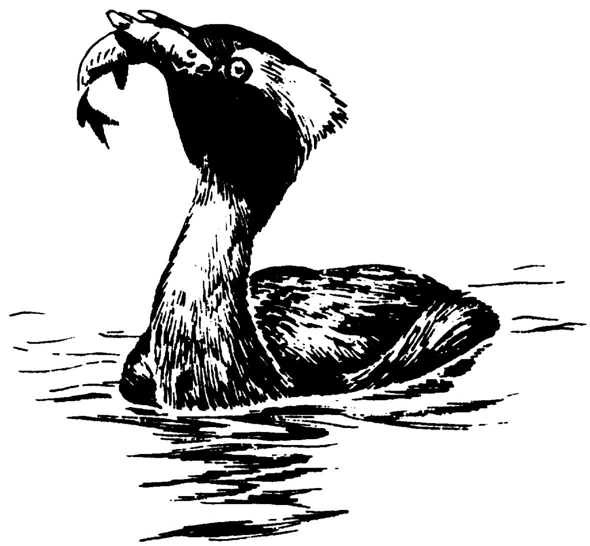
Phase I Watershed Assessment
Final Report

Lake Andes Watershed
Charles Mix County, South Dakota



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

January 2009

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

Lake Andes
Charles Mix County, SD

By

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South Dakota Department of Environment and Natural Resources
Water Resources Assistance Program

Sponsor

South Central Water Development District

January 2009

This project was conducted in cooperation with the State of South Dakota and the United States Environmental Protection Agency, Region 8.

Executive Summary

Lake Andes was first included in the 1998 South Dakota 303(d) list as an impairment-related Total Maximum Daily Load (TMDL) waterbody (SD DENR 1998). Information supporting this listing was derived from SD DENR statewide lake assessment (SWLA) program data (Stueven and Stewart 1996) and the 1996 305(b) Report (SD DENR 1996). Since the original listing in 1998, Lake Andes has been identified in the 2002, 2004, 2006 and 2008 South Dakota Impaired Waterbodies Lists as impaired due to its eutrophic state (as measured by Trophic State Index), and is listed as high priority waterbody in terms of TMDL development (SD DENR 2002, 2004, 2006 and 2008).

The Lake Andes watershed assessment was part of the South Central Lakes Watershed Assessment, 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 were developed and management recommendations made for Corsica, Geddes and Dante Lakes and their watersheds in order to reduce nutrient loadings. TMDLs have not been developed for Lake Andes, Academy Lake or Lake Platte.

Since the South Central Lakes Watershed Assessment project was completed, SD DENR has discontinued use of the Trophic State Index (TSI) lake impairment listing criteria. In the future, lakes will be included on the Section 303(d) Impaired Waterbodies List only if numerical water quality criteria are violated. South Dakota Surface Water Quality Standards, contained in the Administrative Rules of South Dakota (ARSD) § 74:51 do not include the TSI criteria that were originally being used to list lakes as impaired due to eutrophication. However, ARSD § 74:51 does include narrative criteria that may be applied to the undesired eutrophication of lakes and streams. Thus, the lake TSI targets are being retained as an assessment tool to be used for identifying lakes that require a more thorough investigation than that provided by the SD DENR SWLA program to determine if the lake is meeting numeric water quality criteria. If a lake is identified as exceeding a TSI target based on SWLA program data, it will be added to a "Monitoring and Evaluation" list and monitored more intensively to determine whether or not the lake meets applicable numeric water quality standards in ARSD § 74:51.

In addition to TSI, Lake Andes was also identified as impaired due to dissolved oxygen (DO) levels in the 2008 Impaired Waterbodies List. When greater than 10% of lake surface samples violate applicable numeric criteria, a lake is included on the impaired waterbodies list. SD DENR assessment methodology allows for 10% of samples collected from a single waterbody segment to exceed limits in order to account for variability of water quality data due to natural causes (e.g. geology, climate, etc.). Lake data collected from 2000-2007 were used for assessing impairment status of lakes included in the 2008 Impaired Waterbodies List (SD DENR 2008). The Lake Andes DO impairment listing was based on data collected during this assessment as well as data collected as part of the SWLA program.

The DO listing and preparation of this document prompted a more thorough search for additional water quality data. Sando and Neitzert (2003) present data, including DO measurements, that were collected from 1983-2000, which were not included in the data analysis conducted for the 2008 Impaired Waterbodies List due to the age of the data (recall that SD DENR assessment methodology for 2008 Impaired Waterbodies List requires data collected between 2000-2007). However, DO data were collected by USGS beyond what was reported in Sando and Neitzert (2003). USGS collected data at Lake Andes monitoring sites from 21-Feb-90 to 27-Aug-02 (retrieved online from NWIS at http://waterdata.usgs.gov/sd/nwis). After including the USGS data collected after 1-Jan-00 with the data collected by SD DENR, a total of 63 DO measurements were available, of which only four measurements (6.3%) were below the criterion of 4 mg/L. As a result, it was deemed that a TMDL was not required for the Lake Andes DO impairment listing, since less than 10% of lake surface samples were below the criterion.

Despite the decision to not complete a formal TMDL document, water quality goals were established for Lake Andes in this report based on data collected during this assessment as well as data collected by the SWLA program and the USGS. A primary water quality goal for Lake Andes should be to maintain DO concentrations ≥ 4 mg/L in at least a portion of the lake. Lake DO concentrations were found to be negatively correlated with lake total phosphorus concentrations. In eutrophic lakes, high nutrient inputs result in increased productivity, which, in turn, result in bacterial decomposition of organic matter and consumption of DO. Thus, a secondary goal of 0.25 mg/L total phosphorus 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 total phosphorus loads from the watershed by approximately 36%.

Best Management Practices (BMP), including animal nutrient management systems, conservation tillage, reduced fertilizer applications and grassed waterways, are recommended to improve the water quality of Lake Andes and its watershed. Installation of BMPs can be prioritized by sub-watershed based on the results of this assessment. Long-term monitoring is recommended following BMP implementation to evaluate the effects of management activities.

Acknowledgements

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

South Central Water Development District

South Dakota Department of Environment and Natural Resources – Water Resources Assistance Program staff

United States Environmental Protection Agency – Non-Point Source Program

United States Geological Survey

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Introduction

Lake and Watershed Description

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.

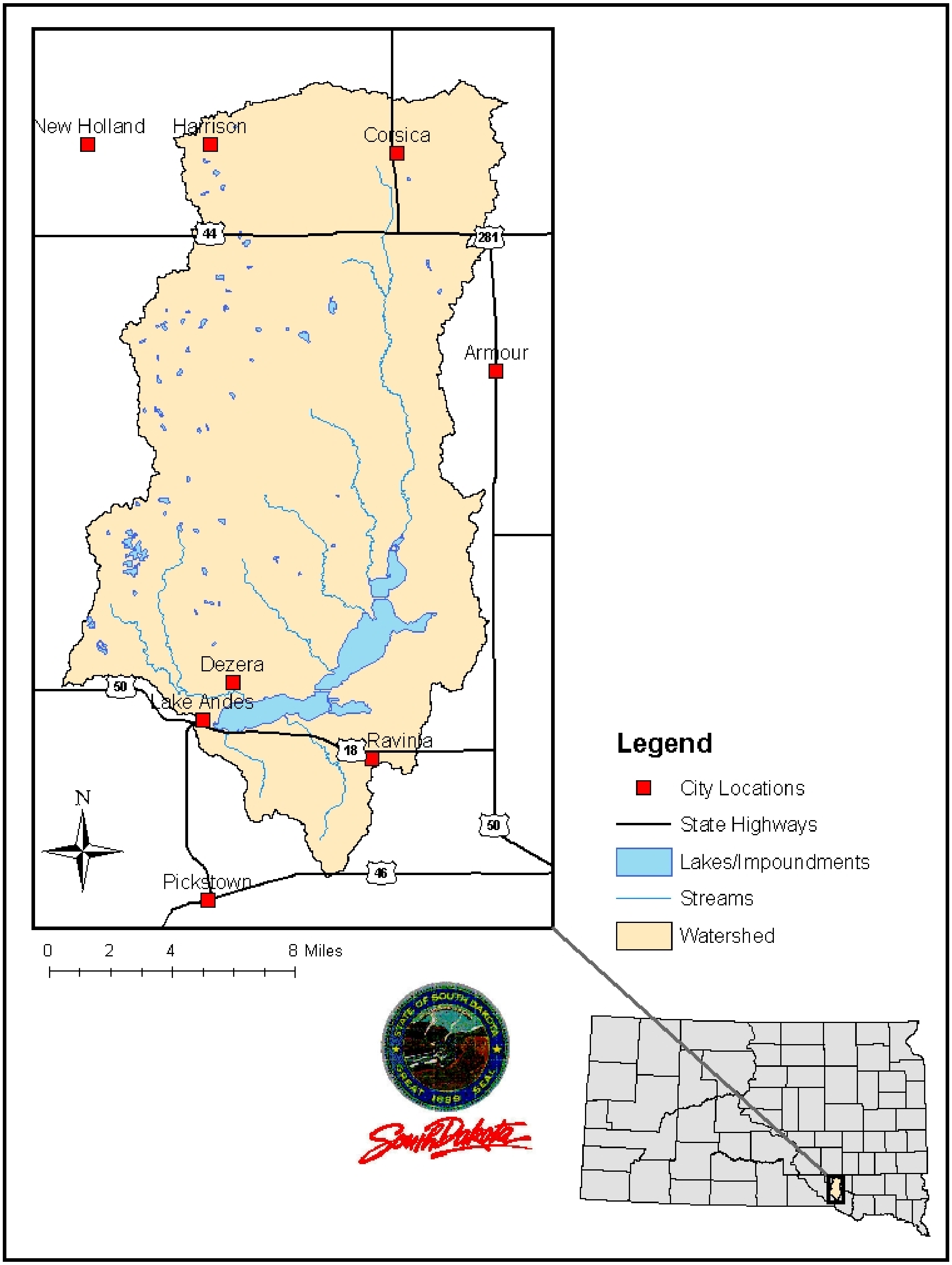


Figure 1. Location of the Lake Andes watershed, Charles Mix and Douglas Counties, SD.

Lake Andes water supply almost entirely originates from watershed runoff. A minor source of water originates from an artesian well draining into Owens Bay. Tributaries 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).

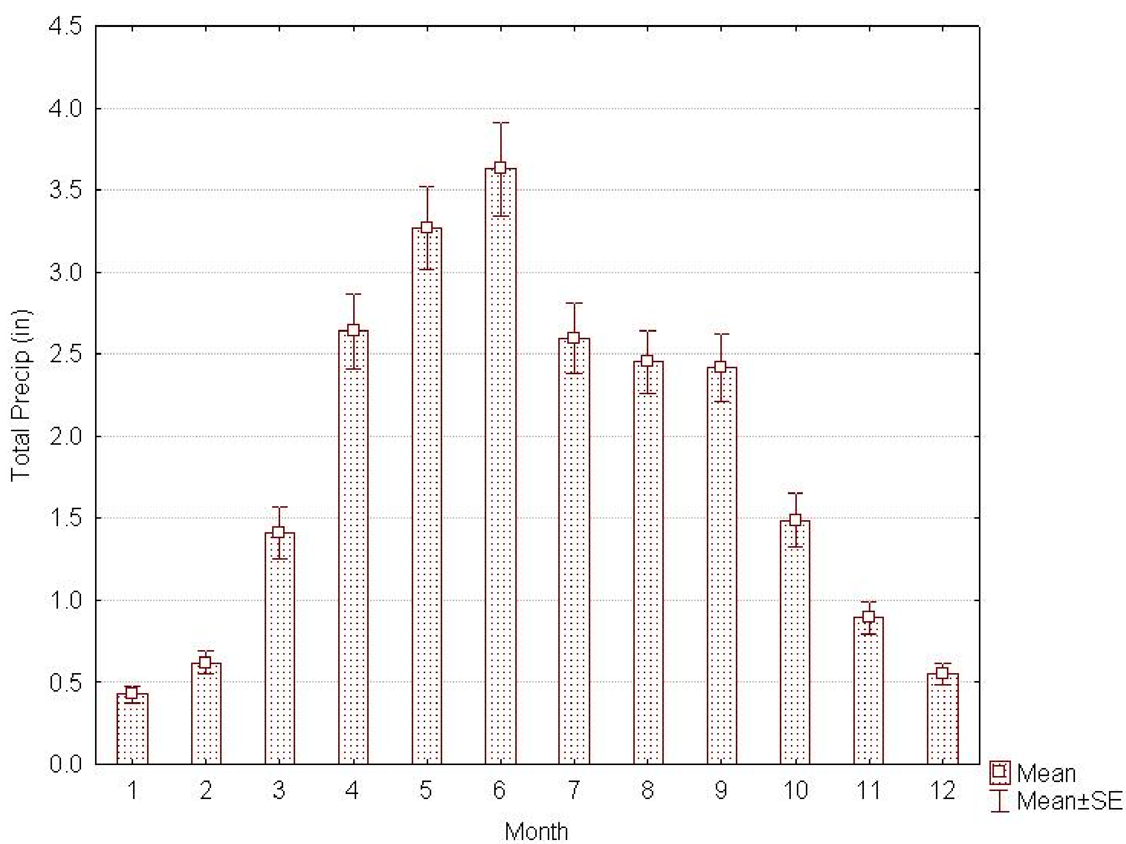


Figure 2. Total monthly precipitation for Pickstown, SD for period of January 1948 to May 2007. **(source: http://climate.sdstate.edu/climate_site/climate.htm)**

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.

Beneficial Use Assignment and Water Quality Standards

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	≥ 4.0 mg/L in any one sample	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 above beneficial uses.

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.

Project Goals, Objectives, and Activities

Project Goals

The purpose of this assessment project was to determine and document sources of impairments to Lake Andes and its watershed and to develop feasible alternatives for restoration. At the time the project proposal was developed, a primary goal of the project was to complete a nutrient TMDL for Lake Andes. However, TMDL will not be developed for Lake Andes at this time for reasons discussed in subsequent sections of this report.

Project Objectives

Objective 1: Lake Sampling

The first objective was to determine current water quality conditions in the lake and calculate the lake's trophic state. This information was used to determine the amount of nutrient trapping, the amount of phosphorus released from the hypolimnion, and the amount of nutrient reduction required to improve the trophic condition of the lake.

Physical, chemical, and biological parameters were examined for 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. Air and water temperature, dissolved oxygen, conductivity, field pH, and water depth were measured in the field using a Yellow Springs Instruments (YSI) meter. All 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). Table 3 lists parameters measured at Lake Andes, and the raw data can be found in Appendix E.

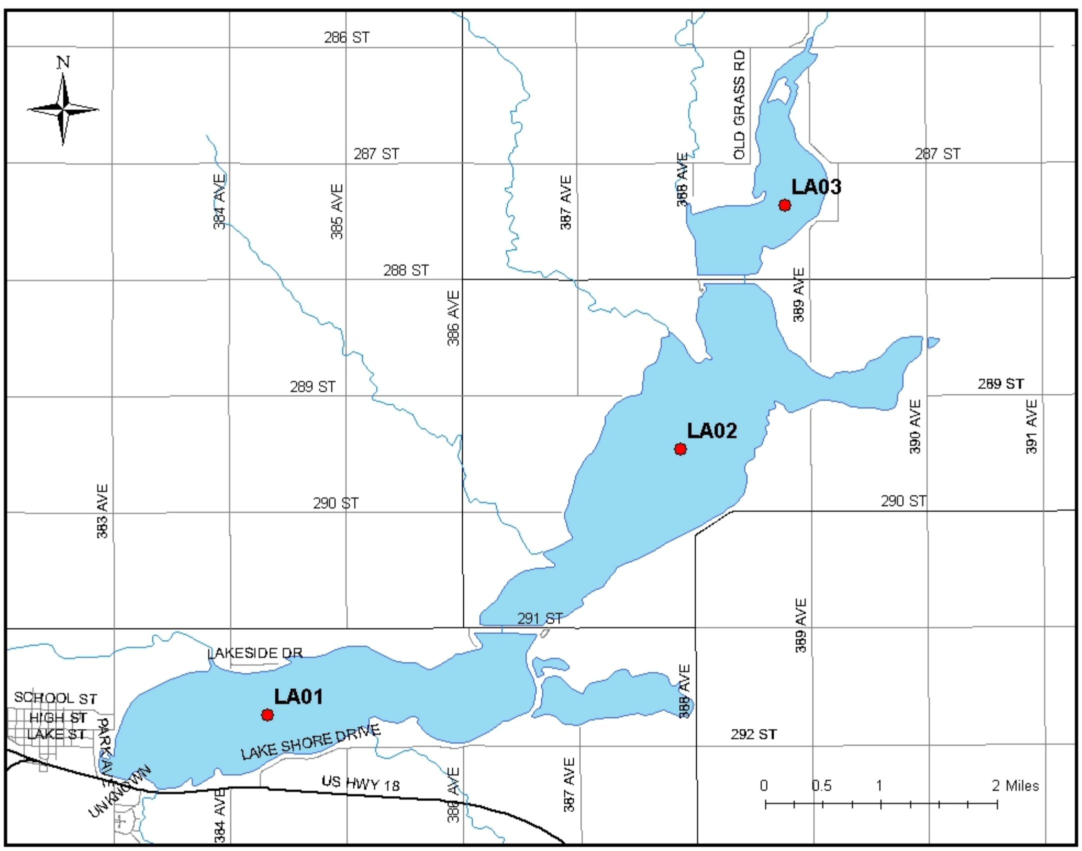


Figure 3. Location of inlake sampling sites for Lake Andes, Charles Mix County, SD.

Table 3. Parameters measured at lake sites.

Physical	Chemical	Biological
Air temperature	Total alkalinity	Fecal coliform bacteria
Water temperature	Un-ionized ammonia	E. coli
Secchi transparency	Total Kjeldahl Nitrogen	Chlorophyll *a*
Total solids	Nitrate+Nitrite	
Total suspended solids	Total Phosphorus	
Depth	Total Dissolved Phosphorus	
	Dissolved oxygen	
	Conductivity	
	Field pH	

Objective 2: Stream Sampling

The second objective was to estimate the sediment and nutrient loadings from streams in the watershed through hydrologic and chemical monitoring. The information was used for lake modeling purposed and to locate critical areas (i.e. subwatersheds) to be targeted for implementation.

Water level recorders were installed on eight inlet streams sites (LAT02, LAT03, LAT04, LAT05, LAT06, LAT07, LAT08, and LAT09) and one outlet stream site (LAO01) to maintain a continuous stage record for those streams for a period of approximately one year. Figure 4 shows the location of the stream monitoring sites.

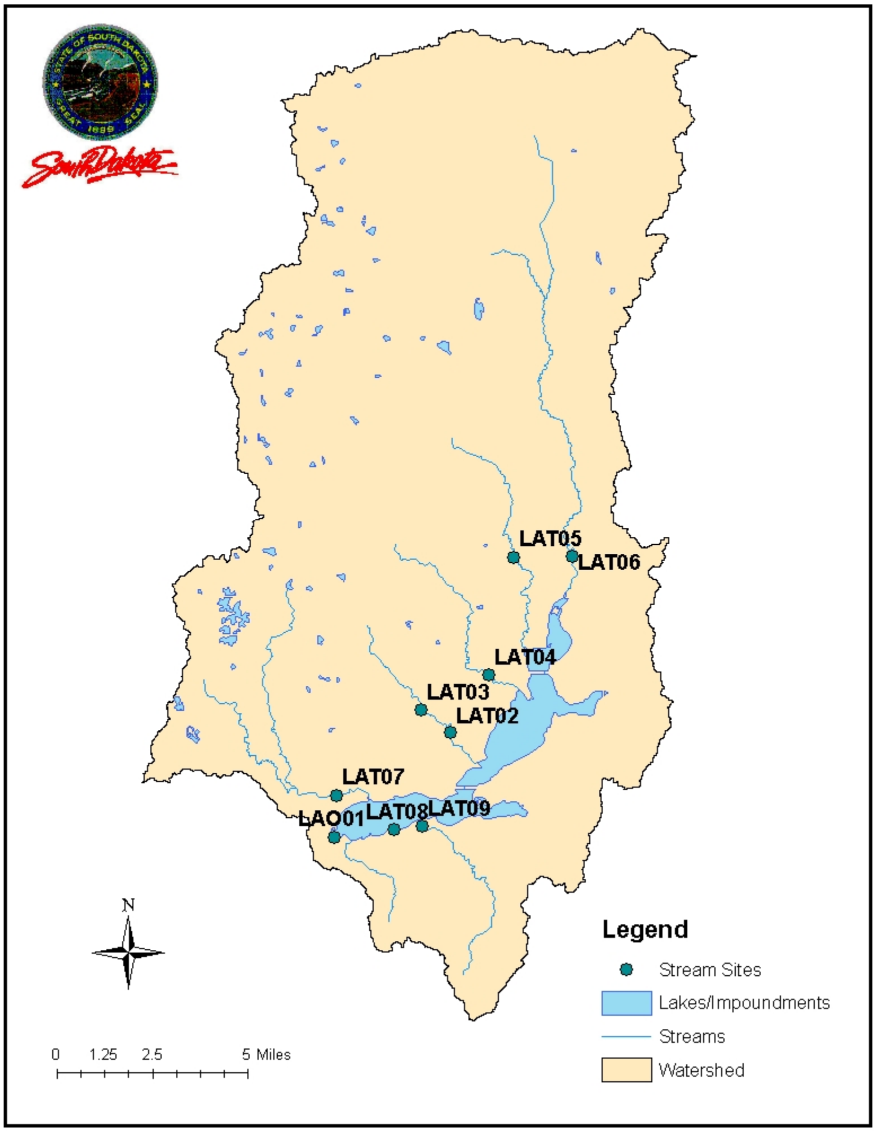


Figure 4. Location of stream sampling sites for the Lake Andes watershed assessment, Charles Mix and Douglas Counties, SD.

Instantaneous discharge measurements were taken with a hand-held current velocity meter. Regression equations were developed from relationships between instantaneous discharge measurements and stage data to estimate continuous discharge and a hydrologic budget for the drainage system. However, many of the stage recording devices were not properly maintained or the stage records were incomplete.

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.

All 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). Grab samples were collected mid-stream from the same location with same method at each visit. Water and air temperature, pH, conductivity, and dissolved oxygen measurements were taken using a YSI meter after water samples were collected, and the raw data can be found in Appendix E.

Table 4. Parameters measured at stream sites.

Physical	**Chemical**	**Biological**
Air temperature	Dissolved oxygen	Fecal coliform bacteria
Water temperature	Ammonia	E. coli
Discharge	Un-ionized ammonia	
Depth	Nitrate+Nitrite	
Visual observations	TKN	
Water level	Total phosphate	
Total solids	Total dissolved phosphate	
Total suspended solids	Field pH	
Conductivity		

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

All QA/QC activities were conducted in accordance with the Water Resource Assistance Program Quality Assurance Project Plan. QA/QC samples consisted of field blanks and field duplicate samples. The activities involved with QA/QC procedures and the results of QA/QC monitoring are reported in a subsequent section of this report.

Objective 4: Modeling

Lake Andes and its inlet and outlet streams were modeled using the BATHTUB and FLUX models. FLUX is a program used to estimate loadings of nutrients or other water quality constituents passing a stream sampling station over a period of time. The BATHTUB program was used to estimate water and nutrient balances and identify factors controlling algal production. The model was also used to determine the nutrient load reduction required for Lake Andes to support its beneficial uses. The model performs calculations on a steady state, spatially segmented hydraulic network and accounts for advective transport, diffusive transport, and nutrient sedimentation.

Results

Stream Physical and Chemical Parameters

Nutrient and Sediment Loading

The total Lake Andes drainage area was divided into seven subwatersheds based on the locations of sampling sites (Figure 5). The ungaged portion of the drainage area was also delineated. 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.

FLUX, a model developed by the Army Corps of Engineers (US ACOE 1999), was also used to estimate 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.

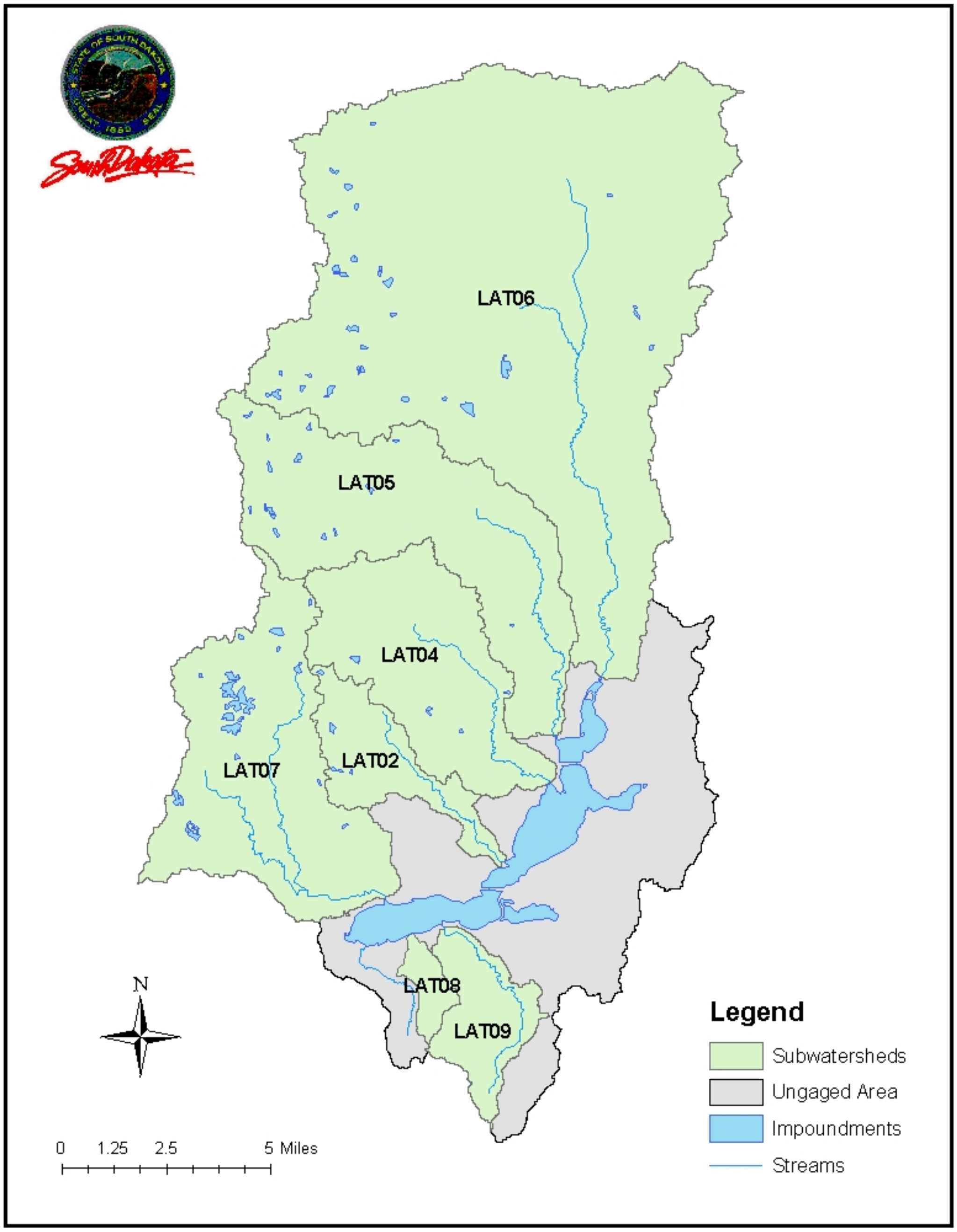


Figure 5. Delineation of subwatershed areas for the Lake Andes watershed assessment.

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

Average annual nutrient (total phosphorus and nitrogen) and sediment (TSS) loads were calculated using average water sample concentrations collected during the assessment period and estimated long-term average annual flows from the EDNA database. Subwatershed LAT06 contributed the largest total phosphorus 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 total phosphorus 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 total phosphorus (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.

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.

Subwatersheds LAT8 and LAT9 are also the smallest in area. The higher export coefficients observed in these smaller watersheds compared to larger subwatersheds may be a function of the proximity of major pollution sources to the stream channel. In other words, a smaller subwatershed may have higher export coefficients simply due to the shorter distance the pollutants must travel before reaching the receiving waterbody. Shorter pollutant travel distances provide less time for sediment to settle out of suspension or for nutrients to be incorporated into plant or algal biomass.

In order to compare the total phosphorus export coefficients for Lake Andes subwatersheds to total phosphorus 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 total phosphorus sample data collected during this assessment and long-term flow estimates from EDNA, the Lake Andes watershed delivers approximately 66.27 kg/km^2[*] of total phosphorus annually. This phosphorus yield is within the range of total phosphorus export coefficients for cropland (7-190 kg/yr/km^2) and less than that of urban runoff (100 kg/yr/km^2) reported by Wetzel (2001) (Table 8).

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

[*] Annual average total phosphorus export coefficient is the sum of the individual subwatershed loads shown 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).

Water Temperature

Water temperature is an influential variable in biological, chemical, and physical processes. Temperature can influence metabolic rates of aquatic organisms, toxicity of pollutants and levels of dissolved oxygen. Stream water temperature is influenced by natural environmental conditions/events, including atmospheric temperatures, precipitation, and vegetation (shade). The greatest source of heat in freshwaters is solar radiation, especially waterbodies that are directly exposed to the sun (Hauer and Lamberti 1996).

As expected, temperature measurements were extremely variable due to seasonal atmospheric temperature differences (Figure 6). Temperatures at the main inlet site (LAT6) ranged from 4.04 to 25.25 degrees Celsius (mean = 15.62), while the outlet site (LAO1) ranged from 4.03 to 15.76 degrees Celsius (mean = 9.23). Higher recorded temperatures at LAT6 may be a function of the longer duration of stream flow through the study period. At LAT6, stream flow persisted until October 24, 2000. At other sites, stream flow ceased earlier in the summer months, resulting in fewer temperature measurements during warmer periods. Streams in the Lake Andes watershed are not designated as fisheries, so water temperature criteria do not exist for these streams.

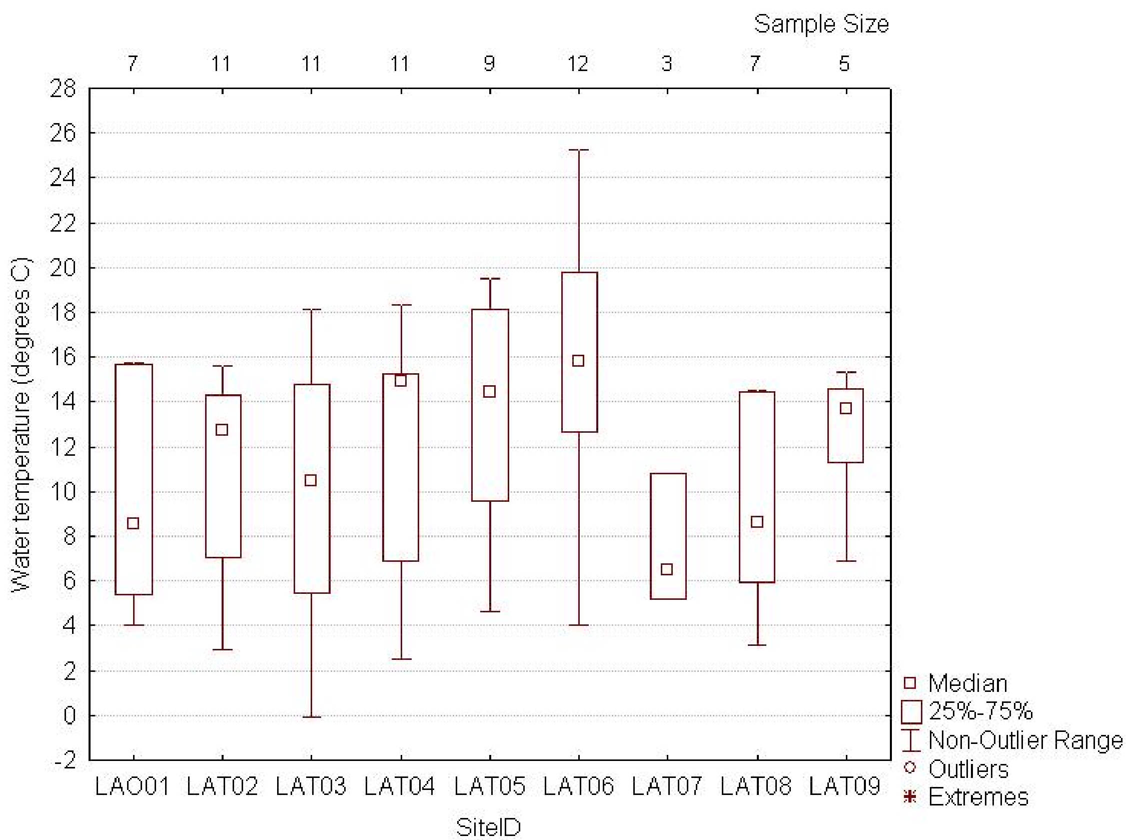


Figure 6. Box plot of temperature by site for Lake Andes stream sites.

Dissolved Oxygen

Concentrations of dissolved oxygen (DO) often vary both spatially and temporally. Physical factors, such as temperature and pressure, also influence concentrations of DO. In fact, atmospheric oxygen solubility is typically most affected by temperature. DO and temperature are inversely related; that is, oxygen saturation increases with decreasing water temperature. Still, seasonal loadings of organic matter can greatly influence DO concentrations (Wetzel 2001).

Concentrations of DO were extremely variable within and across stream sites. Median DO concentrations were highest at the outlet (LAO1) and inlet sites LAT7 and LAT8 (Figure 7). Note that only two DO measurements were collected at site LAT7. Median DO concentrations at sites LAO1, LAT7, and LAT8 were 11.5, 11.3, and 11.5 mg/L, respectively. Lowest DO concentrations were recorded at LAT3 (1.74 mg/L) and LAT4 (1.68 mg/L). Streams in the Lake Andes watershed are not designated as fishery or recreation waters, so DO criteria do not exist for these streams.

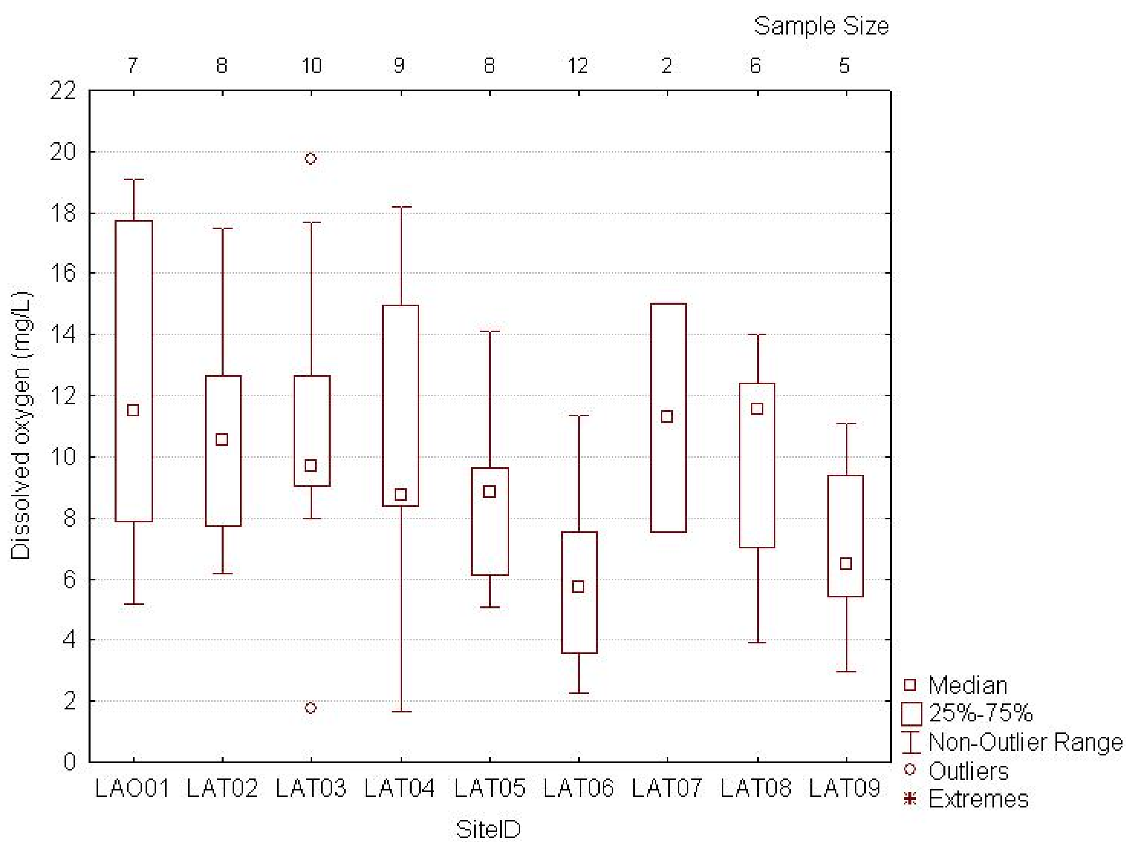


Figure 7. Box plot of dissolved oxygen by site for Lake Andes streams sites.

Acidification and Alkalinity

The primary measurements of acidification are alkalinity and pH. The pH scale ranges from 0 to 14, with 7 being neutral. Water with pH < 7 is considered acidic, while water with pH > 7 is considered basic. The pH of water is regulated mostly by the interaction of H+ ions. Natural waters exhibit wide variations in acidity and alkalinity. The pH of natural waters can range between the extremes of 2 and 12 (Wetzel 2001), yet most forms of aquatic life require an environment with a pH of 6.5 to 9.0. Surface water quality standards require that streams to maintain pH between 6.0 and 9.5 for streams. All pH measurements, except one high measurement at LAO1 (9.15 standard units), fell within this range. Highest median pH was also observed at the outlet site (Figure 8). However, based on current assessment methodologies (SDDENR 2008) one pH violation does not warrant an impairment designation.

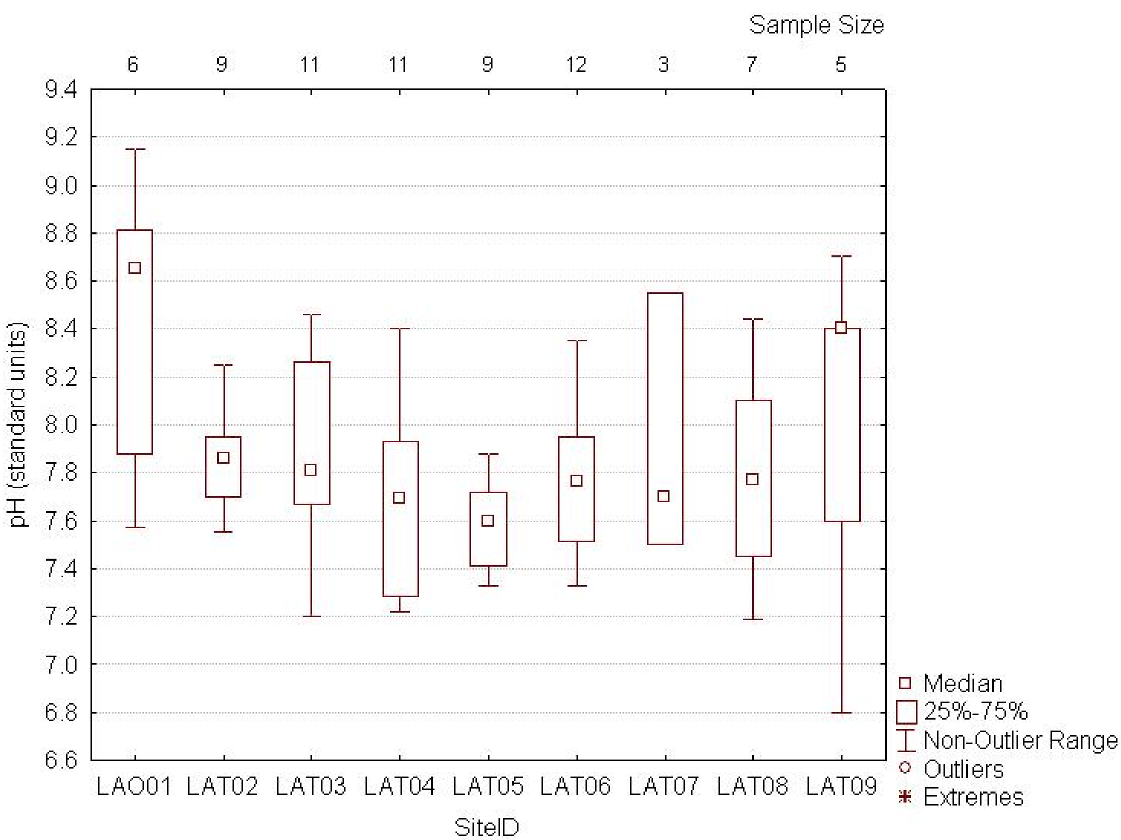


Figure 8. Box plot of field pH by site for Lake Andes stream sites.

Alkalinity is a term that refers to the buffering ability of the carbonate system in water. The term is also used interchangeably with 'acid neutralizing capacity' (ANC), which is the capacity to neutralize strong inorganic acids (Wetzel 2001). Alkalinity is chiefly a product of geological setting. Soils rich in carbonate rock, such as limestone, provide a source of high alkalinity (Monson 2000). In general, increased alkalinity inhibits drastic pH changes. Alkalinity typically ranges from 20 to 200 mg/L in natural environments (Lind 1985).

Among all sites, alkalinity concentrations were far below the surface water quality criterion of 1,313 mg/L. Highest concentrations of alkalinity were observed at sites LAT6 and LAT8 (Figure 9). Site LAT6 displayed the highest median value (333 mg/L), and site LAT8 displayed the highest value overall (499 mg/L).

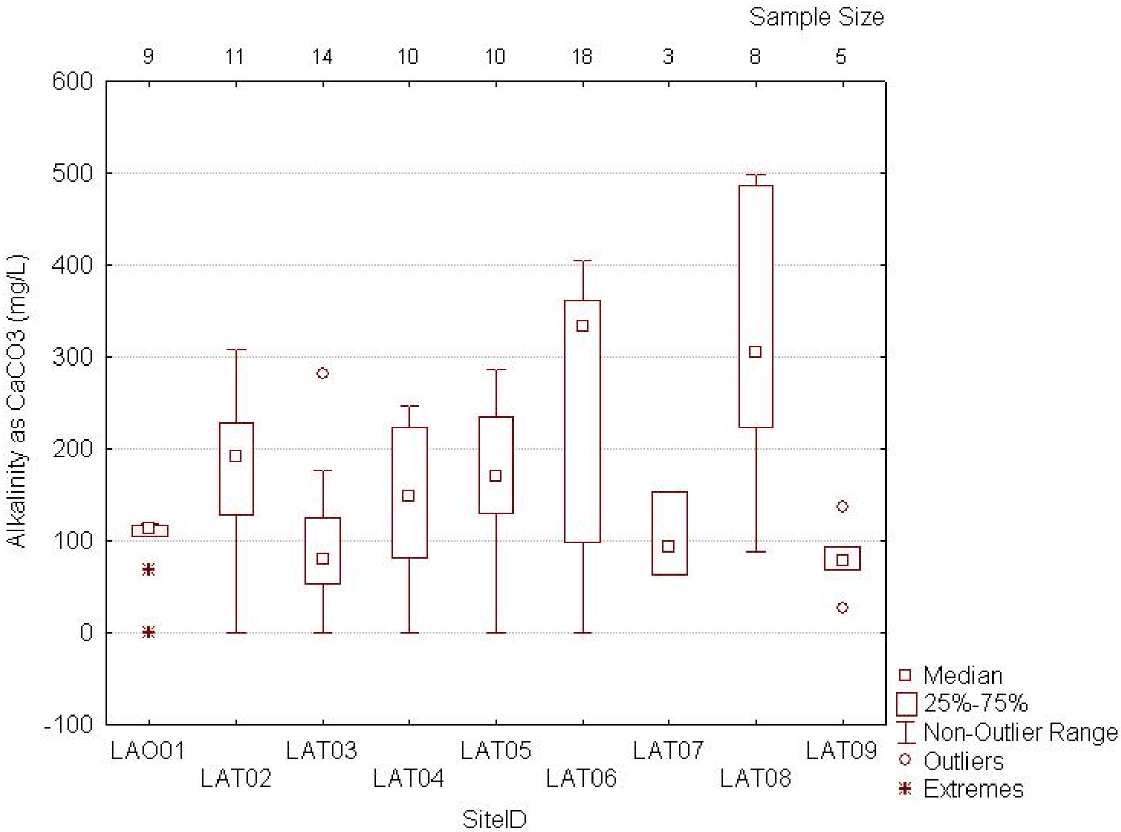


Figure 9. Box plot of alkalinity by site for Lake Andes stream sites.

Solids

"Solids" is a general term that refers to suspended or dissolved materials that are present in the waterway. Two solids parameters were examined in this assessment: total solids and total suspended solids. Total solids include the sum of dissolved and suspended solids. Suspended solids consist of larger materials that do not pass through the filter (i.e. residue). These materials include both organic and inorganic forms.

On average, approximately 90% of total solids consisted of dissolved solids. Concentrations of dissolved and total solids were quite variable, and both parameters were inversely related to stream flow. Among all sites, LAT5 displayed the most variability and greatest concentration (4,933 mg/L) of total solids. Site LAT8 also displayed elevated total solids concentrations with a maximum concentration of 3,940 mg/L. Site LAT9 displayed the lowest median concentrations and low variability, but this is likely a result of the smaller number of samples and relatively high stream flow experienced at this site when the samples were collected (Figure 10).

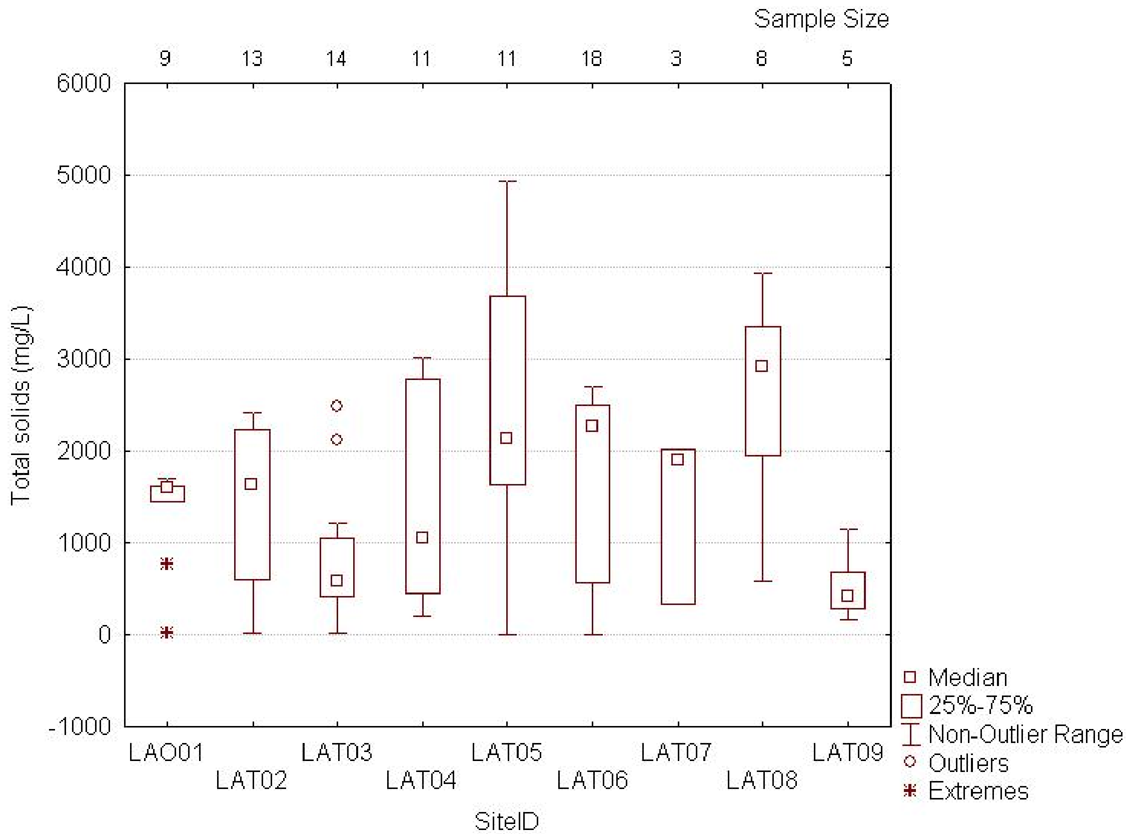


Figure 10. Box plot of total solids by site for Lake Andes stream sites.

Concentrations of total suspended solids (TSS) were used as a measure of the amount of sediment carried in the water column. With the exception of two extremely high TSS samples collected at site LAT3, sample concentrations of TSS were typically highest at site LAT5 (Figure 11). As expected, consistently low TSS concentrations were observed at the outlet site due to settling within the lake. The lake acts as a large retention basin that traps the sediment load from the watershed.

Average TSS export coefficient for the assessed subwatersheds was 0.18 lb/day/acre. The TSS export coefficients were highest for the LAT8 and LAT9 subwatersheds (1.71 and 0.60 lb/day/acre, respectively). The TSS export coefficient for subwatershed LAT5 (0.30 lb/day/acre) was also higher than the average TSS export coefficient.

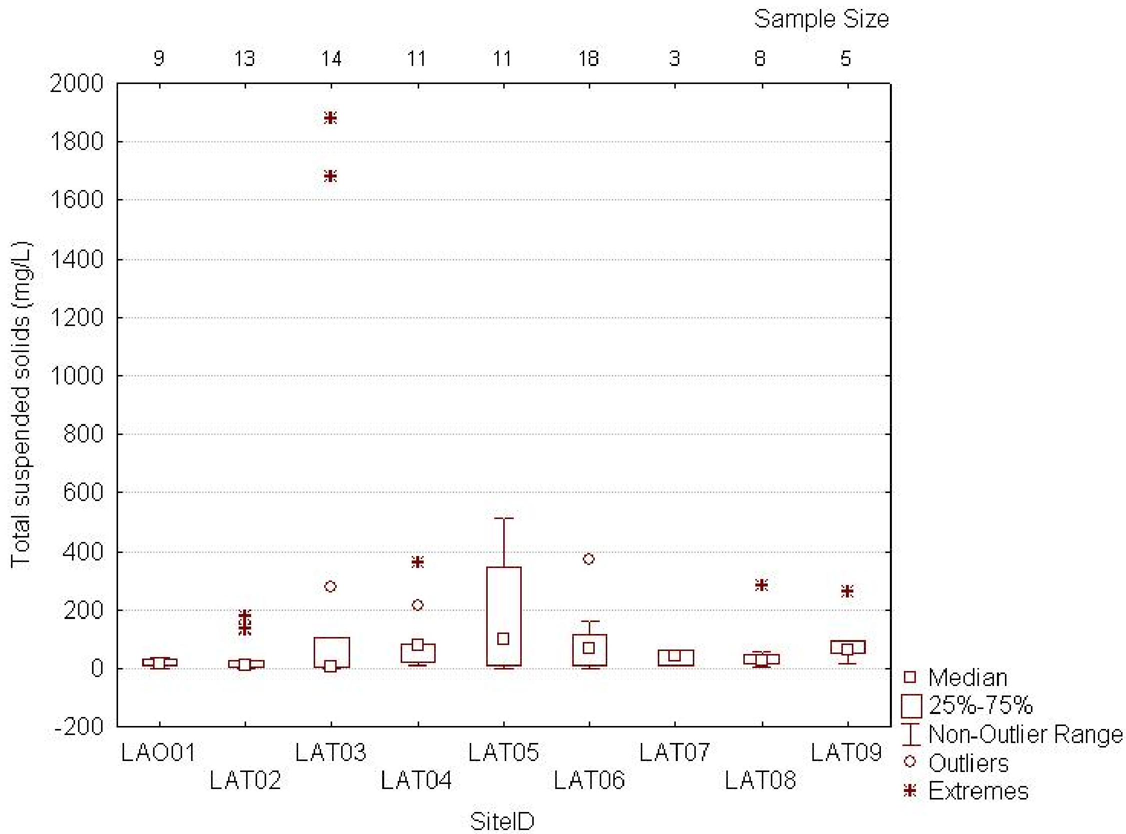


Figure 11. Box plot of total suspended solids (TSS) by site for Lake Andes stream sites.

Nitrogen

Several forms of nitrogen can be found in a waterbody. Natural sources of nitrogen include precipitation, biological processes (i.e. nitrogen fixation), wildlife waste, and surface and groundwater drainage. Anthropogenic nitrogen sources include sewage inputs of organic nitrogen, fertilizer applications, and livestock waste.

Three types of nitrogen were assessed in stream samples: (1) nitrate/nitrite, (2) ammonia, and (3) Total Kjeldahl Nitrogen (TKN). With these three parameters, relative concentrations of organic and inorganic nitrogen can be determined, as well as total nitrogen concentrations. Organic nitrogen was calculated as TKN minus ammonia. Inorganic nitrogen was calculated as the sum of ammonia and nitrate/nitrite. Total nitrogen was calculated by totaling inorganic and organic nitrogen.

The greatest concentrations of total nitrogen (39.0 mg/L), TKN (31.1 mg/L) and ammonia (4.87 mg/L) were observed in a sample collected at LAT8 during a storm event on May 18, 2000. The highest median total nitrogen concentration was observed at LAT5 (Figure 12).

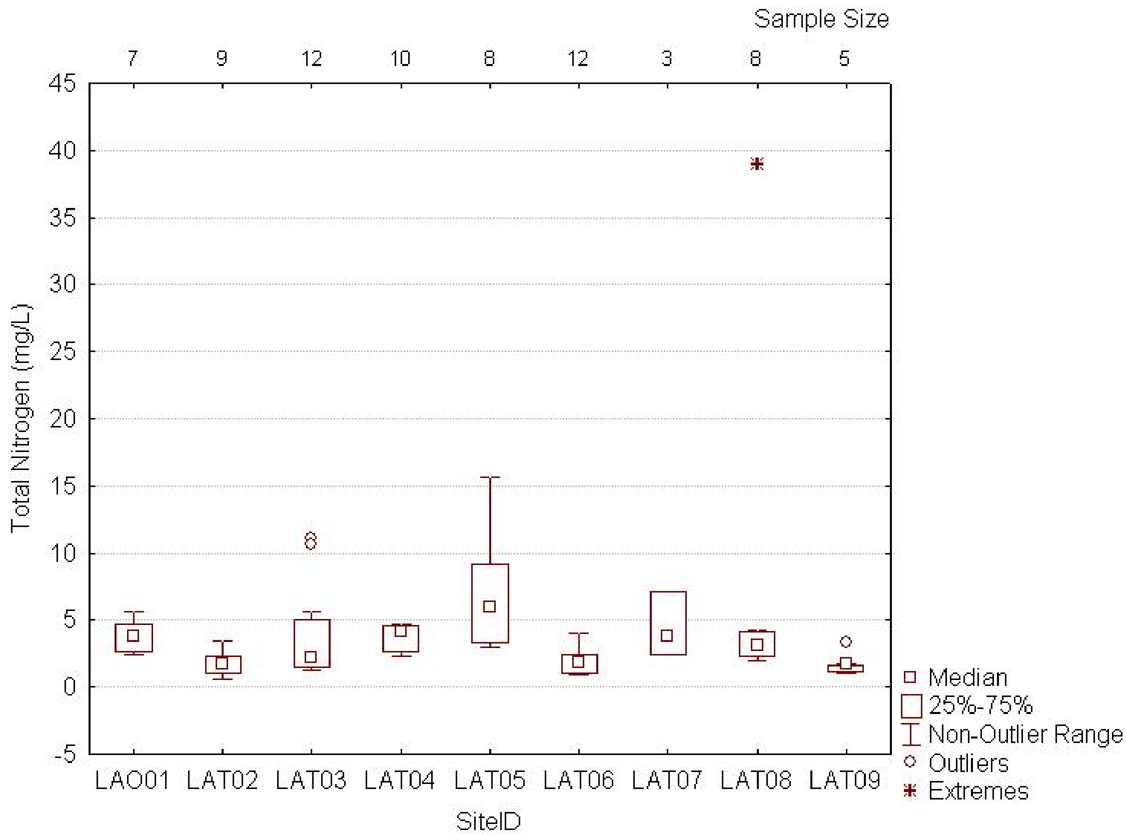


Figure 12. Box plot of total nitrogen by site for Lake Andes stream sites.

Average total nitrogen export coefficient was 0.008 lb/day/acre. The total nitrogen export coefficient was highest for the LAT8 subwatershed (0.227 lb/day/acre). Export coefficients for subwatersheds LAT5 and LAT9 (0.012 and 0.011 lb/day/acre, respectively) were also higher than the average total nitrogen export coefficient.

Quantities of inorganic (nitrate, nitrite, and ammonia) and organic nitrogen compounds in streams are highly diverse and variable due to the variety of inputs from natural and anthropogenic sources. Organic nitrogen concentrations usually constitute a large portion of the total nitrogen in river systems (Wetzel 2001). However, concentrations of inorganic nitrogen were greater than organic nitrogen in approximately 37% of samples collected from the assessed streams, suggesting an anthropogenic source. Concentrations of inorganic nitrogen were occasionally markedly higher than organic nitrogen. In one sample collected from LAT6, all of the nitrogen was is the inorganic form (Figure 13).

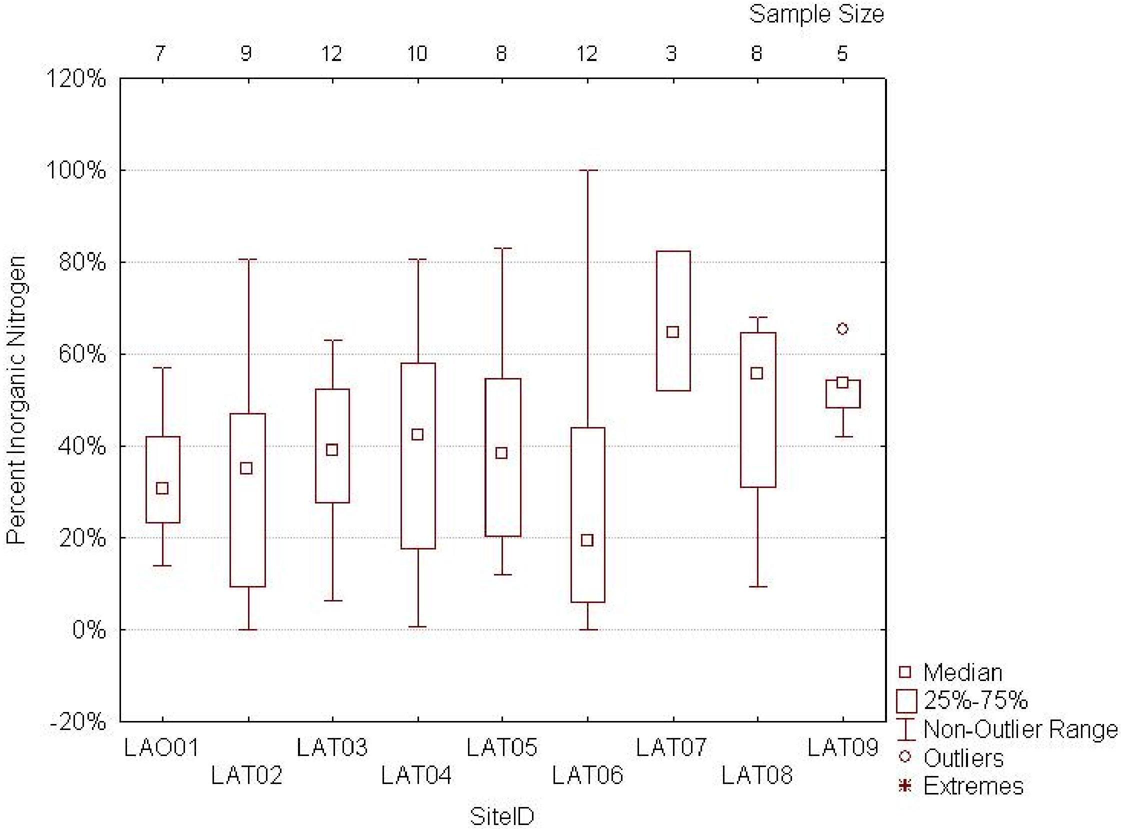


Figure 13. Box plot of percent inorganic nitrogen relative to total nitrogen by site for Lake Andes stream sites.

Ammonia is the nitrogen end-product of bacterial decomposition of organic matter. This form of nitrogen is most readily available to algae and aquatic plants for uptake and growth. Concentrations of ammonia in fresh water are highly variable geographically, temporally, and spatially. Ammonia concentrations can range from 0-5 mg/L in unpolluted surface waters. Ammonia levels in streams and lakes are primarily influenced by the amount of primary productivity and the extent of pollution from organic matter. In general, concentrations of ammonia in well-oxygenated waters are low due to rapid utilization by the algae community (Wetzel 2001).

Among all stream sites, total ammonia concentrations ranged from less than detection to 4.87 mg/L. The maximum concentration was observed at LAT8. The greatest median concentration was observed at site LAO1 (0.80 mg/L), the lake outlet, which is likely due to bacterial decomposition of organic matter within the lake. The amount of ammonia delivered from the watershed and produced from bacterial decomposition of organic matter in the lake appear to exceed the amount consumed by algae and other plants in the lake, resulting in relatively higher concentrations of ammonia at the outlet site.

In unpolluted waters, ammonia is usually the dominant constituent of inorganic nitrogen, and nitrate/nitrite concentrations are typically low. Natural concentrations of nitrate/nitrite rarely exceed 10 mg/L and are normally less than 1 mg/L (Lind 1985). However, nitrate/nitrite concentrations were higher than ammonia concentrations in approximately 38% of samples collected at stream sites. Nitrate/nitrite concentrations ranged from less than detection to 7.9 mg/L. The maximum concentration was observed at LAT8. The greatest median concentration (1.5 mg/L) was observed at LAT5.

Phosphorous

Phosphorus is present in all aquatic systems. Natural sources include the leaching of phosphate-bearing rocks and organic matter decomposition. Potential anthropogenic sources of phosphorus include fertilizers and sewage.

Effects of the reservoir on phosphorus concentrations are apparent when comparing the relatively lower outlet phosphorus concentrations to inlet stream site concentrations. The reservoir acts a sink for phosphorus delivered from the watershed, as phosphorus is incorporated by aquatic plants and algae or adsorbs to particulate matter and settles to the bottom of the lake. The highest total phosphorus concentration (5.57 mg/L) was observed at LAT8, while the highest median concentration (0.801 mg/L) was observed at LAT5 (Figure 14).

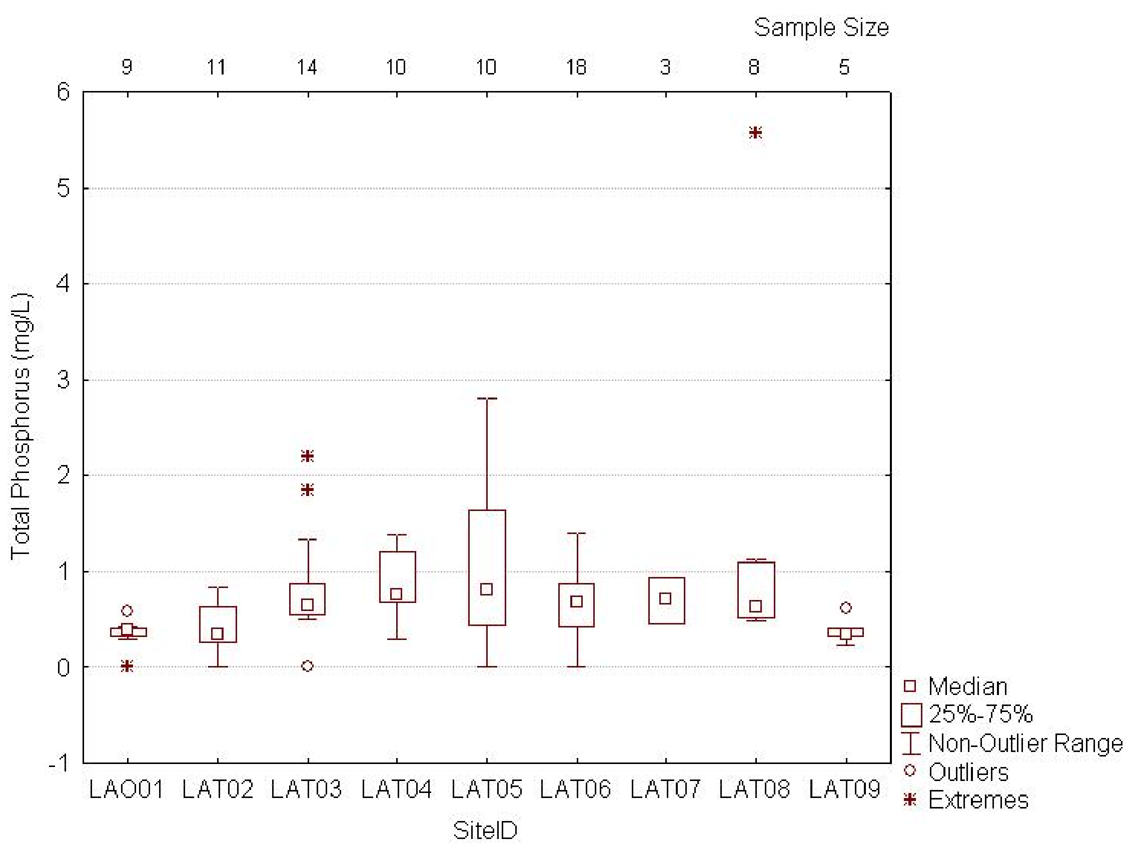


Figure 14. Box plot of total phosphorus by site for Lake Andes stream sites.

Total phosphorus annual load from the watershed was approximately 31,677 kg, which is equivalent to approximately 65 kg per watershed acre. Total phosphorus annual load measured at the outlet site was approximately 11,991 kg. Based on these loading estimates, approximately 19,686 kg of phosphorus (62% of the watershed annual load) is stored in Lake Andes each year. It is expected that much of the external phosphorus load is either incorporated into aquatic plant and algal biomass or attached to suspended solids that eventually settles to the bottom of the lake.

Average total phosphorus export coefficient was 0.0016 lb/day/acre. The total phosphorus export coefficient was highest for the LAT8 subwatershed (0.0394 lb/day/acre). Export coefficients for subwatersheds LAT9, LAT5 and LAT4 (0.0023, 0.0019 and 0.0017 lb/day/acre, respectively) were also higher than the average total phosphorus export coefficient.

Similar to total phosphorus concentrations, total dissolved phosphorus (TDP) concentrations at inlet sites (except LAT9) were higher and more variable than the outlet. Among all sites, highest median and maximum TDP concentrations (0.621 and 4.240 mg/L, respectively) were observed at site LAT4 (Figure 15).

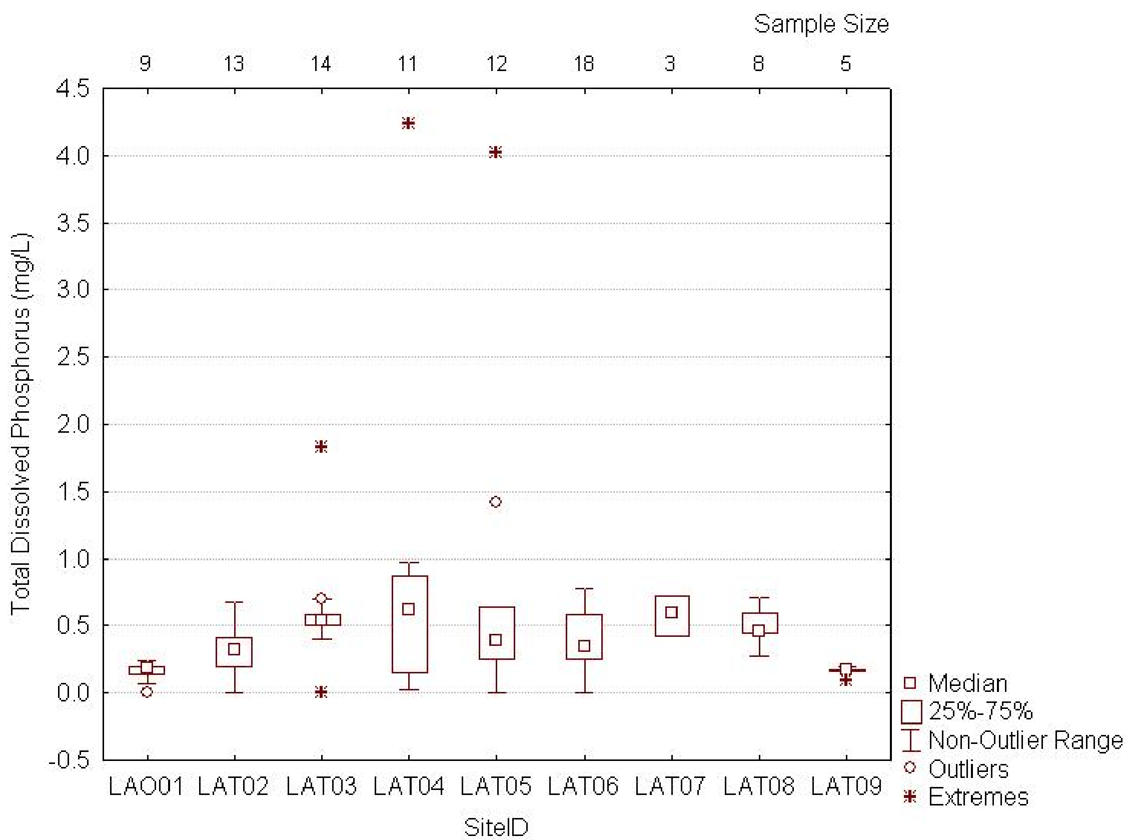


Figure 15. Box plot of total dissolved phosphorus by site for Lake Andes stream sites.

Fecal Coliform Bacteria

Fecal coliform bacteria are found in the intestinal tract of all warm-blooded animals. Although these organisms are not disease-causing organisms themselves, their presence indicates fecal contamination and a higher probability of infectious, water-borne disease.

Fecal bacteria concentrations are often highly variable. Environmental factors (e.g. sunlight exposure and water temperature) can influence concentrations of fecal bacteria in a waterway. The lifespan of fecal bacteria is relatively short compared to the associated animal waste, so the absence of fecal bacteria does not necessarily equate to the absence of animal waste.

The streams in the study watershed do not have a water quality standard for fecal coliform bacteria. However, Lake Andes is assigned the immersion recreation use, and the daily maximum concentration allowed for this use is 400 colony-forming units (CFU)/100 ml.

Fecal coliform bacteria concentrations were directly correlated to concentrations of organic nitrogen and total phosphorus (Spearman r = 0.417 and 0.416, respectively). Similar to total phosphorus and total nitrogen concentrations, the highest fecal coliform bacteria concentration (1,700,000 CFU/100 ml) was observed at LAT8, while the highest median concentration (2,700 CFU/100 ml) was observed at LAT5.

Concentrations of the bacterium *Escherichia coli*, another indicator of fecal contamination, were also analyzed. *E. coli* did not display significant correlations with nutrient parameters, which is likely due, in part, to the inability to quantify sample concentrations greater than 2,420 CFU/100 ml. *E. coli* sample concentrations greater than 2,420 CFU/100 ml are too numerous to count (TNTC) using available *E. coli* testing methods. Concentrations of *E. coli* were TNTC in at least one sample from each of sites LAT2, LAT4, LAT5, LAT6, and LAT8. Livestock waste is a likely source of elevated nutrient and bacteria concentrations in these subwatersheds.

Lake Physical and Chemical Parameters

Water Temperature

Water temperature in Lake Andes ranged from 0.1 to 26.8 (mean = 17.3) degrees Celsius (Figure 16). Maximum temperature was reached in August. State water quality standards require water temperatures to be maintained below 32.2 degrees Celsius to protect the beneficial use of warm water marginal fish life propagation. No temperature measurements exceeded this criterion.

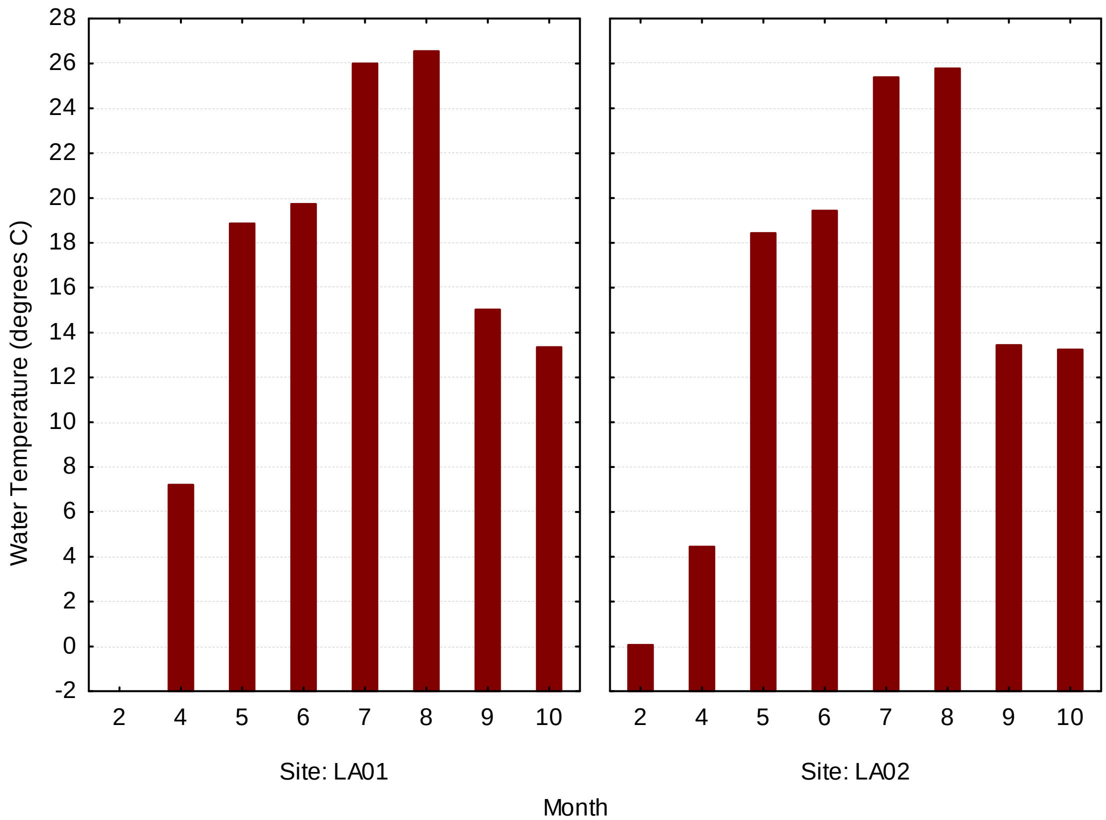


Figure 16. Water temperature by month for Lake Andes monitoring sites. Temperature measurements were collected from February 2000-October 2001 (no measurements were collected in March).

Dissolved Oxygen

Dissolved oxygen (DO) is made available, in part, by photosynthetic inputs from algae and aquatic plants. Conversely, microbial degradation of dead algae and aquatic plants consumes oxygen. In eutrophic lakes (i.e. high in nutrient loading with high organic production), an elevated rate of production and subsequent decomposition of organic matter can result in low or no dissolved oxygen in the lake (Monson 2000).

DO measurements collected during this study from the surface of the lake ranged from 0.9 to 10.8 mg/L (mean = 6.3). State water quality standards require DO concentrations to be maintained at or above 4.0 mg/L to support the warmwater marginal fish propagation use. Four surface DO measurements collected during this assessment were below the DO criterion. DO concentrations were below the criterion during the February, April, July and August 2000 sampling visits. DO levels were significantly lower during the winter and summer compared to the spring and fall seasons (Figure 17). Lowest DO concentrations observed in April are likely the result of high nutrient loads delivered to the lake during spring snow-melt and runoff; in-lake concentrations of ammonia, total phosphorus and dissolved phosphorus were highest during the April sampling event. Low DO concentrations observed in February are likely due to ice and snow cover limiting sunlight penetration and, in turn, algae growth. Whereas, low DO concentrations during the summer months are partially related to warmer water temperatures and higher rates organic matter decay resulting from algal growth and settling.

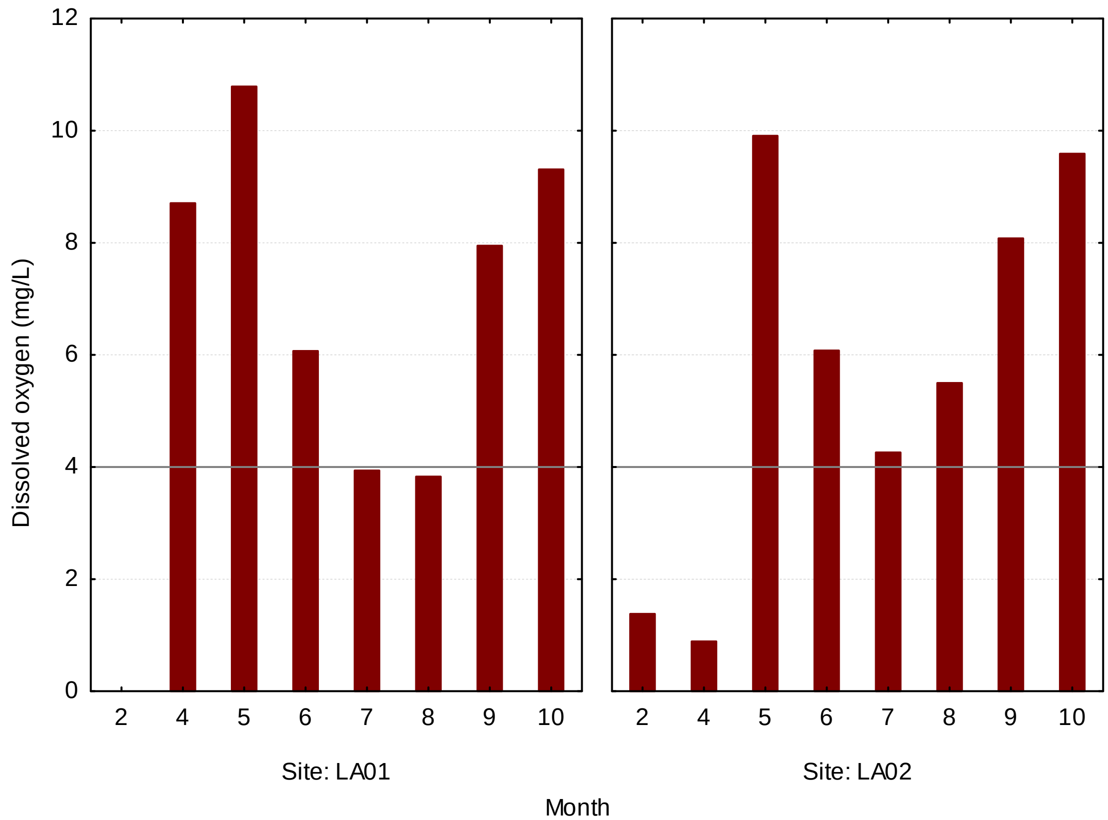


Figure 17. Dissolved oxygen (DO) by month for Lake Andes monitoring sites. DO measurements were collected from February 2000-October 2001 (no measurement collected in March). Daily minimum water quality criterion is indicated by the solid horizontal line (≥ 4 mg/L).

Lake Andes was included in the 2008 SD Impaired Waterbodies List for DO impairment based on data collected during this study as well as lake monitoring conducted by DENR as part of the Statewide Lakes Assessment Program. USGS (Sando and Neitzert 2003) present data, including DO measurements, that were collected from 1983-2000, which were not included in the data analysis conducted for the 2008 Impaired Waterbodies List due to the age of the data (recall that SD DENR assessment methodology for 2008 Impaired Waterbodies List requires data collected between 2000-2007). However, DO data were collected by USGS beyond what was reported in Sando and Neitzert (2003). USGS collected data at Lake Andes monitoring sites from 21-Feb-90 to 27-Aug-02 (retrieved online from NWIS at http://waterdata.usgs.gov/sd/nwis). After including the USGS data collected after 1-Jan-00 with the data collected by SD DENR, a total of 63 DO measurements were available, of which only four measurements (6.3%) were below the criterion of 4 mg/L. As a result, it was deemed that a TMDL was not required for the Lake Andes DO impairment listing, since less than 10% of lake surface samples were below the criterion.

Excessive nutrient loading to Lake Andes has likely contributed to a higher oxygen demand, resulting in seasonally low dissolved oxygen concentrations. During this assessment project, DO concentrations were negatively related to total phosphorus concentrations in the lake (Figure 18). This relationship was used to establish an in-lake total phosphorus concentration goal the Lake. DO concentrations were more variable and occasionally dropped below the standard when total in-lake phosphorus measurements were greater than approximately 0.25 mg/L. Thus, the total phosphorus goal for the lake was set at 0.25 mg/L.

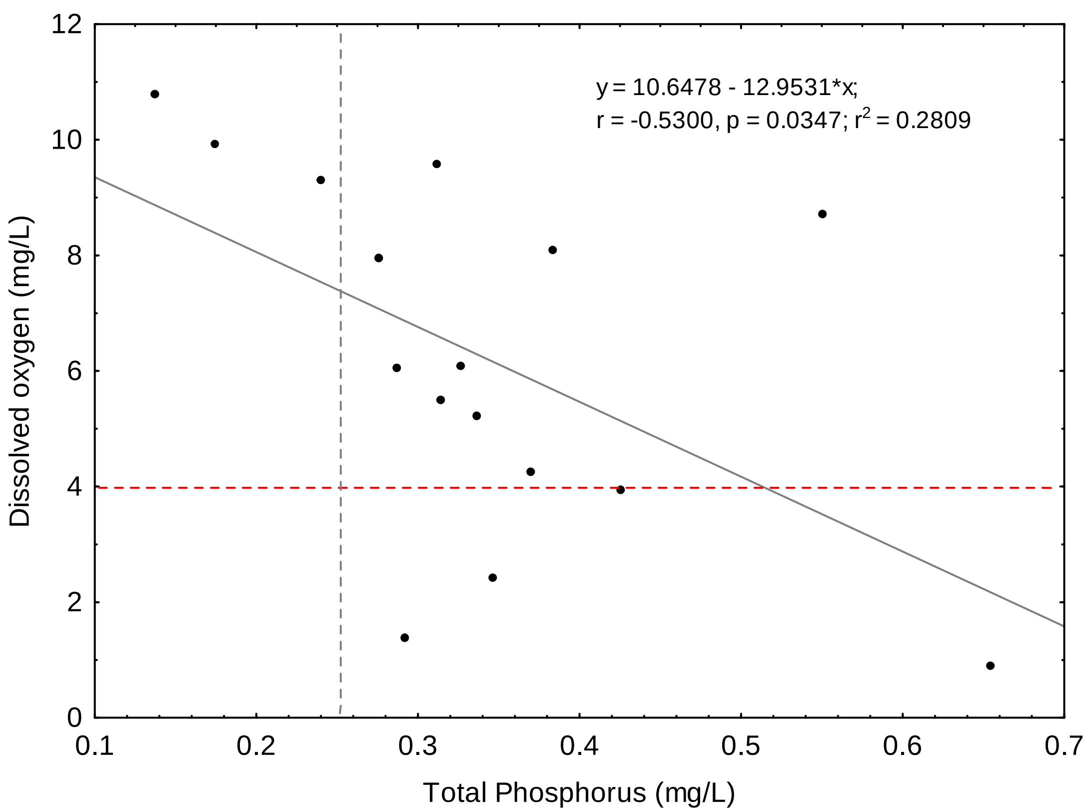
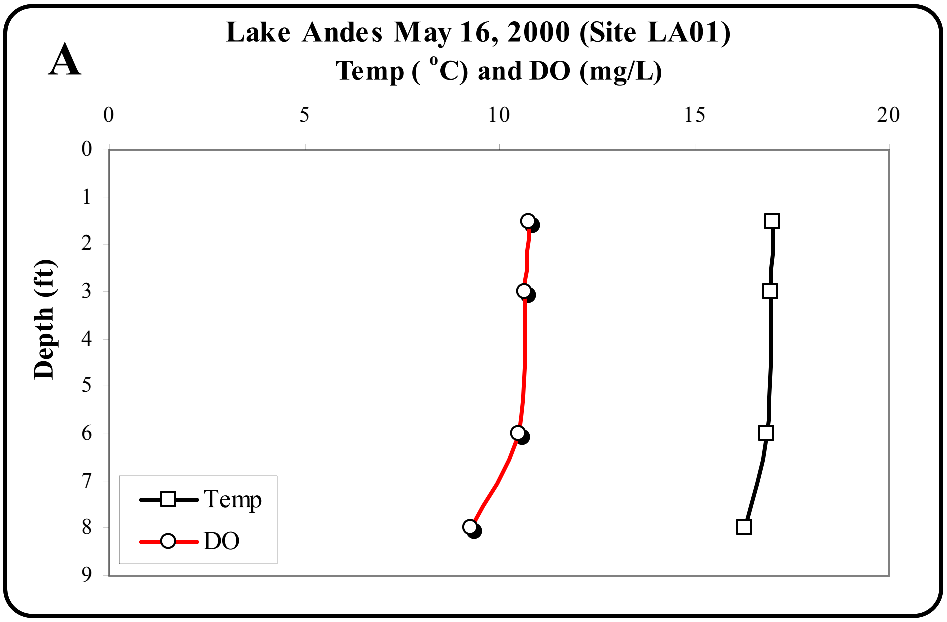


Figure 18. Lake Andes dissolved oxygen concentrations as a function of total phosphorus concentrations. The horizontal dotted line represents DO criterion, and the vertical dotted line represents the in-lake total phosphorus target concentration above which the DO concentrations drop below the criterion.

Temperature and DO profiles of the lake water column were also measured to determine oxygen availability and temperature conditions throughout the water column and to detect stratification (See Appendix G for lake DO and temperature profile plots). Lake Andes does not appear to experience thermal stratification. This is expected for a lake with a high surface area:depth ratio, where the wind and wave action mixes the lake and prevents stratification. Figure 19 shows DO profiles collected in May and August 2000, contrasting the range of DO and temperature conditions from spring to summer.



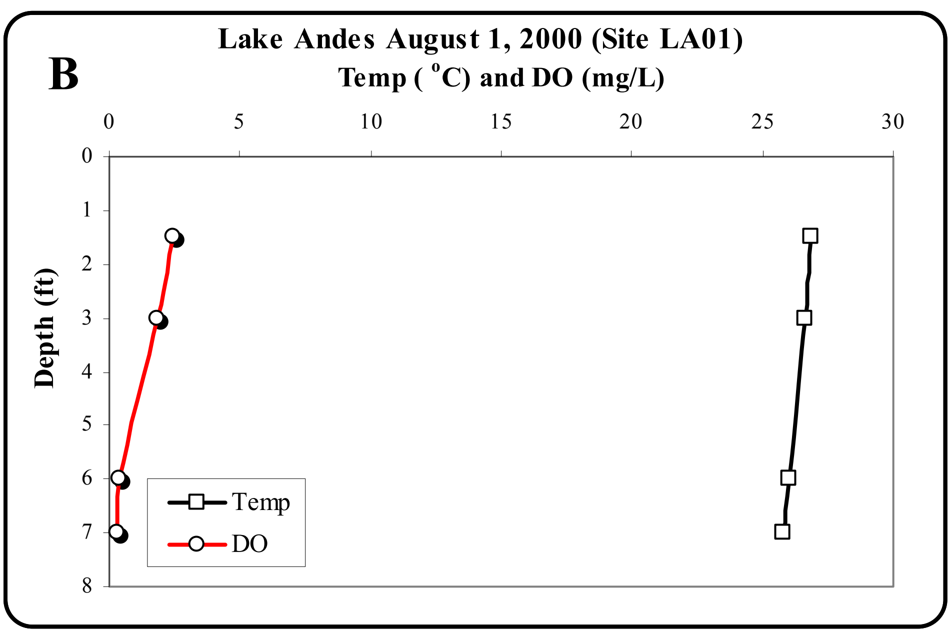


Figure 19. Temperature and dissolved oxygen profile for Lake Andes at site LA01 on May 16, 2000 (A) and August 1, 2000 (B).

Acidification and Alkalinity

As previously stated, the primary measurements of acidification are alkalinity and pH. In Lake Andes, pH values ranged from 6.9 to 8.9 (mean = 8.3). State water quality standards require pH to be maintained between 6.0 to 9.0. No pH violations were observed during the study period (Figure 20). Highest pH values were observed in June, which can be attributed to the photosynthetic utilization of CO_2 by algae and aquatic plants.

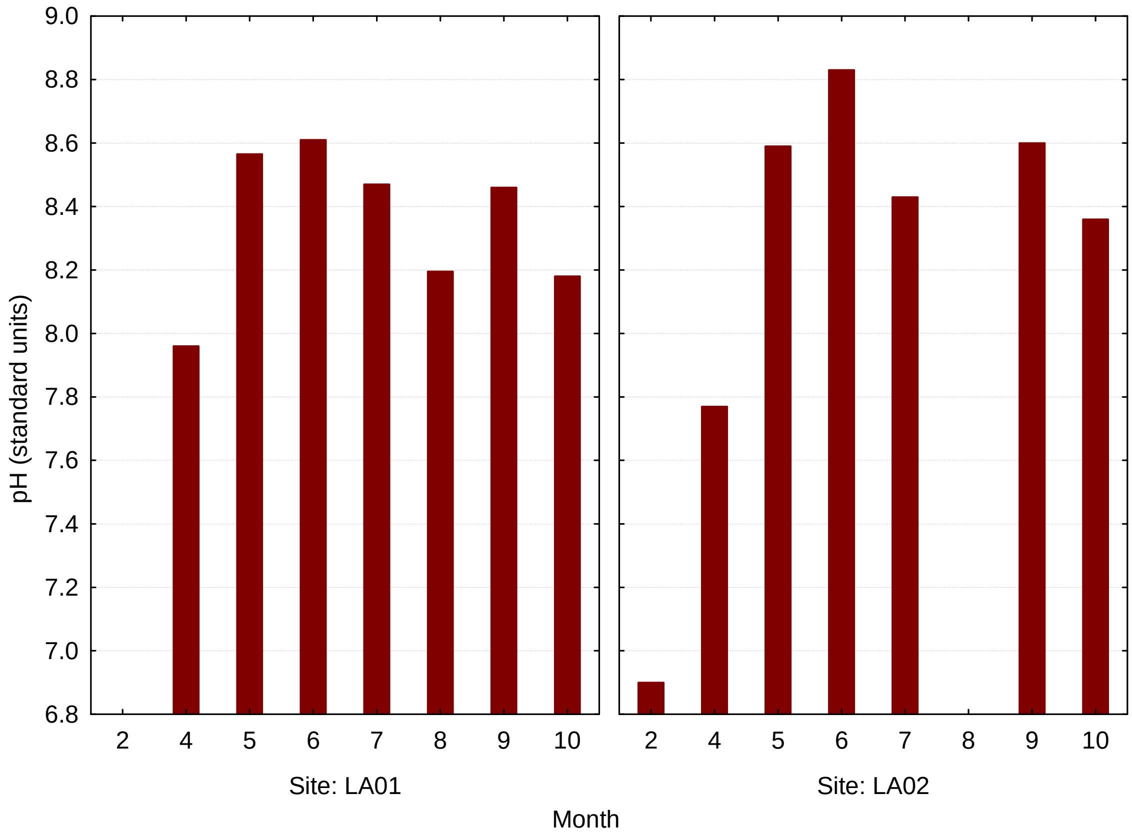


Figure 20. pH by month for Lake Andes monitoring sites.

Alkalinity concentrations ranged from 106 to 170 mg/L (mean = 122). The alkalinity concentrations in Lake Andes were well below the water quality standard, which is ≤1,313 mg/L. Concentrations were low throughout the study period with minimum concentrations occurring in June (Figure 21).

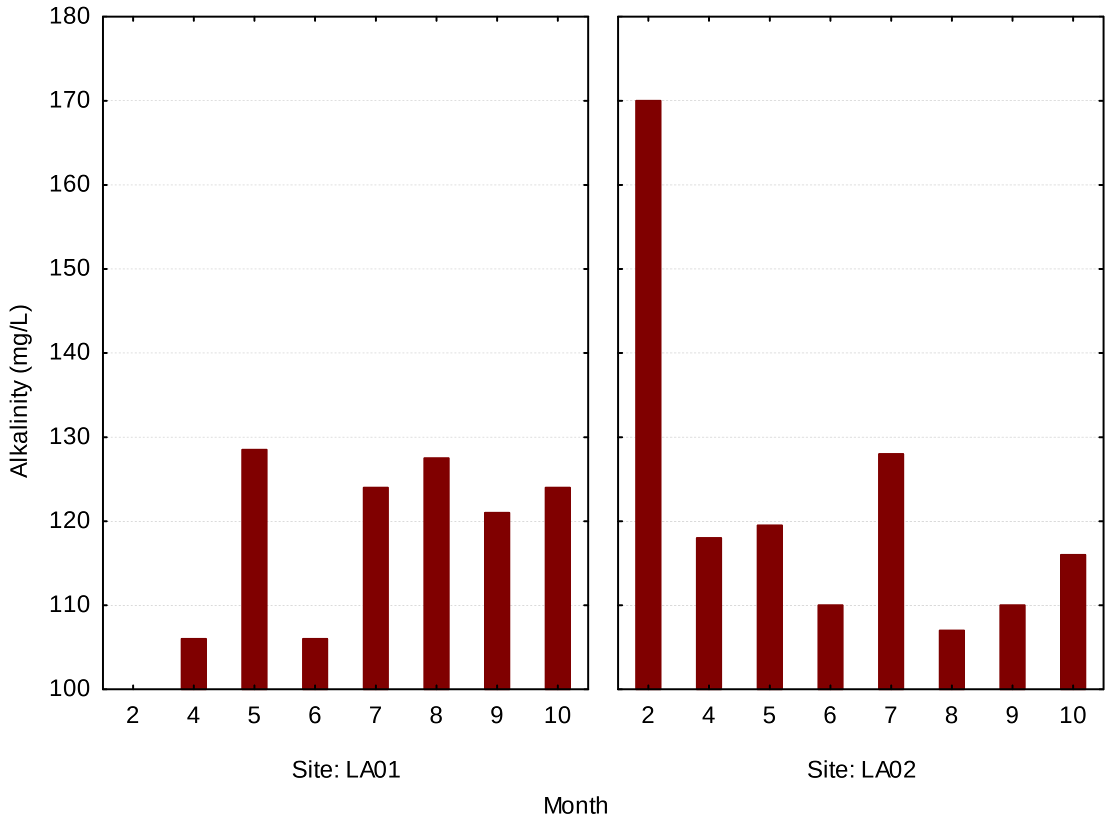


Figure 21. Alkalinity concentrations by month for Lake Andes categorized by site and sample depth.

Solids

Total solids concentrations in Lake Andes ranged from 1,284 to 2,986 mg/L (mean = 2,131). In general, total solids concentrations steadily increased through the year (from spring to winter) with lowest concentrations observed in April at both sites and the maximum concentration occurred in February (Figure 22).

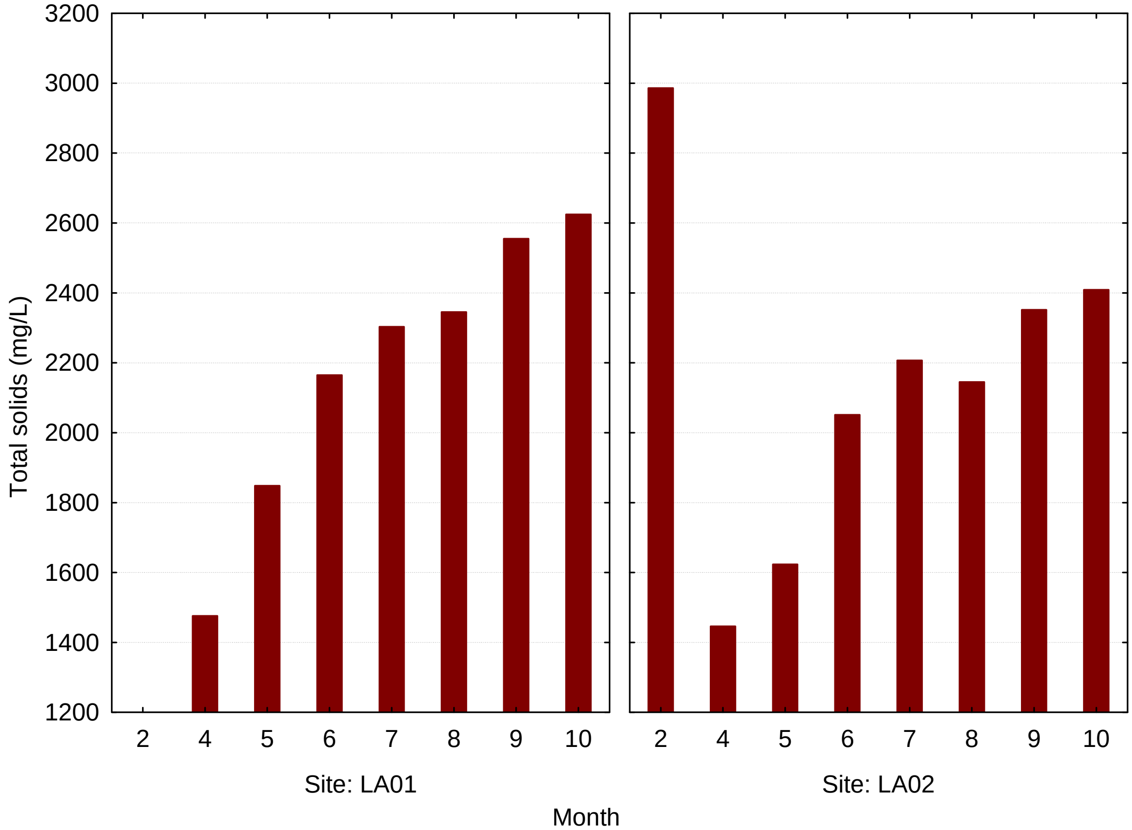


Figure 22. Total solids concentrations by month for Lake Andes monitoring sites.

Typical of most waterways, total solids were mostly comprised of dissolved solids. Concentrations of dissolved solids ranged from 1,262 to 2,980 mg/L (mean = 2,092). Similar to total solids concentrations, minimum concentrations of dissolved solids were observed in April at both sites and maximum concentration was observed in February (Figure 23).

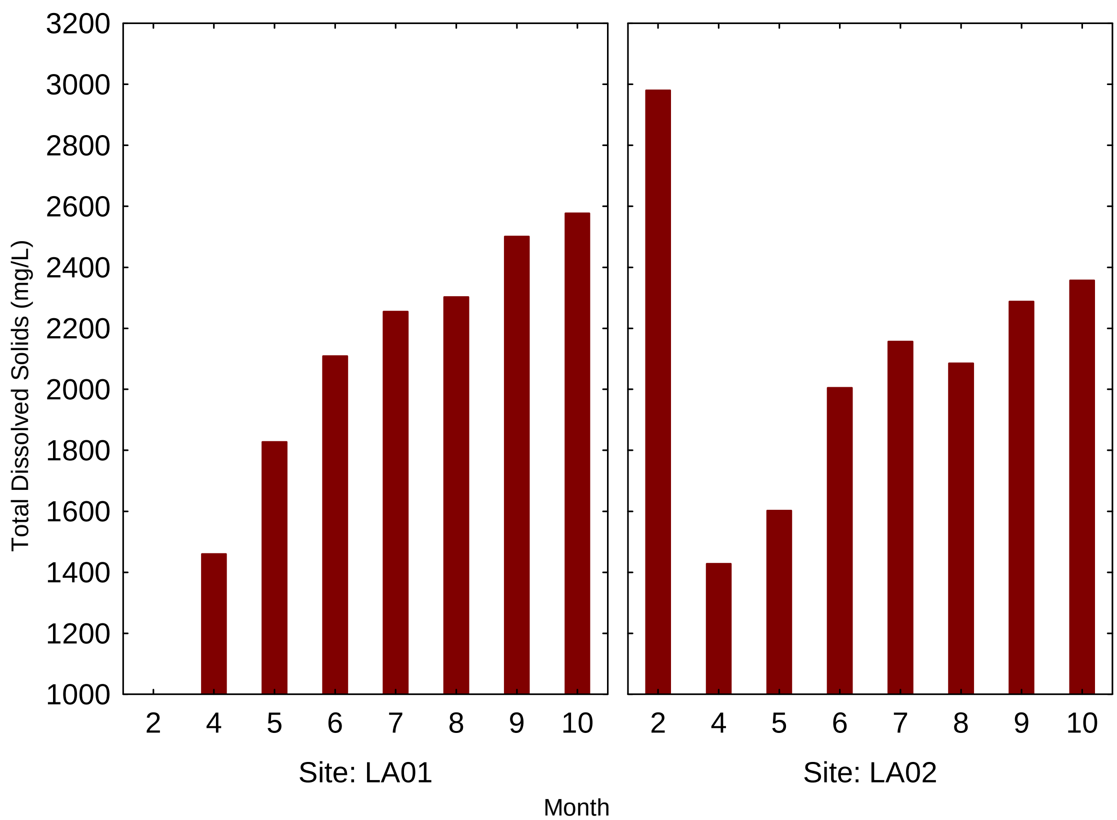


Figure 23. Total dissolved solids concentrations by month for Lake Andes categorized by site and sample depth.

Total suspended solids (TSS) concentrations ranged from 6 to 64 mg/L (mean = 38). TSS concentrations displayed marked seasonality at both sampling locations. Concentrations were lowest in winter and spring months (April for site LA01 and February for LA02) and highest during the summer and fall months (June for site LA01 and September for LA02). Higher TSS concentrations during the summer and fall probably result from higher algal productivity and resuspension of settled solids during storms events in these seasons (Figure 24).

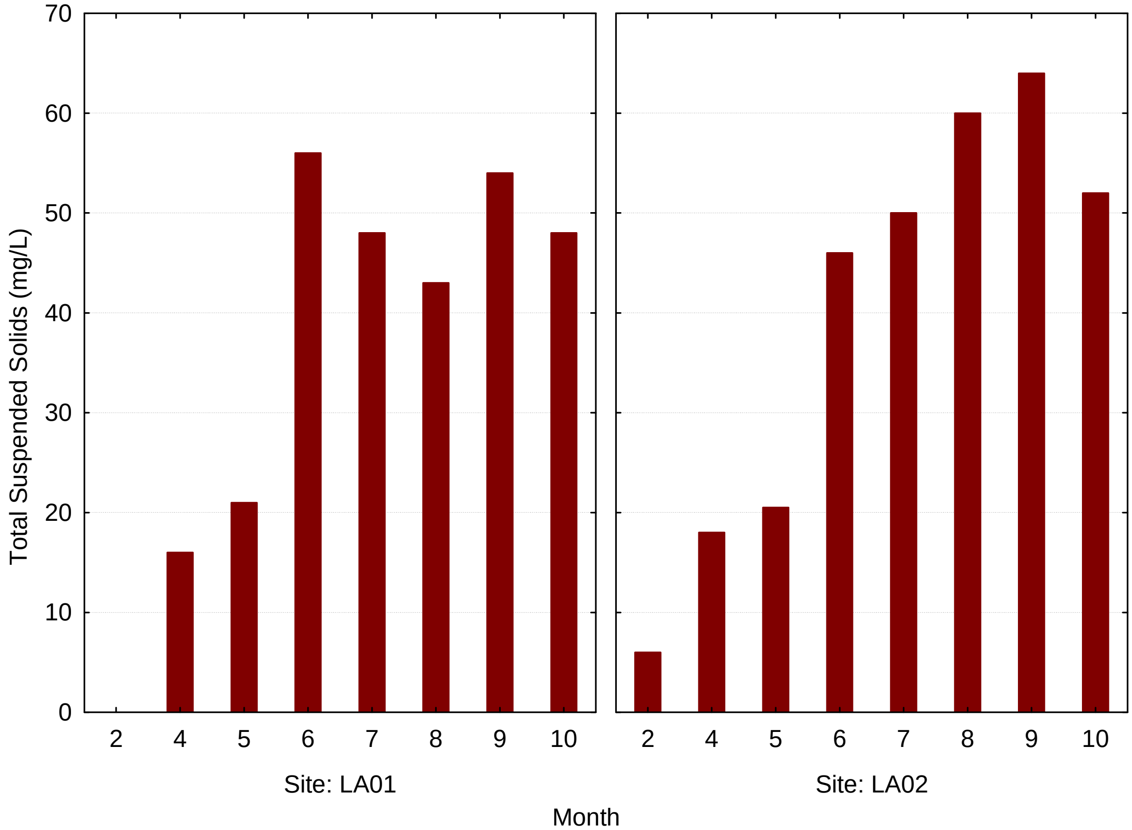


Figure 24. Total suspended solids concentrations by month for Lake Andes monitoring sites.

Nitrogen

Ammonia concentrations ranged from below detection limits to 4.13 mg/L (mean = 0.14). Ammonia appears to be readily consumed by the algae during the peak growing season (Figure 25). Seven out of eight ammonia samples collected during June through September were at concentrations below detectable levels. Elevated ammonia concentrations observed in February are most likely due to the lack of plant and algae utilization of this nutrient during winter months. Elevated ammonia concentrations observed in April and May are likely due to runoff from spring snow-melt and rain events.

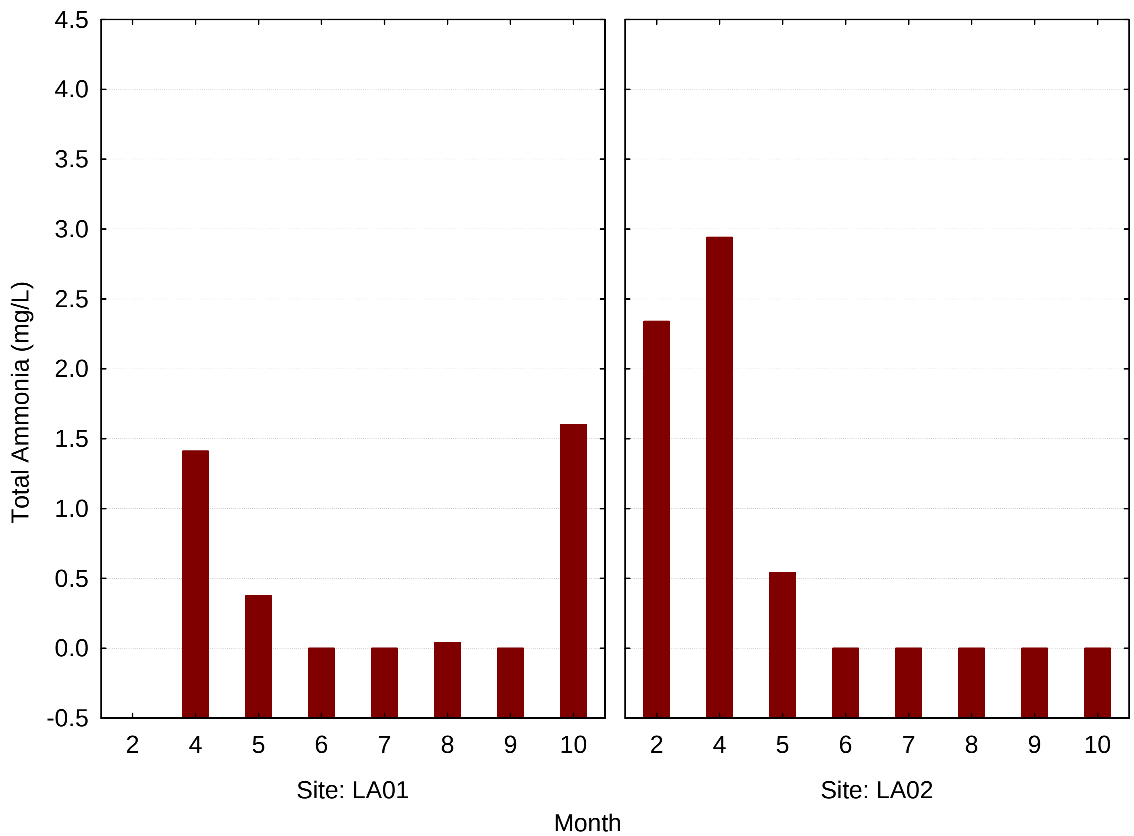


Figure 25. Ammonia concentrations by month for Lake Andes monitoring sites. Sample concentrations below the laboratory detection limit are shown as 0 mg/L.

To protect the warm water marginal fishery beneficial use, the state water quality criterion for total ammonia is dependent upon the pH of the water at the time the sample is collected. All ammonia samples collected from Lake Andes were below the pH-dependent total ammonia criteria.

Similar to ammonia concentrations, nitrate/nitrite concentrations were usually below detection limits during the peak algae growing season. Nitrate/nitrite concentrations ranged from less than detection to 0.3 mg/L (mean = 0.1) (Figure 26). Maximum nitrate concentrations were observed during the spring months (April and May). All sample concentrations were well below the nitrate criterion (≤ 88 mg/L).

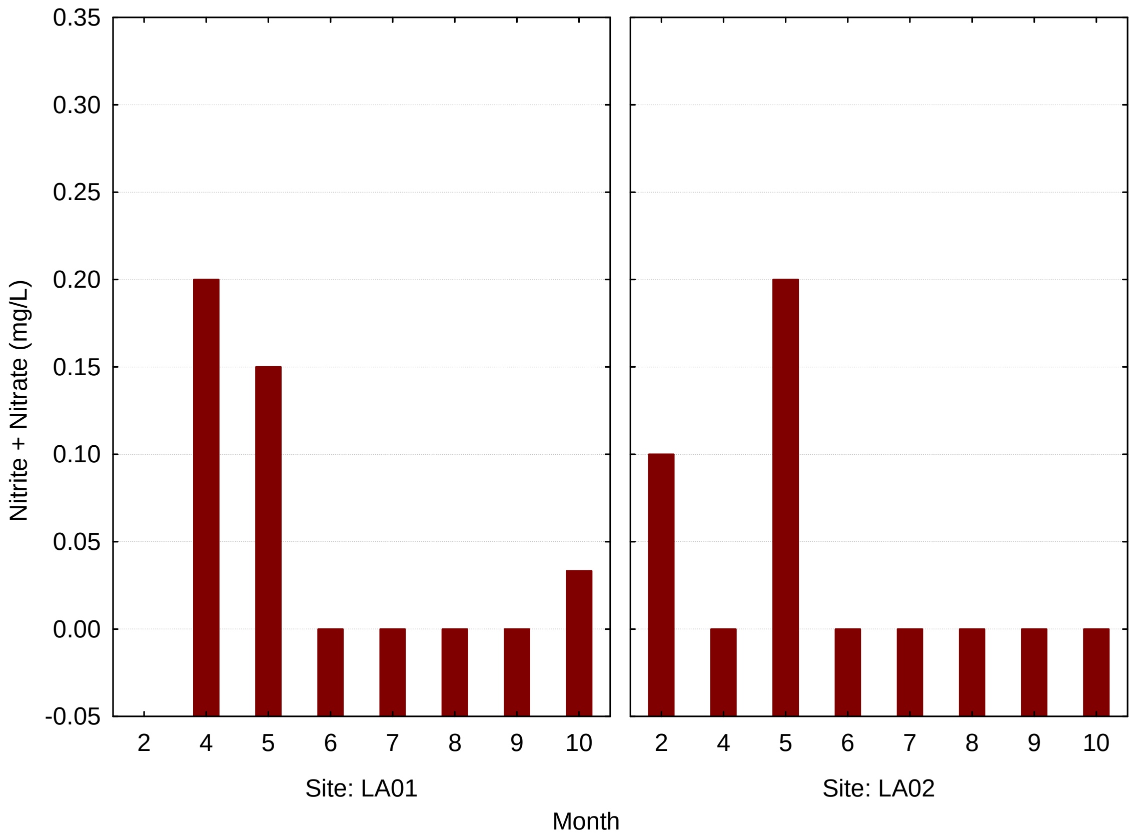


Figure 26. Nitrate plus nitrite concentrations by month for Lake Andes monitoring sites.

Total nitrogen was calculated for each sample by summing TKN and nitrate/nitrite concentrations. Total nitrogen values were used, in part, to determine whether nitrogen is a limiting nutrient in Lake Andes (see limiting nutrient section). Total nitrogen in Lake Andes ranged from 3.32 to 5.85 mg/L (mean = 4.51) (Figure 27).

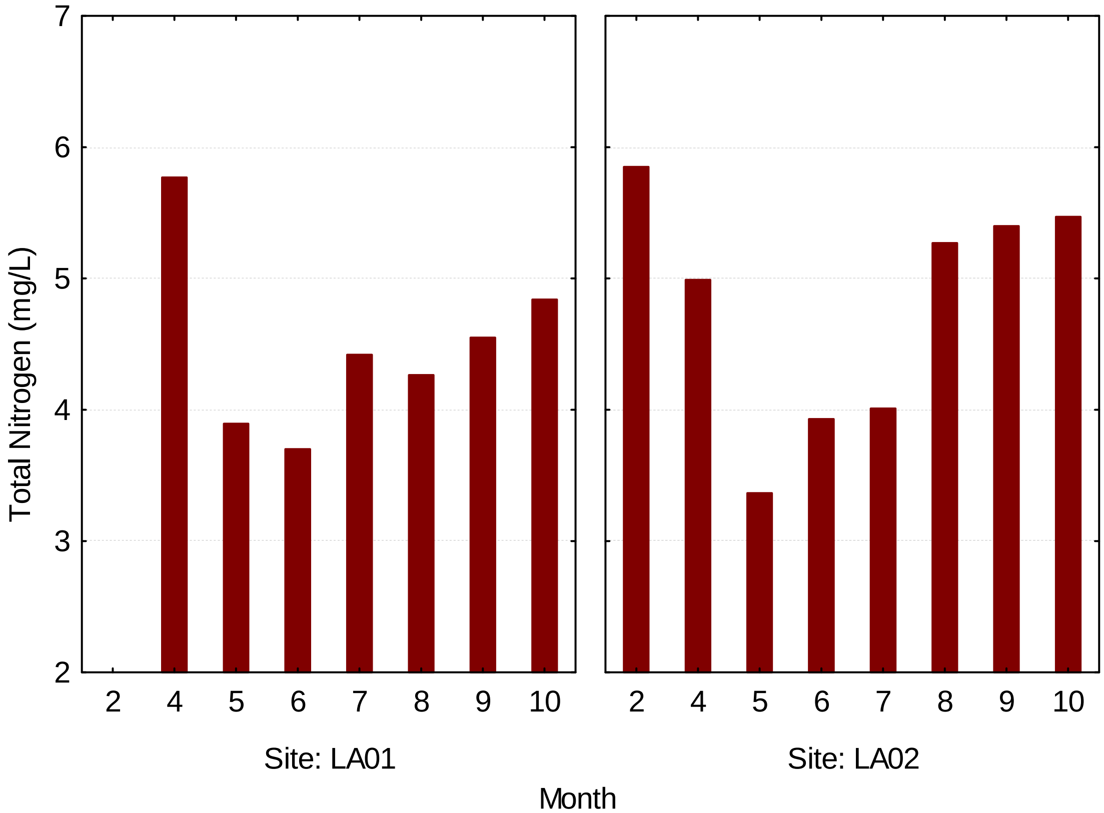


Figure 27. Total nitrogen concentrations by month for Lake Andes monitoring sites.

Phosphorus

Like nitrogen, phosphorus is a biologically active element. It cycles through different states in the aquatic environment, and its concentration in any one state depends on the degree of biological assimilation or decomposition occurring in that system. The predominant inorganic form of phosphorus in lake systems is orthophosphate. Concentrations of orthophosphate were measured as total dissolved phosphorus (TDP) in this study. Phosphorus is often a limiting nutrient to algae and macrophyte production within many aquatic systems. Loading of this nutrient presents an increased eutrophication (primary production) risk.

Total phosphorus concentrations of non-polluted waters are usually less than 0.1 mg/L (Lind 1985). Total phosphorus values in Lake Andes were elevated, ranging from 0.130 to 0.654 mg/L (mean = 0.338) (Figure 28).

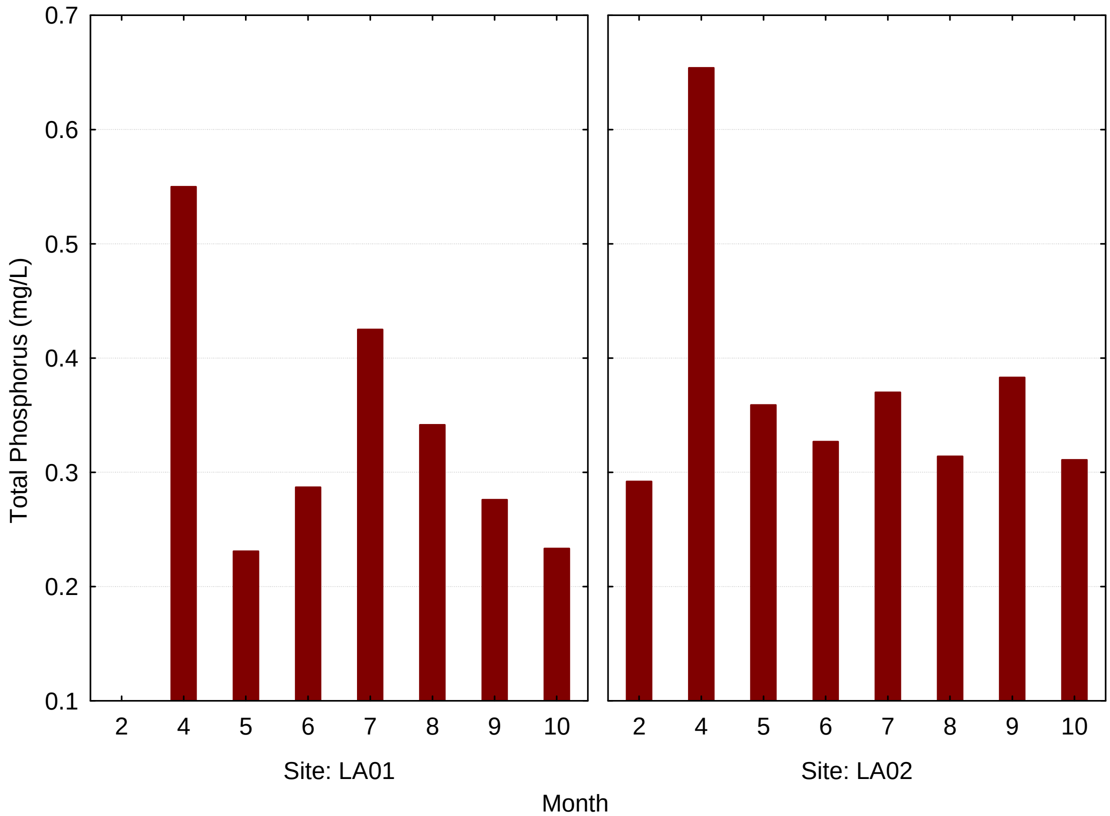


Figure 28. Total Phosphorus concentrations by month for Lake Andes monitoring sites.

TDP is the portion of total phosphorus that is readily available for plant and algae utilization. TDP concentrations in non-polluted waters are usually less than 0.01 mg/L (Lind 1985). TDP concentrations in Lake Andes were also elevated, ranging from 0.023 to 0.516 mg/L (mean = 0.120). All lake sample concentrations were above the minimum amount for rapid algal growth, which requires only 0.02 mg/L (Figure 29). Maximum concentrations of total phosphorus were observed in April at both sites. Concentrations were significantly reduced in May, likely due to rapid utilization of this nutrient by aquatic plants and algae.

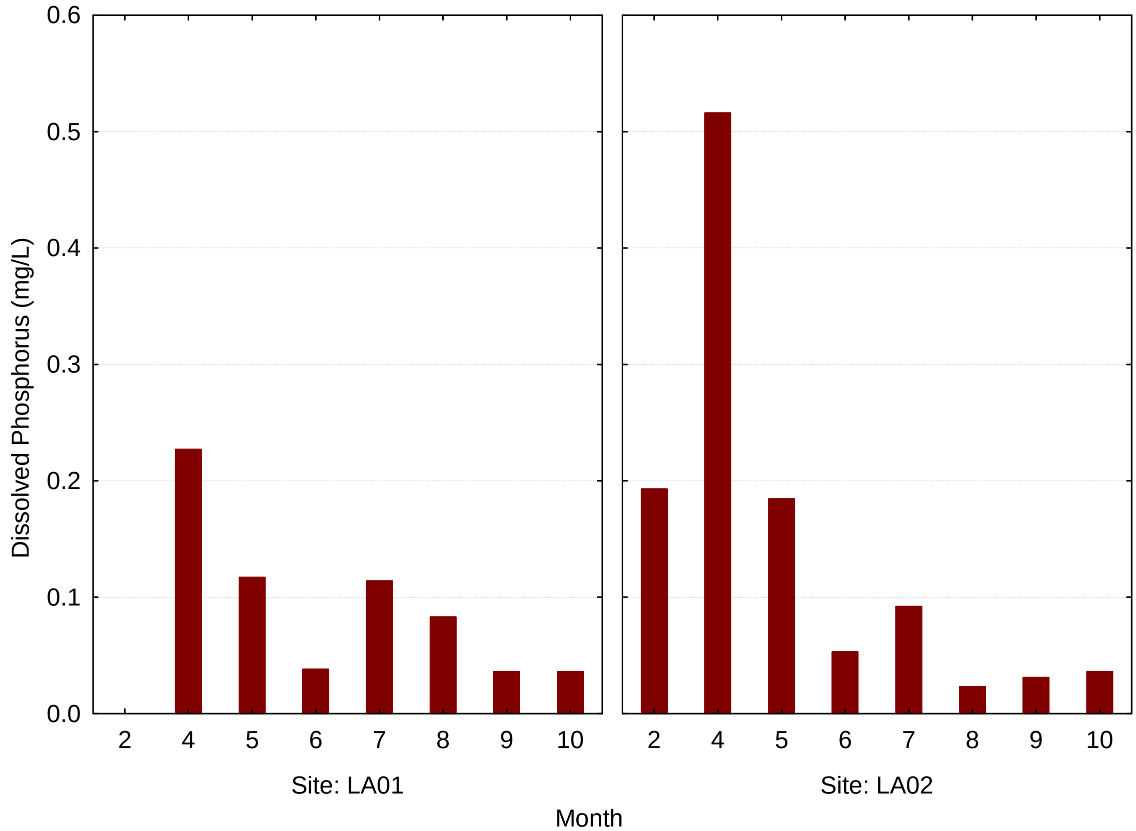


Figure 29. Total dissolved phosphorus concentrations by month for Lake Andes monitoring sites.

Limiting Nutrients

Great emphasis is placed on regulating nutrient loading to waterbodies to control aquatic productivity. In aquatic systems, the most significant nutrient factors causing the shift from a lesser to a more productive state are phosphorus and nitrogen. Nitrogen is difficult to control because of its highly soluble nature, but phosphorus is easier to manipulate from a management perspective. Consequently, it is most often the nutrient targeted for reduction when attempting to control lake eutrophication.

When either nitrogen or phosphorus reduces the potential for algal growth and reproduction, it is considered the limiting nutrient. Optimal nitrogen and phosphorus concentrations for aquatic plant growth occur at a ratio of 10:1 (N:P ratio). N:P ratios greater than 10:1 indicate a phosphorus limited system, while N:P ratios less than 10:1 indicate a nitrogen-limited system (USEPA, 1990).

N:P ratios for Lake Andes ranged from approximately 6.27 to 31.17 (mean = 14.54). All but one sample collected in Lake Andes were considered phosphorus-limited. N:P ratios were seasonally variable with generally lower values observed in the spring and summer and higher values in the fall and winter with the exception of one high value in May 2000 at site LA01 (Figure 30).

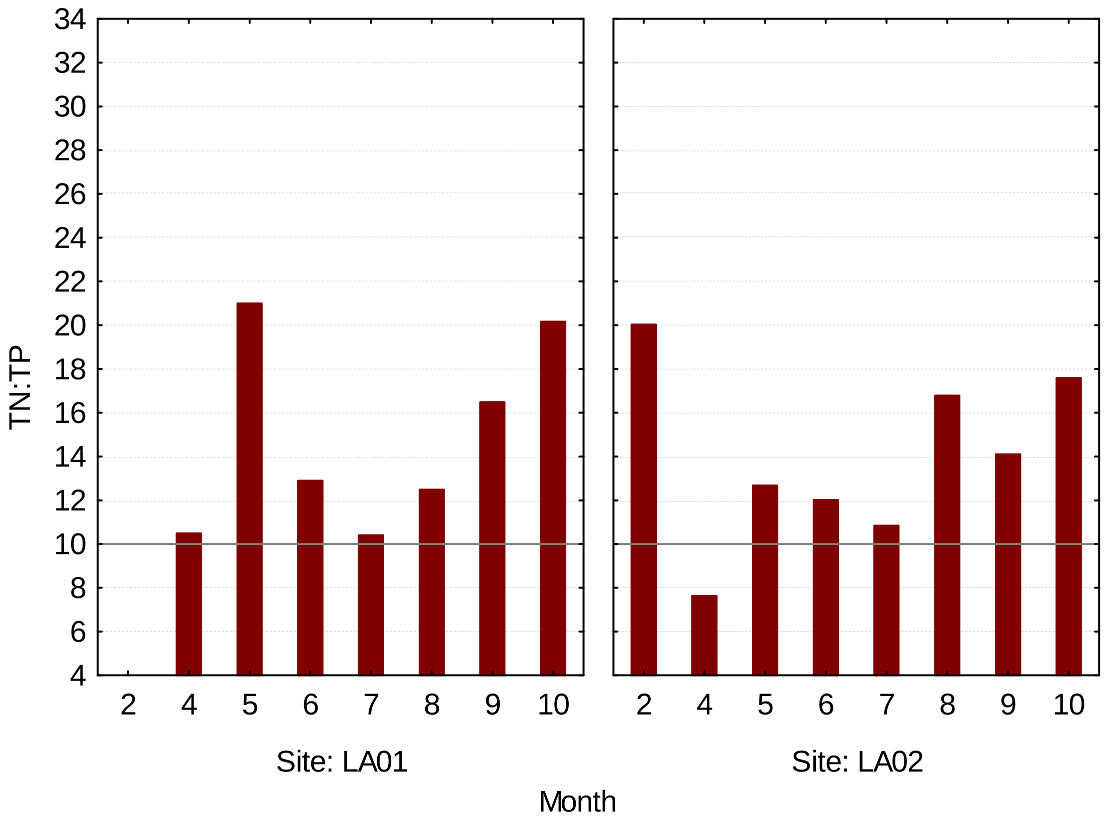


Figure 30. Total nitrogen:Total phosphorus ratios (TN:TP) by month for Lake Andes monitoring sites. The solid horizontal line represents the optimal TN:TP for aquatic plant growth.

Trophic State

Wetzel (2001) defines 'trophy' of a lake as "the rate at which organic matter is supplied by or to a lake per unit time." Trophic state is often measured as the amount of algal production in a lake, one source of organic material. Determinations of trophic state can be made from several different measures including oxygen levels, species composition of lake biota, concentrations of nutrients, and various measures of biomass or production. An index incorporating several of these parameters is best suited to determine trophic state.

Carlson's (1977) Trophic State Index (TSI) was used to determine the approximate trophic state of Lake Andes. This index incorporates measures of Secchi disk transparency, chlorophyll *a*, and total phosphorus into scores ranging from 0 to 100 with each 10-unit increase representing a doubling in algal biomass. Four ranges of index values (Table 9) define Carlson's trophic levels, which include oligotrophic, mesotrophic, eutrophic, and hyper-eutrophic (in order of increasing productivity).

Table 9. Carlson's trophic levels and index ranges for each level.

Trophic Level	TSI Range
Oligotrophic	0 – 35
Mesotrophic	36 – 50
Eutrophic	51 – 65
Hyper-eutrophic	66 – 100

TSI values were calculated for each of the index parameters. Phosphorus TSI values ranged from 74.4 to 97.7 (mean = 87.0), chlorophyll *a* TSI values ranged from 39.0 to 90.6 (mean = 79.5), and Secchi depth TSI values ranged from 67.1 to 90.6 (mean = 78.4). All Secchi depth and phosphorus TSI values indicate hyper-eutrophic condition. Approximately 87% of chlorophyll TSI values were in the hyper-eutrophic range, and the remaining 13% of chlorophyll TSI values were in the eutrophic range.

Lake trophic state assessment methodologies used by SD DENR have varied over the last several years. SD DENR first included lakes on the Section 303(d) impaired waterbodies list in 1998 when a lake's average Trophic State Index (TSI) value (calculated from average phosphorus, chlorophyll, and Secchi depth TSI values) was greater than 55.5. The mean TSI of 55.5 represented a eutrophication threshold from a mesotrophic to a eutrophic state, and lakes displaying mean TSI values above this threshold were identified as impaired.

This assessment or listing methodology was later changed to better account for the variability in TSI values across the state. In the 2002 303(d) report, level-three ecoregions (Omernik 1987) were used as a basis for classifying lakes. Unique TSI targets were established for each level-three ecoregion (Stewart, et al. 2000).

In some cases, the ecoregion approach was still leading to unrealistic water quality expectations due to varying lake characteristics within ecoregions. In a given ecoregion, a shallow "prairie pot-hole" lake classified as a marginal fishery was expected to meet the same TSI target as a deep reservoir classified as a permanent fishery. To address this issue, SD DENR conducted a statistical analysis to determine which geographical attributes, morphological parameters and beneficial use designations could be used to best categorize the assessed lakes. Results of the analysis indicated that three parameters (maximum depth, surface area, and fish-life beneficial use) provided the best classification. This classification scheme lead to the creation of the most recently used lake TSI criteria (Lorenzen 2005), which sets a TSI target for each fish-life beneficial use classification.

SD DENR has discontinued use of TSI as an indicator of lake impairment for the purpose of 303(d) listing requirements. South Dakota Surface Water Quality Standards, contained in the Administrative Rules of South Dakota (ARSD) §74:51, do not include TSI targets that were originally being used to list lakes as impaired due to eutrophication. Lakes are now assessed using strictly numeric water quality criteria and will be included on the 303(d) list if numeric water quality criteria are violated.

However, ARSD § 74:51 does include narrative criteria that may be applied to the undesired eutrophication of lakes and streams:

> 74:51:01:05. *Materials causing pollutants to form in waters*. Wastes discharged into surface waters of the state may not contain a parameter which violates the criterion for the waters' existing or designated beneficial use or impairs the aquatic community as it naturally occurs. Where the interaction of materials in the wastes and the waters causes the existence of such a parameter, the material is considered a pollutant and the discharge of such pollutants may not cause the criterion for this parameter to be violated or cause impairment to the aquatic community.
>
> 74:51:01:06. *Visible pollutants prohibited*. Raw or treated sewage, garbage, rubble, unpermitted fill materials, municipal wastes, industrial wastes, or agricultural wastes which produce floating solids, scum, oil slicks, material discoloration, visible gassing, sludge deposits, sediments, slimes, algal blooms, fungus growths, or other offensive effects may not be discharged or caused to be discharged into surface waters of the state.
>
> 74:51:01:08. *Taste- and odor-producing materials*. Materials which will impart undesirable tastes or undesirable odors to the receiving water may not be discharged or caused to be discharged into surface waters of the state in concentrations that impair a beneficial use.
>
> 74:51:01:09. *Nuisance aquatic life*. 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 an existing or designated beneficial use or create a human health problem.

To address these narrative criteria, the lake TSI targets have been retained as an assessment tool to be used for identifying lakes that require a more thorough investigation than that provided by the SD DENR Statewide Lakes Assessment Program to determine if the lake is meeting numeric water quality criteria. If a lake is identified as exceeding a TSI target, it will be added to a “Monitoring and Evaluation” list and monitored more intensively.

Lake Model

BATHTUB, a eutrophication response model designed by the United States Army Corps of Engineers (US ACOE 1999) was used to predict changes in water quality parameters related to eutrophication (phosphorus, nitrogen, chlorophyll *a*, and transparency) 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 total phosphorus concentrations.

As expected, the predicted inlake concentrations of total phosphorus decreased as modeled stream loads decreased (Figure 31). Based on model results, a reduction in watershed nutrient loads of approximately 36% would be required for the area-weighted mean phosphorus concentration in Lake Andes to be decreased from 0.39 mg/L to 0.25 mg/L. The current average annual total phosphorus load from the Lake Andes watershed is approximately 31,677 kg.

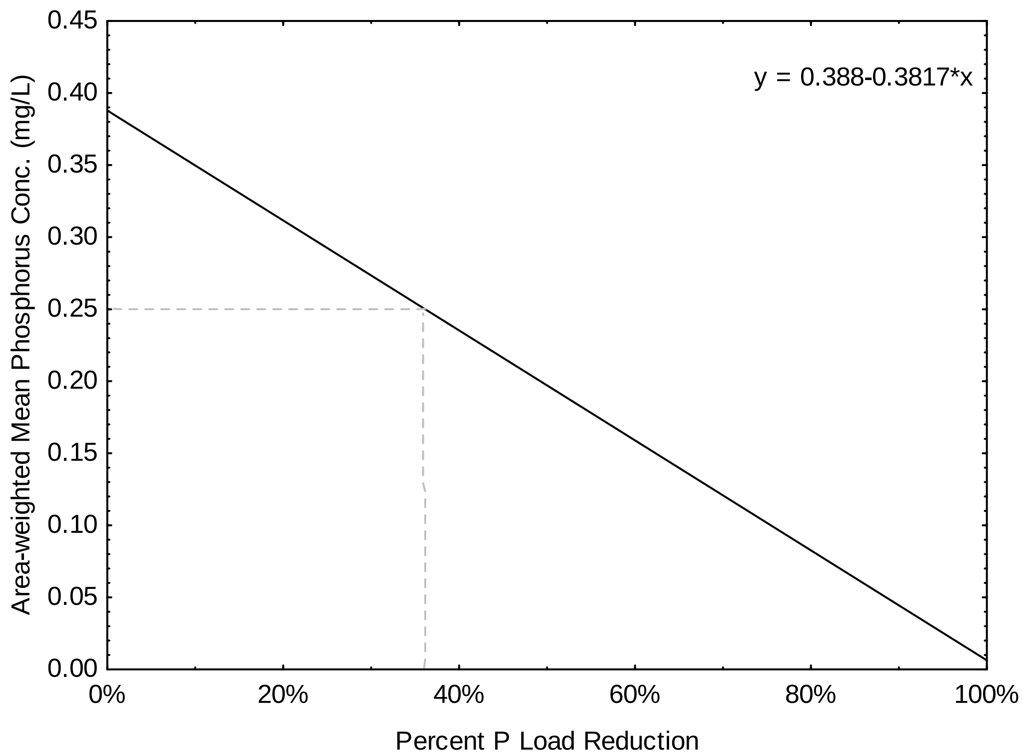


Figure 31. Model-predicted response of lake total phosphorus concentrations (area-weighted) to reductions in total phosphorus loading from the watershed. Dotted line indicates TMDL goal (total phosphorus concentration ≤ 0.25 mg/L; 36% reduction of watershed total phosphorus load).

Lake Biological Data

Bacteria

As previously discussed, the beneficial use of immersion recreation is assigned to Lake Andes. Fecal coliform bacteria concentrations must be ≤ 400 CFU/100 ml in any single sample to support this use. A total of 18 fecal coliform bacteria samples were collected from Lake Andes. Concentrations were all below the daily maximum criterion, ranging from non-detectable to 30 CFU/100 ml. Concentrations of *E. coli* bacteria samples (n=3) ranged from non-detectable to 60 CFU/100 ml.

Quality Assurance/Quality Control

Proper laboratory and field sampling methods require that quality assurance and quality control (QA/QC) samples be collected. These QA/QC sample sets (replicate, duplicate and blank sample) should comprise 10% of the total number of samples taken. Seven replicate and seven blank samples (seven sets) were collected on randomly chosen dates from Lake Andes or one of its tributaries during the project period, during which a total of 172 samples were collected. Thus, the QA/QC sample sets represent only 4% of the total samples collected, falling short of the minimum requirement. Lack of QA/QC samples was likely due to miscommunication between SD DENR and project staff, as blank sample was counted as a QA/QC set.

Values above the detection limit were observed for three parameters in the blank samples: five occurrences of total solids, one occurrence of total dissolved solids and two occurrences of total dissolved phosphorus. These instances of slight contamination were possibly caused by use of different distilled water brands or field contamination during handling.

Replicate samples were compared to the routine samples using the industrial statistic (%I). The value given is the absolute difference between the routine and the replicate sample in percent, as follows:

$$\%I = ABS[(A-B)/(A+B)*100]$$

Where:

%I = Industrial Statistic
ABS = Absolute Value
A = Parameter value for replicate sample
B = Parameter value for routine sample

The average percent differences for analyzed parameters ranged from 0.0% to 35.7%. The following three parameters had an average percent difference greater that 10%: total suspended solids and nitrate/nitrite. The difference between replicate and routine samples for these parameters may be due to contamination of the sample bottles/distilled water by the field sampler, natural variability, or a laboratory error. Overall, approximately 92% of all sample pair difference estimates were less than 10%. See Appendix F for all QA/QC data.

Conclusions and Recommendations

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 ≥ 4 mg/L in at least a portion of the lake. Because DO concentrations were found to be negatively correlated with lake total phosphorus concentrations, a secondary goal of 0.25 mg/L total phosphorus 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 total phosphorus loads from the watershed by approximately 36%. Long-term average total phosphorus annual load from the watershed is approximately 31,677 kg, which is equivalent to approximately 65 kg per watershed acre.

Management of nutrient and sediment 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 and sediment export coefficients, which are discussed on pages 13-14.

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. 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.

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.

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.

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.

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). Total phosphorus 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.

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).

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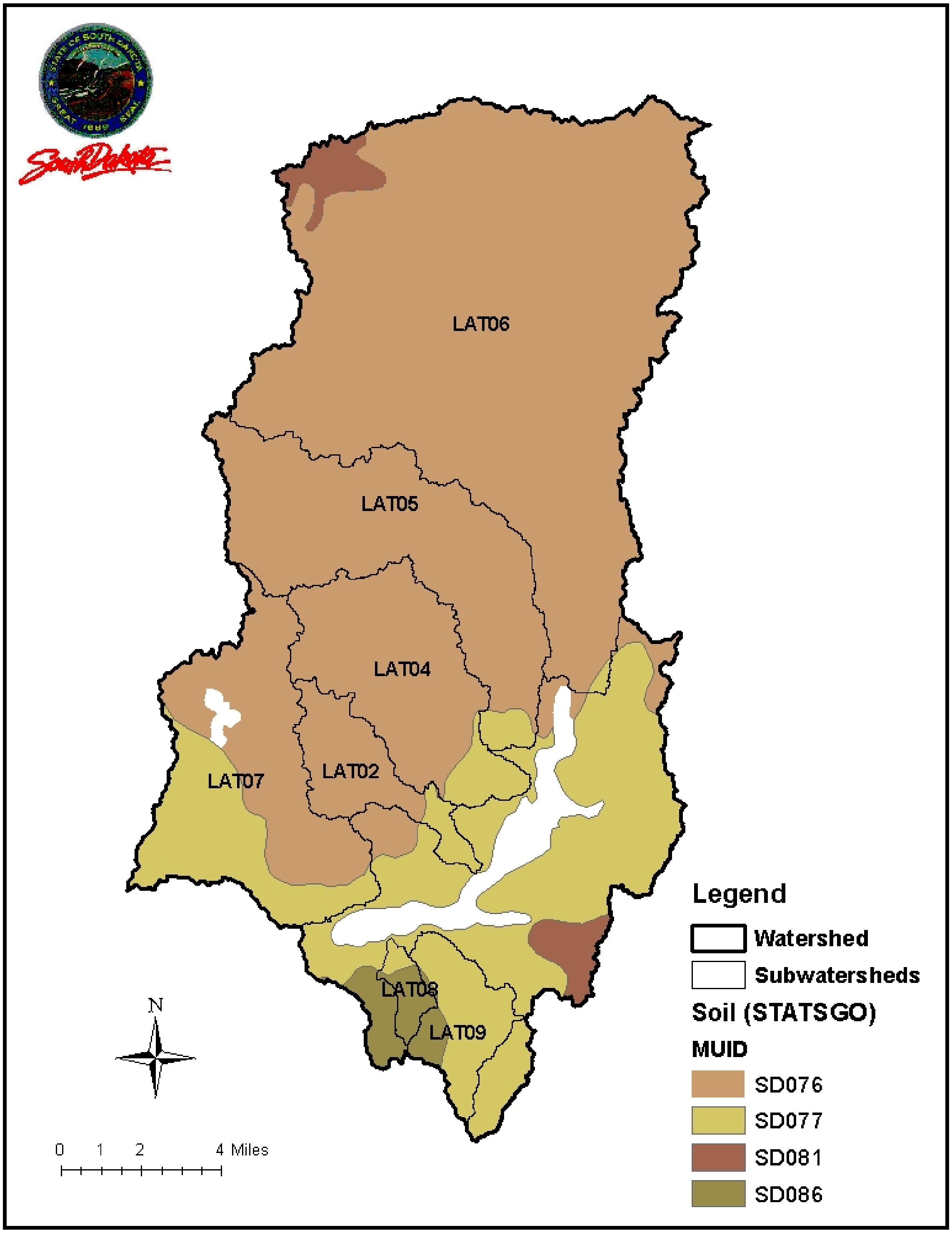
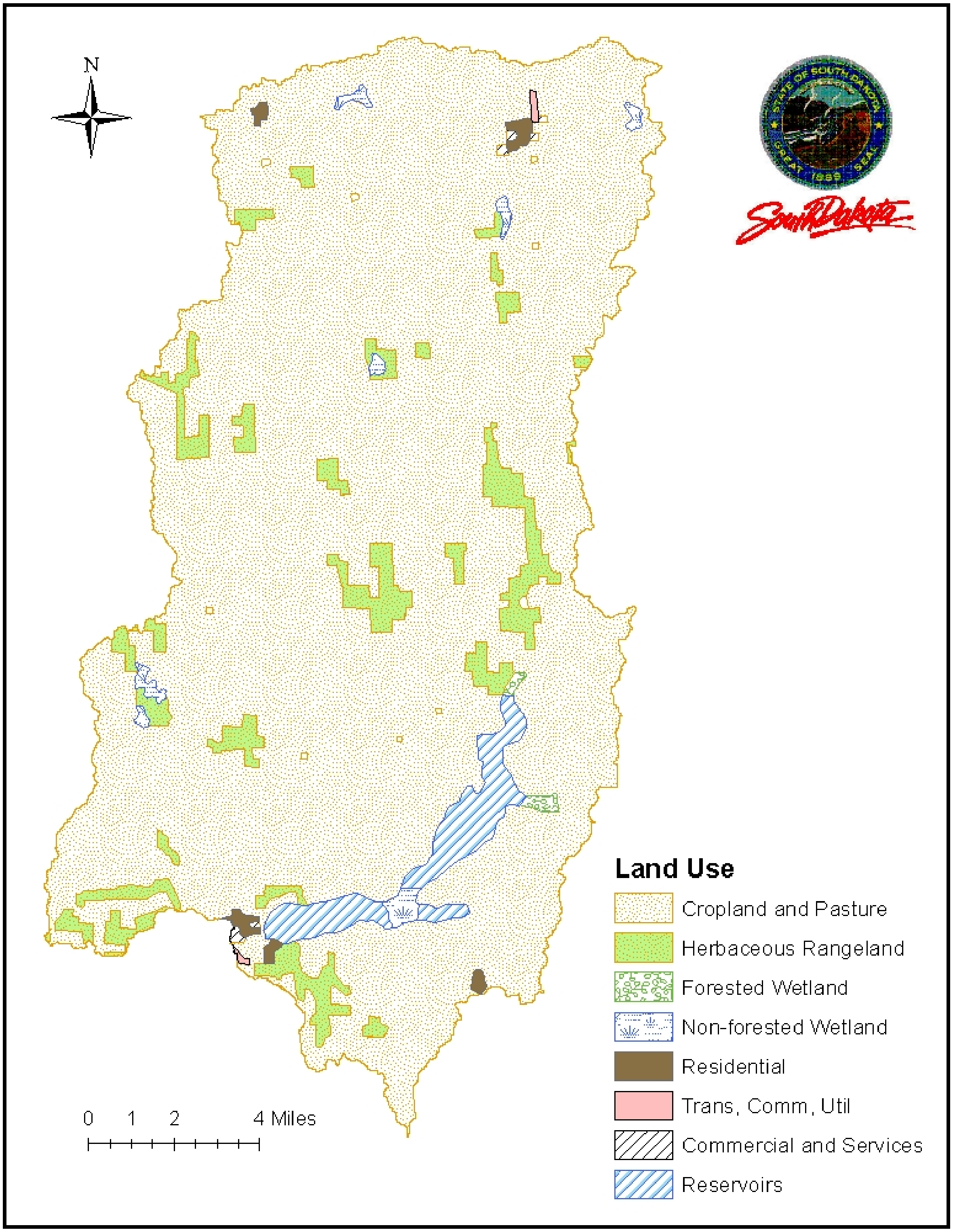
Appendix A

Watershed Soils Map


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

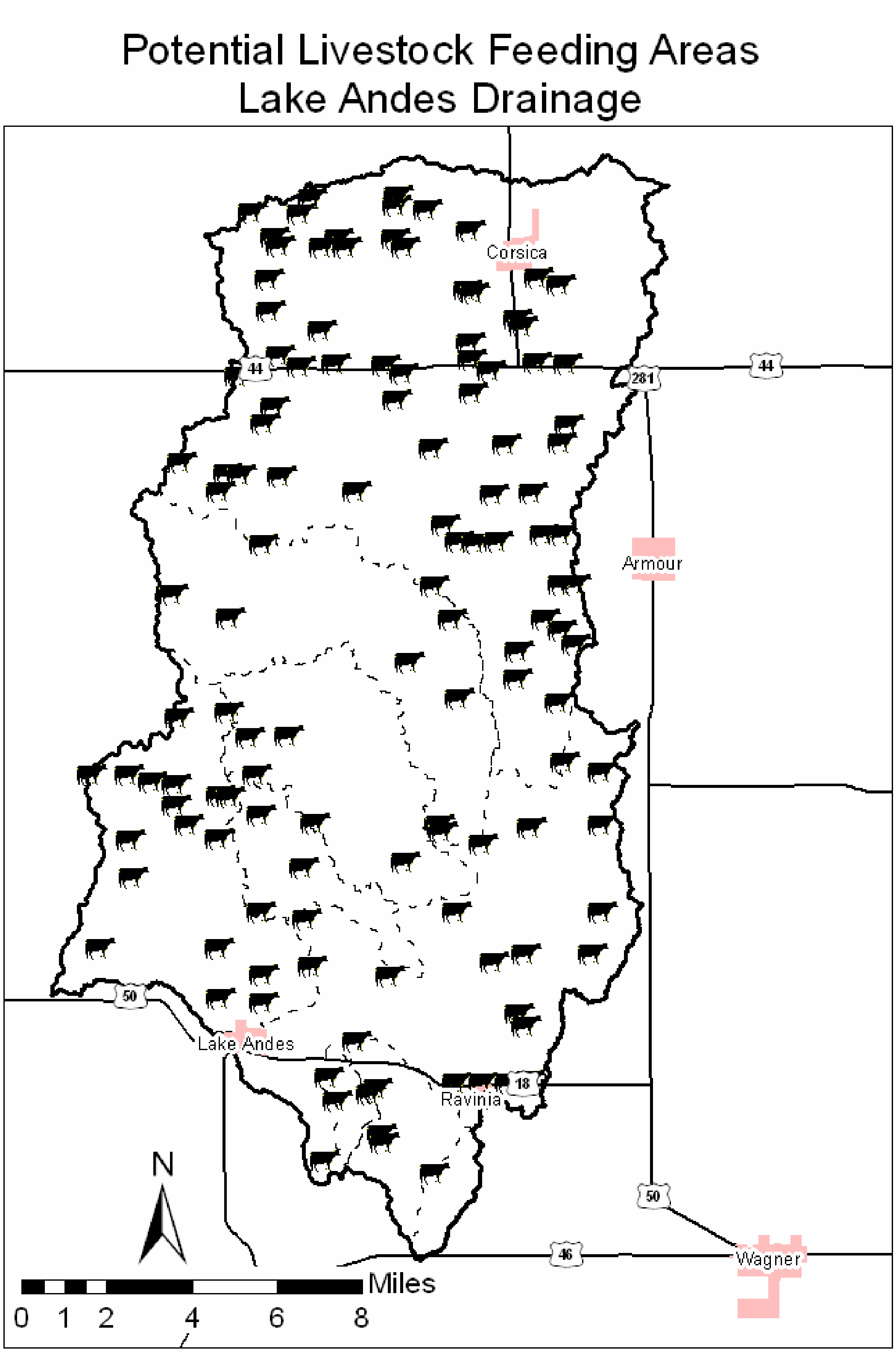
Appendix B

Watershed Land Use Map


N
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

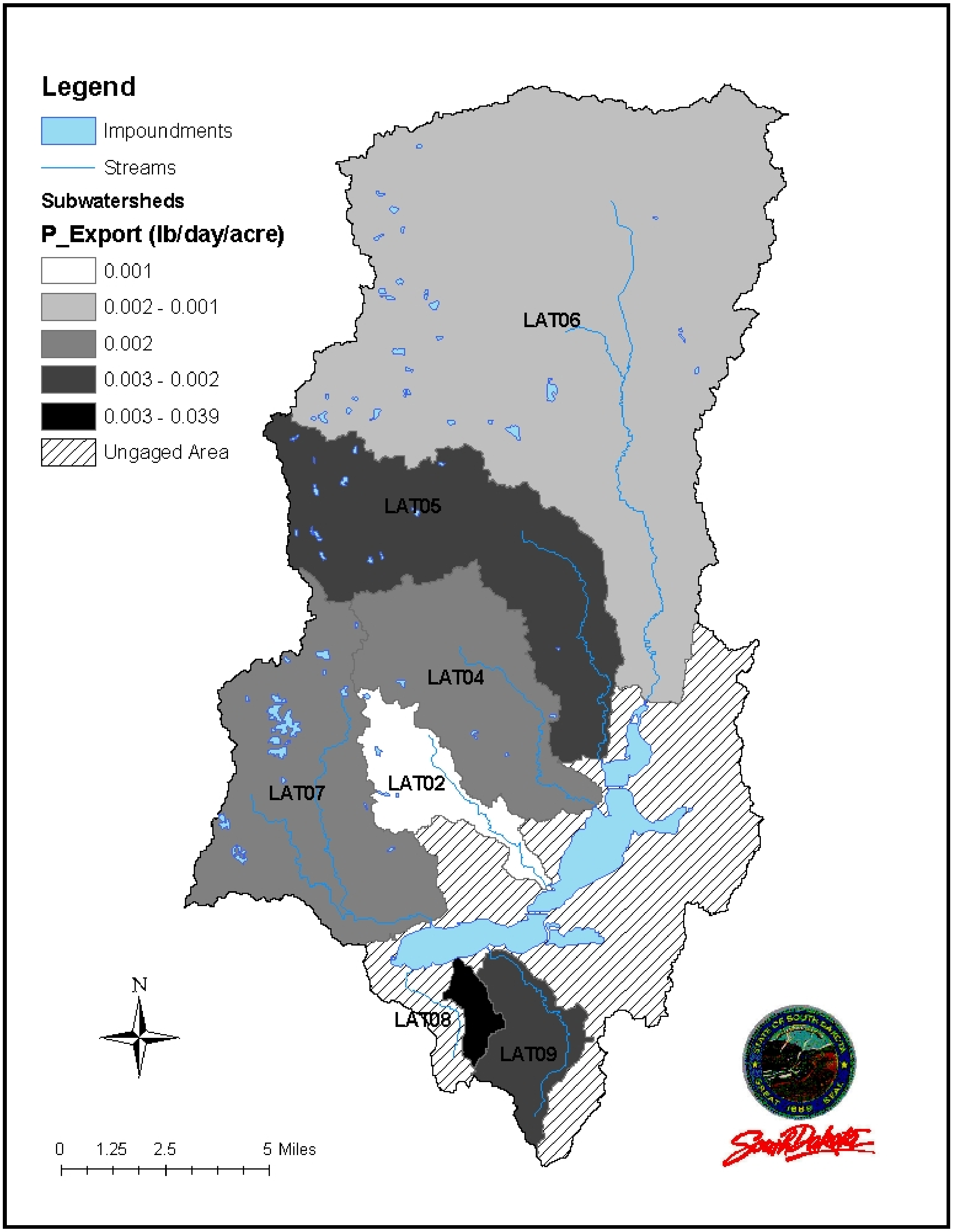
Watershed Map Showing Location of Potential Livestock Feeding Areas

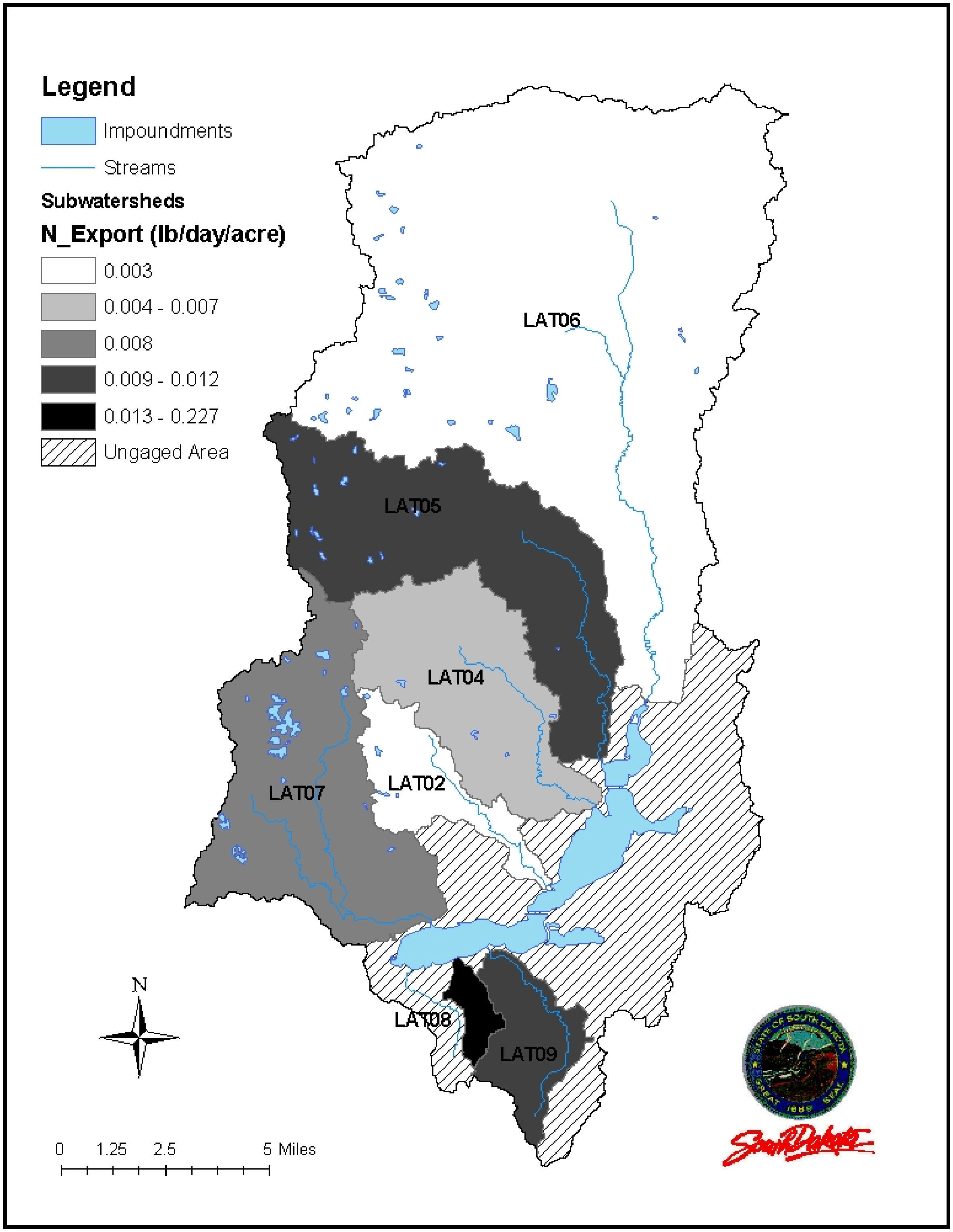


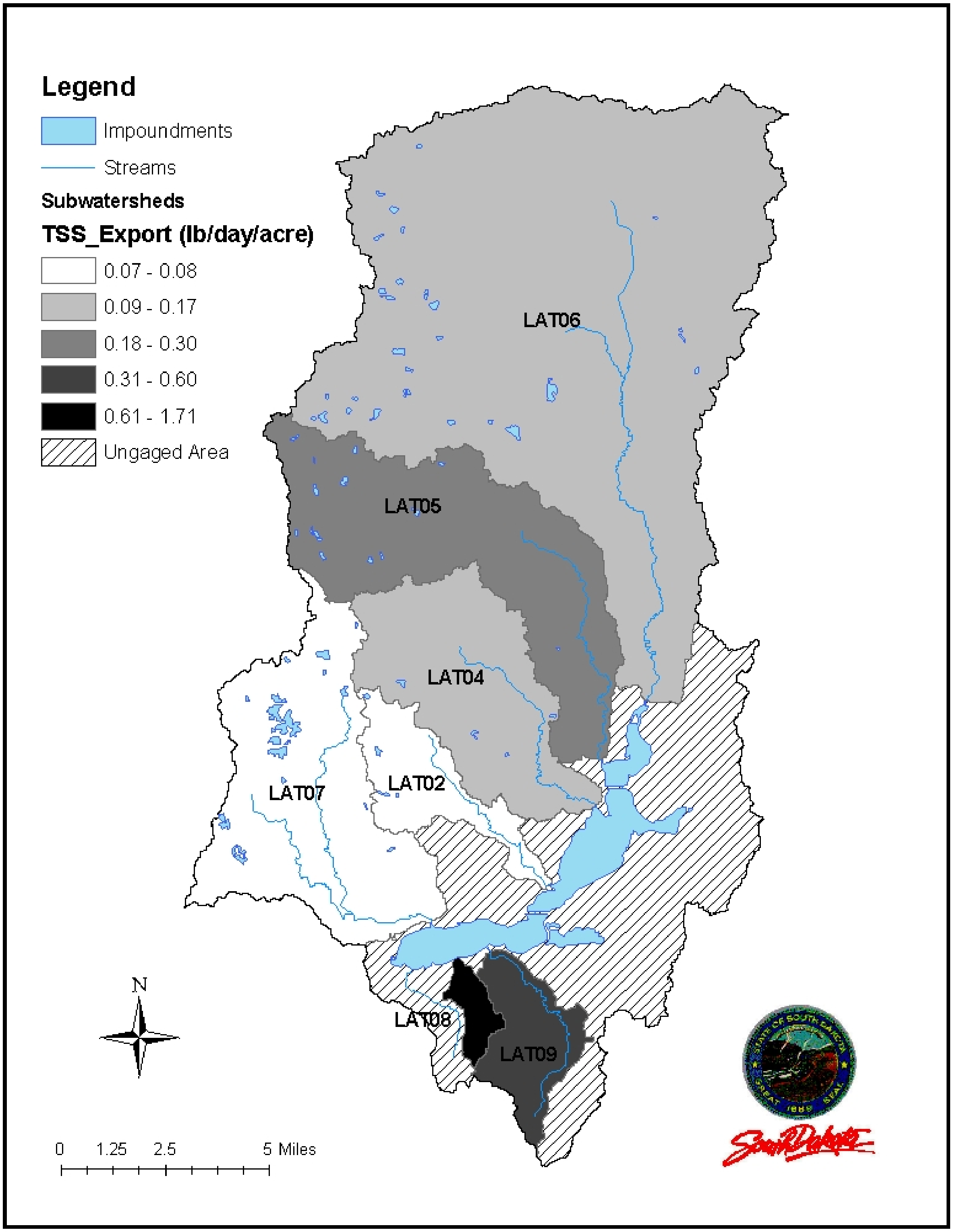
Map and potential livestock feeding area location data provided by Sean Kruger, SD DENR

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

Assessment 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)

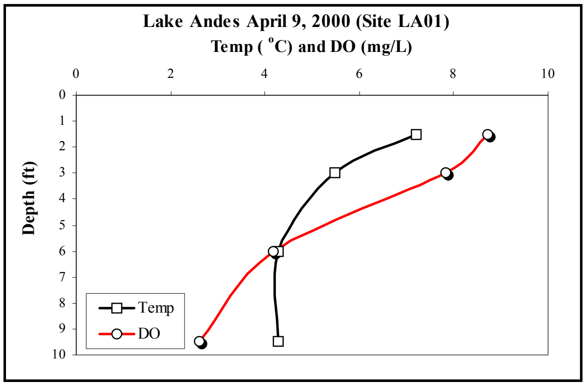
TSS = Total Suspended Solids (mg/L)
Amm = Ammonia (mg/L)
Nit = Nitrate (mg/L)
TKN = Total Kjeldahl Nitrogen (mg/L)
P = Total Phosphorus (mg/L)
TDP = Total Dissolved Phosphorus (mg/L)

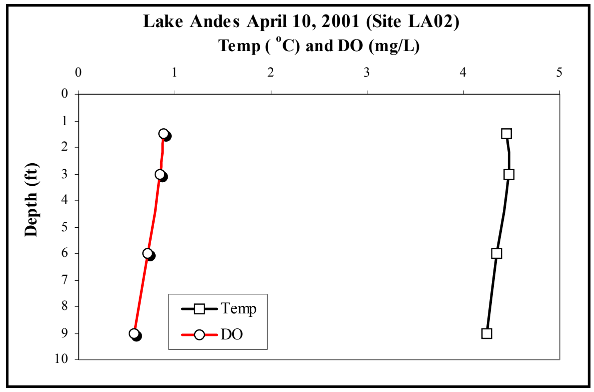
Blank Samples

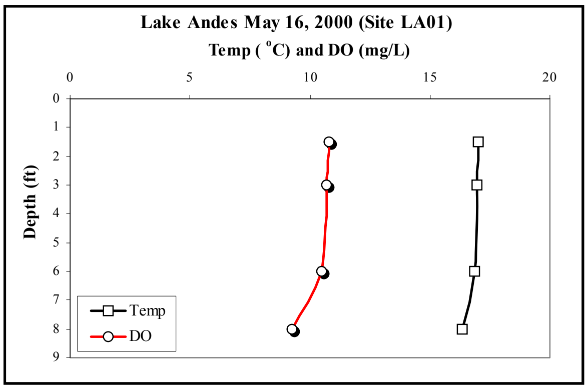
SITE	DATE	Fecal	E. coli	Alk	Sol	TSS	TDS	Amm	Nit	TKN	P	TDP
LAO-1B	12-Apr-01	10	1	0	12	1		0.02	0.1	0.36	0.002	0.003
LAT-2B	19-Apr-01	10	1	0	12	1		0.02	0.1	0.36	0.002	0.003
LAT-3B	4-Apr-01	10	1	0	9	1		0.02	0.1	0.36	0.002	0.002
LAT-5B	5-Apr-01	10	1	0	7	1		0.02	0.1	0.36	0.002	0.002
LAT-6B	19-Jun-00	10		0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

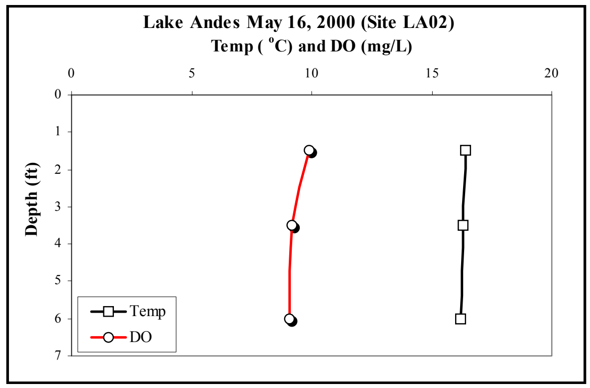
Appendix G

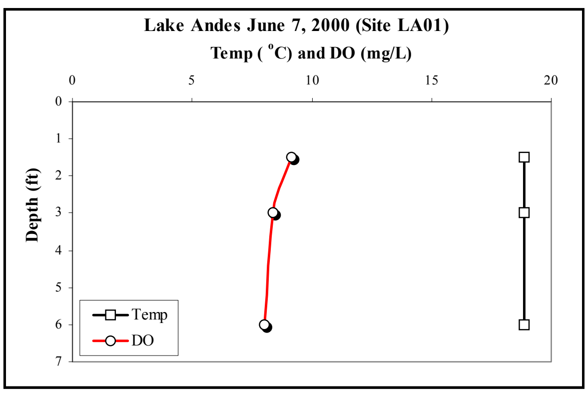
Lake Dissolved Oxygen and Temperature Profiles

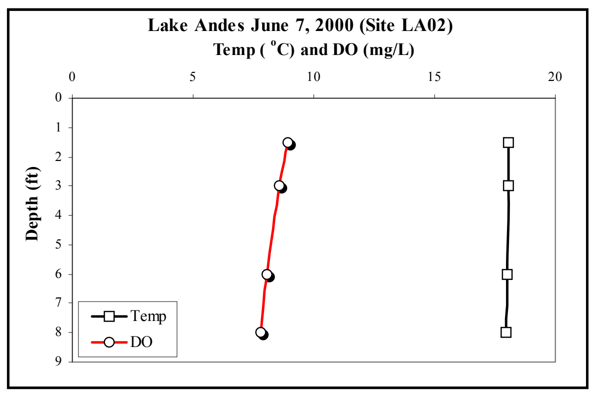

Lake Andes April 9, 2000 (Site LA01)
Temp (°C) and DO (mg/L)
Depth (ft)
Temp
DO

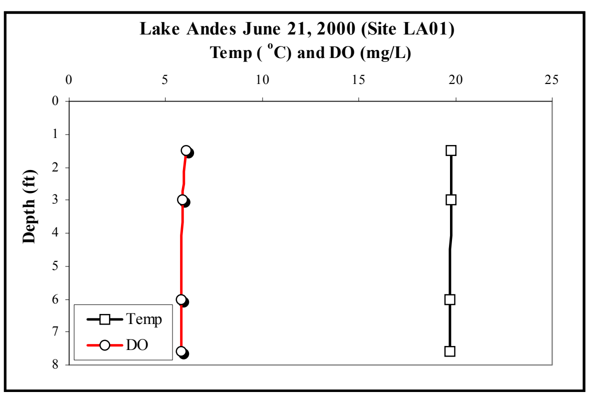

Lake Andes April 10, 2001 (Site LA02)
Temp (°C) and DO (mg/L)
Depth (ft)
Temp
DO

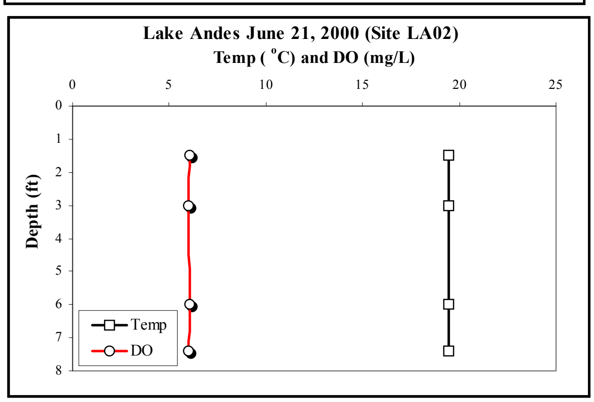

Lake Andes May 16, 2000 (Site LA01)
Temp (°C) and DO (mg/L)
Depth (ft)
Temp
DO


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