Dissolved Oxygen Total Maximum Daily Load (TMDL)
Lake Andes, Charles Mix County, South Dakota

South Dakota Department of
Environment and Natural Resources

Protecting South Dakota's Tomorrow ... Today

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Total Maximum Daily Load Summary Table

Water Body Name/Description: Lake Andes in Charles Mix County, SD

Assessment Unit ID: SD-MI-L-ANDES_01

Size of Impaired Waterbody: 21 km^2

Size of Watershed: 609 km^2

Location: HUC Code 1014010117

Impaired Designated Use(s): Warmwater marginal fish life propagation

Cause(s) of Impairment: Low dissolved oxygen (DO) concentrations

Cycle Most Recently Listed: 2008

TMDL End Points

Indicator Name: DO concentrations
Total phosphorus (TP) concentrations

Threshold Values: Daily minimum lake DO concentrations ≥5 mg/L
Daily maximum in-lake TP concentration ≤0.2 mg/L

Analytical Approach: Linear regression and steady-state lake model

TMDL Allocations:

TMDL Component	Maximum Daily Allocation (kg/day)	Long-term Average Allocation (kg/year)
Wasteload Allocation	0	0
Load Allocation	103	15,839
Margin of Safety	Implicit	Implicit
TMDL	**103**	**15,839**

1.0 Introduction

The intent of this document is to clearly identify the components of the TMDL, support adequate public participation, and facilitate the US Environmental Protection Agency (US EPA) review. The TMDL was developed in accordance with Section 303(d) of the federal Clean Water Act and guidance developed by US EPA. This TMDL document addresses the dissolved oxygen (DO) impairment of Lake Andes in Charles Mix County, SD (SD-MI-L-ANDES_01), which was assigned to priority category 1 (high priority) in the 2008 impaired waterbodies list.

1.1 Lake and Watershed Characteristics

Lake Andes is a shallow, prairie lake located in northern Charles Mix County, SD (Figure 1). Historically, Lake Andes was a natural lake in a bedrock valley buried by mostly glacial till. In 1922, a high water elevation of 1437.25 ft above msl was established for Lake Andes via the construction of an artificial outlet (SD DENR, 1992), resulting in a maximum pool depth of approximately 11 ft, at which the surface area of the lake is approximately 21 km^2 (Sando and Neitzert, 2003). Other structures were constructed for the management of lake volume, including a dike and control structure constructed in 1936 on Owens Bay, allowing an elevation of 1443.55 ft above msl to be maintained in the bay. In addition, two county roadway dikes were constructed in 1938-39 that divide the lake into three units: North Unit, Center Unit, and South Unit. The North Unit receives most of its inflow from Andes Creek and an unnamed tributary with drainage areas of 251 and 76 km^2, respectively. The North Unit has a maximum depth of approximately 7 ft at which the North Unit spills into the Center Unit through a culvert in the roadway dike. The Center Unit receives a majority of is inflow from the North Unit and two of the monitored unnamed tributaries draining approximately 70 km^2. The Center Unit has a maximum depth of approximately 8 ft at which the Center Unit spills into the South Unit through the second roadway dike culvert. A majority of the South Unit inflow originates from the Center Unit and three monitored drainages with a combined drainage area of approximately 100 km^2.

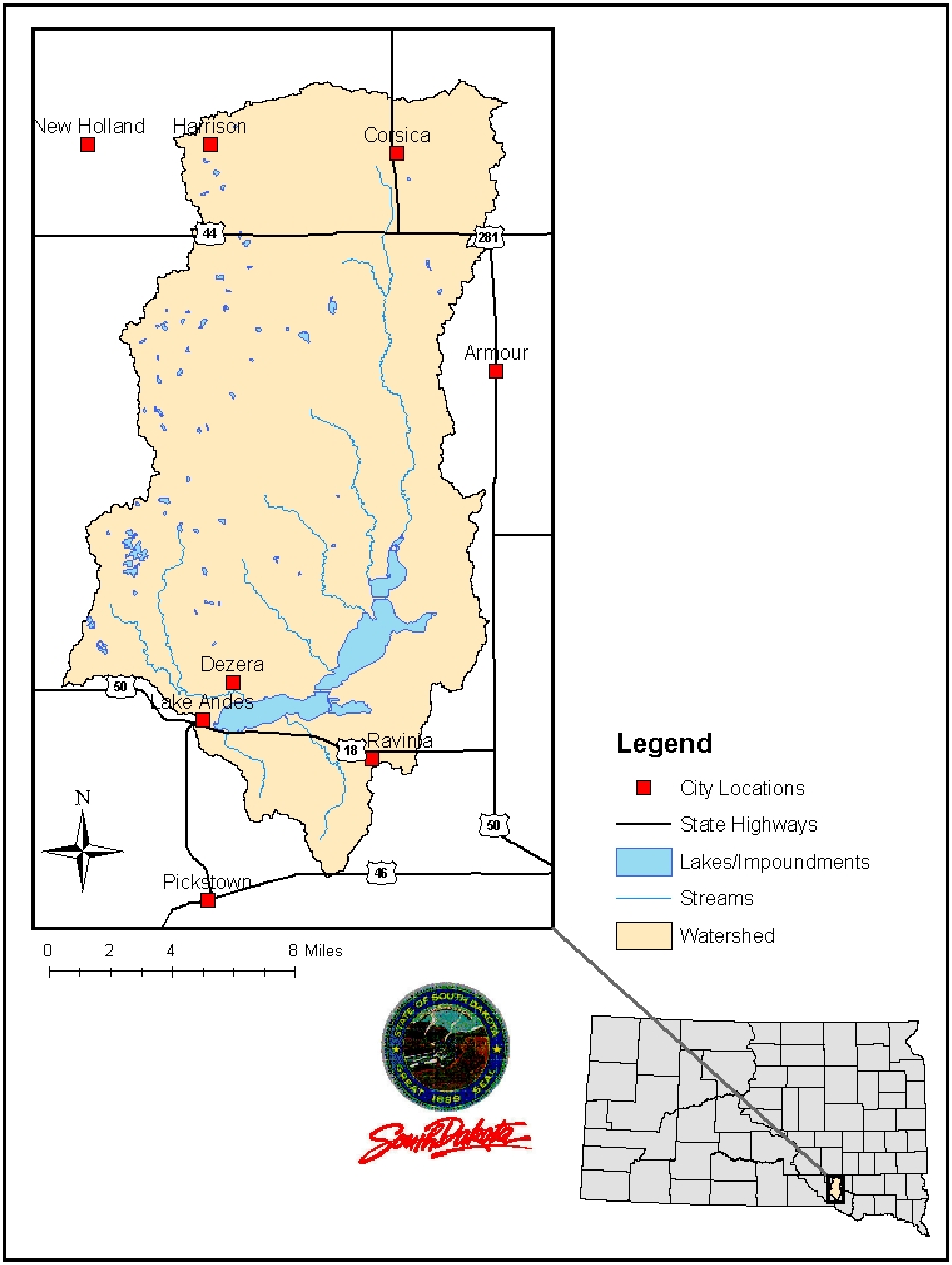


Figure 1. Location of the Lake Andes watershed, Charles Mix and Douglas Counties, SD.

Lake Andes water supply almost entirely originates from watershed runoff. A minor source of water originates from an artesian well draining into Owens Bay. Streams draining to Lake Andes are characterized as ephemeral, frequently experiencing periods of no flow. During the project period, all streams draining the Lake Andes watershed were intermittent and flowed during rainfall runoff events.

Lake Andes is occasionally completely dry. Based on historic accounts, the lake completely dried approximately every 14 years prior to the creation of the outlet canal and approximately every 11.5 years after the completion of the outlet canal (SD DENR, 1992).

Average annual precipitation at the Pickstown Cooperative climate station for the period of record (January 1948 to date) was approximately 22 inches. Annual precipitation at this station in 2000 and 2001 was 17.49 in and 27.58 in, respectively. A majority of the precipitation falls during the spring and summer months. Snowmelt and rain events contribute to highest precipitation in the spring, while short-duration, high-intensity storms are common in the summer months (Figure 2).

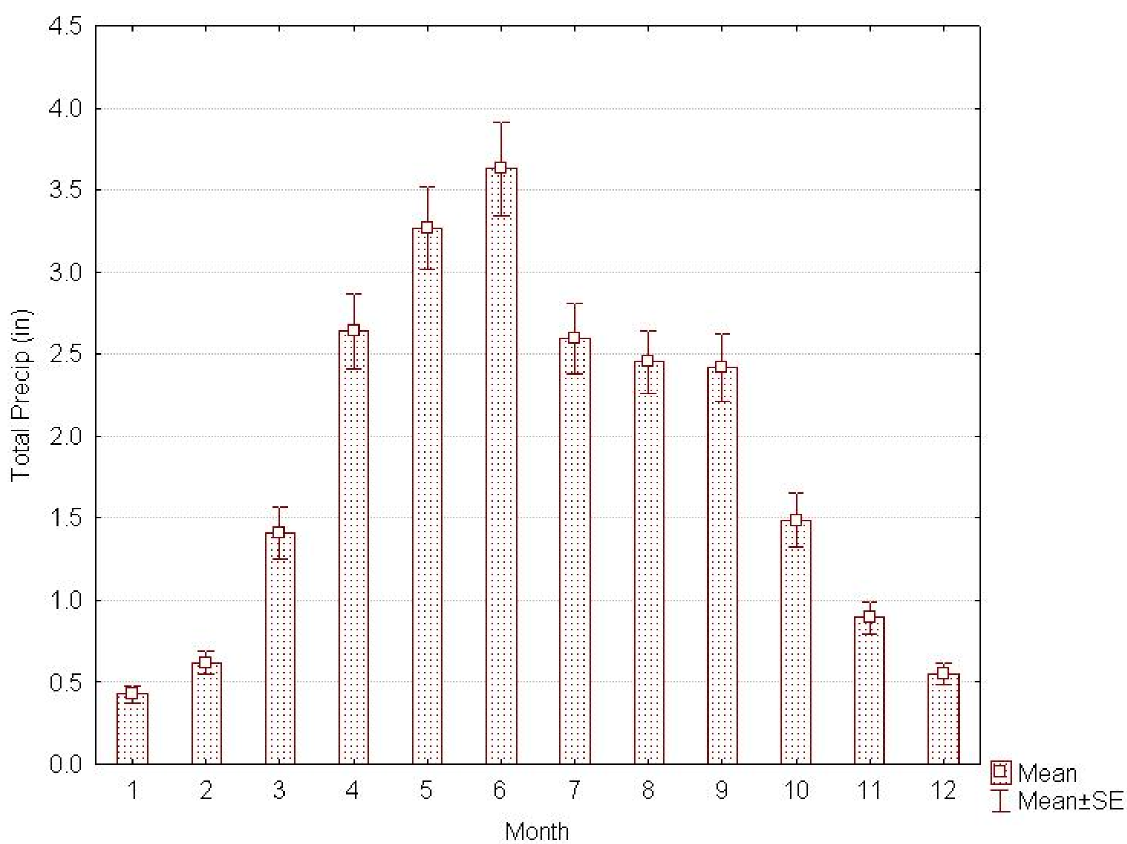


Figure 2. Total monthly precipitation for Pickstown, SD for period of January 1948 to May 2007. (source: http://climate.sdstate.edu/climate_site/climate.htm)

According to State Soil Geographic dataset (STATSGO), most of the soils in the watershed consist of Eakin-Highmore-Ethan complex (SD076), while the soils adjacent to the lake are primarily Highmore-Eakin-Raber complex (SD077). Subwatershed LAT8 is unique in that it consists primarily of Ethan-Clarno-Betts complex (SD086). These soil delineations depict the dominant soils making up the landscape. Other dissimilar soils, too small to be delineated, are present within the delineations. A soils map for the Lake Andes watershed is presented in Appendix A.

The Lake Andes watershed drains approximately 609 km^2 of predominantly agricultural land (90%), including cropland and pasture. A watershed land use map can be found in Appendix B. Nonpoint source nutrient loads from the Lake Andes watershed likely originate from a combination of agricultural uses, including row crop farming, grazing livestock and animal feeding areas, as well as natural sources such as the leaching of phosphate-bearing minerals and organic matter decomposition.

1.2 CWA Section 303(d) Listing Information

The Lake Andes watershed assessment was part of the South Central Lakes Watershed Assessment (SCLWA), a larger, multi-lake assessment project. The goal of the SCLWA project was to locate and document sources of non-point source pollution (primarily excess nutrient loading) in watersheds that drain to the following lakes: Lake Andes, Academy Lake, Corsica Lake, Dante Lake, Geddes Lake, and Lake Platte. At the time of the assessment project, these lakes were considered impaired due to their high trophic state, an indicator of excessive primary productivity. TMDLs have been developed and management recommendations made for Corsica, Geddes and Dante Lakes and their watersheds in order to reduce nutrient loadings.

Lake Andes was included in the 1998, 2002, 2004, and 2006 South Dakota 303(d) Impaired Water Body Lists due to high trophic state (i.e eutrophication) and in the most recent 2008 South Dakota Impaired Waterbody List due to high trophic state index values (algal productivity) and low DO concentrations. Data supporting these listings were derived from DENR statewide lake assessments and the SCLWA project. The 2002, 2004, 2006, and 2008 Impaired Waterbody Lists identify Lake Andes as a high priority waterbody in terms of TMDL development.

1.3 Available Water Quality Data

As part of the SCLWA project, water quality samples were collected from Lake Andes on a semi-monthly basis for approximately one year (from May 2000 – May 2001), excluding the months November 2000, December 2000, January 2001, and March 2001. Samples were collected from three sites (Figure 3) when conditions allowed, and were analyzed by the South Dakota Department of Health Laboratory in Pierre, SD.

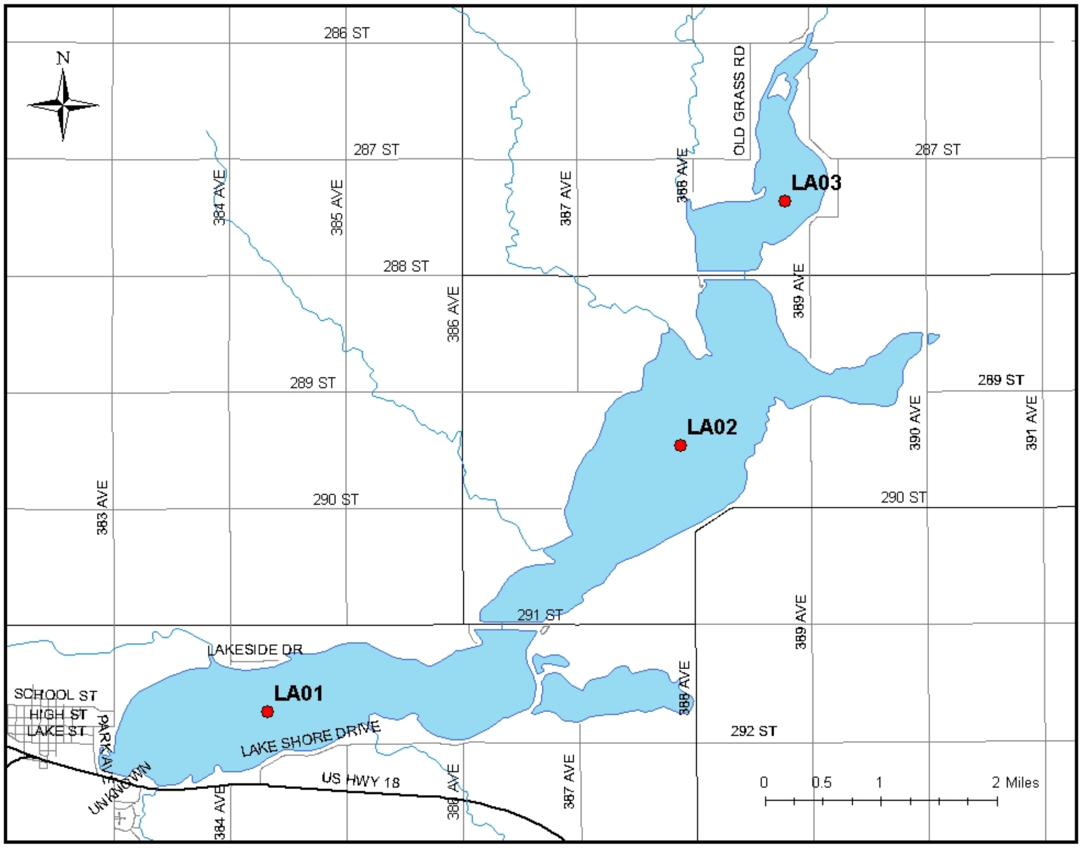


Figure 3. Location of lake sampling sites, Lake Andes, Charles Mix County, SD.

The United States Geological Survey (USGS) also collected data from the same locations in Lake Andes from February 1990 to August 2002. This data was retrieved online from NWIS at http://waterdata.usgs.gov/sd/nwis.

Eight inlet streams sites (LAT02, LAT03, LAT04, LAT05, LAT06, LAT07, LAT08, and LAT09) and one outlet stream site (LAO01) were also monitored during the SCLWA study period. Water level recorders were installed to maintain a continuous stage record for a period of approximately one year. Figure 4 shows the location of the stream monitoring sites. Physical and chemical parameters were examined for study area streams on a semi-monthly basis for approximately one year (from May 2000 – May 2001), excluding the months September 2000, December 2000, January 2001, and February 2001.

Stream flow records during the SCLWA study period were incomplete and inadequate for some monitoring sites, so estimates of stream flow were obtained from the United States Geological Survey (USGS) Elevation Derivatives for National Applications (EDNA) database (http://edna.usgs.gov/) in order to make comparisons of long-term average stream flows (and parameter loads) among all monitoring sites.

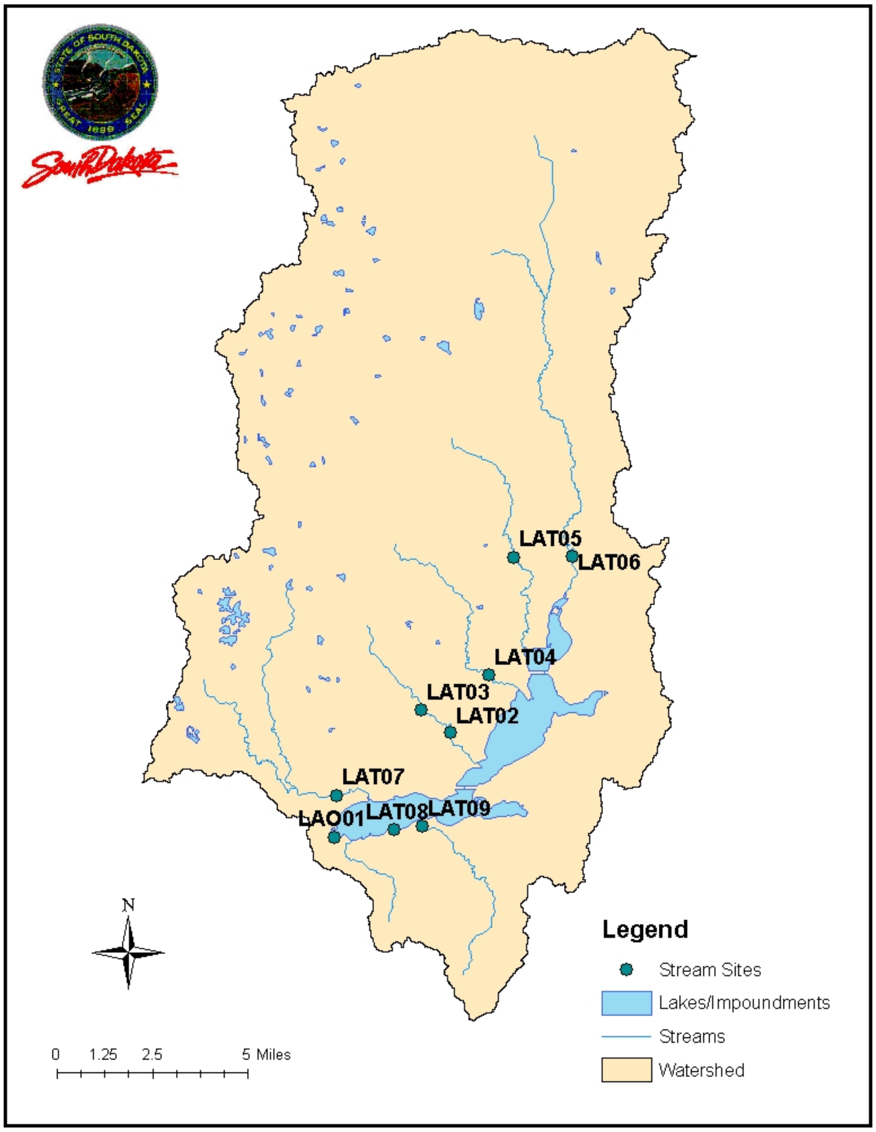


Figure 4. Location of stream sampling sites for the Lake Andes watershed assessment, Charles Mix and Douglas Counties, SD.

During the SCLWA project, all lake and stream samples and measurements were collected using methods described in *Standard Operating Procedures for Field Samplers* for the South Dakota Water Resources Assistance Program (SDDENR 2000). Water and air temperature, pH, conductivity, and DO measurements were taken using a YSI meter. Sample data can be found in Appendix E.

Quality Assurance/Quality Control (QA/QC) samples were collected according to the SD DENR Water Resources Assistance Program Quality Assurance Project Plan (SD DENR, 2009). Further details concerning water sampling techniques, analysis, and quality control are discussed in the assessment final report (Larson, 2008). QA/QC data can be found in Appendix F.

2.0 Water Quality Standards and TMDL Targets

Each waterbody in South Dakota is assigned beneficial uses. All waters (both lakes and streams) are designated with the use of fish and wildlife propagation, recreation, and stock watering. All streams are assigned the use of irrigation. Additional uses are assigned by the state based on a beneficial use analysis of the waterbody.

The Administrative Rules of South Dakota (ARSD 74:51:01, 02, and 03) contain South Dakota's surface water quality standards. Chapter 74:51:01 contains both the numeric and narrative criteria to protect the uses of the state's water bodies. Chapters 74:51:02 and 74:51:03 designate the beneficial uses assigned to each specific water body in the state.

Lake Andes has been assigned the following beneficial uses: warmwater marginal fish life propagation (use # 6), immersion recreation (use # 7), limited contact recreation (use # 8), and wildlife propagation, recreation, and stock watering (use # 9). Table 1 lists the daily maximum/minimum criteria that must be met to maintain the above beneficial uses. When multiple criteria exist for a particular parameter, the most stringent criterion is used.

Table 1. State surface water quality criteria (daily maximum/minimum) for Lake Andes, Charles Mix County, SD.

Parameter	Criteria	Beneficial Use Requiring Criteria
Nitrate – N[1]	≤ 88 mg/L, daily maximum	Wildlife propagation, recreation, and stock watering
Total ammonia[1]	Equal to or less than the result from Equation 2 in Appendix A (SDCL§74:51:01)	Warmwater marginal fish propagation
Alkalinity ($CaCO_3$) [1]	≤ 1,313 mg/L, daily maximum	Wildlife propagation, recreation, and stock watering
pH	6.0 – 9.0 (standard units)	Warmwater marginal fish propagation
Conductivity[1]	≤ 7,000 umhos/cm, daily maximum	Wildlife propagation, recreation, and stock watering
Total dissolved solids[1]	≤ 4,375 mg/L, daily maximum	Wildlife propagation, recreation, and stock watering
Total suspended solids[1]	≤ 263 mg/L, daily maximum	Warmwater marginal fish propagation
Temperature	≤ 90 º F	Warmwater marginal fish propagation
Dissolved oxygen	≥ 5.0 mg/L in any one sample from May 1 – September 30; OR ≥ 4.0 mg/L in any one sample from October 1 – April 30	Warmwater marginal fish propagation
Fecal coliform bacteria[1,2]	≤ 400 CFU/100mL in any one sample	Immersion recreation
Total petroleum hydrocarbon[3]	≤ 10 mg/L	Wildlife propagation, recreation, and stock watering
Oil and grease[3]	≤ 10 mg/L	Wildlife propagation, recreation, and stock watering
Undisassociated hydrogen sulfide[3]	≤ 0.002 mg/L, per sample	Warmwater marginal fish propagation

[1] Daily maximum criterion. Criteria also established for geometric mean, 30-day average and/or early life stage periods.
[2] The fecal coliform criteria are in effect from May 1 to September 30.
[3] Parameters not measured during this project.

All South Dakota streams are assigned the beneficial uses of fish and wildlife propagation, recreation, and stock watering (use # 9) and irrigation (use # 10). No additional beneficial uses have been assigned to streams draining into Lake Andes. Table 2 lists the criteria that must be met to support the beneficial uses assigned to the watershed streams.

Table 2. Surface water quality criteria (daily maximum/minimum) and designated beneficial uses for streams in the Lake Andes watershed, Douglas and Charles Mix County, SD.

Parameter	Criteria	Beneficial Use Requiring Criteria
Alkalinity ($CaCO_3$) [1]	≤ 1,313 mg/L, daily maximum	Wildlife propagation, recreation, and stock watering
pH	6.0 – 9.5 (standard units)	Wildlife propagation, recreation, and stock watering
Conductivity[1]	≤ 4,375 umhos/cm, daily maximum	Irrigation
Total dissolved solids[1]	< 4,375 mg/L, daily maximum	Wildlife propagation, recreation, and stock watering
Nitrate-N[1]	≤ 88 mg/L, daily maximum	Wildlife propagation, recreation, and stock watering
Total petroleum hydrocarbons[2]	≤ 10 mg/L, in any one sample	Wildlife propagation, recreation, and stock watering
Oil and grease[2]	≤ 10 mg/L, in any one sample	Wildlife propagation, recreation, and stock watering
Sodium adsorption ratio (SAR)[2,3]	≤ 10	Irrigation

[1] Daily maximum criterion. Criteria also established for 30-day average.
[2] Parameters not measured during this project.
[3] The SAR is used to evaluate the sodium hazard of irrigation water based on the Gapon equation.

Additional "narrative" standards that may apply can be found in the Administrative Rules of South Dakota: Articles 74:51:01:05; 06; 08; and 09. These contain language that generally prohibits the presence of materials causing pollutants to form, visible pollutants, and nuisance aquatic life.

The daily minimum DO criterion of ≥5.0 mg/L was used as the TMDL target for this TMDL. Based on the regression analyses and lake model results, discussed in more detail below, a TP surrogate TMDL target of ≤0.2 mg/L was determined.

3.0 Significant Sources

3.1 Point Sources

One permitted point source discharge is located in the Lake Andes watershed. SD DENR has issued a Surface Water Discharge Permit (permit # SD0021962) to the Town of Corsica (population 570) for one outfall from their wastewater treatment facility. This outfall, located approximately 20 miles north of Lake Andes, discharges to Andes Creek approximately 2-3 times per year for periods of approximately 1-2 weeks. Due to low frequency and duration of discharges and the distance of the outfall from Lake Andes, this point source is not considered a significant source of phosphorus to Lake Andes.

3.2 Nonpoint Sources

Excessive nutrient loading to Lake Andes has likely contributed to a higher oxygen demand, resulting in seasonally low DO concentrations. Based on review of available information and communication with state and local authorities, the potential nonpoint sources of nutrient loads within the Lake Andes watershed include agricultural runoff from cropland and livestock feeding operations.

Manure from unconfined and confined livestock is a possible source of nutrients to the stream. Livestock contribute nutrient loads to the lake and streams draining the watershed directly by defecating while wading in the stream and indirectly by defecating on rangelands that are washed off during precipitation events. Livestock in the basin are predominantly beef cattle with few dairy cattle operations. Locations of potential livestock feeding areas, identified using aerial photography, are shown on the map in Appendix C.

Approximately 90% of the watershed landuse is agricultural, including cropland and pastureland. Roughly half of the agricultural lands are croplands. Based on USDA National Agricultural Statistics Service data (retrieved online at http://www.nass.usda.gov), crops planted in the watershed are primarily corn, soybeans, wheat, and hay/alfalfa. Other planted crops include oats and sunflower.

4.0 Technical Analyses

4.1 Linear Regression Analysis

Regression analyses are commonly used to model or predict the behavior of one or more variables. Linear regression, the simplest form of regression, can be used to determine the extent to which the value of a water quality variable is influenced by some other environmental variable. Using this approach, a model was constructed to predict lake DO concentrations (dependent variable) from lake TP concentrations (independent variable) using the linear regression tools included in the STATISTICA software package (Statsoft, Inc., version 8.0, Tulsa, OK). TP was selected as the independent variable because previous studies have shown relationships between lake DO (concentrations, areal extent or duration of anoxic conditions) and

TP concentrations (Welch and Perkins, 1979; Cornett and Rigler, 1980; and Nurnberg, 1995). In addition, elevated concentrations of TP were observed during this study at lake and stream monitoring sites, which can be reduced with the installation of watershed management practices.

Five assumptions must be met in order to use linear regression techniques for obtaining an unbiased approximation of the dependent variable, test hypotheses and to estimate confidence or prediction intervals: 1) The model form must be correct (i.e. y is linearly related to x), 2) the data used to fit the model are representative of the data of interest, 3) the variance of the residuals is constant and does not depend on x or anything else, 4) the residuals are independent, and 5) the residuals are normally distributed (USEPA, 1997).

The first step in applying the linear regression was to examine the data on a bivariate scatter plot to determine whether or not linear regression analysis is appropriate (assumption 1). The points on the plot should approximate a straight line, if the dependent and independent variables are linearly related. A scatter plot of the raw concentration data of DO and TP revealed a slight trend of decreasing lake DO concentrations with increasing lake TP concentrations, suggesting that the two variables are related. However, the relationship was not strong, and both the dependent and independent variables displayed right (positive) skew (Figure 5).

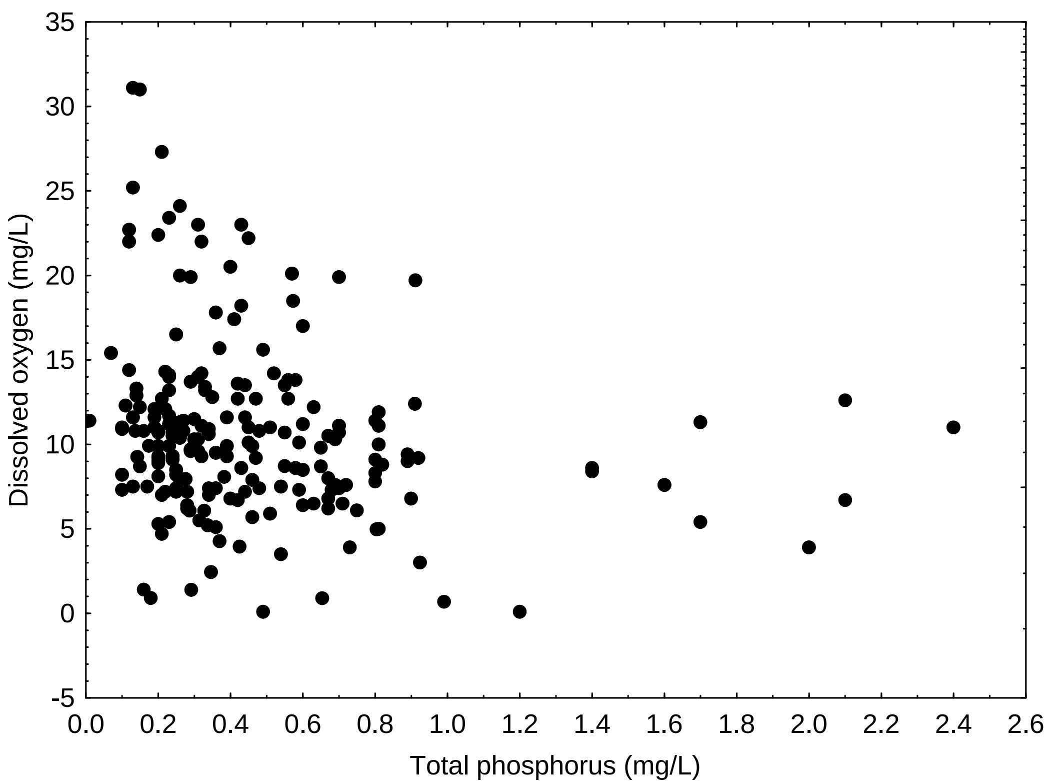


Figure 5. Scatter plot showing lake DO concentrations (mg/L) as a function of lake total phosphorus concentrations (mg/L).

To make the data more symmetric, the relationship more linear and avoid heteroscedasticity (i.e. unequal variance), both variables were log-transformed prior to performing the linear regression analysis (Helsel and Hirsch, 1995). Figure 6 shows the log-transformed data plotted on a bivariate scatter plot along with the linear fit and 95 percent confidence intervals for the mean response and individual estimates. The transformed data used to fit the model were considered representative of the data of interest (i.e. derived from data that is representative of the lake conditions), thus meeting assumption 2 above.

Regression analysis of the log-transformed data resulted in the following linear model:

$$\ln [DO (mg/L)] = 2.145715 - 0.168333 * \ln [TP (mg/L)]$$

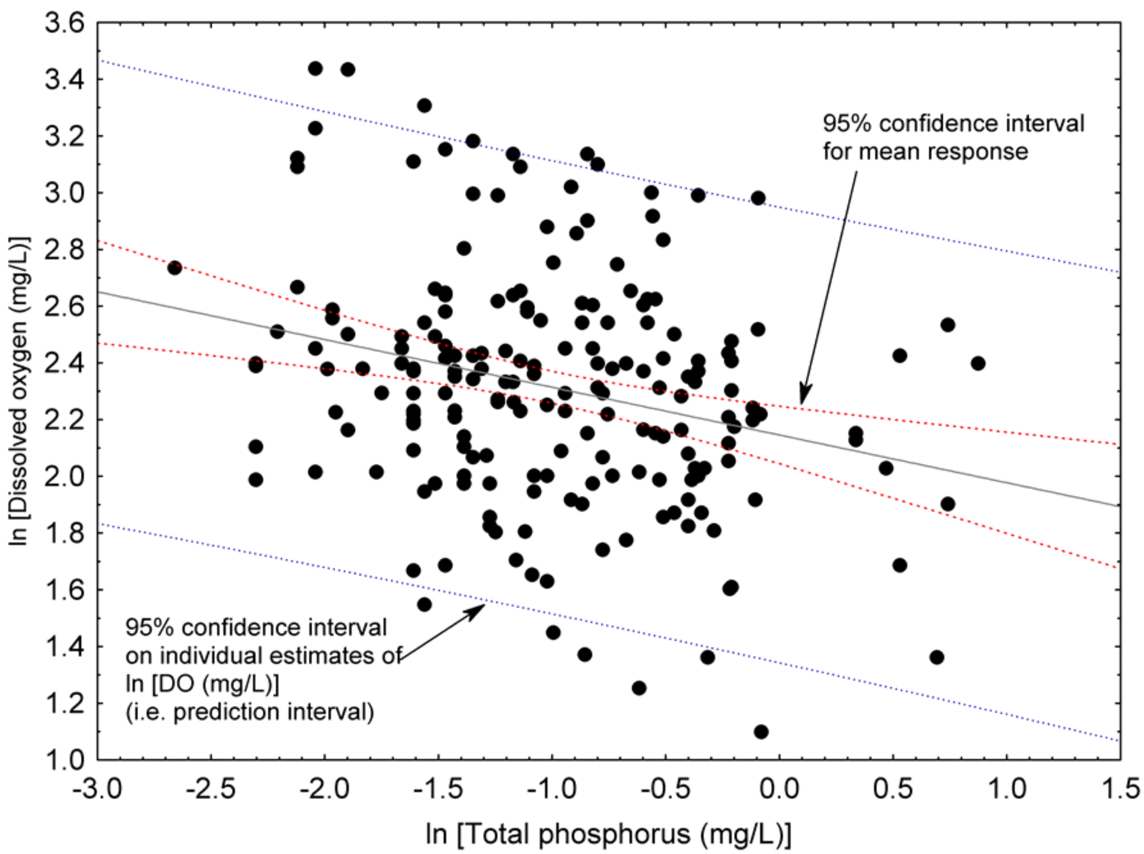
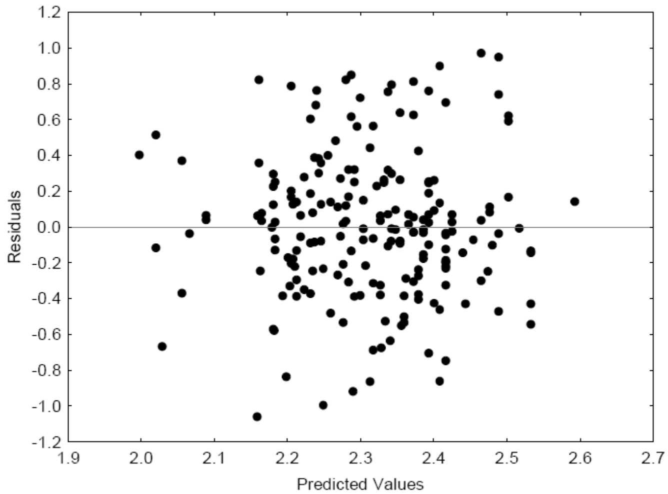
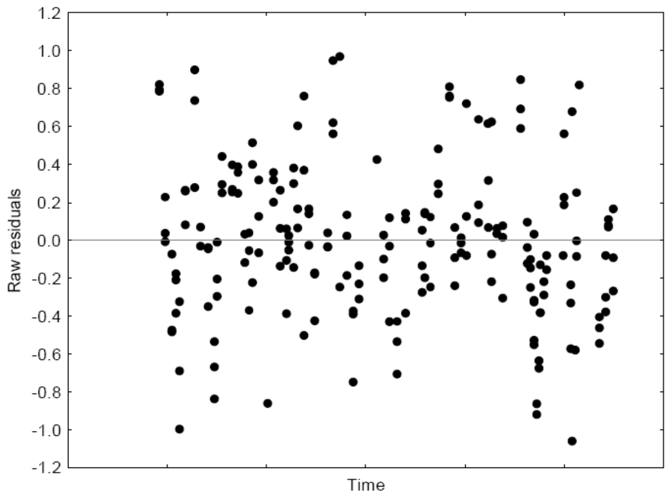


Figure 6. Log-linear regression of ln [DO (mg/L)] and ln [TP (mg/L)]. The fitted model is shown along with 95% confidence intervals for the mean response (inside red bands) and individual estimates of the response variable (outside blue bands; i.e. prediction interval).

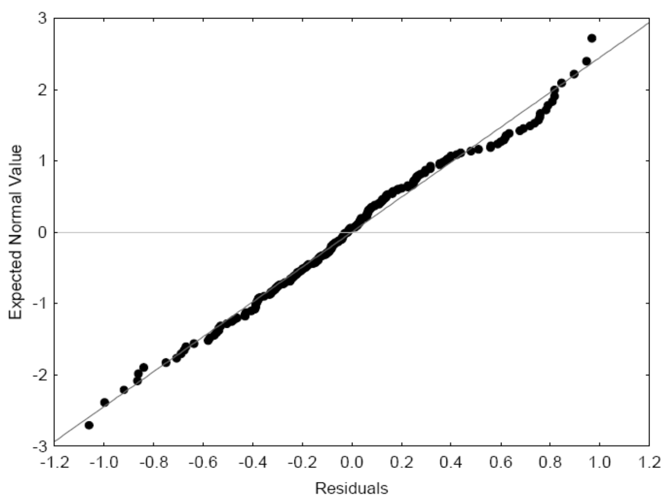
The regression analysis included an evaluation of the final three assumptions for linear regression using methods presented by USEPA (1997). These assumptions all pertain to characteristics of the regression residuals. Residuals can be defined as the difference between the observed values and the predicted values and represent unexplained (or residual) variation after fitting a regression model. Independence of residuals was evaluated by examining residuals plotted as a function of predicted values of y (Figure 7A) and residuals plotted as a function of time (Figure 7B). The plots show residuals as a uniform band around zero, rather than a pattern of increasing or decreasing variance with predicted values of *y* or time, and appear to satisfy the independence assumption. A normal probability plot of residuals (Figure 7C) was used to evaluate the final assumption that the residuals are normally distributed. The residuals appear to be normally distributed, as they reasonably follow the expected normal distribution, represented by the diagonal line. Based on the interpretations of these plots, the final three assumptions for linear regression are satisfied.



A) ln [DO (mg/L)] residuals as a function of ln [DO (mg/L)] predicted values.



B) ln [DO (mg/L)] residuals as a function of time.



C) Probability plot of ln [DO (mg/L)] residuals.

Figure 7. Plots of ln [DO (mg/L)] residuals, including residuals plotted as a function of predicted values of y (A), residuals plotted as a function of time (B) and a normal probability plot of residuals (C).

To estimate how well the regression line fits the data, several evaluation statistics can be calculated. The first evaluation performed on the regression results, was to determine whether the intercept (β_0) and slope (β_1) were significantly different than zero (Helsel and Hirsch, 1995). The standard error for (β_0) and (β_1), which is the same as the standard deviation of the regression residuals, and *t* statistics were calculated, which were then compared to the *t* distribution to determine whether (β_0) and (β_1) were significantly different from zero. In this case, both are significantly different than zero, based on inspection of the associated *p* values that were calculated by the STATISTICA program (Table 3). Since the *p* value is less than 0.05, the model is significant at the 95 percent confidence level.

Table 3. Summary of regression analysis of ln [DO (mg/L)] and ln [TP (mg/L)].

	Coefficients	Std. Error	*t* Statistic	*p* value
Intercept (β_0)	2.145715	0.051922	41.32580	0.000000
ln [TP (mg/L)] (β_1)	-0.168333	0.043437	-3.87537	0.000145

The coefficient of determination (R^2), which measures the reduction in the total variation of the dependent variable due to the independent variable, was 0.071. In other words, approximately 7% of the variance of ln [DO (mg/L)] was explained by ln [TP (mg/L)]. The regression equation explains a relatively small portion of the total variability; however, this is somewhat of an expected result. Indeed, the measured lake DO concentrations were extremely variable, ranging from 0.1 to 31 mg/L (mean = 9.9 mg/L), and this variability can be attributed to both naturally occurring and human-induced processes. For example, natural seasonal and diurnal (daily) fluctuations may result from changes in air/water temperature, photosynthetic processes, and precipitation patterns. Environmental variables that have been altered by human land use, including loadings of nutrients other than TP (e.g. carbon, nitrogen), may contribute to variability of DO concentrations. Sampling methods, including instrumentation error and inconsistent sampling time of day, may also influence the variability of the DO measurements.

DO concentration variability was taken into consideration when using the regression analysis results to develop the TP TMDL target. For any given concentration of TP, a range of DO concentrations could be expected to occur. Thus, uncertainty in the regression analysis must be incorporated into the selection of the TMDL target TP concentration. This was accomplished using the regression equation prediction intervals shown in Figure 6. The prediction interval provides information on individual predictions of the dependent variable. That is, a prediction interval for a predicted value of the dependent variable provides a range of values around which an additional observation of the dependent variable can be expected to be located (with a given level of certainty). Note that the confidence interval will produce a smaller range of values, because it is an interval estimate for an average rather than an interval estimate for a single observation. Since an estimate of a single observation (i.e. target DO concentration) was made, the prediction intervals were used. The TMDL target was identified as the TP concentration that results in a lower 95 percent prediction interval DO concentration of approximately 5 mg/L, which is the daily minimum criterion during the growing/frost-free season (May 1 – September 30). Based on the regression results, a lake TP concentration of 0.2 mg/L will result in a minimum lake DO concentration of approximately 5 mg/L at the 95 percent confidence level.

Thus, the TP goal for the lake was set at a daily maximum concentration of 0.2 mg/L. The lower 95 percent confidence interval value is a conservative estimate of the expected response to reductions in lake phosphorus concentrations and takes into account the inherent variability of lake DO concentrations.

4.2 BATHTUB Modeling

BATHTUB, a eutrophication response model designed by the United States Army Corps of Engineers (US ACOE 1999) was used to predict changes in lake water quality parameters related to eutrophication (phosphorus, nitrogen, chlorophyll *a*, and transparency) in response to changes in external nutrient loading using empirical relationships previously developed and tested for reservoir applications. Lake and stream sample data were used as model inputs to calculate existing conditions in Lake Andes. Stream nutrient loading rates were reduced by increments of 10% to predict the resulting lake TP concentrations.

External nutrient loading to Lake Andes and in-lake nutrient concentrations are directly related. As expected, the predicted inlake concentrations of TP decreased as modeled stream loads decreased (Figure 9). Based on model results, a reduction in watershed nutrient loads of approximately 50% would be required for the area-weighted mean phosphorus concentration in Lake Andes to be decreased from 0.39 mg/L to 0.20 mg/L. The current average annual TP load from the Lake Andes watershed is approximately 31,677 kg, so the TMDL target TP watershed average annual load is approximately 15,839 kg.

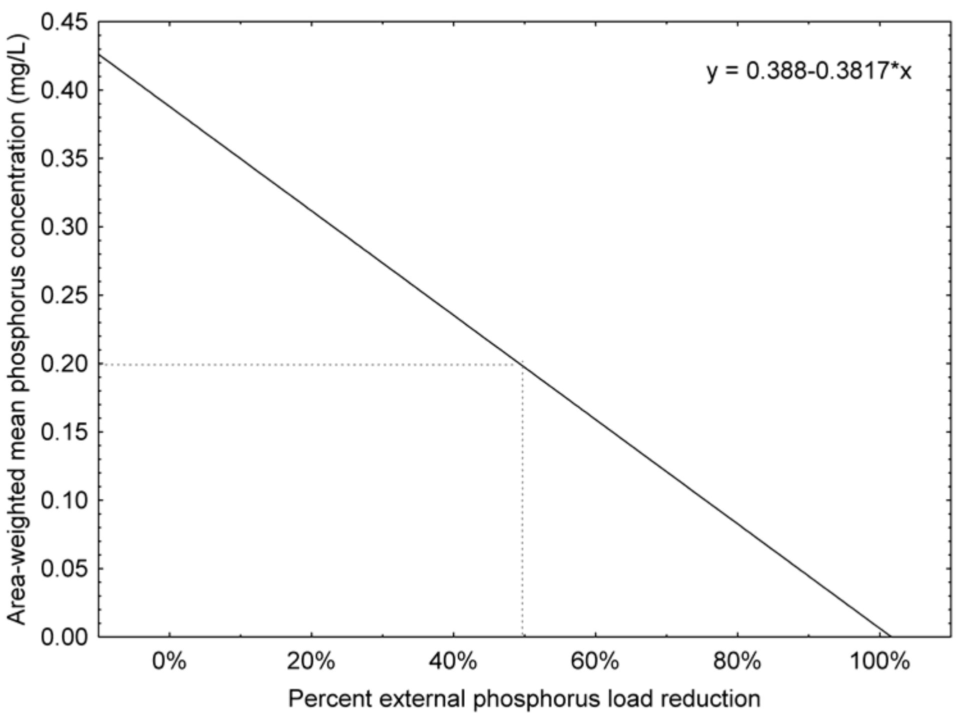


Figure 8. Model-predicted response of lake TP concentrations (area-weighted) to reductions in TP loading from the watershed. Dotted line indicates TMDL goal (TP concentration ≤ 0.20 mg/L; 50% reduction of watershed TP load).

5.0 TMDL and Allocations

5.1 Load Allocation (LA)

To develop the Lake Andes TP load allocation (LA), the loading capacity (LC) was first determined. The LC of Lake Andes was derived from the in-lake TP concentrations required to achieve the most stringent acute DO criterion (≥5 mg/L) based on the linear regression and steady-state lake model analyses. The LC is an average annual TP load of 15,839 kg.

To identify a maximum daily limit, a method from EPA's "Technical Support Document For Water Quality-Based Toxics Control," referred to as the TSD method (USEPA, 1991), was used. This method, which is based on a long-term average load that considers variation in a dataset, is a recommended method in EPA's technical guidance "Options for expressing Daily Loads in TMDLs" (USEPA, 2007).

The TSD method is represented by the following equation:

$$MDL = LTA \times e^{[z\sigma - 0.5\sigma 2]}$$

where,

MDL = maximum daily limit
LTA = long-term average
z = z statistic of the probability of occurrence
$\sigma^2 = \ln(CV^2+1)$
CV = coefficient of variation

The daily load expression is identified as a static maximum daily limit (MDL). A static daily load expression was considered appropriate because a steady-state lake model was used in the analysis of required watershed load reductions. A higher value for the MDL is produced for the same LTAs as the CV increases, in order to allow for fluctuations about the mean. Assuming a probability of occurrence of 95% and a CV of 0.73 (based on TP concentration data), the MDL corresponding with an LTA of 15,839 kg/yr is 103 kg/day (Table 4).

Table 4. Load allocation (kg/yr) summary for Lake Andes.

TMDL Component	Maximum Daily Limit Allocation (kg/day)	Long-term Average Allocation (kg/year)
Wasteload Allocation	0	0
Load Allocation	103	15,839
Margin of Safety	Implicit	Implicit
TMDL	**103**	**15,839**

The TMDL (and LC) is the sum of the LA, waste load allocation (WLA), and margin of safety (MOS). The MOS was implicitly incorporated in the TMDL to account for uncertainty in the calculations of these load allocations, and the WLA is zero value because no point sources of phosphorus occur in the Lake Andes watershed; thus, the LC was fully allocated to nonpoint sources as a load allocation (LA). Details regarding the MOS are discussed below in Section 6.1.

5.2 Baseline Conditions

To assess baseline loading rates, the Lake Andes drainage area was divided into seven subwatersheds based on the locations of sampling sites (Figure 9). Watershed sediment and nutrient loads were determined for all sampled subwatersheds using mean annual stream flow estimates provided by the United States Geological Survey (USGS) Elevation Derivatives for National Applications (EDNA) database and sample concentrations.

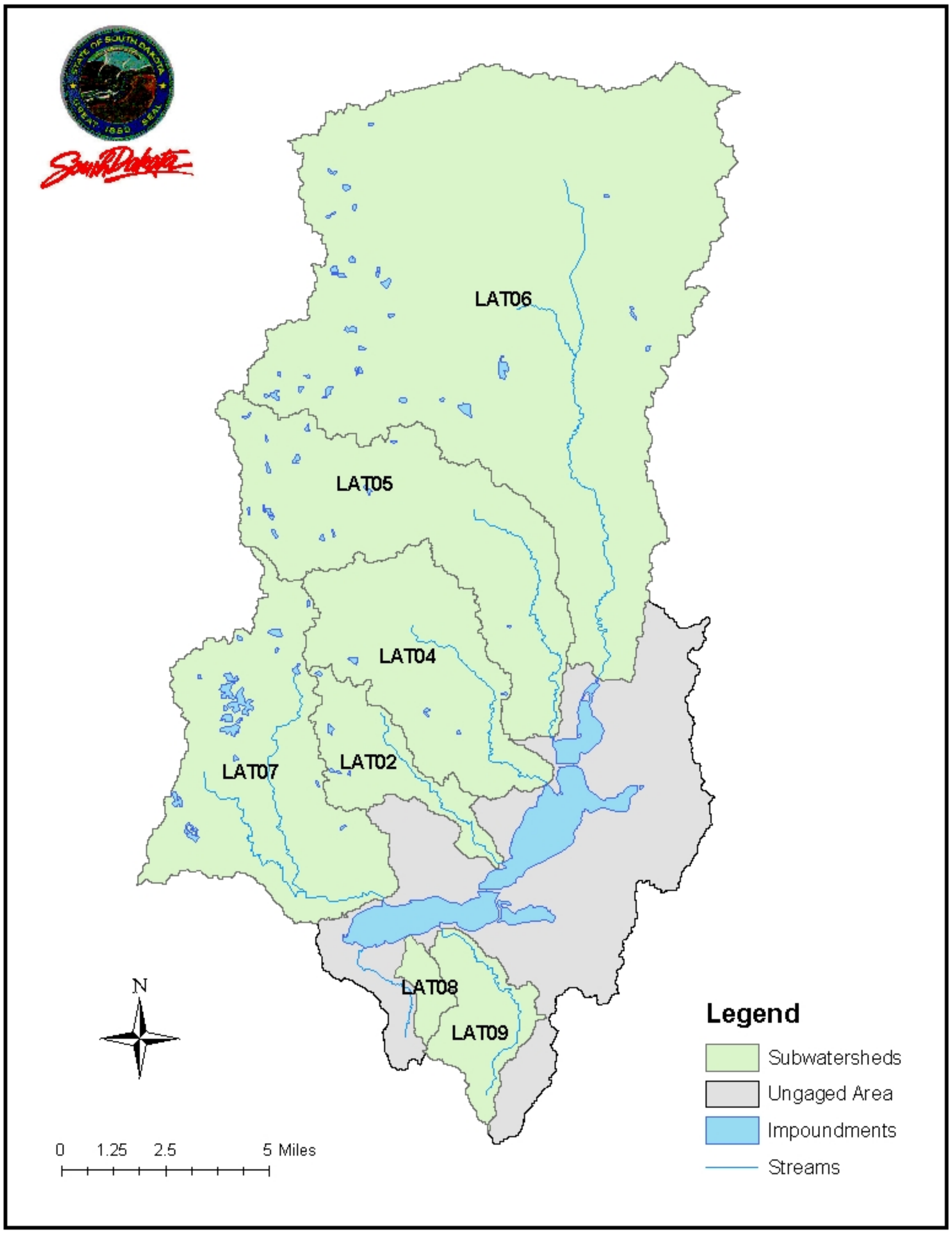


Figure 9. Delineation of subwatershed areas for the Lake Andes watershed assessment.

FLUX, a model developed by the Army Corps of Engineers (US ACOE 1999), was also used to estimate baseline hydrologic, nutrient and sediment loadings for the study period at monitoring sites where adequate stage data were available to develop stage-discharge relationships (sites LAT2, LAT3, LAT4, LAT5, and LAT6). FLUX calculates parameter loadings using several available models (e.g. average flow, flow-weighted, etc.). The model that provides the best estimate, as measured by a low coefficient of variation (CV), was recorded for comparison to the long-term average annual loads estimated using EDNA flows.

Sufficient stage and/or stream flow records were not available for all monitoring sites, so estimates of hydrologic load were obtained from the EDNA database in order to make comparisons of long-term average stream flows and loadings among all monitoring sites. Subwatershed LAT6, which drains the largest area, contributes the greatest long-term average hydrologic load as estimated from the EDNA database (Table 5). Despite having a smaller drainage area than some of the adjacent subwatersheds, the greatest average measured flow (approximately 122 cfs) was observed at site LAT4 during a storm event on April 5, 2001. The high average measured flow at site LAT4 is potentially skewed by this single high flow measurement and may be due to a localized storm with heaviest precipitation occurring within the LAT4 subwatershed.

Table 5. Comparison of estimated long-term average flow (cfs) based on the USGS Elevation Derivatives for National Applications (EDNA) database and average measured flow (cfs) during the study period for subwatersheds.

	LAT2	LAT4	LAT5	LAT6	LAT7	LAT8	LAT9
EDNA Flow (cfs)	1.77	4.24	6.00	15.54	6.00	6.36	4.94
Ave. Measured Flow (cfs)	9.01	16.47	3.92	10.62	9.77	0.90	1.16

To avoid skewing the loading rate data due to spatial and temporal variation in precipitation, estimated long-term average annual flows from the EDNA database, rather than measured flow measurements from the SCLWA project, were used for baseline loading rate calculations. Average annual nutrient (TP and nitrogen) and sediment (TSS) loads were calculated using average water sample concentrations collected during the assessment period and EDNA flow data. Subwatershed LAT06 contributed the largest TP and total suspended solids (TSS) loads (54 and 7,427 lb/day, respectively). Subwatershed LAT5, the second largest subwatershed contributed the largest total nitrogen load (224 lb/day). Nutrient and sediment loading rates for each monitored subwatershed are shown in Table 6.

Table 6. Subwatershed total phosphorus, total nitrogen and total suspended solids loads (lb/day) calculated using sample concentrations and EDNA flow estimates.

	LAT2	LAT4	LAT5	LAT6	LAT7	LAT8	LAT9
Total Phosphorus	4	21	36	54	23	45	10
Total Nitrogen	17	85	224	161	144	258	47
Total Suspended Solids	403	2161	5585	7427	1242	1945	2598

After hydrologic and parameter loadings for each site were calculated, total phosphorus, nitrogen and suspended solids export coefficients were developed for each subwatershed. Export coefficients were calculated by dividing the average daily load (lb/day) by the total area of the subwatershed (acres), resulting in an average amount of sediment and nutrient delivered per day per acre (lb/day/acre) from the respective subwatershed area. Higher export coefficient values indicate higher pollutant export potentials and can be used to identify pollution sources within the drainage area.

Export coefficients of all parameters were greatest for the LAT8 subwatershed (Table 7). Subwatershed LAT9 displayed the second highest TP and TSS export coefficients. High export coefficients for the LAT8 and LAT9 subwatersheds reflect the elevated nutrient and sediment concentrations in samples collected during rain events from these sites. Highest TP (5.57 mg/L) and nitrogen (39.0 mg/L) concentrations were observed in a storm event sample collected on May 18, 2000 at the LAT8 monitoring site. See Appendix D for maps showing subwatershed parameter export coefficients, which could be used as a broad-scale prioritization scheme for the implementation of watershed management practices.

Table 7. Total phosphorus, total nitrogen and total suspended solids export coefficients (lb/day/acre) for each assessed subwatershed.

	LAT2	LAT4	LAT5	LAT6	LAT7	LAT8	LAT9	AVE*
Total Phosphorus	0.0008	0.0017	0.0019	0.0009	0.0013	0.0394	0.0023	0.0016
Total Nitrogen	0.003	0.007	0.012	0.003	0.008	0.227	0.011	0.008
Total Suspended Solids	0.08	0.17	0.30	0.12	0.07	1.71	0.60	0.18

* AVE is the average coefficient calculated by dividing the sum of the parameter loads (lb/day) of the subwatersheds by the sum of the drainage area (acres) of the subwatersheds.

In order to compare the TP export coefficients for Lake Andes subwatersheds to TP export coefficients for other natural and agricultural land uses reported by Wetzel (2001), the coefficient units were converted from lb/day/acre to kg/yr/km^2 using the following conversion factors:

1 pound / day = 165.67 kilograms / year
1 acre = 0.004 square kilometers

Based on TP sample data collected during this assessment and long-term flow estimates from EDNA, the Lake Andes watershed currently delivers approximately 66.27 kg/km^2[1] of TP annually. This phosphorus yield is within the range of TP export coefficients for cropland (7-190 kg/yr/km^2), higher than low intensity pastureland (8-20 kg/yr/km^2), and less than that of urban runoff (100 kg/yr/km^2) reported by Wetzel (2001) (Table 8).

[1] Annual average total phosphorus export coefficient is the sum of the individual subwatershed loads in Table 7 divided by the sum of the subwatershed areas. Units were converted from lb/day/acre to kg/yr/km^2 (lb/day*165.56 = kg/yr; acres*0.004 = km^2).

Table 8. Total phosphorus export ($kg/yr/km^2$) from natural and agricultural land uses (adapted from Wetzel, 2001).

Land Uses	Total P Export, $kg/yr/km^2$
Undisturbed temperate forests	2
Pasture (low intensity)	8-20
Mixed upland	34
Urban runoff	100
Cropland	7-190

5.3 Waste Load Allocation (WLA)

The Town of Corsica has a Surface Water Discharge permit (Permit # SD0021962) for one outfall from their wastewater treatment facility. This outfall is located approximately 20 km north of Lake Andes, and discharges treated wastewater infrequently (approximately 2-3 times per year for 1-2 weeks, on average) to Andes Creek. Due to the distance from the impaired water body and infrequent nature of the discharge, it was determined that this facility is not a significant point-source of phosphorus loads to Lake Andes, and the WLA was assigned a zero value.

6.0 Margin of Safety and Seasonality

6.1 Margin of Safety (MOS)

An implicit MOS is assumed by using the 95 percent prediction interval of the linear model to determine the TMDL target lake TP concentration of 0.2 mg/L. The linear model estimates with 95% certainty that DO concentrations will not be less than 5 mg/L when lake TP concentrations are greater than or equal to 0.2 mg/L. Thus, the lower 95 percent confidence interval value is a conservative estimate of the expected response to reductions in lake phosphorus concentrations and takes into account the inherent variability of lake DO concentrations.

6.2 Seasonality

Streams draining the Lake Andes watershed are characterized as ephemeral, flowing primarily during precipitation-driven runoff. As expected, stream flow gaging sites during the SCLWA project displayed seasonal variation. Highest stream flows typically occur in the spring; the greatest instantaneous stream flow reported on April 12, 2001 (67 cfs). Stream flows typically cease during the fall and winter months.

While neither stream nor lake TP and DO concentrations displayed a statistically significant relationship to stream flow, lake dissolved oxygen and TP concentrations displayed seasonal variation (Figure 10). Highest median TP and lowest median DO concentrations were observed in August. Short duration, high-intensity rainstorms are common during the summer months. These localized summer storms can cause significant runoff and increased bacteria concentrations for a relatively short period of time, while only slightly increasing stream flows.

Critical conditions occur during winter and summer time periods. Low winter temperatures cause the lake surface to freeze and snow to accumulate on the ice, allowing little to no light penetration to the lake water below the ice. Lack of light can cause massive algae and aquatic plant die-offs, resulting in oxygen depletion (due to decaying algae) and fish kills. Summer is also a critical time period due to seasonal differences in precipitation patterns and landuses. Typically, croplands are fertilized and livestock are allowed to graze along the streams during the summer months. Combined with the peak in nutrient sources, high-intensity rainstorm events are common during the summer and produce a significant amount of nutrient load due to wash-off from the watershed.

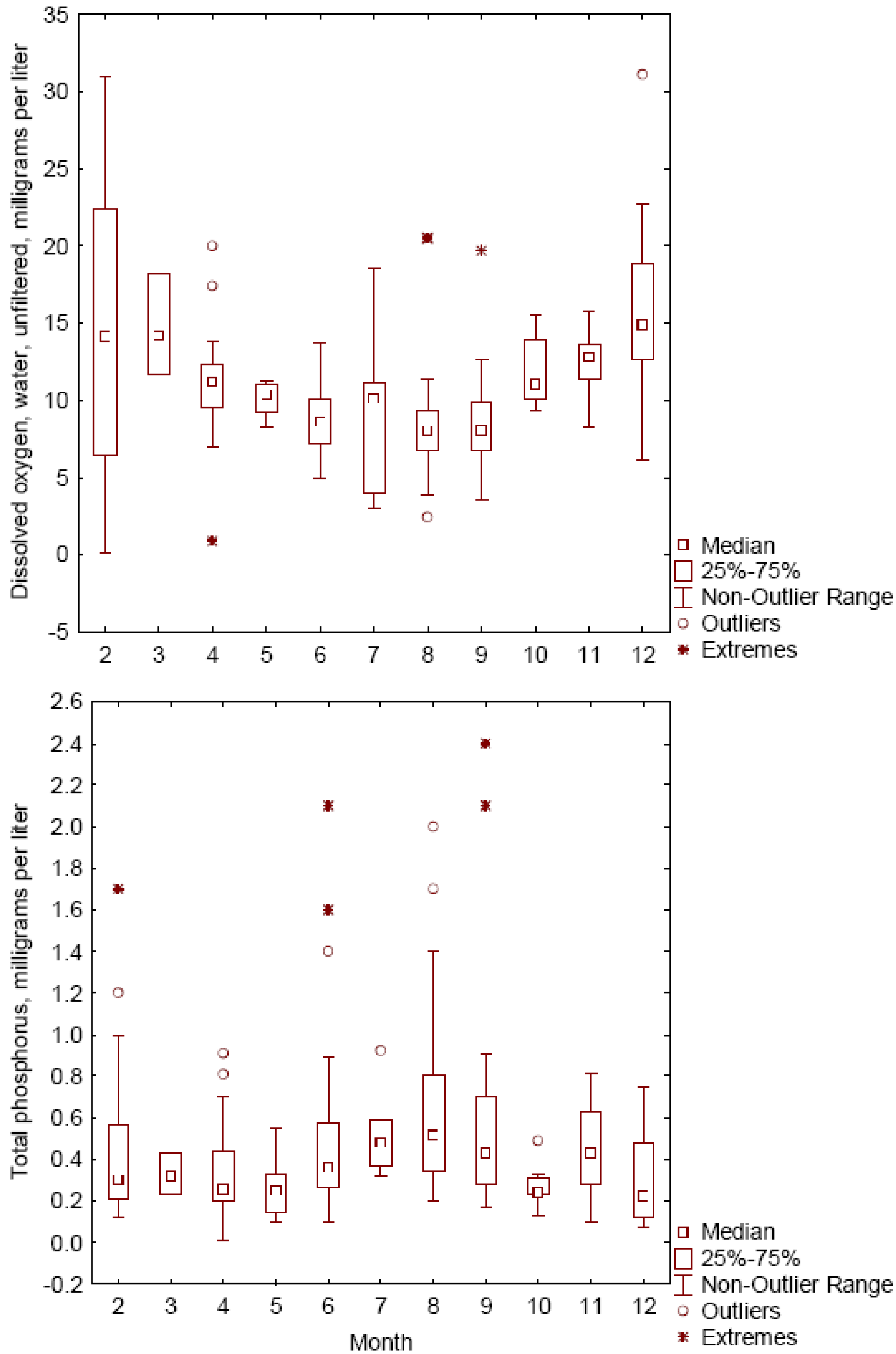


Figure 10. Lake Andes DO and TP concentrations by sample month.

7.0 Public Participation

Efforts taken to gain public education, review, and comment during development of the Lake Andes DO TMDL involved presentations to local groups in the watershed on the findings of the assessment and a 30-day public notice period for public review and comment. The findings from these public meetings and comments have been taken into consideration in development of the TMDL.

8.0 Monitoring Strategy

During and after the implementation of management practices, monitoring will be necessary to assure attainment of the TMDL. Lake water quality monitoring will be accomplished through SD DENR's statewide lakes assessment program.

Additional monitoring and evaluation efforts should be targeted toward the effectiveness of implemented BMPs. Monitoring locations should be based on the location and type of BMPs installed.

SD DENR may adjust the load and/or wasteload allocations in this TMDL to account for new information or circumstances that develop during the implementation phase of the TMDL. New information generated during TMDL implementation may include monitoring data, BMP effectiveness information and land use information. SD DENR will propose adjustments only in the event that any adjusted LA or WLA will not result in a change to the loading capacity; the adjusted TMDL, including its WLAs and LAs, will be set at a level necessary to implement the applicable water quality standards; and any adjusted WLA will be supported by a demonstration that load allocations are practicable. SD DENR will notify EPA of any adjustments to this TMDL within 30 days of their adoption. Adjustment of the load and waste load allocation will only be made following an opportunity for public participation.

9.0 Restoration Strategy

Management practices can control the delivery of nonpoint source pollutants to receiving waters by minimizing pollutants available (i.e. source reduction), retarding the transport and/or delivery of pollutants, or intercepting the pollutant before or after it is delivered to the water through chemical or biological transformation. The recommendations herein are based on known best management practices and professional judgment.

A primary water quality goal for Lake Andes is to maintain DO concentrations ≥5 mg/L. Because DO concentrations were found to be negatively correlated with lake TP concentrations, a secondary goal of ≤0.2 mg/L TP concentration was established to increase DO levels and sustain the beneficial uses of the lake. Based on lake modeling results, this lake phosphorus concentration can be achieved by reducing TP loads from the watershed by approximately 50%. Current TP average annual load from the watershed is approximately 31,677 kg, which is equivalent to approximately 65 kg per watershed acre. Based on the required 50% reduction of watershed load, the TMDL target TP watershed average annual load is approximately 15,839 kg.

Management of nutrient loads from the watershed should be prioritized and ideally implemented prior to in-lake management practices. A broad prioritization scheme could be based on subwatershed nutrient export coefficients.

Funds to implement watershed water quality improvements can be obtained through SD DENR. SD DENR administers three major funding programs that provide low interest loans and grants for projects that protect and improve water quality in South Dakota. They include: Consolidated Water Facilities Construction program, Clean Water State Revolving Fund (SRF) program, and the Section 319 Nonpoint Source program.

9.1 Riparian Zones

Properly functioning riparian areas can significantly reduce nonpoint source pollution by intercepting surface runoff, filtering and storing sediment and associated pollutants, and stabilizing banks. Stream bank stability is directly related to the species composition of the riparian vegetation and the distribution and density of these species (Sheffield, 1997). Proposed BMPs to address riparian area degradation include livestock use exclusion, stream bank stabilization and protection, and reseeding or manual planting of native plant species.

9.2 Livestock Grazing

Restricting cattle and other livestock access to Lake Andes and its tributaries and establishing buffer zones in the areas immediately adjacent to the lake and tributary streams should result in an appreciable reduction of sediment and nutrient loadings. Management of livestock should include prescribed grazing, constructing fences or other barriers to control concentrated livestock access to riparian areas, livestock crossing structures, and alternative water supply. Other alternatives include seasonal access or rotational grazing to reduce the intensity and duration of access to riparian zones and uplands.

9.3 Animal Nutrient Management Systems

Livestock feeding areas are possible sources of excessive nutrient loads to Lake Andes tributaries. Potential livestock feeding area locations were delineated using Geographic Information Systems (GIS), including aerial photographs of the watershed area. A map showing potential locations of feeding areas is presented in Appendix C. A total of 127 feeding areas were identified from the GIS survey. Numbers or density of feeding areas did not correlate well with nutrient or sediment loads measured in the streams. High nutrient and sediment export coefficients were observed for subwatersheds LAT5, LAT8 and LAT9, however LAT5 has the lowest density of livestock feeding areas and LAT8 and LAT9 have the lowest total number of feeding areas with two and four feeding areas, respectively.

9.4 Cropland Conservation

Conservation practices that could be implemented on croplands within the Lake Andes watershed include, but are not limited to, cover crop planting, conservation crop rotation, residue management, reduced fertilizer application and contour farming. These practices can be used to reduce sheet and rill erosion, reduce soil erosion from wind, maintain or improve soil organic matter content, and reduce the transport of sediment and nutrients.

9.5 Wetland Restoration

Wetlands benefit water quality due to natural processes involving wetland vegetation, soils, and their associated microbial assemblages. Wetland plants assimilate nutrients, reducing concentrations in receiving waters.

Studies have demonstrated the non-point source pollutant removal capabilities of wetland systems (Johnson and Higgins, 1997). TP concentrations can be substantially reduced, depending on the amount of phosphorus reduction dependent on wetland size, plant species composition, soil properties, maintenance, etc. It is recommended that wetlands be restored and maintained, especially those on/near inlet streams, to reduce phosphorus loads from the watershed.

9.6 Lake Management

Several lake management alternatives for Lake Andes were discussed in an earlier DENR publication (SD DENR, 1992), including selective dredging and land-based removal of sediment. Selecting dredging will remove nutrient-rich sediment, potentially slowing internal nutrient loading, and provide additional habitat for fish and other aquatic organisms. Land-based removal of sediment may be more economically feasible, considering the frequency of dry periods for the Lake Andes and the relatively lower cost of conventional equipment compared to a dredge. The water quality and aquatic habitat benefits of land-based removal would likely be similar to that of selective dredging.

Lake management should also allow for natural establishment of emergent and submersed aquatic vegetation in the littoral zones, which will further improve water quality. The benefits of aquatic macrophytes are well-documented. Heavy stands of emergent and submerged macrophytes have been linked to a distinct reduction of phytoplankton (Wetzel, 2001). Macrophyte colonization also aids in stabilization of sediments in the littoral zone, provides habitat for fish and invertebrates, and maintains water clarity (Moss et al., 1997).

10.0 Literature Cited

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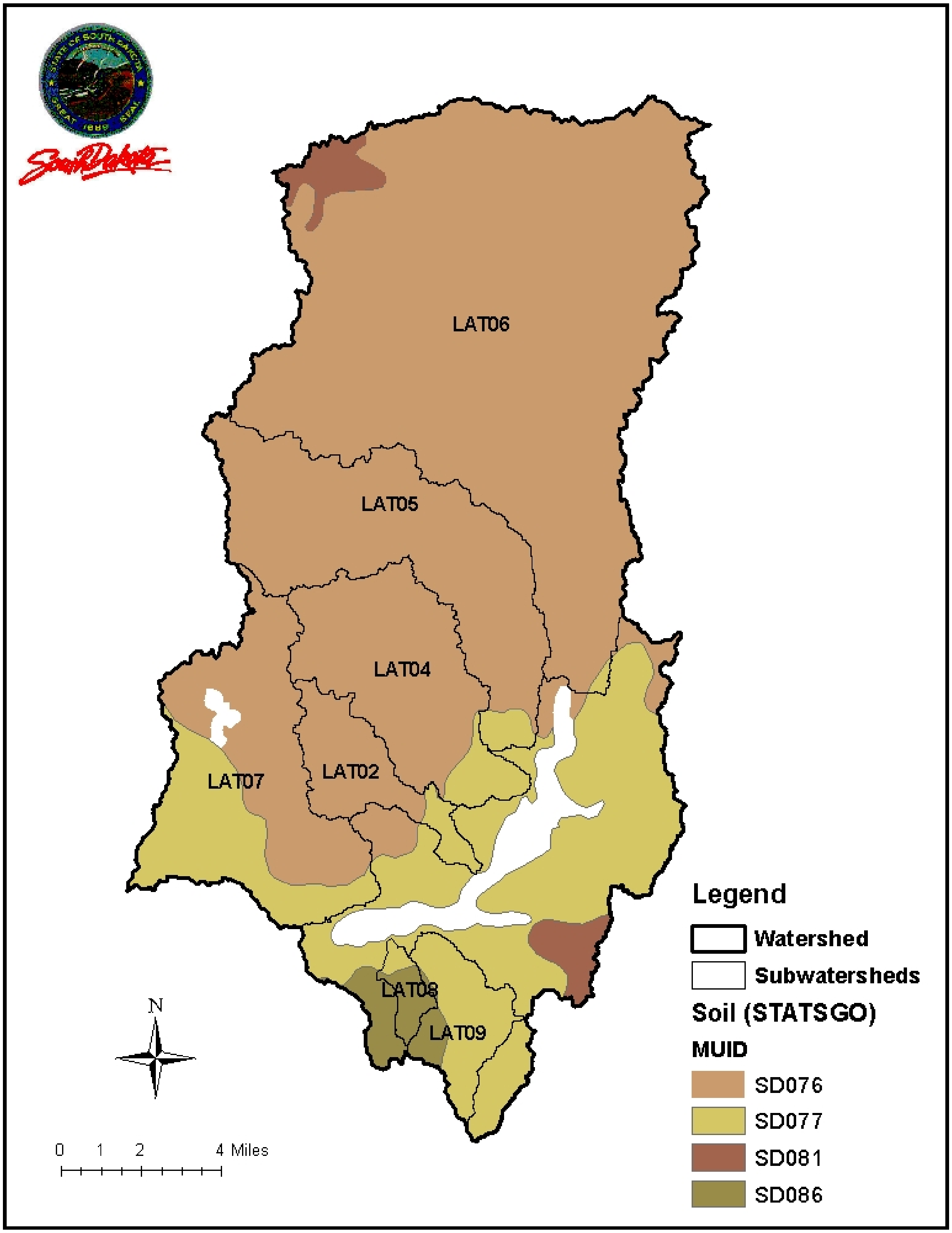
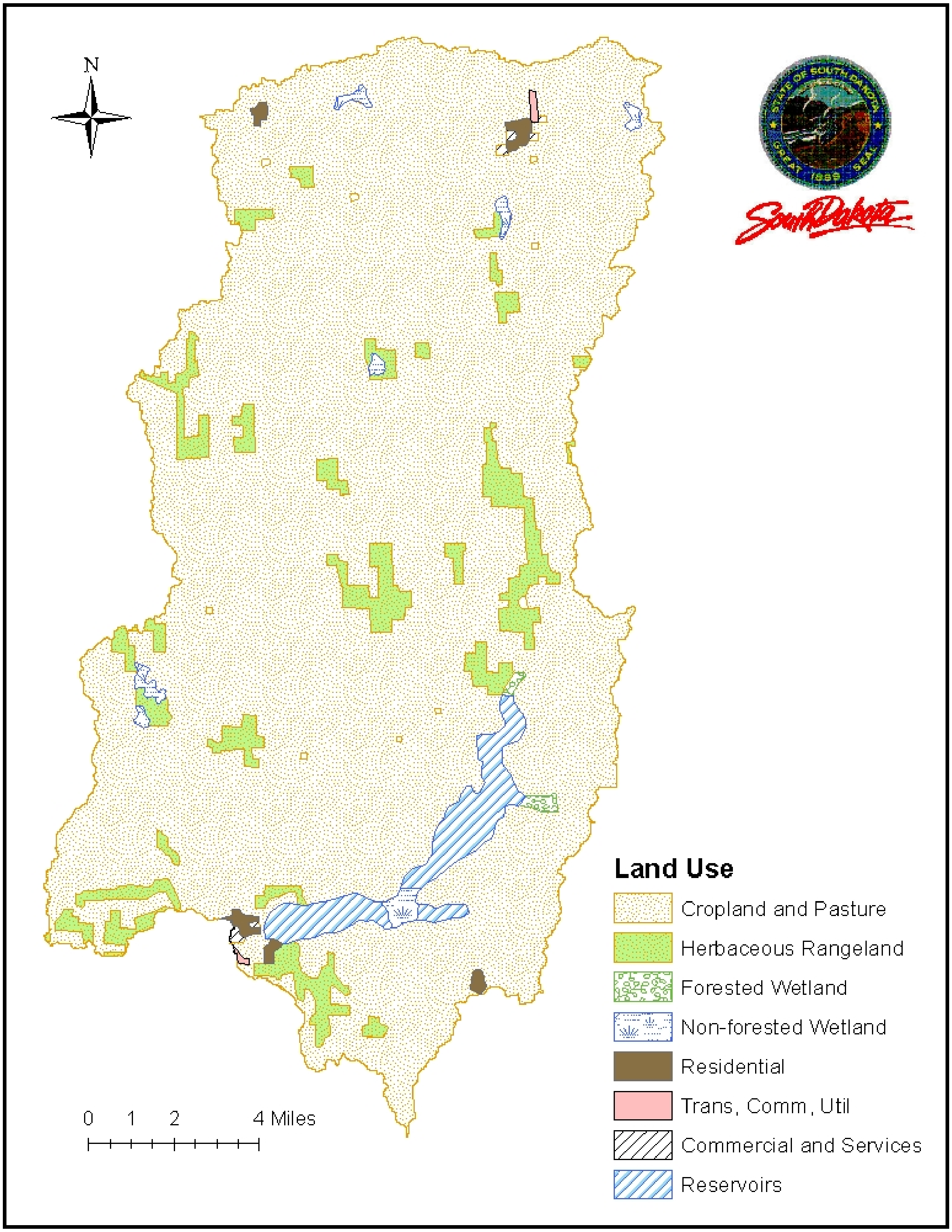
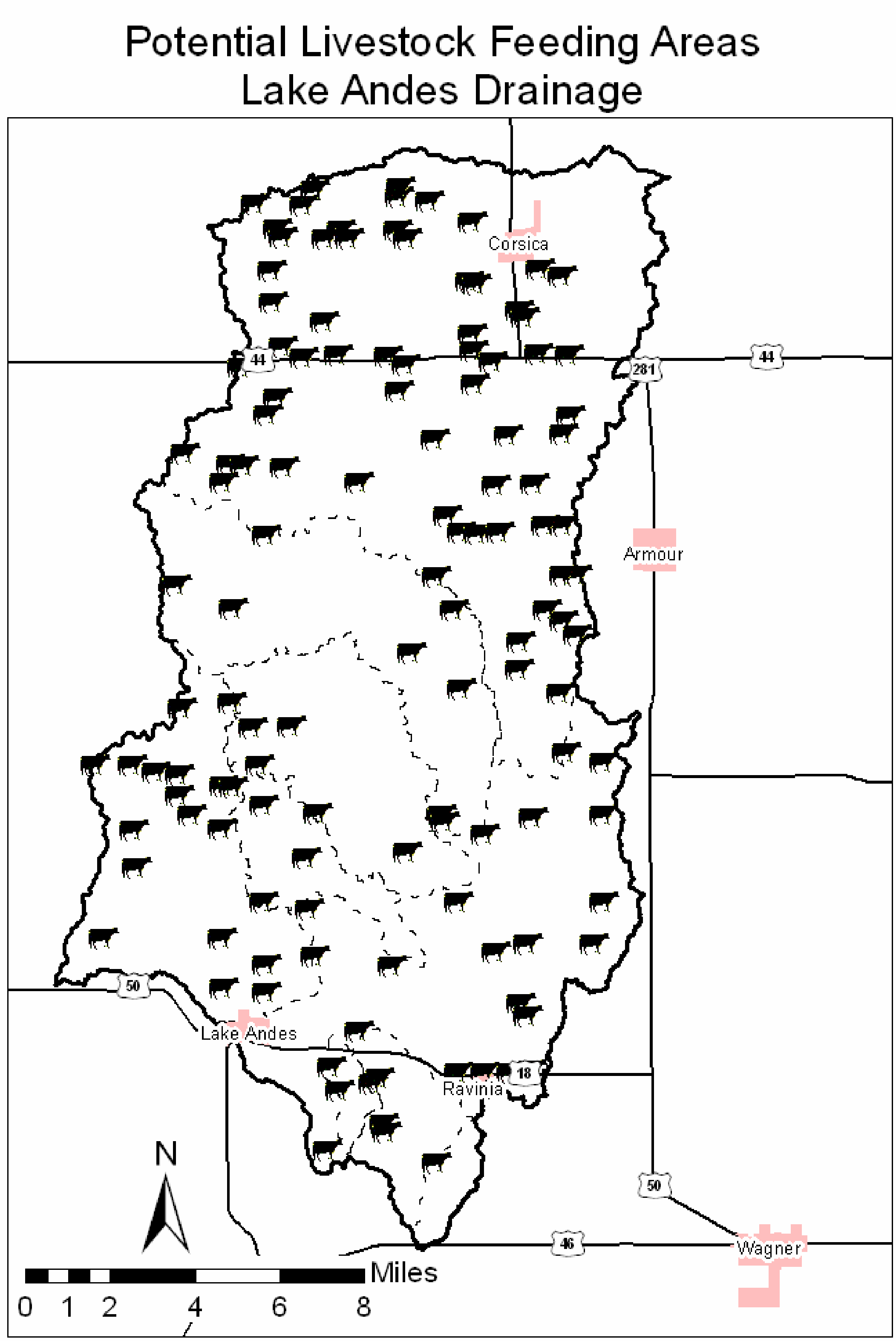
Appendix A: Watershed Soils Map


LAT06
LAT05
LAT04
LAT07
LAT02
LAT08
LAT09
Legend
Watershed
Subwatersheds
Soil (STATSGO)
MUID
SD076
SD077
SD081
SD086
N
0 1 2 4 Miles

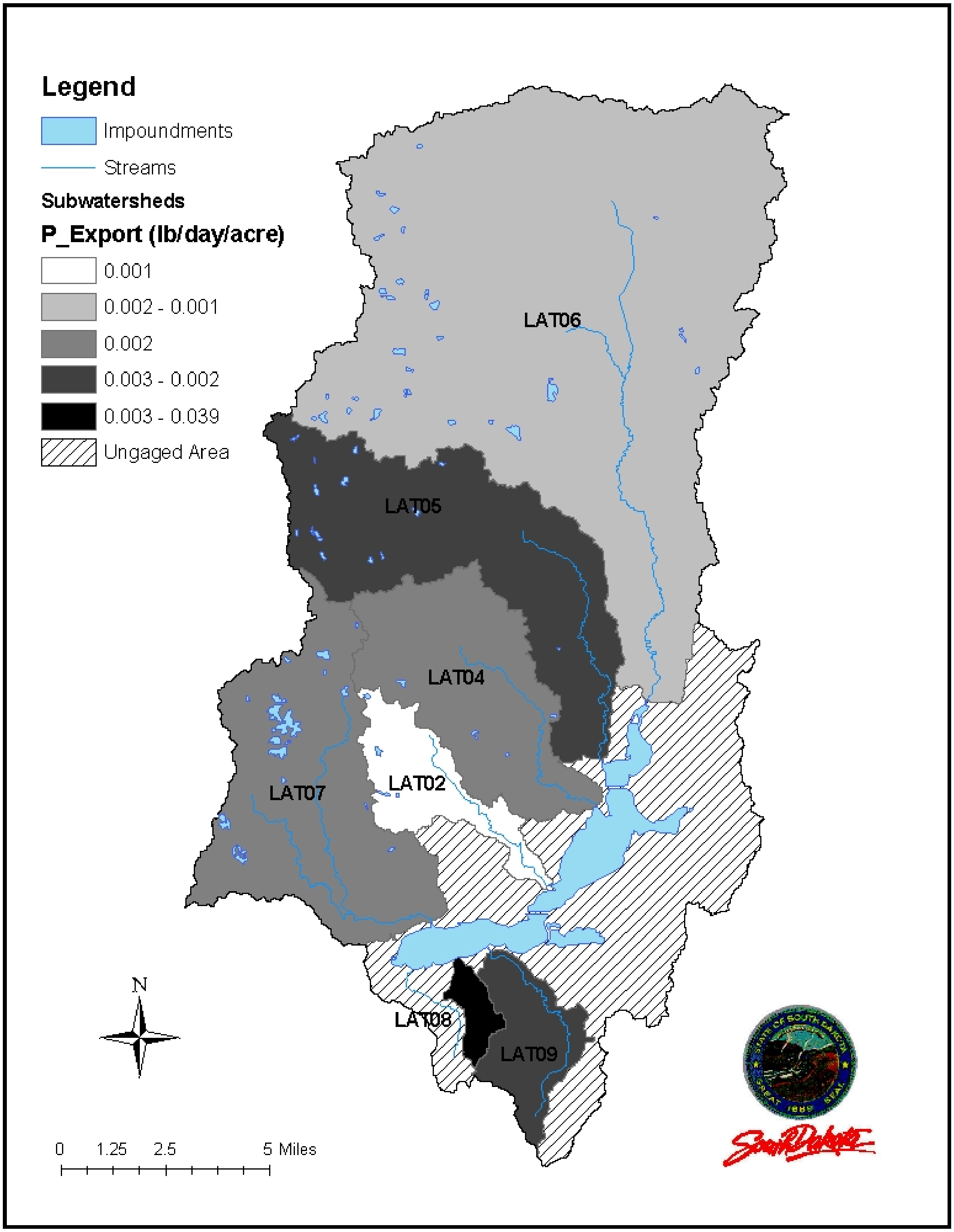
Appendix B: Watershed Land Use Map


N
South Dakota
Land Use
Cropland and Pasture
Herbaceous Rangeland
Forested Wetland
Non-forested Wetland
Residential
Trans, Comm, Util
Commercial and Services
Reservoirs
0 1 2 4 Miles

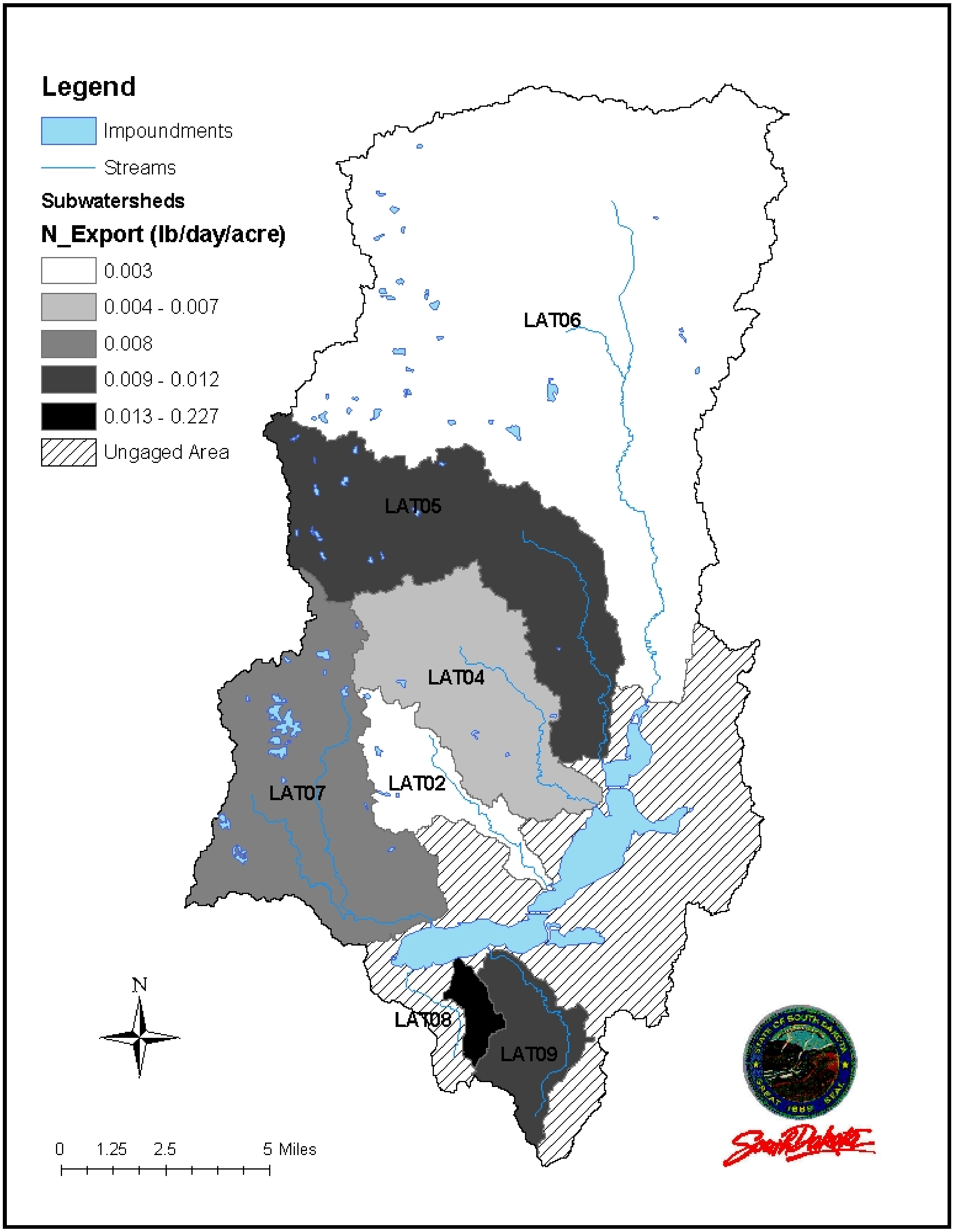
Appendix C: Watershed Map Showing Location of Potential Livestock Feeding Areas

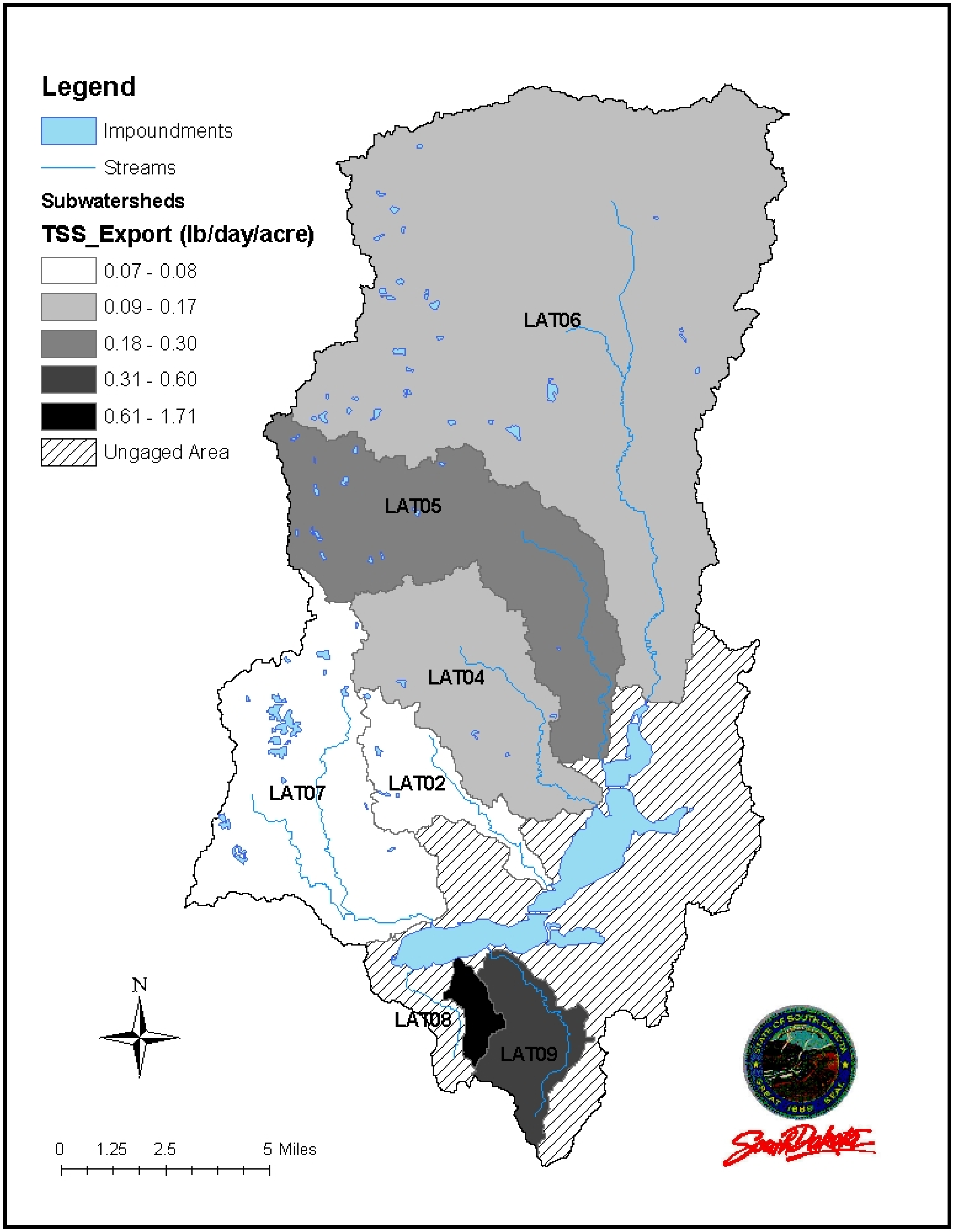

Potential Livestock Feeding Areas
Lake Andes Drainage
Corsica
44
281
44
Armour
50
Lake Andes
18
Ravinia
50
46
Wagner
N
Miles
0 1 2 4 6 8

Appendix D: Maps of subwatersheds showing parameter export coefficients



Legend
Impoundments
Streams
Subwatersheds
P_Export (lb/day/acre)
0.001
0.002 - 0.001
0.002
0.003 - 0.002
0.003 - 0.039
Ungaged Area
LAT06
LAT05
LAT04
LAT02
LAT07
LAT08
LAT09
N
0 1.25 2.5 5 Miles


Legend
Impoundments
Streams
Subwatersheds
N_Export (lb/day/acre)
0.003
0.004 - 0.007
0.008
0.009 - 0.012
0.013 - 0.227
Ungaged Area
LAT06
LAT05
LAT04
LAT07
LAT02
LAT08
LAT09
N
0 1.25 2.5 5 Miles


Legend
Impoundments
Streams
Subwatersheds
TSS_Export (lb/day/acre)
0.07 - 0.08
0.09 - 0.17
0.18 - 0.30
0.31 - 0.60
0.61 - 1.71
Ungaged Area
LAT06
LAT05
LAT04
LAT07
LAT02
LAT08
LAT09
N
0 1.25 2.5 5 Miles

Appendix E: SCLWA water quality data

Lake Water Quality Data

SITE	DATE	TIME	Air T	Cond	DO	pH	Temp	Turb	Secchi	T Depth	Fecal	E. coli	Alk	Sol	TSS	Amm	Nit	TKN	P	TDP
LA-1	16-May-00	1200	22		10.79	8.43	17.02		1.9	8.5	5		143	2109	19	0.5	0.1	4.17	0.137	0.09
LA-1	21-Jun-00	750	15	2555	6.07	8.61	19.74	86.2	0.9	8.5	10		106	2165	56	0.02	0.1	3.7	0.287	0.038
LA-1	17-Jul-00	1140	21	3057	3.94	8.47	26	95.6	0.75	8	10		124	2303	48	0.02	0.1	4.42	0.425	0.114
LA-1	1-Aug-00	1050	25	2541	2.44	8.27	26.83	54.9	1	8	10		128	2349	36	0.08	0.1	4.25	0.346	0.104
LA-1	10-Aug-00	810	19	2704	5.22	8.12	26.27	172.1	0.85	8	10		127	2342	50	0.02	0.1	4.28	0.337	0.062
LA-1	27-Sep-00	1424	18	2740	7.95	8.46	15.03	102.3	0.5	7.1	20		121	2555	54	0.02	0.1	4.55	0.276	0.036
LA-1	24-Oct-00	1145	13	2431	9.31	8.18	13.35	103.3	0.85	6.9	20		124	2625	48	0.02	0.1	4.84	0.24	0.036
LA-1	9-Apr-01	1445	17	1128	8.71	7.96	7.21	17.1	1.5	10.5	10	47.4	106	1476	16	1.41	0.2	5.57	0.55	0.227
LA-1	15-May-01	1000	28			8.7	20.71	34.2	1.5	12.1	10	1	114	1588	23	0.25	0.2	3.32	0.325	0.144
LA-2	16-May-00	1330	23		9.91	8.29	16.42	26	1.5	8.5	20		128	1962	19	0.33	0.1	3.22	0.174	0.027
LA-2	21-Jun-00	930	19	2408	6.08	8.83	19.44	81.9	0.9	7.9	10		110	2051	46	0.02	0.1	3.93	0.327	0.053
LA-2	17-Jul-00	1015	20	2893	4.26	8.43	25.39	78.4	0.85	8.2	10		128	2207	50	0.02	0.1	4.01	0.37	0.092
LA-2	10-Aug-00	910	22		5.5		25.78		0.8	7.6	10		107	2145	60	0.02	0.1	5.27	0.314	0.023
LA-2	27-Sep-00	1324	18	2479	8.08	8.6	13.44	146.3	0.4	7.3	80		110	2352	64	0.02	0.1	5.4	0.383	0.031
LA-2	24-Oct-00	1232	13	2256	9.59	8.36	13.24	134.2	0.7	7.5	10		116	2409	52	0.02	0.1	5.47	0.311	0.036
LA-2	6-Feb-01	1341	2	2595	1.38	6.9	0.07	27.3	2	7.3	10		170	2986	6	2.34	0.1	5.75	0.292	0.193
LA-2	10-Apr-01	1410	9	1113	0.89	7.77	4.45	36.1	1	10	50	60.1	118	1446	18	2.94	0.1	4.99	0.654	0.516
LA-2	15-May-01	1123	28			8.89	20.46	27	1.5	12	10	1	111	1284	22	0.75	0.3	3.11	0.544	0.342
LA-3	6-Feb-01	1246	2	3058	0.68	6.62	0.02	14.5	1.5	4.9	10		285	3722	9	7.16	0.1	10.8	0.991	0.902

Air T = Air Temperature (degrees C)
Cond = Conductivity (uS/cm)
DO = Dissolved Oxygen (mg/L)
Temp = Water Temperature (degrees C)
Turb = Turbidity (NTU)
Secchi = Secchi Disk Depth (meters)
T Depth = Total Depth (feet)
Fecal = Fecal Coliform Bacteria (colony-forming units / 100 ml)
E. coli = *Eschericia coli* (colony-forming units / 100 ml)
Alk = Alkalinity (as Calcium Carbonate) (mg/L)
Sol = Total Solids (mg/L)
TDS = Total Dissolved Solids (mg/L)
TSS = Total Suspended Solids (mg/L)
Amm = Ammonia (mg/L)
Nit = Nitrate (mg/L)
TKN = Total Kjeldahl Nitrogen (mg/L)
P = Total Phosphorus (mg/L)
TDP = Total Dissolved Phosphorus (mg/L)

Stream Water Quality Data

SITE	DATE	TIME	Flow	Air T	Cond	DO	pH	TYPE	Temp	Turb	Fecal	E. coli	Alk	Sol	TSS	Amm	Nit	TKN	P	TDP
LAO-1	4-Apr-01	1640	5.66	11	603	17.71	9.15	GRAB	4.03	14.8	10	8.5	69	768	12	0.36	0.2	2.19	0.403	0.223
LAO-1	9-Apr-01	1535	60.28	17	1052	5.2	7.57	GRAB	5.38	12.6	70	95.9	105	1453	15	1.46	0.2	3.75	0.373	0.239
LAO-1	12-Apr-01	1400	79.52	9	1255	10.08	7.88	GRAB	6.05	22.1	270	517	113	1588	36	1.6	1.6	4	0.408	0.188
LAO-1	19-Apr-01	1406	88.00	20	1442	19.11	8.81	INT	9.19	9.6	10	2	116	1698	17	0.77	0.1	3.65	0.397	0.145
LAO-1	25-Apr-01	1322	81.12	26	1341	11.5	8.35	INT	8.52	17	60	101	118	1632	30	1.25	0.2	4.55	0.578	0.188
LAO-1	3-May-01	1133	87.39	12	1544	14	8.8	INT	15.7	17.5	10	1	116	1621	18	0.26	0.2	3.12	0.325	0.075
LAT-2	1-Jun-00	745	0.08	14.75	1927	6.16	7.8	GRAB	14.86	88.3	28000		308	2422	132	0.04	0.5	1.42	0.284	0.068
LAT-2	8-Aug-00	810		18.6				COMP			320000		23	614	86	0.8	3.3	2.58	0.408	0.186
LAT-2	1-Nov-00	915	0.03	10				GRAB			20000		50	1344	78	0.07	0.9	1.31	0.635	0.432
LAT-2	22-Mar-01	1315	29.20	10			7.07	GRAB	2.94	35.5	10	10.8	92	609	27	1.03	1	2.45	0.815	0.682
LAT-2	4-Apr-01	1615	3.78	11	1537	17.47	8.25	GRAB	5.69	6.3	20	93.2	192	2218	8	0.03	2.1	0.54	0.341	0.317
LAT-2	12-Apr-01	1330	75.34	9	544	9.06	7.95	COMP	7.05	100.5	7100	2420	153	1588	136	0.12	0.7	1.04	0.833	0.399
LAT-2	19-Apr-01	1345	2.36	20	1892	13.58	8.21	GRAB	12.75	3.6	200	308	229	2234	4	0.02	0.2	0.37	0.27	0.243
LAT-2	25-Apr-01	1240	15.53	25	1047	9.8	7.86	GRAB	14.31	22.2	350	525	129	1060	20	0.02	1	1.28	0.628	0.55
LAT-2	30-Apr-01	1016	4.85	18	1507	11.33	7.68	GRAB	15.61	6.6	590	649	192	1638	3	0.02	0.1	0.69	0.355	0.333
LAT-2	10-May-01	725	2.93	14	1865	6.42	7.55	GRAB	14.31	4.2	100	1730	236	2110	7	0.02	0.1	0.97	0.237	0.194
LAT-3	18-May-00	1140		9.24	807	9.48	7.8	COMP	9.13	314.9	20000		125	2110	1680	0.93	3.4	7.68	1.85	1.83
LAT-3	31-May-00	830		17.7	803	9.9	7.71	COMP	14.8	514	7000		282	2490	1880	0.47	6	4.65	2.19	0.399
LAT-3	24-Jul-00	845						GRAB					33	414	275	0.68	1.2	4.4	1.34	0.573
LAT-3	19-Mar-01	1445	59.53	11		1.74	7.67	GRAB	-0.09	42.4	170	308	54	226	46	1.45	0.8	3.75	0.834	0.702
LAT-3	22-Mar-01	1420	19.93	10				GRAB	2.74	61.8	10	8.6	49	237	52	0.93	0.7	2.44	0.87	0.696
LAT-3	4-Apr-01	1535	1.12	11	531	17.69	8.28	GRAB	5.78	7.8	10	10.8	81	644	2	0.02	1.2	0.7	0.549	0.532
LAT-3	12-Apr-01	1250		9	262	9.52	7.95	COMP	5.5	97.8	290	285	62	532	104	0.08	1.2	1.23	0.689	0.532
LAT-3	10-Apr-01	1330		9.5	452	9.06	7.92	GRAB	10.46	9.9	20	11	80	459	1	0.02	0.4	1	0.678	0.581
LAT-3	19-Apr-01	1322		20	960	12.66	8.46	GRAB	14.11	3.7	10	12.1	122	968	2	0.02	0.5	0.78	0.499	0.457
LAT-3	25-Apr-01	1212		25	557	10.4	7.81	GRAB	14.5	9.9	10	18.7	79	532	8	0.02	0.4	1.1	0.61	0.55
LAT-3	30-Apr-01	1105		19	1080	19.72	8.26	GRAB	18.17	4.6	160	201	160	1046	1	0.04	0.1	1.37	0.607	0.546
LAT-3	10-May-01	811		14	1187	7.97	7.63	GRAB	15.17	9.5	90	67.7	177	1214	3	0.02	0.1	1.49	0.55	0.502
LAT-4	18-May-00	1205	1.13	11.04	3004	8.69	7.69	COMP	10.56	316	4700		247	3015	76	0.1	0.3	1.96	0.302	0.028
LAT-4	24-May-00		0.02	20	3000	18.17	8.04	GRAB	15.25		5400		224	2954	82	0.03	0.05	3.91	0.682	0.109
LAT-4	1-Jun-00	813	0.08	14.9	2613	8.39	7.64	COMP	15.25	75.8	4000		242	2780	80	0.05	0.05	4.25	0.714	0.156
LAT-4	25-Jul-00	910	45.50		867	1.68	7.22	COMP	18.36	319	18000		60	424	212	0.37	1.5	3.03	1.38	0.344
LAT-4	8-Aug-00	910	0.21	19	1843	5.87	7.75	GRAB	21.36	56.5	220000		222	1820	128	0.05	0.7	5.03	1.28	0.2
LAT-4	1-Nov-00	1135	0.78	10	1675	6.79	7.55	GRAB	13.92	284.7	3600000		200	1657	208	2.7	2.3	12.7	4.24	1.81
LAT-4	22-Mar-01	1520	0.78	6			7.25	GRAB	2.51	76.6	30		81	443	78	1.79	1	3.54	1.25	0.968

SITE	DATE	TIME	Flow	Air T	Cond	DO	pH	TYPE	Temp	Turb	Fecal	E. coli	Alk	Sol	TSS	Amm	Nit	TKN	P	TDP
LAT-4	5-Apr-01	1423	121.69	10	874	14.95	7.57	GRAB	6.94	25.1	40	29.2	127	1052	23	1.43	2.3	2.33	0.972	0.875
LAT-4	12-Apr-01	1215	121.69	9	477	10.31	7.93	COMP	3.94	176.7	24000	2420	141	1057	360	1.12	1.6	3.08	1.21	0.669
LAT-4	25-Apr-01	1136	22.75	25	815	8.72	7.76	INT	14.68	36.2	330	365	101	823	41	0.15	1.2	1.48	0.748	0.621
LAT-4	30-Apr-01	1134	3.03	22	1201	17.37	7.99	GRAB	16.96	13.7	2300	2420	156	1189	10	0.08	1	1.54	0.539	0.442
LAT-4	10-May-01	833		14	1525	7.18	7.72	GRAB	15.1	9.6	780	830	183	1607	12	0.06	1.1	1.67	0.776	0.664
LAT-5	11-May-00	2100	0.83	15	1805	5.05	7.72	COMP	17.89	145.2	5		220	4933	208	0.35	2.8	6.86	0.868	0.235
LAT-5	18-May-00	1225	8.26	11.6	1304	8.73	7.88	COMP	1124	158.1	230000		235	2781	510	1.11	1.3	14.4	2.8	1.42
LAT-5	1-Jun-00	850	0.05	15	3359	8.99	7.75	GRAB	14.24	49.1	2700		287	4269	10	0.34	1.2	1.91	0.432	0.387
LAT-5	25-Jul-00	945	0.01		2284	5.6	7.41	COMP	18.45	49.7	210000		89	3679	345	0.41	1.8	6.85	2.45	0.344
LAT-2	18-May-00	1100	0.97	9.5	1895	11.78	7.9	Comp.	10.5	29.9	9600		150	2242	176	0.07	0.1	1.71	0.415	0.162
LAT-5	8-Aug-00	1000	0.04	20	2827	6.68	7.71	COMP	19.49	32.2	54000		130	2129	96	0.21	0.7	6.83	1.24	0.255
LAT-5	1-Nov-00	1230	0.51	11	2469	9.5	7.38	COMP	14.35	61.8	4500000		201	2381	920	0.55	2.7	4.88	4.02	0.82
LAT-5	5-Apr-01	1350	1.75	10	1355	14.1	7.33	GRAB	7.88	8.2	480	1046	169	1765	7	0.38	3.2	1.12	0.678	0.641
LAT-5	12-Apr-01	1120	33.90	9	504	9.6	7.06	COMP	4.65	57.5	76000	2420	157	1637	490	0.41	1.7	1.83	1.63	0.511
LAT-5	10-May-01	854		14	2207	9.69	7.48	GRAB	14.66	59.5	5000	2420	257	2622	72	0.02	1.3	1.71	0.421	0.262
LAT-6	11-May-00	2020	0.61	15	2358	7.24	7.88	COMP	18.53	29.7	5		343	2137	70	0.06	0.05	1.34	0.594	0.323
LAT-6	18-May-00	1305	7.15	13.5	2375	7.87	7.99	COMP	13	13.7	4700		322	1949	55	0.05	0.05	1	0.646	0.386
LAT-6	1-Jun-00	908	0.60	15	2005	5.9	7.65	GRAB	15.26	95.3	1800		356	2268	116	0.08	0.05	1.13	0.784	0.365
LAT-6	19-Jun-00	1230	0.19	23	2571	7.15	7.93	GRAB	19.93		760		349	2500	152	0.25	0.1	2.24	0.72	0.268
LAT-6	6-Jul-00	1320	0.15	29	2654	2.28	7.88	GRAB	25.25		900		362	2372	116	0.85	0.1	4.02	1.1	0.611
LAT-6	25-Jul-00	1015	1.12		2068	4.71	7.38	COMP	19.63	47.2	9600		294	2602	372	0.42	0.1	2.9	1.39	0.586
LAT-6	8-Aug-00	1040	0.35	21	2524	2.48	7.45	GRAB	22.33	99.5	4300		310	2707	108	0.41	0.1	1.82	0.801	0.4
LAT-6	3-Oct-00	1130	0.30	12.21		5.56	8.35	COMP	14.75	51.5	700		397	2265	61	0.36	0.3	1.43	0.423	0.252
LAT-6	23-Oct-00	1251	0.30	15	2422	2.44	7.58	GRAB	12.31	98.4	460		405	2608	66	0.8	0.1	0.79	0.515	0.274
LAT-6	5-Apr-01	1322	49.61	10	497	11.37	7.33	GRAB	6.06	13.5	20	68.3	99	573	9	1	0.8	1.85	0.876	0.782
LAT-6	12-Apr-01	1057	49.61	9	389	9.07	7.97	GRAB	4.04	115	4300	2420	74	556	116	0.36	0.7	1.42	0.882	0.57
LAT-6	10-May-01	913		14	1096	4.7	7.62	GRAB	16.37	3.3	20	75.9	177	1038	4	0.02	0.1	1.04	0.663	0.607
LAT-7	18-May-00	845	0.20	8.5	1999	7.55	7.7	GRAB	10.78	62	4200		94	2009	43	0.49	4.1	2.99	0.713	0.598
LAT-7	19-Mar-01	1330		11		0.25	7.5	GRAB	5.21	127.2	10	6.3	63	326	64	1.09	0.9	2.93	0.939	0.717
LAT-7	4-Apr-01	1742		11	1373	15.03	8.55	GRAB	6.49	15.9	40	37.9	154	1898	8	0.02	2	0.43	0.456	0.423
LAT-8	18-May-00	745	0.13	10	2790	7.03	7.65	GRAB	10.8		1700000		499	3178	280	4.87	7.9	31.1	5.57	0.711
LAT-8	24-May-00	1017	0.01	24.25	3894	2.33	7.43	GRAB	14.16		1420		485	3940	56	0.46	0.1	1.83	1.12	0.275
LAT-8	1-Jun-00	658	0.02	14.15	3347	3.94	7.19	GRAB	14.45	71.4	2300		487	3541	29	0.15	0.1	2.58	1.06	0.63
LAT-8	19-Mar-01	1256	6.00	11		0	7.45	GRAB	3.11	40.8	10	10	89	583	40	1.06	1.3	2.93	0.727	0.563
LAT-8	4-Apr-01	1720	0.05	11	2017	14	8.44	GRAB	5.96	5	10	3.1	303	3054	9	0.02	1.4	1.11	0.488	0.45
LAT-8	10-Apr-01	1510	0.17	9	2268	12.43	7.77	GRAB	14.5	4.9	60	101	307	2772	3	0.02	1.5	0.7	0.51	0.474
LAT-8	11-Apr-01	1500	0.95	11	1655	11.08	7.93	GRAB	7.14	19.3	1000	2420	258	2261	19	0.04	2.5	1.52	0.548	0.452

SITE	DATE	TIME	Flow	Air T	Cond	DO	pH	TYPE	Temp	Turb	Fecal	E. coli	Alk	Sol	TSS	Amm	Nit	TKN	P	TDP
LAT-8	23-Apr-01	1313	2.49	6	1305	12.01	8.1	GRAB	8.59	51.5	2800	2420	188	1646	17	0.09	2.3	1.32	0.528	0.452
LAT-9	1-Jun-00	642	0.01	15.25	273	5.41	7.06	GRAB	15.31	108.5	18000		78	290	60	0.5	1.3	2.01	0.337	0.198
LAT-9	3-Oct-00	1000	3.49	12.21		6.5	8.07	GRAB	14.6	41.8	8000		27	164	96	0.2	0.7	0.98	0.405	0.172
LAT-9	11-Apr-01	1430	0.72	11	230	11.1	8.4	GRAB	6.91	42.8	230	219	94	687	260	0.23	0.5	0.62	0.608	0.099
LAT-9	23-Apr-01	1340	1.56	6	403	9.4	8.04	GRAB	11.27	72.4	80	105	68	424	54	0.05	0.4	0.67	0.321	0.175
LAT-9	30-Apr-01	730	0.02	14	1156	2.95	6.8	GRAB	13.69	19.9	1600	1730	137	1154	17	0.31	0.5	1.18	0.234	0.157

Appendix F: Quality assurance/quality control (QA/QC) data

Duplicate pairs

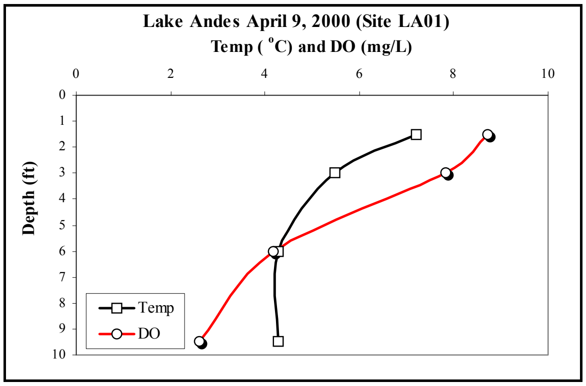
SITE	DATE	Cond.	DO	pH	Temp	Turb.	Fecal	E. coli	Alk	Sol	TDS	TSS	Amm	Nit	TKN	P	TDP
LAO-1	12-Apr-01	1255	10.08	7.88	6.05	22.1	270	517	113	1588	1552	36	1.6	1.6	4	0.408	0.188
LAO-1A	12-Apr-01	1255	10.08	7.88	6.05	22.1	250	517	113	1598	1560	38	1.6	0.2	4.05	0.42	0.195
LAT-2	19-Apr-01	1892	13.58	8.21	12.75	3.6	200	308	229	2234	2230	4	0.02	0.2	0.37	0.27	0.243
LAT-2A	19-Apr-01	1892	13.58	8.21	12.75	3.6	160	206	227	2246	2243	3	0.02	0.2	0.42	0.266	0.237
LAT-3	4-Apr-01	531	17.69	8.28	5.78	7.8	10	10.8	81	644	642	2	0.02	1.2	0.7	0.549	0.532
LAT-3A	4-Apr-01	531	17.69	8.28	5.78	7.8	10	7.3	81	645	640	5	0.02	1.2	0.53	0.564	0.51
LAT-5	5-Apr-01	1355	14.1	7.33	7.88	8.2	480	1046	169	1765	1758	7	0.38	3.2	1.12	0.678	0.641
LAT-5A	5-Apr-01	1355	14.1	7.33	7.88	8.2	470	1046	171	1763	1755	8	0.4	3.2	1.28	0.734	0.63
LAT-6	19-Jun-00	2571	7.15	7.93	19.93		760		349	2500	2348	152	0.25	0.1	2.24	0.72	0.268
LAT-6A	19-Jun-00	2571	7.15	7.93	19.93		780		344	2502	2342	160	0.25	0.1	2.23	0.7	0.251
LAT-6	6-Jul-00	2654	2.28	7.88	25.25		900		362	2372	2256	116	0.85	0.1	4.02	1.1	0.611
LAT-6A	6-Jul-00	2654	2.28	7.88	25.25		1900		368	2357	2237	120	1.16	0.1	3.79	1.12	0.636
LAT-6	3-Oct-00		5.56	8.35	14.75	51.5	700		397	2265	2204	61	0.36	0.3	1.43	0.423	0.252
LAT-6A	3-Oct-00		5.56	8.35	14.75	51.5	800		397	2284	2216	68	0.38	0.3	1.11	0.416	0.241

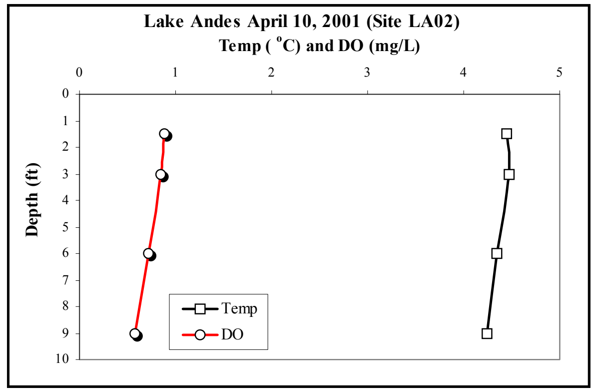
Cond = Conductivity (uS/cm)
DO = Dissolved Oxygen (mg/L)
Temp = Water Temperature (degrees C)
Turb = Turbidity (NTU)
Fecal = Fecal Coliform Bacteria (colony-forming units / 100 ml)
E. coli = *Eschericia coli* (colony-forming units / 100 ml)
Alk = Alkalinity (as Calcium Carbonate) (mg/L)
Sol = Total Solids (mg/L)
TDS = Total Dissolved Solids (mg/L)
Blank Samples

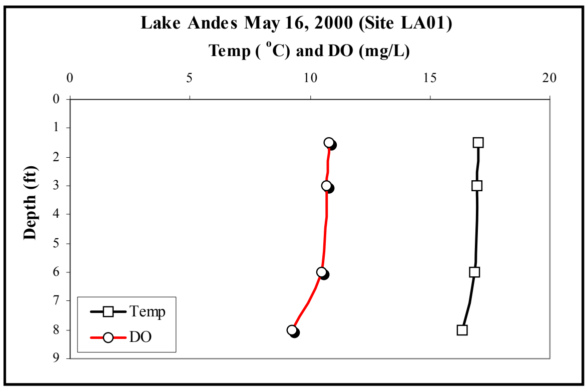
TSS = Total Suspended Solids (mg/L)
Amm = Ammonia (mg/L)
Nit = Nitrate (mg/L)
TKN = Total Kjeldahl Nitrogen (mg/L)
P = Total Phosphorus (mg/L)
TDP = Total Dissolved Phosphorus (mg/L)

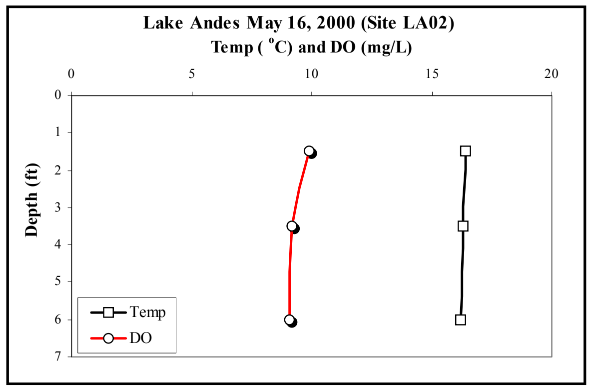
SITE	DATE	Fecal	E. coli	Alk	Sol	TSS	TDS	Amm	Nit	TKN	P	TDP
LAO-1B	12-Apr-01	10	1	0	12	1		0.02	0.1	0.36	0.002	0.003
LAT-2B	19-Apr-01	10	1	0	12	1		0.02	0.1	0.36	0.002	0.003
LAT-3B	4-Apr-01	10	1	0	9	1		0.02	0.1	0.36	0.002	0.002
LAT-5B	5-Apr-01	10	1	0	7	1		0.02	0.1	0.36	0.002	0.002
LAT-6B	19-Jun-00	10		0	18	1		0.02	0.1	0.21	0.002	0.002
LAT-6B	6-Jul-00	10		0	7	1	10	0.02	0.1	0.21	0.002	0.002
LAT-6B	3-Oct-00	10		0	9	1	7	0.04	0.1	0.21	0.002	0.002

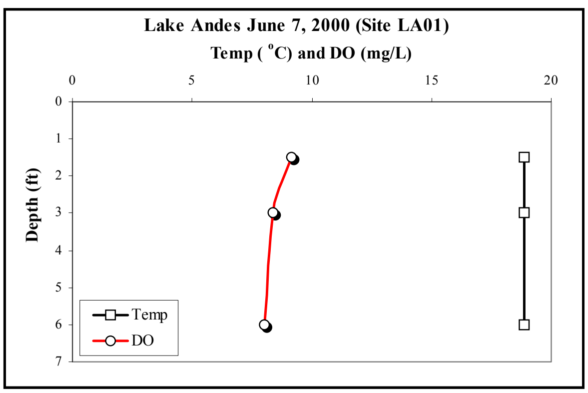
Appendix G: Lake dissolved oxygen and temperature profiles

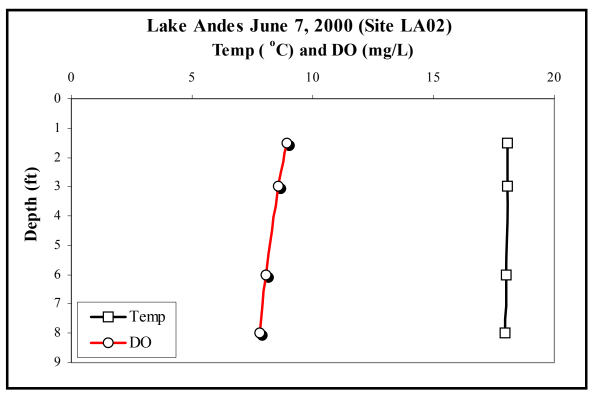

Lake Andes April 9, 2000 (Site LA01)
Temp (°C) and DO (mg/L)
Depth (ft)
Temp
DO

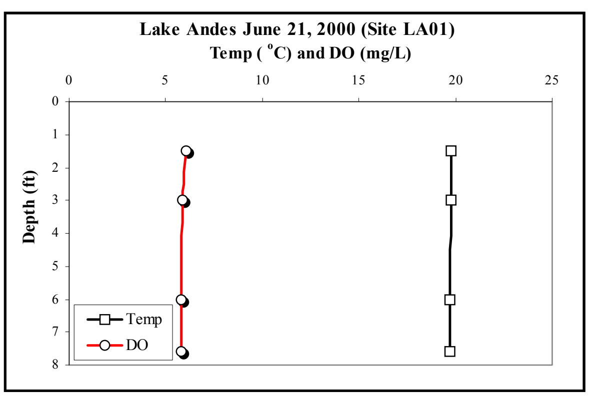

Lake Andes April 10, 2001 (Site LA02)
Temp (°C) and DO (mg/L)
Depth (ft)
Temp
DO

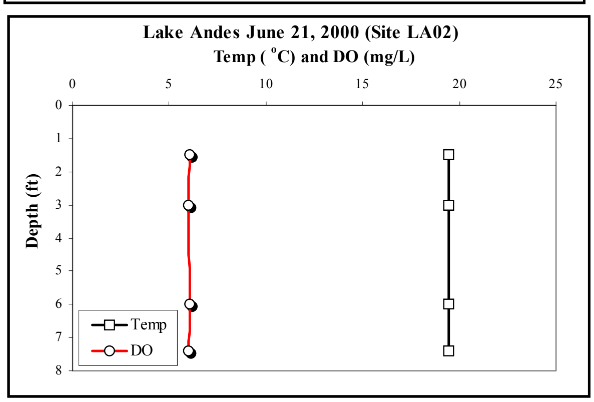

Lake Andes May 16, 2000 (Site LA01)
Temp (°C) and DO (mg/L)
Depth (ft)
Temp
DO


Lake Andes May 16, 2000 (Site LA02)
Temp (°C) and DO (mg/L)
Depth (ft)
Temp
DO


Lake Andes June 7, 2000 (Site LA01)
Temp (°C) and DO (mg/L)
Depth (ft)
Temp
DO


Lake Andes June 7, 2000 (Site LA02)
Temp (°C) and DO (mg/L)
Depth (ft)
Temp
DO


Lake Andes June 21, 2000 (Site LA01)
Temp (°C) and DO (mg/L)
Depth (ft)
Temp
DO


Lake Andes June 21, 2000 (Site LA02)
Temp (°C) and DO (mg/L)
Depth (ft)
Temp
DO