biological processes are temperature sensitive. Blue-green algae tend to dominate warmer waters while green algae grow better under cooler conditions. Water temperature also plays an important role in physical conditions. Oxygen dissolves in higher concentrations in cooler water as cooler water has the capacity to hold more dissolved oxygen than warm water. The toxicity of un-ionized ammonia is also directly related to warmer temperatures.

Water temperature in for Richmond Lake showed seasonal variation that is consistent with the lake's geographic location, steadily increasing in the spring and summer and consistently decreasing in the fall and winter. It can be reasonably expected that during most years the inlake temperatures would be within a few degrees of the project data at their respective dates. The water temperature in the lake exhibited little variation from site RL01, RL02, to RL03. The highest temperature recorded was 26.69 ^{o} C from the surface at site RL01 on August 19, 2003, which is well below the state standards that require a maximum temperature be under 32.2^{o} C.
The single lowest water temperature was recorded in February 2004 at 1.0^{o} C. As expected, during this time the highest dissolved oxygen levels in Richmond Lake were recorded.

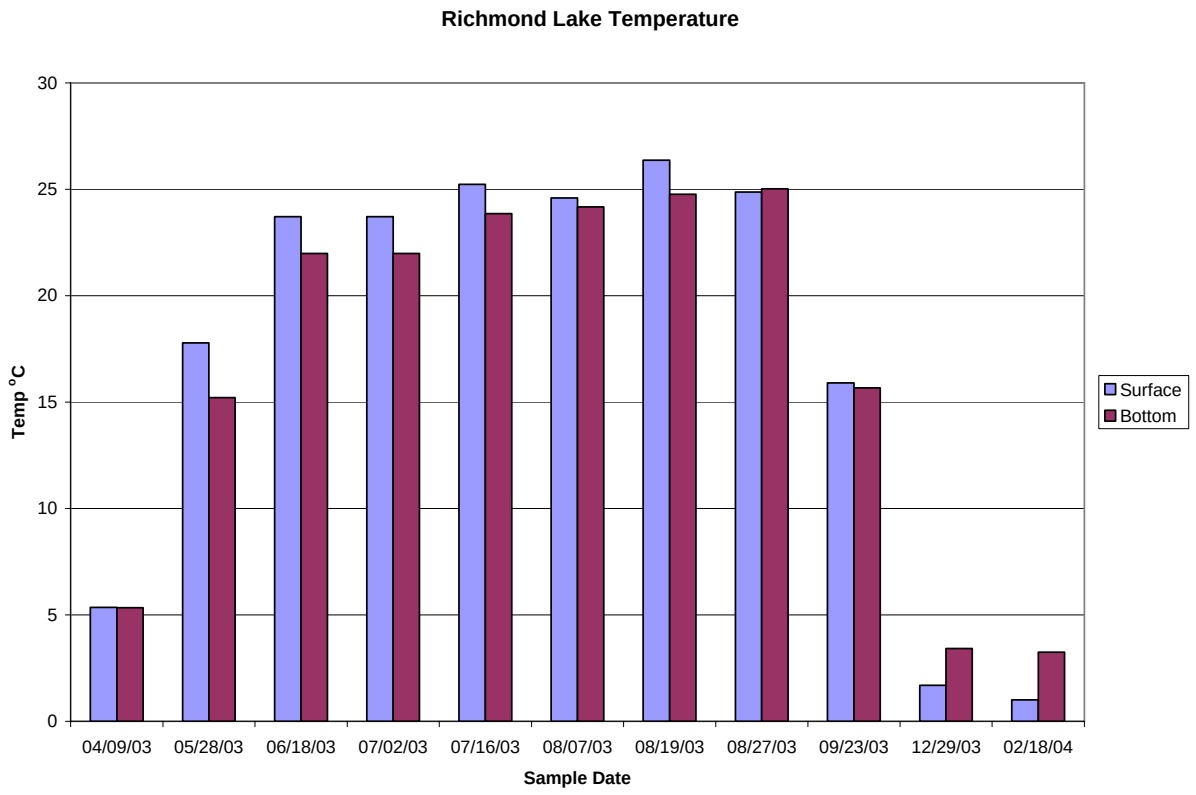

Figure 4. Richmond Lake Water Temperature

Dissolved Oxygen

There are many factors that influence the concentration of dissolved oxygen (DO) in a water body. As previously mentioned, temperature is one of the most important of these factors. As the temperature of water increases, its ability to hold DO decreases. Daily and seasonal fluctuations in DO may occur in response to algal and bacterial action (Bowler, 1998). As algae photosynthesize during the day, they produce oxygen, which raises the concentration in the epilimnion. As photosynthesis ceases at night, respiration utilizes available oxygen causing a decrease in concentration. During winters with heavy snowfall, light penetration may be reduced to the point that the algae and aquatic macrophytes in the lake cannot produce enough oxygen to keep up with consumption (respiration) rates. This results in oxygen depletion and may ultimately lead to a fish kill.

Oxygen levels in Richmond Lake ranged from 0.26 mg/L to 15.23 mg/L in 55 DO recordings taken from the lake throughout the project period. Nine recorded DO levels fell below the state standard of 5.0 mg/L. Seven of those nine were recorded at sampling site RL03, at or near the bottom. Site RL03 is located near the face of the dam of Richmond Lake where water depths are the greatest (20+ feet). Low levels of DO at site RL03 are probably a result of lake stratification and the bottom being anoxic. Elevated levels of total phosphorous at this site suggest the lake was anoxic in the deepest strata at that time, as evidenced by the lower levels of DO. Although DO levels may have been low at or near the bottom, the remainder of the DO

profile at this site was sufficient enough to meet state standards and maintain a healthy fishery. At the remaining lake sites (RL01 and RL02), DO levels were sufficient, accept for one reading at RL01 (north arm of Richmond Lake) taken from the surface on August 27, 2003 and RL02 (west arm of Richmond Lake) taken from the bottom on August 7, 2003. The most likely reason for low DO levels at these sites was a result of warm water in late summer and its inability to hold DO. However, there were sufficient DO levels in the lake profiles at these sites to maintain a healthy fishery. The lowest DO levels in the lake were recorded during the summer months when water temperatures were highest. In October, water temperatures were cooling and the lake's DO levels began to rise.

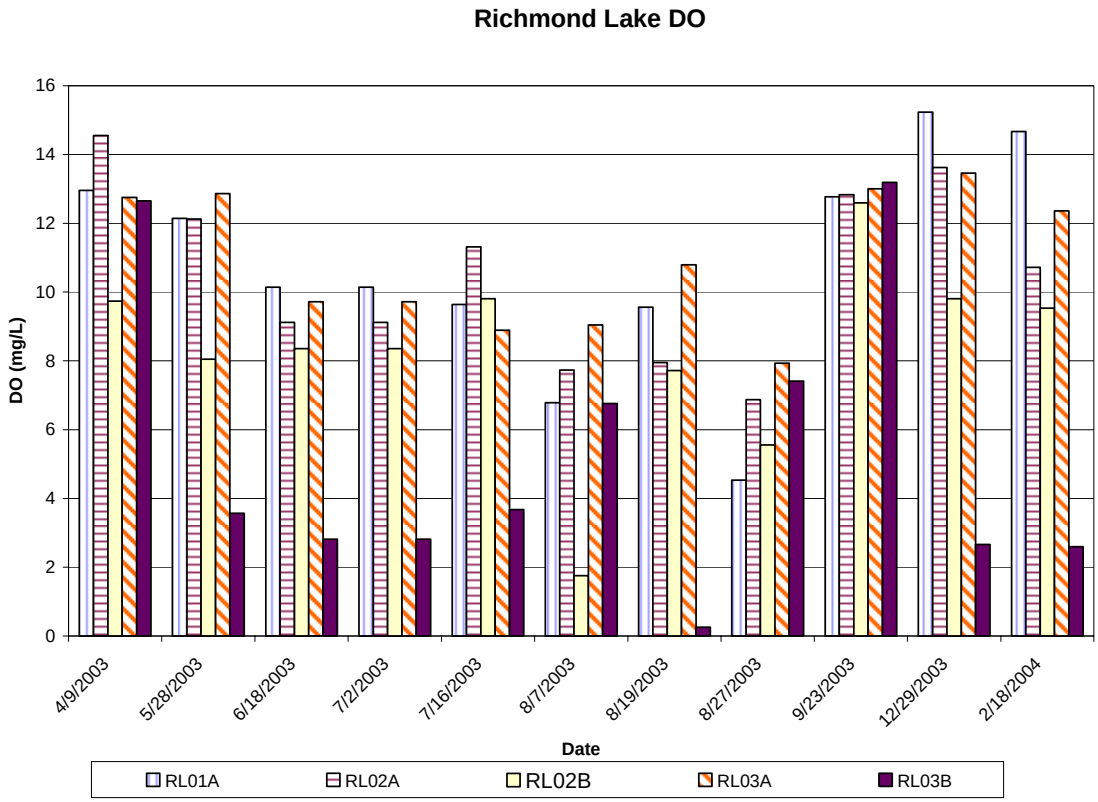

Figure 5. Richmond Lake Dissolved Oxygen

<u>pH</u>

pH is a measure of free hydrogen ions (H+) or potential hydrogen. More simply, it indicates the balance between acids and bases in water. It is measured on a logarithmic scale between 0 and 14 and is recorded as standard units (su). At 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). Algal and macrophyte photosynthesis act to increase a lake's pH. The decomposition of organic matter will reduce the pH. The extent to which this occurs is affected by the lake's ability to buffer against changes in pH. The presence of a high alkalinity (>200 mg/L) represents considerable buffering capacity and will reduce the effects of both photosynthesis and decay in producing large fluctuations in pH.

pH values exhibited only small differences between sampling sites at Richmond Lake. There were five pH values that exceeded state standards of which all five were recorded on the same day (September 23, 2003). At that time, it was noted by the coordinator in his field record that the pH millivolts on the YSI multi probe meter indicated the pH probe was nearing its expiration date. The pH probe was replaced and future pH readings were within acceptable ranges. Due to the bad pH probe in the equipment, it is believed the five pH values recorded over 9.0 were not accurate. South Dakota water quality standards require pH readings in Richmond Lake be maintained between the values of 6.0 and 9.0. The single highest pH with a good probe of 8.56 was recorded in July, 2000. The lowest pH of 7.68 was recorded in February, 2001. Both of these values fall within the limits set forth by the State of South Dakota.

Alkalinity

A lake's total alkalinity affects the ability of its water to buffer against changes in pH. Total alkalinity consists of all dissolved electrolytes (ions) with the ability to accept and neutralize protons (Wetzel, 2000). Due to the abundance of carbon dioxide (CO_2) and carbonates, most freshwater contains bicarbonates as the primary source of alkalinity. It is commonly found in concentrations as high as 200 mg/L or greater. Natural concentrations usually range from 20 mg/L to 200 mg/L (Lind, 1985).

The alkalinity in Richmond Lake varied from a low of 235 mg/L in July 2003 to a peak value of 309 mg/L in February 2004. The increase during the winter months may be attributed to concentration of ions in the water due to the volume of ice that also prevents the escape of carbon dioxide from bicarbonates to the air due to the lack of air-water interface. During the spring and summer, photosynthesis carried on by algae and macrophytes effect the alkalinity. The ice cover and cold temperatures reduced this action during the winter months allowing decomposition on the lake bottom to cause greater accumulation of carbon dioxide and bicarbonates in the water column.

Solids

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

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

Richmond Lake exhibited very little variation in total solids and dissolved solids concentrations through the course of the sampling period. Peak values at all lake sites were observed during periods of ice cover in February 2003 and February 2004 with the highest recorded value of 1,340 mg/L at site RL03. When ice forms and thickens on the lake, dissolved solids tend to be pushed out of the ice crystal structure as it forms and into the water column as previously noted. The lowest values were observed during summer samples collected in July 2003.

Suspended solids concentrations in Richmond Lake remained fairly low throughout the course of the sampling period. The lowest concentrations were recorded during ice cover when the effects of wind and wave action had been reduced. Volatile suspended solids followed the same trend as total suspended solids with increased concentrations during the summer and decreased concentrations during the winter.

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 can fix atmospheric nitrogen, adding it to the nutrient supply in the lake.

Nitrates/nitrites were all recorded below the detection limit (0.10 mg/L) for Richmond Lake. Ammonia levels were recorded above the detection limit of 0.02 mg/L but the un-ionized ammonia levels were all within the state standards of less than 0.05 mg/L. At site RL03B (bottom), elevated levels of ammonia were recorded throughout the project period. At this site, the water is over 20 feet deep. With the absence of oxygen at the bottom, breakdown of organic matter is causing higher detections of ammonia.

The sum of ammonia and the organic nitrogen present in a water body is measured as TKN. Ammonia and nitrate/nitrite are the most readily available forms of nitrogen for plant growth. Macrophytes, along with algae, consume nitrates and ammonia in a waterbody. Richmond Lake does not have a dense population of aquatic macrophytes, but any available form of nitrogen in the water column is immediately consumed by algae. Richmond Lake is extremely nitrogen-limited.

Total 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, 2000). Total phosphorus is the sum of all attached and dissolved phosphorus in the lake. The attached phosphorus is directly related to the amount of total suspended solids present. An increase in the amount of suspended solids increases the fraction of attached phosphorus. Phosphorus loading to lakes can be of an internal or external nature. External loading refers to surface runoff over land, dust, and precipitation. In this case, Richmond Lake has a low amount of

total phosphorus resulting from external loading during a normal precipitation year (<25%). Internal loading refers to the release of phosphorus from the bottom sediments to the water column of the lake. In the case of Richmond Lake, the vast majority of total phosphorus comes from the lakes internal loading. During the assessment, precipitation was minimal. Due to light precipitation, the lake produced even a greater internal load. There was a total of 7,823 kg/yr loaded into the lake of which 7,126 kg/yr (91%) was from internal loading, leaving only 697 kg/yr (9%) coming from the tributaries.

The average in-lake total phosphorus during the assessment was 0.368 mg/L, which is a very high amount considering algae only require 0.02 mg/L of dissolved phosphorus to start growing rapidly. Algal blooms have become a major water quality problem in Richmond Lake the past several years. The higher amounts of total phosphorus present during the study were greatest during the summer months (July and August) when wave action stirs the phosphorus attached to sediment in the shallower parts of the lake releasing phosphorus into the water column while in the deeper portion of the lake, low levels of oxygen caused the lake to turn anoxic, also releasing phosphorus from the bottom sediment. Winter and spring concentrations were considerably lower than the average concentration at approximately 0.209 mg/L. Surface samples had some variation in concentration each month at RL01, RL02, and RL03. It is believed that the phosphorus levels were generally higher at RL01 and RL02 due to sediment that was stirred from wave action in shallow water. Because the maximum depth was less than 10 feet at RL02, bottom samples were not collected at that site.

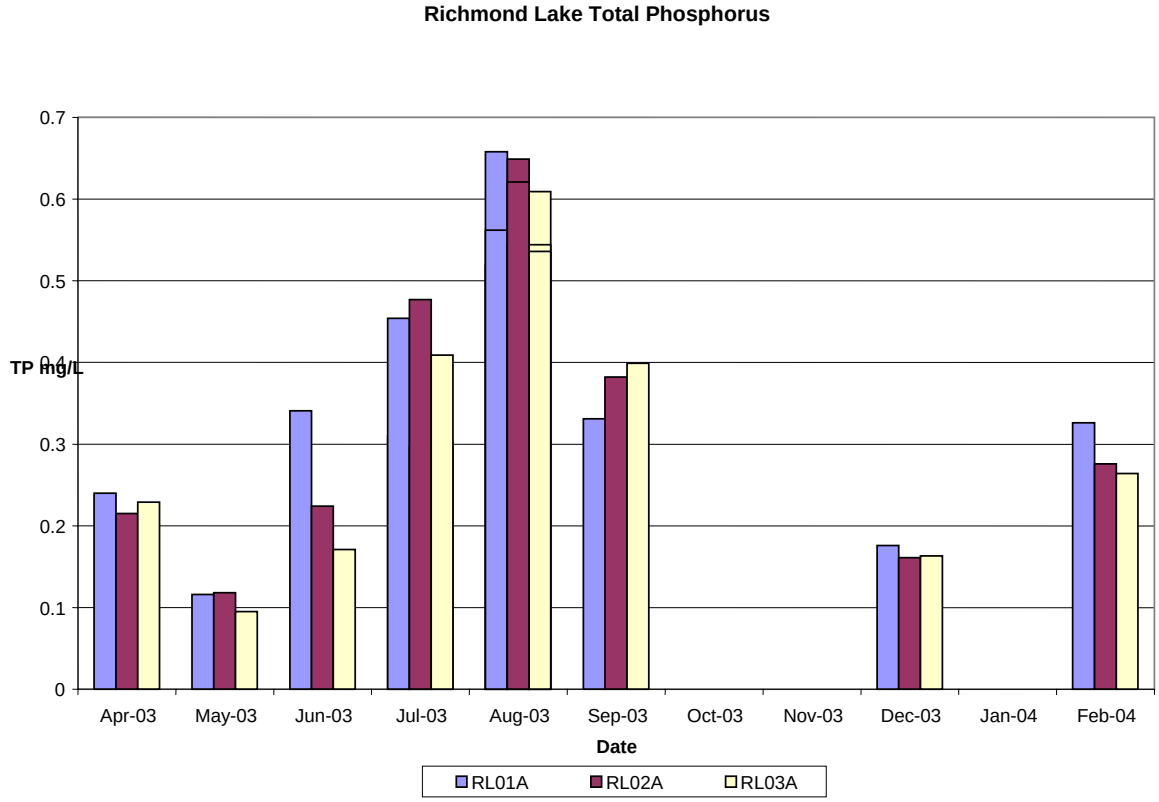

Figure 6. Monthly Total Phosphorus Concentrations for Richmond Lake

Dissolved Phosphorus

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

Dissolved phosphorus concentrations ranged from 0.076 mg/L in May 2003 to 0.597 mg/L at RL03 in August, 2003. The high level of dissolved phosphorus most likely is a result of Richmond Lake going anoxic in July in the deepest portion of the lake (RL03). Low DO concentrations at the bottom of site RL03 is a true indicator that a release occurred. As a result, dissolved phosphorus was released into the water column thus elevating the dissolved concentration causing a robust algal bloom. During July and August of 2003, one of the worst algae blooms ever noted was said to have occurred in Richmond Lake at that time. When looking at average percentages of dissolved phosphorus in suspension, the average percentage of phosphorus in dissolved state over the sampling period was 17.8 %. The remaining 82.2% of the total phosphorus is being held in sediment or algae. The data appears to show that algae are consuming as much of the available dissolved phosphorus as nitrogen becomes available.

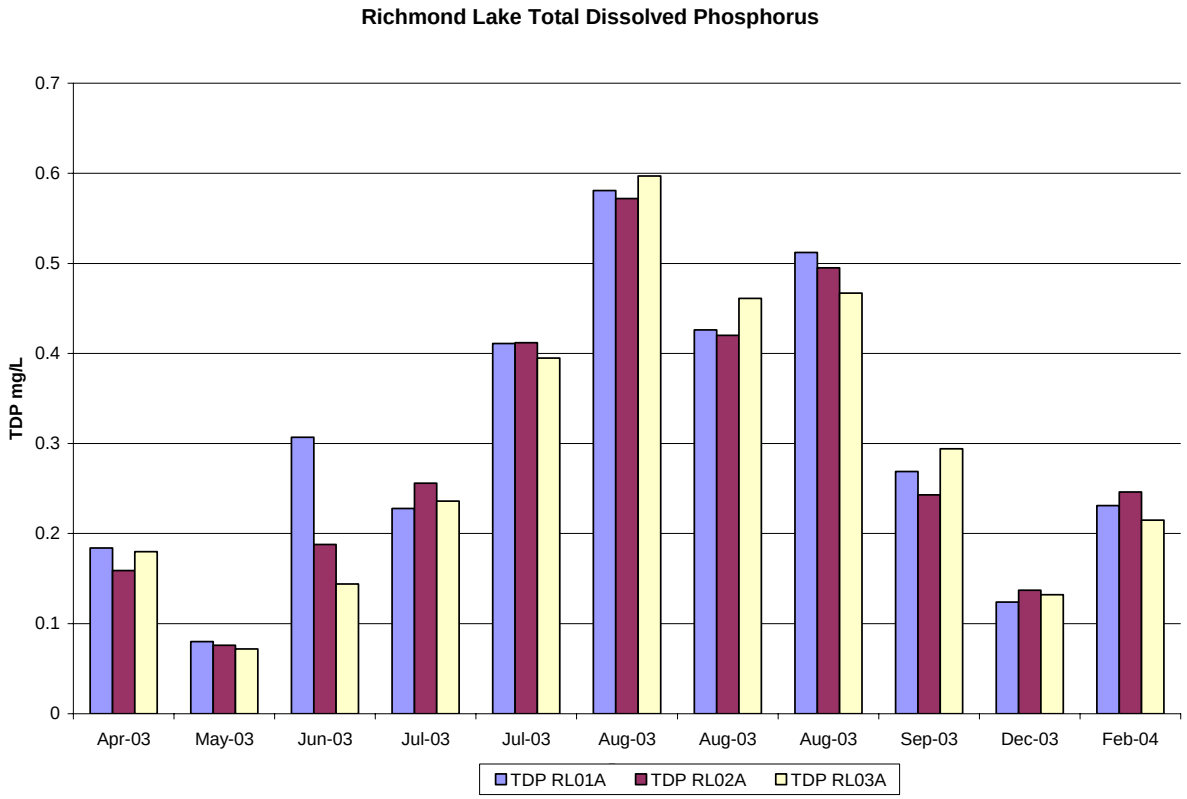

Figure 7. Monthly Total Dissolved Phosphorus for Richmond Lake

Fecal Coliform Bacteria

Fecal coliform bacteria are found in the waste of warm-blooded animals. Some common types of bacteria are *E. coli*, S*almonella*, and *Streptococcus*, which are associated with livestock, wildlife, and human waste (Novotny, 1994). Fecal coliform is used as an indicator to determine if pathogens may be present in a waterbody.

Richmond Lake is listed for the beneficial use of immersion recreation which requires that no fecal coliform single sample exceed 400 colonies/100mL or the 30-day geometric mean (consisting of at least 5 samples) be no more then 200 colonies /100mL. There were no samples that exceeded the state standard during the monitoring process of this project. Only three samples exceeded detection limits (10 colonies per 100 mL). The remaining fecal coliform samples were non-detect.

Chlorophyll

The median chlorophyll-*a* concentration during the project was 19.35 mg/L with values ranging from 2.68 mg/L (December 2003) to 50.57 mg/L (July 2003). An increase in chlorophyll was observed during the summer (May - September) attributable to blue-green algal blooms observed in the upper level of the water column. Some Blue-green algae (not all) are nitrogen fixers and can grow in the absence of nitrogen provided there is adequate phosphorous available. Richmond Lake is nitrogen limited and heavily loaded with phosphorous providing ideal conditions for blue-green algae growth.

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 lake eutrophication. The ideal ratio of nitrogen to phosphorus for aquatic plant growth is 10:1 (EPA, 1990). Ratios higher than 10 indicate a phosphorus-limited system. Those that are less than 10 represent nitrogen-limited systems.

Richmond Lake is severely nitrogen-limited with nearly all available nitrogen being used up during chlorophyll production. The average nitrogen-to-phosphorus ratio for Richmond Lake was 3.76:1 during the project period. Surface samples had relatively close ratios to the lake's overall average. The greatest difference was seen in May 2003 when the ratio jumped to 9.9:1, nearly the ideal ratio of nitrogen-to-phosphorus. The smallest ratio was recorded in August 2003 at 1.63:1. Those results again indicate that Richmond Lake is an extremely nitrogen-limited waterbody.

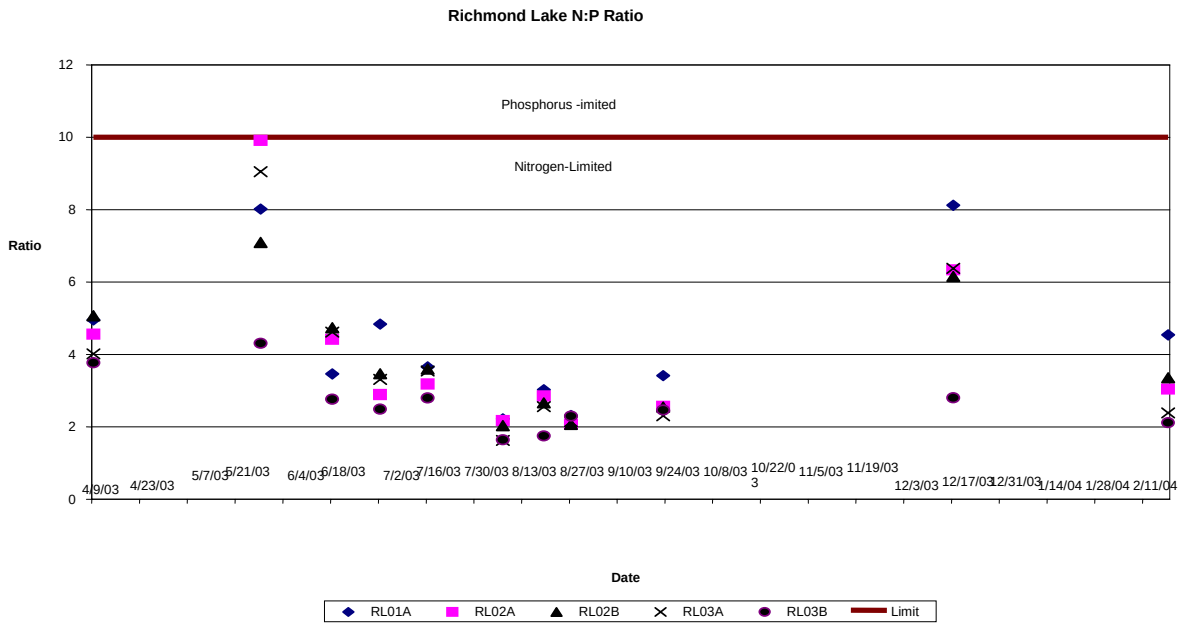

Figure 8. Richmond Lake N:P Ratio

Trophic State

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

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

Table 7. Trophic State Ranges

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

Richmond Lake is classified for warmwater permanent fish life propagation. As determined in "Targeting Impaired Lakes in South Dakota" (WRAP 2006), lakes in this category should have a median TSI Secchi-chlorophyll value of 58.4 or less to be fully supporting the fishery beneficial use. Richmond Lake median TSI values exceed fully supporting at 67.4. Secchi-chlorophyll TSI values for the lake ranged from 47.4 to 73.2 and 50.3 to 78.1, respectively. During the study, the median trophic state for Richmond Lake during 2003 and 2004 was 67.4, placing it in the hypereutrophic category.

Reduction Response Modeling

Inlake reduction response modeling was conducted with BATHTUB, an Army Corps of Engineers eutrophication response model (Walker, 1999). System responses were calculated using reductions in both the loading of phosphorus to the lake and from estimates of internal load. Loading data from the Richmond Lake watershed was taken directly from the results obtained from FLUX modeling at the inlet of each tributary to the lake.

BATHTUB provides numerous models for the calculation of inlake concentrations of phosphorus, nitrogen, chlorophyll *a*, and Secchi depth. Models are selected that most closely predict current inlake conditions from the loading data provided. As reductions in the phosphorus load are predicted in the loading data, the selected models will closely mimic the response of the lake to these reductions. BATHTUB not only predicts the inlake concentrations of nutrients, it also produces a number of diagnostic variables that help to explain the lake responses.

TSI values calculated by the model were based on average growing season lake concentrations and tributary loading data collected and estimated over the course of the project. The model estimated a growing season TSI value of 61.7. This value exceeds the fishery beneficial use target for full support and indicates Richmond Lake as hyper-eutrophic.

Richmond Lake was nitrogen-limited for the entire growing season so modeled inputs focused on the reduction of phosphorus from the watershed. This procedure was used because during the 2003 growing season, internal phosphorus loads were strongly influencing in-lake conditions and phosphorus loads from the watershed were relatively minor. Internal phosphorus loads were extremely high which prevented the model from calibrating properly. Table 8 shows output data generated by the BATHTUB model for percent phosphorus reductions in increments of 10% for that scenario.

Table 8. Output data generated by the BATHTUB model depicting percent phosphorus reductions from the Richmond Lake watershed to derive estimated shifts in mean growing season TSI.

	Percent External Phosphorus Reductions										
Parameter	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Total Phosphorus (mg/m^3)	461.8	416.8	371.8	326.9	281.9	236.9	191.9	146.9	101.9	57.0	16.5
Total Nitrogen (mg/m^3)	1239.0	1239.0	1239.0	1239.0	1239.0	1239.0	1239.0	1239.0	1239.0	1239.0	1239.0
Composite Nutrient (mg/m^3)	89.0	88.7	88.2	87.4	86.4	84.7	82.0	77.2	67.8	48.2	16.2
Chlorophyll-a (mg/m^3)	54.7	54.4	54.0	53.5	52.7	51.4	49.4	45.8	38.9	25.4	6.5
Secchi (meters)	0.7	0.7	0.7	0.7	0.7	0.7	0.8	0.8	1.0	1.4	4.1
Organic Nitrogen (mg/m^3)	1410.4	1403.8	1394.9	1382.3	1363.9	1335.5	1288.9	1206.7	1049.9	742.8	311.4
Total Dissolved Phosphorus (mg/m^3)	95.2	94.7	94.0	93.0	91.5	89.3	85.7	79.3	67.0	43.1	9.4
Antilog PC-1 (principle Components)^2	2024.3	2005.4	1979.7	1943.8	1891.8	1812.7	1686.5	1473.9	1105.3	527.0	57.5
Antilog PC-2 (principle Components)^3	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.7	15.6	15.4	13.6
(Total Nitrogen-150)/Total Phosphorus	2.4	2.6	2.9	3.3	3.9	4.6	5.7	7.4	10.7	19.1	66.1
Inorganic nitrogen/Phosphorus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	5.4	35.7	130.7
Turbidity 1/M (1/Secchi-0.025* Chlorophyll-a)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Mixed Layer Depth * Turbidity	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Mixed Layer Depth * Secchi	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.2	1.1	0.7	0.2
Chlorophyll-*a* * Secchi	37.8	37.8	37.8	37.7	37.7	37.7	37.6	37.4	37.0	35.5	26.8
Mean Chlorophyll-a / Total Phosphorus	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.4
Frequency (Chlorophyll-a > 10)%	99.2	99.2	99.2	99.2	99.1	99.0	98.8	98.4	97.0	88.4	15.8
Frequency (Chlorophyll-a > 20)%	90.5	90.4	90.2	89.9	89.5	88.8	87.5	84.7	77.7	53.1	1.7
Frequency (Chlorophyll-a > 30)%	74.5	74.2	73.9	73.3	72.5	71.2	68.9	64.5	54.3	28.2	0.3
Frequency (Chlorophyll-a > 40)%	57.7	57.4	57.0	56.3	55.3	53.8	51.2	46.3	36.1	14.9	0.1
Frequency (Chlorophyll-a > 50)%	43.4	43.1	42.7	42.0	41.1	39.6	37.1	32.5	23.7	8.1	0.0
Frequency (Chlorophyll-a > 60)%	32.3	32.0	31.6	31.0	30.1	28.8	26.6	22.8	15.6	4.5	0.0
Carlson TSI-(Phosphorus)	92.6	91.1	89.5	87.6	85.5	83.0	80.0	76.1	70.8	62.4	44.6
Carlson TSI-(Chlorophyll-a)	58.0	57.9	57.8	57.7	57.6	57.4	57.0	56.2	54.6	50.4	37.1
Carlson TSI-(Secchi)	65.3	65.3	65.2	65.0	64.8	64.5	63.9	62.9	60.7	55.2	39.6
Median TSI Chlorophyll-Secchi	**61.65**	**61.6**	**61.5**	**61.35**	**61.2**	**60.95**	**60.45**	**59.55**	**57.65**	**52.80**	**44.95**

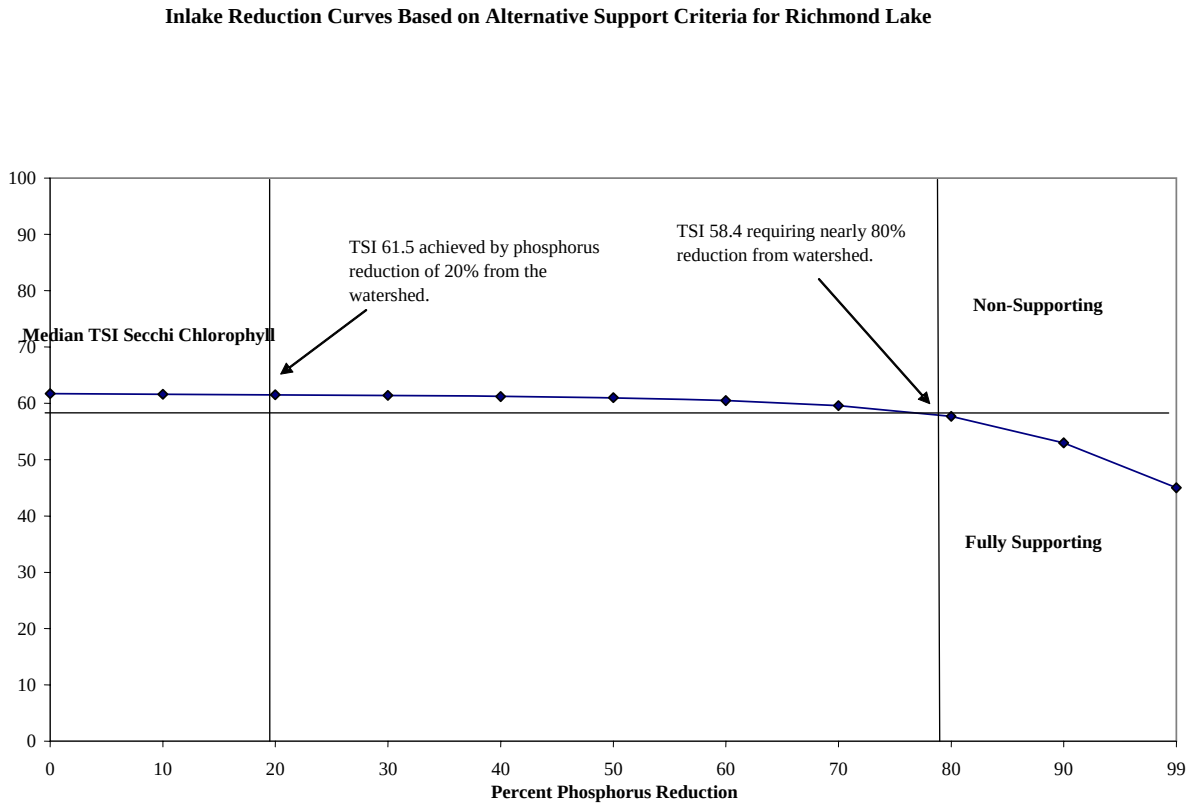

Figure 9. Richmond Lake Reduction Response

According to the modeled reductions, it is not possible to reduce phosphorus loads from the watershed sufficiently to bring the median growing season TSI to full support by previously established beneficial use criteria (Lorenzen 2006). The internal loading in Richmond Lake is so severe that realistic watershed reductions would have little effect on sufficiently lowering the TSI value three points. The model estimates a phosphorus reduction in excess of 80% from the watershed would be required to comply with the current fishery beneficial use classification targeting criteria. Based on social and economic constraints, a TMDL for full support would **not** be attainable under the 2005 fishery beneficial use classification for full support. A subsequent alternative site-specific (watershed-specific) evaluation criterion (fully supporting, median TSI < 61.5) is proposed based on AnnAGNPS modeling, BMPs and watershed specific phosphorus reduction attainability for Richmond Lake. Figure 9 shows an in-lake reduction curve for phosphorus reductions based on alternative site specific criteria (TSI < 61.5) for full support.

Upon careful consideration, the best attainable reduction was modeled. To achieve a modeled median TSI of < 61.5 (alternative full support) phosphorus reductions of 10% may be attained by installing proper BMPs in feedlot areas. Eliminating runoff from the first 4 feedlots (50% of the AFO load) on the list (page 37) will reduce lake loading by approximately 5%. Eliminating runoff from the first 15 lots on the list will eliminate 85% of the AFO load and reduce phosphorus loads to the lake by 8.5%.

Additional phosphorus reductions can improve the median growing season TSI. According to the AnnAGNPS model, a 27% reduction in phosphorus can be achieved by transforming rangeland and crop land into grassland. This scenario is not realistic social economically. In addition to a 10% reduction in AFO contributions, a conservative 10% reduction in crop land/rangeland is also needed to reach the TSI site specific reduction target. Due to the significant impact of internal phosphorus loads on the trophic status of Richmond Lake, inlake treatment would be beneficial to achieve a TSI which falls below the alternative target for full support. According to the AnnAGNPS model, implementing BMPs on the priority cells would not have an appreciable impact on reductions in phosphorus from the watershed. It is imperative that efforts be directed to the watershed prior to an inlake treatment to increase effectiveness.

Tributary Site Summary

As discussed in the "watershed priority areas" section of the ANNAGNPS report, Richmond Lake watershed has 52% or 14,840 acres composed of rangeland while the remaining 48% or 13,346 acres was cropped. There are three distinct groups of critical cells that emerged from the analysis. The first of these groups are those cells located around Richmond Lake and downstream (Southeast) of the community of Wetonka (grazing lands on excessively steep slopes). The second (cropped and are located near the main channel of the stream) is located in the immediate area of the community of Leola, and the third is north and west of Leola in the upper end of the Richmond Lake watershed where there are extensive wetlands with poorly defined drainage.

Watershed Overview

Runoff from 103,128 acres and rainfall are the primary sources of water entering Richmond Lake. The amount of ground water entering the lake is unknown at this time but is estimated to be small or insignificant.

Subwatersheds

The Richmond Lake drainage was divided into seven individual sub-watersheds; sub-watersheds RLT04, RLT05, RLT06, RLT07, RLT08, RLT09, and RLT10. Sub-watersheds RLT05, RLT06, and RLT07 contribute 79% of the total phosphorous load (0.933 tons/yr) and 74% of the total nitrogen (2.45 tons/Yr). Suspected sources of erosion are areas with a slope greater than 2.5% in combination with low grade soils and poor vegetative cover.

The following is a discussion of the sources and loadings of each sub-watershed in the Richmond Lake drainage from the FLUX and AnnAGNPS models:

RLT04

Subwatershed RLT04 was located at the outlet of Richmond Lake. Due to extremely dry conditions during the project period, a lack of water flow over the spillway hindered the ability to collect data at this site. No data was collected at RLT04.

RLT05

Sub-watershed RLT05 accounts for 9.7% of the Richmond Lake watershed area with 10,052 acres of drainage area. FLUX estimated that subwatershed RLT05 contributed approximately 25 tons of total suspended solids, 0.91 tons total nitrogen, and 0.316 tons total phosphorous on an annual basis to Richmond Lake. Sub-watershed RLT05 contributes a mean flow of 68 HM3/yr, 50% of the total sediment load to Richmond Lake, 26.8% of total phosphorus, and 26% of the total nitrogen load.

RLT06

Sub-watershed RLT06 accounts for 14.4% of the Richmond Lake watershed area with 14,864 acres of drainage area. FLUX estimated that subwatershed RLT06 contributed approximately 1.10 tons of total suspended solids, 0.116 tons total nitrogen, and 0.039 tons total phosphorous on an annual basis to Richmond Lake. Sub-watershed RLT06 contributes a mean flow of 69 HM3/yr, 2.2% of the total sediment load to Richmond Lake, 3.3% of total phosphorus, and 3.5% of the total nitrogen load.

RLT07

Sub-watershed RLT07 accounts for 2.5% of the Richmond Lake watershed area with 2,560 acres of drainage area. The FLUX model estimated that subwatershed RLT07 contributed approximately 8.29 tons of total suspended solids, 0.83 tons total nitrogen, and 0.30 tons total phosphorous on an annual basis to Richmond Lake. Sub-watershed RLT07 contributes a mean flow of 67 HM3/yr, 16.6% of the total sediment load to Richmond Lake, 25% of total phosphorus, and 25% of the total nitrogen load.

RLT08

Sub-watershed RLT08 accounts for 5.7% of the Richmond Lake watershed area with 5,892 acres of drainage area. The FLUX model estimated that subwatershed RLT08 contributed approximately 10.1 tons of total suspended solids, 0.45 tons total nitrogen, and 0.113 tons total phosphorous on an annual basis to Richmond Lake. Sub-watershed RLT08 contributes a mean flow of 99 HM3/yr, 20.2% of the total sediment load to Richmond Lake, 9.6% of total phosphorus, and 13.8% of the total nitrogen load.

RLT09

Sub-watershed RLT09 accounts for 22.3% of the Richmond Lake watershed area with 23,040 acres of drainage area. The FLUX model estimated that subwatershed RLT09 contributed approximately 5.28 tons of total suspended solids, 0.71 tons total nitrogen, and 0.32 tons total phosphorous on an annual basis to Richmond Lake. Sub-watershed RLT09 contributes a mean flow of 34 HM3/yr, 10.6% of the total sediment load to Richmond Lake, 27% of total phosphorus, and 21.4% of the total nitrogen.

RLT10

Sub-watershed RLT10 accounts for 45.4% of the Richmond Lake watershed area with 46,720 acres of drainage area. The FLUX model estimated that subwatershed RLT10 contributed approximately 0.18 tons of total suspended solids, 0.28 tons total nitrogen, and 0.10 tons total phosphorous on an annual basis to Richmond Lake. Sub-watershed RLT10 contributes a mean flow of 64 HM3/yr, 0.36% of the total sediment load to Richmond Lake, 8.5% of total phosphorus, and 8.5% of the total nitrogen.

BIOLOGICAL MONITORING

Fishery

The fish community in Richmond Lake was sampled in 2001. Electro-fishing and gill netting were the methods used for gathering fish. A final report was published on the findings of the study and may be obtained from the South Dakota Department of Game, Fish and Parks (SDGF&P). The report shows dates, times, growth and condition rates, abundance, size, species of fish and management recommendations. Richmond Lake is considered a major fishery in the area.

Results indicated a fish community resembling that of a lake managed under the panfish option. Yellow perch, black crappie, and blue gill populations dominate the Richmond Lake fishery. Other fish found during the study include walleye, saugeye, channel catfish, largemouth bass, black bullhead, rock bass, smallmouth bass, northern pike, green sunfish, yellow perch, common carp, pumpkin seed, white sucker, white bass, spottail shiner, and fathead minnow. Due to poor reproduction of some fish species such as walleye and northern pike, SDGF&P frequently stocks the lake with fingerlings to maintain a good fishery. State fishing regulations apply to the lake.

Threatened and Endangered Species

There are no threatened or endangered species documented in the Richmond Lake watershed according to Doug Backlund, SDGF&P. The US Fish and Wildlife Service listed the whooping crane and bald eagle as species that could potentially be found in the area. None of these species were encountered during this study.

Elutriate

As part of the Richmond Lake Assessment, elutriate samples were taken from several predetermined locations (water quality sampling sites) in the lake. The samples were collected by DENR staff and the Richmond Lake project coordinator using a Petite Ponar sampler. The samples were forwarded to the South Dakota State Health Laboratory for analysis. Both the sediment and receiving water were tested for a number of chemicals. There was a minimal amount of toxins detected in the samples and the toxins that were found were at very low levels (Table 9). Phosphorus was found in considerably high amounts in the sediment as well as the receiving water, as expected.

Table 9. Richmond Lake Elutriate

Elutriate Test Toxins	amount detected
Alachlor	**<.100 ug/l**
Chlordane	**<.500 ug/l**
Endrin	**<.500 ug/l**
Heptachlor	**<.400 ug/l**
Heptachlor Epoxide	**<.500 ug/l**
Toxaphene	**none**
Aldrin	**<.500 ug/l**
Diedrin	**<.500 ug/l**
PCB	**<.100 ug/l**
Diazinon	**<.500 ug/l**
DDD	**<.500 ug/l**
DDT	**<.500 ug/l**
DDE	**<.800 ug/l**
Beta BHC	**<.500 ug/l**
Gamma BHC	**<.500 ug/l**
Alpha BHC	**<.500 ug/l**
Mercury	**0.1 ug/l**
Lead	**<0.1 ug/l**
Arsenic	**0.024 mg/l**

Sediment

A sediment survey was conducted on Richmond Lake in February of 2004. Water depth and sediment depth were measured using a 20-foot steel probe. The probe was lowered through holes in the ice until the soft sediment was reached, giving a water depth. Then the probe was pushed through the soft sediment until it reached a solid substrate, giving a sediment depth. There were observations logged at 192 predetermined locations on the lake, which were located on a grid using a Global Positioning System (GPS) (Figure 10).

Richmond Lake covers an expanse of approximately 830 surface acres. About 700 of those acres were surveyed. The completed survey revealed an average sediment depth of 0.82 meter (2.70 feet). The maximum sediment depth observed was 3.1 meters (10.23 feet). Fifty percent of observations were between 0.6 and 0.9 meter. The volume of

sediment in the lake is approximately 2 million cubic yards. The average water depth calculated was 2.8 meters (9.24 feet). Areas of the lake that did not get surveyed were due to lake depths reaching past the 20-foot probe. The maximum water depth of Richmond Lake is 7.3 meters (24 feet).

Macrophyte Survey

A macrophyte survey was conducted on Richmond Lake in late July of 2003. A total of 41 transects were sampled for aquatic plant life. Transects were located using predetermined GPS coordinates that were placed every 275 meters along the shoreline. The area surveyed stretched from the face of the dam to the west and north bridges over Richmond Lake which is considered to be the main body of the lake (Figure 9).

Emergent macrophytes inhabit this area, but they were present in low densities and did not intersect with the sampled transects. Submergent macrophytes were a much larger percentage of the plant community around the lake. Although the diversity of the submergents was low, there was at least one plant found at each transect with the exception of areas with a rock or gravel bottom. Filamentous green algae dominated the shallow water substrate and out-competed many other macrophytes. Samples were collected 79 times throughout the 41 transects located on Richmond Lake. The second most predominant plant was Potamogeton pectinatus (sago pondweed), and it was sampled 47 times during the survey. Other submergent species that were found in the lake in small numbers were Vallisneria americana (eel grass) and Zannichella palustris (horned pondweed).

The average maximum depth for growth of submergent macrophytes in Richmond Lake was 1.54 meters or 5.5 feet. The average Secchi depth for all transects was 0.79 meter, with a maximum depth of 1.5 meters and a minimum of 0.4 meter.

Buffer zone vegetation densities were noted, but plant identification on upland areas was not included. Vegetative protection on the shoreline of the lake had an average score of 5.34 out of a possible 10.0. The survey produced a maximum score of 10 at 1 transect and a minimum score of 1 at 4 transects.

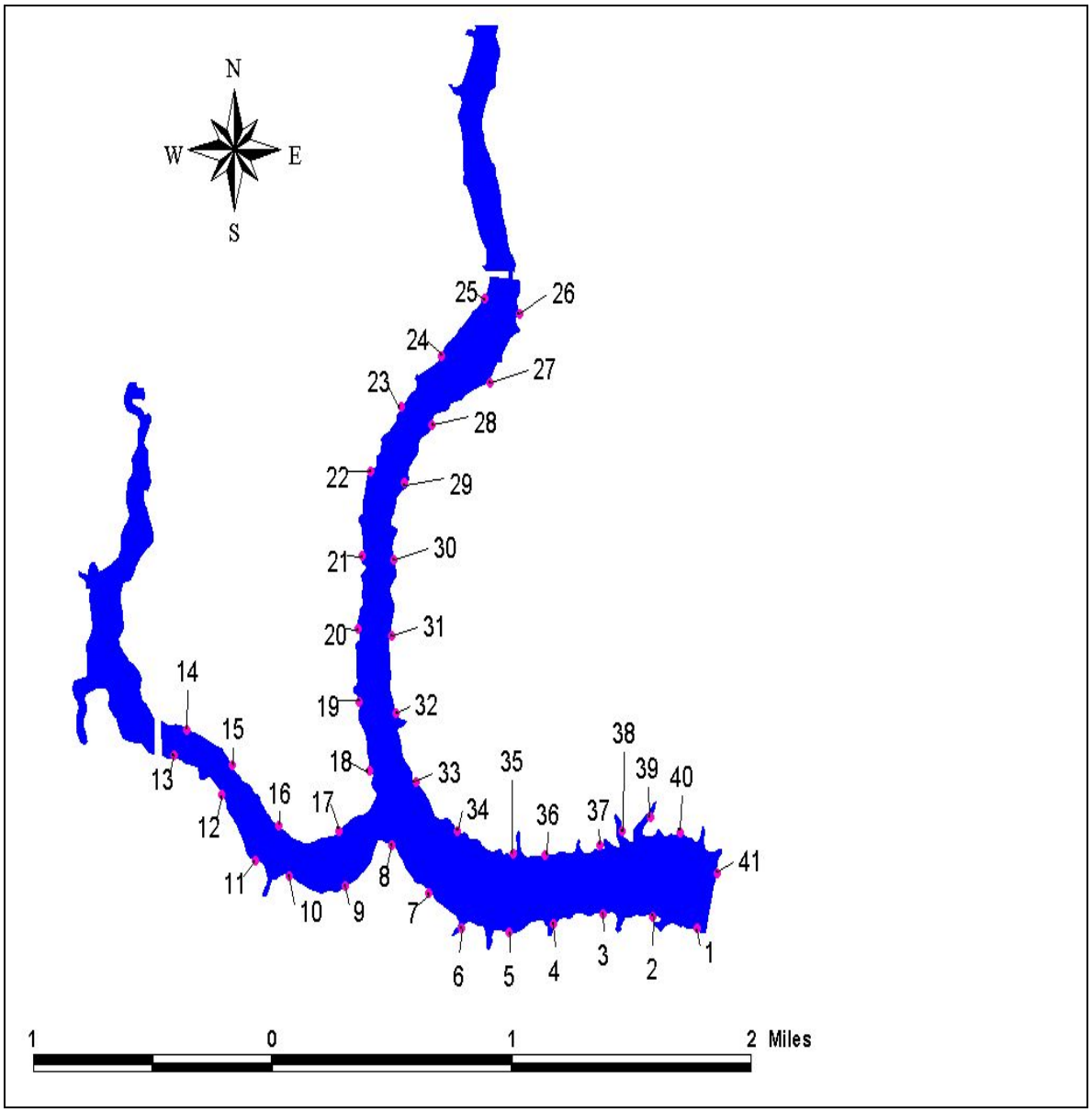

Figure 10. Richmond Lake Sediment Survey Locations

OTHER MONITIORING

ANNUALIZED AGRICULTURAL NON-POINT SOURCE MODEL (AnnAGNPS)

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

The input data set for AnnAGNPS Pollutant Loading Model consists of 33 sections of data, which can be supplied by the user in a number of ways. This model execution utilized; digital elevation maps (DEMs) to determine cell and reach geometry, SSURGO soil layers to determine primary soil types and the associated NASIS data tables for each soils properties, and primary land use based on the Digital Ortho Quads (DOQs). The DOQ was digitized and many land uses were determined directly from it. Additional detail on cropping rotations and grass conditions were added through utilizing Farm Service Agency (FSA) records and through some ground truthing. Climate data was generated using a synthetic weather generator based on climate information from the two closest stations, Huron and Sioux Falls. Mean annual precipitation for this watershed is about 19 inches.

It is important to note that these model results are based on 25 simulated years of data with precipitation ranging from 15 to 27 inches per year. None of these represent the project period, they are instead representations of what may typically occur on any given year, and when analyzed as a group provides a risk analysis for practices in the watershed.

Comparisons between the model results and the water quality data will be difficult to make due to the drought conditions experienced in the watershed. Through the use of the USGS EDNA website, annual runoff from this watershed was estimated to be 1.419 hm^3/yr while water quality data recorded approximately 0.368 hm^3/yr. To check the validity of the model data, an additional 100 years of synthetic weather were generated and extreme drought years from the extended dataset were used to model against the water quality data. Results from these comparisons indicated that the modeled data was adequately calibrated to represent the watershed for drought situations and thus should be representative during years with normal discharge.

The Richmond Lake watershed had 47 animal feeding operation lots located in 36 different cells throughout the watershed. Cell locations are marked in Figure 11 while Table 10 shows the load contributed from the lots in each of the 36 cells.

Table 10 is organized in descending order from the cells contributing the greatest load at the top of the list to those contributing the least at the bottom of the list. The cumulative impact of all of the feeding operations on the lake is approximately 10% of the annual

phosphorus load. Eliminating runoff from the first 4 lots (50% of the AFO load) in the list will reduce lake loading by approximately 5%. Eliminating runoff from the first 15 lots on the list will eliminate 85% of the AFO load and reduce phosphorus loads to the lake by 8.5%.

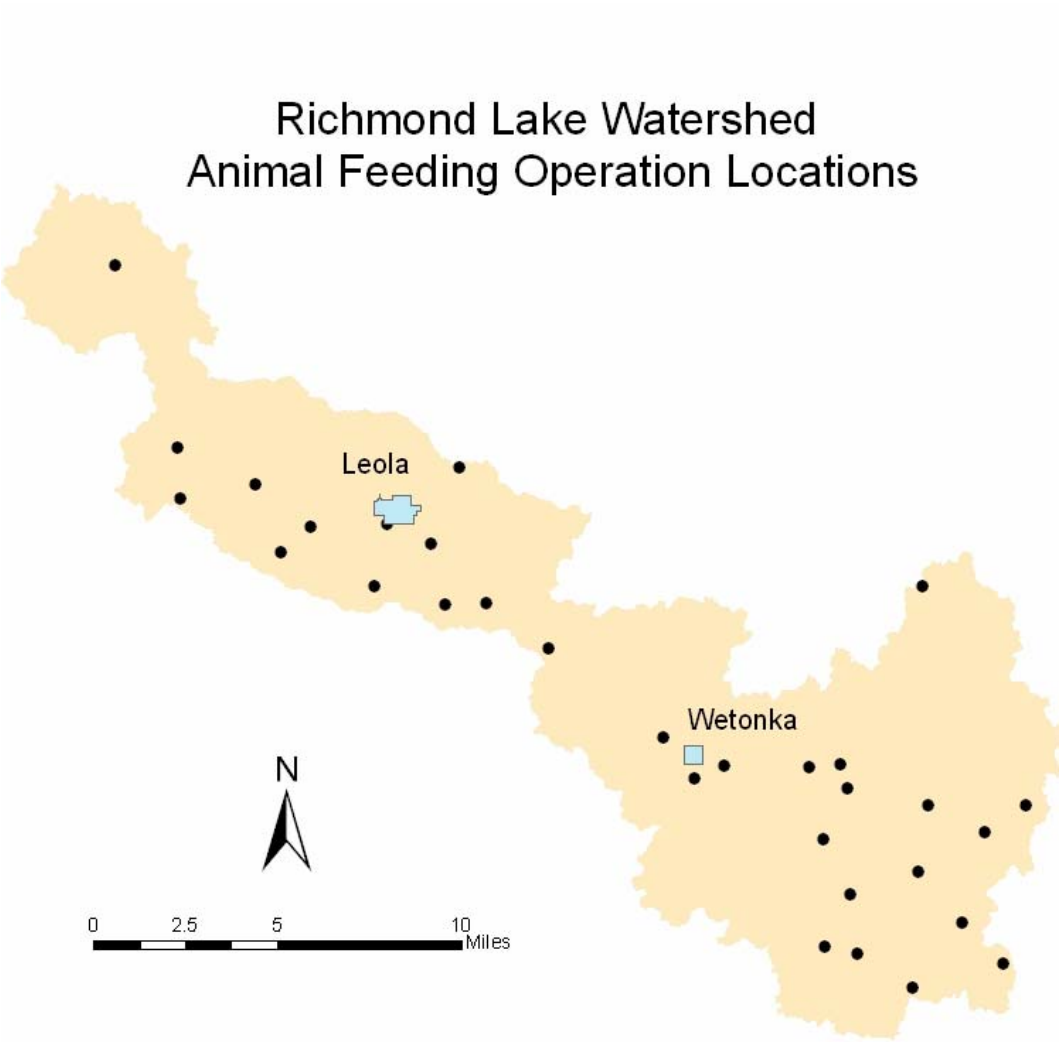

Figure 11. Animal Feeding Operation Locations

Table 10. Animal Feeding Operation Loading Data for 10-Year 24-Hour Rain Event

Cell	Reach	AFO P Load	% of Load	CumulativeLoad	LotID		
3282	328	259.4	22.8%	22.8%	FL06A	FL06B	
3953	395	150.8	13.2%	36.0%	FL10A	FL10B	
4292	429	81.8	7.2%	43.2%	FL01A		
5771	577	76.2	6.7%	49.9%	FL12		
3333	333	53.7	4.7%	54.6%	FL02A	FL02B	
1253	125	51.8	4.5%	59.1%	FL26		
3013	301	50.6	4.4%	63.6%	FL15		
7821	782	46.6	4.1%	67.7%	FL34A		
3212	321	34.2	3.0%	70.7%	FL08	FL08	
3652	365	31.3	2.8%	73.4%	FL14		
3402	340	30.2	2.7%	76.1%	FL16		
7473	747	28.8	2.5%	78.6%	FL05A	FL05B	
4762	476	24.9	2.2%	80.8%	FL37		
4312	431	24.1	2.1%	82.9%	FL01B		
2713	271	22.3	2.0%	84.9%	FL18	FL21A	FL21B
2553	255	18.9	1.7%	86.5%	FL20		
6832	683	17.9	1.6%	88.1%	FL33A	FL33B	
891	89	17.1	1.5%	89.6%	FL27A	FL27B	
3533	353	14.8	1.3%	90.9%	FL03A		
6382	638	14.8	1.3%	92.2%	FL23		
7922	792	11.5	1.0%	93.2%	FL35		
2482	248	10.5	0.9%	94.1%	FL24		
3872	387	9.1	0.8%	94.9%	FL03B		
1132	113	8.3	0.7%	95.6%	FL38		
132	13	8.2	0.7%	96.4%	FL30		
3492	349	7.7	0.7%	97.0%	FL11		
761	76	5.8	0.5%	97.6%	FL29A	FL29B	
1382	138	5.4	0.5%	98.0%	FL25B		
741	74	5.2	0.5%	98.5%	FL28		
3992	399	4.6	0.4%	98.9%	FL07		
1372	137	3.8	0.3%	99.2%	FL25A		
2563	256	3.0	0.3%	99.5%	FL09		
3152	315	2.0	0.2%	99.7%	FL04		
6681	668	1.9	0.2%	99.9%	FL32A	FL32B	
1062	106	1.7	0.1%	100.0%	FL31		
7813	781	0.0	0.0%	100.0%	FL34B		

AnnAGNPS Management Scenarios

Several management scenarios were completed for the Richmond Lake watershed. A comparison of the nutrient and sediment loads at the outlet to the watershed is available in Table 11 These comparisons were completed to obtain an estimate of the nutrient load reductions possible for this watershed. The loads in Table 22 are the accumulated load at the watershed outlet for the entire 25-year simulation period.

Table 11. AnnAGNPS Management Scenario Loads and Reduction Percentages

	Attached Nitrogen	Dissolved Nitrogen	Total Nitrogen	Attached Phosphorus	Dissolved Phosphorus	Total Phosphorus	Sediment
Current Condition	13.3	379.6	392.9	55.3	308.9	364.2	3369
AllGrass	2.7	281.5	284.1	37.2	229.4	266.6	612
No Impoundments	27.2	379.9	407.2	72.6	389.0	461.6	6230
PastPoor	67.7	947.5	1015.2	119.4	608.0	727.4	14357
PastGood	13.3	372.9	386.2	54.8	306.2	361.0	3362
Percent change for Scenarios							
All Grass Reduction	80%	26%	28%	33%	26%	27%	82%
Impoundments	205%	100%	104%	131%	126%	127%	185%
Cropland to Grass			26%			26%	82%
Poor Range	410%	154%	163%	118%	99%	101%	327%

The first simulation completed was the watershed in its "current condition" which is a best estimation of the current land use practices applied to the soils and slopes of the watershed to obtain nutrient and sediment losses from the individual cells as well as the watershed as a whole. Some default values were incorporated in this step such as rangeland condition which was simulated in a fair to good condition. Actual range conditions in the watershed did vary from this condition and would require analysis on a tract by tract basis during the implementation of any activities targeted at their improvement. Cropland acres were defaulted to minimum tillage practices consisting primarily of spring tillage prior to planting with a conventional planter. Actual tillage practices vary considerably between producers and would require a detailed analysis to determine the benefits of the BMP prior to its implementation on any individual tract within the watershed. The estimated sediment load was calculated to be approximately 3,300 tons. Nitrogen and phosphorus loads were 390 tons and 360 tons respectively. As was mentioned earlier in this report, these loads do not represent the measured loads due to the extreme nature of the drought.

The second simulation completed involved simulating the watershed as it may have been prior to settlement. Grass conditions similar to tall grass prairie or CRP were applied to all of the non water cells in the watershed. Reductions were less significant for this scenario than is observed in many watersheds. Sediment reduction was calculated to be approximately 80% while nitrogen and phosphorus were 28% and 27% respectively. These percentages may be primarily attributed to the cropland acres as there is little difference between the current condition simulation and the one simulating the pastures in good condition. The reason for the smaller reductions than is normally calculated can be traced to current watershed conditions including but not limited to the following factors: The first is current landuses throughout the watershed, 81% is grazed or hayed leaving only 18% as tilled cropland, much of which is located a great distance from the lake on fairly level ground. Another influencing factor in this watershed is the number of impoundments and wetlands located throughout the drainage. These percentages are

NOT to be used as a TMDL goal, but are only a reference point from where the TMDL may begin development.

The third simulation completed involved the removal of the impoundments (including small dams and wetland areas) throughout the watershed. There are approximately 5,500 acres of impoundments of 10 acres or larger in size throughout the watershed. Removal of these impoundments increased sediment loading by 185% and nitrogen and phosphorus loading by 104% and 127% respectively. The reductions as a result of the many impounded areas throughout the watershed suggest the strong importance of wetlands to the long-term health of Richmond Lake.

The fourth simulation consisted of current crops with pastures in poor condition. That simulation was intended to represent the watershed with its current cropping practices as determined by the LANDSAT derived dataset with pasturelands in poor conditions. Sediment loadings increased by 327% while nitrogen and phosphorus loads increased by 163% and 101% respectively. These large increases in nutrient and sediment loading suggest the importance of well-managed rangelands in the Richmond Lake watershed.

AnnAGNPS Targeting

The priority areas and acres depicted in Figure 12 were developed from a combination of areas targeted by the model as producing excessive sediment loads in addition to areas that have a high risk of producing excessive sediment loads. Cells scoring parameters are located in Table 12. Each of the four categories was broken into two groups. All of the cell values for each category were averaged and those cells with values greater than two standard deviations over the mean were given the higher of the two listed values while those cells only one standard deviation over the mean were given the lower of the two values. The remainder of the cells received 0 points in that category. A sum of the scores was then prioritized; all areas receiving a composite score of 5 or greater were selected as priority areas. Some of the priority areas may currently be under conservation friendly management, but should be protected to prevent increased loading from them.

The scores for the proximity to higher stream orders were calculated by dividing the AnnAGNPS assigned stream order for each reach by 2. For the Richmond watershed, the highest stream order was a 5, resulting in a maximum score of 2.5 for this category. This was done to give cells closer to the lake greater priority over those along the fringes of the watershed and is also based on the assumption that the transport capacity of higher order streams is greater than lower order streams resulting in greater delivery ratios for nutrients and sediments.

Values for the scores were selected to give equal weight to both the model targeted cells and those cells that met all of the criteria for critical targeting, steep slopes, erosive soils, and close proximity to the lake/ higher order streams. Three regions emerged as critical through this process.

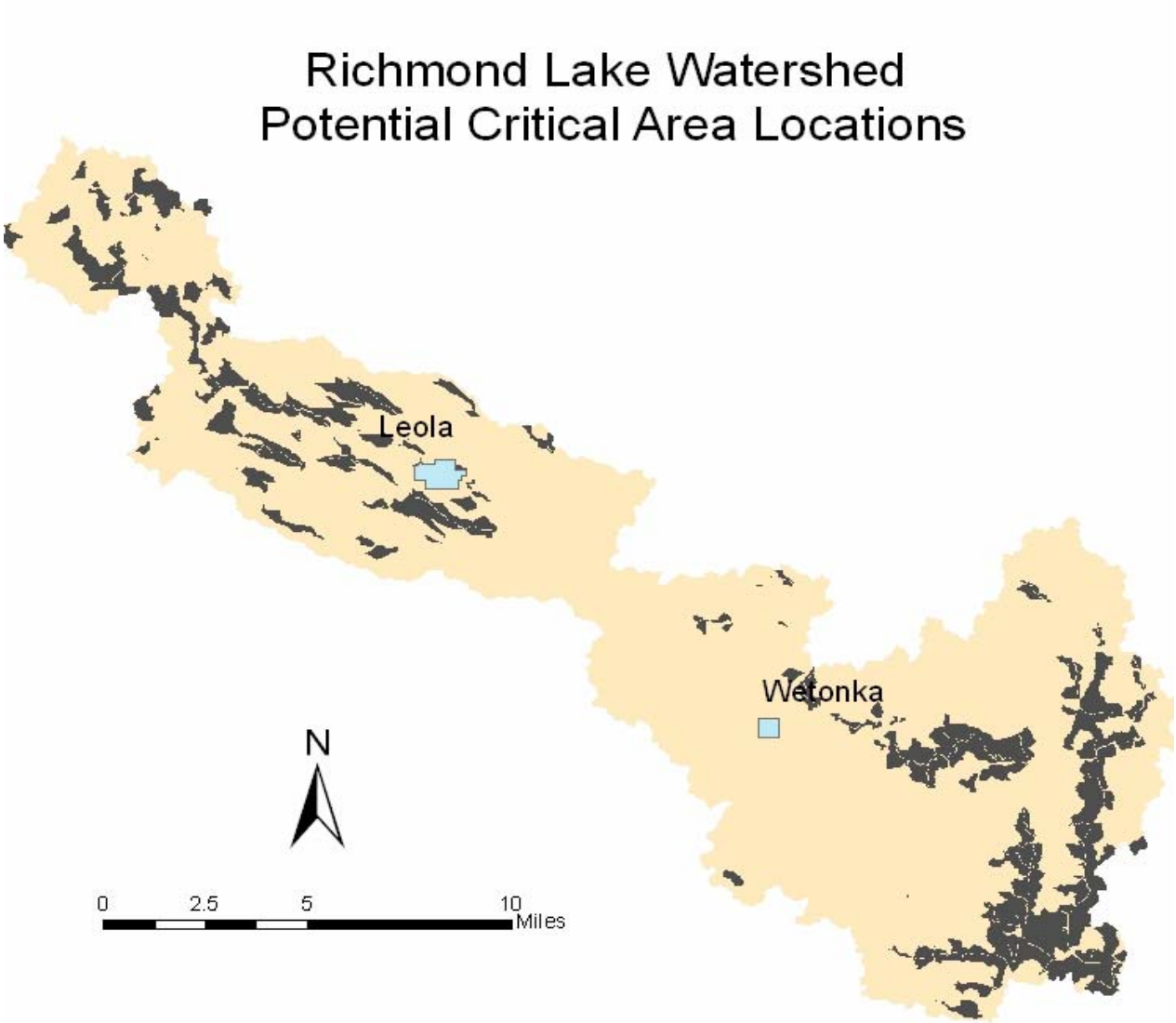

Figure 12. Richmond Lake Watershed Priority Areas

The priority areas account for approximately 28,186 acres of the watershed (Figure 12). A breakdown of this acreage shows that approximately 52% or 14,840 acres are composed of rangeland while the remaining 48% or 13,346 acres was cropped.

There are three distinct groups of critical cells that emerged from the analysis. The first of these groups are those cells located around Richmond Lake and downstream (Southeast) of the community of Watonka. These cells are primarily grazing lands on excessively steep slopes or cropland, all of which is in close proximity to the lake. These cells should be the first of the priority cells examined to determine the necessity and types of BMPs to be implemented.

The second group of cells are those located in the immediate area of community of Leola. This area is characterized by a relatively flat landscape lacking impoundments and primarily cropped. The fact that these areas are cropped and are located near the main channel of the stream resulted in their targeting. Due to the low gradient slopes in the area, it is likely that buffer strips may be extremely effective in detaining sediment and nutrients from crop acres in this area.

The final group of cells are those located to the north and west of Leola in the very upper end of the watershed. These areas are located on the top of the prairie coteau and rarely drain to the lower end of the watershed. The landscape in this area is characterized by extensive wetlands with poorly defined drainage. While the model targeted these cells as critical due to steep slopes and some cropping practices, they should be the last ones targeted for an implementation project with the goal of improving Richmond Lake.

Table 12. Cell Scoring Values and Justifications

	1 std Dev	2 std Dev	Justification
Modeled Erosion	3.5	7.5	Based on current conditions, Landuse is the primary influencing factor
Cell Slope	1.5	2.5	Steeper slopes with a higher erosive potential
Soil Erosive Potential	1.5	2.5	Soils prone to erosion but not necessarily on steep slopes
Proximity to high stream order	0.5 to 2.5		Higher stream orders are closer to the receiving water body and have an increased transport capacity for sediment and nutrients

QUALITY ASSURANCE REPORTING

Three lake replicate samples and 55 lake samples were collected in Richmond Lake during the project period for an overall quality assurance/quality control percentage of 10.9 percent of all inlake samples collected. Four tributary replicate samples and 41 samples were collected in the watershed for an overall QA/QC control of 10.25%. Parameters tested for include alkalinity, ammonia, nitrate, TKN, fecal coliform, E. coli, total solids, total suspended solids, volatile total suspended solids, total phosphorus, and total dissolved phosphorus. Total solids, total dissolved solids, total suspended solids, and volatile total suspended solids concentrations can vary considerably because of variations in sample collection and natural variation. Variations in field sampling techniques, preparation and that the samples are replicate and not duplicate may be some reasons for differences. Complete test results for replicates and blanks may be found in the following table.

Table 13. Lake Duplicates and Blanks

SITE	DATE	Type	DEPTH	TALKA	TSOL	TDSOL	TSSOL	AMMO	NIT	TKN	TPO4	TDPO4	FEC
RL00	6/18/2003	Blank	Bottom	<6	<7	0	<1	0.03	<0.10	<0.11	<0.002	0.002	<10
RL3B	6/18/2003	Replicate	Bottom	259	1148	1145	3	0.19	<0.10	1.22	0.370	.359	
RL3B	6/18/2003	Sample	Bottom	257	1148	1140	8	0.19	<0.10	0.99	0.376	.359	
				0%	0%	0%	62%	0%	0%	9%	1%	0%	0%
RL3A	6/18/2003	Duplicate	Surface	246	1114		8	<0.02	<0.1	1.22	.171	.144	
RL3A	6/18/2003	Sample	Surface	246	1114		8	<0.02	<0.1	0.74	.171	.144	30
RL00	8/19/2003	Blank	Surface	<6	<7	0	<1	<0.02	<0.10	<0.11	0.002		<10
RL2A	8/19/2003	Replicate	Surface	260	1133	1110	23	<0.02	<0.1	1.50	.543	.420	<10
RL2A	8/19/2003	Sample	Surface	257	1133	1109	24	<0.02	<0.1	1.48	.555	.424	<10
				0%	0%	0%	4%	0%	0%	1%	1%	0%	0%
RL00	2/18/2004	Blank	Surface	<6	<7	0	<1	<0.02	<0.10	<0.11	<.002	<.002	<10
RL1A	2/18/2004	Replicate	Surface	308	1339	1331	8	0.02	<0.10	1.36	.303	.225	<10
RL1A	2/18/2004	Sample	Surface	307	1335	1326	9	<0.02	<0.1	1.43	.326	.231	<10
				0%	0%	0%	11%	0%	0%	5%	27%	3%	0%
Average Percent Difference				0%	0%	0%	25%	0%	0%	5%	10%	1%	0%

The June 18, 2003 QA/QC sample at RL03B detected an increase in TSSOL and TKN between the sample and the replicate. The blank sample exceeded the detection limit for Ammonia (0.03). The small difference in TSSOL and TKN are probably due to natural variation.

The August 19, 2003 QA/QC sample at RL02A detected little to no difference between the sample and the replicate sample in all of the parameters tested. However, the blank sample detected Ammonia at 0.03 mg/L.

The February 18, 2004 QA/QC sample at RL01A showed an increase in total suspended solids and total phosphorus. It is possible that a poorly-rinsed sample bottle, poorly-rinsed filter, or natural sample variability may be the cause in the differences.

Table 15. Tributary Duplicates and Blanks

SITE	DATE	Type	DEPTH	TALKA	TSOL	VSSOL	TSSOL	AMMO	NIT	TKN	TPO4	TDPO4	FEC
RLT10	5/9/2003	Blank	Surface	<6	<7	<1	<1	<0.02	<0.1	<.11	<.002	<.002	
RLT10	5/9/2003	Replicate	Surface	98	735	8	31	<0.02	<0.1	1.64	.625	.542	<10
RLT10	5/9/2003	Sample	Surface	98	738	7	25	<0.02	<0.1	1.50	.578	.533	<10
				0%	0%	1%	3%	0%	0%	9%	8%	0%	
RLT07	6/17/2003	Blank	Surface	<6	<7	<1	<1	<.10	<0.1	<.11	<.002	<.002	<10
RLT07	6/17/2003	Replicate	Surface	142	927	12	15	<0.02	<0.1	1.14	.878	0.816	840
RLT07	6/17/2003	Sample	Surface	144	926	14	16	<0.02	<0.1	1.24	.646	.859	780
				1%	0%	0%	7%	0%	0%	8%	27%	5%	7%
RLT06	5/30/2004	Blank	Surface	<6	<7	<1	<1	0.03	<0.1	0.23	<.002	.002	
RLT06	5/30/2004	Replicate	Surface	145	1308	8	30	<0.02	<0.1	1.41	.305	.251	
RLT06	5/30/2004	Sample	Surface	143	1303	7	28	<0.02	<0.1	1.52	.319	.266	
				0%	0%	0%	7%	0%	0%	7%	4%	6%	
RLT07	6/11/2004	Blank	Surface	<6	<7	<1	<1	0.04	<0.1	<.23	<.002	<.002	
RLT07	6/11/2004	Replicate	Surface	170	1914	8	24	<0.02	0.1	1.13	.334	.265	
RLT07	6/11/2004	Sample	Surface	170	1904	4	10	<0.02	<0.1	.94	.328	.267	
				0%	0%	0%	58%	0%	0%	17%	2%	1%	

In the 5/9/2003 QA/QC sample set, there were no significant exceedences with the blank sample or significant differences with the replicate sample. Slight differences in the replicate sample were likely due to natural variation.

The June 17, 2003 QA/QC sample set detected little to no differences when comparing the sample with the replicate except for total phosphorus. The data also shows more dissolved phosphorus then total phosphorus in the sample, which is not possible. This is probably due to poor field methodology in flushing the dissolved phosphorus filter. The 27% difference between the replicate and the sample may be due to natural variability.

On May 30, 2004 at site RLT06, there was a significant exceedence of the blank sample. Extremely small differences were found between the replicate and the sample. Natural variation was most likely the cause of these differences.

The June 11, 2004 QA/QC sample set detected some difference when comparing the sample and the replicate sample. There was a considerable difference (58%) when comparing the TSS for the sample and the replicate sample. There was also a difference in TKN (17%), when comparing the sample and the replicate. These differences can be attributed to the possibility of collecting some extra organic matter in the replicate sample.

PUBLIC INVOLVEMENT AND COORDINATION

State Agencies

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

The South Dakota Department of Game, Fish and Parks (GF&P) aided in the completion of the assessment by providing a complete report on the condition of the fishery in Richmond Lake. GF&P also provided use of their ice auger for water quality sampling during the winter months.

Federal Agencies

The Environmental Protection Agency (EPA) provided the primary source of 319 funds for the completion of the Richmond Lake Assessment.

The Natural Resource Conservation Service (NRCS) provided technical assistance for the assessment coordinator.

The Farms Service Agency provided land use information for the AnnAGNPS model used for watershed modeling.

Local Governments; Industry, Environmental, and other Groups, and Public-at-Large

The South Brown CountyConservation District did not contribute financially to the project but provided the sponsorship that made this project possible.

The James River Water Development District and Ravina Township provided funding for the project. The Richmond Lake Association assisted with funding and provided a boat for lake sampling during the project.

Public involvement consisted of individual meetings with landowners as well as monthly board meetings with the South Brown Conservation District that were open to the public. A meeting with the Richmond Lake Association provided many of the area residents with an opportunity to learn more about the project and the water quality of the lake.

ASPECTS OF THE PROJECT THAT DID NOT WORK WELL

All of the objectives proposed for the project were met in an acceptable time frame with the exception of tributary and macroinvertebrate surveys. The number of tributary samples collected during the project was less than proposed, but adequate for the completion of this report. The number of tributary samples was not met due to a lack of spring snowmelt and rainfall in both 2003 and 2004. The macroinvertebrate survey was not completed because the Richmond Lake tributaries were dry the majority of 2003. The outlet of the lake never spilled and other tributary sites flowed only after high intensity rain events.

The tributaries of this lake are interrupted by many stock dams throughout the watershed. Filling of the stock dams after rain events made it difficult to sample tributary sites on a consistent basis.

FUTURE ACTIVITY RECOMMENDATIONS

During the study it was estimated that 7,126 kg/yr of phosphorus was contributed to the lake through internal loading. This is a significant amount of phosphorus contributing to eutrophication of Richmond Lake. While this internal load was not included in the TMDL, measures taken to reduce internal loads will improve the trophic condition of Richmond Lake. Potential BMPs to address internal loading may be the use of aluminum sulfate, a lake aeration system, and dredging.

The Richmond Lake watershed contains numerous stock dams which act as sediment and nutrient traps. These dams also provide a place for livestock to congregate and contribute waste to the tributary (especially during the hot months of summer). The federal government has a new conservation practice (CP30) which would provide the livestock producers with compensation to fence livestock out of many of these tributary areas, which would include many of the stock dams.

The majority of the feeding areas adjacent to the lake have existing waste containment systems that may need improvement or inspection if the contracts have not already expired. There are pastures adjacent to the lake that would make good candidates for the CP30 CRP program that is administered by the NRCS. This would exclude any livestock from the lake and provide an alternative water source. Installation of BMPs should be used as another means of restoring Richmond Lake.

When reviewing the Richmond Lake sediment survey, it was noted that the average sediment depth of the lake is 2.7 feet and ellutriate samples showed a total of 0.912 mg/L total phosphorus. A possible dredge project would help reduce sediment and phosphorus.

There are two specific livestock feeding areas located 1mile south and 2 ½ miles west of the city of Leola. The feeding areas are located directly adjacent to the tributaries that may be viewed as major contributors to elevated nutrient and fecal levels. These areas were not targeted for discrete grab samples, but visual observations (ie. manure piles and runoff impacted lots) combined with the location and number of livestock would warrant a closer look into these areas.

One livestock feeding area (Calvin and David Nelson) located 2 miles north of the north bridge over Richmond Lake was reported as dumping waste or feeding livestock on the lake during ice conditions in the winter months. This report originated from a Game, Fish and Parks employee who was taking aerial photos near this location and observed a brown area on the frozen lake that was directly adjacent to the Nelson waste containment system.

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Appendix A. Richmond Lake Total Maximum Daily Load Summary (TMDL)

TOTAL MAXIMUM DAILY LOAD EVALUATION

For

RICHMOND LAKE

RICHMOND LAKEWATERSHED

(HUC 10160003)

BROWN COUNTY, SOUTH DAKOTA

SOUTH DAKOTA DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES

July, 2006

Richmond Lake Total Maximum Daily Load

Waterbody Type:	Lake (Impounded)
2006 Integrated Report:	TSI
Designated Uses:	Warmwater Permanent Fish Life Propagation Water; Immersion Recreation Water; Limited Contact Recreation Water; Fish & Wildlife Propagation, Recreation and Stock Watering Water.
Size of Waterbody:	340 hectares (840 acres)
Size of Watershed:	4,168 hectares (103,000 acres)
Water Quality Standards:	Narrative and numeric
Indicators:	Average TSI
Analytical Approach:	AnnAGNPS, BATHTUB, and FLUX
Location:	HUC Code: 10160009
Goal:	20% reduction in total phosphorus
Target:	Site Specific Target Chlorophyll and Secchi TSI of 61.5. Current TSI is 61.7.

Objective:

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

Introduction

Richmond Lake is an 840-acre man-made lake located in Brown County, South Dakota. The 2004 South Dakota integrated report identified Richmond Lake for TMDL development for TSI.

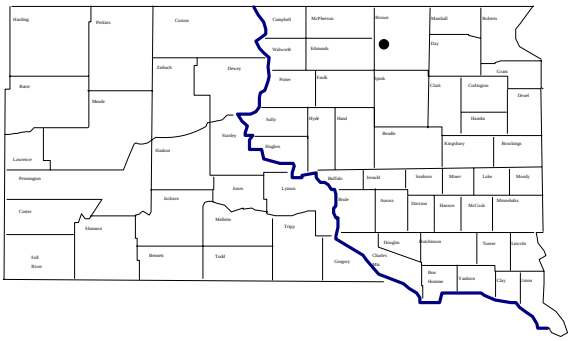

Figure 13. Richmond Lake Watershed Location in South

The Richmond Lake watershed encompasses approximately 103,000 acres and is drained by Foot Creek (Figure 12). The damming of Foot Creek northwest of the city of Aberdeen, South Dakota created the lake, which has an average depth of 12.0 feet and deepest depth being 25+ feet. The entire lake is approximately 840-acres in size. The outlet for the lake empties back into Foot Creek, which empties into Moccasin Creek and eventually reaches the James River.

Problem Identification

The Richmond Lake Watershed is fairly large with upper reaches extending beyond the city of Leola, SD. The tributaries of the Richmond Lake watershed drain predominantly pasture land which accounts for approximately 81 percent of the total, leaving only 18% as cropland. The majority of the cropland was found to be relatively close to Richmond Lake, but is located on flat ground with little to no runoff. The

streams in the watershed carry nutrient (total nitrogen and total phosphorus) and sediment loads, which degrade the water quality of the reservoir, and cause increased eutrophication.

Mean TSI values were originally used to set current fish life propagation beneficial use criteria for lakes in South Dakota (Lorenzen, 2006). The target for full support is ≤58 according to the document "Targeting For Impaired Lakes in South Dakota." However, the current fishery beneficial use target criteria appear not to fit Richmond Lake based on AnnAGNPS watershed loading and BATHTUB in-lake eutrophication modeling. AnnAGNPS model was used to estimate watershed loading under ideal conditions (entire watershed converted to grassland). Modeling indicates that maximum phosphorus reduction in this watershed would be 27 percent.

Most of the watershed sediment and nutrient loading to the lake comes from two major tributaries which feed into the north and west arms of the lake. Loadings of sediment and nutrients has increased the severity of the algal blooms in the lake by overloading the system with phosphorus. However, the majority of the phosphorus loading to Richmond Lake comes from internal loading in the lake itself.

Description of Applicable Water Quality Standards & Numeric Water Quality Targets

Richmond Lake has been assigned certain beneficial uses by the state of South Dakota Surface Water Quality Standards regulations. Along with these assigned uses are narrative and numeric criteria that define the desired water quality of the lake. These criteria must be maintained for the lake to satisfy its assigned beneficial uses, which are listed below:

Richmond Lake:

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

Individual parameters, including the lake's Trophic State Index (TSI) (Carlson, 1977) value, determine the support of beneficial uses and compliance with standards. Richmond Lake is identified in the 2006 South Dakota Integrated Report for TSI.

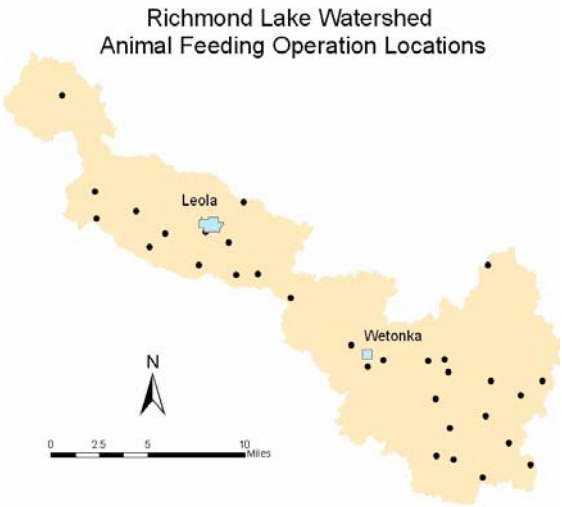

Figure14. Richmond Lake Watershed

Pollutant Assessment

Point Sources

There are no point sources of pollutants of concern in the Richmond Lake watershed.

Linkage Analysis

Water quality data was collected from three in-lake sites at Richmond Lake. Samples collected at each site were taken according to South Dakota's EPA-approved Standard Operating Procedures for Field Samplers. Water samples were sent to the State Health Laboratory in Pierre, SD for analysis. Quality Assurance/Quality Control samples were collected on approximately 10% of the samples. The South Dakota's EPA-approved Non-Point Source Quality Assurance/ Quality Control Plan requires 10% QA/QC sample sets. Details concerning water sampling techniques, analysis, and quality control are addressed on pages 43 through 45 of the assessment final report.

TMDL and Allocations

TMDL

Total Phosphorus (kg) = 20% reduction

0 kg/yr	(WLA)
+ 139.4 kg/yr	(LA)
+ 418.2 kg/yr	(Background)
+ Implicit	(MOS)
557.6 kg/yr	(TMDL)

TMDL

Of the 55 individual lake samples collected during the assessment study, nine dissolved oxygen violations were recorded. All but two of the nine violations occurred at RL03B (bottom) which is the deepest part of the lake. The remainder of the water column at this site held enough dissolved oxygen in the water to sustain a healthy fishery (>5 mg/L). A violation of dissolved oxygen was also recorded at the bottom at site RL02B with the same explanation as for violations at RL03B, anoxia in the hypolimnion. The only surface violation was recorded at RL01 where the water is shallow, more turbid, and warms quickly thus removing the ability to hold higher concentrations of dissolved oxygen. Because of the refuge area in the epilimnion, none of the 9 violations are serious enough to warrant the addition of dissolved oxygen to this TMDL.

As stated in the assessment report, there were five pH values that exceeded state standards of which all five were recorded on the same day (September 23, 2003). At that time, it was noted that the pH millivolts on the YSI multi probe meter indicated the pH probe had neared its life expectancy. The pH probe was replaced and future pH readings were within acceptable ranges. Due to a bad pH probe in the equipment used for monitoring, it is believed the five pH values recorded over 9.0 were not accurate.

Wasteload Allocations (WLAs)

The city of Leola has only discharged four times from October 1, 2002 through the present. The total flow from all discharges over the four year period was 43,930,000 gallons. The discharge drains into an unnamed slough area before draining into Foot Creek. Foot Creek then flows over 25 miles before reaching Richmond Lake. The small amount of phosphorous that may drain from the slough should have minimal effect on the overall phosphorous load to Richmond Lake.

Load Allocations (LAs)

Agriculture related activities are the primary sources of nutrient and sediment loadings in the watershed. As mentioned above, the biggest source of phosphorus loading to the lake comes from internal loading (91%) of the lake itself which could be due to a dry year with no run-off to flush the lake. Low

levels of DO at the bottom are probably a result of the lake's thermocline and the bottom being anoxic producing elevated levels of total phosphorous. During a typical wet year with normal to above average runoff, it would be possible to see a vast majority of the phosphorus loading come from the tributaries and a minor amount from internal loading.

A total maximum annual phosphorus loading rate of 557.6 kg/yr is needed to meet the site specific TSI target goal to maintain the lakes trophic state. This is attained by a 20% reduction of phosphorus loading from the tributaries in order to reach the goal of satisfying the site specific criteria proposed in this report. The phosphorus loading must be reduced by 139.4 kg/yr to result in a TMDL load of 557.6 kg/yr.

In-lake Targets

The numeric TSI target, established to improve the trophic state of Richmond Lake is a growing season median TSI of less then 58.4. In order to meet the fishery beneficial use target, phosphorus loads would have to be reduced in excess of 80% from the watershed. This target is not attainable through recommendations in the Richmond Lake final report. The recommendations were based on alternative site specific (watershed specific) evaluation criteria (full support at a mean TSI <61.5) based on AnnAGNPS modeling, BMPs and watershed specific phosphorus reduction attainability. The recommended target is set at a median modeled growing season TSI of 61.5. This can be achieved by reducing phosphorus loading from the watershed by 20% which includes 10% from feedlots and 10% from rangeland/crop land. Richmond Lake will be fully supporting its TSI Criteria with values less than 61.5.

In-lake targets were established on relationships between chlorophyll *a* and Secchi transparency. For warmwater permanent fishery classification, the TSI target is a median of less than 58.4. Due to excessive inlake phosphorus, a site specific TSI target of 61.5 was established for Richmond Lake based on AnnAGNPS modeled phosphorus reductions. A TSI level of <61.5 will result in full support for Richmond Lake.

Seasonal Variation

Different seasons of the year can yield differences in water quality due to changes in precipitation and agricultural practices. To determine the seasonal differences, samples from Richmond Lake were collected in the spring (March-May), summer (June-August), fall (September-November), and winter (December-February) months.

Seasonality in the lake was typical for a lake in north central South Dakota with summer peaks in algae. Thermal stratification and oxygen depletion at the bottom of the lake occurred during the summer.

Margin of Safety

The margin of safety was implicit as conservative estimations were used in the development of the lake restoration activities. It was recommended that additional activities such as aeration and/or alum treatments be used as lake restoration strategies. Installation of BMPs in the watershed should also be used as a means of treatment for restoring the lake.

Critical Conditions

Potential impairment from phosphorus (internal loading) occurs during the recreational season of May 15 - September 15. During this time the lake stratifies releasing phosphorus from the sediment when water temperatures are warm and dissolved oxygen is lower at the bottom of the lake.

Follow-Up Monitoring

As part of the implementation effort, in-lake monitoring should be used to measure Secchi transparency, chlorophyll *a* levels (algae), pH, and total phosphorus concentrations. If pretreatment of tributaries is implemented, tributary flows should be monitored and water samples collected and analyzed for total phosphorus. Once the implementation project is complete, the lake will be monitored as part of South Dakota's Statewide Lakes Assessment Project to determine if the TMDL and full support of the beneficial uses were achieved.

Public Participation

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

1. South Brown Conservation District Board Meetings.
2. Articles in South Brown conservation digests.
3. Individual contact with landowners in the area.

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

Implementation Plan

The South Dakota DENR is working with the South Brown Conservation District and the Richmond Lake Association to initiate an implementation project beginning in the spring of 2007. It is expected that a local sponsor will request project assistance during the fall 2006 EPA Section 319 funding round.

Lake restoration strategies recommended for consideration are:

1) Potential BMPs such as the use of aluminum sulfate, lake aeration, and dredging to address internal loading.
2) Phosphorus removal from tributaries through best management practices.
3) Waste containment systems for livestock feeding operations.

Appendix B. EPA Approval letter and TMDL Review Form

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

August 8, 2007

Ref: 8EPR-EP

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

Re: TMDL Approvals
Bear Butte Creek; *SD-BF-R-BEAR_BUTTE_02*
Burke Lake; *SD-MI-L-BURKE_01*
Center Lake; *SD-CH-L-CENTER_01*
Richmond Lake; *SD-JA-L-RICHMOND_01*

Dear Mr. Pirner:

We have completed our review, and have received Endangered Species Act Section 7 concurrence from the U.S. Fish and Wildlife Service, on the total maximum daily loads (TMDLs) as submitted by your office for the waterbodies listed in the enclosure to this letter. In accordance with the Clean Water Act (33 U.S.C. 1251 *et. seq.*), we approve all aspects of the TMDLs as developed for the water quality limited waterbodies as described in Section 303(d)(1). Based on our review, we feel the separate elements of the TMDLs listed in the enclosed table adequately address the pollutants of concern as given in the table, taking into consideration seasonal variation and a margin of safety.

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

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EPA REGION VIII TMDL REVIEW FORM

Document Name:	**Richmond Lake Watershed Assessment Final Report**
Submitted by:	**Gene Stueven, SD DENR**
Date Received:	**December 11, 2006**
Review Date:	**January 11, 2007**
Reviewer:	**Vern Berry, EPA**
Formal or Informal Review?	**Informal – Public notice**

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

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

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

1. Water Quality Impairment Status

Criterion Description – Water Quality Impairment Status

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

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

SUMMARY – Richmond Lake is a 840 acre man-made lake located in the Moccasin Creek watershed, Brown County, South Dakota. The Moccasin Creek is within the larger James River Basin. It is listed on South Dakota's 2006 303(d) list as impaired for trophic state index (TSI) due to nonpoint sources and is ranked as priority 1 (i.e., high priority) for TMDL development. The watershed is approximately 103,000 acres and drains predominantly cropland and pastureland. Approximately 18% of the landuse is cropland and 81% is pastureland in the watershed. The mean phosphorous TSI during the period of the project assessment was 67.4, and is not currently meeting its designated beneficial use for warmwater permanent fish life propagation.

2. Water Quality Standards

Criterion Description – Water Quality Standards

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

☒ Satisfies Criterion
☐ Satisfies Criterion. Questions or comments provided below should be considered.

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

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

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

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

Other applicable water quality standards are included on pages 16 and 17 of the assessment report.

3. Water Quality Targets

Criterion Description – Water Quality Targets

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

☐ Satisfies Criterion
☐ Satisfies Criterion. Questions or comments provided below should be considered.

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

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

The actual Secchi/chlorophyll *a* TSI for Richmond Lake during the period of the assessment was 67.4. Nutrient reduction response modeling was conducted with BATHTUB, an Army Corps of Engineers eutrophication response model. The results of the modeling show that 80% or more reduction in the total phosphorous loading from the watershed would be necessary to meet the ecoregion-based beneficial use median Secchi/chlorophyll *a* TSI target of 58.4 or less. However, Richmond Lake does not appear to fit the recommended beneficial use-based target due to legacy phosphorous loading to the lake and the technical and financial inability to fully treat the internal and external loading to the lake. Therefore, a site specific Secchi/chlorophyll *a* TSI of $\leq$ 61.5 was chosen for Richmond Lake.

The proposed water quality target for this TMDL is: **maintain a growing season median Secchi/chlorophyll *a* TSI at or below 61.5.**

COMMENTS – TMDL water quality targets must be set at a level that meets all applicable water quality standards. The Richmond Lake report says that "…a TMDL for full support would **not** be attainable under the current fishery beneficial use classification." This implies that the specified TMDL target of 61.5 TSI would not fully support the Lake's beneficial uses, and thus the WQ standards would not be met. Narrative water quality standards allow some flexibility in the determination of the appropriate target. If the recommended beneficial use-based TSI target does not fit, then an alternate target can be specified if ***it can be expected to meet the beneficial uses of the Lake***. Either the TMDL target needs to be specified at a level which fully supports the beneficial uses of the Lake (e.g., Secchi/chlorophyll *a* TSI of $\leq$ 58.4), or the TMDL needs to include an explanation and statement that the existing specified target (i.e., TSI = 61.5) will fully support the Lake's beneficial uses.

The statements on pages 2, 29 and 54 need to be revised to say that the beneficial use-based target does not appear to fit the recommended beneficial use-based target due to legacy phosphorous loading to the lake and the technical and financial inability to fully treat the internal and external loading to the lake. The TMDL and report also needs to include a statement that the site specific target will "**fully support its beneficial uses and is achievable given the expected landowner participation in the watershed**."

Response to Comment:

The TMDL has been corrected to read that with a TSI of 61.5 the lake will fully support its beneficial uses and the site specific target will fully support its beneficial uses and is achievable given the expected landowner participation in the watershed**.**

4. Significant Sources

Criterion Description – Significant Sources

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

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

SUMMARY – The TMDL identifies the major sources of phosphorous as coming from nonpoint source agricultural landuses within the watershed. In particular, a loading analysis was done for nutrients and sediment considering various agricultural land use and land management factors. Cropland and grazing are the primary sources identified. Approximately 18% of the landuse is cropland and 81% is pastureland in the watershed.

5. Technical Analysis

Criterion Description – Technical Analysis

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

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

SUMMARY – The technical analysis addresses the needed phosphorous reduction to achieve the desired water quality. The TMDL recommends a 20% reduction in average annual total phosphorous loads to Richmond Lake. Based on the loads measured during the period of the assessment the total phosphorous load should be 557.6 kg/yr to achieve the proposed TSI target. This reduction is based in large part on the BATHTUB mathematical modeling of the lake and its predicted response to nutrient load reductions.

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

The Annualized Agricultural Non-Point Source Model (AnnAGNPS) model was used to simulate alterations in land use practices and the resulting nutrient reduction response. The nutrient loading source analysis, that was used to identify necessary controls in the watershed, was based on the identification of targeted or high priority cells. Targeted cells were defined according to the cell scoring values assigned in Table 12 of the assessment report (based on erosion potential, slope and proximity to streams). The cells that met all of the criteria for critical targeting will be the first to have BMPs implemented. Also, eliminating runoff from many of the animal feeding operations in Table 10 of the report will further reduce phosphorous loading to the lake.

6. Margin of Safety and Seasonality

Criterion Description – Margin of Safety and Seasonality

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

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

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

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

7. TMDL

Criterion Description – Total Maximum Daily Load

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

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

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

SUMMARY – The TMDL established for Richmond Lake is a 557.6 kg/yr total phosphorus load to the lake (20% reduction in annual total phosphorus load). This is the "measured load" which is based on the flow and concentration data collected during the period of the assessment. Since the annual loading varies from year-to-year, this TMDL is considered a long term average percent reduction in phosphorous loading.

COMMENTS – We do not recommend a separate allocation to "Background" loading. The background loading should be combined with the load allocation. Typically, the loads from natural or background sources are included as part of the load allocation rather than expressed separately.

Response to comments:

The Background loading has been combined with the Load Allocation in the TMDL.

8. Allocation

Criterion Description – Allocation

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

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

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

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

9. Public Participation

Criterion Description – Public Participation

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

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

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

10. Monitoring Strategy

Criterion Description – Monitoring Strategy

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

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

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

11. Restoration Strategy

Criterion Description – Restoration Strategy

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

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

SUMMARY – The South Dakota DENR is working with the South Brown Conservation District and the Richmond Lake Association to develop a plan for an implementation project for Richmond Lake. Implementation of various best management practices will be necessary to meet or exceed the WQ and TMDL targets/goals. This includes improvements to pasture grazing practices, implementation of no-till residue management on small grain and row crop lands, and converting some cropland to CRP. Additional BMPs that could be implemented if necessary include construction of animal waste management systems, lake aeration and/or alum treatment.

12. Endangered Species Act Compliance

Criterion Description – Endangered Species Act Compliance

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

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

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

13. Miscellaneous Comments/Questions

Appendix C. Richmond Lake Water Quality Data

Tributaries			Total	Susp												Water
Site	Date	Alk	Solids	Solids	VTSS	Ammon	Nitrate	TKN	TP	TDP	Fecal	E. Coli	pH	DO	Conduct	Temp
RLT05	5/5/2003	157	2074	17	10	0	0	1.93	0.58	0.49	8,500	>2,420	7.66	8.26	2004	10.72
RLT06	5/5/2003	167	1934	12	6	0	0	1.76	0.26	0.21	50	63.1	7.73	9.43	1894	11.22
RLT07	5/5/2003	141	1472	17	7	0.13	1.8	2.6	0.72	0.64	1,600	>2,420	7.69	11.3	1447	11.62
RLT08	5/5/2003	150	2011	204	56	0	0	2.26	0.59	0.41	470	687	7.6	8.21	1928	11.59
RLT09	5/5/2003	187	2008	22	9	0.1	0.9	2.43	0.77	0.67	7,600	>2,420	7.74	8.91	1944	10.42
RLT10	5/5/2003	53	234	39	10	0	0.3	1.15	0.59	0.45	6,500	>2,420	8.3	7.48	1430	9.63
RLT05	5/9/2003	140	1425	39	10	0	0.1	1.77	0.74	0.69	20	25.6	7.59	7.51	1445	11.3
RLT06	5/9/2003	143	1290	11	6	0	0	1.51	0.35	0.29	0	0	7.61	9.97	1421	14.62
RLT07	5/9/2003	141	1230	43	10	0.11	1.4	2.4	1.01	0.89	390	980	7.67	10.1	1232	12.04
RLT08	5/9/2003	101	811	23	8	0	0	1.27	0.3	0.26	40	63.8	7.8	8.51	880	10.72
RLT09	5/9/2003	195	1779	25	9	0.11	0.9	2.42	1.2	1.11	120	147	7.73	8.46	1763	10.57
RLT10	5/9/2003	98	738	25	7	0	0	1.5	0.58	0.53	110	192	7.91	7.7	716	9.96
RLT10(duplicate)	5/9/2003	98	735	31	8	0	0	1.64	0.63	0.54			7.91	7.7	716	9.96
RLT11(blank)	5/9/2003	0	0	0.15	0	0	0	0	0	0			NA	NA	NA	NA
RLT05	5/19/2003	199	2132	18	7	0	0	2.81	0.41	0.27			7.95	10.8	2381	16.21
RLT06	5/19/2003	280	2282	10	2	0	0	1.5	0.21	0.2			8.3	10.4	1300	18.45
RLT07	5/19/2003	154	1189	16	0	0	0	2.02	0.58	0.52			8.24	14	1389	16.65
RLT08	5/19/2003	118	753	16	2	0.07	0	1.91	0.38	0.34			8.02	9.79	969	17.27
RLT09	5/19/2003	210	1583	6	1	0	0	1.99	1.51	1.48			8.55	17.6	1771	14.91
RLT10	5/19/2003	190	1550	7	0	0	0	1.72	0.45	0.42			7.58	11.2	1594	13.84
RLT05	6/17/2003	156	1333	114	36	0.14	0.1	1.8	0.85	0.84	4,300	>2,420	7.58	4.2	1671	23.1
RLT06	6/17/2003	128	654	17	13	0	0	1.48	0.66	0.53	650	>2,420	7.5	4.84	906	25.33
RLT07	6/17/2003	144	926	16	14	0	0	1.24	0.86	0.65	780	770	8.06	11	1338	26.04
RLT07(duplicate)	6/17/2003	142	927	15	12	0	0	1.14	0.88	0.82	921	840	8.06	11	1338	26.04

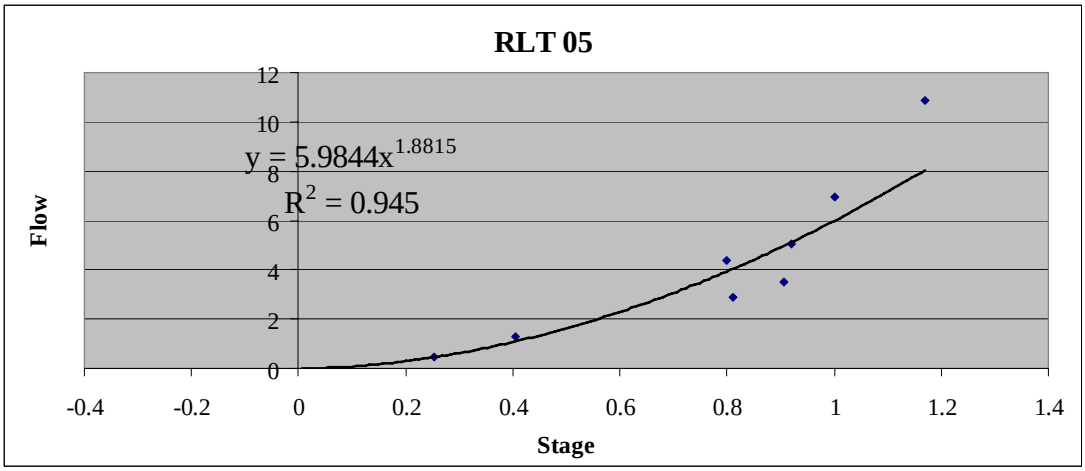
RLT09	6/17/2003	259	1697	22	12	0.05	0	1.87	0.91	0.73	2,800	>2,420	8.54	6.14	2136	21.73
RLT11(blank)	6/17/2003	0	0	0	0	0	0	0	0	0	0	0	NA	NA	NA	NA
RLT05	6/24/2003	211	1160	52	7	0.06	0.2	2.57	0.95	0.82	23,000	>2,420	7.67	5.5	1413	22.76
RLT06	6/24/2003	162	670	16	2	0	0.3	1.9	0.48	0.41	2,700	>2,420	7.47	5.21	828	23.8
RLT07	6/24/2003	276	1848	5	0	0	0	2.13	0.74	0.72	610	921	8.01	11.1	2241	24.57
RLT08	6/24/2003	193	795	47	7	0.4	0.1	2.54	0.7	0.59	15,000	>2,420	8	6.59	1006	23.58
RLT05	5/30/2004	109	1109	80	18	0	0.2	4.68	2.38	2.16			7.46	5.97	1502	14.54
RLT06	5/30/2004	143	1303	28	7	0	0	1.52	0.32	0.27			7.71	6.85	1831	14.99
RLT06(duplicate)	5/30/2004	145	1308	30	8	0	0	1.41	0.31	0.25			7.71	6.85	1831	14.99
RLT07	5/30/2004	143	1705	25	9	0	0	1.21	0.31	0.24			7.91	9.09	2216	14.47
RLT08	5/30/2004	104	1646	200	58	0	0	2.03	0.46	0.33			7.93	7.09	2245	13.94
RLT09	5/30/2004	200	2508	47	12	0.04	0	2.67	0.55	0.42			7.95	7.52	3278	14.24
RLT11(blank)	5/30/2004	0	0	0	0	0.03	0	0	0	0			NA	NA	NA	NA
RLT05	6/11/2004	188	1259	38	9	0.03	0	2.58	0.88	0.81			7.52	4.63	1823	21.99
RLT06	6/11/2004	209	1576	8	6	0	0	1.8	0.22	0.2			7.65	6.47	2193	26.79
RLT07	6/11/2004	170	1904	10	4	0	0	0.94	0.33	0.27			8.3	12.8	2506	26.85
RLT07(duplicate)	6/11/2004	170	1914	24	8	0	0	1.13	0.33	0.27			8.3	12.8	2506	26.85
RLT08	6/11/2004	149	2279	100	30	0	0	0.23	0.53	0.4			7.7	5.91	3130	16.37
RLT09	6/11/2004	222	2650	76	18	0.14	0	3.22	0.74	0.6			7.71	6.97	3483	22.15
RLT10	6/11/2004	41	378	195	45	0.27	0.3	2.02	0.73	0.59			7.37	5.82	194	16.87
RLT11(blank)	6/11/2004	0	0	0	0	0.04	0	0	0	0			NA	NA	NA	NA

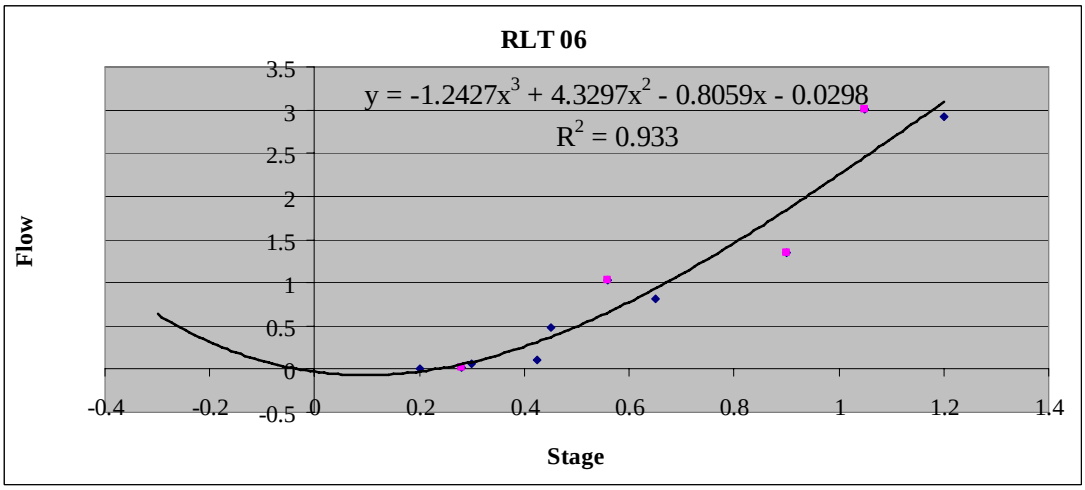
Richmond Lake			Total	Susp												Water
Site	Date	Alk	Solids	Solids	VTSS	Ammon	Nitrate	TKN	TP	TDP	Fecal	E. Coli	pH	DO	Conduct	Temp
RL01A	4/9/2003	264	1154	9	5	0	0	1.14	0.24	0.18	0	0	8.45	13	1046	5.2
RL02A	4/9/2003	260	1142	8	4	0	0	0.93	0.22	0.16	2	0	8.49	14.6	1046	5.44
RL02B	4/9/2003	260	1145	9	4	0.18	0	1	0.21	0.17			8.45	9.74	1046	5.34
RL03A	4/9/2003	267	1162	3	2	0.14	0	0.87	0.23	0.18	0	0	8.47	12.8	1065	5.43
RL03B	4/9/2003	266	1164	4	2	0	0	0.84	0.24	0.18			8.39	12.7	1062	5.33
RL01A	5/28/2003	254	1128	11	4	0	0	0.88	0.12	0.08	0	12.1	8.57	12.1	1410	18.26
RL02A	5/28/2003	253	1139	16	6	0	0	1.12	0.12	0.08	10	0	8.5	12.1	1456	17.03
RL02B	5/28/2003	252	1148	19	6	0	0	1.05	0.16	0.12			8.37	8.05	1406	16.54
RL03A	5/28/2003	256	1131	7	6	0	0	0.81	0.1	0.07	10	19.9	8.62	12.9	1457	18.04
RL03B	5/28/2003	259	1139	13	4	0.15	0	1.23	0.3	0.25			8.06	3.57	1344	13.89
RL00(blank)	6/18/2003	0	0	0	0	0.03	0	0	0	0	0	0	NA	NA	NA	NA
RL01A	6/18/2003	251	1130	17	9	0.1	0	1.13	0.34	0.31	70	48	8.67	10.1	1586	23.92
RL02A	6/18/2003	249	1163	10	9	0.02	0	0.94	0.22	0.19	30	17.1	8.63	9.12	1557	23.64
RL02B	6/18/2003	247	1161	16	10	0	0	0.95	0.21	0.18			8.61	8.36	1552	23.48
RL03A	6/18/2003	246	1114	8	7	0	0	0.74	0.17	0.14	30	29.5	8.64	9.72	1590	23.59
RL03B	6/18/2003	257	1148	8	6	0.19	0	0.99	0.38	0.36			8.25	2.82	1500	20.49
RL03B(duplicate)	6/18/2003	259	1148	3	2	0.19	0	1.22	0.37	0.36			8.25	2.82	1500	20.49
RL01A	7/2/2003	246	1086	18	9	0	0	1.45	0.31	0.23	10	7.4	8.67	10.1	1586	23.92
RL02A	7/2/2003	237	1074	16	4	0	0	0.81	0.3	0.26	0	4.1	8.63	9.12	1557	23.64
RL02B	7/2/2003	235	1087	21	7	0	0	1.01	0.31	0.25			8.61	8.36	1552	23.48
RL03A	7/2/2003	242	1102	12	6	0	0	0.95	0.3	0.24	0	5.2	8.64	9.72	1590	23.59
RL03B	7/2/2003	247	1103	14	6	0.12	0	0.82	0.35	0.32			8.25	2.82	1500	20.49
RL01A	7/16/2003	252	1104	12	6	0	0	1.61	0.45	0.41	0	2	8.77	9.64	1471	25.54
RL02A	7/16/2003	250	1105	17	10	0	0	1.47	0.48	0.41	0	0	8.84	11.3	1457	25.31

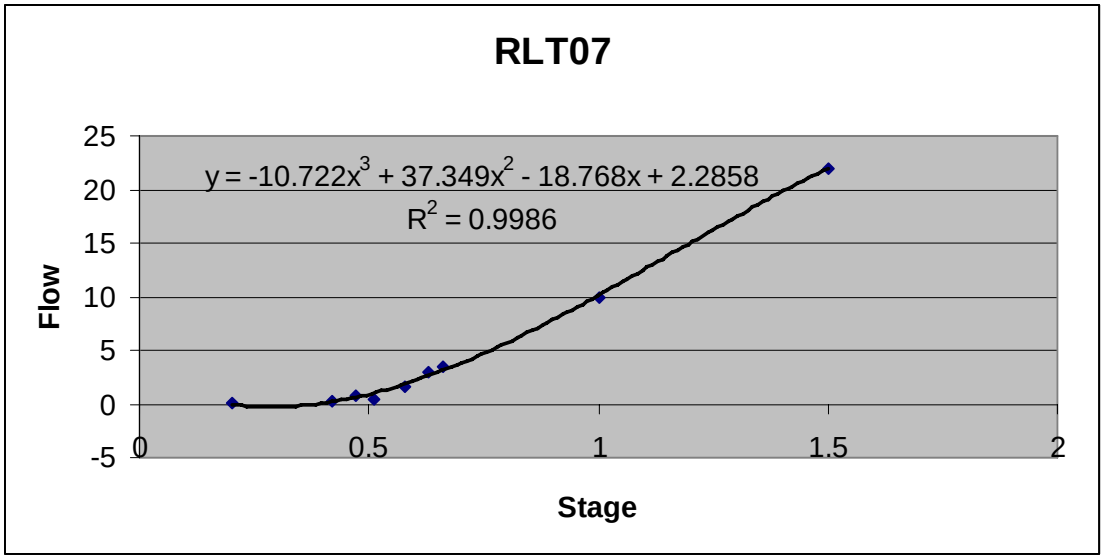
RL02B	7/16/2003	249	1106	19	13	0	0	1.78	0.51	0.41			8.81	9.81	1445	24.81
RL03A	7/16/2003	249	1092	6	5	0.02	0	1.4	0.41	0.4	10	0	8.69	8.89	1455	24.84
RL03B	7/16/2003	253	1090	6	4	0.23	0	1.4	0.52	0.51			8.5	3.68	1403	22.89
RL01A	8/7/2003	258	1139	17	3	0.16	0	1.41	0.66	0.58	10	0	8.67	6.78	1597	23.91
RL02A	8/7/2003	261	1138	19	3	0.06	0	1.36	0.65	0.57	0	0	8.76	7.73	1632	25.15
RL02B	8/7/2003	257	1135	14	1	0.09	0	1.26	0.64	0.56			8.56	1.76	1623	24.52
RL03A	8/7/2003	259	1119	6	0	0.06	0	0.94	0.61	0.6	0	0	8.77	9.04	1615	24.73
RL03B	8/7/2003	259	1121	8	0	0.1	0	0.98	0.63	0.58			8.74	6.76	1587	23.81
RL00(blank)	8/19/2003	0	0	0	0	0.03	0	0	0	not taken	0	0	NA	NA	NA	NA
RL01A	8/19/2003	260	1140	17	4	0	0	1.52	0.52	0.43	10	1	8.91	9.56	1306	26.69
RL02A	8/19/2003	260	1133	23	8	0	0	1.5	0.54	0.42	0	0	8.94	7.95	1303	26.03
RL02A(duplicate)	8/19/2003	257	1133	24	9	0	0	1.48	0.56	0.42	0	0	8.94	7.95	1303	26.03
RL02B	8/19/2003	257	1130	18	8	0	0	1.33	0.52	0.41			8.95	7.72	1301	25.93
RL03A	8/19/2003	257	1126	18	9	0	0	1.34	0.54	0.46	10	2	8.98	10.8	1309	26.4
RL03B	8/19/2003	261	1131	27	8	0.2	0	1.29	0.77	0.56			8.45	0.26	1244	23.6
RL01A	8/27/2003	269	1148	23	9	0.04	0	1.25	0.56	0.51	0	2	8.7	4.53	1266	24.4
RL02A	8/27/2003	264	1151	27	8	0	0	1.24	0.62	0.5	0	0	8.79	6.87	1294	25.13
RL02B	8/27/2003	261	1146	25	9	0	0	1.2	0.6	0.47			8.8	5.55	1294	25.08
RL03A	8/27/2003	264	1131	13	6	0	0	1.1	0.54	0.47	0	1	8.83	7.93	1289	25.08
RL03B	8/27/2003	260	1128	15	6	0	0	1.19	0.54	0.45			8.85	7.41	1287	24.96
RL01A	9/23/2003	272	1165	15	7	0	0	1.08	0.33	0.27	0	0	9.02	12.8	1150	15.88
RL02A	9/23/2003	274	1175	32	10	0	0	0.93	0.38	0.24	0	1	9.08	12.8	1136	15.6
RL02B	9/23/2003	270	1167	30	10	0	0	0.9	0.37	0.26			9.09	12.6	1136	15.57
RL03A	9/23/2003	269	1161	26	11	0	0	0.87	0.4	0.29	0	0	9.01	13	1151	16.24
RL03B	9/23/2003	271	1162	27	11	0	0	0.93	0.4	0.27			9.07	13.2	1142	15.77
RL01A	12/29/2003	286	1230	5	5	0	0	1.38	0.18	0.12	0	0	8.75	15.2	973	1.43

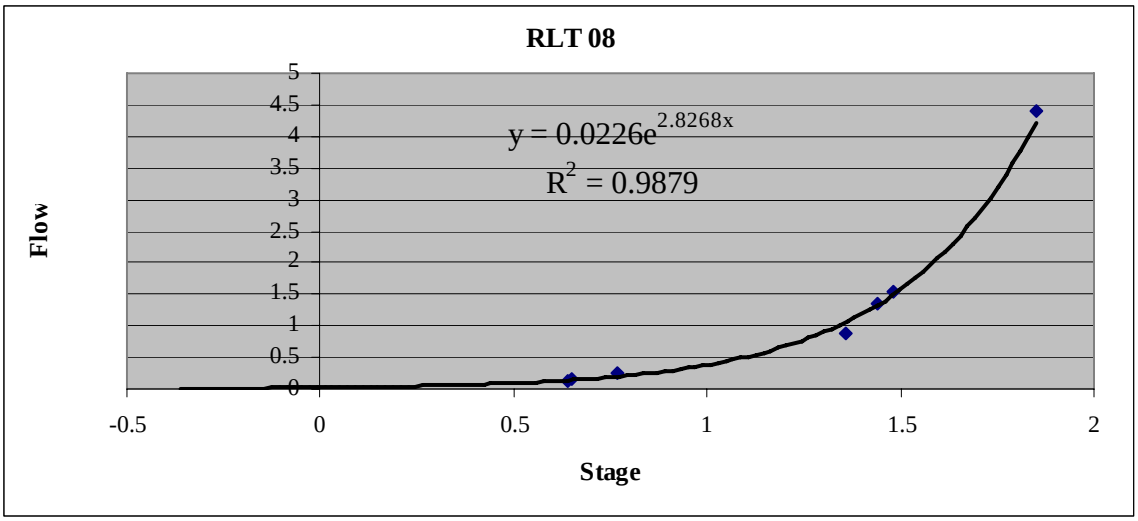
RL02A	12/29/2003	285	1211	2	2	0	0	0.97	0.16	0.14	0	0	8.88	13.6	978	1.94
RL02B	12/29/2003	283	1207	3	3	0	0	0.96	0.16	0.14			8.82	9.81	1031	2.75
RL03A	12/29/2003	285	1211	1	1	0	0	0.99	0.16	0.13	0	0	8.01	13.5	973	1.72
RL03B	12/29/2003	290	1212	3	2	0.08	0	1	0.38	0.33			8.22	2.66	1056	4.09
RL00(blank)	2/18/2004	0	0	0	0	0	0	0	0	0	0		NA	NA	NA	NA
RL01A	2/18/2004	307	1335	9	5	0	0	1.43	0.33	0.23	0		8.91	14.7	1882	1.0
RL01A(duplicate)	2/18/2004	308	1339	8	3	0.02	0	1.36	0.3	0.23	0		8.91	14.7	1882	1.0
RL02A	2/18/2004	309	1327	5	1	0	0	0.79	0.28	0.25	0		8.81	10.7	1875	1.0
RL02B	2/18/2004	308	1333	7	2	0	0	0.83	0.26	0.24			8.77	9.53	1876	2.5
RL03A	2/18/2004	302	1324	5	2	0	0	0.58	0.26	0.22	0		8.88	12.4	1886	1.0
RL03B	2/18/2004	307	1340	7	2	0.14	0	0.68	0.35	0.33			8.34	2.6	1896	4.0

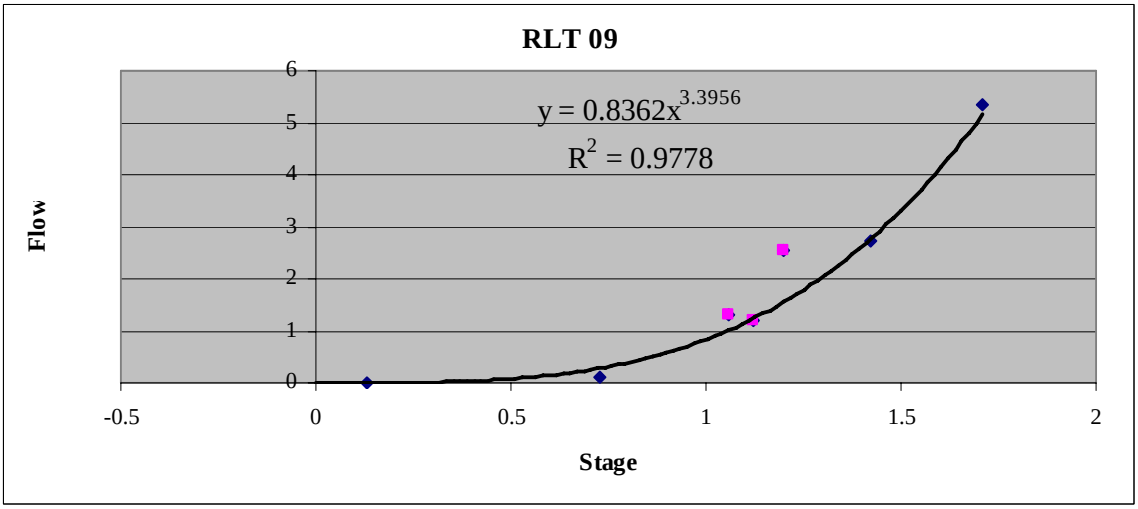
Appendix D. Richmond Lake Stage To Discharge Tables

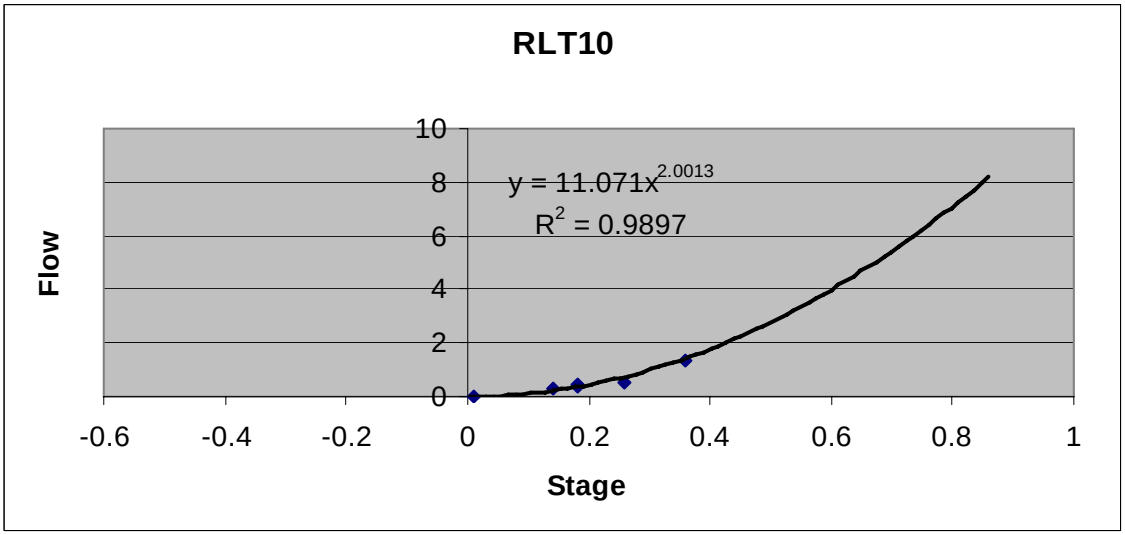

RLT 05
y = 5.9844x^1.8815
R^2 = 0.945
Flow
Stage
12
10
8
6
4
2
0
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4


RLT 06
y = -1.2427x^3 + 4.3297x^2 - 0.8059x - 0.0298
R^2 = 0.933
Flow
Stage
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4


RLT07
y = -10.722x^3 + 37.349x^2 - 18.768x + 2.2858
R^2 = 0.9986
Flow
Stage
25
20
15
10
5
0
-5
0
0.5
1
1.5
2


RLT 08
y = 0.0226e^2.8268x
R^2 = 0.9879
Flow
Stage
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
0.5
1
1.5
2


RLT 09
y = 0.8362x^3.3956
R^2 = 0.9778
Flow
Stage
6
5
4
3
2
1
0
-0.5
0
0.5
1
1.5
2


RLT10
y = 11.071x^2.0013
R^2 = 0.9897
Flow
Stage
10
8
6
4
2
0
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1

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