WATERSHED ASSESSMENT
FINAL REPORT

WAGGONER LAKE/GRINDSTONE CREEK
HAAKON COUNTY, SOUTH DAKOTA

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

Feburary 2007
SECTION 319 NONPOINT SOURCE POLLUTION CONTROL PROGRAM

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AND TMDL
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(SD-BA-L-WAGGONER_01)
(HUC 10140102)

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Prepared By

Paul B. Lorenzen, Environmental Program Scientist

Leonard P. Kuck, Project Consultant

State of South Dakota
Michael M. Rounds, Governor

February, 2007

SECTION 319 NONPOINT SOURCE POLLUTION CONTROL PROGRAM
Conducted in cooperation with the
United States Environmental Protection Agency, Region 8.
Grant # C9998185-01

EXECUTIVE SUMMARY

PROJECT TITLE: Waggoner Lake Dam and Watershed Assessment Project

PROJECT START DATE: 1/1/01 PROJECT COMPLETION DATE: 10/01/04

FUNDING: TOTAL BUDGET: $36,812.64

TOTAL EPA GRANT:	$29,975
TOTAL EXPENDITURES OF EPA FUNDS:	$20,279.98
TOTAL SECTION 319 MATCH ACCRUED:	$6,837.64
BUDGET REVISIONS:	none

TOTAL EXPENDITURES: $27,117.62

SUMMARY ACCOMPLISHMENTS

The Waggoner Lake and Grindstone Creek assessment project began January 1, 2001 and lasted through February of 2007 following completion of the final report. The project did not meet all of its milestones in a timely manner because of a severe drought that resulted in limited tributary runoff for three years.

An EPA Section 319 grant provided a majority of the funding for this project. The West River Water Development District and Haakon County Conservation District provided local matching funds for the project.

Water quality monitoring and watershed modeling resulted in the identification of several sources of excessive nutrient and sediment loading. These sources may be addressed through Best Management Practices (BMPs). An aquatic plant survey and a sediment survey were also completed for the lake.

The primary goal of the project was to determine potential sources of impairment to Waggoner Lake and provide sufficient background data to drive a Section 319-implementation project. This goal was accomplished as several sources within the watershed were identified as contributing excessive nutrients and sediment to Waggoner Lake.

The AGNPS (version 3.62) model identified several cropland cells within the watershed that potentially deliver excessive nutrients and sediment to Waggoner Lake. Implementing Best Management Practices on these critical areas was recommended to reduce nutrient loading to improve or maintain the Trophic State Index (TSI) (Carlson, 1977) value of the lake and maintain support of its beneficial uses. These practices will also reduce the delivery of nutrients and sediment to several large stock dams in the

Grindstone Creek watershed above the Waggoner Lake impoundment. Stock dams serve as a buffer for Waggoner Lake catching sediment that would otherwise reach Waggoner Lake and cause more rapid degradation.

Total dissolved solids concentrations elevated above the water quality standard during periods of low precipitation and associated watershed inflows. As water levels decrease due to evaporation total dissolved solids become concentrated. Additional loading from an artesian well also contributes to the inlake concentrations. Total dissolved solids concentrations recovered and were well within the standard limit in samples collected in 2004 due to significant precipitation and inflow from Grindstone Creek. It was recommended that flow from the well be diverted or regulated at minimum capacity to reduce total dissolved solids loading to Lake Waggoner. Reducing this source of total dissolved solids should allow Lake Waggoner to comply with the water quality standard especially during periods of minimal inflow from the watershed. No other numeric water quality standard violations were observed during this assessment.

The water quality goal for Waggoner Lake is to stabilize or decrease the eutrophication process. Based on average inlake conditions and tributary loadings from 2001 and 2004 Waggoner Lake had a modeled (BATHTUB) median growing season TSI value of 62.9, which suggests a eutrophic condition. A median TSI of 60.6 was proposed based on AGNPS modeling, BMPs and watershed specific phosphorus reduction attainability for Waggoner Lake. Based on BATHTUB estimates a 30% reduction in phosphorus from Grindstone Creek was required to meet this TSI target. The necessary reduction requires treatment of 50% of the cropland priority cells resulting in a 20% reduction of phosphorus. An additional 10% phosphorus reduction should be achieved by implementing grazing management strategies on rangeland and pasture. Additional improvements in trophic state are likely to be achieved by controlling internal phosphorus cycling in Waggoner Lake.

Acknowledgements

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

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SD Department of Game, Fish and Parks

Tanya McIlravy, Haakon County Conservation District

Tom Paulson, Haakon County Conservation District

Jenna Finn, Haakon County Conservation District

Haakon County Conservation District Supervisors

West River Water Development District

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION

The purpose of this assessment is to determine sources of impairment to Waggoner Lake in Haakon County, South Dakota. Grindstone Creek and its small tributaries carry loadings of sediment and nutrients from snowmelt and spring rain events. The loadings transported by Grindstone Creek contribute to the degradation of water quality and advance eutrophication in Waggoner Lake. The discharge from this watershed ultimately reaches the Bad River.

Grindstone Creek is the primary tributary to Waggoner Lake and drains a mix of grazing lands, hay land, Conservation Reserve Program (CRP) acres and cropland acres. Winter feeding areas for livestock are present in the watershed.

Lake Identification and Location

Lake Name: Waggoner Lake	State: South Dakota
County: Haakon	Nearest Municipality: Philip
Latitude: 44 deg. 04 min. 36 sec. NW	Longitude: 101 deg. 39 min. 00 sec.
Location: N1/2 Sec. 6, T1N, R21E	Major Tributary: Grindstone Creek
Receiving Body of Water: Grindstone Creek	Watershed Area: 36,809 acres
(14,897 ha)	
Surface Area: 98 acres (39.7 ha)	Maximum Depth: 22 ft. (6.7 m)
Mean Depth: 6.8 ft. (2.1 m)	Volume at Spillway Elevation: 665 acre-ft
HUC Code: 10140102	HUC Name: Bad River
EPA Region: VIII	

General Description of the Lake

Waggoner Lake is a 98-acre (39.7 ha) impoundment located approximately 2.5 miles north and 1/2 mile east of Philip, South Dakota. In 1940, The Works Progress Administration (WPA) and Haakon County constructed an earth embankment structure (dam) on Grindstone Creek about 3 miles above the confluence of the Creek and the Bad River to create a water supply for the town of Philip. Currently, the pool when full has a mean depth of 6.8 ft (2.1 m) and a maximum depth of 22 ft (6.7 m) with 4.3 mi (6.9 km) of shoreline. The 40,000 cubic yard earth embankment is 800 ft long and holds about 665 ac-ft of water at principal spillway elevation. The spillway is reinforced concrete that was totally reconstructed in 1989. Waggoner Lake is subject to periods of stratification during the summer. An aeration system was installed in the lake to break stratification and improve the quality of drinking water for the town of Philip. The outlet for the lake empties into Grindstone Creek, which joins with Bad River about 3 miles east of Philip, South Dakota which eventually reaches the Missouri River at the town of Fort Pierre in Stanley County, South Dakota. The Waggoner Lake watershed comprises a small portion of the Bad River hydrologic unit 10140102.

The area adjacent to Waggoner Lake is all in native range. The upper north end of the lake is a housing area with 6 to 8 homes. All have their own septic system. The area to the north and east of the housing area and along the dam embankment is native rangeland and is grazed annually. Immediately adjacent to the emergency spillway on the west end of the embankment is the Philip water treatment plant. Just upstream of the emergency spillway is a recreation area, which includes a swimming area, boat ramp, and picnic area. The Haakon County maintenance shop and related structures are to the west of the recreation area. The area from the maintenance shop to the upper end of the lake is mainly native range that is cut for hay and one home site. The Philip municipal golf course is south of the maintenance shop and a fish farm is immediately west of the golf course. None of the drainage from the golf course or the fish farm enters the lake. A deep artesian well is located between the recreation area and the maintenance shop. This well can enter the lake or be bypassed downstream by a pipe system. Normally the overflow is directed into the lake to maintain the lake level and enhance drinking water quality for the town of Philip. Waggoner Lake is subject to periods of stratification during the summer. An aeration system was installed in the lake to break stratification and improve the quality of drinking water. The aeration system was removed in 2002 when the town of Philip began to use the Rural Water System (RWS) for its water needs.

Beneficial Uses

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

Domestic Water Supply: surface waters of the state, which are suitable for human consumption, culinary or food processing purposes, and other household purposes after suitable conventional treatment.
Warmwater Permanent Fish Life Propagation Waters: surface waters of the state which support aquatic life and are suitable for the permanent propagation or maintenance, or both, of warmwater fish.
Immersion Recreation Waters: surface waters of the state which are suitable for uses where the human body may come in direct contact with the water to the point of complete submersion and where water may be accidentally ingested or where certain sensitive organs such as the eyes, ears and nose may be exposed to water.
Limited-Contact Recreation Waters: surface waters of the state which are suitable for boating, fishing, and other water-related recreation other than immersion recreation, where a person's water contact would be limited to the extent that infections of eyes, ears, respiratory or digestive systems, or urogenital areas would normally be avoided.
Fish and Wildlife Propagation, Recreation, and Stock Watering: surface waters of the state which are satisfactory as habitat for aquatic and semiaquatic wild animals and fowl, provide natural food chain maintenance, and are of suitable quality for watering domestic and wild animals.

Individual parameters determine the support of these beneficial uses. Additional "narrative" standards that may apply can be found in the Administrative Rules of South Dakota Articles 74:51:01:05; 06; 08; and 09. These contain language that generally prohibits the presence of materials causing pollutants to form, visible pollutants, and nuisance aquatic life. Carlson's (1977) trophic state indices were originally used during this study as a measure of beneficial use support. The indices are based on total phosphorus, Secchi disc transparency and chlorophyll *a*. The critical values for beneficial use status were derived from a SDDENR study of South Dakota lakes and from regionality of various lake attributes (Lorenzen, 2005). Waggoner Lake was identified in the 2006 Integrated Report as non-supporting its beneficial uses based on support criteria for TSI (DENR 2006).

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

Recreational Use

The South Dakota Department of Game, Fish and Parks provides a list of existing public facilities that are maintained at area lakes (Table 1). Waggoner Lake Recreation Area is located along the west side of the lake above the dam fill and spillway outlet. There is a swimming area and a place to launch a boat. Facilities are limited to some picnic tables and public toilets are available. Fishing access is provided along the lower portion of the west shore and along the middle portion of the north side of the lake. Camping is permitted in the picnic area although no facilities are maintained.

Table 1. Comparison of Recreational Uses and Facilities for Area Lakes.

Lake	Park	B. Ramp	Boating	Camping	Fishing	Picnicking	Swimming	Toilets	County
Brakke	no	yes	yes	no	yes	no tables	no beach	yes	Lyman
Fate	no	yes	yes	no	yes	no tables	no beach	yes	Lyman
Murdo	no	yes	yes	no	yes	no tables	no beach	no	Jones
Freeman	no	no	yes	commercial	yes	no tables	no beach	no	Jackson
Waggoner	**no**	**yes**	**yes**	**no**	**yes**	**yes**	**no beach**	**yes**	**Stanley**
Waggoner	no	yes	yes	no	yes	yes	yes	yes	Haakon
New Wall	no	yes	yes	no	yes	no tables	no beach	no	Pennington

Geology and Soils

Waggoner Lake and its primary tributary, Grindstone Creek, are located within the Pierre Hills region in the Missouri Plateau section of the Great Plains Physiographic Province. The outlet to the lake discharges into Grindstone Creek which flowa into the Bad River. The Bad River flows into the Missouri River at Fort Pierre, South Dakota. Located west of the Missouri River, the Waggoner Lake watershed is part of an ancient seabed, which formed the parent material of the present-day soils. The landscape of the watershed is gently undulating to rolling with well-developed drainage patterns. This is due to the ongoing water erosion.

The climate in Haakon County is continental with dry winters and wet springs. The weather is subject to frequent and extreme changes, with incoming fronts dropping temperatures by as much as 40 to 50 degrees in 24 hours. Annual precipitation can be expected to yield 18 inches of which 80 percent can be expected to fall in the months of April through September.

Waggoner Lake watershed is a 37,018-acre (14,980 ha) drainage which contains three principal soil associations:

<u>Ottumwa-Lakoma:</u> Very deep and moderately deep, well drained, nearly level to strongly sloping, clayey soils on undissected and dissected plains formed in clayed shale residuum. Many knolls, hills and ridges separated by strongly entrenched drainageways, characterize this association. The very deep Ottumwa soils are on back slopes and foot slopes. The moderately deep Lakoma soils are on the summits and back slopes. Ottumwa soils make up about 45% of this association, Lakoma 35%, and 20% are other minor soils. Minor soils in this association include Bullcreek, Capa, Herdcamp, Kirley, Kolls, Opal, Promise and Wendte. This association is located in the central portion of the watershed and comprises about 85 – 90 % of the total area.

<u>Ottumwa-Kirley</u>: Very deep, well drained, nearly level to moderately sloping, clayey and loamy soils on plains and terraces. Ridges and valleys characterize the association. The Ottumwa soils formed in clayey shale residuum and the Kirley soils formed in clayey alluvium. The very deep Ottumwa soils are located on back slopes and foot slopes. The very deep Kirley soils are located on summits, shoulder slopes, and back slopes. Ottumwa soils make up about 45% of this association, Kirley 27% and 28% are other minor soils. Minor soils in this association are Bullcreek, Capa, Herdcamp, Hoven, Kolls, Lakoma, Mosher, and Wendte. This association is located in the upper portion of the watershed and comprises about 5 - 10 % of the total area.

<u>Midway-Razor-Blackpipe:</u> Shallow and moderately deep, well drained, nearly level to very steep, clayey and loamy soils on undissected and dissected plains. This association is chartacterized by prominent buttes, sharp ridges, hills, and nearly level plains. The soils formed in clayey shale residuum. The shallow Midway soils formed on shoulder slopes and upper back slopes. The moderately deep Razor soils are located on back slopes. The moderately deep Blackpipe soils are on summits, back slopes, and foot slopes. The Midway soils make up about 38% of this association, Razor 28%, Blackpipe 20% and 14% are other minor soils. Minor soils in this association include Lohmiller, Savo, Wanblee, and Wortman. This association is located in the lower portion of the watershed and makes up about 5% of the total area.

History

The area around Waggoner Lake and Grindstone Creek has a diverse history. A few of the more outstanding events in the history of the area are covered here. The Sioux were the early inhabitants of this area and French fur traders were frequenting the area before 1800. The first settlement in Haakon County was Leslie located on the Cheyenne River that forms the north boundary of Haakon County. Settlement began to increase around 1890 because of provisions of the Homestead Act. The Chicago and Northwestern Railroad, located along the Bad River which forms the southern boundary of Haakon County, was completed in 1907. This greatly accelerated the number of settlers coming into the area. By 1911, most of the productive land in the area had been settled.

Haakon County was originally a part of Stanley County, which was founded in 1873 by an act of the legislature of Dakota Territory and was formally organized in 1889. The original boundaries of Stanley County included the area that is now the counties of Haakon and Jackson County north of the White River. Haakon County was established in 1914 and organized in 1915. It was named in honor of Haakon VII, King of Norway. The town of Philip, the largest municipality in the county, is the county seat, and was named after James "Scotty" Philips who is credited with much of the effort to save the American buffalo (bison) from extinction.

An earthen embankment was constructed on Grindstone Creek in 1940. The project was funded through the Works Progress Administration and Haakon County and forms Waggoner Lake. Waggoner Lake is a 98-acre (39.7 ha) impoundment located approximately 2.5 miles north and 1 mile east of Philip, South Dakota. The Works Progress Administration and Haakon County constructed the earthen dam on Grindstone Creek about 3 miles above the confluence of the Creek and the Bad River to create a water supply for the town of Philip. The 40,000 cubic yard earth embankment is 800 ft long and holds about 665 ac-ft of water at principal spillway elevation. The spillway is reinforced concrete that was totally reconstructed in 1989. The pool when full has a mean depth of 6.8 ft (2.1 m) and a maximum depth of 22 ft (6.7 m) with 4.3 mi (6.9 km) of shoreline.

The 37,000-acre (14,980 ha) watershed consists of the upper portion of Grindstone Creek. The watershed is about 5 miles wide and 14 miles long. Land use is totally agricultural with a few farmsteads and a lightly developed road infrastructure. Highway 73 borders the upper end of Lake Waggoner and passes through the lower east portion of the watershed. Agricultural use is a combination of cropland and grassland.

Project Goals, Objectives, and Activities

OBJECTIVES AND TASKS

The goals of the Waggoner Lake Watershed Assessment Project were to locate and document sources of non-point source pollution in the watershed and produce potential TMDL targets and/or water quality goals for Waggoner Lake. Lake restoration strategies were also recommended for consideration.

Seven objectives and associated tasks were established to ensure attainment of the project goals. The following objectives and activities were included in the Waggoner Lake Watershed Assessment Project.

OBJECTIVE 1: Determine current conditions in the lake and calculate the trophic state of the lake. This information will be used to determine the total amount of nutrient trapping that is occurring in the lake and the amount of reduction of nutrients required to improve the trophic condition of Waggoner Lake Dam.

TASK 1 Lake Sample Collection

Nutrient and solids parameters will be sampled at two in-lake sites on Waggoner Lake (Figure 1, Table 2). The South Dakota State Health Laboratory in Pierre will analyze all samples. Samples will be collected from the surface and bottom on a monthly schedule except during periods of unsafe ice cover for a period of 1 year. A total of 40 lake samples will be collected.

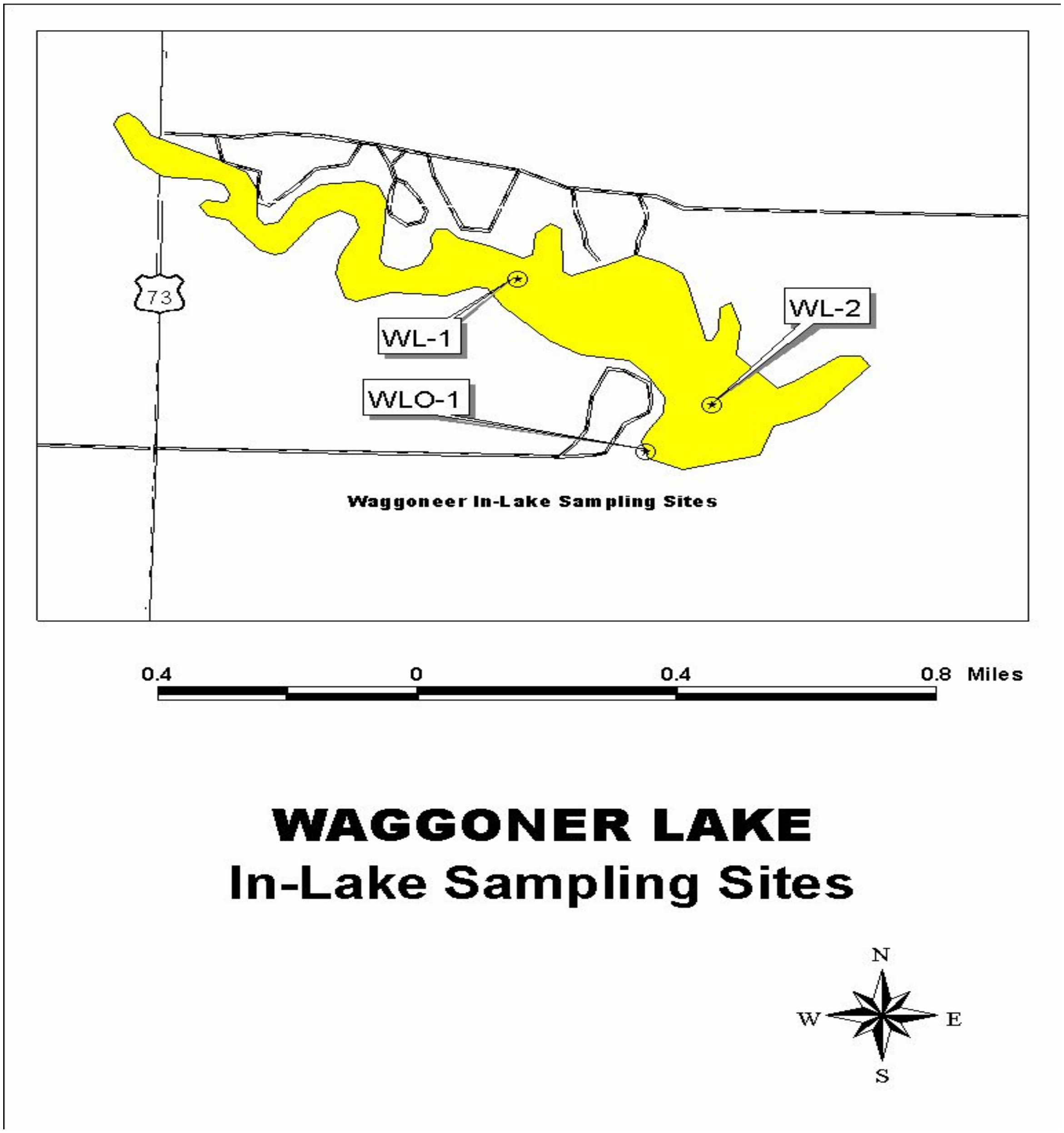


Figure 1. Sample site locations for the Waggoner Lake Assessment Project

Table 2. Parameters measured for inlake samples.

Air temperature	Total solids	Fecal coliform	Chlorophyll *a*
Water temperature	Total susp. solids	*E.coli*	
Visual observations	Ammonia		
Depth	Nitrate-nitrite		
Field pH	TKN		
Dissolved oxygen	Total phosphorus		
	Total dis. phosphorus		
	Volatile suspended solids		

ACCOMPLISHMENT:

During the 2001 sampling season, 15 water quality samples were collected from the surface and bottom at two sites (n=30) respectively. Poor ice conditions attributable to a mild winter prevented collection of the remaining ten samples. The remaining 10 samples (5 surface; 5 bottom) were collected monthly as a composite from both sites April through August of 2004. The total number of lake samples totaled 40 for the project. Data acquired from these samples were used by DENR in the final report.

TASK 2 Lake Profiles and Biological Samples

The purpose of the in-lake samples is to assess ambient nutrient concentrations in the lake and identify trophic state. Water column dissolved oxygen and temperature profiles will be collected on a monthly basis. Water samples will be collected with a Van Dorn sampler and the sample bottles will be iced and shipped to the SD State Health Lab in Pierre by the most rapid means available. The SD State Health Lab in Pierre will analyze fecal coliform samples. Staff from Watershed Protection in the Matthew Training Center Laboratory, Pierre, SD, will analyze all other biological samples.

ACCOMPLISHMENT:

Water column profiles were conducted by project personnel during each sampling visit. Profile data were collected with a YSI multi-probe sonde. The data were recorded in a field notebook. These data were submitted to DENR for analysis. A total of 15 surface fecal coliform samples were collected in 2001. A total of 3 composite fecal coliform samples were collected in April, May and August of 2004. No fecal coliform samples were collected in June and July of 2004. The lake was sampled during these months by DENR personnel as part of the Statewide Lakes Assessment (SWLA) project. Fecal coliform samples are not routinely collected during a SWLA effort. A total of 15 surface chlorophyll-*a* samples were collected from both sites in 2001. Chlorophyll-*a* samples were collected monthly (April-August) in 2004 with composites collected in June and July (total n=8 samples). All samples were processed. The data are managed by DENR. These data were used by DENR in the final assessment report.

TASK 3 Sample Collection Procedures

All samples will be collected using the methods described in the "Standard Operating Procedures (SOP) for Field Samplers" by the State of South Dakota Water Resources Assistance Program (WRAP).

ACCOMPLISHMENT:

All sample collection conducted during the project followed the methods described in the "Standard Operating Procedures (SOP) for Field Samplers" manual (Smith 2005).

OBJECTIVE 2: Estimate the sediment and nutrient loadings from the tributaries in the Waggoner Lake watershed through hydrologic and chemical monitoring. The information will be used to locate critical areas in the watershed to be targeted for implementation.

TASK 4 Install Stage Recorders

Install water level recorders on 2 tributary monitoring sites and maintain a continuous stage record for the project period, with the exception of winter months after freeze up.

ACCOMPLISHMENT:

Two tributary sites and one outlet site were equipped with continuous water level recorders. Both tributary sites were located on the mainstem of Grindstone Creek (Figure 2). The project personnel maintained the gauging sites and instrumentation, and measured stream velocities and cross-sections at the appropriate times and sent the information to DENR for analysis.

TASK 5 Discharge Measurements

Discrete discharge measurements will be taken on a regular schedule and during storm surges. Discharge measurements will be taken with a hand held current velocity meter.

ACCOMPLISHMENT:

Due to dry/drought conditions, discharge measurements were made on an opportunity basis. Flow occurred mainly during the spring of 2001 and the summer of 2004. Four discharge measurements were collected at the outlet site, 10 at site WTS1 and 11 at site WTS2. Flow was measured with a Marsh-McBirney velocity meter. In one instance, an area velocity measurement was made at WTS1 to calculate discharge (Q=VA). All measurements were recorded in a field book and submitted to DENR for analysis.

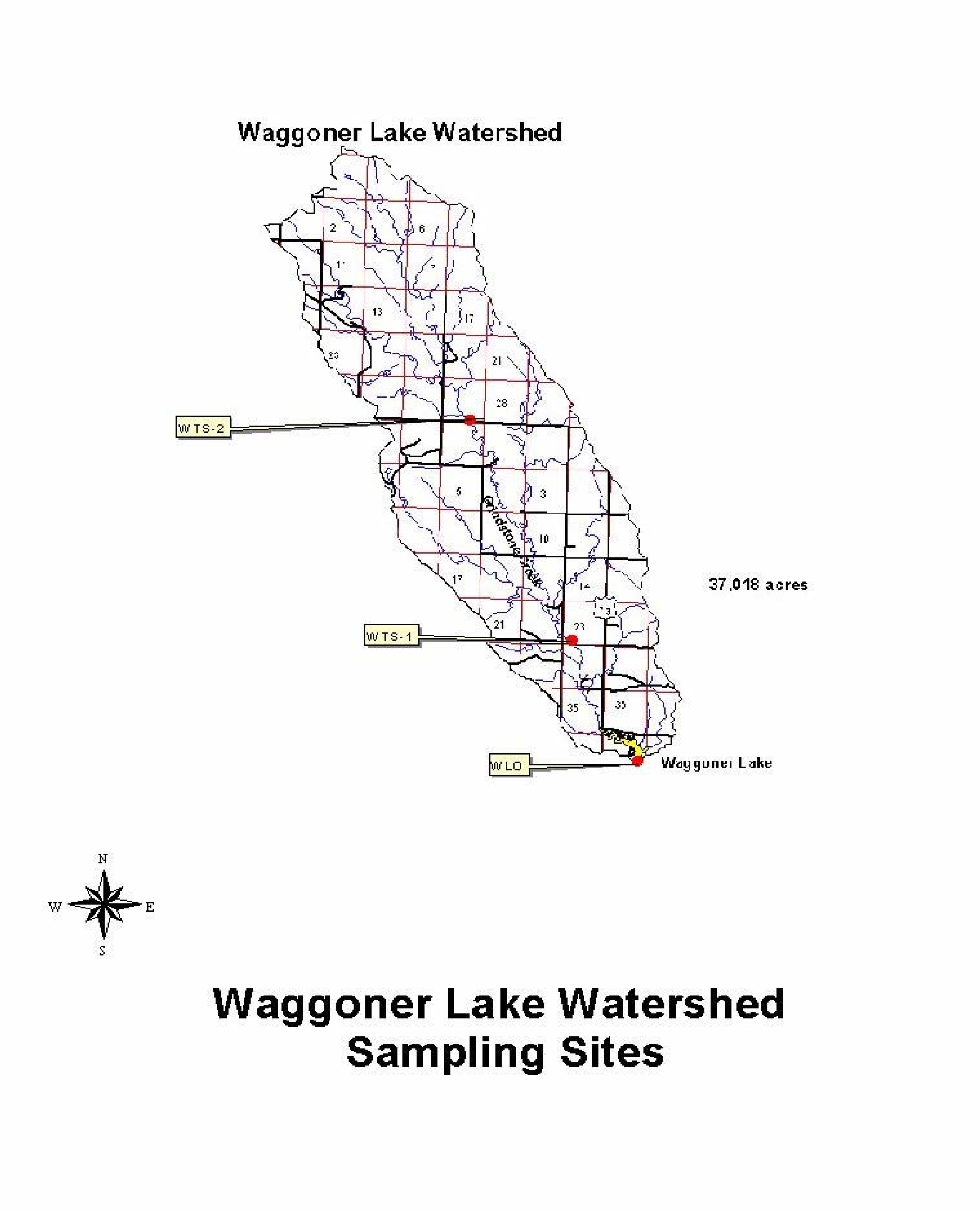


Figure 2. Tributary and lake outlet sampling locations for the Waggoner Lake assessment.

TASK 6 Calculate Hydrologic Budget

Discharge measurements and water level data will be used to calculate a hydrologic budget for the creek system. This information will be used with concentrations of sediment and nutrients to calculate loadings from the watershed.

ACCOMPLISHMENT:

Continuous stream stage information was compiled from the 3 gauge sites. These data were submitted to DENR. DENR used the stage/discharge measurements to develop stage/discharge relationships for determining the hydrologic load from the watershed during the project.

TASK 7&8 Collect Tributary Water Quality Samples

Collect 36 water quality samples from tributary monitoring sites. Samples will be collected during spring runoff, storm events, and monthly base flows. Parameters collected are listed in table 3.

ACCOMPLISHMENT:

Because of drought conditions water quality samples were collected on an opportunity basis when flow occurred during the spring of 2001 and summer 2004. Four samples were collected at the outlet site, 10 and 11 samples (n=25) were collected at sites WTS1 and WTS2, respectively. Because of the drought the project was short 11 tributary samples. Water quality data were used in combination with the flow data to calculate nutrient and solids loads from Grindstone Creek. DENR used the FLUX model to calculate nutrient and sediment loads which were incorporated into the final assessment report for the purpose of TMDL development.

Table 3. Parameters measured for tributary samples.

PHYSICAL	CHEMICAL	BIOLOGICAL
Air temperature	Total solids	Fecal coliform
Water temperature	Total suspended solids	*E.coli*
Discharge	Dissolved oxygen	
Depth	Ammonia	
Visual observations	Un-ionized ammonia	
Water level	Nitrate	
	TKN	
	Total phosphorus	
	Total dis. phosphorus	
	Volatile suspended solids	
	Field pH	

TASK 9 Sample Collections.

The collection of all field water quality data will be accomplished in accordance with the "Standard Operating Procedures for Field Samplers", South Dakota Water Resource Assistance Program.

ACCOMPLISHMENT:

All sample collection conducted during the project followed the methods described in the "Standard Operating Procedures (SOP) for Field Samplers" manual. DENR often incorporates macrophyte surveys, elutriate sampling and sediment surveys into assessment projects. These items were not included in the TASKS within the original 2001 Project Implementation Plan (PIP). However, these tasks were performed during this project in accordance with the SOP. Results from these surveys were incorporated into the final assessment report.

OBJECTIVE 3: Ensure that all water quality samples are accurate and defendable through the use of approved Quality Assurance/Quality Control procedures.

TASK 10 QA/QC

A minimum of 10 percent of all the water quality samples collected will be QA/QC samples. QA/QC samples will consist of field blanks and field duplicate samples. An estimated 10 samples will be collected during the project.

TASK 11 QA/QC

All QA/QC activities will be conducted in accordance with the Water Resource Assistance Program Quality Assurance Project Plan.

TASK 12 QA/QC

The activities involved with QA/QC procedures and the results of QA/QC monitoring will be compiled and reported in a section of the final project report and in all project reports.

ACCOMPLISHMENT:

A total of 56 samples were taken during the project period. Six blank samples and eight replicate samples were collected during the project. This project met the EPA recommended 10 percent QA/QC requirement. All QA/QC activities were conducted in accordance with the Water Resource Assistance Program Quality Assurance Project Plan. The data are presented in the final assessment report.

OBJECTIVE 4: Evaluation of agricultural impacts to the water quality of the watershed through the use of the Annualized Agricultural Nonpoint Source (AGNPS) model.

TASK 13 AGNPS Model Data Collection

The Waggoner Lake watershed will be modeled using the AGNPS model. AGNPS is a comprehensive land use model which estimates soil loss and delivery and evaluates the impact of livestock feeding areas. The watershed will be divided into 40-acre cells. Each cell will be analyzed by using 21 separate parameters with additional information collected for animal feeding operations.

TASK 14 AGNPS Modeling

This model will be used to identify critical areas of nonpoint source pollution to the surface waters in the watershed. Contributors of nutrients and sediments to surface water in the Waggoner Lake watershed will be identified.

ACCOMPLISHMENT:

Project personnel collected all information required to run the AGNPS simulation model. DENR used the information to run the model and identify areas which contribute significant nutrient and sediment loads to Waggoner Lake. DENR produced an AGNPS report and it was incorporated in the final assessment report.

OBJECTIVE 5: Public participation and involvement will be provided for and encouraged

TASK 15 Informational Meetings

Informational meetings will be held on a quarterly basis for the general public and to inform the involved parties of progress on the study. These meetings will provide an avenue for input from the residents in the area.

TASK 16 News Releases

News releases will be prepared and released to local news media on a quarterly basis. These releases will be provided to local newspapers, radio and TV stations.

ACCOMPLISHMENT:

Some of the landowners were contacted to gather assessment information. This area is in the Bad River 319 Project Implementation area and operators have been active in this project. Much of the information for the assessment was already available through the NRCS and FSA offices. Responses to letters, phone calls, and personal contact were excellent. The landowners cooperated to provide needed information. Further information was provided to the community and stakeholders in the project at the Haakon County Conservation District and West Central Water Development District public board meetings. A public meeting was held at the Philip High School in March of 2002. This meeting was to inform the local people of what data had been collected. About 20 people attended.

OBJECTIVE 6: Development of watershed restoration alternatives.

TASK 17 Review Historic and Project Data

Once the field data are collected, an extensive review of the historical and project data will be conducted.

TASK 18 Nutrient and Sediment Budgets

Loading calculations based on project data will be done and hydrologic, sediment and nutrient budgets for the watershed will be developed.

TASK 19 Generate AGNPS Report

The results of the AGNPS modeling of the watershed will be used in conjunction with the water quality and hydrologic budget to determine critical areas in the watershed.

TASK 20 Restoration Alternatives

The feasible management practices will be compiled into a list of alternatives for the development of an implementation project and included in the final project report.

ACCOMPLISHMENT:

DENR prepared a final report for the lake which included hydrologic, sediment and nutrient budgets for the watershed. The final report also includes the results of AGNPS model simulation of the watershed that was used in conjunction with the water quality and hydrologic budget to determine critical areas in the watersheds. Management practices thought to reduce loading from the critical areas were compiled into a list of recommendations for the development of an implementation project that is included in the final project report.

OBJECTIVE 7: Produce and publish a final report containing water quality results and restoration alternatives.

TASK 21 Load Calculations

Produce loading calculations based on water quality sampling and hydrologic measurements.

TASK 22 AGNPS Report

Summarize the results of the AGNPS model for the watershed and report locations of critical areas.

TASK 23 Water Quality Trends

Write a summary of historical water quality and land use information and compare with project data to determine any possible trends.

TASK 24 Evaluate Water Quality

Based on data, evaluate the hydrology of the Waggoner Lake watershed and the chemical, biological, and physical condition of the tributary.

TASK 25 QA/QC Summary Report

Produce a summary report of all QA/QC activities conducted during the project and include in the final project report.

TASK 26 Restoration Alternatives

Write a description of feasible restoration alternatives for use in planning watershed nonpoint source implementation.

ACCOMPLISHMENT:

DENR incorporated tasks 21 through 26 into this comprehensive final assessment report for Waggoner Lake and Grindstone Creek.

Planned and Actual Milestones, Products, and Completion Dates

A summary of project milestones and completion dates is presented in Table 4. Objective 1, lake sampling was on schedule during 2001, except for winter samples because of unsafe ice conditions. Additional lake sampling was conducted during 2004 to compliment tributary samples. Objective 2, the tributary sampling, was extended because of drought conditions in the watershed. Tributary samples were collected during summer 2004 when several rain events produced measurable flow. Objective 3, QA/QC efforts were delayed until 2004 to compensate for additional lake and tributary samples. Objective 4, the AGNPS modeling effort was on schedule during the project. Objective 5, public participation was conducted on schedule. Objective 6, restoration alternatives are behind schedule and will be incorporated into the final report scheduled for completion by DENR during March 2007. Objective 7, final report preparation, is behind schedule.

Evaluation of Goal Achievement and Relationship to the State NPS Management Plan

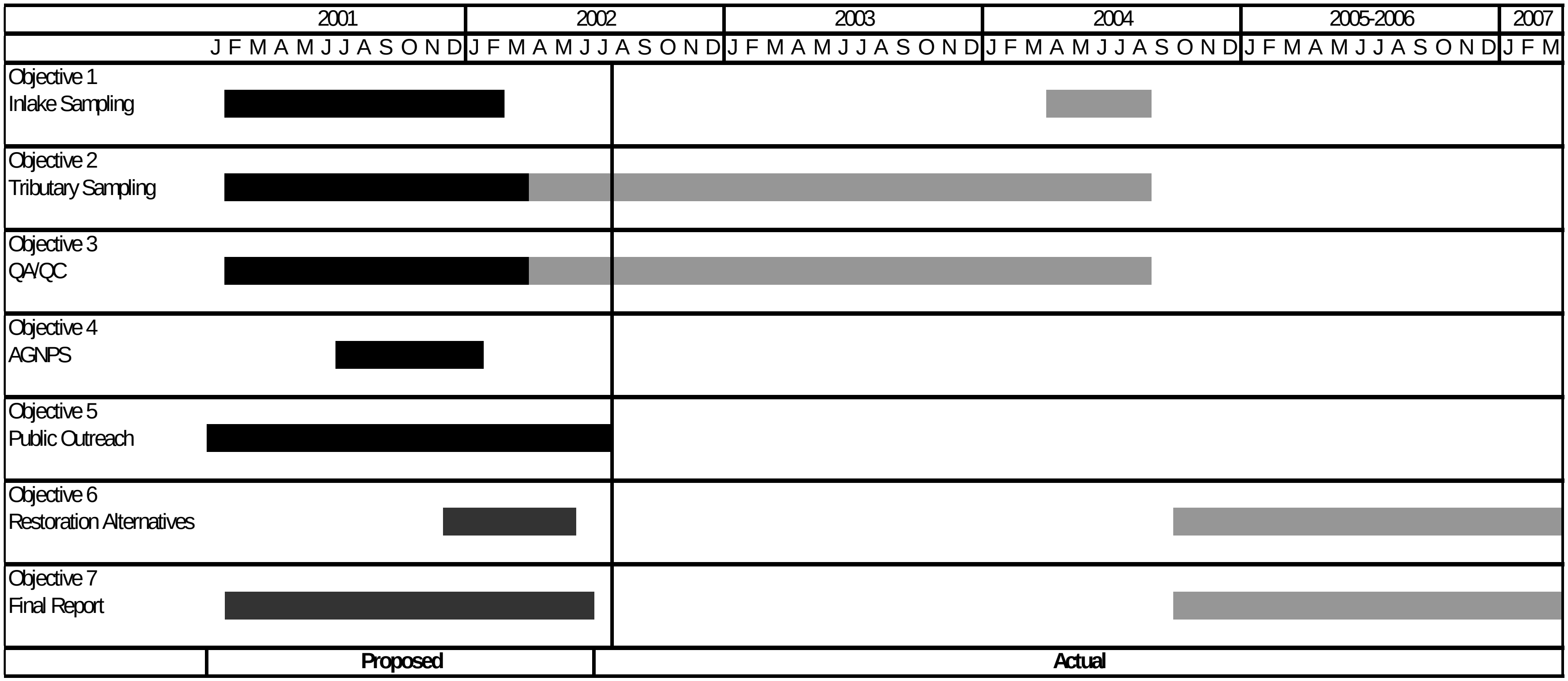
The Waggoner Lake Watershed Assessment Project accomplished its goal by locating and documenting sources of non-point source pollution in the watershed. A Waggoner Lake TSI target and goal will be produced by DENR. Lake restoration strategies will also be recommended in the final assessment document.

Because Waggoner Lake was on the 303(d) list in the South Dakota Integrated Report, this assessment project was deemed necessary and was an integral part of the state's NPS Management Program. Completion of the project goals should lead to a watershed-wide implementation project, another integral part of the state's NPS Program.

The final assessment report will consist of an analysis of the data and include:

1. A summary of project goals, milestones and accomplishments;
2. Discussion of the general limnology of the lake, seasonality, trophic state, stratification, long-term trends in water quality, and any exceedances of state water quality standards criteria;
3. Discussion of tributary water quality, seasonality, and any exceedances of state water quality standards criteria;
4. Use of the FLUX computer program to determine sediment and nutrient loads to the lake;
5. Use of the BATHTUB computer program to predict lake responses to nutrient loadings;
6. A macrophyte survey to locate and quantify relative abundance of macrophytes;
7. A sediment survey to determine water and sediment depths throughout the lake;
8. Elutriate sampling to determine presence and concentration of toxics/metals in the lake sediments;
9. Use of the AGNPS model to predict effects of various watershed BMPs on nutrient and sediment yields;
10. Determination of water quality and loading targets to ensure beneficial use attainment;
11. Discussion of outreach efforts in the watershed;
12. Presentation of lake and watershed restoration techniques that should be considered for implementation in the lake or the watershed;
13. A summary of project expenditures.

Table 4. Proposed and actual objective completion dates for the Waggoner Lake Watershed Assessment Project.



Monitoring Results

Tributary Water Quality

Water quality data were sent to DENR for analysis. Field data, recorded either on a laptop computer or into field log books, were sent to DENR after the sampling effort was complete. DENR has taken the responsibility to analyze the data and prepare the final assessment report and TMDL.

Flow Calculations

Two monitoring sites were selected along the longitudinal profile of Grindstone Creek. Two sites were selected to determine which portions of the watershed were contributing the greatest amount of nutrient and sediment load to the lake. WLT1 and WLT2 had drainage areas of 31,200 and 15,400 acres, respectively. The furthest downstream site (WLT1) was equipped with an Ott Thalamedes stage recorder/data logger. The upstream site (WLT2) was equipped with an ISCO 4230 pressure level recorder. Both monitoring devices recorded water stage to the nearest millimeter and stored the information every 15 minutes. A Marsh-McBirney Model 210D flow meter was used to measure flows in cubic meters per second at various stages. The stage and flow information was used to develop a stage-discharge relationship (regression equation) for each site.

Load Calculations

Nutrient and sediment loads were calculated with the use of the Army Corps of Engineers eutrophication model known as FLUX. FLUX uses individual sample data in correlation with daily discharges to develop six loading calculations for each parameter. As recommended in the application sequence, a stratification scheme and method of calculation was determined using the total phosphorus load. This stratification scheme is then used for each of the additional parameters.

Tributary Sampling Schedule

Due to intermittent flow in Grindstone Creek, samples were collected on an opportunity basis. The samples collected in 2001 were the result of a snowmelt runoff event. The samples collected in 2004 were from runoff created by three major storm events. All samples were collected with a grab sample technique. Water samples were then filtered, preserved, and packed in ice for shipping to the State Health Lab in Pierre, SD. The laboratory then assessed or calculated the following parameters:

Fecal Coliform Counts	Alkalinity
Total Solids	Total Dissolved Solids
Total Suspended Solids	Ammonia
Nitrate	Total Kjeldahl Nitrogen (TKN)

Total Phosphorus
Total Dissolved Phosphorus
E. coli Bacteria
Volatile Total Suspended Solids
Un-ionized Ammonia

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

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

Parameters measured in the field by sampling personnel were:

Water Temperature
Field pH
Air Temperature
Dissolved Oxygen

South Dakota Water Quality Standards for Grindstone Creek

The State of South Dakota assigns the following beneficial uses to all rivers and streams in the state:

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

When two or more standard limits exist for the same parameter, the most stringent standard is applied. Table 5 indicates the most stringent standard limits for Grindstone Creek.

Table 5. State water quality standards applied to Grindstone Creek.

Parameter	Limits
Nitrate (mg/L)	<50 (30-day average) <88 (daily maximum)
Alkalinity (mg/L)	<750 (30-day average) <1,313 (daily maximum)
pH (su)	> 6.5 and <9.5 s.u
Total Dissolved Solids (mg/L)	<2,500 mg/L (30-day average) < 4,375 mg/L (daily maximum)
Conductivity @ 25^{o}C (umhos/cm)	<2,500 (30-day average) <4,375 (daily maximum)

Grindstone Creek Seasonality

Seasonal variation in landuse practices and precipitation throughout the hydrologic year can yield differences in nutrient and solids transport to a receiving water body. To discuss seasonality DENR commonly recognizes March 1st through May 15th as spring, May 16th through September 15th as summer and September 16th through freeze up as fall. Drought conditions prevailed in the Grindstone Creek watershed beginning in the summer of 2001 and extending through the spring of 2004. Despite drought conditions, Grindstone Creek transported nutrient and solids loadings to Waggoner Lake in intermittent flow during the spring of 2001 and again in the summer of 2004.

A combination of snowmelt and storm water run-off was captured during the spring of 2001 in Grindstone Creek. Five sets of water quality samples were collected from WLT1 and WLT2 during March and April of 2001. It wasn't until the summer of 2004 that flow returned to Grindstone Creek produced by 3 major storm events. Five sets of samples were collected from WLT1 and WLT2 during these events. During the entire four-year assessment period it was estimated that 24% of the total discharge to Waggoner Lake occurred in the spring of 2001 and 76% occurred in the summer of 2004. The mean, median and range values for all sample concentrations and flow measurements are presented by season and year in Table 6.

Table 6. Seasonal Descriptive Statistics for Grindstone Creek Water Quality.

	Spring 2001				Summer 2004			
Parameter	Mean	Median	Max	Min	Mean	Median	Max	Min
*D.O mg/L	11	11	13	9	7	6.8	9	5.1
field pH *su*	7.53	7.58	7.94	7.22	7.47	7.42	8.5	6.71
SpCond uS/cm	NA	NA	NA	NA	632	281	3806	95
Alkalinity mg/L	66	52.5	224	20	99	76	284	40
TS mg/L	849	541	4024	162	893	456	4206	273
TSS mg/L	52	31.5	132	12	205	80	680	15
TDS mg/L	797	479	4012	127	687	340	4173	160
*VTSS mg/L	7	6.5	14	0.5	32	17	90	6
Ammonia mg/L	0.12	0.11	0.34	0.01	0.05	0.01	0.18	0.01
*Nitrate mg/L	5.81	1.55	46.5	0.40	0.14	0.05	0.4	0.05
TKN mg/L	1.75	1.78	2.49	1.18	2.13	1.88	4.06	0.99
TP mg/L	0.37	0.36	0.58	0.04	0.69	0.58	1.46	0.137
TDP mg/L	0.25	0.27	0.34	0.02	**0.05	**0.054	**0.054	**0.054
E. coli colonies/100ml	960	515	>2420	12	1430	1298	>2420	137
Fecal colonies/100ml	844	660	3100	5	36057	800	300000	210
Flow cfs	8.5	4.8	42.3	0.001	20.4	3.27	161	0.033

* Represents those parameters that were significantly different between years (KW ANOVA p=<0.05).
** Values are not an average.

Flow

Grindstone Creek flow was intermittent over the course of the project. Flow was considerably higher in summer (2004) than spring (2001) though not significantly different between years (p=>0.05). Flow during both seasons was highly variable ranging from 0.001cfs to 42.3 cfs in spring and 0.033 cfs to 161 cfs in the summer. Local landowners within the watershed reported anywhere from 15.2 to 22.9 centimeters of rainfall in short duration during a storm event that occurred the evening of June 10, 2004. Figure 3 displays the mean daily hydrograph for WLT1 over the course of this impressive event. In general, higher nutrient and solids concentrations were associated with higher flows.

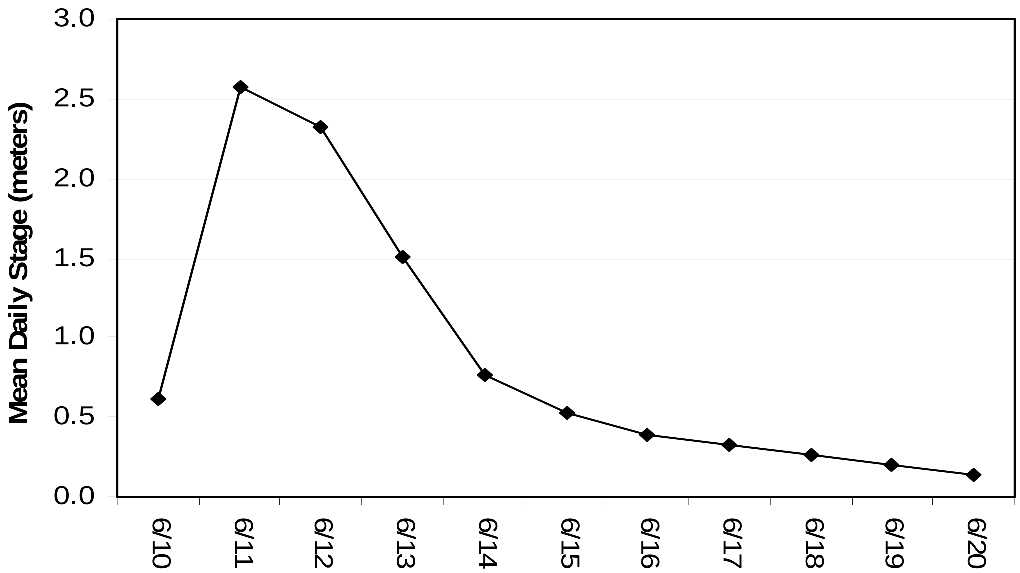


Figure 3. Mean daily hydrograph for WLT1 from a major storm event that occurred June 2004.

Dissolved Oxygen and Temperature

Dissolved oxygen concentrations were significantly higher in the spring (median = 11 mg/L) than the summer (median 6.8 mg/L) between years (p=<0.05). The presence of adequate flow and cooler water temperatures were likely contributing to the higher dissolved oxygen found in the spring. Flow aids to aerate water as it moves along the stream profile and cooler water temperatures allow for higher saturation capacity. As expected, spring water temperatures (median = 4.2^{o}C) were significantly lower than summer temperatures (median = 18.7^{o}C) (p=<0.05). The presence of low dissolved oxygen can become intolerable to aquatic organisms. Wetzel (2001) suggests that most fish species cannot survive when dissolved oxygen concentrations fall below 2 mg/L. The lowest concentration of dissolved oxygen (5.1 mg/L) was observed at the upper site on Grindstone Creek in the summer of 2004. The upper portion of the creek was subject to stagnant water or waterless conditions with flow only occurring in short duration. Dissolved oxygen concentrations were above 6 mg/L in all other samples for both sites and not likely limiting aquatic life during periods of flow.

pH

pH was not significantly different between spring (median = 7.58) and summer (median = 7.42) across years (p=>0.05). Low pH (6.71 and 6.79) was observed during the 1st summer sample from both WLT1 and WLT2, respectively. This low pH is likely attributable to the relatively small rainfall event that occurred following nearly four years of drought. The pH standard limit range (pH > 6.5 and <9.5 su) designated to protect the beneficial uses of Grindstone Creek was not violated by any of the samples collected during the project.

Specific Conductance and Alkalinity

Specific conductance was only measured during the summer of 2004. Specific conductance ranged considerably (range = 3806 to 95 uS/cm) though never exceeded the water quality standard. Alkalinity was not significantly different between spring and summer across years (p=>0.05). Alkalinity was relatively low for nearly all samples (<284 mg/L) and never exceeded the designated water quality standard.

Solids

Most solids parameters were not significantly different between spring and summer across years (KW ANOVA p=>0.05). The exception was total volatile solids, which were significantly lower in the spring than summer (p=<0.05). Higher volatile solids in the summer of 2004 were likely a result of scouring rain events that moved accumulated organic material from the watershed. Total dissolved solids were typically low in the spring (median = 479) and summer (median = 340) samples. Total dissolved solids never exceeded the designated water quality standard.

Nitrogen

Nitrate-nitrogen was significantly higher in spring samples than summer samples between years (p=<0.05). Nitrate-nitrogen samples collected in the spring of 2001 were all above the State Health Laboratory's detection limit (<0.01mg/L) from both sites. Sixty percent of all summer samples collected during 2004 were under the detection limit. A single nitrate-nitrogen sample collected at WLT1 in the spring of 2001 (April) yielded a concentration of 45.5 mg/L. This sample was several orders of magnitude higher than any of the other spring samples. On this date flow was low (0.01 cfs) suggesting groundwater as a likely source of the high nitrate concentration. It is common for spring seeps in Pierre shales to contribute high nitrates especially at low flows (Smith 2004). Ammonia was also typically higher in spring samples though not significantly different between years (p=>0.05). TKN was higher in summer samples though not significantly different between years (p=>0.05). Summer TKN was significantly associated (rho=0.73, R^2=0.67, p=<0.001) with volatile solids (Figure 4). Organic material stored in the watershed over nearly four years of drought was transported by overland flow during heavy rain events. Vegetation was also well established in the channel and may have also been contributing to the higher summer TKN concentrations.

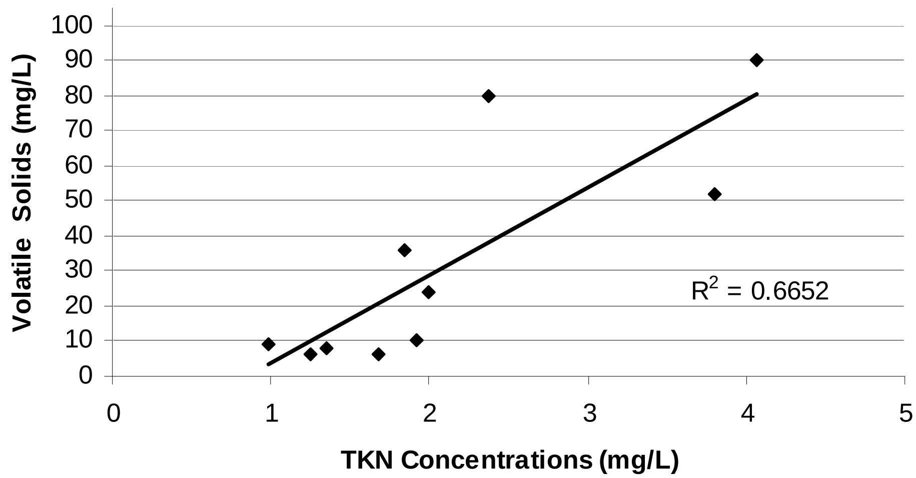


Figure 4. Linear relationship between volatile suspended solids and TKN summer 2004.

Phosphorus

Total phosphorus concentrations were typically higher in summer samples than in spring samples though not significantly different between years (p=>0.05). Summer total phosphorus concentrations were strongly related to total suspended solids (rho= 0.93, R^2=0.69, Figure 5). Heavy rain events were likely contributing to the higher phosphorus and suspended solids concentrations observed in the summer of 2004. Dissolved phosphorus averaged 64% (median = 62%) of the total phosphorus concentration for spring samples. Only one dissolved phosphorus sample (0.054 mg/L) was collected in the summer of 2004 due to difficulties with filtration caused by high suspended solids.

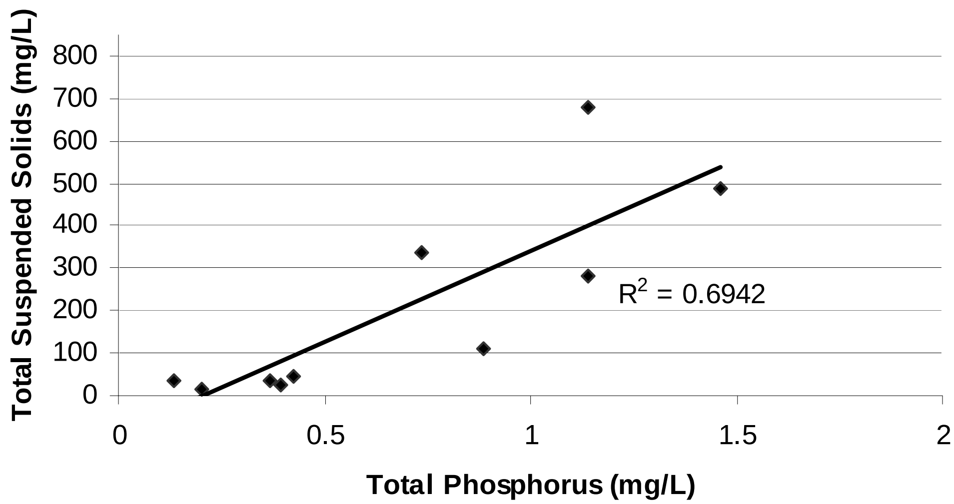


Figure 5. Relationship between total phosphorus and total suspended solids summer 2004.

Bacteria

Concentrations of fecal coliform bacteria and *E. coli* bacteria were not significantly different between spring and summer across years (KW ANOVA p=>0.05). However, the first summer rain event (2004) produced fecal bacteria counts from the upper site (WLT2) higher than all other samples combined. Total *E. coli* counts were above the Health Laboratory's detection limit (>2420) and fecal coliform was 300,000 colonies/100ml from the sample collected May 26, 2004. Fecal coliform downstream (WLT1) on the same date was only 300 colonies/100ml. Pasture adjacent to the upstream monitoring station may have been contributing to this high localized fecal count.

Seasonal Loadings

During the entire assessment period it was estimated that 24% of the total discharge to Waggoner Lake occurred in the spring of 2001 and 76% occurred in the summer of 2004. As a result, the cumulative solids and nutrient load (kg) were considerably higher during the summer of 2004 (Table 7). Spring concentrations were generally lower for most parameters with the exception of ammonia and nitrate. Elevated concentrations of nitrate were likely due to natural groundwater sources. Spring 2001 concentrations contributed negligible loads in comparison to summer 2004 in which several large-scale rain events occurred. The event that occurred June 10th, 2004 contributed 65% more nutrient and solids load to Waggoner Lake than all spring samples of 2001 combined.

Table 7. Grindstone Creek seasonal loadings from spring 2001 and summer 2004.

Season	Site	Parameter	Measured Days	Sample Count	Flow Volume (Acre-Feet)	Total Load (kg)
Spring 2001	WLT1	TSS	47	5	201.05	126842.3
Spring 2001	WLT1	TDS	47	5	201.05	74438.0
Spring 2001	WLT1	Organic-N	47	5	201.05	502.5
Spring 2001	WLT1	Inorganic-N	47	5	201.05	171.6
Spring 2001	WLT1	Total-N	47	5	201.05	674.1
Spring 2001	WLT1	Total-P	47	5	201.05	231.9
Spring 2001	WLT1	TDP	47	5	201.05	66.9
Summer 2004	WLT1	TSS	38	5	629.9	397913.8
Summer 2004	WLT1	TDS	38	5	629.9	233517.1
Summer 2004	WLT1	Organic-N	38	5	629.9	1576.5
Summer 2004	WLT1	Inorganic-N	38	5	629.9	538.3
Summer 2004	WLT1	Total-N	38	5	629.9	2114.8
Summer 2004	WLT1	Total-P	38	5	629.9	727.6
Summer 2004	WLT1	TDP	38	5	629.9	209.8

Grindstone Creek Water Quality and Loadings

Precipitation and Discharge

The Grindstone Creek watershed experienced extreme drought conditions during the four-year assessment period. The short-term average annual precipitation recorded at Philip, South Dakota from 1989 to 2004 was 37.3 cm (14.7 inches). Sub-average annual precipitation was observed from 2000 until 2004 (Figure 6). Despite only 16.3 cm (6.4 inches) of annual precipitation, continuous flow was monitored and water quality samples were collected (snowmelt) during the spring of 2001 (Appendix A). Limited water quality information was collected during 2001 and a decision was made to extend the project. Additional continuous flow and water quality samples were needed to model nutrient and solids loads (FLUX) for estimating the condition and response of Waggoner Lake (BATHTUB). No water quality samples were collected in 2002 due to a lack of measurable flow. A small snowmelt event occurred in the upper portion of the watershed in the spring of 2003 (Appendix A.). Flow was minimal (1.52 cfs) and never reached the lower site (WLT1). Three major storm events produced considerable flow during the summer of 2004. Sufficient flow and water quality data were collected during these events to justify the completion of the project.

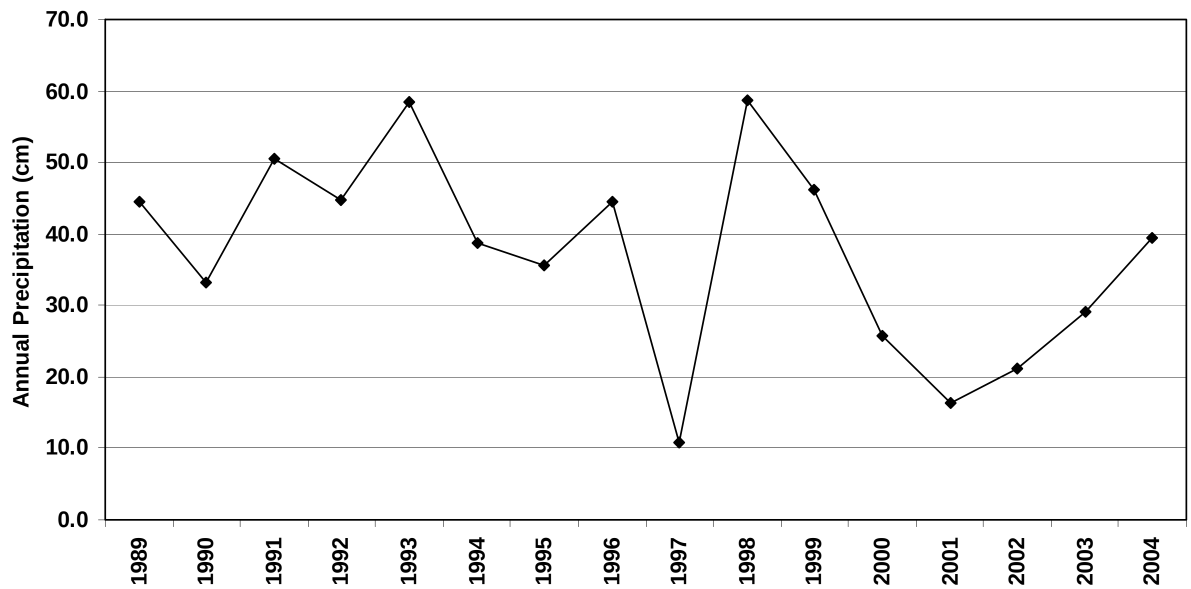


Figure 6. Annual precipitation from the Philip, SD gauge station.

Information received from state climatologist, SDSU Brookings SD. Precipitation data does not accurately reflect that of the watershed. Philip is located just outside (lower end) the watershed and does not account for variation produced by isolated events within the watershed.

Notable differences in water quality among parameters were observed between the upper site (WLT2) and the lower site (WLT1),(Appendix A). Ultimately, WLT1 contributes the cumulative load of nutrients and solids to Waggoner Lake. Seasonal precipitation was often isolated and variable throughout the watershed. Over the course of the project, flow varied noticeably between the upper and lower sites (Figures 7 and 8). In 2001, discharge measurements ranged from 42.3 to 0.01cfs (median =1.82) at WLT2 and 11.93 to 0.001cfs (median = 4.85) at site WLT1. In 2004, discharge measurements ranged from 0.033 to 32.25 cfs (median =3.27) at site WLT2 and 160.6 to 0.044 cfs (median =6.62) at site WLT1. When isolated runoff occurred in the upper portion of the watershed a considerable lag time was observed before flow reached the lower site. In one instance, over 10 cfs was recorded from WLT2 (July 13, 2004) and it wasn't until two days later that flow reached WLT1. Grindstone Creek has a fairly sinuous channel with many small to large stock dams and woody debris piles along the profile. These factors likely slow flow, protecting the bed and bank from the stress of shear velocity.

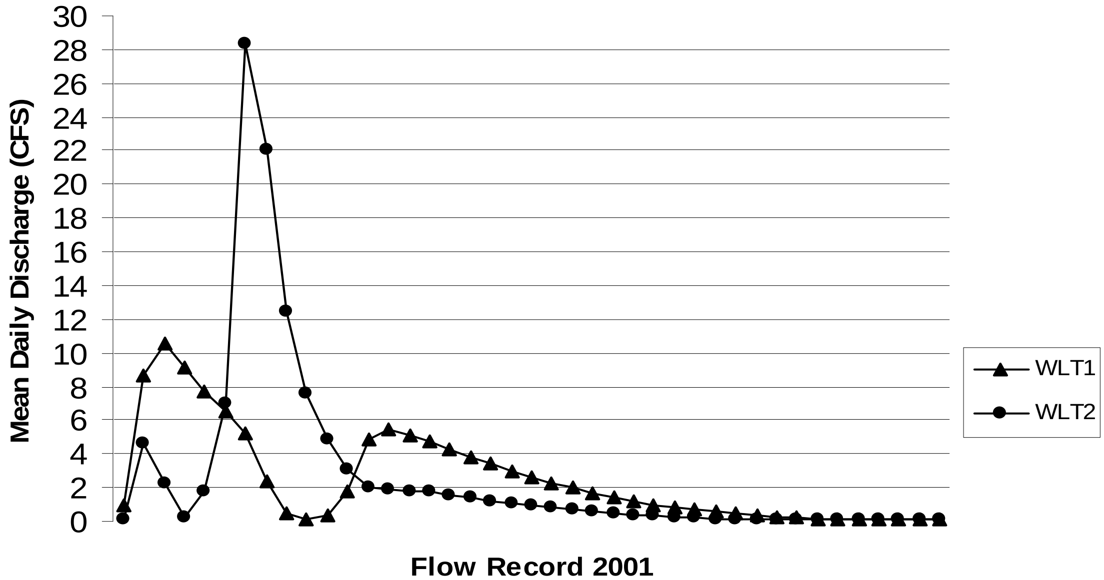


Figure 7. Average positive daily discharge observed during 2001.

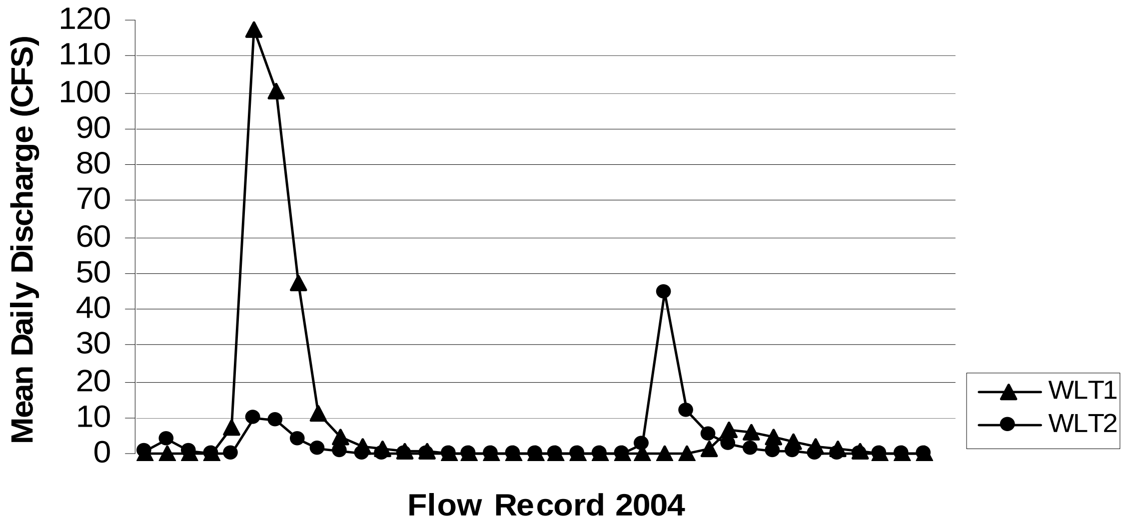


Figure 8. Average positive daily discharge observed during 2004.

The 100-year rain event for the watershed is estimated at 12.2 cm (4.8 inches) of rainfall in a twenty-four hour period (USDA, publication). A single rain event that occurred the evening of June 10, 2004 surpassed the estimated 100-year event for Haakon County. Local landowners in the watershed reported anywhere from 15.2 cm (6 inches) to 22.9 cm (8 inches) of rainfall in 4 to 6 hours during this event. Flood conditions were imminent over the evening hours though stream flow had subsided to approximate bankfull stage by late morning when investigators arrived. Water quality samples were collected near the peak of this event. However, stream flow could not be estimated manually due to deep water and high velocity. As a result, Manning's equation was used to estimate velocity and discharge at bankfull stage for this event:

MANNING'S EQUATION

$$V = (1.49/n)\ (R^{2/3})\ (S^{½})$$

Where:

V = Velocity (feet per second)
N = Manning's Roughness Coefficient (dimensionless)
R = Hydraulic Radius (Depth)* (feet)
S = Slope of Channel Bottom (feet per feet).

$$Q = V\ A$$

$$Q = (A)\ (1.49/n)\ (R^{2/3})\ (S^{½})$$

Q = Discharge
A = Bank full width/ mean bank full depth

Bed and bank measurements were conducted along a cross-section approximately 200 meters upstream of the WLT1 monitoring station. Velocity at bankfull stage was estimated at 2.23 ft/sec and discharge was estimated at 160.6 cfs. The stream dimensions were plotted and the channel type was classified using the Rosgen classification method (Rosgen, 1996, Figure 9). The lower portion of Grindstone Creek was classified as a G4c stream (Rosgen, 1996). A G4c stream has a low width to depth ratio (<12) and is highly entrenched (ratio <1.4), with moderate sinuosity (>12). The channel substrate was predominantly coarse sand and small gravel characteristic of a fairly rough channel. A channel evolution model was used to further classify the lower portion of Grindstone Creek (Simon, 1989). It was determined that this segment of Grindstone Creek was characteristic of a late stage IV in the channel evolution process. A stage IV channel is characteristic of a widening channel with severe slumped or eroded banks and low deposition in the channel. Grindstone Creek showed signs of deposition (accretion) within the channel and is likely moving towards aggradation (Stage V). Since Grindstone Creek is subject to intermittent flow this could be a timely process.

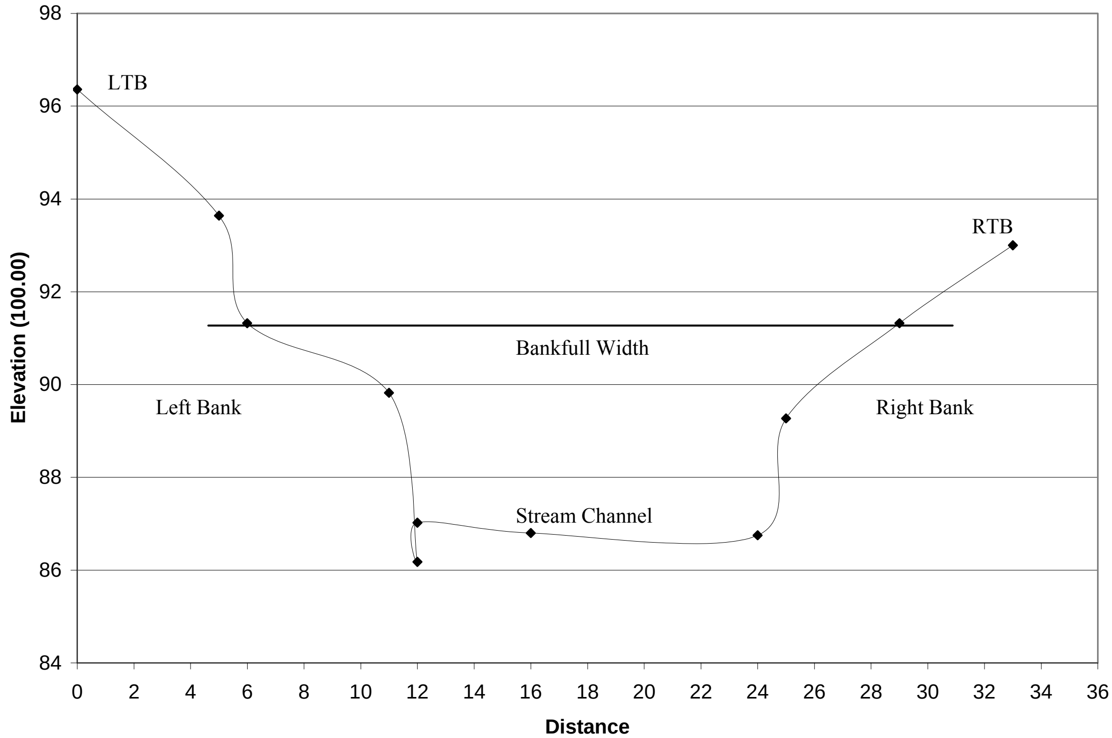


Figure 9. Channel dimensions of Grindstone Creek near site WLT1.

LTB = left top bank and RTB = right top bank. Subsequent points reveal slope changes in the bank and bed of the stream cross-section. The lower end of Grindstone Creek was classified as a G4c stream and a late stage IV in the stream evolution process.

Fecal Coliform Bacteria

Fecal coliform bacteria are found in the waste of warm-blooded animals. Common types of bacteria are *E. coli*, *Salmonella*, and *Streptococcus*, which are generally associated with livestock, wildlife and human waste (Novotny, 1994). *E. coli* counts were generally higher than total fecal coliform counts (Appendix A). This is the result of standard lab testing procedures (Clesceri et al. 1998).

Fecal coliform counts varied considerably among years and between sites (Table 8). In general, high bacteria counts were observed from the upper site compared to the lower site. This may be attributed to the local influence of cattle generally present immediately upstream of WLT2. Ultimately, the load of bacteria can affect the beneficial uses of Waggoner Lake.

Table 8. Grindstone Creek bacteria counts collected during the project period.

Tributary Site	Month	Year	E.coli colonies/100ml	Fecal colonies/100ml
WLT1	March	2001	2420	990
WLT1	March	2001	921	660
WLT1	March	2001	108	40
WLT1	April	2001	1733	1100
WLT2	March	2001	48.8	5
WLT2	March	2001	12.2	10
WLT2	March	2001	13.2	*m
WLT2	March	2001	2420	3100
WLT1	May	2004	249	330
WLT1	June	2004	2420	5400
WLT1	June	2004	866	560
WLT1	June	2004	137	210
WLT1	July	2004	1730	900
WLT2	May	2004	2420	41000
WLT2	May	2004	2420	300000
WLT2	June	2004	2420	10800
WLT2	June	2004	866	700
WLT2	July	2004	770	670

*m= missing data

Alkalinity-pH

Alkalinity is an important component of a freshwater environment. Alkalinity is a quantitative measure of carbon dioxide, carbonic acid, and carbonate and bicarbonate ions capable of neutralizing the pH of water (Wetzel, 1983). Extreme pH values, typically below 5 or above 9 su, can be detrimental to some aquatic organisms (Allan 1995). Alkalinity in natural environments typically ranges from 20 mg/L to 200 mg/L (Lind, 1985).

Grindstone Creek alkalinity ranged from 20 mg/L to 224 mg/L (median = 52.5 mg/L) from samples collected in 2001. Alkalinity was slightly higher in 2004 samples ranging from 40 mg/L to 284 mg/L (median = 75.5 mg/L). As expected, alkalinity was higher (mean = 109.8) at the lower site than the upper site (mean = 54.5 mg/L) due to the larger drainage area. Cumulatively, alkalinity was well below the state standard (<750 mg/L as a mean or < 1,313 mg/L single sample) designated to protect the beneficial uses of Grindstone Creek (Appendix A). pH was also well within the standard limits (>6.5 and < 9.5 su) in all samples collected during the project (Table 9).

Table 9. Grindstone Creek pH values measured during the project period.

Site	Year	pH su	Site	Year	pH su
WLT1	2001	7.37	WLT2	2001	7.35
WLT1	2001	7.71	WLT2	2001	7.24
WLT1	2001	7.58	WLT2	2001	7.22
WLT1	2001	7.94	WLT2	2001	7.81
WLT1	2001	7.58	WLT2	2003	7.5
WLT1	2004	6.71	WLT2	2004	8.5
WLT1	2004	7.82	WLT2	2004	6.79
WLT1	2004	7.37	WLT2	2004	7.93
WLT1	2004	7.41	WLT2	2004	7.45
WLT1	2004	7.59	WLT2	2004	7.42

Solids

Total solids consist of organic and inorganic materials transported in stream flow. Total solids are comprised of dissolved solids and suspended solids. Dissolved solids are typically salts and other inorganic particles that pass through a 0.45 um filter (Clesceri et al. 1998). Suspended solids are larger materials that do not pass through the filter. Suspended solids can be inorganic (sediment) or organic (algae, plant and animal material) in nature. Volatile solids are the organic portion of suspended solids which burn (produce ash) at 500°C.

Grindstone Creek dissolved solids varied considerably from 4,012 mg/L to 127 mg/L (median = 479 mg/L) in samples collected during 2001. In general, dissolved solids were relatively low (mean 797 mg/L) with the exception of one sample (4,012 mg/L) collected April 24, 2001 at the lower site. Flow was low (0.001 cfs) when the sample was collected suggesting groundwater as a likely source for this elevated value. Dissolved solids are typically higher in groundwater due to constant contact with the soils, especially shales common throughout the watershed. This was also the case in 2004 as dissolved solids ranged considerably from 4,173 mg/L to 160 mg/L (median = 340 mg/L). Dissolved solids were generally low (mean = 687 mg/L) with the exception of one sample collected May 26, 2004 at the lower site. Flow recorded on this date was 0.044 cfs strengthening the assumption that higher dissolved solids in Grindstone Creek are probably related to low flow conditions. Smith (2005) also found high dissolved solids during low flow conditions in Medicine Creek, South Dakota. Standard violations in Medicine Creek were often noted at low flows and virtually absent at high flows. The dissolved solids standard (< 4,375 mg/L daily maximum for a grab sample) was not exceeded in Grindstone Creek, despite two isolated high values that occurred during the project.

The dissolved solids loading (kg) was relatively low throughout the entire project period. The cumulative load of dissolved solids to Lake Waggoner was estimated at 308,275 kg

(Table 10). For comparison, Frozenman Creek in Stanley County contributed 809,919 kg to Lake Waggoner during 2001 while contributing less water volume (543.17 acre/ft) than Grindstone Creek (835.02 acre/ft) did during this project period.

Table 10. Grindstone Creek cumulative total dissolved solids (TDS) loading from the upper and lower site 2001 to 2004.

Station	Drainage Area (acres)	Watershed Gauged (%)	Hydrologic Load acre/ft	TDS cumulative Load (kg)	TDS Total Load (%)	TDS (kg/yr)	Export Coefficient (kg/acre)
Upper Site							
WLT2	15400	41.22	421.56	139,956	45.39	34,989	9.08
Lower Site							
WLT1	31200	83.51	835.02	308,275	100	77,069	9.88

* WLT1 contributes the cumulative load to Lake Waggoner.

Total suspended solids (TSS) ranged from 132 mg/L to 12 mg/L (median = 31.5 mg/L) for samples collected in 2001. Total suspended solids ranged from 680 mg/L to 15 mg/L (median = 79.5) for samples collected in 2004. The linear relationship between TSS and flow suggest that only 53% of the variability in TSS could be explained by flow (Figure 10). As expected, low flows corresponded well with low TSS. However, one data point (indicated by a circle) skewed the relationship. This sample was collected at the upstream site (WLT2) where considerable cattle use in and along the stream channel was evident. Without this point, flow would explain 75% of the variability in TSS.

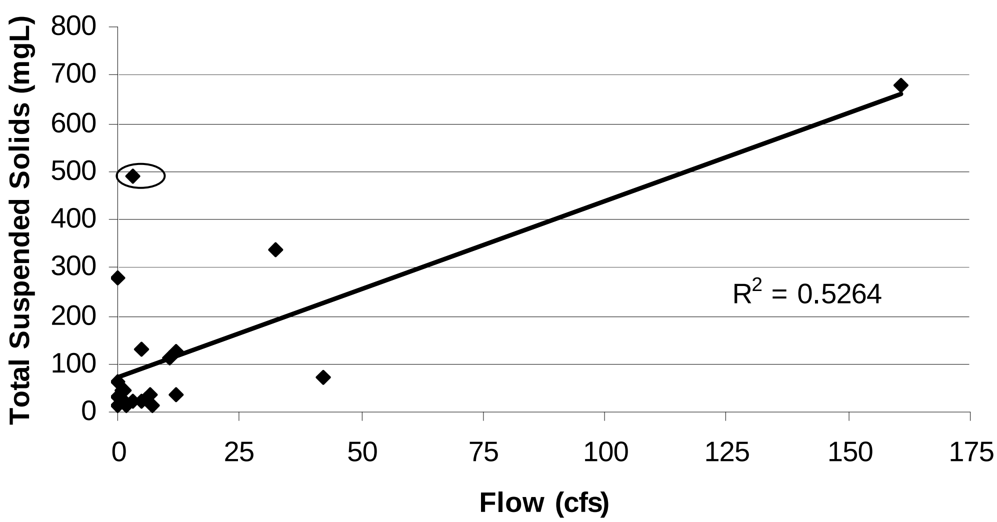


Figure 10. Linear relationship between TSS and flow using 2001 and 2004 data.

Grindstone Creek contributed an estimated 525,301 kg of suspended solids to Lake Waggoner during the project period (Table 11). The high flow event that occurred June 10, 2004 contributed an estimated 70% of the total load. This uncharacteristic flow provided overland and instream sediment movement which was ultimately delivered to Waggoner Lake. The majority of the TSS load (86.2%) occurred below the WLT2 monitoring site. The export coefficient at WLT1 (16.8 kg/acre) was higher than that of WLT2 (4.7 kg/acre). The stream channel is in considerably better condition in the upper portion of the watershed becoming more incised proportionally downstream. This is the result of the increase in drainage area and the incidence of sheer velocity.

Table 11. Grindstone Creek cumulative total suspended solids (TSS) loading from the upper site and lower site 2001 to 2004.

Station	Drainage Area (acres)	Watershed Gauged (%)	Hydrologic Load acre/ft	TSS cumulative Load (kg)	TSS Total Load (%)	TSS (kg/yr)	Export Coefficient (kg/acre)
Upper Site WLT2	15400	41.22	421.56	72430	13.78	18108	4.7
Lower Site WLT1	31200	83.51	835.02	525301	100	131325	16.83

* WLT1 contributes the cumulative load to Lake Waggoner.

Nitrogen

Nitrogen was measured as ammonia, nitrate and Total Kjeldahl Nitrogen (TKN). These parameters were used to estimate organic, inorganic and total nitrogen. During 2001 inorganic nitrogen (ammonia + nitrate) ranged from 46.8 mg/L to 0.41 mg/L. A high nitrate concentration (46.5 mg/L) was collected at WLT1 on April 24th. Flow was very low (0.001 cfs) when this sample was collected indicating groundwater influence. Seepage from groundwater is in constant contact with the soils which are characteristically high in nitrates within the watershed. All other nitrate concentrations collected in 2001 were < 2.0 mg/L (Appendix A). Inorganic nitrogen was significantly higher in 2001 samples (median = 1.65 mg/L) in comparison to those collected in 2004 (median = 0.13 mg/L, p=<0.05).

Organic nitrogen ranged from 2.15 mg/L to 1.17 mg/L with median and average concentrations of 1.68 mg/L and 1.63 mg/L, respectively for samples collected in 2001. Organic nitrogen ranged from 3.94 mg/L to 0.98 mg/L with median and average concentrations of 2.08 mg/L to 1.85 mg/L, respectively for samples collected in 2004. No significant differences in organic nitrogen were observed between years (p=>0.05). The percentage of organic to total nitrogen was significantly higher in 2004 in comparison to 2001 (p=<0.05, Table 12). The higher proportion of inorganic nitrogen observed in 2001 was likely a function of decomposition and snowmelt run-off which had greater contact with the soil. In 2004, most nitrogen was likely tied up in plant material which was at peak growth when the flow events occurred.

Table 12. Grindstone Creek total and organic nitrogen concentrations.

Monitoring Station	Date	Organic Nitrogen mg/L	Total Nitrogen mg/L	Percent Organic Nitrogen
WLT1	Mar-01	2.15	3.89	55.3
WLT1	Mar-01	1.62	3.46	46.8
WLT1	Mar-01	1.85	3.77	49.1
WLT1	Mar-01	1.17	2.88	40.6
WLT1	Apr-01	1.64	48.15	3.4
WLT2	Mar-01	1.7	2.29	74.2
WLT2	Mar-01	1.88	2.92	64.4
WLT2	Mar-01	1.62	3.67	44.1
WLT2	Mar-01	1.18	2.69	43.9
WLT2	Apr-01	1.48	1.89	78.3
WLT1	May-04	1.91	2.32	82.3
WLT1	Jun-04	2.19	2.77	79.1
WLT1	Jun-04	1.24	1.35	91.9
WLT1	Jun-04	1.34	1.4	95.7
WLT1	Jul-04	1.67	1.73	96.5
WLT2	May-04	3.94	4.11	95.9
WLT2	May-04	3.7	3.85	96.1
WLT2	Jun-04	1.8	2.04	88.2
WLT2	Jun-04	0.98	1.04	94.2
WLT2	Jul-04	1.98	2.04	97.1

Grindstone Creek contributed an estimated 2,081 kg of organic nitrogen during the project period (Table 13). The contribution of organic nitrogen was relatively consistent between the upper and lower portions of the watershed. The organic nitrogen export coefficients were similar (0.065 and 0.066 kg/acre) between sites WLT2 and WLT1, respectively.

Table 13. Grindstone Creek cumulative organic nitrogen (ON) loading from the upper site and lower site 2001 to 2004.

Station	Drainage Area (acres)	Watershed Gauged (%)	Hydrologic Load acre/ft	ON cumulative Load (kg)	ON Total Load (%)	ON (kg/yr)	Export Coefficient (kg/acre)
Upper Site WLT2	15400	41.22	421.56	1012.7	48.65	253.2	0.065
Lower Site WLT1	31200	83.51	835.02	2081.2	100	520.3	0.066

Grindstone Creek contributed an estimated 2,792 kg of total nitrogen during the project period (Table 14). An estimated 75% of the total nitrogen load to Lake Waggoner over the course of the project was in an organic form. The export coefficients (0.088 and 0.089 kg/acre) were again similar between the upper and lower subwatersheds.

Table 14. Grindstone Creek cumulative total nitrogen (TN) loading from the upper site and lower site 2001 to 2004.

Station	Drainage Area (acres)	Watershed Gauged (%)	Hydrologic Load acre/ft	TN cumulative Load (kg)	TN Total Load (%)	TN (kg/yr)	Export Coefficient (kg/acre)
Upper Site WLT2	15400	41.22	421.56	1363.7	48.8	340.9	0.088
Lower Site WLT1	31200	83.51	835.02	2791.8	100	698	0.089

Phosphorus

Total phosphorus is the sum of all attached and dissolved phosphorus in water. Phosphorus is an important nutrient with respect to primary production. During 2001, total phosphorus ranged from 0.58 mg/L to 0.04 mg/L with median and average concentrations of 0.36 mg/L and 0.37 mg/L, respectively. During 2004, total phosphorus ranged from 1.46 mg/L to 0.137 mg/L with median and average concentrations of 0.58 mg/L and 0.69 mg/L, respectively. Total phosphorus concentrations were significantly higher in 2004 in comparison to 2001 ($p = <0.05$). The higher total phosphorus concentrations were likely a function of flow and total suspended solids. Total suspended solids explained 73% of the variability in total phosphorus for all samples collected during the project period (Figure 11). These data demonstrate the importance of erosion control within the watershed. Best Management Practices (BMPs) tailored to minimize sediment transport during run-off events would likely decrease phosphorus transport throughout the watershed and ultimately into Lake Waggoner.

Total dissolved phosphorus is the unattached portion of the total phosphorus concentration. In 2001, total dissolved phosphorus ranged from 0.344 mg/L to 0.016 mg/L with median and average concentrations of 0.27 mg/L and 0.25 mg/L. The percentage of dissolved to total phosphorus ranged from 95% to 35% with an average of 66%. Only one total dissolved phosphorus sample was collected in 2004 (Appendix A).

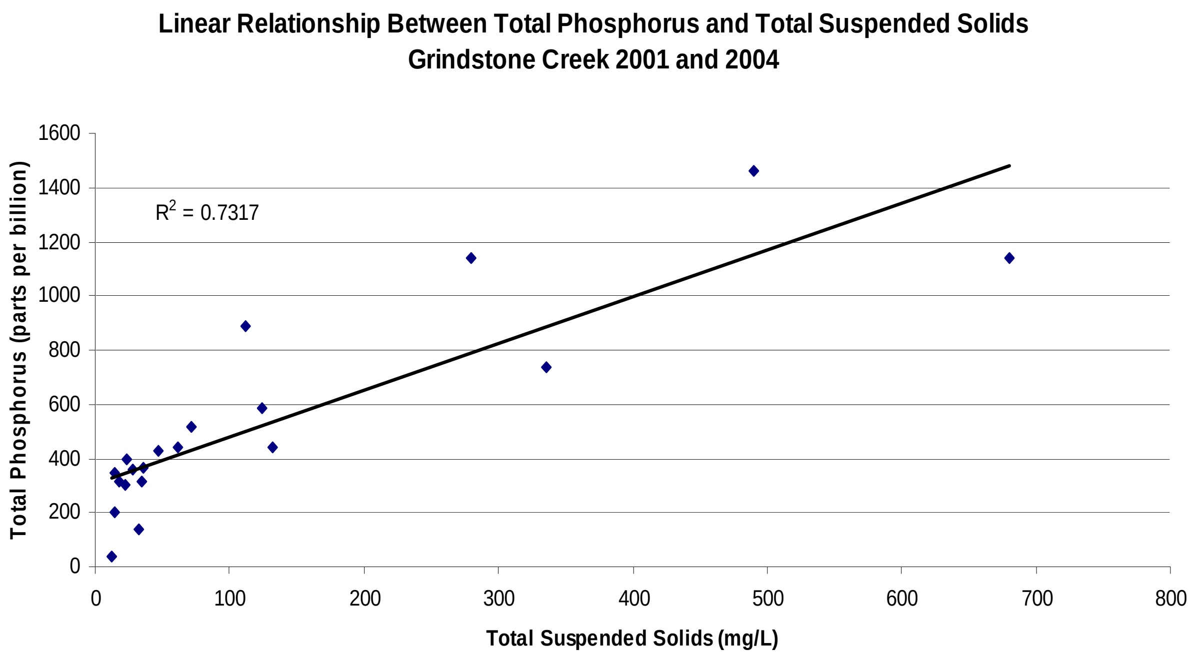


Figure 11. Linear relationship between total phosphorus and total suspended solids in Grindstone Creek 2001 and 2004.

Grindstone Creek contributed an estimated 961 kg of total phosphorus during the project period (Table 15). The contribution of total phosphorus was relatively consistent between the upper and lower portions of the watershed. The total phosphorus export coefficients were similar (0.02 and 0.03 kg/acre) between sites WLT2 and WLT1, respectively.

Table 15. Grindstone Creek cumulative total phosphorus (TP) loading from the upper site and lower site 2001 to 2004.

Station	Drainage Area (acres)	Watershed Guaged (%)	Hydrologic Load acre/ft	TP cumulative Load (kg)	TP Total Load (%)	TP (kg/yr)	Export Coefficient (kg/acre)
Upper Site WLT2	15400	41.22	421.56	339.9	35	85	0.02
Lower Site WLT1	31200	83.51	835.02	960.5	100	240.1	0.03

An annual load estimate was also calculated for the artesian well based on the permitted flow allowance (0.8 cfs, DENR Permit No. 574-2) and concentration data from a sample collected March 2003 (Appendix A). Based on this information the artesian well was estimated to contribute a total phosphorus load of 6.4 kg/yr. However, the actual flow is expected to be less than the permitted level, inflating this estimated TP load by at least ½ or 3.2 kg/yr.

Grindstone Creek contributed an estimated 277 kg of total dissolved phosphorus during the project period (Table 16). An estimated 29% of the total phosphorus load to Lake Waggoner over the course of the project was in dissolved form. The export coefficients (0.01 and 0.0088 kg/acre) were again similar between the upper and lower subwatersheds.

Table 16. Grindstone Creek cumulative total dissolved phosphorus (TDP) loading from the upper site and lower site 2001 to 2004.

Station	Drainage Area (acres)	Watershed Guaged (%)	Hydrologic Load acre/ft	TDP cumulative Load (kg)	TP Total Load (%)	TP (kg/yr)	Export Coefficient (kg/acre)
Upper Site WLT2	15400	41.22	421.56	164.5	59.3	41.1	0.01
Lower Site WLT1	31200	83.51	835.02	277	100	69.3	0.0088

Waggoner Lake Nutrient and Solids Budget

Lake Waggoner retained nitrogen, phosphorus and suspended solids loads during the project period (Table 17). The lake at the outlet had removed an estimated 80% of the nitrogen load from Grindstone Creek, while only 41% of the phosphorus load was removed by the time lake water reached the outlet during the project period. An estimated 563 kg of phosphorus was retained in Lake Waggoner over the project period. An estimated 78% of the suspended solids load (409,421 kg) from Grindstone Creek (2001-2004) was retained within Lake Waggoner.

A significant net reduction in dissolved solids load was estimated during the project period (Table 17). An estimated 722,798 kg of dissolved solids were discharged via the lake outlet while only 308,274 kg was loaded to the lake from Grindstone Creek during the project hydroperiod. This net loss (414,524 kg) is likely attributable to the heavy internal load of TDS that was present in Lake Waggoner prior to overflow. The artesian well that discharges to Waggoner Lake is relatively high in TDS and may have contributed to higher inlake concentrations. This and evaporation from the lake surface were likely responsible for concentrating TDS during the dry cycle.

Due to drought and the non-typical rain event (June 2004) that occurred during this 3.5-year monitoring effort the budget does not reflect an average annual storage. However, excess phosphorus storage could support an increase in primary production over time and a resulting increase in sedimentation can contribute to a loss in volume, ultimately impacting the beneficial uses of Lake Waggoner.

Table 17. Lake Waggoner nutrient and solids budget from the 2001-2004 hydroperiod.

Site	TSS (kg)	TDS (kg)	TN (kg)	TP (kg)
Lake Outlet	115,880	722,798	2,218	398
WLT1	525,301	308,274	2,791	961
Net Gain	**409,421**	**- 414,524***	**573**	**563**

* indicates a net loss

Waggoner Lake Hydrologic Budget

Hydrologic inputs to Waggoner Lake were estimated as inflow from Grindstone Creek (WLT1), annual precipitation, artesian well and ungaged sources. During the project period flow was not directly measured from the artesian well and lake level was not monitored. As a result, several assumptions had to be made with respect to the contribution of the artesian well to the overall hydrologic budget. The city of Philip holds a discharge permit (Permit No. 574-2) with DENR, which allows 0.8 cfs to flow into Lake Waggoner. However, the actual flow volume that enters the lake directly was unknown. Since limited inflow was experienced during the 2001 hydroperiod the contribution of the artesian well was estimated as the balancing factor of the hydrologic budget. To balance the 2001 hydrologic budget the well was estimated to have contributed ½ of the permitted 0.8 cfs or 0.4 cfs. This estimated flow volume was also used to construct the 2004 hydrologic budget. Since the lake level was at an undetermined stage below the spillway in both years, this flow rate was assumed to be over-estimated.

During the 2001 hydroperiod an estimated 53% of the hydrologic budget was attributed to the artesian well. In addition, 37% and 10% of the hydrologic budget was attributed to Grindstone Creek and annual precipitation, respectively (Figure 12). Following nearly four years of drought (summer 2001 to summer 2004) the local project coordinator visually estimated the lake level at only 2 feet below spillway elevation in the spring of 2004. While this was a rough estimate it demonstrates the well's ability to maintain water levels during periods of drought.

During the 2004 hydroperiod an estimated 59% of the hydrologic budget was attributed to Grindstone Creek inflows. This was not surprising given the numerous rain events including the large-scale rain event that occurred in June 2004. However, this contribution was likely underestimated as the lake level below spillway elevation was not taken into account. Nonetheless, the artesian well, annual precipitation and ungaged sources accounted for an estimated 27%, 12% and 2% of the hydrologic budget, respectively (Figure 13). The ungaged portion was attributed to run-off from the immediate landscape adjacent to Lake Waggoner.

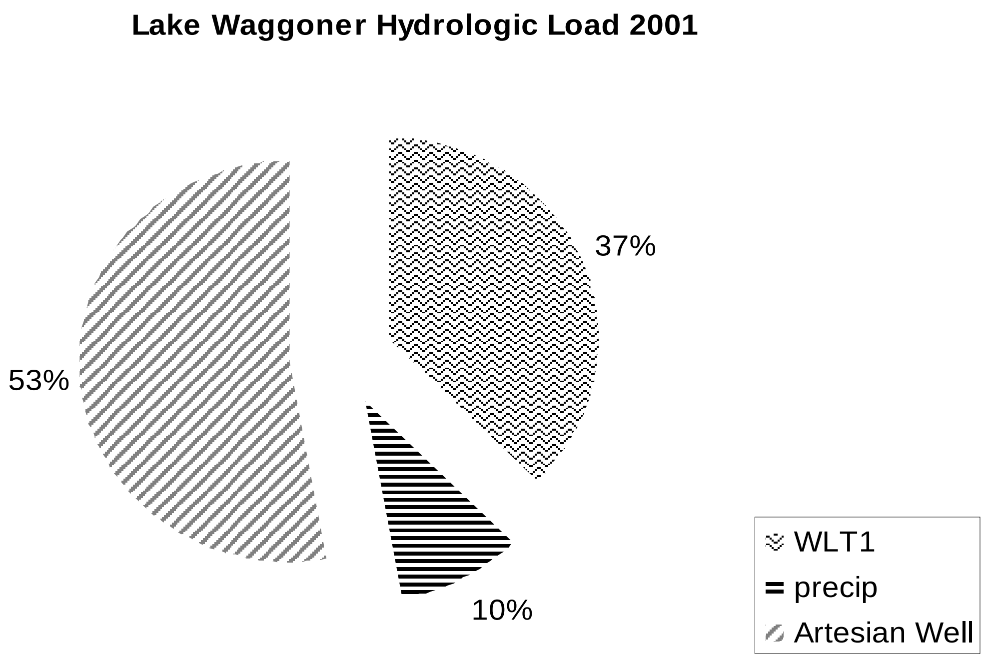


Figure 12. Hydrologic budget for Waggoner Lake during the 2001 sampling season.

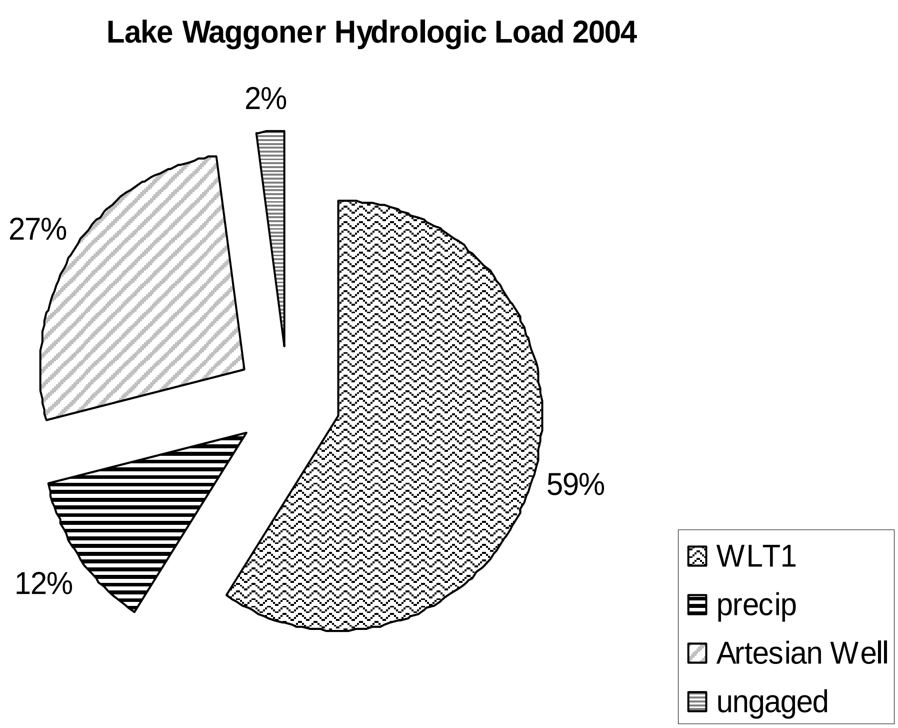


Figure 13. Hydrologic budget for Waggoner Lake during the 2004 sampling season.

Grindstone Creek Summary

The Grindstone Creek watershed experienced a severe drought during the majority of the project period. Despite these conditions nutrient and solids concentrations and loadings were collected and estimated (FLUX) from snowmelt run-off (2001) and summer storm events (2004). No water quality standard violations were experienced from any samples collected on Grindstone Creek during this assessment. In June of 2004 the watershed experienced a rainfall event that produced anywhere from 6 to 8 inches over a few hours. As a result, Grindstone Creek experienced flood stage flows in the upper portion of the watershed (WLT2) and bankfull stage in the lower more incised portion of the watershed (WLT1). Grindstone Creek delivered 579.6 acre-feet of water to Waggoner Lake from this flow event. This volume represented near complete flushing as the volume of Lake Waggoner at the spillway is 665 acre-feet. This flow event contributed the majority of the nutrient and solids loading to Waggoner Lake during the project period.

Concentrations

Dissolved solids and nitrate concentrations were elevated in samples collected during low or base flow conditions. Dissolved solids and nitrates are typically higher in groundwater due to constant contact with the soils, especially shales common throughout the watershed. The inorganic proportion of the total nitrogen concentrations was significantly higher in 2001 in comparison to 2004. In 2004, most nitrogen was likely tied up in plant material which was at peak growth when the flow events occurred. A significant linear relationship (R^2=0.73) was observed between suspended solids and total phosphorus. This relationship demonstrates the importance of erosion control to reduce the incidence of phosphorus migration from the watershed to Lake Waggoner.

Loadings

Most nutrient and sediment per acre loading rates (export coefficients) were similar between the upper and lower sites with the exception of total suspended solids. The lower site was estimated to contribute 16.7 kg/acre or 4 times more suspended solids than the upper site. This difference was likely the result of downstream channel instability and elevated bed and bank transport during storm events. The lake outlet removed an estimated 80% and 41% of the nitrogen and phosphorus load from Grindstone Creek, respectively. An estimated 563 kg of phosphorus was retained in Lake Waggoner over the project period. An estimated 78% of the suspended solids load from Grindstone Creek (2001-2004) was retained within Lake Waggoner. Total dissolved solids displayed a net loss (414,524 kg) attributable to the internal load of TDS that was present in Lake Waggoner prior to overflow. The artesian well that discharges to Waggoner Lake is relatively high in TDS and together with natural lake evaporation higher inlake concentrations were observed during the drought.

<u>Waggoner Lake Water Quality</u>

Inlake water quality sample collection began in February 2001 and was conducted on a monthly basis, except during unsafe ice conditions, until October 2001 at two pre-selected sites (Figure 14). Lakes samples were also collected April through August of 2004. The South Dakota State Health Laboratory analyzed all samples. In the case when a nutrient parameter was not detectable by standard analytical procedures, a numeric value of ½ the detectable limit was used to represent the concentration for a given parameter. Undetectable concentrations do not necessarily indicate absence. However, an undetectable concentration is considered insignificant. Samples were collected at the surface and bottom at all sites. The purpose of these samples was to assess nutrient concentrations in the lake and to determine lake trophic state. All samples were collected in compliance with the "South Dakota Standard Operating Procedures for Field Samplers" (SOP), (Smith 2005).

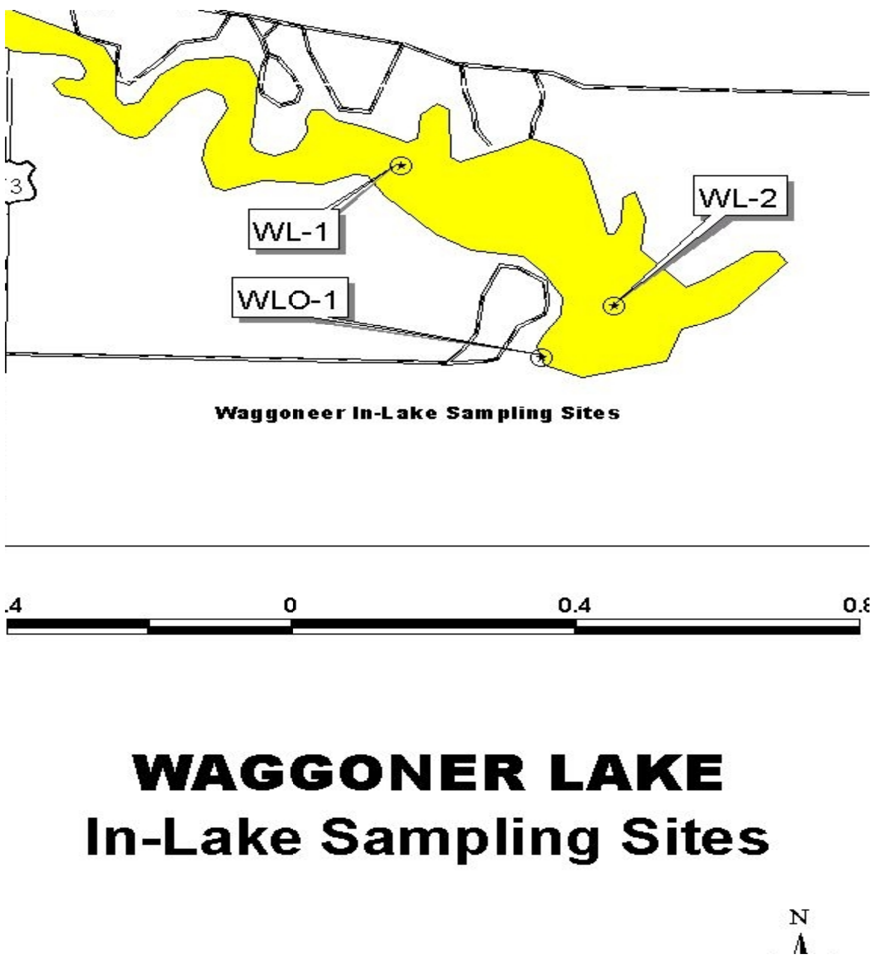


Figure 14. Waggoner Lake Inlake Monitoring Stations.

Water samples were filtered, preserved, and packed in ice for shipping to the State Health Lab in Pierre, SD. Sample data collected at Waggoner Lake may be found in Appendix C. The laboratory then assessed the following parameters:

Fecal Coliform Counts	Alkalinity
Total Solids	Total Suspended Solids
Ammonia	Nitrate
Total Kjeldahl Nitrogen (TKN)	Total Phosphorus
Volatile Total Suspended Solids	

The laboratory calculated these parameters:

Total Dissolved Phosphorus	Total Dissolved Solids
Un-ionized Ammonia	

Chlorophyll *a* was determined at the DENR laboratory.

Personnel conducting the sampling at each of the sites recorded visual observations of weather and lake characteristics. Observations recorded were:

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

Parameters measured in the field by sampling personnel were:

Water Temperature	Air Temperature
Secchi Depth	Dissolved Oxygen
Field pH	

*All physical and biological parameters were collected using the standard methods described in the South Dakota Standard Operating Procedures for Field Samplers manual (Smith 2005).

Quality Assurance/ Quality Control samples were collected in accordance to South Dakota's EPA-approved Clean Lakes Quality Assurance/Quality Control Plan. This document can be obtained by contacting the South Dakota Department of Environment and Natural Resources at (605) 773-4254. A summary of QA/QC samples can be found in a subsequent section of this report.

South Dakota Water Quality Standards

The beneficial use classifications of surface waters of the state listed in this section do not limit the actual use of such waters. The classifications designate the minimum quality at which the surface waters of the state are to be maintained and protected (South Dakota Surface Water Quality Standards, 74:51:01:42. Beneficial uses of waters established).

Waggoner Lake has been assigned the following water quality beneficial uses:

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

In the case when beneficial uses have different standard limits for the same parameter, the most stringent standard is applied. Table 18 indicates the most stringent standard limits for Lake Waggoner for the parameters analyzed in this study.

Table 18. Waggoner Lake designated water quality standards.

Parameter	Standard	
Total Dissolved Solids	<1,000 mg/L (30-day average) <1,750 mg/L (daily maximum)	
Nitrates	<10 mg/L	
pH	>6.5 & <9.0 units	
Fecal Coliform	<200/100mL	Geometric mean of a minimum of 5 samples during separate 24-hour periods for a 30-day period and may not exceed this value in more than 20 percent of the samples examined in the same 30-day period
	<400/100mL	In any one sample
Total Chlorine Residual	<250 mg/L	30-day average
	<438 mg/L	Daily maximum
Total Ammonia Nitrogen as N	Equal or less than the result from Equation 3 or 4* in Appendix A	30-day average March 1 – October 31 * November 1 –February 29
	Equal to or less than the result from Equation 2 in Appendix A	Daily maximum
Dissolved Oxygen	> 5.0 mg/L	
Undisassociated Hydrogen Sulfide	<0.002 mg/L	
Total Suspended Solids	<90 mg/L	30-day average
	158 mg/L	Daily maximum
Temperature	< 90 ^{o}F	see 74:51:01:31
Total Alkalinity as Calcium Carbonate	<750 mg/L	30-day average
	1313 mg/L	Daily maximum
Conductivity at 25 deg. C	4,000 micromhos/cm	30-day average
	7,000 micromhos/cm	Daily maximum
Barium	<1.0 mg/L	
Sulfate	<500 mg/L	30-day average
	<875 mg/L	Daily maximum
Fluoride	<4.0 mg/L	
Total Petroleum Hydrocarbons	<1.0 mg/L	

74:51:01:31: refer to chapter 74:51:01 of the South Dakota Surface Water Quality Standards

Inlake Water Quality Parameters

Water Temperature

Water temperature is of great importance to any aquatic ecosystem. Many organisms and biological processes are temperature sensitive. Blue-green algae tend to dominate warmer waters while green algae and diatoms generally do better under cooler conditions. Water temperature also plays an important role in physical conditions. Oxygen dissolves in higher concentrations in cooler water. Higher toxicity of un-ionized ammonia is also related directly to warmer temperatures.

Surface water temperature ranged from 3.5 ^{o}C (February) to 24.9^{o}C (July) across all months sampled in 2001. The median growing season temperature was 21.4 ^{o}C (average = 20.0 ^{o}C) for surface samples and 20.0 ^{o}C (average =19.8 ^{o}C) for bottom samples. No significant difference in water temperature was observed between sites or between surface and bottom samples (p=>0.05, Appendix A). All measured water temperature values fell below the water quality standard (<32.2 ^{o}C) designated to protect the warmwater semipermanent fish life propagation beneficial use. Thermal stratification was minimal during the 2001 sampling period (Appendix B).

Surface water temperature ranged from 12.4 ^{o}C (April) to 22.5^{o}C (July) across all months sampled in 2004. The median growing season temperature was 19.2^{o}C (average = 19.3 ^{o}C) for surface samples and 18.7 ^{o}C (average =18.6 ^{o}C) for bottom samples. No significant difference in water temperature was observed between surface and bottom samples (p=>0.05, Appendix A). All measured water temperature values fell within the water quality standard limit. Thermal stratification was again minimal during the 2004 sampling period (Appendix B).

Dissolved Oxygen

There are many factors that can influence the dissolved oxygen (DO) concentration of a waterbody. Temperature is one of the most important of these factors. As water temperature increases the ability to hold DO in saturation decreases. Daily and seasonal fluctuations in DO may also occur in response to algal and bacterial action (Bowler, 1998). As algae and aquatic plants photosynthesize during the day they produce oxygen, which raises the concentration in the epilimnion. As photosynthesis ceases at night respiration utilizes available oxygen causing a decrease in concentration.

As algae bloom in the late spring and summer they create a shading effect. The shading condition blocks light penetration and reduces oxygen production by aquatic plants. The lack of oxygen production at lower depths coupled with oxygen consumption in the sediment can create anoxic conditions in the hypolimnion or deeper portion of the lake. Anoxic sediments release metals (iron, manganese) and gases (hydrogen sulfide) which can cause taste and odor problems in drinking water. Anoxic sediments also decrease the redox potential or binding capability of phosphorus to the sediments. The result is phosphorus transfer from the sediments to the water column where it becomes available to algae and other primary producers.

Waggoner Lake is classified as a domestic water supply for the city of Philip. Prior to 2002 the city operated and maintained an aeration system to break oxygen stratification and improve the quality of drinking water. The air injection system was located in the deeper portion of the lake near the dam. Air injection systems deliver air through perforated pipe(s) placed near the bottom. Rising air bubbles cause water in the hypolimnion to rise to the surface or epilimnion. As the hypolimnetic water flows across the surface it becomes re-oxygenated with atmospheric oxygen and later sinks back into the epilimnion. The process acts to break the metalimnion (transition zone between the hypolimnion and epilimnion) providing a homogenous (well distributed) mixture of DO and temperature. A well oxygenated aquatic system benefits many abiotic and biotic processes.

Dissolved oxygen ranged from 14.2 mg/L to 7.6 mg/L for surface measurements and 12.8 mg/L to 7.2 mg/L for bottom measurements collected across sampling dates in 2001. The median growing season DO was 8.3 mg/L (average = 8.3 mg/L) for surface samples and 8.6 mg/L (average = 8.5 mg/L) for bottom samples. No significant difference in DO was observed between sites or between surface and bottom samples (p=>0.05, Appendix X). All DO measurements collected in 2001 were above the water quality standard (> 5.0 mg/L) designated to protect the warmwater semi-permanent fishery.

An oxygen-temperature profile measures the change in concentration of DO and corresponding temperature at different depths of the lake. The purpose of the profiles is to check for the presence and extent of stratification. Dissolved oxygen and temperature profiles were recorded at the sampling sites monthly beginning in April 2001. Dissolved oxygen and temperature profiles were recorded from the surface to the bottom at one meter intervals. Profiles for all sampling dates are graphically represented in Appendix B.

The profile data indicate that temperature and oxygen stratification was not evident at either site during the sampling periods in 2001 (Appendix B). Most profiles displayed slight albeit subtle differences in DO and temperature from the surface to the bottom. The lowest dissolved oxygen concentrations observed near the bottom in any profile was above 7 mg/L indicating aerobic conditions in the bottom sediments. The absence of stratification and a well oxygenated water column likely favored growth and maintenance of aquatic biota, in particular fish species that inhabit Lake Waggoner. Since stratification is a natural process, the aeration system was likely responsible for preventing stratification and anoxic conditions in 2001.

Dissolved oxygen ranged from 10.5 mg/L to 7.9 mg/L for surface measurements and 8.7 mg/L to 1.1 mg/L for bottom measurements collected across sampling dates in 2004. The median growing season DO was 8.0 mg/L (average = 8.6 mg/L) for surface samples and 6.1 mg/L (average = 5.2 mg/L) for bottom samples. Most DO measurements collected in

2004 were above the water quality standard (> 5.0 mg/L) with the exception of June when near anoxic conditions were prevalent near the bottom at both sites.
The 2004 profile data indicated that oxygen stratification was beginning to occur in May. Dissolved oxygen concentrations near the dam were above 8.0 mg/L near the surface diminishing to 5.9 mg/L near the bottom (Figure 15). Oxygen stratification was evident in June below 3 meters of depth from both sites (Figures 16 and 17). Oxygen consumption (respiration) from decomposing organic material in the bottom sediments coupled with minimal wind and wave action likely allowed the oxygen poor hypolimnetic zone to establish. Oxygen concentrations in the hypolimnion were below that required by most aquatic organisms (Allan 1995). Concentrations were also below the water quality standard (< 5 mg/L). The DO standard for fish life propagation only applies to the upper mixed layer or epilimnion portion of the water column for making a support or impairment determinations based on the water quality standard. Since DO concentrations were above the water quality standard in the first 3 meters of depth it is assumed that fish and other aquatic organisms can seek refuge in this zone and impairment was not recognized.

Oxygen stratification was not evident in July and August of 2004, especially near the dam (WL2). It is difficult to speculate why oxygen stratification was lacking during July and August. According to coordinator notes considerable algae production was evident, while wind was relatively calm in both months, respectively. It is possible that oxygen production by algae and macrophytes exceeded respiration even in the lower depths. However, Secchi depths were less than 0.75 meters (July and August) suggesting limited photosynthesis in the lower depths. Nonetheless, Lake Waggoner is prone to stratification especially in the absence of artificial aeration.

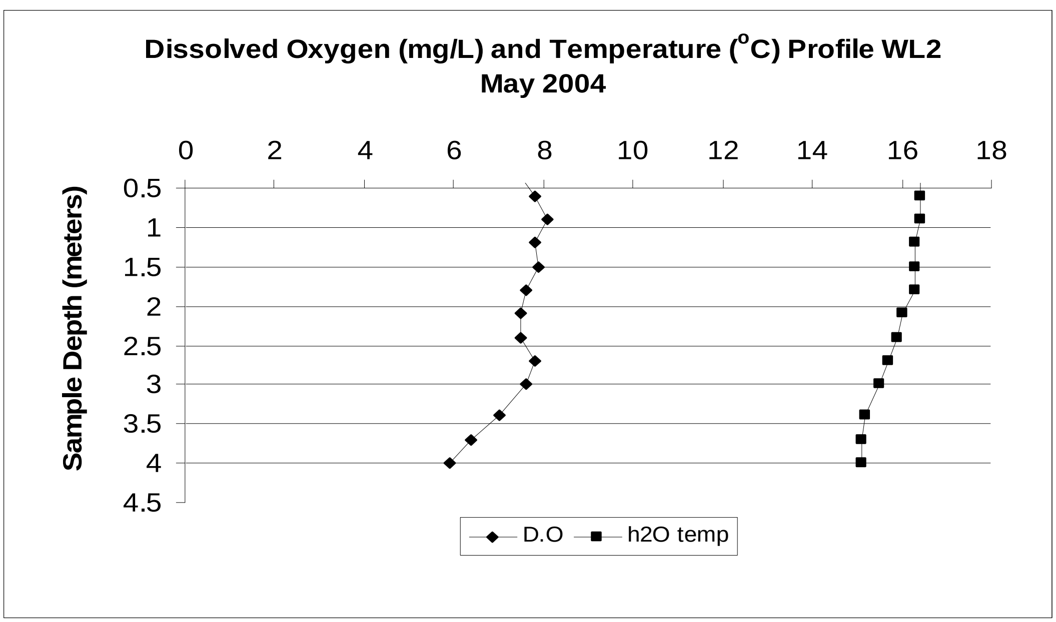


Figure 15. Dissolved oxygen and temperature profile WL2, May 2004.

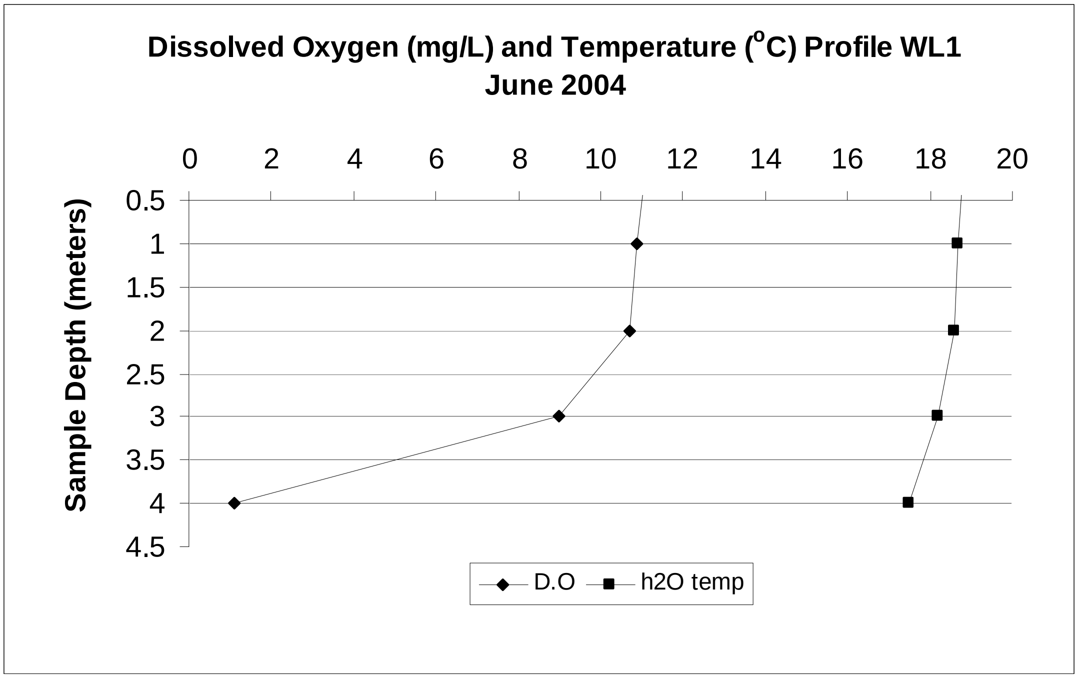


Figure 16. Dissolved oxygen and temperature profile WL1, June 2004.

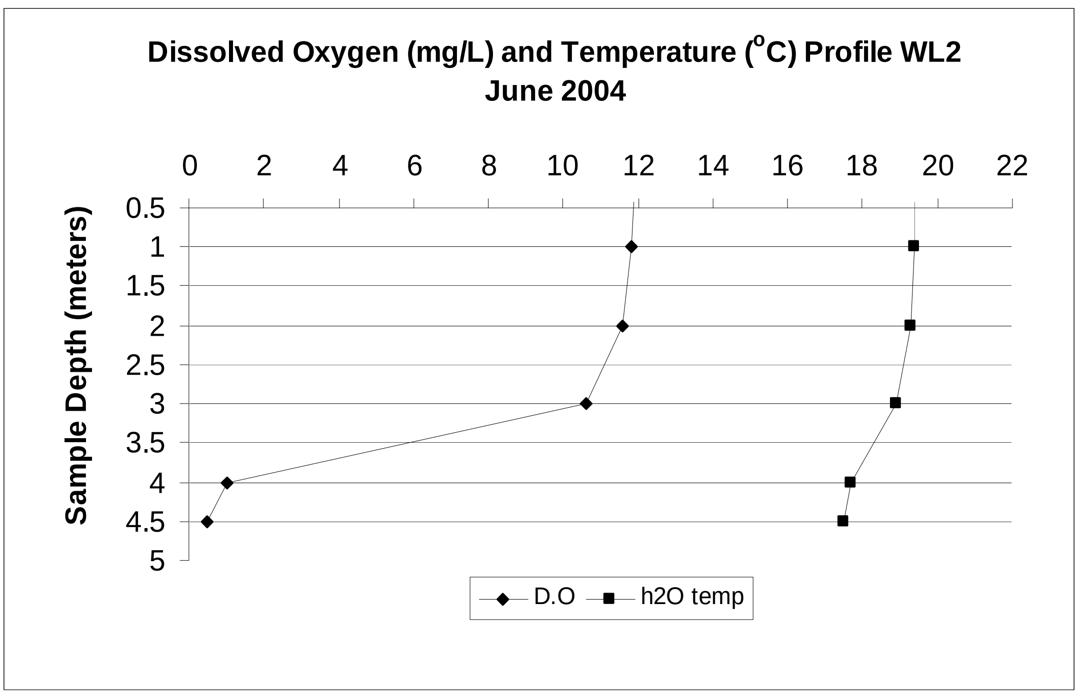


Figure 17. Dissolved oxygen and temperature profile WL2, June 2004.

pH

pH is a measure of free hydrogen ions (H^+) or potential hydrogen. More simply it indicates the balance between acids and bases in water. It is measured on a logarithmic scale between 0 and 14 and is recorded as standard units (su). At neutral (pH of 7) acid ions (H^+) equal the base ions (OH^-). Values less than 7 are considered acidic (more H^+ ions) and greater than 7 are basic (more OH^- ions). Algae and macrophyte photosynthesis act to increase a lake's pH. Respiration and the decomposition of organic matter will reduce the pH. The extent to which this occurs is affected by the lake's ability to buffer against changes in pH. The presence of alkalinity represents buffering capacity and will reduce the effects of both photosynthesis and decay in producing large fluctuations in pH.

During the 2001 sampling period, the surface pH ranged from 9.00 s.u (April) to 8.53 s.u (June). The bottom pH ranged from 9.02 s.u (April) to 8.45 s.u (June). No significant differences in pH were observed between surface and bottom samples across sites in 2001 ($p=>0.05$). pH measurements recorded in April 2001 from sites WL1 and WL2 were 9.00 s.u and 9.02 s.u, respectively. These two pH measurements exceeded the water quality standard limit ($\leq$9.00 s.u). The highest chlorophyll biomass (77.4 mg/m^3) was also recorded in April 2001 and may have contributed to the pH exceedances. All other pH measurements collected during the 2001 sampling period were within the water quality standard limit.

Lake Waggoner was not considered impaired for pH based on the two exceedances observed during the 2001 sampling period. The most recent pH data collected in 2004 displayed no exceedances in the water quality standard limit. All pH data available for Waggoner Lake shows only a 2% exceedance rate, which is below 10% allowable exceedances used to make 303(d) listing determinations. The pH in Lake Waggoner over the project period was well within the range to support the health and maintenance of aquatic organisms (Alan 1995).

During the 2004 sampling period, the surface pH ranged from 8.40 s.u (April) to 7.22 s.u (August). The bottom pH ranged from 8.44 s.u (April) to 7.72 s.u (August). No significant differences were observed between surface and bottom samples across sites ($p>0.05$). The summer (May-August) pH in Lake Waggoner was significantly lower in 2004 in comparison to 2001 (Figure 18). The lower pH in the summer of 2004 may be attributed to a change in ionic composition (hydrogen and carbon ions), which was reflected in the pH of Grindstone Creek inflows (Appendix A). Alkalinity was likely buffering any major fluctuations in pH.

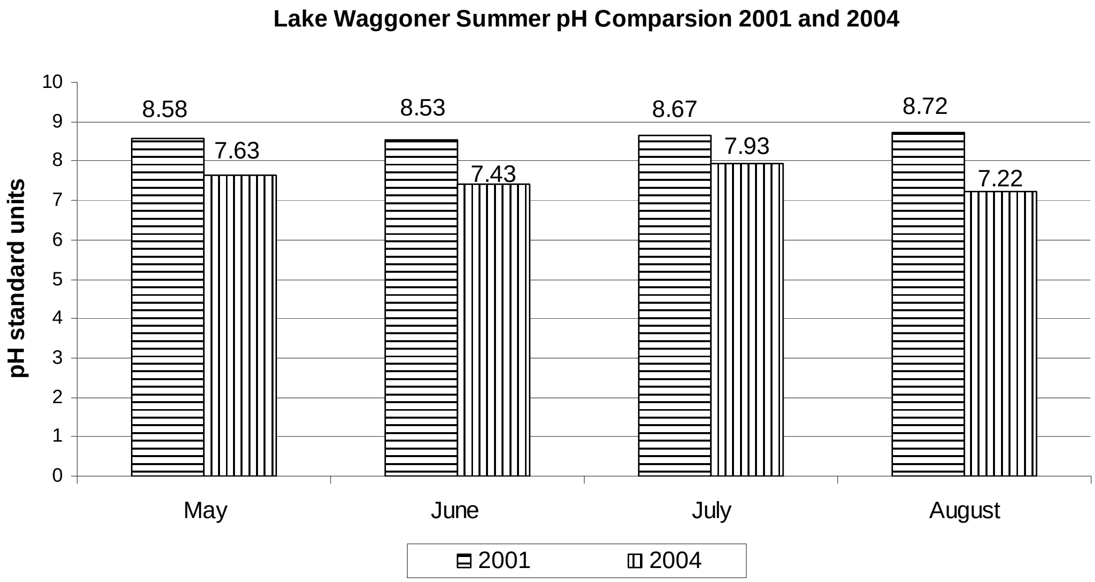


Figure 18. Lake Waggoner summer pH comparison 2001 and 2004.

Alkalinity

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

During the 2001 sampling period total alkalinity concentrations ranged from 196 mg/L to 152 mg/L and 206 mg/L to 150 mg/L for surface and bottom samples, respectively. No significant differences in total alkalinity were observed between surface and bottom across sites (p=>0.05). Total alkalinity was significantly higher in 2001 (median = 183 mg/L) in comparison to 2004 (median = 122 mg/L) as values ranged from 136 mg/L to 74 mg/L in surface and bottom samples. No significant differences in total alkalinity were observed between surface and bottom across sites (p=>0.05). The lower alkalinity concentrations observed in 2004 may be attributed to higher water levels which dilute concentrations. All total alkalinity samples were well below the water quality standard.

Fecal Coliform Bacteria

Fecal coliform are bacteria that are found in the waste of warm-blooded animals. Some common types of bacteria are *E. coli*, S*almonella,* and *Streptococcus,* which are associated with livestock, wildlife, and human waste. (Novotny, 1994). Fecal coliform bacteria are an indicator of the possibility of pathogens in the water. Inlake concentrations are typically low in a large body of water because of exposure to sunlight and dilution.

During the 2001 sampling period fecal coliform concentrations were low and never exceeded the water quality standard (400 colonies in one grab sample) designated to protect the immersion recreation beneficial use. Eleven of the 15 samples collected yielded concentrations below the laboratory detection limit (Figure 19). Detectable fecal coliform concentrations ranged from 10 to 20 colonies/100ml. These concentrations were observed exclusively during the summer months when watershed inputs were non-existent. As a result, these fecal coliform concentrations can be attributed to a local influence such as wildlife or cattle which had direct access to the southeast portion of the lake. During the 2004 sampling period only three fecal coliform samples were collected. The first two samples (April & May) both yielded concentrations of 20 colonies/100ml, while the third (August) was less than the detection limit. Fecal coliform contamination did not appear to be a problem during the project period. However, controlling manure run-off from the watershed during storm events would minimize the risk of fecal coliform contamination and the associated human health risks.

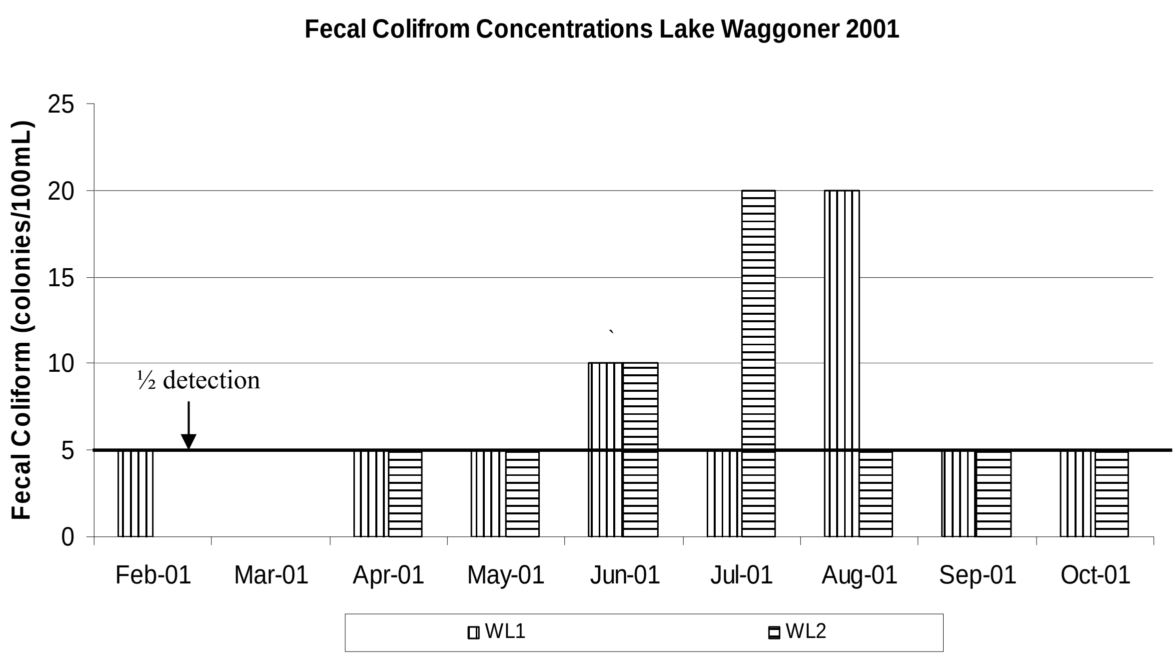


Figure 19. Fecal coliform concentrations Lake Waggoner 2001.

Secchi Depth Transparency

Secchi depth transparency is a common measure used to assess the clarity of water. Secchi depth transparency has also been related to the photic zone or depth at which photosynthesis occurs (Cole 1994). Secchi depth provides a quantitative value useful for making water clarity comparisons within and between lakes. In general, lower Secchi values equate to increased productivity and poorer water quality. Factors such as primary production (algae) and other organic-inorganic suspended solids can suppress the clarity of water. In shallow windswept lakes re-suspension of bottom sediments coupled with shoreline erosion act to reduce water clarity. The pigments (chlorophyll) contained within algae and leachates from leaves and other organic materials can cause discoloration leading to reduction in water clarity.

During the 2001 sampling period Secchi depth ranged from 2.0m to 0.55m from WL1 and 2.2m to 0.5m from WL2. No significant differences were observed between sites ($p>0.05$). The median Secchi depth for sites WL1 and WL2 was 0.93m (average = 1.0m) and 0.90m (average = 1.0m), respectively. Secchi depth transparency was relatively low in the winter and spring (including May) increasing significantly by June. A sharp drop in transparency was observed in July with an increasing trend by late summer/early fall. Results from the Secchi depth measurements conducted in 2001 are depicted in figure 20.

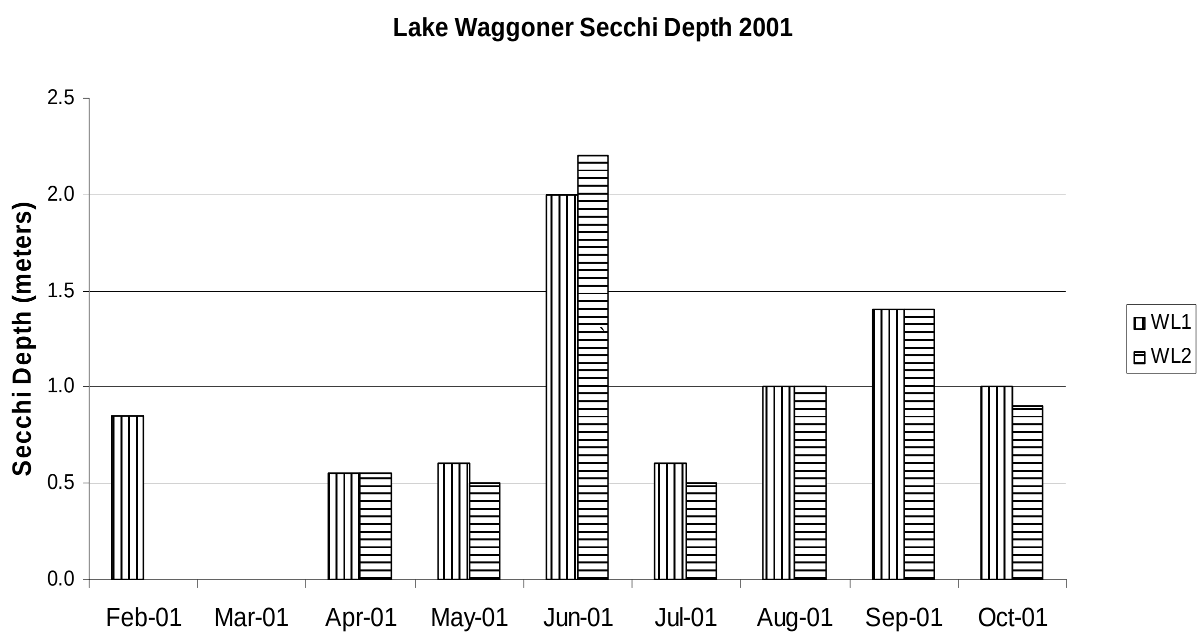


Figure 20. Lake Waggoner Secchi measurements conducted in 2001.

A series of relationships were developed to investigate potential factors affecting the water clarity of Lake Waggoner in 2001. The data collected in February 2001 was not included in the regression analysis due to the potential for ice to skew the relationships. Total suspended solids (TSS) were found to explain 83% of the variability in Secchi Depth. This is not unusual as an increase in particles (i.e. TSS) in the water column would be expected to refract light and decrease water clarity. Chlorophyll-*a* was found to explain only 41% of the variability in TSS (Figure 21). Without the samples collected in May (considered outliers) the relationship strengthened and the regression coefficient indicated that nearly 70% of the variability in TSS was explained by chlorophyll-*a* (Figure 21).

The relationship between Secchi depth and chlorophyll-*a* was also strongly dictated by May data. With May data included; chlorophyll explained 36% (R^2=0.0355) of the variability in Secchi depth. Without May data chlorophyll explained 81% of the variability in Secchi depth (Figure 22). These results suggest that algal biomass was an important contributor to water clarity during most of the 2001 sampling period, though inconclusive in May.

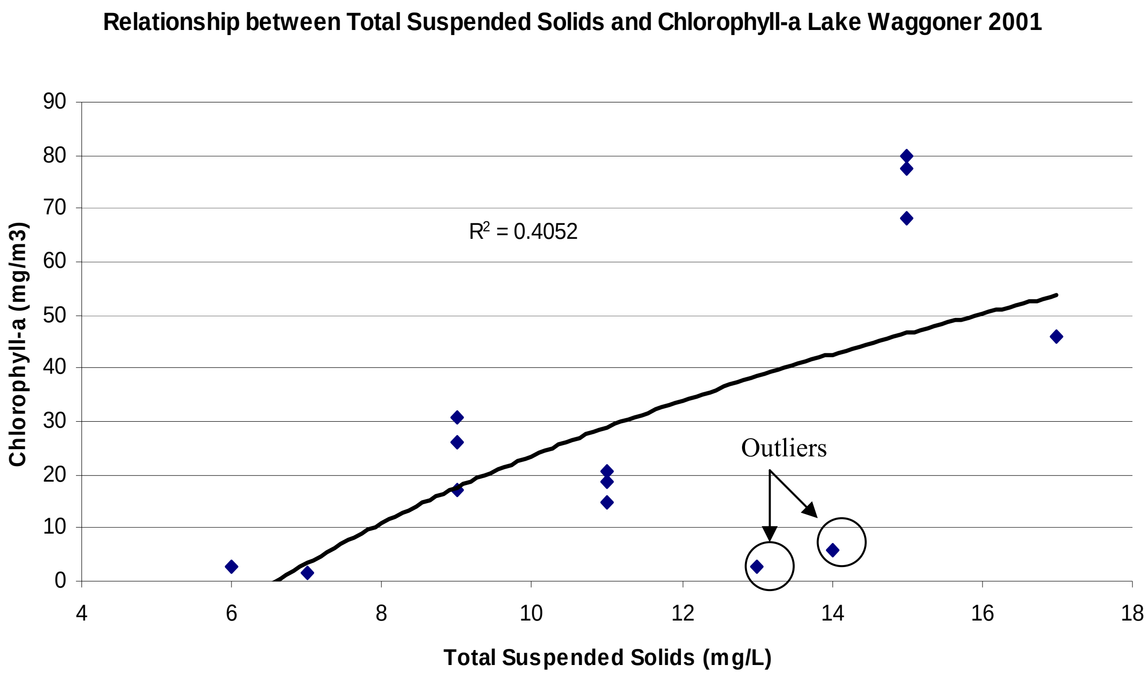


Figure 21. Logarithmic relationship between TSS and chlorophyll-*a* (including May data), Lake Waggoner 2001.

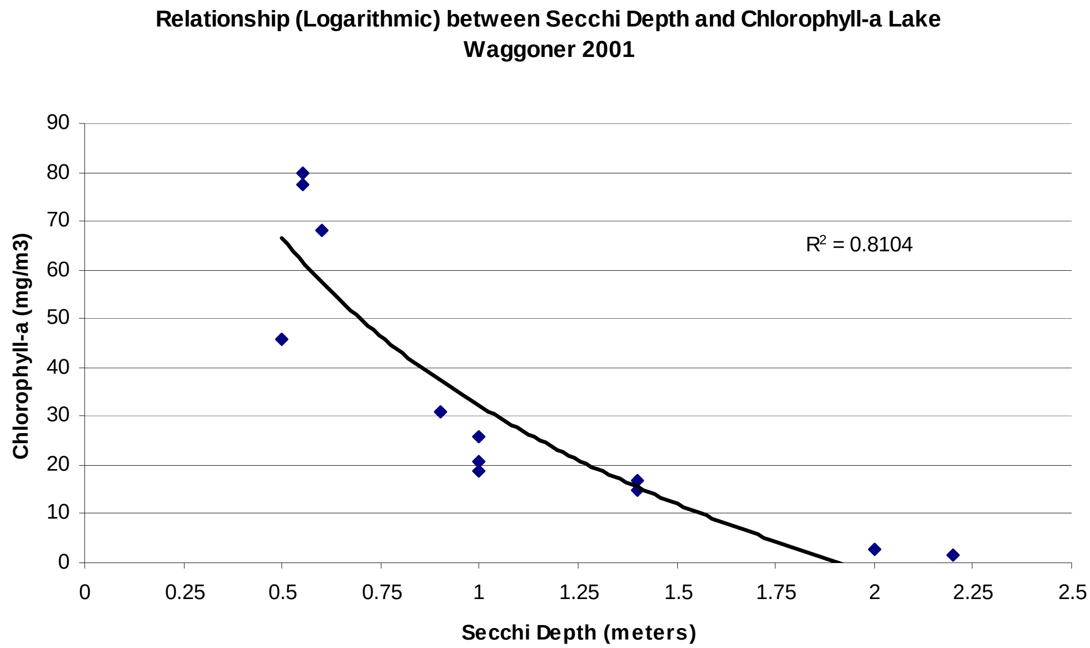


Figure 22. Logarithmic relationship between Secchi Depth and chlorophyll-*a* (excluding May data), Lake Waggoner 2001.

During the 2004 sampling period average Secchi depth ranged from 1.3 m (May) to 0.54 m (July) with a median of 0.7 m and an average of 0.8 m. With the exception of May and July, Secchi depth remained fairly similar (0.7 m) through most of the summer. Secchi depths were generally lower in 2004 in comparison to 2001, though not significantly different (p=>0.05). Secchi depth was almost exclusively dictated by algal biomass in the summer (June-August) of 2004 (Figure 23). Chlorophyll-*a* explained 97% of the variability in Secchi depth.

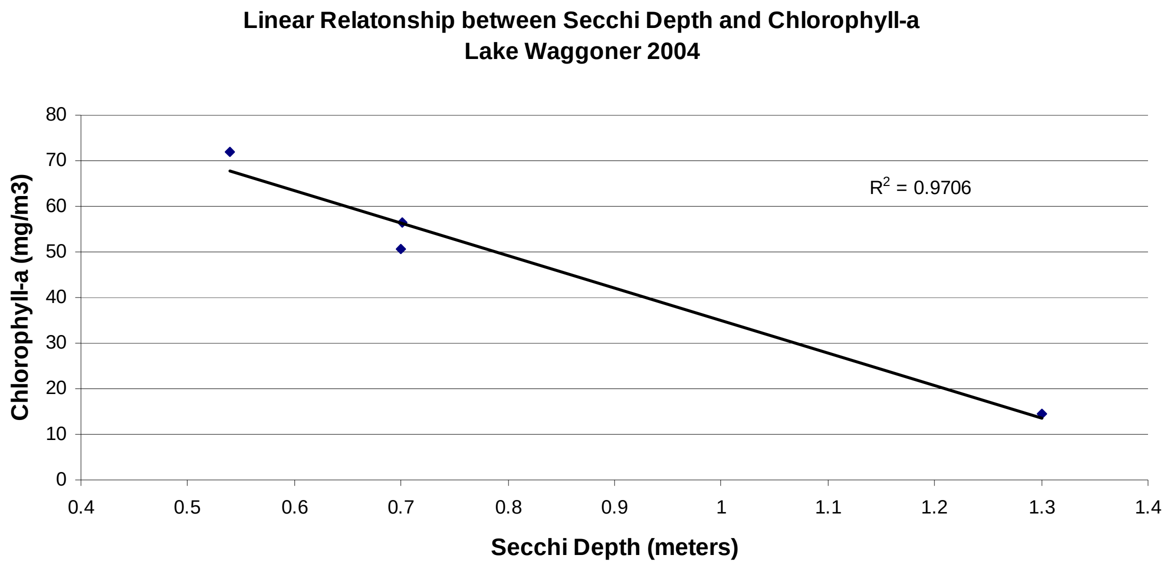


Figure 23. Linear relationship between Secchi depth and chlorophyll-*a*, Lake Waggoner summer 2004.

Chlorophyll-a

Chlorophyll *a* is the primary photosynthetic pigment found in oxygen producing organisms (Wetzel, 1982). Chlorophyll-*a* provides an estimate of algae biomass which is an indicator of lake productivity.

During the 2001 sampling period chlorophyll-a concentrations ranged from 77.4 mg/m^3 to 2.8 mg/m^3 at site WL1 and 80.0 mg/m^3 to 1.5 mg/m^3 at site WL2. No significant differences were observed between sites ($p>0.05$). The median chlorophyll-*a* for sites WL1 and WL2 was 16.7 mg/m^3 (average = 28.4 mg/m^3) and 20.8 mg/m^3 (average = 28.4 mg/m^3), respectively.

Waggoner Lake chlorophyll *a* levels were elevated right after the ice went out (Figure 24). This was due to large numbers of pigmented flagellates and small diatoms present in the algal community during late March and April 2001. Chlorophyll *a* levels fell in May and June because of the collapse of the spring algae population as part of the normal seasonal transition from cold-water to warm-water species. Chlorophyll *a* increased again in July 2001 probably with the appearance of large numbers of warm-water blue-green algae. These soon declined in August, possibly due to a depletion of nutrients (Figure 24). Waggoner Lake has a significant amount of water area that is five feet or less in depth and produces abundant macrophyte communities. The macrophytes keep the available nitrogen at almost zero (nitrate and ammonia readings during the growing season were below detectable levels). The lack of nitrogen (used up by the abundant plant growth) limits the amount of nuisance algae that can be produced.

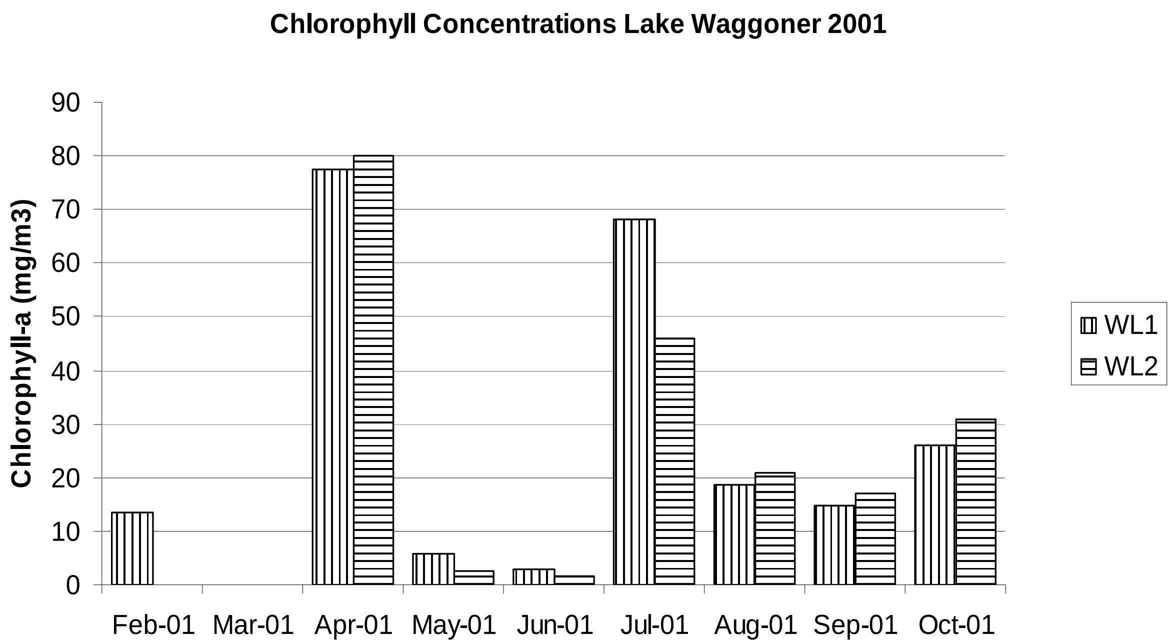


Figure 24. Chlorophyll-*a* concentrations Lake Waggoner 2001.

During the 2004 sampling period chlorophyll-*a* concentrations ranged from 72.1 mg/m^3 (July) to 14.7 mg/m^3 (May). The median and average chlorophyll-*a* concentrations were 45.5 mg/m^3 and 40.5 mg/m^3, respectively. With the exception of July, chlorophyll-*a* concentrations were significantly different between years (p=<0.05).

Abundant rainfall in the watershed, beginning in May, brought in greater nutrient loads including nitrogen, through tributary inflow, than were available in Waggoner Lake during the drought year of 2001. This soon had the effect of increasing chlorophyll levels in June that remained high through August 2004, the end of the sampling season (Figure 25). Most of the initial chlorophyll increase was probably due to larger numbers of flagellated algae and green algae. Algal dominance soon shifted to blue-green algae in July and August which consisted mostly of *Oscillatoria agardhii* (203,000 cells/ml and 730,685 cells/ml, respectively). Because *Oscillatoria* cannot fix atmospheric nitrogen like some other blue-greens (*Anabaena* and *Aphanizomenon*) nitrogen and other nutrient supplies were likely sufficient in Waggoner Lake in summer 2004 to produce these massive blue-green blooms. This species of cyanobacteria is capable of rapid colonization following a disturbance. The flushing event in 2004 produced ideal conditions for *Oscillatoria agardhii*.

Planktonic species of *Oscillatoria* do not usually form conspicuous blooms like the other common planktonic blue-green algae, *Aphanizomenon, Anabaena,* and *Microcystis* that are frequently abundant in other state lakes. While *Oscillatoria agardhii* may discolor the water, this species of cyanobacteria does not clot or aggregate as the latter species to form noticeable floating mats or masses on the lake surface.

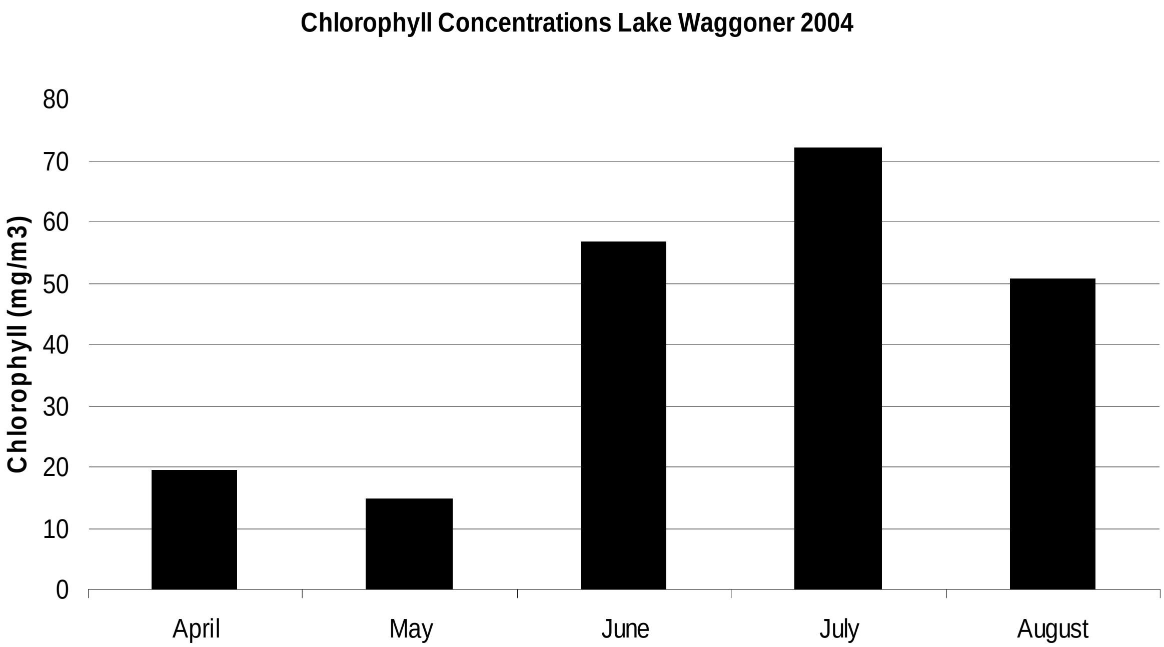


Figure 25. Chlorophyll-*a* concentrations Lake Waggoner 2004.

Solids

Total solids are composed of suspended and dissolved materials in water. Suspended solids are larger materials (sediment and algae) that do not pass through a 0.45 *u* filter. Dissolved solids constitute chemical ions such as calcium (Ca^{2+}), sodium (Na^{+}), potassium (K^{+}), chloride (Cl^{-}), and sulfate (SO^{2-}) which pass through a 0.45 *u* filter. Subtracting the suspended solids from the total solids, yields total dissolved solids. Total volatile suspended solids (VTSS) are the proportion of the total suspended solids that burn off at 550°C.

During the 2001 sampling period total suspended solids (TSS) ranged from 15 mg/L to 6 mg/L at WL1 and 17 mg/L to 7 mg/L at WL2. Bottom samples ranged from 12 mg/L to 6 mg/L from WL1 and 16 mg/L and 7 mg/L from WL2. No significant differences were observed between surface and bottom samples across sites (p=>0.05). The median TSS was 11 mg/L for both WL1 and WL2 (average = 10.9 mg/L. All TSS concentrations collected during the 2001 sampling period were well within the water quality standard limit (< 158 mg/L).

Volatile suspended solids concentrations were used to determine the organic proportion of the corresponding total suspended solids concentrations. The percentages ranged from 68% (August) to 23% (June) with an average of 47%. Figure 26 depicts the average total suspended and total volatile solids concentrations including the corresponding percent organics.

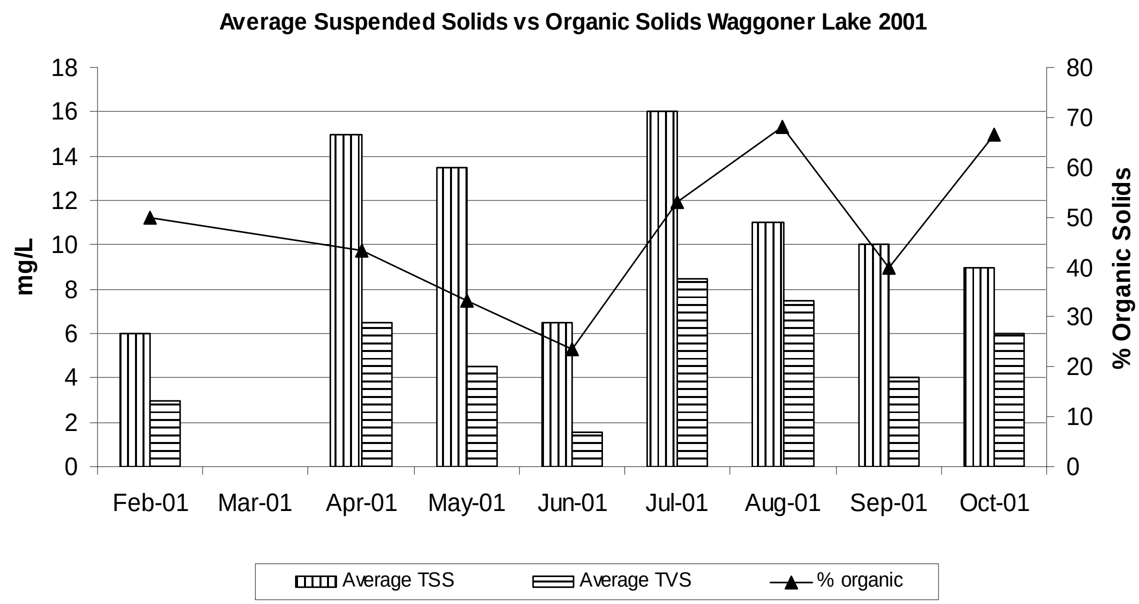


Figure 26. Average surface suspended solids vs. percent organic solids Waggoner Lake 2001.

Considerable variation in the percent organic solids was evident between months. Volatile suspended solids were $\leq$ 50% of the total suspended solid concentrations in all months except July, August and October. These results suggest that a considerable proportion of suspended solids concentrations were composed of inorganic (i.e. silt) solids, especially in the spring and early summer. This is also supported by the linear relationship between TSS and chlorophyll-*a* (Figure 27). However, the relationship strengthens considerably (R^2=0.72) when May data are removed from the analysis. Algae were likely the source of higher organics in the summer and fall. Since watershed inputs and precipitation were minimal during 2001, inorganic TSS was likely a result of windswept shorelines and agitation of bottom sediments in the shallower portions (littoral zone) of the lake.

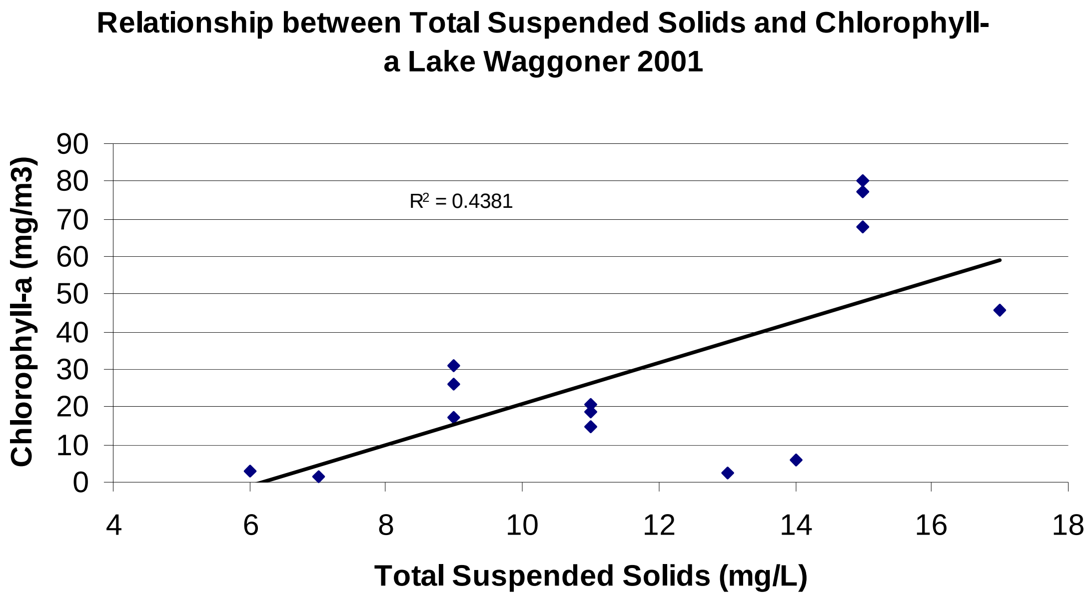


Figure 27. Linear relationship between total suspended solids and chlorophyll-*a* Lake Waggoner 2001.

During the 2004 sampling period surface and bottom total suspended solids (TSS) ranged from 28 mg/L to 12 mg/L and 34 mg/L to 7 mg/L, respectively. No significant differences were observed between surface and bottom samples (p=>0.05). The median and average surface TSS concentrations were 19.0 mg/L and 18.2 mg/L, respectively. Total suspended solids were higher in 2004 in comparison to 2001 though not significantly different (p=>0.05). All TSS concentrations collected during the 2004 sampling period were well within the water quality standard limit (< 158 mg/L).

A considerable percentage of the TSS was inorganic in May and June, while July and August displayed $\geq$ 50% organic solids (Figure 28). A considerable increase in TSS was observed between May and June 2004. The inorganic portion was above 50% for both months suggesting Grindstone Creek inflows as the likely source. A strong linear relationship was evident between chlorophyll and TSS (R^2=0.92). This indicates that the organic proportion of the TSS was likely from algae biomass.

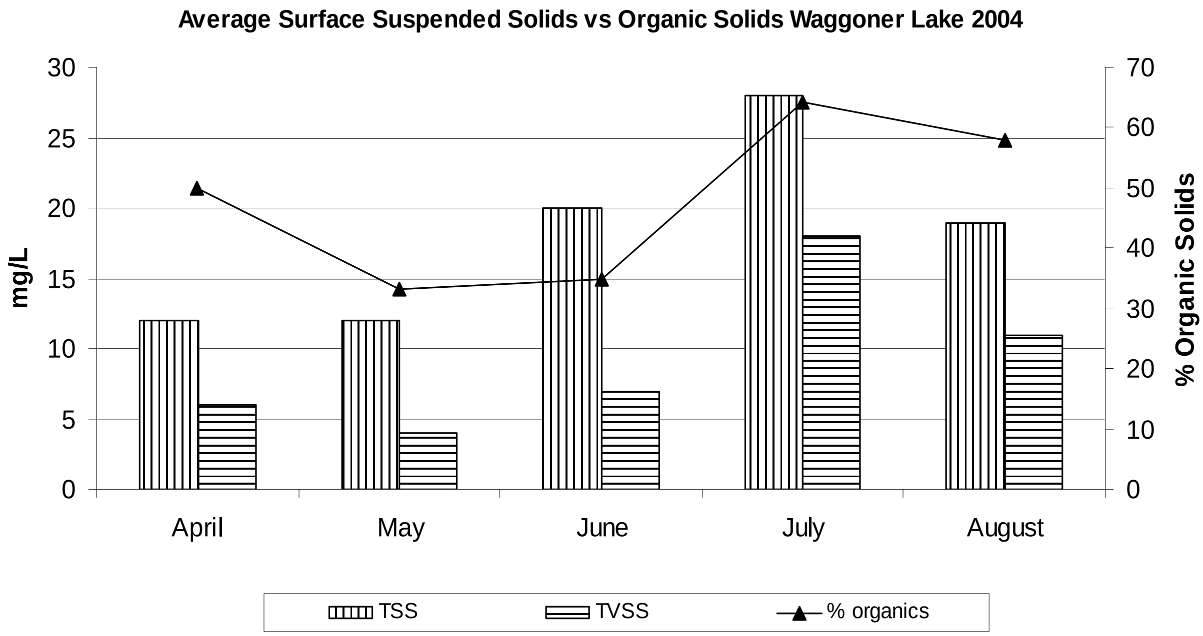


Figure 28. Average surface suspended solids vs. percent organic solids Waggoner Lake 2004.

During the 2001 sampling period surface total dissolved solids (TDS) ranged from 3,246 mg/L to 2,185 mg/L at WL1 and 2,811 mg/L to 2,179 mg/L at WL2. The highest TDS (3,246 mg/L) was collected under the ice in February (only WL1 was sampled). Bottom TDS ranged from 3,482 mg/L to 2,175 mg/L at WL1 and 2,809 mg/L to 2,174 mg/L at WL2. No significant differences were observed between surface and bottom samples across months. The median surface TDS was 2,563 mg/L (average=2,596 mg/L) for WL1 and 2,513 mg/L (average=2,504 mg/L) for WL2. The median bottom TDS was 2,575 mg/L (average=2,629 mg/L) for WL1 and 2,508 mg/L (average=2,507 mg/L) for WL2.

During the 2004 sampling period surface TDS ranged from 2,839 mg/L to 631 mg/L. Bottom TDS ranged from 2,841 mg/L to 636 mg/L. No significant difference was observed between surface and bottom samples ($p=>0.05$). The surface and bottom median TDS was 878 mg/L (average = 1,583 mg/L) and 892 mg/L (average = 1,589 mg/L), respectively. Total dissolved solids concentrations were significantly lower in 2004 in comparison to 2001 ($p=<0.05$). Total dissolved solids concentrations collected in 2001 and April-May 2004 were above the water quality standard limit. However, during summer 2004, Waggoner Lake TDS recovered dramatically in June, July and August (< 900 mg/L) following inflows from Grindstone Creek (Figure 29).

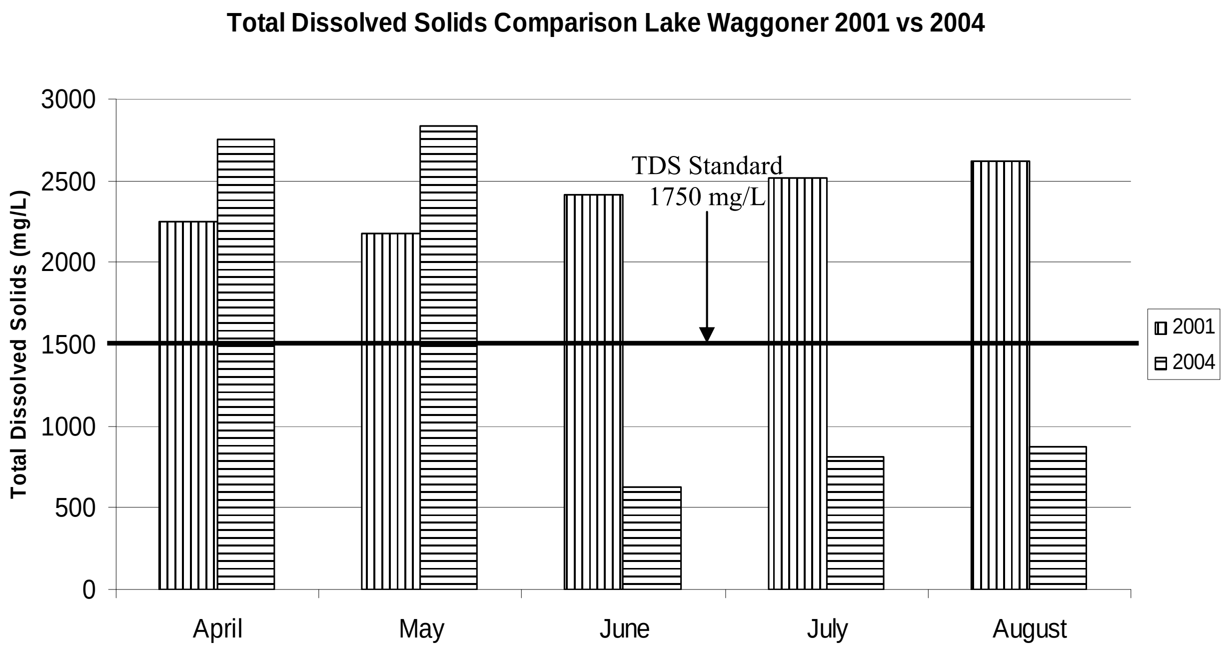


Figure 29. Total dissolved solids comparison Lake Waggoner 2001 versus 2004.

The elevated TDS observed in Lake Waggoner during 2001 and early 2004 was a function of drought conditions. This is supported by historic TDS and average annual precipitation data examined over six years of data availability. A pattern of increasing TDS (above the standard) is evident when average annual precipitation drops below 30 cm (Figure 30). In addition, the linear relationship ($R^2 = 0.76$) between average annual precipitation and TDS suggests that over 75% of the variability in TDS can be explained by precipitation (Figure 31). This is heavily supported by the most recent data (summer 2004), which confirmed that TDS concentrations decrease significantly (below standard) following considerable flow from Grindstone Creek. The remaining variability in TDS can likely be explained by inputs associated with loading from the artesian well.

While the exact discharge of the well was not calculated during the study period, a sample collected March 13, 2003 yielded a TDS concentration of 1235 mg/L. Steady loading from the artesian well likely contributes to the elevated inlake TDS concentrations. This constant loading compounded by minimal watershed inputs and evaporation allowed dissolved ions to become concentrated above the water quality standard (2001).

While it is difficult to control precipitation, runoff and evaporation in Lake Waggoner, controlling the TDS load via the artesian well is recommended to reduce inlake TDS, especially when watershed inflows are minimal. Since the city of Philip only uses Lake Waggoner as a back-up water supply, this well is no longer providing a drinking water benefit. The TDS concentrations in Lake Waggoner are well in range of supporting the fish and wildlife propagation, recreation and stock watering beneficial use (< 4,375 mg/L).

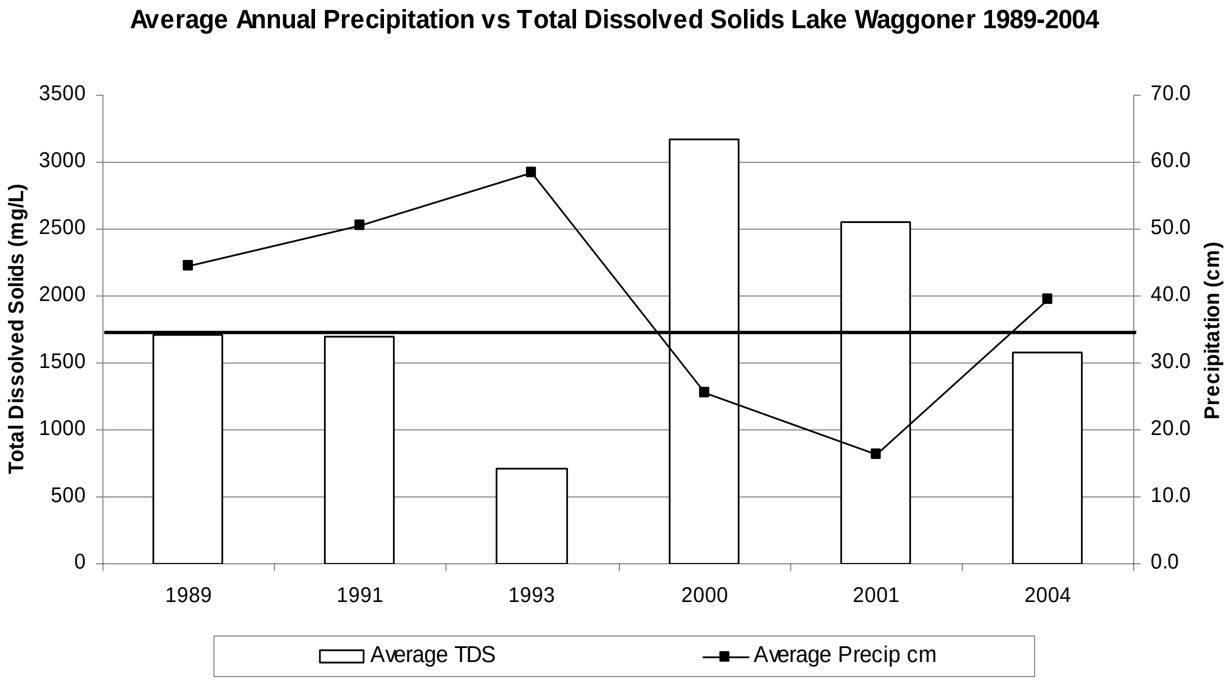


Figure 30. Comparsion between average total dissolved solids and annual precipitation in Waggoner Lake based on available data.

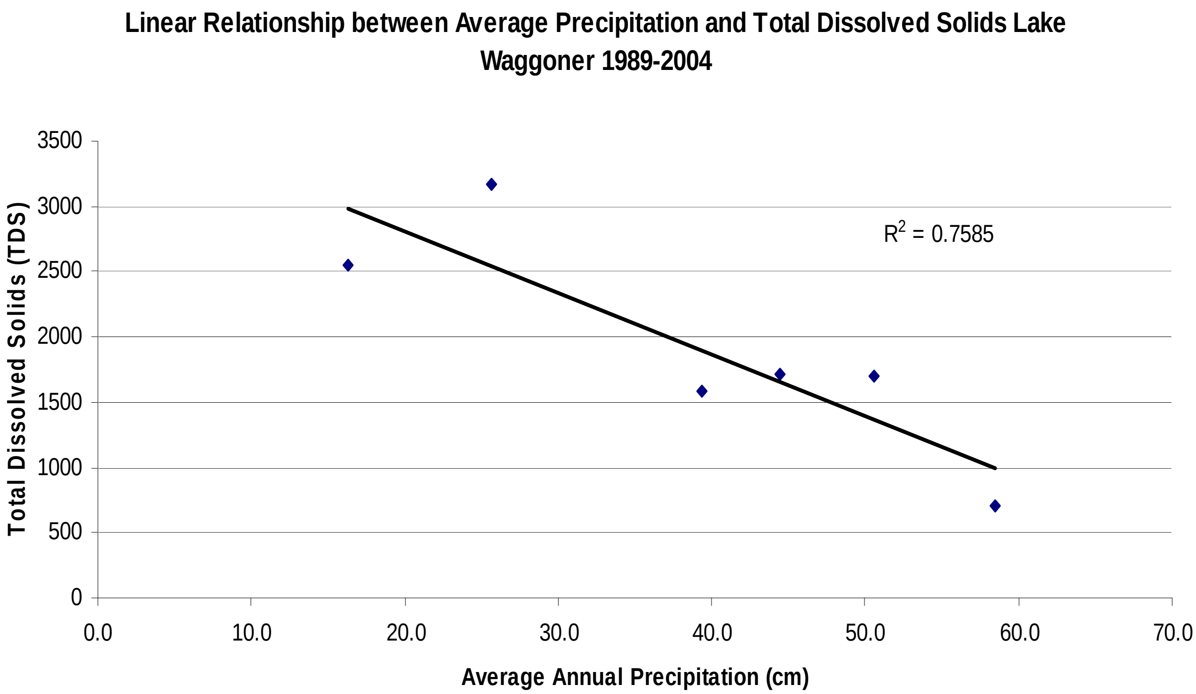


Figure 31. Linear relationship between average total dissolved solids and average annual precipitation from available data.

Nitrogen

Nitrogen was measured as ammonia, nitrate and Total Kjeldahl Nitrogen (TKN). These parameters were used to estimate organic, inorganic and total nitrogen. Organic nitrogen was calculated by subtracting ammonia from TKN. Inorganic nitrogen was calculated as the sum of nitrate and ammonia. Total nitrogen was calculated as the sum of TKN and nitrate. When ammonia and nitrate concentrations were below the health laboratory detection limit; ½ the detection limit was used for the purpose of data analysis.

Nitrogen compounds are major cellular components of organisms. Because availability may be less than the biological demand, environmental sources may limit productivity in freshwater ecosystems. Nitrogen is difficult to manage because it is highly soluble and very mobile.

Ammonia

Ammonia (NH_3) is the nitrogen by-product of bacterial decomposition of organic matter and is the form of nitrogen most readily available to plants and algae for uptake and growth. Aquatic organisms also excrete ammonia as a waste metabolite (Cole 1994). The un-ionized fraction of ammonia can be detrimental to gilled organisms in particular fish. Unionized ammonia increases with elevated temperature and pH furthered by low dissolved oxygen. The ammonia standard (Total Ammonia Nitrogen as N) designated to protect Lake Waggoner as a semipermanent fishery is based on equation 2 in Appendix A of the state water quality standards (DENR 2004). The following equation was used to evaluate total ammonia nitrogen as N.

$$(0.411/(1+10^{7.204\text{-pH}})) + (58.4 / (1+10^{\text{pH-}7.204}))$$

Based on the above equation, total ammonia as N was well below the water quality standard range in all samples collected during the 2001 and 2004 sampling period (Appendix A). Low ammonia concentrations coupled with stable pH, lower temperature and adequate dissolved oxygen contributed to the incidence of low total ammonia as N. Therefore, fish and other gilled organisms inhabiting Lake Waggoner were not likely subject to ammonia toxicity.

Three samples yielded detectable (>0.02 mg/L) ammonia concentrations during the project period. The highest ammonia concentration (0.21 mg/L) was collected at the surface of WL2 in June 2001. This was an isolated concentration as the respective bottom sample was below the detection limit. In addition, both samples (surface and bottom) collected at WL1 on the same date were also below the detection limit. It is difficult to speculate the cause of this elevated concentration; however it was most likely due to a localized biological process.

Detectable ammonia concentrations were also observed from the bottom of WL1 (0.06 mg/L) and WL2 (0.03 mg/L) in September 2001. The surface concentrations collected from both sites on the same date were below the detection limit. Since these samples were collected near the end of the peak growing season they were likely the result of bacterial decomposition of macrophytes and algae within the bottom sediments. In most instances, available ammonia is used by macrophytes and algae though both communities were in transition by early fall. All ammonia concentrations collected during the 2004 sampling period were below the detection limit. Most ammonia was likely sequestered by primary producers for growth.

Nitrate

Nitrate is an inorganic form of nitrogen easily assimilated by macrophytes and algae. Nitrate is often associated with agricultural practices and direct input from septic tanks and other forms of organic waste. Nitrate can also be found naturally in soils especially those associations found in the Grindstone Creek watershed. Ammonia can be converted to nitrate through bacterial denitrification processes. Nitrate can also be converted to nitrogen gas (N_2) and lost to the atmosphere. Some nuisance blue-green algae (cyanobacteria) can convert many forms of nitrogen for their own use (i.e. atmospheric nitrogen), thus making it difficult to control in an aquatic ecosystems. Nitrate can be lethal to juvenile mammals in concentrations exceeding 20 mg/L (Lind 1985).

The highest nitrate concentration observed during the project sampling period was 0.7 mg/L from the surface of WL2 in April 2001. This concentration was several orders of magnitude higher than any other samples collected during 2001 (Figure 32). Since watershed loads were minimal it was likely due to algae. Chlorophyll-*a* concentration was significantly elevated in April 2001. Since chlorophyll-*a* is an estimate of both living and dead cells (pheophyton) it may have been possible that the algae community was beginning to decay releasing nitrate in the denitrification process. The rate of algae decay likely varied throughout the lake being heaviest near the dam (WL2). The spring 2001 inorganic load (nitrate) from Grindstone Creek may have originally contributed to the increase in algal biomass observed in April 2001.

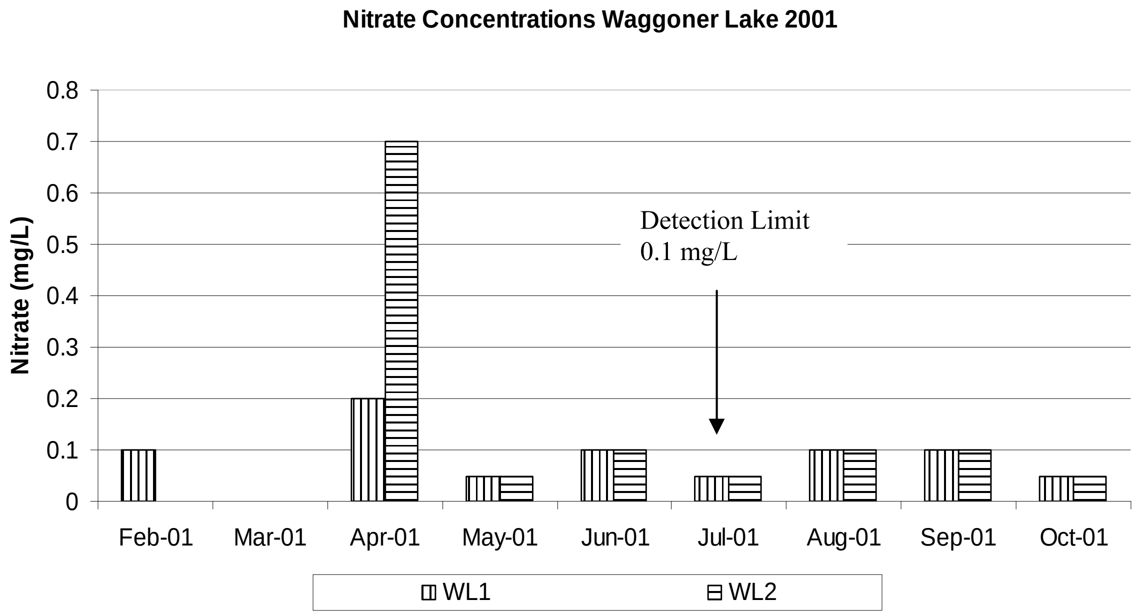


Figure 32. Nitrate concentrations Lake Waggoner 2001.

All samples collected during the 2004 sampling period were below the laboratory detection limit (<0.1 mg/L). Nitrate (inorganic nitrogen) loading from the summer of 2004 should have increased inlake concentrations. However, high biological productivity (algae) likely used available nitrate transforming it into an organic form. All nitrate concentrations collected during the entire sampling period (2001 & 2004) were well within the water quality standard limit (<10 mg/L).

Total Kjeldahl Nitrogen (TKN) and organic Nitrogen

Total Kjeldahl Nitrogen (TKN) is a measure of organic nitrogen (TKN minus ammonia = organic nitrogen). Sources of organic nitrogen can include living or dead organic matter, lake shore septic systems or agricultural waste. Organic nitrogen is not readily available for uptake by macrophytes and algae. However, organic nitrogen can be transformed (denitrification) into more usable forms of inorganic nitrogen.

Organic nitrogen ranged from 1.76 mg/L (WL2 – July) to 0.59 mg/L (WL2 – June) for samples collected in 2001 (Figure 33). Organic nitrogen was slightly variable between sites though no significant differences were observed (p=>0.05). In addition, no significant differences were observed between surface and bottom samples (p=>0.05). Organic nitrogen did not correspond well with chlorophyll-a (R^2=0.06) with the exception of July. This suggests that other sources of organic matter in addition to algae were contributing to the organic nitrogen concentrations. Organic matter associated with macrophyte vegetation was a potential source.

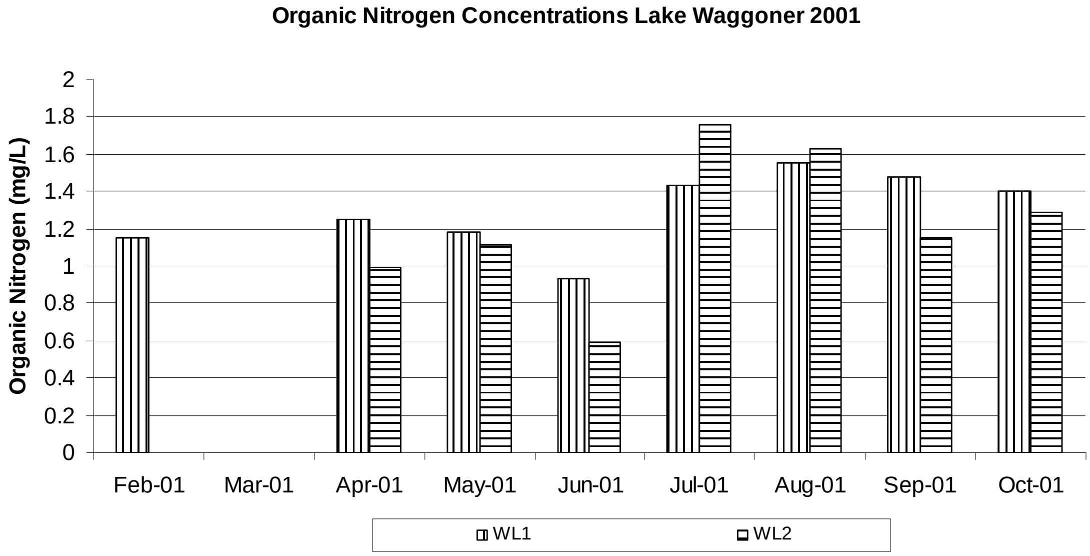


Figure 33. Organic nitrogen concentrations for Lake Waggoner 2001.

Inorganic forms of nitrogen were relatively scarce in Lake Waggoner during the 2004 sampling period. While a significant load of inorganic nitrogen entered the lake from Grindstone Creek (mostly in June), inlake concentrations of ammonia and nitrate were below the laboratory detection limit in all samples collected in 2004. The linear relationship between TKN and chlorophyll-a suggests that algal biomass accounted for nearly 75% of the organic nitrogen in Lake Waggoner during 2004 (Figure 34). The algae community, in particular *Oscillatoria agardhii*, likely converted all available inorganic nitrogen to organic nitrogen during proliferation. Additional organic nitrogen can be attributed to inlake macrophytes and organic matter washed in from the watershed.

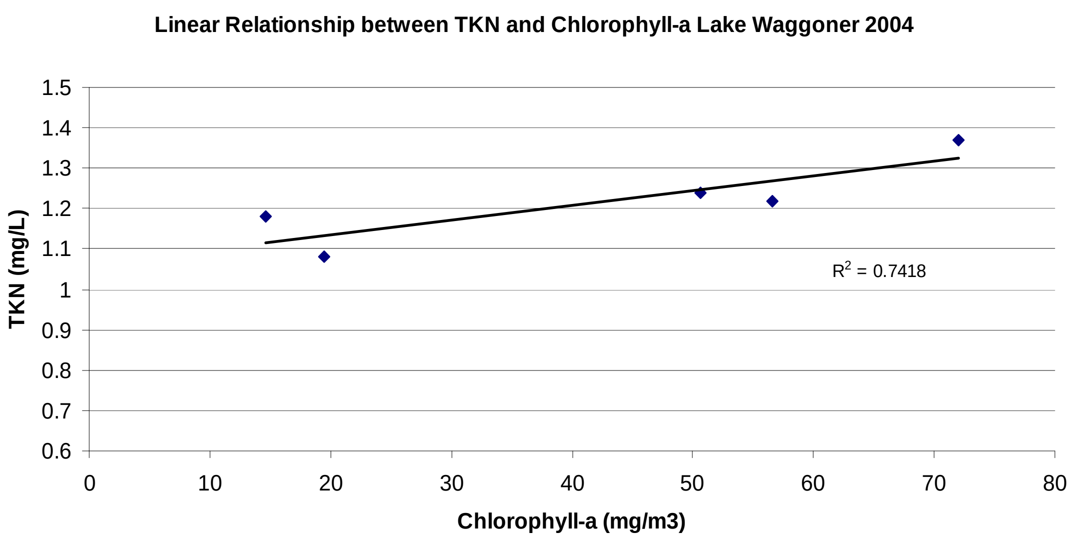


Figure 34. Linear relationship between TKN and chlorophyll-*a* Lake Waggoner 2004.

Total Nitrogen

Total nitrogen provides an overall estimate of nitrogen concentration in the lake. Nitrogen availability may differ depending on the biological community's ability to assimilate usable forms (i.e. nitrate & ammonia) though organic nitrogen can be conditionally converted (denitrification) to a usable form. For instance, cyanobacteria (blue-green algae) can process many forms of nitrogen (nitrogen fixation) for growth and maintenance. However, many primary producers are not capable of nitrogen fixation making nitrogen a potential limiting nutrient for biological production.

During the 2001 sampling period, total nitrogen ranged from 1.66 mg/L to 1.04 mg/L at WL1 and 1.82 mg/L to 0.90 mg//L at WL2. No significant differences were observed between surface and bottom samples across sites (p=>0.05). The median surface total nitrogen concentration was 1.46 mg/L (average = 1.4 mg/L) for WL1 and 1.35 mg/L (average 1.42 mg/L) for WL2. A majority of the total nitrogen observed in Lake Waggoner over the 2001 sampling period was organic (Figure 35). Inorganic sources were most prevalent in April (42%) and June (34%).

During the 2004 sampling period, total nitrogen ranged from 1.4 mg/L to 1.1 mg/L for surface samples and 1.59 mg/L to 1.24 mg/L for bottom samples. No significant differences were observed between surface and bottom concentrations (p=>0.05). The median total nitrogen concentration was 1.3 mg/L (average = 1.3 mg/L). Total nitrogen consisted of $\geq$ 95% organic nitrogen. As aforementioned, all available inorganic nitrogen was likely used to support the proliferation of algal biomass.

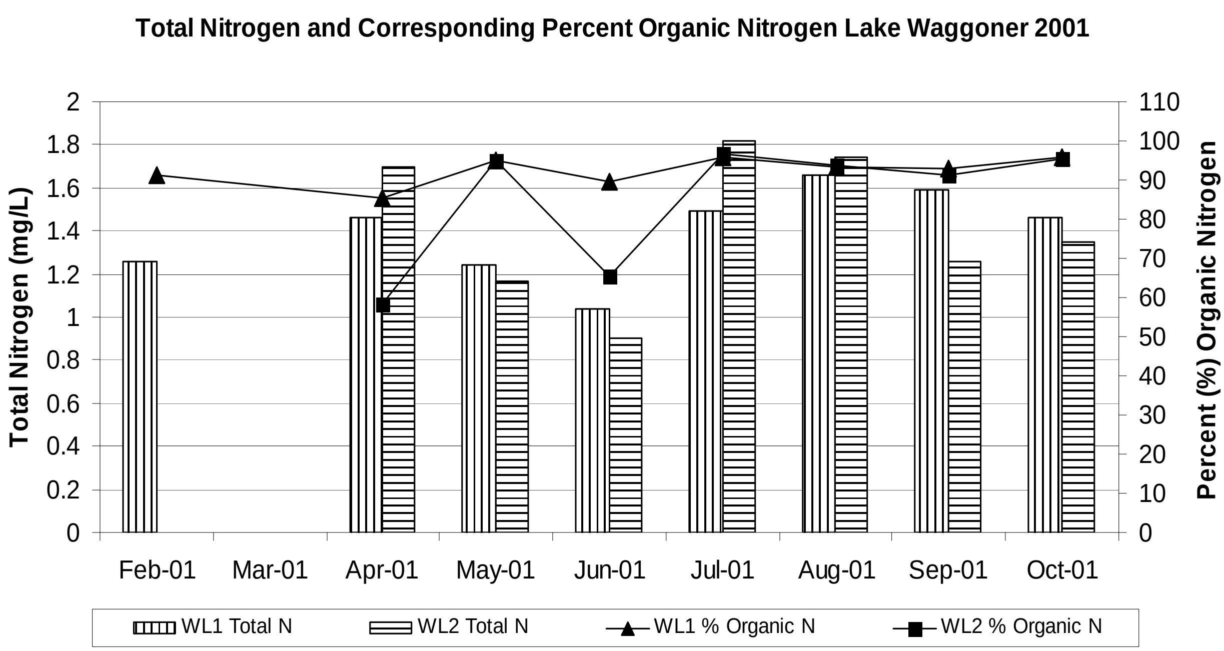


Figure 35. Total nitrogen and corresponding percent organic nitrogen for Lake Waggoner 2001.

Phosphorus

Typically, phosphorus is the single best chemical indicator of the nutrient condition of a lake. Phosphorus differs from nitrogen in that it is not as water-soluble and will attach to sediments and other substrates. Once phosphorus attaches a substrate, it is not as readily available for uptake by algae. Phosphorus sources can include geology and soil, decaying organic matter, and waste from septic tanks or agricultural run-off. Once phosphorus enters a lake, it may become part of the lake sediments. Phosphorus will remain in the sediments unless released by the loss of oxygen and the reduction of the redox potential in the microzone or by wind re-suspension. The microzone is located at the sediment-water interface. As the dissolved oxygen levels are reduced, the ability of the microzone to hold phosphorus in the sediments is also reduced. The re-suspension of phosphorus into a lake from the sediments is called internal loading and can be a large contributor of the phosphorus available to algae.

During the 2001 sampling period, total phosphorus concentrations ranged from 0.295 mg/L to 0.054 mg/L for surface samples and 0.291 mg/L to 0.056 mg/L from bottom samples. No significant differences were observed between surface and bottom across sites ($p=>0.05$). The median surface and bottom total phosphorus concentrations were 0.11 mg/L (average = 0.15 mg/L) and 0.12 mg/L (average = 0.15 mg/L), respectively.

Phosphorus concentrations in April (median = 0.11 mg/L) were slightly elevated in comparison to winter and early summer concentrations (median = 0.071). This may have been a reflection of phosphorus loading from the Grindstone Creek watershed in March. Total phosphorus concentrations spiked in July and August, suggesting a pattern consistent with internal loading as there was no inflow from Grindstone Creek (Figure 36). Total phosphorus declined in a stepwise fashion in late summer to early fall. Chlorophyll and phosphorus were seemingly related in April and July though the overall linear relationship between the two parameters was poor (R^2=0.066, p=0.68), suggesting that some other (i.e. nitrogen limitation-macrophyte community) environmental factor other than phosphorus was responsible for limiting algal biomass.

Internal phosphorus loading was evident in the summer of 2001 and is likely a normal phenomenon despite the use of aeration. Internal loading is usually related to anoxic conditions in the bottom sediments. Oxygen stratification was not evident during July and August of 2001. However, the bottom sediments may have been anoxic. Aeration only serves to oxygenate the water column and is generally not capable of oxygenating the bottom sediments.

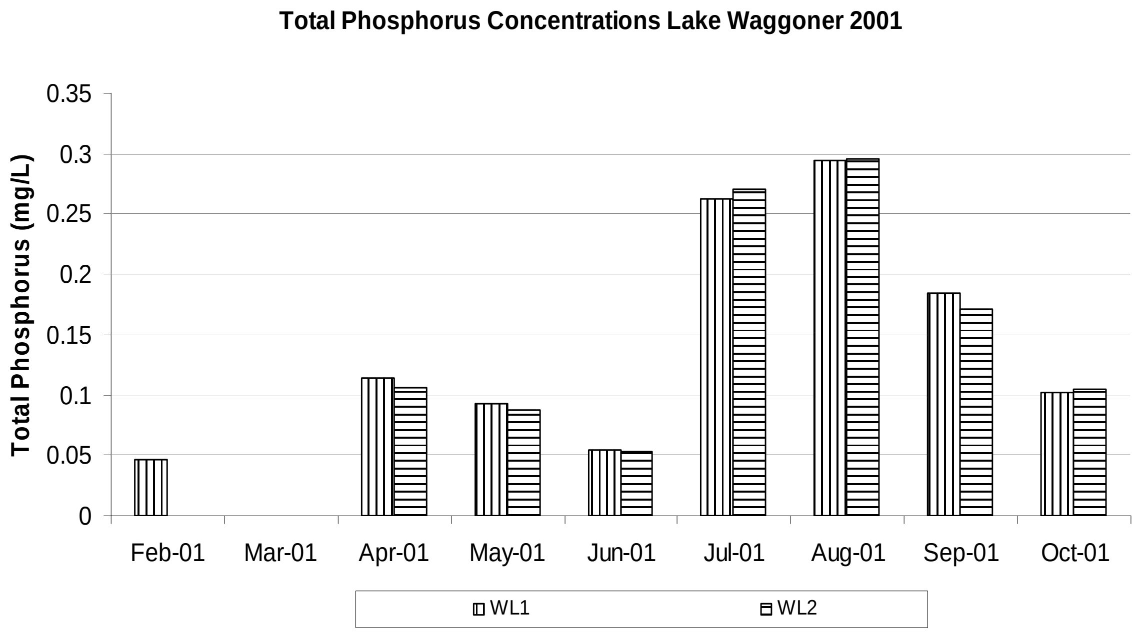


Figure 36. Total phosphorus concentrations Lake Waggoner 2001.

During the 2004 sampling period surface total phosphorus ranged from 0.2 mg/L to 0.05 mg/L and bottom ranged from 0.2 mg/L to 0.06 mg/L. No significant differences were observed between surface and bottom samples (p=>0.05). The surface median and average phosphorus concentrations were 0.2 mg/L and 0.1 mg/L, respectively. Total phosphorus concentrations were lowest in April and May before spiking significantly in June (Figure 37). The elevated summer phosphorus concentrations may have been the result of internal phosphorus loading. The lake experienced an oxygen deficit in the hypolimnion which indicated the presence of anoxic bottom sediments. Anoxia in the bottom sediments could have reduced the redox potential or the binding ability of phosphorus to inorganic particles allowing release into the water column.

Despite the fact that conditions appeared favorable for internal loading, the lake nearly experienced a total flushing event from Grindstone Creek in June 2004. New inputs of phosphorus were also responsible for the increase in-lake concentration observed in June and throughout the remaining 2004 sampling period.

The May total phosphorus concentration was 0.049 mg/L, at this concentration the lake water column contained an estimated 40.2 kg of phosphorus. Following the major inflow event in June the concentration changed to 0.209 mg/L which equated to 278 kg of inlake phosphorus. Since the net load to the lake in 2004 was 563 kg, roughly ½ of the load likely settled out or became sequestered. Based on these rudimentary results, the inlake summer (June, July and August) phosphorus concentration was likely due to a combination of internal load and inputs from the watershed.

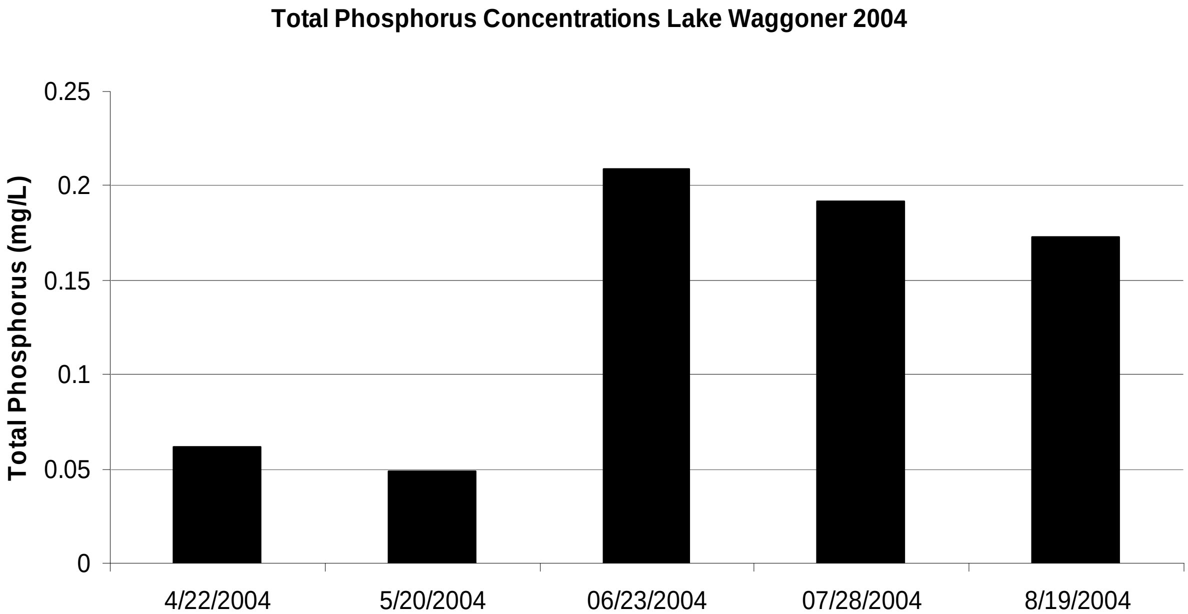


Figure 37. Total phosphorus concentrations Lake Waggoner 2004.

Algal biomass displayed a definitive response to total phosphorus concentrations in 2004. This is supported by the significant linear relationship (R2=0.91, p=0.003), observed between total phosphorus and chlorophyll-*a* (Figure 38). Over 90% of the variability in chlorophyll-*a* was explained by total phosphorus. Prior to the major influx of nutrients from Grindstone Creek (April-May) inlake inorganic nitrogen and phosphorus concentrations were relatively low, which corresponded to the chlorophyll-a concentrations. Following nutrient loading (i.e. nitrogen and phosphorus) from Grindstone Creek and potential internal phosphorus loading (June) chlorophyll-*a* concentrations responded accordingly. This major increase in algal biomass was surprising considering the short residence time (2 weeks) of the newly acquired nutrients. However, the community was dominated by a pioneer species (*Oscillatoria agardhii*) that was able to capitalize on this disruptive situation.

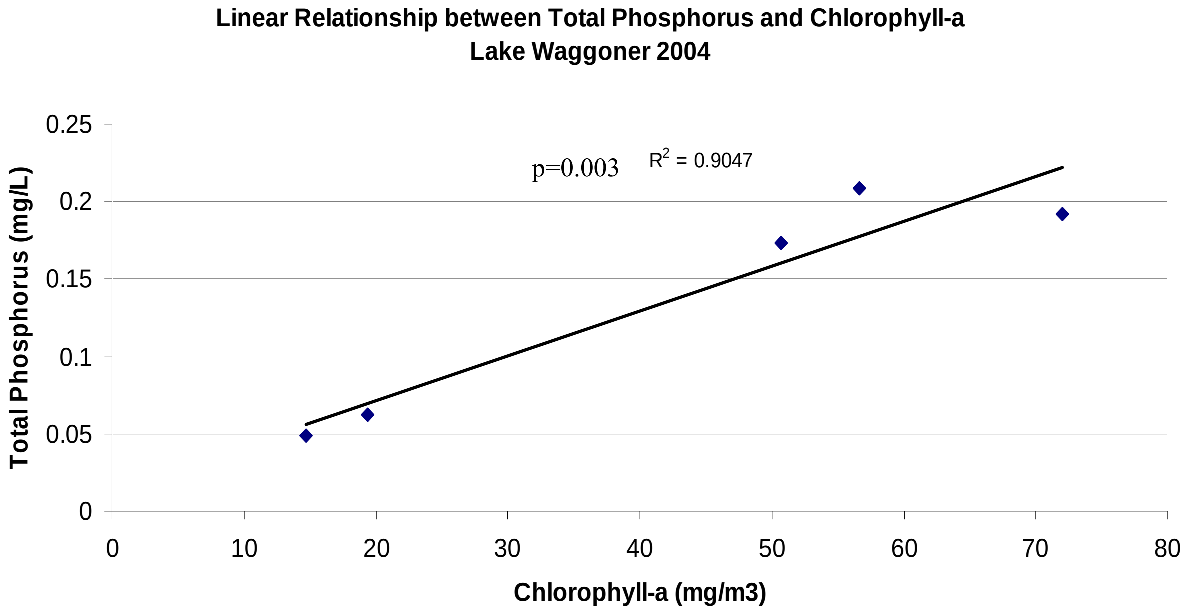


Figure 38. Linear relationship between total phosphorus and chlorophyll-*a* Lake Waggoner 2004.

Total dissolved phosphorus is the fraction of total phosphorus that is readily available for use by plants and algae. Algae need as little as 0.02 mg/L of phosphorus to produce nuisance blooms. Dissolved phosphorus may attach to suspended materials (organic or inorganic) present in the water column. During the 2001 sampling period, surface total dissolved phosphorus concentrations ranged from 0.198 mg/L to 0.016 mg/L at WL1 and 0.21 mg/L to 0.013 mg/L at WL2. Bottom samples ranged from 0.21 mg/L to 0.002 mg/L at WL1 and 0.21 mg/L to 0.017 mg/L at WL2. No significant differences were observed between surface and bottom concentrations across sites (p=>0.05). The median surface dissolved phosphorus concentration was 0.034 mg/L (average = 0.075 mg/L) and 0.04 mg/L (average = 0.09 mg/L) for sites WL1 and WL2, respectively. The lowest percentage of dissolved to total phosphorus was observed in May, while the highest percentage was observed in September (Figure 39).

Dissolved phosphorus concentrations and corresponding percent of total phosphorus displayed a decreased pattern in the spring (April) and early summer (May) of 2001 before increasing throughout the summer months peaking in September and declining by October. In general, dissolved phosphorus concentrations were all above that required by algae to support proliferation. However, a significant linear relationship was not observed (R^2=0.03, p=0.004) between dissolved phosphorus and chlorophyll-*a*. In addition, dissolved phosphorus was not related to total suspended solids (R^2=0.04). Macrophytes were likely using available dissolved phosphorus for growth in the spring of 2001 while algae and macrophytes were releasing it as they decayed in the summer and early fall.

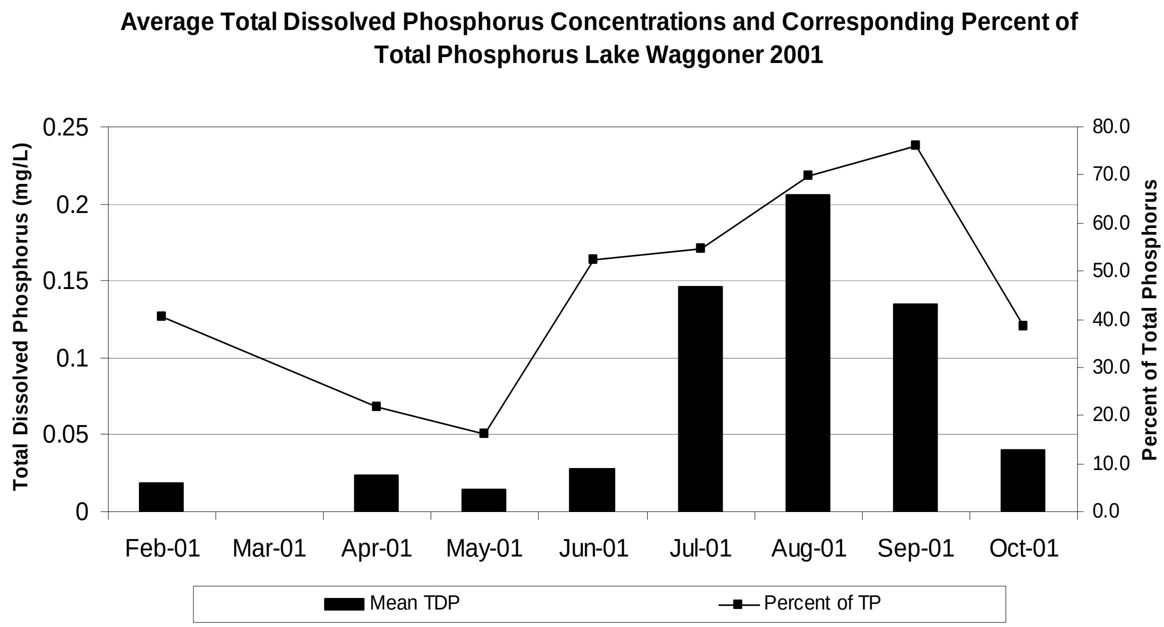


Figure 39. Average total dissolved phosphorus concentrations and corresponding percent total phosphorus, Lake Waggoner 2001.

During the 2004 sampling period, surface and bottom total dissolved phosphorus concentrations ranged from 0.110 mg/L to 0.016 mg/L and 0.111 mg/L to 0.059 mg/L, respectively. No significant differences were observed between surface and bottom samples (p=>0.05). The median and average surface dissolved phosphorus concentrations were 0.055 mg/L and 0.059 mg/L, respectively. The lowest percentage of dissolved to total phosphorus was observed in April, while the highest percentage was observed in June (Figure 40). Higher dissolved phosphorus in June was likely from the influx of phosphorus delivered from Grindstone Creek. Algal biomass was using phosphorus for growth in the summer of 2004 though dissolved phosphorus concentrations were not depleted suggesting the potential for nitrogen or other limitation.

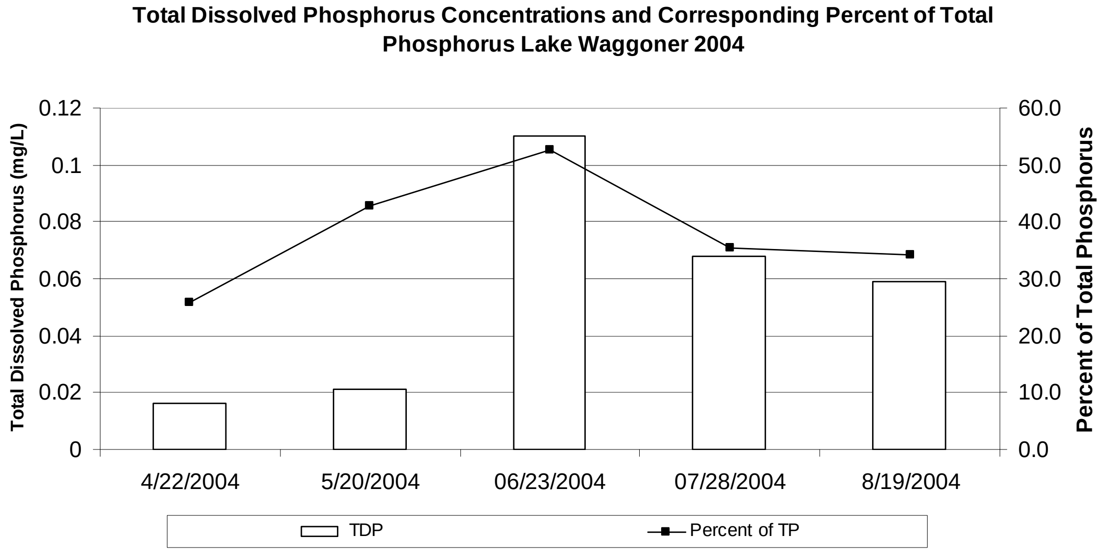


Figure 40. Total dissolved phosphorus concentrations and corresponding percent total phosphorus Lake Waggoner 2004.

Limiting Nutrients

For an organism (algae) to survive, it must have the necessary nutrients and environment to maintain life and reproduce. If an essential component approaches a critical minimum, this component will become the limiting factor (Odum, 1959). Nutrients such as phosphorus and nitrogen are most often the limiting factor in highly eutrophic lakes. Typically, phosphorus is the most limiting nutrient for algal growth. However, if the lake has very high phosphorus concentrations, algal growth could be more limited by available nitrogen. Lakes that are phosphorus-limited respond more quickly to watershed Best Management Practices (BMPs) and inlake restoration practices than lakes that are nitrogen-limited.

In order to determine which nutrient is the limiting factor, EPA (1990) has suggested a total nitrogen to total phosphorus ratio of 10:1. If the ratio of nitrogen divided by phosphorus is greater than 10:1, the waterbody is assumed to be phosphorus-limited. A ratio of less than 10:1 assumes the waterbody to be nitrogen-limited. Total nitrogen to total phosphorus ratios ranged from 26.8 to 5.7 with a median and average of 12.9 and 12.4, respectively, for all samples collected during the 2001 sampling period. Lake Waggoner experienced phosphorus limitation in the winter, spring and early summer and became nitrogen-limited in the summer and early fall (Figure 41). Lake Waggoner likely switched to nitrogen limitation due to the incidence of internal phosphorus loading. In 2004, total nitrogen to total phosphorus ratios ranged from 25.1 to 7.4. Again Lake Waggoner was phosphorus-limited in the spring to early summer and became nitrogen limited in the summer following watershed inflows from Grindstone Creek including potential internal phosphorus loading (Figure 42). Reducing phosphorus loads from the watershed and controlling internal phosphorus re-cycling is required to help maintain phosphorus limitation in Lake Waggoner.

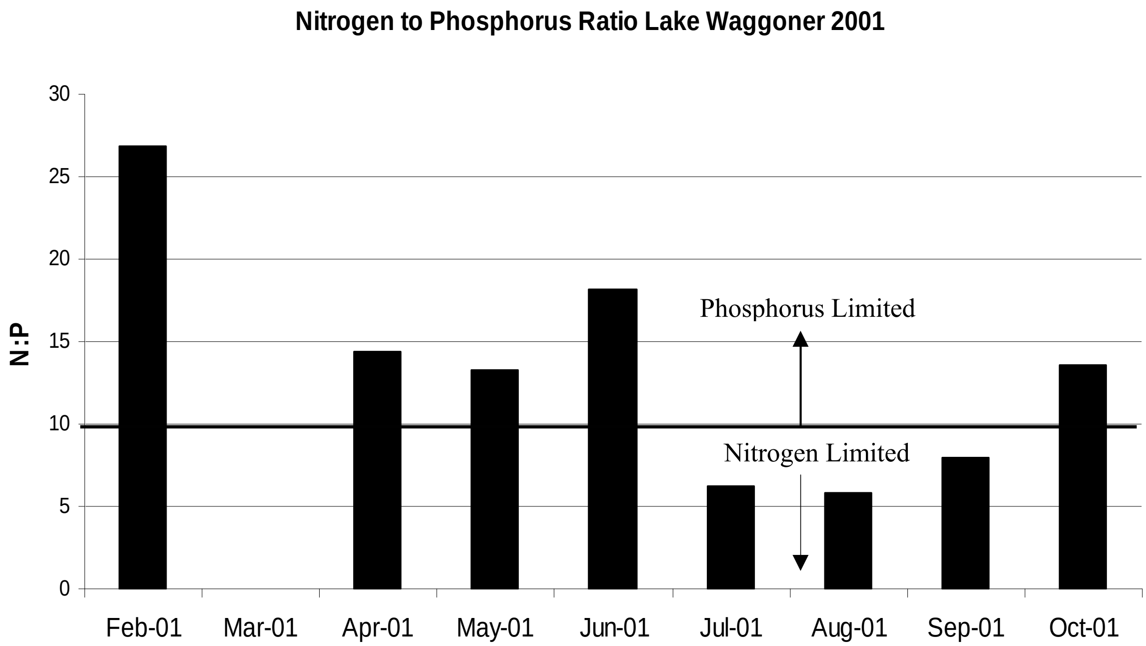


Figure 41. Nitrogen to phosphorus ratio, Lake Waggoner 2001.

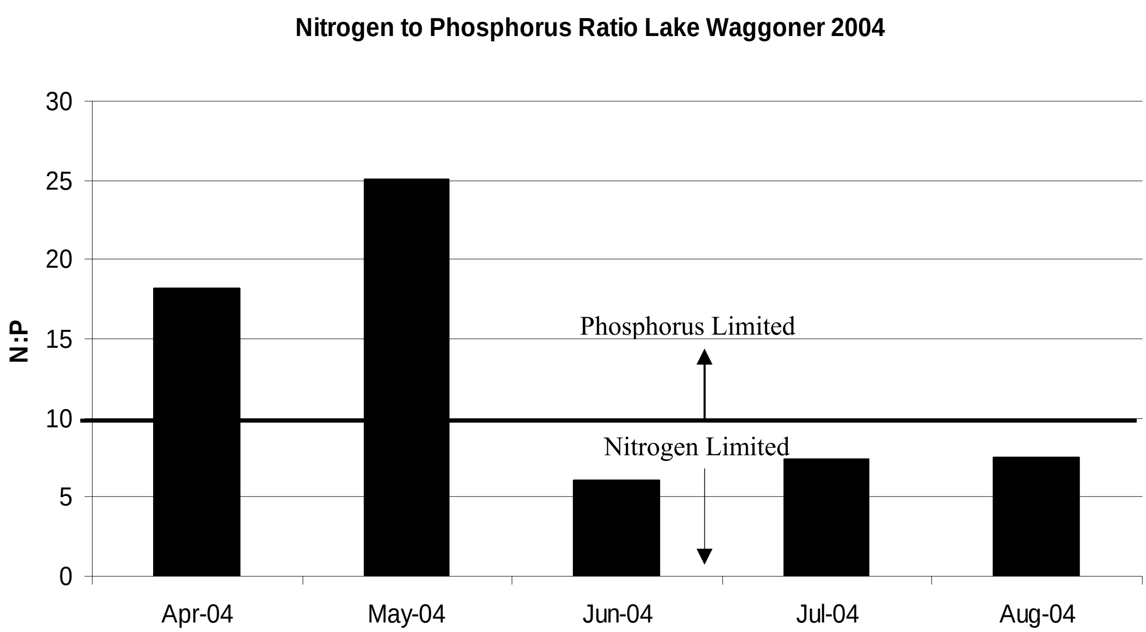


Figure 42. Nitrogen to phosphorus ratio, Lake Waggoner 2004.

Trophic State

Trophic state refers to the degree of nutrient enrichment within a lake and its relation to primary production and water clarity. The Trophic State Index (TSI) developed by Carlson (1977) is a commonly used and widely accepted method for quantifying the trophic state of lakes. The TSI transforms measures of total phosphorus (nutrient), chlorophyll-*a* (algal biomass), and Secchi depth (water clarity) using linear regression models and logarithmic transformation to produce unitless index scores typically ranging from 0-100. The greater the index scores; the more phosphorus, primary production and correspondingly less water clarity waterbodies are expected to exhibit. Carlson (1977) assigned numeric ranges to classify the trophic state of a waterbody (Table 21).

Table 19. Trophic state categories established by Carlson (1977).

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

Lakes with TSI values less than 35 are considered to be oligotrophic and contain very small amounts of nutrients, low primary production and are very clear. Lakes that obtain a score of 35 to 50 are considered to be mesotrophic and have more nutrients and primary production than oligotrophic lakes. Eutrophic lakes have a score between 50 and 65 and have moderate nutrients and are susceptible to algae blooms and reduced water clarity. Hyper-eutrophic lakes have scores greater than 65 and contain excessive nutrients, sustainable nuisance algae blooms and poor water clarity.

The three TSI indices are expected to be interrelated as a function of the regression models. Therefore, it is assumed that any one of the three indices could be used to classify the trophic state of a waterbody. When the TSI is presented as an average or median value it is imperative that the indices are interrelated. Carlson (1991) suggests that if any TSI parameter deviates significantly ($\pm$ 5 TSI points) from the chlorophyll TSI (main measure of primary production) then that parameter is contributing to the misclassification of the trophic state.

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

To characterize the trophic state of Lake Waggoner it is necessary to examine differences between the trophic state indices. Significant deviation was evident between all TSI parameters though phosphorus TSI was most discernible during the summer for both years (Figures 43 and 44). Secchi and chlorophyll TSI were relatively similar during the summer of both years. One exception was June of 2001 when all three TSI parameters were significantly different. The chlorophyll TSI was 37.6, Secchi TSI was 49.3 and phosphorus TSI was 61.6. This indicates that water transparency was not driven by chlorophyll contained in algae, but from non-algal turbidity (Carlson 1991). In May 2001, both Secchi and phosphorus TSI were interrelated, while the chlorophyll TSI was several orders of magnitude lower. Again, non-algal turbidity was likely dictating the trophic state of Lake Waggoner.

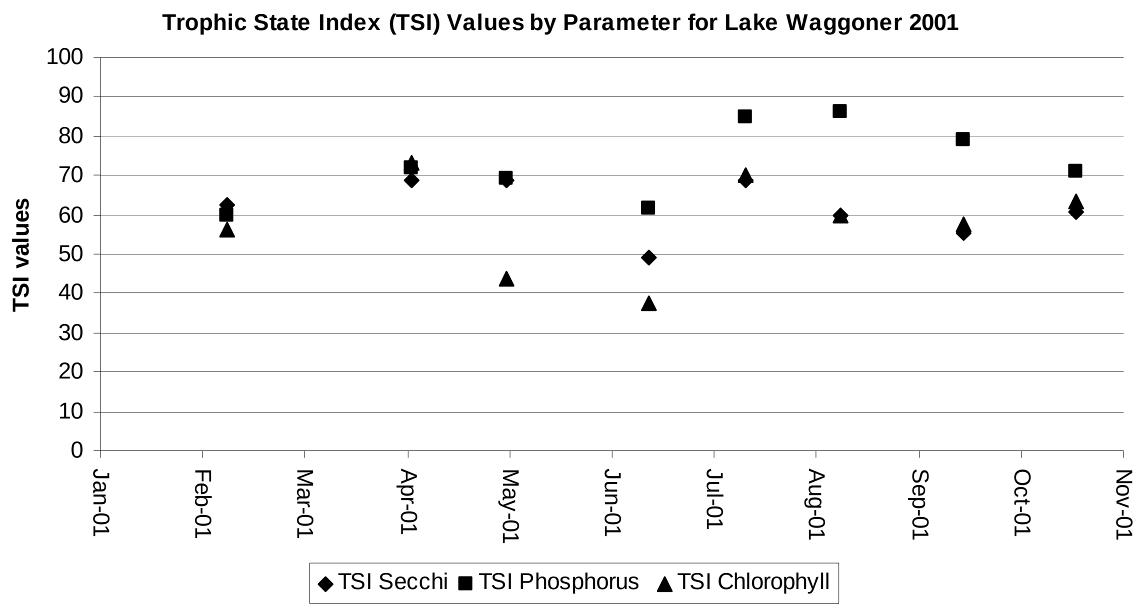


Figure 43. Trophic State Index (TSI) values by parameter for Lake Waggoner 2001.

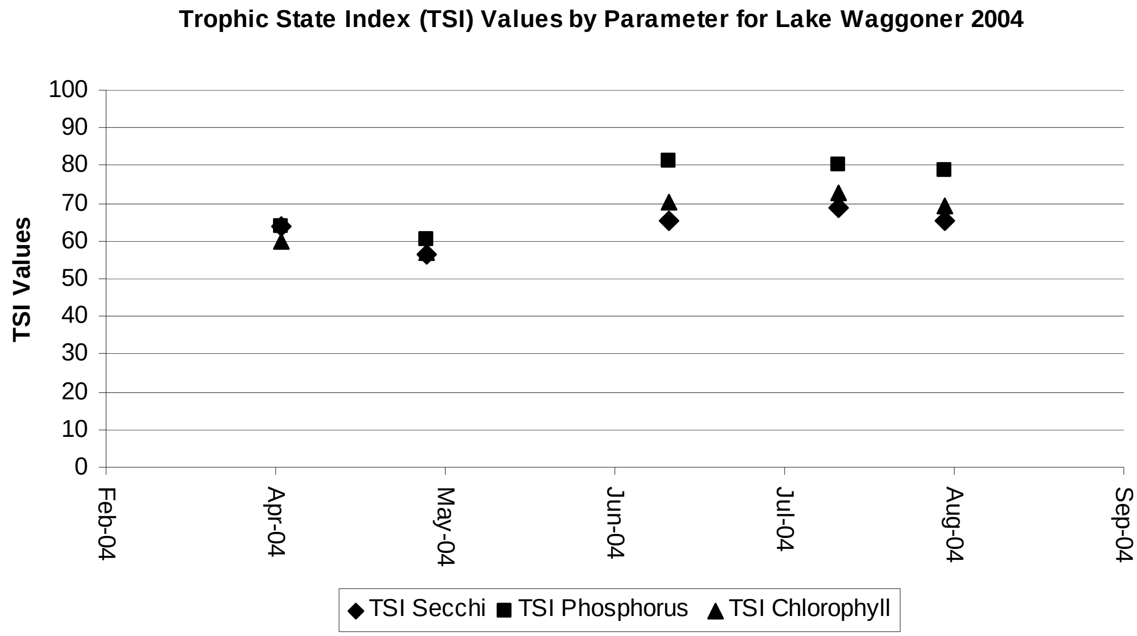


Figure 44. Trophic State Index (TSI) values by parameter for Lake Waggoner 2004.

The median Secchi-chlorophyll TSI changed considerably within and between years. In 2001, the median TSI ranged from 70.9 observed in April to a 44.6 observed in June. In 2004, the TSI ranged from 56.6 observed in May to a 70.7 observed in July. These ranges indicate that the trophic state of Lake Waggoner changed seasonally. The primary focus on median TSI is during the growing season when public use is most prominent. The DENR recognizes May 15 through September 15 as the growing season for TSI (DENR 2006). Since sampling ended in August of 2004, growing season TSI computations were made using May through August data for both years, respectively.

The 2001 growing season median Secchi-chlorophyll TSI was 60.0. This indicates Lake Waggoner as mid-range eutrophic. In 2004, the median TSI was 67.0. This indicates Lake Waggoner as low range hypereutrophic. This significant trophic state deviation is likely due to differences in inflow rates between the two years of investigation. The 2001 growing season trophic state of Lake Waggoner was likely a reflection of internal conditions. The 2004 trophic state was likely influenced by inflow from Grindstone Creek. The 2001 median growing season TSI was significantly influenced by Secchi depth, while the 2004 median TSI was significantly influenced by chlorophyll (Table 22). The median growing season phosphorus TSI was significantly elevated from the median Secchi and chlorophyll TSI in both years indicating non-phosphorus limitation.

Table 20. Lake Waggoner median growing season TSI by parameter 2001 and 2004.

Parameter	2001	2004
Median Growing Season TSI Secc-Chlor	60.0	67.0
Median Growing Season TSI Secchi	63.7	65.1
Median Growing Season TSI Chlorophyll	53.5	70.2
Median Growing Season TSI Phosphorus	77.0	80.0

An ordination graph derived from Carlson (1991) was generated to examine potential environmental factors associated with variation between the trophic state indices (Figure 45). During the 2001 growing season the Secchi and phosphorus TSI values were significantly greater than the chlorophyll TSI values. This suggests that non-algal turbidity from dissolved organic or inorganic solids were limiting algae growth and dictating water transparency. Total dissolved solids were relatively elevated in 2001 (> 2,000 mg/L) in comparison to the summer of 2004 when substantial inflows reduced concentrations by half. The median chlorophyll TSI was indicating that algal blooms were minor even though abundant phosphorus was available for growth.

During the 2004 growing season the chlorophyll TSI values were higher than the Secchi TSI values though phosphorus TSI was significantly higher than both indices. This indicates some factor other than phosphorus was limiting algal growth. Zooplankton grazing and nitrogen limitation are potential candidates. The algae community and therefore chlorophyll biomass was dominated by *Oscillatoria agardhii*, a blue-green algae or cyanobacteria. Many cyanobacteria can process atmospheric nitrogen though this particular species is not capable of such nitrogen fixation. This indicates that nitrogen may have limited the proliferation of *Oscillatoria agardhii* relative to the available phosphorus, leading to the variation between chlorophyll and phosphorus TSI. *Oscillatoria agardhii* are also known to contain less chlorophyll than larger blue-green species which may have also lead to deviation between the two indices. Nonetheless, nitrogen and phosphorus concentrations were substantial enough to support substantial algal biomass.

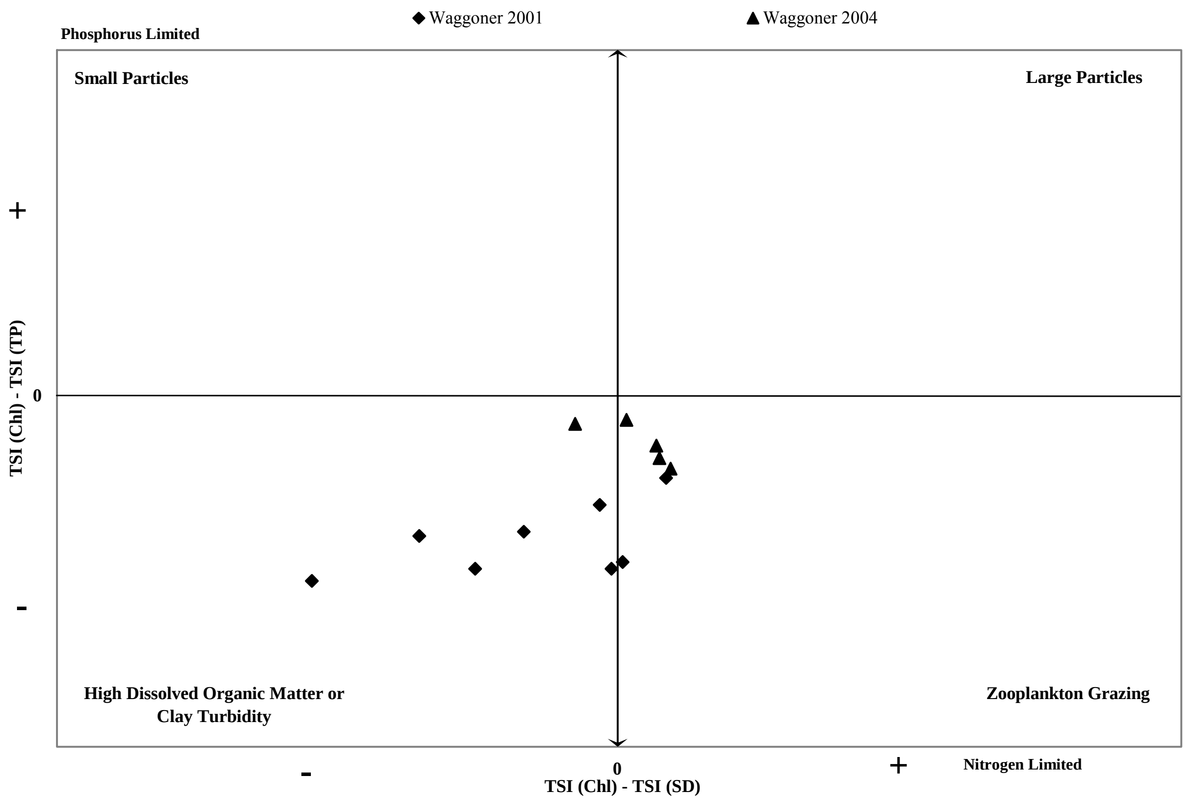


Figure 45. Ordination graph depicting environmental factors associated with variation in the trophic state indices.

Despite evidence that chlorophyll biomass can be limited by certain environmental factors, Lake Waggoner contains (internal) and receives (external) phosphorus sufficient to support excessive algae blooms. When inflow was minimal the trophic state was dominated by non-algal turbidity. When watershed inflows were significant the trophic state shifted towards algal turbidity. Since phosphorus was non-limiting and rather abundant, significant reductions are warranted to improve the trophic state of Lake Waggoner especially during periods when considerable inflows occur.

Seasonal In-Lake Water Quality

Water quality will vary with season due to changes in temperature, precipitation and agricultural practices. Thirty water quality samples were collected during 2001 (15 surface and 15 bottom samples) and ten composite (5 surface and 5 bottom) samples were collected in 2004. The surface data were separated seasonally into winter (February) spring (April), summer (May – August), and fall (September – October). In 2001, one discrete surface sample was collected in the winter, two in the spring, eight in the summer and four in the fall. In 2004, one composite sample was collected in the spring and the remaining composites were collected in the summer. No significant differences were observed between surface and bottom samples within and between years respectively ($p=>0.05$).

Seasonal In-lake Concentrations

Nutrient and solids concentrations can change dramatically with changes in season. Minimal run-off from snowmelt and rainfall was encountered during the spring of 2001, resulting in low nutrient and solids loadings. As a result, seasonal concentrations in Lake Waggoner during 2001 were likely a reflection of internal dynamics. Grindstone Creek produced substantial inflow and resultant nutrient and sediment loadings in the summer of 2004, which directed changes in in-lake concentrations. Average surface concentrations of in-lake sampling sites and sampled parameters by season and year are listed in Tables 19 and 20.

Dissolved Oxygen

In 2001, dissolved oxygen concentrations were highest in the winter. Minimal snow pack and open water attributed to thermal discharge from the artesian well, likely allowed productivity to compensate respiration. The lowest single dissolved oxygen surface sample (7.2 mg/L) was observed in the fall and was well above the water quality standard of $\geq$ 5 mg/L. The aeration pump in Waggoner Lake was likely responsible for maintaining adequate dissolved oxygen during the summer of 2001. Average surface dissolved oxygen concentrations ranged from 9.5 mg/L to 7.9 mg/L in the spring and summer of 2004, respectively. Severe oxygen stratification occurred in June of 2004 producing near anoxic conditions 0.5 meter from the bottom at both sites (WL1 and WL2). Decomposing organic matter stored in the sediments was a likely source of oxygen demand in the lower strata. Dissolved oxygen levels recovered during the rest of the summer of 2004 following major inflow from Grindstone Creek. The aeration pump was not operational in 2004.

Table 21. Average seasonal surface water concentrations of measured parameters by site from Waggoner Lake 2001.

	Spring 2001		Summer 2001		Fall 2001		Winter 2001
	WL1	WL2	WL1	WL2	WL1	WL2	WL1
PARAMETER	*	*	Average	Average	Average	Average	*
Water temp (oC)	9.0	9.0	20.0	20.0	12.0	11.9	3.5
Field pH S.U	9.00	9.02	8.63	8.60	8.94	8.83	N/A
DO (mg/L)	10.40	10.70	8.30	8.95	8.20	8.30	14.20
Alkalinity (mg/L)	153.00	152.00	174.75	174.75	192.50	192.00	196.00
Secchi (meters)	0.55	0.55	1.05	1.05	1.20	1.15	0.85
Total Solids (mg/L)	2264.0	2265.0	2445.3	2443.8	2778.5	2783.5	3252.0
Total Dissolved Solids (mg/L)	2249.0	2250.0	2433.8	2431.8	2768.5	2774.5	3246.0
Total Suspended Solids (mg/L)	15.00	15.00	11.50	12.00	10.00	9.00	6.00
Volatile Total Suspended Solids (mg/L)	6.00	7.00	4.51	6.50	5.50	4.50	3.00
Ammonia (mg/L)	0.01	0.01	0.01	0.06	0.01	0.01	0.01
Un-ionized Ammonia (mg/L)	0.0015	0.0015	0.0015	0.0064	0.0016	0.0013	N/A
Nitrate (mg/L)	0.20	0.70	0.08	0.08	0.08	0.08	0.10
TKN (mg/L)	1.26	1.00	1.28	1.33	1.45	1.23	1.16
Total Nitrogen (mg/L)	1.46	1.70	1.36	1.41	1.53	1.31	1.26
Total Phosphorus (mg/L)	0.11	0.11	0.18	0.18	0.14	0.14	0.05
Total Dissolved Phosphorus (mg/L)	0.02	0.02	0.10	0.10	0.08	0.09	0.02
N:P ratio	12.81	16.04	10.98	10.73	11.48	10.11	26.81
Chlorphyll-a (mg/m3)	77.40	80.00	23.83	17.70	20.38	23.93	13.62
E. Coli (# colonies/100ml)	0.05	1.00	3.60	1.58	0.05	0.05	461.00
Fecal Coliform (# colonies/100ml)	5.00	5.00	10.00	10.00	5.00	5.00	5.00
TSI (Secchi)	68.62	68.62	61.18	62.16	57.57	58.33	62.34
TSI (Phosphorus)	72.48	71.43	75.48	75.32	75.13	74.81	59.70
TSI (Chlorophyll-a)	73.23	73.56	54.93	50.74	59.76	61.29	56.19

* Only one sample was collected from inlake monitoring site, values not an average.

pH

The highest pH occurred in the spring of 2001. Samples collected at both sites were slightly above the water quality standard limit (9.0 standard units). The pH recovered in the summer and fall of 2001 ranging from 8.45 to 8.95, respectively. The spring samples collected in 2004 were well within the standard limit. The pH was significantly lower in the summer of 2004 in comparison to the summer of 2001 ($p<0.05$).

Table 22. Average seasonal surface water concentrations of measured parameters by site from Waggoner Lake 2004.

PARAMETER	*Spring 2004 Composite	Summer 2004 Composite
Water temp (oC)	12.4	19.3
Field pH S.U	8.4	7.55
DO (mg/L)	9.5	7.9
Conductivity (us/cm^3)	NA	1397.5
Alkalinity (mg/L)	125	112.8
Secchi (meters)	0.76	0.8
Total Solids (mg/L)	2767	1310.0
Total Dissolved Solids (mg/L)	2755	1290.3
Total Suspended Solids (mg/L)	12	19.8
Volatile Total Suspended Solids (mg/L)	6	10.0
Ammonia (mg/L)	0.01	0.01
Nitrate (mg/L)	0.05	0.05
TKN (mg/L)	1.08	1.25
Total Nitrogen (mg/L)	1.14	1.31
Total Phosphorus (mg/L)	0.062	0.156
Total Dissolved Phosphorus (mg/L)	0.016	0.065
N:P ratio	18.39	11.6
Chlorophyll-*a* (mg/m3)	19.41	48.5
E. coli (# colonies/100ml)	12.00	5.4
Fecal Coliform (# colonies/100ml)	20.00	12.5
TSI (Secchi)	63.7	63.8
TSI (Phosphorus)	63.7	75.0
TSI (Chlorophyll-a)	59.7	67.2

* Only one composite sample was collected from inlake monitoring sites, values not an average.

Alkalinity and Solids

Alkalinity concentrations were highest in the fall and winter of 2001. Alkalinity decreased in the summer of 2004 and was significantly lower than concentrations observed across all sampled seasons in 2001 ($p<0.05$). The decrease in alkalinity can be attributed to a shift in the ionic composition from significant watershed inflows. Total dissolved solids (TDS) increased slightly across all seasons in 2001, until peaking in the winter of 2001. Drought conditions likely attributed to the increase in TDS over the seasons as the lake level dropped and TDS became concentrated. In addition, the artesian well contributes an annual TDS load. Ice cover in the winter of 2001 further decreased the water volume contributing to the higher TDS. Total suspended solids (TSS) decreased progressively from spring to winter of 2001. The TSS was significantly higher in the summer of 2004 in comparison to the summer of 2001 ($p<0.05$). Grindstone Creek inflow was likely responsible for the increase in TSS in the summer of 2004. Volatile suspended solids were also highest in the summer of 2004 with respect to all sampled seasons across years.

Nitrogen

Nitrate-nitrogen was significantly higher across all seasons in 2001 in comparison to the spring and summer of 2004 ($p<0.05$). Nitrate concentrations were below the detection limit in all samples collected in 2004. Ammonia concentrations were low and non-detectable (<0.02 mg/L) in all samples collected seasonally across both years. The only exception was site WL2 in June of 2001 when ammonia was 0.21 mg/L. This was a localized spike in ammonia and was not likely detrimental to aquatic biota as the unionized portion did not exceed the water quality standard. The average TKN concentration was highest at WL1 in the fall of 2001. In general, TKN was relatively consistent across the sampled seasons of both years. The average seasonal N:P ratios across years suggest phosphorus limitation (>10:1) though average summer ratios were near nitrogen limitation for both years, respectively.

Phosphorus and Chlorophyll

Total and dissolved phosphorus concentrations were highest in the summer of both years. Total phosphorus decreased progressively by the winter of 2001. Chlorophyll-*a* concentrations were highest in the spring and lowest in the fall of 2001. Chlorophyll-*a* was considerably lower in the spring of 2004 than in the spring of 2001. A significant increase in chlorophyll-*a* was evident between the summers of 2001 and 2004.

Bacteria

Fecal coliform counts (colonies/100mL) were generally low and never exceeded the state water quality standard (>400) in any of the samples collected seasonally across years. *E. coli* counts were also low with the exception of the sample collected in the winter of 2001. The *E. coli* sample yielded 461 colonies/100ml, while fecal coliform was below the detection limit.

Trophic State

Secchi TSI was highest in the spring and lowest in the fall of 2001 for both sites. Secchi TSI was lower in the spring of 2004 in comparison to the spring of 2001. Summer Secchi TSI was only slightly higher in 2004 then 2001. Phosphorus TSI was relatively similar for all sampled seasons across years. However, phosphorus TSI was significantly lower in the spring of 2004 and lowest in the winter of 2001. The chlorophyll TSI was relatively similar between seasons though significantly higher in the spring and summer of 2001 and 2004.

Reduction Response Modeling

Inlake reduction response modeling was conducted with BATHTUB, an Army Corps of Engineers eutrophication response model (Walker, 1999). System responses were calculated using reductions in phosphorus loading to the lake. Loading data for the lower site (WLT1) on Grindstone Creek was taken directly from the results obtained from the FLUX modeling data calculated for the inlet to the lake.

BATHTUB provides numerous mathematic models that simulate the response of inlake limnology (phosphorus, nitrogen, chlorophyll *a* and Secchi depth) based on watershed loading. The model initially produces a standardized output of observed inlake conditions based on user-provided inlake concentrations and respective watershed load information. A series of parameter models are selected in combination to best imitate the observed conditions. These "best fit" models simulate inlake parameter-specific and trophic state (TSI) responses to general reductions in watershed loading.

Average growing season in-lake concentrations and associated FLUX load data were used to fulfill BATHTUB input requirements. Since loading from Grindstone Creek displayed two extremes; low in 2001 (dry year) and high (wet year) in 2004 a decision was made to model the average conditions of both years. Average growing season inlake concentrations and FLUX load data from 2001 and 2004 were collectively used to model the trophic state response of Lake Waggoner. The modeled median TSI Secchi-chlorophyll based on average conditions was 62.9. Output data generated by BATHTUB with respect to trophic state responses to incremental phosphorus reductions associated with data input from average conditions is presented in table 25, and figure 49.

Table 23. Output generated by the BATHTUB model depicting percent phosphorus reductions from the Grindstone Creek watershed to derive estimated shifts in Waggoner Lake median TSI Secchi-chlorophyll based on average conditions 2001-2004.

	Percent Phosphorus Reductions Grindstone Creek Based on Average Flow 2001-2004											
Parameter	0%	10%	20%	**30%**	35%	40%	50%	60%	70%	80%	90%	90%
Total Phosphorus (mg/m^3)	130.6	123.0	115.1	106.7	102.4	97.8	88.2	77.7	66.0	52.6	36.6	17.4
Total Nitrogen (mg/m^3)	1209.0	1209.0	1209.0	1209.0	1209.0	1209.0	1209.0	1209.0	1209.0	1209.0	1209.0	1209.0
Composite Nutrient (mg/m^3)	73.1	71.7	70.0	68.0	66.8	65.5	62.4	58.3	52.9	45.2	33.8	17.1
Chlorophyll-a (mg/m^3)	36.6	34.4	32.2	29.9	28.7	27.4	24.7	21.8	18.5	14.7	10.2	4.9
Secchi (meters)	1.0	1.1	1.1	1.2	1.3	1.3	1.4	1.6	1.8	2.2	3.0	4.9
Organic Nitrogen (mg/m^3)	996.5	948.5	897.7	844.5	816.4	787.3	726.0	659.0	584.4	499.1	396.5	274.3
Total Dissolved Phosphorus (mg/m^3)	62.9	59.1	55.2	51.0	48.8	46.5	41.8	36.5	30.7	24.0	16.0	6.5
Antilog PC-1 (principle Components)[2]	1066.0	976.5	884.0	789.6	741.0	691.4	590.1	484.4	374.6	260.6	144.3	44.3
Antilog PC-2 (principle Components)[3]	15.2	15.1	15.0	14.8	14.7	14.7	14.5	14.3	14.0	13.7	13.3	12.2
(Total Nitrogen-150)/Total Phosphorus	8.1	8.6	9.2	9.9	10.3	10.8	12.0	13.6	16.0	20.1	29.0	60.7
Inorganic nitrogen/Phosphorus	3.1	4.1	5.2	6.5	7.3	8.2	10.4	13.4	17.7	24.8	39.5	85.4
Turbidity 1/M (1/Secchi-0.025* Chlorophyll-a)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Mixed Layer Depth * Turbidity	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Mixed Layer Depth * Secchi	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.6	0.5	0.4	0.3	0.2
Chlorophyll-*a* * Secchi	36.8	36.6	36.4	36.1	36.0	35.8	35.4	34.9	34.1	32.9	30.5	24.2
Mean Chlorophyll-a / Total Phosphorus	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Frequency (Chlorophyll-a > 10)%	96.3	95.4	94.3	92.7	91.7	90.6	87.5	82.7	75.2	62.4	39.3	7.1
Frequency (Chlorophyll-a > 20)%	74.6	71.5	67.7	63.2	60.7	57.8	51.2	43.1	33.1	21.1	8.2	0.5
Frequency (Chlorophyll-a > 30)%	50.4	46.5	42.3	37.6	35.1	32.4	26.6	20.4	13.8	7.3	2.0	0.1
Frequency (Chlorophyll-a > 40)%	32.4	29.1	25.5	21.8	19.8	17.8	13.8	9.8	6.0	2.7	0.6	0.0
Frequency (Chlorophyll-a > 50)%	20.7	18.1	15.4	12.7	11.4	10.0	7.4	4.9	2.8	1.1	0.2	0.0
Frequency (Chlorophyll-a > 60)%	13.4	11.4	9.5	7.6	6.7	5.8	4.1	2.6	1.4	0.5	0.1	0.0
Carlson TSI-(Phosphorus)	74.4	73.5	72.6	71.5	70.9	70.2	68.7	66.9	64.6	61.3	56.1	45.4
Carlson TSI-(Chlorophyll-a)	**65.9**	**65.3**	**64.7**	**63.9**	**63.5**	**63.1**	**62.1**	**60.8**	**59.2**	**57.0**	**53.4**	**46.2**
Carlson TSI-(Secchi)	**59.9**	**59.1**	**58.2**	**57.3**	**56.7**	**56.1**	**54.8**	**53.2**	**51.2**	**48.4**	**44.3**	**37.0**
Median TSI Secchi-Chlorophyll-a	**62.9**	**62.2**	**61.5**	**60.6**	**60.1**	**59.6**	**58.4**	**57.0**	**55.2**	**52.7**	**48.9**	**41.6**

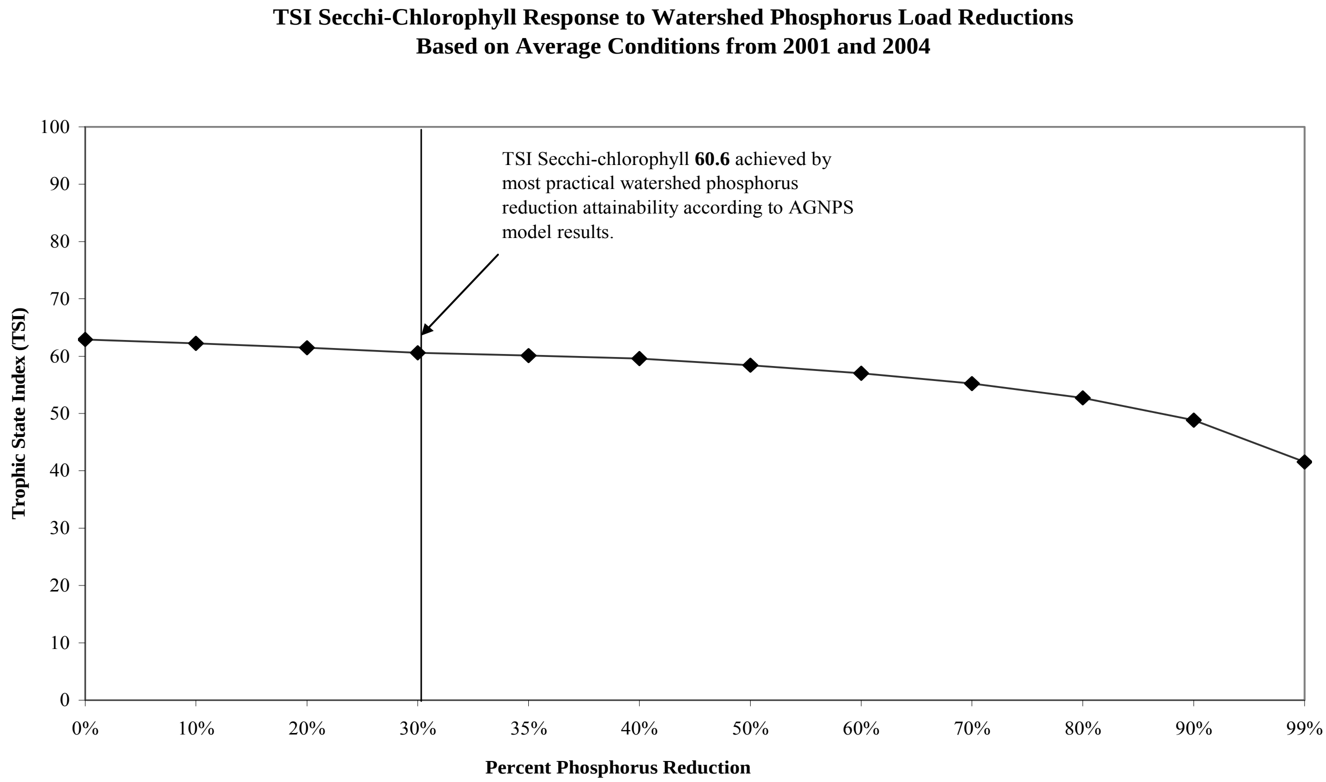


Figure 46. TSI Secchi-chlorophyll reduction response curve based on average conditions for Lake Waggoner 2001- 2004.

Significant phosphorus reductions are required to improve the trophic state of Waggoner Lake. Modeled reductions suggest minimal improvement in TSI until a watershed phosphorus reduction in excess of 80 % is achieved (Figure 49). The magnitude of this phosphorus reduction is not achievable based on socioeconomic restraints, watershed specific phosphorus reduction attainability and modeled reductions. According to the BATHTUB model a median Secchi-chlorophyll TSI of 60.6 can be achieved with a 30% reduction in phosphorus loading from the Grindstone Creek watershed. The AGNPS model (pages 94-104) suggested that BMP installation on 50% of the priority 1 through 4 cropland acres would result in a 20% reduction in watershed phosphorus. The AGNPS model was not capable of defining a quantitative reduction in phosphorus from native range and pasture though these landuse types make up the majority (70%) of the watershed acres. An additional 10% phosphorus reduction should be possible through grazing management BMPs that promote healthy vegetation and increase infiltration which are proven to limit nutrient and sediment runoff.

While a TSI target of 60.6 will not likely improve the overall trophic state of Waggoner Lake it should help maintain the current trophic condition. Waggoner Lake is currently meeting its beneficial uses based on numeric criteria and the recommended phosphorus reductions would likely help maintain this support status. A 30% reduction in watershed phosphorus load is likely to achieve the TSI goal based on the strong linear relationship (R^2=0.91) observed between phosphorus and chlorophyll-*a* (pages 71-72). Internal phosphorus loading was described to occur during the summer months in Lake Waggoner. This source was not accounted for in the BATHTUB model. Controlling the incidence of internal phosphorus loading during the growing season would further improve the TSI.

Long-Term TSI Trend

Waggoner Lake was listed in the 303(d) section of the 2006 Integrated Report (IR) as an impaired waterbody for TSI. While TSI is no longer used as a measure of impairment the median TSI Secchi-chlorophyll of Lake Waggoner displayed an increasing trend based on 5 years of data availability (Figure 50). As observed during this assessment the trophic state of Lake Waggoner can vary significantly over a short period of time due to local effects and watershed inflows. The long-term TSI dataset available for Lake Waggoner is not likely able to accurately detect a plausible trend. The slope (3%) of the linear regression line did not suggest a significant increase in TSI. However, the long-term median trophic state of Lake Waggoner is of concern and best management strategies may need to be implemented to stabilize and/or improve the trophic state of Lake Waggoner.

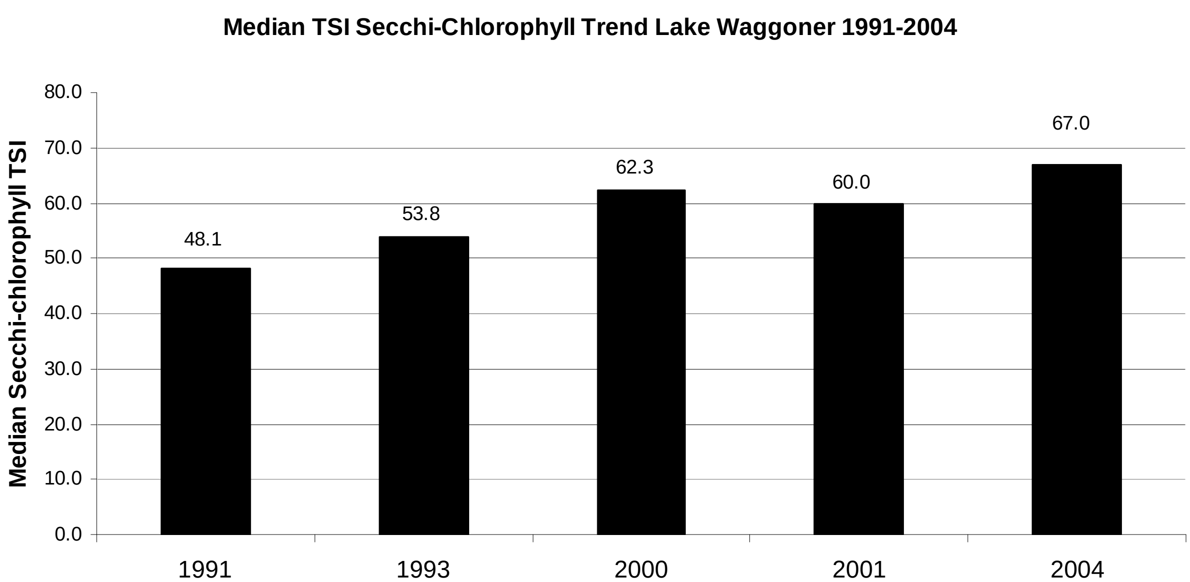


Figure 47. Median Secchi-chlorophyll TSI Lake Waggoner based on available data 1991-2004.

Other Monitoring

Agricultural Nonpoint Source Model (AGNPS version 3.62)

AGNPS is a data intensive watershed model that routes sediment and nutrients through a watershed by utilizing land uses and topography. The watershed is broken up into equally sized portions, or cells of 40 acres. Each of these cells requires 26 parameters to be collected and entered into the program. The present land use in the 37,360 acres of the Grindstone Creek watershed above Lake Waggoner is 49% native range (18,160 acres, 454 cells), 15% Conservation Reserve Program (5,520 acres, 138 cells), 16% cropland (6,080 acres, 152 cells) and 20% pastureland, hay land, roads, water and farmsteads (7,600 acres, 190 cells). This data is based on cropping history from 1998 through 2000.

AGNPS GOALS

The primary purpose of running AGNPS on the Waggoner Lake-Grindstone Creek watershed was to:

1. Evaluate and quantify NPS yields from each cell and selected reaches of the watershed and determine the net loading to Waggoner Lake;
2. Define critical cells within the watershed (cells that have elevated sediment and/or nitrogen and/or phosphorus); and
3. Determine if the feeding of livestock in the watershed can be evaluated using the AGNPS ranking system to quantify the nutrient loadings from the feeding areas and develop a numerical ranking for the feeding areas.

DELINEATION AND LOCATION OF SELECTED REACHES

The Grindstone Creek watershed that provides runoff to Waggoner Lake is about 13 miles long and five miles wide. Access to the watershed was limited for gauging sites because of all weather road access. The watershed had two reaches selected on the tributaries for gauging. Reach 2 samples all the runoff in the upper portion of the watershed. Reach 1 measures the runoff from the entire watershed to a point about one and one half miles above the inlet to Lake Waggoner. Reach O is located at the outlet of Lake Waggoner on the spillway.

GAUGING STATION DATA

Table 24. AGNPS Watershed gauge information.

Subwatershed	Watershed Drainage Area	Reach Drainage Area	Outlet Cell Number	Description
Reach 2	15,400	15400	398	County road bridge
Reach 1	31,200	15,760	805	Haligan wood bridge
Reach O	37,360	6,160	933	Spillway Outlet

AGNPS allows you to input the watershed data for different amounts of rainfall and to alter existing conditions to see what type of effect these alterations would have on the nutrient yield from the watershed. As an example the current conditions of the watershed using a 24-hour, 25-year storm which is 3.85 inches of rainfall for this area of Haakon County, results in the following nutrient and sediment yields delivered to the outlet:

Grindstone Creek **per acre** loading of each reach for a 24 hour-25year storm of 3.85 inches of rainfall is indicated in the following table for the immediate watershed for each reach. For example, the immediate watershed for reach #O is actually of the contributing watershed below the outlet of reach #1. By calculating per acre loads for each reach in this manner, it is possible to estimate which reaches are contributing the largest loads to the creek on per acre of watershed basis (Tables 27-28).

Table 25. AGNPS generated per acre loading of each reach sediment and nutrients 24 hour-25 year storm event.

Reach Number	Drainage Area (Acres)	Sediment Yield (T. /Ac.)	Attached Nitrogen (#/ac.)	Soluble Nitrogen (#/ac.)	Total Nitrogen (#/ac.)	Attached Phos. (#/ac.)	Soluble Phos. (#/ac.)	Total Phos. (#/ac.)
2	15,400	0.0304	0.19	0.44	0.63	0.10	0.04	0.14
1	15,760	0.2729	0.81	0.84	1.65	0.40	0.13	0.53
O	6,160	-0.0443	0.67	0.77	1.44	0.33	0.11	0.44
Watershed	37,360	0.1204	0.53	0.66	1.19	0.26	0.09	0.39

Table 26. AGNPS generated reach loading sediment and nutrients 24 hour-25 year storm event.

Reach Number	Drainage Area (Acres)	Sediment Yield (Tons)	Attached Nitrogen (Tons)	Soluble Nitrogen (Tons)	Total Nitrogen (Tons)	Attached Phos. (Tons)	Soluble Phos. (Tons)	Total Phos. (Tons)
2	15,400	469	1.47	3.40	4.86	.077	0.23	1.08
1	15,760	4,301	6.38	6.62	13.00	3.15	2.60	4.18
O	6,160	-273	2.06	2.37	4.44	1.02	0.95	1.36
Watershed	37,360	4,498	9.91	12.39	22.30	4.94	1.67	6.61

Runoff for the watershed is 1.99 in/ac, with a total yield of 6,195 ac-ft. The watershed peak flow is 5,582 cfs. Sediment delivery is 25%.

For comparison you can change the watershed data so that the entire watershed is in the same condition as those acres that are presently enrolled in CRP. This produces a modeled condition that reflects a grass ecosystem that probably exceeds the "pristine" condition that is thought to have occurred before the settlement of this area. This scenario is being used to show how the model reduces loading. It is unrealistic to expect these conditions in the Lake Waggoner watershed. The nutrient and sediment yield for this condition is as follows (Tables 29-30).

Table 27. AGNPS generated per acre loading of each reach sediment and nutrients 24 hour-25 year storm event CRP.

Reach Number	Drainage Area (Acres)	Sediment Yield (T. /Ac.)	Attached Nitrogen (#/ac.)	Soluble Nitrogen (#/ac.)	Total Nitrogen (#/ac.)	Attached Phos. (#/ac.)	Soluble Phos. (#/ac.)	Total Phos. (#/ac)
2	15,400	0.00303	0.03	0.38	0.41	0.02	0.03	0.05
1	15,760	0.01183	0.07	0.54	0.61	0.04	0.06	0.10
O	6,160	-0.00224	0.06	0.53	0.59	0.03	0.06	0.09
Watershed	37,360	0.00587	0.05	0.47	0.52	0.03	0.05	0.08

Table 28. AGNPS generated reach loading sediment and nutrients 24 hour-25 year storm CRP treatment.

Reach Number	Drainage Area (Acres)	Sediment Yield (Tons)	Attached Nitrogen (Tons)	Soluble Nitrogen (Tons)	Total Nitrogen (Tons)	Attached Phos. (Tons)	Soluble Phos. (Tons)	Total Phos. (Tons)
2	15,400	46.8	0.23	2.93	3.17	0.15	0.23	0.39
1	15,760	186.4	0.55	4.26	4.81	0.32	0.47	0.79
O	6,160	-13.8	0.18	1.63	1.82	0.09	0.18	0.28
Outlet	37,360	219.3	0.97	8.82	9.79	0.56	0.89	1.45

Runoff for the watershed is 1.87 in/ac with a total yield of 5,355 ac-ft. The watershed peak flow is 4,972 cfs. Sediment delivery is 17%.

ANNUAL YIELD

The AGNPS 3.65 model provides data for different storm amounts and storm intensities. In order to determine the annual yield from a watershed using this model, annual conditions must be determined as well as the storm amount and intensities. For South Dakota annual yield is computed using one annual (one-year) storm, two six-month storms and ten monthly storms. The following data were used.

RAINFALL DATA FOR THE WAGGONER LAKE
WATERSHED STUDY, HAAKON COUNTY, SOUTH DAKOTA

EVENT	RAINFALL	ENERGY INTENSITY
Monthly	0.85	3.0
6 Month	1.25	8.1
Annual	1.65	14.4
2 Year	2.00	21.8
5 Year	2.80	45.3
10 Year	3.40	69.1
25 Year	3.85	90.6
50 Year	4.40	121.2
100 Year	4.90	153.3

NRCS R factor for Grindstone Creek Watershed = 60

Annual Loading Calculations

Monthly events = 10 events x 3.0 = 30.0
6 month events = 2 events x 8.1 = 16.2
1 year event = 1 event x 14.4 = 14.4

Modeled Cumulative R factor = 60.6

Table 29. AGNPS generated per acre loading of each reach sediment and nutrients annual yield watershed.

Reach Number	Drainage Area (Acres)	Sediment Yield (T. /Ac.)	Attached Nitrogen (#/ac.)	Soluble Nitrogen (#/ac.)	Total Nitrogen (#/ac.)	Attached Phos. (#/ac.)	Soluble Phos. (#/ac.)	Total Phos. (#/ac.)
2	15,400	0.0228	0.21	0.46	0.67	0.14	0.03	0.17
1	15,760	0.0813	0.57	1.74	2.31	0.22	0.33	0.55
O	6,160	0.0195	0.53	1.56	2.09	0.21	0.31	0.52
Watershed	37,360	0.0462	0.41	1.18	1.60	0.19	0.20	0.39

Table 30. AGNPS-generated reach loading sediment and nutrients annual yield outlet.

Reach Number	Drainage Area (Acres)	Sediment Yield (Tons)	Attached Nitrogen (Tons)	Soluble Nitrogen (Tons)	Total Nitrogen (Tons)	Attached Phos. (Tons)	Soluble Phos. (Tons)	Total Phos. (Tons)
2	15,400	352	1.62	3.55	5.17	1.08	0.23	1.31
1	15,760	1,281	4.49	13.71	18.20	1.73	2.60	4.33
O	6,160	123	1.63	4.82	6.44	0.65	0.95	1.60
Outlet	37,360	1,726	7.75	22.07	29.81	3.46	3.79	7.25

TARGETED CELLS

The results of the AGNPS model can help determine the targeted or critical cells in the watershed. The targeted or "critical" cells are identified by the amount of nutrients that they produce that ultimately reaches the outlet of the watershed.

The cells in the Grindstone Creek watershed were broken into four levels of priority. Cell priority was assigned based on average nutrient loads produced by cells within the watershed. Cells that produced nitrogen, sediment, **and** phosphorus loads greater than three standard deviations over the mean for the watershed were given a priority ranking of 1. Cells that produced nitrogen **and** phosphorus or nitrogen **and** sediment or sediment **and** phosphorus loads greater than three standard deviations over the mean were given a priority ranking of 2. Cells that produced nitrogen **or** sediment **or** phosphorus loads greater than three standard deviation **or** cells that produced sediment, nitrogen, **and** phosphorus levels over two standard deviations were given a priority ranking of 3. Cells that produced nitrogen **and** phosphorus or nitrogen **and** sediment or sediment **and** phosphorus loads greater than two standard deviations over the mean were given a priority ranking of 4. After determining priority ranking the number of cells in priority 4 was only five, so priority 4 was combined with priority 3

The critical cells are determined and the land use in these cells is altered by simulating different Best Management Practices (BMPs) on individual cells of the computer model. The effects of the treated cells on the nitrogen, phosphorus, and sediment delivered at the outlet of the watershed may be found in tables. The average pounds per acre delivered by the watershed are compared before and after implementation of proposed Best Management Practices.

The Grindstone Creek watershed is composed of 934 cells resulting in a total acreage of 37,360. Of this, 360 acres or one percent of the watershed falls within the priority 1 category. Implementing Best Management Practices on 200 acres, which is 55 % of priority 1 cells, 0.5% of the watershed area and 3.3% of the cropland. By seeding 80 acres to permanent vegetation through the Conservation Reserve Program (CRP) and treating 120 acres of cropland with a four-year rotation of corn/sorghum, grain, sunflowers and grain, and reduced tillage, and using a 24 hour 25 year rainfall event in the AGNPS model which is 3.85 inches of rainfall in Haakon County, provides a reduction of 0.3% in total nitrogen, 0.0% in total phosphorus, and 0.6% in sediment delivered to the outlet of the watershed.

An additional 920 acres or 3.4 percent of the watershed fall within the priority 2 category. Implementing BMP's on 50% of the priority 2 areas by treating 240 acres with reduced tillage and seeding 240 acres to CRP brings the total treated acreage to 640 acres or 1.75% of the entire watershed and 10.5% of the cropland. Treatment of these additional acres increases the reduction in total nitrogen to 3.5%, a 4.7% reduction in total phosphorus, and an 11.8% reduction in total sediment delivered to the outlet of the watershed.

A total of 25 cells (1,000 acres) fell within the priority 3 ranking. Best Management Practices for priority 3 cells include 240 acres of reduced tillage and 240 acres seeded to CRP, bringing the total treated acreage to 1,120 acres or 3.1 % of the watershed and 18.4% of the cropland.

Priority 4 cells totaled 200 acres. Since the amount of cells in priority 4 was small these cells were combined with priority 3 cells. The total priority cells in category 1to 4 is 2,480 acres or 6.6% of the watershed. The total treated acres would be 1,200 acres or 3.3 % of the watershed and 19.7% of the cropland. Treating this additional area increases the total sediment reduction to 16.5%, with a total nitrogen reduction of 14.1 % and the total phosphorus reduction to 19.9%.

Table 31. Priority rated cells to be targeted for BMP implementation.

Priority	Cell Number
1	583, 610, 628, 629, 730, 857, 870, 894, 905
2	326, 413, 420, 560, 586, 587, 588, 605, 606, 608, 630, 651, 652, 653, 694, 712,713, 774, 856, 869, 881, 904, 915
3	305, 325, 370, 412, 536, 537, 542, 559, 565, 611, 617, 618, 635, 640, 674, 678, 692, 693, 714, 715, 716, 731, 732, 733, 903
4	631, 773, 882, 883, 890

Table 32. Expected Annual Nutrient and Sediment Reductions in the Grindstone Creek Watershed after BMP Implementation.

	Lbs. N/acre at outlet	Total N	Lbs. P/acre at outlet	Total P	Sed. T/ac.	Total tons
Current	1.60	59,620	0.39	14,500	0.0462	1,726
Priority 1 (200 ac. Treated, 0.5% of the Watershed)	1.59	59,400	0.39	14,500	0.0459	1,715
% Reduction		0.3		0.0		0.6
Priority 2 (680 ac. Treated 1.75% of the Watershed)	1.54	57,520	0.37	13,820	0.0408	1,523
% Reduction		3.5		4.7		11.8
Priority 3 & 4 (1,240 ac Treated 3.3% of the Watershed)	1.37	51,240	0.31	11,620	0.0386	1,442
% Reduction		14.1		19.9		16.5

Table 33. Expected Nutrient Reductions in the Grindstone Creek Watershed after BMP Implementation for a 25 Year-24 Hour Storm (3.85 inches)

	Lbs. N/acre at outlet	Total N	Lbs. P/acre at outlet	Total P	Sed. T/ac.	Total tons
Current	1.19	44,600	0.35	13,220	0.1204	4,498
Priority 1 (200 ac. Treated, 0.5% of the Watershed)	1.19	44,600	0.35	13,220	0.1161	4,337
% Reduction		0.0		0.0		3.6
Priority 2 (680 ac. Treated 1.75% of the Watershed)	1.15	43,100	0.34	12,720	0.1056	3,945
% Reduction		3.4		3.8		12.3
Priority 3 & 4 (1,240 ac Treated 3.3% of the Watershed)	1.10	41,060	0.31	11,600	0.0980	3,661
% Reduction		7.9		12.2		18.5
All Priority Cells Treated (2,480 ac Treated 6.6% of the Watershed)	1.01	37,880	0.31	10,420	0.0980	2,971
% Reduction		15.1		21.2		33.9

The treatment of additional cropland acres in the watershed will result in little additional reductions in nutrient loading to the lake. Likewise the treatment of non-priority cells will have a minimal effect on nutrient load reductions.

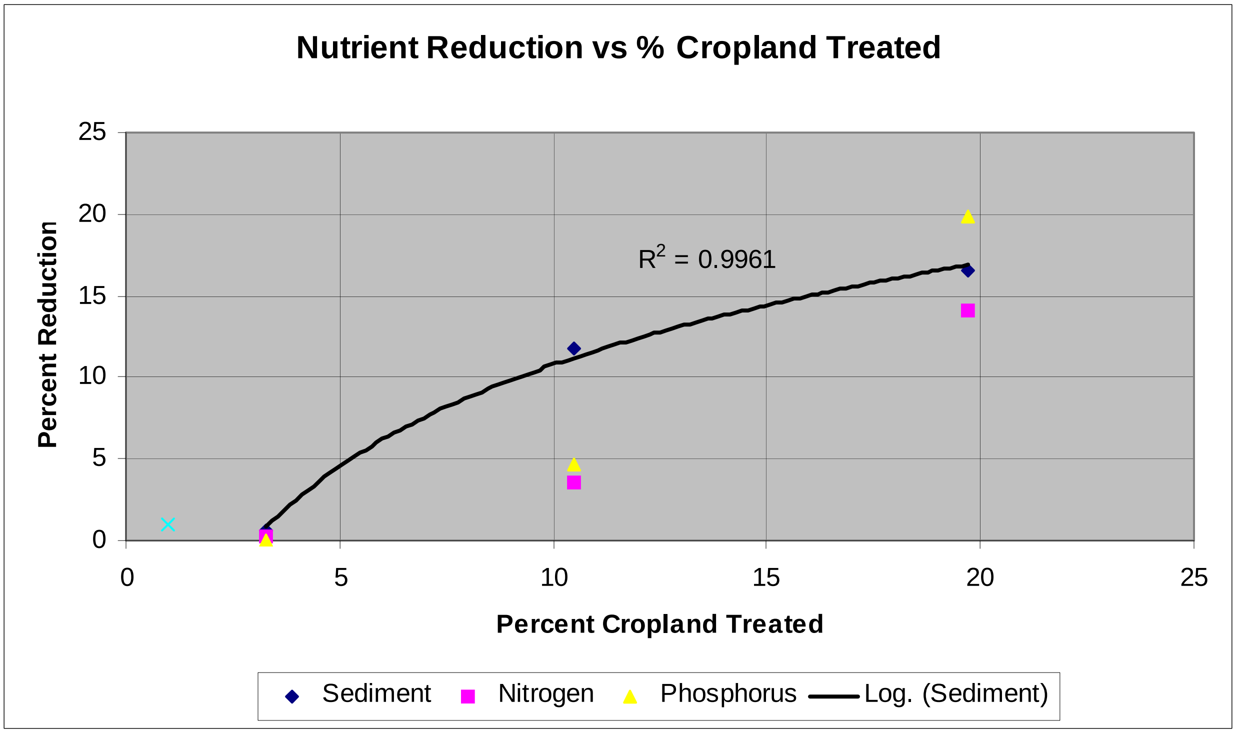


Figure 48. Percent of Grindstone Creek Cropland in the Watershed Treated with BMPs vs. Percent of Nutrient Load Reduced Annual Yield

The scenarios indicate above only treated 3.3% of the total watershed. Figure 14 represents the AGNPS predicted diminishing nutrient load reductions as additional cropland acres are treated with BMPs using 25 Year storm data. Loading reductions begin to significantly decrease when BMP's are implemented and continue to decrease in significant amounts until **20% to 30%** of the cropland acres in the watershed are implemented with BMPs. By treating all of the priority 1 through 4 cells 40.9% of the watershed cropland acres would receive some type of BMP. This falls within the range of treated cropland acres that is optimum for this watershed. It is interesting that treating all of the priority cells results in a total reduction of phosphorus of about 21% while treating half of the priority cells achieves a 12 % reduction.

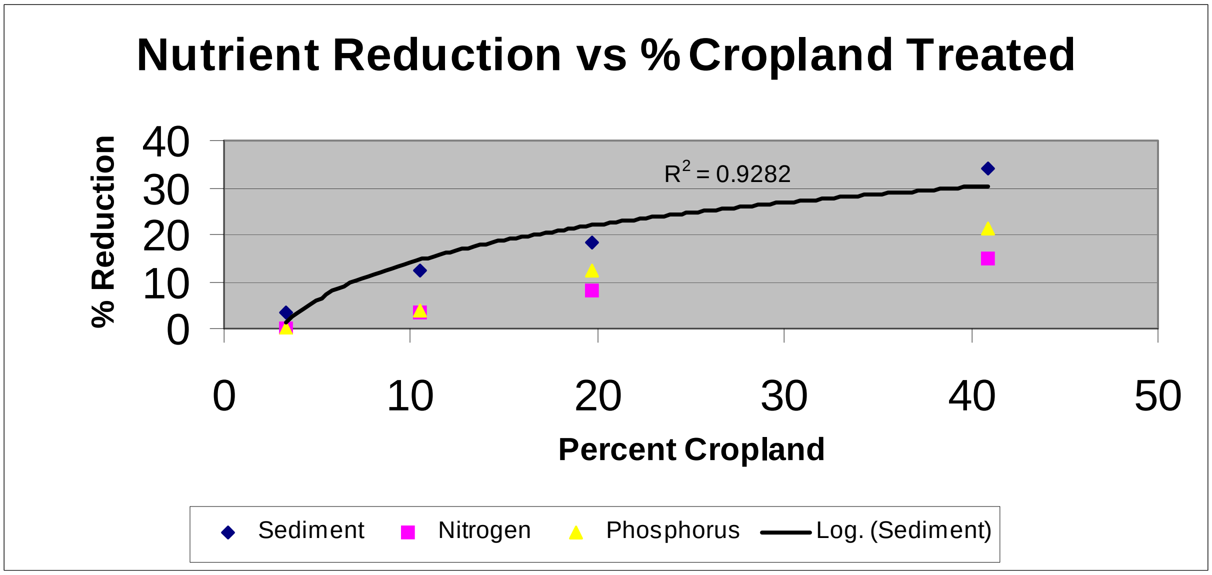


Figure 49. Percent of Grindstone Creek Cropland in the Watershed Treated with BMPs vs. Percent of Nutrient Load Reduced 25 Year-24 Hour Storm

The AGNPS program is not designed to adequately assess range conditions. The present land use in the 37,360 acres of the Grindstone Creek watershed above Lake Waggoner is 49% native range, 15% Conservation Reserve Program, 15% cropland and 21% pastureland, hay land, roads, water and farmsteads. Rangeland, hayland and CRP cells did not occur as priority cells. This does not mean that rangelands and water quality will not benefit from improved grazing management practices. Rotational grazing and management of riparian zones to improve the vegetative vigor and health by timing of livestock grazing will provide benefits that are difficult to simulate by this model. The modeled improvements were based on implementing 19.7 % (1200 acres) of the 6,060 acres of cropland in the watershed. The AGNPS model indicated that 2,480 acres of cropland were in the priority 1 to 4 ranking which is 41% of the total cropland. This is not surprising as the soils of this watershed are very erosive both from wind and water if the surface is not protected by vegetation or crop residue.

The Natural Resource Conservation Service completed a River Basin Study in March of 1994 that included the Grindstone Creek watershed. Most of this watershed exists in the area the study referred to as the tablelands. The study indicated that these tableland areas that still exist in native range are not a significant source of sediment to the Bad River and the same logic could be used for Lake Waggoner. Small-plot rainfall simulators were used with this study and determined that steady state infiltration rates decreased by as much as 98% on heavily grazed areas dominated by buffalograss and blue gramma. The majority of the 18,160 acres of native range in Grindstone Creek watershed have a significant under-story of buffalo and blue gramma grasses, so grazing management practices that encourage the increase of taller grasses would increase rainfall infiltration, benefit water quality, and help to reduce storm event runoff.

When using a model to simulate actual events that occur in the natural environment, a certain amount of error is expected. This error is dependent on the quality of the model, the quality of the data collected, and the quality of the actual measurements that are used to compare with the model data.

Eight livestock operations that feed livestock during the winter were identified in the watershed. There are no livestock feeding operations that feed year-around. All livestock are grazed during the growing season. Some of the livestock spend the entire year in the watershed; others are moved during the growing season to areas outside the watershed.

All of these operations that do feed during the winter were reviewed during the spring of 2003. The cattle are fed around farmsteads and headquarters on the open range using baled hay and other dry forage. The eight operations that do feed during the winter were not ranked using the AGNPS model because these operations do not fit the criteria used in the AGNPS model. A field review of these operations indicated that feeding was carried out over large areas of rangeland with no permanent damage to existing vegetation. Some areas had significant build up of manure but it was spread out across the rangeland and dissolved and was trapped in the native grass after spring thaw and as spring rains occurred. The nutrient factor from these operations is not significant, however, the use of terraces to further trap manure movement in the spring or the development of buffer areas or creating riparian pastures that are managed to keep the vegetation along Grindstone Creek in a healthy condition would reduce fecal coliform and nutrients delivered during spring runoff.

Total watershed reductions were calculated for the proposed AGNPS Best Management Practices. The model was set up to treat 50% of priority 1, 2, 3, and 4 areas with a 4 year rotation of grain, corn, grain and sunflowers using reduced tillage and to reseed **25% to permanent vegetation in the CRP. This treatment resulted in an annual reduction of 14.1% nitrogen, 19.9% phosphorus and reduced the sediment entering the lake by 16.5%.**

With the data available, it would not be possible to accurately estimate the reductions that are possible from grazing management practices. It is recognized that they do ultimately improve water quality and should be a part of any restoration efforts conducted in this watershed. Visual observations of the watershed indicate that there is no significant channeling in the riparian areas that remain in native grass whether they are grazed or hayed. The areas in CRP have good and improving riparian zones. Most of the cropland exists in the central and lower portions of the watershed and several areas could use grassed waterways to protect the drainage ways that are farmed. Most of the cropland that exists closer to the lake and borders Grindstone Creek is not farmed in the floodplain. These areas have been left in native range and are not used, or are grazed, or are cut for hay.

Another factor that the AGNPS model doesn't model well is the large dams in the Grindstone Creek watershed that have been built for stockwater. There are 5 or 6 dams in the watershed of 25 to 30 surface acres that collect sediment and reduce the peak flow of smaller storms. Some of these dams are located below areas of cropland with several of the priority-designated cells. These dams will fill with sediment and their value as a reservoir to hold sediment and nutrients will be lost. Treating the priority rated cells will prolong the life of these structures, which will benefit Lake Waggoner down stream.

Conclusions from the AGNPS Model

- The grazing land, hay land and CRP land are not a nutrient or sediment problem in Grindstone Creek watershed.
- There are areas of cropland that have significant erosion and are providing excess nutrients to Lake Waggoner. These areas have been designated priority areas 1, 2, 3, and 4. Many of these critical areas have land slopes that equal or exceed 6%.
- **Treatment of 50% of the priority areas as modeled would reduce the nitrogen load by 14%, the phosphorus load by 20% and the sediment load by 16.5%.**
- The CRP land is presently providing good resource protection, but will eventually come out of this program. All of the area in CRP has a cropping history. CRP areas that are returned to cropland could cause similar problems as some of the priority cells.
- Grazing systems that keep the livestock moving over the grazing area have proven to be effective in maintaining good grass cover and encourage the increase in tall grass species. The result is healthier riparian areas and higher infiltration rates in the uplands, which results in better water quality.

Sediment Survey

The volume of soft sediment contained within a reservoir provides an indication of erosion from the watershed. Increased sedimentation to a waterbody over time will decrease storage capacity. The soft sediment on the bottom of lakes is often rich in phosphorus. When lakes turn over in the spring and fall, sediment and attached nutrients are suspended in the water column making them available for plant growth. The accumulation of sediments in the bottom of lakes may also have a negative impact on fish and aquatic invertebrates. Sediment accumulation may often cover bottom habitat used by invertebrate species. The end result may be a reduction in the diversity of aquatic insect, snail and crustacean species.

Records do not indicate that any previous sediment surveys have been conducted on Lake Waggoner since it was constructed in 1940. A formal sediment survey was conducted in October of 2004. Results of this sediment survey indicated that Lake Waggoner has approximately 170,000 cubic yards of sediment with an average sediment depth of 1 foot and a maximum depth of 6.5 feet. Most of the soft sediment within Lake Waggoner is located in the upper third of the reservoir (Figure 53).

Observations from the survey indicated that most of the sediment volume was located in the upper one third of the lake. There was a well-defined creek channel present when the lake was formed (should have been similar to the present channels above and below the lake) and the sediment survey located this channel several times. The channel throughout the entire lake has silted full and has sediment depths of four to seven feet. The remainder of the lake (the larger portion) has sediment that varies in depth from three or four feet in the area near the highway bridge to a foot or less near the dam fill. The dam is approaching 70 years of age and the sediment present in the lake does not indicate a significant sediment load delivered from the 37,000 acre watershed.

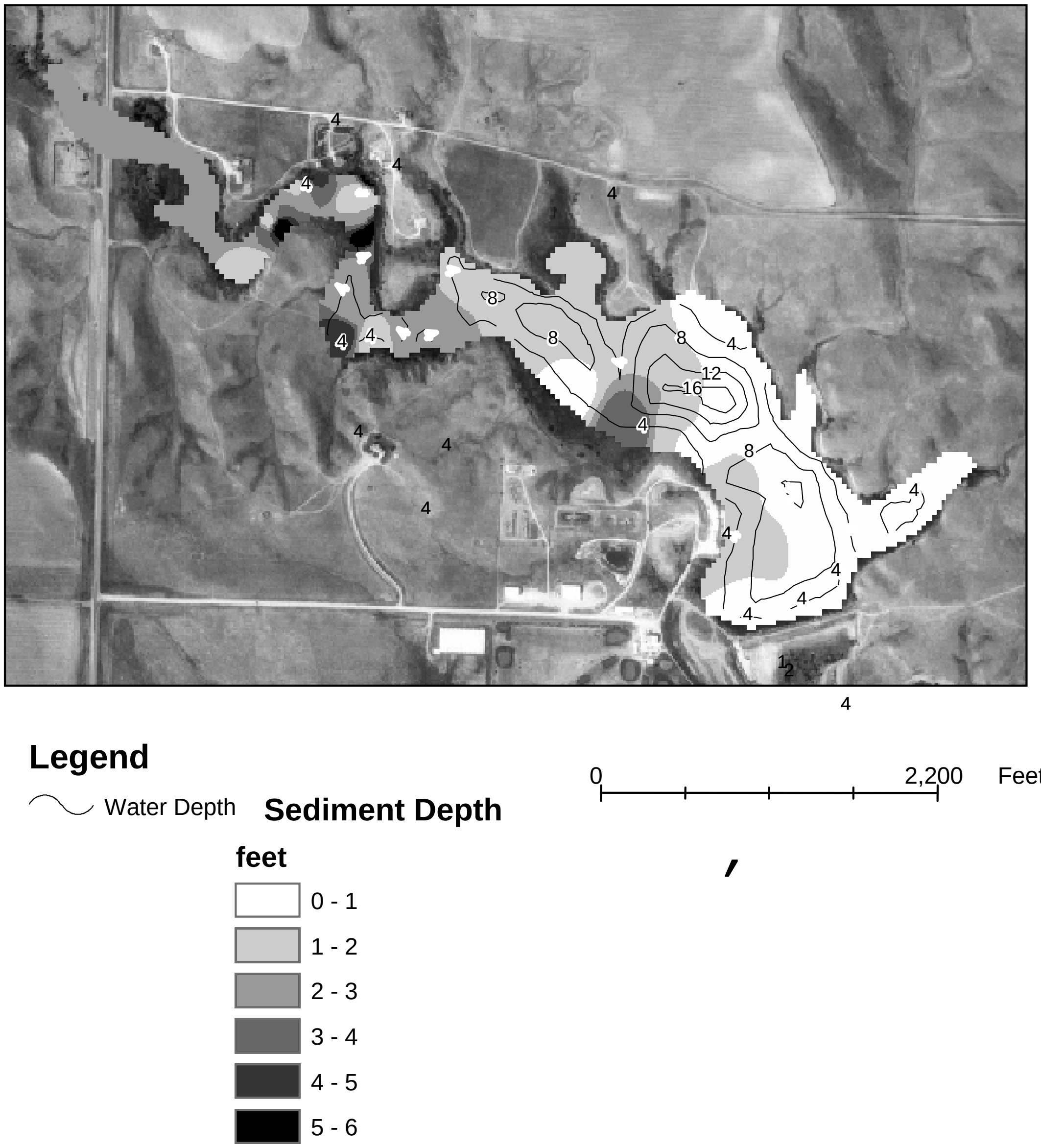


Figure 50. Bathymetric sediment map of Lake Waggoner 2004.

*Sediment depths are represented by color shading and contour lines and associated numeric values indicate water depth.

An analysis of the water and elutriate mix was conducted on samples collected on May 15, 2001. The results of this test may be found in Table 36. Elutriate samples are water samples that compare the toxins in the lake water to the toxins in the sediment from the bottom of the lake.

Elutriate test results indicated low to undetectable levels of all contaminants tested. The elutriate was tested for a multitude of chemicals commonly used in agricultural operations. The following chemicals were detected in the sediment but were below any level of concern: alachlor, chlordane, endrin, heptachlor, heptachlor epoxide, and methoxychlor.

The following chemicals were at undetectable levels: aldrin, dieldrin, PCB aroclor 1016, 1221, 1232, 1242, 1248, 1254, and 1260, diazinon, DDD, DDT, DDE, beta BHC, gamma BHC, alpha BHC, endosulfan II, and toxaphene. While some detectable levels were observed they were all below concentrations of concern (Table 37).

Table 34. Elutriate toxins test for Lake Waggoner 2001.

Parameter	Water	Elutriate	units
COD	38.8	47.0	mg/L
Phosphorus	0.212	0.095	mg/L
TKN	1.04	4.10	mg/L
Hardness	940	1000	mg/L
Nitrate	0.1	<0.1	mg/L
Aluminum	4.7	10.7	ug/L
Zinc	11.2	12.6	ug/L
Silver	<0.2	<0.2	ug/L
Selenium	5.6	3.3	ug/L
Nickel	4.7	5.5	ug/L
Mercury	0.25	<0.2	ug/L
Lead	0.8	<0.8	ug/L
Copper	0.02	<0.02	ug/L
Cadmium	<0.2	<0.2	ug/L
Arsenic	8.5	9.5	ug/L
Nitrite	<0.02	<0.02	mg/L
Atrazine	<0.5	<0.50	ug/L
Ammonia	<0.02	2.64	mg/L

Note: The elutriate water sample indicated suspect mercury contamination for mercury and lead amounts.

Table 35. Waggoner Lake receiving water and elutriate chemical concentrations collected in August 2001.

Parameter	Receiving Water Waggoner Lake	Elutriate Sample Waggoner Lake	Actual in Sediment Waggoner Lake	Unit
COD	38.8	47.0	8.2	mg/L
Phosphorus, total	0.212	0.095	-	mg/L
TKN	1.04	4.10	3.06	mg/L
Hardness	940	1000	-	mg/L
Nitrate	0.1	<0.1	<0.1	mg/L
Nitrite	<0.02	<0.02	<0.02	mg/L
Aluminum	4.7	10.70	6.0	µg/L
Zinc	11.2	12.6	1.4	µg/L
Silver	<0.2	<0.2	<0.2	µg/L
Selenium	5.6	3.3	-2.3	µg/L
Nickel	4.7	5.5	0.8	µg/L
Mercury, total	0.25	<0.2	<0.1	µg/L
Lead	0.8	<0.8	<0.1	µg/L
Copper	20.0	<20	<1.0	µg/L
Cadmium	<0.2	<0.2	<0.2	µg/L
Arsenic	8.5	9.5	1.0	µg/L
Ammonia	<0.02	2.64	2.62	mg/L
Endosulfan II	< 0.500	< 0.500	< 0.500	µg/L
Atrazine	< 0.500	< 0.500	< 0.500	µg/L
Endrin	< 0.500	< 0.500	< 0.500	µg/L
Heptachlor	< 0.400	< 0.400	< 0.400	µg/L
Heptachlor Epoxide	< 0.500	< 0.500	< 0.500	µg/L
Methoxychlor	< 0.500	< 0.500	< 0.500	µg/L
Toxaphene	ND	ND	ND	-
Aldrin	< 0.500	< 0.500	< 0.500	µg/L
Dieldrin	< 0.500	< 0.500	< 0.500	µg/L
Aroclor 1016	< 0.100	< 0.100	< 0.100	µg/L
Aroclor 1221	< 0.100	< 0.100	< 0.100	µg/L
Aroclor 1232	< 0.100	< 0.100	< 0.100	µg/L
Aroclor 1242	< 0.100	< 0.100	< 0.100	µg/L
Aroclor 1248	< 0.100	< 0.100	< 0.100	µg/L
Aroclor 1254	< 0.100	< 0.100	< 0.100	µg/L
Aroclor 1260	< 0.100	< 0.100	< 0.100	µg/L
Diazinon	< 0.500	< 0.500	< 0.500	µg/L
DDD	< 0.500	< 0.500	< 0.500	µg/L
DDT	< 0.500	< 0.500	< 0.500	µg/L
DDE	< 0.500	< 0.500	< 0.500	µg/L
BETA BHC	< 0.500	< 0.500	< 0.500	µg/L
GAMMA BHC	< 0.500	< 0.500	< 0.500	µg/L
ALPHA BHC	< 0.500	< 0.500	< 0.500	µg/L

ND = compounds screened for but not detected

Biological Monitoring

Fishery

The most recently published fisheries survey for Waggoner Lake was completed during the fall of 2003. Previous surveys were completed during 2002 and a detailed survey was carried out in the fall of 2001. Copies of the South Dakota Game, Fish and Parks Fisheries Survey for Waggoner Lake can be found in Appendix D.

The survey discusses in detail six of the eleven fish species found in the lake. The species identified during the survey were primary species largemouth bass and bluegill and secondary species black crappie, black bullhead, northern pike, yellow perch, green sunfish, walleye, channel catfish, smallmouth bass and white sucker.

The lake experienced a partial winterkill in 2000 and the local conservation officer and local anglers stocked adult bass from surrounding ponds in the lake to increase the large mouth bass population. The survey indicated the species were healthy and of good length. Largemouth bass and bluegill are the most common species and recent surveys indicate both are experiencing reproduction in the lake. The survey indicates that the lake is experiencing sedimentation which has not caused any fishery problems to date and has emergent vegetation problems for fishing in the summer months. The lake has primarily been managed for quality-size largemouth bass and bluegill.

Aquatic Macrophyte Survey

DENR staff conducted an aquatic plant survey on August 14 of 2001. Submerged and emergent aquatic vegetation was located, sampled, identified, and recorded at eighteen predetermined sampling transects. Due to the dense amount of cattails and bulrushes around the shore, an independent survey for emergent vegetation was also conducted along the shoreline. In addition, the presence or absence of livestock was also recorded at each transect. Transects were located every 225 meters proceeding in a clockwise fashion around the lake beginning at the boat access. A range finder was used to select the 225 meter points along the lakeshore. Figure 54 represents the approximate locations of each transect around Waggoner Lake.

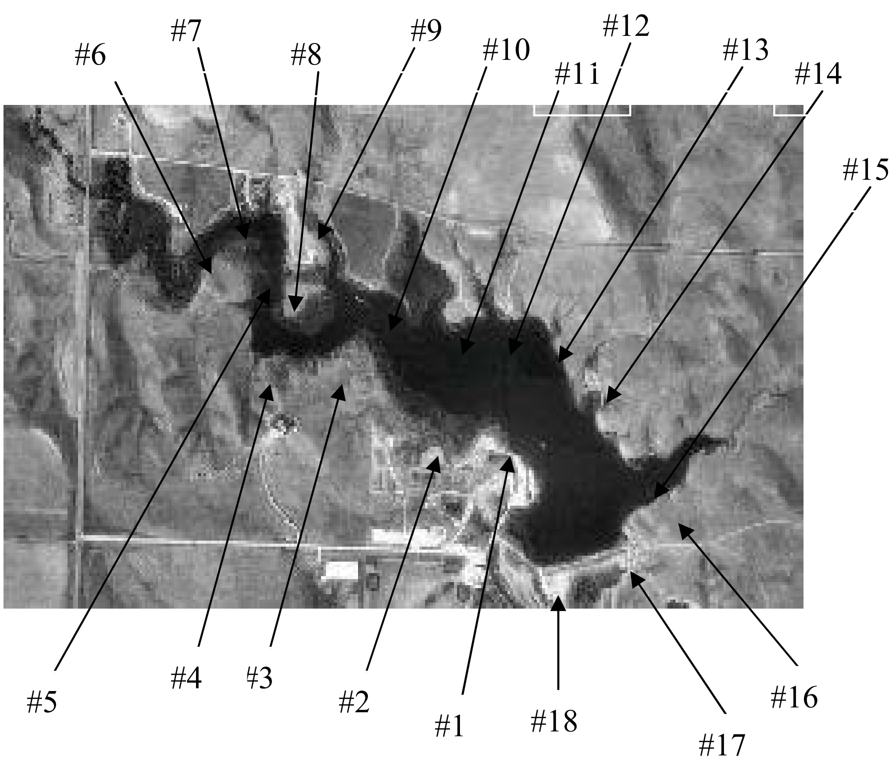


Figure 51. Approximate transect locations for the macrophyte survey conducted on Lake Waggoner 2001.

Submergent vegetation was predominantly located in the littoral zone or shallow margins along the shoreline. Most macrophytes were collected in 0.5 foot to 3 feet of depth. Plants were sampled with a standard rake head in four standard directions at all sampling sites. The density rating found in the SOP (2003) was used to rate the density of plants at each transect (Tables 38-39).

Table 36. Aquatic macrophyte species and corresponding density score for transects 1-9 Lake Waggoner 2001.

Transect	Depth (ft)	Species	*Density Score
1A	0.8	clasping leaf pondweed	1
1A	0.8	unidentified weed	2
1A	0.8	filamentous algae	3
1B	1.2	clasping leaf pondweed	2
1B	1.2	sago pondweed	2
1B	1.2	unidentified weed	2
2A	0.6	sago pondweed	1
2A	0.6	filamentous algae	3
2B	0.6	sago pondweed	1
2B	0.6	filamentous algae	1
3A	2.5	coontail	1
4A	2.1	filamentous algae	3
4A	2.1	sago pondweed	1
5A	0.9	water milfoil	1
5A	0.9	coontail	5
5A	0.9	filamentous algae	3
6A	1.1	coontail	1
6A	1.1	filamentous algae	4
7A	1.5	coontail	4
7A	1.5	filamentous algae	2
8A	1.3	coontail	3
8A	1.3	filamentous algae	1
9A	1.1	coontail	3
9A	1.1	sago pondweed	1
9A	1.1	filamentous algae	2

***Density Score: 1 = sparse 2 = scattered 3 = moderate 4 = heavy 5 = dense**

Table 37. Aquatic macrophyte species and corresponding density score for transects 10-18 Lake Waggoner 2001.

Transect	Depth (ft)	Species	*Density Score
10A	1.4	coontail	4
10A	1.4	sago pondweed	1
10A	1.4	filamentous algae	2
11A	1	coontail	1
11A	1	unidentified plant	4
11A	1	filamentous algae	1
12A	3.2	clasping leaf pondweed	3
12A	3.2	coontail	2
12A	3.2	unidentified plant	2
13A	1.5	unidentified plant	2
13A	1.5	coontail	1
13A	1.5	sago pondweed	1
13A	1.5	clasping leaf pondweed	2
13A	1.5	water milfoil	3
14A	1.2	unidentified plant	5
15A	0.6	coontail	3
15A	0.6	sago pondweed	2
15A	0.6	water milfoil	1
15A	0.6	filamentous algae	4
16A	1.2	unidentified plant	4
16A	1.2	coontail	2
16A	1.2	clasping leaf pondweed	1
16A	1.2	sago pondweed	1
16A	1.2	filamentous algae	3
17A	3.2	unidentified plant	2
18A	0.8	coontail	3
18A	0.8	filamentous algae	4

***Density Score: 1 = sparse 2 = scattered 3 = moderate 4 = heavy 5 = dense**

Emergent species in the riparian zone were identified and recorded as present or absent within 5 meters of the transect flag. Species recorded were limited to those identified as aquatic or wetland species in “Aquatic and Wetlands Plants of South Dakota”, written by Gary E. Larson. Submergent and emergent species were sampled using different methods, which restricts comparative analyses. Nonetheless, both submergent and emergent species were identified at each transect (Table 40).

Livestock had access to a portion of the shoreline during the summer. Transects #11 to #17 are located in an area where livestock were present from June through October. Emergent vegetation in this vicinity showed less density and vigor because livestock were present on the shore and entering the lake to drink. Emergent vegetation at transects identified as not having livestock present were much denser and vigorous. Cattails, bulrush, and reeds in many of these areas were so dense that access to the lake was limited or denied.

Only two submergent /floating plant species were common from the 18 transects (Tables 38 and 39). Coontail was found to be both more widely distributed and more abundant than sago pondweed during this survey. Sago pondweed was present mostly in sparse and scattered patches. Also frequently sampled was an unidentified aquatic plant which was abundant only at sites 14 and 16 in northeast Waggoner Lake. The most frequently sampled plants were filamentous algae (periphyton) that were large and abundant enough to be conspicuous and easily seen clinging to sampled macrophytes throughout the lake. Filament algae were reported on field data sheets as “moss”.

Table 38. Macrophyte species and associated submergent or emergent habitat, Lake Waggoner 2001.

Common Name	Genus	Species	Habitat
Coontail Clasping Leaf Pondweed	*Ceratophyllum* *Potamogeton*	*demersum* *richardsonii*	Submergent Submergent
Curly Leaf Pondweed	*Potamogeton*	*crispus*	Submergent
Flat Stem Pondweed	*Potamogeton*	*zosteriformis*	Submergent
Floating Leaf Pondweed	*Potamogeton*	*natans*	Submergent
Water-Milfoil filamentous algae(“moss”)	*Myriophyllum* -	sp. -	Submergent Submergent
Sago Pondweed	*Potamogeton*	*pectinatus*	Submergent
Common Cattail	*Typha*	*latifolia*	Emergent
Curly Dock	*Rumex*	*crispus*	Emergent
Hardstem Bulrush	*Scirpus*	*acutus*	Emergent
Plantain	*Alisma*	sp.	Emergent
Sedge	*Carex*	spp.	Emergent
Water Smartweed	*Polygonum*	*punctatum*	Emergent
Sandbar Willow	*Salix*	*exigua.*	Emergent
Peachleaf Willow	*Salix*	*amygdaloides*	Emergent

No significant differences were observed between submergent species and sites with and without livestock. Species of submergent vegetation seemed to relate more to the type of shoreline topography and associated soils then from local lake influences. Livestock were present for an extended period of time and they did appear to make frequent use of the lake as a water source and resting area. The presence of livestock in the riparian area around Waggoner Lake did not appear to reduce the diversity of submergent species. The intensity of use around a lake by livestock is often influenced by the timing of grazing, availability of other sources of water and availability of forage. Many lakes and stock ponds experience strong negative influences from livestock use of the riparian zone, especially in the months of July through September. When the assessment was conducted the emergent vegetation did appear to show negative impacts from livestock (Figure 55).

Lakeshore Habitat Assessment

A lakeshore (riparian) habitat survey was conducted on August 14, 2001 as part of the present watershed assessment and together with the foregoing aquatic macrophyte survey. The shoreline was examined in the vicinity of the 18 transects established for the aquatic macrophyte survey (Figure 54). Lakeshore segments were rated on a scale of 0 to10 representing degrees of lake riparian quality from poor to optimal for each of the parameters of bank stability (severity of erosion), density of vegetative cover, and width of the riparian zone.

The combined (sum) habitat parameter rating for each transect has a potential maximum of 30 units, representing the best obtainable lakeshore habitat. Combined ratings (total scores) for the shoreline survey ranged from 3 (poor) to 28 (optimal) (Figure 55). Five of the 18 transects evaluated (28%) were arbitrarily rated as poor lakeshore habitat (combined scores : 3 – 11). Three (16%) as marginal (scores: 15-17) and ten or 56% with total scores of 19-28 points were rated as of good to optimal quality.

This survey indicated that nearly three-fourths of the lakeshore sites surveyed were at least in an adequate condition, of which more than half were considered to be in good to optimal condition. Therefore, most of the lake shoreline is reasonably well protected from erosion and that, in general, Lake Waggoner is adequately though not well buffered against sediment and nutrient-laden runoff from the immediate watershed. Figure 55 shows the potential effects of heavy cattle use on the northeast shoreline at transects 12-17.

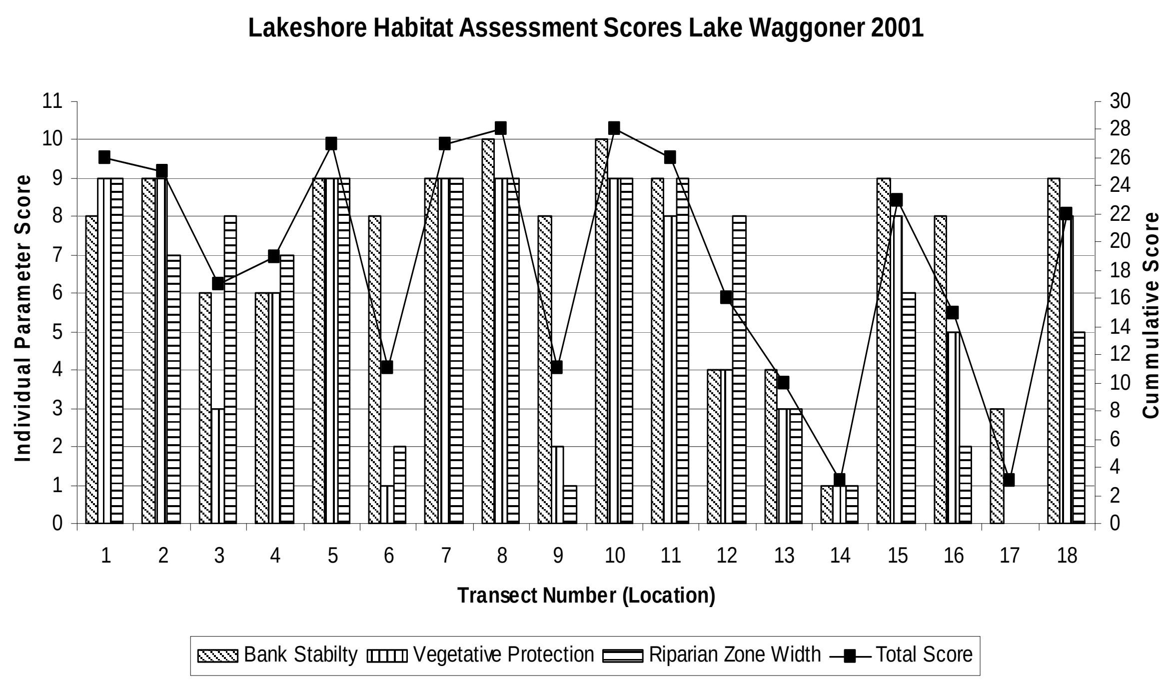


Figure 52. Lakeshore Habitat Assessment Scores Lake Waggoner 2001.

Threatened and Endangered Species

There are no threatened or endangered species documented in the Grindstone Creek watershed. The US Fish and Wildlife Service lists the whooping crane, bald eagle, piping plover, and least tern as reported in Haakon County and the American burying beetle as a possible species that could potentially be found in the area. None of these species were encountered during this study; however, care should be taken when conducting mitigation projects in the Grindstone Creek watershed.

Bald eagles typically prefer large trees for perching and roosting. Large trees in the Grindstone Creek watershed are few and far between. As there is no confirmed documentation of bald eagles within the Grindstone Creek watershed, little impact to the species should occur. Any mitigation processes that take place should avoid the destruction of large trees that may be used as eagle perches, particularly if an eagle is observed using a tree as a perch or roost.

Whooping cranes are not and never have been documented in the Grindstone Creek watershed. Sightings in this area are likely only during fall and spring migration. When roosting, cranes prefer wide, shallow, open water areas such as flooded fields, marshes, artificial ponds, reservoirs, and rivers. Their preference for isolation and avoidance of areas that are surrounded by tall trees or other visual obstructions makes it highly unlikely that they will be present to be negatively impacted as a result of the implementation of BMPs.

Least terns and piping plover are birds that would most likely be found along sandy lakeshores or sand bars in river conditions such as the Bad or Cheyenne River and Lake Oahe and Lake Sharpe areas. It is highly unlikely that they would occur in the Grindstone Creek watershed.

The American burying beetle is normally associated with upland range and has never been documented in Haakon County or the Grindstone Creek area. Any mitigation processes that take place will have to address the possible presence of any threatened and endangered species in the watershed.

Quality Assurance Reporting (QA/QC)

A total of 56 samples were collected during the project period. Six blank samples and eight replicate samples were collected to fulfill the EPA recommended 10 percent QA/QC requirement. In general, all replicate samples were reasonably close to the values expected for all parameters tested (Table 41). One nitrate parameter (blank) yielded a concentration above the laboratory detection limit. All other parameters collected with distilled water yielded values below the laboratory detection limit.

Table 39. Quality Assurance and Quality Control results from sampling conducted during the project period.

Site	Date	Time	Sample Type	Relative Depth	Alkalinity (mg/L)	Total Solids (mg/L)	Total Suspended Solids (mg/L)	Total Dissolved Solids (mg/L)	Volatile Suspended Solids (mg/L)	Ammonia (mg/L)	TKN (mg/L)	Nitrate (mg/L)	Total Phosphorus (mg/L)	Total Dissolved Phosphorus (mg/L)	Fecal Coliform (colonies/100 mL)	E-coli (colonies/100 mL)
WL01	6/23/04	14:00	sample	Surface	74	651	20	631	7	<0.02	1.22	<0.1	0.209	0.11		
WL01	6/23/04	14:00	Duplicate	Surface	73	651	18	633	5	<0.02	1.07	<0.1	0.218	0.103		
Standard Deviation					**0.707**	**0.000**	**1.414**	**1.414**	**1.414**	**0.000**	**0.106**	**0.000**	**0.006**	**0.005**		
WL01	7/28/04	13:00	sample	Surface	119	841	28	813	18	<0.02	1.37	<0.1	0.192	0.068		
WL01	7/28/04	13:00	Duplicate	Surface	119	842	27	815	18	<0.02	1.37	<0.1	0.191	0.063		
Standard Deviation					**0.000**	**0.707**	**0.707**	**1.414**	**0.000**	**0.000**	**0.000**	**0.000**	**0.001**	**0.004**		
WL01	7/28/04	13:05	sample	Bottom	119	848	34	814	16	<0.02	1.54	<0.1	0.199	0.074		
WL01	7/28/04	13:05	Duplicate	Bottom	119	859	35	824	17	<0.02	1.59	<0.1	0.205	0.072		
Standard Deviation					**0.000**	**7.778**	**0.707**	**7.071**	**0.707**	**0.000**	**0.035**	**0.000**	**0.004**	**0.001**		
Blank	7/28/04	13:30	Blank	Surface	<6	<7	<1	<5	<1	<0.02	<0.23	<0.1	<0.002	<0.002		
WL01	8/19/04	12:30	sample	Surface	136	897	19	878	11	<0.02	1.24	<0.1	0.173	0.059	<10	1
WL01	8/19/04	13:30	Duplicate	Surface	136	914	21	893	12	<0.02	1.48	<0.1	0.168	0.058	<10	1
Standard Deviation					**0.000**	**12.021**	**1.414**	**10.607**	**0.707**	**0.000**	**0.170**	**0.000**	**0.004**	**0.001**	**0.000**	**0.000**
WL01	8/19/04	12:30	sample	Bottom	136	912	20	892	11	<0.02	1.3	<0.1	0.166	0.056		
WL01	8/19/04	13:30	Duplicate	Bottom	135	910	20	890	13	<0.02	1.69	<0.1	0.173	0.06		
Standard Deviation					**0.707**	**1.414**	**0.000**	**1.414**	**1.414**	**0.000**	**0.276**	**0.000**	**0.005**	**0.003**		
WLT2	3/19/01	15:40	sample	Surface	57	605	14	591	2	0.15	1.77	1.9	0.348	0.271	<10	13.2
WLT2	3/19/01	15:40	Duplicate	Surface	58	608	15	593	4	0.17	1.78	1.8	0.34	0.272	<10	8.5
Standard Deviation					**0.707**	**2.121**	**0.707**	**1.414**	**1.414**	**0.014**	**0.007**	**0.071**	**0.006**	**0.001**	**0.000**	**3.323**
Blank	3/19/01	15:40	Blank	Surface	<6	7	<1	<5	<1	<0.02	<0.36	0.1	<0.002	<0.002	<10	<1.0
Blank	7/17/01	14:35	Blank	Surface	<6.0	<7.0	<1.0	<5	<1.0	<0.02	<0.36	<0.10	<0.002	<0.002	<10	<1.0
WL01	10/22/01	8:30	sample	Surface	192	2822	9	2813	6	<0.02	1.41	<0.10	0.102	0.04	<10	<1.0
WL01	10/22/01	8:30	Duplicate	Surface	193	2823	8	2815	6	<0.02	1.37	<0.10	0.103	0.04	<10	<1.0
Standard Deviation					**0.707**	**0.707**	**0.707**	**1.414**	**0.000**	**0.000**	**0.028**	**0.000**	**0.001**	**0.000**	**0.000**	**0.000**
Blank	10/22/01	8:30	Blank	Surface	<6.0	<6.0	<1.0	<5	<1.0	<0.02	<0.36	<0.10	<0.002	<0.002	<10	<1.0
Blank	10/23/01	8:30	Blank	Surface	<6.0	<6.0	<1.1	<5	<1.1	<0.03	<0.36	<0.10	<0.002	<0.002	<11	<1.1
WLT2	7/13/04	13:00	sample	Surface	101	373	112	261	24	<.02	1.99	<.1	0.886	m	770	670
WLT2	7/13/04	13:30	Duplicate	Surface	101	369	118	251	24	<.02	2.05	<.1	0.906	m	308	900
Standard Deviation					**0.000**	**2.828**	**4.243**	**7.071**	**0.000**	**0.000**	**0.042**	**0.000**	**0.014**	**0.000**	**326.683**	**162.635**
Blank	7/13/04	21:00	Blank	Surface	<6	<7	<1	<5	<1	<.02	<.23	<.1	<.002	m	<1	<10
Median Standard Deviation					**0.354**	**1.768**	**0.707**	**1.414**	**0.707**	**0.000**	**0.039**	**0.000**	**0.005**	**0.001**	**0.000**	**1.662**
Average Standard Deviation					**0.354**	**3.447**	**1.237**	**3.977**	**0.707**	**0.002**	**0.083**	**0.009**	**0.005**	**0.002**	**81.671**	**41.489**

Public Involvement and Coordination

The Haakon County Conservation District held regularly scheduled monthly public meetings. During these meetings the district manager updated participants as to the status of the project and future activities.

State Agencies

The South Dakota Department of Environment and Natural Resources administered the 319 funds for the project. DENR also took the lead in the AGNPS modeling, and was responsible for preparing this final assessment report and TMDLs. The SD Department of Game, Fish and Parks provided information about threatened and endangered species.

Federal Agencies

The US Environmental Protection Agency provided 319 Program funds. The USDA Natural Resource Conservation Service provided technical assistance.

Local Governments, other Groups, General Public

The Haakon County Conservation District was the project sponsor. District personnel conducted the water quality sampling, stream velocity measurements, stream stage recording, data compilation, and local outreach. The West River Water Development District and the city of Philip provided local support.

Other Sources of Funds

The Haakon County Conservation District provided in-kind services to the project. The West River Water Development District and the city of Philip provided local cash match for the project.

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Conclusions and Recommendations

Conclusions:

The beneficial uses of Lake Waggoner become threatened as the trophic state index (TSI) increases. Based on average inlake and tributary water quality conditions observed between a dry year (2001) and a wet year (2004) the growing season modeled median Secchi-chlorophyll TSI was estimated at 62.9, indicating a eutrophic state. The TSI trend of Lake Waggoner exhibited a slight increase over the course of data availability. Based on the TSI differences observed between 2001 (58.9) and 2004 (65.9) most of the difference in trophic state is likely due to seasonal loading from Grindstone Creek.

The AGNPS model identified several priority cells associated with cropland that were producing moderate nutrient and sediment loads to Grindstone Creek. This erosion and nutrient transport ultimately impacts Waggoner Lake. An estimated 15% of the land in the Grindstone Creek watershed is enrolled in the CRP. When the contracts expire the land will be eligible to return to cropland use. Depending on the farming methods used, the return of this area to cropland could have a negative impact on the water quality of the lake. The majority of the watershed acreage is native range and pastureland. AGNPS was not able to effectively model nutrient and sediment run-off from these landuse types.

Comparison of water quality results to parameters associated with water quality standards yielded minimal exceedances. The main parameter to display exceedances was total dissolved solids. All total dissolved solids concentrations observed in 2001, exceeded the water quality standard limit ($\leq$ 1,750) assigned to protect the domestic water supply beneficial use. Total dissolved solids concentrations tend to elevate above the standard during periods of low precipitation and associated watershed inflows. As water levels decrease due to evaporation, total dissolved solids become concentrated. Total dissolved solids loading from the artesian well also contributes to elevated inlake concentrations. The artesian well provides supplemental water necessary to dilute chemical constituents during dry periods to maintain a healthy water supply for the city of Phillip. However, the city of Phillip no longer uses Lake Waggoner as a domestic water supply. Total dissolved solids concentrations recovered and were well within the standard limit in samples collected in 2004 due to significant precipitation and inflow from Grindstone Creek.

Lake Waggoner did not exhibit oxygen stratification during any of the sampling events conducted in 2001. The lack of oxygen stratification in 2001 was attributed to bubble diffusion created by an artificial aeration system. This aeration system was primarily used to break stratification and promote aerobic conditions near the sediment-water interface. Anoxic sediments can cause the release of gases and other elements which result in the poor taste of drinking water. When the city of Philip went to rural water as their primary water source this aeration system was removed from the lake. In the absence of artificial aeration the lake experienced oxygen stratification (June 2004).

Lake Waggoner was identified as phosphorus-limited (ratio nitrogen to phosphorus > 10:1) primarily in the winter, fall, spring and early summer. However, phosphorus concentrations increased dramatically in the summer months of both years (2001-2004) and the lake experienced ratios consistent with nitrogen limitation. The incidence of nitrogen limitation during the summer months suggests that Lake Waggoner is subject to internal phosphorus loading. An increase in phosphorus concentrations in the summer months leads to nuisance algae blooms.

Recommendations:

A median TSI Secchi-chlorophyll of 60.6 is recommended based on AGNPS modeling, BMPs and watershed- specific phosphorus reduction attainability for Lake Waggoner. A 30% reduction in phosphorus from Grindstone Creek is required to meet this TSI target. The necessary reduction requires treatment of 50% of the cropland priority cells resulting in a 20% reduction of phosphorus. An additional 10% phosphorus reduction should be achieved by implementing grazing management strategies on rangeland and pasture. The AnnAGNPS (newest version) model should be used to identify and validate phosphorus reductions from rangeland and pasture. A 30% reduction in watershed phosphorus load is likely to achieve the TSI goal based on the strong linear relationship (R^2=0.91) observed between phosphorus and chlorophyll-*a*.

Technical assistance should be provided to the Grindstone Creek watershed partners to formulate a plan which directs the implementation of BMPs necessary to treat identified priority cells and expiring CRP contract acres. This assistance would aid the Natural Resource Conservation Service personnel that are assigned to Haakon County. The existing farm program should be used where eligible to implement practices. Additional funding sources such as EPA 319 should be applied for to help implement or add additional incentives to entice land owners to implement practices. For example, providing funding to replace a boundary fence to implement a grazing system may provide the additional incentive to keep an expired CRP contract in a grazing system instead of converting it back to cropland. These funds should be made available on an identified need basis.

A plan should be administered to reduce or prevent total dissolved solids loading from the artesian well into Lake Waggoner. This is a complex situation since the well is also an intricate component of other municipalities associated with the city of Philip. Lake Waggoner is no longer used as a primary water supply for the city of Phillip. Therefore, it is recommended that flow from the well be regulated at minimum capacity or diverted downstream to reduce total dissolved solids loading to Lake Waggoner. Eliminating this source of total dissolved solids should allow Lake Waggoner to comply with the water quality standard especially during periods of minimal inflow from the watershed. Controlling summer internal phosphorus re-cycling to promote phosphorus limitation is recommended to further improve trophic state and ultimately protect the beneficial uses of Lake Waggoner. Lake Waggoner has acquired an estimated 170,000 cubic yards of sediment since it was constructed in 1940. This sediment volume is not significantly impacting the basin’s storage capacity though it provides a phosphorus-rich environment.

Three solutions (dredging, aluminum sulfate and aeration) are commonly recommended to reduce phosphorus re-cycling in lake basins. Dredging the sediment through conventional and/or drawdown tactics is one potential strategy. However, the logistics and expense of dredging is often a limiting factor. For example, a barge style dredge could cost an estimated $3.00/ cubic yard of sediment removed or just over $500,000 to perform a complete dredging of the basin. This is likely a conservative estimate and costs could soar closer to $1,000,000 for total removal and reclamation. Treating the lake with aluminum sulfate (alum) to suppress phosphorus migration is another potential strategy. However, alum treatments are also expensive and offer only a temporary solution. Alum applications have been most successful in small deep lakes with minimal watershed loading. Diffuse aeration would provide yet another potential strategy. The premise of diffuse aeration is to break oxygen stratification and provide aerobic conditions near the sediment-water interface which acts to keep phosphorus bound to sediments. Aeration could also provide additional benefits such as increasing fish habitat, hindering blue-green algae growth and accelerating organic decomposition. Since the city of Phillip already possesses an aeration system it is recommended that it be re-installed and operated exclusively in June, July and August. It is expected that initial set-up and maintenance costs will likely be substantial since the system has not been operational in recent years. However, monthly operation costs ($35-$40) are minimal. Additional aeration systems may need to be installed to make sure the entire lake is oxygenated. If substantial efforts are directed towards controlling internal phosphorus re-cycling it is imperative that watershed loads be reduced prior to inlake treatment to allow an internal treatment to be successful.

Aspects of the Project That Did Not Work Well

The project worked out well with the exception of drought conditions that plagued most of the region from 2001 to the summer of 2004. Grindstone Creek experienced substantial flows in the summer of 2004 in which adequate hydrologic, nutrient and solids data were collected to complete this final assessment report.

Future Activity Recommendations

This assessment and final report provides necessary information to justify a 319-implementation project on Lake Waggoner and the Grindstone Creek watershed. Water quality goals and TSI targets are described and can be achieved by implementing Best Management Practices (BMPs) throughout the watershed. To enhance the project sponsor's ability to identify target areas of the watershed, an updated AnnAGNPS model is strongly encouraged for the Grindstone Creek watershed. Technical assistance for the AnnAGNPS model will be provided by DENR.

LITERATURE CITED

Carlson, R.E. 1977. A trophic state index for lakes. Limnology and Oceanography. 22:361-369.

Carlson, R.E. 1991. Expanding the trophic state concept to identify non-nutrient limited lakes and reservoirs. Lake Management Programs. Department of Biological Sciences. Kent State University, Kent Ohio.

Downing, J.A., S.B. Watson and E. McCauley. 2001. Predicting Cyanobacteria dominance in lakes. Canadian Journal of Fish and Aquatic Science. 58: 1905-1908.

Larson, G., 2000. Aquatic and Wetlands Plants of South Dakota. South Dakota State University, Brookings, SD.

Novotny and Olem, V. and H., 1994. Water Quality, Prevention, Identification, and Management of Diffuse Pollution, Van Nostrand Reinhold, New York

Prescott, G.W. 1962. Algae of the Western Great Lakes Area. Wm. C. Brown Publ., Dubuque, Iowa. 977 pp.

South Dakota Surface Water Quality Standards. Beneficial Uses of Waters Established, Administrative Rules of South Dakota, Chapter 74:51:01:42. State of South Dakota, Pierre, SD.

U.S Department of Interior, Fish, and Wildlife Service and U.S. Department of Commerce, Bureau of Census 1997.

U.S. Environmental Protection Agency, 1990. Clean Lakes Program Guidance Manual. EPA-44/4-90- 0006. Washington D.C.

Walker, W. W., 1999. Simplified Procedures for Eutrophication Assessment and Prediction: User Manual, U.S. Army Corps of Engineers

Water Resource Assistance Program 2005., Targeting For Impaired Lakes in South Dakota. South Dakota Department of Enviornment and Natural Resources, Division of Financial and Technical Assistance, Pierre, South Dakota.

Wetzel, R.G. 1983. Limnology 2rd Edition. Saunders Publishing Company, Philadelphia, Pennsylvania.

Wetzel, R.G. 2000. Limnological Analyses 3rd Edition. Springer-Verlag New York Inc., New York.

Wetzel, R.G. 2001. Limnology 3rd Edition. Saunders Publishing Company, Philadelphia, Pennsylvania.

Appendix A

Lake Waggoner and Grindstone Creek sample data 2001 and 2004

Surface Data Lake Waggoner 2001

Lake ID	Date	Field pH S.U	Secchi meters	Water Temp. (^oC)	DO mg/L	Alkalinity mg/L	TS mg/L	TDS mg/L	TSS mg/L	VTSS mg/L	Ammonia mg/L	Un-ionized Ammonia mg/L	Nitrate mg/L	TKN mg/L	TN mg/L	TP mg/L	TDP mg/L	N:P ratio	Chlorophyll a mg/m^3	E. Coli colonies/ 100 ml	Fecal Coliform colonies/ 100 ml	Mean TSI
WL1	Feb-01	M	0.85	3.5	14.2	196	3252	3246	6	3	0.01	M	0.1	1.16	1.26	0.047	0.019	26.81	13.62	461	<10	59.41
WL1	Apr-01	9	0.55	9	10.4	153	2264	2249	15	6	0.01	0.0015	0.2	1.26	1.46	0.114	0.024	12.81	77.4	<1.0	<10	71.45
WL1	May-01	8.58	0.6	12.2	7.6	163	2199	2185	14	3	0.01	0.00077	0.05	1.19	1.24	0.093	0.016	13.33	5.81	4.1	<10	61.58
WL1	Jun-01	8.53	2	19.8	9	171	2431	2425	6	0.05	0.01	0.0012	0.1	0.94	1.04	0.054	0.028	19.26	2.8	6.3	10	50.79
WL1	Jul-01	8.67	0.6	24.9	8.6	182	2528	2513	15	7	0.01	0.0021	0.05	1.44	1.49	0.263	0.148	5.67	68.08	1	<10	74.63
WL1	Aug-01	8.72	1	23	8	183	2623	2612	11	8	0.01	0.0021	0.1	1.56	1.66	0.294	0.198	5.65	18.62	3	20	68.47
WL1	Sep-01	8.93	1.4	15.4	7.8	193	2735	2724	11	5	0.01	0.0019	0.1	1.49	1.59	0.184	0.124	8.64	14.82	<1.0	<10	63.85
WL1	Oct-01	8.95	1	8.5	8.6	192	2822	2813	9	6	0.01	0.0013	0.05	1.41	1.46	0.102	0.04	14.31	25.93	<1.0	<10	64.46
WL2	Apr-01	9.02	0.55	9	10.7	152	2265	2250	15	7	0.01	0.0015	0.7	1	1.7	0.106	0.024	16.04	80	1	<10	71.20
WL2	May-01	8.65	0.5	12.2	9	164	2192	2179	13	6	0.01	0.0009	0.05	1.12	1.17	0.088	0.013	13.30	2.6	1	<10	59.56
WL2	Jun-01	8.45	2.2	19.9	9.6	168	2421	2414	7	3	0.21	0.021	0.1	0.8	0.9	0.053	0.028	16.98	1.5	5.2	10	48.20
WL2	Jul-01	8.64	0.5	24.9	9	184	2530	2513	17	10	0.01	0.002	0.05	1.77	1.82	0.27	0.144	6.74	45.86	<1.0	20	74.34
WL2	Aug-01	8.66	1	23	8.2	183	2632	2621	11	7	0.01	0.002	0.1	1.64	1.74	0.295	0.214	5.90	20.83	<1.0	<10	68.85
WL2	Sep-01	8.83	1.4	15.3	8.2	192	2747	2738	9	3	0.01	0.0016	0.1	1.16	1.26	0.171	0.146	7.37	17.02	<1.0	<10	63.95
WL2	Oct-01	8.82	0.9	8.5	8.4	192	2820	2811	9	6	0.01	0.001	0.05	1.3	1.35	0.105	0.04	12.86	30.84	<1.0	<10	65.67

Bottom Data Lake Waggoner 2001

Lake ID	Date	Water Temp. (^oC)	DO mg/L	Alkalinity mg/L	TS mg/L	TDS mg/L	TSS mg/L	VTSS mg/L	Ammonia mg/L	Nitrate mg/L	TKN mg/L	TN mg/L	ON mg/L	TP mg/L	TDP mg/L	N:P ratio
WL1	Feb-01	4.5	12.8	206	3488	3482	6	1	0.01	0.2	1.16	1.36	1.15	0.058	0.049	23.45
WL1	Apr-01	8	10.5	150	2280	2270	10	4	0.01	0.2	1.19	1.39	1.18	0.12	0.002	11.58
WL1	May-01	13	9.2	163	2186	2175	11	5	0.01	0.1	1.55	1.65	1.54	0.086	0.012	19.19
WL1	Jun-01	17	9	163	2429	2423	6	<1.0	0.01	0.1	0.91	1.01	0.9	0.056	0.029	18.04
WL1	Jul-01	23	7.4	184	2542	2531	11	5	0.01	0.05	1.68	1.73	1.67	0.249	0.148	6.95
WL1	Aug-01	26	8.2	185	2631	2619	12	8	0.01	0.1	1.65	1.75	1.64	0.3	0.21	5.83
WL1	Sep-01	15.4	7.2	191	2737	2729	8	4	0.06	0.1	1.46	1.56	1.4	0.178	0.13	8.76
WL1	Oct-01	7.6	8.4	192	2806	2798	8	6	0.01	0.1	1.39	1.49	1.38	0.097	0.041	15.36
WL2	Apr-01	8	10.4	152	2282	2266	16	5	0.01	0.2	1.34	1.54	1.33	0.116	0.023	13.28
WL2	May-01	13	9	163	2185	2174	11	4	0.01	0.05	1.15	1.2	1.14	0.09	0.017	13.33
WL2	Jun-01	18	9	170	2446	2439	7	3	0.01	0.1	0.95	1.05	0.94	0.053	0.029	19.81
WL2	Jul-01	23	8	182	2523	2508	15	7	0.01	0.05	1.57	1.62	1.56	0.265	0.191	6.11
WL2	Aug-01	22.2	8.4	186	2634	2623	11	9	0.01	0.1	1.52	1.62	1.51	0.291	0.208	5.57
WL2	Sep-01	15.3	7.5	191	2736	2727	9	4	0.03	0.1	1.2	1.3	1.17	0.179	0.134	7.26
WL2	Oct-01	8	8.3	192	2819	2809	10	6	0.01	0.05	1.37	1.42	1.36	0.105	0.04	13.52

Composite Data Lake Waggoner 2004

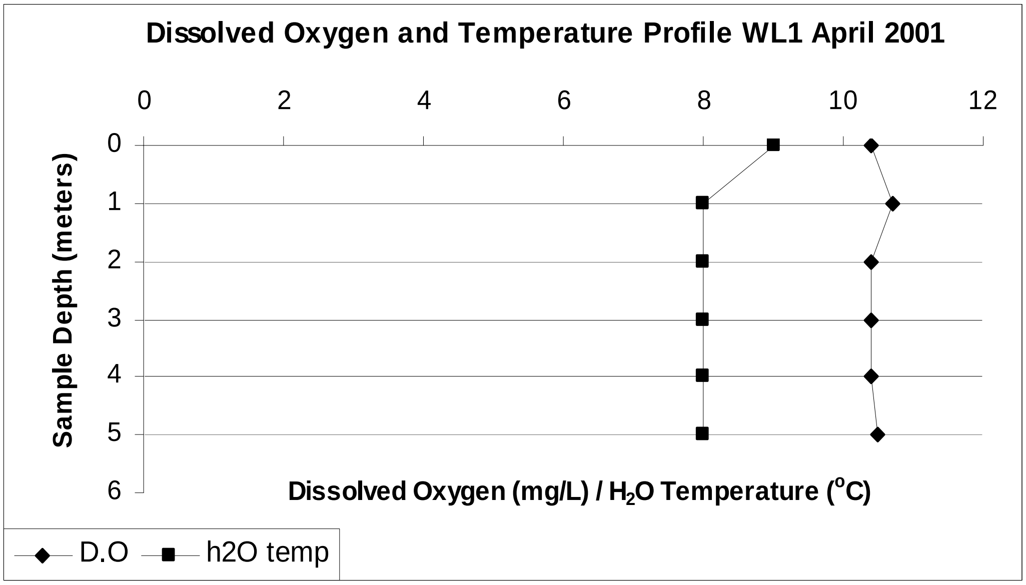
Lake ID	Date	Depth	Field pH S.U	Secchi meters	Water Temp. (oC)	Specifc Cond. ug/m3	DO mg/L	Alkalinity mg/L	Total Solids mg/L	Total Dissolved Solids mg/L	Total Suspended Solids mg/L	Volatile Suspended Solids mg/L	Ammonia mg/L	Nitrate mg/L	TKN mg/L	Total Nitrogen mg/L	Total Phosphorus mg/L	Total Dissolved Phosphorus mg/L	N:P ratio	Chlorophyll *a* mg/m3	E. Coli colonies/ 100 ml	Fecal Coliform colonies/ 100 ml
WL01	4/22/04	Surface	8.4	0.76	12.41	2839	9.5	125	2767	2755	12	6	0.01	0.05	1.08	1.13	0.062	0.016	18.2	19.4	20	12
WL01	5/20/04	Surface	7.63	1.3	16.15	2555	7.88	122	2851	2839	12	4	0.01	0.05	1.18	1.23	0.049	0.021	25.1	14.7	20	9.8
WL01	6/23/04	surface	7.43	0.701	18.76	928	10.52	74	651	631	20	7	0.01	0.05	1.22	1.27	0.209	0.11	6.1	56.6		
WL01	7/28/04	surface	7.93	0.54	22.54	1014	5.2	119	841	813	28	18	0.01	0.05	1.37	1.42	0.192	0.068	7.4	72.06		
WL01	8/19/04	Surface	7.22	0.7	19.6	1093	8.05	136	897	878	19	11	0.01	0.05	1.24	1.29	0.173	0.059	7.5	50.7	5	1
WL01	4/22/04	Bottom	8.44		12.62	2838	8.96	124	2775	2763	12	8	0.01	0.05	1.19	1.24	0.073	0.035	17.0			
WL01	5/20/04	Bottom	7.83		15.31	2510	6.9	123	2848	2841	7	0.05	0.01	0.05	1.19	1.24	0.058	0.019	21.4			
WL01	6/23/04	bottom	8.08		17.67	1965	1.12	74	657	636	21	6	0.01	0.05	1.27	1.32	0.202	0.111	6.5			
WL01	7/28/04	bottom	7.72		22.2	1026	1.12	119	848	814	34	16	0.01	0.05	1.54	1.59	0.199	0.074	8.0			
WL01	8/19/04	Bottom	7.82		19.6	1093	7.74	136	912	892	20	11	0.01	0.05	1.3	1.35	0.166	0.056	8.1			

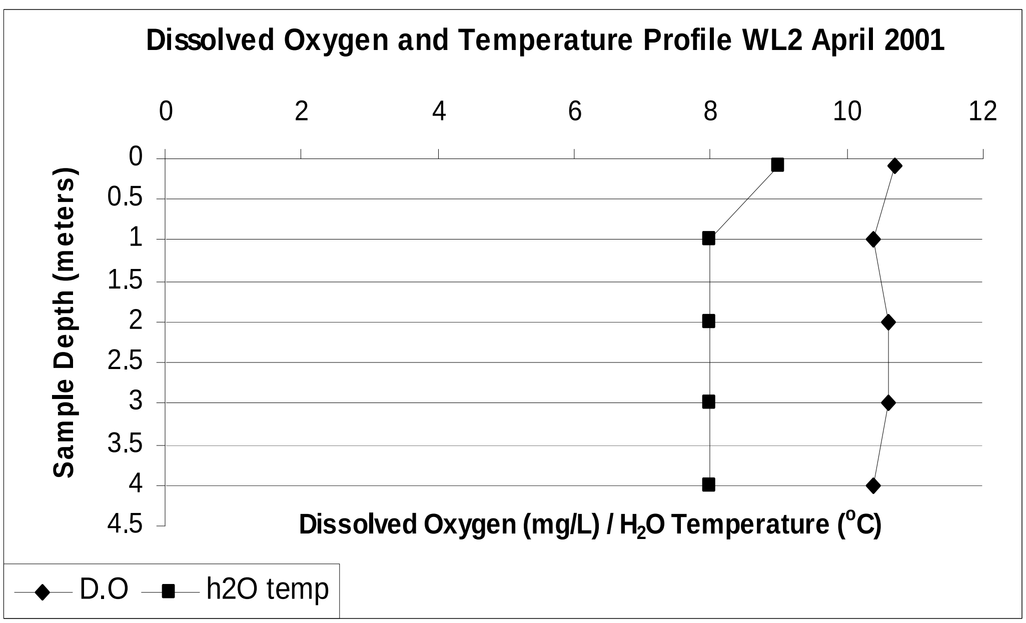
Tributary Data Including Lake Outlet and Artesian Well 2001-2004

Trib ID	Date	pH su	temp W ^{o}C	DO mg/L	Cond uS/cm	Alkalinity mg/L	TS mg/L	TSS mg/L	TDS mg/L	VTSS mg/L	Ammonia mg/L	Nitrate mg/L	TKN mg/L	TP mg/L	TDP mg/L	E. Coli colonies/ 100ml	Fecal colonies/ 100ml	Discharge (cfs)
WLO	06/11/2004	7.85	17.24	6	671	46	608	88	520	6	0.12	0.6	1.02	0.294	m	2420	2000	439
WLO	06/14/2004	7.19	20.63	7.17	627	53	472	28	444	5	0.02	0.5	0.85	0.263	m	49.6	100	10.62
WLO	3/22/01	9.06	2.4	13.2	m	91	1268	19	1249	5	<0.02	0.7	1.39	0.263	0.087			6.45
WLO	3/19/01	8.8	3.2	12	m	94	1355	28	1327	10	<0.02	0.9	2.43	0.353	0.111	3.1	<10	8.13
WLT1	3/8/01	7.37	1.00	13.00	m	32	426	124	302	14	0.34	1.4	2.49	0.584	0.344	2420	990	11.93
WLT1	3/13/01	7.71	1.00	m	m	50	631	132	499	14	0.24	1.6	1.86	0.443	0.155	921	660	4.85
WLT1	3/19/01	7.58	4.30	11.40	m	67	671	28	643	4	0.12	1.8	1.97	0.362	0.318	108	40	5.56
WLT1	3/22/01	7.94	4.70	9.00	m	79	759	22	737	4	<0.02	1.7	1.18	0.3	0.212			4.76
WLT1	4/24/01	7.58	7.10	10.50	m	224	4024	12	4012	3	<0.02	46.5	1.65	0.04	0.016	1733	1100	0.001
WLT1	05/26/2004	6.71	11.85	8.8	3806	284	4206	33	4173	10	<.02	0.4	1.92	0.137	0.054	249	330	0.044
WLT1	06/11/2004	7.82	16.09	6.6	281	45	926	680	246	80	0.18	0.4	2.37	1.14	m	>2420	5400	160.6
WLT1	06/14/2004	7.37	22.18	6.33	511	74	412	36	376	6	<.02	0.1	1.25	0.367	m	866	560	6.62
WLT1	06/16/2004	7.41	18.8	6.85	500	90	374	23	351	8	<.02	<.1	1.35	0.394	m	137	210	3.175
WLT1	07/15/2004	7.59	26.3	m	603	153	416	15	401	6	<.02	<.1	1.68	0.201	m	1730	900	7
WLT2	3/8/01	7.35	1.00	13.00	m	20	162	35	127	9	0.09	0.5	1.79	0.317	0.3	48.8	<10	11.94
WLT2	3/13/01	7.24	1.00	m	m	34	364	72	292	10	0.24	0.8	2.12	0.519	0.322	12.2	10	42.3
WLT2	3/19/01	7.22	4.30	11.20	m	57	605	14	591	2	0.15	1.9	1.77	0.348	0.271	13.2		1.82
WLT2	3/22/01		4.00	8.80	m	55	477	18	459	<1.0	<0.02	1.5	1.19	0.318	0.254			1.62
WLT2	4/24/01	7.81	14.60	10.80	m	40	367	61	306	9	<0.02	0.4	1.49	0.441	0.272	>2420	3100	0.01
WLT2	3/14/03	7.5	2.00	m	m	62	252	45	207	8	0.18	0.2	1.63	0.482	m	m	m	1.52
WLT2	5/24/04	8.5	13.66	8.26	95.0	60	822	490	332	90	0.12	0.05	4.06	1.46	m	>2420	41000	3.27
WLT2	05/26/2004	6.79	18.74	5.06	220	77	627	280	347	52	0.1	<.1	3.8	1.14	m	>2420	300000	0.033
WLT2	06/11/2004	7.93	15.55	6.75	149	40	496	336	160	36	0.04	0.2	1.84	0.734	m	>2420	10800	32.25
WLT2	06/14/2004	7.45	24.09	7.23	226	61	273	47	226	9	<.02	<.1	0.99	0.427	m	866	700	0.893
WLT2	06/16/2004	7.2	16.42	8.9	248	m	m	m	m	m	m	m	m	m	m	m	m	0.106
WLT2	07/13/2004	7.42	24.4	6.2	308	101	373	112	261	24	<.02	<.1	1.99	0.886	m	770	670	10.73
Well	3/14/2003	NA	NA	NA	NA	119	1237	2	1235	1	0.02	0.1	0.11	0.009	NA	NA	NA	NA

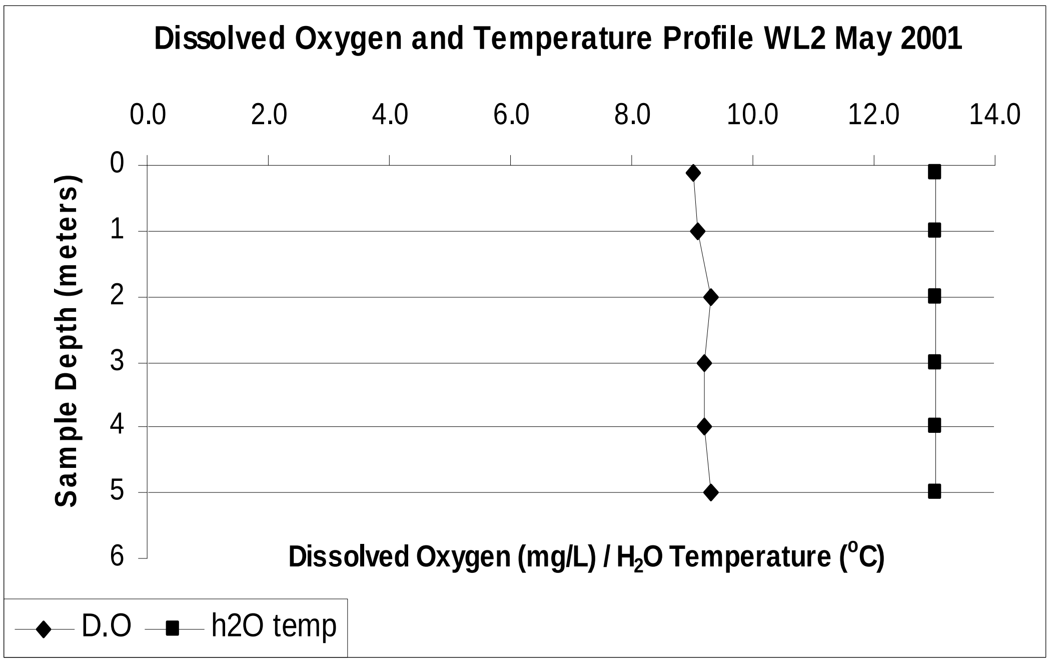
Appendix B

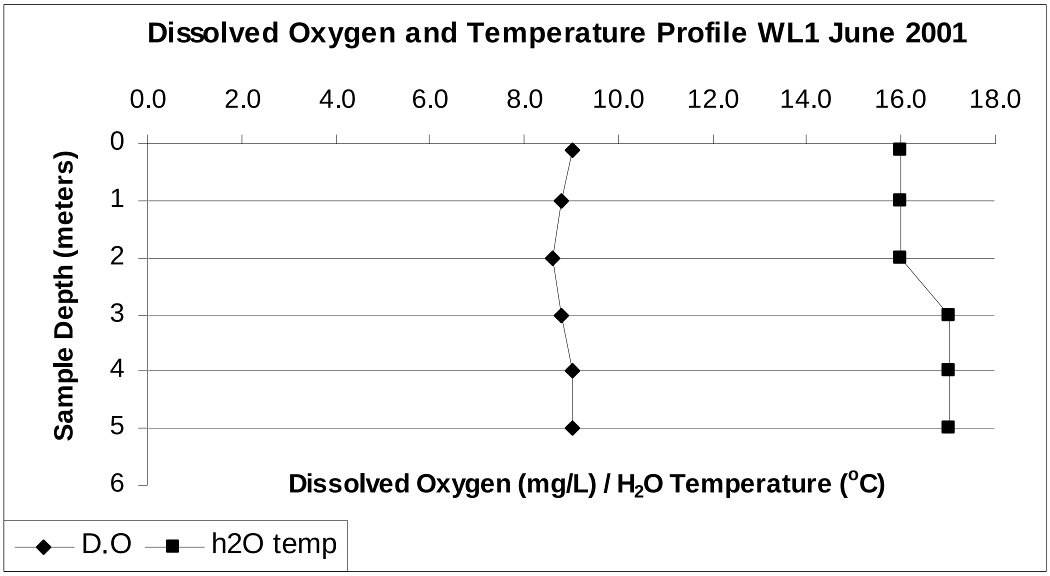
Dissolved oxygen and temperature profile graphs for Lake Waggoner
2001-2004

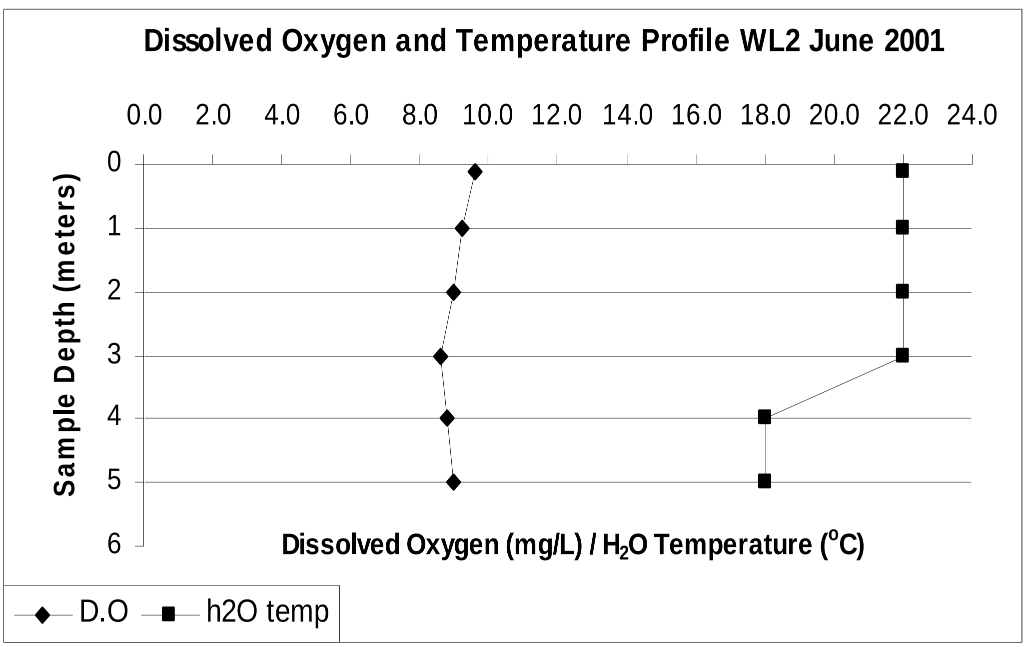

Dissolved Oxygen and Temperature Profile WL1 April 2001
0
2
4
6
8
10
12
0
1
2
3
4
5
6
Sample Depth (meters)
Dissolved Oxygen (mg/L) / H2O Temperature (oC)
D.O
h2O temp

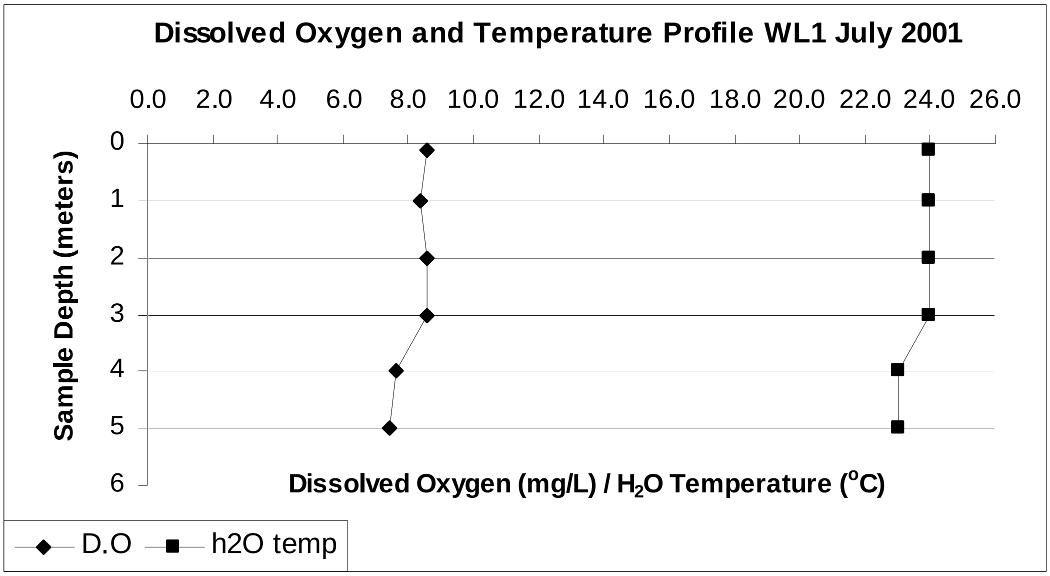

Dissolved Oxygen and Temperature Profile WL2 April 2001
0
2
4
6
8
10
12
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Sample Depth (meters)
Dissolved Oxygen (mg/L) / H2O Temperature (oC)
D.O
h2O temp

No data for WL1 May 2001

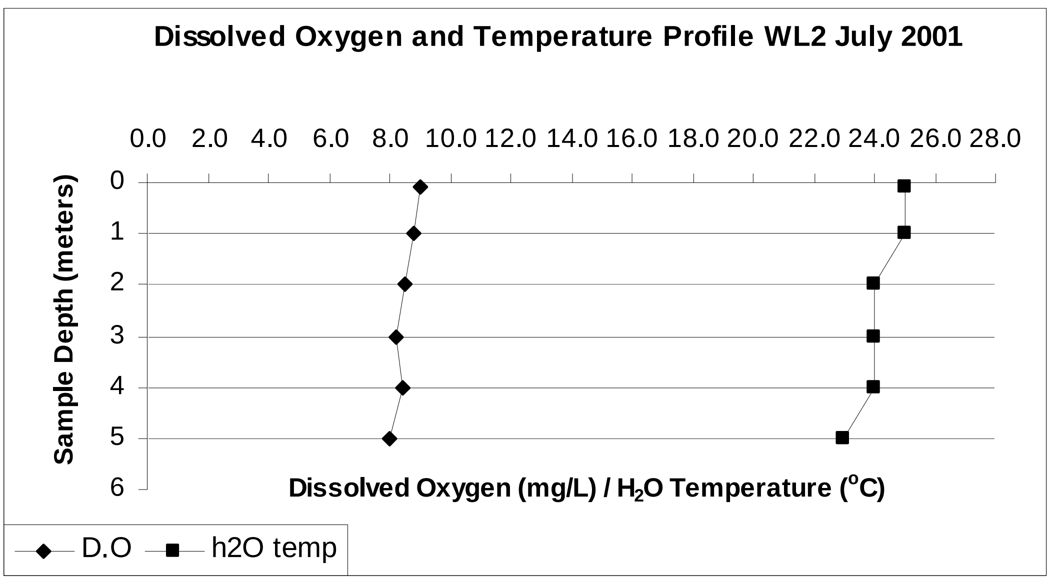



Dissolved Oxygen and Temperature Profile WL1 June 2001
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
0
1
2
3
4
5
6
Sample Depth (meters)
Dissolved Oxygen (mg/L) / H_2O Temperature (^oC)
D.O
h2O temp

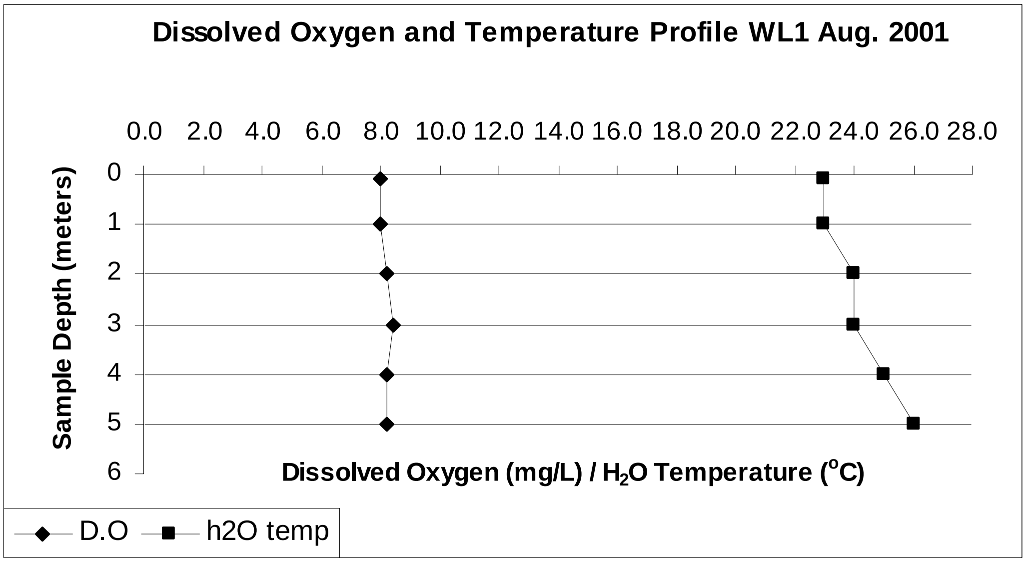

Dissolved Oxygen and Temperature Profile WL2 June 2001
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
0
1
2
3
4
5
6
Sample Depth (meters)
Dissolved Oxygen (mg/L) / H_2O Temperature (^oC)
D.O
h2O temp

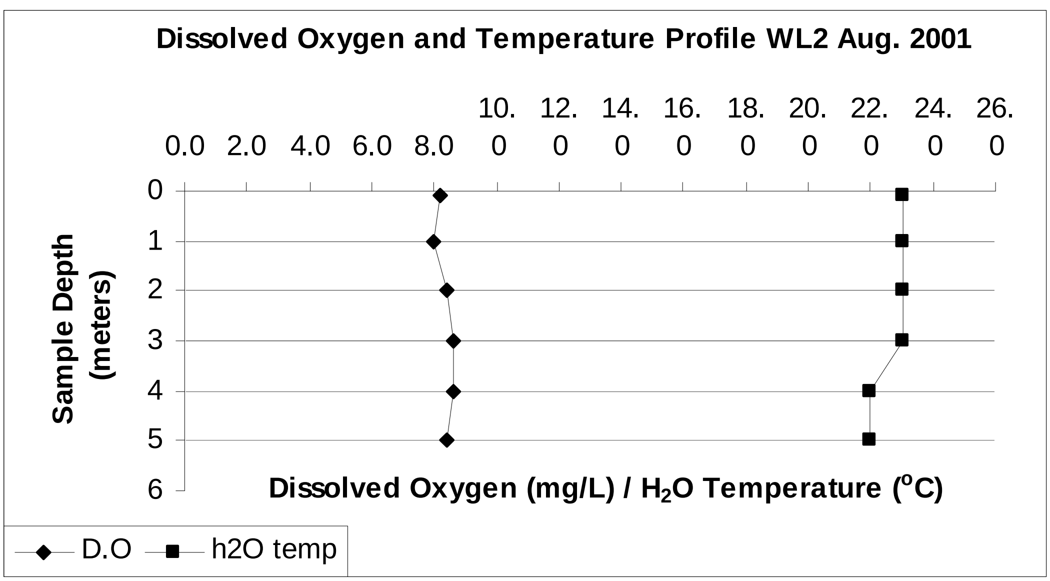


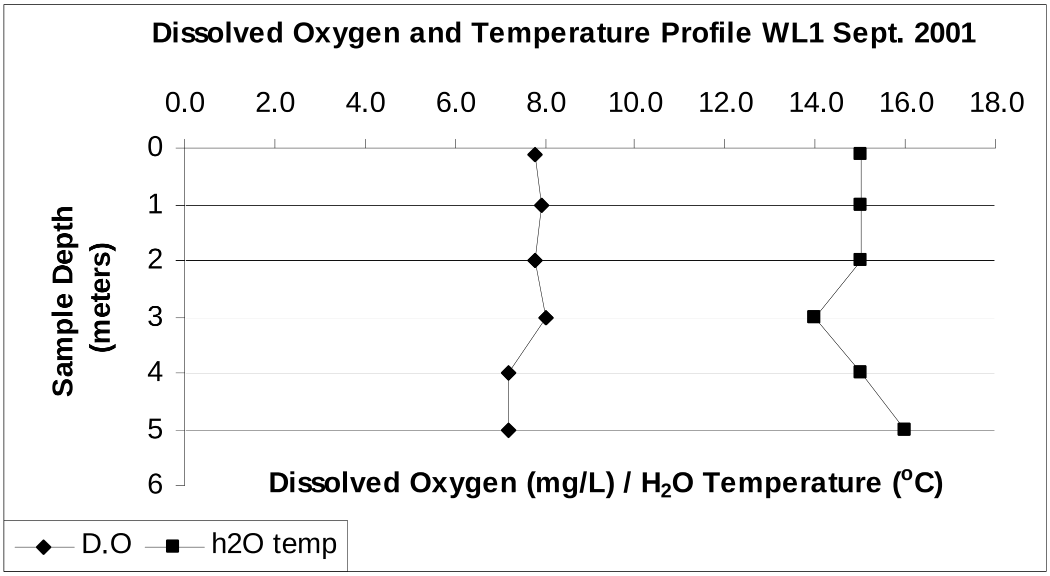
Dissolved Oxygen and Temperature Profile WL1 July 2001
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0 16.0 18.0 20.0 22.0 24.0 26.0
0
1
2
3
4
5
6
Sample Depth (meters)
Dissolved Oxygen (mg/L) / H_2O Temperature (^oC)
D.O
h2O temp

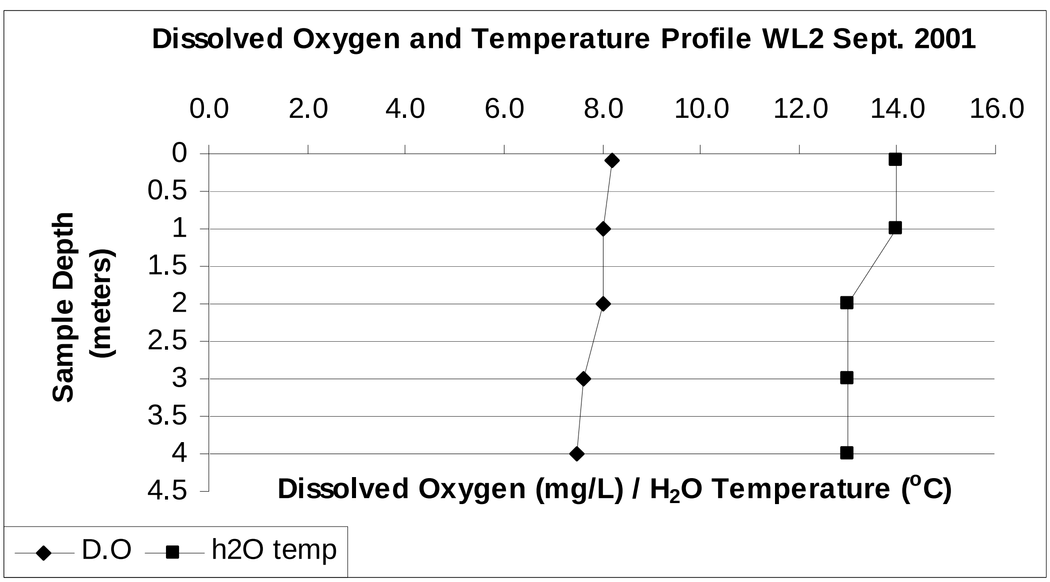


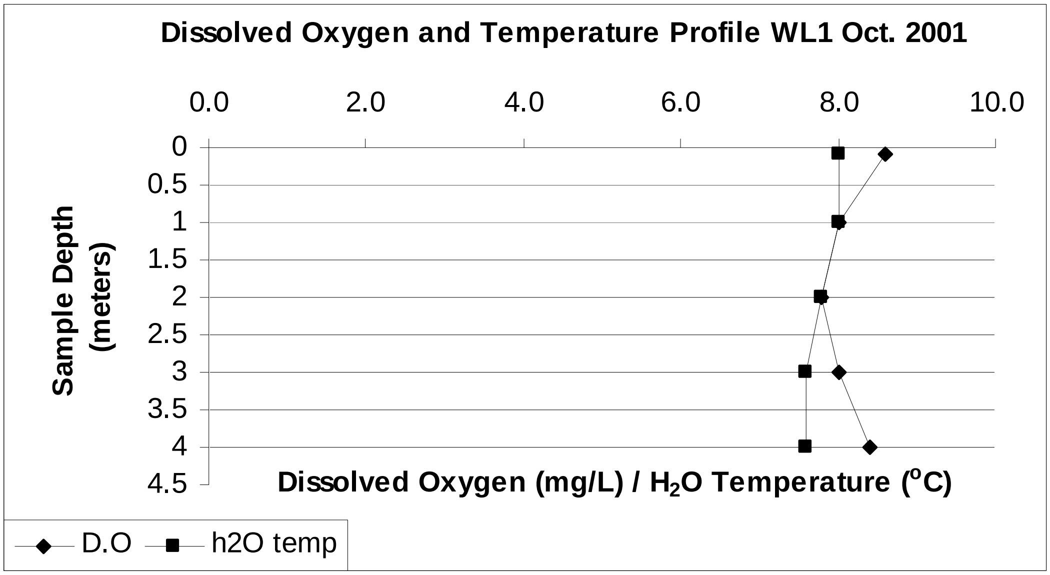
Dissolved Oxygen and Temperature Profile WL2 July 2001
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0 16.0 18.0 20.0 22.0 24.0 26.0 28.0
0
1
2
3
4
5
6
Sample Depth (meters)
Dissolved Oxygen (mg/L) / H_2O Temperature (^oC)
D.O
h2O temp


Dissolved Oxygen and Temperature Profile WL1 Aug. 2001
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0 16.0 18.0 20.0 22.0 24.0 26.0 28.0
0
1
2
3
4
5
6
Sample Depth (meters)
Dissolved Oxygen (mg/L) / H2O Temperature (oC)
D.O
h2O temp

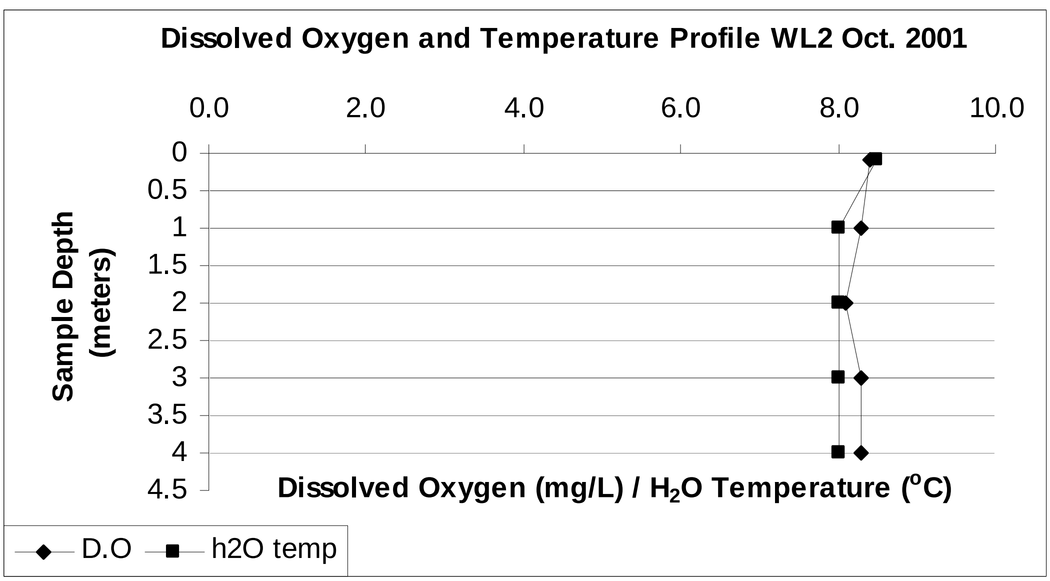

Dissolved Oxygen and Temperature Profile WL2 Aug. 2001
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0 16.0 18.0 20.0 22.0 24.0 26.0
0
1
2
3
4
5
6
Sample Depth (meters)
Dissolved Oxygen (mg/L) / H2O Temperature (oC)
D.O
h2O temp


Dissolved Oxygen and Temperature Profile WL1 Sept. 2001
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
0
1
2
3
4
5
6
Sample Depth (meters)
Dissolved Oxygen (mg/L) / H2O Temperature (oC)
D.O
h2O temp

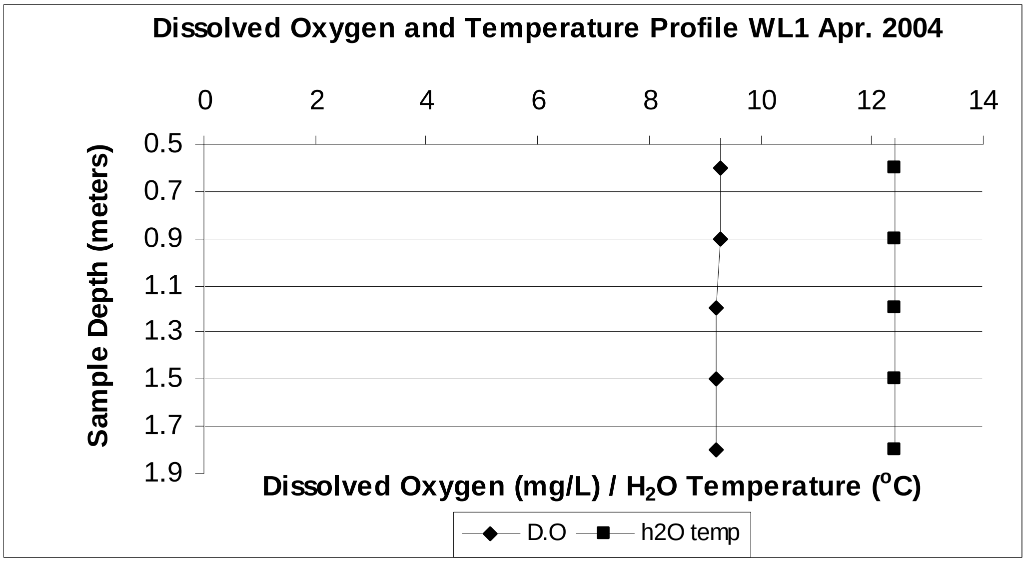

Dissolved Oxygen and Temperature Profile WL2 Sept. 2001
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Sample Depth (meters)
Dissolved Oxygen (mg/L) / H2O Temperature (oC)
D.O
h2O temp

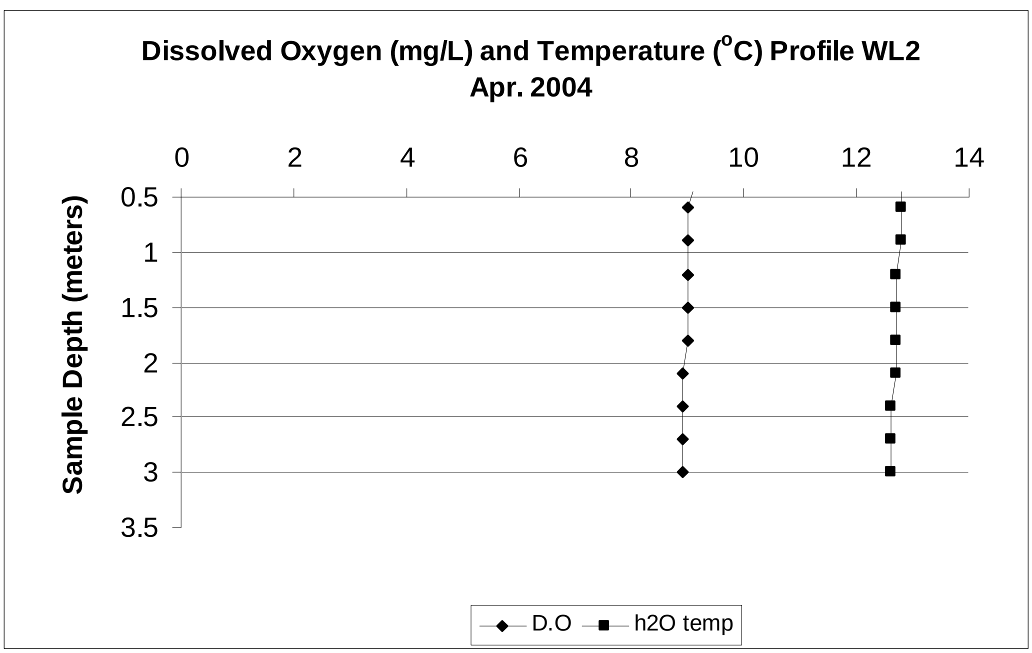


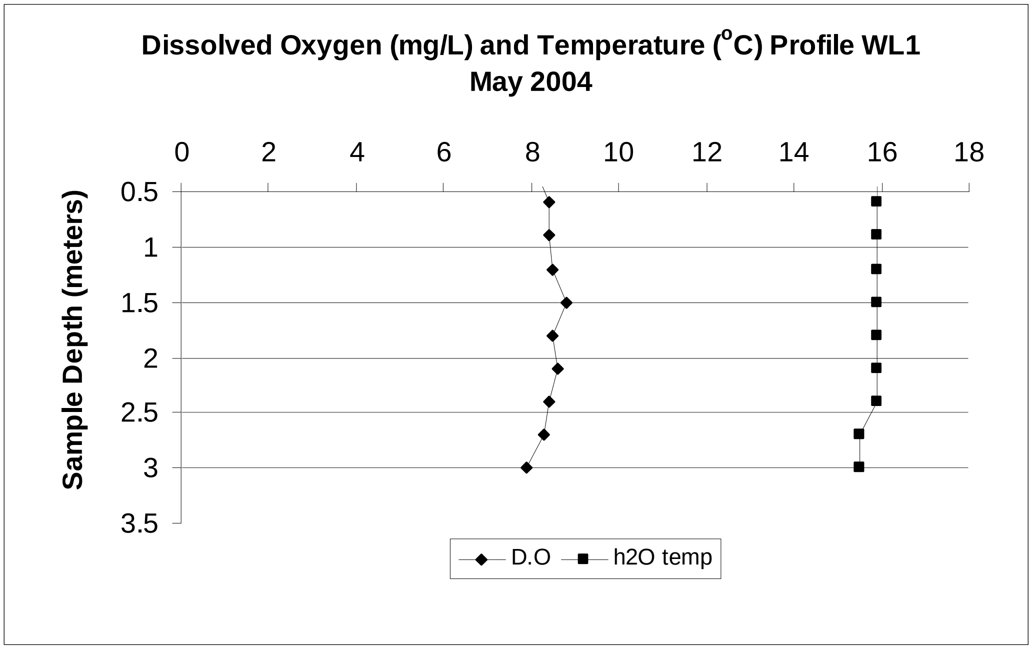
Dissolved Oxygen and Temperature Profile WL1 Oct. 2001
0.0
2.0
4.0
6.0
8.0
10.0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Sample Depth (meters)
Dissolved Oxygen (mg/L) / H_2O Temperature (^oC)
D.O
h2O temp

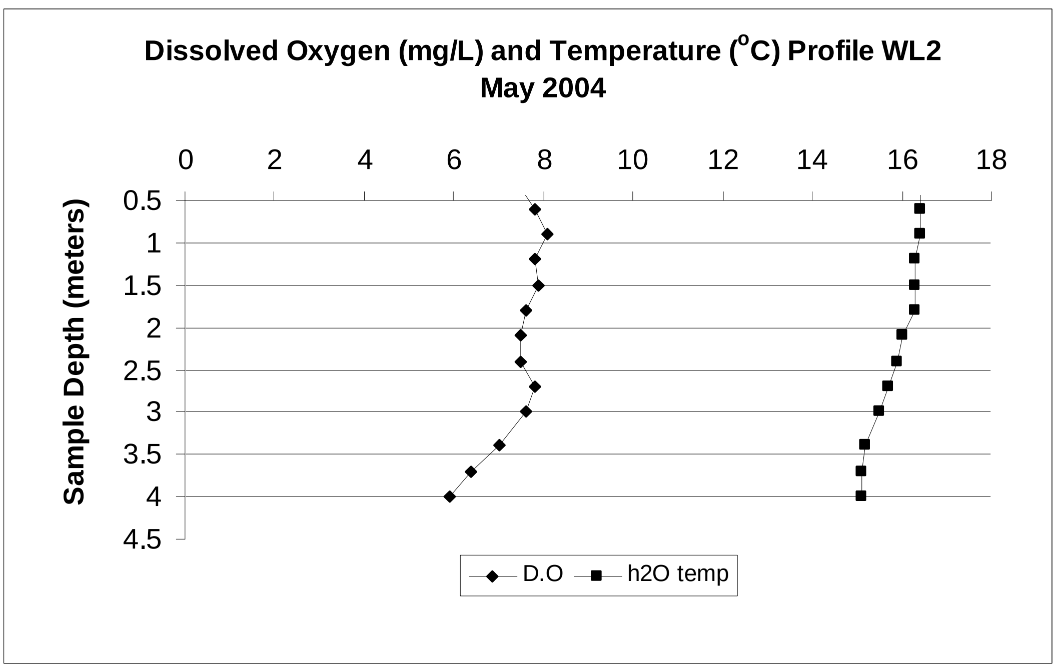


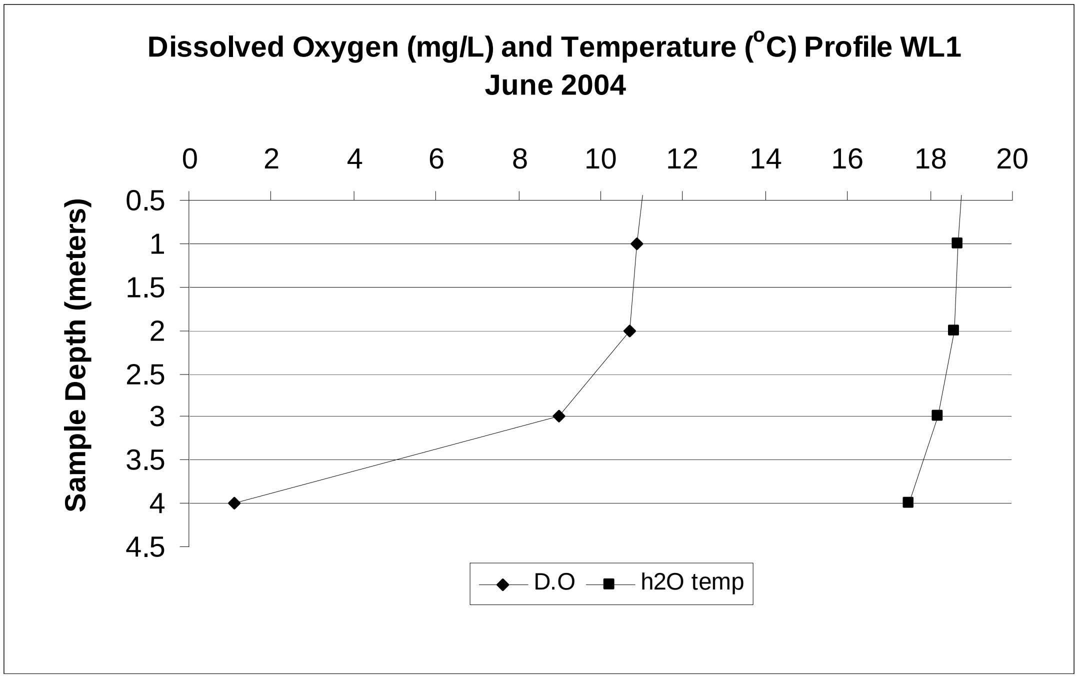
Dissolved Oxygen and Temperature Profile WL2 Oct. 2001
0.0
2.0
4.0
6.0
8.0
10.0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Sample Depth (meters)
Dissolved Oxygen (mg/L) / H_2O Temperature (^oC)
D.O
h2O temp

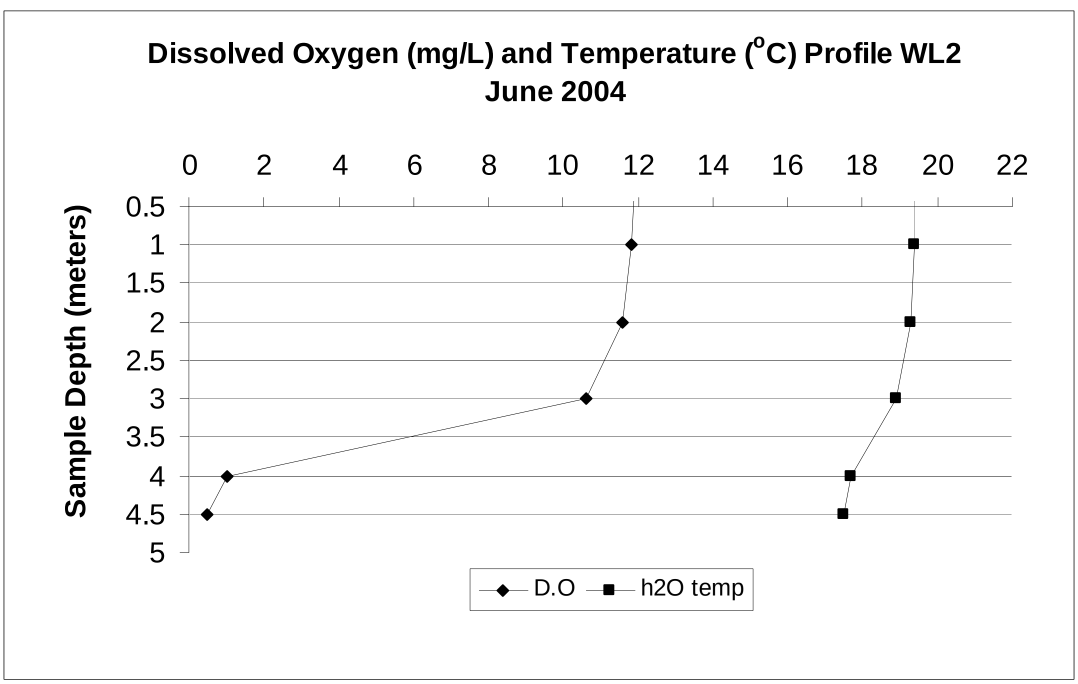

Dissolved Oxygen and Temperature Profile WL1 Apr. 2004
0 2 4 6 8 10 12 14
0.5 0.7 0.9 1.1 1.3 1.5 1.7 1.9
Sample Depth (meters)
Dissolved Oxygen (mg/L) / H_2O Temperature (^oC)
D.O
h2O temp

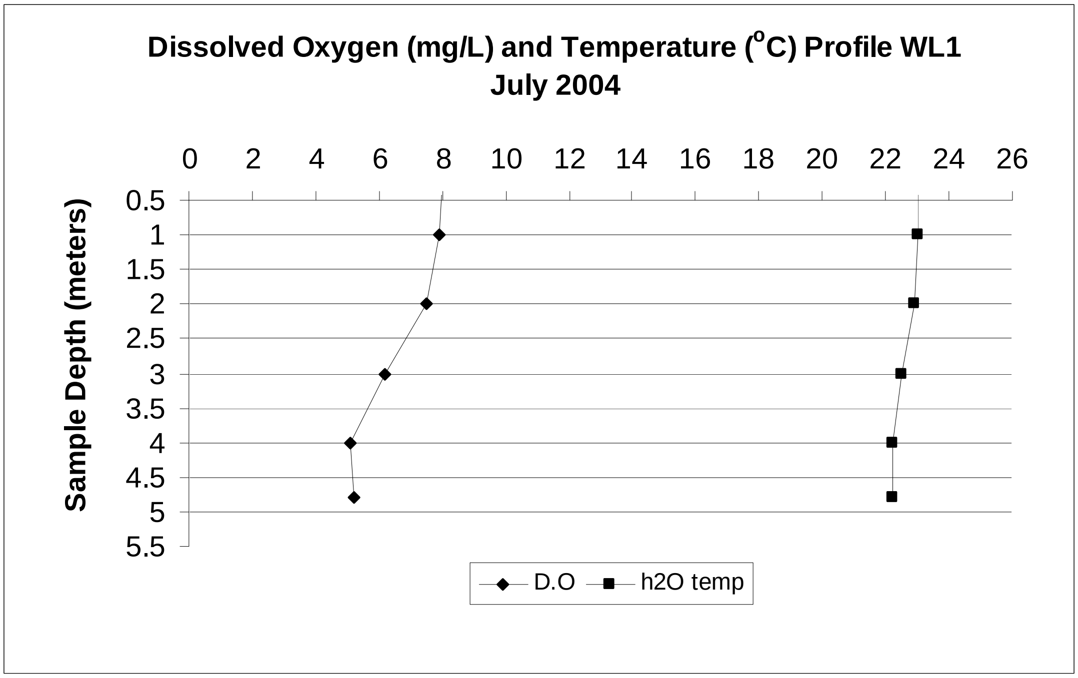

Dissolved Oxygen (mg/L) and Temperature (^oC) Profile WL2 Apr. 2004
0 2 4 6 8 10 12 14
0.5 1 1.5 2 2.5 3 3.5
Sample Depth (meters)
D.O
h2O temp


Dissolved Oxygen (mg/L) and Temperature (^oC) Profile WL1
May 2004
0
2
4
6
8
10
12
14
16
18
Sample Depth (meters)
0.5
1
1.5
2
2.5
3
3.5
D.O
h2O temp

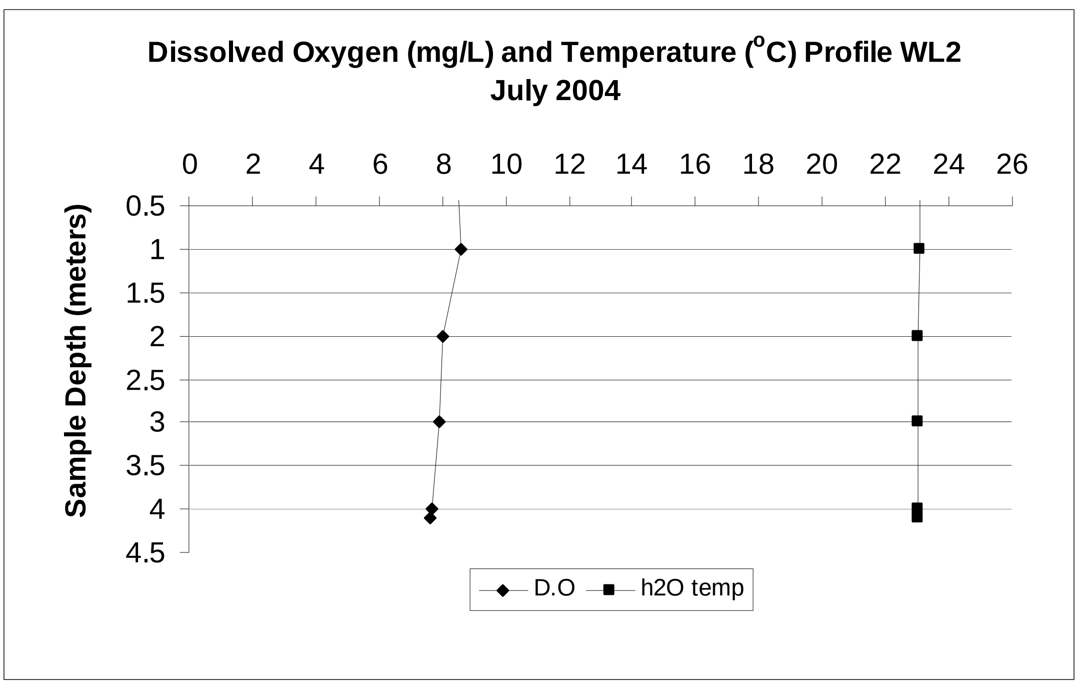

Dissolved Oxygen (mg/L) and Temperature (^oC) Profile WL2
May 2004
0
2
4
6
8
10
12
14
16
18
Sample Depth (meters)
0.5
1
1.5
2
2.5
3
3.5
4
4.5
D.O
h2O temp


Dissolved Oxygen (mg/L) and Temperature (°C) Profile WL1
June 2004
0
2
4
6
8
10
12
14
16
18
20
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Sample Depth (meters)
D.O
h2O temp

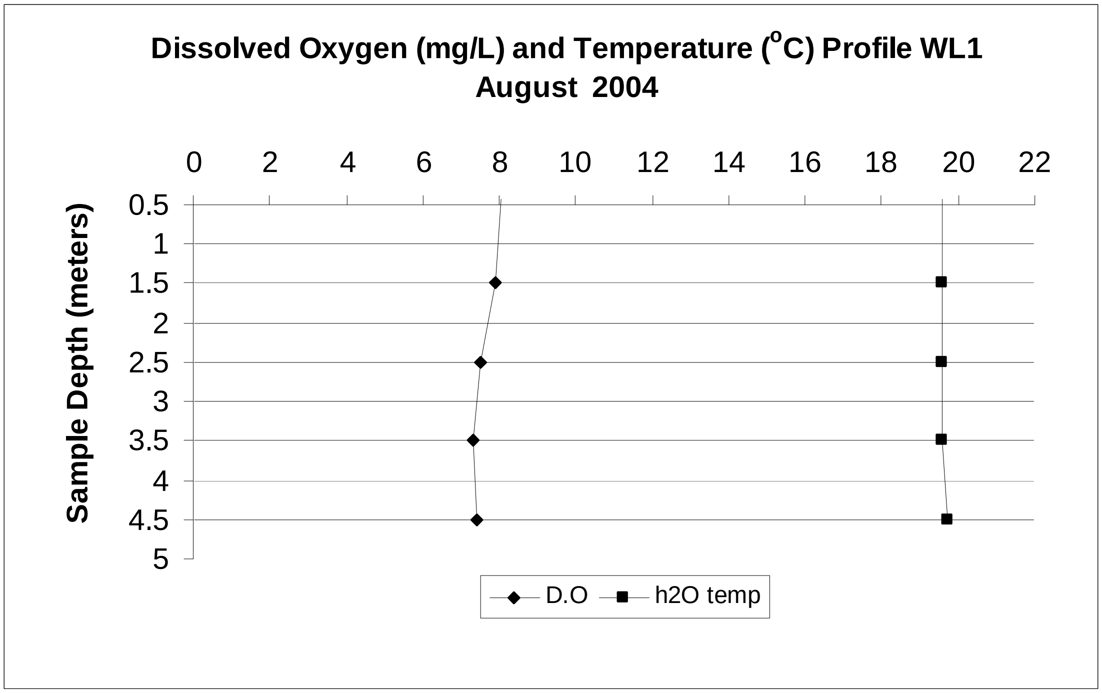

Dissolved Oxygen (mg/L) and Temperature (°C) Profile WL2
June 2004
0
2
4
6
8
10
12
14
16
18
20
22
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Sample Depth (meters)
D.O
h2O temp

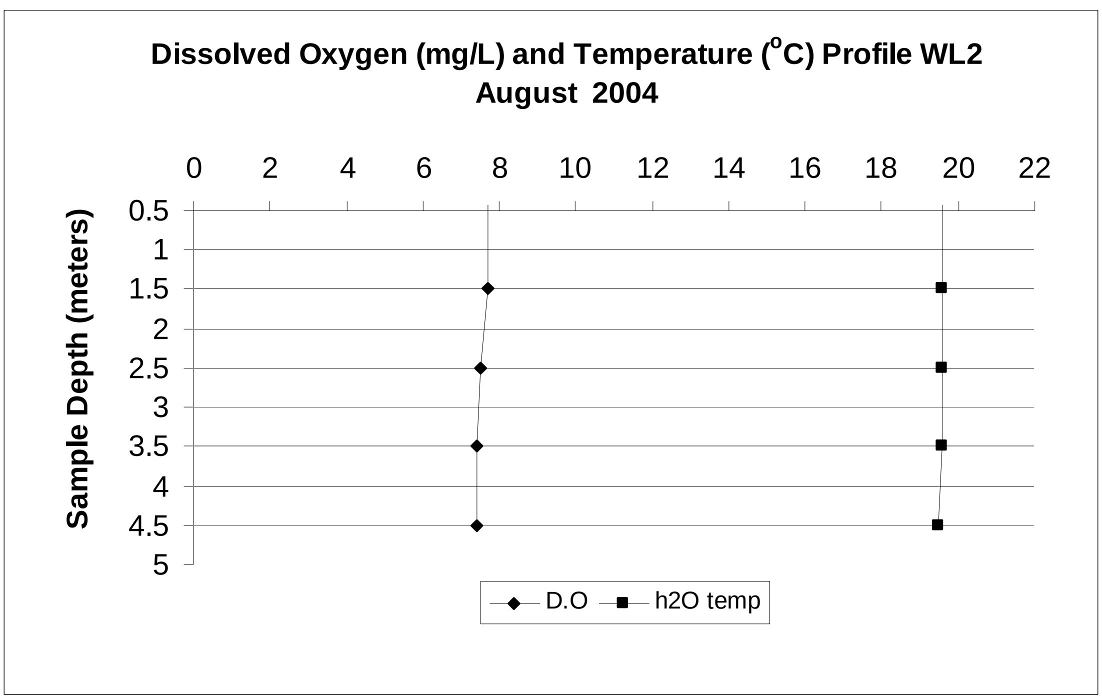


Dissolved Oxygen (mg/L) and Temperature (°C) Profile WL1
July 2004
0 2 4 6 8 10 12 14 16 18 20 22 24 26
0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5
Sample Depth (meters)
D.O
h2O temp



Dissolved Oxygen (mg/L) and Temperature (°C) Profile WL2
July 2004
0 2 4 6 8 10 12 14 16 18 20 22 24 26
0.5 1 1.5 2 2.5 3 3.5 4 4.5
Sample Depth (meters)
D.O
h2O temp


Dissolved Oxygen (mg/L) and Temperature (^oC) Profile WL1
August 2004
0
2
4
6
8
10
12
14
16
18
20
22
Sample Depth (meters)
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
D.O
h2O temp


Dissolved Oxygen (mg/L) and Temperature (^oC) Profile WL2
August 2004
0
2
4
6
8
10
12
14
16
18
20
22
Sample Depth (meters)
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
D.O
h2O temp

Appendix C

South Dakota Game Fish and Parks fishery survey reports
2000, 2002 and 2003

SOUTH DAKOTA STATEWIDE FISHERIES SURVEY

2102-F21-R-34

Name: Waggoner Lake County(ies): Haakon
Legal description: T 1N, R 20E Sec. 1 and T 1N, R 21E Sec. 6
Location from nearest town: 3 miles north of Philip, SD
Dates of present survey: September 20, 2000
Date last surveyed: October 4, 1999; 10/19/98; 10/16/97
Most recent lake management plan: F21-R-32 Date: 1998
Management classification: Warmwater permanent
Contour mapped: Date 1995

Primary Species: (game and forage)	Secondary and other species:
1. Largemouth bass	1. Black crappie
2. Bluegill	2. Northern pike
3.	3. Yellow perch
4.	4. Green sunfish
5.	5. Walleye
6.	6. Channel catfish
7.	7. Smallmouth bass
8.	8. White sucker

PHYSICAL CHARACTERISTICS

Surface Area: 107 acres; Watershed: 16,600 acres
Maximum depth: 21 feet; Mean depth: 10 feet
Lake elevation at survey (from known benchmark): full

1. Describe ownership of lake and adjacent lakeshore property:

The State of South Dakota has an easement for public access up to 12 feet above the high water mark. A majority of the lakeshore property is privately owned with small portions owned by the city of Philip and Haakon County.

2. Describe watershed condition and percentages of land use:

Approximately 90% of the watershed consists of livestock grazing. An increasing portion of the watershed has been tilled for small grain row crops. The increased tillage has accelerated siltation of the lake. The primary source of water for Waggoner Lake is a city owned hot water well and Grindstone Creek. A continual water supply is rare for lakes in western South Dakota; the lake does experience fluctuations as the well water is also used by a nearby golf course. The hot water well provides some benefit to fish in the winter months; however, it makes ice conditions near the inlet unpredictable.

3. Describe aquatic vegetative condition:

Emergent vegetation is limited to bulrushes and cattails, which are abundant in the bays and inlet areas of the lake. Submerged vegetation is a problem annually in mid-summer. Coontail and curly leaf pondweed are the predominant species. Approximately fifty percent of the shoreline was covered by submergent vegetation.

4. Describe pollution problems:

There is moderate siltation from run-off. Currently no pollution problems have been detected by Departmental personnel during lake surveys.

5. Describe condition of all structures, i.e. spillway, level regulators, boat ramps, etc.:

The Department of Game, Fish and Parks provided cement planks for a boat ramp on the city owned property. The cement planks used for boat launching are uneven and no longer can be used to launch a boat.

CHEMICAL DATA

1. Describe general water quality characteristics.

Water chemistry parameters were collected on August 1, 2001 at 2 established stations (Figure 1). Field measurements included temperature and dissolved oxygen profile, surface pH, surface conductivity and transparency (Appendix A). Water samples were collected from the surface using 2 liter sampling bottles and sent to the laboratory for total phosphorus and chlorophyll A analysis. No obvious problems were identified from the results of this testing. Secchi depth, chlorophyll A, and total phosphorous values were combined for both sites and mean values were used to calculate the Trophic State Index (TSI) (Carlson 1977) of Angostura Reservoir. The TSI ranking is from 1-100. Lakes with low TSI values (<40) are considered oligotrophic, while those with higher values (>50) indicate eutrophic conditions. The TSI values categorize Waggoner as eutrophic (Table 1). The TSI trend for Waggoner is shown in Figure 2.

2. Thermocline: Yes ___ No _X_; location from surface ___ m

3. Secchi disc reading: Station A= 1.82m; Station B= 1.21 m

4. Stations for water chemistry located on attached lake map: Yes _X_ No ___

Station A=Dam grade
Station B=Middle of lake

Table 1. Trophic State Indices (TSI) of Waggoner Lake 2001. Indices include secchi depth (SD), chlorophyll A (Chl A), total phosphorus (TP) and mean TSI.

TSI Values	1979-1980	1989	1991	1992	1993	1995	1996	2001
SD	56	62	53	60	40	55	54	54
Chl A	31	62	58	50	52	27	33	
TP	36	---	35	35	35	37	---	79
Mean TSI	41	62	49	48	31	40	46	66.5

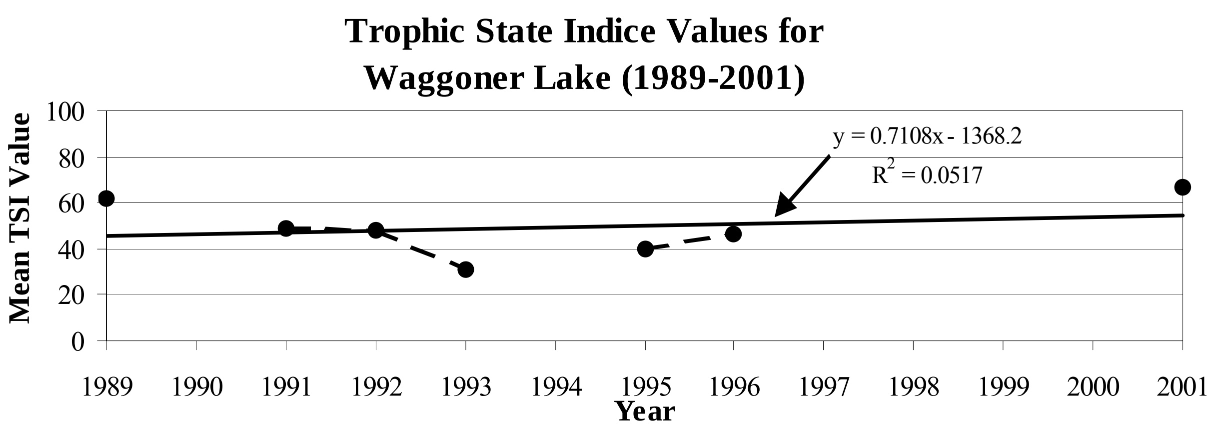


Figure 2. Trophic State Index values for Waggoner Lake, Haakon County, 1989-2001.

BIOLOGICAL DATA

Methods

Age-0 fish were collected with a 6.4 mm (1/4 inch) mesh bag seine, measuring 30.5 m (100 ft) long and 1.8 m (6 ft) deep. All seining was conducted on July 30, 2001 at 4 established stations (Figure 1). One seine haul was completed at each station. Each seine haul covered 0.2 acres for a total of 3.2 acres lake wide. All fish collected were identified, counted, and classified as age-0 or "other".

A lake survey was conducted on Waggoner Lake July 29, 2001 to August 1, 2001. Sampling consisted of 3 gill net nights and 6 trap net nights (Figure 2). All gill nets were monofilament experimental nets. Each net was 45.7 m (150-ft) long and 1.8 m (6-ft) deep with six 7.6 m (25-ft) panels of bar mesh sizes: 12.7 mm (0.5 in), 19.1 mm (0.75 in), 25.4 mm (1.0 in), 31.8 mm (1.25 in), 38.1 mm (1.5 in), and 50.8 mm (2.0 in). Trap nets were set at four stations consisting of 4 trap net nights each. All trap nets were modified fyke-nets with a 1.3 X 1.5-m frame, 19.1 mm (0.75 inch) mesh and a 1.2- X 23-m (3.9- X 75.5-ft) lead. Collected fish were measured for total length (TL; mm) and weighed (g). In addition, scale samples for the first five fish per centimeter group were collected from selected fish per gear type for age and growth analysis. Scale samples were pressed onto acetate slides and viewed with a microfiche projector (40X) and the distance between scale annuli were recorded on paper strips. All data was entered into WinFin 2.95 (Francis 1999).

Night electrofishing was conducted at Waggoner Lake on October 3, 2001. Electrofishing was conducted using a Coffelt VVP-15 control unit with pulsed-DC at approximately 150 volts and 6.0-8.0 amps. Current electrofishing protocol requires 2 hours of shocking or as many 20 minute stations that can be completed within one complete trip around the lake (Figure 1). All smallmouth bass and largemouth bass were collected, measured for total length (TL; mm) and weighed (g). In addition, scale samples were collected (Carlander 1982) from upto 5 fish per centimeter group for age and growth analysis. All data was entered into WinFin 2.95.

Fish population parameters, confidence intervals and standard errors were computed using WinFin Analysis (Francis 2000). Parameters calculated were catch per unit effort (CPUE), proportional stock density (PSD), relative stock density (RSD) and relative weight (Wr) based on length categories. Abundance was expressed as the mean catch per unit effort (CPUE; mean number per net night or mean number per hour of electrofishing). Actual pedal time (time the electrofishing unit produced current) was recorded from the digital display on the Coffelt control box and used to calculate electrofishing CPUE. Population structural characteristics were expressed as length frequency histograms and stock density indices (PSD and RSD-P). Fish condition was expressed as mean Wr.

Results and Discussion

Age-0 Fish Survey

¼ Arch Seining

A total of 39 age-0 fish (4 species) were collected during seining (Table 2). Largemouth bass were the most common age-0 fish (N=18) and golden shiner were the second most common (N=14). Other age-0 fish collected were bluegill (N=5) and yellow perch (N=2). The lack of age-0 fish is discouraging. Waggoner Lake suffers occasional fish kills and establishing sportfish populations is difficult. The occurrence of age-0 largemouth bass does indicate natural reproduction is occurring and recruitment to the population is not only stocked fish.

Fish Community Survey

Gill and Trap Net Catch

Nine species were collected in both gill nets and trap nets during the 2001 survey of Waggoner Lake. Seven species, totaling 97 fish, were collected in experimental gill nets (Table 3). Black crappie (N=43) was the most common species collected and white sucker (N=29) the second most common. The occurrence of 6 walleye was a surprise. Walleye haven't been stocked into Waggoner Lake by the SD GF&P since 1987 and haven't been sampled in a lake survey since

Table 2. Field form depicting total catch by station of 1/4 arc seine pulls, Waggoner Lake, July 30, 2001.

1/4 Arc Seine Field Form

Lake: Waggoner Lake
County: Haakon
Date: 7-30-01
Collected By: Galinat, Gust, Witcraft

Seine Measurements; Length: 100 ft
Depth: 6 ft
Mesh Size: 1/4 inch square

	Station Number			
	1	2	3	4
Total area covered (acres)	0.8	0.8	0.8	0.8
Water depth (ft)	6	6	6	6
Bottom soil type	cobble/mud	cobble/mud	cobble/mud	cobble/mud
Water Temperature	NA			
Wind Speed (mph; direction)	0 - 5	0 - 5	5 – 10	0 - 5
Time of collection	10:15AM	10:40AM	11:20AM	11:45AM

Station 1			Station 2		Station 3		Station 4		TOTAL		
Spp.	yoy	1+	yoy	1+	yoy	1+	yoy	1+	yoy	1+	All
BLC		27				4		24	0	55	55
BLG		7		13	5	3			5	23	28
GOS	3				11	139		84	14	223	237
LMB	11		5	1	2				18	1	19
NOP				1					0	1	1
YEP				2			2		2	2	4
Totals									39	305	344

1989 when a single walleye was captured in the trap nets and a single walleye in the gill nets. The current existence of walleye in Waggoner is most likely due to stockings by anglers trying to develop a fishery. Other species collected in gill nets were black bullhead (N=3), golden shiner (N=1), northern pike (N=3) and yellow perch (N=12).

Eight species, totaling 315 fish, were collected in trap nets during the 2001 survey. Black crappie were the most common (N=143), bluegill the second (N=82) and black bullhead the third (N=62) (Table 4). Other species collected were largemouth bass (N=1), northern pike (N=9), white sucker (N=13), yellow perch (N=1) and two adult walleye.

Night electrofishing Catch

Waggoner Lake was night electrofished for a total of 6,028 seconds (1.67 hours) pedal time. Only largemouth bass (N=56) and smallmouth bass (N=13) were targeted (Table 5). Most largemouth bass collected were likely a result of angler stockings from nearby ponds. In addition, smallmouth bass were either accidentally or illegally stocked into Waggoner Lake. There are no records indicating the Game, Fish and Parks Department has introduced or has intended to introduce smallmouth bass into Waggoner Lake.

Table 3. Total catch (N), catch per net night (CPUE; 80% CI's in parentheses), catch per net night of stock length fish (CPUE-S; 80%CI's), and proportional stock densities (PSD, RSD; 90% CI's in parentheses) for all fish species collected from three 150-ft experimental sinking gill nets in Waggoner Lake, Haakon County, July 30-31, 2001.

Species	N	CPUE	CPUE-S	PSD	RSD-P
Black bullhead	3	1.0 (0.0, 2.1)	1.0 (0.0, 2.1)	100 (100, 100)	100 (100, 100)
Black crappie	43	14.3 (9.4, 19.2)	14.3 (9.4, 19.2)	79 (69, 90)	0 (0, 0)
Golden shiner	1	0.3 (0.0, 1.0)	NA	NA	NA
Northern pike	3	1.0 (0.0, 2.1)	1.0 (0.0, 2.1)	67 (0, 100)	0 (0, 0)
Walleye	6	2.0 (0.9, 3.1)	2.0 (0.9, 3.1)	67 (24, 100)	0 (0, 0)
White sucker	29	9.7 (6.2, 13.2)	9.7 (6.2, 13.2)	100 (100, 100)	93 (85, 100)
Yellow perch	12	4.0 (1.1, 6.9)	4.0 (1.1, 6.9)	17 (0, 37)	0 (0, 0)
Totals	97				

Table 4. Total catch (N), catch per net night (CPUE; 80% CI's in parentheses), catch per net night of stock length fish (CPUE-S; 80%CI's), and proportional stock densities (PSD, RSD; 90% CI's in parentheses) for all fish species collected from 12 modified-fyke trap nets in Waggoner Lake, Haakon County, July 30-31, 2001. A = too few fish to calculate SE or CI's.

Species	N	CPUE	CPUE-S	PSD	RSD-P
Black bullhead	62	7.8 (2.8, 12.8)	7.8 (2.8, 12.8)	100 (100, 100)	76 (67, 85)
Black crappie	143	17.9 (7.7, 28.1)	17.9 (7.7, 28.1)	94 (90, 97)	1 (0, 3)
Bluegill	82	10.3 (4.1, 16.4)	10.3 (4.1, 16.4)	99 (97, 100)	7 (3, 12)
Largemouth bass	1	0.1 (0.0, 0.3)	0.1 (0.0, 0.3)	100 (A)	100 (A)
Northern pike	10	1.3 (0.7, 1.8)	1.3 (0.7, 1.8)	100 (100, 100)	50 (19, 81)
Walleye	2	0.3 (0.0, 0.6)	0.3 (0.0, 0.6)	100 (100, 100)	0 (0, 0)
White sucker	13	1.6 (0.0, 3.4)	1.6 (0.0, 3.4)	100 (100, 100)	100 (100, 100)
Yellow perch	2	0.3 (0.0, 0.6)	0.3 (0.0, 0.6)	10 (100, 100)	0 (0, 0)
Totals	315				

Table 5. Total catch (N), catch per hour of electrofishing (CPUE) with 80% CI's in parentheses, catch per hour of stock length fish (CPUE-S) with 80% CI's, and proportional stock densities (PSD, RSD-P) with 90% CI's in parentheses for largemouth bass and smallmouth bass collected by electrofishing in Waggoner Lake, Haakon County, October 3, 2001.

Species	N	CPUE	CPUE-S	PSD	RSD-P
Largemouth bass	56	33.5 (28.9, 38.1)	26.3 (21.8, 30.9)	52 (40, 65)	0 (0, 0)
Smallmouth bass	13	7.8 (0.0, 17.6)	2.4 (0.0, 5.1)	0 (0, 0)	0 (0, 0)
Totals	69				

Table 6. Mean relative weight values by length categories (standard error values are in parentheses) for fish from selected gear types from Waggoner Lake, 2001. S-Q = stock to quality length; Q-P = quality to preferred length; P-M = preferred to memorable length.

Species	Mean Wr			
	Sub-stock	S-Q	Q-P	P-M
Black bullhead[b]	NA	NA	92 (89, 95)	90 (88, 91)
Black crappie[b]	NA	101 (97, 105)	89 (88, 90)	67 (0, 162)
Bluegill[b]	NA	NA	103 (103, 104)	88 (84, 92)
Largemouth bass[c]	NA	105 (104, 106)	96 (94, 98)	NA
Northern pike[b]	NA	NA	81 (73, 88)	92 (78, 107)
Smallmouth bass[c]	98 (69, 127)	99 (96, 102)	NA	NA
Walleye[a]	NA	95 (95, 95)	85 (80, 89)	NA
White sucker[a]	NA	NA	121 (9, 233)	94 (90, 98)
Yellow perch[a]	NA	100 (95, 105)	75 (75, 75)	NA

[a] = Values from experimental gill nets. [c] = Values from night electrofishing.
[b] = Values from standard frame nets.

Black bullheads

Black bullheads were the third most abundant fish captured in trap nets. Mean CPUE in trap nets was 7.8. Stock density indices were high (PSD=100; RSD-P=76) with fish ranging from 270 mm to 360 mm (Figure 3). Mean condition ranged from 90 to 92 for all length groups (Table 6). No age and growth analysis were completed.

The bullhead population in Waggoner Lake was low to moderate in abundance. Size of bullheads was excellent with a large portion of them greater than 300 mm. Mean condition of the bullheads was good.

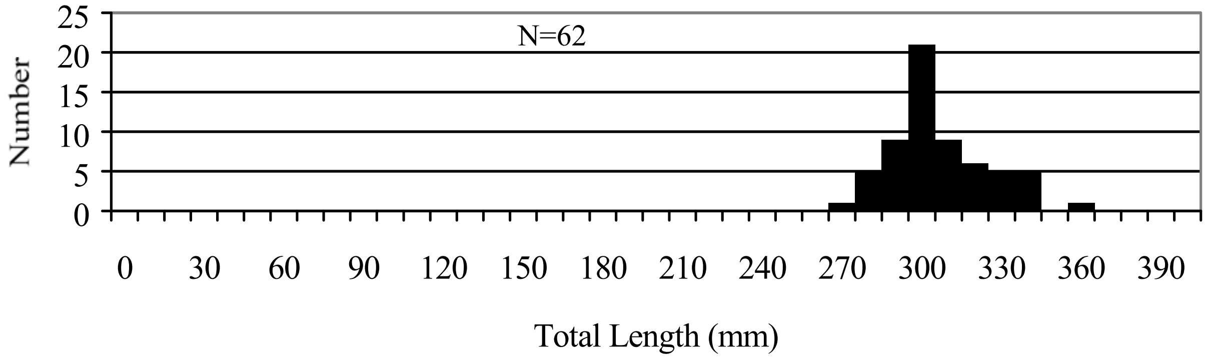


Figure 3. Length histogram of black bullheads collected in trap nets from Waggoner Lake, Haakon County, July 30 and 31, 2001

Black crappies

Abundance of black crappies was high. Mean CPUE in trap nets was 17.9. Size of black crappies ranged from 130 mm to 260 mm (Figure 4). Stock density indices show nearly all sampled crappies are quality length, PSD=94 and RSD-P=1 (Table 4). Mean condition of the sampled black crappies was 101 for stock to quality length fish and dropped to 67 for preferred to memorable length fish (Table 6). Black crappie back-calculated mean lengths at age were slightly faster than the regional mean upto age 3 and slower than the statewide mean after age 1. Black crappies were collected from all age groups upto 6 years old (Table 8).

Although abundance of crappies was relatively high the population appears healthy. Size structure was rather small and condensed with mean lengths from 4 year classes found within 200 mm and 230 mm. Condition of crappies was excellent for stock to quality length fish but dropped substantially with fish length. This is typical of black crappie populations where there is a lack of available forage fish for larger adults as was seen in Waggoner Lake during seining (Table 2). The age structure appears relatively consistent. The age 6 year class seems particularly strong. This, however, is most likely due to aging only a small portion (N=18) of the sampled crappies and the extrapolation of age structure to the entire sample.

Table 8. Waggoner Lake black crappie year class, age in 2001, sample size (N), mean back-calculated total length at age, the Region 1 mean length at age, and the South Dakota state-wide black crappie mean length at age (Willis et al 2001). Standard errors are in parentheses.

Year Class	Age	N	Age 1	2	3	4	5	6
2000	1	0						
1999	2	23	118	176				
1998	3	65	97	156	199			
1997	4	10	114	149	185	211		
1996	5	8	66	108	136	164	181	
1995	6	32	73	111	147	179	197	215
Pop. Mean (SE)		138	94 (10)	139 (13)	167 (15)	185 (14)	189 (8)	215 (0)
Region 1			74 (3)	122 (7)	158 (9)	197 (13)	217 (16)	
South Dakota			83 (2)	147 (4)	195 (5)	229 (6)	249 (6)	

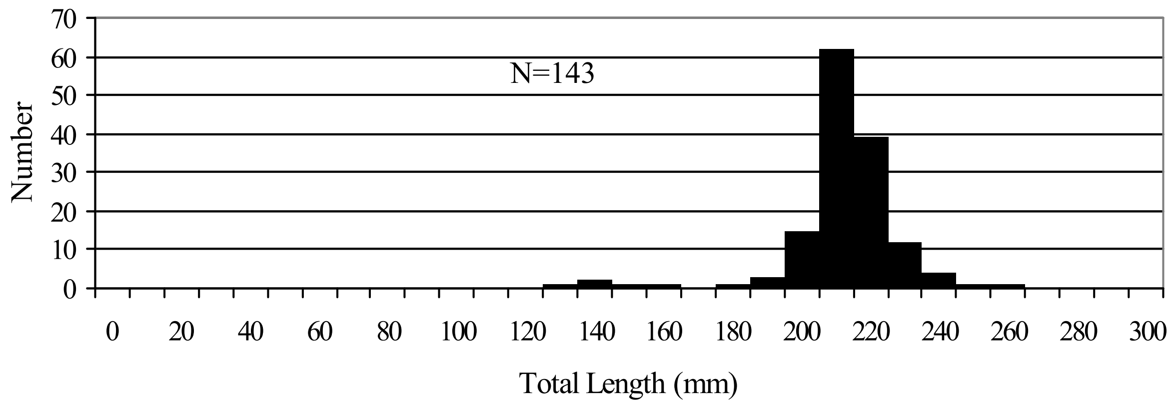


Figure 4. Length histogram of black crappies collected in trap nets from Waggoner Lake, Haakon County, July 30 and 31, 2001.

Bluegill

Bluegill were the second most abundant fish captured in trap nets in 2001. Mean CPUE in trap nets was 10.3 during the 2001 sampling (Table 4). Size of bluegills sampled ranged from 140 mm to 270 mm (Figure 5). Stock density indices were good (PSD=99, RSD-P=7) and lie within or above the generally accepted values for a balanced population (Willis et al. 1993). Bluegill mean condition was good but dropped as size increased. Mean Wr values for quality to preferred length fish was 103 and for preferred to memorable it was 88.

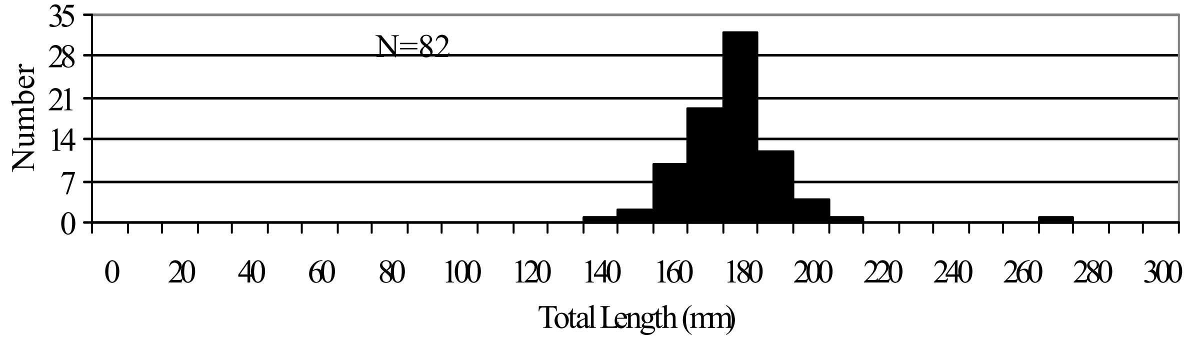


Figure 5. Length histogram of bluegill collected in trap nets from Waggoner Lake, Haakon County, July 30 and 31, 2001.

Largemouth bass

A total of 56 largemouth bass were captured during night electrofishing (Tables 5 and 10). Mean CPUE was 33.5 for all largemouth bass and mean CPUE for largemouth bass stock length or greater was 26.3. Size of fish collected ranged from 60 mm to 370 mm (Figure 6). Stock density indices were low. PSD was 52 and RSD-P was 0. Mean Wr values were 105 for stock to quality length fish and 96 for quality to preferred length fish. Largemouth bass upto 6 years old were collected. Mean back-calculated lengths were greater than the regional mean upto 5 years old but remained slower for all ages than the statewide mean (Table 9).

Largemouth bass density was low during 2000 and may have been lower in 2001 than was observed except for the stockings of adult fish throughout the year. The low densities were most likely due to fish kills during winter. To supplement the population Game, Fish and Parks personnel, with help from local anglers, removed fish from local ponds with overabundant bass populations and relocated them to Waggoner Lake. Stocking of the small adult bass resulted in a large portion of quality size bass and no preferred length bass (i.e. PSD=52; RSD-P=0). Mean condition of bass was good. Growth of largemouth bass in Waggoner Lake, however, is misleading due to the supplemental stockings. It appears older bass are experiencing growth greater than the regional mean but these fish may be life-long Waggoner Lake residents while the majority of smaller, younger adult bass are new to the lake.

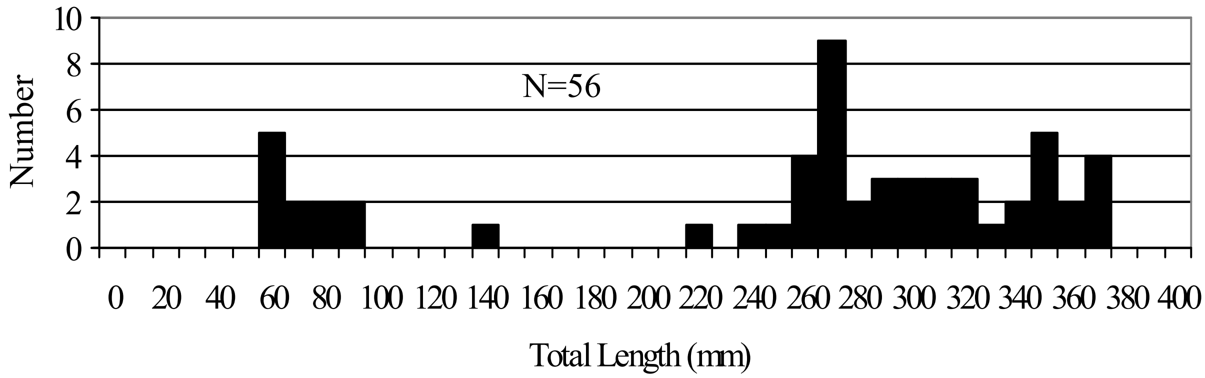


Figure 6. Length histogram of largemouth bass collected during night electrofishing from Waggoner Lake, Haakon County, October 3, 2001.

Table 9. Waggoner Lake largemouth bass year class, age in 2001, sample size (N), mean back-calculated total length at age, population standard error (SE), and the Region 1 and the South Dakota statewide mean length at age for largemouth bass (Willis et al. 2001).

Year Class	Age	N	Age 1	2	3	4	5	6
2001	0	0						
2000	1	1	88					
1999	2	6	83	178				
1998	3	16	92	170	230			
1997	4	10	90	169	238	285		
1996	5	7	76	149	221	270	313	
1995	6	6	96	152	214	270	321	350
Mean (SE)		46	88 (3)	164 (6)	226 (5)	275 (5)	317 (4)	350 (0)
Region 1 Mean			78 (4)	154 (10)	214 (11)	272 (13)	318 (13)	
S.D. Mean			96 (3)	182 (6)	250 (7)	305 (8)	342 (8)	

Table 10. Total catch (N), pedal time (seconds), catch per hour of electrofishing (CPUE), mean total length (TL, standard error is given in parentheses), and proportional stock densities (PSD, RSD; 90% confidence intervals are given in parentheses) for largemouth bass collected by electrofishing in Waggoner Lake, Haakon County, 1994-2001.

Year	N	Pedal Time (sec)	CPUE	CPUE-S	PSD	RSD-P
1994	86	--	43		38	30
1995	76	3,003	91.1	88.7	73 (64,82)	53 (43,62)
1996	96	2,942	117.5	111.4	66 (58,74)	29 (21,36)
1997	88	6,944	45.6	42.5	63 (55,72)	24 (16,32)
1998	107	4,200	91.7	90.9	72 (64,79)	24 (17,30)
1999	111	6,350	62.9	62.4	56 (48, 64)	17 (11, 23)
2000	19	4,140	18.1	18.1	74 (56, 92)	16 (1, 31)
2001	56	6,028	33.5	26.3	52 (40, 65)	0 (0, 0)

Northern pike

Density of northern pike was low. Only 10 northern pike were collected in trap nets (Table 4). Sizes of pike ranged from 560 mm to 820 mm (Figure 7) and stock density indices were high; PSD=100 and RSD-P=50. Mean condition of northern pike was low but increased with size. Condition of quality to preferred length fish was 81 and for preferred to memorable length fish mean condition was 92 (Table 6). No age and growth analysis was completed.

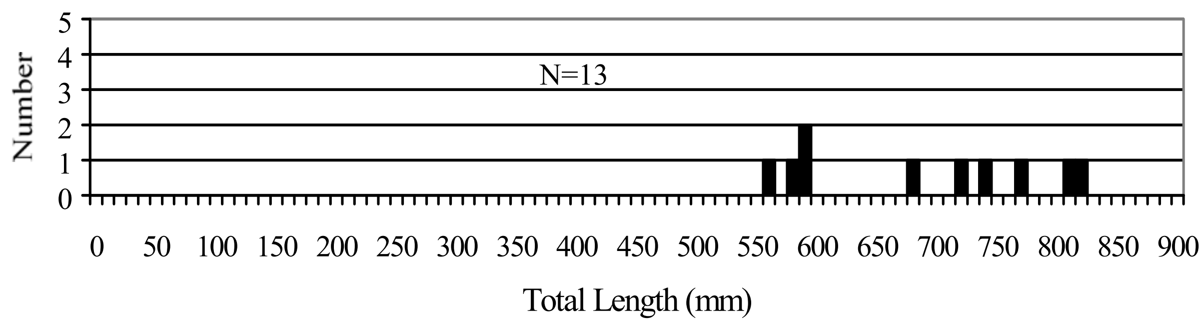


Figure 7. Length histogram of northern pike collected in trap nets from Waggoner Lake, Haakon County, July 30-31, 2001.

Smallmouth bass

Thirteen smallmouth bass were captured during night electrofishing (Table 5). Size of smallmouth bass ranged from 60 mm to 250 mm (Figure 8). Mean condition of fish was good at 98 and 99, respectively, for sub-stock length and stock to quality length fish. No age and growth analysis was completed.

Density of smallmouth bass in Waggoner Lake was extremely low. There are no records indicating stocking of smallmouth bass by the South Dakota Game, Fish and Parks Department. In addition, no smallmouth bass have ever been sampled in previous lake surveys. The existence of smallmouth in Waggoner was possibly a result from angler assisted stockings in 2001. The local conservation officer and anglers transported hook and line captured bass from nearby ponds. Most likely anglers didn't identify or care if all bass transported were largemouth and, therefore, smallmouth bass were also stocked.

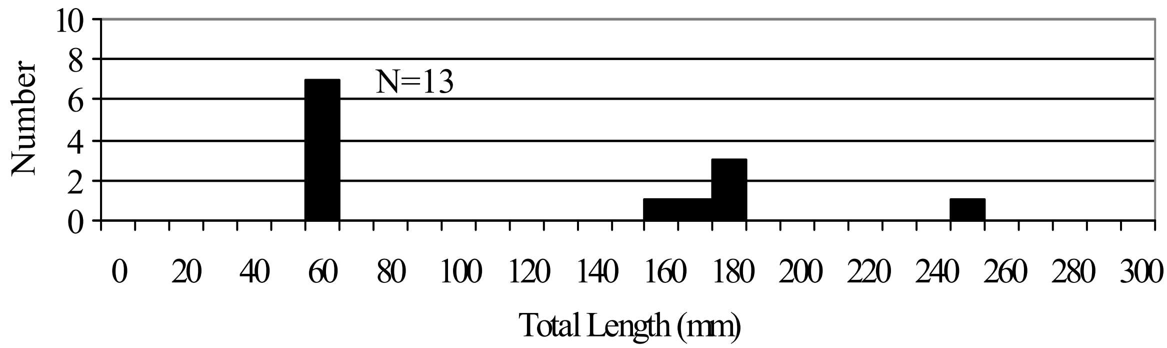


Figure 8. Length histogram of smallmouth bass collected during night electrofishing at Waggoner Lake, Haakon County, October 10, 2001.

Other fish species

Three other fish species were collected during the annual lake survey; walleye, white sucker and yellow perch. The occurrence of walleye is surprising since walleye haven't been stocked in Waggoner Lake since 1987 (Appendix B). Although it is assumed smallmouth bass may have been mistakenly stocked by anglers and the local conservation officer, walleye were, no doubt, an illegal stocking. Waggoner Lake is a rather small impoundment that would not sustain an ample walleye fishery. White suckers were collected in both trap nets and gill nets in low to moderate numbers. The number and species of predators in Waggoner should keep the white sucker density down. Yellow perch were also collected in trap nets and gill nets. Perch density was low with only 12 adult fish collected in gill nets and 2 adults collected in trap nets.

LITERATURE CITED

Francis, J. 1999. Winfin, Version 2.95; Microsoft Access Program for data entry. Nebraska Game and Parks Commission, Lincoln.

Francis, J. 2000. WinFin Analysis Program. Version 1.5. Nebraska Game and Parks Commission, Lincoln.

Willis, D.W., D.A. Isermann, M.J. Hubers, B.A. Johnson, W.H. Miller, T.R. St. Sauver, J.S. Sorenson, E.G. Unkenholz, and G.A. Wickstrom. 2001. Growth of South Dakota Fishes: A Statewide Summary with means by region and Water Type. Special Report. South Dakota Department of Game, Fish and Parks. Pierre, South Dakota.

RECOMMENDATIONS

Continue conducting lake surveys once every 5 years to evaluate fish populations and stocking success.

Continue annual fall night electrofishing to develop long-term trend data of largemouth bass and continue monitoring the smallmouth bass population.

Consider a slot-length limit to increase size of largemouth bass.

APPENDICES

Appendix A. Water chemistry results from sites A and B on Waggoner Lake, Haakon County, August 1, 2001.

Site	Depth (ft)	Temp (^oC)	D.O. (mg/l)	pH	Conductivity (*u*mhos/cm)	Secchi disk (ft)	Total PO_4 (mg/l)	Chl A (mg/m^3)
A	Surface	26	7.8	8.6	----	6	0.189	
	2	26	7.6					
	4	26	7.6					
	6	26	7.4					
	8	26	7.6					
	10	26	7.8					
	12	26	7.8					
	14	26	7.8					
	16	26	3.0					
B	Surface	26	7.2	8.6	----	4	0.173	
	2	26	6.4					
	4	26	6.2					
	6	26	6.2					
	8	26	6.0					

Appendix B. Stocking record for Waggoner Lake, Haakon County, 1987-2001.

Year	Number	Species	Size
1987	3,500	Largemouth bass	Fingerling
	417	Walleye	Fingerling
1988	151	Largemouth bass	Adult
	7,000	Largemouth bass	Fingerling
1990	4,000	Largemouth bass	Fingerling
1991	2,000	Largemouth bass	Fingerling
1992	9,000	Largemouth bass	Fingerling
	2,000	Golden shiner	Adult
1994	2,000	Golden shiner	Adult
	120	Largemouth bass	Adult
1995	4,000	Largemouth bass	Fingerling
1996	4,000	Largemouth bass	Fingerling
1997	12,000	Largemouth bass	Fingerling
1998	12,000	Largemouth bass	Fingerling
1999	6,000	Largemouth bass	Fingerling
2000	12,000	Largemouth bass	Fingerling
2001	905	Largemouth bass	Adults
	12,620	Largemouth bass	Fingerling

SOUTH DAKOTA STATEWIDE FISHERIES SURVEY

2102-F21-R-35

Name: Waggoner Lake County: Haakon
Legal description: T 1N, R 20E Sec. 1 and T 1N, R 21E Sec. 6
Location from nearest town: 3 miles north of Philip, SD
Dates of present survey: September 24, 2002
Date last surveyed: September 20, 2001
Most recent lake management plan: F21-R-32 Date: 1998
Management classification: Warmwater permanent
Contour mapped: Date 1995

Primary Species: (game and forage)
1. Largemouth bass
2. Bluegill
3.
4.
5.
6.
7.
8.

Secondary and other species:
1. Black crappie
2. Northern pike
3. Yellow perch
4. Green sunfish
5. Walleye
6. Channel catfish
7. Smallmouth bass
8. White sucker

PHYSICAL CHARACTERISTICS

Surface Area: 107 acres; Watershed: 16,600 acres
Maximum depth: 21 feet; Mean depth: 10 feet
Lake elevation at survey (from known benchmark): -1 ft

1. Describe ownership of lake and adjacent lakeshore property:

The State of South Dakota has an easement for public access up to 12 feet above the high water mark. A majority of the lakeshore property is privately owned with small portions owned by the city of Philip and Haakon County.

2. Describe watershed condition and percentages of land use:

Approximately 90% of the watershed consists of livestock grazing. An increasing portion of the watershed has been tilled for small grain row crops. The increased tillage has accelerated siltation of the lake. The primary source of water for Waggoner Lake is a city owned hot water well and Grindstone Creek. A continual water supply is rare for lakes in western South Dakota; the lake does experience fluctuations as the well water is also used by a nearby golf course. The hot water well provides some benefit to fish in the winter months; however, it makes ice conditions near the inlet unpredictable.

3. Describe aquatic vegetative condition:

Emergent vegetation is limited to bulrushes and cattails, which are abundant in the bays and inlet areas of the lake. Submerged vegetation is a problem annually in mid-summer. Coontail and curly leaf pondweed are the predominant species. Approximately fifty percent of the shoreline was covered by submergent vegetation.

4. Describe pollution problems:

There is moderate siltation from run-off. Currently no pollution problems have been detected by Departmental personnel during lake surveys.

5. Describe condition of all structures, i.e. spillway, level regulators, boat ramps, etc.:

The Department of Game, Fish and Parks provided cement planks for a boat ramp on the city owned property. The cement planks used for boat launching are uneven and no longer can be used to launch a boat.

Methods

Night electrofishing was conducted at Waggoner Lake on September 24, 2002. Electrofishing was conducted using a Coffelt VVP-15 control unit with pulsed-DC at approximately 150 volts and 6.0-8.0 amps. Five, ten-minute runs were conducted during this survey. More runs would have been completed but high winds moved in and made sampling impossible. All largemouth bass were collected, measured for total length (TL; mm) and weighed (g). In addition, scale samples were collected from upto 5 fish per centimeter group for age and growth analysis. Age and growth was not analyzed, do the small sample size. All data was entered into WinFin 2.95.

Fish population parameters, confidence intervals and standard errors were computed using WinFin Analysis (Francis 2000). Parameters calculated were catch per unit effort (CPUE), proportional stock density (PSD), relative stock density (RSD) and relative weight (Wr) based on length categories. Abundance was expressed as the mean catch per unit effort (CPUE; mean number per net night or mean number per hour of electrofishing). Actual pedal time (time the electrofishing unit produced current) was recorded from the digital display on the Coffelt control box and used to calculate electrofishing CPUE. Population structural characteristics were expressed as length frequency histograms and stock density indices (PSD and RSD-P). Fish condition was expressed as mean Wr.

Results and Discussion

Night Electrofishing Catch

Waggoner Lake was night electrofished for a total of 2959seconds of pedal time on 9/24/02. Only largemouth bass (N=24) and smallmouth bass (N=0) were targeted. Most largemouth bass collected were likely a result of angler stockings from nearby ponds. Smallmouth bass have been sampled in Waggoner in the past, but none were caught this year Smallmouth bass were either accidentally or illegally stocked into Waggoner Lake. There are no records indicating the Game, Fish and Parks Department has introduced or has intended to introduce smallmouth bass into Waggoner Lake.

Table 1. Total catch (N), catch per hour of electrofishing (CPUE) with 80% CI's in parentheses, catch per hour of stock length fish (CPUE-S) with 80% CI's, proportional stock densities (PSD, RSD-P) with 90% CI's in parentheses, and mean (Wr) for fish over stock length with 90% CI's in parentheses for largemouth bass and smallmouth bass collected by electrofishing in Waggoner Lake, Haakon County, September 24, 2002.

Species	N	CPUE	CPUE-S	PSD	RSD-P	Wr≥S
Largemouth bass	24	29.2(14.6)	29.2(14.6)	71(16)	4(7)	110.3(2.7)
Smallmouth bass	0					
Totals	24					

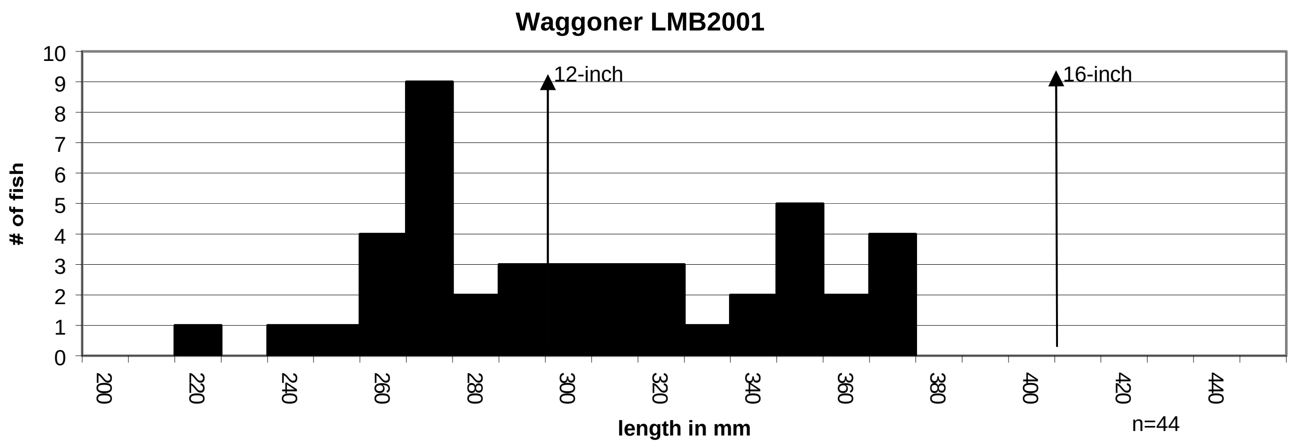
Largemouth bass

A total of 24 largemouth bass were captured during night electrofishing (Tables 1 and 2). Mean CPUE was 29.2 for all largemouth bass and all bass sampled were stock length or greater. Size of fish collected ranged from 230 mm to 440 mm (Figure 1). Stock indices have improved. Last year PSD was 52 with an RSD-P of 0, the 2002 survey gave a PSD of 71 and RSD-P of 4. Fish condition was excellent with a mean Wr for stock length and greater fish of 110. All length categories had Wr values well over 105.

Waggoner apparently suffered a partial winterkill during the winter of 1999-2000. To supplement the population, Game, Fish and Parks personnel, with help from local anglers, removed fish from local ponds with overabundant bass populations and relocated 900 adult bass to Waggoner Lake in 2001. Since these fish would not give an accurate picture of growth rates, age and growth was not analyzed in 2002. In addition to the supplemental stocking, a slot limit has been implemented to help protect the bass population. Fish 12 to 16 inches must be released with only one fish over 16 inches being allowed in the daily limit of five.

Table 2. Total catch (N), pedal time (seconds), catch per hour of electrofishing (CPUE), mean total length (TL, standard error is given in parentheses), and proportional stock densities (PSD, RSD; 90% confidence intervals are given in parentheses) for largemouth bass collected by electrofishing in Waggoner Lake, Haakon County, 1994-2002.

Year	N	Pedal Time (sec)	CPUE	CPUE-S	PSD	RSD-P
1995	76	3,003	91.1	88.7	73 (64,82)	53 (43,62)
1996	96	2,942	117.5	111.4	66 (58,74)	29 (21,36)
1997	88	6,944	45.6	42.5	63 (55,72)	24 (16,32)
1998	107	4,200	91.7	90.9	72 (64,79)	24 (17,30)
1999	111	6,350	62.9	62.4	56 (48, 64)	17 (11, 23)
2000	19	4,140	18.1	18.1	74 (56, 92)	16 (1, 31)
2001	56	6,028	33.5	26.3	52 (40, 65)	0 (0, 0)
2002	24	2,959	29.2	29.2	71(16)	4(7)



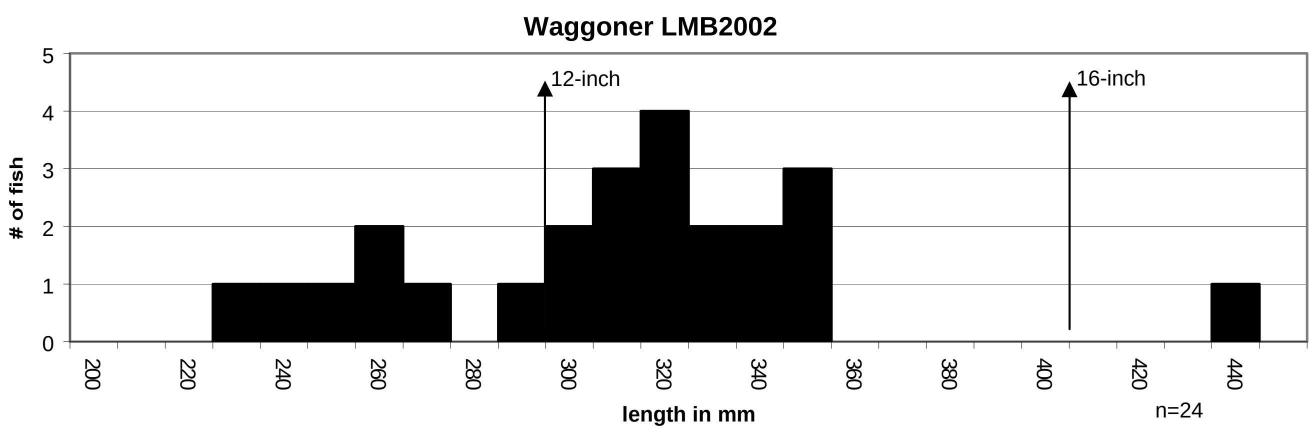


Figure 1. Length frequency histogram for largemouth bass in Waggoner Lake, Haakon County 2001-2002.

LITERATURE CITED

Francis, J. 1999. Winfin, Version 2.95; Microsoft Access Program for data entry. Nebraska Game and Parks Commission, Lincoln.

Francis, J. 2000. WinFin Analysis Program. Version 1.5. Nebraska Game and Parks Commission, Lincoln.

Willis, D.W., D.A. Isermann, M.J. Hubers, B.A. Johnson, W.H. Miller, T.R. St. Sauver, J.S. Sorenson, E.G. Unkenholz, and G.A. Wickstrom. 2001. Growth of South Dakota Fishes: A Statewide Summary with means by region and Water Type. Special Report. South Dakota Department of Game, Fish and Parks. Pierre, South Dakota.

RECOMMENDATIONS

Continue conducting lake surveys once every 3 years to evaluate fish populations and stocking success.

Continue annual fall night electrofishing to develop long-term trend data of largemouth bass and continue monitoring the smallmouth bass population, especially with the new slot regulations.

APPENDICES

Appendix A. Stocking record for Waggoner Lake, Haakon County, 1987-2002.

Year	Number	Species	Size
1990	4,000	Largemouth bass	Fingerling
1991	2,000	Largemouth bass	Fingerling
1992	9,000	Largemouth bass	Fingerling
	2,000	Golden shiner	Adult
1994	2,000	Golden shiner	Adult
	120	Largemouth bass	Adult
1995	4,000	Largemouth bass	Fingerling
1996	4,000	Largemouth bass	Fingerling
1997	12,000	Largemouth bass	Fingerling
1998	12,000	Largemouth bass	Fingerling
1999	6,000	Largemouth bass	Fingerling
2000	12,000	Largemouth bass	Fingerling
2001	905	Largemouth bass	Adults
	12,620	Largemouth bass	Fingerling
2002	none		

SOUTH DAKOTA STATEWIDE FISHERIES SURVEY

2102-F21-R-35

Name: Waggoner Lake County: Haakon
Legal description: T 1N, R 20E Sec. 1 and T 1N, R 21E Sec. 6
Location from nearest town: 3 miles north of Philip, SD
Dates of present survey: September 18, 2003
Date last surveyed: September 24, 2002
Most recent lake management plan: F21-R-32 Date: 1998
Management classification: Warmwater permanent
Contour mapped: Date 1995

Primary Species: (game and forage)	Secondary and other species:
1. Largemouth bass	1. Black crappie
2. Bluegill	2. Northern pike
3.	3. Yellow perch
4.	4. Green sunfish
5.	5. Walleye
6.	6. Channel catfish
7.	7. Smallmouth bass
8.	8. White sucker

PHYSICAL CHARACTERISTICS

Surface Area: 107 acres; Watershed: 16,600 acres
Maximum depth: 21 feet; Mean depth: 10 feet
Lake elevation at survey (from known benchmark): -1 ft

1. Describe ownership of lake and adjacent lakeshore property:

The State of South Dakota has an easement for public access up to 12 feet above the high water mark. A majority of the lakeshore property is privately owned with small portions owned by the city of Philip and Haakon County.

2. Describe watershed condition and percentages of land use:

Approximately 90% of the watershed consists of livestock grazing. An increasing portion of the watershed has been tilled for small grain row crops. The increased tillage has accelerated siltation of the lake. The primary source of water for Waggoner Lake is a city owned hot water well and Grindstone Creek. A continual water supply is rare for lakes in western South Dakota; the lake does experience fluctuations as the well water is also used by a nearby golf course. The hot water well provides some benefit to fish in the winter months; however, it makes ice conditions near the inlet unpredictable.

3. Describe aquatic vegetative condition:

Emergent vegetation is limited to bulrushes and cattails, which are abundant in the bays and inlet areas of the lake. Submerged vegetation is a problem annually in mid-summer. Coontail and curly leaf pondweed are the predominant species. Approximately fifty percent of the shoreline was covered by submergent vegetation.

4. Describe pollution problems:

There is moderate siltation from run-off. Currently no pollution problems have been detected by Departmental personnel during lake surveys.

5. Describe condition of all structures, i.e. spillway, level regulators, boat ramps, etc.:

The Department of Game, Fish and Parks provided cement planks for a boat ramp on the city owned property. The cement planks used for boat launching are uneven and no longer can be used to launch a boat.

Methods

Night electrofishing was conducted at Waggoner Lake on September 18, 2003. Electrofishing was conducted using a Smith-Root 7.5gpp unit with pulsed-DC. Six, ten-minute runs were conducted during this survey. All largemouth bass were collected, measured for total length (TL; mm) and weighed (g). Age and growth was not analyzed, due to recent adult stockings from other lakes. All data was entered into WinFin 2.95 (Francis 1999).

Fish population parameters, confidence intervals and standard errors were computed using WinFin Analysis (Francis 2000). Parameters calculated were catch per unit effort (CPUE), proportional stock density (PSD), relative stock density (RSD) and relative weight (Wr) based on length categories. Abundance was expressed as the mean catch per unit effort (CPUE; mean number per net night or mean number per hour of electrofishing). Actual pedal time (time the electrofishing unit produced current) was recorded from the digital display on the control box and used to calculate electrofishing CPUE. Population structural characteristics were expressed as length frequency histograms and stock density indices (PSD and RSD-P). Fish condition was expressed as mean Wr.

Results and Discussion

Night Electrofishing Catch

Waggoner Lake was night electrofished for a total of 3800 seconds of pedal time on 9/18/2003. Conductivity was 2700 uhmos with a water temperature of 14.6 degrees Celsius. Only largemouth bass (N=39) and smallmouth bass (N=0) were targeted. Most largemouth bass collected were likely a result of angler stockings from nearby ponds. Smallmouth bass have been sampled in Waggoner in the past, but none were caught this year. Smallmouth bass were either accidentally or illegally stocked into Waggoner Lake. There are no records indicating the Game, Fish and Parks Department has introduced or has intended to introduce smallmouth bass into Waggoner Lake.

Table 1. Total catch (N), catch per hour of electrofishing (CPUE) with 80% CI's in parentheses, catch per hour of stock length fish (CPUE-S) with 80% CI's, proportional stock densities (PSD, RSD-P) with 90% CI's in parentheses, and mean (Wr) for fish over stock length with 90% CI's in parentheses for largemouth bass and smallmouth bass collected by electrofishing in Waggoner Lake, Haakon County, September 18, 2003.

Species	N	CPUE	CPUE-S	PSD	RSD-P	Wr≥S
Largemouth bass	39	38.5(21.5)	18.8(10.7)	95(9)	58(20)	115(3)
Smallmouth bass	0					
Totals	39					

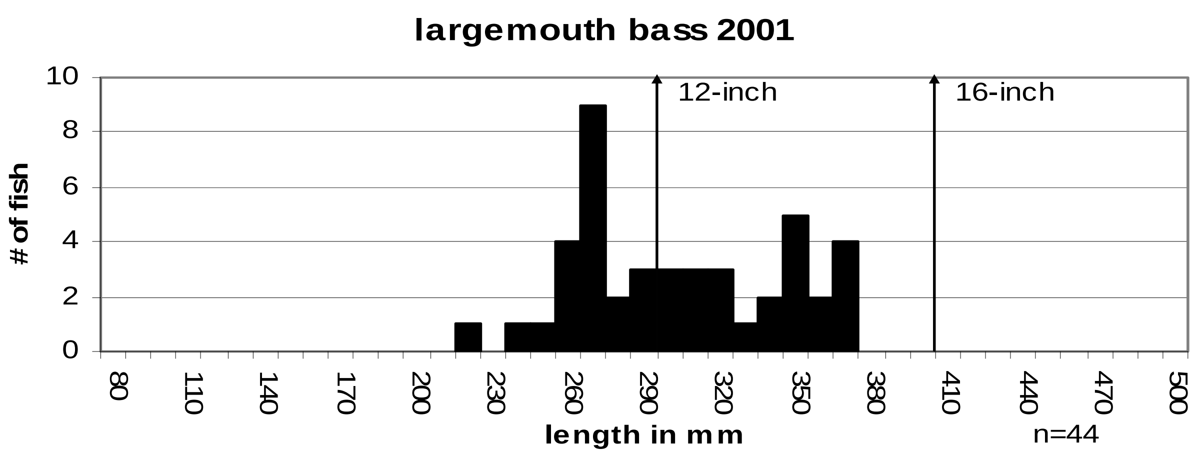
Largemouth bass

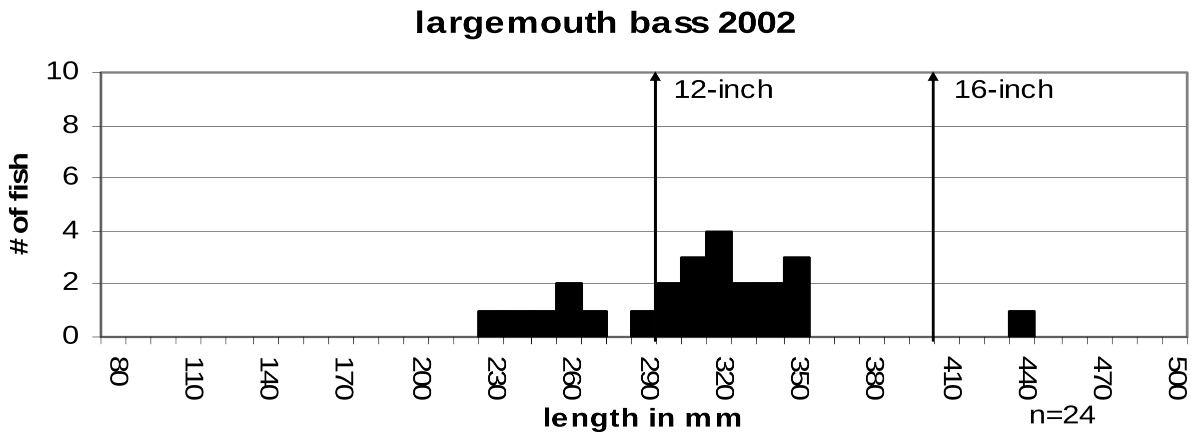
A total of 39 largemouth bass were captured during night electrofishing (Tables 1 and 2). Mean CPUE was 38.5 for all largemouth bass and 18.8 for bass that were stock length or greater. Stock indices have improved for the third straight year. In 2001, PSD was 52 with an RSD-P of 0; the 2002 survey gave a PSD of 71 and RSD-P of 4. This year PSD was 95 with an RSD-P of 58 (Table 1 and 2). Fish condition was excellent with a mean Wr for stock length and greater fish of 115. All length categories had Wr values well over 110. Figure 1 shows an upcoming year class, which is the first in several years.

Waggoner apparently suffered a partial winterkill during the winter of 1999-2000. To supplement the population, Game, Fish and Parks personnel, with help from local anglers, removed fish from local ponds with overabundant bass populations and relocated 900 adult bass to Waggoner Lake in 2001. Since these fish would not give an accurate picture of growth rates, age and growth was not analyzed in 2003. In addition to the supplemental stocking, a slot limit has been implemented to help protect the bass population. Fish 12 to 16 inches must be released with only one fish over 16 inches being allowed in the daily limit of five.

Table 2. Total catch (N), pedal time (seconds), catch per hour of electrofishing (CPUE), mean total length (TL, standard error is given in parentheses), and proportional stock densities (PSD, RSD; 90% confidence intervals are given in parentheses) for largemouth bass collected by electrofishing in Waggoner Lake, Haakon County, 1996-2003.

Year	N	Pedal Time (sec)	CPUE	CPUE-S	PSD	RSD-P
1996	96	2,942	117.5	111.4	66 (8)	29 (8)
1997	88	6,944	45.6	42.5	63 (8)	24 (8)
1998	107	4,200	91.7	90.9	72 (8)	24 (7)
1999	111	6,350	62.9	62.4	56 (8)	17 (6)
2000	19	4,140	18.1	18.1	74 (18)	16 (15)
2001	56	6,028	33.5	26.3	52 (13)	0 (-)
2002	24	2,959	29.2	29.2	71(16)	4(7)
2003	39	3,800	38.5	18.8	95(9)	58(20)





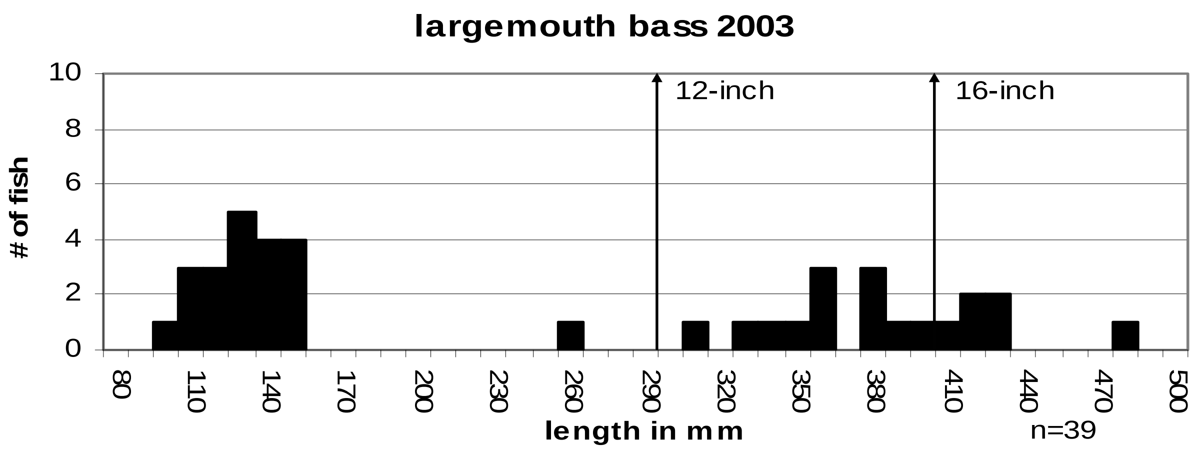


Figure 1. Length frequency histogram for largemouth bass in Waggoner Lake, Haakon County 2001-2003.

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1992	9,000	Largemouth bass	Fingerling
	2,000	Golden shiner	Adult
1994	2,000	Golden shiner	Adult
	120	Largemouth bass	Adult
1995	4,000	Largemouth bass	Fingerling
1996	4,000	Largemouth bass	Fingerling
1997	12,000	Largemouth bass	Fingerling
1998	12,000	Largemouth bass	Fingerling
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