PHASE I WATERSHED ASSESSMENT FINAL REPORT

ELM LAKE BROWN COUNTY SOUTH DAKOTA



South Dakota Watershed Protection Program Division of Financial and Technical Assistance South Dakota Department of Environment and Natural Resources Nettie H. Myers, Secretary



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Prepared By

Eugene H. Stueven, Environmental Program Scientist

Mark McIntire, Natural Resource Engineer



State of South Dakota William J. Janklow, Governor

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EXECUTIVE SUMMARY

Elm Lake is a reservoir on the Elm River located in northwest Brown County in northeast South Dakota. The total watershed for Elm Lake is approximately 165,240 acres, including 59,520 acres that drain into Pheasant Lake, another reservoir on the Elm River located approximately 4 miles north of Elm Lake.

Elm Lake is classified as a drinking water supply for the city of Aberdeen. The city uses Elm Lake as a storage reservoir for dry periods and has the legal right to the top 12 feet of the pool below the crest of the dam. Water can be released from the lake through draw-down tubes in the earthen embankment. The water flows down the Elm River approximately 30 miles where the city of Aberdeen pumps the water into their treatment plant. Other beneficial uses of Elm Lake are; warmwater permanent fish life propagation, immersion recreation, limited contact recreation, wildlife propagation and livestock watering.

The Brown – Marshall Conservation District was the local sponsor of the Elm Lake Watershed Assessment project. Elm Lake was one of the top priorities of the Section 319 Nonpoint Source Control Program for South Dakota, and when the conservation district was approached about the assessment they accepted sponsorship of the project. Funds for the project were from Section 314 Clean Lakes funds administered by the Environmental Protection Agency (EPA). EPA granted the money to the State of South Dakota for the water quality assessment. The 30% local match needed for the project was from the conservation district, the city of Aberdeen and Brown County.

Results from the study indicated that Elm Lake has excessive nutrients and relatively low sedimentation from the tributaries (approximately one acre-foot a year). Erosion from the shoreline is adding sediment to Elm Lake and, in turn, reducing Secchi disk measurements. Of the 120 documented shoreline erosion areas, 37 were categorized as severe. These 37 areas make up over 75% of the total erosion areas around the lake. The sediment in the water column is colloidal. The densities of colloidal particles do not show up well in laboratory analysis, so the concentrations of suspended solids expressed in mg/L are not inordinately high. Although algae and chlorophyll *a* production can be quite high in Elm Lake (140 mg/m³), the colloidal particles in the water column appear to limit sunlight penetration in the water which limits algae growth.

The Agricultural Non-point Source (AGNPS) model agreed with the water quality monitoring in that it predicted very little overall sediment coming from the watershed. There are, however, a few cultivated areas that lose higher than acceptable amounts of soil. These areas are those with very little residual crop cover and also slopes greater than 4%.

Nutrient loads from the watershed were greatest in the spring with winter snow-melt and spring rains. There was a major discharge of animal waste into Site #6 which increased the loadings for that subwatershed. However, samples collected at Site #6 the following year were as high or higher than the year of the discharge. Site #1 was the other

subwatershed that was a major contributor of nutrients to Elm Lake. Site #1 is the outlet of Pheasant Lake and responsible for the majority of hydrologic load into Elm Lake. Along with the hyper-eutrophic water from Pheasant Lake, an animal feeding area located between Pheasant Lake and Site #1 adds to the high nutrient loads.

The average inlake concentration of phosphorus (0.349 mg/L) is more than enough to support an algal bloom in Elm Lake. Nitrogen concentrations were also relatively high, however, the lake is nitrogen limited a majority of the time. The major source of nutrients in the watershed is from animal feeding areas and/or summer long grazing. The AGNPS model found 10 feedlots with rankings over 20, and of these 10, five had rankings over 60.

The recommended target for improving the water quality of Elm Lake is to change the lake from being nitrogen limited to phosphorus limited. This can be accomplished by reducing the average inlake phosphorus concentration 60%. According to the AGNPS model, eliminating feeding areas with rankings over 60 will result in a 58.6% reduction in phosphorus. This does not include removing the animal waste from the large confined feeding area, a phosphorus reduction well over 60% should be reached.

Although the overall suspended sediment loads to Elm Lake are low, there are a few cultivated areas with larger sediment losses. These should be addressed though the implementation of Best Management Practices (BMP's).

Finally, a watershed analysis should be completed on the Pheasant Lake watershed while implementation is taking place on the Elm Lake watershed. The model should estimate reduction targets for Pheasant Lake and the two projects should be combined to improve the water quality of both Pheasant Lake and Elm Lake.

ACKNOWLEDGEMENTS

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Tim Wilson US EPA Clean Lakes Program Brown Marshal Conservation District Natural Resource Conservation Service – Brown County Mc Pherson County Conservation District Natural Resource Conservation Service – Mc Pherson County Natural Resource Conservation Service – Dickey County City of Aberdeen Brown County North Dakota Department of Health and Consolidated Laboratory Services SD Department of Game Fish and Parks SD Department of Environment and Natural Resources – Water Rights SD Department of Environment and Natural Resources – Environmental Services SD Department of Environment and Natural Resources – Watershed Protection US Geological Survey.

Executive Summary i
Acknowledgementsiii
Table of Contents iv
List of Equations vi
List of Tables
List of Figures vii
Introduction1
Historical Information1
Fisheries Data
Shoreline Erosion
Methods and Materials7
Hydrological Data7
Water Quality Sampling8
Agricultural Non-Point Source Model (AGNPS)9
Seasonal Water Quality10
Concentrations10
Loadings12
Tributary Water Quality
Discussion of Water Quality by Tributary Site14
Discussion of Water Quality by Tributary Site
Discussion of Water Quality by Tributary Site

TABLE OF CONTENTS

Table of Contents continued.

Sites #3 and #4	0
Site #5	2
Sites #6 and #6a2	3
Site #7	6
Un-gauged Tributaries2	7
Nutrient and Sediment Budget	8 8
Suspended Solids Budget	0
Nitrogen Budget3	1
Phosphorus Budget	2
Inlake Data Methods and Materials	4
South Dakota Water Quality Standards	6
Inlake Water Quality	7
Water Temperature	7
Dissolved Oxygen	7
pH40	0
Secchi Depth4	0
Alkalinity42	2
Solids4	2
Ammonia44	4
Ammonia44 Nitrate-Nitrite4	4 5

Table of Contents Continued.

Total Nitrogen46
Total Phosphorus48
Total Dissolved Phosphorus49
Chlorophyll a50
Fecal Coliform Bacteria52
Trophic State Index53
Long Term Trends55
Reduction Response Model56
Limiting Factor for Chlorophyll <i>a</i> Production58
Recommended Targeted Reduction61
Conclusions
Recommendations
References Cited
Appendix A Agricultural Non-Point Source Model
Appendix B 1996 Fisheries Annual Report for Elm Lake
Appendix C Elm Lake Dissolved Oxygen Profiles111
Appendix D Elm Lake Inlake Samples
Appendix E Elm Lake Tributary Samples
Appendix F Elm Lake QA/QC Samples

LIST OF EQUATIONS

Equation 1.	Calculating the Load of Un-gauged Tributaries	.8
Equation 2.	Elm Lake Spillway Equation	.8

Equation 3.	Line Equation for the Phosphorus to Chlorophyll <i>a</i> Relationship	52
Equation 4.	Equation for Vollenweider's Reduction Response Model	56
Equation 5.	Equaiton for Calculating Residence Time of Phosphorus	56

LIST OF TABLES

Table 1. Catches Per Unit Effort of Black Bullhead	4
Table 2. Seasonal Mean and Median Concentrations	
Table 3. Comparison of Total Seasonal Loads	12
Table 4. North Dakota Water Quality Standard Limits	13
Table 5. South Dakota Water Quality Standard Limits	14
Table 6. Loading of the Subwatersheds to Site #2	19
Table 7. Loss Per Acre of the Subwatershed Draining to Site #2	19
Table 8. Percent Load of Site #4 to Site #3 in 1995	21
Table 9. Input and Output Sources of Elm Lake	29
Table 10. South Dakota Water Quality Limits for Elm Lake	
Table 11. Trophic Level Ranges	53
Table 12. Elm Lake Trophic State Index	54
Table 13. Effects of Reducing Phosphorus Inputs on TSI	57
Table 14. Loadings to Elm Lake	65

LIST OF FIGURES

Figure 1.	Location of the Elm Lake Watershed	2
Figure 2.	Areas of Severe Erosion in Elm Lake	6
Figure 3.	Location of Site #11	5

Figure 4. Location of Site #2	16
Figure 5. Location of Site #3a	18
Figure 6. Location of Site #3b	18
Figure 7. Location of Site #3c	18
Figure 8. Location of Site #3	20
Figure 9. Location of Site #4	20
Figure 10. Location of Site #5	22
Figure 11. Location of Site #6 and #6a	23
Figure 12. Location of Site #7	26
Figure 13. Percent Suspended Solids Loads from Tributary Sites	30
Figure 14. Percent of Load of Nitrogen Inputs	31
Figure 15. Percent of Load of Ammonia Inputs	32
Figure 16. Percent of Load of Total Phosphorus Inputs	33
Figure 17. Location of Inlake Sites on Elm Lake	35
Figure 18. Dissolved Oxygen EL3, January 16, 1996 1:40P	38
Figure 19. Dissolved Oxygen EL4, July 12, 1995 9:45A	39
Figure 20. Dissolved Oxygen EL3, July 12, 1995 10:30A	39
Figure 21. Secchi Disk	41
Figure 22. Mean Secchi Depth – Elm Lake	41
Figure 23. Mean Total Alkalinity Concentrations – Elm Lake	42
Figure 24. Mean Total Suspended Solids Concentrations – Elm Lake	43
Figure 25. Mean Ammonia Concentrations – Elm Lake	44
Figure 26. Mean Nitrate-Nitrite Nitrogen Concentrations – Elm Lake	45

Figure 27.	Mean Total Organic Nitrogen Concentrations – Elm Lake47
Figure 28.	Mean Total Nitrogen Concentrations – Elm Lake
Figure 29.	Mean Total Phosphorus Concentrations – Elm Lake
Figure 30.	Suspended Solids to Percent of Dissolved Phosphorus for All Samples .49
Figure 31.	Suspended Solids to Percent of Dissolved Phosphorus in 199649
Figure 32.	Mean Total Dissolved Phosphorus Concentrations – Elm Lake50
Figure 33.	Chlorophyll <i>a</i> TSI Ratings – Elm Lake (1)50
Figure 34.	Chlorophyll <i>a</i> TSI Ratings – Elm Lake (2)
Figure 35.	Total Phosphorus to Chlorophyll <i>a</i> for All Project Data51
Figure 36.	Total Phosphorus to Chlorophyll <i>a</i> for All Project Data Except Summer and Fall of 199551
Figure 37.	Elm Lake Inlake Fecal Coliform Concentrations by Site53
Figure 38.	Elm Lake TSI54
Figure 39.	Long Term Trends of Chlorophyll <i>a</i> , Phosphorus, and Secchi Depth, Elm Lake – All Samples
Figure 40.	Long Term Trends of Chlorophyll <i>a</i> , Phosphorus, and Secchi Depth, Elm Lake – Summer Samples Only
Figure 41.	Predicted Reduction of Chlorophyll <i>a</i> and Phosphorus Trophic State Index in Elm Lake
Figure 42.	Total Nitrogen to Total Phosphorus Ratio
Figure 43.	Total Inorganic Nitrogen to Total Dissolved Phosphorus Ratio59
Figure 44.	Total Nitrogen to Total Dissolved Phosphorus Ratio (Limiting Nutrient for Blue Green Algae)
Figure 45.	Predicted – Nitrogen:Total Diss. Phosphorus Ratio, 60% Reduction of Phosphorus

Introduction

Elm Lake is located in northwest Brown County in northeast South Dakota (Figure 1). The north boundary of Elm Lake is located at the North Dakota-South Dakota border. The reservoir is shaped like a reverse "L" with the north-south fetch approximately 6 miles in length and the horizontal fetch extending west approximately 2 miles. The main tributary to Elm Lake is the Elm River. The Elm River begins in Dickey County, North Dakota and is first dammed at Pheasant Lake before reaching Elm Lake. Pheasant Lake is located approximately 4 miles north of Elm Lake. The total watershed is approximately 165,240 acres. The watershed that flows directly into Elm Lake (not including Pheasant Lake) is approximately 105,720 acres. The watershed for Pheasant Lake is approximately 59,520 acres. Due to contractual restraints, the study was completed on the immediate watershed to Elm Lake and not Pheasant Lake. Water quality data needed from Pheasant Lake was taken from the 1993 study conducted by the North Dakota Department of Health.

Elm Lake is classified as a drinking water supply for the city of Aberdeen. The pumps for Aberdeen's drinking water supply are approximately 30 miles below the outlet of Elm Lake. Although the information collected for this study stopped at the outlet of Elm Lake, the quality and quantity of water leaving Elm Lake is of concern to the citizens of Aberdeen.

The study was initiated in the spring of 1995, after the State of South Dakota received EPA Section 314 Clean Lakes money. Because Elm Lake was on the priority list of Section 319 Nonpoint Pollution Control projects, the Brown-Marshall Conservation District was approached and asked if they were interested in participating in a watershed assessment of Elm Lake. The conservation district agreed and secured additional match funds from the Brown County and the city of Aberdeen. The 314 Clean Lake grant was 70% federal and 30% local. The federal grant totaled \$100,000 and the local cash and in-kind totaled \$42,857. Money was spent on water quality analysis, equipment and supplies, travel, and wages for the local coordinator. Sampling began in the fall of 1994 and ended in the summer of 1996.

Historical Information

Elm Lake Dam was designed and constructed under W.P.A. project #1-544 in 1937 (1978, COE). The purpose of the dam was to serve as a recreation area and drinking water storage for the city of Aberdeen. Currently, South Dakota School and Public Lands hold the easement for Elm Lake Dam. The City of Aberdeen owns the water rights to the top 12 feet of the pool below the crest elevation of the primary spillway. The city has a draw down outlet consisting of two 24-inch cast iron pipes extending through the earthen embankment. The gate valves to each outlet pipe are located in a control house near the crest of the embankment. Elm Lake is considered a high hazard (Category 1) dam because of a farmstead in close proximity below the dam embankment.



Figure 1. Location of the Elm Lake Watershed.

In 1993, the North Dakota State Department of Health and Consolidated Laboratories published a study on Pheasant Lake. Below is the summary of the assessment taken from the actual report (Ell, 1993).

Summary of the 1991 Lake Water Quality Assessment of Pheasant Lake

Pheasant Lake was created in 1963 by damming a portion of the Elm River in South Central Dickey County. The fishery was to be developed by removing, through eradication, all unwanted fish species within the entire watershed. However, the dam was breached in the spring of 1963 and recontamination of unwanted fish species occurred. The first fish stocking occurred in 1964 and with rainbow trout, as a transition species, preparing the way for permanent fishery of northern pike, crappie, bluegill, perch, catfish, largemount bass and smallmouth bass. The fishery has been sustained by annual stockings, but has never truly developed due to periodic winter kills and an over abundance of black bullheads.

Through the combined efforts of the NDG&F, Dickey County Wildlife Club and concerned area residents a number of restoration procedures have been implemented. These include additions of hypolimnetic drawdown and aeration systems, increased stockings of adult bluegill and game fish, creation of a rearing pond and bullhead removal.

Pheasant Lake's general water chemistry is fairly good with relatively low concentrations of total dissolved solids and alkalinity. However, the principle nutrients, nitrogen and phosphorus, are quite high resulting in frequent algal blooms,

large macrophyte biomass, naturally low dissolved oxygen concentration and poor water clarity.

Much time and energy has been invested by state and local groups to correct these problems. Indicating it is a valuable resource to the surrounding community. This energy has been directed towards treating symptoms of nonpoint source pollution entering Pheasant Lake from the surrounding watershed.

Indicators that nonpoint source pollution, primarily from agricultural and lake shore development, is impacting Pheasant Lake are the detectable quantities of DDE and Trefaln in the flesh of fish and the high concentrations of nutrients in the water column. These sources need to be addressed or Pheasant Lake will continue to degrade. Obvious pollution sources are poorly treated agricultural acres within the watershed, areas of concentration livestock, lake property waste systems and new construction within the immediate area of the lake.

A substantial reduction in contaminants, nutrients and sediment loadings to Pheasant Lake can be realized through a watershed plan which incorporates soil and water conservation practices. This coupled with the lake restoration apparatus already in place should preserve Pheasant Lake for future generation.

Fisheries Data

The latest fisheries data was collected in Elm Lake in 1996. The results and discussion of the survey are discussed below. The complete report is given in Appendix B. The report stated low numbers of yellow perch might be the result of eroding shoreline and limited submergent vegetation. An increase in saugeye numbers may also be impacting the yellow perch population. Perch ranged from 12 - 26 cm (4.7 - 10.2 inches). Black crappies are the second most abundant pan fish in Elm Lake ranging in length from 12 - 35 cm (4.7 to 13.8 inches). Game Fish and Parks personnel are going to assess if the increased saugeye population will have any effect on the black crappie population. At the present time the report suggests that current size and abundance give anglers acceptable opportunity to catch crappie. Bluegills were the third species most abundant pan fish species seen in the nets from Elm Lake. Length for the 19 fish collected in Elm Lake ranged from 14.5 to 24.2 cm (5.7 - 9.5 inches). Habitat conditions are not favorable for bluegills and this species may never provide a fishery in Elm Lake.

In 1991, saugeye were added to Elm Lake as part of a South Dakota State University study on the effects of saugeye introduction to panfish. Prior to adding saugeye to Elm Lake, walleye populations were low. Following the stocking, the gill net catches increased dramatically. The type of fish collected were most likely saugeye as opposed to walleye. The deteriorated state of the gill net samples made identification difficult. During 1996 all previous year classes (1990 – 1995) were sampled. The walleye/saugeye were meeting the minimum length limit of 356-mm (14 inches) by the fourth growing season (age 3). Length distribution of gill net samples showed fish from 26 - 42 cm (10.2 - 16.5 inches).

Frame and gill net samples of northern pike suggest moderate abundance. Over the last four years pike have been doing better, most likely due to high water. The net sizes of

these fish were quite small for northern pike ranging from 32 - 58 cm (12.6 to 22.8 inches). If the current population ages without difficulty, a satisfactory fishery may result.

Black bullhead populations appeared to have increased dramatically in Elm Lake. The catches per unit effort are listed in the table below from 1992 - 1996. As can be seen, catches went from near zero to the elevated number in 1996.

	YEAR				
	1992	1993	1994	1995	1996
Frame Net	1.6	0.0	0.0	0.4	120.5
Gill Net	-	_	0.0	0.0	27.4

Table 1. Catches Per Unit Effort of Black Bullhead.

The bullhead populations may have increase because they did not get caught in the nets until their sizes reached 16 - 22 cm. A more likely reason is that the high waters caused an overflow of other bullhead rich lakes in the watershed. A study of Pheasant Lake from North Dakota Department of Health (1993) revealed that the fishery in Pheasant Lake is predominately black bullheads. The wet years of 1993 - 1996, most likely flushed bullheads from Pheasant Lake to Elm Lake. If the abundance of bullhead continues to increase, serious impacts may occur to other species in Elm Lake.

Channel catfish were present in low numbers in 1996. In 1996 only one individual was sampled. It is believed suitable spawning habitat is lacking. At best, this species serve as an incidental catch.

Carp were sampled in low numbers and do not appear to be a problem at this time.

The South Dakota Game, Fish and Parks recommend that Elm Lake be managed for saugeye and black crappies. Saugeye populations should be monitored through netting and fish surveys, and then socked to raise consistent numbers of saugeye.

Shoreline Erosion

Typical of many reservoirs, Elm Lake has experienced severe erosion along its banks. In the summer of 1996, the project coordinator and DENR staff conducted a shoreline survey to estimate the size and severity of erosion along the banks of Elm Lake. A total of 126 documented erosion areas were categorized in states of *Light*, *Moderate*, or *Severe* erosion. These classifications were estimated by multiplying the estimated length by the estimated maximum height of the erosion area. The *Light* classification was given to any erosion areas were classified as those with the product of the length and height less than 1,000 sq. ft. The *Moderate* erosion areas were classified as those with the product of the length and height between 1,000sq. ft. and 4,000 sq. ft.. The *Severe* erosion areas were those with the product of the length and height greater than 4,000 sq. ft. Thirty-seven (29.4%) of the 126 erosion

areas were categorized as *Severe* along the shores of Elm Lake. Nineteen sights were categorized as *Light* erosion areas and 70 sites were in the *Moderate* erosion category.

After summing the total erosion areas (length and height) the *Severe* erosion category was found to have 74% of the total area. The *Light* category totaled approximately 2 percent and the *Moderate* category totaled approximately 24% of the total erosion areas. Figure 2 shows areas of Elm Lake which are severely eroded. During the survey it was noted that the shoreline eroded for two main reasons. First was the natural cutting by wind and wave action. The drop of the banks along the old river corridor is quite steep. Wind, waves, and ice have cut back into the hills along the shore, especially near bends in the old river channel. The cutting and erosion was probably increased by the changing water elevation. The second cause for loss of shoreline appears to be cattle grazing along the banks of Elm Lake. As cattle come down to the lake for water and to cool, they eat vegetation naturally protecting the shoreline. Without the vegetation, the shoreline becomes more susceptible to the effects of the wind and waves. The loss of future shoreline will reduce the overall volume of the lake, increase the amount of suspended solids, and add to the overall eutrophication of Elm Lake. As shown throughout the rest of the report, suspended solids are probably a limiting factor for algae production in Elm Lake





Methods and Materials

Hydrologic Data

Ten tributary locations were chosen for collecting hydrologic and nutrient information from the Elm Lake watershed. Due to the large size of the watershed, tributary site locations were chosen which would best show watershed managers which sub-watersheds were contributing the largest nutrient and sediment loads. Stevens Type F paper graph recorders were placed at six of the sites to record the water height. The recorders were checked weekly to change the graph paper and reset the chart. After the chart was changed, daily averages were calculated to the nearest 1/100th of a foot. Campbell Scientific data loggers with float and pulley attachments were placed at four sites which ran intermittently. Every fifteen minutes the water stage was logged and then averaged every two hours. Daily averages were calculated after the loggers were down loaded to a laptop computer. A Marsh-McBirney flow meter was used to measure velocity at different heights in most of the round or small culverts. Complete flow measurements were taken in most square culverts or from bridges in the larger tributaries. Where only velocities were collected, the Hastad-Methods computer model Flow Master was used to estimate flows. The sizes of the culverts were entered into the computer and the model was manipulated to match the velocities collected in the field with the Marsh Mc-Birney flow meter. Actual slopes and Manning's coefficients could not be used in many cases because of flow altered by differing headwater and backwater conditions. From the model, stage discharge tables were calculated for each site. When complete flow measurements were collected, actual stage and discharge measurements were entered into a regression equation and a stage discharge table was calculated. The stage discharge table was use to calculate an average daily loading for each site. The daily loadings were then totaled for an annual loading.

As with every project, problems exist when trying to collect accurate discharge data. Site #2 was located as far from the lake as possible, however a back-flow situation developed from rising lake levels. Estimates from the AGNPS model and actual flows from Sites #3, #3a, #3b, #3c were used to help calculate the flow at Site #2.

The initial discharge from spring run-off was missed at many sites because of the conditions that existed when the snow melted. In many cases the initial flush was so large, the local coordinator could not get to the sites due to impassable roads and flooding conditions. There were also many times during the spring run-off when ice and snow blocked the culverts and stages could not be read. Other days, water was running underneath thick layers of ice and snow and discharges could not be calculated. During these times, the weather was cold enough to freeze the float in the stilling basin and stages could not be read. To estimate the volume of lost flow data, the loadings from the first day that the actual stages could be read at each site were averaged over the days the stages could not be read. Many of the sites were reached after peak run-off, conservative increases were added each day prior to the first day the stages could be read. In 1995, it

was estimated that run-off totaling approximately 9,000 acre-feet was missed between March and April 15.

After data was entered into the AGNPS model, it was found that approximately 23,280 (14% of the watershed) acres of the watershed was not gauged. Because of the lack of roads and back-flow problems in the Elm Lake watershed, it was difficult to gauge all of the tributaries running into the lake. To estimate the loading from this drainage, the total gauged load was divided by 0.86 (100% - 14% = 86%). The gauged totals were then subtracted from the new value (this amount is used as the estimated load for the ungauged tributaries). Because of the relative flat slope of the ungauged area, as opposed to the western steep hills in most of the other tributaries, only 80% of the above total estimated discharge was used for the increased run-off. The amount for the ungauged tributaries was added to the total gauged tributaries for an overall estimated load. The example below more clearly shows the equations used to estimate the loadings from the ungauged tributaries.

{Equation 1} Total gauged tributaries = 100
Total un-gauged tributaries = X
% Acreage of un-gauged tributaries = 14%
% Taken from un-gauged tribs. for flat slopes = 80%

$$100 / .86 = 116.3$$

 $116.3 - (116.3 * .86, \text{ or } 100) = 16.3$
 $16.3 * .80 = 13.04$
 $100 + 13.04 = 113.04$
 $13.04 / 113.04 = 11.5\%$ of the total load

This 11.5% is the approximated load for all of the parameters in the un-gauged watershed.

Outlet data for the Elm Lake spillway was calculated by using the following standard equation:

{Equation 2}

$$Q = C * L * (H^{3/2})$$

Where: Q = Flow in CFS
L = Length (150 feet)
H = Stage Height
C = Coefficient
C = 3.1 If the stage is greater than 2 feet
C = 3.0 If the stage is between 1 and 2 feet
C = 2.8 If the stage is below 1 foot

Water Quality Sampling

Samples collected at each site were taken according to South Dakota's EPA approved *Standard Operating Procedures for Field Samplers*. Water samples were then sent to the

State health Laboratory in Pierre for analysis. Quality Assurance/Quality Control samples were collected on 10% of the samples according to South Dakota's EPA approved *Clean Lakes Quality Assurance/Quality Control Plan*. These documents can be referenced by contacting the South Dakota Department of Environment and Natural Resources at (605) 773-4254.

Agricultural Non-Point Source Model (AGNPS)

In addition to water quality monitoring, information was collected to complete a comprehensive watershed landuse model. The AGNPS model was developed by the United States Department of Agriculture (Young et al, 1986) to give comparative values for every forty acre cell in a given watershed. Twenty-one parameters were collected for every 40 acre cell in the watershed.

The twenty-one main parameters included:

• •		
1) Cell Number	2) Receiving Cell	3) Aspect Ratio
4) NRCS Curve #	5) Land Slope	6) Slope Length
7) Slope Shape	8) Manning's Coeff.	9) Soil Erodibility
10) Cropping Factor	11) Practice Factor	12) Surface Constant
13) Soil Texture	14) Fertilizer Level	15) Available Fertilizer
16) Point Source	17) Gully Source	18) COD Factor
19) Impoundment	20) Channel Indicator	21) Channel Slope
-		-

The point source indicator cell lets the data collector enter a value if an animal feeding area is present in the cell. If the cell does contain an animal feeding area, there are approximately eight more parameters to collect on the feeding area. These parameters are:

1) Cell Number	2) Feedlot Area	3) Curve #
4) Roofed Area	5) Area of land contributi	ng water through the lot
6) Buffer Data	7) Area of land between t	he lot and channeled flow
8) Animal Data		

Parameters 5, 6, and 7, in the feedlot section may require multiple sets of sub data if the curve numbers change over the land areas. The animal data (#8) may also require multiple parameters depending on how many different types of animals are in a given feeding area.

If one cell contained two different values for the same parameter, such as soil curve number, the local coordinator took a weighted average of the two values. Each 40-acre cell was given an export value for phosphorus, nitrogen, and suspended solids. After the report is completed, the cells with the high export values are field checked to make sure the model is highlighting the correct problem areas in the watershed. The export values of each subwatershed were compared to each other and also to the water quality data on a relative basis only. Findings from the AGNPS report can be found throughout the water quality discussion. The conclusions and recommendations will rely heavily on the AGNPS data. The entire AGNPS report can be found after the water quality conclusions in Appendix A.

Season Water Quality

Different seasons of the year can yield differences in water quality due to changes in precipitation and agricultural practices. To discuss seasonal differences, Elm Lake samples were separated into spring (March 13 – May 31, 1995), summer (June 1 – August 31, 1995), and fall (September 1 – November 6, 1995). The Elm Lake watershed experienced heavy snows during the 1994 – 1995 winter, a fairly wet spring, dry summer, and a little more precipitation in the fall. During the 1995 sampling season, 73 samples were collected in the spring samples, and 6 samples were collected in each summer and fall. The summer and fall samples were collected after heavy rainfalls that occurred in scattered areas of the watershed. Not all sites were sampled during the summer and fall due to the scattered rains and intermittent flow.

Concentrations

In 1995, it is estimated that 95% of the total discharge to Elm Lake occurred between March and May 31. Slightly less than 5% of the run-off occurred in the summer and less than 1% of the run-off occurred in the fall. The average and median concentrations of different parameters changed throughout the seasons as shown in the following table.

Parameter		Spring	5	Summer			Fall		
	Count	Mean	Median	Count	Mean	Median	Count	Mean	Median
Diss. Oxygen	73	11.3	11.5	6	7.1	7.0	6	10.5	11.2
Field pH	73	8.0	8.0	6	8.0	8.0	6	7.7	7.9
Alkalinity	73	189	146	6	338.7	374	6	246	292
Total Solids	73	624	525	6	1,240	1,239	6	1,712	1,711
Susp. Solids	73	30	16	6	16	3	6	14	12
Diss. Solids	73	594	481	6	1,224	1,234	6	1,698	1,690
Ammonia	73	0.48	0.03	6	0.03	0.01	6	0.33	0.02
Nitrate-Nitrite	73	0.45	0.30	6	0.13	0.05	6	1.13	0.25
Total Kjeldahl – N	73	1.73	1.15	6	1.63	1.73	6	2.52	1.78
Total Phosphorus	73	0.406	0.320	6	0.553	0.413	6	0.83	0.842
Total Diss. Phosphorus	73	0.331	0.264	6	0.538	0.441	6	0.700	0.728
Fecal Coliform	67	1,847	40	5	1,006	1,200	6	20,092	250

 Table 2. Seasonal Mean and Median Tributary Concentrations.

*Highlighted areas are the seasons that recorded the highest concentrations for a given parameter.

Dissolved oxygen concentrations are highest in the spring. This is most likely due to the heavy flow of the water, becoming aerated as it moves along the stream. The lower oxygen concentrations in the summer are probably due to warm water temperatures and lower flows.

The alkalinity seems to be related to surface run-off. The highest concentrations are in the summer when the groundwater levels were most likely the lowest. Groundwater typically has higher alkalinity than rainwater because of the dissolved minerals from constant contact with the soil.

Higher total dissolved solids concentrations in the fall are most likely due to groundwater springs running from the Forbes hills. The summer had lower concentrations most likely from the rainwater, which, like alkalinity, typically has lower concentrations than groundwater springs. The spring samples had the highest concentrations of suspended solids. The large volume of water coming over the ground during snowmelt and rainfall on the fallow fields is the most likely cause of these higher concentrations. Although the concentrations of suspended solids are not extremely high, the largest concentrations did occur during the highest flows and may impact Elm Lake by decreasing volume and increasing nutrients.

The average nutrient concentrations are highest in fall except for ammonia. Two samples collected in the spring of 1995, had ammonia concentrations slightly over 10 mg/L. These two samples more than doubled the mean concentration to 0.48 mg/L. As with the spring samples, one sample in the fall increased the mean concentration greater than a factor of 10. The median samples are much lower than the mean samples for both spring and fall samples. The standard deviations for the spring and fall are both more than double the mean. This shows a high variability in the samples collected. The high ammonia concentrations do not appear to coincide with any other parameter. Sources for high ammonia concentrations could be animal feeding areas, decomposition of organic matter, or runoff from applied fertilizer.

The other two nitrogen parameters sampled, nitrate-nitrite and total kjeldahl nitrogen (TKN), did not show as much sample variability as ammonia. The fall season had the highest mean and median. The range of the nitrate-nitrite in the fall, however, was from a minimum of 0.015 to a maximum of 5.2 mg/L. The maximum sample was collected at Site #6a on November 11, 1995. Again this relatively high maximum raised the overall mean. The maximum sample concentration in the spring was 1.9 mg/L and the maximum sample in the summer was 0.438 mg/L. Most of the concentrations in the fall coincided with higher fecal coliform concentrations. This would point to waste of warm-blooded animals as the most probable source of nitrogen. Ammonia from animal waste was most likely converted to nitrate and nitrite.

As stated earlier TKN had the highest concentrations in the fall. The same fall sample with the maximum nitrate-nitrite concentration (November 11, 1995, Site 6A) also increased the TKN concentration by almost 3 times the mean concentration. Two spring samples however, had even higher concentrations. On May 10, 1995, at Site #6 and May

12, 1995, at Site #6a, the TKN concentration reached 12.3 and 13.7 mg/L respectively. These extremely high samples were not typical of most spring samples because the mean, median and the standard deviation were all below 2.0 mg/L. The time the majority of TKN is in organic form most likely form manure. The only time ammonia (inorganic nitrogen) was found to be the majority of TKN was when large amounts of animal waste were known to be in the stream.

Total phosphorus and dissolved phosphorus concentrations were also highest in the fall. The mean fall concentration was 0.830 mg/L and 0.700 mg/L for total phosphorus and total dissolved phosphorus respectively. Higher phosphorus concentrations seem to coincide with higher fecal coliform concentrations, especially in the fall samples. In the other seasons high phosphorus concentrations can also be found with high coliform concentrations. When elevated phosphorus samples are found without high fecal coliform concentrations, high suspended solids concentrations are usually present. These samples would point to sediment as the major carrier of phosphorus. Most of the high phosphorus concentrations seem to be related to animal waste not to suspended solids.

Fecal coliform samples are also highest in the fall. Two samples on October 5, 1995 had concentrations of 100,000 for Site #7 and 20,000 for Site #5. These areas experience heavy summer grazing which most likely concentrated in the dry streams during the summer and was flushed during the October rain. Although the spring and summer mean and median concentrations were not quite as high as the fall samples, there were elevated concentrations both seasons. The spring fecal coliform bacteria samples ranged from non-detectable to 30,000 colonies/100ml. The summer samples ranged from 210 – 1,800 colonies/100ml. The spring concentrations are more likely due to summer long grazing.

Loadings

Loadings are defined as discharge multiplied by concentrations. Seasonal loads are summarized below (Table 3).

Parameter	Spring	Summer	Fall
Discharge	94.0%	5.6%	0.4%
Alkalinity	88.8%	10.4%	0.7%
Total Solids	87.4%	11.8%	0.7%
Susp. Solids	97.3%	2.5%	0.2%
Diss. Solids	86.7%	12.5%	0.8%
Ammonia	99.6%	0.4%	0.0%
Nitrate-Nitrite	98.0%	1.9%	0.1%
Total Kjeldahl – N	93.7%	6.0%	0.3%
Total Phosphorus	89.4%	10.2%	0.4%
Total Diss. Phosphorus	87.3%	12.3%	0.4%
Fecal Coliform	82.7%	17.1%	0.1%

 Table 3. Comparison of Total Seasonal Loads.

Due to the high spring flows, the total loadings from the summer and fall combined are almost negligible when compared to the spring loadings. As can be seen in the above table, the spring loadings are over 87% of the total loading in all parameters except fecal coliform (82.7%). With the lack of summer and fall precipitation, there was not enough flow to carry nutrients through the watershed. Nutrients most likely accumulated in the watershed during the dry season and were carried through the system with the heavy flushing of the spring snowmelt and rains. This does not mean that the agricultural practices performed in the summer and fall can be ignored. If proper grazing, cropping, and nutrient management practices were used in the summer and fall, some of the nutrients and sediment would not be available for run-off in the spring.

In conclusion, because of less flow, the fall samples have increased concentrations. The high flows from spring snowmelt and rain diluted the sample concentrations although the total load was magnitudes higher than the other seasons. Spring rains and snowmelt carried more sediment than the other seasons. The reduced sediment concentrations in summer and fall are most likely due to grass and vegetation growth in the stream channels after the spring flush and established crops reducing the amount of sediment coming from the agricultural ground in the watershed. Nutrients appear to accumulate in the watershed until the heavy flushes carry the nutrients and sediment to Elm Lake.

Tributary Water Quality

North and South Dakota Water Quality Standards

Because Elm Lake watershed crosses into North Dakota, both North Dakota and South Dakota water quality standards will be discussed. The northern half of the Elm Lake watershed is located mostly in North Dakota. North Dakota includes all of its waters under a given criteria. The sample sites that fall under North Dakota's water quality standards are Sites #1, #3a, #3b, and #3c. Even though the sites are in different water quality classes (Site #1 Class II stream, Sites #3a, #3b, #3c Class III), all of the sites in North Dakota fall under the same criteria found in Table 4.

Parameter	Limits		
Unionized ammonia	Dependent on Temperature and pH (see discussion below)		
Dissolved Oxygen	> 5.0 mg/L		
pH	> 6.0 and < 9.0 su		
Temperature	< 29.44 °C		
Fecal Coliform	< 200 counts/100 ml (grab)		
*Total Phosphorus	< 0.10 mg/L		
*Nitrates	< 1.0 mg/L		

 Table 4. North Dakota Water Quality Standard Limits.

* The standards for nitrate (N) and phosphorus (P) are intended as interim guideline limits. Since each stream or lake has unique characteristics which determine the level of these parameters that will cause excessive plant growth (eutrophication), the department reserves the right to review these standards after additional study and to set specific limitations on any waters of the state.

Unionized ammonia is the fraction of ammonia that is toxic to aquatic life. The limit for unionized ammonia is calculated and dependent on temperature and pH. As temperature and pH increase so does the percent of ammonia which is toxic. In 52 samples at the various sites in North Dakota, 20 samples exceeded the unionized ammonia standard. When the same ammonia concentrations, temperatures, and pH levels were run with South Dakota's water quality standards, no violations of unionized ammonia were found.

In the North Dakota samples, there were no standards violations of dissolved oxygen, field pH, or temperature. Fecal coliform bacteria standards were exceeded 7 times during the sampling season. Most of the exceedences took place in May and June. Nitrate concentrations exceeded the interim guideline limits 7 times during the sampling season. The majority of these exceedences took place during snowmelt run-off. No nitrite concentration came close to limit for domestic water supply (10 mg/L). Phosphorus concentrations exceeded the interim guideline limits in all but 7 of the 52 samples. As stated earlier, the North Dakota Department of Health reserves the right to set specific limitations for those parameters that have interim guidelines.

In South Dakota, the main stem of the Elm River from the North Dakota boarder to Elm Lake is given the beneficial use of domestic water supply, warm water semi-permanent fish propagation, limited contact recreation and wildlife propagation and stock watering. No water quality monitoring sites were placed in this portion of the Elm River because lack of access. All streams in South Dakota are under the beneficial use of wildlife propagation and stock watering. The parameters for each specific criterion are listed in the table below.

Parameter	Limits		
pH	> 6.0 and < 9.0 su		
Dissolved Solids	< 2,500 mg/L		
Alkalinity	<750 mg/L		

 Table 5. South Dakota Water Quality Standard Limits.

There were no violations of the wildlife propagation and stock watering criteria in any of the tributary sites during the time of the study.

Discussion of Water Quality by Tributary Site

<u>Site #1</u>

Site #1 is the main inlet to Elm Lake. Site #1 drains approximately 60,760 acres, which includes 59,520 acres from the Pheasant Lake drainage (Figure 1) and 1,240 acres from the watershed after Pheasant Lake and before Elm Lake (Figure 3). Out of Elm Lake's total watershed acreage (165,240 acres), Site #1 drainage comprises approximately 37%. Fifty-four percent of the estimated total discharge passes through Site #1. Along with the majority of the discharge comes the majority of the loads; Total Solids (47.8%), Total

Suspended Solids (51.1%), Total Dissolved Solids (47.6%), Nitrate-Nitrite (48.8%), TKN (39.8%), Total Phosphorus (28.6%) and Fecal Coliform (35.7%).

Because the majority of the water that comes through Site #1 passes through Pheasant Lake, it is difficult to calculate a loss per acre on any of the parameters. Many chemical changes occur to the water in Pheasant Lake and do not reflect what may be actually going on in the watershed. Phosphorus and nitrogen concentrations may increase or decrease depending on the production or decomposition of organic matter in Pheasant Lake. Although many of the fecal coliform concentrations are low coming from Pheasant Lake, two samples, May 10, 1995, and July





6, 1995, had bacteria counts of 6,000 and 1,600 respectively. Since these higher concentrations occurred after the spring run-off, the most likely cause of these higher counts is animals in the subwatershed below Pheasant Lake and above Elm Lake. Suspended solids concentrations were also higher on these two dates, 76 mg/L on each occasion. The higher concentrations suggest either direct run-off from an animal feeding area to the stream or animals grazing in the riparian area. Both practices would add fecal bacteria and increase the suspended sediment sample concentrations. According to the AGNPS model there is a feedlot in this subwatershed with a ranking of 81. The AGNPS model ranks feedlots from 0 to 100, with 100 being the worst case.

On a per acre basis, Site #1 has the highest concentration of suspended solids. It is not possible to say if the suspended solids are organic (algae/vegetation) or inorganic (silt/clay or sand). Pheasant Lake most likely acts as a sediment trap for its 59,520 acre watershed. Most inorganic sediments that pass through Site #1 probably come from the 1,240 acres between Elm Lake and Pheasant Lake. Much of the land below Pheasant Lake is flat and much is used for grazing which would not show high sediment yields. Using 135 lbs/ft³ of sediment (Kuck, 1998) and estimating approximately 2.5 million pounds of sediment passing through Site #1, the total annual input of sediment to Elm Lake is approximately 0.43 acre/feet.

Seasonally, Site #1 had higher total phosphorus and ammonia concentrations in the spring. These are most likely due to feedlot run-off below Pheasant Lake or decaying organic matter coming from the watershed. An algae bloom under the ice in Pheasant Lake may also have been pushed over the outlet during the spring run-off. All of these

scenarios may have been responsible for the higher phosphorus and ammonia concentrations. No other parameters seem to have seasonal patterns.

The AGNPS model used the outlet of Pheasant Lake as a point source. The loadings for the point source were calculated by using 90% of the total discharge at Site #1. Nutrient concentrations were estimated for total nitrogen and total phosphorus concentrations from both the 1993 study in Pheasant Lake and inlake concentrations in Elm Lake. Pheasant Lake nutrient concentrations were used to more realistically estimate what might be coming from Pheasant Lake. There are no inputs for total suspended solids in the point source part of the model. For this reason, the percent of total suspended solids from the AGNPS model does not coincide with the water quality modeling. The model estimated only 8% of the total load of suspended sediments coming through Site #1, while the tributary water quality samples estimated 51% of the suspended solid load coming through Site #1. The elevated suspended solids found in the water quality sampling are most likely from algae and the previously mentioned animal feeding area below Pheasant Lake.

The phosphorus loadings from the AGNPS model were closer to the water quality loading percentages than the solids estimations. AGNPS estimated the total loads of phosphorus to Elm Lake from Site #1 at 27%. The loads to Elm Lake from the water quality data collected at Site #1 were estimated at 29% for phosphorus. AGNPS estimated the nitrogen load at 25%. The tributary water quality samples estimated the total nitrogen load for Site #1 to be 25% while the AGNPS model estimated the 42%.

Since much of the watershed of Site #1 and Elm Lake is located in the Pheasant Lake watershed, any significant changes to the nutrient and sediment concentrations must be addressed in that watershed. Even though the acreage is small, any poor grazing management, unconfined feeding area run-off, or poor cropping practices between Pheasant lake and Elm Lake will have a direct effect on Elm Lake and should also be addressed.

Site #2

Site #2 is the second largest inlet Elm Lake to encompassing approximately 46,680 acres or 28.2% of the watershed (Figure 4). The majority of the drainage into Site #2 is in the northwest part of the Elm Lake watershed in southern Dickey County of North Dakota. Typically when placing a site for a watershed project, backwater situations are avoided. In the





case of Site #2, the furthest the site could be placed away from Elm Lake was on the North Dakota/South Dakota State line (Figure 4). After the spring run-off, it was clear the site would be in a backwater situation. An attempt was made to gauge the site, however no accurate stage discharge table could be made. To help in the estimation of the load to the lake, two methods were used. Four smaller tributaries flow in to Site #2 (Sites 3, 3a, 3b, and 3c). The loadings of these tributaries were added together along with a percentage of the land not gauged (approximately 16%). These discharge loadings were used with the sample concentrations taken from Site #2 to get nutrient and sediment loads. The total discharge through Site #2 was estimated at 7,194 acre/feet (approximately 16.6% of the total load to Elm Lake). The AGNPS model was also use to give a percentage of flow as compared to the other inlets to the lake. Because of the backwater situation, some lake effects may have been taking place at Site #2 reflecting more inlake concentrations instead of the tributaries concentrations.

The mean phosphorus concentration for Site #2 sampled in 1995 was 0.357 mg/L (median 0.394 mg/L). The concentrations fall in the middle of the average concentrations of the other inlet sites. Site #2 input approximately 17.9% (3,366 kg or 7,421 lbs.) of the total phosphorus load to Elm Lake. Approximately 57% of the load of total phosphorus was dissolved, 43% of the total phosphorus was particulate. Compared to the other sites, Site #2 had a larger percent of particulate phosphorus. This is also reflected in the fact that 23% of the suspended solids load enters Elm Lake through Site #2. As mentioned earlier there may have been lake effects taking place at Site #2. The suspended solids may have been an algal bloom occurring in the shallow slow waters of the back flow situation crated by rising lake levels. The high percentage of organic nitrogen concentrations at Site #2 also points to organic matter instead inorganic matter as the source of suspended sediment later in the season. Earlier in the year when lake levels were lower, increased sediment concentrations were most likely inorganic from large fallow wheat fields located upstream in the watershed.

The overall nitrogen parameters were low to average in percent and concentration. Ammonia concentrations were especially low at Site #2. The mean ammonia concentration was 0.04 mg/L (median 0.01 mg/L). The load of ammonia is almost the lowest of all the inlet sites at 254 kg making up only 1.4% of the total load. The TKN and nitrate-nitrite loading are average (9,700 kg and 3,548 kg respectively).

According to the AGNPS model, there are two animal feeding areas with rankings greater than 60 in the Site #2 watershed. These feeding areas are most likely adding excessive nutrients to Elm Lake. The AGNPS model also found there to be a large number of cells with excessive losses of sediment. AGNPS estimated the total suspended solids load to Elm Lake from the watershed draining Site # 2 to be approximately 53%. The watershed draining Site #2 has a larger percentage of cropland as opposed to rangeland. These crop areas are most likely the cause of the elevated suspended solids loadings.

Sites 3a, 3b, 3c

Sites #3a, 3b, and 3c eventually empty into Site #2. One other site, Site #3, also drains into Site #2 but it will be discussed later. Each of the three subwatersheds are close to the same size, and the drainages are very similar. Water from the far end of these watersheds comes from the Forbes Hills and then drains to a long flat area. Agricultural practices in the hills are mostly grazing and crops are grown in the flat area below the hill. The watershed sizes for Sites 3a, 3b, and 3c are 9,160 acres, 9,640 acres, and 6,800 acres respectively. The approximate areas for these sub watersheds can be found on Figures 5, 6, and 7.

Even though Site 3b is the largest of the three subwatersheds, it has the smallest loading of nutrients and sediments when compared to the other two sites according to the water quality monitoring data. Site 3b also has smaller concentrations of fecal coliform bacteria. The mean fecal concentration for Site 3b is 84. Sites 3a and 3c mean fecal concentrations are 807 counts/100ml and 3,412 counts/100 ml respectively. Site 3c had one sample on May 10, 1995, that was 17,000 counts/100ml. The concentration of fecal coliform at Site #3a on the same day was 6,000 counts/ml. When looking at the median concentration of the three sites. Site 3a appears to have the highest overall concentrations of fecal coliform. The median concentration for Site #3a was 60 counts/100ml. Sites 3b and 3c both had a median concentration of 9 counts/100ml. From the fecal concentrations, it appears all the sites have livestock waste draining into the tributaries with the highest concentrations coming from Site #3a.

The discharge from these three subwatersheds is reflected largely in the drainage area. Both Sites 3a and 3b are between 9,000 and 10,00 acres in drainage. The annual discharge from Site #3a is slightly higher for its size than Site 3b. Site 3a discharged approximately 1,900 acre-feet while Site 3b discharged only 1,159 acre-feet. This can









Figure 7. Location of Site #3c.



easily be explained by the fact that discharges at Site #3a were collected starting March 14, 1995 and discharge readings at Site #3b were collected starting March 23, 1995. The majority of the flow for these sites occurred in the spring, and one week of spring run off was typically a large volume of water. This may also be the reason the loadings for Site #3b are so much smaller than the loadings for Site #3a. However, Site #3c sampling began the same time Site #3b and its loadings are greater than Site #3b.

The total load in tons for each of the sites that drain to Site #2 is located on the following table. As can be seen from the table, Site #3b has the lowest loading for most of the parameters.

Parameter	3a	3 b	3 c	3
Discharge (Acre-feet)	1,900	<mark>1,159</mark>	1,243	1,954
Alkalinity (tons)	682	348	<mark>296</mark>	453
Total Solids (tons)	1,466	1,059	<mark>985</mark>	1,681
Susp. Solids (tons)	63	<mark>30</mark>	71	118
Diss. Solids (tons)	1,402	1,030	<mark>908</mark>	1,562
Ammonia (tons)	0.14	<mark>0.04</mark>	0.09	0.22
Nitrate-Nitrite (tons)	1.43	<mark>0.44</mark>	0.94	1.24
Total Kjeldahl – N (tons)	2.75	<mark>1.67</mark>	<mark>1.67</mark>	2.90
Total Phosphorus (tons)	0.71	<mark>0.22</mark>	0.32	0.94
Total Diss. Phosphorus (tons)	0.57	<mark>0.22</mark>	0.29	0.82
Fecal Coliform (colonies/100ml)	2.6 E+13	1.2 E+12	4.7 E+13	2.0 E+12

Table 6. Loading of the Subwatersheds to Site #2.

____ The lowest loading to Site #2

The loss per acre, calculated by dividing the loading by the subwatershed acreage, also showed Site #3b to be extremely low when compared to the other watersheds.

 Table 7. Loss per acre of the Subwatersheds Draining to Site #2.

Parameter	3a	3 b	3 c	3
Drainage Size (Acres)	9,160	9,640	<mark>6,800</mark>	13,440
Discharge (Liter/Acre)	255,792	<mark>148,261</mark>	225,410	179,313
Total Solids (kg/Acre)	145	<mark>100</mark>	131	113
Susp. Solids (kg/Acre)	6.23	<mark>2.79</mark>	9.49	7.98
Diss. Solids (kg/Acre)	139	<mark>97</mark>	121	105
Ammonia (kg/Acre)	0.014	<mark>0.004</mark>	0.011	0.015
Nitrate-Nitrite (kg/Acre)	0.141	<mark>0.042</mark>	0.125	0.084
Total Kjeldahl – N (kg/Acre)	0.272	<mark>0.157</mark>	0.222	0.196
Total Phosphorus (kg/Acre)	0.070	<mark>0.021</mark>	0.043	0.063
Total Diss. Phosphorus (kg/Acre)	0.056	<mark>0.021</mark>	0.038	0.055

The lowest lost per acre to Site #2

Where Sites #3a and #3c lost 0.07 and 0.04 kg/acre/year of phosphorus, Site #3b lost only 0.02 kg/acre/year. Sites #3a and #3c each lost 0.014 kg/acre/year of ammonia, Site #3b

lost only 0.0045 kg/acre/year. The loss per acre per year of suspended solids is also between 25% and 30% lower at Site #3b.

For the size of the watershed, Site #3c appears to have a sedimentation problem. The sediment is most likely coming from the spring fallow wheat field at the lower end of the watershed. Site #3a appears to have the highest nutrient and sediment concentrations and loads of the three sites. Most of the high phosphorus concentrations appear to accompany higher fecal coliform concentrations. Grazing management and agricultural waste systems would reduce the fecal coliform concentrations. Because of the high sediment loss per acre from the subwatershed, better cropping practices should also be considered.

The AGNPS model agrees with the water quality modeling in that Site #3a has the highest per acre loss of the three subwatersheds discussed above. In the AGNPS model Site #3b does not look as clean as Site #3c however, this may be due to several high erosion rate cells located adjacent to the sampling site at #3b.

Sites #3and #4

Site #3 is the fourth tributary that runs into Site #2 (Figure 8). Site #3's watershed acreage (13,440) is larger than Sites #3a, 3b, and 3c. Since Site #3 has more than one stream draining to the site, Site #4 was placed upstream of Site #3 to help target areas that may be contributing more nutrients and sediments (Figure 9). The watershed area in Site #4 is 10,920 acres, 81% of the watershed for Site #3. Table 7 shows the percent loadings of Site #4 to Site #3 in 1995.



Parameter	Percent		
	Load		
Discharge	74.8%		
Alkalinity	62.0%		
Total Solids	72.4%		
Susp. Solids	71.0%		
Diss. Solids	72.2%		
Ammonia	73.8%		
Nitrate-Nitrite	78.0%		
Total Kjeldahl – N	94.4%		
Total Phosphorus	109.5%**		
Total Diss. Phosphorus	101.2%**		
Fecal Coliform	2,813%**		

Table 8. Percent Load of Site #4 to Site #3 in 1995

** The percentages greater than 100%, show dilution between Site #4 and Site #3.

Site #4 was responsible for 70 to 80 percent of all the nitrogen and suspended solids load to Site #3. The TKN, total phosphorus, dissolved phosphorus and fecal coliform loadings were closer to 100% or greater from Site #4. According to the AGNPS model, the watershed for Site #3 has 9 animal feeding areas, 8 of which are in the subwatershed above Site #4. The water appears to be a diluted between Site #4 and Site #3 for the phosphorus parameters and fecal coliform bacteria. However, nitrogen concentrations remain high. Nitrogen is more water-soluble than phosphorus and fecal bacteria and it most likely travels through Site #4 to Site #3. As can be seen in the above table the fecal coliform concentrations are much higher at Site #4. This confirms that much of the nutrient load from the Site #4 watershed is from animal feeding areas.

Most other parameter concentrations are also higher at Site #4 than Site #3. This is most likely due to the dilution of the water between the two sites. The suspended solids concentrations are generally lower at Site #3 than Site #4, although on April 3, 1995, the suspended solids concentration at Site #3 reached 151 mg/L. The total phosphorus concentration was also highest on this date (0.877 mg/L). No fecal sample was collected at Site #3, so it is difficult to know the source of the nutrients and sediment. The same day, a fecal coliform sample was collected at Site #4 with a concentration of 1,500 counts/100ml. The total phosphorus concentration at Site #4 was 0.807 mg/L indicating animal feeding areas as the most likely source of the nutrient load.

Being the largest subwatershed of Site #2, Site #3 is the largest contributor of nutrients and sediment to Site #2. From the data collected in 1995, Site #3 contributed 78% of the ammonia concentration to Site #2. Site #3 was also responsible for 25.9% of the total suspended solids load and 25.3% of the total phosphorus load to Site #2.

For the size of the watershed, Sites #3 and #4 have a large concentration of animal feeding areas. The feeding areas seem to be responsible for high nutrient and sediment

concentrations at both sites. According to AGNPS data collected, one of the feedlots above Site #4 ranked 60. This feeding area, along with summer long grazing are most likely contributing the large fecal and phosphorus loadings. The area that does not drain into Site #4 but does drain into Site #3 appears to dilute the nutrient and sediment concentrations because it does not appear to have the sediment and nutrient losses that come from the watershed above Site #4.

Site #5

The watershed that flows through Site #5, (10,840 acres), drains directly to Elm Lake (Figure 10). The mean fecal coliform concentration was 16.299 counts/100ml (median 75). Two samples collected from Site#5 had extremely high fecal coliform counts raising the mean far above the median. On May 10, 1995, and 5. 1995. fecal October bacteria concentrations reached 100.000 and 30,000 counts/100ml respectively. There are a total of 6 animal feeding operations above Site #5. One feeding area is

Figure 10. Location for Site #5.



approximately 500 yards from the sample site. The close proximity of the feeding area to the site may have increased fecal concentrations at Site #5 when compared to other tributary sites. The total phosphorus concentrations were 0.908 and 1.19 mg/L on May 10, 1995 and October 5, 1995, showing a correlation between the fecal coliform bacteria and the total phosphorus concentrations. The sampling data shows Site #5 input 12.6% of the total phosphorus load to the lake totaling 2,371 kg. The mean total phosphorus concentration of Site #5 was 0.645 mg/L (median 0.605).

Suspended solids concentrations and loads are fairly low at Site #5. In 1995, Site #5 was responsible for only 5.9% of the suspended sediment loading to Elm Lake. Most of the land in the upper end of the watershed is grazed, as are the areas adjacent to the main tributaries. Since the stream is intermittent, vegetation can grow in the channel trapping any sediment that may make it to the channel until high flows occur.

Nitrogen concentrations for Site #5 vary between average for organic nitrogen and higher for inorganic nitrogen when comparing Site #5 to other sites of relatively the same size and drainage characteristics. Mean concentration of ammonia, nitrate-nitrite, and TKN were 0.44, 0.713, and 2.00 mg/L respectively. Higher nitrate-nitrite concentrations were present when higher fecal coliform bacteria concentrations are found. Nitrate-nitrite concentrations can usually be found with the conversion from ammonia of organic nitrogen. The most likely source of the high nitrate-nitrite concentrations is animal waste in the stream channel left from the previous fall or run-off from feeding areas that have held cattle over the winter.

The maximum ammonia concentration at Site #5 was sampled on May 15, 1995. This is the same time a large ammonia concentration was also sampled at Site #6. The high ammonia concentrations at Site #5 may have been from the winter feeding area adjacent to the stream or it may have come from the gun irrigator used by a large confined feeding operation. During 1995, the gun irrigator was placed on the north side of the building sites and discharged to a small drainage that runs from that field east, until it eventually drains into Site #5. Although there is no standard for this site, the unionized ammonia concentrations. If present, the State water quality standards are 0.04 or 0.05 mg/L. Because no other samples come remotely close to 0.04 mg/L typically set by water quality standards, a large flushing of animal waste is suspected in the watershed.

In addition to the potential nutrient problem from the gun irrigator, the AGNPS model also targeted two other feeding areas that may be contributing to the increased nutrient loads at Site #5. One of the feeding areas was ranked at 60 and the other was ranked at 30. Both the AGNPS model and the water quality sampling estimated the total load to Elm Lake from this subwatershed at approximately 10% for total phosphorus and 8.5% for total nitrogen. Even though suspended solids are not shown as significant in the water quality sampling, the AGNPS model shows a large block of critical erosion cells in this watershed. Critical erosion cells were those with a 5 ton per acre loss or greater. This area should be field verified and problems addressed to prevent sediment and its attached nutrients from reaching Elm Lake.

Sites #6 and #6a

The subwatershed of Site #6 drains approximately 12,040 acres directly to Elm Lake. Site #6a is a subwatershed of Site #6 that starts at the Forbes Hills and covers the drainage 1-mile south of a large confined feeding operation (Figure 11). The

subwatershed for Site #6a is 2,800 acres. The confined feeding operation is the only documented animal feeding area above Site #6a. The confined operation has approximately 11,500 feeder pig, 1,200 sows, and 70,000 turkeys along with various other animals in buildings on site at one time. The operation has built animal waste pits and disposes of the waste by gun irrigation or by spreading the waste over fields by truck or wagon. At the present time the waste application rates and methods are not known.

Total phosphorus concentrations at Sites #6 and #6a were higher than any other site. Phosphorus concentrations





at these two sites were high throughout the sampling year. The minimum sample concentration for both sites was 0.745 mg/L. The first samples were collected at Site #6a on May 12, 1995, after the local coordinator noticed the strong smell of animal waste at Site #6 on May 10, 1995. The local coordinator called DENR after the May 10 sample at Site #6 and was told to sample upstream until he could find the source. The road with public access farthest upstream from Site #6 was what became Site 6a. Later it was discover the confined operation called DENR for permission to empty some manure out of their holding ponds so the ponds wouldn't overtop. Permission was given to the operation. The total phosphorus concentration at Site #6 on May 10 1995, was 1.97 mg/L. The total phosphorus concentration at Site #6a on May 12, 1995 was 1.06 mg/L. Three days later, on May 15, samples were collected at both Sites #6 and #6a. The sample concentrations for total phosphorus at Sites #6 and 6a were 1.17 and 0.745 mg/L respectively. As stated earlier, all samples collected at these two sites were extremely high in phosphorus concentrations. The mean sample concentration at Site #6 was 0.913 mg/L (median (0.856 mg/L). Year round high nutrient concentrations at Site #6a are evidence that the confined feeding operation has a nutrient problem throughout the year. Intense sampling continued at Site #6a in 1996, to see if the spring flush would clean out nutrients left in the tributary. Only one phosphorus sample collected in 1996 at Site #6a was below 1.0 mg/L. Actually, one-half (three) of the samples were above 2.0 mg/L in 1996.

Ammonia concentrations at Site #6a were also higher than at any other tributary site. Typically, unless there is a large fecal coliform concentration, ammonia concentrations are less than 0.10 mg/L. The three samples collected on May 12, May 15, and November 1, of 1995, at Site #6a were 10.02 mg/L, 0.17 mg/L, and 1.86 mg/L respectively. The average ammonia concentration in 1996 was 0.985 mg/L (median 0.975 mg/L). The average ammonia concentrations at Site #6 were not as high as at Site #6a, however, when large fecal coliform concentrations were present, individual ammonia concentrations were extremely high. At Site #6 on May 10, 1995 the fecal coliform concentration was 27,000 counts/100ml and the ammonia concentration was 10.9 mg/L. On May 15, 1995, the ammonia concentration at Site #6 was 6.09 mg/L even though the fecal coliform concentration was only 800 counts/100ml. Unionized ammonia concentrations at Sites #6 and #6a were at toxic levels when ammonia concentrations were above 5.0 mg/L. The two samples at Site #6 on May 12 and May 15, 1995, had unionized ammonia concentrations of 0.15 mg/L and 0.188 mg/L respectively. The next highest calculated concentration was collected on June 7, 1995, and was only 0.00034 mg/L. Only one sample at Site #6a had an elevated unionized ammonia concentration. The sample was collected on May 12, 1995, had a concentration of 0.19 mg/L. The unionized concentration on May 15 at Site #6a was only 0.0165 mg/L. It appears the flush of animal waste had passed Site #6a by that time. The large in flow of animal waste was responsible for the high unionized ammonia concentrations. Even thought the high ammonia concentrations obviously reached the lake, high unionized ammonia concentrations were never detected in Elm Lake most likely because algal uptake.

Inorganic nitrate-nitrite concentrations were not as exceptionally high at Site #6 with a mean concentration in 1995 of 0.52 mg/L. The nitrate-nitrite concentration at Site #6a on

November 5, 1995, was 5.2 mg/L. This high concentration could have been from the breakdown of organic nitrogen in the channel over the dry summer and released back into the stream through the flush of a fall rainstorm.

Fecal coliform samples from Site #6 and #6a were high although not as high as other sites in the watershed. In 1995, Site #6 had an average of 3,397 counts/100ml with a median of 190 counts/100ml. The high mean was the result of one sample reaching 27,000 counts/100ml. By removing the one extremely high sample the site average was reduced to 446 counts/100ml, still indicating the presence of waste from livestock in the water. Site #6a had only one sample that did not detect fecal coliform bacteria in the sample. The mean concentration at Site #6a for all samples collected in 1995 and 1996 was 289 counts/100ml, the median concentration over the same time was 205 counts/100ml.

Because Site #6a was started after spring run-off and did not become a gauged site until the summer of 1995, there is no data to compare loadings at Site #6 and Site #6a. The AGNPS estimated the watershed size of Site #6a is approximately 23% of the watershed of Site #6. AGNPS also estimated that Site #6a discharged approximately 30% of the discharge to Site #6. If Site #6a is estimated at 30% of the phosphorus loading to Site #6, for the watershed size, the per acre loading of phosphorus at Site #6a would be the highest of any site in the watershed. There are three documented feeding areas between Sites #6 and #6a however the AGNPS model ranked all of them at 0, indicating no impact. The majority of the phosphorus that is passing through Site #6a is the dissolved fraction and most likely travels down to Site #6.

The suspended sediment concentrations and loads at Site #6 and #6a are not as high proportionately as the nutrient loads. Approximately 74.3% of the land in Site #6a's watershed is grazed. The high percentage of grazing land is most likely due to the hills in the upper reaches. A high percentage of grazing is also found for the watershed above Site #6 (67.4%). The AGNPS model did highlight a large block of cells in the upper reaches of the watershed with relatively high erosion rates. These highlighted cells were generally those with slopes over 4% without adequate management practices. The suspended solids may also be coming from the animal feeding areas or grazing near riparian areas throughout the watershed.

The total loading of nutrients from Site #6 are extremely high. These high loadings are again reflected in the estimated loss per acre from the watershed. While only having 7% of the watershed, Site #6 was responsible for 27.8% of the phosphorus and 64.5% of the ammonia load to Elm Lake in 1995. At the same time water passing through Site #6 contained only 8.1% of the suspended solids load. From the water quality data, the estimated amount of phosphorus that passed through Site #6 was 5,228 kg (11,526 lbs.). The amounts of ammonia and TKN were 11,714 kg (25,825 lbs.) and 20145 kg (44,412 lbs.) respectively.

The water quality data suggests Site #6 has the highest lost per acre of nutrients of all the tributary sites and is responsible for the majority of the nutrient load to Elm Lake. Animal waste appears to be the most likely source of the nutrients in this subwatershed.
The animal waste may be direct run-off from feedlots, cattle grazing in riparian areas or poor nutrient management of agricultural waste. Because the large confined feeding area has storage pits and buildings to eliminate animal waste run-off, it was not possible to run the AGNPS model on the animal feeding operation. However, because of the high nutrient concentrations above Site #6a, animal waste management in or around confined feeding area should be addressed. The potential reductions of total phosphorus to Elm Lake from the AGNPS model would be greatly increased if the nutrient loadings collected in the water quality samples collected at the confined feeding area were reflected in the AGNPS model.

Site #7

The drainage for Site #7 covers the southern most part of the Elm Lake watershed (Figure 12). The total watershed drained into Site #7 is approximately 11,640 acres. According to the AGNPS data collected, 74.9% of this subwatershed was grazed. The western edge of the subwatershed does not have a large area of steeper slopes found in many of the other tributary sites. Site #7 contains 7% of the watershed, however, because of the more level slopes and the large percent of grazing land, Site #7 is responsible for only 2.9% of the total discharge to Elm Lake.



data, Site #7 has the smallest concentrations and loadings of all of the major tributary sites. The loss of nutrients and sediment per acre are also very small from Site #7. Because of the large percent of grazing in the watershed, the yearly load of suspended solids was only 10,628 kg (23,430 lbs.). This load makes up only 0.5% of the load to Elm Lake. The loss acre from per the subwatershed in 1995 was only .91 kg (2.01 lbs.) per acre/year.



There were some fecal coliform bacteria in samples collected at Site #7. Spring concentrations had fewer bacteria than summer or fall concentrations. In three spring samples there was no fecal coliform bacteria detected. The larger concentrations of fecal coliform found in the late spring, summer and fall were most likely from cattle grazing in pastures near or around riparian areas. Some of the initial snowmelt fecal coliform concentrations may have been from animal waste left in the channel from fall grazing. There are three concentrated animal feeding areas in the Site #7 watershed. Two of these

feeding areas ranked 0 with AGNPS and one ranked 7. So from the model, these three feeding areas do not seem to be contributing nutrients to the Elm Lake system.

Total phosphorus concentrations were slightly higher during the first sample year; the next spring, samples had smaller concentrations. When the fecal coliform bacteria concentrations increased in the summer and fall samples, total phosphorus concentrations again increased. The mean total phosphorus sample was 0.236 mg/L (median 0.161 mg/L). The mean total dissolved phosphorus concentration was 0.207 mg/L (median 0.131 mg/L). Because of the low suspended solids concentrations found at Site #7, most of the phosphorus is in the dissolved fraction. The total yearly load in 1995 was 295 kg (651 lbs.) which made up approximately 1.5% of the total load to Elm Lake.

All of the nitrogen parameters sampled were also very low in concentrations and loads. Most all ammonia concentrations were non-detectable. The only dates in 1995 that had detectable ammonia concentrations were March 14, and October 10. The spring sample had a concentration of 0.29 mg/L and the fall sample had a concentration of 0.02 mg/L. The mean ammonia concentration was 0.04 mg/L (median (0.01 mg/L). The percent loading to Elm Lake in 1995 from Site #7 was 0.6%, with a total loading of 114 kg (252 lbs.). TKN concentrations were also low, however the loading was slightly higher than the other parameters (2.3%). The majority of TKN is usually organic nitrogen. Even though the organic nitrogen percentage is slightly higher than the other nutrient parameters coming from Site #7 it is still extremely low when compared to the overall load to Elm Lake. The nitrate-nitrite concentration is also low for Site #7. The mean concentration is 0.22 mg/L (median 0.10 mg/L). There was only 0.03 kg of nitrate-nitrite lost per acre per year in 1995. The percent load of nitrate-nitrite to Elm Lake in 1995 was 1.3%.

The AGNPS model revealed slightly higher percentages of overall loads compared to the water quality monitoring. The model did find Site #7 to have smaller losses per acre of total phosphorus and suspended solids. However the nitrogen inputs were higher per acre than both Sites #1 and #6. This could be because of the high nutrient concentrations found in Site #6 that were not modeled or the fact that the model estimated a smaller percentage of inputs from Site #1 (the Pheasant Lake point source).

Overall the watershed above Site # 7 appears to have less agricultural management problems than the other sites in the watershed. Because of the higher phosphorus and fecal coliform bacteria in the summer and fall samples, improved grazing management in the watershed could benefit Elm Lake.

Un-gauged Tributaries

Because of the lack of roads and back-flow problems in the Elm Lake watershed, it was difficult to gauge all of the tributaries running into the lake. It was estimated from the AGNPS model that 14% of the total watershed (including Pheasant Lake's drainage) was not gauged. To estimate the loading from this drainage, the total gauged load was divided by 0.86 (1 - .14 = .86). The old gauged totals were then subtracted from the new

value arrived at in the previous sentence (this amount is the load for the un-gauged tributaries). Because of the relative flat slope of the un-gauged area, as opposed to the western steep hills in most of the other tributaries, only 80% of the above total was used to make up for the increase in infiltration due to the level slopes. The amount for the un-gauged tributaries was added to the total gauged tributaries for an overall estimated load. The example below more clearly shows the equations used to estimate the loadings from the un-gauged tributaries.

Total gauged tributaries = 100 Total un-gauged tributaries = X % acreage of un-gauged tributaries = 14% % taken from un-gauged tribs. for increased infiltration = 80%

> 100 / .86 = 116.3 116.3 - (116.3 * .86 or 100) = 16.3 16.3 * .80 = 13.04 100 + 13.04 = 113.0413.04 / 113.04 = 11.5% of the total load

As the formula shows, all of the parameters for the un-gauged sites are 11.5% of the total load.

Nutrient and Sediment Budget

Hydrologic Budget

The hydrologic budget explains how much water entered the lake and how much water left the lake. As mentioned in the above section, monitoring all the possible inputs to the lake is very difficult and also not practical. Often the earliest run-off cannot be gauged because of ice in culverts or in the case of 1995, the run-off came in such a flurry many of the sites were not reachable due to over the road flow. Also, the spring of 1995 experienced a thaw in early March then a freeze with large amounts of snow. Some tributaries kept running under the snow and ice and could not be gauged. When the second thaw occurred many of the same problem experienced in the first thaw were repeated. Unfortunately the tributaries were even more difficult to gauge in 1996. For lack of data, and because the project ended early June 1996, only 1995 data will be used for hydrology, nutrient and sediment budgets.

The hydrologic inputs to Elm Lake include precipitation, tributary run-off gauged and ungauged, and groundwater. Monthly precipitation data was taken from the Leola and Aberdeen field stations and averaged. Hydrologic outputs from Elm Lake included the volume of water below the level of the spillway before and after the project, the water leaving over the spillway of the dam, evaporation, and groundwater. Monthly evaporation data was estimated for the northeast region of South Dakota. Both precipitation and evaporation data was acquired from the State Climatologist. Tributary sites were gauged when possible and as stated in the previous section, un-gauged discharge was estimated using the gauged data.

As stated earlier, many of the sites were not gauged the exact day the streams started running, missing the peak flows in many cases. With the missed water that was running under the snow and ice between the thaws in March and April, it is estimated that approximately 9,000 acre-feet of water was missed or was not gauged. This number was estimated by looking at the average daily discharge at the time the gauging commenced. In the case of Site #5, the first recorded discharge was approximately 165 CFS. Samples were taken two days before the flow was gauged. The site dropped over 60 CFS four days following the first gauging date. As with most first spring run-offs, the initial flush happened on the weekend. Since samples cannot be collected until Monday because of mailing and laboratory constraints at least two days were missed from the sampling and flow. Assuming a constant drop for the entire weekend, the day before the gauging began the flow would have been 225 CFS, the day before that 285 CFS. Just for those two days, approximately 1,000 acre-feet passed through he site. There were two other sites much larger than Site #5 and two gauged sites approximately the same size. After looking at all the sites, a conservative estimate of 9,000 acre-feet of water passed through the sites without being gauged.

After all of the inputs were subtracted from the outputs the water budget was short only 1,731 acre-feet of inputs. The only source not yet estimated was groundwater. Groundwater inputs or outputs are typically very difficult to estimate. If surficial aquifers are near the streams and reservoirs they can add or take away large quantities of water. In the Elm Lake watershed, there is not any high storage aquifers, so the additional 1,731 acre-feet through out the year could have been from groundwater.

The local sampler gathered outlet information with a Marsh McBirney flow recorder. The data collected with the Marsh McBirney was compared with the weir discharge equation. Since the information was fairly close to the discharge equation, the weir equation was used. The following table and graph show the amounts of inputs and outputs to Elm Lake.

Input Sources		Output Sources		
Source	Load in Acre-feet	Source	Load in Acre-feet	
Precipitation	2,377	Evaporation	2,557	
Gauged Tributaries	38,423	Outlet Flow	51,560	
		Water below the		
Un-Gauged Tributaries	5,004	Spillway (2 feet)	2,418	
Missing Flow Estimates	9,000			
Groundwater	1,731			
Total	56,535	Total	56,535	

 Table 9. Input and Output Sources of Elm Lake.

Suspended Solids Budget

As described in the tributary section of the report, overall suspended solids from the watershed did not appear to have a significant impairment to Elm Lake. According to the data collected and estimated from all of the tributaries, Elm Lake received approximately 1 acre-foot of sediment in 1995. Because the water quality data might have underestimated the total sediment due to the missing flow data, the sediment from the AGNPS model was considered. According to the AGNPS model only 3 acre-feet of sediment was estimated in the annual loading. The volume of sediment was calculated by dividing the annual pounds of sediment by 135. One cubic foot of sediment weighs approximately 135 pounds (NRCS). The volume in cubic feet was then divided by 43,560 to change the units to acre-feet. This small amount of loading is most likely the result of the large amount of pasture compared to cropland in the watershed. Also, Pheasant Lake acts as a sediment basin for the 59,520 acres that drain into it. Even if the loading was underestimated by a magnitude of 10, the loading to Elm Lake would be only 0.2 inches over the entire surface per year. The areas in the watershed that appear to be contributing large amount of suspended solids, according to the AGNPS model, are areas below the Forbes Hills, which are planted in small grain. Typically these high erosion areas are on land with slopes greater than 4%. It is not known how much of the suspended solids are inorganic sediment or organic matter (decaying plant and vegetation). Due to the amount of grassland and the flat slopes in the watershed, some of the suspended solids will be organic matter.

Figure 13 below shows the estimated percentage of load from the watershed areas derived from the water quality sampling. As can be seen from the chart, Sites #1 and #2 input the majority of the suspended sediment to Elm Lake (Pheasant Lake drains into Site #1). Because it acts as a sediment basin, filtering large solid particles, it can be assumed that most of the solids coming from Pheasant Lake are organic. There is some grazing in the riparian area immediately upstream from Site #1 and this may also be adding suspended solids to Elm Lake. Site #2 has a fairly large watershed and a larger

percentage of wheat fields in its drainage. These cropping grounds appear to be the cause of the larger sediment loads to Elm Lake.

The amount of solids leaving Elm Lake through the outlet were approximately one-half of what was entering from the tributaries (approximately 0.4 acre-feet from the water quality data collected). Since most of the inorganic sediments entering Elm Lake settle out, it can be assumed most of the solids leaving Elm Lake through the outlet are organic. The outlet of





Elm Lake ran into late July. Algal blooms that rose to the surface of the water could have been blown near the outlet throughout the summer could have been collected in samples taken at the spillway, adding to the suspended sediment load at the outlet. Many algae, however, do not leave the lake and are broken down to release nutrients. This process is a form of internal loading.

Nitrogen Budget

Inputs for the nitrogen budget for Elm Lake were the tributaries, precipitation and groundwater. Tributary loadings were taken from the water quality data collected. Groundwater estimates were made by taking the estimated discharge of groundwater, 1,731 acre-feet, multiplied by an estimated groundwater total nitrogen concentration of 0.50 mg/L. The groundwater nitrogen was estimated from water quality data collected from wells placed by the South Dakota Department of Environment and Natural Resources and the United States Geological Survey (Armstrong, 1978). Due to the volume of estimated groundwater, the inputs from groundwater to Elm Lake was insignificant (< 1% of the total). Input from precipitation was estimated at 13.1 kg/ha/yr (11.685 pounds/acre/year) (EPA, 1990). The estimated unguaged spring run-off (9,000 acre-feet) was multiplied by the median spring concentration for each given parameter. A chart of total nitrogen inputs is shown in Figure 14.





According to the samples collected the inlake quantity of total nitrogen in Elm Lake increased by 44,994 kg (49.6 tons) during the project sample period. Nitrogen from precipitation and direct fallout is extremely variable depending on meteorological conditions and the land uses surrounding the waterbody. Atmospheric nitrogen can enter a waterbody in many forms: as nitrogen, nitric acid, ammonia, nitrite, and as organic compounds either dissolved or particulate (Wetzel, 1983). It is impossible to know what ratio of inorganic to organic nitrogen entered the lake from the atmosphere.

Figure 16.

The ammonia budget for Elm Lake showed an increase in inlake ammonia of 15,414 kg (17 tons) for the project period. As can be seen from Figure 15, the largest input was from Site #6. Ammonia is inorganic and used readily by algae for uptake and growth. The other inorganic parameter sampled was nitrate-nitrite. The nitrate-nitrite budget for Elm Lake also showed a slight increase to Elm Lake. The estimated amount of nitrate-nitrite added to Elm Lake in 1995 was 3,468 kg (3.8 tons). Plants can take up nitrate-nitrite nitrogen if available and then convert it to ammonia for use through a nitrate reduction process. Assuming that most of the atmospheric nitrogen was inorganic and in the form of nitrate-nitrite, this amount could increase by over three tons. Organic nitrogen to Elm Lake was 18,637 kg (20.5 tons). Organic nitrogen can come in many forms and, once broken down, can be converted to inorganic nitrogen and used by algae.





Phosphorus Budget

Total phosphorus inputs to Elm L 22,486 kg (24.8 tons). Inputs to El gauged tributaries, groundwater an calculated by multiplying the estim low groundwater phosphorus co precipitation load was multiplied l areas (Wetzel, 1983). Missed spr spring sample (0.32 mg/L) by the e

The total load out of Elm Lake w sampling season, there was an estir



lake than entering the lake. The outlet of Elm Lake ran until late July. June and July can be very productive in terms of algal growth. It is likely that large summer floating blooms of blue-green algae were flushed out of the lake through the outlet. The excess total phosphorus most likely came from internal loading. Internal loading is the release of usable phosphorus from sediments, where it is usually trapped. As dissolved oxygen concentrations decline so does the ability of the sediments to hold the phosphorus. Phosphorus releases from the lake sediments also increase if the sediments are disturbed from turbulence (Zicker 1956). With the long fetch of Elm Lake and many shallow areas along the shorelines, re-suspended sediments from wind action is another likely cause of the increase inlake phosphorus concentrations in Elm Lake.

The inputs of total dissolved phosphorus in Elm Lake were estimated at 16,606 kg (18.3 tons). However, a larger percentage of total phosphorus left the lake as dissolved phosphorus than entered the lake (79% leaving -73.8% entering). Approximately 1,606 kg (1.77 tons) more of total dissolved phosphorus left the lake than entered the lake. Again, the larger output load when compared to inputs were most likely caused by the release of phosphorus from the sediments due to either loss of oxygen near the sediments during nighttime respiration (not sampled) or release from the sediments from turbulence caused by wind or motorboats .

Even though there was evidence of a flushing of phosphorus from Elm Lake, the difference was less than 0.6 tons for total phosphorus and 1.77 tons of dissolved phosphorus. These small amounts could be errors in sampling or in the estimated phosphorus loads from the un-gauged tributaries. Even if the estimates were accurate, the tons of phosphorus entering the lake are more than sufficient to keep Elm Lake hyper-eutrophic.

INLAKE DATA

Methods and Materials

Four inlake sample locations were chosen for collecting nutrient and sediment information from Elm Lake during the study. The locations of the inlake sampling sites are shown Figure 17. A sample set, consisting of both a surface and a bottom sample were collected from each site each month. After the winter of 1996, surface and bottom samples at Sites #1 and #2 were combined into one composite. There was no significant difference between sites or at the different depths of any of the parameters. Additional inlake data was collected in 1989, 1991, and 1993 for the state sponsored annual lake assessment. These samples were used to analyze water quality trends over time. Samples collected for the Statewide Lake Assessment were collected by compositing three widely separated sub-sample sites in each lake. Individual surface and bottom samples were collected for the assessment. The samples were collected and analyzed according to the *South Dakota Standard Operating Procedures for Field Samplers*.

The water quality sample set analyzed by the State Health Laboratory consisted of the following parameters:

Total Alkalinity	Total Solids	Total Suspended Solids
Ammonia	Nitrate-Nitrite	Total Kjeldahl Nitrogen
Fecal Coliform	Total Phosphorus	Total Dissolved Phosphorus

Water quality parameters that were calculated from the parameters analyzed above were: Unionized Ammonia Organic Nitrogen Total Nitrogen Total Dissolved Solids

In addition to the chemical water quality data above, inlake field parameters and biological data were also collected. The following are a list of field parameters collected:

Water TemperatureAir TemperatureDissolved Oxygen ProfilesField pHSecchi Depth

The only biological parameter collected was chlorophyll *a*.

The chlorophyll *a* samples were used with the phosphorus and Secchi disk data to evaluate the eutrophic status and trends of Elm Lake. The hydrologic and nutrient budgets were used to find the lake response if phosphorus inputs were reduced. The model was taken from Vollenweider and Kerekes, 1980.

All samples collected at the inlake sites were taken according to South Dakota's EPA approved *Standard Operating Procedures for Field Samplers*. Water samples were sent to the State Health Laboratory in Pierre, SD for analysis. Quality Assurance/Quality Control samples were collected in accordance with South Dakota's EPA *approved Clean Lakes Quality Assurance/Quality Control Plan*. These documents can be obtained by contacting the Department of Environment and Natural Resources at (605) 773-4254.

Figure 17. Location of Inlake Sites on Elm Lake.



South Dakota Water Quality Standards

Elm Lake has been assigned the beneficial uses of:

- Domestic water supply
- Warmwater permanent fish life propagation
- Immersion recreation
- Limited contact recreation
- Wildlife Propagation and Livestock watering

When the above uses have standard limits of the same parameter, the most stringent standard is applied. Table 9 shows the most stringent standards for the parameters sampled in Elm Lake during the study.

Parameter	Limits	
Unionized ammonia	< 0.04 mg/L	
Dissolved Oxygen	> 5.0 mg/L	
pH	> 6.5 and < 9.0 su	
Suspended Solids	< 90 mg/L	
Temperature	< 26.67 °C	
Fecal Coliform	< 400 counts/100 ml (grab)	
Alkalinity	<750 mg/L	
Nitrates	< 10 mg/L	

 Table 10. South Dakota Water Quality Limits for Elm Lake.

Of all inlake samples collected, only four samples exceeded any of the above standards. Two of the exceedences occurred with dissolved oxygen in the bottom sample of site #3, the deepest site in the lake (24-ft.). The first exceedence, 4.9 mg/L, occurred on a calm, sunny day on July 12, 1995. Typically, prairie lakes will stratify under the proper conditions. According to the sampler's log, an algae bloom was in progress at the time of the sample. Detritus was also using oxygen for the decomposition of organic matter. Typically wind will not allow stratification in shallow prairie lakes. However as stated earlier, the wind was calm at the time the sample was collected. The second sample that exceeded the standards occurred on January 16, 1996 (4.5 mg/L). There was no defined oxygen stratification on the sample date, rather, a gradual decline of oxygen from the surface to the bottom. During the sample collection the Secchi depth measured 17 feet, so light was clearly reaching the bottom sediments. However, very little algae were present at the time of the sample, so not as much oxygen was being produced. In addition, decomposition at the sediment water interface requires oxygen and will lower in-lake oxygen levels.

The only other parameter that exceeded water quality standards was pH. One sample collected on May 3, 1995, reached 9.01 *su* and the exceedence reached 9.02 *su* on May 9, 1996. Elm Lake is a eutrophic prairie lake with hard waters typical of calcareous glacial temperate regions in the Midwestern United States. Waters in these areas typically have

higher pH levels (Wetzel, 1983). The soils, along with the increased biological activity such as photosynthesis, probably cause the elevated pH readings.

Inlake Water Quality

Inlake sampling started on September 28, 1994. Samples were collected monthly when possible. Winter samples were not collected when ice conditions were not safe for travel. The last sample was collected on August 6, 1996. A total of 15 samples were collected for the Elm Lake Project. Two samples were collected in the fall of 1994, 8 samples were collected in 1995, and 5 samples in 1996. The following discussion will be based on individual parameters. The discussion will include the importance of the parameter and its effect on the water quality of Elm Lake.

Water Temperature

Water temperature is important to the biology of a lake, as it effects many chemical processes in the lake. Higher temperatures increase the potential for raising the unionized fraction of ammonia (toxic to fish). Algae have optimal temperature ranges for growth. Blue-green algae are more prevalent in warm waters. Green algae and diatoms are often found to be more dominant in cooler waters. Fish life and propagation are also dependent on water temperature. The overall mean in Elm Lake over the sampling season was 12.85 °C. The mean for bottom samples was 11.8°C and the mean for surface samples was 12.3 °C. The maximum temperature sampled during the sampling season was 26.5 °C taken from a surface sample in July, 1995. There is not a permanent thermocline in Elm Lake, although in some summer samples a sharp drop in temperature begins at approximately 15 feet. Overall the temperature varies little from surface to bottom in Elm Lake. The wind and wave action most likely keep Elm Lake's water mixed throughout the water column. Complete temperature profiles for all of the sites can be found in Appendix C.

Dissolved Oxygen

Dissolved oxygen changes with the growth and decomposition of living organisms in a lake system. As algae and plants grow and photosynthesize, they release oxygen into the water. When living organisms decompose, bacteria use oxygen from the system and replace it with carbon dioxide (CO₂). Dissolved oxygen can also change at the surface air-water interface. Wave action and other turbulence can increase the oxygen level of a lake. Dissolved oxygen averaged 9.89 mg/L (median 9.85mg/L) over the entire duration of the study. There was only about 1 mg/L difference between the average surface and bottom dissolved oxygen concentrations.

The maximum oxygen concentration in Elm Lake was 14.8 mg/L. That sample was collected in the surface sample at Site #4 on January 11, 1995. Algal blooms under the ice are common when sunlight can penetrate the ice and snow in winter. There was a bloom under the ice on January 11 according to the chlorophyll a concentrations. The

dissolved oxygen level was most likely a product of the algal photosynthesis. The agitation from an ice auger can also cause an increase dissolved oxygen concentration and may have helped increase the dissolved oxygen concentration. The minimum dissolved oxygen concentration was 4.5 mg/L in the bottom sample at Site #3 on January 16, 1996. Site #3 was the deepest site sampled in the lake (approximately 24 feet). Because ice and snow cover can impede light from reaching deeper in the water, many times in the winter, algae will not be able to photosynthesize and produce oxygen. However, the depth of the Secchi measurement showed light to be reaching approximately 15 feet. Even though there was sufficient light, there was almost no chlorophyll a concentration at the surface on that day. Decomposition typically takes place in the bottom sediments and can deplete oxygen supplies. As can be seen in the surface to the bottom of the lake. It appears that the lack of algal production near the surface and decomposition of organic matter at near the bottom sediments depleted the dissolved oxygen levels.



Figure 18.



Figure 20.







from the surface to the bottom. It does appear however, oxygen levels at Site #3 were effected by lack of light from suspended sediments as opposed to algal shading. Furthermore, decomposition of organic matter in the sediments helped in lowering the oxygen concentrations. Seasonally, the summer oxygen levels are lower than spring and winter samples. Shading from suspended sediments in the water column and increased biological activity in the warmer water are the most likely reasons for the decreased oxygen levels.

One factor not taken into consideration in this study was the drop in oxygen at night. Typically, as much oxygen as is produced by photosynthesis in the day, is used in respiration, or uptake of oxygen, at night. The maximum oxygen concentration usually occurs in the afternoon on clear days, and the minimum immediately after dawn (Reid, 1961). Most of the lower oxygen levels in Elm Lake were collected on the bottom samples before noon. The one exception was a bottom sample taken in the winter, where respiration was most likely the reason for the lower oxygen levels.

Even though there are a few low oxygen levels in the deeper depths, fish and other aquatic animals will migrate to a depth in the lake with the most optimum temperature and oxygen levels that will not stress them. At all times during the study there was sufficient oxygen at some depth in the lake.

<u>рН</u>

pH is the measure of the hydrogen ion. More free hydrogen ions lower the pH in water. During decomposition, carbon dioxide is released from the sediments. The carbon dioxide (CO₂) reacts with water to create carbonic acid. The carbonic acid creates and a hydrogen ion. Bicarbonate can be converted to carbonate and another hydrogen ion. These extra hydrogen ions created from decomposition will tend to lower the pH in the hypolimnion (bottom of the lake). Increases in the different species of carbon come at the expense of oxygen. Decomposers will use oxygen to break down the material into different carbon species. Also, the lack of light in the hypolimnion prevents plant growth, so no oxygen can be created through photosynthesis. Typically, the higher the decomposition rates the lower the oxygen concentrations and the lower the pH in the hypolimnion.

The inverse occurs when photosynthesizing plants increase pH. Plants use carbon dioxide for photosynthesis and release oxygen to the system. This process can reverse the process explained above, increasing pH.

Elm Lake experienced the typical pH scenario explained above to a small degree. The pH at the surface of the lake was slightly higher than the pH concentrations found in the bottom samples. Due to the well-mixed system, there is very little difference between the surface and bottom pH concentrations. The pH concentrations in Elm Lake are not extreme in any samples. The relatively high alkalinity concentrations in Elm Lake work to buffer dramatic pH changes. Since increases in decomposition decrease pH, increases in pH can be an indication of increased organic matter in a lake over time.

Secchi Depth

Secchi is a measure of lake clarity or turbidity. The Secchi disk is 20 cm in diameter and usually painted with opposing black and white quarters (Lind, 1985) (Figure 21). The Secchi disk is used worldwide as a comparison of the clarity of water. Secchi disk readings can also be used in Carlson's Trophic State Index (TSI). Carlson's TSI is a

measure of trophic condition, or the overall health of a lake. One limitation of the Secchi disk is that it cannot differentiate between organic and inorganic solids limiting the depths that the disk can be seen. At first, a low Secchi depth reading may indicate hyper-eutrophy, or high chlorophyll *a* concentrations.

Elm Lake seems to demonstrate this scenario. Secchi depth readings collected through the ice are relatively clear and as chlorophyll increases the Secchi depth decreases. In the spring, summer, and fall, however Secchi depth readings do not appear to mirror chlorophyll *a* concentrations. There are low

Figure 21. Secchi Disk



Secchi depth readings on certain days with very little chlorophyll *a* concentrations. One sample, in September of 1995, had extremely low chlorophyll *a* concentrations and the Secchi depth was just over 0.5 meters (1 foot 8 inches). On the same day suspended solids concentrations were at a project high. The sampler noted the wind was particularly strong on that day. Wind most likely mixed the bottom sediments through the water column lowering the Secchi reading. The project average for Secchi disk readings was 1.4 meters (4.6 feet). Seasonally, the winter average was 3.7 meters (12.1 feet), while the summer average was 0.90 meters (3.9 feet). Figure 22 shows the average Secchi depth

Figure 22.



for every day a sample was collected. With the lack of wind stirring up the bottom

sediments, the winter samples had only algae to decrease clarity and snow to block light, reducing the Secchi disk reading.

Turbidity in Elm Lake appears to be caused by suspended sediments, and to lesser degree algae. When looking at the Secchi depth readings, one must remember that the low readings do not necessarily mean high chlorophyll *a* concentrations in Elm Lake.

Alkalinity

Alkalinity refers to the quantity of different compounds that shift the pH to the alkaline side of neutral (>7). Alkalinity is usually dependent on geology. Alkalinity in natural environments usually range from 20 to 200 mg/L (Lind, 1985). The average alkalinity in Elm Lake was 182.7 mg/L with a standard deviation of 25.3 mg/L. The minimum alkalinity concentration (118 mg/L) was collected in May of 1996. The pH was also at the maximum on the same day. For the most part, the alkalinity concentrations were between 170 mg/L and 200 mg/L (71%). Seasonally, there is a increase in concentration from spring to summer and into the fall (Figure 23). The gradual increase in alkalinity is most like due to evaporation in the lake concentrating the dissolved solids in less water. Because alkalinity is mostly a result of the natural environment, the concentrations do not change dramatically.



Figure 23.

<u>Solids</u>

Total solids are the materials, suspended or dissolved, present in water. Dissolved solids include materials that pass through a water filter. Suspended solids are the materials that do not pass through a filtered water sample, e.g. sediment and algae. Subtracting the suspended solids from the total solids derived total dissolved solid concentrations. The dissolved solids concentrations in Elm Lake averaged 606 mg/L. The lowest concentrations were found in the spring in both 1995 and 1996. The lower dissolved solids concentrations were from the snow melt and spring run-off diluting the concentrations in the lake. Snowmelt and rain generally have lower concentrations of dissolved solids. Dissolved solids are typically made up of salts and compounds that keep the alkalinity high. As the total dissolved solids dropped so did the alkalinity. Typically there is very little change in total dissolved solids concentrations from year to year and from surface and bottom samples.

Daily average total suspended solids are graphed in Figure 24. Total suspended solids in Elm Lake averaged 10.12 mg/L. The largest surface concentrations were collected on September 25, 1995. The average suspended solids concentration was 28.25 mg/L, approximately 3 times the average. The chlorophyll concentrations on the same day were noticeable (17.4 mg/m³), but still under Elm Lake's average. The local coordinator noted that the winds were moderate to strong. These strong winds caused the re-suspension of bottom sediments throughout the water column. Due to the long north south fetch of Elm Lake and the many shallow areas along the shoreline, suspended sediments caused by wind and wave action limit clarity in Elm Lake. The nutrient levels in Elm Lake are

Figure 24.



relatively high, however, the overall chlorophyll *a* concentrations are relatively small. The suspended sediments in the lake shade the light from the algae and limit its growth.

The bottom samples in Elm Lake are slightly higher in suspended solids concentrations than the surface samples. This is further evidence that the sediments are being well mixed from the bottom to the surface. Even though there are some elevated suspended solids concentrations, all of the concentrations are well below the water quality standard (90 mg/L). It may be that the suspended particles are small colloidal materials that retard algal growth, but does not show up by weight (mg/L) from laboratory analysis. There are some shale and clay soils around the shoreline of Elm Lake that may be depositing this type of material. These particles can be coming from shoreline erosion, which, as discussed earlier, is extreme all around Elm Lake. Re-suspension of materials by wind and waves can also increase the suspended solids concentration in Elm Lake.

<u>Ammonia</u>

Ammonia is the nitrogen end product of bacterial decomposition of organic matter and is the form of nitrogen most readily available to plants for uptake and growth. Even though there are high ammonia concentrations entering the lake from the watershed, those concentrations are not consistently found in Elm Lake. The mean concentration in Elm Lake was 0.04 mg/L with a median of 0.01 mg/L. The standard deviation was 0.07 mg/L which shows a large variation in the samples. One sample date, June 14, 1995, the ammonia concentration average was 0.26 mg/L, six times higher than the average for the entire sampling season (Figure 25). These concentrations were the result of the manure release from the large confined feeding operation in the middle of May. The ammonia concentrations gradually decreased at the sites further away from the inlet that received the discharge. The eight samples, which were collected on June 14, 1995, doubled the inlake average. The large inputs of ammonia to Elm Lake in June may be the reason for the increased algae and the high chlorophyll *a* concentrations in August.



Figure 25

The average inlake ammonia concentration was high again in June of 1996. These concentrations are again most likely the result of animal waste. These large flushes of animal waste must be controlled if improvements are to be realized in Elm Lake.

Nitrate-Nitrite

Since Elm Lake is classified as a drinking water source, there is a more stringent water quality standard for nitrates (10 mg/L) as compared to most lakes (50 mg/L). The nitrate concentration did not come close to exceeding the water quality standard. Nitrate and nitrite are inorganic forms of nitrogen easily assimilated by algae and other macrophytes. Sources of nitrate and nitrite can be from agricultural practices and direct input from septic tanks, and other forms of waste. Nitrate-nitrite can also be converted from ammonia through denitrification by bacteria. The process increases with increasing temperature and decreasing pH.

Decomposing bacteria in the sediments and blue-green algae in the water column can convert the free nitrogen (N_2) to ammonia. Blue-green algae can use the ammonia for growth. Although algae use both nitrate-nitrite and ammonia, highest growth rates are found when ammonia is available (Wetzel, 1983). Since nitrogen is water soluble, and blue-green algae can convert many forms of nitrogen for its own use, it is more difficult to remove nitrogen than phosphorus from a lake system.



Figure 26

The average nitrate-nitrite concentration for Elm Lake was 0.19 mg/L (median 0.20) for the entire project. Although the effects of manure on the nitrate-nitrite are not as dramatic as they were with the ammonia, the increased concentrations of nitrate-nitrite lasted for a longer period of time. The mean of the nitrate-nitrite samples collected in

June and July in 1995 was 0.4 mg/L, twice the mean for the entire project, as can be seen in Figure 26. There is little difference in the surface and bottom concentrations of nitratenitrite as the parameter is water-soluble and the lake is well mixed. These higher nitratenitrite concentrations are most likely product of the high ammonia concentrations in the spring being converted to nitrate and nitrite.

Total Kjeldahl Nitrogen

Total kjeldahl nitrogen (TKN) is used to calculate both organic and inorganic nitrogen. TKN minus ammonia equals organic nitrogen. TKN plus nitrate-nitrite equals total Total nitrogen is basically used to determine if the lake is nitrogen or nitrogen. phosphorus limited. The limiting factor of the Elm Lake will be discussed later. Sources of organic nitrogen can include release from dead or decaying organic matter, lake septic systems, or agricultural waste. Organic nitrogen is broken down to more usable ammonia and other forms of inorganic nitrogen. The mean and median organic nitrogen concentrations were 0.96 mg/L and 0.90 mg/L respectively. There is a slight increase in the concentration in the summer months (Figure 27). This is most likely due to the increase in alga concentrations. Organic nitrogen makes up approximately 80% of the total nitrogen. The only samples where inorganic nitrogen is close to making a larger percentage than organic nitrogen was in June and July of 1995. The average percentage of organic nitrogen for those two months was approximately 68%. Increase in inorganic concentration was again due to the input of manure in mid May. There is little difference in the surface and bottom concentrations of organic nitrogen. If anything, the surface differs from the bottom samples in that the surface has a slightly higher percentage of organic nitrogen and the bottom has a slightly higher percentage of inorganic nitrogen.

Total Nitrogen

Total nitrogen is the sum of the nitrate-nitrite and the TKN concentrations. Total nitrogen is used mostly in determining the limiting nutrient discussed later in the report. The maximum total nitrogen concentration found in Elm Lake was 2.11 mg/L in a surface sample at Site #4 on July 12, 1995. The surface and bottom samples showed little variance. The mean concentration for both surface and bottom samples was 1.20 mg/L. The concentration for the surface samples varied only 0.32 mg/L from the mean and the bottom samples varied only 0.31 mg/L from the mean. As seen in Figure 28, the nitrogen concentrations slowly decline from a project average high in June of 1995, to closer to the project mean throughout the summer of 1995. The nitrogen from the large influx of animal waste was either being used up for growth by plants, flushed out the outlet, or released to the atmosphere.

Figure 27.



Figure 28



Total Phosphorus

Typically phosphorus is the single best chemical indicator of the condition of a nutrient rich lake. Algae need as little as 0.02 mg/L of phosphorus for blooms to occur. Phosphorus differs from nitrogen in that it is not as water-soluble and will sorb on to sediments and other substrates. Once phosphorus sorbs on to any substrate it is not as readily available for uptake by algae. Phosphorus sources can be natural in the geology and soil, from decaying organic matter, and waste from septic tanks or agricultural runoff. 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 resuspension. 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.

The average concentration of total phosphorus throughout the study period was 0.349 mg/L (median 0.352 mg/L). There was approximately a 25% deviation from the mean with a standard deviation of 0.089 mg/L. The surface and bottom samples also showed very little difference, if any, in most samples. The maximum sample concentration was collected in the bottom sample on July 12, 1995. The concentration sampled at Site #4 reached 0.836 mg/L. Inlake Site #4 is the closest site to the tributary in which animal waste was dumped in mid May. This high concentration was most likely due to the inflow of phosphorus from the dumping. There was also a slight drop in the dissolved oxygen concentration at that site. As explained in the dissolved oxygen discussion, nighttime respiration can reduce oxygen levels. Since the sample was collected at 9:45 am, the dissolved oxygen levels may have been low enough at night to release a large phosphorus concentration from the sediments. The process of phosphorus being released

from the sediments is explained in the previous paragraph.

As can be seen from the graph in Figure 29, there seems to be an increase in phosphorus from May to August in both 1995 and 1996. The higher concentrations may have been due to evaporation concentrating the nutrients in less water, a continual release of phosphorus from the sediments, the increase production of algae in the lake or a combination of





all of these factors. Whatever the case, the increase in phosphorus concentration in Elm Lake will mean an increase in the productivity of the lake. Since phosphorus is usually the cause of algal blooms, by removing the phosphorus sources coming into the lake, in time Elm Lake would see a decline in algal blooms and better water quality for domestic use, fishing and immersion recreation.

Total Dissolved Phosphorus

Total dissolved phosphorus is the fraction of total phosphorus that is readily available for use by algae. Dissolved phosphorus will sorb on to suspended materials if they are present in the water column and if the are not already saturated with phosphorus. There no noticeable is difference in the percent dissolved from the surface and the bottom samples. Because of the influx of phosphorus in May of 1995, the suspended dissolved solids and phosphorus concentrations did not have any relationship (Figure 30). In 1996 however. after the lake has some time to recover, there was a noticeably better relationship as can be seen in Figure 31 (R^2) = 0.5793). As can be seen in the figures, there is relatively little suspended sediment present in Elm Lake. The average percent of phosphorus that was dissolved during the project was 89%. The average dissolved phosphorus concentraion in Elm Lake was









0.310 mg/L (median 0.325 mg/L). Since algae only need 0.02 mg/L of phosphorus for growth, Elm Lake averages over 15 times the algal minimal requirements.

* R^2 = is a value given for a group of points with a statistically calculated line running through them. The higher the R^2 value the better the relationship, with a perfect relationship reached when $R^2 = 1.0$.

As can be seen from the graph in Figure 32, dissolved phosphorus concentrations follow the same pattern as total phosphorus by increasing concentrations throughout the summer months. The same reasons, evaporation, algal production, or release of phosphorus from the sediments most likely caused these increases. Since dissolved phosphorus is so closely linked to total phosphorus, decreasing the sources and loadings of total phosphorus will show the best results in decreasing total dissolved phosphorus.





Chlorophyll a

Chlorophyll *a*, a pigment in plants, may be used to estimate the biomass of algae found in a water sample. Chlorophyll *a* samples were collected with the all the surface samples during the project except for the first two fall sample dates in 1994. Overall, the

chlorophyll *a* concentrations in Elm Lake were relatively low. If chlorophyll were the only parameter estimating the eutrophy of a lake. Elm Lake would be between eutrophic and mesotrophic (Figure 33). Only 5 out of 48 samples collected were hyper-eutrophic. Just because the chlorophyll *a* concentrations are not high does not mean the lake is not eutrophic to hyper-eutrophic. Suspended sediments or other factors in Elm Lake are limiting the algal growth.





The average chlorophyll *a* concentration for Elm Lake during the project was 20.43 mg/m^3 (median 12.0 mg/m^3). The maximum chlorophyll *a* sample was collected on August 9, 1995 (140.3). Even thought the nutrient concentrations were available in June and July, lake conditions must not have been adequate for a major algal bloom until August. Figure 34 shows that the high readings found in August were 5 to six times higher that the project average. If these large algal blooms increase in frequency the internal organic loading to the sediments will increase and the lake will become increasingly more eutrophic.





Typically chlorophyll *a* and total phosphorus have a relationship in regards to increasing concentrations. As total phosphorus increases so does chlorophyll *a*. Each lake usually shows a different relationship because of factors including but not limited to; nutrient ratios, temperature, light, suspended sediment, and water retention time. Such a relationship was attempted using all of the data from the project. However, as can be seen from Figure 35, the data was too scattered to have any kind of relationship (\mathbb{R}^{2*} 0.0033). However, when summer samples from 1995 were removed, a better relationship developed, ($\mathbb{R}^2 = 0.3785 - Figure 36$). It may have been that the lake could not, or did not have time to assimilate the extremely large load of nutrients from the watershed in the









spring of 1995. The excessive load from the animal waste in one tributary in particular may have altered the relationship. With so much phosphorus available for the chlorophyll, other parameters and physical conditions most likely limited the algae production. Even after removing the summer samples, the relationship is still not as good as in other lakes. The low residence time and the interference from suspended sediment are most likely the cause of low R^2 value.

The relationship between phosphorus and chlorophyll a can be used to estimate a reduction in chlorophyll by reducing inlake phosphorus concentrations. The better the relationship the more confident lake managers can be in the expected results. The data will be used in the reduction response model later in the report. The equation for the line in Figure 36 will be used to predict chlorophyll a from inlake phosphorus concentrations. The line equation is shown below.

$y = 0.4621e^{7.5278x}$ {Equation 3} y = predicted chlorophyll a concentrationx = phosphorus concentration

Fecal Coliform Bacteria

Fecal coliform bacteria are found in the intestinal tract of warm-blooded animals. Fecal coliform bacteria are used as indicators of waste in a waterbody. Many outside factors can influence the concentration of fecal coliform. Sunlight and time seem to lessen fecal concentrations even though the nutrient concentrations remain high. As a general rule, just because fecal bacteria concentrations are low or non-detectable, does not mean animal waste is not present in a waterbody.

Inlake concentrations are typically low because of the exposure to sunlight and the dilution of the bacteria in the large body of water. Of the 100 individual samples collected, 75% of the fecal coliform concentrations were below detection limits (Figure 37). The maximum concentration was collected in a sample on June 12, 1995. This sample may have been the result of the animal waste dumping in tributary Site #6, or from another tributary since there is another peak in June of 1996. The project average for Elm Lake is 12.50 counts/100ml. The fact that the inlake concentrations of fecal coliform are not relatively high, except in a few cases, does not mean that fecal coliform bacteria are not present in Elm Lake as can be seen from the tributary samples entering Elm Lake. Since high nutrient concentrations usually accompany the fecal bacteria counts, controlling animal waste will decrease both fecal concentrations and nutrient concentrations.





Trophic State Index

Carlson's (1977) Trophic State Index (TSI) is an index that can be used to measure the relative trophic state of a waterbody. The trophic state is how much production occurs in the waterbody. The smaller the nutrient concentrations are in a waterbody, the lower the trophic level and the larger the nutrient concentrations the more eutrophic the waterbody. Oligotrophic is the term used to describe the least productive lakes and hyper-eutrophic is the term used to describe lakes with excessive nutrients and production. Table 10 describes the different numeric limits with the various levels of the Carlson Index.

Table 11. Trophic Level Ranges

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

Three different parameters can be used to compare the trophic index of a lake; 1) total phosphorus, 2) Secchi disk, and 3) chlorophyll *a*. The TSI level are shown on Table 11 and a graph showing all of the TSI readings is shown on Figure 38.

Parameter	Chlorophyll a	Total	Saaahi Danth	Parameters
Calculation	Chiorophyn <i>a</i>	Phosphorus	Seccili Deptil	Combined
Mean TSI	51.29	88.22	58.36	66.69
Median TSI	54.92	88.72	64.76	64.76
Standard Deviation	15.78	3.30	10.37	19.34

Table 12. Elm Lake Trophic State.

The mean and median for total phosphorus are far into the hyper-eutrophic level of the index. The Secchi depth and the chlorophyll a are in the eutrophic level. The phosphorus TSI concentrations are another indication of the excessive amounts of nutrients in Elm Lake. The average TSI rating over the entire project was 66.69, slightly over the eutrophic line into hyper-eutrophic.





The relatively lower chlorophyll a TSI ratings are most likely due to wind driven sediments and turbulence keeping the algae from forming blooms and floating mats. From the data collected, there is more than enough phosphorus in Elm Lake to cause nuisance blue green algal blooms. Secchi depths ratings are also relatively low, compared to the phosphorus, but well into the eutrophic range. Since there is not a lot of chlorophyll a, suspended sediments are most likely responsible for raising the Secchi TSI to the eutrophic level.

Long Term Trends

Because there are a number of samples collected from both the Elm Lake Watershed Assessment and the Statewide Lake Assessment (Stueven, 1996), it is possible to make some assumptions about the water quality trends in Elm Lake over time. During the years of the watershed assessment, Elm Lake appears to be flushing out many of its nutrients. Figure 39 shows **Figure 39**.

that all the parameters are improving in water quality. However, since the samples taken from 1989 to 1993 were collected in the summer, the Secchi disk and chlorophyll samples could vary greatly because of seasonal changes. The next graph, Figure 40, was developed displaying only summer samples. As can be seen from this graph. chlorophyll *a* concentrations are showing declining water quality instead of improving, and the Secchi depth measurements do not show as dramatic of an improvement as they do in the previous chart. The improving Secchi depth may be due to improved soil management over the years. Less soil in the water column would mean more chlorophyll production. In addition the winter samples, which were included in the first graph, do not have any suspended sediment because of ice eliminating turbulence from wind. Removing the







winter samples from the graph greatly changed the trend in Secchi depth in the second graph. The improving phosphorus trend graphs are most likely due to the increased concentration of the phosphorus in the drier years of the early 1990's and the diluting of the concentrations in the wetter years of the project, 1995—1996. The graph makes it appear the trend in Elm Lake is for improving water quality, however, this is most likely

due to flushing of nutrients out of the lake and short residense time of the wet years. Even though there has been a decrease in phosphorus over the past years, the overall inlake concentrations are still high enough to cause nuisance algal blooms. The decline in suspended sediment is most likely the cause of the increased Secchi disk measurements over time. If the chlorophyll concentrations continue to increase, the Secchi readings may again become smaller.

Reduction Response Model

Inlake total phosphorus concentrations are a function of the total phosphorus load delivered to the lake by the watershed. Vollenweider and Kerekes (1980) developed a mathematical relationship for inflow of total phosphorus and the inlake total phosphorus concentration. They assumed that if you change the inflow of total phosphorus, you change inlake phosphorus concentration by a relative but steady amount. The variables used in the relationship are:

- 1) $[\overline{P}]\lambda$ = Average inlake total phosphorus concentration
- 2) $[\overline{P}]i$ = Average concentration of total phosphorus that flows into the lake
- 3) $\overline{T}p$ = Average residence time of inlake total phosphorus
- 4) $\overline{T}w$ = Average residence time of lake water

Data collected from 1995 to 1996 provided enough information to estimate $[\overline{P}]\lambda$, $[\overline{P}]i$, and $\overline{T}w$. In order to estimate the residence time of total phosphorus $(\overline{T}p)$ it was necessary to back calculate Equation 4 below, and solve for $\overline{T}p$ by forming Equation 5 (Wittmuss, 1996):

{Equation 4}
$$\left[\overline{P}\right]\lambda = \left[\frac{\overline{T}_p}{\overline{T}_w}\right]\overline{P}_i$$

{Equation 5} $\left(\overline{T}_p\right) = \frac{\overline{P}_i\lambda}{\overline{P}_i}\left(\overline{T}_w\right)$

Values for $[\overline{P}]\lambda$, $[\overline{P}]i$, and $\overline{T}w$ were determined in the following manner:

 $[\overline{P}]\lambda$ was determined by averaging all of the surface total phosphorus samples from 1994 - 1995.

 $[\overline{P}]i$ was determined by adding all of the input loadings for total phosphorus in milligrams and dividing that number by the total number of liters that entered the lake. The values for both of these numbers came from tributaries, un-gauged run-off, groundwater, and the atmosphere.

 $\overline{T}w$ was determined by averaging the total volume of Elm Lake (21,762 acre-feet) by the total outputs of water from the lake (56,535 acre-feet/days of discharge measurements).

$$\overline{T}_{w} = \frac{21,762}{56,535/acre/feet/239} = 92 \ days = 0.25 \ years$$

The final values for $[\overline{P}]\lambda$ and $[\overline{P}]i$ are:

$$[\overline{P}]\lambda = 0.349 \text{ mg/L}$$
 $[\overline{P}]i = 0.322$

By inserting the numbers in the proper places as discussed in Equation 5, \overline{T}_p would be:

$$(\overline{T}p) = \left[\frac{0.349}{0.322}\right](0.25) = 0.27 \text{ years} = 99 \text{ days}$$

Once all factors for the four variables are calculated, certain variables can be changed to show a response of another variable. For our reduction model, the phosphorus residence time (\overline{T}_p) divided by the hydaulic residence time (\overline{T}_w) is a standard coefficient and will not change (1.08). With only one year of sampling, there is no way to estimate the reduction in the retention time of total phosphorus. This leaves two factors; average phosphorus inputs $([\overline{P}]_i)$ and average inlake phosphorus concentration $([\overline{P}]_{\lambda})$. By inserting a reduced value for $[\overline{P}]_i$ in Equation 4, a reduction in inlake phosphorus $([\overline{P}]_{\lambda})$ can be calculated. This is assuming constant inputs of water. Theoretically, the phosphorus retention time should also be reduced. As can be seen in Table 12, a reduction in phosphorus inputs to Elm Lake by 60% will reduce the inlake phosphorus to 0.140 mg/L.

Reduction of	Input	Inlake	Predicted	Phosphorus	Chlorophyll a
Phosphorus	Concentration	Concentration	Chlorophyll a	TSI	TSI
Inputs	Reduction	Reduction	Reduction	Reduction	Reduction
0%	0.322	0.349	6.39	88.62	48.77
10%	0.290	0.314	4.92	87.10	46.19
20%	0.258	0.279	3.78	85.40	43.61
30%	0.225	0.244	2.91	83.48	41.04
40%	0.193	0.209	2.24	81.25	38.46
50%	0.161	0.175	1.72	78.62	35.88
60%	0.129	0.140	1.32	75.40	33.31
70%	0.097	0.105	1.02	71.25	30.73
80%	0.064	0.070	0.78	65.40	28.15
90%	0.032	0.035	0.60	55.40	25.57

Table 13. Effects of Reducing Phosphorus Inputs on TSI

There is typically a relationship between total phosphorus and chlorophyll a. However, because of various chemical and physical factors, the R^2 value for the relationship is approximately 0.38 (1.00 being a perfect relationship and 0.00 being no relation-ship at all). As stated earlier, suspended solids may be preventing the algae from blooming as much as it would in other lakes with similar nutrient concentrations. From the graph in Figure 41 it appears that the chlorophyll a concentration could almost reach the oligotrophic status with a fifty-percent reduction of inlake phosphorus.



Figure 41.

At the same time the phosphorus concentrations would be well above the hyper-eutrophic level. Until the phosphorus to chlorophyll a relationship improves, it is not possible to make an accurate prediction of the resulting reduction in chlorophyll from reducing inlake phosphorus.

Limiting Factor for Chlorophyll Production

For an organism (algae) to survive in a given environment, it must have the necessary nutrients and environment to maintain life and to be able to 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 limiting nutrient for algal growth. However, in many highly eutrophic lakes with an over abundance of phosphorus, nitrogen can become the limiting factor.

In order to determine which nutrient will be the limiting factor, EPA (1980) has suggested a total nitrogen to total phosphorus ratio of 15:1. They also suggest an inorganic nitrogen to dissolved phosphorus ratio of 7:1. If the ratio of nitrogen divided by phosphorus is greater than either 15:1 or 7:1 (for the respective parameters) the waterbody is assumed to be phosphorus limited. A ratio less than the above mentioned ratios assumes the waterbody to be nitrogen limited.

From the following two figures, (Figures 42, 43) Elm Lake is shown to be highly nitrogen limited. The average total nitrogen to total phosphorus ratio in Figure 41 is 1.2 (phosphorus limited at 15) with a very small standard deviation (0.14). The average inorganic nitrogen to total dissolved phosphorus ratio is 0.83 (phosphorus limited at 7.0) with a standard deviation form the mean at 0.66 (Figure 43).









As mentioned in the discussion on nitrogen, blue-green algae can assimilate usable nitrogen from both the organic and inorganic forms of nitrogen. Because the major algae species in Elm Lake is blue green (Stueven, 1996), a graph was produced to see if algae were still nitrogen limited if they were assimilating nitrogen and using the most readily available form of phosphorus (Figure 44). Only in a few cases was the lake phosphorus limited.





Wetzel, 1983, gives general relationships of inorganic and organic nitrogen along with the general trophic level. On only a few occasions were organic and inorganic nitrogen concentrations at the hyper-eutrophic level, and many times the concentrations showed productivity to be in mesotrophic level. However there was no relationship between the nitrogen parameters and the chlorophyll *a* concentrations.

As stated earlier, limiting factors can be anything physical or chemical that limits the growth or production of an organism. Even though nitrogen limitation may be effecting algal growth, other factors such as light blocking sediments are even more limiting than nutrient concentrations. If the suspended sediment concentrations subsided and did not block light, chlorophyll *a* concentrations in Elm Lake would most likely become hyper-eutrophic.

Recommended Targeted Reduction

Nutrient concentrations in Elm Lake are excessive, especially phosphorus. However, due to the light blocking effect of suspended solids, Elm Lake has relatively low chlorophyll *a* production. Typically, a reduction in phosphorus is related to a corresponding reduction in a chlorophyll TSI rating. As shown in Figure 36, there was not a good relationship between phosphorus and chlorophyll *a*. Because of the poor relationship the primary goal for Elm Lake is to move from being nitrogen limited to phosphorus limited. To accomplish this goal, SD DENR is recommending a total nitrogen to total dissolved phosphorus ratio of 7.5. A 60% reduction of the tributary phosphorus load will be needed to reach this goal. After implementing the BMP's needed to reduce phosphorus loads, a post monitoring program will need to be established to see if the goal (N:P > 7.5) has been reached.

This target was established because the AGNPS model estimated a 60% reduction of phosphorus in the watershed by eliminating waste from selected feeding areas. And since the AGNPS model did not include the high nutrient concentrations from the large confined feeding operation, even greater than 60% reduction may be achievable. As can be seen from the following graph, the lake may reach phosphorus limitation by a 60% reduction. Figure 45 shows what the total nitrogen to total dissolved phosphorus ratio would be. The explanation of this ratio can be found in the previous section. Once phosphorus limitation is achieved, a better phosphorus to chlorophyll a relationship may be calculated, and a reduction of chlorophyll a can be predicted.

It is also recommended that an attempt be made to establish shoreline vegetation around the perimeter of Elm Lake. Established littoral vegetation would reduce shoreline erosion, reduce re-suspension of bottom sediments, and provide fishery habitat. It must be remembered however, if sedimentation is reduced, algal growth may increase.

Because the success of the vegetative plantings is not predictable, a targeted amount of sediment reduction will not be included in the report.




Conclusions

AGNPS

The complete AGNPS model can be found in Appendix A.

Watershed/Subwatershed Analysis

The overall sediment load to Elm Lake from the watershed, according to the AGNPS model, is 7.6 acre-feet for a 25 year/24 hour storm event. Six of the primary 16 subwatersheds were targeted as having higher sediment delivery rates. These subwatersheds contributed 58% of the load and occupied only 38% of the watershed. The suspected source of sediment loss is from cropland with poor vegetative cover and slopes greater than 4%. Implementing high residue management or converting the crops to rangeland would reduce the volume of sediment from the watershed.

For a 25-year storm event the model estimated 240 tons of nitrogen entering the lake and 72 tons of phosphorus entering the lake. Four of the 16 primary watersheds had elevated nutrient delivery rates. The model indicates these higher loadings are from animal feeding areas located close to the lake or channelized flow. The four subwatersheds deliver 67% of the nitrogen and 68% of the phosphorus to Elm Lake and make up only 30% of the watershed area.

Feeding Area Evaluation

A total of 53 animal feeding areas were evaluated as part of the AGNPS model. AGNPS ranks the feeding areas on a scale of 0 to 100, with 100 being the worse case. Of these 53, five feeding areas had a ranking between 20 and 60 and five had an AGNPS ranking greater than 60. The AGNPS model was run after removing the 5 feeding areas rated over 60 from the watershed data. With the removal of these five feeding areas, the model estimated a 59% and 60% reduction of phosphorus and nitrogen respectively. With the removal of the five feeding areas between 20 and 60, an estimated additional 3% of phosphorus and 4% of nitrogen could be eliminated.

General Data

Pheasant Lake

Pheasant Lake has relatively low dissolved solids and alkalinity, however nitrogen and phosphorus concentrations are quite high. Primary sources of nutrients are from agricultural land and lake shore development. Pheasant Lake has large a macrophyte population, and at times experiences frequent algae blooms, low dissolved oxygen, and poor water clarity.

Fishery

Elm Lake has had a consistent fishery throughout the years of its existence. In 1991, saugeye were stocked to replace the declining walleye populations. Panfish, northern pike, and catfish numbers are steady but not abundant. Black bullhead populations increased dramatically since 1995. The most likely the large volumes of water from 1993 to 1996 flushed the black bullheads from Pheasant Lake to Elm Lake. There are concerns that the black bullhead population may replace some of the more desired species in the lake. Elm Lake will be managed for saugeye and black crappies.

Shoreline Erosion

Elm Lake has excessive shoreline erosion. The erosion was most likely caused by a combination of the raising and lowering of Elm Lake, and wind and wave action due to the long fetch of the lake. Of the 120 documented shoreline erosion sites, 37 sites were categorized as severe. Even though there are only 37 sites with severe erosion, they make up 79% of the eroded area. Suspended sediment appears to be a limiting factor in Elm Lake. Very little suspended solids are entering the lake through the watershed. Most of the inlake suspended solids appear to be from the shoreline and re-suspended solids from shallow areas along the shoreline.

Tributary Water Quality Sampling

Seasonal Water Quality

Due to heavy flow, the concentrations of nutrients and sediment sampled in the spring were not as high as the fall concentrations in the 1995, sampling season. Fall concentrations most likely were elevated because of nutrients concentrating in the waterways during the dry summer months and not being flushed through the system until fall rainfall events. Spring loadings (March 1, to May 31) made up close to 85% of all the loads for all of the parameters to Elm Lake.

North and South Dakota Water Quality Standards

In North Dakota samples, unionized ammonia concentrations were exceeded in 20 of 52 samples. Fecal coliform standards were exceeded 7 times during the study. Nitrates exceeded the interim guideline 7 times during the study. Phosphorus concentrations exceeded North Dakota's interim guidelines in all but 7 of the 52 samples collected.

There were no sites located in South Dakota which were over the stock watering and wildlife propagation standard. There is only pH, dissolved solids, and alkalinity standards for these beneficial uses and no water quality standards were violated.

<u>Site #1</u>

Site #1 is the main inlet to Elm Lake draining an approximate 60,720 acres. Because the majority of the water passes through Site #1 the majority of nutrient and sediment loads also come through the site. Much of the water that passes through Site #1 comes from the outlet of Pheasant Lake. Due to the algae produced in Pheasant Lake, it is not known what percent of suspended solids sampled at Site #1 were algae or sediment. There is one feeding area in the drainage with a high AGNPS ranking. Other sources of nutrients from the watershed may be from summer long grazing in the riparian areas. Approximately 47% of the suspended solids load passed through Site #1 as well as 23.9% of the phosphorus and 34.4% of the nitrogen.

Site #2

Site # 2 is the second largest drainage in the watershed (46,680 acres). Due to its large size the watershed was broken into four subdrainages (3, 3a, 3b, and 3c). The majority of the drainage for Site #2 is in North Dakota. Compared to other subwatersheds Site #2 has a larger percentage of cropping ground. These croplands may be responsible for higher load of suspended solids entering Elm Lake (23%). Nitrogen and phosphorus loads to Elm Lake were 10.3% and 15% respectively.

Sites #3 and #3a are the subwatersheds with the largest inputs of nutrients to Site #2. Potential sources of nutrients to Site #2 could be nitrogen from over fertilized fields, animal waste, or summer long grazing.

<u>Site #5</u>

The watershed area for Site #5 is approximately 10,840 acres and drains the uppermost part of Mc Pherson County. Although there are areas of high sediment loss as modeled by AGNPS, the overall suspended solids were fairly low in Site #5 (5.4%). The nitrogen and phosphorus concentrations were fairly high at Site #5. The percent loadings to Elm Lake for nitrogen and phosphorus were 8.1% and 10.5% respectively. Sources of the nutrients are most likely animal waste from feeding areas or summer long grazing.

Site #6 and #6a

Site #6 drains approximately 12,040 acres of Mc Pherson County. Phosphorus loads through Site #6 were approximately 23% of the total load to Elm Lake. Site #6a was placed up stream of Site #6 to help isolate and target the nutrient load. Phosphorus and ammonia concentrations at Site #6a were extremely high. Of the six phosphorus samples collected at Site #6a in 1996, three had concentrations over 2.0 mg/L. A large confined feeding operation is the only documented animal feeding site above Site #6a. Even though the operation has animal waste storage pits, fecal coliform colonies are still found in most of the samples. Nutrient management is the most likely cause of the high nutrient concentrations at Site #6a. Of the three other animal feeding operations between Site #6

and #6a, all have an AGNPS raking of 0. The nutrients that pass through Site #6a appear to make it to Site #6 and most likely to Elm Lake. The total load of ammonia to Elm Lake from Site #6 was 63.4%. The phosphorus load to Elm Lake through Site #6 was 23.3%. Management of the waste at Site #6 could reduce the nutrient loads to Elm Lake by 20 - 25%.

<u>Site #7</u>

Site #7 drains approximately 11,640 acres of the southern part of Elm Lake's watershed. Approximately 75% of this watershed is grazed. The loadings of suspended solids and nutrients from this subwatershed are the lowest of any draining to Elm Lake (0.4%). Nutrient loadings to Elm Lake were also low at Site #7. The loading of nitrogen was approximately 0.7% and the loading of phosphorus was approximately 1.3%. There were some fecal coliform colonies detected in some of the samples at Site #7 that probably came from cattle grazing in the riparian areas. Better summer grazing management could further reduce nitrogen and phosphorus loads to Elm Lake.

Hydrologic and Nutrient Loads

Overall suspended sediment load to Elm Lake is low from data collected in the 1995 sampling season. Approximately one acre-foot of sediment was calculated as entering the lake. Approximately 0.4 acre-feet were calculated as leaving through the outlet of Elm Lake. The following table below summarizes the loading to or out of Elm Lake in the 1995 sampling season.

Nitrogen appears to be accumulating in Elm Lake. The total phosphorus loads to Elm Lake are more than enough for nuisance algal blooms and unless the loadings are reduced, Elm Lake will remain in a hyper eutrophic condition.

Parameter	Total Inputs	Total Outputs	Left in Elm Lake		Removed from Elm Lake	
	(Tons)	(Tons)	Tons	%	Tons	%
Suspended Solids	2,661.0	1,218.0	1,443.0	54.2		
Ammonia	20.4	3.4	17.0	83.3		
Organic-N	81.0	60.7	20.3	25.1		
Nitrate-Nitrite	31.9	28.1	3.8	11.9		
Total Nitrogen	141.7	92.1	49.6	35.0		
Total Phosphorus	24.8	25.4			0.6	2.4
Total Diss. Phos.	18.3	20.1			1.8	9.8

Table 14. Loadings to Elm Lake

Inlake

Elm Lake is a well mixed lake with very little difference in surface and bottom samples. Oxygen levels are sufficient through the water column and temperatures do not rise to were fish would be impacted. Suspended sediment levels in Elm Lake are not excessively high, however, they appear to be one of the main factors in limiting the algal blooms. The particles may be colloidal, and small enough that the volume is not well expressed in milligrams per liter, yet the concentration is large enough to block sunlight.

The average ammonia concentration in Elm Lake was 0.04 mg/L with the highest concentrations found in the summer. The average concentration of nitrate-nitrite was 0.19 mg/L. The average total phosphorus concentration in Elm Lake was 0.349 mg/L. The phosphorus concentration is high enough to produce large algal blooms if favorable conditions exist.

Chlorophyll a concentrations are relatively low with respect to the nutrient concentrations found in Elm Lake. When high nutrient concentrations are found in other lakes algal blooms persist throughout the summer months and many times in the winter. The production of chlorophyll a in Elm Lake is either limited by lack of nitrogen or more likely light blocking sediments.

Fecal coliform bacteria counts were below detection limits in 75% of the samples. Fecal coliform is not often found in lake samples, however samples collected in June and August of 1995, found fecal coliform concentrations were above 100 mg/L.

Trophic State Index

The average TSI in Elm Lake was 66.69 ranking Elm Lake as eutrophic. However, there was quite a large range for the three parameters used to calculate TSI. The average chlorophyll a TSI was 51.29 (lower eutrophic), the average phosphorus TSI was 88.22 (hyper eutrophic), and the average Secchi disk TSI was 58.36 (eutrophic). It appears that the suspended sediments are blocking chlorophyll a production even through there is plenty of phosphorus for nuisance algal blooms.

Long Term Trends

The long-term trends in Elm Lake from 1989 to 1996 appear to be improving. The late 1980's were drought years and nutrients may have been concentrated in lakes. The wet year of 1993 - 1996 may have flushed many of the nutrients out of the lake and thus trends seem to be improving. When summer samples alone were compared, the lake seemed to be improving in Secchi depth and phosphorus concentrations, however, the trend for chlorophyll *a* showed declining water quality.

Reduction Response Model

To accurately calculate a reduction response model there needs to be a good relationship between phosphorus and chlorophyll a concentrations. Due to the limiting factor of the nitrogen or the suspended solids, a good relationship could not be reached, so the information from the model may be suspect. However, from the data collected during the project, a 50% reduction in phosphorus inputs to the lake would reduce chlorophyll a concentrations to mesotrophic.

Limiting Factor for Chlorophyll a Production

Due to the high phosphorus concentrations and the low nitrogen concentrations, Elm Lake is nitrogen limited. However, the suspended solids blocking light needed for photosynthesis may be more limiting than the lack of nitrogen. Many times, when samples were collected on windy day with high turbidity, chlorophyll *a* concentrations were low. Nitrogen concentrations on these occasions were high enough to promote an algal bloom.

Recommended Targeted Reduction

It is recommended that a target of 60% reduction in phosphorus inputs to Elm Lake be reached. The 60% reduction will most likely make Elm Lake phosphorus limited. After phosphorus limitation has been reached, sampling should be conducted to see if a better phosphorus to chlorophyll a relationship can be reached. If the relationship improves, a new target should be set to remove lower chlorophyll a production.

Recommendations

According to the water quality data and the AGNPS model, animal feeding areas are the most likely source of nutrients to Elm Lake. It is recommended that the five feeding areas with AGNPS ratings greater than 60 have animal waste systems constructed to eliminate nutrient and sediment run-off. Also, the animal waste from the large confined animal feeding area above Site #6 should be controlled. The feeding areas with AGNPS rankings between 20 and 60 should be field checked and considered for animal waste systems.

It is also recommended that the croplands targeted by the AGNPS model with slopes greater than 4% and high soil erodibility be field checked and if needed, Best Management Practices applied.

Even though no target of improvement is set for turbidity, an attempt should be made to establish shoreline vegetation around Elm Lake. The shoreline vegetation would reduce shoreline erosion, reduce re-suspension of bottom sediments, and provide better fish habitat. Managers should be reminded that the improved light penetration in Elm Lake would most likely cause an increase in algal production until inlake nutrient concentrations are reduced.

It is also recommended that an extensive watershed assessment be completed on the Pheasant Lake watershed. After completing the watershed assessment, targets should be set for lowering phosphorus in Pheasant Lake. The two implementation projects could then be combined as one project.

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Appendix A

Agricultural Non-Point Source Model (AGNPS) Appendix D

Elm Lake Inlake Data

Appendix E

Elm Lake Tributary Data

Appendix F

Elm Lake QA/QC Data



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