Oklahoma Water Resources Board

Water Quality Evaluation of the Eucha/Spavinaw Lake System

February 2002

Table of Contents

TABLE OF CONTENTS .... **II**

LIST OF FIGURES .... **V**

LIST OF TABLES .... **VII**

ACKNOWLEDGEMENT .... **IX**

ACRONYMS AND ABBREVIATIONS .... **XI**

EXECUTIVE SUMMARY **1**

GOALS AND OBJECTIVES 1
STUDY DESCRIPTION 1
STUDY RESULTS 1
Current Status of Lake Eucha and Spavinaw Lake *1*
Lake Phosphorus Budgets *2*
Modeling of Phosphorus and Chlorophyll-a *3*
The Algae Community and Drinking Water Taste and Odor *4*
LAKE MANAGEMENT OPTIONS AND RECOMMENDATIONS 6
Evaluation of Lake Management Options *6*
Recommendations *8*

INTRODUCTION **10**

HISTORICAL DATA **12**

HISTORY OF TULSA POTABLE WATER SUPPLY SYSTEM 12
HISTORICAL DATA SUMMARY 13

HYDROLOGY **15**

LAKE BATHYMETRY 17
Methods *17*
Results *17*
HYDRAULIC BUDGET 22
TRIBUTARY WATER QUANTITY AND QUALITY 23
Baseline Model *24*
Calibration *24*
Period of Record *25*
Flow Calibration Results *25*
GROUNDWATER 27

CURRENT LIMNOLOGY **30**

OVERVIEW 30
DATA SUMMARY 31
Water Quality of Spavinaw Lake and Lake Yahola *40*
Spatial and Temporal Evaluation *43*
Temperature and Dissolved Oxygen *46*
BIOLOGICAL EVALUATION 65
Water Transparency *66*
Trophic State Indices *70*
Phytoplankton, Zooplankton, and Taste and Odor chemicals *82*

Potential Algae Control Options ... *92*
Aquatic Macrophytes ... *94*
Sediment Phosphorus Load ... *101*

WATER QUALITY MODELING ... **106**

NUTRIENT BUDGET ... 106
Lake Eucha ... *106*
Spavinaw Lake ... *108*
LAKE MODELING ... 111
Lake Load Models ... *112*
In-Lake Modeling ... *116*
Predictive Results ... *119*
NUTRIENT GOAL SETTING ... 123
Oklahoma Water Quality Standards ... *123*
Nutrient Reduction Goal ... *124*

RECOMMENDATIONS ... **127**

INTRODUCTION ... 127
PHOSPHORUS LOADING GOALS ... 127
IN-LAKE NUTRIENT REDUCTION ALTERNATIVES ... 128
Water Level Drawdown ... *128*
Aeration ... *129*
Chemical treatment ... *130*
Biological ... *131*
Watershed Management ... *132*
FUTURE CONSIDERATIONS ... 132
Lake Management Options ... *132*
Water Quantity ... *133*
Water Quality ... *133*
Sample Frequency ... *134*
Data Evaluation ... *135*

COMMUNITY INVOLVEMENT AND OKLAHOMA WATER WATCH ... **137**

REFERENCES ... **139**

APPENDIX A: HISTORICAL DATA ... **143**

HISTORICAL DATA ... 144
LAKE EUCHA ... 144
Physical/Chemical ... *144*
Trophic State ... *151*
SPAVINAW LAKE ... 156
Physical /Chemical ... *157*
Trophic State ... *162*
HISTORICAL DATA SUMMARY ... 166
REFERENCES ... 167

APPENDIX B: BATHYMETRY ... **168**

GIS PROCEDURES FOR LAKE SPAVINAW BATHYMETRIC MAPPING ... 169
GIS PROCEDURES FOR LAKE EUCHA BATHYMETRIC MAPPING ... 185
GPS PROCEDURES ... 201

APPENDIX C: HYDRAULIC BUDGETING ... **203**

INTRODUCTION ... 204
GROUNDWATER ... 205
SURFACE RUNOFF ... 206

EVAPORATION 207
TRANSPIRATION 207
SEEPAGE 208
WATER RELEASES 209
WATER SUPPLY 210
CHANGE IN LAKE VOLUME 210
RESULTS 211
RECOMMENDATIONS TO REDUCE FUTURE ERROR 217
APPENDICES 219

APPENDIX D: GROUNDWATER 245

INTRODUCTION 247
HYDROGEOLOGY 247
GROUNDWATER FLOW 252
WATER QUALITY 260
STATISTICAL ANALYSIS 266
DISCUSSION AND RECOMMENDATIONS FOR FURTHER STUDY 272
SUMMARY 273

APPENDIX E: SEDIMENT PHOSPHORUS LOAD 282

APPENDIX F: BATHTUB 295

APPENDIX G: ALGAE/ZOOPLANKTON 390

METHODOLOGY 392
CHLOROPHYLL A AND TSI 451
TOTAL ZOOPLANKTON ABUNDANCES AND BIOMASS 456
ZOOPLANKTON GROUP ABUNDANCE AND BIOMASS TOTALS 460
ZOOPLANKTON SPECIES ABUNDANCES 474
DISCUSSION AND CONCLUSIONS 509

List of Figures

FIGURE 2-1 GRAPHIC REPRESENTATION OF THE LAND USAGE OF THE EUCHA/SPAVINAW WATERSHED 13

FIGURE 3-1 MONTHLY RAINFALL TOTALS FROM LAKE EUCHA DAM (APRIL 1998—MARCH 2000) COMPARED AGAINST THE 50-YEAR MEAN (PERIOD OF RECORD). 16
FIGURE 3-2 MONTHLY RAINFALL TOTALS FROM SPAVINAW LAKE DAM (APRIL 1998—MARCH 1999) COMPARED AGAINST THE 66-YEAR MEAN (PERIOD OF RECORD........ 16
FIGURE 3-3 LAKE EUCHA BATHYMETRIC MAP INCLUDING WATER QUALITY, SEDIMENT, AND AQUATIC PLANT SAMPLE SITES........ 20
FIGURE 3-4 SPAVINAW LAKE BATHYMETRIC MAP INCLUDING WATER QUALITY, SEDIMENT, AND AQUATIC PLANT SAMPLE SITES. 21
FIGURE 3-5 AREAS OF THE EUCHA/SPAVINAW BASIN........ 25
FIGURE 3-6 OBSERVED AND SIMULATED FLOW AT SPAVINAW GAUGE STATION. 26
FIGURE 3-7 MAP OF GROUNDWATER INVESTIGATION RESULTS 29

FIGURE 4-1 TIME VERSUS DEPTH ISOPLETHS OF LAKE EUCHA AT THE DAM MARCH 10, 1992 - FEBRUARY 16, 1993........ 45
FIGURE 4-2 LAKE EUCHA PROFILE: SITE 1, AUGUST 25, 1993 (OCC) 46
FIGURE 4-3 LAKE EUCHA TEMPERATURE APRIL 1998-MARCH 2000 48
FIGURE 4-4 SPAVINAW LAKE TEMPERATURE APRIL 1998-MARCH 2000........ 49
FIGURE 4-5 LAKE EUCHA DISSOLVED OXYGEN APRIL 1998-MARCH 2000. 50
FIGURE 4-6 SPAVINAW LAKE DISSOLVED OYGEN APRIL 1998-MARCH 2000. 51
FIGURE 4-7 LAKE EUCHA DISSOLVED OXYGEN PERCENT SATURATION APRIL 1998-MARCH 2000. 52
FIGURE 4-8 SPAVINAW LAKE DISSOLVED OXYGEN PERCENT SATURATION APRIL 1998-MARCH 2000. 53
FIGURE 4-9 LAKE EUCHA REDOX POTENTIAL APRIL 1998-MARCH 2000........ 54
FIGURE 4-10 SPAVINAW LAKE REDOX POTENTIAL APRIL 1998-MARCH 2000........ 55
FIGURE 4-11 MEAN PHOSPHORUS CONCENTRATIONS IN LAKE EUCHA APRIL 1998-MARCH 2000........ 56
FIGURE 4-12 LAKE EUCHA SITE 1 PHOSPHORUS ISOPLETHS APRIL 1998-MARCH2000........ 57
FIGURE 4-13 SPAVINAW LAKE SITE 1 PHOSPHORUS ISOPLETHS APRIL 1998-MARCH 2000........ 58
FIGURE 4-14 MEAN NITROGEN CONCENTRATIONS IN LAKE EUCHA APRIL 1998-MARCH 2000. 59
FIGURE 4-15 LAKE EUCHA SITE 1 NITROGEN ISOPLETHS APRIL 1998-MARCH 2000. 60
FIGURE 4-16 SPAVINAW LAKE SITE 1 NITROGEN ISOPLETHS APRIL 1998-MARCH 2000. 61
FIGURE 4-17. MEAN SILICA CONCENTRATIONS IN LAKE EUCHA APRIL 1998-MARCH 2000 63
FIGURE 4-18 LAKE EUCHA DISSOLVED SILICA CONCENTRATION APRIL 1998-MARCH 2000........ 63
FIGURE 4-19 SPAVINAW LAKE DISSOLVED SILICA CONCENTRATION APRIL 1998-MARCH 2000. 64
FIGURE 4-20 LAKE EUCHA CALCULATED TOTAL N/TOTAL P RATIO APRIL 1998-MARCH 2000........ 64
FIGURE 4-21 SPAVINAW LAKE CALCULATED TOTAL N/TOTAL P RATIO APRIL 1998-MARCH 2000........ 65
FIGURE 4-22 MEAN SECCHI DEPTH AT LAKE EUCHA FROM APRIL 1998 THROUGH MARCH 2000. 66
FIGURE 4-23 MEAN CHLOROPHYLL-A CONCENTRATIONS AS µG/L IN LAKE EUCHA APRIL 1998-MARCH 2000........ 67
FIGURE 4-24 MEAN SEASONAL SECCHI DEPTH AT THE LACUSTRINE SITES AT LAKE EUCHA DURING THE COURSE OF THE STUDY........ 67
FIGURE 4-25 MEAN SEASONAL CHLOROPHYLL-A CONCENTRATIONS AT THE LACUSTRINE SITES AT LAKE EUCHA DURING THE COURSE OF THE STUDY........ 68
FIGURE 4-26 LINEAR REGRESSION OF CHLOROPHYLL-A CONCENTRATION VERSUS TURBIDITY AT LAKE EUCHA. 68
FIGURE 4-27 MEAN SEASONAL SECCHI DEPTH AT THE LACUSTRINE SAMPLE SITES IN LAKE SPAVINAW DURING THE COURSE OF THE STUDY........ 69
FIGURE 4-28 MEAN CHLOROPHYLL-A CONCENTRATIONS AT THE LACUSTRINE SAMPLE SITES IN LAKE SPAVINAW DURING THE COURSE OF THE STUDY. 69
FIGURE 4-29 LINEAR REGRESSION OF CHLOROPHYLL-A CONCENTRATION VERSUS SECCHI DEPTH IN LAKE SPAVINAW........ 70

FIGURE 4-30 COMPARISON OF EUCHA LAKE TROPHIC STATE FOR WATER YEAR 1998. 72
FIGURE 4-31 COMPARISON OF EUCHA LAKE TROPHIC STATE FOR WATER YEAR 1999. 73
FIGURE 4-32 COMPARISON OF EUCHA LAKE TSI BY SITE FOR WATER YEAR 1998. 74
FIGURE 4-33 COMPARISON OF EUCHA LAKE TSI BY SITE FOR WATER YEAR 1999. 75
FIGURE 4-34 EUCHA LAKE RIVERINE ZONE TSI FOR MONITOR YEARS 1998 AND 1999. 76
FIGURE 4-35 EUCHA LAKE TRANSITION ZONE TSI FOR MONITOR YEARS 1998 AND 1999. 76
FIGURE 4-36 EUCHA LAKE LACUSTRINE ZONE TSI FOR MONITOR YEARS. 77
FIGURE 4-37 COMPARISON OF SPAVINAW LAKE TROPHIC STATE FOR WATER YEAR 1998. 78
FIGURE 4-38 COMPARISON OF SPAVINAW LAKE TROPHIC STATE FOR WATER YEAR 1999. 78
FIGURE 4-39 COMPARISON OF SPAVINAW LAKE TSI BY SITE FOR WATER YEAR 1998. 79
FIGURE 4-40 COMPARISON OF SPAVINAW LAKE TSI BY SITE FOR WATER YEAR 1999. 80
FIGURE 4-41 SPAVINAW LAKE TRANSITION ZONE TSI BY MONITOR YEARS 1998 AND 1999 81
FIGURE 4-42 SPAVINAW LAKE LACUSTRINE ZONE TSI BY MONITOR YEARS 1998 AND 1999. 81
FIGURE 4-43 *CYLINDROSPERMOPSIS RACIBORSKI*, PHOTOGRAPHS TAKEN AT 400X, UNDER PHASE OPTICS. 82
FIGURE 4-44 *ANABAENA FLOS-AQUAE*, PHOTOGRAPH TAKEN AT 200X, UNDER PHASE OPTICS.. 83
FIGURE 4-45 *STEPHANODISCUS NIAGARE*, PHOTOGRAPH TAKEN AT 400X, UNDER PHASE OPTICS 83
FIGURE 4-46 *MELOSIRA ITALICA*, PHOTOGRAPH TAKEN AT 400X, UNDER PHASE OPTICS 84
FIGURE 4-47 ALGAE COMMUNITY ABUNDANCE BIOVOLUME FOR EUCHA AND SPAVINAW (DAM). 85
FIGURE 4-48 RATIO OF CALANOIDS TO CLADOCERANS AND CYCLOPOIDS 88
FIGURE 4-49 TASTE AND ODOR SPECIES, SPAVINAW LAKE. 90
FIGURE 4-50 TASTE AND ODOR SPECIES, EUCHA LAKE 91
FIGURE 4-51 CUSTOMER COMPLAINTS, MOHAWK. 91
FIGURE 4-52 HYPOLIMNETIC IRON AND SULFIDE CONCENTRATIONS FOR EUCHA AND SPAVINAW 100

FIGURE 5-1. COMPARISON OF LAKE EUCHA INFLOW TO RESIDENT PHOSPHORUS MASS APRIL 1998–MARCH 2000. 107

FIGURE 6-2. OWW VOLUNTEER MONITORING SAMPLE SITES KANSAS PUBLIC SCHOOLS 138

List of Tables

TABLE ES-1 RELATIVE DOMINANCE OF POTENTIAL TASTE AND ODOR PRODUCING ALGAE AND THEIR RELATION TO TASTE AND ODOR EVENTS. 5

TABLE 3-1 COMPARISON OF ANNUAL RAINFALL (INCHES) RECORD TO 66-YEAR AVERAGE (APRIL-MARCH) FOR LAKES EUCHA AND SPAVINAW. 15
TABLE 3-2 SUMMARY OF LAKE EUCHA AND SPAVINAW LAKE MORPHOMETRIC FEATURES. 17
TABLE 3-3 TABULAR SUMMARY OF AREA AND CAPACITY VERSUS DEPTH FOR LAKES EUCHA AND SPAVINAW. 18
TABLE 3-4 COMPARISON OF MORPHOLOGIC FEATURES OVER TIME WITH ESTIMATED SEDIMENTATION RATES FOR LAKES EUCHA AND SPAVINAW. 18
TABLE 3-5 INFLOW SOURCES AS PERCENT OF TOTAL FOR LAKES EUCHA AND SPAVINAW. 23
TABLE 3-6 IMMEDIATE GROUNDWATER AND SURFACE WATER DRAINAGE AREAS (ACRES) FOR LAKES EUCHA AND SPAVINAW 23
TABLE 3-7 MAJOR OUTFLOW SOURCES AS A PERCENT OF TOTAL FOR LAKES EUCHA AND SPAVINAW 23
TABLE 3-8 ANNUAL (APRIL-MARCH) RESULTS OF HYDRAULIC RESIDENCE CALCULATIONS FOR LAKES EUCHA AND SPAVINAW 23
TABLE 3-9 AVERAGE MONTHLY FLOW COMPARISONS (M^3/S) FOR BLACK HOLLOW, SPAVINAW, AND BEATY GAUGE STATIONS 25
TABLE 3-10 OBSERVED AND SWAT PREDICTED LOADING TO LAKE EUCHA. 27

TABLE 4-1 EPILIMNETIC, METALIMNETIC, AND HYPOLIMNETIC DEPTHS (IN METERS) OF LAKE EUCHA DURING STRATIFICATION IN 1998 AND 1999. 32
TABLE 4-2 EPILIMNETIC, METALIMNETIC, AND HYPOLIMNETIC DEPTHS (IN METERS) OF SPAVINAW LAKE DURING STRATIFICATION IN 1998 AND 1999. 33
TABLE 4-3 STATISTICAL SUMMARY OF WATER QUALITY FOR LAKE EUCHA FROM APRIL 14, 1998 THROUGH MARCH 9, 2000 DURING ISOTHERMAL OR COMPLETELY MIXED LAKE CONDITIONS. 34
TABLE 4-4 STATISTICAL SUMMARY OF WATER QUALITY FOR LAKE EUCHA EPILIMNION FROM APRIL 14, 1998 THROUGH MARCH 9, 2000 DURING STRATIFICATION. 35
TABLE 4-5 STATISTICAL SUMMARY OF WATER QUALITY FOR LAKE EUCHA METALIMNION AND HYPOLIMNION FROM APRIL 14, 1998 THROUGH MARCH 9, 2000 DURING STRATIFICATION. 36
TABLE 4-6 STATISTICAL SUMMARY OF WATER QUALITY FOR SPAVINAW LAKE FROM APRIL 16, 1998 THROUGH MARCH 7, 2000 DURING ISOTHERMAL OR COMPLETELY MIXED LAKE CONDITIONS. 37
TABLE 4-7 STATISTICAL SUMMARY OF WATER QUALITY FOR SPAVINAW LAKE EPILIMNION FROM APRIL 16, 1998 THROUGH MARCH 7, 2000 DURING STRATIFICATION. 38
TABLE 4-8 STATISTICAL SUMMARY OF WATER QUALITY FOR SPAVINAW LAKE METALIMNION AND HYPOLIMNION FROM APRIL 16, 1998 THROUGH MARCH 7, 2000 DURING STRATIFICATION. 39
TABLE 4-9 STATISTICAL SUMMARY OF WATER QUALITY FOR LAKE YAHOLA FOR THE MONTHS OF JUNE 1998 - MARCH 2000. 40
TABLE 4-10 STATISTICAL SUMMARY OF WATER QUALITY PARAMETERS OF SPAVINAW LAKE SITE 1, DEPTHS 3-7 METERS FOR PAIRED COMPARISON TO LAKE YAHOLA SAMPLE RESULTS. 41
TABLE 4-11 STATISTICAL SUMMARY OF WATER QUALITY OF LAKE YAHOLA FOR PAIRED COMPARISON TO SPAVINAW LAKE SAMPLE RESULTS. 42
TABLE 4-12 RESULTS OF T-TEST ON PAIRED COMPARISON OF WATER QUALITY PARAMETERS: SPAVINAW LAKE VERSES LAKE YAHOLA.. 43
TABLE 4-13: RELATIVE DOMINANCE OF POTENTIAL TASTE AND ODOR PRODUCING ALGAE AND THEIR RELATION TO TASTE ODOR EVENTS. 93
TABLE 4-14 ESTIMATED NUTRIENT CONTENT IN KILOGRAMS AND AS A PERCENTAGE OF THE TOTAL BY PLANT GENUS FOR LAKE EUCHA JULY 1998 AND 1999. 95
TABLE 4-15 ESTIMATED NUTRIENT CONTENT IN KILOGRAMS AND AS A PERCENTAGE OF THE TOTAL BY PLANT GENUS FOR SPAVINAW LAKE JULY 1998 AND 1999. 96
TABLE 4-16. LAKE SEDIMENT ANALYSIS OF FEBRUARY 16, 1999, SAMPLES. 97

TABLE 4-17 LOOSELY SORBED (SOLUBLE) PHOSPHORUS CONTENT IN MG/L, FEBRUARY 16, 1999. 98
TABLE 4-18 PHOSPHORUS SORPTION INDEX VALUES FOR SAMPLED LAKE SEDIMENT, FEBRUARY 16, 1999. 98
TABLE 4-19 CALCULATED RATE (M_S) OF HYPOLIMNETIC SEDIMENT PHOSPHORUS RELEASE DURING STRATIFICATION IN MG/M^2-DAY. 101
TABLE 4-20 ESTIMATED HYPOLIMNETIC SEDIMENT PHOSPHORUS RELEASE DURING STRATIFICATION.. 102
TABLE 4-21 INTERNAL PHOSPHORUS LOAD ESTIMATES FOR LAKE EUCHA AND LAKE SPAVINAW......... 102
TABLE 4-22 ENTRAINMENT OF PHOSPHOROUS MASS FOR LAKE EUCHA AND SPAVINAW LAKE............ 103
TABLE 4-23 SEDIMENT DERIVED PHOSPHOROUS LOAD ESTIMATION FOR LAKE EUCHA DURING 1998-1999 STRATIFICATION SEASON. 103
TABLE 4-24 SEDIMENT DERIVED PHOSPHOROUS LOAD ESTIMATION FOR LAKE SPAVINAW DURING 1998-1999 STRATIFICATION SEASON. 104

TABLE 5-1 LAKE EUCHA ITEMIZED ANNUAL PHOSPHORUS LOAD. 106
TABLE 5-2. LAKE EUCHA ITEMIZED MONTHLY PHOSPHORUS BUDGET IN KILOGRAMS. 107
TABLE 5-3 SPAVINAW LAKE ITEMIZED ANNUAL PHOSPHORUS LOAD. 109
TABLE 5-4 SPAVINAW LAKE ITEMIZED MONTHLY PHOSPHORUS BUDGET IN KILOGRAMS. 110
TABLE 5-5 LAKE EUCHA AND SPAVINAW LAKE BACKGROUND PHOSPHORUS CONCENTRATION.......... 110
TABLE 5-6 AVERAGE ANNUAL BACKGROUND PHOSPHORUS INFLOWS (IN KILOGRAMS)..... 113
TABLE 5-7 EUCHA AND SPAVINAW LAKE RESPONSE TO BACKGROUND ESTIMATED TOTAL-PHOSPHOROUS LOADING USING THE OECD MODEL. 113
TABLE 5-8 OECD PREDICTED LAKE TP CONCENTRATION AND TROPHIC STATE BASED ON CURRENT INFLOW LOAD ESTIMATES. 114
TABLE 5-9 MORPHOLOGY FEATURES OF WATER QUALITY RESEVOIR ZONES. 1107
TABLE 5-10 COMPARISON OF EUCHA LAKE ANNUAL PHOSPHORUS BUDGETS..... 118
TABLE 5-11 COMPARISON OF SPAVINAW LAKE ANNUALIZED PHOSPHORUS BUDGET. 119
TABLE 5-12 COMPARISON OF EUCHA LAKE PHOSPHORUS BUDGETS. 119
TABLE 5-13 COMPARISON OF SPAVINAW LAKE PHOSPHORUS BUDGET. 120
TABLE 5-14 BATHTUB PREDICTED EUCHA LAKE QUALITY WITH ITEMIZED NUTRIENT INPUTS. 120
TABLE 5-15 PREDICTED SPAVINAW LAKE RAW WATER QUALITY BASED ON VARYING INFLOW QUALITY.121
TABLE 5-16 LEVELS OF ALGAE MANAGEMENT WITH ASSOCIATED PHOSPHORUS CONCENTRATION AND LOAD. 124

Acknowledgement

This report is the final product under contract # TMUA 97-17 funded by the Tulsa Metropolitan Utility Authority through 1998 Capital Improvements Program project "Water Quality Plan". The Oklahoma Water Resources Board (OWRB) provided a 50% cost share to complete this project. Specific contacts for the OWRB project were as follows: Marsha Slaughter for the Tulsa Metropolitan Utility Authority, Richard Smith for the Indian Nations Council of Governments (INCOG) and Paul Koenig for the OWRB. Tulsa Metropolitan Utility Authority provided routine field sampling, served as the primary laboratory for analysis, and performed data quality assurance. In addition, they maintain environmental records related to this project. The Monitoring/Assessment/Evaluation (MAE) Workgroup, formed through the Indian Nations Council of Governments (INCOG), provided project oversight and coordination with other contracted projects in the Spavinaw Creek basin. OWRB provided technical guidance and oversight, specialized field sampling, data assessment, data evaluation, and document preparation. Within each of these primary organizations many other groups and individuals were critical to the success of the project.

The USGS provided instantaneous flow measurements for three sites in the basin through contractual agreements with the Tulsa Metropolitan Utility Authority. Oklahoma State University (OSU) Biosystems and Agricultural Engineering Department on contract to the Tulsa Metropolitan Utility Authority performed Spavinaw Creek watershed evaluation. CH2M Hill and Exponent provided technical comments. CH2M Hill also provided preliminary report editing and finalization under contract to the Tulsa Metropolitan Utility Authority. Many Tulsa staff members were instrumental in the completion of this project. Harry Chichester, Jerry Youngblood, and Bill Rainwater deserve much of the credit. These "fishheads" provided routine field sampling, data review, and good humor throughout the entire effort. Ken Burman provided laboratory oversight for the Tulsa Metropolitan Utility Authority while Bill Orric directed analysis and reporting. Steve Minor served as the Quality Assurance Officer for the Tulsa Metropolitan Utility Authority. Al Komarek provided data compilation and reporting for Tulsa Metropolitan Utility Authority.

OWRB contracted with the City County Health Department of Oklahoma County (CCHDOC) for specialized laboratory services such as chlorophyll-a, aquatic plant, and sediment analyses. Warm gratitude is extended to the hard-working individuals from the 3rd floor of the CCHDOC. BSA Incorporated was contracted by the OWRB to provide zooplankton identification and enumeration. Phycotech was contracted to provide algae identification and enumeration. Phycotech also performed data evaluation and reporting of the zooplankton, algae, and taste and odor data. OWRB specialized field sampling has largely been the collective effort of Scott Carlton, Jason Post, Juli Ridgway, Tony Mensah, Mike Suhgru, and Paul Koenig. The fishheads - Bill Rainwater, Jerry Youngblood, and Harry Chichester - provided assistance during many specialized field sample events. OWRB employees instructive in data analysis, data evaluation, and data reporting were Jay Hua, Tony Mensah, Michelle Scheuler, Ken Del Regno, Larry Sullivan, Scott Carlton, Juli Ridgway, Mike Sughru, and Allyson Childress. Numerous other employees of the OWRB assisted over the course of this 3-½ year project.

The OWRB appreciates the gracious manner and actions of the Tulsa Metropolitian Utility Authority Lake Eucha Office. A special appreciation is due Dr. Bert Fisher of Exponent for his dogged pursuit of fact and insightful perspective throughout the project. A special “thank you” is extended to Dr. David Stites and Jean Koch of CH2M Hill for David’s invaluable input and Jean’s meticulous attention to detail. Special appreciation is also due Patsy Bragg, Richard Sevenoaks, Marsha Slaughter, Richard Smith, and Derek Smithee for their efforts to “patch the rough spots in the road” that developed over the seasons of this project.

Acronyms and Abbreviations

ANOVA	Analysis of variance
BDL	Below laboratory detection limits
CCHDOC	City County Health Department of Oklahoma County
DEM	Digital event marker
DO	Dissolved oxygen
GAP	General area plot
GIS	Geographic Information System
GPS	Global Positioning System
HRU	Hydraulic Response Unit
INCOG	Indian Nations Council of Governments
LWQA	Lake Water Quality Assessment Program
MAE	Monitoring/Assessment/Evaluation
MEI	Morphoedaphic Index
MGD	Million gallons per day
NH_4^+	Ammonia
NLW	Nutrient-Limited Watersheds
NO_2	Nitrite
NO_3	Nitrate
NO_x	Nitrate+nitrite nitrogen
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NWS	National Weather Service
OECD	Organization for Economic Cooperation and Development
OSU	Oklahoma State University Biosystems and Agricultural Engineering Department
OWQS	Oklahoma Water Quality Standards
OWRB	Oklahoma Water Resources Board
OWW	Oklahoma Water Watch
PSI	Phosphorus sorption index
QA	Quality assurance
QAPP	Quality Assurance Project Plan
SCS	Soil Conservation Service
SRP or DOP	Dissolved orthophosphorus
SWAT	Soil and Water Assessment Tool
TKN	Total kjeldahl nitrogen
TMDL	Total maximum daily load
TMUA	Tulsa Municipal Utility Authority
TP	Total phosphorus
USGS	United States Geological Survey

Executive Summary

Goals and Objectives

The primary goals of this study were to evaluate the water quality of the Lake Eucha/Spavinaw/Yahola water supply system and to recommend nutrient reductions to achieve desirable lake water quality in Lake Eucha and Spavinaw Lake. Several objectives were met in order to fulfill these goals:

- The current chemical and biological status of Eucha Lake, Lake Spavinaw, and Lake Yahola were assessed and the effects of changing nutrient loads were modeled.

- Potential lake management options for achieving the recommended nutrient reductions and for reducing offensive taste and odor conditions in the lakes were evaluated and specific options recommended.

- A long-term basin management and monitoring program to improve and track water quality was recommended.

Study Description

The Eucha/Spavinaw watershed is a 415 square mile drainage basin in Mayes County and Delaware County, Oklahoma (70%), and Benton County, Arkansas (30%). Eucha Lake and Lake Spavinaw collect and store water from Spavinaw Creek (the main drainage channel for the basin) and other sources to supply the Tulsa Metropolitan area and other local water users. The system was studied from April 1998 to March 2000. Samples were collected regularly from Lake Eucha, Spavinaw Lake, and Lake Yahola (the immediate storage lake for the City of Tulsa Mohawk Water Treatment Plant). Over 800 lake samples and 450 tributary samples were used for evaluative purposes. Chemical analyses and water quality sampling followed the procedures and protocols detailed in the Quality Assurance Project Plan. Tributary stormwater runoff and baseflow were estimated from stream water quality and basin land use analyses developed by Oklahoma State University. Comprehensive limnological analyses were used to assess the current trophic status of the lakes. Lake water quality modeling was employed to investigate the effect of changed lake loadings on the trophic status and to estimate acceptable phosphorus loads to the lakes. Potential lake management options were evaluated and specific options were recommended to restore the lakes to recommended water quality.

Study Results

Current Status of Lake Eucha and Spavinaw Lake

Both Lake Eucha and Spavinaw Lake are nutrient-enriched and display high or excessive levels of algal production. Phosphorus was the limiting nutrient during most of the project period. Average water quality values showed Lake Eucha and Spavinaw Lake to be eutrophic or hypereutrophic. Examination of each separate year showed a significant increase of algae growth for both lakes between 1998 and 1999. The increased algae growth was concurrent with an increase in phosphorus load. Significant taste and odor events occurred during the two-year study period. There was a relationship between particular phytoplankton species present and taste and odor events in both years. The presence of specific diatoms and blue-green algae species known to produce undesirable taste and odors was associated with the taste and odor events.

Lake water quality data was applied to the Oklahoma Water Quality Standards to determine the support level of Aesthetics and Fish and Wildlife beneficial use. The City of Tulsa has documented the avoidance of using Spavinaw Lake water due to excessive concentrations of taste and odor chemical concentrations. This interference due to excessive taste and odors represents threatened Aesthetic beneficial use. Dissolved oxygen levels showed both lakes to be partially supporting (impaired) for Fish and Wildlife beneficial use. Both the threatened Aesthetic and impaired Fish and Wildlife beneficial use are negatively impacted due to excessive algae content. Trophic State Index based on chlorophyll-a content (TSI) is a common measure of algae content. The average TSI for each lake represents the amount of algae causing the threatened and impaired beneficial use.

Lake Phosphorus Budgets

Lake Eucha and Spavinaw Lake make up a single surface water system. Lake Eucha receives the great majority of its water and nutrients from Spavinaw Creek. Lake Spavinaw receives most of its water and nutrients from the Lake Eucha dam discharge. In a separate study funded by Tulsa Metropolitan Utility Authority (TMUA), Oklahoma State University (OSU)[1] determined external lake loads using land-use watershed modeling while the Oklahoma Water Resources Board (OWRB) determined in-lake nutrient loads. The annual phosphorus budget analysis for Lake Eucha showed that 93 percent of the phosphorus entering the lake originated in the drainage basin, and most of that entered the lake through Spavinaw Creek, the lake's main tributary. The remaining 7 percent of the phosphorus entering the lake came from lake sediments. Phosphorus diffused out of the sediments into the water during the summer and was an important part of the phosphorus budget at that time. The lake sediments, however, trapped more phosphorus than they released each year. Approximately 10 percent of the phosphorus stored in the sediments each year was re-released. Of the phosphorus entering Lake Eucha, about 20 percent passed through to Spavinaw Lake. On an annual basis, the phosphorus in the discharge from Lake Eucha accounts for about 85 percent of the phosphorus entering Spavinaw Lake. Approximately equal amounts of phosphorus enter Spavinaw Lake from its immediate drainage basin and from the lake bottom. Spavinaw Lake sediments also stored more phosphorus than was re-released. Approximately 25 percent of the phosphorus entering the sediment of Spavinaw Lake was re-released, also primarily during the summer.

Phosphorus entering Lake Eucha from its tributaries is mostly in dissolved form. As it passes through Lake Eucha, it is absorbed by algae for their use in growth and reproduction. By the time the phosphorus leaves Lake Eucha (and reaches Spavinaw Lake), most of the phosphorus that entered Lake Eucha in dissolved form has been converted to algae.

[1] Biosystems and Agricultural Engineering Department

Modeling of Phosphorus and Chlorophyll-a

Lake water quality models were used to investigate the relationship between phosphorus and chlorophyll-a levels in Lake Eucha and Spavinaw Lake. The model BATHTUB[2] was used to predict the effect of both increasing and decreasing phosphorus loading to each lake. BATHTUB predicts in-lake concentrations of phosphorus and chlorophyll-a, which is a measure of algal abundance. Each lake was analyzed independently. Inflowing water quantity, phosphorus concentration, and physical characteristics of each lake provided by the data collection efforts were used as inputs to the models developed for each lake. Current water quality data were used to calibrate the model to existing lake conditions. Predictions of chlorophyll-a concentrations in each lake were then generated for a range of phosphorus loadings. Carlson's Trophic State Index[3] (TSI) was used to categorize the current and predicted lake quality conditions and to estimate the phosphorus reduction necessary to achieve recommended water quality condition.

During the study period Lake Eucha had an average TSI value of approximately 60. This TSI level is reflective of the hypereutrophic status of Lake Eucha. The level of water quality desired in Lake Eucha would reflect a maximum TSI of 50[4]. Reduction of the average TSI from hypereutrophy to 50 (the threshold for mesotrophy) represents a level where algae production will not impair Fish and Wildlife beneficial use. This load reduction is predicted to reduce algae biomass in Eucha Lake by approximately one half. To achieve this goal, at least a 54 percent reduction of the current phosphorus load to Lake Eucha is necessary.

Spavinaw Lake has a current TSI value of approximately 57. A 45 percent phosphorus load reduction would be necessary to achieve a TSI of 50, which is the highest TSI recommended. Reduction of the average TSI from eutrophy to 50 represents a level where algae production will not impair Fish and Wildlife beneficial use. This recommended level also approximates a 3/8 reduction of the algae content of Spavinaw Lake. Spavinaw Lake algae content is contingent upon the quality of water exiting Eucha Lake. Although achieving a 54 percent reduction in phosphorus load to Lake Eucha will restore beneficial use in Lake Eucha, this will not necessarily translate into restored beneficial uses in Spavinaw Lake. In order for the phosphorus load to Spavinaw Lake to be reduced by 45 percent, the phosphorus load to Lake Eucha would have to be reduced by 70 percent, independent of any other measures.

Both point and non-point source reductions will be necessary to meet recommended algae levels based on reduced phosphorus load. Complete elimination of point source loads within the basin would result in a 34 percent phosphorus load reduction to Lake

---

[2] BATHTUB was developed for the U. S. Army Corps of Engineers specifically for reservoir water quality modeling.

[3] The Trophic State Index is a number ranging between 1 and 100. It is used to estimate algal biomass and is calculated from a consideration of several measurements related to algal production. Each 10-unit change in TSI value reflects a doubling or halving of algal biomass. Classification values for TSI indices in Oklahoma water bodies were set forth by Oklahoma's 1990 Lake Water Quality Assessment (LWQA). Oklahoma lakes with TSI values less than 40 are considered to be oligotrophic (low algae content), 40-50 are mesotrophic (increasing algae content), 50-60 are eutrophic (high algae content), and greater than 60 are considered hypereutrophic (excessive algae content). The Oklahoma LWQA TSI assigns the months of April through September as the algae growing season.

[4] A TSI of 50 is the boundary between eutrophic and mesotrophic conditions for a wide range of lakes

Eucha, and result in a TSI of 54 for that lake. A TSI of 54 does not meet the recommendation.

The Algae Community and Drinking Water Taste and Odor

Even though chlorophyll-a is an indicator of phytoplankton quantity, it is the abundance of particular species of algae that is important in causing taste and odor events. The presence of taste and odor producing algal species, combined with clear water and a rich nutrient supply, allows for the growth of large quantities of algae in both lakes, which increase the probability of experiencing taste and odor events. Taste and odor events were evidenced as customer complaints and verified by chemical analysis. Events occurred in the spring of 1998 (moderate levels of complaints) and winter-spring 1999 (high levels of complaints). These complaints were associated with algal species known to produce unacceptable taste and odor being present at dominant and subdominant levels in the algal assemblage in Lake Eucha and Spavinaw Lake. Direct measures of taste and odor chemicals such as geosmin and methyl isoborneols and other similar compounds (MIB) in 1999 support the connection between particular algal species and customer complaints. During this study, taste and odor events did not take place during summer, the peak period of algal production. Table ES-1 demonstrates the relative dominance of potential taste and odor producing algae in Lake Eucha and Spavinaw Lake during taste and odor events.

Table ES-1 Relative Dominance of Potential Taste and Odor Producing Algae and Their Relation to Taste and Odor Events.

Source: Dr. Ann St. Amand 2001. *Algae, Zooplankton and Taste and Odor Events of Eucha, Spavinaw and Yahola Lakes. Final Report to the Oklahoma Water Resources Board*. **(S) =** Spavinaw Lake **(E) =** Lake Eucha MIB = methyl isoborneols and other similar compounds

Season	**Taste and Odor-Producing Algae**					**Taste and Odor Indicator**	
	Cylindrospermopsis raciborski	***Anabaena flos-aquae***	***Oscillatoria limnetica***	***Stephanodiscus niagara***	***Melosira italica***	**Geosmin MIB**	**Customer Complaints**
Spring 1998	None	None	None	Dominant	None	No data	Moderate customer complaints
Summer 1998	Dominant (S), Subdominant (E)	Dominant (E), Subdominant (S)	Minor	None	None	No data	Few to no customer complaints
Fall 1998	Dominant	Dominant	Subdominant	None	None	No data	Few customer complaints
Winter 1999	None	None	Subdominant early; none late	Dominant	Subdominant	High Geosmin, no MIB	High customer complaints
Spring 1999	None	None	None	Dominant	Subdominant	High Geosmin, no MIB	High customer complaints
Summer 1999	None (E), Dominant (S)	Minor	Subdominant	Subdominant early	Subdominant early	Low Geosmin (E only), no MIB	Few to no customer complaints
Fall 1999	Dominant	Subdominant	Subdominant	Minor	Minor	No Geosmin, no MIB	Few customer complaints
Winter 2000	None	None	Minor (S)	Minor (E), subdominant (S)	Dominant	Moderate Geosmin, high MIB	Few customer complaints

Lake Management Options and Recommendations

Lake water quality management consists broadly of directly managing the lake (in-lake management), managing the watershed, or both. The effectiveness of any of these approaches or combinations of approaches is situation-dependent. Therefore, it is necessary assess the options for each situation prior to making recommendations.

After evaluating the currently available management techniques in light of the limnological and modeling analyses of the lakes, reduction of the amount of phosphorus coming from the watershed was recommended. This technique was identified as the most appropriate and reasonable method of ensuring a water supply of recommended quality and restoring the lakes to beneficial use.

Evaluation of Lake Management Options

There are two basic approaches to management of algae in drinking water reservoirs: management of nutrients or direct management of the algae and other problem-causing organisms in the lakes

In-lake options for reducing phosphorus load involve one or more of the following:

- Treatment or management of lake sediments to inhibit re-cycling of phosphorus
- Chemical treatment of the water
- Re-routing phosphorus within the reservoir system.

In-lake options for managing taste and odor algae directly include:

- Chemical control of algae
- Alteration of water intake structures
- Biomanipulation

Reduction of external phosphorus loading to the lakes involves:

- Reduction of point source discharges of phosphorus
- Reduction of non-point source discharges of phosphorus

These options were each evaluated for management of Lake Eucha and/or Lake Spavinaw, and a recommendation concerning the use of each one was made.

- **Treatment of lake sediments**: (*Not Recommended)*

  In-lake management practices aimed at inhibiting sediment phosphorus re-cycling would only reduce the annual phosphorus load in Lake Eucha by six to nine percent. In-lake management without reduction of external sources will likely not produce recommended water quality.

  Aeration of the water column has been used in reservoirs during stratified periods to increase dissolved oxygen near the sediments and reduce the amount of phosphorus diffusing from the sediments. Such a system constructed for Lake Eucha might cost between $570,000 - $2,270,000 for six months operation. The cost for a similar system in Spavinaw Lake operating six months a year would be between $350,000 - $1,400,000. The potential for low iron concentrations to limit phosphorus precipitation (as noted in the Sediment Phosphorus Load section) should be eliminated prior to any aeration technique. Currently this technique is not recommended.

Estimated costs to control sediment phosphorus by chemical treatment in Lake Eucha would require 3,000 tons of dry alum costing about $870,000. Using the same prescription rate for Spavinaw Lake requires 600 tons of dry alum costing about $175,000. These alum applications approximate the uppermost amount of alum safe for application to the hypolimnion of each reservoir. Exact dosage and chemical formulation would be determined before actual application. Current water quality data suggests significant external lake load reductions are needed before nutrient inactivation presents long-term water quality benefits, therefore alum treatments are not recommended at this time.

Inhibiting phosphorus re-cycling would positively impact water quality for short periods of time (July, August, and September) when phosphorus re-cycling is taking place. The benefit of such water quality improvement, however, is unlikely to have any immediate impact on taste and odor events. Taste and odor events, in the course of this study, did not take place during the summer.

- **Chemical Treatment of Inflowing Water:** (*Not Recommended)*

The very short-term benefits and potential concerns with this method do not recommend it for use at this time. Copper sulfate is commonly used to kill alga growths in drinking water reservoirs. A whole lake treatment of approximately 270 tons of copper sulfate costing $285,000 would be needed for a single treatment of both lakes. The general herbicidal action of copper sulfate may serve to give taste- and odor-causing algae a competitive advantage over more desirable (non-noxious) species. Copper sulfate treatment delay algae growth for approximately two to three weeks until an additional treatment is needed.

Removal of phosphorus from the water column could produce acceptable water quality, but this method of phosphorus load reduction is impractical. It would require an ongoing treatment process. Acceptable water quality in both Lake Eucha and Spavinaw Lake might require the annual application of about 56,000 tons of alum to the main surface water sources at an annual cost for the alum alone of $6,750,000. This method is not recommended for phosphorus management in the lakes as it is prohibitively expensive.

- **Re-routing phosphorus:** *(Not Recommended)*

Re-routing phosphorus-laden water within Lake Eucha for the purpose of reducing algal production would require construction of a deflecting barrier to channel Spavinaw Creek water downward in the hope that this water would lose much of its phosphorus to the sediments. This is an untested technology in this configuration. Moreover, such re-routing of water within Lake Eucha might simply shift the center of algal production to Spavinaw Lake. This method is not recommended as a management tool for this system.

- **Chemical control of algae** *(Not Recommended)*

  The low potential for effective control of taste and odor algae resulted in a decision not to recommend this technique. Chemical control of algae has been historically employed to reduce taste and odor problems in water supply reservoirs. A potential means of eliminating algae from the water column is the application of copper sulfate. A single treatment of Lake Eucha and Spavinaw Lake would require the application of 270 tons of copper sulfate. Treatment would be required prior to algal blooms, treatment may not be effective against some deleterious species of algae, and the cost per treatment was estimated at about $285,000.

- **Alteration of water intake structures** *(Not Recommended)*

  To avoid entraining large masses of algae, water withdrawals might be made from the hypolimnion near Lake Spavinaw dam. An evaluation of hypolimnetic taste and odor chemicals would be necessary to evaluate the effectiveness of this approach. This approach would not have any advantage when the lake was well mixed. During the study period, taste and odor events occurred during the winter-spring period when the lake was well mixed. Thus the expenditure of changing the location of the water intake is not recommended.

- **Biomanipulation** *(Not Recommended)*

  Removal of filter-feeding fish to allow algae-consuming zooplankton to increase has been used effectively to reduce algae content without reducing nutrients in shallow European lakes and relatively small lakes (primarily) in the northeastern United States following the reduction of external nutrient load. Its effectiveness in a large reservoir with high water clarity is untested and the technique is not recommended for either Lake Eucha or Spavinaw Lake.

- **Reduction of external phosphorus loading from the Watershed – (*Recommended)***

  Available in-lake management techniques aimed at phosphorus management have the potential to contribute no more than 10 percent (at 100 percent effectiveness) to the total reductions needed for minimum recommended algae growth in both lakes. Neither direct management of taste and algae organisms or avoidance of them is likely to be successful in the short-term or long-term either. A reduction of phosphorus within the watershed of each lake system is necessary. Spavinaw Creek comprises the largest portion of Eucha Lake watershed while Eucha Lake comprises the largest portion of Spavinaw Lake watershed.

Recommendations

1) Reduce loading to Spavinaw Lake by 45 percent

A 45 percent phosphorus load reduction to Spavinaw Lake is needed to reduce the current TSI of approximately 57 to a TSI of 50. Nutrient budgeting showed 85% of Spavinaw Lake phosphorus to be from Lake Eucha. In order for the phosphorus load to Spavinaw Lake to be reduced by 45 percent, the phosphorus load to Lake Eucha would have to be reduced by 70 percent, independent of any other measures.

2) Implement a phosphorus management plan

- Curbing phosphorus loads entering the Eucha/Spavinaw lake system from the lake basin will involve developing and implementing a watershed-wide management plan that uses the water quality of Lakes Eucha and Spavinaw as the ultimate measure of success:

- Involve all the stakeholders in the basin (including the Eucha/Spavinaw Watershed Management Team [Tulsawater.com] and others) in creating and implementing a comprehensive and fair management program.

- Identify the amount and source or sources (non-point and point) of phosphorus coming from each sub-basin and identify the changes that will most cost-effectively achieve the reduction goal.

- Identify and implement the most cost-effective technologies and management tools to reduce the flow of phosphorus from the watershed.

- Identify and obtain the resources necessary to apply those methods in a sufficient fashion to meet the phosphorus loading goals.

3) Long-term Monitoring and Adaptive Management

A monitoring program to track nutrient loads entering the lake from all sources, lake water quality, and lake algae abundance and composition has been recommended. This may provide some warning of taste and odor events, and will provide the means to track the effectiveness of management changes in the basin designed to reduce phosphorus loading. As improvements are documented, managers should evaluate progress and assess future options. For example, if the phosphorus within the basin is reduced and Lake Eucha improves, it may become more cost-effective to divert acceptable Lake Eucha water for municipal water supply rather than to continue to treat the water from Lake Spavinaw.

Introduction

Oklahoma manages its water resources through a number of initiatives. The cornerstone of all water quality management activities is the Oklahoma Water Quality Standard (OWQS). The OWQS assigns beneficial uses, criteria, and an anti-degradation provision to all waters of the state and is used in the permitting process, Total Maximum Daily Load (TMDL) process, and beneficial use assessment process to manage our waters such that Oklahomans have a plentiful supply of clean water.

Historically, the Oklahoma Water Resources Board (OWRB) has participated in the §314 Federal Clean Lakes Program by conducting Phase I and Phase II Clean Lakes studies as well as the Oklahoma Lake Water Quality Assessment Program (LWQA). The LWQA served as the backbone for work OWRB performed in accordance with Senate Bill (SB) 1175, which was enacted into law in 1998. SB 1175 instructed OWRB to identify "nutrient-limited watersheds" (NLW) in the OWQS. NLW identification would result in certain poultry production regulatory actions being taken in the watershed to control nutrients entering the water body. The OWRB has moved forward with this mandate and has listed 13 lakes in the OWQS as NLW, including Lake Eucha and Spavinaw Lake. Data to support this listing came predominantly from the City of Tulsa with supplemental information from OWRB and Oklahoma Conservation Commission. Listing of the reservoirs as NLW is the first step in addressing nutrient problems in the lake and watershed. Listing Lake Eucha as a NLW watershed in the OWQS has triggered a 303(d) listing and required completion of TMDLs.

Lake Eucha is listed on the state's 303(d) list of waters. The 303(d) list is a federally mandated list of waters that have threatened or impaired beneficial uses and that require performance of a TMDL on the lake and watershed. The TMDL process calculates the amount of pollutants (in this case nutrients) entering the system compared with the maximum loading that would still allow the water body to meet its designated beneficial uses. As a result of the TMDL, point source permits may be modified to meet the loading goal or nonpoint source controls may be required to meet the goal. In most instances, a combination of point and nonpoint source controls will be required to address the problem. Nonpoint source means a source of pollution without a well defined point of origin. Point source means any discernible, confined and discrete conveyance (usually a pipe) from which pollutants are or may be discharged. The definition of point and nonpoint source can be found in the Oklahoma Water Quality Standards, OAC 785:45-1-212.

Due to the increased frequency of taste and odor events attributable to Spavinaw Lake water, the City of Tulsa and OWRB partnered to address water quality issues with a three-year water quality study. This cooperative project was funded through the City of Tulsa's 1998 Capital Improvements Program project "Water Quality Plan" (50 percent) with a cost match by OWRB (50 percent). The project was formalized in "Workplan for Establishing a Nutrient-Algae Relationship and Target Nutrient Concentration for the Spavinaw-Eucha-Yahola Lake Complex" as part of contract #TMUA 97 – 17. The objectives outlined in the Workplan are as follows:

1) Establish the relationship between Spavinaw Lake nutrients and phytoplankton,

2) Use the relationship to develop a target nutrient value to control algae,

3) Examine methods of system management to achieve the target concentration, and

4) Recommend a long-term water quality monitoring plan for the lakes.

This three-year project will provide explanations to these questions.

The Monitoring/Assessment/Evaluation (MAE) work group was formed through the Indian Nations Council of Governments (INCOG) to provide project oversight and coordination with other projects in the Spavinaw Creek basin. Through MEA oversight and input OWRB and City of Tulsa Environmental Operations (CoT) staff developed and documented the water quality monitoring system with EPA approvable Quality Assurance and Quality Control protocols. This system was memorialized as a Quality Assurance Project Plan (QAPP) executed jointly by OWRB and City of Tulsa staff April 15, 1998 (Tulsa). The executed QAPP was reviewed by Region VI EPA and determined to be consistent with systems funded as EPA water quality projects. This project is designed to establish a technical foundation for the TMDL process and to become a stepping stone toward improved lake water quality.

Historical Data

History of Tulsa Potable Water Supply System

Since its earliest days, the City of Tulsa has established itself as an ideal urban metropolitan area. As the population continued to rise, citizens needed a safe and dependable drinking water supply. Thus, Tulsa undertook what was one of the biggest civil engineering projects during its time—Spavinaw Lake Dam. Constructed with the idea that Spavinaw Lake would supply Tulsans with water through the 20th century, construction on Spavinaw Lake Dam began in 1922 and was completed in 1924. A series of pipelines 60-miles long, from the base of Spavinaw Lake dam to the City of Tulsa, were constructed to transfer diverted Spavinaw Lake water to a treatment plant within City limits. Upon completion of the dam and treatment of water by the newly constructed Mohawk treatment plant, Spavinaw Lake supplied Tulsans with a safe, reliable water supply until 1950. During that year, city officials decided to create an impoundment of Spavinaw Creek four miles upstream from Spavinaw Lake to serve as "an environmental and hydrologic barrier" (Tulsa Metropolitan Utility Authority, 2001) for Spavinaw Lake to insure a constant supply of clean water. This second dam came to be known as Lake Eucha Dam and was finished in 1954.

Prior to the creation of Lake Eucha, the general land usage of the watershed was farming corn, wheat, and oats (Kesler, 1936). In the western Arkansas portion of the watershed, apple and peach orchards along with vineyards were abundant. Nearly 80 percent of the watershed was scrub timber before Lake Eucha was created (Kesler, 1936). After Lake Eucha was created, particularly within the past several years, land within the watershed has been used to support the commercial poultry industry (Figure 2-1). Today, the Eucha/Spavinaw watershed has the capacity to produce over 84 million birds, along with some 1,500 tons of phosphorous rich waste per year (Tulsa Metropolitan Utility Authority, 2001).

Today, the Eucha/Spavinaw system continues to be designated as a system for public water supply along with recreation, fish and wildlife, and aesthetics. Eucha/Spavinaw provides a yield of 59 million gallons per day (MGD) to the Tulsa metropolitan area. Under drought conditions, the system can handle a maximum of 100 MGD (Tulsa Metropolitan Utility Authority, 2001). Raw water from the reservoir system is supplied to the newly renovated Mohawk water treatment plant through a pipe system beginning at Spavinaw Lake, approximately 55 miles northeast of Tulsa. Lake Yahola, located immediately adjacent to the Mohawk Plant, provides short-term storage of Lake Spavinaw water prior to treatment.

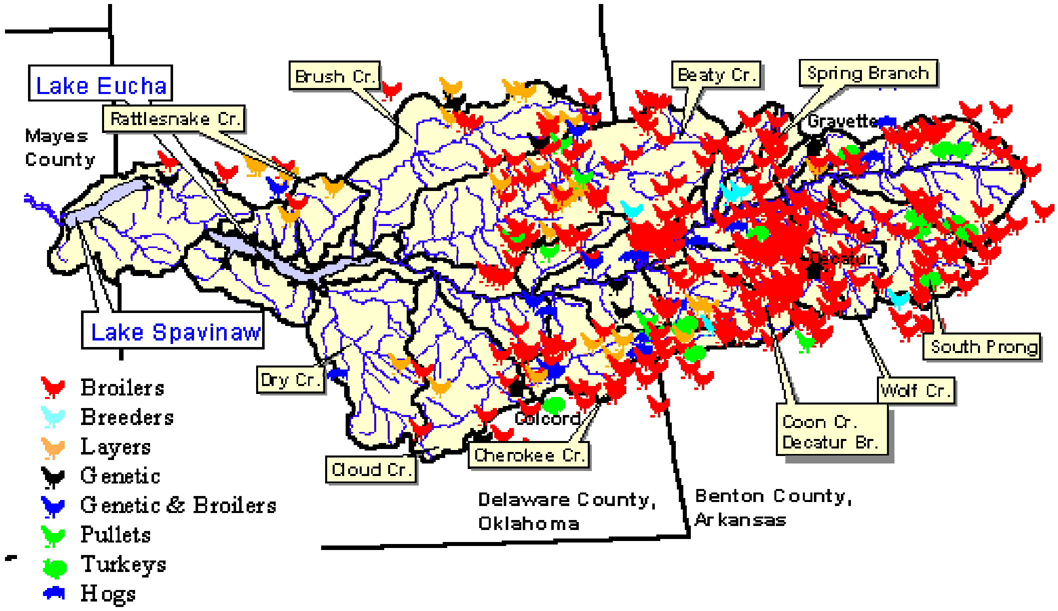


Figure 2-1

Graphic Representation of the Land Usage of the Eucha/Spavinaw Watershed*
Source: Tulsa Metropolitan Utility Authority, 2001

Historical Data Summary

The City of Tulsa has a large quantity of historical water quality data for both Lake Eucha and Spavinaw Lake spanning from 1968 to 1997. Monitoring on Spavinaw Lake began in 1968 with the field water quality parameters of dissolved oxygen and temperature. In 1974, monitoring was expanded to include laboratory parameters and additional field parameters. Also in 1974, monitoring began on Lake Eucha. Both lakes were monitored for nitrogen and phosphorus starting in 1989. In general, monitoring was performed seasonally from May through September. Occasionally, observations were taken year-round. All data collected prior to the beginning of this study in 1997 were considered historical data. This includes the data collected for the OCC Phase I Clean Lakes Project for Lake Eucha, which consisted of regular monitoring of physical, chemical, and biological parameters for a one-year period, March 10, 1993, to February 16, 1994. Historical data was examined to evaluate variability between sites and to detect for trends over time. When possible, historical data was used to describe nutrient dynamics within each reservoir. The following is a summary of these evaluations. Appendix A presents a complete description of the evaluation process.

Both Lake Eucha and Spavinaw Lake showed the onset of stratification in April. Lake turnover occurs generally in October for Spavinaw Lake and in November for Lake Eucha. Depletion of hypolimnetic oxygen (anoxia) followed Spavinaw Lake stratification, while anoxia in Lake Eucha hypolimnion seemed to follow stratification by about one month. The quicker turnover and relative quickness of anoxia in Spavinaw Lake can be attributed to the fact that it is relatively smaller than Lake Eucha. The fact that both hypolimnions go anoxic quickly indicates high algae productivity and eutrophic conditions.

Lake Eucha and Spavinaw Lake showed similar seasonal trends for nutrient dynamics. Two general sources of inorganic nitrogen were noted during separate times of the year: nitrate nitrogen concentrations were greatest in the winter, representing tributary inputs, and ammonia concentrations are greatest in the fall, most likely representing hypolimnetic release. Both sources of inorganic nitrogen are utilized for algae growth. Hypolimnetic phosphorus concentrations suggest that sediment releases orthophosphorus.

Eucha Lake In general EUC01 and EUC02 can be considered to represent the lacustrine zone of the reservoir. EUC03 could be considered the riverine zone of the lake. The various trophic state indices indicate that the lacustrine zone was borderline between mesotrophic and eutrophic while the riverine zone is borderline between eutrophic and hypereutrophic. No significant trends were detected in the historical data set except for the Tulsa data TSI-SD, which showed a positive slope at EUC02 and EUC03. A positive slope means water clarity is degrading over time. Although indicative of eutrophication, the slope value predicted a slow rate of eutrophication. TN:TP ratios indicated that the system was likely limited by phosphorus.

Spavinaw Lake SPA01 and SPA02 represent the lacustrine zone of the reservoir. Phosphorus and secchi disk trophic state indices indicate the lacustrine zone as eutrophic. Spavinaw Lake showed a decreasing trend in secchi disk depth for SPA01 and SPA02 and a corresponding increase in TSI-SD for SPA01. Again, this means that water clarity is degrading over time. Although an indicator of eutrophication, the rate of TSI increase detected was nominal. The implementation of aeration may have contributed to the decrease in secchi depth. Aeration tended to decrease stability of thermal stratification, but did not always consistently oxygenate the hypolimnion.

Hydrology

Documentation of data collection and evaluation to determine current lake morphometry was performed by OWRB staff and is provided in Appendix B. OWRB staff completed lake morphometric data collection and evaluation. The United States Geological Survey (USGS) provided instantaneous flow measurements for three sites in the basin. Water quantity data such as dam release amounts and rainfall were recorded and reported by City of Tulsa staff. The National Weather Service (NWS) provided additional climatological data. Lake evaporation data was taken from the Tulsa District Army Corps of Engineers web site http://www.swt-wc.usace.army.mil. Documentation of data evaluation procedures used for hydraulic budgeting is compiled in Appendix C. Oklahoma State University (OSU) Biosystems and Agricultural Engineering Department on contract to the City of Tulsa performed Spavinaw Creek watershed evaluation. Dr. Daniel Storm directed the OSU work with assistance by Michael White. The groundwater portion of the study was directed by Noel Osborne of OWRB and is presented as Appendix D. City of Tulsa staff provided base flow measurements and assisted with field sampling for the groundwater study. Sample analysis of groundwater parameters were performed by the City County Health Department of Oklahoma County.

Rainfall data collected by the City of Tulsa for NWS were examined to compare the two sample seasons against long-term averages. Both 1998 and 1999 sample seasons (April through March) were above average years for rainfall (Table 3-1). Figures 3-1 and 3-2 plot the data to allow for monthly comparisons. Examination of these two figures showed the largest deviations (above average) occurred from August through September of 1998 and February through May of 1999. During these same time periods, Spavinaw Lake dam accumulated greater precipitation than Lake Eucha dam.

Table 3-1 Comparison of annual rainfall (inches) record to 66-year average (April-March) for Lakes Eucha and Spavinaw.

Period	Lake Eucha	Spavinaw Lake
66 Year Average	43.4	43.5
1998	49.8	49.5
1999	50.2	52.5

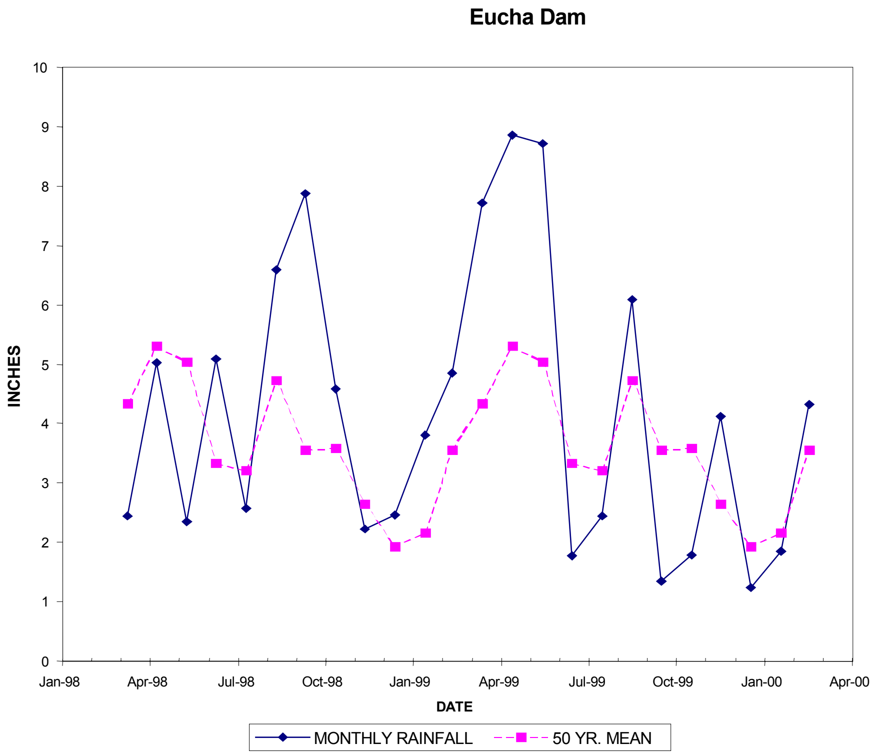


Figure 3-1. **Monthly rainfall totals from Lake Eucha dam (April 1998—March 2000) compared against the 50-year mean (period of record).**

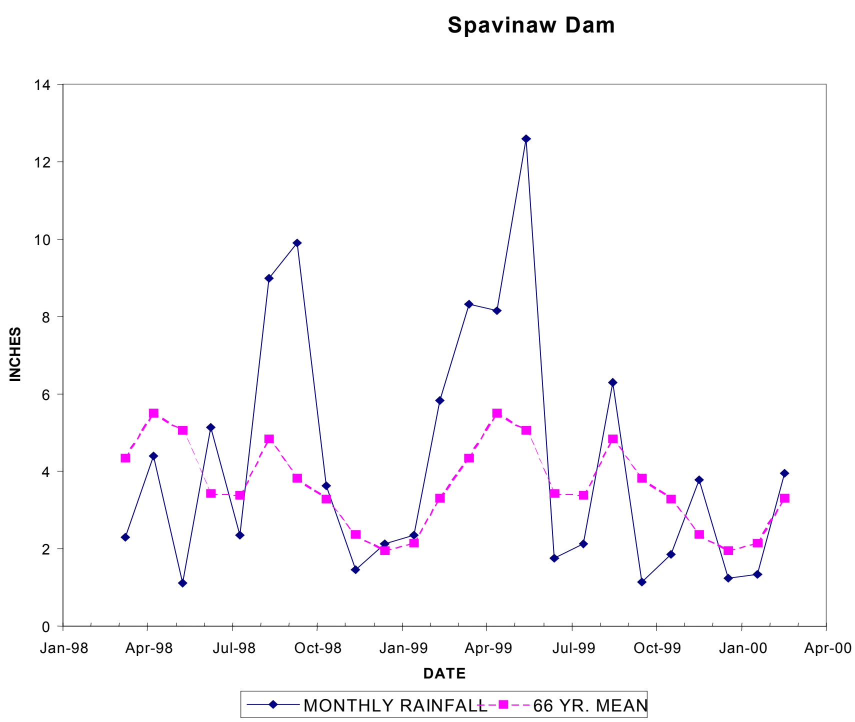


Figure 3-2 **Monthly rainfall totals from Spavinaw Lake dam (April 1998—March 1999) compared against the 66-year mean (period of record.**

Lake Bathymetry

The OWRB staff collected morphometric data of Lake Eucha and Spavinaw Lake in December 1999 and August 1999, respectively. The following is a brief description of the methods used to define morphometric features and a presentation of the results.

Methods

Complete documentation of data collection and interpretations are compiled in Appendix B. In brief, a differential GPS, acoustic depth sounder, and oceanographic mapping software were used to collect the raw morphometric data. After completion of field surveying, the software package was used to process the data and construct ASCII files in an XYZ format. GIS technology was used for boundary determination and data interpolation. Methods outlined by Håkanson (1981) were used to provide the most accurate capacity possible following GIS applications. By following these procedures, the relative percent error for capacity determination was 0.02 percent for Lake Eucha and 0.2 percent for Spavinaw Lake. The probability of correctly identified error for Lake Eucha and Spavinaw Lake are 4.9 percent and 5.6 percent, respectively.

Results

Table 3-2 summarizes selected morphometric features in metric units of Lake Eucha and Spavinaw Lake. Table 3-3 lists area and capacity information by depth in English units for both lakes and Figures 3-3 and 3-4 are bathymetric maps for Lake Eucha and Spavinaw Lake, respectively. Current capacity was compared to original design capacity for estimates of sedimentation rates. The sedimentation survey performed by the Soil Conservation Service (SCS) (Kesler, 1936) on Spavinaw Lake was incorporated into the sedimentation estimates presented in Table 3-4.

Table 3-2 Summary of Lake Eucha and Spavinaw Lake morphometric features.

Parameter	Lake Eucha December 1999	Spavinaw Lake August 1999
Maximum Length	9.0 km	6.4 km
Maximum Width	2.04 km	1.67 km
Surface area	11.36 km^2	6.37 km^2
Capacity	93,602,155 m^3	32,562,903 m^3
Maximum Depth	25.6 m	14 m
Mean Depth	8.2 m	5.1 m
Median Depth	5.1 m	3.4 m
Relative Depth	0.67%	0.49%
Direction of Major Axis	NW-SE	SW-NE
Shoreline	77.8 km	43.7 km
Shoreline Development	6.50	4.86

Table 3-3 Tabular summary of area and capacity versus depth for Lakes Eucha and Spavinaw.

Lake Eucha December 1999			Spavinaw Lake August 1999		
Depth (meters)	Area (acres)	Capacity (acre-feet)	Depth (meters)	Area (acres)	Capacity (acre-feet)
0	2,807	75,884	0	1,575	26,399
2	2,286	59,212	1	1,267	21,746
4	2,073	44,923	2	1,164	17,758
6	1,728	32,476	3	1,063	14,104
8	1,346	22,420	4	956	10,793
10	1,093	14,436	5	800	7,916
12	748	8,435	6	648	5,545
14	461	4,508	7	528	3,619
16	300	2,030	8	364	2,164
18	138	628	9	220	1,215
20	23	152	10	154	604
22	10	44	11	82	224
24	3	1	12	27	54
			13	5	7
			14	0	0

Table 3-4 Comparison of morphologic features over time with estimated sedimentation rates for Lakes Eucha and Spavinaw.

Parameter	Lake Eucha		Spavinaw Lake		
Year	1954	1999**	1924*	1935*	1999**
Area (acres)	2,880	2,807	1,800	1,638	1,575
Volume (acre-feet)	79,576	75,884	31,686	30,509	26,399
Mean Depth (feet)	27.6	27.0	17.6	18.6	16.8
Maximum Depth (feet)	90	84	52	N/A	46
Cumulative Sedimentation Rate (acre-feet/year)	N/A	80.6	N/A	107.1	64.1 (1935-1999) 70.2 (1924-1999)

*—SCS Sedimentation Survey, 1935
**—OWRB Sedimentation Survey, 1999

Estimated sedimentation rates for Spavinaw Lake indicate the rate has slowed over time. Kesler (1936) also assessed 1935 erosion conditions in the watershed. His results showed that 40 percent of the basin had severe erosion, 34 percent with moderate erosion, and 26 percent of the basin with little to no erosion. It is likely that erosive land use practices early in the life of Spavinaw Lake resulted in increased tributary sediment input. The construction of Lake Eucha in 1954 directly above Spavinaw Lake reduced tributary inputs of sediment. Lake Eucha served to reduce the immediate watershed of Spavinaw Lake from approximately 400 square miles to 78 square miles.

Spavinaw Lake tributary water quality data suggest nominal sediment input from the immediate watershed. The 1935-1999 sedimentation is largely due to in-lake or autochthonous (aquatic macrophyte, algae, and chemical precipitation) processes. Distributed over the entire surface area of Spavinaw Lake, a sedimentation rate of 64.1 acre-feet/year converts to 0.48 inch/year or 1.54 cm/yr. Spavinaw Lake has lost 10 feet of maximum depth since impoundment. Lake Eucha sedimentation follows a similar pattern where in-lake or autochthonous sources dominate with a reduction of maximum depth by 6 feet since 1954. Distributed over the entire surface area of Lake Eucha, a rate of 80.6 acre-feet/year converts to 0.34 inch/year or 1.13 cm/yr.

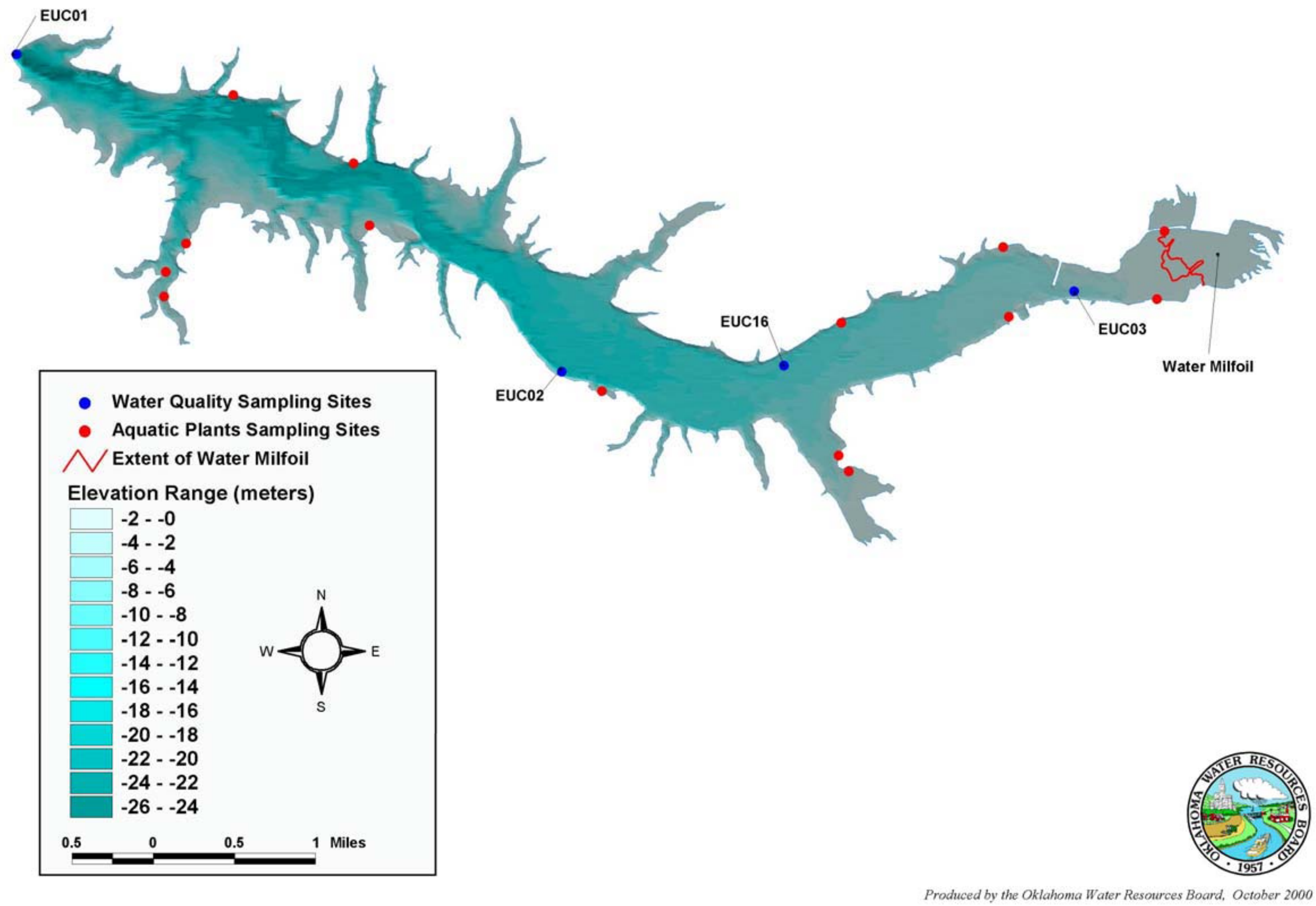


Figure 3-3 **Lake Eucha bathymetric map including water quality, sediment, and aquatic plant sample sites.**

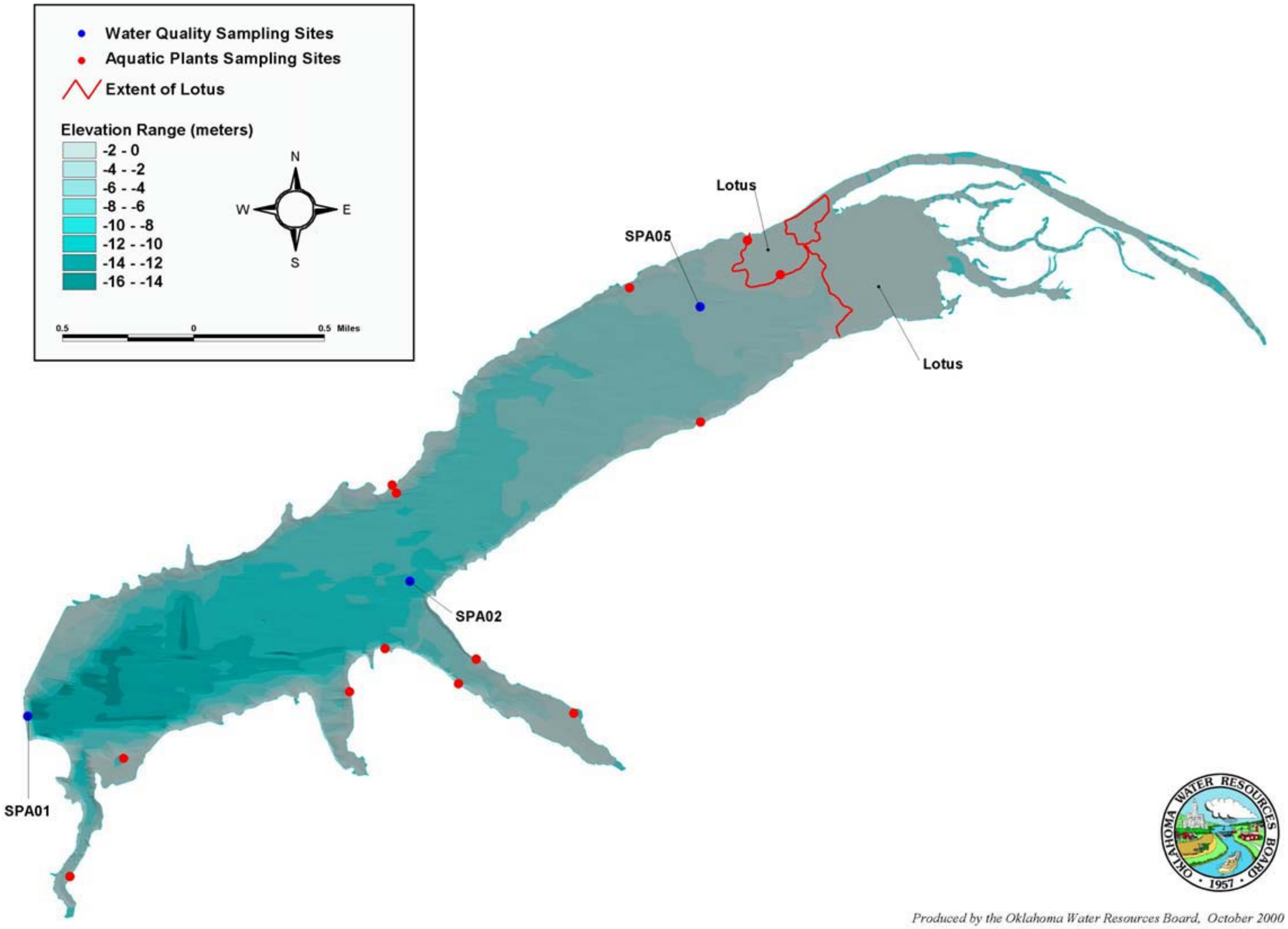


Figure 3-4 **Spavinaw Lake bathymetric map including water quality, sediment, and aquatic plant sample sites.**

Hydraulic Budget

Water inputs to Lake Eucha include precipitation or rainfall, surface runoff, and groundwater. The outputs are evaporation, transpiration (plants in the lake), seepage, water releases (spilled), and water supply. The water releases include gated and valve releases and flow over the dam. Lake water is supplied to the Eucha Water Treatment Plant and City of Jay Water Treatment plant. Inflows into Spavinaw Lake include precipitation, surface runoff, groundwater, and tributary flow (including water released from Lake Eucha). Since the two lakes are fairly close to one another, water released from Eucha flows directly into Spavinaw Lake by way of Spavinaw Creek. The outputs from Spavinaw Lake include evaporation, transpiration, seepage, flow over the dam, and water supply, which includes water exported to the City of Tulsa (Lake Yahola) and the Spavinaw Water Treatment Plant.

A hydraulic budget was constructed using results from OWRB's groundwater investigation, USGS, NWS, City of Tulsa data, and OSU watershed modeling results. Appendix C contains a complete description of hydraulic budgeting and detailed evaluation of accuracy.

Errors were noted in the hydraulic budget. Total monthly error averaged over the entire monitoring period for Lake Eucha was 6,597 acre-feet or 8.7 percent lake capacity. Total monthly error averaged over the entire monitoring period for Spavinaw Lake was -619 acre-feet or 2.3 percent of lake capacity. Average monthly error was relatively small. When examined on a monthly basis, error varied considerably (Appendix C). Several recommendations were developed to reduce error in any future budgeting. The following list of recommendations targets areas where budgeting assumptions could be checked. This should reduce error in future efforts:

- Check the accuracy of lake level gauges.
- Install a stream flow gauge located below Eucha dam and above Spavinaw Lake (at site EUC14, for instance). This would ensure accurate daily inflow rates to Spavinaw Lake.
- Check or resurvey lake stage-discharge nomographs.
- Request field staff to include stream flow measurements as part of their routine stream water quality monitoring routine. This additional information allows for better estimate of base flow and perhaps runoff estimates.
- Groundwater study (discharge measurements) to cover all seasons of the year.

Lake Eucha inflow was dominated by surface runoff while Spavinaw Lake inflow was dominated by Lake Eucha dam release water (Table 3-5). Another contrast between the lakes was the relative contribution of groundwater with Lake Eucha at 29.7 percent and Spavinaw Lake at 7.1 percent. The placement of Lake Eucha dam directly upstream of Spavinaw Lake explains these differences. Examination of immediate drainage basins for these lakes places this into perspective (Table 3-6). Lake Eucha dam has short-circuited the normal hydraulic budget by reducing the immediate drainage basin and regulating the release of trapped groundwater and surface runoff.

Table 3-5 Inflow sources as percent of total for Lakes Eucha and Spavinaw.

	Precipitation	Eucha Dam	Surface Runoff	Groundwater
Lake Eucha	4.0	N/A	66.3	29.7
Spavinaw Lake	2.4	74.7	15.8	7.1

Table 3-6 Immediate groundwater and surface water drainage areas (acres) for Lakes Eucha and Spavinaw

	Lake Eucha	Spavinaw Lake
Surface Water Drainage Area	203,902	47,206
Groundwater Drainage Area	215,670	49,930

Water supply use had a large impact on the outflow percentage of Spavinaw Lake (Table 3-7). The affect of water supply use on Lake Eucha was nominal. The combination of Lake Eucha releases and water supply withdrawals combine to give Spavinaw Lake water a short hydraulic residence (Table 3-8). Over the two-year monitoring period, the average annual hydraulic residence for Eucha was 0.34 years and that of Spavinaw was 0.11 years. Comparisons between monitoring years (April-March) show shorter residence in the second year.

Table 3-7 Major outflow sources as a percent of total for Lakes Eucha and Spavinaw

	Evaporation	Dam	Water Supply
Lake Eucha	6.9	92.6	0.5
Spavinaw Lake	3.5	68.2	28.3

Table 3-8 Annual (April-March) results of hydraulic residence calculations for Lakes Eucha and Spavinaw

Annual Period (April -March)	Lake Eucha	Spavinaw Lake
1998-1999	0.39	0.13
1999-2000	0.29	0.09
Annual Average	0.34	0.11

Tributary Water Quantity and Quality

OSU was contracted by the Tulsa Municipal Utility Authority (TMUA) to provide detailed analyses of tributary quality and quantity in cooperation with USGS. OSU utilized a distributed hydrologic model to estimate the annual phosphorus load and has provided this tributary water quantity and quality information to OWRB. The following is an abbreviation excerpted from OSU's report detailing model parameters and phosphorus load results.

SWAT (Soil and Water Assessment Tool) is a distributed hydrologic model. Distributed hydrologic models allow a basin to be broken into many smaller sub-basins to incorporate spatial detail. Water yield and loadings are calculated for each sub-basin, and then routed through a stream network to the basin outlet. SWAT goes a step further with the concept of Hydraulic Response Units (HRUs). A single sub-basin can be further divided into areas with the same soil and land use. These areas are called HRUs. Processes within an HRU are calculated independently. The total yield for a sub-basin is the sum of all the HRUs it contains. HRUs allow more spatial detail to be included by allowing more land use and soil classifications to be represented.

SWAT continuously simulates on a daily time step. Long term simulations can be performed using simulated or observed weather data. Observed precipitation and climate data from several weather stations were used to model the Eucha/Spavinaw basin. The model is physically based. Relative impacts of different management scenarios can be quantified. Management is set as a series of individual operations such as planting, tillage, harvesting, or fertilization. This level of spatial detail results in relatively high data requirements. An ArcView GIS Interface is available to generate the model inputs. The Eucha/Spavinaw basin is divided into 58 sub-basins and 351 HRUs. More than 2,000 input files are required. The interface is designed to use GIS layers of elevation, soils, and land use to generate the input files. The most detailed GIS data available for the area are used in the model.

The SWAT model version 99.2 was calibrated using observed stream and nutrient data. Three USGS stream gage stations and ten City of Tulsa water quality stations were used in the calibration (Figure 3-5). Loadings were calculated at each station by developing a relationship between flow and observed nutrient concentration. Loadings were developed for soluble phosphorous, total phosphorous, and nitrate. The SWAT model was first calibrated on surface runoff and baseflow at each of the three gages. After hydrologic calibration, the model was calibrated for nutrients.

Baseline Model

The baseline model contained 58 sub-basins. Sub-basin outlets were added at stream flow gauge stations and water quality stations. The sub-basins were developed using USGS 1:24,000 Digital Event Markers and a digitized stream network. HRUs were defined using general area plot land cover data and a combination of Natural Resources Conservation Service soils data.

Average soil test phosphorous was estimated for the pasture areas of each sub-basin using observed data. An estimate for forested areas was made, based on computer simulations of an undisturbed forested area of north central Arkansas. A separate simulation was performed to back calculate soil test phosphorous from observed water quality data.

Litter application rates were determined for each sub-basin based on the number of poultry houses and the amount of pasture in that sub-basin. All litter produced in a sub-basin was assumed to be applied in that sub-basin.

Calibration

Three gauge stations were used in the calibration. All stations were calibrated on total flow, surface runoff, and base flow. The period of available data from the three stations was not constant. Beaty Creek and Black Hollow had less observed flow data with which to calibrate. Spavinaw Creek had much more observed data and should be considered a more accurate calibration.

Period of Record

- Beaty Creek August 1998 to April 2000
- Black Hollow August 1998 to April 2000
- Spavinaw Creek January 1990 to April 2000

The basin was spilt into three areas (Figure 3-5), each area having a different set of calibration parameters. Each sub-basin that is not upstream of a gauge was calibrated by lumping it with the most similar calibrated area. Land use, topography, and distance were used to determine how the basins were lumped.

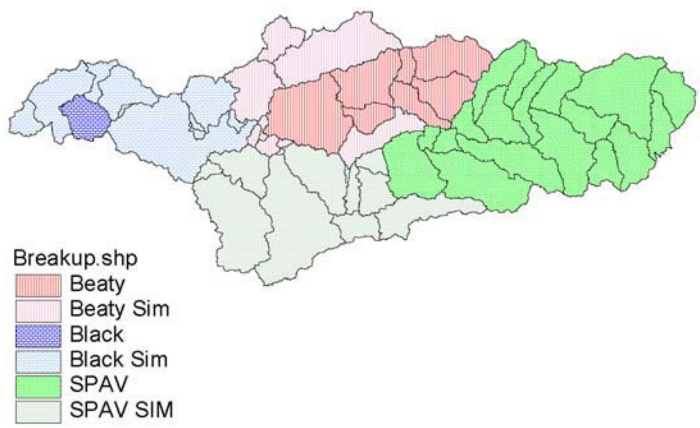


Figure 3-5—Areas of the Eucha/Spavinaw basin.

Flow Calibration Results

Acceptable calibration results were obtained at each gauge station (Table 3-9). Base flow and surface flow fractions were also acceptable.

Table 3-9 Average monthly flow comparisons (m^3/s) for Black Hollow, Spavinaw, and Beaty gauge stations

Gauge Station	Observed Flow	Simulated Flow	Relative Difference
Black Hollow	0.12	0.13	-8.9%
Spavinaw	3.80	3.83	-0.8%
Beaty	1.78	1.65	7.3%

Observed and simulated average monthly flows are compared at each gauge. Figure 3-6 is an example at the Spavinaw gauge station.

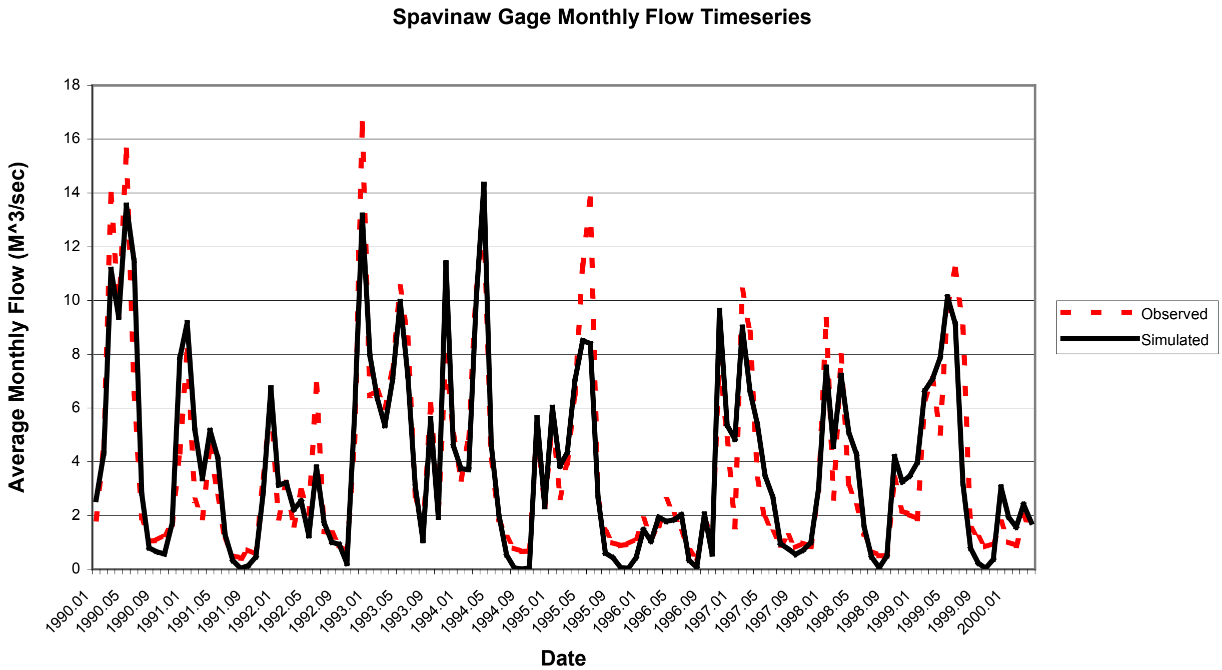


Figure 3-6—Observed and simulated flow at Spavinaw gauge station.

Stochastic Rainfall Simulations

The effect of soil test phosphorous, litter application, grazing, and point sources were each evaluated through SWAT model simulations. The stochastic uncertainty associated with rainfall was quantified by performing multiple simulations using differing periods in the observed rainfall record. Thirty simulations were performed to estimate confidence intervals.

Sediment-Bound Phosphorous Adjustments

Sediment-bound phosphorous was under predicted in all SWAT simulations (Table 3-10). We assume this is the result of phosphorous being deposited with sediment in the stream, but not being re-entrained during high flow periods due to an error or limitation of the SWAT model. In addition, sediment that is re-entrained does not appear to contain phosphorous. To adjust for this, a correction factor was employed using the calibrated SWAT model and observed loadings. Sediment-bound phosphorous was underestimated by a factor of approximately 24 in the calibrated model. This fraction was assumed to be constant for all scenarios. Total phosphorous predictions calculated using this adjustment are labeled as (ADJ.).

Table 3-10 Observed and SWAT predicted loading to Lake Eucha.

Predicted average annual refers to average loading of 30 years of stochastic rainfall simulations. (ADJ.) indicates sediment-bound phosphorous loading was adjusted.

Parameter	Observed 8-98 to 4-00	Predicted 8-98 to 4-00	Predicted 8-98 to 4-00 (ADJ.)	Predicted Average Annual	Predicted Average Annual (ADJ.)
Flow (m'3/sec)	9.80	9.80	9.80	9.13	9.13
Soluble P (kg/yr)	32,800	34,500	34,500	31,200	31,200
Sediment P (kg/yr)	14,800	613	14,712	665	15,960
Total P (kg/yr)	47,600	35,100	49,212	31,865	47,160
Nitrates (kg/yr)	680,000	644,000	644,000	507,000	507,000

Considerable variance is noted when estimating the inflowing load of phosphorus to Eucha lake. OSU copied active spreadsheets of SWAT derived nutrient load estimates to the OWRB as input to in-lake modeling. These estimated were compiled on a monthly basis. Monthly SWAT estimates allowed for input to nutrient budget construction as well as estimating the average annual phosphorus load. Total average annual phosphorus load during the monitoring peroid (4/98 – 3/00) to Eucha Lake was estimated as 34,433 kg/yr. This value falls within the range given in Table 3-10. Using the same spreadsheet the average annual phosphorus load used for Spavinaw Lake modeling was 621 kg/yr.

Groundwater

In cooperation with the City of Tulsa, OWRB conducted a groundwater investigation of each lake's watershed. The complete text of the investigation can be found in Appendix D. The following is a report summary.

The Eucha/Spavinaw watershed is underlain by two aquifers: the shallower Boone aquifer and the deeper Roubidoux aquifer. The Boone aquifer discharges to Lake Eucha and Spavinaw Lake and was the primary focus of this investigation.

Water-level elevations from 28 wells completed in the Boone aquifer and from springs and streams that discharge water from the aquifer were used to construct a water-level elevation map. The map illustrates that the water table surface of the Boone aquifer generally reflects the surface topography. Groundwater appears to flow relatively short distances, from where it receives recharge from precipitation on topographically high areas, to where it discharges along streams by way of springs and seeps.

As determined from the water-level map, the hydraulic gradient varies across the study area, from about 21 ft/mi (0.004) along the flat-topped ridges to about 105 ft/mi (0.02) in the steep valleys. The regional hydraulic gradient is about 26 ft/mi, or 0.005. Average groundwater velocity over the study area is estimated to be 1.6 ft/day.

The boundary of the groundwater watershed was determined from the water-level elevation map just as the boundary of the surface watershed was determined from a topographic map. Examination of the groundwater and surface watersheds indicates the two watersheds correspond closely. The total groundwater watershed area for Lake Eucha and Spavinaw Lake in Oklahoma and Arkansas is estimated to be 415 mi^2. Figure 3-7 illustrates the groundwater recharge watershed and potentiometric map resulting from this investigation.

Discharge measurements taken on major perennial streams in February 1999 were used to estimate the rate of groundwater discharge to the lakes. Spavinaw and Beaty Creeks provided a substantial contribution of base flow to the lakes. Spavinaw Creek gained 110.31 cfs of groundwater in Arkansas and Oklahoma, and Beaty Creek gained 35.35 cfs. Groundwater was discharged to Lake Eucha and Spavinaw Lake from the 415-mi^2 groundwater watershed at an estimated rate of 218.08 cfs, or about 433 acre-feet per day.

Water samples from 11 domestic wells and five springs were analyzed to determine the general water quality of the study area. The predominate water type was high in calcium bicarbonate, reflecting dissolution of limestone. Four of the 16 samples had high levels of carbonates, bicarbonates, and chlorides of sodium and calcium.

Concentrations of nutrients were generally low. Total phosphorus ranged from <0.005-0.044 mg/L, with a median of 0.01 mg/L. Nitrite is unstable in aerated water, and tends to oxidize to nitrate. In 12 of the 16 samples, nitrite concentrations were less than the detection limit of 0.005 mg/L. Ammonia concentrations were greater than the detection limit of 0.03 mg/L in only one sample; sample SP11, from the Spavinaw Roadside Park Spring, which had an ammonia concentration of 0.04 mg/L.

Nitrate was detected in all 16 samples. Concentrations ranged from 0.10-3.63 mg/L, and the median concentration was 0.99 mg/L. Eight samples had concentrations greater than the regional background level of 0.98, as determined by Adamski (1997). Although greater than background levels, nitrate concentrations are well below the drinking water standard of 10 mg/L. Probable sources of nitrate include chemical fertilizer, animal manure, and septic tanks.

Because the discharge measurements were taken in February, when discharge to wells and evapotranspiration were at a minimum, the aquifer was assumed to be in equilibrium. The recharge rate was estimated by dividing the base-flow (218.08 cfs) by the drainage area (415 mi^2), resulting in a recharge rate of 7.13 in/yr. This recharge rate is about 16 percent of the 45-in/yr average annual precipitation for the study area, which is less than the 25 percent for the Ozark region determined by Imes and Emmett (1994).

To determine seasonal variation in discharge, base flow should be measured at various times throughout the year. Future measurements should include Cherokee Creek near the Arkansas border. Water quality sampling and analysis should accompany seasonal well monitoring to determine the extent of water quality variation.

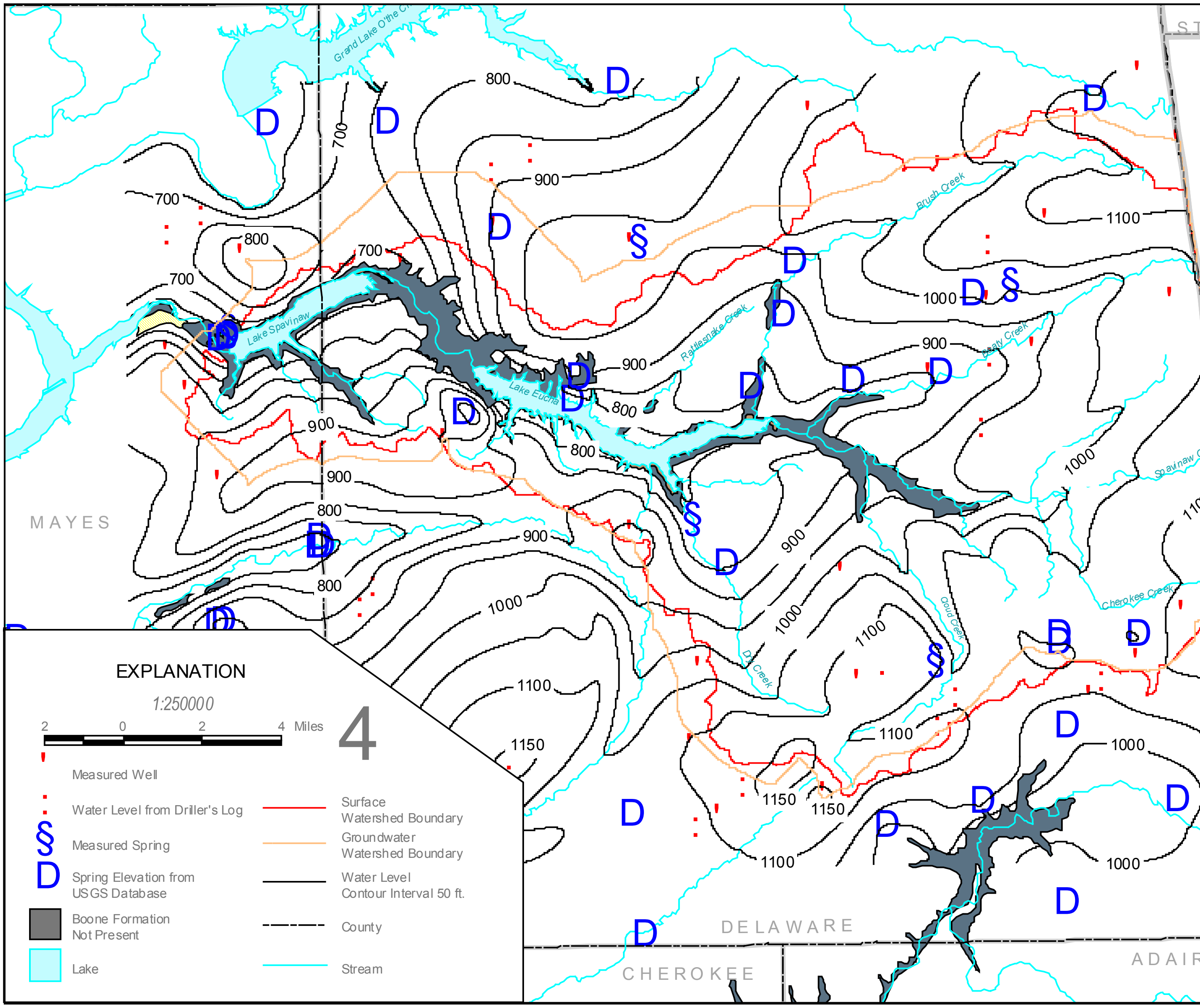


Figure 3-7 **Groundwater investigation results showing water level map of the Boone aquifer, surface watershed boundary, and groundwater watershed boundary.**
Groundwater results derived from 1999 well.

Figure 3. Water level map of the Boone aquifer from wells measured in January 1999.

Current Limnology

Overview

Current limnology is a compendium of the monitoring data used to assess and evaluate the relationship between Spavinaw Lake nutrients and algae content. Prior to actual water quality sampling a rigorous regime of documentation was established. The Monitoring/Assessment/Evaluation (MAE) work group, formed through the Indian Nations Council of Governments (INCOG), provided project oversight and coordination with other contracted projects in the Spavinaw Creek basin. Specific contacts for the OWRB project included Marsha Slaughter, P.E., for the City of Tulsa, Richard Smith for the INCOG, and Paul Koenig for the OWRB. Early in the project the OWRB and City of Tulsa resolved to coordinate City of Tulsa laboratory and field resources and memorialize the City's Spavinaw Creek water quality monitoring efforts as EPA approvable in a Quality Assurance Project Plan (QAPP). Under OWRB direction and Tulsa implementation the monitoring methods and materials were jointly executed as documented by the City of Tulsa and OWRB in the QAPP (1998). Both MEA and Region VI EPA reviewed and concurred with the QAPP.

The primary focus of the study was nutrients and algae in Spavinaw Lake and their possible relation to taste and odor complaints. In order to understand taste and odor complaints the terminal reservoir for diverted Spavinaw Lake water, Lake Yahola, located immediately adjacent the the Mohawk Water Treatment Plant, was included in the study. In order to understand nutrients entering Spavinaw Lake, Lake Eucha was included in the study. Customer complaints from Mohawk treatment plant were also included in the evaluation. In 1999 all diverted Spavinaw Lake water was routed through Yahola lake prior to Mohawk Plant treatment.

The examination of Lake Eucha, Spavinaw Lake, and Lake Yahola water quality combined with Mohawk Plant complaints allowed for a preliminary evaluation of the relationship between taste and odor complaints and Spavinaw Lake water quality. Data collection spanned a two-year period covering physical, chemical and biological parameters starting in April 1998 and ending in March 2000. Field and laboratory data is on file with the City of Tulsa. Most of the data can be accessed electronically on the world-wide-web at www.tulsawater.com. The bulk of this report concerns the evaluation and presentation of current limnological data. The main body of this report contains the results of data evaluation. In many instances the legwork of constructing these results has been relegated into the appendices of the report.

No one person or group performed the entire evaluation and presentation of current limnological data. Additional sampling for aquatic macrophytes, lake sediment and morphometric measurements were performed by OWRB staff. Laboratory analysis of routine samples was provided by the Quality Assurance (QA) Lab, City of Tulsa. Steve Minor provided data oversight and checks as the City of Tulsa Quality Assurance officer. The City County Health Department of Oklahoma County performed additional sample analyses (such as sediment, macrophyte and chlorophyll-a parameters). Zooplankton identification and enumeration was completed and reported by *BSA* Environmental Services, Inc. Algae identification and enumeration was performed by Phycotech, Inc.

PhycoTech also compiled and evaluated algae, zooplankton and taste and odor data for the OWRB. Much of the data evaluation and analysis was performed by the OWRB.

Over 800 lake samples and 400 tributary samples were taken over the course of this project. Each sample was analyzed for 20 to 28 individual parameters encompassing physical, chemical, and biological aspects of water quality. These data provide the foundation for objective decision making to improve lake water quality.

Data Summary

Water quality parameters of Lake Eucha and Spavinaw Lake were analyzed for descriptive statistics of the 37 lake samples from April 1998 through March 2000. Sample frequency was twice monthly during stratification and once monthly when fully mixed. Lake Yahola data were analyzed for the time period in which data were present. These dates include June 1998, October 1998, February 1999, March 1999, April 1999, May 1999, June 1999, July 1999, August 1999, September 1999, October 1999, November 1999, December 1999, January 2000, February 2000, and March 2000. Sites included in the analysis include Lake Eucha sites 1, 2, 3, and 16; Spavinaw Lake sites 1, 2, and 5; and Lake Yahola site 1. Transformation of data was not needed for chlorophyll-a, secchi depth, pH, dissolved oxygen (DO), water temperature, and percent DO saturation data. Due to the relatively clean or clear ambient water quality of the region, several water quality parameters were frequently reported below laboratory detection limits (BDL). The large number of BDL reports required the substitution of a numerical value to allow for statistical evaluation. The substitution method used to treat BDL reports was replacement with a value of one-half the median detection limit. All data receiving statistical evaluation were treated in this manner.

Lake Eucha and Spavinaw Lake were categorized by the stratification season. Generally speaking, both lakes underwent stratification in late April until middle October. Stratification layers were determined using DO/temperature profiles. Slope changes were calculated for both DO and temperature and were used as the criteria for determination of the epilimnion, metalimnion, and hypolimnion. The depths of the representative layers are tabulated (Tables 4-1 and 4-2) for Lake Eucha and Spavinaw Lake, respectively.

Table 4-1 Epilimnetic, metalimnetic, and hypolimnetic depths (in meters) of Lake Eucha during stratification in 1998 and 1999.

Lake Eucha			
Date	**Epilimnion**	**Metalimnion**	**Hypolimnion**
April 14, 1998	0-16	17-18	19-22
April 30, 1998	0-11	12-13	14-22
May 13, 1998	0-5	6-7	8-22
May 28, 1998	0-5	6-7	8-21
June 10, 1998	0-4	5-6	7-22
June 23, 1998	0-4	5-6	7-21
July 14, 1998	0-4	5-6	7-22
July 28, 1998	0-4	5-6	7-21
August 12, 1998	0-6	7-8	9-21
August 25, 1998	0-5	6-8	9-20
September 9, 1998	0-7	8-9	10-20
September 23, 1998	0-6	7-10	11-20
October 14, 1998	0-11	12-13	14-22
October 27, 1998	0-10	11-14	15-23
November 12, 1998	0-18	19	20-22
April 13, 1999	0-9	10-12	13-22
April 28, 1999	0-9	10-11	12-22
May 13, 1999	0-7	8-14	15-22
May 25, 1999	0-7	8-13	14-22
June 9, 1999	0-3	4-5	6-22
June 28, 1999	0-4	5-6	7-22
July 13, 1999	0-3	4-5	6-22
July 27, 1999	0-3	4-6	7-21
August 10, 1999	0-4	5-8	9-21
August 24, 1999	0-5	6-7	8-21
September 15, 1999	0-6	7-10	11-21
September 30, 1999	0-10	11-12	13-21
October 13, 1999	0-10	11-13	14-21

Table 4-2 Epilimnetic, metalimnetic, and hypolimnetic depths (in meters) of Spavinaw Lake during stratification in 1998 and 1999.

Spavinaw Lake			
Date	**Epilimnion**	**Metalimnion**	**Hypolimnion**
April 16, 1998	0-9	10-11	12-14
April 29, 1998	0-10	11-12	13-14
May 12, 1998	0-4	5-6	7-14
May 27, 1998	0-5	6-7	8-14
June 11, 1998	0-5	6-7	8-14
June 25, 1998	0-5	6-7	8-14
July 15, 1998	0-3	4-5	6-14
July 30, 1998	0-5	6-7	8-14
August 13, 1998	0-7	8-9	10-14
August 26, 1998	0-6	7-8	9-14
September 8, 1998	0-7	8-9	10-14
September 21, 1998	0-8	9-10	11-14
October 13, 1998	0-10	11-12	13-14
April 20, 1999	0-9	10-11	12-14
April 29, 1999	0-5	6-8	9-14
May 12, 1999	0-5	6-8	9-14
May 26, 1999	0-2	3-5	6-14
June 10, 1999	0-3	4-5	6-14
June 24, 1999	0-5	6-7	8-14
July 15, 1999	0-4	5-7	8-14
July 29, 1999	0-3	4-5	6-14
August 11, 1999	0-3	4-5	6-14
August 26, 1999	0-5	6-7	8-14
September 16, 1999	0-8	9-10	11-14
September 29, 1999	0-10	11	12-14
October 12, 1999	0-10	11	12-14

Descriptive statistics on Lake Eucha (Tables 4-3, 4-4, and 4-5) and Spavinaw Lake (Tables 4-6, 4-7, and 4-8) were calculated segregated by lake layers: epilimnion, hypolimnion, and isothermal, or mixed lake conditions.

Table 4-3 Statistical summary of water quality for Lake Eucha from April 14, 1998 through March 9, 2000 during isothermal or completely mixed lake conditions.

Lake Eucha					
Parameter	**Minimum**	**Median**	**Maximum**	**Average**	**Standard Deviation**
Water Temperature (°C)	4.1	9.4	16.7	9.9	3.5
pH	6.8	7.9	8.6	7.9	0.3
Dissolved Oxygen (mg/L)	0.1	9.8	13.1	9.3	2.7
% Dissolved Oxygen Saturation	0.9	86.8	104.2	80.5	20.9
Ammonia (mg/L)	0.012*	0.041	0.880	0.115	0.186
Nitrite (mg/L)	0.007*	0.007*	0.098	0.018	0.019
Nitrite+Nitrate (mg/L)	0.02*	1.06	3.95	1.31	0.93
Nitrate (mg/L)	0.02*	1.04	3.92	1.29	0.92
Total Kjeldahl Nitrogen (mg/L)	0.26*	0.29*	1.18	0.43	0.24
Nitrogen/Phosphorous Ratio	13	51	162	62	35
Total Phosphorous (mg/L)	0.01	0.03	0.20	0.03	0.02
Dissolved Phosphorous (mg/L)	0.004*	0.005*	0.041	0.009	0.008
Silica (mg/L)	0.30*	1.55	4.10	1.81	1.05
Total Suspended Solids (mg/L)	2*	6	12	6	2
Total Dissolved Solids (mg/L)	74	140	424	146	45
Turbidity (mg/L)	1.2	3.9	9.1	4.3	1.9
Alkalinity (mg/L)	86	100	110	99	6
Hardness (mg/L)	94	106	126	108	8
Settleable Solids (ml/L)	0.1	0.1	0.1	0.1	0.0
Sulfate (mg/L)	3.00	6.10	7.80	5.95	0.96
Secchi Depth (m)	0.9	1.5	3.8	1.7	0.7
Chlorophyll-a (μg/L)	0.62	14.79	39.18	15.59	11.38

* below the detection limit.

Table 4-4 Statistical summary of water quality for Lake Eucha epilimnion from April 14, 1998 through March 9, 2000 during stratification.

Lake Eucha Epilimnion					
Parameter	**Minimum**	**Median**	**Maximum**	**Average**	**Standard Deviation**
Water Temperature (°C)	12.0	20.7	31.9	21.5	5.5
pH	6.7	8.2	9.5	8.1	0.6
Dissolved Oxygen (mg/L)	0.1	8.4	14.5	8.1	2.6
% Dissolved Oxygen Saturation	0.7	93.4	183.5	91.7	30.6
Ammonia (mg/L)	0.1	0.1	0.6	0.1	0.1
Nitrite (mg/L)	0.02*	0.02*	0.09	0.02*	0.01
Nitrite+Nitrate (mg/L)	0.02*	0.85	3.09	0.96	0.77
Nitrate (mg/L)	0.02*	0.82	3.08	0.94	0.77
Total Kjeldahl Nitrogen (mg/L)	0.2*	0.4	2.1	0.4	0.3
Nitrogen/Phosphorous Ratio	9	54	427	69	63
Total Phosphorous (mg/L)	0.01	0.03	0.23	0.03	0.02
Dissolved Phosphorous (mg/L)	0.003*	0.003*	0.074	0.006	0.011
Silica (mg/L)	0.30*	3.30	5.50	2.98	1.53
Total Suspended Solids (mg/L)	2*	4	26	5	4
Total Dissolved Solids (mg/L)	51	125	412	128	42
Turbidity (mg/L)	0.1	3.9	24.0	4.9	3.7
Alkalinity (mg/L)	38	83	119	80	14
Hardness (mg/L)	42	86	124	83	17
Settleable Solids (ml/L)	0.1	0.1	0.1	0.0	0.0
Sulfate (mg/L)	2	5	11	5	1
Secchi Depth (m)	0.6	1.5	6.6	1.8	1.1
Chlorophyll A (µg/L)	1.00	15.52	88.49	19.32	15.31

* below detection limit.

Table 4-5 Statistical summary of water quality for Lake Eucha metalimnion and hypolimnion from April 14, 1998 through March 9, 2000 during stratification.

Lake Eucha Metalimnion and Hypolimnion					
Parameter	**Minimum**	**Median**	**Maximum**	**Average**	**Standard Deviation**
Water Temperature (°C)	9.3	16.1	30.4	16.7	3.6
pH	6.5	7.2	8.6	7.2	0.3
Dissolved Oxygen (mg/L)	0.02	0.2	11.6	1.6	2.6
% Dissolved Oxygen Saturation	0.2	1.8	129.5	16.6	26.6
Ammonia (mg/L)	0.1	0.4	2.8	0.6	0.6
Nitrite (mg/L)	0.02*	0.02*	0.20	0.03	0.03
Nitrite+Nitrate (mg/L)	0.02*	0.69	2.42	0.74	0.64
Nitrate (mg/L)	0.02*	0.68	2.40	0.72	0.63
Total Kjeldahl Nitrogen (mg/L)	0.2*	0.6	3.3	0.9	0.8
Nitrogen/Phosphorous Ratio	2	38	269	57	57
Total Phosphorous (mg/L)	0.01	0.05	0.69	0.09	0.11
Dissolved Phosphorous (mg/L)	0.003*	0.018	0.345	0.056	0.079
Silica (mg/L)	0.30*	3.80	7.30	3.69	1.66
Total Suspended Solids (mg/L)	2*	4	36	5	5
Total Dissolved Solids (mg/L)	84	142	252	143	27
Turbidity (mg/L)	1.0	4.1	39.7	7.1	6.8
Alkalinity (mg/L)	74	100	130	100	15
Hardness (mg/L)	65	105	120	102	10
Settleable Solids (ml/L)	0.1	0.1	0.1	0.0*	0.0*
Sulfate (mg/L)	1	5	10	5	2

* below detection limit.

Table 4-6 Statistical summary of water quality for Spavinaw Lake from April 16, 1998 through March 7, 2000 during isothermal or completely mixed lake conditions.

Spavinaw Lake					
Parameter	**Minimum**	**Median**	**Maximum**	**Average**	**Standard Deviation**
Water Temperature (°C)	3.2	11.5	19.4	11.8	4.2
pH	7.0	7.8	8.6	7.9	0.4
Dissolved Oxygen (mg/L)	0.7	8.3	12.8	8.7	2.2
% Dissolved Oxygen Saturation	7.7	76.7	107.4	78.7	15.6
Ammonia (mg/L)	0.03*	0.03*	0.24	0.07	0.07
Nitrite (mg/L)	0.02*	0.02*	0.05	0.02*	0.01*
Nitrite+Nitrate (mg/L)	0.02*	0.30	1.81	0.43	0.35
Nitrate (mg/L)	0.02*	0.28	1.78	0.42	0.35
Total Kjeldahl Nitrogen (mg/L)	0.2	0.4	4.6	0.4	0.5
Nitrogen/Phosphorous Ratio	5	31	205	35	21
Total Phosphorous (mg/L)	0.01	0.02	0.22	0.03	0.02
Dissolved Phosphorous (mg/L)	0.003*	0.003*	0.040	0.005*	0.005*
Silica (mg/L)	0.30*	0.94	3.70	1.45	1.08
Total Suspended Solids (mg/L)	2*	5	22	6	3*
Total Dissolved Solids (mg/L)	38	130	449	134	45
Turbidity (mg/L)	0.1*	0.1*	0.1*	0.1*	0.0*
Alkalinity (mg/L)	79	95	105	94	7
Hardness (mg/L)	81	103	114	99	9
Settleable Solids (ml/L)	0.1*	0.1*	0.1*	0.1*	0.0*
Sulfate (mg/L)	1	6	12	5	2
Secchi Depth (m)	0.3	1.4	2.8	1.5	0.5
Chlorophyll A (µg/L)	6.83	11.29	21.62	12.17	3.54

* below detection limit.

Table 4-7 Statistical summary of water quality for Spavinaw Lake epilimnion from April 16, 1998 through March 7, 2000 during stratification.

Spavinaw Lake Epilimnion					
Parameter	**Minimum**	**Median**	**Maximum**	**Average**	**Standard Deviation**
Water Temperature (°C)	14.1	24.3	32.0	23.7	5.1
pH	6.9	8.2	9.0	8.1	0.5
Dissolved Oxygen (mg/L)	0.1	7.9	14.5	7.6	2.5
% Dissolved Oxygen Saturation	0.9	91.4	184.9	89.3	30.5
Ammonia (mg/L)	0.1*	0.1*	1.4	0.1*	0.1*
Nitrite (mg/L)	0.02*	0.02*	0.10	0.02*	0.01*
Nitrite+Nitrate (mg/L)	0.02*	0.11	1.35	0.43	0.49
Nitrate (mg/L)	0.02*	0.12	1.34	0.45	0.49
Total Kjeldahl Nitrogen (mg/L)	0.2	0.4	1.6	0.5	0.3
Nitrogen/Phosphorous Ratio	5	47	200	58	49
Total Phosphorous (mg/L)	0.01*	0.02	0.05	0.02	0.01*
Dissolved Phosphorous (mg/L)	0.003*	0.003*	0.015	0.003*	0.001*
Silica (mg/L)	0.30*	3.30	5.50	2.76	1.72
Total Suspended Solids (mg/L)	2*	4*	11	5	2*
Total Dissolved Solids (mg/L)	50	120	248	121	32
Turbidity (mg/L)	0.1*	0.1*	0.1*	0.1*	0.0*
Alkalinity (mg/L)	54	77	95	78	11
Hardness (mg/L)	54	79	104	81	14
Settleable Solids (ml/L)	0.1*	0.1*	0.1*	0.0*	0.0*
Sulfate (mg/L)	1*	5	8	5	1*
Secchi Depth (m)	0.7	1.4	3.9	1.6	0.7
Chlorophyll A (µg/L)	1.56	14.61	36.19	15.58	3.84

* below detection limit.

Table 4-8 Statistical summary of water quality for Spavinaw Lake metalimnion and hypolimnion from April 16, 1998 through March 7, 2000 during stratification.

Spavinaw Lake Metalimnion and Hypolimnion					
Parameter	**Minimum**	**Median**	**Maximum**	**Average**	**Standard Deviation**
Water Temperature (°C)	12.4	17.8	30.2	18.9	3.7
pH	6.4	7.2	8.5	7.1	0.4
Dissolved Oxygen (mg/L)	0.1	0.2	11.7	1.3	2.4
% Dissolved Oxygen Saturation	0.5	1.6	123.0	13.5	25.3
Ammonia (mg/L)	0.1*	0.3	3.8	0.7	0.9
Nitrite (mg/L)	0.02*	0.02*	0.07	0.02*	0.01*
Nitrite+Nitrate (mg/L)	0.02*	0.04	1.29	0.30	0.40
Nitrate (mg/L)	0.02*	0.05	1.28	0.33	0.40
Total Kjeldahl Nitrogen (mg/L)	0.2*	0.8	4.4	1.1	1.0
Nitrogen/Phosphorous Ratio	5	56	298	60	57
Total Phosphorous (mg/L)	0.01*	0.02	0.50	0.07	0.12
Dissolved Phosphorous (mg/L)	0.003*	0.005	0.410	0.047	0.095
Silica (mg/L)	0.38	4.20	8.70	4.05	1.91
Total Suspended Solids (mg/L)	2*	6	30	7	5
Total Dissolved Solids (mg/L)	80	140	248	141	34
Turbidity (mg/L)	0.1*	0.1*	0.1*	0.1*	0.0*
Alkalinity (mg/L)	65	34	145	96	19
Hardness (mg/L)	67	102	135	101	15
Settleable Solids (ml/L)	0.1*	0.1*	0.1*	0.1*	0.0*
Sulfate (mg/L)	1*	4	8	5	1*

* below detection limit.

Lake Yahola is used as a storage reservoir for waters prior to entering Mohawk treatment plant. Single grab sampling precluded the division of water quality data into stratified layers. Table 4-9 summarizes descriptive statistics for Lake Yahola.

Table 4-9 Statistical summary of water quality for Lake Yahola for the months of June 1998 - March 2000.

Lake Yahola					
Parameter	**Minimum**	**Median**	**Maximum**	**Average**	**Standard Deviation**
Water Temperature (°C)	7.2	18.3	31.4	17.4	7.7
pH	1.7	8.1	8.9	7.8	1.6
Dissolved Oxygen (mg/L)	6.4	9.8	12.8	9.3	1.5
% Dissolved Oxygen Saturation	76.9	98.0	123.6	92.3	11.1
Ammonia (mg/L)	0.030*	0.030*	0.860	0.066	0.154
Nitrite (mg/L)	0.015*	0.015*	0.140	0.024*	0.027*
Nitrite+Nitrate (mg/L)	0.015*	0.238	1.320	0.306	0.331
Nitrate (mg/L)	0.015*	0.238	1.300	0.291	0.309
Total Kjeldahl Nitrogen (mg/L)	0.208*	0.475	1.850	0.590	0.358
Nitrogen/Phosphorous Ratio	7	36	182	47	43
Total Phosphorous (mg/L)	0.005*	0.022	0.051	0.025	0.011
Dissolved Phosphorous (mg/L)	0.003*	0.003*	0.013	0.005*	0.004*
Silica (mg/L)	0.295*	0.295*	0.295*	0.295*	0.000*
Total Suspended Solids (mg/L)	2.000*	2.000*	13.500	4.7	4.995
Total Dissolved Solids (mg/L)	5.000*	5.625*	127.000	27.885	44.155
Turbidity (mg/L)	0.050*	0.170	4.810	0.934	1.692
Alkalinity (mg/L)	5.000*	5.000*	5.000*	5.000*	0.000*
Hardness (mg/L)	5.000*	5.000*	5.000*	5.000*	0.000*
Settleable Solids (ml/L)	0.050*	0.050*	0.050*	0.050*	0.000*
Sulfate (mg/L)	0.420	0.700	6.300	2.030	2.850
Secchi Depth (m)	0.5	1.0	1.6	1.0	0.4
Chlorophyll A (µg/L)	5.83	13.24	66.38	20.58	17.13

* below detection limit.

Generally speaking, there is a pattern of decrease in average concentrations of the water quality parameters as water flows downstream from Lake Eucha into Spavinaw Lake and further downstream into Lake Yahola.

Water Quality of Spavinaw Lake and Lake Yahola

Water quality parameters from Spavinaw Lake and Lake Yahola were statistically evaluated for changes when water was diverted from Spavinaw Lake into Lake Yahola. Parameters evaluated include ammonia, nitrite, nitrite+nitrate, nitrate, total kjeldahl nitrogen, nitrogen/phosphorous ratio, total phosphorous, silica, total suspended solids, total dissolved solids, turbidity, alkalinity, hardness, and sulfate.

Spavinaw Lake Site 1 samples within the 3 to 7-meter depth were statistically compared to similar sample dates of Lake Yahola. This restriction was made to simulate the water depth at which Spavinaw Lake dam water is withdrawn for diversion to the City of Tulsa. A summary of the results is reported in Tables 4-10 and 4-11 for Spavinaw Lake and Lake Yahola, respectively.

Table 4-10 Statistical summary of water quality parameters of Spavinaw Lake site 1, depths 3-7 meters for paired comparison to Lake Yahola sample results.

Spavinaw Lake Site 1, Depths 3-7 meters					
Parameter	**Minimum**	**Median**	**Maximum**	**Average**	**Standard Deviation**
Water Temperature (°C)	8.9	20.5	31.3	19.4	5.7
pH	6.9	7.7	8.8	7.8	0.5
Dissolved Oxygen (mg/L)	0.1	6.7	13.2	6.1	3.6
% Dissolved Oxygen Saturation	0.6	72.5	165.5	65.0	39.2
Ammonia (mg/L)	0.03*	0.03*	0.50	0.09	0.10
Nitrite (mg/L)	0.02*	0.02*	0.06	0.02*	0.01*
Nitrite+Nitrate (mg/L)	0.02*	0.21*	1.27	0.43	0.42
Nitrate (mg/L)	0.02*	0.21	1.24	0.42	0.41
Total Kjeldahl Nitrogen (mg/L)	0.2*	0.4	1.3	0.4	0.2*
Nitrogen/Phosphorous Ratio	15	42	119	48	27
Total Phosphorous (mg/L)	0.01*	0.02	0.06	0.02	0.01*
Dissolved Phosphorous (mg/L)	0.003*	0.003*	0.012	0.004*	0.002*
Silica (mg/L)	0.30*	2.20	5.30	2.33	1.71
Total Suspended Solids (mg/L)	3*	4*	5.6	4	1
Total Dissolved Solids (mg/L)	38	130	210	125	30
Turbidity (mg/L)	0.1*	0.1*	0.1*	0.1*	0.0*
Alkalinity (mg/L)	54	89	102	87	12
Hardness (mg/L)	55	92	108	90	14
Settleable Solids (ml/L)	0.1*	0.1*	0.1*	0.1*	0.0*
Sulfate (mg/L)	3	5	8	5	1*

* below detection limit.

Table 4-11 Statistical summary of water quality of Lake Yahola for paired comparison to Spavinaw Lake sample results.

Lake Yahola					
Parameter	**Minimum**	**Median**	**Maximum**	**Average**	**Standard Deviation**
Water Temperature (°C)	7.2	18.3	31.4	17.4	7.7
pH	1.7	8.1	8.9	7.8	1.6
Dissolved Oxygen (mg/L)	6.4	9.8	12.8	9.3	1.5
% Dissolved Oxygen Saturation	76.9	98.0	123.6	92.3	11.1
Ammonia (mg/L)	0.030*	0.030*	0.860	0.066	0.154
Nitrite (mg/L)	0.015*	0.015*	0.140	0.024*	0.027*
Nitrite+Nitrate (mg/L)	0.015*	0.238	1.320	0.306	0.331
Nitrate (mg/L)	0.015*	0.238	1.300	0.291	0.309
Total Kjeldahl Nitrogen (mg/L)	0.208*	0.475	1.850	0.590	0.358
Nitrogen/Phosphorous Ratio	7	36	182	47	43
Total Phosphorous (mg/L)	0.005*	0.022	0.051	0.025	0.011
Dissolved Phosphorous (mg/L)	0.003*	0.003*	0.013	0.005*	0.004*
Silica (mg/L)	0.295*	0.295*	0.295*	0.295*	0.000*
Total Suspended Solids (mg/L)	2.000*	2.000*	13.500	4.7	4.995
Total Dissolved Solids (mg/L)	5.000*	5.625*	127.000	27.885	44.155
Turbidity (mg/L)	0.050*	0.170	4.810	0.934	1.692
Alkalinity (mg/L)	5.000*	5.000*	5.000*	5.000*	0.000*
Hardness (mg/L)	5.000*	5.000*	5.000*	5.000*	0.000*
Settleable Solids (ml/L)	0.050*	0.050*	0.050*	0.050*	0.000*
Sulfate (mg/L)	0.420	0.700	6.300	2.030	2.850

* below detection limit.

Two-tailed t-tests were calculated for each parameter between both lakes. A general null hypothesis states there is a no significant difference between the parameter values for Spavinaw Lake and Lake Yahola. All statistical testing was performed at a 5 percent alpha level. Results of the t-tests are reported in Table 4-12.

Table 4-12 Results of t-test on paired comparison of water quality parameters: Spavinaw Lake verses Lake Yahola. Significance at the 5 percent level is noted with an asterisk (*).

Spavinaw Lake and Lake Yahola t-test values		
Parameter	**t-test value**	**Number of cases**
Ammonia (mg/L)	1.747	43
Nitrite (mg/L)	1.468	43
Nitrite+Nitrate (mg/L)	2.519*	43
Nitrate (mg/L)	2.624*	43
Total Kjeldahl Nitrogen (mg/L)	0.429	43
Nitrogen/Phosphorous Ratio	0.946	42
Total Phosphorous (mg/L)	-0.855	42
Dissolved Phosphorous (mg/L)	2.737*	43
Silica (mg/L)	8.171*	43
Total Suspended Solids (mg/L)	1.504	11
Total Dissolved Solids (mg/L)	18.908*	39
Turbidity (mg/L)	-0.919	43
Alkalinity (mg/L)	43.885*	39
Hardness (mg/L)	41.405*	43
Sulfate (mg/L)	8.738*	19

T-tests did indicate a significant change in the water quality of waters exiting Spavinaw Lake and flowing into Lake Yahola. Results of the t-tests indicate a significant decrease in nitrate as waters flow from Spavinaw Lake into Lake Yahola. Other significant decreases were found in silica, dissolved phosphorous, sulfate, total dissolved solids, alkalinity, and hardness. Prior to reaching Lake Yahola, diverted Spavinaw Lake water is treated chemically to yield in-line concentrations of 0.5 mg/L of potassium permanganate ($KMnO_4$). The addition of this acidic chemical and its ability to precipitate suspended and dissolved solids can account for the decrease in alkalinity, hardness, dissolved silica, dissolved phosphorus, sulfate, and total dissolved solids.

Spatial and Temporal Evaluation

Algae preferentially utilize dissolved nutrients in the mixed water column. Any lake management strategy must target the reduction of dissolved nutrients. Dissolved nutrients are introduced into the water column through basin inflow and lake sediment. Stratification plays an important role in the availability of these nutrients for algae growth. Thermal stratification serves to partition hypolimnetic waters from the mixed epilimnion layer. When the hypolimnion becomes anoxic, a diffusion gradient sets up across the thermocline, with the potential to introduce dissolved nutrients. The rate of diffusion is generally slow, with the bulk of the hypolimnetic nutrients mixing with surface waters following erosion of the thermocline. Dissolved nitrogen, phosphorus, and silica are important nutrients showing annual patterns controlled by algae growth and bacterial respiration.

Monitoring results have been summarized and displayed using bar charts and isopleth plots wherever possible. Bar charts have been used to display significant differences between lake sample sites while isopleths have been used to display data variances at one site over time and depth. Isopleth plots have the advantage of distilling hundreds of data points in three dimensions into one figure. Isopleths prepared for this report chart water quality parameters collected with depth against time. For ease of presentation and reference, these isopleths have been grouped by site reporting first field, then laboratory parameters. Lake Eucha, then Spavinaw Lake are presented for each category. This order represents the flow of water down Spavinaw Creek: first into Lake Eucha, then from Lake Eucha into Spavinaw Lake. Lake Yahola data will follow Spavinaw Lake when comparisons are possible.

The following is a primer to assist with isopleth interpretation. Figure 4-1 contains two isopleths describing the temperature and dissolved oxygen dynamics at the Eucha dam during the OCC Clean Lakes project. Isopleths seem confusing, but they allow a lake manager to view all data in one illustration. It may be helpful to think of the temperature and oxygen figures as contour maps. Just as a hiker can use a topographic map to stay at one elevation, each line of an isopleth represents a particular temperature and can be followed throughout the monitoring period. Warmest temperatures are colored dark red. The red gradually turns to blue as temperature drops. High oxygen concentrations are colored blue. The blue gradually shifts to red as the concentration drops to zero.

The following is an example of reading the temperature isopleth in Figure 4-1 and an introduction of limnological terms. At mid-April water temperature was 8°C throughout the water column (from 0 to 23 meters depth), depicted in the temperature isopleth by the 8°C isobar running nearly vertically. This indicates that the water body is well mixed with water quality conditions similar from surface to bottom. Examination of the temperature plot in Figure 4-2 for late August shows a very different pattern of temperature versus depth. This is called thermal stratification. Temperature isobars run horizontally, indicating a strong temperature gradient from top to bottom. Strong vertical temperature gradients lead to stratified water quality conditions.

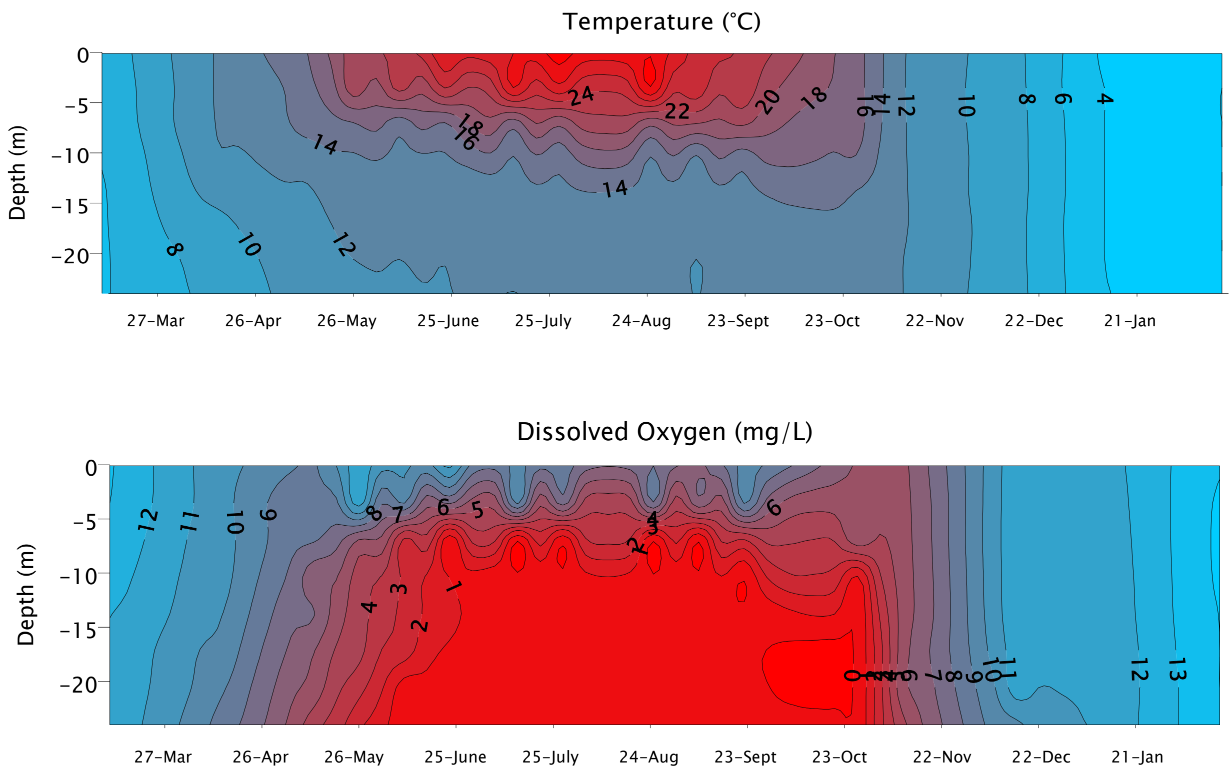


Figure 4-1 **Time versus depth isopleths of Lake Eucha at the dam March 10, 1992 - February 16, 1993 constructed from the Eucha Clean Lakes project data (OCC).**

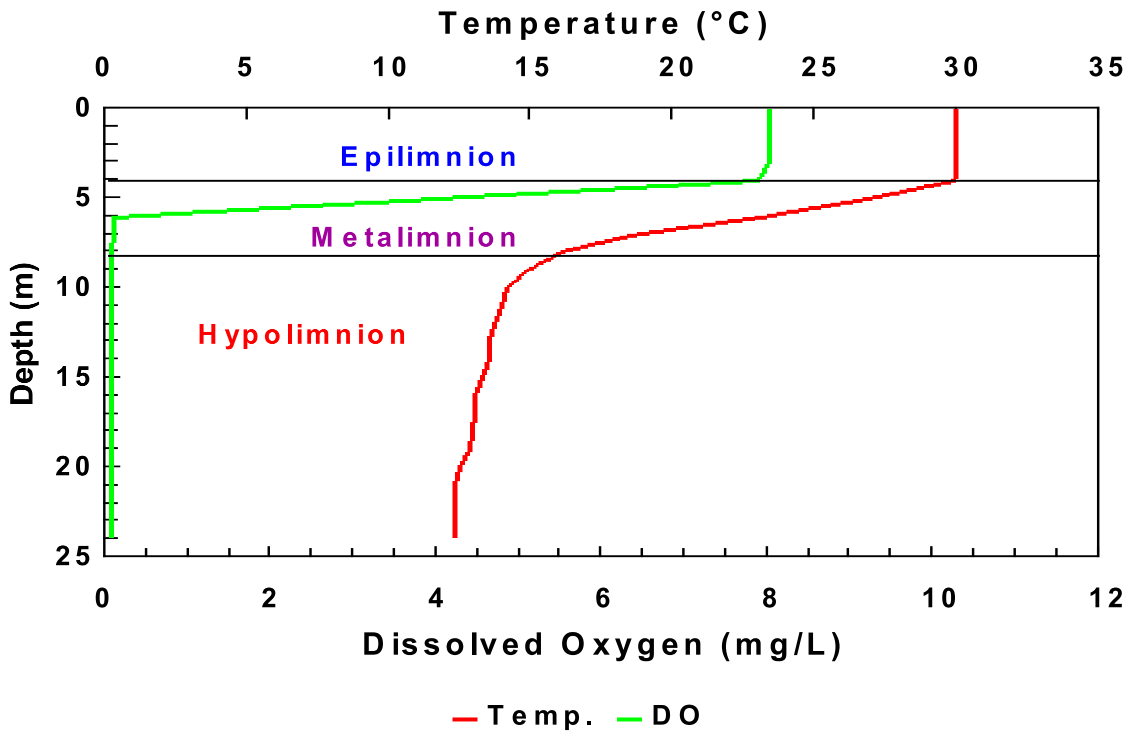


Figure 4-2. **Lake Eucha Profile: Site 1, August 25, 1993 (OCC).**

Figure 4-2 plots the same temperature and oxygen data for late August. Here the change of temperature and oxygen content shown in Figure 4-1 may be easier to understand. The three layers of water (epilimnion, metalimnion, and hypolimnion) associated with a stratified lake are also identified. These three sections or layers of a lake are based on water density differences. It is these density differences that determine the relative amount of mixing and consequently the water quality within each lake layer. The epilimnion, the warmest and uppermost layer of lake, is generally the same temperature throughout. The epilimnion mixes fully and freely, facilitating exchange of gases with the atmosphere. Plant growth is the primary biological activity in the epilimnion. Bacterial respiration occurs in the epilimnion. Epilimnetic gas exchange minimizes the impact of respiration to dissolved oxygen. The metalimnion is the layer of water that serves as a transition from the epilimnion to the hypolimnion. The metalimnion is distinguished by a sharp change in temperature. This rapid change in temperature translates into a rapid change in density. Dead and dying algae cells will collect on the density gradient. The hypolimnion is the colder bottom layer of the lake. Bacterial respiration is the primary biological activity in the hypolimnion. Plant growth is not normally noted in the hypolimnion.

Temperature and Dissolved Oxygen

Both Spavinaw Lake and Lake Eucha show consistent spring stratification and late fall destratification or “turnover”. A principal difference between the lakes is the onset of fall turnover. Turnover occurs much later in the fall for Lake Eucha than Spavinaw Lake. This is due to the cooler hypolimnetic mass of Lake Eucha. Comparing Figure 4-3 (Lake

Eucha temperature) to Figure 4-4 (Spavinaw Lake temperature) shows a one-month delay in fall turnover from Spavinaw to Eucha. The start of anoxic concentration in the hypolimnion also plays a role in the onset of lake anoxia, as noted by low dissolved oxygen (below 2 mg/L) in the Lake Eucha hypolimnion (Figure 4-5) approximately one month after stratification started. In Spavinaw Lake low dissolved oxygen (less than 2 mg/L) in the hypolimnion follows stratification (Figure 4-6). Hypolimnetic oxygen deficit calculations indicate similar rates of oxygen consumption. The greater mass of oxygen trapped in Lake Eucha's hypolimnion explains the delay in the onset of stratification and anoxia.

Oxygen Percent of Saturation and Reduction-Oxidation (Redox) Potential: Low (<50) and high (>100) percent oxygen saturation values are indicative of intense biological activity. Saturation above 100 percent, called supersaturation, represents intense algae growth. Saturation below 50 percent represents intense cellular respiration, generally bacteria. The largest contrast in this variable is seen during stratification of both lakes (Figures 4-7and 4-8). Epilimnetic algae that create oxygen supersaturation eventually die and settle into the hypolimnion. These dead algae cells then become food for bacteria. This process of settling dead algae cells drives hyperlimnetic bacterial respiration. Redox potential reflects the physical environment shaped by biological activity. Redox potential determines the oxidation state of elements such as iron, sulfur, and nitrogen. Low redox potential (<100 mV) (Figures 4-9 and 4-10) follows the onset of anoxic waters and is generally driven by bacterial respiration (Lerman, 1977). High algae growth and an anoxic redox in the hypolimnion are inextricably linked in stratified lakes. The greater the epilimnetic algae production, the greater the hypolimnetic bacterial activity and potential for low redox.

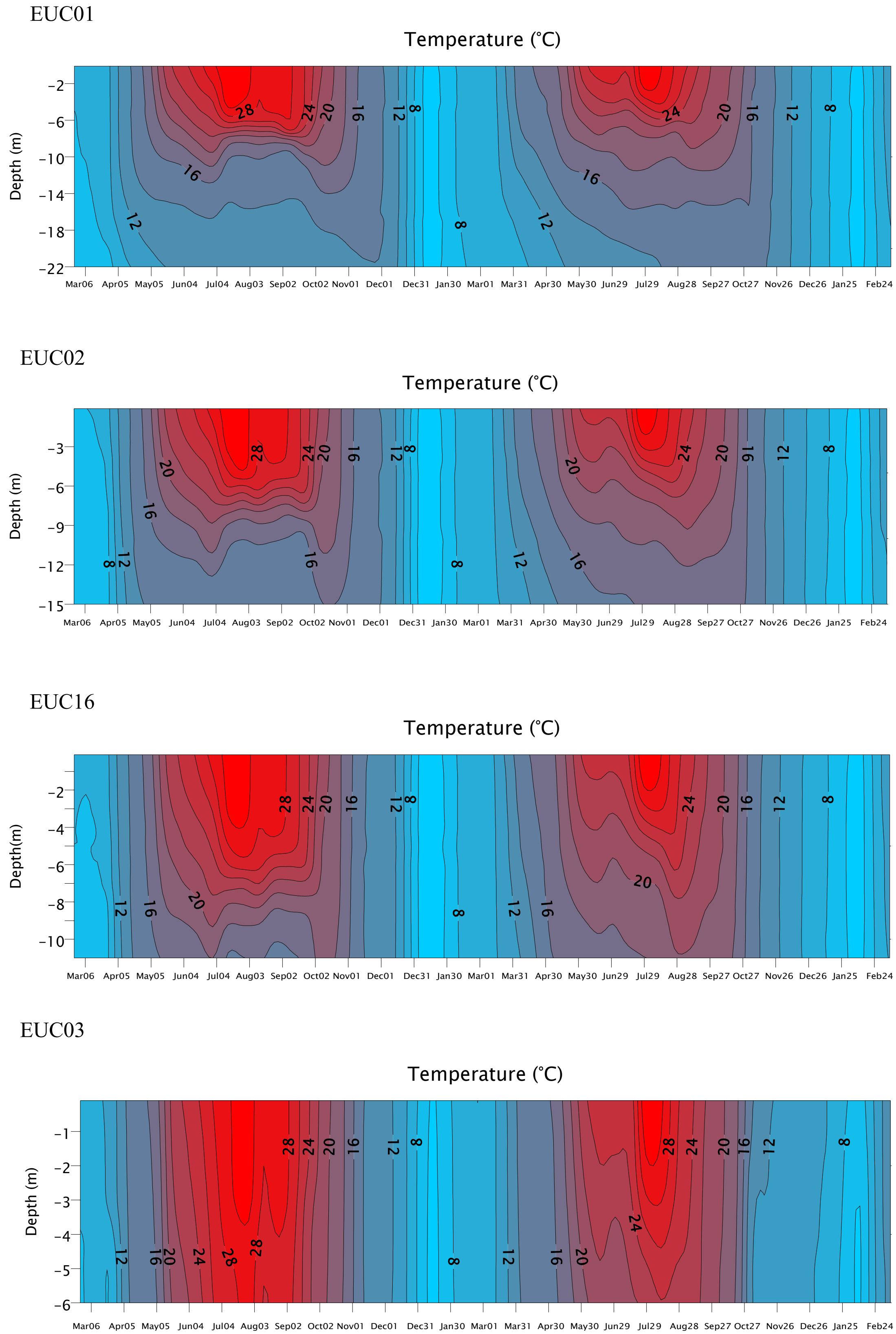
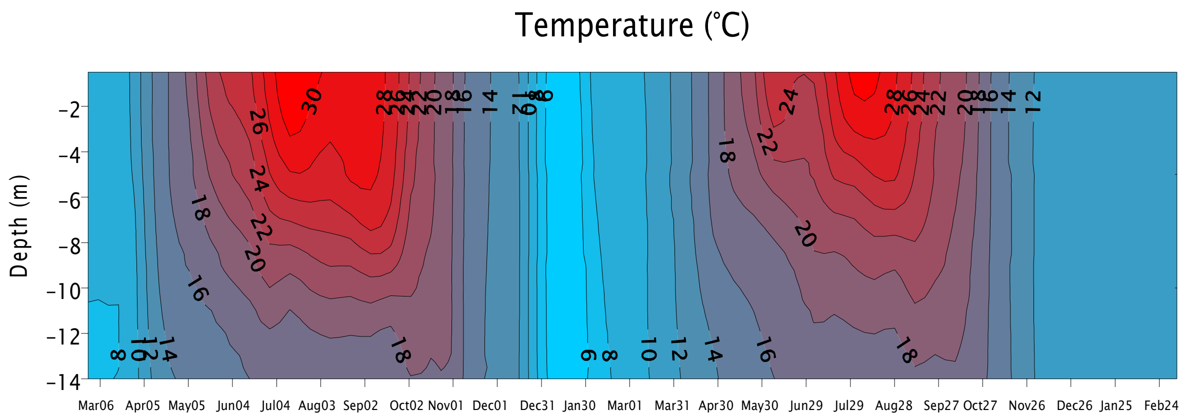
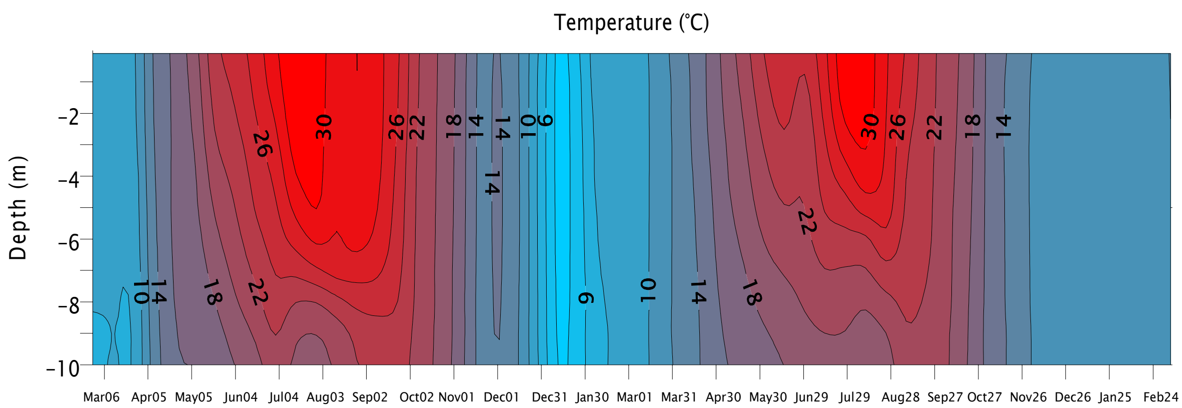


Figure 4-3. Lake Eucha temperature April 1998 - March 2000. Upper plot is Site EUC01 followed by EUC02, EUC16 and EUC03.

SPA01



SPA02



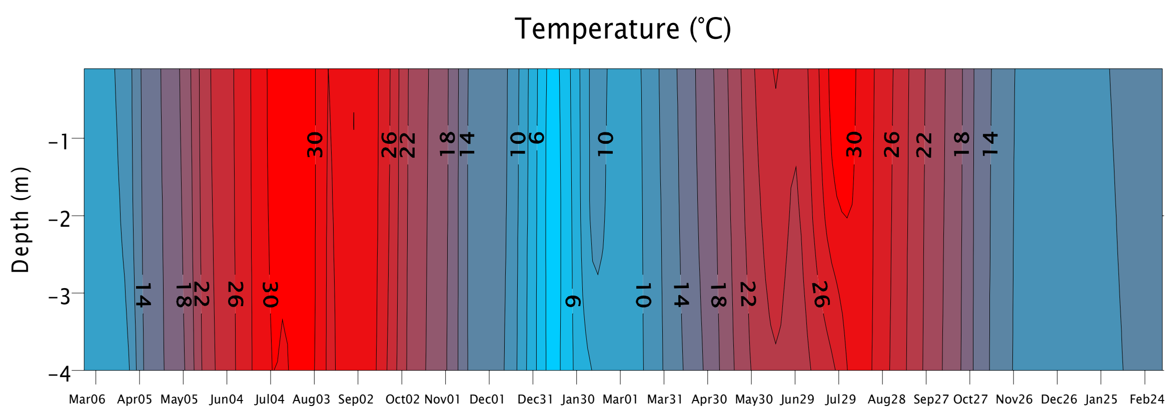


Figure 4-4. Spavinaw Lake temperature April 1998 - March 2000. Upper plot is site SPA01 followed by SPA02 and SPA05.

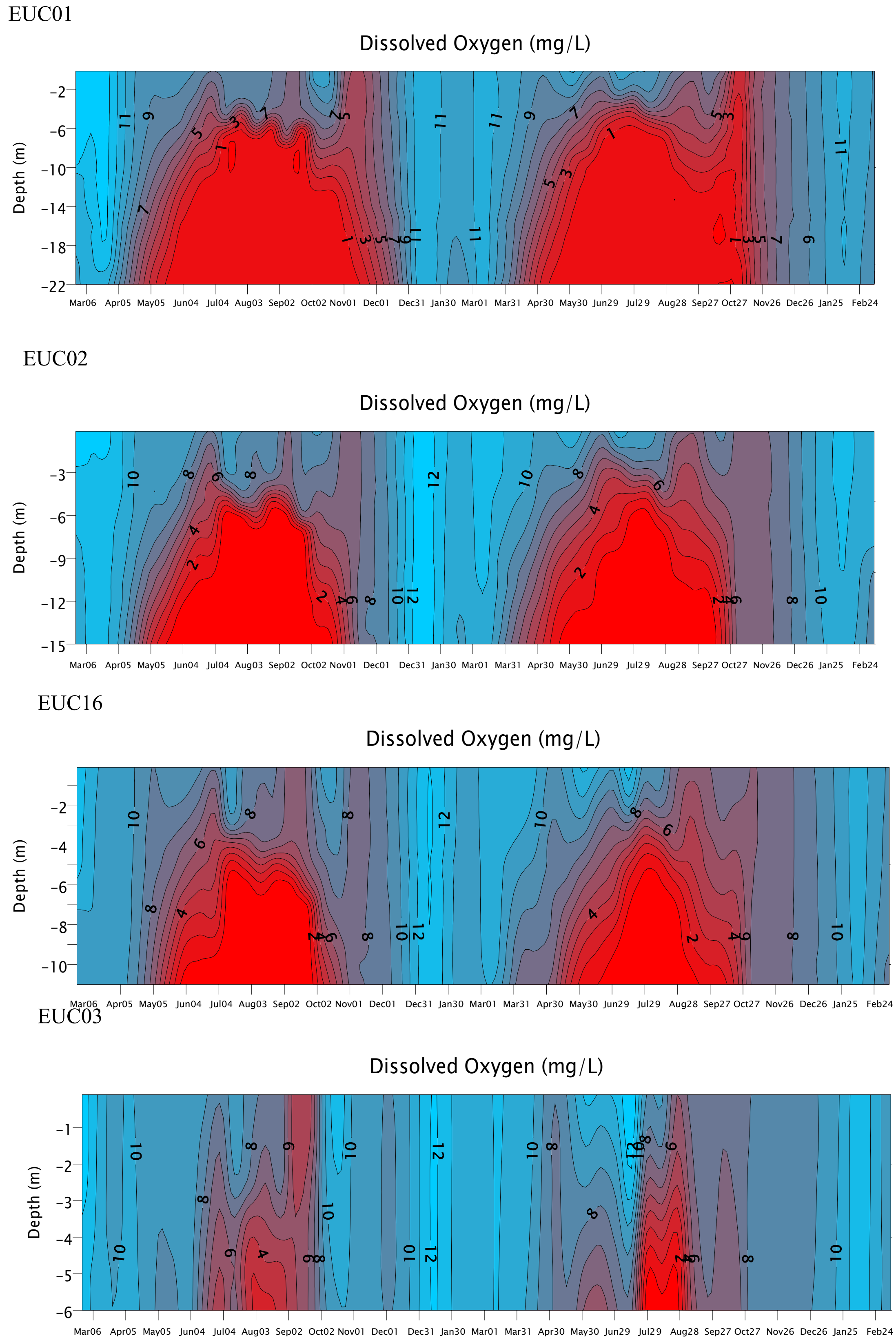
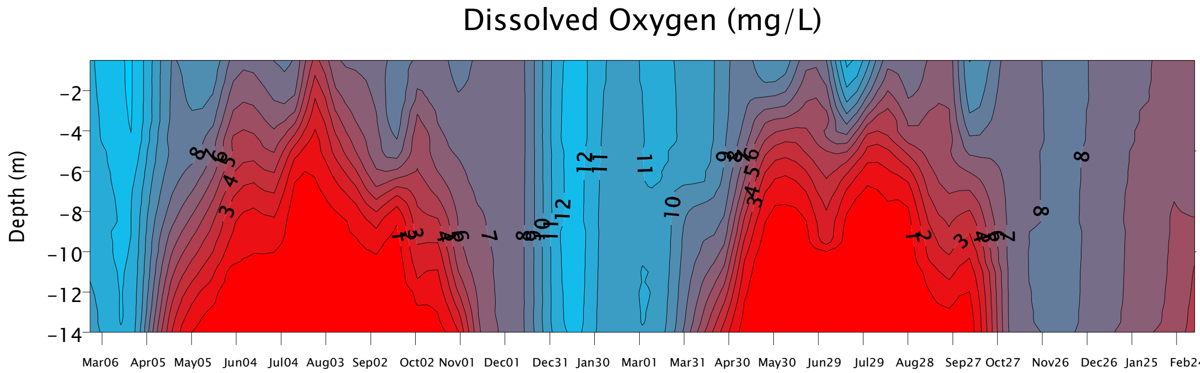
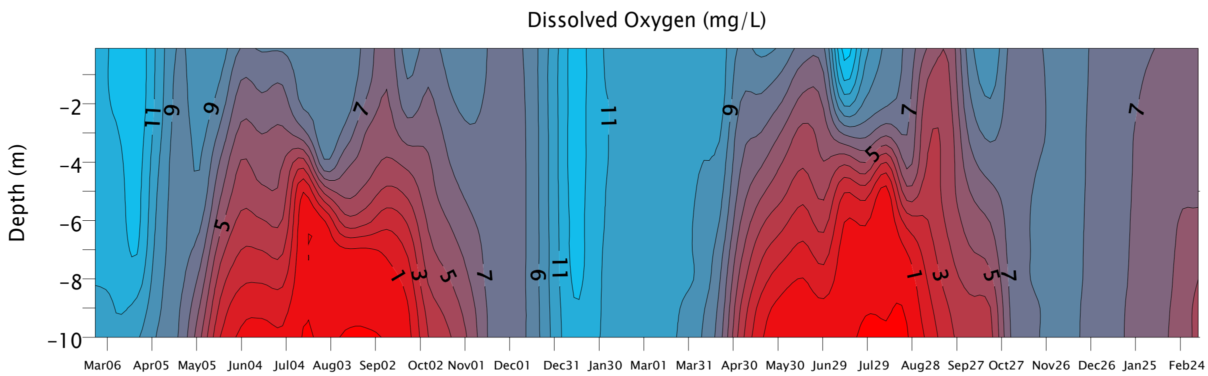


Figure 4-5. Lake Eucha dissolved oxygen (mg/L) April 1998 - March 2000. Upper plot is Site EUC01 followed by EUC02, EUC16 and EUC03.

SPA01



SPA02



SPA05

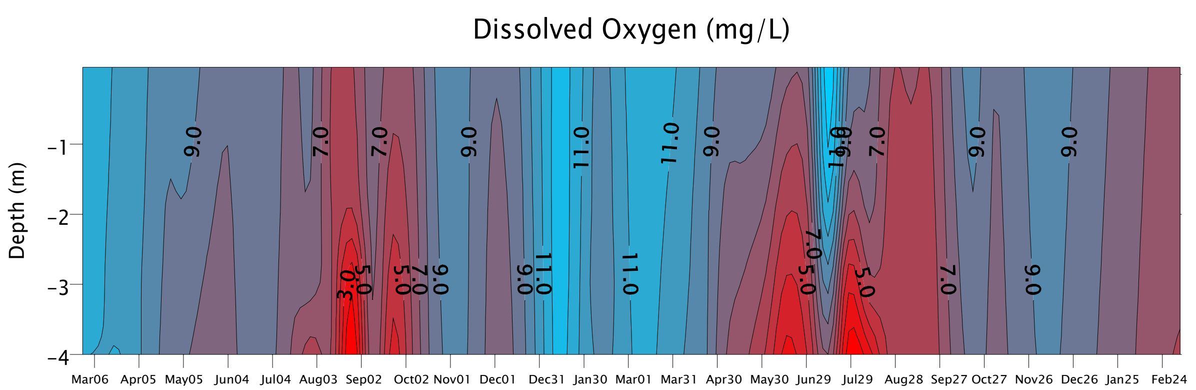
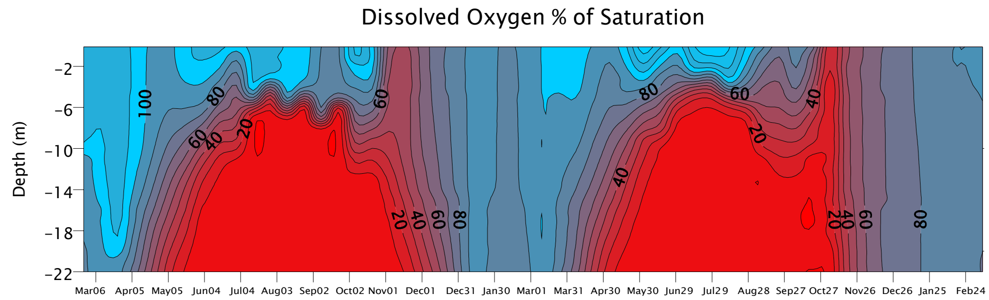
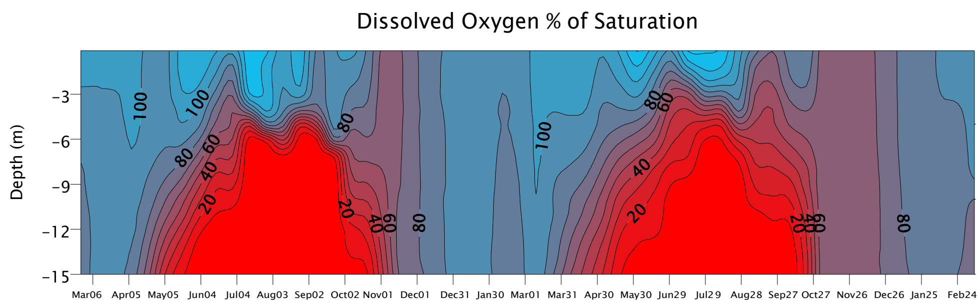


Figure 4-6. Spavinaw Lake dissolved oxygen (mg/L) April 1998 - March 2000. Upper plot is site SPA01 foowed by SPA02 and SPA05.

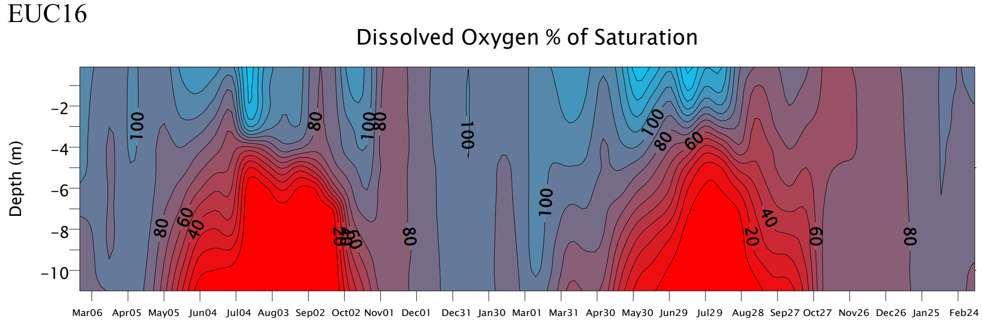
EUC01



EUC02



EUC16



EUC03

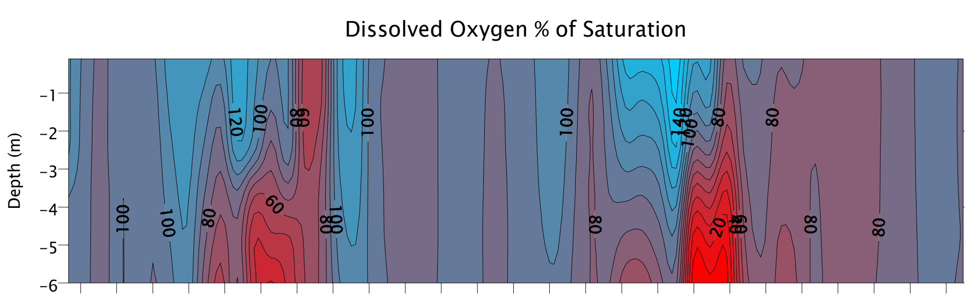
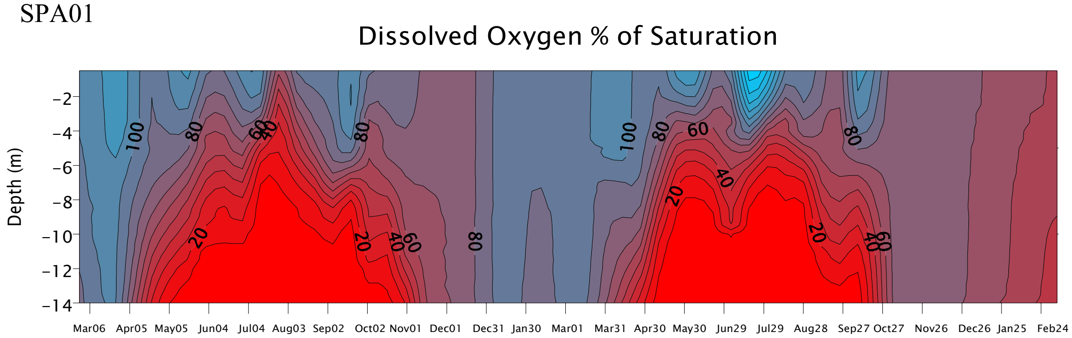
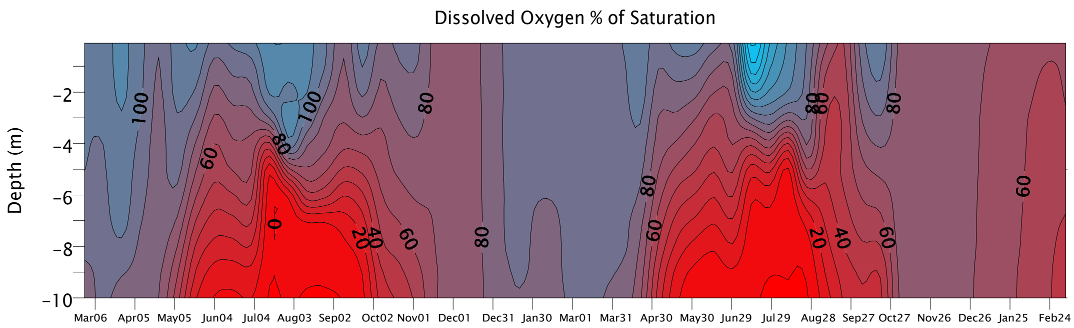


Figure 4-7. Lake Eucha dissolved oxygen percent of saturation April 1998 - March 2000. Upper plot is Site EUC01 followed by EUC02, EUC16 and EUC03.

SPA01



SPA02



SPA05

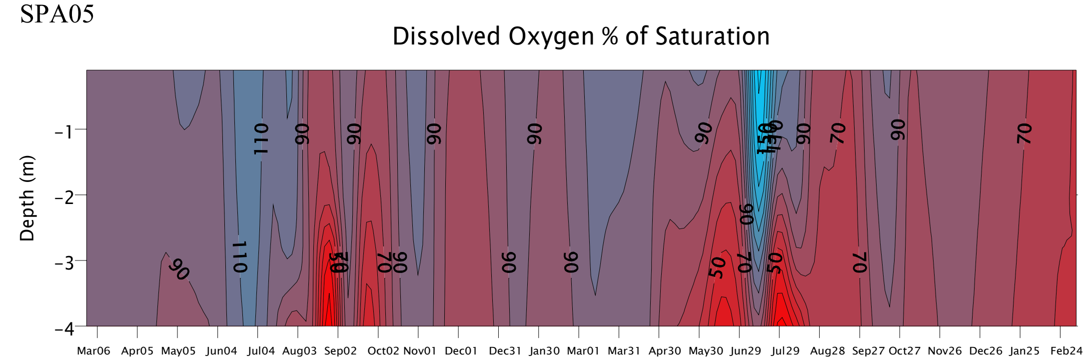
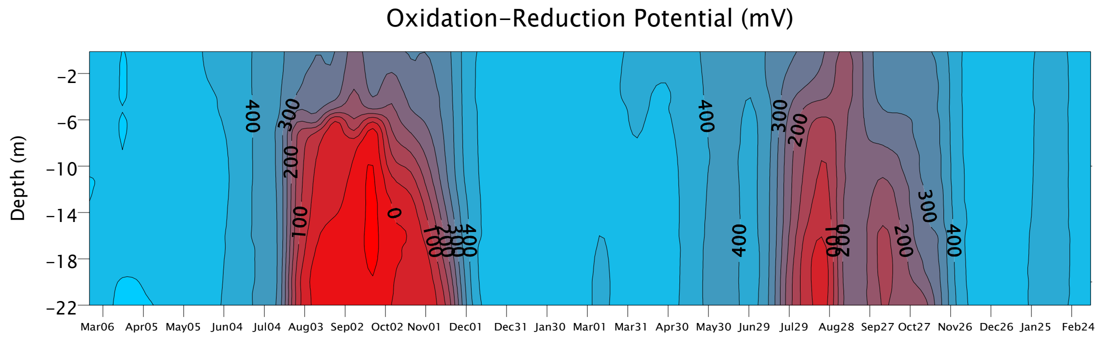
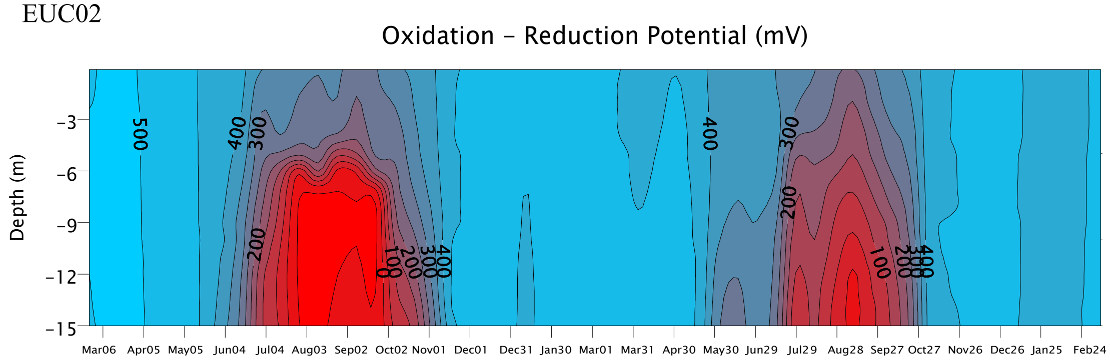


Figure 4-8. **Spavinaw Lake dissolved oxygen percent of saturation April 1998 - March 2000. Upper plot is site SPA01 foowed by SPA02 and SPA05.**

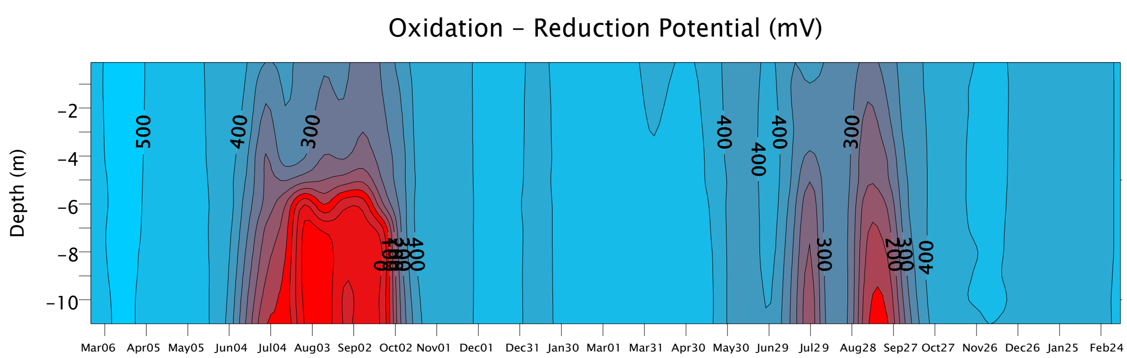
EUC01



EUC02



EUC16



EUC03

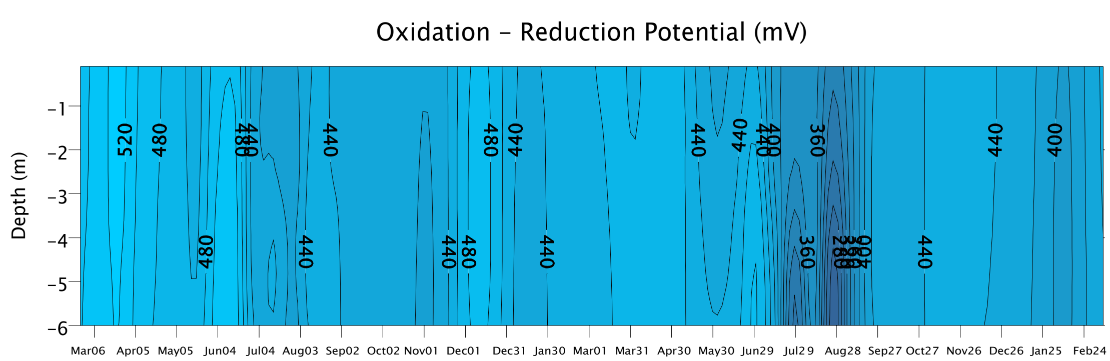
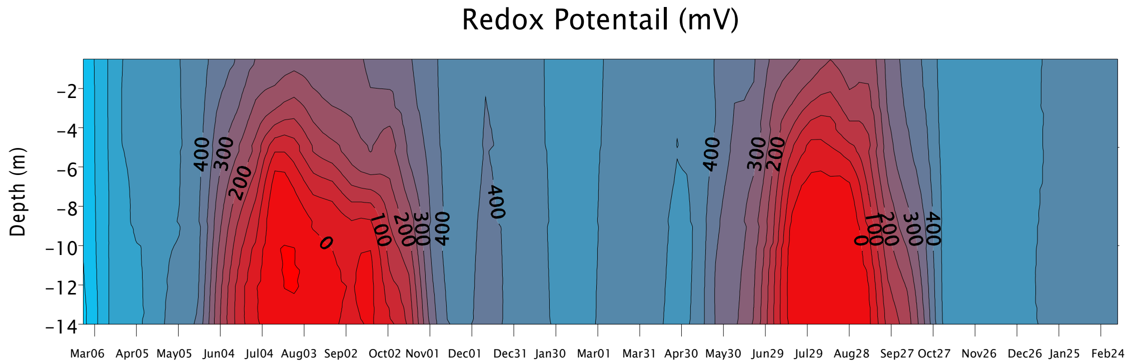
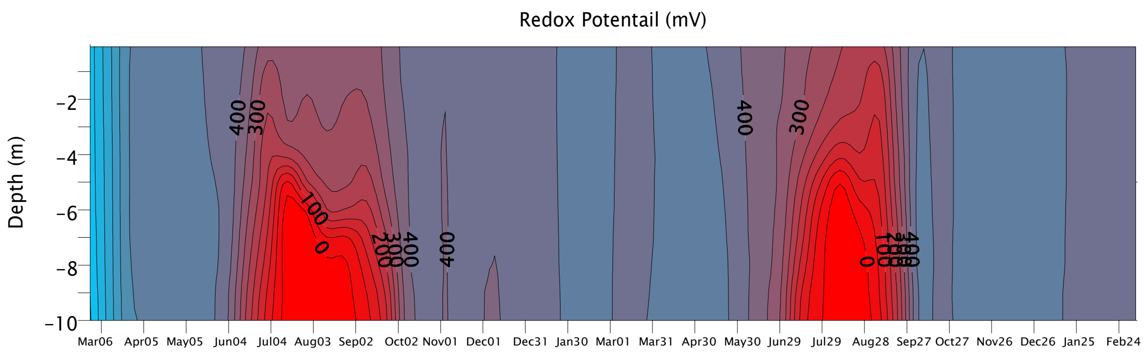


Figure 4-9. Lake Eucha redox potential April 1998 - March 2000. Upper plot is Site EUC01 followed by EUC02, EUC16 and EUC03.

SPA01



SPA02



SPA05

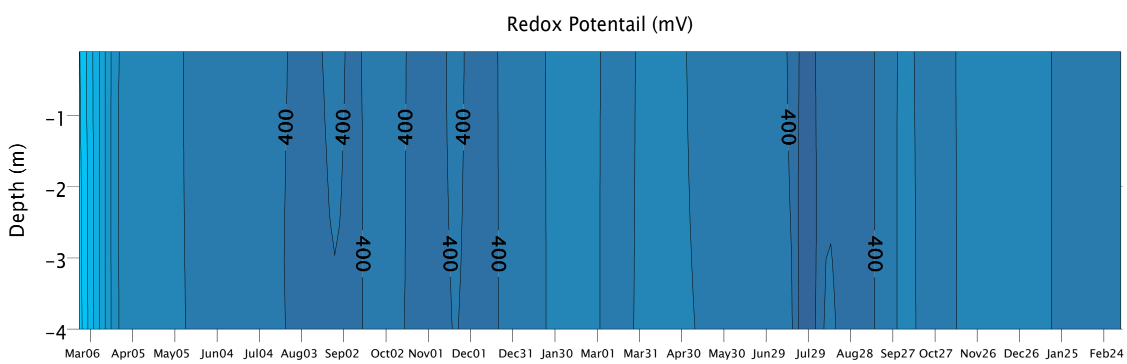


Figure 4-10. Spavinaw Lake redox potential April 1998 - March 2000. Upper plot is site SPA01 foowed by SPA02 and SPA05.

Phosphorus: Spatial differences in nutrient concentrations were noted among sites in both lakes, similar to those seen in turbidity measurements. Lake Eucha phosphorus concentrations increased as samples moved upstream from the area of the dam (0.022 mg/l, range = .005 - .053) to a high of 0.034 mg/l in the riverine zone (range = .010 - .099). Orthophosphate had similar patterns, although the degree of variation was less. These phosphorus spatial patterns are easily discernable and are presented in Figure 4-11, a plot of total phosphorus and orthophosphate concentrations in Lake Eucha.

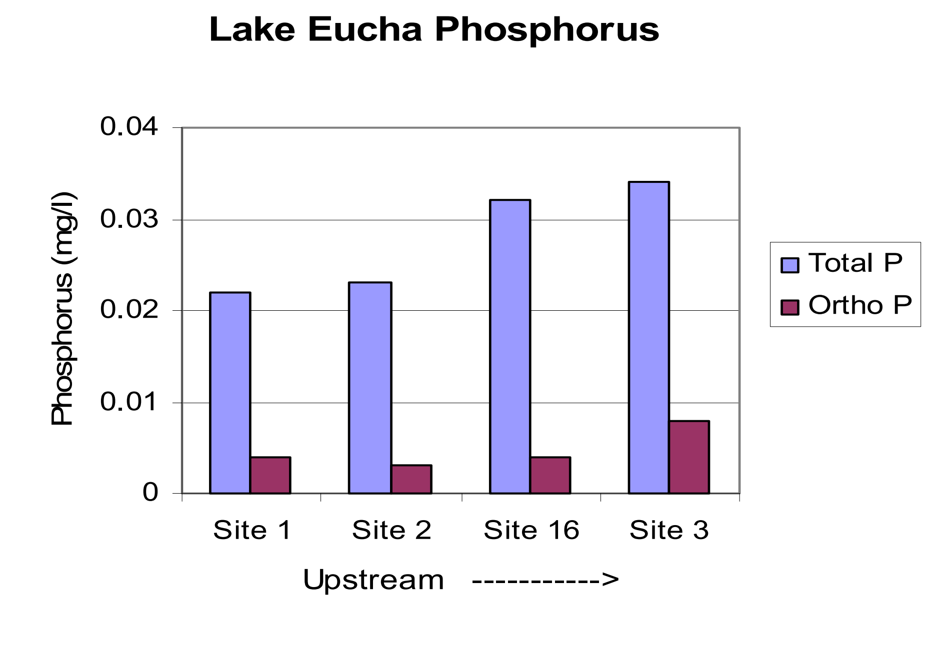


Figure 4-11 Mean phosphorus concentrations in Lake Eucha from April 1998 through March 2000.

Phosphorus concentrations also varied throughout time and depth. A build up of phosphorus was noted in the hypolimnion (Figure 4-12). In general, hypolimnetic accumulation of phosphorus occurs through the settling of detritus from the metalimnion and the lake sediment. The orthophosphate isopleth shows hypolimnetic phosphorus accumulation in Lake Eucha due to sediment release of orthophosphate. Figure 4-3 shows sediment phosphorus release is concurrent with hypolimnetic anoxia. The process of dissolved phosphorus flux into the epilimnion is not readily evident. The fate of sediment released nutrients will be examined in the last section of this chapter: Sediment Nutrient Load.

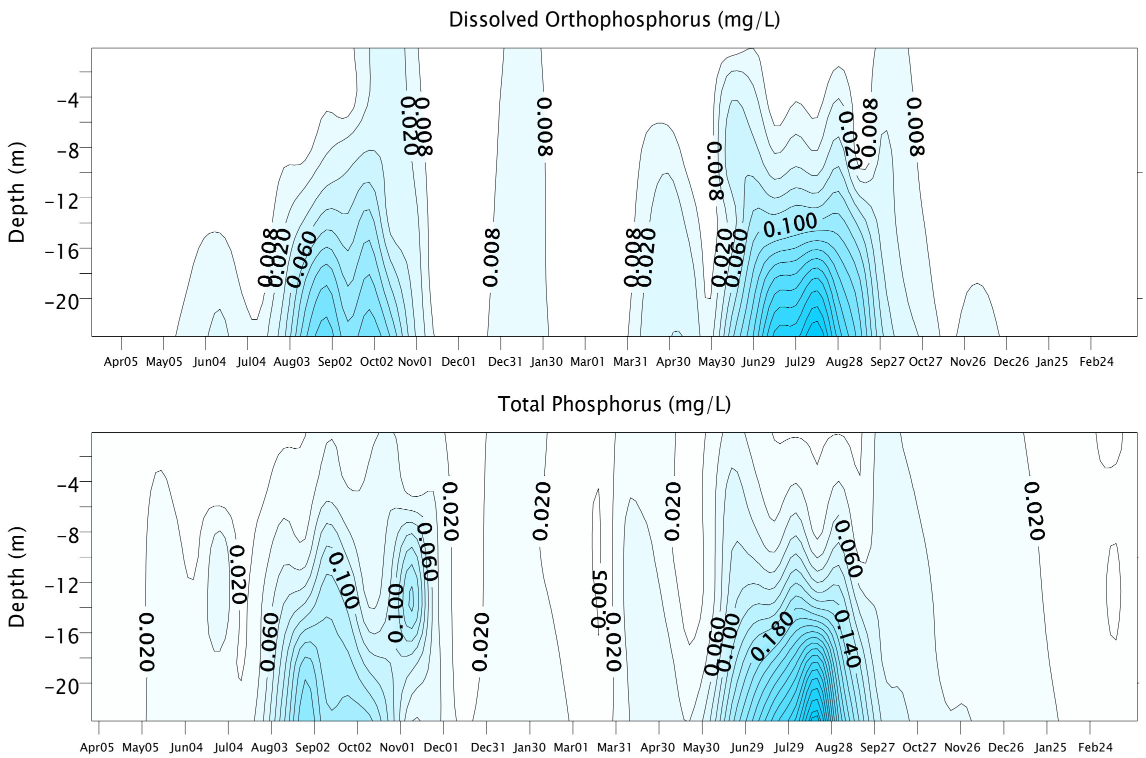


Figure 4-12. Lake Eucha Site 1 phosphorus isopleths April 1998 - March 2000.

Spatial differences in nutrient concentrations were also noted among sites in Spavinaw Lake. Mean total phosphorus concentrations in Spavinaw Lake ranged from a low of 0.017 mg/l at Site 1 (range = .005 - .037), near the dam, to a maximum of 0.07 mg/l in the transitional area at Site 5 (range = .005 - .094).

Spavinaw Lake phosphorus concentrations also varied throughout time and depth. A build up of phosphorus was noted in the hypolimnion (Figure 4-13). In general, hypolimnetic accumulation of phosphorus occurs through the settling of detritus from the metalimnion, lake sediment, and release of phosphate rich water Lake Eucha water. The orthophosphate isopleth shows hypolimnetic phosphorus accumulation in Lake Eucha due to sediment release of orthophosphate. Hypolimnetic Lake Eucha releases did not follow the consistent seasonal build up of phosphorus noted in Figure 4-13. This supports sediment phosphorus release concurrent with hypolimnetic anoxia.

Total phosphorus can be separated into inorganic and organic fractions. Of the total organic phosphorus in lakes, about 70 percent is within the particulate organic material, principally algae. The remainder is present as dissolved and colloidal organic phosphorus. Within the epilimnion, approximately 95 percent of the total phosphorus is present in particulate form. The remainder is present as reactive inorganic soluble orthophosphate (PO_4^{-3}), low molecular weight organic phosphorus compounds, and soluble high molecular weight colloidal phosphorus. Orthophosphate has a very short turnover time. Inorganic orthophosphate is the form that is chemically available for algal growth. Consequently, almost all of the phosphorus occurring in lakes is biologically unavailable until it undergoes bacterial degradation. The bacteria function as particulate

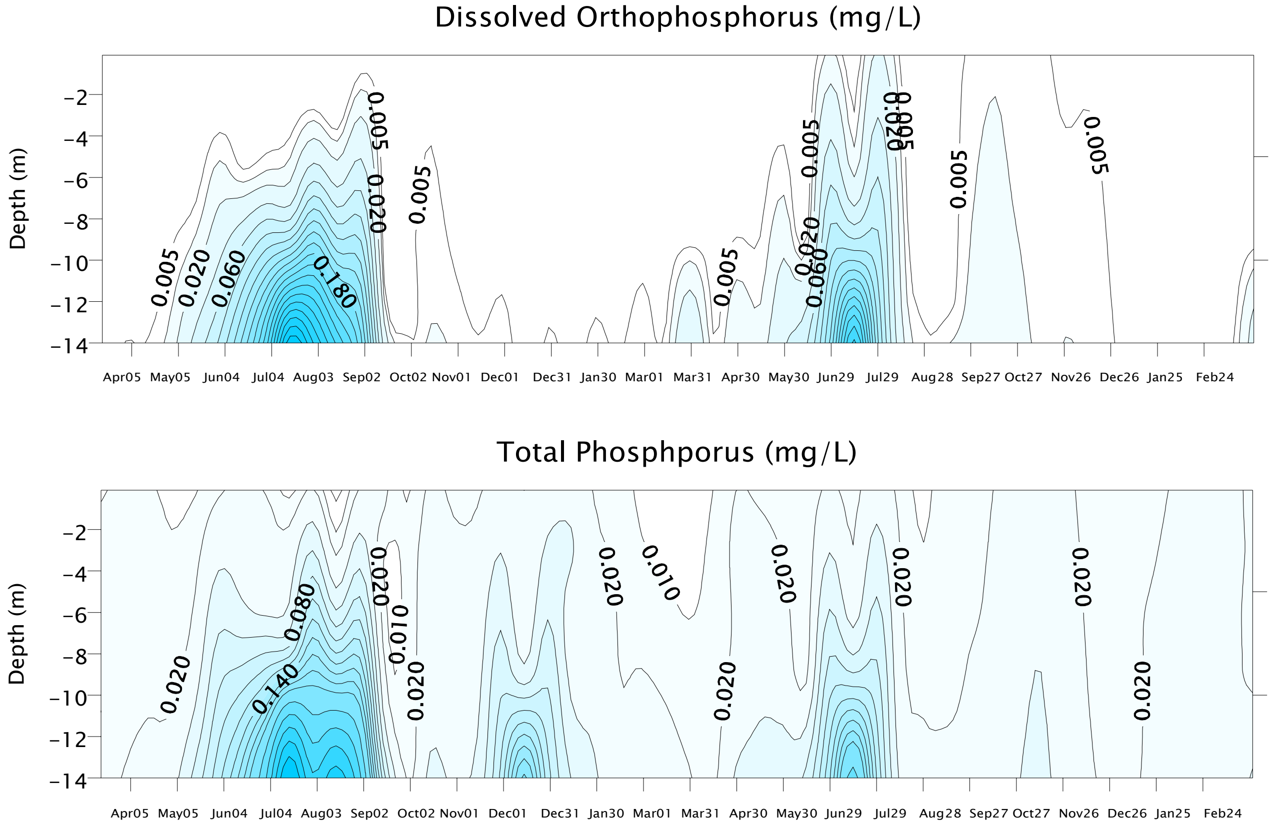


Figure 4-13. Spavinaw Lake Site 1 phosphorus isopleths April 1998 - March 2000.

phosphorus intermediaries in the degradation of dissolved organic phosphorus to dissolved inorganic phosphorus . Phosphorus dynamics are further complicated by thermal stratification. Lake sediments contain much higher concentrations of phosphorus than the water (Olsen, 1958, 1964; Holden, 1961; Hepher, 1966). Under aerobic conditions and when a lake is not stratified, phosphorus exchange equilibria are largely unidirectional toward the sediments. Therefore, during most of the year, phosphorus is continuously deposited on the lake bottom. Under the anaerobic conditions that form in the hypolimnion during stratification, sediment exchange is strongly influenced by redox conditions and considerable amounts of phosphorus are released to the lake water. The presence of a metalimion restricts the amount of phosphorus that is able to move to the areas of algal production in the epilimnion of a lake. This is one reason that external phosphorus sources are important in sustaining large algae populations during summer stratification. An additional source of available phosphorus during summer is provided by conversion of colloidal and particulate forms in the epilimnion and by some resuspension of shallow bottom sediments.

Nitrogen: In Lake Eucha, total nitrogen ranged from 1.12 mg/l at the dam (range = .076 – 2.73) to a high of 1.76 mg/l in the upper portion of the lake (range = .024 – 3.99). Nitrate had similar increases with increasing distance from the dam (0.625, 0.706, 0.845, 1.39). Figure 4-14 graphically demonstrates this phenomenon in Lake Eucha.

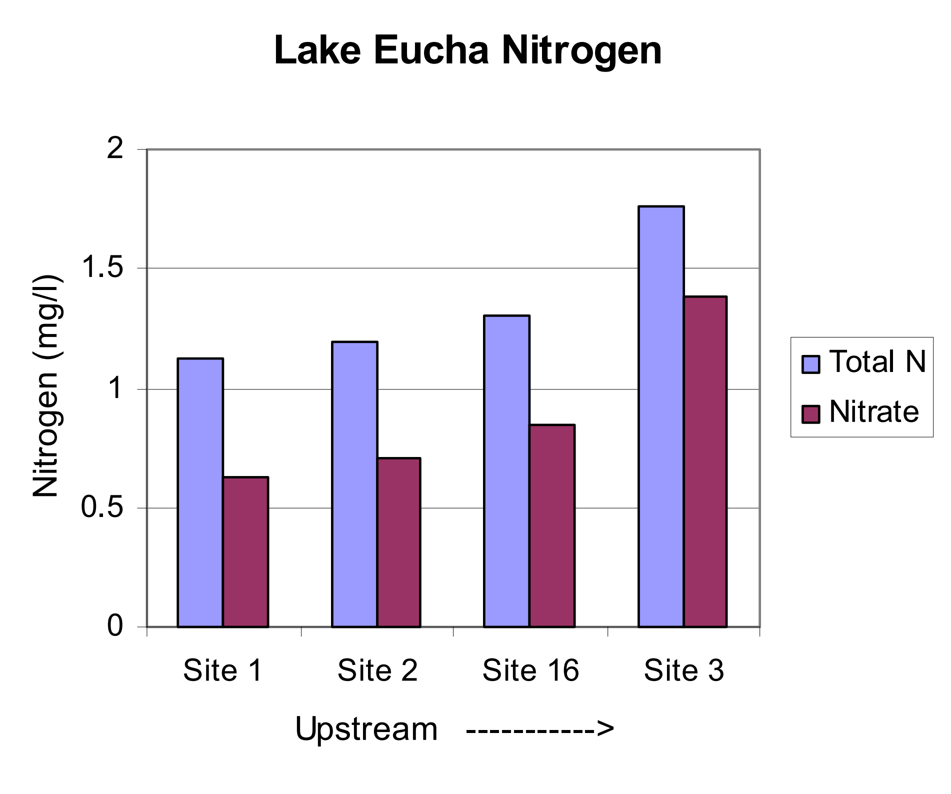


Figure 4-14. Mean nitrogen concentrations in Lake Eucha from April 1998 through March 2000.

Nitrogen concentrations also varied throughout time and depth. Total nitrogen showed hypolimnetic maximums each summer. A maximum was also reached during isothermal conditions (December 1998 – January 1999). These maximums are explained by observing the distributions of dissolved nitrogen: nitrate and ammonia. A build up of nitrogen was noted in the hypolimnion (Figure 4-15). Hypolimnetic maximum is due to sediment release of ammonia while the winter isothermal maximum is due to influent nitrate.

Nitrate levels in Lake Eucha were depleted approximately three months following stratification. Epilimnetic depletion preceded hypolimnetic depletion (Figure 4-15). Epilimnetic nitrate consumption is generally a function of uptake for plant growth. Nitrate uptake by algae follows the depletion of available ammonia. Hypolimnetic consumption of nitrate is generally as an oxidant source for bacterial respiration. Comparing redox potential (Figure 4-9) to nitrate concentration shows nitrate depletion in the hypolimnion is concurrent with redox potential below 100mV. Lake Eucha in September 1998 and July 1999 show the effect of epilimnetic nutrient utilization (for algae growth) and hypolimnetic oxidant consumption (as bacterial respiration). Concentration of nitrates

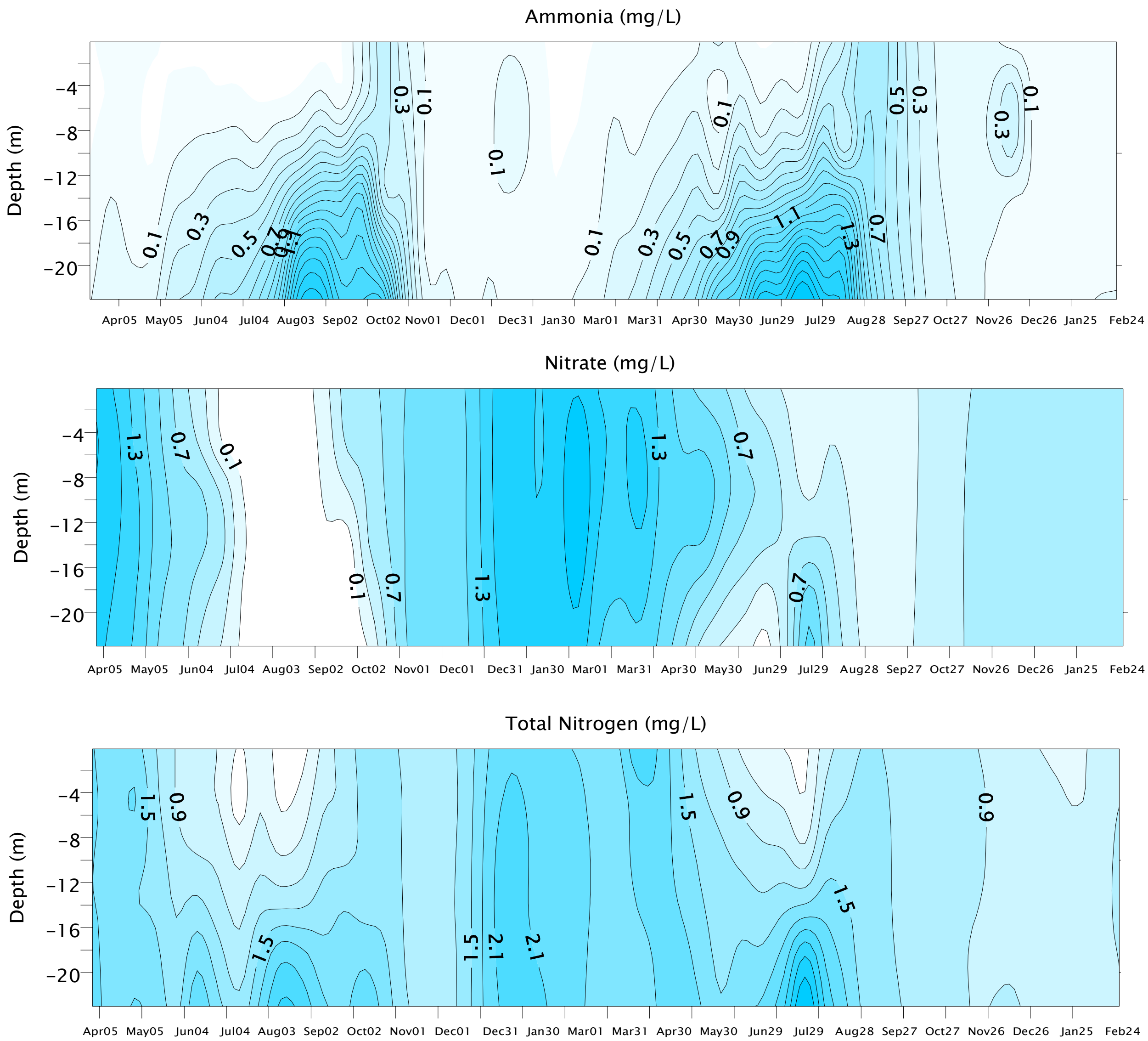


Figure 4-15. Lake Eucha Site 1 nitrogen isopleths April 1998 - March 2000.

increased following destratification. Sources of nitrate to both lake systems are groundwater and tributary inflow.

Ammonia release from the lake sediment is evident in Lake Eucha (Figure 4-16). The timing of this nutrient release is directly linked to the onset of hypolimnetic anoxia. The increase of epilimnetic ammonia closely follows sagging dissolved oxygen levels in the fall.

Mean nitrogen concentrations in Spavinaw Lake showed a similar spatial pattern to Lake Eucha. In Spavinaw Lake, total nitrogen ranged from 0.798 mg/l at the dam (range = .062 – 1.62) to a high of 1.13 mg/l in the transitional zone (range = .057 – 4.92). Nitrate nitrogen, the most biologically available form, also ranged linearly from the dam to the upper portion of the lake. The mean values were 0.379, 0.392, and 0.446, moving in an upstream direction. Nitrogen concentrations also varied throughout time and depth

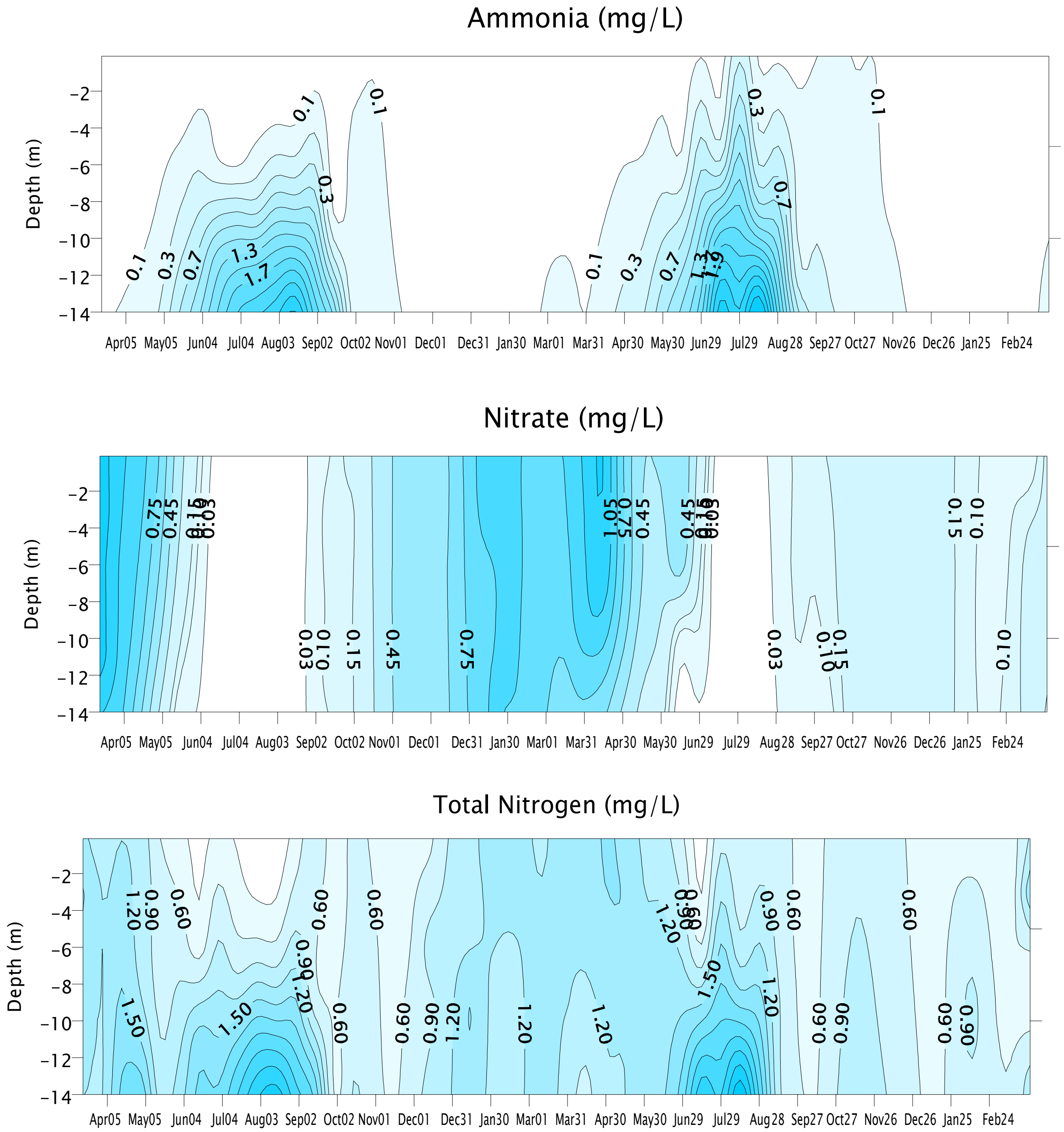


Figure 4-16. Spavinaw Lake Site 1 nitrogen isopleths April 1998 - March 2000.

(Figure 4-16). Total nitrogen showed hypolimnetic maximums each summer. A maximum was also reached during isothermal conditions (December 1998 – January 1999). These maximums are explained by observing the distributions of ammonia. Hypolimnetic maximum is due to sediment release of ammonia while the winter isothermal maximum is due to influent nitrate.

Nitrate levels in Spavinaw Lake were depleted approximately 1½ months following stratification. In 1998, epilimnetic and hypolimnetic depletion was concurrent. In 1999, nitrates were again depleted approximately 1½ months following stratification. Interestingly enough, hypolimnetic depletion preceded epilimnetic depletion by nearly one month (Figure 4-16). Epilimnetic nitrate consumption is generally a function of uptake for plant growth. Nitrate uptake by algae follows the depletion of available ammonia. Hypolimnetic consumption of nitrate is generally as an oxidant source for bacterial respiration. Comparing redox potential (Figure 4-10) to nitrate concentration (Figure 4-16) shows nitrate depletion in the hypolimnion concurrent with redox potential below 100mV. Spavinaw Lake in September 1998 and June 1999 shows the effect of epilimnetic nutrient utilization (for algae growth) and hypolimnetic oxidant consumption (as bacterial respiration). Concentration of nitrates increased following destratification. Sources of nitrate to both lake systems are groundwater and tributary inflows.

Ammonia release from the lake sediment is evident in Spavinaw Lake (Figure 4-16). The timing of this nutrient release is directly linked to the onset of depletion of hypolimnetic oxygen. Erosion of the thermal gradient between the epilimnion and hypolimnion in the fall resulted in hypolimnetic ammonia being distributed in the epilimnion. Sediment releases of ammonia ceased with fall turnover.

The nitrogen cycle in lakes is more complex than that for phosphorus. Nitrogen occurs in fresh waters in many forms: dissolved molecular N_2, large numbers of organic compounds, ammonium (NH_4^+), nitrite (NO_2^-), and nitrate (NO_3^-). Plant nitrogen uptake for cellular growth is preferential, starting with ammonium, then nitrate, and finally elemental nitrogen (dinitrogen). This preferential plant uptake combined with aerobic nitrification usually keeps epilimnetic ammonia concentrations below detection limit. Although ammonia is a good source of nitrogen for algae, some algae and submersed macrophytes grow better with nitrate as their nitrogen source. As nitrate is assimilated by algae, it is reduced to ammonia.

Sources of nitrogen include precipitation on the lake surface, nitrogen fixation in the water and sediments, and inputs from surface and groundwater drainage. Losses occur by lake outflow, reduction of nitrate to N_2 by bacteria with subsequent return to the atmosphere, permanent loss of both inorganic and organic forms to the sediments, and by fish harvest. The cycling of nitrogen in lakes can be greatly altered by increased sedimentation due to increased water retention time. This is apparently the situation in Lake Eucha and, to a lesser extent, Spavinaw Lake, as evidenced by the decreasing concentrations of total nitrogen and nitrate as one moves downstream toward the dams.

Dissolved Silica: In Lake Eucha, spatial differences among sites were significant. Site 3, in the upstream riverine zone, was significantly higher in silica than the other three lake sites (Figure 4-17). Lake Eucha dissolved silica showed annual cycling (Figure 4-18) with silica below detection limit each winter. Lake Eucha indicated wintertime depletion of dissolved silica in the winter of 1998 – 1999, but not in the winter of 1999 – 2000. Lake Eucha also showed higher dissolved silica concentrations in the summer of 1999 then in 1998. Smaller diatom populations and/or continuous recharge of dissolved silica from the basin could explain higher concentations in 1999-2000. Dissolved silica depletion by diatoms did occur each late winter/early fall.

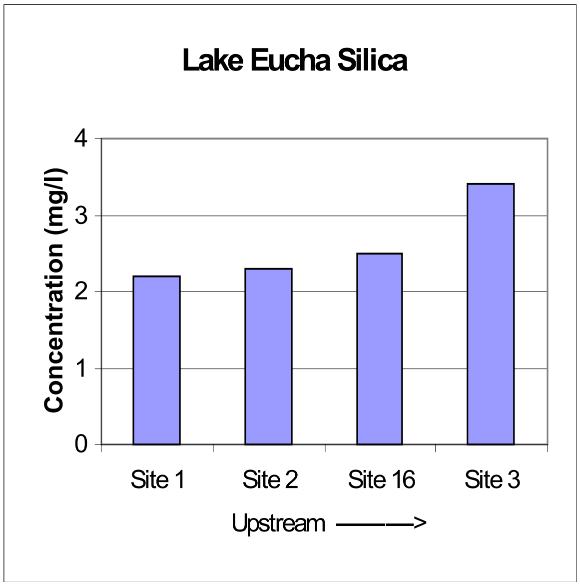


Figure 4-17. Mean silica concentrations in Lake Eucha from April 1998 through March 2000

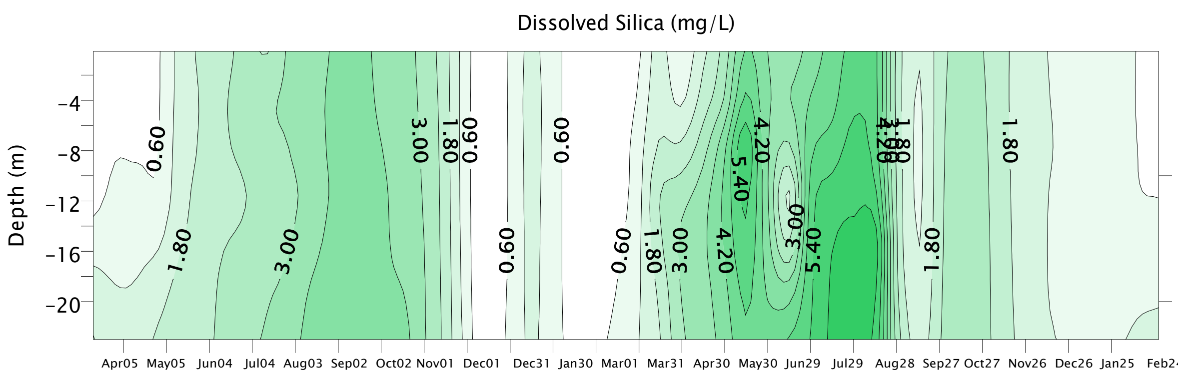


Figure 4-18. Lake Eucha dissolved silica concentration April 1998 – March 2000.

Silica concentrations did not vary significantly among sites in Spavinaw Lake. Site 1, at the dam, silica ranged from 0 – 5.3 mg/l (mean = 2.2). At Site 5, the mean silica was 2.4 mg/l (range 0.3 – 5.1). Spavinaw Lake dissolved silica showed annual cycling (Figure 4-19) with silica below detection limit each winter and the highest concentrations during 1999 stratification. Above detection limit reports first appeared in the hypolimnion of Spavinaw Lake. During stratification, silica seemed to be solubilized from the sediment of Spavinaw Lake. Groundwater is another dissolved silica source. Hypolimnetic dissolved silica maximum indicates that silica may be a limiting nutrient for diatom growth in Spavinaw Lake. Unfortunately the detection limit (0.5 mg/L) was greater than the limit established by Welch (personal communication) of 0.23 mg/L. Replenishment of silica to Spavinaw Lake also comes from tributary inflow, groundwater, and Lake Eucha.

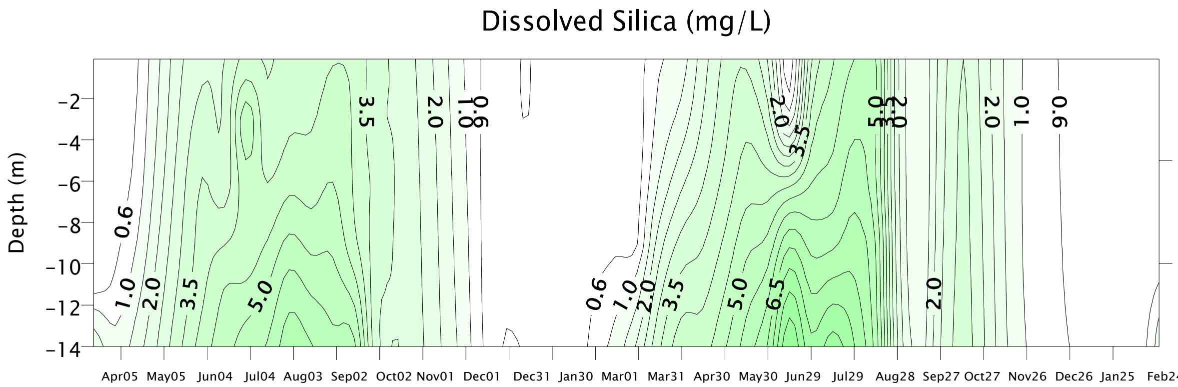


Figure 4-19. Spavinaw Lake dissolved silica concentration April 1998 – March 2000.

Silica, as SiO_2, occurs in natural waters as suspended particles, as colloidal or polymeric forms, and as silicic acids or silicate ions. A major component of particulate silica is found in biotic material, particularly diatoms and a few other organisms that use large amounts of silica. The extent of loadings from watershed sources varies directly with the type of substrate in the drainage. The higher concentration of silica at the riverine site in Lake Eucha was due to watershed runoff that was independent of time of year.

Nitrogen/Phosphorus Ratio: Lake Eucha showed consistently high ratio of total nitrogen to total phosphorus predicting phosphorus limitation (Figure 4-20). A brief dip in the ratio during late June of 1999 predicts a short period of nitrogen limitation in Lake Eucha. Interestingly enough, both dissolved nitrogen (nitrate) and dissolved phosphorus (orthophosphorus) were detectable in Lake Eucha epilimnion in June 1999. During this same time period, chlorophyll-a concentrations were at a peak for the entire monitoring period (90 µg/L) with a subsequent low secchi depth. In this case, the low nitrogen/phosphorus ratio may be an indicator of phosphorus cycling through at a faster rate than nitrogen.

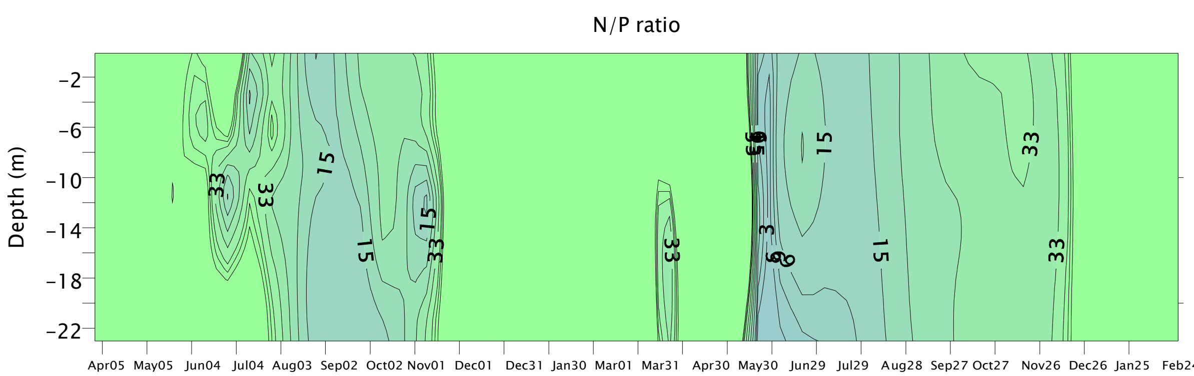


Figure 4-20. Lake Eucha Calculated Total-N/Total-P ratio April 1998 - March 2000.

Spavinaw Lake showed consistently high ratios predicting phosphorus limitation (Figure 4-21). Spavinaw Lake had a period of low ratio in June of 1998 and early July of 1999. Spavinaw Lake epilimnetic nitrate, ammonia, and orthophosphorus were all below detection limit in June 1998. Low levels show uptake of both (phosphorus and nitrogen) exceeding supply. This also indicates that nitrogen may have been the limiting nutrient during this period. The brief low ratio seen in late June and early July of 1999 shows significant ammonia in the water column. This is likely due to large water releases from Eucha Dam and thus the N/P ratio was not a good indicator of nitrogen limitation by algae.

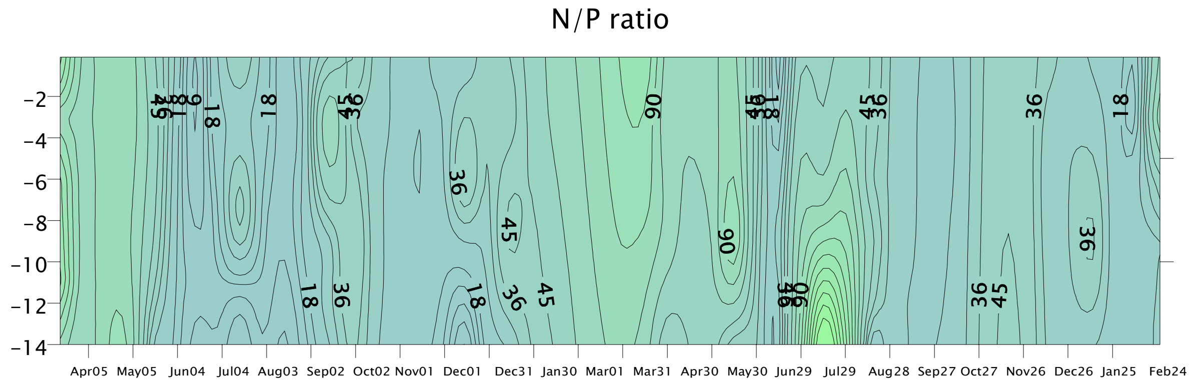


Figure 4-21. Spavinaw Lake Calculated Total -N/Total-P ratio April 1998 - March 2000.

Both lakes exhibited phosphorus limitation most of the time. N:P ratios usually exceeded 14:1 and varied somewhat among lacustrine versus transitional sampling locations. N:P ratios were highest in the transitional sites in both lakes, but any effects of those differences are probably negligible. In highly eutrophic lakes like Eucha and Spavinaw, the concept of phosphorus limitation should not be confused with constraints on total algae population size. Regardless of which nutrient restricts algae growth it is the magnitude of nutrient supply that determines the maximum algal biomass. In this case total phosphorus concentration is the determining factor. Nitrogen may be limiting briefly during early summer but high availability of phosphorus drove nitrogen ratio down until phosphorus cycled faster than nitrogen. Cycling from unavailable to available forms and other strategies such as luxury uptake appear to contribute ample phosphorus to maintain the high populations. Nutrient limitations in eutrophic lakes are more important in determining the characteristics of the algal community, i.e., which type dominates the total population. When blue-green algae become the dominant algal form, the importance of nutrient limitation becomes more obvious. For example nitrogen limitation favors nitrogen fixing blue-greens.

Biological Evaluation

Several biotic measures were employed to evaluate the database; water transparancy, trophic state indices, algae abundances, zooplankton abundances and aquatic plant distribution. Each are independently examined and then portions used to synthesize a comprehensive view of each lake. OWRB staff evaluated water transparency, trophic state indices and aquatic plant distribution. Phycotech and BSA, Inc. performed algae and zooplankton identification respectively. Phycotech also performed the technical evaluation of both algae and zooplankton data sets. Appendix G is the completed zooplankton and algae evaluative report prepared by Phycotech. Figures 3-3 and 3-4 in the previous section of this report represent the location of sample sites and mapped macrophtye distribution.

The longitudinal gradients noted in the historical data were checked against current limnological data. Results of current data evaluation assigned each site into one of the three traditional reservoir zones; riverine, transition or lacustrine (Thornton et al., 1990). The riverine zone is characterized as a headwater region of the reservoir where flow velocities rapidly slow down. The change in flow is usually associated with the settling of course particulates such as leaves, stems, twigs and logs. This area is usually aerobic and well mixed throughout the year. The transition zone represents where more organic matter is generated within the lake then what washes in from the riverine zone. The transition zone also represents the transition from more "river-like" characteristics to more "lake-like" or lacustrine characteristics. As the term implies the lacustrine zone is characteristic of a lake system with a separation between upper and lower lake layers and generally clear water quality. It is in the lacustrine zone that nutrient limitation is most often observed.

Water Transparency

Several measures of transparency were taken over the course of this project. For both Lake Eucha and Spavinaw Lake, water transparency, or clarity, is inversely proportional to algae content. This relationship can allow for fast, inexpensive measures of clarity, such as Secchi depth, to estimate algae or chlorophyll-a content. Previous research has shown that the reduction in light transmission in relation to Secchi transparency is associated in large part with increased light scattering by particulate matter suspensoids, including algae (Stepanek, 1959; Szczepanski, 1968). This is particularly true in very productive lakes such as Spavinaw and Eucha and was noted in this data. One effect of increased algae growth (eutrophication) will be decreased water clarity and Secchi Depth. In a generalized way, Secchi depth can be useful to estimate the approximate density of phytoplankton populations where these populations constitute a large portion of turbidity. These relationships show the value of continuing Secchi depth measurements in any lake management plan.

Mean Secchi depth decreased as distance increases from the dams in both lakes. A pronounced decrease in water clarity among sites was noted at Lake Eucha, with Secchi depth decreasing from a mean of 2.3 m at Site 1 (range = 0.6 – 6.6), near the dam to a mean of 1.2 m (range = 0.6 – 3.8) in the transitional zone at Site 3 (Figure 4-22). One-way ANOVA showed that these differences among sites at Lake Eucha were statistically significant ($p < 0.05$). Mean turbidity followed a similar pattern.

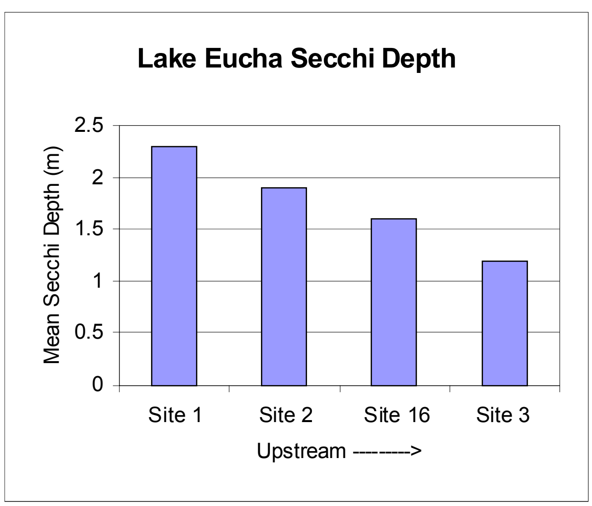


Figure 4-22. Mean Secchi depth at Lake Eucha from April 1998 through March 2000.

In Lake Eucha, mean chlorophyll-a ranged from 16.8 µg/l at Site 1 (range = 1.2 - 88.5) to 19.2 µg/l at Site 3 (range = 0.6 – 54.6), in the riverine zone. These differences among sites were significant (Figure 4-23).

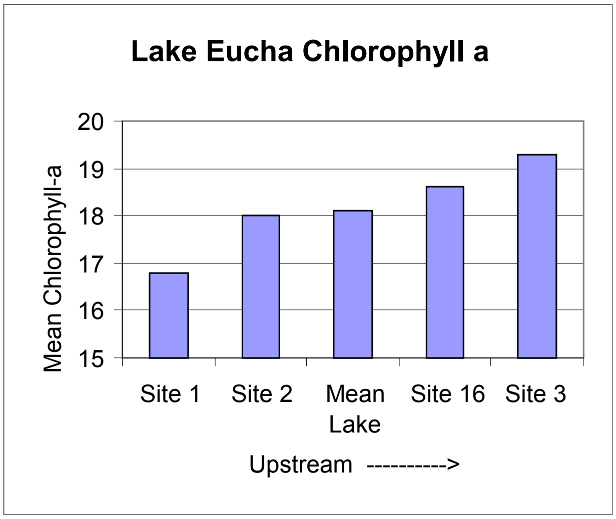


Figure 4-23. Mean chlorophyll-a concentrations as µg/L in Lake Eucha from April 1998 through March 2000. The mean lake site is an average of the three lacustrine sites (1, 2, and 16).

Eucha Lake transparency data showed seasonal trends as well as spatial trends. In Lake Eucha, mean Secchi depth was highest in spring (2.7 m) and was significantly greater than all other seasons (Figure 4-24). Secchi depth was lowest in summer (1.5 m) and was most likely related to higher algae biomass.

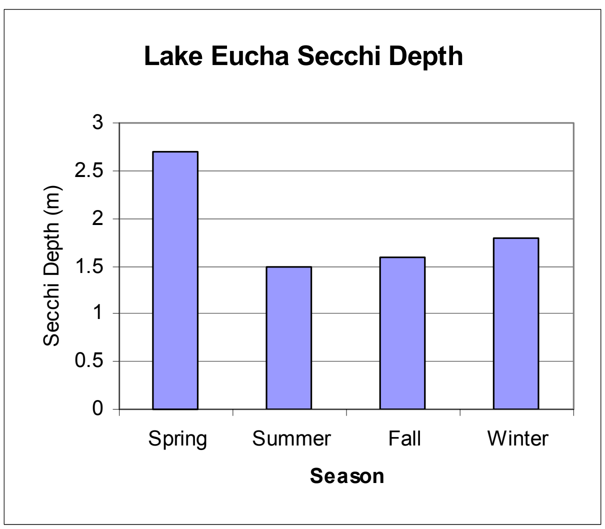


Figure 4-24. Mean seasonal Secchi depth at the lacustrine sites at Lake Eucha during the course of the study.

Mean seasonal chlorophyll-a concentrations in Lake Eucha (Figure 4-25) did not vary significantly. The relatively high values (range 15.8 µg/l – 20.4 µg/l) reflected the persistently high productivity of the lake. The highest chlorophyll-a value during the study (88.5 µg/l) was recorded on June 9, 1999, at the Lake Eucha dam. These chlorophyll-a levels were considerably higher than those in Lake Spavinaw.

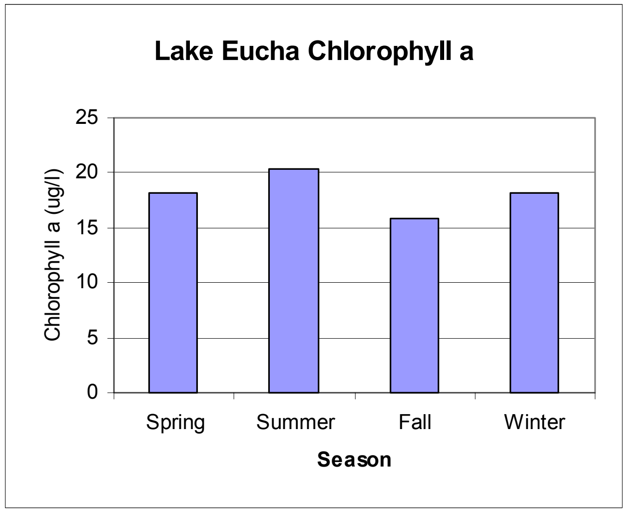


Figure 4-25. Mean seasonal chlorophyll-a concentrations at the lacustrine sites at Lake Eucha during the course of the study.

These analyses were performed on pooled data from the lacustrine and transition sites. Figure 4-26 shows the regression of chlorophyll-a versus turbidity in the lacustrine sites of Lake Eucha spanning the length of the study. The correlation coefficient of 0.77 indicates that a large portion of the variation in turbidity can be attributed to variations in the chlorophyll-a concentrations.

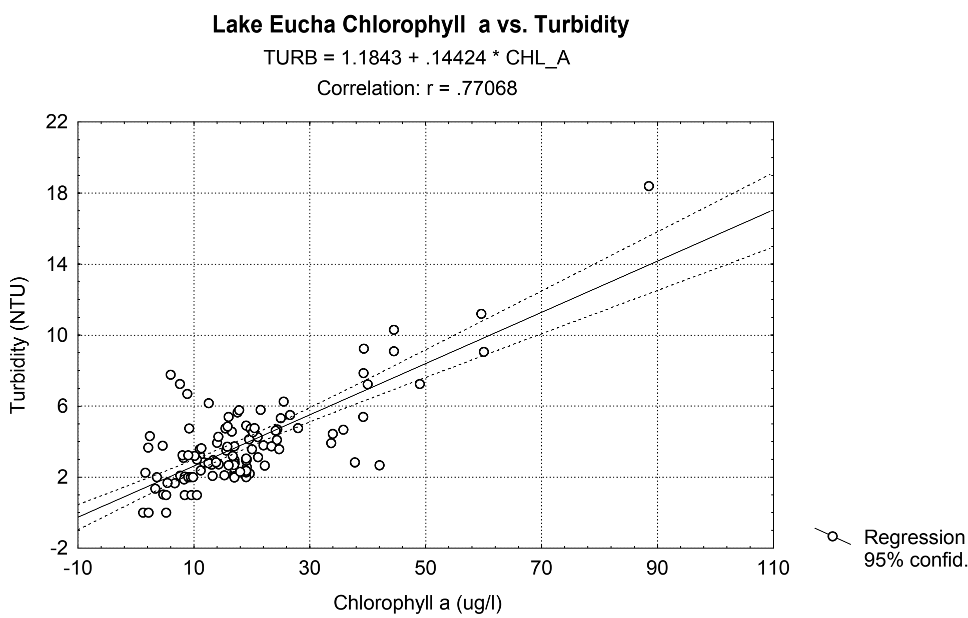


Figure 4-26. Linear regression of chlorophyll-a concentration versus turbidity at Lake Eucha.

In Lake Spavinaw, mean Secchi depth at Site 1, near the dam, was 1.7 m for the study period (range = 1.1 – 3.9). It decreased to 1.6 m at Site 2 (range = 0.8 – 3.4) and was 1.3 m at Site 5 (range = 0.3 – 2.8), located in the upper lake transitional zone. Concurrently, mean turbidity followed a similar pattern, increasing from a mean of 4.1 NTU at Site 1 to a mean of 5.7 at Site 5. Mean chlorophyll-a concentrations showed a similar spatial pattern. Mean chlorophyll-a increased from a minimum of 13.5 µg/l at Site 1 (range = 2.5 - 35.4) to a maximum of 14.8 µg/l at Site 5 (range = 1.6 - 35.2). In Lake

Spavinaw, there were no statistically different seasonal differences in mean Secchi depth, although clarity was greater in winter and spring (Figure 4-27).

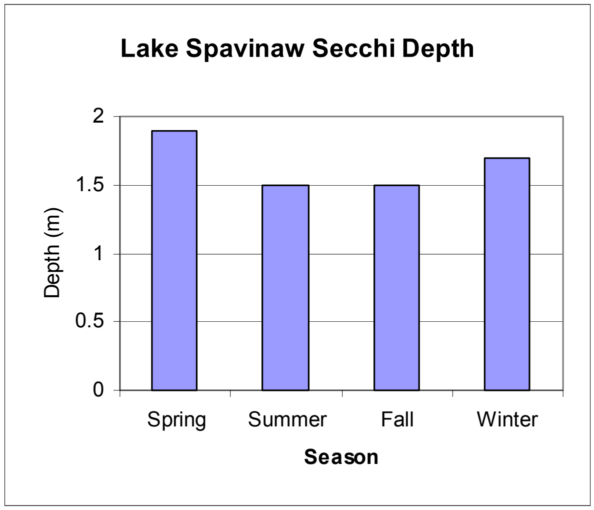


Figure 4-27. Mean seasonal Secchi depth at the lacustrine sample sites in Lake Spavinaw during the course of the study.

Mean Lake Spavinaw chlorophyll-a concentrations also varied among seasons, but not significantly. Concentrations remained fairly high throughout the year and ranged from a mean 11.8 µg/l during winter to a high of 14.9 µg/l during summer. The range of individual values for chlorophyll-a was quite large, with a high value of 35.4 µg/l recorded at Site 1 of Lake Spavinaw. Values were lowest during winter during both years (Figure 4-28). Compared to Eucha Lake, chlorophyll-a concentrations showed less seasonal variability.

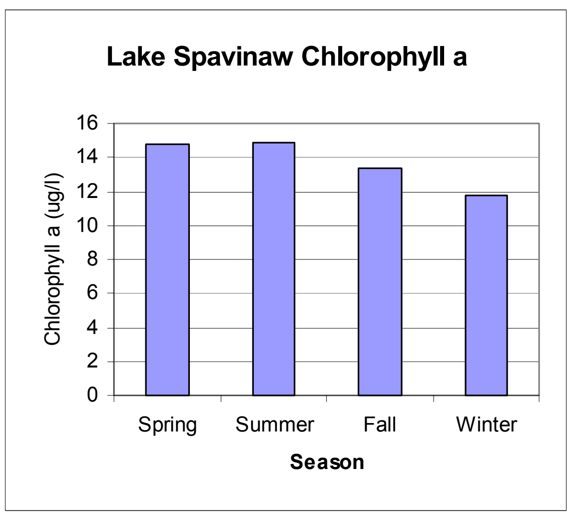


Figure 4-28. Mean chlorophyll-a concentrations at the lacustrine sample sites in Lake Spavinaw during the course of the study.

The relationship between phytoplankton populations and turbidity is demonstrated in Spavinaw Lake by linear regression of chlorophyll-a against Secchi depth. These analyses were performed on pooled data from the lacustrine sites. Figure 4-29 shows the strong inverse relationship between chlorophyll-a concentration and Secchi depth in Lake Spavinaw.

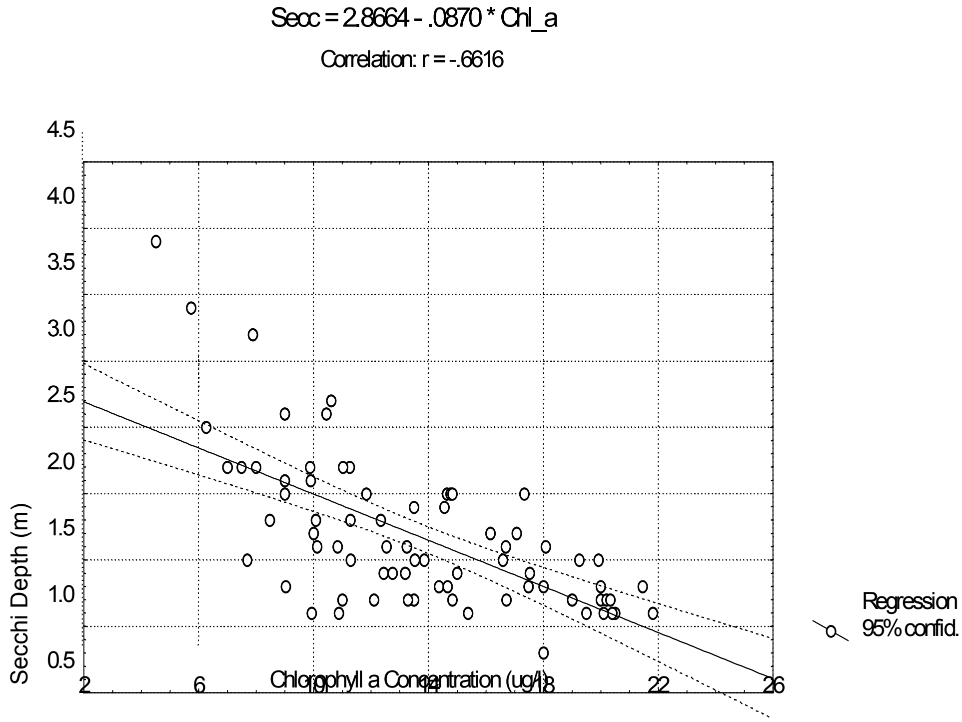


Figure 4-29. Linear regression of chlorophyll-a concentration versus Secchi depth in Lake Spavinaw.

Trophic State Indices

Trophic state indices are commonly used for expressing lake quality in a water body. Carlson (1979) developed a set of indices that uses three separate measures: Secchi depth, chlorophyll-a content, and total phosphorus concentration. The application of Carlson's TSI to a water body allows managers to consolidate water quality information into one value on a scale from 0 -100. This can help to streamline decision-making processes for lake management. Carlson's TSI for Lake Eucha and Spavinaw Lake were calculated from epilimnetic data collected during summer in 1998 and 1999.

Each measure or index was designed to reflect a doubling of phytoplankton biomass for every 10-unit increase in the TSI value, ranging form 0 -100. The chlorophyll-a TSI, TSI(chl), was developed as the most direct and accurate measure of trophic state. The total phosphorus, TSI(TP), serves as a measure of trophic state potential for the water body. Secchi depth, TSI(SD), was developed to directly reflect the trophic status of the water body. The underlying assumption for the application of Secchi TSI is that water transparency is indirectly related to algal biomass. This assumption is valid for waters where turbidity is low and a considerable portion of particulate matter is organic in nature, such as commonly occurs in Lakes Eucha and Spavinaw.

TSI classification of Oklahoma water bodies was set forth by Oklahoma's 1990 Lake Water Quality Assessment (LWQA). Oklahoma lakes with TSI values less than 40 are considered to be oligotrophic (having high clarity and low algae growth). TSI values between 40 and 50 are considered mesotrophic (water moderately clear, transition from oligotrophic to eutrophic). Values between 50 and 60 are eutrophic (relatively cloudy water, high algae growth) and lakes that are greater than 60 are considered hypereutrophic (low water clarity, excessive algae growth). The Oklahoma LWQA assigns the months of April through September as the algae growing season for TSI designations.

TSI data for these lakes can determine whether differences exist among sites at each lake and also can determine how runoff from Lake Eucha affects Lake Spavinaw. Box and whisker plots were generated and data analyzed using Fisher's individual error rate. Box and whisker plots graphically depict the range of a given data set and its distribution. In each box, the statistical median or 50th percentile is indicated by the middle horizontal bar, the mean by a solid red dot and the 25th and 75th percentiles range to the top and bottom bars of the box. The vertical bars, or whiskers, indicate the general extent of the data, and asterisks indicate outlier or extreme values. By comparing the box and whisker plots one can more easily see differences among sites. Statistical differences can be tested using analysis of variance (ANOVA).

Eucha Lake

In the course of data evaluation a significant difference was noted between the two sample years: April 1998 – March 1999 (1999) and April 1999 – March 2000(1999). Data evaluation and presentation has been segregated accordingly. TSI values across the lake were pooled to a lake-wide overview of TSI indices. All three indices were determined to be significantly different (using analysis of variance) during each year. Of the 1998 TSI indicators TSI(chl) and TSI(SD) showed a tendency for eutrophy, with mean values of 54.2 and 50.3, respectively (Figure 4-30). Total phosphorous TSI values showed a tendency toward mesotrophy with a mean of 45.7. Of the 1999 TSI indicators TSI(SD) and TSI (TP)showed a tendency for eutrophy with means of 56.6 and 52.5 while chlorophyll-a data indicated hypereutrophy with a mean of 61.3 (Figure 4-31). The lower P-TSI values for both 1998 and 1999 suggest that excess nutrient levels for algal growth during this period. The slight under prediction of TSI by secchi depth could also indicate that large particulates might be dominating the lake's turbidity. However, since both secchi disk and chlorophyll-a values are within the eutrophic range, there appears to be good agreement among the values. This indicates that algae concentration is an important constituent of Eucha Lake water transparency.

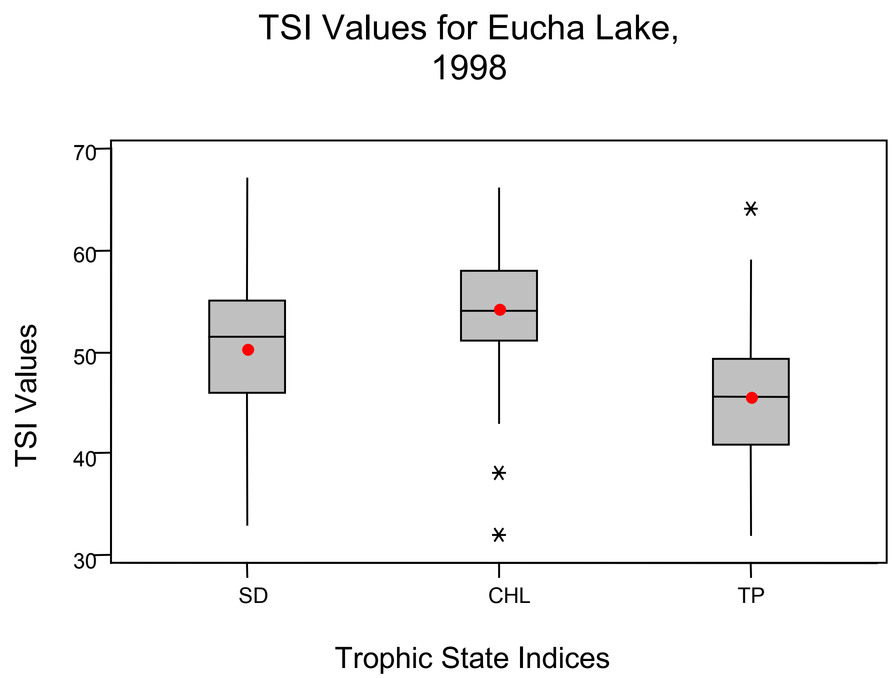


Figure 4-30. Comparison of Eucha Lake trophic state indices for water year 1998 (April 1998 – March 1999).

The middle horizontal bar represents to median, the solid red dot the mean, the top and bottom bars represent the 25th and 75th percentile range; vertical bars, or whiskers, indicate the general extent of the data, and asterisks indicate outlier or extreme values.

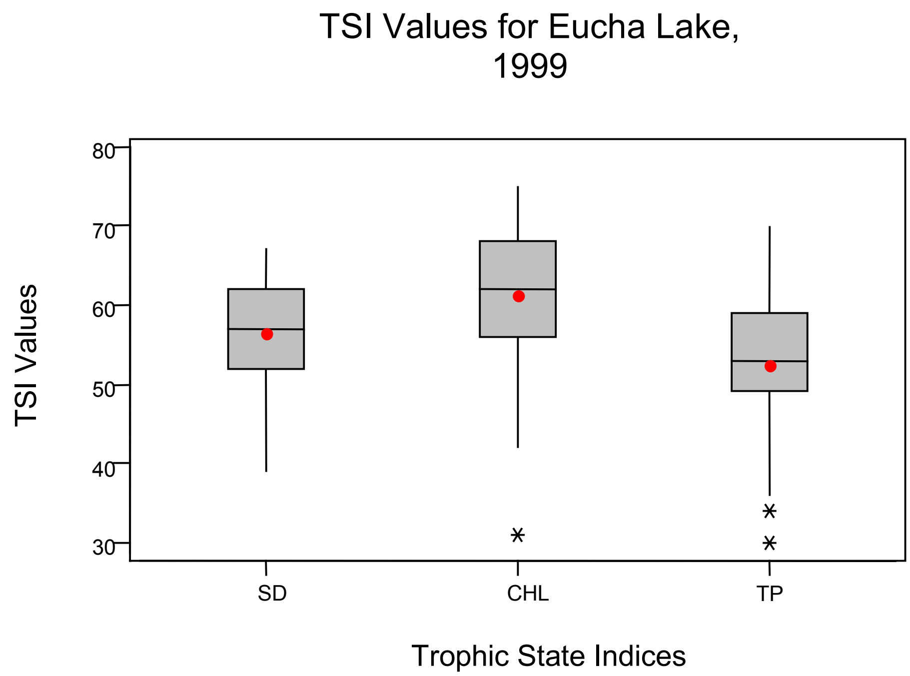


Figure 4-31. Comparison of Eucha Lake trophic state indices for water year 1999 (April 1999 – March 2000). Figure 30 explains box and whisker components.

Lake Eucha Secchi disk depth trophic state, TSI(SD), illustrates reservoir zonation assignment for each sample site. Analysis of variance (ANOVA) of 1998 data revealed that EUC03 differed significantly from EUC01 and EUC02, and EUC16 was significantly different from EUC01 (Figure 4-32). This shows decreasing TSI(SD) values from the tributary to the dam. ANOVA of 1999 data revealed that EUC01 and EUC02 were significantly different than EUC03. EUC16 was shown to be statistically the same as all of the other sites (Figure 4-33). Again, a decreasing trend of TSI(SD) was seen across the lake. Figures 4-32 and 4-33 support the assignment of river, transition and lacustrine zones to the sample sites since suspended solids decreased from the riverine zone (EUC03) to the lacustrine zone (EUC01 and EUC02).

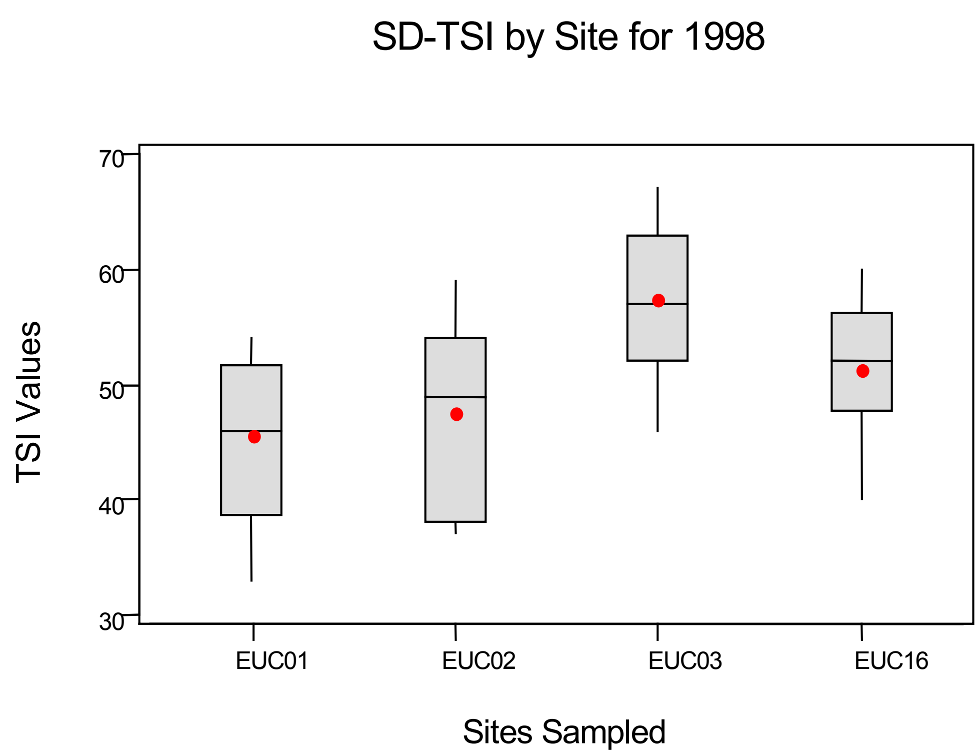


Figure 4-32. Comparison of Eucha Lake TSI(SD) by site for water year 1998 (April 1998 – March 1999). Figure 30 explains box and whisker components.

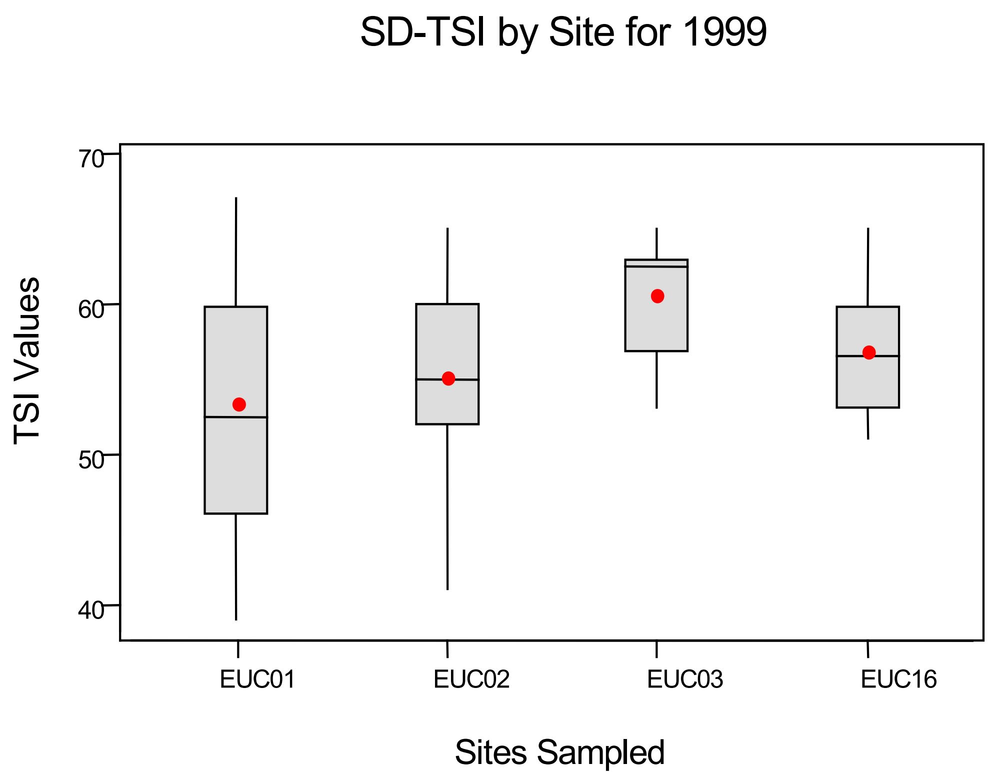


Figure 4-33. Comparison of Eucha Lake TSI(SD) by site for water year 1999 (April 1999 – March 2000). Figure 30 explains box and whisker components.

Chlorophyll-a trophic state indicators showed Eucha Lake to be eutrophic in 1998 and hypereutrophic in 1999. Riverine zone TSI(chl) seemed to increase from 1998 to 1999 from 57.8 to 60.4: from eutrophy to hypereutrophy respectively (Figure 4-34). However this difference was not statistically significant. The comparison of transition zone TSI (chl) shows an increase from 55.0 to 62.3 (Figure 4-35).

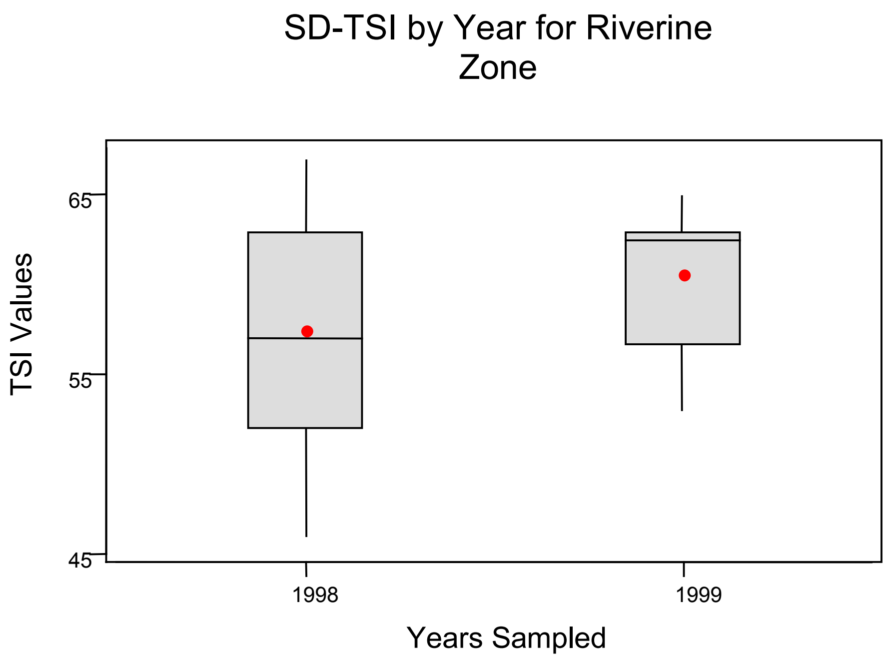


Figure 4-34. Eucha Lake riverine zone TSI (chl) for monitor year (April – March) 1998 and 1999. Figure 30 explains box and whisker components.

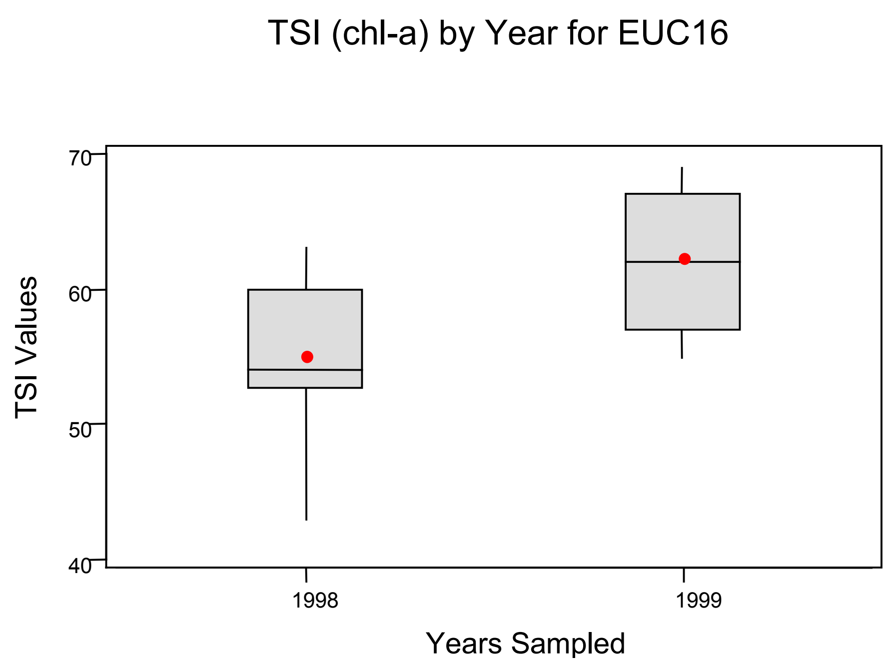


Figure 4-35. Eucha Lake transition zone TSI (chl) for monitor year (April-March) 1998 and 1999. Figure 30 explains box and whisker components.

Statistical testing showed each year to be significantly different. Figure 4-36 shows an increase in lacustrine zone Chl-TSI values from a mean of 52.0 to 61.4. This increase of 9.4 points represents an increase from eutrophy in 1998 to hypereutrophy in 1999. ANOVA statistics shows the two years to be significantly different.

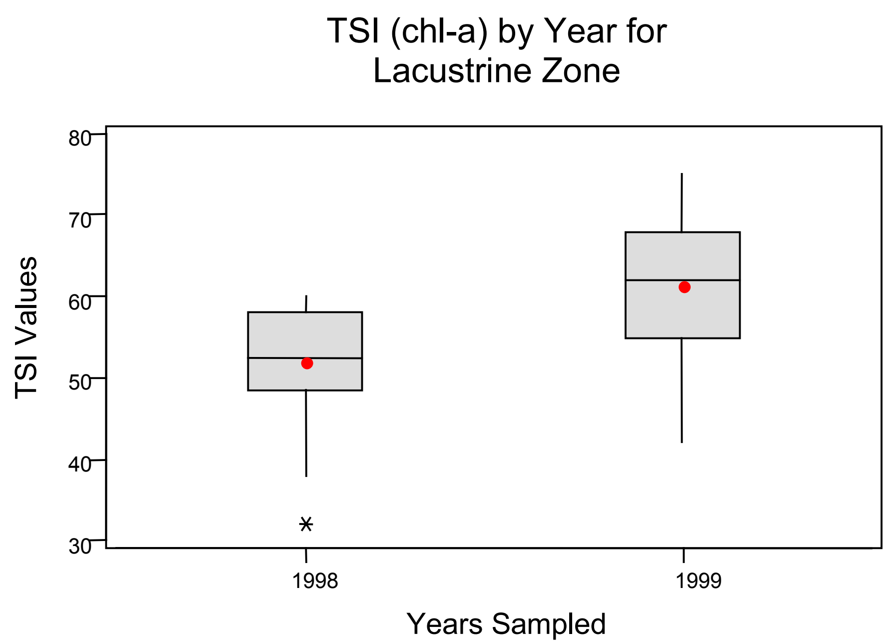


Figure 4-36. Eucha Lake lacustrine zone TSI (chl) for monitor year (April – March) 1998 and 1999.
Figure 30 explains box and whisker components.

In the course of data evaluation a significant difference was noted between the two sample years: April 1998 – March 1999 (1999) and April 1999 – March 2000(1999). Data evaluation and presentation has been segregated accordingly. TSI values across the lake were pooled to a lake-wide overview of TSI indices.

Spavinaw Lake

Of the 1998 TSI indicators TSI(chl) and TSI(SD) showed a tendency for eutrophy, with mean values of 54.3 and 52.7, respectively (Figure 4-37). Statistical comparison of 1998 data between the three indices showed pooled total phosphorous TSI values to be separate from the other indices. Of the 1999 TSI indicators TSI(chl) showed a tendency towards the boundary between eutrophy and hypereutrophy with a mean of 59.0 while TSI(SD) showed a tendency of eutophy with a mean of 56.2 and TSI (TP)showed a tendency for mesotrophy with a mean of 45.6 (Figure 4-38). Comparison of 1999 data between the three indices showed all three indicators to be statistically significant.

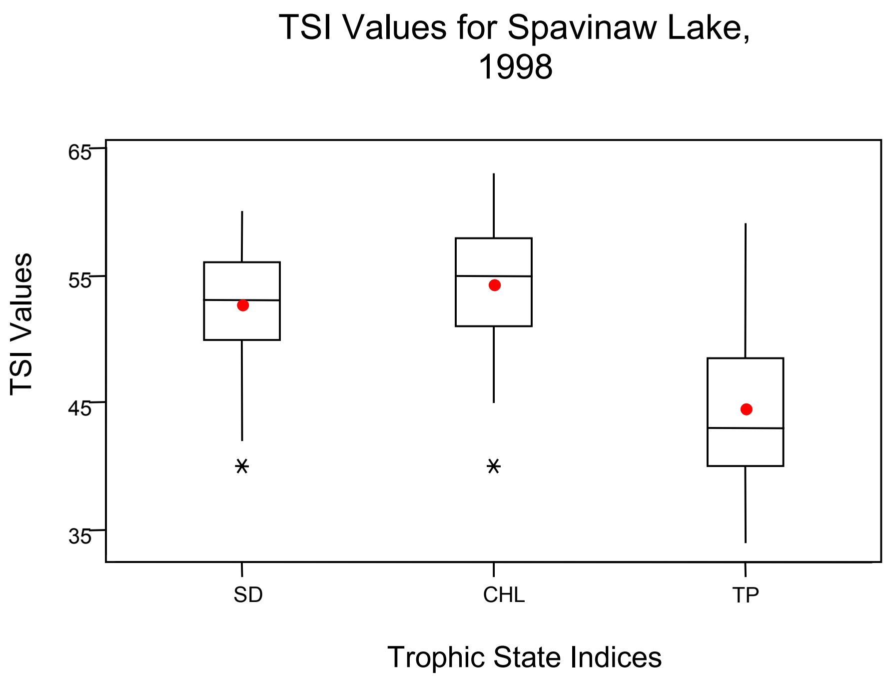


Figure 4-37. Comparison of Spavinaw Lake trophic state indices for water year 1998 (April 1998 – March 1999).

Figure 30 explains box and whisker components.

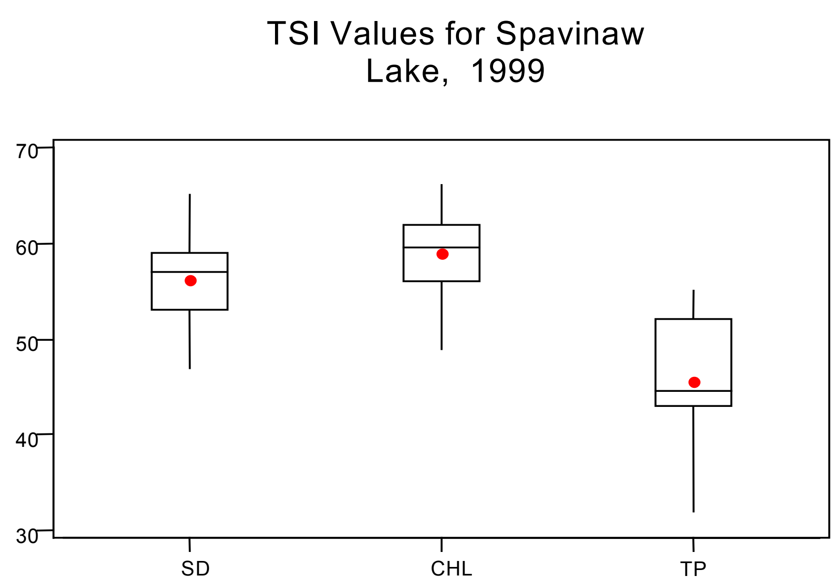


Figure 4-38. Comparison of Spavinaw Lake trophic state indices for water year 1999 (April 1999 – March 2000).

Figure 30 explains box and whisker components.

The consistent under-prediction of TSI by phosphorous during both 1998 and 1999 suggests excess nutrient levels for algae growth on a lake-wide basis. The slight under prediction of TSI by Secchi depth may indicate that large particulates could be dominating lake turbidity. However, since both Secchi disk and chlorophyll-a values fall within the eutrophic category, the differences are not critical. This indicates that algae concentration is an important factor of water transparency.

Spavinaw Lake Secchi disk depth trophic state, TSI(SD), illustrates reservoir zonation assignment for each sample site. ANOVA of 1998 data revealed that SPA05 to be significantly greater than SPA01 and SPA02 (Figure 4-39) showing decreasing TSI(SD) values from the tributary to the dam. The mean values as one transverses the lake from riverine (SPA05) to lacustrine zones SPA02 to SPA01 were 55.2, 52.2 and 50.2, respectively. ANOVA of 1999 data confirmed a trend of decreasing TSI(SD) as one transverses form the riverine zone towards the dam (Figure 4-40) with SPA05 statistically separate from SPA02 and SPA01. Mean values for these sites were 59.9, 55.4,and 53.4, respectively. Figures 4-39 and 4-40 support the assignment of transition and lacustrine zones to the sample sites since suspended solids decreased from the transition zone (SPA05) to the lacustrine zone (SPA01 and SPA02).

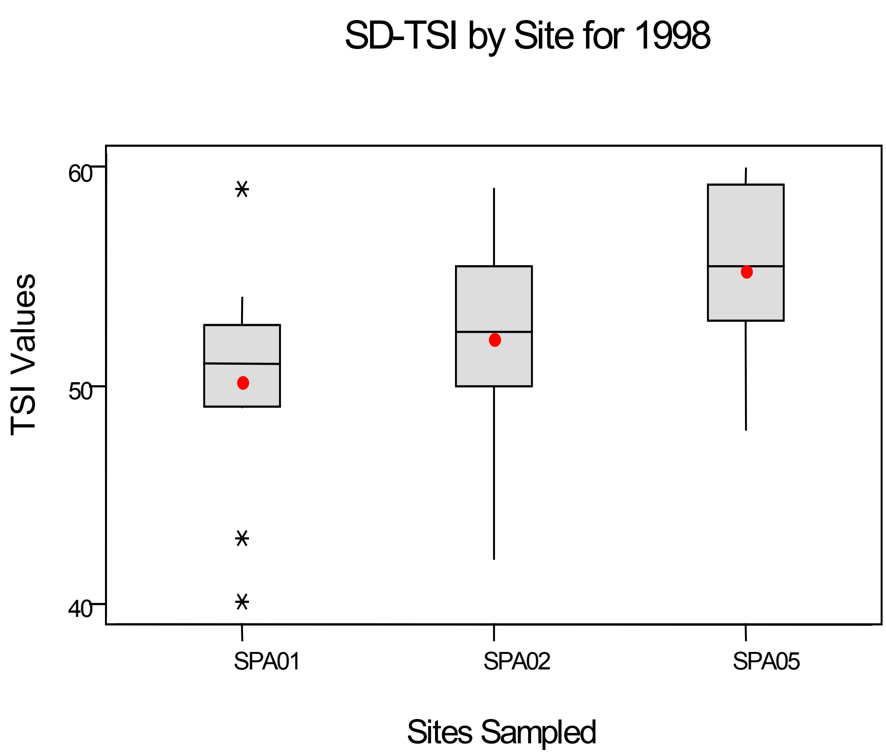


Figure 4-39. Comparison of Spavinaw Lake TSI(SD) by site for water year 1998 (April 1998 – March 1999). Figure 30 explains box and whisker components.

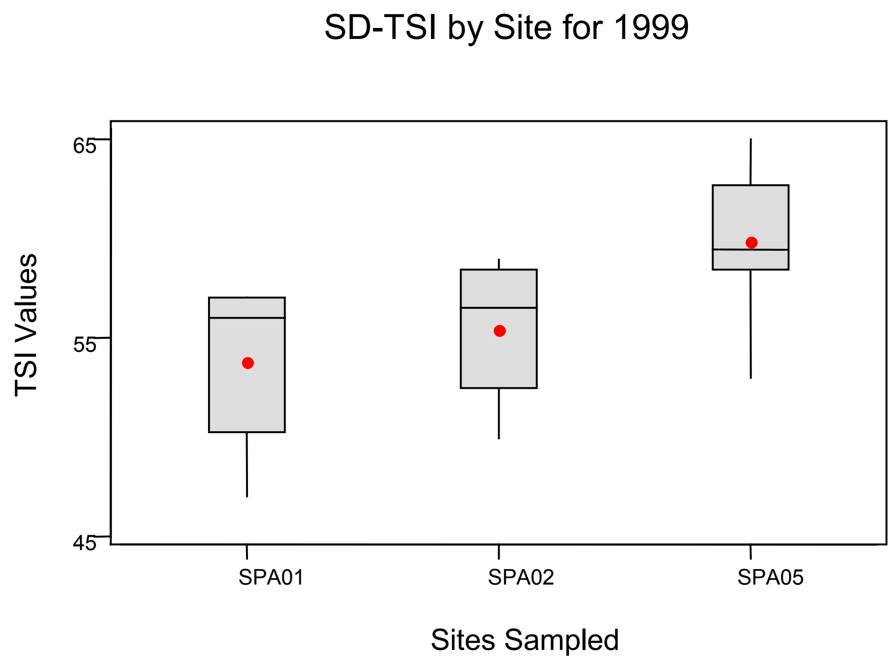


Figure 4-40. Comparison of Spavinaw Lake TSI(SD) by site for water year 1999 (April 1999 – March 2000). Figure 30 explains box and whisker components.

Chlorophyll-a trophic state indicators of Spavinaw Lake showed algae growth to have significantly increased between 1998 and 1999. Riverine zone TSI(chl) increased from a 1998 mean of 55.3 to a 1999 mean of 60.6 (Figure 4-41). The transition zone of Spavinaw Lake was eutrophic in 1998 and increased to the eutrophic/ hypereutrophic border in 1999. Lacustrine zone TSI(chl) indicated an increase from a mean of 53.7 to a mean of 58.3 (Figure 4-42) however the increase was not statistically significant. As a whole Spavinaw Lake can be classified as eutrophic for both years but the upper portion did have significantly higher algae growth in 1999 than 1998.

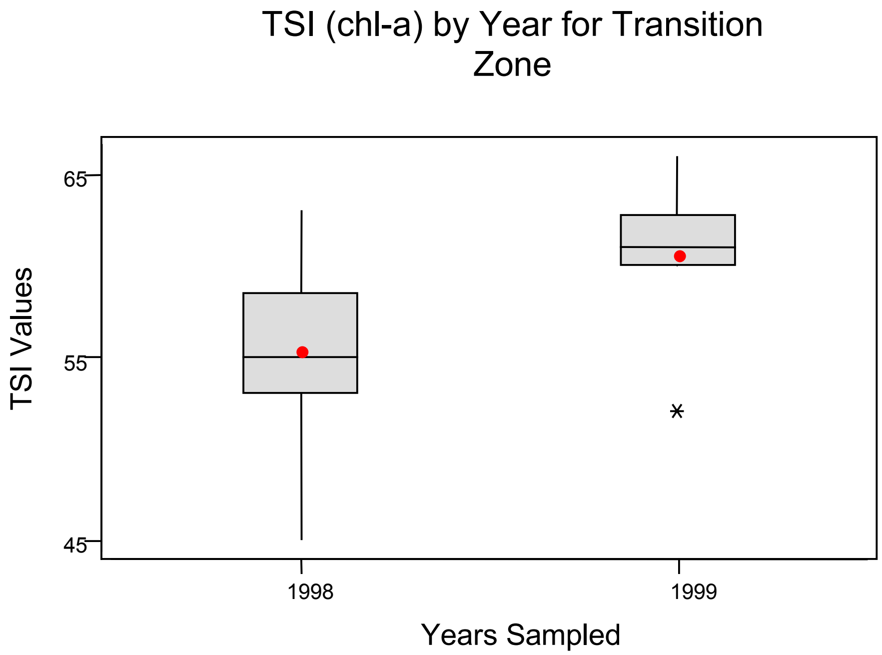


Figure 4-41 Spavinaw Lake transition zone TSI (chl) by monitor year (April – March) 1998 and 1999. Figure 30 explains box and whisker components.

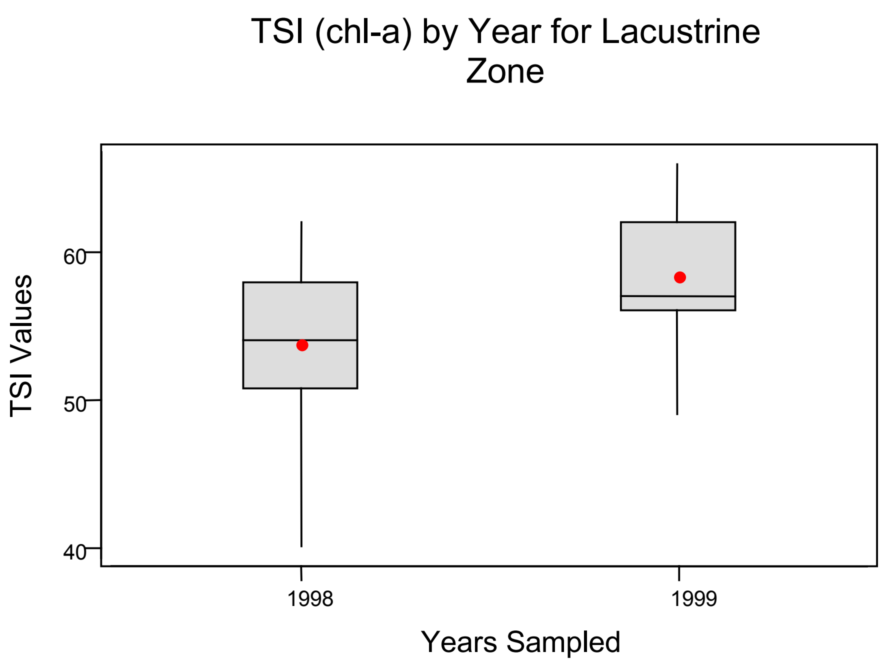


Figure 4-42. Spavinaw Lake lacustrine zone TSI (chl) by monitor year (April – March) 1998 and 1999. Figure 30 explains box and whisker components.

Phytoplankton, Zooplankton, and Taste and Odor chemicals

Extensive description of the spatial and temporal distribution of algae and zooplankton species has been performed under contract to Phycotech Inc. The entire report has been furnished in this report as Appendix G. The interaction of algae (plants) and zooplankton (grazers) can sometimes be as important as nutrient levels when determining the cause for algae community abundance. Deterministic interactions are considered to explain particular seasonal algae species dominance. The importance of these interactions becomes apparent when a particular taste and odor producing algae species blooms. While these specific ecological plant and grazer interactions in Lake Eucha and Spavinaw Lake may not present direct management options, it is important to acknowledge their ecological significance.

All three reservoirs are considered eutrophic or hypereutrophic systems based on multiple indicators. Eucha is the more productive lake; it drains a much larger area and receives a much larger nutrient load. The algal data from all three lakes indicated very productive systems. Quantitatively, total algal abundances were well above the 15,000-cells/mL threshold considered eutrophic (EPA, 1974). A total of 289 algae species were identified over the course of the project. Of these 289 species, approximately 34 different genera were present at dominant levels during the study. Of those 34 genera, four associated with troublesome algal blooms were present, *Cylindrospermopsis, Anabaena, Stephanodiscus,* and *Melosira* (Figures 4-43 – Figure 4-46)). These species are generally associated with taste and odor production.

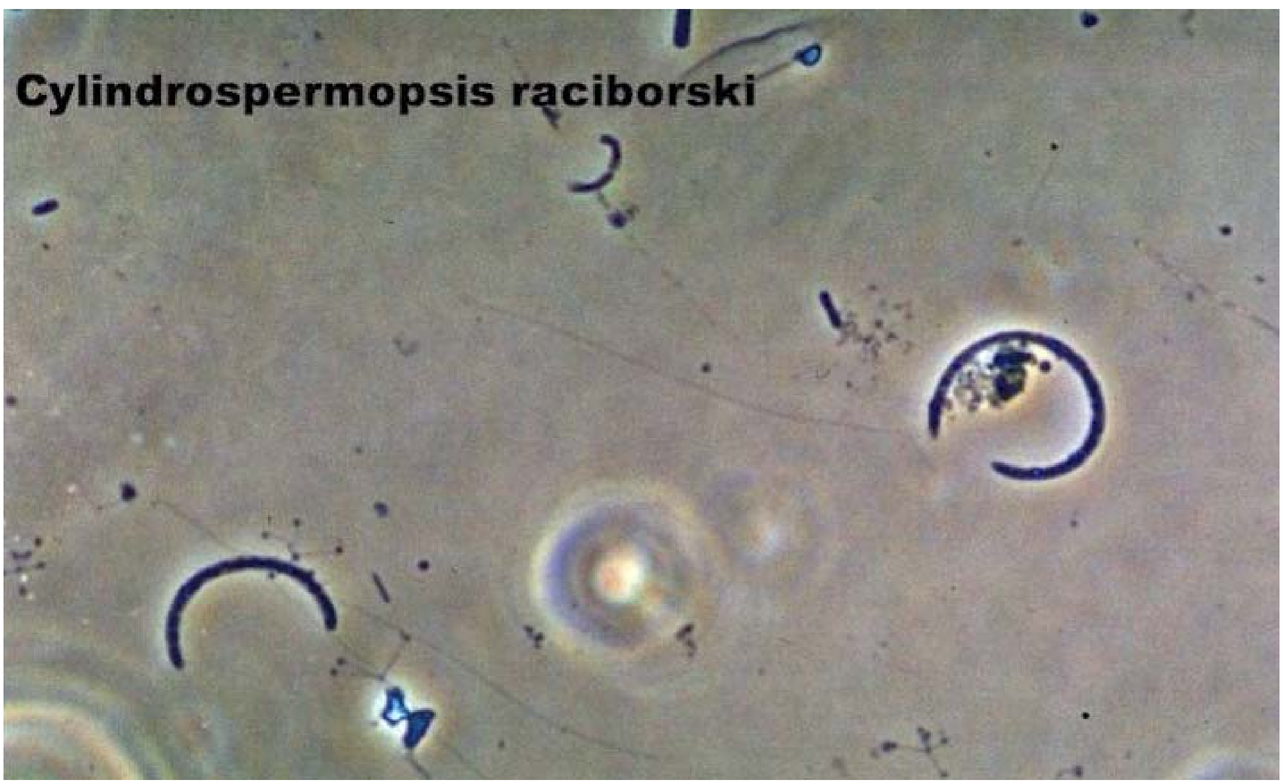


Figure 4-43. ***Cylindrospermopsis raciborski*****, photographs taken at 400x, under Phase optics. Notice lack of heterocysts.**

Figure 4-44. ***Anabaena flos-aquae*****, photograph taken at 200x, under Phase optics. Note the heterocyst identified with the arrow. Heterocysts indicate nitrogen fixation and represent nitrogen limitation for algae.**

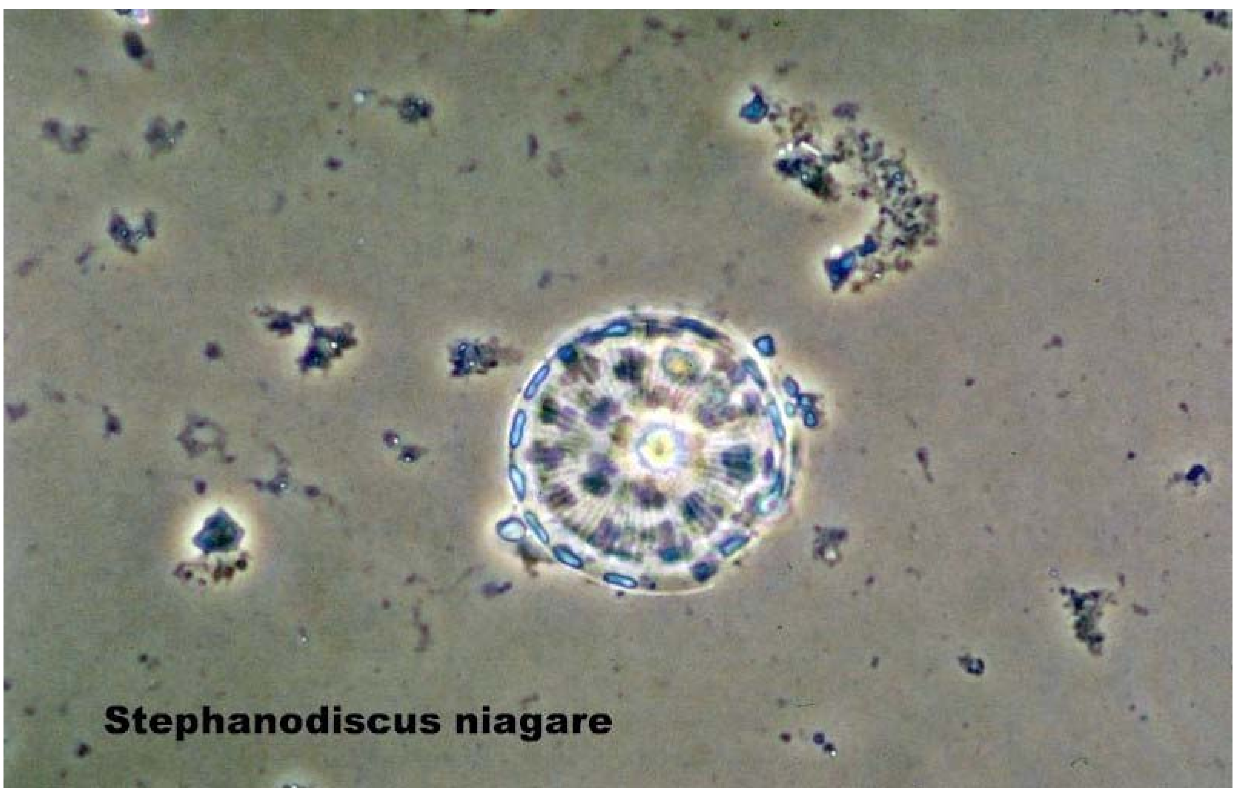
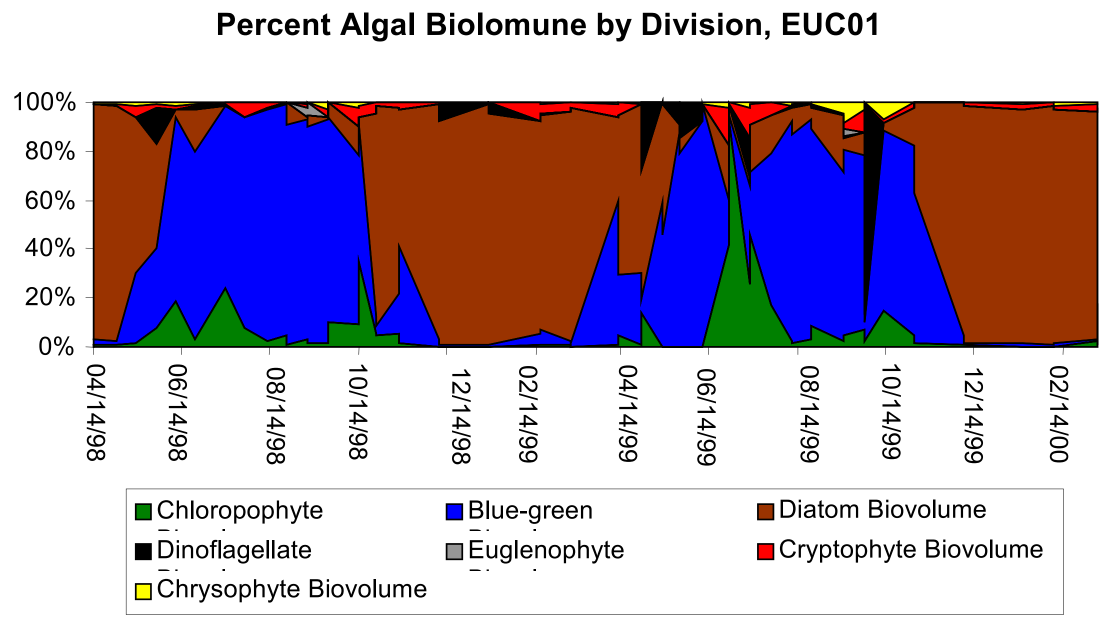


Figure 4-45. ***Stephanodiscus niagare*****, photograph taken at 400x, under Phase optics**

Figure 4-46. ***Melosira italica*, photograph taken at 400x, under Phase optics**

Chlorophyll-a values were consistently high and peaked to values well over 60 µg/l on occasion. Although no mathematical relationship was noted between chlorophyll-a concentrations and algae abundances, abundances of enumerated taste and odor causing algae and detection of taste and odor causing chemicals in Lake Eucha and Spavinaw Lake indicate a strong relationship exists. Algae identified as dominant or co-dominant in the community are presented by taxonomic division. In general, these are the diatoms and blue-green algae (Figure 4-47). This is evident by the fields of brown representing diatom genera dominance and fields of blue representing blue-green algae dominance. Ecological significance of species within each division is discussed here. Algae species with the potential to produce taste and odor chemicals are also discussed in these sections. In many instances, potential links with zooplankton are presented. Following this is a brief discussion of potential controlling factors of zooplankton abundance. Finally, customer complaints and measured taste and odor chemical reports are linked to the observed algae assemblages.



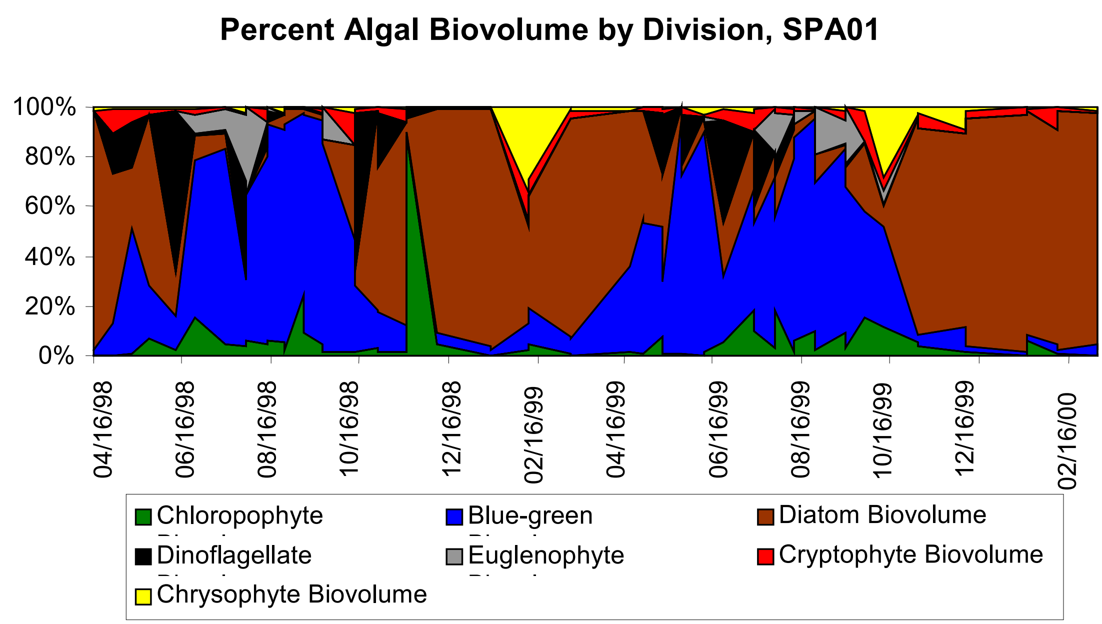


Figure 3-47. Algae community abundance by division biovolume for Eucha and Spavinaw lakes at the dam.

Blue-green algae

The blue-green algae dominated numerically much of the year in all three lakes, although the primary taxa to dominate numerically are the picoplankton blue-greens. These types of blue-greens were not an important contributor to biomass during much of the year or during taste and odor events. Picoplankton are common in large numbers in western reservoirs with reasonably high particulate loads and serve a vital function in recycling nutrients and as a food source for the rotifers and calanoid copepods, as well as other small micro-zooplankton (Waterbury, et al. 1986; Gηde. 1989; St. Amand. 1990). Other important blue-green algae associated with eutrophic conditions include *Cylindrospermopsis raciborski* (a toxic, invading sub-tropical species*), Oscillatoria limnetica* (produces taste and odor compounds) (Figure 4-49) (Matsumoto and Juttner. 1993), and several species of *Anabaena* including *A. flos-aquae*, *A. macrospora*, and *A. circinalis* (also documented to be toxic and to produce taste and odor compounds) (Mohren and Juttner. 1983; Rosen, et al. 1992; Negoro, et al. 1988).

The filamentous, nitrogen-fixing blue-green algae such as *Cylindrospermopsis* and *Anabaena* are not easily available to smaller zooplankton grazers in the lake (above 22 µm in length, Sorrano, et al. 1993). In addition, there were no large daphnid grazers, which could effectively graze the larger filaments, present during the late summer/early fall periods. This condition was present in both 1998 and 1999. Lack of large daphnids could be related to competition from rotifers and copepods for the smaller, more edible algal taxa or could also be a response to algal toxins produced by the blue-green algae. During the higher biomass 1999 period, *Cylindrospermopsis* exhibited a decreased cell size, possibly in response to higher nutrients and/or faster growth rates. *Cylindrospermopsis* and *Anabaena* did not often exhibit heterocysts (common with a high N:P ratio), indicating a surplus of nitrogen in the system. The N:P ratio was well above 15, the threshold for favoring blue-green algae (Reynolds. 1984), during much of the study period. The exception to this rule came in late summer 1999 in Lake Eucha, when the ratio dropped below 10 for a few weeks. *Cylindrospermopsis* grew best when the lake was stratified and warm, and when phosphorus release from the sediments was at a maximum.

Lake Eucha experienced larger blue-green algal blooms than Spavinaw Lake, and the blooms in Spavinaw generally followed Eucha by 1-2 weeks. *Anabaena* started to grow in very small concentrations in the winter, when the lake was fully de-stratified, but did not bloom until summer, after the lakes had stratified. The blue-green species in these lakes may be hard to control because they are already well developed during summer periods when the N:P ratio indicates no nutrient competitive advantage from nitrogen fixation. Additional factors that favor blue-green algae are a stable water column and high water retention time.

Diatoms

The diatoms dominated most dates when the blue-greens did not, although the other divisions were sporadically important during the year, especially in transition periods such as late fall and early spring. The diatoms did not often dominate numerically, due to their large size (often between 20 and 100+ µm), but in the late fall and winter, they dominated the algal biovolume. Diatom blooms that dominated the biovolume occurred during periods of low dissolved silica in the lakes. This was especially true when *Stephanodiscus* and *Melosira* were blooming. There were several small *Cyclotella* species that also bloomed during the late fall and winter, as well as smaller blooms during the summer, but they did not dominate the biovolume as the larger diatoms did. *Stephanodiscus* was another species that showed a decreased cell size in 1999, compared with the previous year, again, potentially due to a release from competition and resultant increased growth and reproductive rates. For *Stephanodiscus*, though, the decreased size put it into the more edible category. *Daphnia pulex*, the largest, most effective daphnid grazer in Eucha and Spavinaw (up to 3 mm) (Herbert, 1995), was present in much larger numbers during the late fall 1999 and winter 2000 than at any other time in the study period. This situation likely prevented an extreme *Stephanodiscus* bloom in the lakes in winter 2000, compared to winter 1999. This effect was especially notable in Eucha where the *D. Pulex* population was present in higher densities than in Spavinaw. The larger, non-edible, *Melosira* bloomed in much higher densities in winter 2000 in all three lakes. The situation was reversed in winter 1999, when there was not a population of larger daphnids available to exert grazing pressure on the diatom community, allowing *Stephanodiscus* to bloom more fully.

Other Divisions

The chyrsophytes, green algae, euglenophytes and dinoflagellates occasionally were co-dominant with the diatoms and blue-greens during the study period. During winter months, *Uroglena sp.*, a colonial chrysophyte, accounted for up to 35 percent of the biovolume. It sometimes dominated during the same period numerically as well, because the colonies dissociate upon fixation and single cells are generally tallied. The colonies are relatively large and thus exempt from grazing. Like many chrysophytes, *Uroglena* does well in lower temperature and light circumstances present in spring (Sandgren. 1988). Euglenophytes accounted for 10-20 percent of the assemblage during the late summer in 1998 and 1999, although the 1998 bloom was earlier than in 1999. *Euglena ssp.* and *Trachelomonas ssp.* were the most prevalent euglenophyte taxa. The euglenophytes do well in high organic carbon situations (Wetzel, 1983); hence, they were generally present in higher numbers at depth rather than at the surface. Euglenophyte motility allows them to congregate near the metelimnion where dying algae cells serve as a food source. Cryptophytes were present in small numbers and at times often represented 10-plus percent of the biovolume. The primary contributors were *Cryptomonas erosa* and *Rhodomonas minuta v. nannoplantica*, both excellent zooplankton food. Rotifers, calanoid copepods, and *Daphnia ssp.* all graze on *Cryptomonas* and *Rhodomonas*, either selectively or generally. Dinoflagellates were sporadically important in mid-summer of both 1998 and 1999. The green algae were present in small numbers consistently throughout the summer, often in grazable taxa like *Chlamydomonas sp.*, but were not very important overall.

Zooplankton Community

The zooplankton in Eucha and Spavinaw followed a seasonal pattern generally atypical of temperate lakes (Beaver and Havens. 1996), with biomass abundance the highest in winter months when algal productivity was not at its maximum. The ratio of calanoid copepods to cladocerans and cyclopoid copepods generally increases with decreasing productivity (Johannsson, et al. 1999). Despite the lower productivity in Spavinaw Lake, the ratio of calanoid copepods to cladocerans and cylcopoid copepods combined was not lower than in Lake Eucha. This could reflect a threshold effect, where the productivity is high, even when it is relatively lower than another lake. The ratio was lower in the winter periods when there were fewer zooplankters present overall, and it lagged in Spavinaw Lake compared to Lake Eucha, by a period of several weeks. We would also have expected the ratios of calanoids to be higher in 1998 as compared to 1999, in both lakes; this was also not the case (Figure 4-50).

Zooplankton abundance was often at a minimum when algal biomass was at a maximum, this could be due to two different pressures on the zooplankton. First, fish predation could be very important in regulating the presence of large bodied cladocerans (primarily daphnids) and other edible zooplankton during the summer and early fall (Brooks and Dodson, 1965). Fish data were not available for confirmation about the young-of-the-year (YOY) fish population in the lake. Secondly, the periods when the highest biomass of summer algae was present was dominated by relatively large inedible species (e.g., *Cylindrospermopsis raciborski*). There may not have been a suitable food supply to support the expected zooplankton community at higher productivities. Zooplankton were abundant overall, especially the rotifers and small-medium sized cladocerans during periods of high numbers of smaller, more edible algal species, such as *Rhodomonas minuta*, *Cryptomonas erosa, Cyclotella* ssp. and small green algae, but not during periods when more inedible algal taxa were present. In both years, blue-green picoplankton biomass peaked when the effective grazers, daphnids, were not present in the lake. At the same time, rotifers and copepods were abundant, indicating these groups were benefiting from the higher food supply available in the smaller algal cells. Rotifers generally graze on food particles in the 1-5 μm range, while the calanoid copepods will graze particles up to 10-22 μm (Sorrano, et al. 1993).

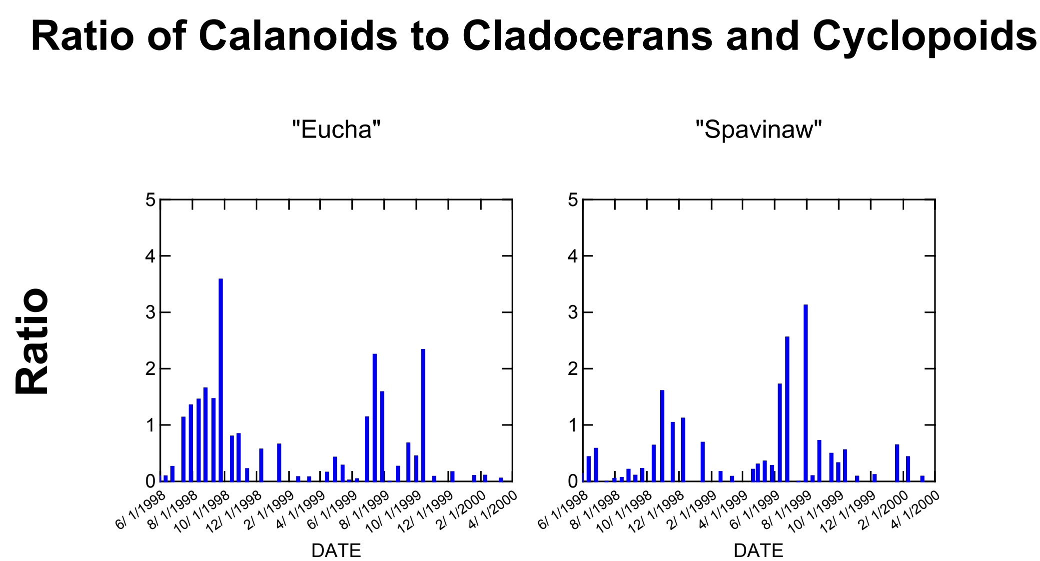


Figure 4-48. Ratio of Calanoids to Cladocerans and Cyclopoids

Because there was not significant grazing pressure on the mid to late summer blue-greens in either year, the drop in diatom cell size was likely due to higher available nutrients and faster growth rates, rather than from indirect grazing effects. There was evidence, though, for the drop in *Stephanodiscus* cell size to be related to increased zooplankton grazing pressure. In 1999, there was a significant winter population of *Daphnia pulex*, a large, effective cladoceran grazer (Herbert, 1995; Mills, et al., 1987). The smaller size made *Stephanodiscus* more available to *D. pulex*, in contrast to 1998 when no *D. pulex* was present. As a result, the winter *Stephanodiscus* bloom was replaced by *Melosira italica* and *M. granulata*, both too large for *D. pulex* to graze.

Daphnia lumholtzi was found in both Eucha and Spavinaw Lakes during a very short late fall period in both 1998 and 1999. *D. lumholtzi* is an invasive species that is very difficult for YOY fish to eat (Havel, et al, 1995). There is also concern that *D. lumholtzi* might out-compete other native daphnids such as *D. pulex*, *D. laevis,* and *D. retrocurva* (Havel, et al. 1995). Although there has been concern since its detection in the early 1990's about potential deleterious effects on other daphnids, there is no evidence to of that effect (Goulden, et al, 1995). There is still concern over its affect on fish communities and decreased food supply available for YOY larval fish. Because *D. lumholtzi* is present later in the season than in more eastern lakes (Hebert, 1995), it is still unclear what permanent effect its presence will have on the fish community and its abundance needs to be watched closely.

Customer Complaints, Taste and Odor Reports, and the Algae Community

From data collected by the Mohawk water plant, it appears that diatoms are the most likely source of Geosmin and MIB (Figures 4-51 and 4-52). It's also possible that there is a contributing population of *Anabaena flos-aquae* and *A. circinalis* during the same period as well. The blue-greens, though, are present at much lower biomass than the diatoms and are likely secondary contributors, at best. Lake Yahola had a large diatom bloom during its highest documented Geosmin/MIB peak event as well. Also interesting is the customer complaint data (Figure 4-53) for the Mohawk finished water. Complaints increased dramatically during the late fall 1998 and winter1999 and in late fall 1999. Although data do not extend back to 1998 for Geosmin and MIB, the algal data confirm that the late fall 1998 period was experiencing a bloom of the same diatom species (*Stephanodiscus niagare*) that dominated during the March event in 1999 in both Eucha and Spavinaw, and the October/November 1999 event in Yahola. None of the blue-greens that produce Geosmin and MIB were dominant, either numerically or by biovolume during any of the time periods (1999 and 2000) when Geosmin and MIB were detected. Two *Melosira* species were present during the late fall/ winter blooms as well, but only contributed a fraction of the biomass compared to *S. niagare*, in Eucha and Spavinaw, especially during the two earlier periods in late 1998 and early 1999. In Eucha and Spavinaw, when *S. niagare* dominated in March 1999, Geosmin was the primary chemical detected. Melosira was more important in winter 2000, in Eucha and Spavinaw, when MIB was also more prevalent during the bloom. In Lake Yahola, both Geosmin and MIB were high in the late fall 1999 bloom, which was dominated by *M. italica* and *M. granulata*, with *Stephanodiscus niagare* as a secondary contributor. It appears from the species data of all three lakes that MIB is more likely produced when *Melosira* (Geosmin and MIB) is present and dominating, than if *Stephanodiscus* (primarily Geosmin) is present and dominating. Both diatom genera are likely contributing to the production of Geosmin and MIB, though.

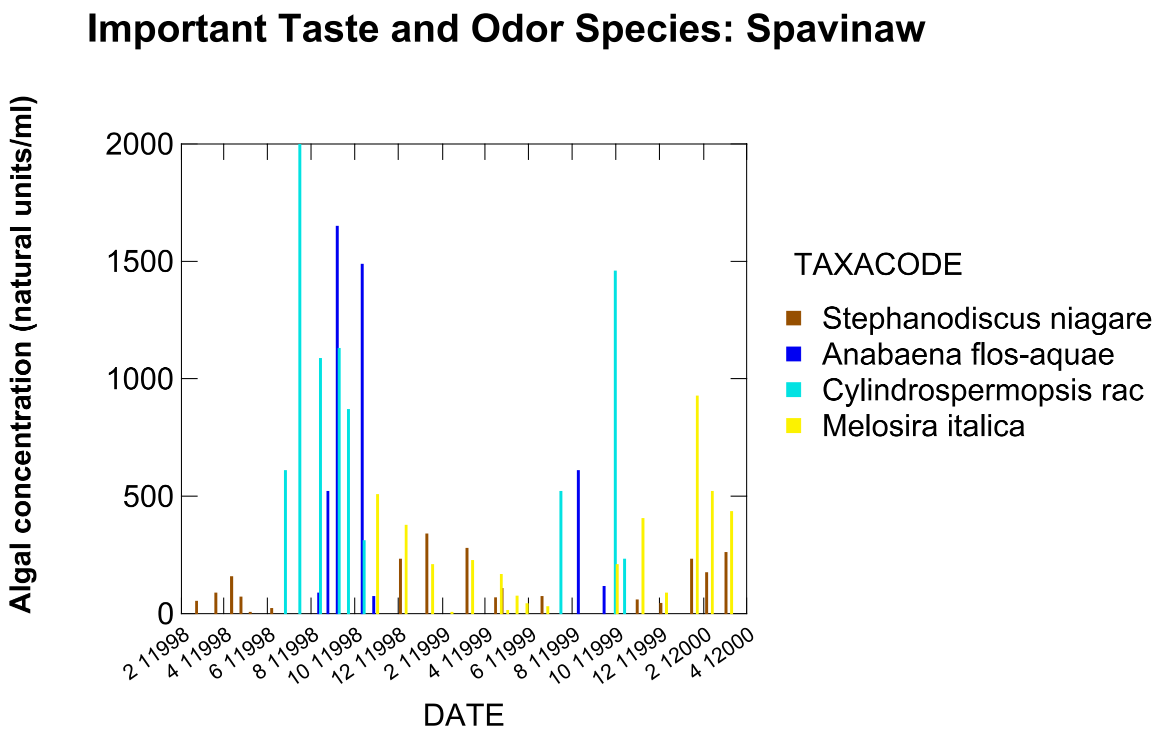


Figure 4-49. Taste and Odor Species, Spavinaw Lake

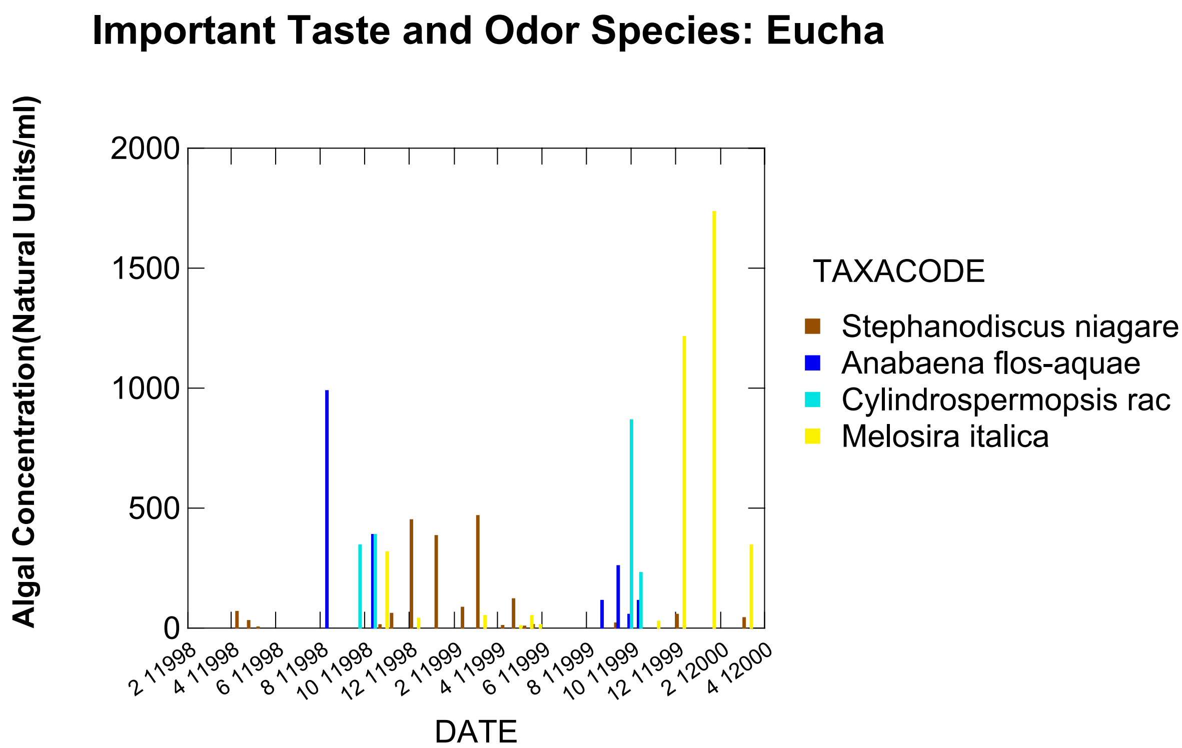


Figure 4-50. Taste and Odor Species, Eucha Lake

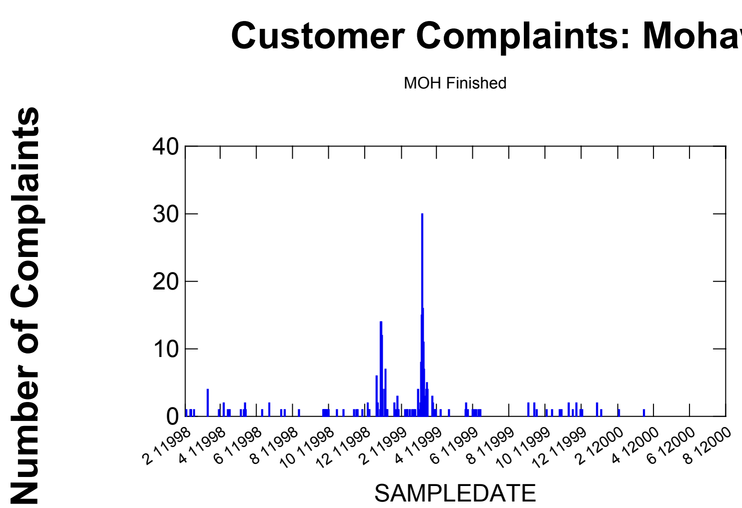


Figure 4-51. Customer Complaints, Mohawk

Alternative contributors to the production of Geosmin and MIB include attached algae growing in the littoral zone (shallow areas) of all three lakes. Several species of *Oscillatoria* and *Lyngbya*, as well as filamentous bacteria in the *Actinomycetes* group, have been documented to produce Geosmin and/or MIB. No samples or data were provided on the periphytic algal or bacterial communities in Eucha, Spavinaw, or Yahola Lakes.

There are two issues that confuse the possibility of the *Stephanodiscus* and *Melosira* causing the taste and odor events observed in December 1998, March 1999, and winter 2000. First, although *Melosira* reached or exceeded the concentration threshold for producing detectable taste and odor compounds (250,000cells/100 mL, Seppovaara, 1971 and AWWA, 1987), *Stephanodiscus* was well below the threshold stated for similar diatom species such as *Cyclotella*. *Stephanodiscus* has been documented to produce taste and odor compounds, but was not mentioned specifically as to the threshold required for the population to produce detectable compounds. However, *Stephanodiscus niagare* is an extremely large celled diatom with an axial dimension (GALD) often over 30 μm and an average biovolume of approximately 12,000 μm^3/cell during the study period. *Melosira* italica exhibited a biovolume per cell of approximately only 400 μm^3. When the populations are assessed in terms of biovolume, *Stephanodiscus* biovolume in 1998 and 1999 far exceeded the equivalent biovolume of a taste and odor producing population of *Melosira* in winter 2000. When determining whether there is a sufficient population of a suspected taste and odor producer, analysis should include relative size as well as concentration.

Secondly, although both *Stephanodiscus* (AWWA, 1987) and *Melosira* (Arruda and From, 1989) are documented taste and odor producers, neither taxa has been documented to produce Geosmin or MIB, instead producing “fishy and musty” taste and odor compounds that have not been fully identified. Culture work on these two genera and the species involved has not been completed, and the discrepancy could be lack of data. However, it’s possible that, although the species data correspond very well, there was another cause of the taste and odor events. The most dominant and obvious taxa are not always the ones that are causing the problem (AWWA, 1987). Despite the possible role of alternative sources, the documented diatom blooms remain the most likely explanation (Table 4-13).

Potential Algae Control Options

The presence of large daphnid grazers may have significantly limited the winter 2000 bloom of diatoms, suggesting that one way to decrease the winter bloom would be to encourage the presence of large daphnids by manipulating the fish community (Mills, et al, 1987). Using chemicals, such as copper sulfate, to control the algae exclusively may have an undesired effect on productivity. Lower blue-green blooms in the summer of 1998 were followed by higher diatom blooms in the winter. Also, the potential for the increase in *Cylindrospermopsis raciborki* could be problematic because of its potential for toxicity. Algae producing toxic chemicals are usually not eaten by the grazing zooplankton. By reducing other competing taxa and not reducing nutrients, there would likely be an increase in *C. raciborski* and other potentially toxic and taste and odor producing species such as *Anabaena circinalis* and *A. flos-aquae*, which could be substantially more difficult to control. There was some evidence that *Anabaena* was co-dominant (along with *Melosira*) in a taste and odor event in late fall 2000, decreasing competition for the bloom forming blue-greens may only exacerbate the problem.

Table 4-13: Relative dominance of potential taste and odor producing algae and their relation to taste odor events.

(S) = SPAVINAW LAKE (E) = EUCHA LAKE

	Taste and Odor-Producing Algae Identified					**Taste and Odor Indicators**	
Season	***Cylindrospermopsis raciborski***	***Anabaena flos-aquae***	***Oscillatoria limnetica***	***Stephanodiscus niagara***	***Melosira italica***	**Geosmin &MIB**	**Customer Complaints**
Spring 1998	None	None	None	Dominant	None	No data	Moderate customer complaints
Summer 1998	Dominant **(S),** Subdominant **(E)**	Dominant **(E)**, Subdominant **(S)**	Minor	None	None	No data	Few to no customer complaints
Fall 1998	Dominant	Dominant	Subdominant	None	None	No data	Few customer complaints
winter 1999	None	None	Subdominant early, none late	Dominant	Subdominant	High Geosmin, no MIB	High customer complaints
Spring 1999	None	None	None	Dominant	Subdominant	High Geosmin, no MIB	High customer complaints
Summer 1999	None **(E)**, dominant **(S)**	Minor	Subdominant	Subdominant early	Subdominant early	Low Geosmin **(E only)**, no MIB	Few to no customer complaints
Fall 1999	Dominant	Subdominant	Subdominant	Minor	Minor	No Geosmin, no MIB	Few customer complaints
winter 2000	none	None	Minor **(S)**	Minor **(E)**, subdominant **(S)**	Dominant	Moderate Geosmin, High MIB	Few customer complaints

Source: Algae, Zooplankton, and Taste and Odor events of Eucha, Spavinaw and Yahola Lakes, Dr. Ann St. Amand

Aquatic Macrophytes

Spavinaw and Eucha Lakes both have seasonal aquatic macrophyte communities. Above ground biomass starts around March with subsequent senescence around October. In general, aquatic macrophytes will tend to take nutrients from the sediment and release them into the water column during plant growth and senescence (Wetzel, 1983). When the water column nutrient concentration is high enough, absorption from the water column may dominate. Direct impact of macrophytes on water column nutrient dynamics depends largely on plant distribution (total biomass), nutrient content, tuber formation (below ground food storage), and timing of senescence.

The three general categories of macrophytes have been have been ranked in order for their potential to impact water column nutrient flux:

1. Submersed plants; Coontail (*Ceratophyllum desmersum*), Chara (*Chara* spp.), Pondweed (*Potamogeton* spp.), Water Stargrass (*Heteranthera dubia*), and Water Milfoil (*Myriophylum* spp.) with the least amount of below ground biomass, complete senescence of above ground biomass and highest percentage of non-structural above ground biomass, represent the highest potential.

2. Water Willow with a higher proportion of structural above ground biomass and incomplete senescence of the plant represents a lesser potential.

3. American Lotus with its tuber (below ground) storage of nutrients and higher percentage of structural above ground biomass represents the lowest potential.

Methods: Macrophyte surveys were performed in late July to approximate the maximum standing crop. Assessment focused on species and categories of plants with large biomass and potential for nutrient contribution to the water column. For this reason, plants growing at or below the "normal" pool elevation with large biomass were assessed while macrophytes above normal pool elevation or with little biomass were disregarded. An aquatic plant survey was performed July 28 and 29, 1998, for Spavinaw and Eucha lakes, respectively. Transects were run perpendicular to the shoreline from a point measured using a global positioning system (GPS). The GPS point locations are illustrated in Figures 3-3 and 3-4. Distance was measured using measuring tape, depth estimated within 0.5-foot, and community composition recorded. Records were made at the start and finish, and when changes in community composition were noted. Transects were run for each lake recording absence or presence of aquatic plants with depth. Percent coverage for each lake was developed using these data. American Lotus (*Nelumbo lutea*) coverage was mapped by recording GPS locations as the boat slowly motored along the outer edge of the plant bed. Water Milfoil (*Myriophyllum* spp.) coverage was extensive in 1998; mapped by recording GPS points as the boat slowly motored along the outer edge of the plant bed. Polygons were created in a Geographic Information System (GIS) program from the mapped plant bed edge and total area colonized by each plant type was estimated. The survey was repeated on July 22, 1999, at the same GPS transect points for transect data collection. Quadrant sampling for laboratory determination of plant biomass and nutrient determination by species occurred at each transect. Quadrants were taken at the approximate mid-point of a given plant community. Nutrient content of the aquatic plant community was estimated based on the 1999 laboratory analysis and the percent coverage of each year's survey.

Eucha Lake: Eucha Lake had a variable submersed community with a relatively stable emergent community dominated by Water Willow ringing the shoreline. A relatively small population of American Lotus was noted in the uppermost portion of Eucha Lake. The submersed aquatic plant was not stable year to year and tended to be dominated by an invasive species.

In the summer of 1997, a substantial crop of curly-leaved pondweed (*Potomageton crispis*) was noted in the upper end of Lake Eucha. The rapid growth and mid-summer senescence of this species of macrophyte may have been a significant source of nutrients. In 1999, Water Milfoil (*Myriophyllum* spp.) had replaced curly-leaved pondweed as an upper lake nuisance macrophyte. Both plant species have the ability for nutrient uptake from the water column and sediment. Water Milfoil was estimated as having gross phosphorus content of 180 kilograms (Table 4-14). This stand of macrophytes was completely desiccated with dropping pool elevation by early September 1998. A portion of the Water Milfoil bound phosphorus would be expected to be released as the pool dropped. Lake Eucha experienced a 6-foot increase in pool elevation on October 6, 1998. The bulk of nutrients remaining in the desiccated Water Milfoil would have been rapidly released following this inundation. In summer of 1999, no nuisance macrophyte growth was noted in the upper end of Eucha Lake. Large pool elevation fluctuations in recent years may have had a role in this drastic annual shift in submersed aquatic plant presence in the upper end of Eucha Lake.

Table 4-14 Estimated nutrient content in kilograms and as a percentage of the total by plant genus for Lake Eucha July 1998 and 1999.

Plant genus	Total estimated nutrient content in kilograms				Total estimated nutrient content as a percent of the total estimatedplant nutrient content			
	1998		1999		1998		1998	
	Total-N	Total-P	Total-N	Total-P	Total-N	Total-P	Total-N	Total-P
*Myriophyllum**	1111.1	161.6			71.6	90.3		
Nelumbo	24.3	2.1	24.3	2.1	1.6	1.2	5.5	12.2
Justicia	415.9	15.2	415.9	15.2	26.8	8.5	94.5	87.8
Totals	1551.3	178.9	440.2	17.3	100.0	100.0	100.0	100.0

Myriophyllum nutrient content estimated by multiplying Spavinaw Lake *Ceratophyllum* biomass values by nutrient percentages from the literature (Hutchinson, 1977).

Based on the estimated nutrient content and relative ranking for nutrient contribution Water Willow or American Lotus have low potential to contribute significant nutrients to the water column of Lake Eucha.

Spavinaw Lake: Spavinaw Lake supports a stable, diverse aquatic plant community with a mixture of submersed plants species. A substantial American Lotus colony was noted in the upper end of the lake and Water Willow was found along the shoreline that received direct sunlight. The uppermost end of Spavinaw Lake contained a diverse mixture of obligate wetland emergent macrophytes. The relatively small coverage of this community did not warrant further assessment. Estimated nutrient content indicates that the submersed plant community has a high potential to contribute nutrients to the water column of Spavinaw Lake than the emergent community (Table 4-15). Within this category Coontail (*Ceratophyllum*) dominated nutrient content. This could translate to a loading of 120 to 150 kg of phosphorus during the fall of 1998 and 1999, respectively. Compared to the total estimated phosporus load to spavinaw lake, approximately 8,400 kilograms, 150 kg is less than 2% of the total budget. The potential for aquatic plants to impact the nutrient dynamics on an annual basis is nominal. Differences between 1998 and 1999 nutrient content are largely explained by the reduction of Coontail biomass. It is likely that the reduced water clarity (as noted by decreased secchi depth) in summer 1999 reduced the distribution of this submersed plant.

Table 4-15 Estimated nutrient content in kilograms and as a percentage of the total by plant genus for Spavinaw Lake July 1998 and 1999.

Plant Genus	Total estimated nutrient content in kilograms				Total estimated nutrient content as a percent			
	1998		1999		1998		1998	
	Total-N	Total-P	Total-N	Total-P	Total-N	Total-P	Total-N	Total-P
Ceratophyllum	2770.3	153.4	2170.1	120.2	61.7	59.5	57.4	54.8
Chara	2.4	0.2	2.4	0.2	0.1	0.1	0.1	0.1
Potamogeton	381.5	12.4	450.9	14.7	8.5	4.8	11.9	6.7
Heterathera	77.5	5.6	45.2	3.3	1.7	2.2	1.2	1.5
Nelumbo	814.7	70.3	814.7	70.3	18.1	27.3	21.5	32.1
Justicia	442.5	15.9	299.0	10.8	9.9	6.2	7.9	4.9
Totals	4488.8	257.9	3782.3	219.4	100.0	100.0	100.0	100.0

Sediment: Sediment samples from each monitoring site were analyzed for composition and nutrient content. Sampling and analysis of hypolimnetic water quality was undertaken to document biogeochemical cycling (fate of phosphorus) within the hypolimnion (parameters of dissolved iron and sulfide).

Reservoir water quality was monitored within one week of sediment sampling (February 10, 1999, for Spavinaw Lake and February 17, 1999, for Lake Eucha. Field parameters showed the water column at each sample site to be isothermal and oxygenated. Lake Eucha and Spavinaw Lake sediment were sampled February 16 1999, using an Eckman Dredge. The Eckman Dredge was scrubbed and rinsed between sites using ambient water. Approximately the top 10-cm of sediment were sampled. Two Eckman grabs were taken per site and homogenized using a Teflon spatula. The homogenized sample was then partitioned into two glass sample containers. The one-liter container was delivered to the City County Health Department of Oklahoma County (CCHDOC) for analysis. The 0.5-liter sample was delivered to the OSU Biosystems and Agricultural Engineering Department for analysis. Field sampling and homogenization were performed in an aerobic environment. The dark color and slight odor of all samples indicate that aerobic sampling may have biased the relative fraction of redox labile constituents; sulfur, nitrogen, and phosphorus. Every effort was made to reduce sample handling time and ensure minimum chemical transformations. Both CCHDOC and OSU preserved sediment samples in the dark at 40° until analysis or testing. OSU provided testing within 30 hours of sample receipt. CCHDOC performed sample analysis within holding times prescribed within this project's QAPP.

Particle size results are consistent with reservoir zonation: higher clay content (45 percent-50 percent) at the deeper sites, and larger particle fractions at the upper lake sites (Table 4-16).

The high silt (55 percent–70 percent) and low sand (21 percent–24 percent) content of the upper sites are representative of low sediment load washing in from Spavinaw Creek to both reservoirs. Generally Eucha Lake sediment had higher nitrate nitrogen content than Spavinaw Lake. An iron-phosphorus ratio was also calculated. The relatively high ratio was noted at sites SPA05 and SPA02. This indicates the possibility of active iron oxide precipitation and control of phosphorus solubility by iron. The relatively large orthophosphorus concentration in the sediment suggests that during anaerobic conditions phosphorus would diffuse from the sediment into the water column (Wetzel, 1983).

Table 4-16. Lake sediment analysis of February 16, 1999, samples.

Parameter	EUC01	EUC02	EUC16	EUC03	SPA01	SPA02	SPA05
Depth (m)	**22**	**14**	**11**	**6**	**14**	**9**	**4**
Sample volume (l)	1	1	1	1	1	1	1
Ammonia as N (mg/kg)	46.6	43.3	31.0	41.4	38.0	14.2	17.3
Nitrate as N (mg/kg)	104	80.7	74.8	62.5	51.7	39	66.2
Nitrite as N (mg/kg)	0.34	0.67	1.08	0.16	0.80	0.13	0.09
Kjeldahl as N (mg/kg)	804	834	832	843	958	857	711
Organic N (mg/kg)	757	791	801	802	920	843	694
Phosphorus, Ortho (mg/kg)	0.20	0.66	0.19	0.89	0.48	0.27	0.19
Phosphorus, Total (mg/kg)	266	457	460	362	492	265	174
Sulfide (mg/kg)	440	80	56	240	128	5	72
Sulfate (mg/kg)	601	2	292	113	374	177	80.6
Iron, Total (mg/kg)	3,472	4,245	5,484	5,627	5,560	5,462	3,987
Fe/P ratio	13	9	12	16	11	21	23
% Organic Content	1.8	1.9	2.1	2.4	2.1	2.0	2.0
% Sand	20.0	17.5	16.3	23.8	25.0	12.5	21.3
% Silt	30.0	31.3	56.3	58.8	30.0	52.5	68.8
% Clay	50.0	51.3	27.5	17.5	45.0	35.0	10.0

OSU performed additional sediment laboratory testing with statistical testing. Methods used were the same as those used to determine the phosphorus sorption index (PSI) and exchangeable phosphorus content described by Haggard et al. (1999). Samples were extracted using manganese chloride and the extractant analyzed for phosphorus content to measure the amount of loosely sorbed phosphorus. For both lakes the upper sites contain the lowest levels of loosely sorbed phosphorus while the lower, deeper sites contain the higher levels of loosely sorbed phosphorus (Table 4-17). Application of the Student's T-test indicated SPA05 to be distinct from SPA02 and SPA01 at a 0.10 probability of a Type-I error. Application of the same test to Lake Eucha sediments showed EUC03 distinct from EUC01, EUC02, and EUC16 at a 0.10 probability of a Type I error. Application of this same statistical test to every sediment sample showed only the two upper lake sites to be similar. The higher levels of loosely sorbed phosphorus in the deeper sites are consistent with the relatively higher clay content of the deeper lake sites. The high surface area of clays enables a greater amount of substrate for sorption and precipitation products containing phosphorus (Lerman, 1978).

Table 4-18 presents the results of an experiment determining the relative ability of each sediment sample to adsorb phosphorus. Test results are indexed with higher values representing a greater ability to bind phosphorus while lower values represent a lower ability to bind phosphorus. Lower PSI values were determined at the shallower, upper lake sites. Higher PSI values denoting greater sorption ability were noted at the deeper lake sites. Student's T-test was also applied to this data set. Results showed each Spavinaw Lake site to be distinct from each other at a 0.10 probability of a Type-I error. Lake Eucha t-test results showed EUC03 to be distinct from EUC01 and EUC02 at a 0.10 probability of a Type-I error while EUC16 showed to be distinct from EUC01 at a 0.10 probability of a Type-I error. PSI results of Lake Eucha and Spavinaw Lake sediments support the binding ability of clays in the deeper lake sites. Without further chemical reactions, this sorbed phosphorus would also be released under anaerobic conditions.

Table 4-17 Loosely sorbed (soluble) phosphorus content in mg/L, February 16, 1999.

Accompanying Student T-test results are also presented. Statistical values represent p-values.

Replicate	SPA01	SPA02	SPA05	EUC01	EUC02	EUC16	EUC03
1	1.0	1.6	0.18	0.84	1.2	0.86	0.17
2	1.5	1.5	0.22	0.50	0.56	0.85	0.16
3	1.5	1.9	0.35	0.52	0.62	0.55	0.13
mean	1.4	1.7	0.25	0.62	0.78	0.75	0.15
std	0.278	0.219	0.085	0.193	0.332	0.174	0.023
Student's T-test		SPA02	SPA05	EUC01	EUC02	EUC16	EUCH03
	SPA01	0.214	0.014	0.024	0.082	0.042	0.017
	SPA02		0.003	0.004	0.024	0.006	0.006
	SPA05			0.062	0.101	0.022	0.183
	EUC01				0.521	0.427	0.050
	EUC02					0.911	0.081
	EUC16						0.025

Table 4-18 Phosphorus sorption index values for sampled lake sediment, February 16, 1999.

Accompanying Student T-test results are also presented. Statistical values represent p-values.

Replicate	SPA01	SPA02	SPA05	EUC01	EUC02	EUC16	EUCH03
1	20.7	11.8	9.66	19.0	18.5	12.5	11.3
2	19.6	15.1	9.41	32.7	24.8	16.6	12.6
3	19.9	15.3	8.94	33.4	16.6	14.0	10.1
Mean	20.0	14.0	9.34	28.4	20.0	14.4	11.3
std	0.6	2.0	0.37	8.1	4.3	2.1	1.2
variance	0.341	3.867	0.136	65.623	18.427	4.381	1.554

Replicate	SPA01	SPA02	SPA05	EUC01	EUC02	EUC16	EUCH03
Student's T-test		SPA02	SPA05	EUC01	EUC02	EUC16	EUCH03
	SPA01	0.026	0.000	0.217	0.975	0.035	0.002
	SPA02		0.049	0.085	0.124	0.849	0.125
	SPA05			0.055	0.049	0.049	0.101
	EUC01				0.210	0.088	0.065
	EUC02					0.139	0.063
	EUC16						0.111

Direct examination of lake sediment indicates a capacity for short-term storage of phosphorus. Total iron and sulfide measurements of bottom water samples were made following the onset of anoxic hypolimnetic waters. These parameters were chosen to serve as direct indicators of hypolimnetic oxidation-reduction state and sediment nutrient release. Figure 4-54 plots hypolimnetic iron and sulfide concentrations during stratification for Lake Eucha and Spavinaw Lake. All sites show an accumulation of sulfide and iron with the greatest concentrations at the dam of both lakes. Reductions of sulfide and iron concentrations are concurrent with thermal destratification. Sulfide concentrations represent a shift toward increasingly reducing conditions within the hypolimnion. Increasing iron concentrations during stratification closely follows that of dissolved orthophosphorus. This pattern indicates the bulk of released phosphorus has been bound with iron. Without further chemical reactions (mineralization), this sorbed phosphorus would be released under anaerobic conditions.

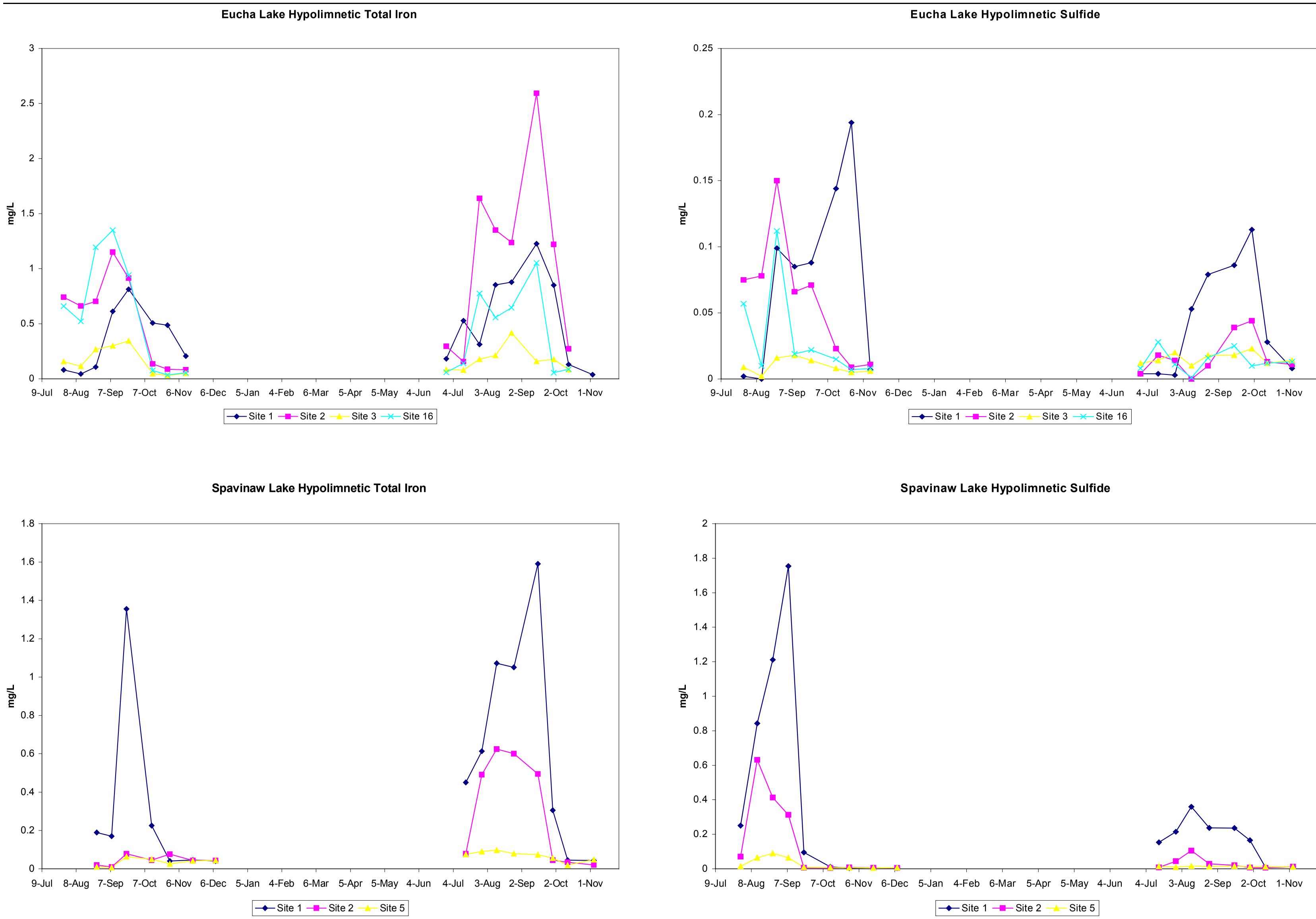


Figure 4-52 . Hypolimnetic iron and sulfide concentrations for Eucha and Spavinaw Lakes

Sediment Phosphorus Load

Water quality data were examined to evaluate the potential of the deeper lake sediments to release phosphorus for algae uptake. Examination of orthophosphorus isopleths (Figures 4-12 and 4-13) shows a distinct gradient from the lake bottom toward the surface. Because water quality data are indicative, a three-step method to estimate sediment phosphorus load was employed:

1. A rate of sediment phosphorus release was calculated using hypolimnetic phosphorus concentrations (Snow and DiGiano, 1976)
2. A rate of diffusion across the metalimnion was calculated using temperature data to estimate internal load (Chapra and Reckhow, 1983)
3. Phosphorous mass release through entrainment was included

The first step allows for estimates of phosphorus sediment release. This value constitutes the amount of phosphorus available for migration to the epilimnion. The second step provides a diffusion coefficient to estimate the amount of phosphorus reaching the epilimnion based on thermal properties. The third step estimates a phosphorous mass that is entrained into the epilimnion as stratification erodes. Appendix E is a complete description of calculation methods and results.

Sediment Release: Spavinaw Lake and Eucha Lake had a mean release rate of 2.50 mg/m^2-day and 2.39 mg/m^2-day, respectively, in 1998 (Table 4-19). 1999 mean release rates for Spavinaw Lake and Eucha Lake were 1.81 mg/m^2-day and 2.86 mg/m^2-day, respectively. These release rates translated into a total mass of phosphorus released from the sediment by integration over each stratification period. In general, greater amounts of phosphorus were released in 1999 than in 1998 in Lake Eucha and smaller amounts released in 1999 than 1998 in Spavinaw Lake (Table 4-20). Considerable sediment-bound phosphorus was released each stratification period.

Table 4-19 Calculated rate (m_s) of hypolimnetic sediment phosphorus release during stratification in mg/m^2-day.

Lake	Year	Mean	Coefficient of Variation
Eucha	1998	2.4	2.2
	1999	2.9	5.8
Spavinaw	1998	2.5	3.1
	1999	1.8	4.5

Table 4-20 Estimated hypolimnetic sediment phosphorus release during stratification.

Lake	Year	Duration (Day)	Total released Phosphorus (kg)
Eucha	1998	212	2,027.4
	1999	183	3,337.2
Spavinaw	1998	180	938.4
	1999	175	339.6

Internal Load: The next step is to estimate the amount of hypolimnetic phosphorus reaching the epilimnion as an internal phosphorus load. To do this, a rate of diffusion ($W_{diffusion}$) across the metalimnion was calculated using temperature data (Chapra and Reckhow, 1983). Diffusive rate calculations encompassed time periods when hypolimnetic phosphorus accumulation was observed (Table 4-20). Estimated internal load values indicate the greatest amount occurred at Eucha Lake in 1999 (Table 4-21). Internal load captures one method of hypolimnetic phosphorus flux into the epilimnion.

Table 4-21 Internal phosphorus load estimates for Lake Eucha and Lake Spavinaw.

Lake	Year	Thermal Diffusion Coefficient (V_t) (m/day)	Duration (Day)	Phosphorus Load (kg)
Eucha	1998	0.0012	212	7.4
	1999	0.0058	183	197.4
Spavinaw	1998	0.0003	180	1.7
	1999	0.0008	175	1.2

Entrainment Load: An aditional method of introduction is through the degredation of the hypoimnion (entrainment) as epimimnetic waters cool in the fall. Entrainment calculations involved the use of average transformed ortho-phosphorous values and the change in lake volume at the hypolimnetic depth. Entrainment was calculated during stratification when a graphical trend was apparent in the decrease of the hypolimnion as evidenced by a pattern in decreasing water temperature. Generally speaking, this pattern was observed in the later months of the stratification season as the thermacline began to erode.

For Lake Eucha in 1998, entrainment dates of July 28 to November 12, indicated 1,984.2 kg of phosphorous was present (Table 4-22). In 1999, 2,840 kg of phosphorous was calculated to enter the epilimnion by entrainment data for the dates of July 27 through October 13. These dates correspond to a pattern where the lake water temperature was beginning to cool and, hence, the stratification layers apparent during the earlier, warmer time periods were starting to break down.

For the time period of July 30 through October 13, entrainment calculations indicate a total of 635.1 kg of phosphorous entered the epilimnion in Lake Spavinaw during the 1998 season (Table 4-22). During the 1999 season, 455.4 kg of phosphorous was calculated from entrainment data from August 11 through October 12. As in Lake Eucha, the dates observed in entrainment calculations relate to a time period where waters in Lake Spavinaw were beginning to cool as a result of the lake beginning the early stages of becoming isothermal.

Table 4-22 Entrainment of phosphorous mass for Lake Eucha and Spavinaw Lake

Phosphorous Release (kg) by Entrainment			
Eucha 1998	Eucha 1999	Spavinaw 1998	Spavinaw 1999
1,984.2	2,840	635.1	455.4

Total Phosphorus Load from Sediment: The total flux of phosphorus into the epilimnion is a combination of internal and entrainment loadings. These two calculations were combined to yield an annual estimate of hypolimnetic phosphorus reaching the epilimnion (Table 4-23 and 4-24). Sediment derived load calculations were used as input to the lake water quality model and distributed on a monthly basis for lake nutrient budgeting.

Table 4-23 Sediment derived phosphorous load estimation for Lake Eucha during 1998-1999 stratification season.

Total annual load is a summation of thermal diffusion release and entrainment release.

<table>
<tr><th colspan="3">Lake Eucha</th></tr>
<tr><th>Time Period</th><th>Thermal Diffusion Release (kg)</th><th>Entrainment Release (kg)</th></tr>
<tr><td>April 14, 1998</td><td rowspan="15">7.5</td><td></td></tr>
<tr><td>April 30, 1998</td><td></td></tr>
<tr><td>May 13, 1998</td><td></td></tr>
<tr><td>May 28, 1998</td><td></td></tr>
<tr><td>June 10, 1998</td><td></td></tr>
<tr><td>June 23, 1998</td><td></td></tr>
<tr><td>July 14, 1998</td><td></td></tr>
<tr><td>July 28, 1998</td><td>824.5</td></tr>
<tr><td>August 12, 1998</td><td>146.3</td></tr>
<tr><td>August 25, 1998</td><td>382.3</td></tr>
<tr><td>September 9, 1998</td><td>121.4</td></tr>
<tr><td>September 23, 1998</td><td>0</td></tr>
<tr><td>October 14, 1998</td><td>143.2</td></tr>
<tr><td>October 27, 1998</td><td>344.3</td></tr>
<tr><td>November 12, 1998</td><td>22.3</td></tr>
<tr><td>Total 1998 Load</td><td colspan="2">1,991.7</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>April 13, 1999</td><td rowspan="2"></td><td></td></tr>
<tr><td>April 28, 1999</td><td></td></tr>
</table>

Lake Eucha		
May 13, 1999		
May 25, 1999		
June 9, 1999		
June 28, 1999		
July 13, 1999		
July 27, 1999		919.1
August 10, 1999		0
August 24, 1999		1,134.9
September 15, 1999		700.3
September 30, 1999		4.3
October 13, 1999		81.4
Total 1999 Load	3,037.3	

Table 4-24 Sediment derived phosphorous load estimation for Lake Spavinaw during 1998-1999 stratification season.

Total annual load is a summation of thermal diffusion release and entrainment release.

Lake Spavinaw		
Time Period	**Thermal Diffusion Release (kg)**	**Entrainment Release (kg)**
April 16 ,1998		
April 29, 1998		
May 12, 1998		
May 27, 1998		
June 11, 1998		
June 25, 1998		
July 15, 1998	1.7	
July 30, 1998		250.6
August 13, 1998		0
August 26, 1998		179.4
September 8, 1998		110.5
September 21, 1998		94.3
October 13, 1998		0.3
Total 1998 Load	636.8	

Lake Spavinaw		
Time Period	**Thermal Diffusion Release (kg)**	**Entrainment Release (kg)**
April 20, 1999	1.2	
April 29, 1999		
May 12, 1999		
May 26, 1999		
June 10, 1999		
June 24, 1999		
July 15, 1999		
July 29, 1999		
August 11, 1999		442.5
August 26, 1999		12.0
September 16, 1999		0.5
September 29, 1999		0
October 12, 1999		0.4
Total 1999 Load	456.6	

Water Quality Modeling

Nutrient Budget

Phosphorus budgets for Lake Eucha and Spavinaw Lake were prepared with Soil and Water Assessment Tool (SWAT) estimated inflows and lake monitored data. A summary of SWAT model results used for external inputs of phosphorus are given in the Tributary Water Quantity and Quality section of the Hydrology chapter. Lake monitored data was used for internal inputs and outputs of phosphorus. Internal inputs are described in the Sediment Phosphorus Load section of the Current Limnology chapter. The two phosphorus inputs represent the gross or total phosphorus gain to each lake. Water quantity and quality data were used to estimate the mass of phosphorus leaving each lake as outflow on a monthly basis. The difference between the gross phosphorus gain and the outflow loss yeilded the amount retained in the lake sediment. Tabulation of these monthly gains and losses allowed for construction of annual phosphorus budgets.

Lake Eucha

Average annual values for Lake Eucha shows basin inputs to dominate (93 percent of the total load) (Table 5-1). Average annual phosphorus load during the monitoring period was 36,948 kg with about 80 percent of the phosphorus retained by the lake. Lake Eucha experienced a greater phosphorus gains and losses in 1999 than in 1998.

Table 5-1 Lake Eucha itemized annual phosphorus load.

Monitor Year (April-March)	Phosphorus Gain			Phosphorus Loss		Percent Retention
	Lake Basin	Sediment	Total Gain	Outflow	Sediment	
annual load in kilograms						
1998	31786	1992	33778	5958	27820	82.4
1999	37080	3037	40117	8935	31182	77.7
average	34433	2515	36948	7447	29501	79.8
annual load as percent of total						
1998	94.1	5.9	100.0	17.6	82.4	
1999	92.4	7.6	100.0	22.3	77.7	
average	93.2	6.8	100.0	20.0	80.0	

To check monthly lake loads, current influent mass was added to the previous month's resident mass. This monthly comparison of predicted versus actual meaured lake mass indicated monthly phosphorus load was underestimated by 1,400 kg in August and September of 1998 and 5,000 kg in August and September of 1999. Figure 5-1 reflects this discrepancy. Sediment-released phosphorus to the hypolimnion was the determining factor for this discrepancy.

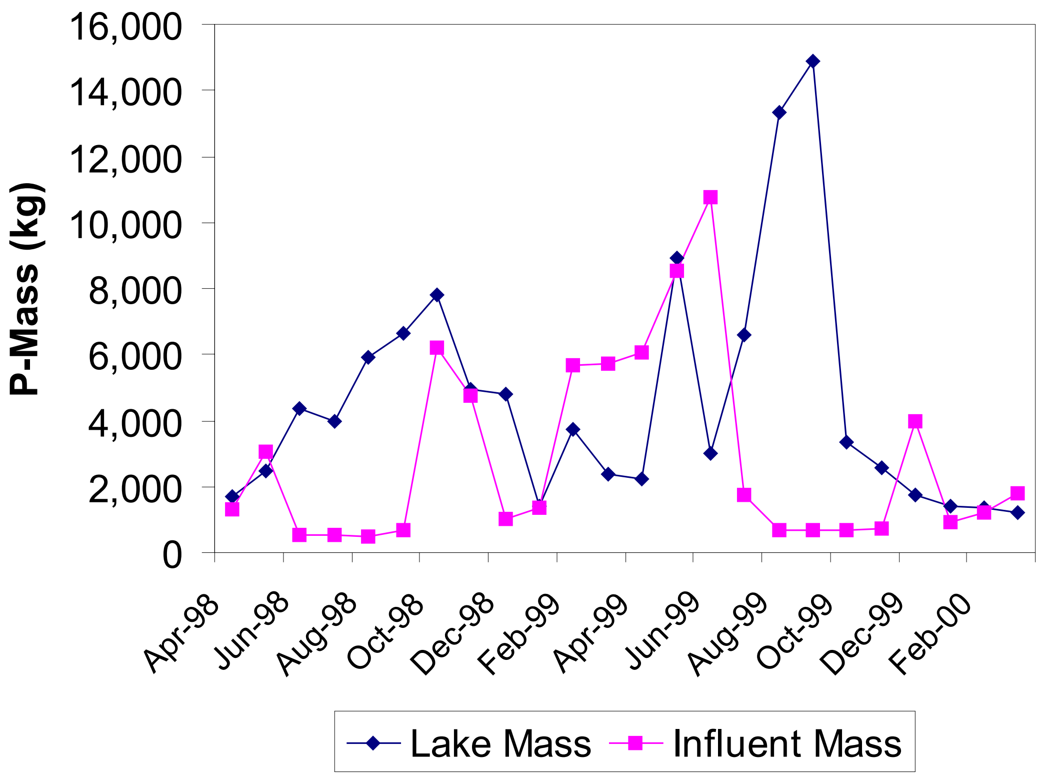


Figure 5-1. Comparison of Lake Eucha inflow to resident phosphorus mass April 1998–March 2000.

Seasonal phosphorus dynamics are evident in the monthly, itemized phosphorus budget for Lake Eucha (Table 5-2). Inflow mass minus outflow mass divided by inflow mass yielded the percent retention. Phosphorus is retatined in a lake by precipitation to the sediment. Lake Eucha sediment trapped most of the phosphorus that entered the lake. The lower values in the sediment column correspond to lower percent retention for that month. The lowest retention value corresponds to July 2-3, 1999, when Lake Eucha crested and approximately 10,500 acre-feet of Lake Eucha water was released. Phosphorus retention was greatest in May 1998 and January 1999 when water inflow greatly exceeded water outflow (the reservoir was filling).

Table 5-2. Lake Eucha itemized monthly phosphorus budget in kilograms.

Month	Phosphorus Gain			Phosphorus Loss		Percent Retention
	Basin	Sediment	Total	Outflow	Sediment	
April-98	1334	1.0	1335	356	979	73.3
May-98	3060	1.0	3061	148	2913	95.2
June-98	533	1.2	534	197	337	63.2
July-98	553	825.5	1378	188	1190	86.3
August-98	499	529.6	1029	123	905	88.0
September-98	669	122.6	792	113	680	85.8
October-98	6278	488.5	6767	1153	5613	83.0

Month	Phosphorus Gain			Phosphorus Loss		Percent Retention
	Basin	Sediment	Total	Outflow	Sediment	
November-98	4772	22.3	4794	550	4244	88.5
December-98	1039	0.0	1039	328	711	68.4
January-99	1391	0.0	1391	78	1314	94.4
February-99	5810	0.0	5810	1628	4182	72.0
March-99	5847	0.0	5847	1096	4752	81.3
April-99	5974	32.4	6006	515	5492	91.4
May-99	8459	29.1	8488	2644	5844	68.9
June-99	10806	36.7	10843	851	9992	92.2
July-99	1574	949.3	2523	2258	265	10.5
August-99	499	1173.7	1673	525	1148	68.6
September-99	504	734.8	1239	180	1059	85.4
October-99	504	81.4	585	182	403	68.9
November-99	731	0.0	731	527	204	27.9
December-99	4004	0.0	4004	623	3382	84.4
January-00	962	0.0	962	135	826	85.9
February-00	1238	0.0	1238	209	1029	83.1
March-00	1825	0.0	1825	286	1539	84.3

Spavinaw Lake

The annual average phosphorus budget values for Spavinaw Lake shows that Eucha dam inputs to dominate (87 percent of the total load) (Table 5-3). Average annual phosphorus load during the monitoring period was 8,484 kg, with about 30 percent of the basin phosphorus retained in lake sediment. Spavinaw Lake experienced greater phosphorus inflow gains and losses as well as phosphorus outflow in 1999 than in 1998 (an additional 80,000 acre-feet flow-through). Examination of monthly lake phosphorus content shows that although the 1999 water year had a higher phosphorus load, water year 1998 had higher phosphorus content (Figure 5-2). This was especially evident during the summer season. Sediment released phosphorus to the hypolimnion was the determining factor for this discrepancy (Table 5-5).

Table 5-3 Spavinaw Lake itemized annual phosphorus load.

Monitor Year (April-March)	Phosphorus Gains				Phosphorus Losses			Percent Retention
	Eucha Dam	Basin	Sediment	Total	Dam	Water Supply	Sediment	
annual load in kilograms								
1998	5,712	542	637	6,891	3,778	1,890	1,223	17.8
1999	9,031	589	457	10,077	4,706	1,645	3,726	37.0
Average	**7,372**	**566**	**547**	**8,484**	**4,242**	**1,768**	**2,475**	**29.2**
annual load as percent of total								
1998	82.9	7.9	9.2	100	54.8	27.4	17.8	
1999	89.6	5.8	4.5	100	46.7	16.3	37.0	
Average	**86.9**	**6.7**	**6.4**	**100**	**50.0**	**20.8**	**29.2**	

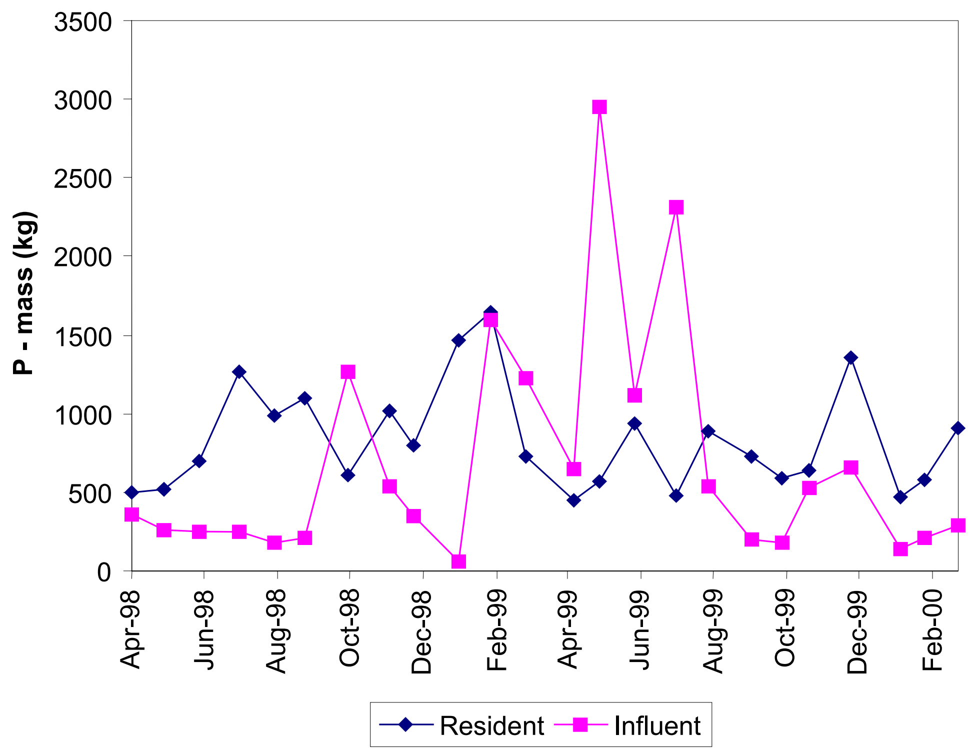


Figure 5-2. Comparison of Spavinaw Lake influent to resident phosphorus mass April 1998 - March 2000

An itemized monthly phosphorus budget was also prepared (Table 5-4). Phosphorus sources are itemized into sediment, Lake Eucha release water (Eucha Dam), and SWAT estimated runoff of the immediate basin (Basin). Phosphorus losses are itemized according to the mechanism: water lost over the spillway (Dam), water diverted to Tulsa

(Water Supply) for municipal drinking water and phosphorus retained by the lake through precipitation (Sediment).

Table 5-4 Spavinaw Lake itemized monthly phosphorus budget in kilograms.

Month	Phosphorus Gain				Phosphorus Loss			Percent Retention
	Eucha Dam	Basin	Sediment	Total	Dam	Water Supply	Sediment	
April-98	350.3	12.6	0.2	363	161	113	89	24.6
May-98	144.0	60.0	0.3	204	164	114	-73	-35.7
June-98	196.6	0.0	0.3	197	7	141	49	24.8
July-98	188.4	0.0	250.9	439	2	176	261	59.5
August-98	123.5	0.0	179.6	303	0	186	117	38.6
September-98	112.6	41.8	205.1	360	0	145	214	59.6
October-98	1128.0	140.4	0.3	1269	451	80	737	58.1
November-98	507.0	34.3	0.0	541	256	235	50	9.2
December-98	310.3	40.0	0.0	350	137	144	69	19.8
January-99	62.7	0.0	0.0	63	65	155	-157	-250.5
February-99	1531.7	63.4	0.0	1595	1301	267	27	1.7
March-99	1057.1	149.6	0.0	1207	1234	134	-160	-13.3
April-99	507.2	116.2	0.2	624	918	100	-394	-63.2
May-99	2757.4	181.3	0.2	2939	1005	114	1,819	61.9
June-99	841.0	225.0	0.2	1066	932	150	-15	-1.5
July-99	2257.8	35.2	0.2	2293	928	110	1,256	54.8
August-99	525.1	0.0	454.7	980	0	140	840	85.7
September-99	180.4	0.0	0.7	181	0	114	67	37.2
October-99	182.2	0.0	0.4	183	0	141	42	22.8
November-99	527.3	0.0	0.0	527	5	133	389	73.8
December-99	622.8	30.3	0.0	653	559	278	-184	-28.2
January-00	135.2	0.0	0.0	135	9	99	28	20.7
February-00	208.8	0.0	0.0	209	0	112	97	46.4
March-00	286.1	0.8	0.0	287	350	155	-218	-76.0

Spavinaw Lake phosphorus retention varied from a maximum of +86 percent (August 1999) to a minimum of –251 percent (January 1999). For the most part, the negative percentage retention values reflect greater water consumption than was replenished that month. Spavinaw Lake's short hydraulic retention is a contributor to the relatively low phosphorus retention. Dominant phosphorus sources and sinks varied with flow. During high flow, Eucha Dam release water dominated as the source and spillway flow from Spavinaw Dam dominates losses during high flow. During low flow, sediment constitutes up to 45 percent to 60 percent (July 1998 - August 1998 and August 1999) of the phosphorus gain while water supply dominated phosphorus losses.

Lake Modeling

Several lake models have been developed to relate the inflow of phosphorus to a lake's trophic state. The Morphoedaphic Index (MEI) (Vighi and Chiaudani, 1985) is used to estimate water quality prior to human impact. Two of the most commonly applied models, the Vollenweider model and the OECD model, use information from many lakes to predict water quality classification. These three models have been applied to the Eucha-Spavinaw lake system to estimate background water quality conditions and load reductions needed to improve water quality. These models, although instructive, cannot be used as primary tools for reservoir system diagnosis because they were constructed for application to natural lake systems. The greatest utility of these models in this project is to gain general limnological understanding and substantiate additional modeling efforts.

The MEI was applied to evaluate the background phosphorus concentrations of both Lake Eucha and Spavinaw Lake. The MEI uses the ratio between mean depth and alkalinity or conductivity to calculate the total mean phosphorus levels of the lake in a natural state. That is, the phosphorus concentration that the lake would reach in relation to its morphometry and the natural characteristics of the drainage basin, where anthropogenic nutrient inputs are excluded (Vighi and Chiaudani, 1985).

For both lakes, background phosphorus levels were calculated using the MEI for both alkalinity (equation1) and conductivity (equation 2).

Eq.1 $$\mathrm{Log}[\mathrm{P}] = 1.48 + 0.33(\pm 0.09)\log\left(alk. \middle/ MeanDepth \right)$$

alk. is alkalinity as milliequivalents/L and mean depth as meters

Eq.2 $$\mathrm{Log}[\mathrm{P}] = 0.75 + 0.27(\pm 0.11)\log\left(Cond. \middle/ MeanDepth \right)$$

Cond. is conductivity as µSiemens and mean depth as meters

Both equations 1 and 2 contain a constant to indicate model variance. This is represented by the (±0.09) in equation 1 and the (±0.11) in equation 2. Median values taken from the historical data set were used for MEI predictions. Application of each model yielded three results: the median values without factoring in variance, a minimum value calculated by factoring the negative value for variance, and finally a maximum value calculated by factoring in the positive variance for Lake Eucha. The alkalinity MEI resulted in a background phosphorus concentration ranging from .028 mg/L to .031 mg/L (Table 5-5). The conductivity MEI for Lake Eucha produced results ranging from .005 mg/L to .006 mg/L. Considerable variation is noted comparing alkalinity and conductivity models results. For Spavinaw Lake, calculating the alkalinity MEI resulted in estimates of natural background phosphorus concentrations ranging from .029 mg/L to .031 mg/L. Calculating the conductivity MEI for Spavinaw Lake resulted in a background phosphorus concentration ranging from .005 mg/L to .006 mg/L. As with Lake Eucha, considerable variation is noted between the two methods to estimate background concentation. These results suggest further investigation is needed to estimate background lake phosphorus concentrations.

Table 5-5 Lake Eucha and Spavinaw Lake Background Phosphorus Concentrations.

	Lake Eucha	Spavinaw Lake
Alkalinity MEI	.028 mg/L to .031 mg/L	.029 mg/L to .031 mg/L
Conductivity MEI	.005 mg/L to .006 mg/L	.005 mg/L to .006 mg/L

Lake Load Models

The semi-empirical models developed by OECD (OECD, 1982) and Vollenweider (1986) also predict lake total phosphorus concentration. These models are modifications of the basic mass-balance equation (2) . Both models employs the use of equation 2 to calculate the in-lake total phosphorus concentration; C_{TP}:

$$C_{TP} = \frac{R_{TP}*T}{D_M} \quad \ldots\ldots\ldots\ldots\ldots..(2)$$

Where R_{TP} = Annual areal load to the lake as mg TP/m^2/yr
D_m = Lake mean depth as meters
T = water retention time as years

The Vollenweider model is presented in the following formula:

$$C_{TP} = \frac{C_{TPin}}{\left(1+\sqrt{T}\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots...(3)$$

The Organization for Economic Cooperation and Development (OECD) also developed a model to predict total lake phosphorous concentrations (equation 4). The OECD model is similar in structure to Vollenweider but includes three constants to increase predictive ability.

$$C_{TP} = \frac{1.55*C_{TPin}}{\left(1+\sqrt{T}\right)^{0.82}} \quad \ldots\ldots\ldots\ldots\ldots\ldots.(4)$$

The first step to apply these models is to tabulate inflow conditions. The annual detention times for the lakes were determined from the hydraulic budget of the lakes. Annual detention is the ratio of volume of lake to the outflow. The river input of total phosphorous that will be used will be obtained from the SWAT model output. Based on the OECD refinements from Vollenweider's model, the OECD model was applied to Eucha and Spavinaw lakes. Carlson's total phosphorus Trophic State Index model was used to relate the OECD output to trophic state. The SWAT phosphorus inflow for current and background conditions were applied to the OECD model.

The lake response to background phosphorous inflows estimated from SWAT were the primary input for this application (Table 4-6). The BATHTUB model was used to predict the phosphorus released from Lake Eucha with inflowing phosphorus at background levels. BATHTUB is a hybrid water quality model predicting in-lake and outflow water quality and quantity. BATHTUB model description and results are detailed further in this section.

Table 5-6 Average Annual Background Phosphorus Inflows (in kilograms)

Obtained from the SWAT and BATHTUB Models.

	Flow (m^3/sec)	SWAT	BATHTUB	Total Load
EUCHA	8.221	1749	--	1749
SPAVINAW	0.626	74	1049	1123

These output values were used in the OECD to calculate the lake response to background loading (Table 5-7). The trophic states of the lakes considering only background loading were found to be oligotrophic. Comparison of derived background values for Spavinaw Lake was close (0.005mg/L – 0.007mg/L) while Lake Eucha had more variability (0.002mg/L - 0.006mg/L).

Table 5-7 Eucha and Spavinaw Lake response to background estimated total-phosphorous loading using the OECD model.

Water Year (April – March)	Total P as mg/m^3	Total P as mg/l	TSI(TP)	Trophic Designation
Lake Eucha				
1998	2.20	0.0022	15.5	Oligotrophic
1999	2.30	0.0023	16.2	Oligotrophic
Spavinaw Lake				
1998	7.10	0.0071	32.4	Oligotrophic
1999	7.34	0.0073	32.9	Oligotrophic

Another approach used in the determination of the lake background phosphorous concentrations was by the use of EUTROMOD. This is a watershed model that is used to predict the lakes trophic state from nutrient inputs for the management of eutrophication. EUTROMOD uses land use, pollutant concentrations, and lake characteristics estimate the nutrient loading and various trophic state parameters in the lake. Application of EUTROMOD was not applicable because Lake Eucha and Spavinaw Lake are in a series (85 percent of the inflow of Spavinaw lake is Lake Eucha release water). This did not allow the reservoirs to be modeled with this method.

All three (MEI, OECD and EUTROMOD) models predict lake total P (background) that fall within oligotrophic range with predicted concentrations ranging from 0.002 mg/L to

0.008 mg/L. The relative agreement of these models suggests theoretical lower limit of phosphorus concentrations for the system. These results also imply that considerable improvement of lake water quality is reasonable based on reductions of inflowing phosphorus.

The current trophic state for both lakes was assessed using Vollenweider's equation and the OECD equation. Both show each lake near the boundary between eutrophy and hypereutrophy, far into the eutrophic range. Figure 5-3 is a graphic representation of each lake's current status and how far each is from changing its trophic status. OECD values in Table 5-8 can be placed on the load diagram developed by OECD (Figure 5-4) to estimate how far each lake is from changing trophic state.

Comparison of OECD TP predictions to the current data summary and TP total phosphorus median values (listed in the data summary section of Section 3: Current Limnology) shows that the OECD model predicts TP concentrations approximately 1.5 times greater than those measured current for Lake Eucha and approximately 2 times greater than those measured current for Spavinaw Lake (Table 5-8). The predicted total phosphorus concentrations were greater than the observed total phosphorus for either lake. The OECD derived TSI (TP) value approximated the current TSI (chl) for each lake. The variable results of the OECD model indicate the need for a reservoir water quality model to establish a relationship between phosphorus and chlorophyll-a.

Table 5-8 OECD predicted lake TP concentration and trophic state based on current inflow load estimates.

Water Year (April – March)	Mean Depth (m)	OECD		
		T-P (mg/L)	TSI(TP)	Trophic Designation
Eucha Lake	8.2	0.045	59	Eutrophic
Spavinaw Lake	5.1	0.047	60	Eutrophic

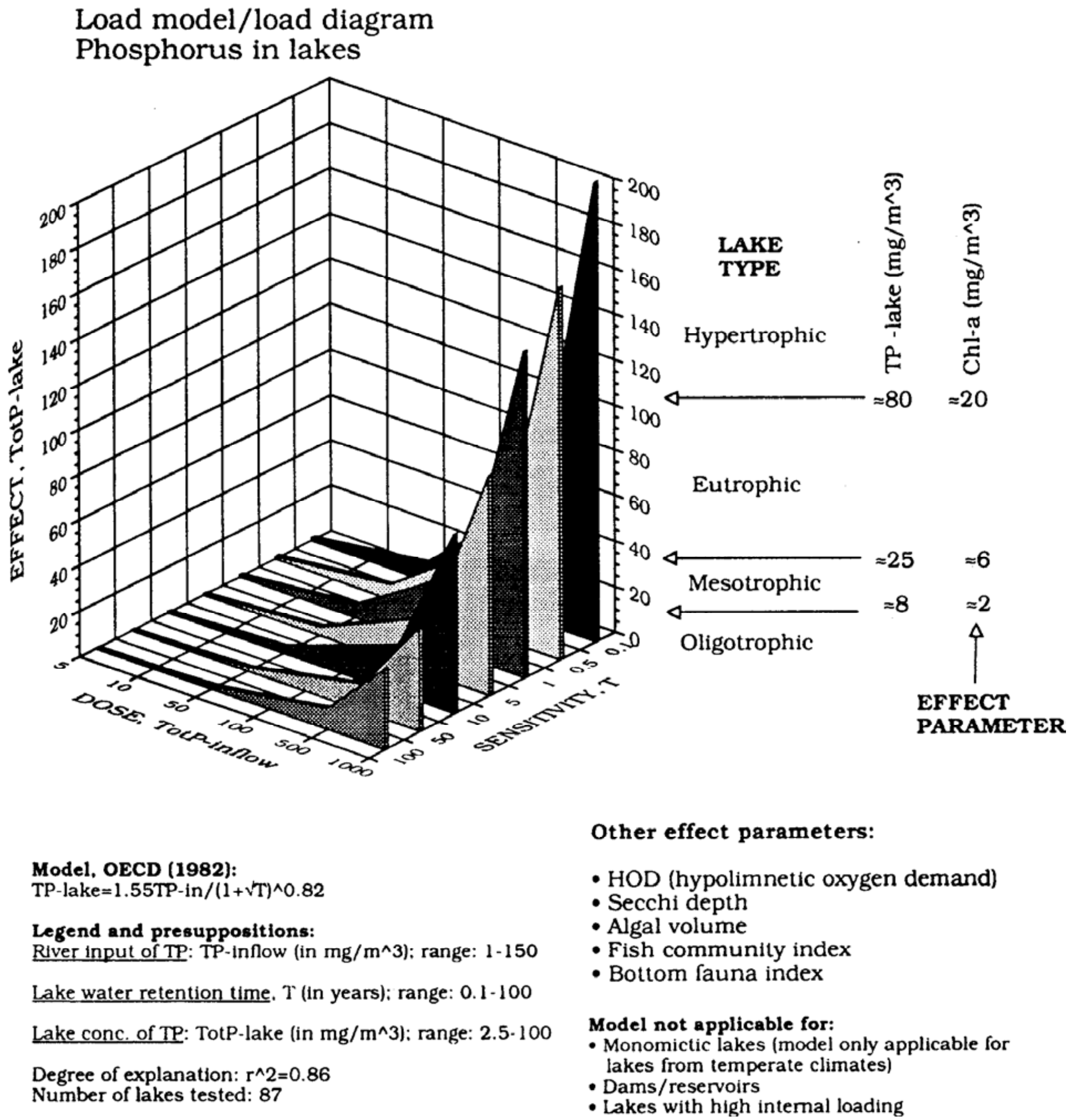


Figure 5-3 Load model and load diagram for phosphorous in lakes. Source: Håkanson, 1981.

In-Lake Modeling

Although instructive, the OECD and Vollenweider models were not designed for application to reservoir systems. To complete the selection of a nutrient reduction goal an in-lake water quality model developed for reservoir systems (BATHTUB) was employed (Walker 1996). The BATHTUB program applies empirical eutrophication models to morphometrically complex reservoirs or to collections of reservoirs. The program performs water and nutrient balance calculations in a steady-state, spatially segmented hydraulic network that accounts for advective transport, diffusive transport, and nutrient sedimentation. Eutrophication-related water quality conditions (expressed in terms of total phosphorus, total nitrogen, chlorophyll a, transparency, organic nitrogen, particulate phosphorus, and hypolimnetic oxygen depletion rate are predicted using empirical relationships previously developed and tested for reservoir applications (Walker 1983).

BATHUB offers a variety of diagnostic and predictive measures that afford flexibility to the modeler when choosing a target nutrient concentration. Perhaps most important is the ability to predict exiting water quality based on basin water quality. The Eucha Lake outflow then becomes the inflow to Spavinaw Lake. This in turn is used to predict outflow (raw drinking water) quality at Spavinaw Lake dam. The two-year water quality data set allows for model calibration for each step of the process.

The first step in model preparation was to compare annual (April – March) versus seasonal (April – September) fit. Input files were assembled using hydraulic and hydrolgic data compiled on a monthly basis. SWAT watershed load estimates incorporated precipitation and runoff nutrient loads for the entire basin including the lake area. For this reason, atmospheric inputs to BATHTUB were not directly inputted.

Lake model construction segregated monitored water quality according to reservoir zonation from the Current Limnology section. Lake nutrient inputs were assembled using the itemized nutrient budget. Outflow water quality was an additional input parameter for each lake and was also derived from the itemized nutrient budget. Morphological attributes of each reservoir zone (Table 5-9) were based on sample site location and hypolimnetic coverage. The length, area and mean depth of the lacustrine zone was determined through comparison of the area coverage of the hypolimnion. The transition zone for Eucha Lake was defined as the non-lacustrine zone downstream of the SH59 bridge (constriction on the upper end of Eucha Lake). Eucha Lake transition zone morphology was approximated from this boundary. Eucha Lake riverine zone and Spavinaw Lake transition zone boundaries were defined as the lake remainder. Small adjustments were made to morphological assignments so that each lake length and area summation equaled lake capacity.

Table 5-9 Morphology features of water quality based reservoir zones.

Parameter	Reservoir Zone		
	Lacustrine	Transition	Riverine
	Eucha Lake		
Length (km)	6.12	1.35	1.53
Area (km^2)	7.72	1.7	1.93
Mean depth (m)	15	10	6
	Spavinaw Lake		
Length (km)	4.16	2.24	
Area (km^2)	4.14	2.23	
Mean depth (m)	10	4	

Eucha Lake was broken into three separate segments with sampling sites 1 and 2 in the lacustrine zone, site 16 in the transition zone, and site 3 in the riverine zone. Eucha Lake nutrient inputs were also segregated into three groups: basin inputs estimated using the SWAT model, sediment released inputs calculated using water quality data, and dam outflow using water quality data. Spavinaw Lake was broken into two lake segments with sites 1 and 2 in the lacustrine zone and site 5 in the riverine zone. Spavinaw Lake nutrient inputs were segregated into three groups: basin inputs from the immediate drainage basin, Eucha Dam release water, and sediment inputs calculated from water quality data. Modeled lake water quality was compared to monitored exiting water quality to determine best fit.

The least amount of calibration was needed for the annual model to fit the observed data as compared to the summer seasonal model. For this reason, the annual model yielded the best fit and was used for the remaining modeling routines. Eucha Lake load estimates from BATHTUB (Table 5-10) compared favorably to the water quality based phosphorus budget (Table 5-11). A discrepancy was noted in the outflow mass. BATHTUB had a higher exiting flow rate and thus a higher phosphorus mass outflow. BATHTUB uses exiting flow to balance inflow. It should be noted that the phosphorus concentration closely matched measured water quality data. Both budgets gave a current lake phosphorus load of approximately 37,000 kg of phosphorus per year.

In order for the Eucha Lake BATHTUB model to match the in-lake water quality data, the phosphorus sedimentation rate was calibrated by increasing phosphorus sedimentation to 2.204 (BATHTUB default factor is 1.000). Following the completion of lake modeling runs, some variance was allowed for the SWAT-estimated annual total phosphorus load to Eucha Lake. These values ranged from 47,600 kg/yr to 31,865kg/yr. A brief run of BATHTUB showed that the phosphorus calibration factor required adjustment to match the in-lake water quality data. The annual phosphorus loads higher than 37,000 kg required a higher phosphorus sedimentation rate (3.4465 for 47,700 kg/yr) and the lower loads required a lower rate (1.973 for 31,865 kg/yr). Using the adjusted calibration factor (phosprus sedimentation rate) each load scenario predicted nearly identical water quality (chlorohphyll a) results.

Table 5-10 Comparison of Eucha Lake annual phosphorus budgets.

Monitor Year (April-March)	Lake Basin	Internal	Total Gain	Loss	Percent Retention
Water Quality Budget					
Kg/yr.	34,433	2,515	36,948	7447	79.8
% of total	93.2	6.8	100.0		
BATHTUB Segmented Model Budget					
Kg/yr.	34,400	2,515	36,915	9,605	72.1
% of total	93.2	6.8	100.0		

BATHTUB Spavinaw Lake load (Table 5-11) also closely matched the water quality derived budget (Table 4-3). Again, a discrepancy was noted in the outflow mass. As with Eucha Lake, BATHTUB had a higher exiting flow rate and thus a higher phosphorus mass outflow. BATHTUB uses exiting flow to balance inflow. The phosphorus concentration closely matched measured water quality data. BATHTUB did not split outflow into two separate sections as was documented with the water quality data. BATHTUB assumed that exiting water quality was equal throughout the water column at the dam of Spavinaw Lake. Both budgets gave a current lake phosphorus load of approximately 8,500 kg of phosphorus per year. Both BATHTUB lake models performed adequately to predict outflowing water quality based on inflowing water quality.

The Spavinaw Lake BATHTUB model required different calibration factors than the Eucha Lake BATHTUB model. Uncalibrated BATHTUB runs for Spavinaw Lake showed a good match between predicted phosphorus loads and in-lake water quality data but a poor match between predicted and in-lake chlorophyll-a concentration. This is because the source of water and form of phosphorus coming in to Spavinaw Lake is very different than that which flows into Eucha. Monthly budgeting showed that the majority of water and phosphorus flowing into Spavinaw Lake is released by Eucha Lake. In general, phosphorus leaves Eucha Lake in the release water bound up by algae. This explains why phosphorus concentrations matched well but chlorophyll-a concentration did not. No adjustment was made to the phosphorus sedimentation rate calibration of Spavinaw Lake. Chlorophyll-a was calibrated by a factor of 1.875 (default value of 1.000) to match in-lake water quality data.

Table 5-11 Comparison of Spavinaw Lake annualized phosphorus budget.

Monitor Year (April-March)	Eucha Dam	Lake Basin	Internal	Total Gain	Dam	Water Supply	Total Loss	Percent Retention
Water Quality Budget								
kg/yr	7,372	566	547	**8,484**	4,242	1,768	**6,009**	24.3
% of total	86.9	6.7	6.4	100.0	70.6	29.4	100	
BATHTUB Budget								
kg/yr	7,449	627	547	**8,622**	-	-	**6,705**	17.0
% of total	86.4	7.3	6.3	100.0	-	-		

Predictive Results

Area-weighted parameters from annualized seasonal models were used as the baseline for BATHTUB predictive work. Area-weighting combines a multi-segmented model into one segment. The use of an area-weighted model allowed for multiple runs of the same lake, varying only the input concentrations for each run. Tables 5-12 and 5-13 compare the area-weighted phosphorus budget against the previous prepared budgets. Area-weighted and segmented model phosphorus budgets were close to the water quality based budget. Although there was some drift in predictive accuracy, most of the budget error lies in the water budgeting and not the water quality. Water quality results of the area-wieghted model were assumed to be the exiting water quality. For example, the predicted area-weighted water quality of Eucha Lake was used as the input to Spavinaw Lake. The following explains how the lake response to variable phosphorus loads were assessed.

The hydraulic budget of each lake was not changed during the calculations. Varying the phosphorus concentration reflected changes in the annual phosphorus load. First, Eucha Lake inflow phosphorus concentrations were varied from the current load to 2.2 percent of the current load (pristine or background condition). Sediment load was then dropped to zero holding the same range of external loads. Results from these model runs gave a range of outflow phosphorus concentrations (Table 5-14) from 34.5 mg/m^3 to 4.8 mg/m^3. Outflow water quality using background inflow quality varied between 9 mg/m^3 and 4.8 mg/m^3 depending on the presence of internal loading. This result lends credibility to the MEI predicted background lake concentration of 6 mg/m^3 total phosphorus.

Table 5-12 Comparison of Eucha Lake phosphorus budgets.

Monitor Year (April-March)	Lake Basin	Sediment	Total Gain	Outflow	Percent Retention
Water Quality Budget					
Kg/yr.	34,433	2,515	36,948	7447	79.8
% of total	93.2	6.8	100.0		
BATHTUB Segmented Model Budget					

Monitor Year (April-March)	Lake Basin	Sediment	Total Gain	Outflow	Percent Retention
Kg/yr.	34,400	2,515	36,915	9,605	72.1
% of total	93.2	6.8	100.0		
BATHTUB Area-Weighted Model Budget					
Kg/yr.	34,400	2,514	36,914	9,920	71.2
% of total	93.2	6.8	100.0		

Table 5-13 Comparison of Spavinaw Lake phosphorus budget.

Monitor Year (April-March)	Eucha Dam	Basin	Sediment	Gain	Dam	Water Supply	Total Loss	Percent Retention
Water Quality Budget								
kg/yr	7,372	566	547	**8,484**	4,242	1,768	**6,009**	24.3
% of total	86.9	6.7	6.4	100.0	70.6	29.4	100	
BATHTUB Segmented Model Budget								
kg/yr	7,449	627	547	**8,622**	-	-	**6,705**	17.0
% of total	86.4	7.3	6.3	100.0	-	-		
BATHTUB Area-Weighted Model Budget								
kg/yr	7,439	627	547	**8,612**	-	-	**6,397**	20.7
% of total	86.4	7.3	6.3	100.0	-	-		

Table 5-14 BATHTUB predicted Eucha Lake quality with itemized nutrient inputs.

External Inflow		Sediment	Lake Load	Load Reduction	Exiting WQ		
					TSI (chl)	P-conc	% Reduction
mg/m^3	kg/yr	kg/yr	kg	%		Mg/m^3	
121.0	34,400	2,514	36,914	0	56.7	34.5	0
127.1	36,135	0	36,135	(2)	56.5	34.1	(1)
115.0	32,695	2,514	35,208	(5)	56.3	33.6	(3)
121.0	34,400	0	34,400	(7)	56.1	33.2	(4)
115.0	32,695	0	32,695	(11)	55.7	32.2	(7)
102.9	29,255	2,514	31,768	(14)	55.4	31.7	(8)
102.9	29,255	0	29,255	(21)	54.7	30.2	(12)
90.8	25,814	2,514	28,328	(23)	54.5	29.6	(14)
90.8	25,814	0	25,814	(30)	53.7	28	(19)
78.7	22,374	2,514	24,888	(33)	53.4	27.4	(21)

External Inflow		Sediment	Lake Load	Load Reduction	Exiting WQ		
					TSI (chl)	P-conc	% Reduction
mg/m³	kg/yr	kg/yr	kg	%		Mg/m³	
78.7	22,374	0	22,374	(39)	52.5	25.8	(25)
60.5	17,200	2,514	19,714	(47)	51.4	23.97	(31)
60.5	17,200	0	17,200	(53)	50.2	22	(36)
42.4	12,054	2,514	14,568	(61)	48.7	19.8	(43)
42.4	12,054	0	12,054	(67)	47.1	17.6	(49)
30.3	8,614	2,514	11,128	(70)	46.3	16.8	(51)
30.3	8,614	0	8,614	(77)	44.0	14.2	(59)
20.6	5,857	2,514	8,370	(77)	43.7	13.9	(60)
20.6	5,857	0	5,857	(84)	40.3	11	(68)
6.6	1,876	2,514	4,390	(88)	37.4	9	(74)
6.6	1,876	0	1,876	(95)	28.4	4.8	(86)

Spavinaw Lake predictive modeling used Eucha Lake as the primary inflow. Basin water quality input was also varied to simulate varying land use. Model results were presented as predicted raw water supply quality (Table 5-15). When inflow parameters were set at background conditions (80 percent reduction) the predicted outflow phosphorus concentration was 6.0 mg/m^3. This result matched the conductivity-MEI lake concentration of 6 mg/m^3 total phosphorus.

Table 5-15 Predicted Spavinaw Lake raw water quality based on varying inflow quality.

Inflow		Outflow		
Reduction	Lake Load	TSI (chl)	chla	T-P
%	kg/yr		ppb	ppb
0	8612	57.0	14.68	22.9
(5)	8202	56.4	13.87	22.0
(5)	8142	56.3	13.75	21.9
(10)	7732	55.7	12.94	21.0
(21)	6775	54.2	11.07	18.9
(31)	5935	52.6	9.44	16.9
(36)	5515	51.7	8.63	15.9
(41)	5095	50.8	7.83	14.9
(51)	4255	48.6	6.26	12.8
(60)	3415	45.8	4.73	10.6

Inflow		Outflow		
Reduction %	Lake Load kg/yr	TSI (chl)	chla ppb	T-P ppb
(65)	3033	44.3	4.06	9.5
(70)	2623	42.5	3.36	8.3
(70)	2563	42.2	3.26	8.2
(76)	2064	39.4	2.45	6.7
(80)	1735	37.1	1.94	6.0

Nutrient Goal Setting

Oklahoma Water Quality Standards

Both lakes are listed as Nutrient Limited Watersheds (NLW) in the Oklahoma Water Quality Standards (OWQS) due to nutrient loading (OWRB, 2001). When NLW are identified each lake requires an impairment study to determine whether beneficial uses are impaired. When impairment is documented, that waterbody is recommended to the state 303(d) list for Total Maximum Daily Load (TMDL) allocation. TMDL allocation is a regulated process designed to restore impaired beneficial uses. Both reservoirs have the following beneficial uses assigned through the OWQS: Warm Water Aquatic Community for Fish and Wildlife, Agriculture, Industrial and Municipal Process and Cooling Water, Primary Body Contact, Public and Private Water Supply, and Aesthetics. Chapter 46 of the OWQS provides use support assessment protocols (USAP) to determine whether particular beneficial uses are impaired or not. Data collection for this project did not allow for the assessment of Agriculture, Industrial and Municipal Process and Cooling Water, Primary Body Contact, or Public and Private Water Supply beneficial use attainment. Data collection did allow for the assessment of Aesthetics and Fish and Wildlife beneficial use.

Application of USAP showed both lakes to be partially supporting (impaired) for dissolved oxygen. On July 30, 1998, dissolved oxygen was 1.81 mg/L at 3 meter depth in Spavinaw Lake. 3.25 meters depth represents 50% reservoir capacity. On June 28, 1999, July 13, 1999, July 27, 1999, and August 10, 1999, dissolved oxygen was less than 2.0 mg/L (0.2mg/L - 0.8 mg/L) at 5 meter depth in Eucha Lake. 5.2 meter depth represents 50% reservoir capacity for Eucha Lake. When greater than 50% but less than 70% of the reservoir capacity is shown to be anoxic (less than 2.0mg/L), the reservoir is concluded to be partially supporting Fish and Wildlife Beneficial Use. Aesthetics beneficial use is threatened as well. Nutrients in Eucha and Spavinaw Lake provide for excessive algae growth (TSI above 60) 32% of the time in Eucha lake and 21% for Spavinaw Lake. This frequency of excessive algae growth represents threatened lakes. The City of Tulsa has documented the avoidance of using Spavinaw Lake water due to excessive concentrations of taste and odor chemical concentrations. This interference due to excessive taste and odors represents threatened Aesthetic beneficial use. Both the threatened Aesthetic and impaired Fish and Wildlife beneficial use are negatively impacted due to excessive algae content.

Several lake water quality models were applied to establish a relationship between algae and nutrient concentrations. The BATHTUB models were useful in that inflow conditions could be varied fairly easily and an outflow quality predicted. Model setup closely followed observed water quality conditions. For these reasons BATHTUB model results were used to recommend phosphorous lake load reductions based on an in-lake water quality goal. The average TSI for each lake represents the amount of algae causing the threatened and impaired beneficial use. Lake water quality modeling (BATHTUB) provide a calibrated link between algae and nutrient input for each lake. Reduction of the average TSI from 56 or 57 (eutrophy) to 50 (the threshold for mesotrophy) represents a level where algae production will not impair Fish and Wildlife beneficial use. A 50 TSI represents a highest value for managing algae content for beneficial use.

A 50 TSI with its associated phosphorus concentration and load is recommended as the threshold level for regaining Fish and Wildlife beneficial use. This level is far short of water quality improvements necessary to reach no impact or pristine levels (Table 5-16). EPA has recently published suggested reservoir nutrient criteria or levels to protect designated beneficial uses (EPA, 2000). Four interrelated parameters, total phosphorus and total nitrogen as causal parameters and chlorophyll-a and Secchi Disk depth as response variables, are suggested as nutrient criteria. Two of the EPA-suggested parameters, chlorophyll-a and total phosphorus, are directly comparable to our study's recommendations (Table 5-16). EPA suggested a criterion for chlorophyll-a (TSI of 48), less than this study's recommendation. EPA's suggested criterion is more stringent than the maximum or threshold recommended. EPA criterion is supportive of the recommendation of 50 TSI as the minimum algae content needed to reflect water quality improvements. EPA suggested criterion for total phosphorus is relatively higher than this study's recommendation. This discrepancy is reconciled when one considers that EPA used a conglomerate of lakes (a more generalized approach) while this study's recommendations are based on a specific calibrated lake water quality model.

Table 5-16 Levels of algae management with associated phosphorus concentration and load.

	TSI (chl)	Tot-P (µg/L)	Total-P Load
	Pristine Conditions (No Impact)		
Eucha Lake	29	4.8	1,876 (95%)
Spavinaw Lake	37	6.0	1,735 (80%)
	EPA Criteria		
EPA Criteria	48	24.4	-
	OWRB Recommendation		
Eucha Lake	50	21.5	20,100 (54.4%)
Spavinaw Lake	50	14.1	3,841(44.6%)

Nutrient Reduction Goal

Eucha Lake phosphorus load was 36,948 kg or 40.7 tons and Spavinaw Lake phosphorus load was 8,484 kg or 9.4 tons. These loads corresponded to a predicted average annual TSI (chl) for Eucha and Spavinaw Lakes of 56.7 and 57.0 respectively. These values mean that algae growth is accelerated in both lakes while sometimes reaching excessive levels. The first step in reducing algae abundance would be to reduce algae growth to the border between eutrophic and mesotrophic conditions: TSI (chl) of 50. Mesotrophic represents the transition from accelerated algae growth (eutrophic) to slow algae growth (oligotrophic). A reduction of this magnitude approximates halving the algae standing crop for both lakes. This reduction of the lake's biomass (reported as TSI (chl)) should significantly reduce the frequency and magnitude of taste and odor reports. This reduction would also significantly reduce the oxygen depletion rate caused by algae growth. The calibrated BATHTUB model predicts decreased chlorophyll-a concentrations through reductions of in-lake phosphorus concentrations. Furthermore the calibrated BATHTUB model directly relates this phosporus concentration to external annualized load.

Eucha Lake: A 54.4 percent reduction of phosphorus to Eucha Lake would produce acceptable chlorophyll-a water quality conditions (TSI=50). Figure 5-5 illustrates the algae response, as TSI (chl), to phosphorus reductions in Eucha Lake. Return of the

Spavinaw Creek basin tributary to predicted background (no basin industrial or agricultural development) estimates a 94.2 percent phosphorus reduction to Eucha lake and predicts a TSI (chl) of 29.3; indicative of algae biomass one-eighth of current levels or at oligotrophic levels. Reduction of Eucha Lake phosphorus by 54.4 percent does not come close to pristine conditions, but represents a break point where a algae biomass should be approximately half of current levels and result in a decrease of taste and odor complaints by the City of Jay and Eucha Lake office.

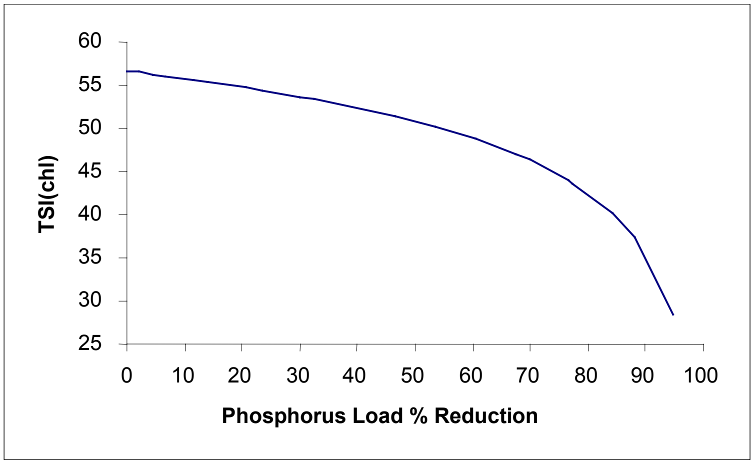


Figure 5-4. Eucha Lake relationship between phosphorus load reduction and TSI (chl).

Spavinaw Lake: A 44.6 percent reduction of phosphorus load to Spavinaw Lake is predicted to produce chlorophyll-a water quality conditions of TSI=50. Meeting this TSI (chl) recommendation approximates a halving of the algae standing crop. Figure 5-6 illustrates the algae response, as TSI (chl), to phosphorus reductions in Spavinaw Lake. As with Eucha, a Spavinaw Lake phosphorus load reduction by 44.6 percent does not come close to pristine conditions, but does represent a break point to one-half current algae biomass and should result in significant reduction of taste and odor complaints. This nutrient reduction scenario will reduce the algae abundance in the raw water supply to the City of Tulsa Mohawk water treatment plant.

Return of the entire Spavinaw Lake drainage basin (including Eucha Lake) to background or pristine conditions would constitute a 79.9 percent phosphorus load reduction and a 37.1 TSI (chl). Although not a low as Eucha Lake this TSI value is still in the oligotrophic range. Recycling of phosphorus by Eucha Lake sediment dampens the response of Spavinaw Lake. In-lake processes of phosphorus recycling become a greater portion of the total load as external reductions are achieved. Another way of stating this is as external reductions are achived phosphorus retention by Eucha lake will gradually decrease. This illustrates the fact that as load reduction to Eucha Lake are achieved the importance of sediment recycling increases.

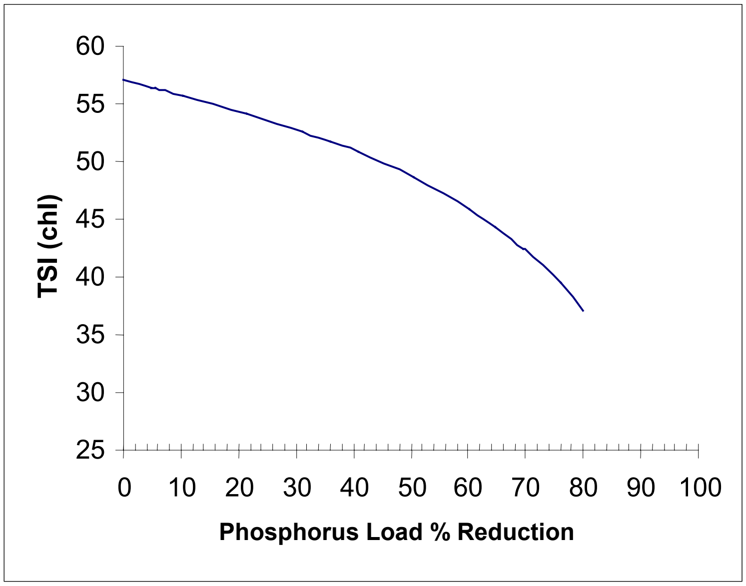


Figure 5-5. **Spavinaw Lake relationship between phosphorus load reduction and TSI (chl).**

Eucha-Spavinaw Lake Complex

Although modeled separately, Lake Eucha and Spavinaw Lake are inextricably linked. The application of the BATHTUB model recognized these differences through differing calibration factors (phosphorus for Eucha Lake and chlorophyll-a for Spavinaw Lake) and the routing of BATHTUB predicted Eucha Lake phosphorus concentrations into Spavinaw Lake. The connection between the two reservoirs is best represented when examining the effect on Spavinaw Lake chlorophyll-a concentration of meeting recommended water quality conditions on Eucha Lake. A 54.4 percent reduction of phosphorus to Eucha Lake translates to a 33 percent reduction to Spavinaw Lake. A 44.6 percent reduction to Spavinaw Lake is needed to reach recommended water quality conditions. This means that meeting recommended water quality conditions in Eucha Lake will not meet acceptable water quality conditions in Spavinaw Lake. To reach recommended water quality in Spavinaw Lake through Eucha Lake reductions alone, 70.4 percent of the Eucha Lake phosphorus load must be removed.

Recommendations

Introduction

Water withdrawn from the upper end of Lake Eucha serves local populations' water supply needs. Water withdrawn from the dam of Spavinaw Lake serves the City of Spavinaw and the Tulsa metropolitan area water supply needs. Reducing taste and odor complaints must target algae abundance at the point of withdrawal. The relatively high water clarity and enriched nutrient chemical quality of each lake stimulate not only high algae growth but also high levels of taste and odor causing species of algae throughout the year. Nutrient levels, algae growth, and taste and odor reports are inextricably linked. Managing nutrient dynamics to control algae in both Spavinaw Lake and Lake Eucha is critical to controlling taste and odor reports in finished drinking water.

Comparison of the collected water quality data to the Oklahoma Water Quality Standards shows each lake to be impaired by nutrient enrichment. The algae growth stimulated by nutrient enrichment was high enough to impair the beneficial use of fish and wildlife propagation through oxygen depletion. Reports of avoidance by the City of Tulsa to using Spavinaw Lake Water due to excessive taste and odor chemical content constitutes a threat to the Aesthetic benefitial use as well. Reduction of algae content is the key to restoring the threatened and impaired beneficial uses.

Whether the reduction of water supply taste and odor reports or decrease of oxygen depletion long-term, reliable control of algae growth is needed in each lake. This control can only be achieved through direct reduction of the nutrients stimulating algae growth. Phosphorus was determined to be the primary chemical nutrient controlling algae growth in both lakes. Setting phosphorus nutrient reduction goals linked to a measure of algae abundance is the first step toward the development of a comprehensive lake management plan.

Phosphorus Loading Goals

Calibrated BATHTUB models provided a predictive link between phosphorus load and chlorophyll-a concentration. Chlorophyll-a has been indexed to trophic state to aid decision-making. Actual average TSI (chl) was 59 for Eucha Lake and 57 for Spavinaw Lake.

The OWRB recommends reducing algae abundance to the border between eutrophic and mesotrophic conditions: TSI (chl) of 50. Mesotrophic represents the transition from accelerated algae growth (eutrophic) to slow algae growth (oligotrophic). A reduction of this magnitude approximates halving the algae standing crop for both lakes. This reduction of each lake's algae would reduce the frequency and magnitude of taste and odor reports to water supply. This reduction would also significantly reduce the oxygen depletion rate caused by algae growth.

BATHTUB predictive models allow TSI=50 to be directly linked to phosphorus load of each lake. A 54 percent reduction of total phosphorus to Lake Eucha would produce chlorophyll-a TSI of 50. A 44.6 percent reduction of phosphorus to Spavinaw Lake would produce chlorophyll-a TSI of 50. Because of the large influence Eucha Lake has on the phosphorus load to Spavinaw Lake any Spavinaw Lake reductions will require Eucha lake reductions. For example a 70.4 percent reduction of phosphorus loading to Lake Eucha is needed to reach the recommended TSI for Spavinaw Lake should no other control measures be employed.

Phosphorus load reduction targeting non-point source pollution is a critical component to attaining acceptable Lake Eucha quality. Although appreciable, the theoretical elimination of point source and internal phosphorus load to Lake Eucha would not be great enough (39 percent out of a 54 percent total) to achieve recommended chlorophyll-a water quality. Recent estimates of the Decatur National Pollutant Discharge Elimination System (NPDES) discharge data indicate that 11,600 kg of phosphorus are discharged a year to the Lake Eucha basin. Nutrient budgeting showed that 2,515 kg phosphorus a year (approximately 6%) was attributed to Lake Eucha sediment sources. There are no similarly important point sources of phosphorus loading specifically to the immediate Spavinaw Lake basin.

In-lake Nutrient Reduction Alternatives

In-lake nutrient reduction targets sediment-related phosphorus releases. Although variable, sediment mediated release of phosphorus occurred every year while the hypolimnion of each lake was anoxic. Periods of hypolimnetic anoxia were roughly six and one-half months for Lake Eucha and roughly five and one-half months for Spavinaw Lake. Greatest releases to the epilimnion occurred over a four-month period (July – October) in Lake Eucha and a three-month period (July – September) for Spavinaw Lake. Treatment of this source would require control over a five-to-seven month period (sediment release period) to achieve load reductions during a three-to-four month period (when most of the nutrients reach the lake surface). The following paragraphs describe application of various in-lake techniques and assess the potential of each to reduce lake phosphorus budgets by about 6 percent.

Water Level Drawdown

Water level drawdown is a multipurpose technique used in pond and reservoir management that can aid with aquatic plant control. Water level drawdown has been applied by lowering the lake level below normal pool elevation for a season, normally during the summer or winter, or an annual period. This technique functions to control aquatic plants through drying out and/or freezing the exposed plant and root system. Nuisance plant growth was observed and documented for Lake Eucha in 1998. A diverse and stable aquatic plant community was documented in Spavinaw Lake. Assessments of aquatic plant populations in both lakes indicate the potential to contribute little to the phosphorus budget. The Lake Eucha milfoil population assessed in 1998 was estimated with the maximum potential to contribute approximately 0.5 percent to the total lake phosphorus budget. The Spavinaw Lake coontail population, *Ceratophyllum desmersum*, was estimated with the maximum potential to contribute approximately 1¾ percent to the 1998 lake phosphorus budget. There was no evidence to consider water level drawdown as a technique to control nutrient levels within either lake.

Examination of this technique, as discussed by Cooke, et.al., (1993), indicates the application of a drawdown may impose damage to the lake system by eliminating or severely reducing the water willow population, *Justicia americana*, observed in both lakes. This plant serves to protect shorelines and provide refuge to young fish. This technique is not recommended for either lake to control aquatic plant populations.

Aeration

Whole-lake treatments of artificial circulation (mixing the entire lake) or hypolimnetic aeration (aeration of the colder, deeper layer of the lake) would inhibit phosphorus release though maintaining oxygenated water over the lake sediment. These methods are most effective when external loads have been reduced.

- **Artificial circulation** would allow oxygen to always reach the lake sediment by keeping the lake from stratifying. A pneumatic device would be used to overcome the thermal resistance to mixing. Caution is advised to ensure that iron is controlling phosphorus solubility when applying artificial circulation to control hypolimnetic nutrient release. Where iron does not control phosphorus, release would be a function of decomposition of organic matter (Cooke et.al., 1993). Iron-phosphorus ratios in the Appendix F were inconclusive whether iron controlled phosphorus solubility during stratification. The possibility of limited aerobic phosphorus binding due to low iron concentrations merits additional investigation. This could be an important factor when considering artificial circulation as a nutrient control technique.

  The size of an effective artificial circulation system is a function of lake surface area. Minimum costs to install and run an artificial circulation system have been cited as $290/hectare and $86/hectare, respectively (Cooke et al. 1993). Applied to Lake Eucha at a surface area of 2,812 acres, the first year costs would be approximately $422,750. Installation in Spavinaw Lake is estimated at $210,000 with an operations cost of $65,000 per year. A spreadsheet has been constructed for the U.S. Army Corps of Engineers to determine optimal design of an artificial circulation system and is available from the Waterways Experiment Station in Vicksburg, Mississippi, as Water Operations Technical Support Publication E-91-1 (Meyer, 1991). Davis (1980) also outlines the design and construction of a system to provide artificial circulation.

- **Hypolimnetic aeration** targets the zone of anoxia (the part of the water column that has low or no oxygen during periods of stratification) and can minimize the effects of whole lake circulation. Hypolimnetic aeration is similar to whole lake aeration with an additional structure to aerate the cooler portion of the lake to minimize the destratification force of aeration. This method is recommended for lakes greater than twelve meters in depth and has been successful in providing increased dissolved oxygen and decreased dissolved metals, ammonium, and phosphorus concentrations. Iron amendment may be necessary to ensure successful nutrient control with hypolimnetic aeration.

  Cost estimates for hypolimnetic aeration systems are based on the oxygen depletion rate. Lake Eucha hypolimnetic oxygen depletion rate was estimated at 3,154 kg (3.48 tons) O_2/day during thermal stratification and hypolimnetic anoxia. Estimated cost to install a hypolimnetic system into Lake Eucha would be about $2.50 ± $1.50/kg O_2 or $570,000 - $2,270,000 for six months operation, although this cost would likely decrease over time (Cooke et.al., 1993). Spavinaw Lake hypolimnetic oxygen depletion rate was estimated at 1,944 kg (2.14 tons) O_2/day during thermal stratification and hypolimnetic anoxia. Estimated cost to install a hypolimnetic system into Spavinaw Lake would be about \$2.50 ± \$1.50/kg O_2 or \$350,000 - \$1,400,000 for six months operation, although this cost would likely decrease over time. Although initial costs are high, long-term costs may be modest. Morphology and hydrology (shallow average depth and short residence time) of Spavinaw Lake will limit the effectiveness of hypolimnetic aeration.

Chemical treatment

Chemical treatment refers to the use of chemicals to bind and remove nutrients from the water column or to directly kill the algae in the water column. Both approaches have been widely used, and the necessary dose rates and treatment schedules can be accurately estimated on a lake-by-lake basis.

- **Water Column and Sediment Phosphorus Treatment**

  Iron, calcium, and aluminum have salts that can bind with dissolved phosphorus or remove phosphorus containing particulate matter. The low iron/phosphorus ratio noted in the sediment phosphorus load section suggests that iron addition may or may not help reduce epilimnetic phosphorus migration. However, the low reduction-oxidation conditions noted during stratification indicate iron addition would not substantially increase sediment phosphorus retention.

  The application of calcium salts to remove or inactivate P in ponds has recorded some success (Cooke et.al., 1983). However most successful cases were natural lakes much smaller than Spavinaw or Eucha Lake. This brings to question the feasibility of applying such salts to a reservoir as large as Eucha Lake. The potential hazard of decreasing pH below the limit for aquatic life was also cited as a concern.

  Aluminum salts such as alum have the ability to bind phosphorus from the water column and bind phosphorus as sediment. Treatments of this sort have been term "nutrient inactivation." This method is essentially a one-time chemical treatment applied to the water column. The treatment permanently binds the phosphorus with which it comes into contact and forms a floc that settles to the sediment surface, where it remains. Application rates are typically calculated to be sufficient to bind all the water column phosphorus present at the time of application and the full amount of phosphorus diffusing from the sediments for a set period of years. The upper limit of alum to apply is determined by the pH and alkalinity of each lake. This is because the alum lowers water pH when forming the floc. Care must betaken not to decrease the system's pH below the limit of aquatic life. Such a treatment would act as a cap over the sediment. The cost of nutrient inactivation may be amortized over as much as 10 years when combined with substantial external nutrient reductions. If external loading reductions do not occur, however, the period of effective treatment is much shorter. The incoming phosphorus is absorbed by the floc on the sediment surface and the binding capacity of the floc layer is rapidly used up. Nutrient activation has been successful when internal loading dominates the annual phosphorus budget.

  The most effective chemical for nutrient inactivation is aluminum (as aluminum sulfate or a buffered aluminum sulfate mixture) (USEPA, 1990). An application at the rate necessary for hypolimnetic water column treatment in Lake Eucha would require

3,000 tons of dry alum costing about $870,000. Using the same prescription rate for Spavinaw Lake requires 600 tons of dry alum costing about $175,000. These alum applications approximate the uppermost amount of alum safe for application to the hypolimnion of each reservoir. Exact dosage and chemical formulation would be determined before actual application. Current water quality data suggests significant external lake load reductions are needed before nutrient inactivation presents long-term water quality benefits.

- **Chemical Treatment of Inflowing Water**

  Copper sulfate is commonly used to kill algal growths in drinking water reservoirs. The most effective approach for Lake Eucha might be copper sulfate treatments of the upper end above State Highway 10. This would delay algal growth for a short amount of time, but would do little to solve the long-term problem. A whole lake treatment of approximately 270 tons of copper sulfate costing $285,000 would be needed for a single treatment of both lakes. The general herbicidal action of copper sulfate may serve to give taste- and odor-causing algae a competitive advantage over more desirable (non-noxious) species. Precipitation of algae and nutrients in this same area would last only until the next rain event.

  Constant treatment of inflow water to both lakes with alum would require a total annual application of 56,000 tons at a cost of about $6,750,000 for the materials, alone. For taste and odor reports to decrease, nutrient load reductions are needed from these two tributaries. Major changes in Spavinaw Creek basin landowner behavior will be necessary to reduce nutrient load to Lake Eucha.

Biological

Biomanipulation (food web manipulation) is based on reducing phytoplankton levels by altering the food web to select against filter-feeding fish and thus select for algae eating zooplankton. Interaction between zooplankton and algae were noted earlier in the report. In particular, the data indicated that during the project period, a lower density of edible algae were noted when larger zooplankton were present. In addition, both Lake Eucha and Spavinaw Lake are known to contain large populations of gizzard shad, a filter-feeding fish. The shad are indiscriminate feeders, eating the zooplankton that would otherwise eat the algae along with the algae. The net result of this feeding is a stimulation of algal growth and production. Two general methods are employed to effect biomanipulation: direct removal of the filter-feeding fish and introduction of large carnivorous fish.

- Generally, removal of the filter-feeding fish population is accomplished through a gill-net harvest program. Removal of the fish leads to an increase in the zooplankton population, and with greater amounts of zooplankton to eat the phytoplankton, phytoplankton content decreases (Cooke et.al., 1993). Both Eucha and Spavinaw support thriving gamefish populations. Gizzard shad serve as the primary forage for these gamefish in both lakes. Drastic removal measures would be unadvisable unless alternative forage was provided for resident gamefish populations. The method has been successfully applied in some large shallow, turbid reservoir systems in Europe, and some smaller lakes in the United States. Although this method has potential for reducing algae content without changing external loading or nutrient status of the lakes, the effectiveness of this technique is difficult to predict accurately . Application of biomanipulation to Lake Eucha or Spavinaw Lake would be novel, as these lakes are not turbid (they have good water clarity) and the application of the technique has not been otherwise proven for reservoirs of this type in United States.

- Another method of biomanipulation is to increase the fish predator biomass. This is usually accomplished by introducing a species of fish (predator) that grows large enough to eat the gizzard shad. It is important to note that the addition of predators may not produce any measurable algae control when nutrient loading is high or when algae species are dominated by inedible species (USEPA, 1990). Current data indicate high nutrient levels and seasonal algae dominance by inedible species. City of Tulsa fishery experts document good gamefish populations. Current conditions preclude consideration of this method. Should nutrient loads reduce and the algae community shift to edible species, a fish study is recommended to evaluate the merit of this technique. A careful and quantitative multi-year analysis of the fish populations in the reservoirs would be the first step in evaluating the potential for use of this method.

Watershed Management

Phosphorus reductions can occur through reduced import, greater retention within the watershed and greater export of phosphorus. Control at the source (avoiding transport) is always the best strategy. Reducing nutrient flows (implementing drainage basin best land management practices) to Eucha and Spavinaw lakes is the best long-term strategy to reduce algae levels.

Future Considerations

Lake Management Options

Evaluation of remedial measures should consider factors such as operation and maintenance costs, relative amount of nutrient control, and amortized benefits over the life of the measure. This evaluation should be in the form of a proposed restoration plan. Spavinaw Lake restoration should consist of a phased plan of implementation: first targeting the measure with the highest probability of success and then additional measures to enhance nutrient reductions. Evaluation checks should be incorporated targeting benchmarks. Real time monitoring should be an integral part of determining the success of each implemented measure.

Water Quality Monitoring could be an integral part of any lake management strategy. A sampling plan is given at the end of this report to provide a minimized monitoring schedule. This schedule is designed to allow for diagnostic checks on the Eucha-Spavinaw lake system based on phosphorus, algae species, and detection of taste and odor chemicals. This plan is given as the minimum to track lake water quality and quantity. This plan does not include comprehensive basin monitoring to track non-point source load.

Water Quantity

Instantaneous flow is a critical component to accurate lake load calculations. USGS flow measurements on Beaty and Spavinaw creeks have been critical and these stations should continue to record instantaneous flow. Flow over and through Eucha and Spavinaw lakes are critical to the water budget. Several items were considered to bolster lake quantity budgeting. The following is an itemized list of options to consider:

- Check the accuracy of lake level gauges.
- Check or resurvey lake stage-discharge nomographs for both lakes.
- Install a stream flow gauge located below Lake Eucha dam and above Spavinaw Lake (at site EUC14, for instance) to eliminate flow rate checks on Lake Eucha releases.
- Request field staff to include stream flow measurements as part of their routine stream water quality monitoring. This additional information allows for better estimate of base flow and perhaps runoff estimates.
- Perform groundwater (well and discharge) measurements during all seasons of the year to estimate seasonal variability.

The USGS site on Black Hollow provided critical information to estimate flow within the immediate basin of Spavinaw Lake. Should funding be tight, the USGS station at Black Hollow could be dropped. This station performed its function of estimating phosphorus load from the immediate basin. These estimates indicate the load from this area is not a major portion of the lake load.

Water Quality

Through determined effort, the OWRB and City of Tulsa established routine water quality collection, laboratory analysis, and data quality control protocols utilizing existing systems within the City of Tulsa. City of Tulsa staff at Lake Eucha and Spavinaw Lake perform routine water quality sampling of the lakes and tributaries, while the City of Tulsa Quality Assurance (QA) laboratory provides high quality analytical services. The City of Tulsa also provides quality control/assurance and centralized data storage. This system of standardized sample collection, analysis, evaluation, and data storage will enable accurate documentation of water quality improvements in the Spavinaw Creek drainage basin. These documented procedures will also allow state agencies to use these data regarding Clean Water Act programs (TMDL, non-point source, Clean Lakes, etc.). Water quality monitoring should reflect the goals and objectives of an improvement effort. Water quality monitoring is focussed to assess in-lake status, calculate flow-weighted external loads, and explore alternative taste and odor causes.

Analytical parameters: Baseline monitoring of field parameters such as dissolved oxygen, pH, specific conductance, temperature, and turbidity should be performed at all sites. Basic laboratory analysis parameters should include at least the following: nitrate+nitrite nitrogen (NO_x), total kjeldahl nitrogen (TKN), dissolved orthophosphorus (SRP or DOP), total phosphorus (TP) , turbidity and dissolved silica, and other minerals. Lake sample sites should include the additional surface parameters of Secchi disk depth, chlorophyll-a, and algae grab sampling. The algae sample should be enumerated to the species level and include biovolume measurements. Should in-lake management to reduce sediment release of phosphorus during stratification be implemented, the dissolved and total fractions of iron and manganese should also be monitored at the dam of each lake. Should biomanipulation be implemented, then zooplankton vertical tows with subsequent enumeration to the species level and biovolume determination is recommended.

Site selection: Grab sampling is sufficient for all sites. Watershed sites should include Beaty and Spavinaw Creeks immediately upstream of Lake Eucha (currently EUC06 and EUC09) and one site between the two reservoirs (EUC14). These sites were selected for their ability to link water quality data with continuous water quantity data. Recording of water quantity information from these sites should continue. The site SPA06 currently has USGS gauge recording continuous flow. This site is not critical for long-term tracking but does provide valuable information on flow characteristics for the immediate drainage basin of Spavinaw Lake. Lake sample sites should include one site at the dam for each lake and the upper end of Lake Eucha (current sites SPA01, EUC01, and EUC03). A Van Dorn or similar sub-surface type sampler is sufficient for lake sampling. Sampling at the dam of each lake should include five samples distributed with depth to include two samples in the epilimnion, one sample in the metalimnion, and two samples in the hypolimnion while stratification is evident and two samples with depth during isothermal conditions. One surface sample at EUC03 is sufficient.

Sample Frequency

Watershed Sites: Watershed sampling efforts should emphasize sampling during periods of changing flow. This will increase the accuracy of nutrient load calculations using field data. All three recommended tributary sample sites should be sampled once a quarter during low flow periods. Twelve to fifteen samples per site should be taken during periods of changing flow regime. These samples should be taken on a “as-can” basis. Special considerations are needed to enable field staff to capture these samples.

Creek Sites: Above a lake (for example Spavinaw and Beaty creek above Lake Eucha) sample frequency should follow rainfall events capturing samples from the three sections of creek stage height: rise, peak, and fall. Sampling of Spavinaw Creek between the two reservoirs should be according to changes in Eucha dam releases. For example, when gate or valve settings are changed in Eucha dam, sampling should occur. Sampling Spavinaw Creek between the lakes in this manner is intended to capture any potential changes in water quality resulting from a change in the flow regime out of Lake Eucha. These two flow-based strategies should enable more robust nutrient load calculations.

Lake Sites: Monitoring of water quality with field measurements (temperature, dissolved oxygen, pH, and specific conductance) should be once a month during isothermal conditions and twice a month during stratified conditions. Surface measurements of Secchi disk depth, turbidity, and chlorophyll-a should accompany these trips. Water quality sampling for laboratory analysis should occur at least five times in an annual period: once prior to stratification (usually March to April), three times distributed during stratification (perhaps June, August and October), and once following lake turnover (usually December).

Algae Monitoring: The Current Limnology section implicated several algae species as the most likely contributors to recorded taste and odor events. The following text outlines recommended algae monitoring beyond the routine sampling and monitoring of algae community species. Although implicated, alternative explanations for taste and odor events are possible. Visual observations for dense algae mats on the lake bottom should be made in Lake Eucha and Spavinaw Lake to confirm or deny this possibility. Observation of algae mats warrants additional investigation, starting with sampling of the mats for species identification and analysis for taste and odor chemicals. Once identified, algae mats should be tracked on a biweekly basis. Observations for algae mats should follow routine lake water sampling frequency. A suggested search method for algae mats is to choose a north and east shoreline with a slope less than 3:1 starting at the depth limit for aquatic vegetation. The search continues with depth until the hypolimnion is reached. The potential for nuisance algae species to produce toxic chemicals was also identified. Routine lake sampling includes surface grab samples for algae species enumeration. Monitoring for toxic and taste and odor chemicals such as *cylindrospermopsin*, *anatoxin-a*, *anatoxin-a(s)*, *microcystin*, *saxitoxin, geosmin*, and *MIB* is recommended to provide a link between species identification and taste and odor complaints. Toxin and taste and odor chemical sampling should follow routine lake sampling with a minimum of an epilimnetic and hypolimnetic from the dam sites (EUC01 and SPA01) and epilimnetic sample from the upper end of Lake Eucha (EUC03).

Data Evaluation

Most data evaluations will be comparisons against the current data set. These comparisons will serve as annual and relative indicators of lake health.

Long-term trend detection requires a ten-year data set before performing calculations. Data evaluation should be scheduled to compliment a lake management plan and used to check progress toward preset goals for each lake. The following text provides examples of how the proposed data set can be used.

Field parameters can be used to track the physical properties of each reservoir. This will directly assist any implemented in-lake management option. Secchi disk depth and chlorophyll-a should be evaluated using Carlson's trophic state indices and annual averages compared against the current data set. Chemical data can be averaged to represent lake conditions during stratified and isothermal conditions. Calculations of sediment nutrient release can also be performed using available physical and chemical data. Algae species enumeration should be examined for the presence of taste and odor species segregating by biovolume. The algae report (Appendix G) provides extensive discussion and references to identify taste and odor causing algae. Algae enumeration should also be plotted by date. Comparison against the current data set will suggest if any shifts in algae community composition have occurred. Comparisons to toxin and taste and odor chemical levels will bolster conclusions about the relationship between algae species and customer drinking water complaints.

Finally, USGS and Eucha dam flow data should be combined with tributary nutrient concentration data to provide calculations of annual load. Several methods exist to calculate load. The suggested monitoring regime has been structured to facilitate flow-weighted calculations.

Monitoring results can be used to assess progress toward phosphorus load reductions, in-lake nutrient reductions, and lake algae reductions. As lake quality improves, the City of Tulsa should consider re-evaluating the applicability of aeration, chemical, and biological methods toward reaching a water quality based goal. Perhaps the best measure of success toward reaching a goal is the occurrence of taste and odor complaints.

Should taste and odor events be restricted to summer and fall periods (during stratification), then avoidance of the algae cells may be an option. In general, this would work by releasing hypolimnetic water from Lake Eucha and modifying the Spavinaw Lake withdrawal to pull from the hypolimnion, in essence, routing Lake Eucha hypolimnetic water through the lower layer of Spavinaw Lake. Although this method would reduce living algae cells, it would not avoid all algae cells as dead and dying algae cells accumulate in the hypolimnion. Chemicals released by these dead and dying cells would also be in the hypolimnetic water. In addition, a curtain may need to be installed in Spavinaw Lake to ensure proper water routing. This specific application is untried in Oklahoma.

Should Lake Eucha reach acceptable algae levels while Spavinaw has not, then management methods should be reviewed. The cost of reaching acceptable levels in Spavinaw Lake should be weighed against the cost of extending the municipal point of diversion from Spavinaw dam to Eucha dam. Here, the cost of additional Spavinaw Lake treatment would be weighed against the cost of avoiding Spavinaw Lake water entirely.

Community Involvement and Oklahoma Water Watch

Involvement of the water consumers and citizens of the Eucha / Spavinaw watershed is an essential component of long-term improvement in water quality. Programs that promote and support community involvement should be incorporated into the monitoring program, if possible. One program already active is the Oklahoma Water Watch (OWW).

The OWW is a volunteer, water quality monitoring program that provides citizens of all ages and backgrounds an opportunity to become involved in the protection and management of Oklahoma's water resources. Today, OWRB is working in cooperation with citizens in collecting baseline environmental data used to monitor the trends in water quality. After completing a three-phased training workshop and becoming OWW Certified Water Quality Monitors, citizens sample their local lakes and streams on a monthly basis and report their findings.

The OWW promotes understanding, awareness, protection, and restoration of Oklahoma lakes and streams through the leadership and initiative of volunteers. Through this program, citizens can learn more about lakes and streams while helping to ensure the quality of Oklahoma's valuable resources. With the heightened interest of the Spavinaw Creek watershed, OWW worked with OWRB's Clean Lakes section to recruit water quality monitoring volunteers within the basin.

An OWW volunteer monitoring group was established in the spring of 2000. The group originally consisted of approximately 25 students and 2 teachers from Kansas Middle School. The group monitored three sites in the Eucha/Spavinaw area (Figure 6-1). The original group tested for basic parameters such as air and water temperature, dissolved oxygen, pH, Secchi disk depth, and water color as well as site observations and recent rainfall. The group has since expanded to add 15 new students and will undergo training to test chlorophyll-a in the spring. On April 24th, 2001, the Speaker of the Oklahoma House of Representatives, Larry Adair, and Senator Rick Littlefield will present the group with a House-Senate Joint Citation for their hard work and commitment to clean water.

The combination of technical programs with citizen education / involvement programs can be a powerful engine with which to develop the effort to improve the lakes and then maintain them for the long-term benefit of the citizens of Tulsa and Oklahoma.

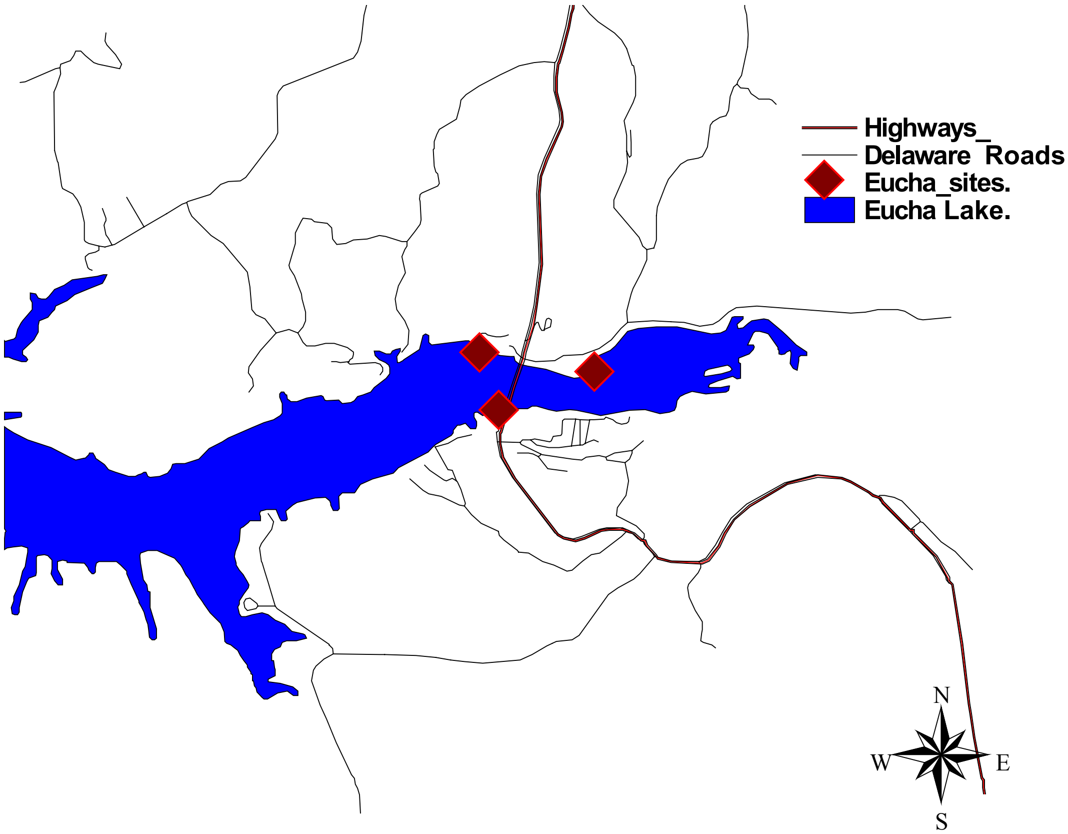


Figure 6-2. OWW volunteer monitoring sample sites Kansas public schools

References

Adamski, J.C., 1997. *Nutrients and Pesticides in Ground Water of Ozark Plateaus in Arkansas, Kansas, Missouri, and Oklahoma*. U.S. Geological Survey Water-Resources Investigations Report 96-4313, 28 p.

Adamski, J.C., 2000. *Geochemistry of the Springfield Plateau Aquifer of the Ozark Plateaus Province in Arkansas, Kansas, Missouri and Oklahoma.* USA: Hydrological Processes, vol. 14, p. 849-866.

Adamski, J.C., Petersen, J.C., Freiwald, D.A., and Davis, J.V., 1995. *Environmental and Hydrogeologic Setting of the Ozark Plateaus Study Unit, Arkansas, Kansas, Missouri, and Oklahoma*. U.S. Geological Survey Water-Resources Investigations Report 94-4022, 69 p.

AEDS, 1999. Eucha/Spavinaw NPDES Release Data.December 1999. http://www.tulsawater.com/tmuadata.html. Aley, T., 1984. Septic Fields and the Protection of Groundwater Quality in Greene County, Missouri, unpublished report for the City of Springfield, Missouri, 18 p.

Arnold, J.G., R. Srinivasan, R. S. Mittiah, and J. R. Williams, 1998. “Large Area Hydraulic Modeling and Assessment: Part I- Model Development.” Journal of the American Water Resources Association 34(1):000-000.

Carlson, R.E. 1977. *A Trophic State Index for Lakes.* Limnol. Oceanogr. 22: 361-369.

Cederstrand, J.R., 1996a. Digital Geologic Map of Fort Smith Quadrangle, East-Central Oklahoma: U.S. Geological Survey Open-File Report 96-375, based on a scale of 1:250,000.

Cederstrand, J.R., 1996b. Digital Geologic Map of Tulsa Quadrangle, Northeastern Oklahoma: U.S. Geological survey Open-File Report 96-381, based on a scale of 1:250,000.

Chapra, S.C. and K.H. Reckhow, 1983. *Engineering Approaches for Lake Management, Volume 2: Mechanistic Modeling*. Butterworth Publishers, Stoneham, MA.

Chiaudani G. and Vighi M. 1985. “A Simple Method to Estimate Lake Phosphorus Concentrations Resulting from Natural, Background, Loadings. Water Resources. Vol. 19, No. 8, pp. 987-991.

Chichester, H., City of Tulsa. Personal Communication, May 2, 2000.

Christenson, S.C., Parkhurst, D.L., and Fairchild, R.W., 1994, *Geohydrology and Water Quality of the Roubidoux Aquifer, Northeastern Oklahoma.* Oklahoma Geological Survey Circular 96, 70 p.

Davis, J. M, 1980. “Destratification of Reservoirs – A design approach for perforated-pipe compressed-air systems”, Water Serv. 84:497-504.

Driscoll, F.G., 1986. *Groundwater and Wells* (second edition): Johnson Filtration Systems, Inc., St. Paul, Minnesota, 1089 p.

Dugan, J.T., and Peckenpaugh, J.M., 1986, *The Effects of Climate on Consumptive Water Use and Ground-Water Recharge in Parts of Arkansas, Colorado, Kansas, Missouri, Nebraska, Oklahoma, South Dakota, and Texas*. U.S. Geological Survey Water-Resources Investigations Report 85-4326, 78 p.

Fenneman, N.M., 1946. Physical Divisions of the United States: U.S. Geological Survey Map.

Ford, D.C., and Williams, P.W., 1989. *Karst Geomorphology and Hydrology.* Unwin Hyman Ltd., Winchester, Massachusetts, 601 p.

Haggard, Brian E., E. H. Stanley and R. Hyler. *Sediment-Phosphorus Relationships in Three Northcentral Oklahoma Streams.* American Society of Agricultural Engineers, Vol. 42(6): 1709-1714.

Håkanson, Lars, 1981. *A Manual of Lake Morphometry*. Springer-Verlag Berlin Heidelberg. 78 pp.

Helsel, D.R., and Hirsch, R.M., 1992. *Statistical Methods in Water Resources*. Elsevier Science Publishers B.V., Amsterdam, The Netherlands, 529 p.

Hem, J.D., 1985. *Study and Interpretation of the Chemical Characteristics of Natural Water:* U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Hutchinson, G.E. 1977. *A Treatise on Limnology. Volume* 3 Limnological Botany. Wiley, New York, NY. 660 p.

Imes, J.L., and Davis, J.V., 1990. *Water Type and Concentration of Dissolved Solids, Chloride, and Sulfate in Water from the Ozark Aquifer in Missouri, Arkansas, Kansas, and Oklahoma.* U.S. Geological Survey Hydrologic Investigations Atlas HA-711-K, 4 sheets.

Imes, J.L., and Emmett, L.F., 1994. *Geohydrology of the Ozarks Plateaus Aquifer System in Parts of Missouri, Arkansas, Oklahoma, and Kansas.* U.S. Geological Survey Professional Paper 1414-D, 127 p.

Kesler, T.L. 1936. *Advance Report on the Sedimentation Survey of Lake Spavinaw, Spavinaw, Oklahoma*. U.S. Soil Conservation Service, SCS-SS-1, 5 p.

Kesler, Thomas L., March 15 1936. *Advance Report on the Sedimentation Survey of Lake Spavinaw, Spavinaw, Oklahoma*. U.S. Soil Conservation Service SCS-SS-1. Washington, D.C. 5pp.

Lerman, Abraham (ed). 1978. *Lakes - Chemistry, Geology, Physics*. Springer-Verlag New York. 363 pp.

Marcher, M.V., 1969. *Reconnaissance of the Water Resources of the Fort Smith Quadrangle, East-Central Oklahoma.* Oklahoma Geological Survey Hydrologic Atlas 1, 4 sheets, scale 1:250,000.

Marcher, M.V., and Bingham, R.H., 1971. *Reconnaissance of the Water Resources of the Tulsa Quadrangle, Northeastern Oklahoma.* Oklahoma Geological Survey Hydrologic Atlas 2, 4 sheets, scale 1:250,000.

Mull, S.D., Liebermann, T.D., Smoot, J.L., and Woosley, L.H., Jr., 1988. *Application of Dye-Tracing Techniques for Determining Solute-Transport Characteristics of Ground Water in Karst Terranes.* U.S. Environmental Protection Agency, EPA 904/6-88-001, 103 p.

Neitsch, S.L., J.G. Arnold, J.R. Williams, "Soil and Water Assessment Tool User's Annual Version 99.2." Blackland Research Center, 1999. ftp://ftp.brc.tamus.edu/pub/swat/doc/manual992.zip (November 14, 2000).

OECD, 1982. *Eutrophication of Waters. Monitoring, Assessment and Control.* OECD, Paris, 77pg.

Oklahoma Climatological Survey, 1997. Data and Products. http://climate.ocs.ou.edu. Decmenber 1997.

Osborn, N.I., and Hardy, R.H., 1999. Statewide Groundwater Vulnerability Map of Oklahoma: OWRB Technical Report 99-1, 34 p.

Plummer, L.N. and Friedman, L.C., 1999. *Tracing and Dating Young Ground Water.* U.S. Geological Survey Fact Sheet 134-99.

Reckhow, K.H., K. Kepford, and W. Warren Hicks. 1993. *Methods for the Analysis of Lake Water Quality Trends.* EPA 841-R-93-003.

Reed, E.W., Schoff, S.L., and Branson, C.C., 1955. *Groundwater Resources of Ottawa County, Oklahoma.* Oklahoma Geological Survey Bulletin 72, 203 p.

Reese, D.L., 1963. Areal Geology of the Spavinaw Lakes Area, Delaware County, Oklahoma: unpublished thesis, University of Oklahoma, 67 p.

Sakamoto, M. 1966. *Primary Production by Phytoplankton Community in Some Japanese Lakes and Its Dependence upon Lake Depth*. Arch. Hydrobiol. 62:1-28.

Sanders, L.L., 1998. *A Manual of Field Hydrogeology.* Prentice Hall, Upper Saddle River, New Jersey, 381 p.

Schindler, D.W. 1977. *Evolution of Phosphorous Limitation in Lakes.* Science 179:382-384.

Snow, P.D. and F.A. DiGiano. 1976. "Mathematical Modeling of Phosphorous Exchange Between Sediments and Overlying Water in Shallow Eutrophic Lakes," Environmental Engineering, Department of Civil Engineering, University of Massachusetts, Amherst, Report No. E. 54-76-3.

Soil and Water Assessment Tool Online Documentation Blackland Research Center, 2000. http://www.brc.tamus.edu/swat/newmanual/intro/intro.html (November 14, 2000)

Thomann R. V., J. A. Mueller, 1987. *Principles of Surface Water Quality Modeling and Control.* Harper Collins Pub. Inc., New York, NY, pp. 173-218.

Thornton, K.W., B.L. Kimmel, and F.E. Payne. 1990. *Reservoir Limnology: Ecological Perspectives.* John Wiley & Sons, Inc. New York, NY. 246 pp.

Tulsa Metropolitan Utility Authority. 2001. Eucha/Spavinaw Watershed Project: http://www.tulsawater.com/eucha.html

Tulsa, City of and Oklahoma Water Resources Board, April 15, 1998. Quality Assurance Project Plan, Eucha - Spavinaw-Yahola Lake System Monitoring and Assessment: http://www.tulsawater.com/tmuadata.html

United States Environmental Protection Agency. 1990. *The Lake and Reservoir Restoration Guidance Manual*. Office of Water. Washington, D.C. EPA-440/4-90-006.

Vollenweider, R. 1968. *Scientific Fundamentals of the Eutrophication of Lakes and Flowing Waters, with Particular Reference to Nitrogen and Phosphorus as Factors in Eutrophication.* Organization for Economic Cooperation and Development, DAS/CSIO/68.27, Paris, France, 192 pp.

Walker, W. W. (1996). *Simplified Procedures for Eutrophication Assessment and Prediction: User Manual.* Instruction Report W-96-2 (Updated April 1999), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Walker, W.W. 1983. “Data Analysis and Model Development for the Lake Morey 314 Diagnostic Study.” Prepared for Vermont Agency of Environmental Conservation, Department of Water Resources, Lakes Program, Montpelier, VT.

Wetzel, Robert G., 1983. *Limnology, Second Edition*. W.B.Saunders Company, New York, NY. 767 p.

Winter, T.C., Harvey, J.W., Franke, O.L., and Alley, W.M., 1999. *Ground Water and Surface Water A Single Resource.* U.S. Geological Survey Circular 1139, 79 p.

Winter, T.C., U.S. Geological Survey. Personal communication from Noel Osborne regarding estimated groundwater contribution estimate for two streams in the Ozark region in proximity of Spavinaw Creek. April 27, 2000.

Appendix A: Historical Data

Historical Data

The City of Tulsa has a large record of historical water quality data for both Lakes Eucha and Spavinaw spanning from 1968 to 1997. Monitoring on Spavinaw Lake began in 1968 with the field water quality parameters of dissolved oxygen and temperature. In 1974, the monitoring was expanded to include laboratory parameters and additional field parameters. Also in 1974, monitoring began on Lake Eucha. Both lakes were monitored for the nutrients nitrogen and phosphorus starting in 1989. In general, monitoring was performed seasonally from May through September. Occasionally, observations were taken year-round. All data collected prior to the beginning of this study in 1997 were considered historical data. This included the data collected for the OCC Phase I Clean Lakes Project for Lake Eucha, which consisted of regular monitoring of physical, chemical, and biological parameters for a one-year period, March 10, 1993 to February 16, 1994. The historical data will be used to assess differences at a site and between sites and to evaluate changes in the concentrations of these parameters over time. These data will also be used to characterize general lake dynamics.

Lake Eucha

Lake Eucha was monitored from May 16, 1974 to May 21, 1997. Three sites were initially selected for monitoring and these sites have not changed throughout the monitoring of Eucha, although additional sites have been added. Site 1, referred to as EUC01, is located in the western tip of the lake by the dam. Site 2 (EUC02) is located to the east of EUC01 in open water near the middle of the lake. Site 3 (EUC03) is located further east towards the main lake tributary, Spavinaw Creek. These sites are shown in Figure A-1.

Physical/Chemical

Figure A-2 contains two isopleths describing the temperature and dissolved oxygen dynamics at the Eucha dam during the OCC Clean Lakes project. Isopleths seem confusing, but they allow a lake manager to view all data in one illustration. It may be helpful to think of the temperature and oxygen figures as contour maps. Just as a hiker can use a topographic map to stay at one elevation, each line of an isopleth represents a particular temperature and can be followed throughout the monitoring period. Warmest temperatures are colored dark red. The red graduates into blue as temperature drops. High oxygen concentrations are colored blue. The blue graduates into red as the concentration drops to zero.

The following is an example of reading the temperature isopleth in Figure A-2 and an introduction of limnological terms. At mid-April water temperature was 8°C throughout the water column (from 0 to 23 meters depth), depicted here by the 8°C isobar running vertically. This indicates that the water body is well mixed with water quality conditions similar from surface to bottom. Examination of the temperature plot for late August shows a very different pattern of temperature with depth known as thermal stratification. Here temperature isobars run horizontally, indicating a strong temperature gradient from top to bottom. Strong vertical temperature gradients indicate stratified water quality conditions.

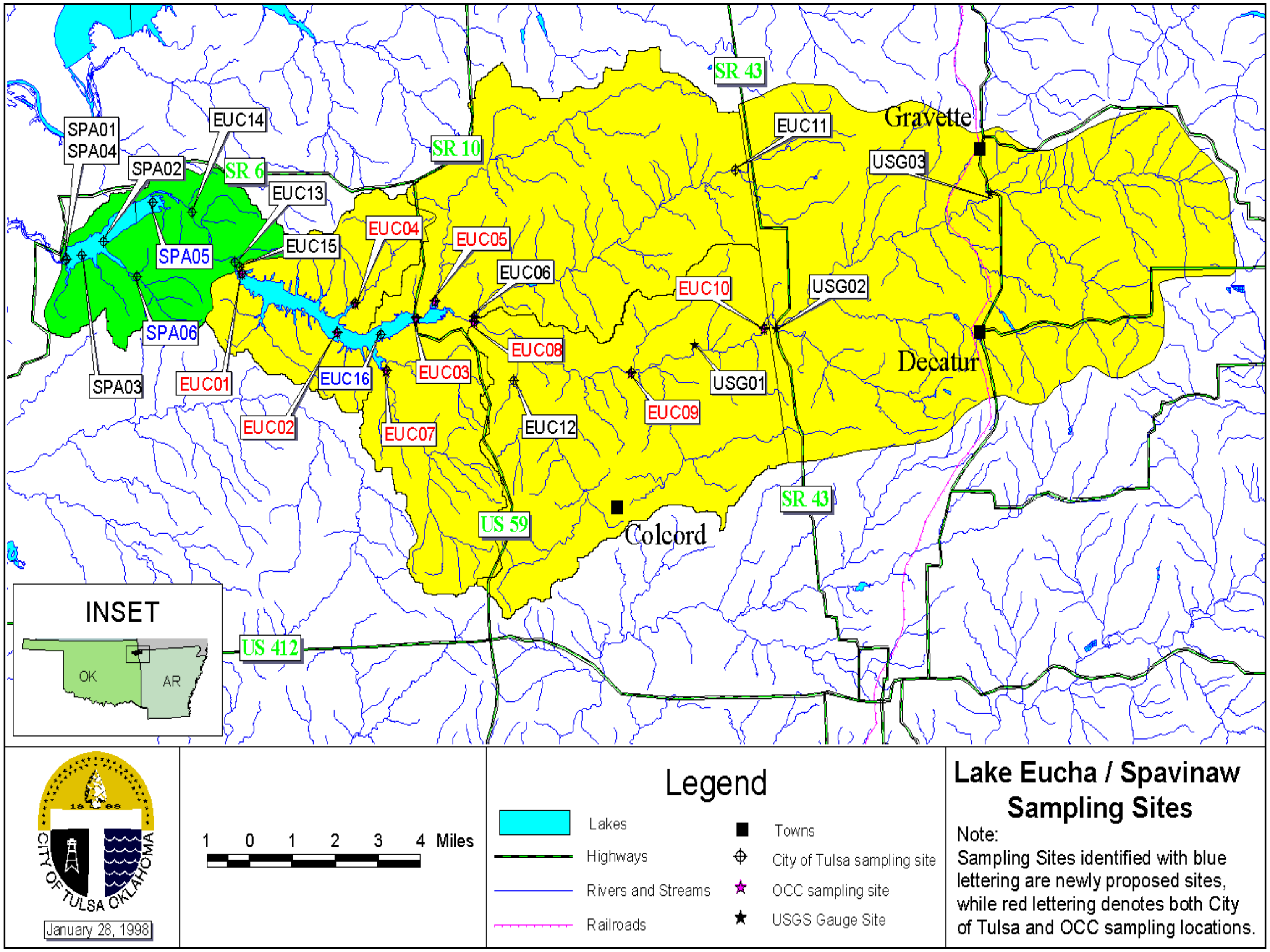


Figure A-1 Map of Lake Eucha and Spavinaw Sampling Sites

Appendix B: Bathymetry

GIS Procedures for Lake Spavinaw Bathymetric Mapping

09/26/00

1) Create an Accurate Lake Boundary File

In order to create an accurate boundary file for Lake Spavinaw, it was determined that the best source data was the USGS Digital Orthophoto Quarter Quads (DOQQ). The DOQQs have a spatial resolution of 1 meter. Three DOQQs cover the entire lake. They are the SE quarter of the Spavinaw quad, the SW quarter of the Choleta quad, and the NE quarter of the Salina SE quad. The photo date for each of the images was February 25, 1995. On this date, the lake elevation was 680.1 feet. The normal pool elevation for the lake is 680.0 feet.

The DOQQs were in the UTM coordinate system with NAD83 as the horizontal datum. These DOQQs were reprojected into the Oklahoma North State Plane coordinate system with the NAD83 horizontal datum using ARCINFO 8.01 GIS software from ESRI.

Using ArcView 3.1 GIS Software from ESRI, the reprojected DOQQs were used as a reference to digitize the boundary of the lake on-screen. The boundary was digitized at a screen scale of 1:3000.

The total surface area of the created lake boundary excluding the island areas was 1,575 acres.

2) Import the Collected Bathymetric Data into a GIS Format

The bathymetric data was delivered in a Microsoft Excel spreadsheet format. This data was converted to a comma delimitated ASCII text file containing the X, Y, and Z point information. This file was imported into ArcView and converted into a shapefile. <SPAV_COLLECTED.SHP>

3) Addition of Artificial Information

Because several areas of the lake lacked collected data, some artificial data points were created. The majority of these points were added in the eastern end of the lake. The survey crew was unable to collect data in this area due to the shallowness of the water. A general depth of 3 feet was given to this area. Without adding the artificial data points the GIS would interpolate the depth of this area with a near zero depth value. <SPAV_ADD_POINTS.SHP>

Artificial Contour lines were also added to some areas of the lake. In areas along steep shorelines without collected data, the interpolation software tended to lessen the steepness of the slope. To correct this problem, contour lines were drawn between two collected data points with similar depths, parallel to the shoreline. <SPAV_ADD_CONTOURS.SHP>

4) Create a Point Coverage of all Data Points.

The lake polygon boundary coverage was densified to create more vertex points. This coverage was then converted to a point coverage and each point was given a depth value of zero. This coverage was then merged with the collected data points and the artificial data points to create a point coverage with all of the data points. <SPAV_POINTS>

5) Create the TIN Model

ArcInfo's Arc ToolBox, Create Tin Wizard, was used to create the TIN surface model. This model created an elevation surface based on the point data coverage, the artificial contours, and the lake boundary. <SPAV_TIN>

6) Contour Depth Coverage

ArcInfo's Arc ToolBox, Contour Wizard was used to create a 1-meter interval contour depth coverage from the TIN surface model. <SPAV_CONT>

7) Lake Volume Calculations

The surface area of each 1-meter contour interval was calculated and used in the lake volume calculation model.

Lake Spavinaw, Results and Statistics

Surface Area Calculated from Digitized Lake Boundary = 1,575 acres

TIN Calculations

Volume: 25,941 ac-ft

Area: 1,578 ac

Minimum Value = -46.400

Maximum Value = 0.000

GRID Calculations (10ft cells)

Volume: 25,725 ac-ft

Area: 1,578 ac

Minimum Value = -45.701 feet

Maximum Value = 0.715 feet

Mean = -16.110 feet

Standard Deviation = 11.262

Depth Range Statistics from Edited Tin Model

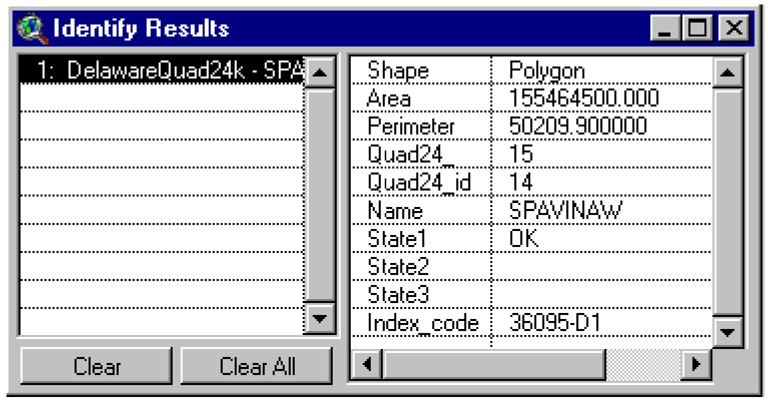
Depths (m)	# of Areas	Acres
0 - 1	1	307.8310
1 - 2	1	102.3770
2 - 3	4	101.1810
3 - 4	6	107.5000
4 - 5	6	155.8020
5 - 6	12	151.9440
6 - 7	20	119.8430
7 - 8	13	164.2140
8 - 9	24	143.3730
9 - 10	25	66.9020
10 - 11	18	71.8770
11 - 12	12	54.5110
12 -13	12	22.3900
13 - 14	11	4.5960
14 - 15	3	0.1630
Sum	**168**	**1574.5040**

1) Procedures for Bathymetric Mapping

1) Create a boundary file for the lake
In order to get an accurate boundary of the lake for mapping purposes, you must digitize the lake boundary from the Digital Orthophotos (DOQQs).

a) Using ArcView determine the DOQQs needed to cover the lake's extent
-In ArcView, start a new view and add the "Lakes" coverage and the "1:24,000" USGS Quad Index Map"

-Overlay the Quad Index Map over the lake and using the “Identify” tool, click on the quads that intersect with the lake.
-Write down the quad name and the corresponding id number ex: “36095 G1”



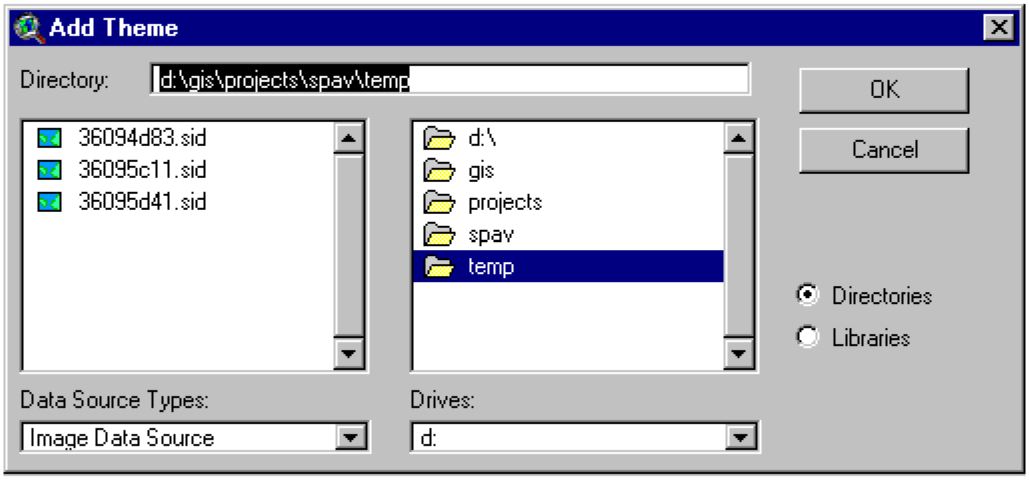
-Determine which quarter of the quad that you need. Ex: NE, NW, SE, SW
-In the example above, the index_code for the Spavinaw quad is: 36095-D1
-You will need the SE quarter quad for the Spavinaw quad, the SW quarter quad for Chloeta, and the NE quarter quad for Salina SE.
Therefore, the file names that you will need are:
36095d14.bil 36095d14.hdr
36094d82.bil 36094d82.hdr
36095c11.bil 36095c11.hdr

b) Download the DOQQs
-Start an FTP program
-Go to: ftp:\\okmaps.onenet.net
-Login as “anonymous” and the Password is your Email address
-Go to the DOQ folder
-Scroll down until you see the folder “36095” double-click on it
-Scroll down until you see the files that you want.
-Select the files individually by holding down the “Ctrl” key and clicking
-Make sure the transfer type is set to “Binary”
-Copy the files to your workspace

c) Using ARCINFO, Reproject the DOQQs
-Start ARCINFO
-Navigate to the workspace that contains the DOQQs
-Run the “Doq_con.aml”
ARC: &r doq_con.aml
The output projection will be: State Plane
From the dialog box, double click on the image you want to process
For the State Plane Zone enter: 1, for North
-After you have processed all three images, go back to your ArcView project
-Open the View
-Click the “Add Theme” button 
-Set the “Data Source Type” to Image Data Source

-Select the files and click “OK”

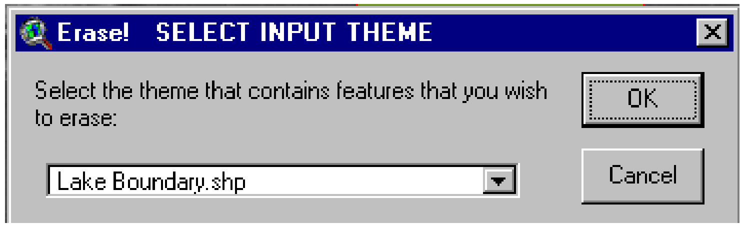
d) Digitize the Lake Boundary



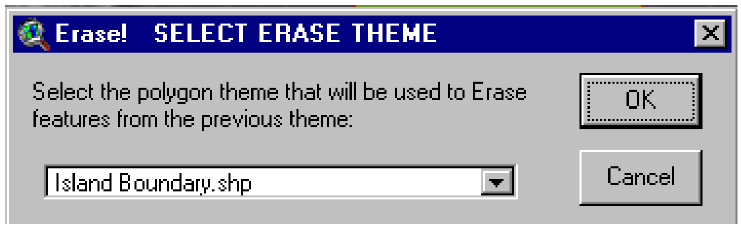
-Set the View scale at 1:3000
-Click the graphic polygon tool and start digitizing the lake boundary
-Since you can not draw and pan at the same time, you will have to create multiple polygons for the lake boundary
-When you get a section of the lake completed you can convert the graphic polygons into a Shapefile.
-Using the “Pointer” Tool Select all of the graphic polygons
-Load the “Xtools” extension into ArcView
-Click the “Xtools” menu, “Convert Graphics to Shapes”
-Click the text in the dialog box and click “OK”
-To merge multiple Shapefiles together:
-Click the “Xtools” menu, “Merge Themes”
-After you merge all of the Shapefiles together then you need to make the lake one polygon
-Make sure the merged shapefile is active and click “Themes”, “Start Editing”
-Select all of the Polygons
-Click “Edit”, “Union Features”
-Click “Theme”, “Stop Editing” and Save edits
-The output .shp file will be called <**spav_boundary.shp**>
-Add a new field to the <**spav_boundary.shp**> table
Name: Spot
Type: Number
Width: 10
Decimal Places: 0

e) Digitize the Island Boundaries
-You will then need to digitize all of the islands in the lake.
-Use the same procedure as the lake boundary
-The output .shp file will be called <**spav_islands.shp**>

f) Clip the <**spav_islands.shp**> from the <**spav_boundary.shp**>
-Click “Xtools”, “Erase Features”
-For the Input Theme Select the lake boundary shapefile



-For the Erase Theme Select the island boundary shapefile



-The output file will be called <**spav_lake.shp**>

2) Convert the Shapefile Boundary to an ARCINFO Coverage

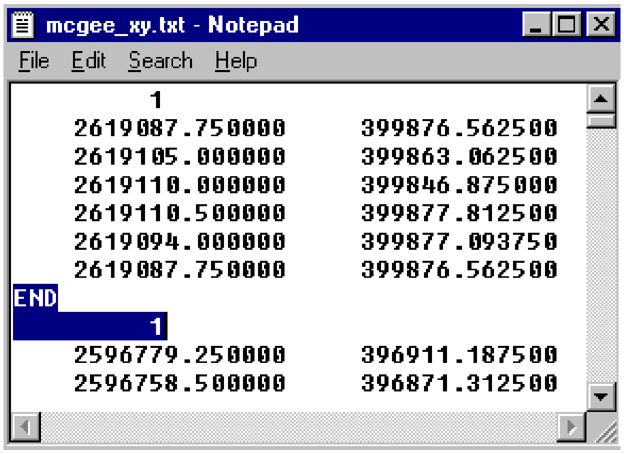
a) Convert the Shapefile
-Start ARCINFO
-Make sure the directory you are working in is an ARCINFO WORKSPACE
-If not, use the CW command to make the directory a WORKSPACE
-Navigate to the WORKSPACE
-Set the AMLPATH arc: &AMLPATH g:\aml\conversions
-Run the shape2cover.aml
arc: &r shape2cover <**spav_lake.shp**> <**spav_lk**>
-Build the new coverage
arc: Build < **spav_lk** > Poly

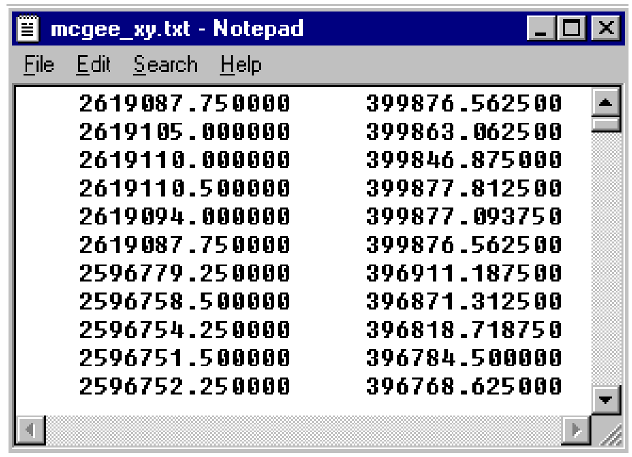
b) Create a dense point coverage
-Use the DENSIFYARC command in ARCINFO
arc: DENSIFYARC < **spav_lk** > <**spav_lk_den**> <25> <vertex>
-Use an interval value of (25)
-Build the new coverage
arc: Build < **spav_lk_den**> Poly

c) Create a .DXF File
-Use the ARCDXF command
arc: arcdxf <**spav_lk.dxf**> < **spav_lk_den** > # # # #

d) Create an XY Text File
-Use the UNGENERATE command in ARCINFO
arc: UNGENERATE LINE < **spav_lk_den** > <**spav_lk_den.txt**> # <fixed>

e) Edit the XY Text File
-Open the <**spav_lk_den.txt**> file in NOTEPAD
-Remove all text that is not associated with an X,Y Point





-Use the “Edit” , “Find” tool to search for the word “End”
-Make sure there are no spaces between lines and there are no “Returns” after the last line
-Save the file

f) Convert the Text File to a Comma Delimitated Text File
-Open the <**spav_lk_den.txt**> file in MS Excel
-Add a new Row to the top of the file
-Add an “Xcoor” and “Ycoor” at the top of the Columns
*Note: You may need to add a “Z” value to the file
Add a “Z” in the third Column and enter the normal pool lake elevation for
All of the X , Y locations
-Save the file as a comma delimitated text file .csv
-Name the file <**spav_lk_xy.csv**>
-Open <**spav_lk_xy.csv**> in NOTEPAD
-Save this file as <**spav_lk_xy.txt**>

The <**spav_lk.dxf**> and <**spav_lk_xy.txt**> files are now ready for the preliminary bathymetric setup.

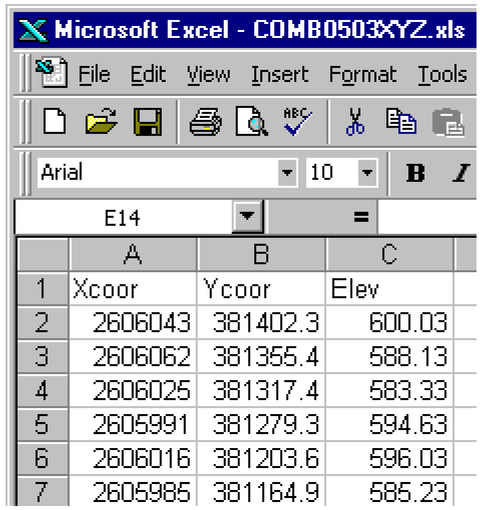
***Notes:**

USGS QUADS	Reference #	Photo Date	Lake Level	Normal
Chloeta	36095-D1 4 SE	2/25/95 680.1’	680.0’	
Spavinaw	36094-D8 3 SW	2/25/95 680.1’	680.0’	
Salina SE	36095-C1 1 NE	2/25/95 680.1’	680.0’	
Lake Eucha	West 36094-C8 2 NW	2/25/95	680.1’	680.0’

2) Processing Corrected X,Y,Z Bathymetric Text Files

1) After the survey crew has corrected the X,Y,Z data, It should be in an MS Excel spreadsheet format (.xls).
-The file will be in a State Plane projection, North, NAD83 datum, and feet as the units.

2) Open the <**spav.xls**> file in Excel
-Make sure you are at the top of the spreadsheet
-Make sure there are three columns
-Go to the top row and insert a new blank row
-Add the following field headings
Xcoor Ycoor Elev



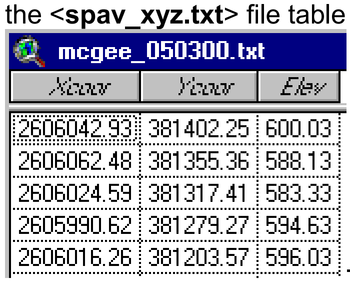
	A	B	C
1	Xcoor	Ycoor	Elev
2	2606043	381402.3	600.03
3	2606062	381355.4	588.13
4	2606025	381317.4	583.33
5	2605991	381279.3	594.63
6	2606016	381203.6	596.03
7	2605985	381164.9	585.23

3) After you add the field names, save the Excel file as a comma delimitated text file <**spav_xyz.csv**> and close Excel.

4) Using Notepad, open the new <**spav_xyz.csv**> file and save it as <**spav_xyz.txt**>

5) Start ArcView

6) From the Project Window, click on the Tables Icon
-Click the “Add” button and add the <**spav_xyz.txt**> file table



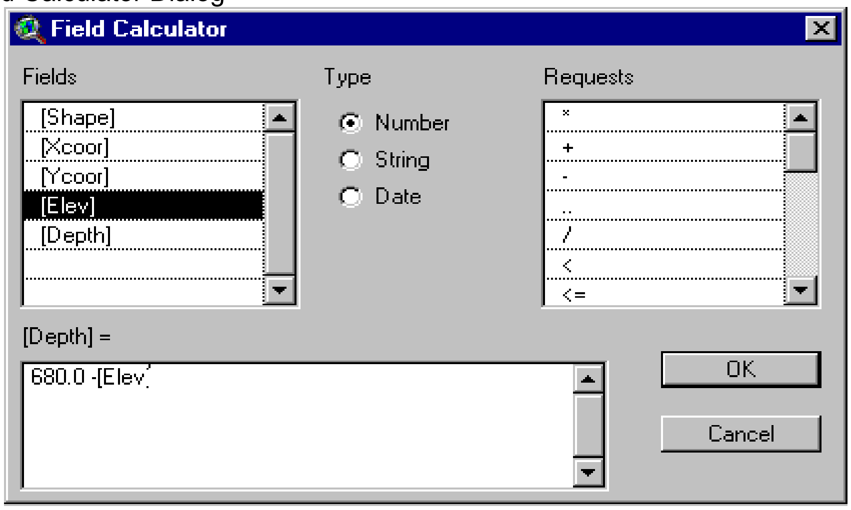
Xcoor	Ycoor	Elev
2606042.93	381402.25	600.03
2606062.48	381355.36	588.13
2606024.59	381317.41	583.33
2605990.62	381279.27	594.63
2606016.26	381203.57	596.03

Make sure the table looks ok, and your field names are in the field heading

7) Go back to the project window and open a View
-From the “View” menu, select “Add Event Theme”
-Make sure the table field is set to your <**spav_xyz.txt**> table
-The Xfield has the “Xcoor” field
-The Yfiled has the “Ycoor” field
-Click “OK”
-A new theme will be added to the View showing the collected data points
-Convert this theme to a new Shapefile
-Name the shapefile <**spav_collected.shp**>

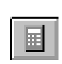
8) Open the table for <**spav_collected.shp**>
-From the “Table” menu, select “Start Editing”
-From the “Edit” menu, select “Add Field”
-Add the following: Name: Depth
Type: Number
Width: 10
Decimal Places: 2
-Click “OK”

9) Populate the Depth Field
-Make sure the "Depth" field is active
-Click the "Calculate" Button 
-In the Field Calculator Dialog



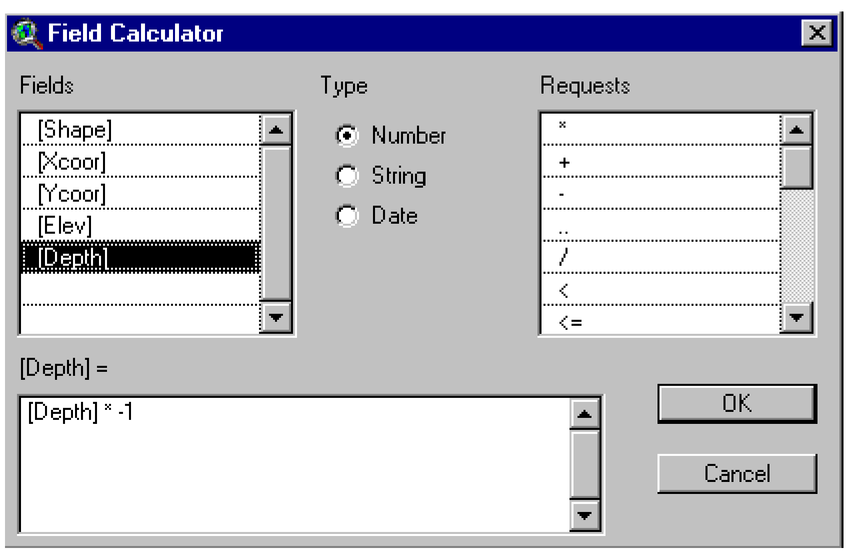
The [Depth] = field should contain the normal pool elevation – the [Elev] field
-Click "OK"
-The "Depth" Field in your table should now contain the lake depths for each point.
-From the "Table" menu, select "Stop Editing" and save edits.

*Do a query on the Depth field of <spav_collected.shp> to make sure there are no zero values. If there are zeros, go to the View window, make the theme active and start editing the theme. Remove any data points that have a zero value, and stop editing and save the edits.

10) Create a Point Coverage of the Lake Boundary
-Get the original X,Y text file created for the pre-survey data
-The file is <**spav_lk_xy.txt**>
-Import the table into ArcView, and open it.
-Make sure the table is active.
-From the "File" menu, select "Export", then "DBASE", and "OK"
-Name the file <**spav_lk_xyz.dbf**>
-You will then have to add the new <**spav_lk_xyz.dbf**> file into ArcView
-From the "Table" menu, select "Start Editing"
-From the "Edit" menu, select "Add Field"
-The First Field will be normal pool lake level elevation: 680 ft
Name: Elev
Type: Number
Width: 10
Decimal Places: 2
-The Second Field will be the lake depth
Name: Depth
Type: Number
Width: 10
Decimal Places: 2
- Highlight the "Elev" field and click the "Calculate" button 
- In the "[Elev] =" field type in the normal pool lake elevation level
ex: 680.0 for Spavinaw Lake
-Highlight the "Depth" Field and click the "Calculate" button

-In the “[Depth] = “ field type: 0
 Since the lake boundary has no depth
-From the “Table” menu, select “Stop Editing” and Save edits.
-Open the View window
-From the “View” menu, select “Add Event Theme”
-For the Table: <**spav_lk_xyz.dbf**>
-For the X field: Xcoor
-For the Y field: Ycoor
-Click “OK”
-Make the new theme active, and convert it to a new shapefile
-Name the shapefile <**spav_lk_points.shp**>

11) Merge the Collected Survey Points shapefile with the Lake Boundary Point Shapefile.
 -Make sure the ArcView “Xtools” extension is loaded in your AV project
 -Make sure both the <**spav_collected.shp**> file and the <**spav_lk_points.shp**> file are in the same View and have no selected records
 -From the “Xtools” menu, select “Merge Themes”
 -The Input Theme will be: <**spav_collected.shp**>
 -The Theme to Merge With will be: <**spav_lk_points.shp**>
 -Name the new theme: <**spav_col_lk_points.shp**>
 -Open the table for < **spav_col_lk_points.shp** >
 -From the “Table” menu, select “Start Editing”
 -Highlight the “sourcethm” field
 -From the “Edit” menu, select “Delete Field”
 -Click “Yes” to delete the “sourcethm” field
 -Convert the depth values to negatives
 -Highlight the “Depth” field
 -Click the “Calculate” button 
 -Multiple the “Depth” field by –1



 -From the “Table” menu, select “Stop Editing” and Save Edits

12) Merge the < **spav_col_lk_points.shp** > file with the Additional Points
 -Make sure both the < **spav_col_lk_points.shp** > file and the <**spav_add_points.shp**> file are in the same View and have no selected records
 -From the “Xtools” menu, select “Merge Themes”
 -The Input Theme will be: < **spav_col_lk_points.shp** >

-The Theme to Merge With will be: <**spav_add_points.shp**>
-Name the new theme: <**spav_all_points.shp**>

13) Convert the Shapefile of All Points to an ARCINFO Coverage.
-Start ARCINFO and move to the Workspace containing **<spav_all_points.shp** >
-Set the AML path
arc: &AMLPATH g:\aml\conversions
-Run the shape2cover.aml
arc: &r shape2cover.aml < **spav_all_points.shp** > <**spav_points**>

14) Create an ARCINFO Coverage of the Lake Boundary without Islands
a) Convert the original <**spav_boundary.shp**> file to an ARCINFO coverage
-Start ARCINFO and move to the Workspace containing <**spav_boundary.shp**>
-Using ARCINFO ArcToolbox, Select: "Conversion Tools / Import to Coverage / Shapefile to Coverage"
-The input shapefile will be <**spav_boundary.shp**>
-The output AI Coverage will be <**spav1**>
b) Densify the <**spav1**>Coverage
-Use the DENSIFYARC command in ARCINFO
arc: DENSIFYARC <**spav1**> <**spav_den**> <25> <vertex>
-Use an interval value of (25)
-Build the new coverage
arc: Build < **spav_den** > Poly
c) Convert <**spav_den**> to a shapefile <**spav_outline.shp**>
d) Convert <**spav_outline.shp**> to an ARCINFO coverage
-Start ARCINFO and move to the Workspace containing <**spav_outline.shp**>
-Set the AML path
arc: &AMLPATH g:\aml\conversions
-Run the shape2cover.aml
arc: &r shape2cover.aml <**spav_outline.shp**> <**spav_bnd**>
-Build <**spav_bnd**> Poly

3) Creating a TIN From Bathymetric Mapping Points

1) Create an ARCINFO TIN Surface Model
-Start ARCINFO Arc Toolbox
-From the "Conversion Tools / Import to Tin" menu, select "Create Tin Wizard"
-In the "Create Tin Wizard" dialog, click "Next"

2) Add the Data Points Coverage to the TIN Wizard
-Click the "Add Coverage" button
-Click the "Folder" icon to select the 1st input coverage
-The 1st input coverage will be: <**spav_points**>
-The Feature Class should be: "Point"
-The Weed Tolerance will be: "25.01125"
-Click "Next"
-Click the "Choose a Z-value item" radio button
-Click the "Depth" field
-Click "Next"
-Click "Next"

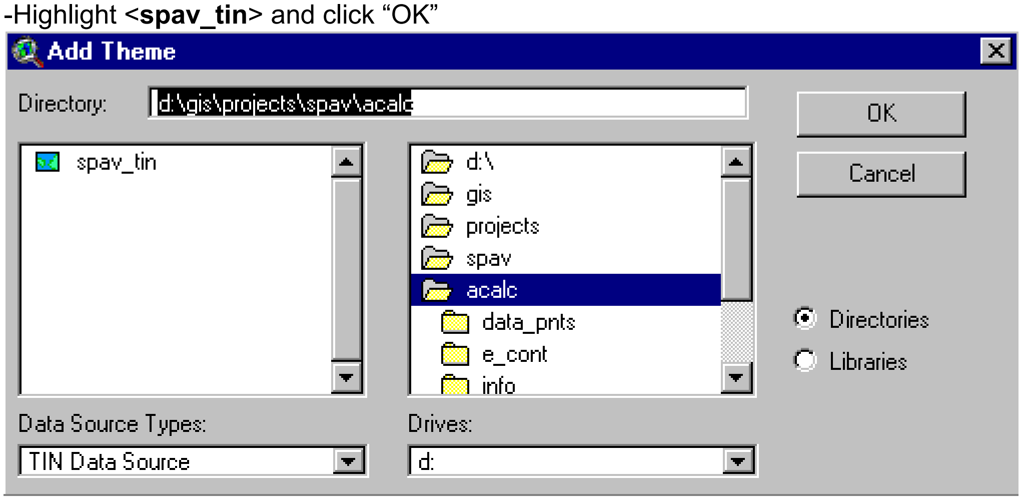
2) Add the Artificial Contour Lines Coverage to the TIN Wizard
-Click the "Add Coverage" button
-For the "Input Coverage", select <**spav_add_cnt**>
-The Feature Class should be: "Line"
-The Weed Tolerance should be: "12.0465"
-Click "Next"
-Click the "Choose a Z-value item" radio button

-Click the “Depth” field
-Click “Next”
-Click the “Choose a surface type keyword” radio button
-Click “Mass”
-Click “Next”
-Click “Next”

3) Add the Lake Boundary Polygon Coverage to the TIN Wizard
-Click the “Add Coverage” button
-For the “Input Coverage”, select <**spav_bnd**>
-The Feature Class should be: “Poly”
-The Weed Tolerance should be: “25.01125”
-Click “Next”
-Click the “Choose a Z-value item” radio button
-Click the “Spot” field
-Click “Next”
-Click the “Choose a surface type keyword” radio button
-Click “HardClip”
-Click “Next”
-Click “Next”

4) Select the Output TIN Information
-Click “Next” to move to the Output Dialog
-For the “Output tin”, type <**spav_tin**>
-The “Proximal Tolerance:” should be: “<Optional>
-The “Z-factor:” should be: 1
-Click “Next”
-Click “Finish”

5) Add the New Tin into your ArcView Project
-In ArcView, Click the “Add Theme” button
-Change the “Data Source Types” option to “TIN Data Source”
-Highlight <**spav_tin**> and click “OK”



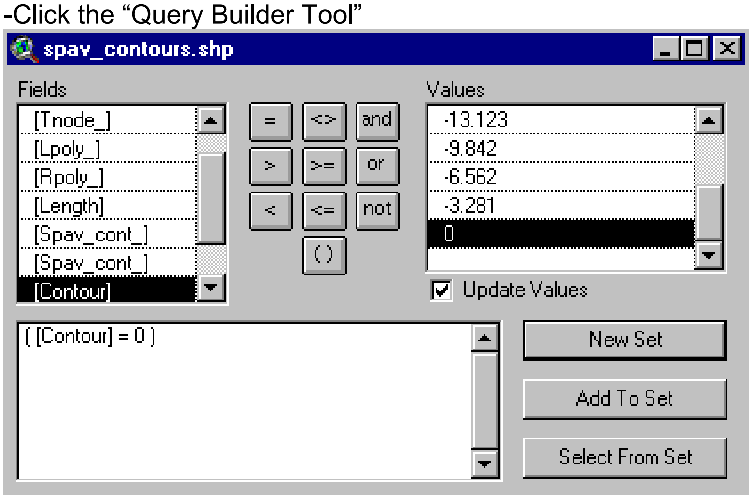
4) Creating the Contour Depth Areas Coverage

1) Create an ARCINFO Contour Depth Coverage
-Start ARCINFO Arc Toolbox
-From the “Analysis Tools / Surface” menu, select “Contour Wizard”
-To select the “Input Surface”, click the folder icon
-Select the <**spav_tin**> file and click “Open”
-Click “Next”
-Change the Contour Interval to “3.2808333” to represent 1 meter depths

-Click “Next”
-The “Base Contour:” should be 0
-Click “Next”
-The “Output Item:” Should be: “Contour”
-Click “Next”
-Set the “Subdivision Degree” to 7
-Click “Next”
-Set the “Weed Tolerance” to 5
-Click “Next”
-The “Z-factor” should be: 1
-The “Output Coverage” should be <**spav_cont**>
-Click “Next’
-Click “Finish”

2) Create a Lake Boundary Line File
-In ArcView, add the <**spav_lk_den**> line coverage
-Convert the <**spav_lk_den**> ARCINFO coverage to a .shp file
-Name the .shp file, <**spav_line.shp**>

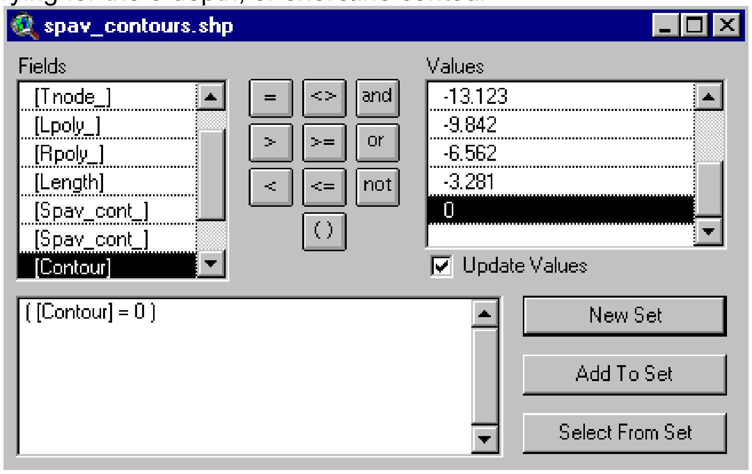
3) Convert <**spav_cont**> to an ArcView .shp file
-In ArcView, add the < **spav_cont** > line coverage
-Convert the < **spav_cont** > ARCINFO coverage to a .shp file
-Name the .shp file, <**spav_pre_cont.shp**>
-Make the <**spav_pre_cont.shp**> theme active in the View
-Click the “Query Builder Tool”



-Perform a query to find all contour lines with a depth value of 0
-Click “New Set” to perform the query
-Make the View window active
-From the “Theme” menu, select “Start Editing”
-All of the 0 depth contour lines should be selected
-From the “Edit” menu, select “Delete Features”
-From the “Theme” menu, select “Stop Editing” and Save Edits

4) Merge the Lake boundary line with the Depth Contours
-In ArcView, make sure both the < **spav_pre_cont.shp** > and <**spav_line.shp**> are in the View Window.
-Using the Xtools extension, Select Xtools / Merge Themes
-The “Input theme” will be < **spav_pre_cont.shp** >
-The “Merge With” theme will be <**spav_line.shp**>
-The “Output Theme” should be <**spav_contours.shp**>

5) Create individual .shp Files for Each 1 Meter Depth Range
-Make sure < **spav_contours.shp** > is the active theme in your ArcView View Window
-Click the "Query Builder Tool"
-Set up a query to select each depth range (0-14) meters and save them as new .shp file.
-Start by querying for the 0 depth, or shoreline contour



-After the line is selected, make the View Window Active
-From the "Theme" menu, select "Convert to Shapefile"
-This will save only the selected 0 depth lines to a new .shp file
-Name the new .shp file <**cont_0m.shp**>
-Repeat this process through <**cont_14m.shp**>

6) Convert Each of the Contour .shp Files to ARCINFO Coverages
-Start ARCINFO Arc Toolbox
-From the "Conversion Tools / Import to Coverage" menu select "Shapefile to Coverage"
-For the "Input Shapefile", click the "open folder" icon
-Select all of the .shp files <**cont_0m.shp**> … <**cont_14m.shp**>
-Click "Open"
-In the Batch Job box at the bottom of the dialog, enter the output coverage names. <**c0m**> … <**c14m**>
-Click "OK"

7) Clean and Build the New Coverages
-From Arc Toolbox, Select "Data Management Tools / Topology / Clean
-For the "Input Coverage", click the "open folder" icon
-Select all of the coverages <**c0m**> … <**c14m**>
-Click "Open"
-The "Dangle Length" should be "0"
-Change the "Fuzzy Tolerance" to: "6"
*Note: If after this process one of the new coverages is not a good polygon coverage, increase the Fuzzy Tolerance
-Change the "Feature Class" to: "Poly"
-Change the "Output Coverage" names to: <**c0mcl**> … <**c14mcl**>
-Click "OK"
-From Arc Toolbox, Select "Data Management Tools / Topology / Build
-For the "Input Coverage", click the "open folder" icon
-Select all of the Coverages <**c0mcl**> … <**c14mcl**>
-Click "Open"
-Change the "Feature Class" to "Poly" for each coverage
-Click "OK"

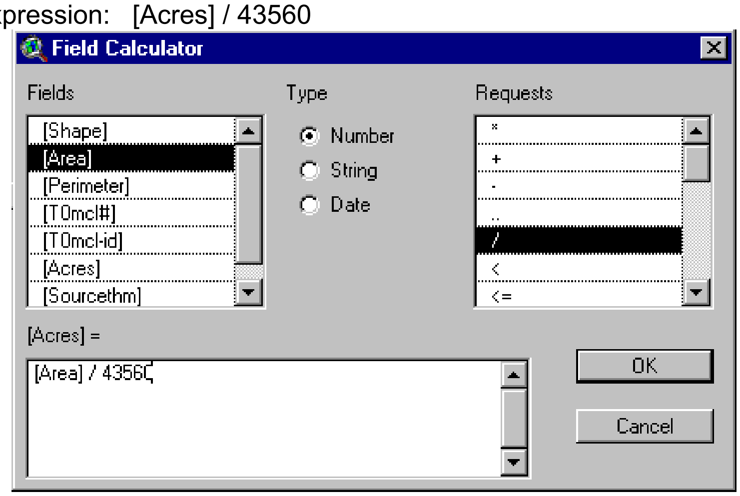
8) Convert the New Coverages to .shp Files

-Open the new coverages <**c0mcl**> … <**c14mcl**> in ArcView
-Make all of the coverages active
-From the “Theme” menu, click “Convert to Shapefile”
-Name each of the new coverages <**c0.shp**> … <**c14.shp**>

9) Remove the Internal Polygons From Each of the New .shp Files
-Make the <**c0.shp**> file active
-From the “Theme” menu, select “Start Editing”
-Open the Table for <**c0.shp**>
-From the Table, go through a process of selecting each one of the polygon features and then going back to the view window and zooming to the extent of the polygon feature to see if the feature is an internal polygon. If the feature is an internal polygon delete it.
-Once you have removed all of the internal polygons from <**c0.shp**>, From the “Theme” menu, select “Stop Editing” and Save the Edits.
-Repeat this process for the rest of the <**c1.shp**> … <**c14.shp**>

10) Erase the Overlapping Areas of Adjacent Depths
-Using the “Xtools / Erase Features” tool, select <**c0.shp**> as the first input theme. The second input theme will be <**c1.shp**>. The output .shp file should be named <**e_0_1.shp**>
-The next step would be to Erase the overlap between <**c1.shp**> and <**c2.shp**>. The output file name would be <**e_1_2.shp**>
-Repeat this process for the rest of <**c2.shp**> … <**c14.shp**>
-There will not be any overlap for the <**c14.shp**> so just make this theme active and use the “Convert to Shapefile” function and name the output <**e_14_15.shp**>

11) Merge the “Erased” .shp Files Together
-Using the “Xtools / Merge Themes” tool, select <**e_0_1.shp**> as the first input theme and for the second input select all the rest of the <**e_1_2.shp**> … <**e_14_15.shp**>. Name the Output .shp file <**spav_depth_ranges.shp**>
-Open the Table for < **spav_depth_ranges.shp** >
-Start Editing the Table
-Highlight the “Acres” Field Tab
-Click the “Field Calculate” button
-Enter the Expression: [Acres] / 43560



-This will update the correct acreage values.
-Add a new Field called “Depths_m”
Name: “Depths_m”
Type: “String”
Width: “16”
-Open the “Query Builder” tool
-Perform a query to find all of the depths between 0 and 1 meters

([Sourcethm] = "e_0_1.dbf") , click “New Set”
-Click the “Field Calculate” button
-Enter the expression: "0 - 1"
-Repeat the process for the rest of the depth ranges
-Delete the “Sourcethm” Field
-Stop Editing the Table and Save the Edits

12) Add an Identification Field to the Table
-Open the < **spav_depth_ranges.shp** > Table
-Start Editing the Table
-Add a new field
Name: Legend_Id
Type: Number
Width: 10
Decimal Places:0
-Populate the records by using the Query Builder and the Field Calculator
-The depth range of “0 – 1” should have a value of 1
-The depth range of “1 – 2” should have a value of 2
-Repeat this process through “14 - 15” with a value of 15
-Stop Editing and Save the Edits

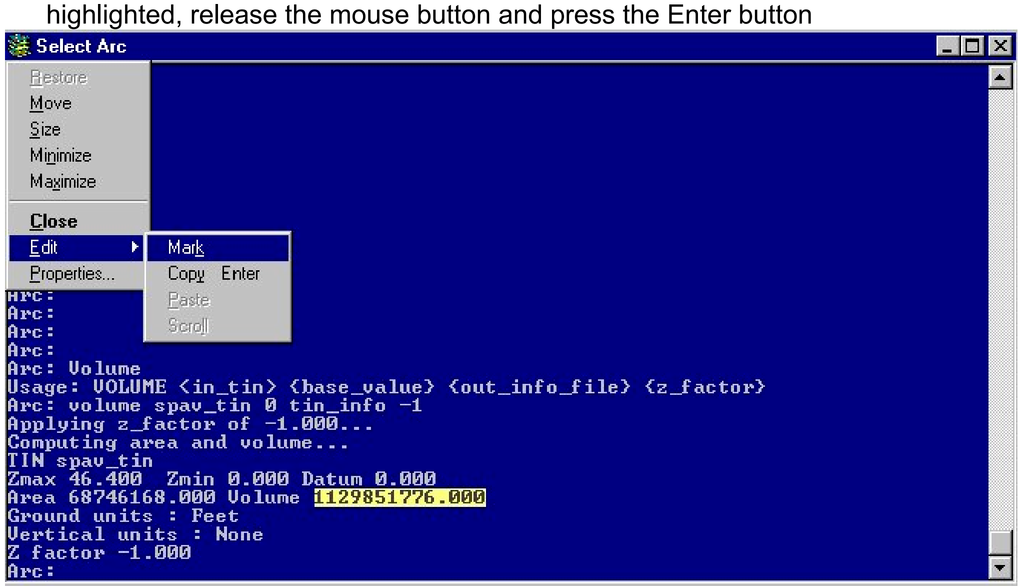
13) Determine the Area of Each Depth Range
-Open the < **spav_depth_ranges.shp** > Table
-Click on the “Depths_m” field Tab to make it Active
-From the “Field” menu, select “Summarize”
-From the “Summary Table Definition” dialog, select the “Field” drop-down menu, and select the “Acres” field.
-From the “Summarize by” menu, select “Sum”
-Click the “ADD” button
-Click “OK”
-A new Table will be created that shows the number of polygons (Count) and the total acres of all the polygons (Acres) for each depth range

4) **Methods to Determine Volumes and Areas**

1) Cut Fill Method (GRID)
-Start ARCINFO
-Use a DESCRIBE on the input GRID
arc: DESCRIBE <**spav_grid**>
-Note the Minimum and Maximum values
ex: Minimum Value = -45.701
Maximum Value = 0.715
-Start ARCINFO GRID
arc: GRID
-Use the SETNULL option to set the maximum value of <**spav_grid**> to 0.
The output GRID will be <**cut_grid**>
arc: <**cut_grid**> = SETNULL(<**spav_grid**> > 0, <**spav_grid**>)
-Start Notepad program
-Type the following on the first line:
-46 0 : 0
-Save the file as a .text file to your current workspace as “rec.rmp”
-View the rec.rmp file with your NT Explorer to make sure the file does not have an additional .txt extension (rec.rmp.txt) if it does, remove the .txt
*This will create a reclass table. All values between –45.701 and 0 will be set to 0 when the reclass is run.
-Go back to ARCINFO GRID

-Perform a RECLASS on the <**cut_grid**>
    grid: <**fill_grid**> = RECLASS(<**cut_grid**>, rec.rmp, data, #, #)
-Quit GRID
    grid: q
-Use the CUTFILL command in ARCINFO
    arc: CUTFILL <**fill_grid**> <**cut_grid**> <**cf_grid**> <**cf_cov**> -1
    <**cf_grid**> is an output grid with values of change +/-
    <**cf_cov**> is and output coverage with areas of change +/-
    *Note: If your XY-Units and Z-Units are the same use the –1 z-factor
        If your XY-Units are in meters and your Z-Units are in feet,
        use a z-factor of –0.305
-To get the Volume and Area statistics from the CUTFILL
    arc: list <**cf_cov**>.cf
-To convert cubic meters to acre-feet, multiply the sum by **.000810698**
-To convert cubic feet to acre-feet, multiply the sum by **.00002296**
-To convert square meters to acres, multiply the sum by **.000247104**

2) Volume Command (TIN)
-Start ARCINFO
-Use the VOLUME command to determine the volume and area of a TIN
    arc: VOLUME <**input_tin**> <**base_value**> <**out_info_file**> <z-factor>
    arc: VOLUME <**spav_tin**> 0 tin_info –1
*For volumes of lake use a z-factor of –1
*For other surface volumes use a z-factor of 1
*Note: If your XY-Units and Z-Units are the same use the –1 z-factor
    If your XY-Units are in meters and your Z-Units are in feet,
    use a z-factor of –0.305
-An easy way to get your data results into the Calculator Program
    -Left-Click on the upper left-hand corner of the ARC Window
    -Click on Edit / Mark
    -Left-Click in front of the value that you want to copy and hold-down the the left mouse button and move over the entire value. When the value is highlighted, release the mouse button and press the Enter button



-You can now paste the value in your Calculator Program.

GIS Procedures for Lake Eucha Bathymetric Mapping

10/02/00

1) Create an Accurate Lake Boundary File

In order to create an accurate boundary file for Lake Eucha, it was determined that the best source data was the USGS Digital Orthophoto Quarter Quads. The DOQQs have a spatial resolution of 1 meter. Three DOQQs cover the entire lake. They are the; NW quarter of the Lake Eucha West quad, the NW quarter of the Lake Eucha East quad and the NE quarter of the Lake Eucha East quad. The photo date for each of the images was February 25, 1995. On this date, the lake elevation was 778.1 feet. The normal pool elevation for the lake is 778.0 feet.

The DOQQs were in the UTM coordinate system with NAD83 as the horizontal datum. These DOQQs were reprojected into the Oklahoma North State Plane coordinate system with the NAD83 horizontal datum using ARCINFO 8.01 GIS software from ESRI.

Using ArcView 3.1 GIS Software from ESRI, the reprojected DOQQs were used as a reference to digitize the boundary of the lake on-screen. The boundary was digitized at a screen scale of 1:3000.

The total surface area of the created lake boundary excluding the island areas was 2,807 acres.

2) Import the Collected Bathymetric Data into a GIS Format

The bathymetric data was delivered in a Microsoft Excel spreadsheet format.
This data was converted to a comma delimitated ASCII text file containing the X, Y, and Z point information. This file was imported into ArcView and converted into a shapefile.
<EUCHA_COLLECTED.SHP>

3) Addition of Artificial Information

Because several areas of the lake lacked collected data, some artificial data points were created. The majority of these points were added in the eastern end of the lake. The survey crew was unable to collect data in this area due to the shallowness of the water. A general depth of 3 feet was given to this area.

Without adding the artificial data points the GIS would interpolate the depth of this area with a near zero depth value. <EUCHA_ADD_POINTS.SHP>

Artificial Contour lines were also added to some areas of the lake. In areas along steep shorelines without collected data, the interpolation software tended to lessen the steepness of the slope. To correct this problem, contour lines were drawn between two collected data points with similar depths, parallel to the shoreline. <EUCHA_ADD_CONTOURS.SHP>

4) Create a Point Coverage of all Data Points.

The lake polygon boundary coverage was densified to create more vertex points. This coverage was then converted to a point coverage and each point was given a depth value of zero. This coverage was then merged with the collected data points and the artificial data points to create a point coverage with all of the data points. <EUCHA_POINTS>

5) Create the TIN Model

ArcInfo's Arc ToolBox, Create Tin Wizard, was used to create the TIN surface model. This model created an elevation surface based on the point data coverage, the artificial contours, and the lake boundary. <EUCHA_TIN>

6) Contour Depth Coverage

ArcInfo's Arc ToolBox, Contour Wizard was used to create a 2-meter interval contour depth coverage from the TIN surface model. <EUCHA_CONT>

7) Lake Volume Calculations
The surface area of each 2-meter contour interval was calculated and used in the lake volume calculation model.

Lake Eucha, Results and Statistics

Surface Area Calculated from Digitized Lake Boundary = 2,807 acres

TIN Calculations

Volume: 74,456 ac-ft

Area: 2,812 ac

Minimum Value = -84.02 feet

Maximum Value = 0.000 feet

GRID Calculations (10ft cells)

Volume: 74,237 ac-ft

Area: 2,817 ac

Minimum Value = -83.192 feet

Maximum Value = 4.482 feet

Mean = -26.071 feet

Standard Deviation = 18.030 feet

Depth Range Statistics from Edited Tin Model

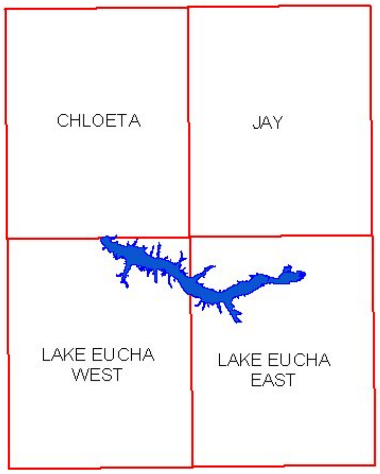
Depths (m)	# of Areas	Acres
0 - 2	1	521.003
2 - 4	1	212.858
4 - 6	9	345.02
6 - 8	23	381.916
8 - 10	30	253.01
10 - 12	25	345.544
12 - 14	32	286.282
14 - 16	27	161.252
16 - 18	31	162.359
18 - 20	41	114.272
20 - 22	23	13.151
22 - 24	6	6.956
24 - 26	5	3.287
> 26	3	0.069
Sum	**257**	**2806.9790**

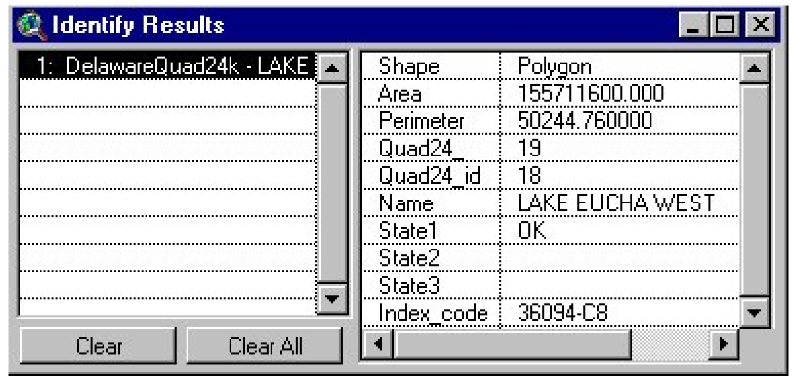
1) Procedures For Bathymetric Mapping

3) Create a boundary file for the lake
In order to get an accurate boundary of the lake for mapping purposes, you must digitize the lake boundary from the Digital Orthophotos (DOQQs).

g) Using ArcView determine the DOQQs needed to cover the lake's extent
-In ArcView start a new view and add the "Lakes" coverage and the "1:24,000" USGS Quad Index Map"

-Overlay the Quad Index Map over the lake and using the "Identify" tool, click on the quads that intersect with the lake.
-Write down the quad name and the corresponding id number ex: "36094 C8"
-Determine which quarter of the quad that you need. Ex: NE, NW, SE, SW

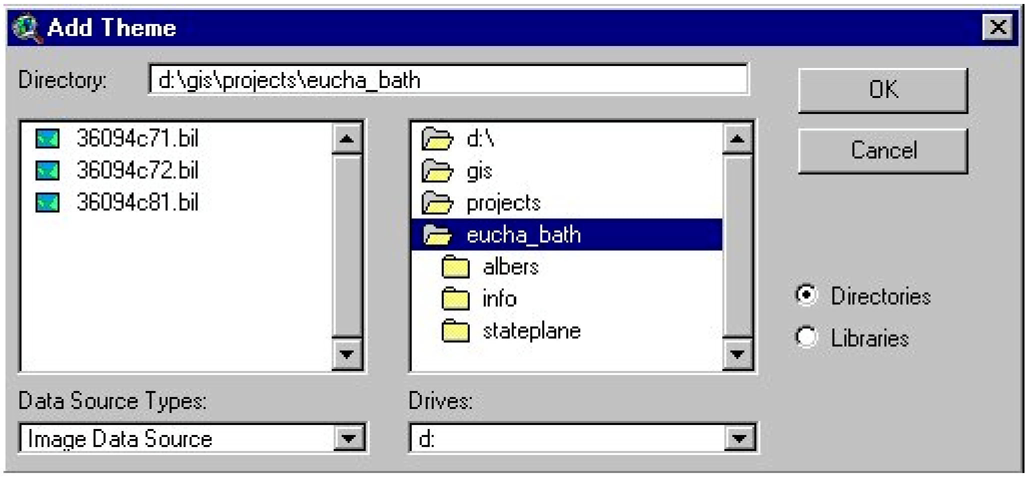




-In the example above, the index_code for the Lake Eucha West quad is: 36094-C8
-You will need the NE quarter quad for the Lake Eucha West quad, the NW quarter quad for Lake Eucha East quarter quad, and the NE quarter quad for Lake Eucha East quarter quad.
Therefore, the file names that you will need are:
36094c81.bil 36094c81.hdr
36094c71.bil 36094c71.hdr
36094c72.bil 36094c72.hdr

h) Download the DOQQs
-Start an FTP program
-Go to: ftp:\\okmaps.onenet.net
-Login as "anonymous" and the Password is your Email address
-Go to the DOQ folder
-Scroll down until you see the folder "36094" double-click on it
-Scroll down until you see the files that you want.
-Select the files individually by holding down the "Ctrl" key and clicking
-Make sure the transfer type is set to "Binary"
-Copy the files to your workspace

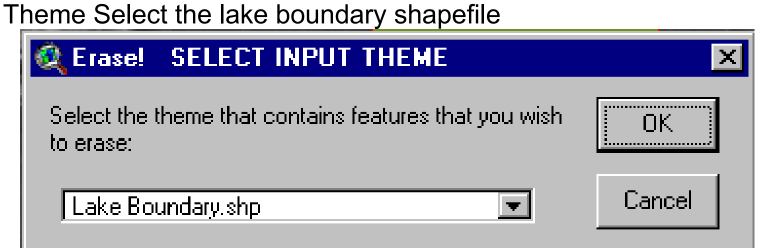
i) Using ARCINFO, Reproject the DOQQs
-Start ARCINFO
-Navigate to the workspace that contains the DOQQs
-Run the "Doq_con.aml"
ARC: &r doq_con.aml
The output projection will be: State Plane
From the dialog box, double click on the image you want to process
For the State Plane Zone enter: 1, for North
-After you have processed all three images, go back to your ArcView project
-Open the View
-Click the "Add Theme" button 
-Set the "Data Source Type" to Image Data Source
-Select the files and click "OK"



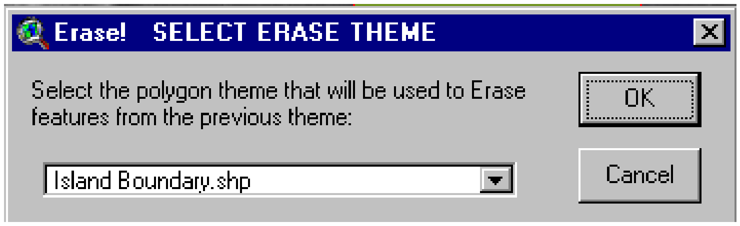
j) Digitize the Lake Boundary
-Set the View scale at 1:3000
-Click the graphic polygon tool and start digitizing the lake boundary
-Since you can not draw and pan at the same time, you will have to create multiple polygons for the lake boundary
-When you get a section of the lake completed you can convert the graphic polygons into a Shapefile.
-Using the "Pointer" Tool Select all of the graphic polygons
-Load the "Xtools" extension into ArcView
-Click the "Xtools" menu, "Convert Graphics to Shapes"
-Click the text in the dialog box and click "OK"
-To merge multiple Shapefiles together:
-Click the "Xtools" menu, "Merge Themes"
-After you merge all of the Shapefiles together then you need to make the lake one polygon
-Make sure the merged shapefile is active and click "Themes" , "Start Editing"
-Select all of the Polygons
-Click "Edit" , "Union Features"
-Click "Theme" , "Stop Editing" and Save edits
-The output .shp file will be called <**eucha_boundary.shp**>
-Add a new field to the <**eucha_boundary.shp**> table
Name: Spot
Type: Number
Width: 10
Decimal Places: 0

k) Digitize the Island Boundaries
-You will then need to digitize all of the islands in the lake.
-Use the same procedure as the lake boundary
-The output .shp file will be called <**eucha_islands.shp**>

l) Clip the <**eucha_islands.shp**> from the <**eucha_boundary.shp**>
-Click "Xtools" , "Erase Features"
-For the Input Theme Select the lake boundary shapefile



-For the Erase Theme Select the island boundary shapefile



-The output file will be called <**eucha_lake.shp**>

4) Convert the Shapefile Boundary to an ARCINFO Coverage

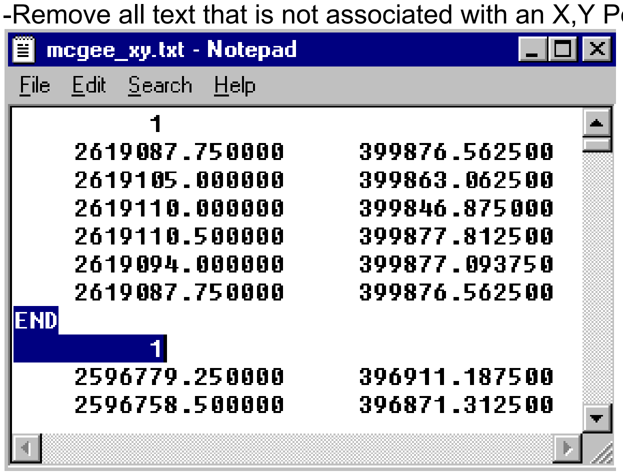
c) Convert the Shapefile
- -Start ARCINFO
- -Make sure the directory you are working in is an ARCINFO WORKSPACE
- -If not, use the CW command to make the directory a WORKSPACE
- -Navigate to the WORKSPACE
- -Set the AMLPATH   arc: &AMLPATH g:\aml\conversions
- -Run the shape2cover.aml
  - arc: &r shape2cover <**eucha_lake.shp**> <**eucha_lk**>
- -Build the new coverage
  - arc: Build < **eucha_lk** > Poly

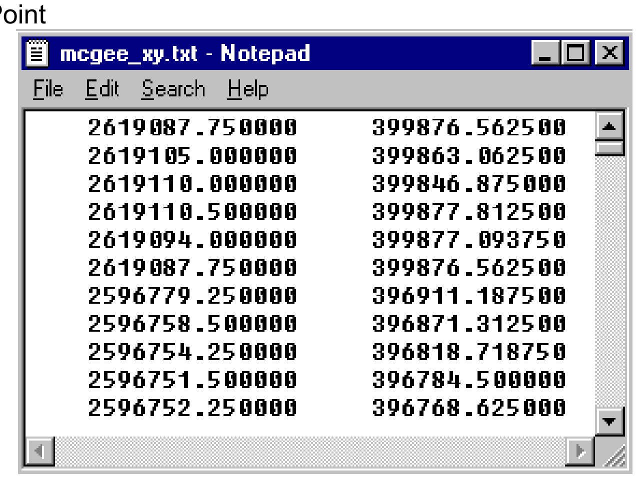
d) Create a dense point coverage
- -Use the DENSIFYARC command in ARCINFO
- arc: DENSIFYARC < **eucha_lk** > <**eucha_lk_den**> <25> <vertex>
- -Use an interval value of (25)
- -Build the new coverage
  - arc: Build < **eucha_lk_den**> Poly

c) Create a .DXF File
- -Use the ARCDXF command
  - arc: arcdxf <**eucha_lk.dxf**> < **eucha_lk_den** > # # # #

g) Create an XY Text File
- -Use the UNGENERATE command in ARCINFO
- arc: UNGENERATE LINE < **eucha_lk_den** > <**eucha_lk_den.txt**> # <fixed>

h) Edit the XY Text File
- -Open the <**eucha_lk_den.txt**> file in NOTEPAD
- -Remove all text that is not associated with an X,Y Point





- -Use the “Edit” , “Find” tool to search for the word “End”
- -Make sure there are no spaces between lines and there are no “Returns” after the last line
- -Save the file

i) Convert the Text File to a Comma Delimitated Text File
- -Open the <**eucha_lk_den.txt**> file in MS Excel
- -Add a new Row to the top of the file
- -Add an “Xcoor” and “Ycoor” at the top of the Columns

*Note: You may need to add a “Z” value to the file
Add a “Z” in the third Column and enter the normal pool lake elevation for
All of the X , Y locations
-Save the file as a comma delimitated text file .csv
-Name the file <**eucha_lk_xy.csv**>
-Open <**eucha_lk_xy.csv**> in NOTEPAD
-Save this file as <**eucha_lk_xy.txt**>

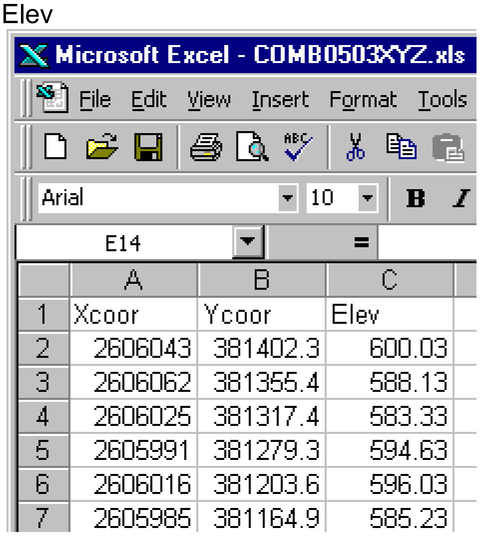
The <**eucha_lk.dxf**> and <**eucha_lk_xy.txt**> files are now ready for the preliminary bathymetric setup.

***Notes:**

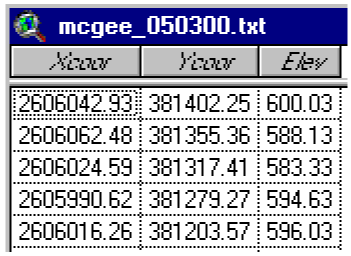
USGS QUADS	**Reference #**	**Photo Date**	**Lake Level**	**Normal**
Lake Eucha East	36094-C7 1 NE	2/25/95	778.1’	778.0’
Lake Eucha East	36094-C7 2 NW	2/25/95	778.1’	778.0’
Lake Eucha West	**36094-C8 2 NW**	**2/25/95**	**778.1’**	**778.0’**

2) Processing Corrected X,Y,Z Bathymetric Text Files

11) After the survey crew has corrected the X,Y,Z data, It should be in an MS Excel spreadsheet format (.xls).
-The file will be in a State Plane projection, North, NAD83 datum, and feet as the units.
12) Open the <**eucha.xls**> file in Excel
-Make sure you are at the top of the spreadsheet
-Make sure there are three columns
-Go to the top row and insert a new blank row
-Add the following field headings
Xcoor Ycoor Elev



13) After you add the field names, save the Excel file as a comma delimitated text file <**eucha_xyz.csv**> and close Excel.
14) Using Notepad, open the new <**eucha_xyz.csv**> file and save it as <**eucha_xyz.txt**>
15) Start ArcView
16) From the Project Window, click on the Tables Icon
-Click the “Add” button and add the <**eucha_xyz.txt**> file table



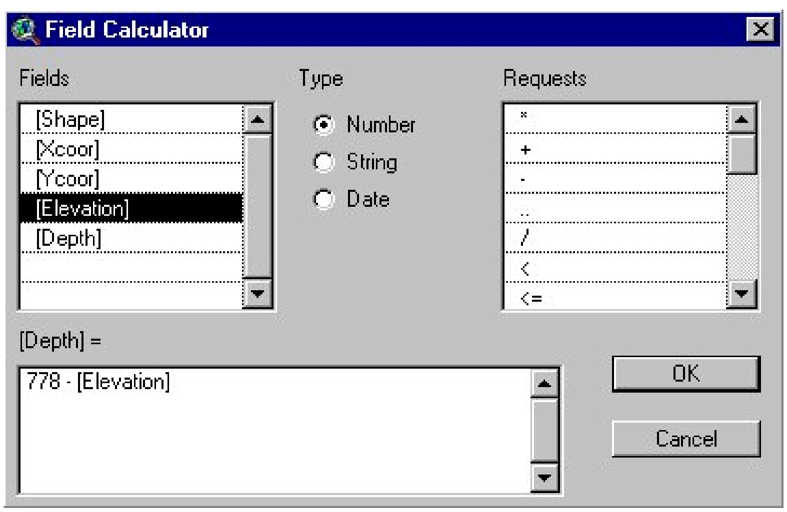
Xcoor	Ycoor	Elev
2606042.93	381402.25	600.03
2606062.48	381355.36	588.13
2606024.59	381317.41	583.33
2605990.62	381279.27	594.63
2606016.26	381203.57	596.03

-Make sure the table looks ok, and your field names are in the field heading

17) Go back to the project window and open a View
-From the "View" menu, select "Add Event Theme"
-Make sure the table field is set to your <**eucha_xyz.txt**> table
-The Xfield has the "Xcoor" field
-The Yfiled has the "Ycoor" field
-Click "OK"
-A new theme will be added to the View showing the collected data points
-Convert this theme to a new Shapefile
-Name the shapefile <**eucha_collected.shp**>

18) Open the table for <**eucha_collected.shp**>
-From the "Table" menu, select "Start Editing"
-From the "Edit" menu, select "Add Field"
-Add the following: Name: Depth
Type: Number
Width: 10
Decimal Places: 2
-Click "OK"

19) Populate the Depth Field
-Make sure the "Depth" field is active
-Click the "Calculate" Button 
-In the Field Calculator Dialog
The [Depth] = field should contain the normal pool elevation – the [Elev] field



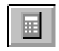
-Click "OK"

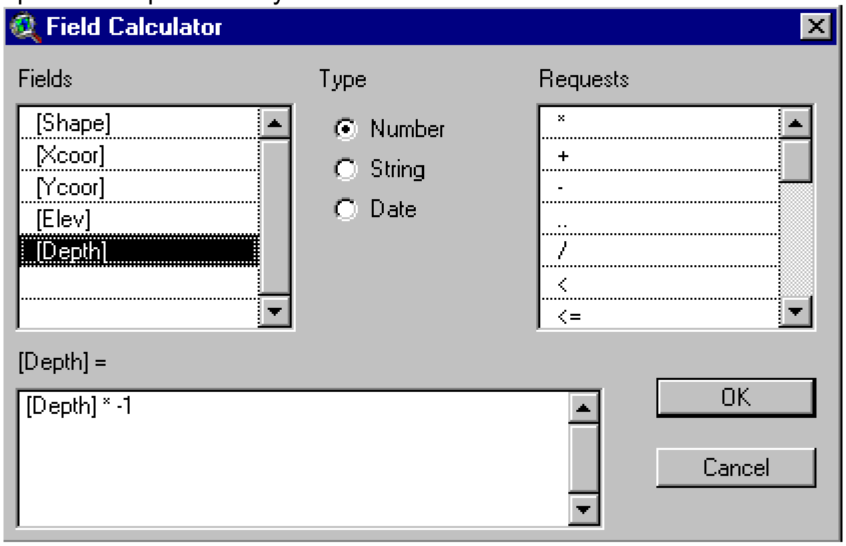
-The "Depth" Field in your table should now contain the lake depths for each point.
-From the "Table" menu, select "Stop Editing" and save edits.

*Do a query on the Depth field of <eucha_collected.shp> to make sure there are no zero values. If there are zeros, go to the View window, make the theme active and start editing the theme. Remove any data points that have a zero value, and stop editing and save the edits.

20) Create a Point Coverage of the Lake Boundary
-Get the original X,Y text file created for the pre-survey data
-The file is <**eucha_lk_xy.txt**>
-Import the table into ArcView, and open it.
-Make sure the table is active.
-From the “File” menu, select “Export”, then “DBASE”, and “OK”
-Name the file <**eucha_lk_xyz.dbf**>
-You will then have to add the new <**eucha_lk_xyz.dbf**> file into ArcView
-From the “Table” menu, select “Start Editing”
-From the “Edit” menu, select “Add Field”
-The First Field will be normal pool lake level elevation: 778 ft
Name: Elev
Type: Number
Width: 10
Decimal Places: 2
-The Second Field will be the lake depth
Name: Depth
Type: Number
Width: 10
Decimal Places: 2
- Highlight the “Elev” field and click the “Calculate” button 
- In the “[Elev] =” field type in the normal pool lake elevation level
ex: 778.0 for Eucha Lake
-Highlight the “Depth” Field and click the “Calculate” button
-In the “[Depth] = “ field type: 0
Since the lake boundary has no depth
-From the “Table” menu, select “Stop Editing” and Save edits.
-Open the View window
-From the “View” menu, select “Add Event Theme”
-For the Table: <**eucha_lk_xyz.dbf**>
-For the X field: Xcoor
-For the Y field: Ycoor
-Click “OK”
-Make the new theme active, and convert it to a new shapefile
-Name the shapefile <**eucha_lk_points.shp**>

11) Merge the Collected Survey Points shapefile with the Lake Boundary Point Shapefile.
-Make sure the ArcView “Xtools” extension is loaded in your AV project
-Make sure both the <**eucha_collected.shp**> file and the <**eucha_lk_points.shp**> file are in the same View and have no selected records
-From the “Xtools” menu, select “Merge Themes”
-The Input Theme will be: <**eucha_collected.shp**>
-The Theme to Merge With will be: <**eucha_lk_points.shp**>
-Name the new theme: <**eucha_col_lk_points.shp**>
-Open the table for < **eucha_col_lk_points.shp** >
-From the “Table” menu, select “Start Editing”
-Highlight the “sourcethm” field
-From the “Edit” menu, select “Delete Field”
-Click “Yes” to delete the “sourcethm” field
-Convert the depth values to negatives
-Highlight the “Depth” field

-Click the “Calculate” button 
-Multiple the “Depth” field by –1



-From the “Table” menu, select “Stop Editing” and Save Edits

12) Merge the < **eucha_col_lk_points.shp** > file with the Additional Points
-Make sure both the < **eucha_col_lk_points.shp** > file and the <**eucha_add_points.shp**> file are in the same View and have no selected records
-From the “Xtools” menu, select “Merge Themes”
-The Input Theme will be: < **eucha_col_lk_points.shp** >
-The Theme to Merge With will be: <**eucha_add_points.shp**>
-Name the new theme: <**eucha_all_points.shp**>

13) Convert the Shapefile of All Points to an ARCINFO Coverage.
-Start ARCINFO and move to the Workspace containing <**eucha_all_points.shp** >
-Set the AML path
arc: &AMLPATH g:\aml\conversions
-Run the shape2cover.aml
arc: &r shape2cover.aml < **eucha_all_points.shp** > <**eucha_points**>

14) Create an ARCINFO Coverage of the Lake Boundary without Islands
e) Convert the original <**eucha_boundary.shp**> file to an ARCINFO coverage
-Start ARCINFO and move to the Workspace containing <**eucha_boundary.shp**>
-Using ARCINFO ArcToolbox, Select: “Conversion Tools / Import to Coverage / Shapefile to Coverage”
-The input shapefile will be <**eucha_boundary.shp**>
-The output AI Coverage will be <**eucha1**>
f) Densify the <**eucha1**>Coverage
-Use the DENSIFYARC command in ARCINFO
arc: DENSIFYARC <**eucha1**> <**eucha_den**> <25> <vertex>
-Use an interval value of (25)
-Build the new coverage
arc: Build < **eucha_den** > Poly
g) Convert <**eucha_den**> to a shapefile <**eucha_outline.shp**>
h) Convert <**eucha_outline.shp**> to an ARCINFO coverage
-Start ARCINFO and move to the Workspace containing <**eucha_outline.shp**>
-Set the AML path
arc: &AMLPATH g:\aml\conversions
-Run the shape2cover.aml

arc: &r shape2cover.aml <**eucha_outline.shp**> <**eucha_bnd**>
-Build <**eucha_bnd**> Poly

3) Creating a TIN From Bathymetric Mapping Points

5) Create an ARCINFO TIN Surface Model
-Start ARCINFO Arc Toolbox
-From the “Conversion Tools / Import to Tin” menu, select “Create Tin Wizard”
-In the “Create Tin Wizard” dialog, click “Next”

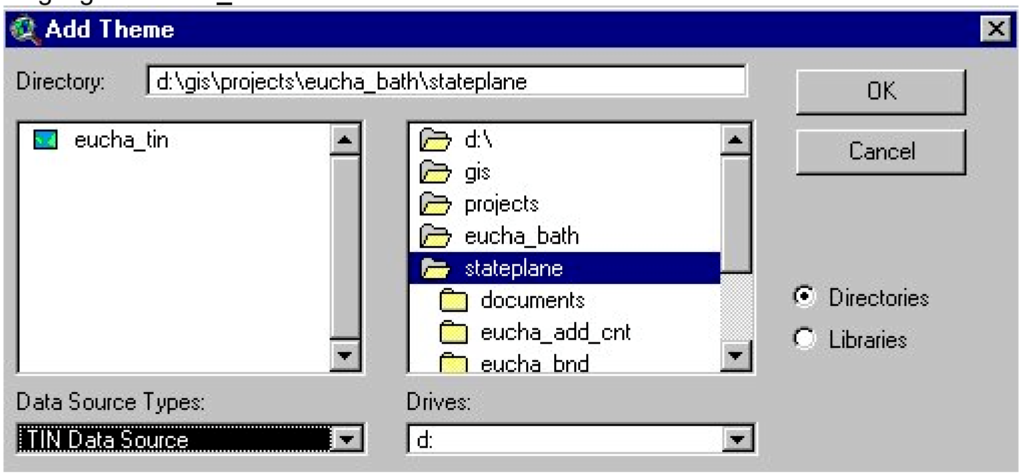
2) Add the Data Points Coverage to the TIN Wizard
-Click the “Add Coverage” button
-Click the “Folder” icon to select the 1st input coverage
-The 1st input coverage will be: <**eucha_points**>
-The Feature Class should be: “Point”
-The Weed Tolerance will be: “Default Value”
-Click “Next”
-Click the “Choose a Z-value item” radio button
-Click the “Depth” field
-Click “Next”
-Click “Next”

6) Add the Artificial Contour Lines Coverage to the TIN Wizard
-Click the “Add Coverage” button
-For the “Input Coverage”, select <**eucha_add_cnt**>
-The Feature Class should be: “Line”
-The Weed Tolerance should be: “Default Value”
-Click “Next”
-Click the “Choose a Z-value item” radio button
-Click the “Depth” field
-Click “Next”
-Click the “Choose a surface type keyword” radio button
-Click “Mass”
-Click “Next”
-Click “Next”

7) Add the Lake Boundary Polygon Coverage to the TIN Wizard
-Click the “Add Coverage” button
-For the “Input Coverage”, select <**eucha_bnd**>
-The Feature Class should be: “Poly”
-The Weed Tolerance should be: “Default Value”
-Click “Next”
-Click the “Choose a Z-value item” radio button
-Click the “Spot” field
-Click “Next”
-Click the “Choose a surface type keyword” radio button
-Click “HardClip”
-Click “Next”
-Click “Next”

4) Select the Output TIN Information
-Click “Next” to move to the Output Dialog
-For the “Output tin”, type <**eucha_tin**>
-The “Proximal Tolerance:” should be: “<Optional>
-The “Z-factor:” should be: 1
-Click “Next”
-Click “Finish”

5) Add the New Tin into your ArcView Project
-In ArcView, Click the “Add Theme” button
-Change the “Data Source Types” option to “TIN Data Source”
-Highlight <**eucha_tin**> and click “OK”

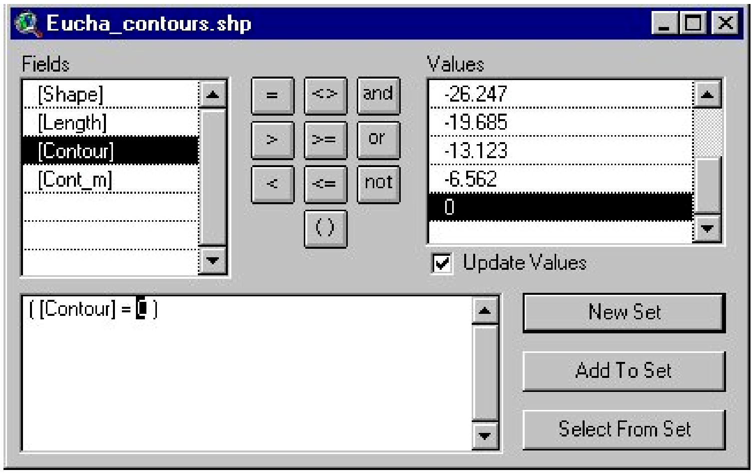


4) Creating the Contour Depth Areas Coverage

14) Create an ARCINFO Contour Depth Coverage
-Start ARCINFO Arc Toolbox
-From the “Analysis Tools / Surface” menu, select “Contour Wizard”
-To select the “Input Surface”, click the folder icon
-Select the <**eucha_tin**> file and click “Open”
-Click “Next”
-Change the Contour Interval to “6.5616666” to represent 2 meter depths
-Click “Next”
-The “Base Contour:” should be 0
-Click “Next”
-The “Output Item:” Should be: “Contour”
-Click “Next”
-Set the “Subdivision Degree” to 7
-Click “Next”
-Set the “Weed Tolerance” to 5
-Click “Next”
-The “Z-factor” should be: 1
-The “Output Coverage” should be <**eucha_cont**>
-Click “Next’
-Click “Finish”

15) Create a Lake Boundary Line File
-In ArcView, add the <**eucha_lk_den**> line coverage
-Convert the <**eucha_lk_den**> ARCINFO coverage to a .shp file
-Name the .shp file, <**eucha_line.shp**>

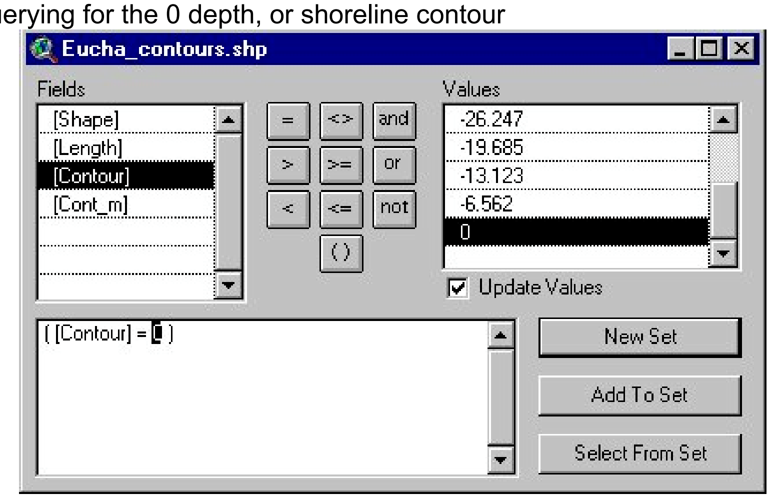
16) Convert <**eucha_cont**> to an ArcView .shp file
-In ArcView, add the < **eucha_cont** > line coverage
-Convert the < **eucha_cont** > ARCINFO coverage to a .shp file
-Name the .shp file, <**eucha_pre_cont.shp**>
-Make the <**eucha_pre_cont.shp**> theme active in the View
-Click the “Query Builder Tool”



-Perform a query to find all contour lines with a depth value of 0
-Click “New Set” to perform the query
-Make the View window active
-From the “Theme” menu, select “Start Editing”
-All of the 0 depth contour lines should be selected
-From the “Edit” menu, select “Delete Features”
-From the “Theme” menu, select “Stop Editing” and Save Edits

17) Merge the Lake boundary line with the Depth Contours
-In ArcView, make sure both the < **eucha_pre_cont.shp** > and <**eucha_line.shp**> are in the View Window.
-Using the Xtools extension, Select Xtools / Merge Themes
-The “Input theme” will be < **eucha_pre_cont.shp** >
-The “Merge With” theme will be <**eucha_line.shp**>
-The “Output Theme” should be <**eucha_contours.shp**>

18) Create individual .shp Files for Each 2 Meter Depth Range
-Make sure < **eucha_contours.shp** > is the active theme in your ArcView View Window
-Click the “Query Builder Tool”
-Set up a query to select each depth range (0-26) meters and save them as new .shp file.
-Start by querying for the 0 depth, or shoreline contour



-After the line is selected, make the View Window Active
-From the “Theme” menu, select “Convert to Shapefile”
-This will save only the selected 0 depth lines to a new .shp file
-Name the new .shp file <**cont_0_2m.shp**>
-Repeat this process through <**cont_24_26m.shp**>

19) Convert Each of the Contour .shp Files to ARCINFO Coverages
-Start ARCINFO Arc Toolbox
-From the “Conversion Tools / Import to Coverage” menu select “Shapefile to Coverage”
-For the “Input Shapefile”, click the “open folder” icon
-Select all of the .shp files <**cont_0_2m.shp**> … <**cont_24_26m.shp**>
-Click “Open”
-In the Batch Job box at the bottom of the dialog, enter the output coverage names. <**c0_2m**> … <**c24_26m**>
-Click “OK”

20) Clean and Build the New Coverages
-From Arc Toolbox, Select “Data Management Tools / Topology / Clean
-For the “Input Coverage”, click the “open folder” icon
-Select all of the coverages <**c0_2m**> … <**c24_26m**>
-Click “Open”
-The “Dangle Length” should be “0”
-Change the “Fuzzy Tolerance” to: “6”
*Note: If after this process one of the new coverages is not a good polygon coverage, increase the Fuzzy Tolerance
-Change the “Feature Class” to: “Poly”
-Change the “Output Coverage” names to: <**c0_2mcl**> … <**c24_26mcl**>
-Click “OK”
-From Arc Toolbox, Select “Data Management Tools / Topology / Build
-For the “Input Coverage”, click the “open folder” icon
-Select all of the Coverages <**c0_2mcl**> … <**c24_26mcl**>
-Click “Open”
-Change the “Feature Class” to “Poly” for each coverage
-Click “OK”

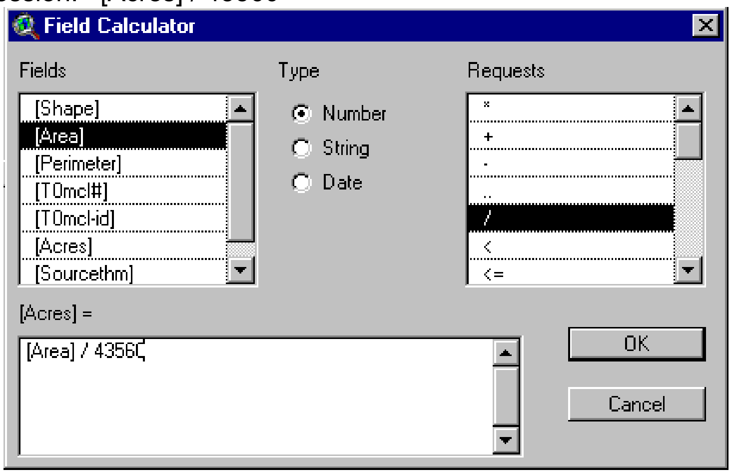
21) Convert the New Coverages to .shp Files
-Open the new coverages <**c0_2mcl**> … <**c24_26mcl**> in ArcView
-Make all of the coverages active
-From the “Theme” menu, click “Convert to Shapefile”
-Name each of the new coverages <**c0_2.shp**> … <**c24_26.shp**>

22) Remove the Internal Polygons From Each of the New .shp Files
-Make the <**c0_2.shp**> file active
-From the “Theme” menu, select “Start Editing”
-Open the Table for <**c0_2.shp**>
-From the Table, go through a process of selecting each one of the polygon features and then going back to the view window and zooming to the extent of the polygon feature to see if the feature is an internal polygon. If the feature is an internal polygon delete it.
-Once you have removed all of the internal polygons from <**c0_2.shp**>, From the “Theme” menu, select “Stop Editing” and Save the Edits.
-Repeat this process for the rest of the <**c2_4.shp**> … <**c_24_26.shp**>

23) Erase the Overlapping Areas of Adjacent Depths
-Using the “Xtools / Erase Features” tool, select <**c0_2.shp**> as the first input theme. The second input theme will be <**c2_4.shp**>. The output .shp file should be named <**e_2_4.shp**>
-The next step would be to Erase the overlap between <**c2_4.shp**> and <**c4_6.shp**>. The output file name would be <**e_4_6.shp**>
-Repeat this process for the rest of <**c6_8.shp**> … <**c24_26.shp**>
-There will not be any overlap for the <**c24_26.shp**> so just make this theme active and use the “Convert to Shapefile” function and name the output <**e_24_26.shp**>

24) Merge the “Erased” .shp Files Together

-Using the “Xtools / Merge Themes” tool, select <**e_0_2.shp**> as the first input theme and for the second input select all the rest of the <**e_2_4.shp**> … <**e_24_26.shp**>. Name the Output .shp file <**eucha_depth_ranges.shp**>
-Open the Table for < **eucha_depth_ranges.shp** >
-Start Editing the Table
-Highlight the “Acres” Field Tab
-Click the “Field Calculate” button
-Enter the Expression: [Acres] / 43560



-This will update the correct acreage values.
-Add a new Field called “Depths_m”
Name: “Depths_m”
Type: “String”
Width: “16”
-Open the “Query Builder” tool
-Perform a query to find all of the depths between 0 and 2 meters
([Sourcethm] = "e_0_2.dbf") , click “New Set”
-Click the “Field Calculate” button
-Enter the expression: "0 - 2"
-Repeat the process for the rest of the depth ranges
-Delete the “Sourcethm” Field
-Stop Editing the Table and Save the Edits

25) Add an Identification Field to the Table
-Open the < **eucha_depth_ranges.shp** > Table
-Start Editing the Table
-Add a new field
Name: Legend_Id
Type: Number
Width: 10
Decimal Places:0
-Populate the records by using the Query Builder and the Field Calculator
-The depth range of “0 – 2” should have a value of 1
-The depth range of “2 – 4” should have a value of 2
-Repeat this process through “24 – 26” with a value of 7
-Stop Editing and Save the Edits

26) Determine the Area of Each Depth Range
-Open the < **eucha_depth_ranges.shp** > Table
-Click on the “Depths_m” field Tab to make it Active
-From the “Field” menu, select “Summarize”

-From the “Summary Table Definition” dialog, select the “Field” drop-down menu, and select the “Acres” field.
-From the “Summarize by” menu, select “Sum”
-Click the “ADD” button
-Click “OK”
-A new Table will be created that shows the number of polygons (Count) and the total acres of all the polygons (Acres) for each depth range

Methods to Determine Volumes and Areas

4) Cut Fill Method (GRID)

-Start ARCINFO
-Use a DESCRIBE on the input GRID
arc: DESCRIBE <**eucha_grid**>
-Note the Minimum and Maximum values
ex: Minimum Value = -84.192
Maximum Value = 4.482
-Start ARCINFO GRID
arc: GRID
-Use the SETNULL option to set the maximum value of <**eucha_grid**> to 0.
The output GRID will be <**cut_grid**>
arc: <**cut_grid**> = SETNULL(<**eucha_grid**> > 0, <**eucha_grid**>)
-Start Notepad program
-Type the following on the first line:
-85 0 : 0
-Save the file as a .text file to your current workspace as “rec.rmp”
-View the rec.rmp file with your NT Explorer to make sure the file does not have an additional .txt extension (rec.rmp.txt) if it does, remove the .txt
*This will create a reclass table. All values between –84.192 and 0 will be set to 0 when the reclass is run.
-Go back to ARCINFO GRID
-Perform a RECLASS on the <**cut_grid**>
grid: <**fill_grid**> = RECLASS(<**cut_grid**>, rec.rmp, data, #, #)
-Quit GRID
grid: q
-Use the CUTFILL command in ARCINFO
arc: CUTFILL <**fill_grid**> <**cut_grid**> <**cf_grid**> <**cf_cov**> -1
<**cf_grid**> is an output grid with values of change +/-
<**cf_cov**> is and output coverage with areas of change +/-
*Note: If your XY-Units and Z-Units are the same use the –1 z-factor
If your XY-Units are in meters and your Z-Units are in feet,
use a z-factor of –0.305
-To get the Volume and Area statistics from the CUTFILL
arc: list <**cf_cov**>.cf
-To convert cubic meters to acre-feet, multiply the sum by **.000810698**
-To convert cubic feet to acre-feet, multiply the sum by **.00002296**
-To convert square meters to acres, multiply the sum by **.000247104**

5) Volume Command (TIN)

-Start ARCINFO
-Use the VOLUME command to determine the volume and area of a TIN
arc: VOLUME <**input_tin**> <**base_value**> <**out_info_file**> <z-factor>
arc: VOLUME <**eucha_tin**> 0 tin_info –1
*For volumes of lake use a z-factor of –1
*For other surface volumes use a z-factor of 1
*Note: If your XY-Units and Z-Units are the same use the –1 z-factor
If your XY-Units are in meters and your Z-Units are in feet,

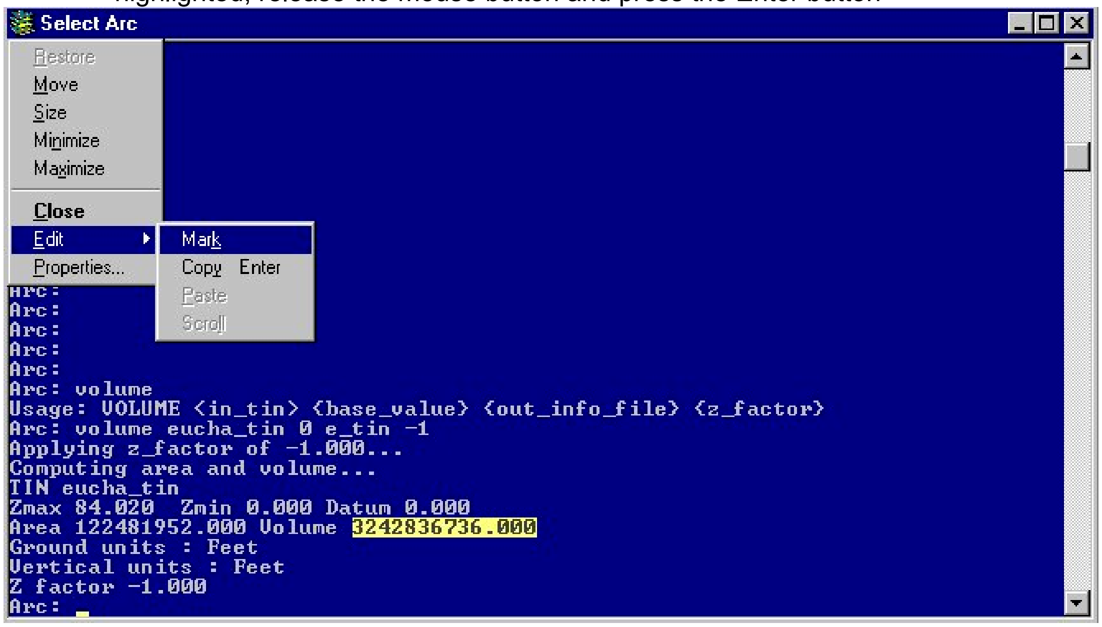
use a z-factor of –0.305

-An easy way to get your data results into the Calculator Program

-Left-Click on the upper left-hand corner of the ARC Window

-Click on Edit / Mark

-Left-Click in front of the value that you want to copy and hold-down the the left mouse button and move over the entire value. When the value is highlighted, release the mouse button and press the Enter button



-You can now paste the value in your Calculator Program.

GPS Procedures

Bathymetric Mapping is the process utilized to determine the storage capacity of reservoirs. The process uses a differential global satellite positioning system (DGPS)5, an acoustic depth sounder (Echosounder)6, and Coastal Oceanographic software7. The implementation of this technology in bathymetric mapping has allowed the surveying process to become more efficient and accurate. This mapping process was utilized to survey Spavinaw and Eucha reservoirs between the months of August 1999 and January 2000.

The process of conducting a bathymetric survey consists of three successive procedures. These procedures include setup, field surveying, and post-processing of collected data. In the first procedure setup, Hypack software from Coastal Oceanographic is used to create virtual track lines that are laid across a digital rendering of the reservoir that has GPS coordinates. These virtual track lines are spaced between 300 or 400 feet apart. The determination of the spacing is related to the accuracy that is required for the surveying project. The closer the virtual lines are together the more data that will be collected in the surveying process. The data directories for which the collected data will be stored are also created in the setup procedure. The next step in the surveying process is the field surveying.
Field Surveying consists of the actual data collection. Once the destination reservoir has been reached the equipment is setup on the boat (Carolina Skiff) and networked together. The equipment is then tested to ensure that the individual components are working properly together. The echosounder is calibrated to the salinity concentration of the reservoir to provide accurate depth readings. Once on the lake, each virtual line is followed across the reservoir until the entire navigable surface area of the reservoir has been covered. A DGPS (XY) point and a depth reading (Z) are collected every one to three seconds (depending on desired accuracy) while navigating on each virtual line that cuts across the reservoir. The raw data is collected in State Plane 1983 Geodetic Parameters. In this mode, the XYZ coordinates are collected in feet. The Coastal Oceanographic Hypack software is used to display the map of the reservoir, the virtual lines, and store all data points that are logged while on the reservoir. After the field surveying has been completed the mapping process continues back in the office where post-processing takes place.

The last procedure in the bathymetric mapping process is the post-processing. The raw data collected in the field is brought back to the office. Using the Hypack Software, the raw data is reviewed. The reason for reviewing the data is that when surveying in the field there is always the possibility that the equipment has processed a false reading, whether it is a DGPS reading or echosounder reading. The raw data is viewed using the Hypack Single Beam Editing program. The Editing program can allow one to see a virtual line and the data collected on that line. Each virtual line is reviewed individually. In the process of reviewing a line, each XYZ point collected on that line is examined to ensure that it is an accurate value. XYZ Coordinate points on the line that are not accurate are corrected to closely match other accurate surrounding points. The day to day fluctuations in lake levels are also adjusted in the raw data during this process. This is done by recording the lake levels on the days that the surveying takes place and then this data is used to adjust the raw Z coordinate values. Once the raw data has been corrected, the data is sorted.

---

5 Trimble, AgGPS122
Sub meter accuracy
DGPS antennae
6 Raytheon Depth Sounder Precision Surveying Fathometer
Model: DE719D MK2
Range 500' or 150m
Resolution 0.1 units
Accuracy +/- 0.5% of indicated depth (ft or m)
7 Coastal Oceanographics, Inc. Hypack for Windows
(Bathymetric surveying, dredging maintenance, construction, and general navigation software.)

The Sort program can eliminate conflicting data points based on either a Radius or DX-DY distances. With a Radius, which is preferred, the program eliminates any other data record that is within the radial distance of the accepted point. The smaller the accepted point the less edited data is rejected and a larger accepted value results in more edited data that is rejected. The Sort program then saves the edited data to an ASCII XYZ data file with the .XYZ extension. Once the edited data has been sorted, it can be rendered in a map, such as a contour map, or some other form of graphical representation to satisfy the needs of the project.

Appendix C: Hydraulic Budgeting

Introduction

A hydrologic or water balance is of considerable importance in water quality analyses and management. A general and simple hydrologic budget equation for a given water body such as a lake is given by

$dV/dt = Q_{in} - Q + PA_s - E_vA_s$ ……………………………..(1)

where V = lake volume [L^3],

A_s = lake surface area [L^2],

Q_{in} and Q [L^3/T] represent net flows into and out of the lake due to river and or groundwater flows,

P [L/T] is the precipitation directly on the lake,

E_v [L/T] is the lake evaporation.

In other words, the rate of change in storage of the volume of water in or on the given area per unit time is equal to the rate of inflow from all sources minus the rate of outflows.

The input or inflows to a lake may include surface inflow, subsurface inflow and water imported into the lake. The outputs may include surface and subsurface outputs and water exported (e.g. water supply) from the lake. The change in storage in the lake may also include subsurface storage or ‘bank’ storage of water (Thomann et al, 1987).

The inputs and outputs to the two lakes under consideration are as categorized below and the methods used to compute each parameter are also outlined.

The inputs to Lake Eucha are precipitation or rainfall, surface runoff and groundwater. The outputs are evaporation, transpiration (plants in the lake), seepage, water releases (spilled) and water supply. The water releases include gated and valve releases and flows over the dam. Lake water is supplied to the Eucha Water Treatment Plant and City of Jay Water Treatment plant.

Inflows into Lake Spavinaw include precipitation, surface runoff, groundwater, and tributary flow (including water released from Lake Eucha). Since the two lakes are fairly close to one another, water released from Eucha flows directly into the Spavinaw Lake by way of the Spavinaw Creek. The outputs from Spavinaw Lake includes evaporation, transpiration, seepage, flow over the dam and water supply, which includes water exported to the City of Tulsa (Lake Yahola) and the Spavinaw Water Treatment Plant.

Precipitation (directly on the lake surface)

Precipitation was estimated from the direct rainfall measurements/data provided by the City of Tulsa. The precipitation contribution to the total inflows was obtained by multiplying the monthly rainfall amounts by the surface area of the lakes, as shown in equation 2.

$$Q_P = P * A_s \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2),$$

where P [L/T] is rainfall amount and A_s [L^2] is the surface area of the lake.

Groundwater

Groundwater discharge in the basin is considered a part of the total runoff to the lakes. A groundwater investigation undertaken by the Planning and Management division of the Oklahoma Water Resources Board in February 1999 had, as one of its objectives, to characterize the groundwater component of the lakes by determining the rate of groundwater discharge to the lakes **(Noel et al, 2000).**

The groundwater discharge to the lakes and streams for the entire drainage area of 415 mi^2 was 218.12cfs or 433acre-ft per day. Therefore the total groundwater discharge per unit area is 0.5256cfs/mi^2. According to the study the, the groundwater drainage area approximately coincides with the total watershed area. As a result the individual groundwater drainage areas for each lake estimated on a percentage basis is as shown in table 1

Table C-1
Groundwater and Surface Water Drainage Areas

	SPAVINAW	EUCHA
Watershed/Drainage Area (acres)	251108	203902
Percent of total drainage area	100	81.2
Groundwater Drainage Area, (mi2)	415	337
Groundwater Drainage Area, (acres)	265600	215669.6
Lake Surface Area (acres)	1637	2880

The ground water discharge to each lake, in cubic feet per second (cfs), is therefore obtained by multiplying the groundwater discharge per unit area by the respective groundwater drainage area the lake. The results are given below.

Table C-2
Groundwater Discharges in cfs to the Lakes

Eucha	177.12
Spavinaw	218.12
Spavinaw minus Eucha	41.01

These discharges are based on February 1999 measurements when discharge would be most representative of an annualized groundwater contribution. Since the study was done for just this month, an adjustment had to be made in order to estimate the groundwater discharges to the lake for the other months of the year.

Adjustments:

Groundwater was adjusted on a seasonal basis. The year was divided into four quarters and it was assumed that the groundwater discharge remained the same in a quarter. The seasons are winter (December to February), spring (March - May), summer (June – August) and fall (September – November). The adjustments were made using the discharge in February as a benchmark, which is assumed to be the maximum discharge for the year. Stream discharge data obtained from the USGS were used as a guide in the adjustment. The seasonal adjustments are presented in table 3.

Table C-3
Groundwater Adjustments

Season	Percent of Benchmark
Winter	100
Spring	70
Summer	50
Fall	70

Surface Runoff

Surface runoff from a rainfall event into the lakes was estimated using the rational formula:

Q_R = C* I *A ………………….(3)

where Q_R [L^3/T] is the runoff flow, I [L/T] is the rainfall rate, A [L^2] is watershed area, and C is the runoff coefficient. Runoff coefficient depends on land use, population density and degree of imperviousness. Typical runoff coefficients (**source of info**) are presented below.

Urban residential …………………… 0.3

Apartments …………………………. 0.5

Commercial and Industrial …………. 0.9

Forests ……………………………… 0.05-0.20

Parks; farms ………………………... 0.05-0.30

Asphalt and pavement ……………… 0.85-1.00

Some of the assumptions made in the rational method are outlined. The method is used for relatively small areas, under 100 acres, but occasionally it is used for up to 1200 acres. Frequency of runoff is the same as frequency of rainfall. Design rainfall is uniform over watershed and intensity is constant.

The runoff to the lakes was calculated from a modified form of equation 3;

$Q_R = k\ A$............ (4)

where k = C*I [L/T], is assumed to be constant within the particular watershed of area A. From equation 3, it implies that k can be determined from known values of discharges and areas, by dividing the discharges by the drainage area of the creek. Data collected at the three USGS stations in the watershed were used to determine k values for each creek for each month. Runoff was estimated by multiplying k by the drainage area. The three stations are sited at Beatty Creek near Jay, Spavinaw creek near Sycamore, Black Hollow near Spavinaw. The k values calculated for Beatty and Spavinaw creeks were used to estimate the runoff to Lake Eucha due the proximity of the creeks to the lake. Values for Black Hollow creek were used to estimate the direct runoff to Spavinaw Lake.

Another approach used in the estimation of runoff was by the direct application of the rational formula (equation 3). The coefficients of runoff for the lakes were assumed based on land type and use, topography, population density and degree of imperviousness. The C values used are 0.3 for Lake Eucha drainage area and 0.25 for the Spavinaw drainage basin. Rainfall data obtained from the Oklahoma Climatological Service were used to determine intensities. Inflows to the lakes estimated using the Soil and Water Assessment Tool (SWAT) model were also compared to the calculated runoff values (estimated inputs) in table 4. Soil and Water Assessment Tool is a watershed model that allows the watershed to be divided into cells or subwatersheds and it is used to predict the impact of land management practices on water, sediment and agricultural chemical yields, land use and management conditions. The inflows predicted by SWAT were obtained from OSU. Incorporated in the SWAT inflows are surface runoff, groundwater, and precipitation. The former approach yielded better results, and thus was used in the budget calculations.

Evaporation

A simple and direct approach utilizing the measurement of water losses in evaporation pans was adopted in calculating evaporation. Monthly evaporation rates were calculated by averaging the rates from three lakes in the vicinity of Lakes Eucha and Spavinaw; Hudson, Pensacola, and Tenkiller Lakes, since there were no direct pan evaporation measurements for Lakes Eucha and Spavinaw. The same rates were used for both lakes. These rates are multiplied by the surface area of the lakes to give the amount of water evaporated per unit time.

$Q_E = E_v * A_s$ ....(5)

where E_v [L/T] is the evaporation rate and As [L^2] is the surface area of the lake.

Transpiration

An estimate of emergent aquatic plant transpiration was prepared based on the aquatic plant survey. The survey was performed by the OWRB. These estimates showed that the seasonal plant coverage in the lakes was very small compared to the entire lake surface area. Water losses due to transpiration by these plants were assumed to be negligible compared to the other outputs.

Table C-4
Comparison of Total Inflows (in acre-ft per month) to Lakes Eucha and Spavinaw determined from different calculation methods.

	Eucha		Spavinaw	
Month	**Rational Inputs**	**SWAT Inputs**	**Rational Inputs**	**SWAT Inputs**
Jan-98	58998.07	**57045.72**	63006.59	**57929.14**
Feb-98	22170.81	**23540.72**	24174.62	**21386.67**
Mar-98	49153.93	**44093.41**	55379.80	**46356.36**
Apr-98	22626.35	**23219.51**	27741.58	**24198.39**
May-98	19989.61	**17401.88**	15214.63	**11390.54**
Jun-98	11648.24	**6143.91**	10913.69	**8250.11**
Jul-98	9395.44	**3833.63**	11828.41	**9325.99**
Aug-98	7757.20	**1549.83**	11082.66	**9146.96**
Sep-98	10634.70	**4715.93**	6666.55	**3539.79**
Oct-98	26070.77	**26719.41**	29613.33	**23407.56**
Nov-98	18582.42	**12654.84**	14142.25	**10246.58**
Dec-98	20665.37	**13707.13**	12970.89	**8874.71**
Jan-99	19840.11	**13858.79**	9362.08	**5385.52**
Feb-99	40157.16	**34444.91**	40449.71	**32375.11**
Mar-99	44536.01	**39676.49**	48080.76	**39806.32**
Apr-99	33858.90	**35631.12**	41517.99	**36646.08**
May-99	59885.36	**52821.21**	67384.64	**56180.36**
Jun-99	62791.01	**55134.95**	54315.75	**42701.98**
Jul-99	51844.79	**34684.90**	52932.36	**42695.25**
Aug-99	13006.79	**7418.33**	14667.00	**12130.80**
Sep-99	13880.27	**5219.74**	11164.18	**8094.46**
Oct-99	11146.13	**3585.46**	10033.59	**8394.05**
Nov-99	11702.88	**4237.98**	11077.92	**8916.81**
Dec-99	19693.17	**19829.46**	18946.20	**15073.72**
Jan-00	15159.65	**11373.89**	7451.94	**5097.85**
Feb-00	14399.54	**11111.01**	11370.84	**8598.10**
Mar-00	16986.88	**18103.87**	20788.38	**17469.63**

Seepage

There was no direct measurement of the seepage of water through the dams, but considering the fact that the dam was built with materials that do not permit water transmission, it was assumed that seepage was negligible.

Water Releases

Water released from Lake Eucha includes over-the-dam releases, gated and valve releases. For Spavinaw lake there was only over-the-dam releases. The overflows or the over the dam releases were calculated using spillway overflow data/table (elevation-flow data), furnished by the City of Tulsa (**Appendix E**). Interpolation and extrapolation were used to calculate the flow values corresponding to pool elevations greater than 778 ft (for Eucha) and 680ft (for Spavinaw). It was assumed that on the days when the pool elevations were less than the minimum values, there were no overflows.

Gated and valve release data were obtained from City of Tulsa. The following is the methodology used by City of Tulsa in calculating the gated releases.

Notes on Eucha Dam discharges 9/7/00

At the direction on Monte Hannon, Harry Chichester, Bill Rainwater, Jerry Youngblood and Rob Bagby, a state employee went below the Eucha Dam to take flow measurements in the tailwater. At the time we got there, Bruce Sawyer had the number 2 radial gate open 8" on the wheel. Bruce said that this was just a reference on the wheel and may not be the actual gate opening. We set stakes and stretched a tape across the stream approximately 100 yards downstream from the high bridge. We took readings every two feet across the stream.the stream width at this level was a little over 61 feet. When we finished at that level we called Bruce and had him cut the opening to 4" and waited for over an hour for the discharge to stabilize. We then took readings every two feet across the stream. The stream width at this level was a little over 57 feet.

We moved our stakes approximately 50 yards farther downstream because we figured the next rise would put some of our measurements in the weeds growing on the gravel bar. We then had Bruce to open the gate 12" and we waited about an hour for the discharge to stabilize. The stream width at this level was 103 feet wide so we took readings every 5 feet. At those readings that were over 1.5 feet, we multiplied the depth by 2 and took readings at this measurement off the bottom and down from the surface of the water and averaged the two flow readings for that depth when we got back to the office. For example, if the reading was 2 feet we multiplied it by two to get 4. We then took a reading that was .4 feet off the bottom and .4 feet down from the surface.

the calculated cubic feet/second for the openings were as follows: 4" = 91.97

8" = 168.85

12" = 250.35

These readings gave and r^2 of 9997. Using these readings, I calculated the regression and came up with a regression line of y = 19.8x+11.99 which gives the following:

GATE OPENING	*CALC.CFS*	*MGD*
4"	*91.19*	*59*
5"	*110.99*	*72*
6"	*130.79*	*85*
7"	*150.59*	*97*
8"	*170.39*	*110*

9”	*190.19*	*123*
10”	*209.99*	*136*
11”	*229.79*	*149*
12”	*249.59*	*161*

The water release date set shows instances when the gate openings were greater than 12’’, notably 14”, 16”, 20”, 40” and 120” (Water Release Data furnished by City of Tulsa). Extending or extrapolating the regression beyond 12’’ assuming a linear relationship could introduce some errors in the flow calculations. The total water release from Eucha was the sum of overflows, gated and valve releases. There were just over the dam releases from Spavinaw.

Water Supply

Water is withdrawn from both lakes for the purposes of drinking water supply. The city of Jay Water treatment plant and the Eucha Water treatment plant get their water supply from Lake Eucha. Spavinaw Lake supplies water to the City of Tulsa and Spavinaw Water Treatment Plant. The amount of water withdrawn for treatment is estimated on a monthly basis (given by City of Tulsa). The monthly intakes are presented in table 5.

Change in Lake Volume

Change in volume or storage was calculated from the lake stages at the beginning and end of the month. The lake volumes corresponding to the stages were computed and the difference between them is the change in volume for that month. The volumes were estimated from elevation-capacity curves generated from current bathymetric maps of the lakes (**Appendix A**). These values were used to evaluate the accuracy of the constructed hydraulic budget and were assumed to be accurate.

Table C-5
Monthly Water Supply

	SPAVINAW TO		EUCHA TO	
	TULSA WTP	SPAVINAW WTP	JAY WTP	EUCHA WTP
MONTH	Gallons (10^6)	Gallons (10^6)	Gallons (10^6)	Gallons (10^6)
Jan-98	620	1.1423	32.0540	0.0400
Feb-98	1680	1.2520	28.0680	0.0366
Mar-98	1860	1.5591	30.8370	0.1200
Apr-98	1800	1.3812	30.9070	0.0653
May-98	1938	1.4834	31.2000	0.1879
Jun-98	2034	1.8192	33.6640	0.0737
Jul-98	2198	1.6628	36.6950	0.2280
Aug-98	2410	1.7090	32.3210	0.1564
Sep-98	1919	1.4390	33.3150	0.1241
Oct-98	1930	1.2907	31.7460	0.0428

	SPAVINAW TO		EUCHA TO	
	TULSA WTP	SPAVINAW WTP	JAY WTP	EUCHA WTP
MONTH	Gallons (10^6)	Gallons (10^6)	Gallons (10^6)	Gallons (10^6)
Nov-98	1800	1.1935	25.4810	0.0142
Dec-98	1860	1.3320	34.2090	0.0270
Jan-99	1860	1.0887	25.7110	0.0200
Feb-99	1680	0.9695	27.2810	0.0161
Mar-99	1680	1.1446	28.1540	0.0216
Apr-99	1600	1.2686	27.2840	0.0309
May-99	1860	1.3891	29.0510	0.1881
Jun-99	1800	1.5311	28.8160	0.0700
Jul-99	1932	1.8569	35.3720	0.0776
Aug-99	2543	1.8822	32.3010	0.1478
Sep-99	2069	1.3369	30.3670	0.0805
Oct-99	1860	1.3431	27.4520	0.0628
Nov-99	1800	1.3197	28.0850	0.0336
Dec-99	1860	1.2244	26.8930	0.0191
Jan-00	1860	0.0647	26.3400	0.0137
Feb-00	1740	1.1876	28.4860	0.0323
Mar-00	1860	1.3171	31.5329	0.0079

Results

A summary of the water budget calculations on a monthly basis for the Eucha and Spavinaw Lakes, using inflows generated by the SWAT model, is presented in tables 6 and 7 respectively, and that estimated by the use of the rational formula is presented in tables 8 and 9 respectively. The input is the sum of all the flows into the lake. The output is the sum of all the outflows from the lake. A comparison between the inputs and the outputs for Eucha and Spavinaw Lakes is presented in figures 2 and 3 (using SWAT) and figures 4 and 5 (using rational approach) respectively. From equation 1, the difference between the inputs and the outputs must be the same as the change in volume of the lake. This difference is entered in the I-O columns of tables 7 through 9. The total error is the difference between the change in Lake Volume and Input minus Output. Eliminating or minimizing the errors identified in the next section can reduce the total errors, and thus a well-balanced budget may be obtained.

The SWAT model inflow estimates decreased the annual error compared to the rational formula approach. The budget constructed from the rational approach was used to partition the total inflows into the various sources.

Examination of the estimated budget for both reservoirs shows a consistent overestimation of monthly inflow and/or consistent underestimation of monthly flow.

The hydraulic detention time is the ratio of lake capacity at normal pool elevation to the exiting flow (usually on an annual basis). This represents the time it would take a given molecule of water to flow through the reservoir.

Table C-6
Constructed Budget for Eucha Lake using SWAT Inflows

	INPUTS (Acre-ft)		OUTPUTS (Acre-ft)						
Month	Swat	**TOTAL**	Evaporation	Water Releases	Water Supply	**TOTAL**	I-O	ΔV	Total error
Jan-98	57045.72	**57045.72**	311.22	54482.20	98.48	**54891.90**	2153.82	30.0	2124
Feb-98	23540.72	**23540.72**	480.87	19036.05	86.24	**19603.15**	3937.57	-1040.4	4978
Mar-98	44093.41	**44093.41**	946.53	43447.01	94.99	**44488.53**	-395.11	1610.4	-2006
Apr-98	23219.51	**23219.51**	1535.04	22333.96	95.04	**23964.04**	-744.53	-1155.7	411
May-98	17401.88	**17401.88**	1646.19	10281.59	96.31	**12024.10**	5377.79	528.9	4849
Jun-98	6143.91	**6143.91**	2170.35	8196.62	103.52	**10470.49**	-4326.58	-2044.5	-2282
Jul-98	3833.63	**3833.63**	2265.12	9260.43	113.29	**11638.85**	-7805.21	-4546.8	-3258
Aug-98	1549.83	**1549.83**	1956.24	9100.87	99.65	**11156.77**	-9606.94	-6820.2	-2787
Sep-98	4715.93	**4715.93**	1646.19	3381.38	102.60	**5130.17**	-414.24	-2323.9	1910
Oct-98	26719.41	**26719.41**	976.95	22703.09	97.54	**23777.58**	2941.82	16213.9	-13272
Nov-98	12654.84	**12654.84**	561.60	9612.99	78.23	**10252.82**	2402.02	120.0	2282
Dec-98	13707.13	**13707.13**	469.17	8116.84	105.05	**8691.06**	5016.07	0.0	5016
Jan-99	13858.79	**13858.79**	463.32	4624.69	78.95	**5166.97**	8691.83	0.0	8692
Feb-99	34444.91	**34444.91**	809.64	31051.29	83.76	**31944.69**	2500.22	0.0	2500
Mar-99	39676.49	**39676.49**	1095.12	37268.79	86.45	**38450.36**	1226.13	300.0	926
Apr-99	35631.12	**35631.12**	1296.36	33003.40	83.81	**34383.58**	1247.54	600.0	648
May-99	52821.21	**52821.21**	1581.84	52930.51	89.72	**54602.07**	-1780.86	150.0	-1931
Jun-99	55134.95	**55134.95**	1455.48	38596.79	88.63	**40140.90**	14994.05	-150.0	15144
Jul-99	34684.90	**34684.90**	2090.79	40794.38	108.77	**42993.94**	-8309.04	-5115.3	-3194
Aug-99	7418.33	**7418.33**	2288.52	11509.57	99.57	**13897.65**	-6479.33	-3536.4	-2943
Sep-99	5219.74	**5219.74**	1287.00	7456.21	93.43	**8836.64**	-3616.89	-707.3	-2910
Oct-99	3585.46	**3585.46**	1158.30	7385.64	84.43	**8628.37**	-5042.91	-2323.9	-2719
Nov-99	4237.98	**4237.98**	1035.45	8223.31	86.28	**9345.04**	-5107.06	-2147.1	-2960
Dec-99	19829.46	**19829.46**	593.19	14028.72	82.58	**14704.49**	5124.97	-959.9	6085
Jan-00	11373.89	**11373.89**	617.76	3847.77	80.86	**4546.40**	6827.49	3915.3	2912
Feb-00	11111.01	**11111.01**	878.67	7876.58	87.51	**8842.76**	2268.25	2399.7	-131
Mar-00	18103.87	**18103.87**	1076.40	16572.43	96.78	**17745.61**	358.26	1263.0	-905

Table C-7
Constructed Budget for Spavinaw Lake using SWAT Inflows

	INPUTS (Acre-ft)			OUTPUTS (Acre-ft)						
Month	Eucha Release	Swat	**TOTAL**	Evaporation	Water Releases	Water Supply	**TOTAL**	I-O	**ΔV (acre-ft)**	total error
Jan-98	54482.20	3446.93	**57929.14**	174.56	54439.55	1905.91	**56520.03**	1409.11	113.44	1296
Feb-98	19036.05	2350.62	**21386.67**	269.72	6691.57	5158.75	**12120.04**	9266.63	-141.80	9408
Mar-98	43447.01	2909.35	**46356.36**	530.91	43156.13	5712.01	**49399.04**	-3042.68	425.40	-3468
Apr-98	22333.96	1864.43	**24198.39**	861.00	13090.71	5527.36	**19479.07**	4719.32	-382.86	5102
May-98	10281.59	1108.95	**11390.54**	923.34	9469.08	5951.11	**16343.54**	-4952.99	0.00	-4953
Jun-98	8196.62	53.49	**8250.11**	1217.34	505.67	6246.71	**7969.72**	280.38	-241.06	521
Jul-98	9260.43	65.56	**9325.99**	1270.50	59.53	6749.45	**8079.47**	1246.52	-283.60	1530
Aug-98	9100.87	46.08	**9146.96**	1097.25	0.00	7400.09	**8497.34**	649.62	127.62	522
Sep-98	3381.38	158.41	**3539.79**	923.34	0.00	5892.68	**6816.02**	-3276.23	70.90	-3347
Oct-98	22703.09	704.47	**23407.56**	547.97	16612.93	5925.97	**23086.87**	320.69	141.80	179
Nov-98	9612.99	633.59	**10246.58**	315.00	6291.75	5526.78	**12133.54**	-1886.96	283.60	-2171
Dec-98	8116.84	757.87	**8874.71**	263.16	5033.10	5711.31	**11007.56**	-2132.85	-127.62	-2005
Jan-99	4624.69	760.83	**5385.52**	259.88	2392.12	5710.56	**8362.56**	-2977.04	-141.80	-2835
Feb-99	31051.29	1323.82	**32375.11**	454.13	31962.30	5157.89	**37574.31**	-5199.20	141.80	-5341
Mar-99	37268.79	2537.54	**39806.32**	614.25	43477.69	5158.42	**49250.37**	-9444.05	141.80	-9586
Apr-99	33003.40	3642.68	**36646.08**	727.13	40760.63	4913.33	**46401.08**	-9755.00	538.84	-10294
May-99	52930.51	3249.85	**56180.36**	887.25	60367.70	5711.49	**66966.44**	-10786.08	-141.80	-10644
Jun-99	38596.79	4105.19	**42701.98**	816.38	32838.94	5527.82	**39183.13**	3518.85	-141.80	3661
Jul-99	40794.38	1900.87	**42695.25**	1172.72	51874.06	5933.85	**58980.63**	-16285.38	-3658.44	-12627
Aug-99	11509.57	621.23	**12130.80**	1283.63	0.00	7808.72	**9092.34**	3038.46	-297.78	3336
Sep-99	7456.21	638.25	**8094.46**	721.88	0.00	6352.62	**7074.50**	1019.96	51.05	969
Oct-99	7385.64	1008.41	**8394.05**	649.69	0.00	5711.35	**6361.03**	2033.02	70.90	1962
Nov-99	8223.31	693.49	**8916.81**	580.78	208.34	5527.17	**6316.29**	2600.51	368.68	2232
Dec-99	14028.72	1045.00	**15073.72**	332.72	12254.27	5710.98	**18297.97**	-3224.24	113.44	-3338
Jan-00	3847.77	1250.07	**5097.85**	346.50	505.67	5707.42	**6559.59**	-1461.75	-978.42	-483
Feb-00	7876.58	721.52	**8598.10**	492.84	0.00	5342.66	**5835.50**	2762.60	340.32	2422
Mar-00	16572.43	897.21	**17469.63**	603.75	12333.43	5711.27	**18648.45**	-1178.82	694.82	-1874

Table C-8
Constructed Budget for Eucha Lake using the Rational Formula Approach

	INPUTS (Acre-ft)				OUTPUTS (Acre-ft)						
Month	Precipitation	Surface Runoff	Groundwater	TOTAL	Evaporation	Water Releases	Water Supply	TOTAL	I-O	ΔV (acre-ft)	Total error
Jan-98	1251.90	47908.87	9837.30	58998.07	311.22	54482.20	98.48	54891.90	4106.17	30.0	4076
Feb-98	259.74	12073.77	9837.30	22170.81	480.87	19036.05	86.24	19603.15	2567.66	-1040.4	3608
Mar-98	1319.76	40948.06	6886.11	49153.93	946.53	43447.01	94.99	44488.53	4665.40	1610.4	3055
Apr-98	573.30	15166.94	6886.11	22626.35	1535.04	22333.96	95.04	23964.04	-1337.69	-1155.7	-182
May-98	1177.02	11926.48	6886.11	19989.61	1646.19	10281.59	96.31	12024.10	7965.51	528.9	7437
Jun-98	547.56	6182.03	4918.65	11648.24	2170.35	8196.62	103.52	10470.49	1177.75	-2044.5	3222
Jul-98	1212.12	3264.67	4918.65	9395.44	2265.12	9260.43	113.29	11638.85	-2243.41	-4546.8	2303
Aug-98	524.16	2314.39	4918.65	7757.20	1956.24	9100.87	99.65	11156.77	-3399.57	-6820.2	3421
Sep-98	1542.06	2206.53	6886.11	10634.70	1646.19	3381.38	102.60	5130.17	5504.53	-2323.9	7828
Oct-98	1841.58	17343.08	6886.11	26070.77	976.95	22703.09	97.54	23777.58	2293.19	16213.9	-13921
Nov-98	1071.72	10624.59	6886.11	18582.42	561.60	9612.99	78.23	10252.82	8329.60	120.0	8210
Dec-98	521.82	10306.25	9837.30	20665.37	469.17	8116.84	105.05	8691.06	11974.31	0.0	11974
Jan-99	580.32	9422.49	9837.30	19840.11	463.32	4624.69	78.95	5166.97	14673.14	0.0	14673
Feb-99	889.20	29430.66	9837.30	40157.16	809.64	31051.29	83.76	31944.69	8212.47	0.0	8212
Mar-99	1134.90	36515.00	6886.11	44536.01	1095.12	37268.79	86.45	38450.36	6085.65	300.0	5786
Apr-99	1804.14	25168.65	6886.11	33858.90	1296.36	33003.40	83.81	34383.58	-524.68	600.0	-1125
May-99	2073.24	50926.01	6886.11	59885.36	1581.84	52930.51	89.72	54602.07	5283.29	150.0	5133
Jun-99	2038.14	55834.22	4918.65	62791.01	1455.48	38596.79	88.63	40140.90	22650.10	-150.0	22800
Jul-99	414.18	46511.96	4918.65	51844.79	2090.79	40794.38	108.77	42993.94	8850.85	-5115.3	13966
Aug-99	570.96	7517.18	4918.65	13006.79	2288.52	11509.57	99.57	13897.65	-890.87	-3536.4	2646
Sep-99	1425.06	5569.10	6886.11	13880.27	1287.00	7456.21	93.43	8836.64	5043.63	-707.3	5751
Oct-99	315.90	3944.12	6886.11	11146.13	1158.30	7385.64	84.43	8628.37	2517.76	-2323.9	4842
Nov-99	416.52	4400.25	6886.11	11702.88	1035.45	8223.31	86.28	9345.04	2357.84	-2147.1	4505
Dec-99	556.92	9298.95	9837.30	19693.17	593.19	14028.72	82.58	14704.49	4988.68	-959.9	5949
Jan-00	290.16	5032.19	9837.30	15159.65	617.76	3847.77	80.86	4546.40	10613.25	3915.3	6698
Feb-00	594.36	3967.88	9837.30	14399.54	878.67	7876.58	87.51	8842.76	5556.78	2399.7	3157
Mar-00	1010.88	9089.89	6886.11	16986.88	1076.40	16572.43	96.78	17745.61	-758.73	1263.0	-2022

Table C-9

Constructed Budget for Spavinaw Lake using the Rational Formula Approach

	INPUTS (Aacre-ft)					OUTPUTS (Acre-ft)						
Month	Precipitation	Eucha Release	Surface Runoff	Groundwater	TOTAL	Evaporation	Water Releases	Water Supply	TOTAL	I-O	ΔV (acre-ft)	Total error
Jan-98	628.69	54482.20	5617.99	2277.71	63006.59	174.56	54439.55	1905.91	56520.03	6486.56	113.44	6373
Feb-98	65.63	19036.05	2795.24	2277.71	24174.62	269.72	6691.57	5158.75	12120.04	12054.58	-141.80	12196
Mar-98	858.38	43447.01	9480.02	1594.40	55379.80	530.91	43156.13	5712.01	49399.04	5980.76	425.40	5555
Apr-98	301.88	22333.96	3511.35	1594.40	27741.58	861.00	13090.71	5527.36	19479.07	8262.51	-382.86	8645
May-98	577.50	10281.59	2761.14	1594.40	15214.63	923.34	9469.08	5951.11	16343.54	-1128.91	0.00	-1129
Jun-98	147.00	8196.62	1431.22	1138.85	10913.69	1217.34	505.67	6246.71	7969.72	2943.97	-241.06	3185
Jul-98	673.31	9260.43	755.81	1138.85	11828.41	1270.50	59.53	6749.45	8079.47	3748.94	-283.60	4033
Aug-98	307.13	9100.87	535.81	1138.85	11082.66	1097.25	0.00	7400.09	8497.34	2585.33	127.62	2458
Sep-98	1179.94	3381.38	510.84	1594.40	6666.55	923.34	0.00	5892.68	6816.02	-149.47	70.90	-220
Oct-98	1300.69	22703.09	4015.15	1594.40	29613.33	547.97	16612.93	5925.97	23086.87	6526.45	141.80	6385
Nov-98	475.13	9612.99	2459.73	1594.40	14142.25	315.00	6291.75	5526.78	12133.54	2008.71	283.60	1725
Dec-98	190.31	8116.84	2386.03	2277.71	12970.89	263.16	5033.10	5711.31	11007.56	1963.33	-127.62	2091
Jan-99	278.25	4624.69	2181.43	2277.71	9362.08	259.88	2392.12	5710.56	8362.56	999.52	-141.80	1141
Feb-99	307.13	31051.29	6813.58	2277.71	40449.71	454.13	31962.30	5157.89	37574.31	2875.40	141.80	2734
Mar-99	763.88	37268.79	8453.70	1594.40	48080.76	614.25	43477.69	5158.42	49250.37	-1169.61	141.80	-1311
Apr-99	1093.31	33003.40	5826.87	1594.40	41517.99	727.13	40760.63	4913.33	46401.08	-4883.10	538.84	-5422
May-99	1069.69	52930.51	11790.04	1594.40	67384.64	887.25	60367.70	5711.49	66966.44	418.20	-141.80	560
Jun-99	1653.75	38596.79	12926.36	1138.85	54315.75	816.38	32838.94	5527.82	39183.13	15132.62	-141.80	15274
Jul-99	231.00	40794.38	10768.13	1138.85	52932.36	1172.72	51874.06	5933.85	58980.63	-6048.26	-3658.44	-2390
Aug-99	278.25	11509.57	1740.33	1138.85	14667.00	1283.63	0.00	7808.72	9092.34	5574.66	-297.78	5872
Sep-99	824.25	7456.21	1289.32	1594.40	11164.18	721.88	0.00	6352.62	7074.50	4089.68	51.05	4039
Oct-99	140.44	7385.64	913.12	1594.40	10033.59	649.69	0.00	5711.35	6361.03	3672.56	70.90	3602
Nov-99	241.50	8223.31	1018.72	1594.40	11077.92	580.78	208.34	5527.17	6316.29	4761.63	368.68	4393
Dec-99	486.94	14028.72	2152.83	2277.71	18946.20	332.72	12254.27	5710.98	18297.97	648.23	113.44	535
Jan-00	161.44	3847.77	1165.02	2277.71	7451.94	346.50	505.67	5707.42	6559.59	892.34	-978.42	1871
Feb-00	297.94	7876.58	918.62	2277.71	11370.84	492.84	0.00	5342.66	5835.50	5535.34	340.32	5195
Mar-00	517.13	16572.43	2104.43	1594.40	20788.38	603.75	12333.43	5711.27	18648.45	2139.93	694.82	1445

The combination of Eucha lake releases and Water supply withdrawals combine to give Spavinaw Lake water a short hydraulic residence (**Table 12**). Over the two-year monitoring period the average annual hydraulic residence for Eucha was 0.34 years and that of Spavinaw was 0.11 years. Comparisons between years (April - March) show shorter residence the second year of monitoring (April 1998 - March 2000).

Table C-10

Inflow sources as percent of total

	Precipitation	Eucha Dam	Surface Runoff	Groundwater
Eucha	4.0	na	66.3	29.7
Spavinaw	2.4	74.7	15.8	7.1

Water supply use had a large impact on the outflow percentage of Spavinaw Lake (**Table 11**). The effect of water supply use on Eucha Lake was nominal.

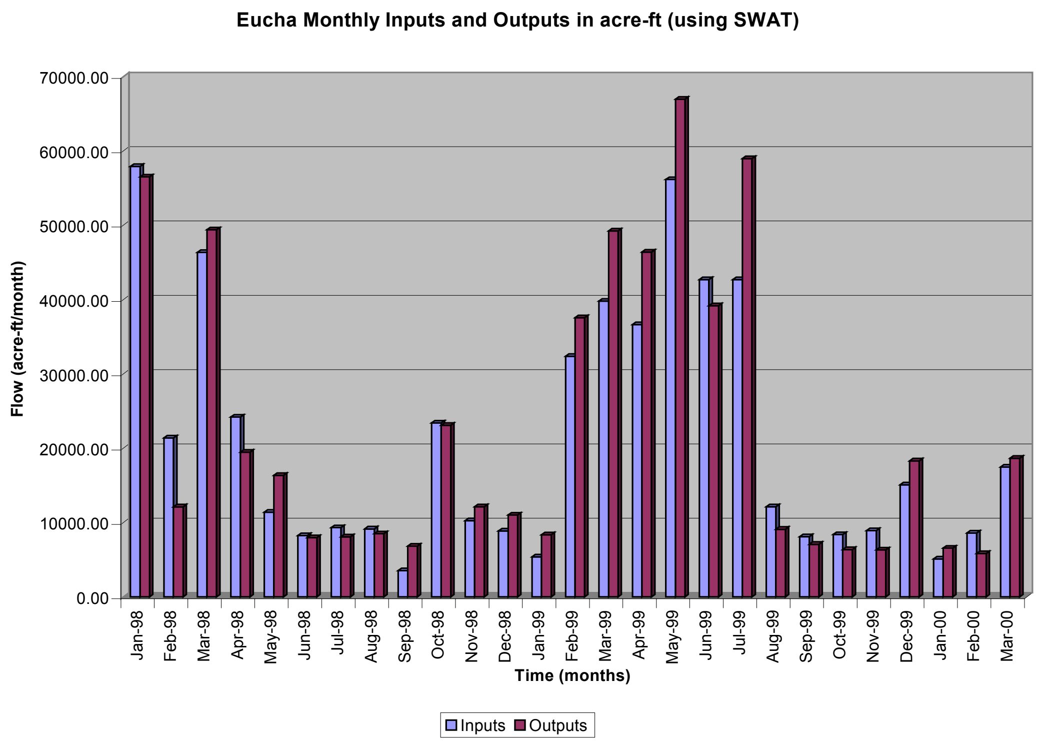
Table C-11

Major outflow sources as a percent of the total

	Evaporation	Dam	Water Supply
Spavinaw	3.5	68.2	28.3
Eucha	6.9	92.6	0.5

Table C-12
Annualized (April - March) results of hydraulic residence calculations

	Eucha	Spavinaw
1998 - 1999	0.39	0.13
1999 - 2000	0.29	0.09
Annual Average	0.34	0.11



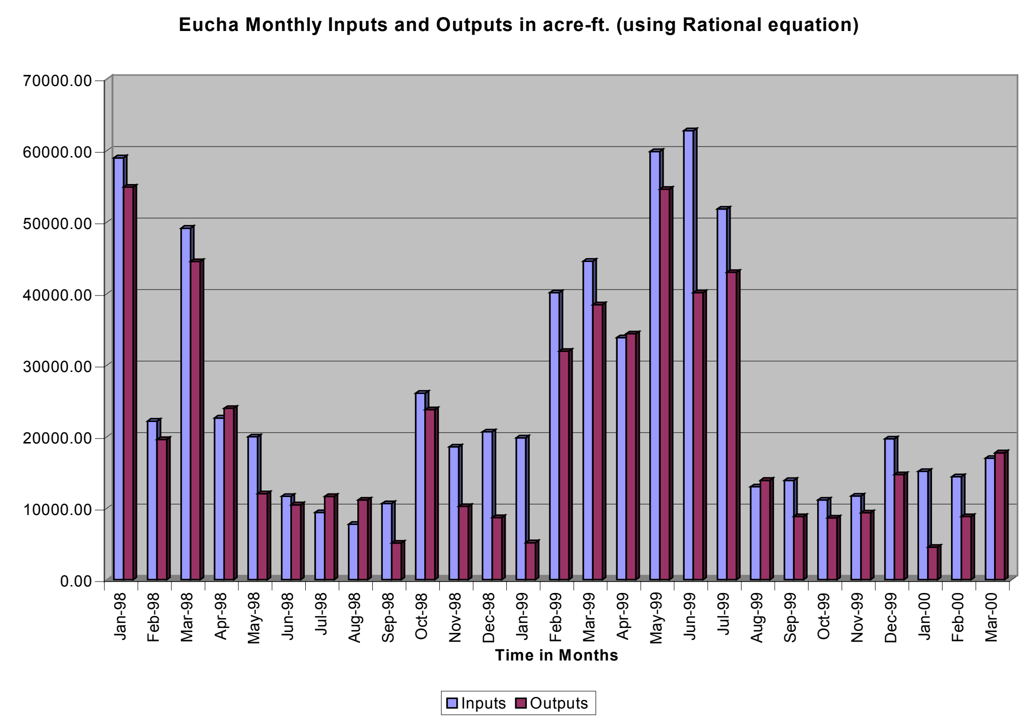
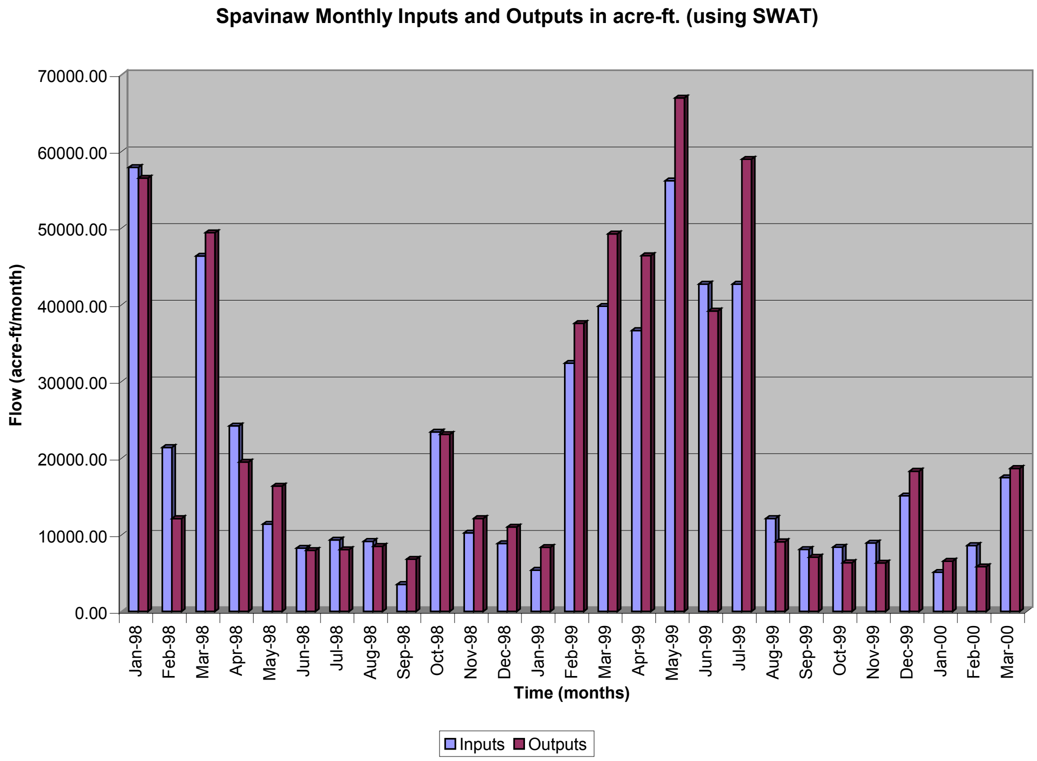


Figure C-2. Total inflows to the lake compared with total outflows for Lake Eucha



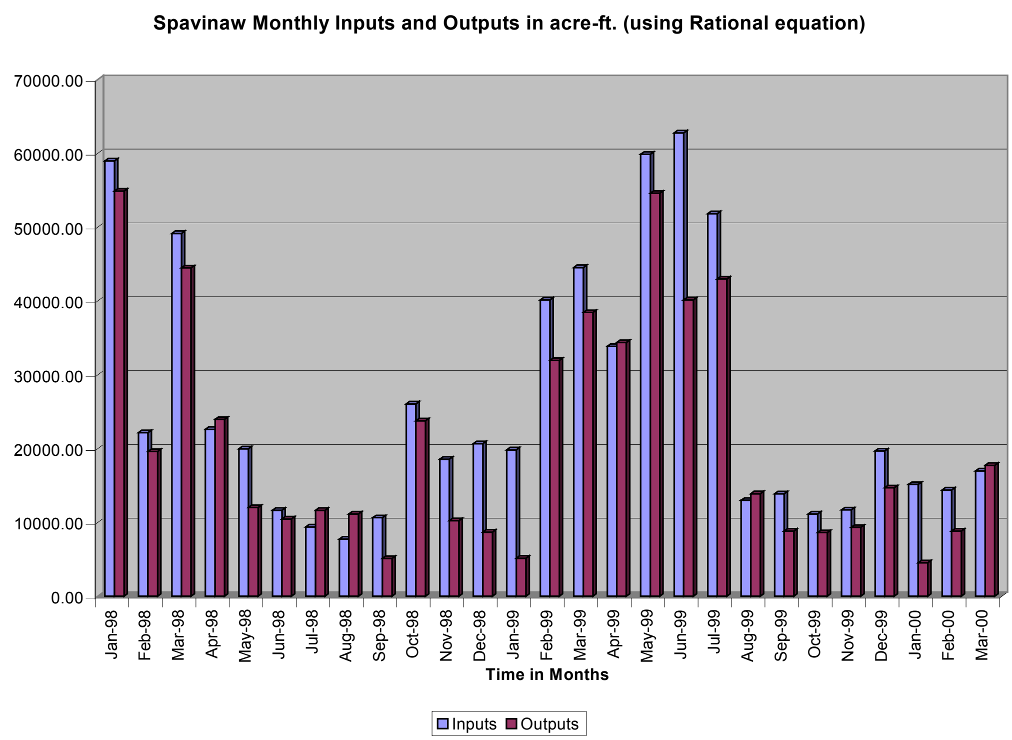


Figure C-3 Total inflows to the lake compared with total outflows for Lake Spavinaw

Sources of Error

Based on the simplifying assumptions made in calculating some of the parameters, the following potential sources of error have been identified.

- Lake level readings were assumed to be accurate and were used as the standard of measure to estimate error. Soil and Water Assessment Tool and groundwater adjustments could not explain all of the error noted in the budget. Assumptions of the lake release and stage measurements should be checked.

- Evaporation rates used in the calculation of water losses due to evaporation were derived from lakes other than Eucha and Spavinaw. Climatic conditions at these lakes may be different from those at Eucha and Spavinaw.

- Groundwater estimates were based on just one winter measurement (February discharge). This discharge rate was adjusted for all the other months. Monthly error during low flow periods (when surface runoff is minimal) can be attributed to this factor. Adjustments to this factor should be made based on field measurements instead of office extrapolations.

- Transpiration and seepage were assumed to be negligible.

- The elevation-capacity, elevation-area and stage-flow curves/charts all date to 1978 or earlier. There is the possibility that the relationships established earlier in the lives of these reservoirs have shifted over time. Soil and Water Assessment Tool and groundwater adjustments could not explain all of the error noted in the budget. Assumptions of the lake release and stage measurements should be checked.

- Water releases flow rates were based on a regression of three data points and extrapolated beyond the range of data points. The water release data set shows instances when the gate openings were greater than 12'', notably 14", 16", 20", 40" and 120". Extending or extrapolating the regression beyond 12'' assumes a linear relationship. This assumption could introduce errors in the flow calculations. Three months had days with gate openings greater than the regression range, July 1999, December 1999 and March 2000. Of these months the percentage of volume released outside of the regression range were 23, 55, and 73 % respectively. Comparing the historical nomograph relating Eucha Lake gate openings to flow it is reasonable to assume that the exiting flow from Eucha Lake was underestimated for these months. Consequently it is reasonable to assume that the inflow to Spavinaw Lake was underestimated. Water budget error due to the regression cannot account for every month of positive (inflow greater than outflow) monthly error.

Recommendations to Reduce Future Error

Considerable error was noted in the constructed budget. The following list of recommendations targets areas where assumptions can be checked to provide a water budget with less possibilities of error.

- Check the accuracy of lake level gages.

- Install a stream flow gage located below Eucha Lake dam and above Spavinaw Lake (at site EUC14 for instance). This would ensure accurate daily inflow rates to Spavinaw Lake and outflow from Eucha Lake.

- Check or resurvey Lake Stage-discharge nomographs for both lakes.

- Request field staff to include stream flow measurements as part of their routine stream water quality monitoring. This additional information allows for better estimate of base flow and perhaps runoff estimates.

- Groundwater study (discharge measurements) to cover all seasons of the year.

Appendices

Appendix A

Tabular summary of area and capacity verses depth.

Eucha Lake: 12/1999			Spavinaw Lake: 8/1999		
Depth (meter)	**Area (acres)**	**Capacity (acre-feet)**	**Depth (meter)**	**Area (acres)**	**Capacity (acre-feet)**
0	75884	2807	0	1575	26399
2	59212	2286	1	1267	21746
4	44923	2073	2	1164	17758
6	32476	1728	3	1063	14104
8	22420	1346	4	956	10793
10	14436	1093	5	800	7916
12	8435	748	6	648	5545
14	4508	461	7	528	3619
16	2030	300	8	364	2164
18	628	138	9	220	1215
20	152	23	10	154	604
22	44	10	11	82	224
24	1	3	12	27	54
			13	5	7
			14	0	0

Appendix B

Calculation of Change in Volume

EUCHA : Used 75884 as 778 elevation capacity plugged in calculated slope from capacity data

Month	Average Stage	Capacity (acre-ft)	Average stage (acre-ft)	DV (acre-ft)	Begin &end stage Actual (acre-ft)
Jan-98	778.24	76604.00		29	30
Feb-98	777.88	75580.88	-1023.12	-1189	-1040
Mar-98	778.09	76154.00	573.12	1740	1610
Apr-98	777.94	75732.44	-421.56	-1218	-1156
May-98	777.93	75707.18	-25.26	580	529
Jun-98	777.75	75252.50	-454.68	-2320	-2045
Jul-98	776.68	72549.67	-2702.83	-5220	-4547
Aug-98	774.00	65779.96	-6769.71	-7830	-6820
Sep-98	771.98	60677.42	-5102.54	-2668	-2324
Oct-98	777.13	73686.37	13008.95	18560	16214
Nov-98	778.07	76094.00	2407.63	116	120
Dec-98	778.13	76274.00	180.00	0	0
Jan-99	778.10	76184.00	-90.00	0	0
Feb-99	778.26	76664.00	480.00	0	0
Mar-99	778.30	76784.00	120.00	290	300
Apr-99	778.26	76675.00	-109.00	580	600
May-99	778.28	76724.97	49.97	145	150
Jun-99	778.11	76218.00	-506.97	-145	-150
Jul-99	777.51	74651.14	-1566.86	-5655	-5115
Aug-99	775.79	70305.59	-4345.55	-4060	-3536
Sep-99	774.72	67593.64	-2711.96	-812	-707
Oct-99	774.09	66008.93	-1584.70	-2668	-2324
Nov-99	773.34	64101.01	-1907.93	-2465	-2147
Dec-99	772.59	62215.03	-1885.98	-1102	-960
Jan-00	773.07	63425.07	1210.04	4495	3915
Feb-00	773.83	65339.21	1914.15	2755	2400
Mar-00	775.71	70100.25	4761.04	1450	1263
			-6503.748058	**-6612**	**-5740.3432**

Appendix C

SPAVINAW Based on 680 = 26390 676.72 = 21739

DATE	LAKE STAGE	Volume	DV
1-Jan-98	680.12	26560.16	
31-Jan-98	680.2	26673.6	113.44
1-Feb-98	680.2	26673.6	
28-Feb-98	680.1	26531.8	-141.8
1-Mar-98	680.1	26531.8	
31-Mar-98	680.4	26957.2	425.4
1-Apr-98	680.37	26914.66	
30-Apr-98	680.1	26531.8	-382.86
1-May-98	680.1	26531.8	
31-May-98	680.1	26531.8	0
1-Jun-98	680.1	26531.8	
30-Jun-98	679.93	26290.74	-241.06
1-Jul-98	680.02	26418.36	
31-Jul-98	679.82	26134.76	-283.6
1-Aug-98	679.78	26078.04	
31-Aug-98	679.87	26205.66	127.62
1-Sep-98	679.85	26177.3	
30-Sep-98	679.9	26248.2	70.9
1-Oct-98	679.9	26248.2	
31-Oct-98	680	26390	141.8
1-Nov-98	680	26390	
30-Nov-98	680.2	26673.6	283.6
1-Dec-98	680.14	26588.52	
31-Dec-98	680.05	26460.9	-127.62
2-Jan-99	680.1	26531.8	
31-Jan-99	680	26390	-141.8
1-Feb-99	680	26390	
28-Feb-99	680.1	26531.8	141.8
1-Mar-99	680.1	26531.8	
31-Mar-99	680.2	26673.6	141.8
1-Apr-99	680.22	26701.96	
30-Apr-99	680.6	27240.8	538.84
1-May-99	680.5	27099	
31-May-99	680.4	26957.2	-141.8

DATE	LAKE STAGE	Volume	DV
1-Jun-99	680.5	27099	
30-Jun-99	680.4	26957.2	-141.8
1-Jul-99	682.48	29906.64	
31-Jul-99	679.9	26248.2	-3658.44
1-Aug-99	679.91	26262.38	
31-Aug-99	679.7	25964.6	-297.78
1-Sep-99	679.7	25964.6	
30-Sep-99	679.736	26015.648	51.048
1-Oct-99	679.7	25964.6	
31-Oct-99	679.75	26035.5	70.9
1-Nov-99	679.75	26035.5	
30-Nov-99	680.01	26404.18	368.68
1-Dec-99	680	26390	
31-Dec-99	680.08	26503.44	113.44
1-Jan-00	680.08	26503.44	
31-Jan-00	679.39	25525.02	-978.42
1-Feb-00	679.4	25539.2	
29-Feb-00	679.64	25879.52	340.32
1-Mar-00	679.63	25865.34	
31-Mar-00	680.12	26560.16	694.82

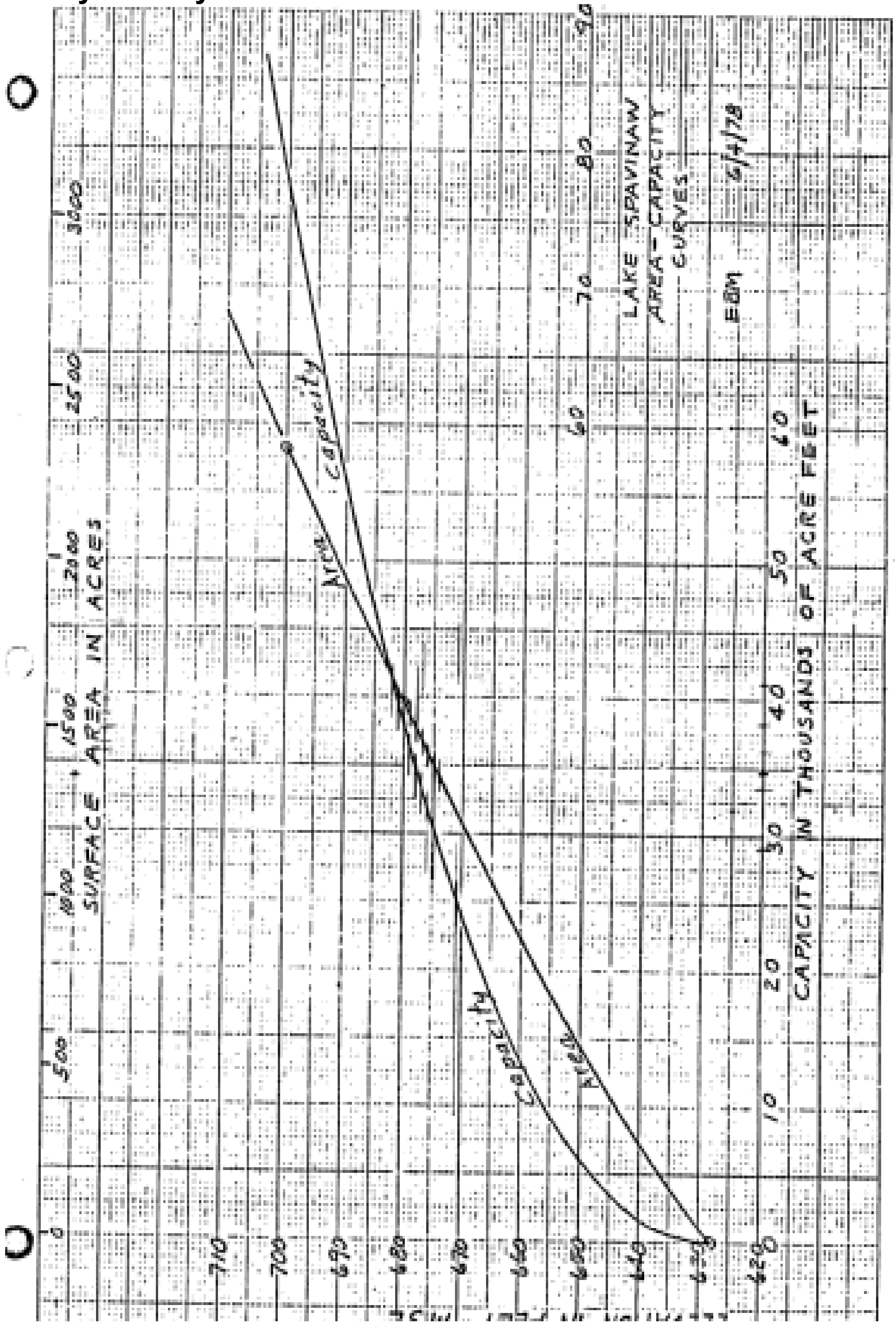
Appendix D

MONTHLY RAINFALL IN INCHES

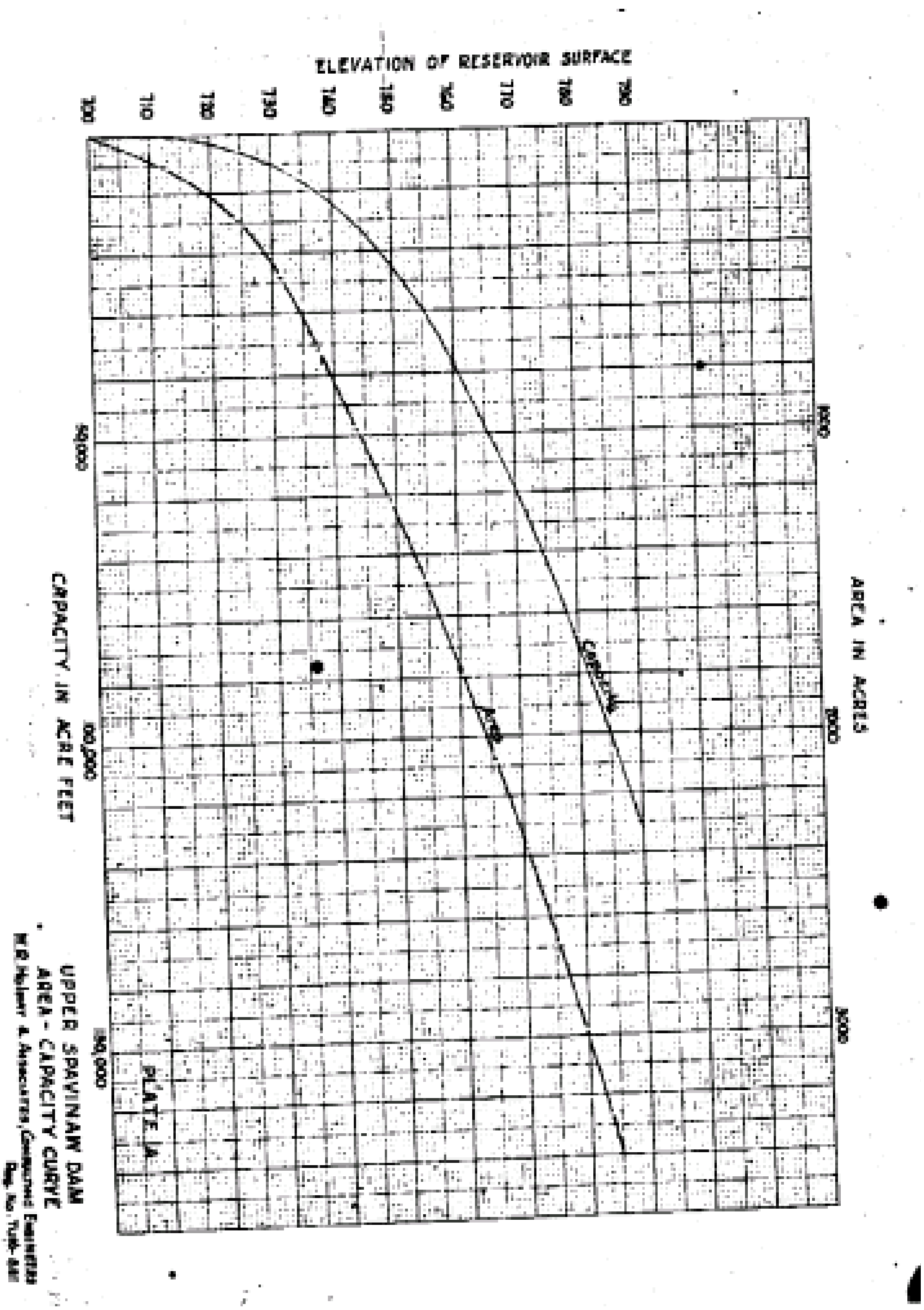
	EUCHA		SPAVINAW		HUDSON		PENSACOLA		TENKILLER	
DATE	DAILY AVE.	MONTHLY	DAILY AVE.	MONTHLY	DAM	BSN	DAM	BSN	DAM	BSN
Jan-98	0.173	5.350	0.165	4.790	4.390	4.570	3.230	4.400	8.840	5.180
Feb-98	0.040	1.110	0.018	0.500	0.450	0.710	0.200	1.260	1.580	1.640
Mar-98	0.182	5.640	0.211	6.540	6.700	6.270	4.990	5.260	6.550	4.510
Apr-98	0.082	2.450	0.077	2.300	1.250	3.010	1.550	3.420	2.000	1.720
May-98	0.162	5.030	0.142	4.400	4.210	4.040	3.150	2.590	2.330	3.470
Jun-98	0.078	2.340	0.037	1.120	2.040	2.000	1.090	4.540	2.720	1.850
Jul-98	0.167	5.180	0.165	5.130	3.480	3.510	4.580	4.160	2.980	2.590
Aug-98	0.072	2.240	0.075	2.340	1.080	2.170	2.370	2.170	1.290	1.550
Sep-98	0.220	6.590	0.300	8.990	7.980	7.110	10.290	5.950	8.650	4.420
Oct-98	0.254	7.870	0.320	9.910	2.500	5.010	8.600	5.920	6.570	4.720
Nov-98	0.153	4.580	0.121	3.620	3.720	3.560	2.120	3.210	4.180	3.320
Dec-98	0.074	2.230	0.048	1.450	2.230	1.250	1.350	1.090	2.830	1.670
Jan-99	0.086	2.480	0.073	2.120	2.490	2.170	1.390	1.230	1.990	1.780
Feb-99	0.136	3.800	0.084	2.340	2.880	1.860	1.440	1.340	0.870	1.390
Mar-99	0.156	4.850	0.188	5.820	3.700	4.280	3.290	2.450	6.140	4.370
Apr-99	0.257	7.710	0.278	8.330	7.870	7.840	8.340	4.940	5.910	4.130
May-99	0.286	8.860	0.263	8.150	11.770	9.120	5.840	4.410	5.730	7.480
Jun-99	0.290	8.710	0.420	12.600	9.760	10.310	9.030	5.590	8.540	5.750
Jul-99	0.057	1.770	0.057	1.760	1.520	1.340	2.050	1.280	0.690	1.080
Aug-99	0.079	2.440	0.068	2.120	0.900	1.990	1.110	1.570	0.250	1.110
Sep-99	0.203	6.090	0.209	6.280	6.220	4.760	4.050	2.950	4.430	3.510
Oct-99	0.044	1.350	0.035	1.070	1.150	1.530	1.300	1.200	1.580	1.410
Nov-99	0.059	1.780	0.061	1.840	1.510	3.540	2.310	2.690	1.800	4.620
Dec-99	0.077	2.380	0.120	3.710	4.270	4.830	3.430	5.010	2.660	4.490
Jan-00	0.040	1.240	0.040	1.230	0.690	0.850	0.650	0.550	2.080	1.710
Feb-00	0.088	2.540	0.078	2.270	3.110	2.230	1.420	2.020	0.990	1.890
Mar-00	0.139	4.320	0.127	3.940	4.100	4.300	3.030	3.660	2.580	3.250

Appendix E

(a) Lake stage-capacity and stage-area curves for Lake Spavinaw furnished by the City of Tulsa.



(b) Lake stage-capacity and stage-area curves for Lake Eucha furnished by the City of Tulsa.


ELEVATION OF RESERVOIR SURFACE
710
720
730
740
750
760
770
780
790
CAPACITY IN ACRE FEET
100,000
150,000
AREA IN ACRES
1000
2000
3000
CAPACITY
AREA
PLATE IA
UPPER SPAVINAW DAM
AREA - CAPACITY CURVE

Appendix F
Overflows

EUCHA

DATE	STAGE>778	Q(cfs)	Q(MGD)
Jan-98	778.01	9.7	6.26939
	778.01	9.7	6.26939
	778.01	9.7	6.26939
	778.01	9.7	6.26939
	778.01	9.7	6.26939
	778.01	9.7	6.26939
	778.01	9.7	6.26939
	778.01	9.7	6.26939
	778.01	9.7	6.26939
	778.02	19.4	12.53878
	778.05	48.5	31.34695
	778.1	97	62.6939
	778.1	97	62.6939
	778.15	188	121.5098
	778.2	279	180.3257
	778.2	279	180.3257
	778.2	279	180.3257
	778.2	279	180.3257
	778.3	519	335.4447
	778.4	889	574.5863
	778.43	964.9	623.6427
	778.5	1142	738.1075
	778.7	1920	1240.951
	778.7	1920	1240.951
	778.75	2140	1383.144
	778.9	2836	1832.989
	778.9	2936	1897.622
	TOTAL	16920.1	10935.95
Feb-98	778.01	9.7	6.26939
	778.01	9.7	6.26939

SPAVINAW

DATE	STAGE>680	Q(cfs)	Q(MGD)
Jan-98	680.12	102.4	66.18407
	680.12	102.4	66.18407
	680.16	157.2	101.6029
	680.2	212	137.0217
	680.2	212	137.0217
	680.2	212	137.0217
	680.2	212	137.0217
	680.2	212	137.0217
	680.2	212	137.0217
	680.2	212	137.0217
	680.2	212	137.0217
	680.2	212	137.0217
	680.2	212	137.0217
	680.23	266	171.9235
	680.3	392	253.3609
	680.32	435.2	281.2823
	680.34	478.4	309.2037
	680.38	564.8	365.0465
	680.42	657.4	424.8966
	680.5	855	552.6112
	680.58	1071.8	692.7353
	680.67	1333.9	862.1381
	680.79	1711	1105.869
	680.94	2229.2	1440.796
	681.02	2547.6	1646.587
	681.12	2910.6	1881.205
	681.12	2910.6	1881.205
	681.13	2950.9	1907.252
	681.3	3654	2361.686
	TOTAL	27450.4	17741.99

EUCHA				SPAVINAW			
DATE	**STAGE>778**	**Q(cfs)**	**Q(MGD)**	**DATE**	**STAGE>680**	**Q(cfs)**	**Q(MGD)**
	778.01	9.7	6.26939	Feb-98	680.1	75	48.47466
	778.01	9.7	6.26939		680.1	75	48.47466
	778.01	9.7	6.26939		680.1	75	48.47466
	778.01	9.7	6.26939		680.1	75	48.47466
	778.01	9.7	6.26939		680.1	75	48.47466
	TOTAL	67.9	43.88573		680.1	75	48.47466
					680.1	75	48.47466
Mar-98	778.1	97	62.6939		680.1	75	48.47466
	778.1	97	62.6939		680.1	75	48.47466
	778.1	97	62.6939		680.12	102.4	66.18407
	778.1	97	62.6939		680.12	102.4	66.18407
	778.1	97	62.6939		680.12	102.4	66.18407
	778.12	133.4	86.22027		680.12	102.4	66.18407
	778.15	188	121.5098		680.12	102.4	66.18407
	778.18	242.6	156.7994		680.12	102.4	66.18407
	778.2	279	180.3257		680.12	102.4	66.18407
	778.2	279	180.3257		680.12	102.4	66.18407
	778.2	279	180.3257		680.12	102.4	66.18407
	778.2	279	180.3257		680.12	102.4	66.18407
	778.22	327	211.3495		680.14	129.8	83.89349
	778.25	399	257.8852		680.15	143.5	92.74819
	778.3	519	335.4447		680.16	157.2	101.6029
	778.3	519	335.4447		680.18	184.6	119.3123
	778.38	815	526.758		680.2	212	137.0217
	778.4	889	574.5863		680.2	212	137.0217
	778.5	1142	738.1075		680.2	212	137.0217
	778.59	1475	953.3351		680.2	212	137.0217
	778.6	1512	977.2492		680.2	212	137.0217
	778.62	1593.6	1029.99		TOTAL	3374.1	2180.778
	TOTAL	11355.6	7339.452				
Apr-98	778.01	9.7	6.26939	Mar-98	680.1	75	48.47466

EUCHA

DATE	STAGE>778	Q(cfs)	Q(MGD)
	778.02	19.4	12.53878
	778.1	97	62.6939
	778.1	97	62.6939
	778.1	97	62.6939
	778.1	97	62.6939
	778.15	118	76.2668
	778.15	118	76.2668
	778.15	118	76.2668
	778.2	279	180.3257
	TOTAL	1050.1	678.7099
May-98	778.05	48.5	31.34695
	778.05	48.5	31.34695
	778.05	48.5	31.34695
	778.05	48.5	31.34695
	778.1	79	51.05998
	778.1	79	51.05998
	778.1	79	51.05998
	778.1	79	51.05998
	778.1	79	51.05998
	778.1	79	51.05998
	778.1	79	51.05998
	TOTAL	747	482.8077
Jun-98	778.05	48.5	31.34695
	TOTAL	48.5	31.34695
Jul-98	0	0	0
	TOTAL	0	0
Aug-98	0	0	0
	TOTAL	0	0

SPAVINAW

DATE	STAGE>680	Q(cfs)	Q(MGD)
	680.1	75	48.47466
	680.1	75	48.47466
	680.1	75	48.47466
	680.1	75	48.47466
	680.1	75	48.47466
	680.1	75	48.47466
	680.2	212	137.0217
	680.23	266	171.9235
	680.3	392	253.3609
	680.3	392	253.3609
	680.3	392	253.3609
	680.31	413.6	267.3216
	680.32	435.2	281.2823
	680.34	478.4	309.2037
	680.36	521.6	337.1251
	680.38	564.8	365.0465
	680.4	608	392.9679
	680.4	608	392.9679
	680.4	608	392.9679
	680.43	682.1	440.8609
	680.44	706.8	456.8252
	680.5	855	552.6112
	680.54	963.4	622.6732
	680.6	1126	727.7663
	680.62	1185.4	766.1582
	680.74	1551	1002.456
	680.88	2015.8	1302.87
	680.88	2015.8	1302.87
	680.9	2084	1346.949
	680.9	2084	1346.949
	TOTAL	21685.9	14016.22

EUCHA				**SPAVINAW**			
DATE	**STAGE>778**	**Q(cfs)**	**Q(MGD)**	**DATE**	**STAGE>680**	**Q(cfs)**	**Q(MGD)**
				Apr-98	680.1	75	48.47466
Sep-98	0	0	0		680.1	75	48.47466
	TOTAL	0	0		680.1	75	48.47466
					680.1	75	48.47466
Oct-98	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.12	102.4	66.18407
	778.1	79	51.05998		680.12	102.4	66.18407
	778.1	79	51.05998		680.12	102.4	66.18407
	778.1	79	51.05998		680.12	102.4	66.18407
	778.1	79	51.05998		680.13	116.1	75.03878
	778.1	79	51.05998		680.14	129.8	83.89349
	778.1	79	51.05998		680.15	143.5	92.74819
	778.1	79	51.05998		680.16	157.2	101.6029
	778.1	79	51.05998		680.18	184.6	119.3123
	778.1	79	51.05998		680.18	184.6	119.3123
	778.1	79	51.05998		680.2	212	137.0217
	778.12	133.4	86.22027		680.2	212	137.0217
	778.14	169.8	109.7466		680.2	212	137.0217
	778.18	242.6	156.7994		680.2	212	137.0217
	778.2	279	180.3257		680.28	356	230.0931
	778.23	351	226.8614		680.3	392	253.3609
	778.25	399	257.8852		680.3	392	253.3609
	778.3	519	335.4447		680.3	392	253.3609
	778.4	889	574.5863		680.3	392	253.3609
	778.5	1142	738.1075		680.3	392	253.3609
	778.75	2140	1383.144		680.36	521.6	337.1251
	TOTAL	7370.8	4763.961		680.36	521.6	337.1251
					680.37	543.2	351.0858
Nov-98	778.05	48.5	31.34695		TOTAL	6600.8	4266.287
	778.06	58.2	37.61634				

EUCHA				**SPAVINAW**			
DATE	**STAGE>778**	**Q(cfs)**	**Q(MGD)**	**DATE**	**STAGE>680**	**Q(cfs)**	**Q(MGD)**
	778.08	77.6	50.15512	May-98	680.04	30	19.38987
	778.09	87.3	56.42451		680.09	67.5	43.6272
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.15	188	121.5098		680.1	75	48.47466
	778.15	188	121.5098		680.1	75	48.47466
	778.15	188	121.5098		680.12	102.4	66.18407
	778.15	188	121.5098		680.12	102.4	66.18407
	778.15	188	121.5098		680.14	129.8	83.89349
	778.15	188	121.5098		680.15	143.5	92.74819
	778.15	188	121.5098		680.2	212	137.0217
	778.15	188	121.5098		680.2	212	137.0217
	778.15	188	121.5098		680.2	212	137.0217
	TOTAL	2990.6	1932.911		680.21	230	148.6556
					680.24	284	183.5574
Dec-98	778.1	79	51.05998		680.28	356	230.0931
	778.1	79	51.05998		680.3	392	253.3609
	778.1	79	51.05998		680.3	392	253.3609
	778.1	79	51.05998		680.3	392	253.3609
	778.1	79	51.05998		680.3	392	253.3609
	778.1	79	51.05998		TOTAL	4774.6	3085.962

EUCHA				SPAVINAW			
DATE	STAGE>778	Q(cfs)	Q(MGD)	DATE	STAGE>680	Q(cfs)	Q(MGD)
	778.1	79	51.05998				
	778.1	79	51.05998	Jun-98	680.02	15	9.694933
	778.1	79	51.05998		680.02	15	9.694933
	778.1	79	51.05998		680.04	30	19.38987
	778.1	79	51.05998		680.06	45	29.0848
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.11	115.2	74.45708		TOTAL	255	164.8139
	778.12	133.4	86.22027				
	778.13	151.6	97.98345	Jul-98	680.02	15	9.694933
	778.13	151.6	97.98345		680.02	15	9.694933
	778.13	151.6	97.98345		TOTAL	30	19.38987
	778.13	151.6	97.98345				
	778.13	151.6	97.98345	Aug-98	0	0	0
	778.15	188	121.5098		TOTAL	0	0
	778.15	188	121.5098				
	778.15	188	121.5098	Sep-98	0	0	0
	778.15	188	121.5098		TOTAL	0	0
	778.15	188	121.5098				
	778.15	188	121.5098	Oct-98	680.02	15	9.694933
	778.15	188	121.5098		680.02	15	9.694933
	778.18	242.6	156.7994		680.05	37.5	24.23733
	778.18	242.6	156.7994		680.08	60	38.77973
	778.18	242.6	156.7994		680.1	75	48.47466
	TOTAL	4077.4	2635.341		680.1	75	48.47466
					680.1	75	48.47466
Jan-99	778.05	48.5	31.34695		680.1	75	48.47466
	778.05	48.5	31.34695		680.14	129.8	83.89349
	778.05	48.5	31.34695		680.16	157.2	101.6029
	778.1	79	51.05998		680.2	212	137.0217
	778.1	79	51.05998		680.3	392	253.3609
	778.1	79	51.05998		680.3	392	253.3609

EUCHA				SPAVINAW			
DATE	STAGE>778	Q(cfs)	Q(MGD)	DATE	STAGE>680	Q(cfs)	Q(MGD)
	778.1	79	51.05998		680.36	521.6	337.1251
	778.1	79	51.05998		680.38	564.8	365.0465
	778.1	79	51.05998		680.5	855	552.6112
	778.1	79	51.05998		680.5	855	552.6112
	778.1	79	51.05998		680.7	1423	919.726
	778.1	79	51.05998		681	2447	1581.567
	778.1	79	51.05998		TOTAL	8376.9	5414.232
	778.1	79	51.05998				
	778.1	79	51.05998	Nov-98	680.08	60	38.77973
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.12	133.4	86.22027		680.1	75	48.47466
	778.15	118	76.2668		680.1	75	48.47466
	778.15	118	76.2668		680.1	75	48.47466
	TOTAL	2331.9	1507.174		680.1	75	48.47466
					680.12	102.4	66.18407
Feb-99	778.1	79	51.05998		680.12	102.4	66.18407
	778.1	79	51.05998		680.12	102.4	66.18407
	778.1	79	51.05998		680.12	102.4	66.18407
	778.1	79	51.05998		680.12	102.4	66.18407
	778.1	79	51.05998		680.13	116.1	75.03878
	778.1	79	51.05998		680.14	129.8	83.89349
	778.1	79	51.05998		680.2	212	137.0217

EUCHA				**SPAVINAW**			
DATE	**STAGE>778**	**Q(cfs)**	**Q(MGD)**	**DATE**	**STAGE>680**	**Q(cfs)**	**Q(MGD)**
	778.1	79	51.05998		680.2	212	137.0217
	778.1	79	51.05998		680.48	805.6	520.6825
	778.1	79	51.05998		TOTAL	3172.5	2050.478
	778.1	79	51.05998				
	778.12	133.4	86.22027	Dec-98	680.01	7.5	4.847466
	778.15	118	76.2668		680.03	22.5	14.5424
	778.15	118	76.2668		680.05	37.5	24.23733
	778.15	118	76.2668		680.05	37.5	24.23733
	778.15	118	76.2668		680.06	45	29.0848
	778.18	242.6	156.7994		680.06	45	29.0848
	778.2	279	180.3257		680.08	60	38.77973
	778.2	279	180.3257		680.08	60	38.77973
	778.2	279	180.3257		680.08	60	38.77973
	778.22	327	211.3495		680.08	60	38.77973
	778.3	519	335.4447		680.1	75	48.47466
	778.3	519	335.4447		680.1	75	48.47466
	778.35	704	455.0155		680.1	75	48.47466
	778.5	1142	738.1075		680.1	75	48.47466
	778.64	1675.2	1082.73		680.1	75	48.47466
	778.9	2836	1832.989		680.1	75	48.47466
	779.4	5381	3477.896		680.1	75	48.47466
	TOTAL	15657.2	10119.7		680.1	75	48.47466
					680.1	75	48.47466
Mar-99	778.05	48.5	31.34695		680.1	75	48.47466
	778.07	67.9	43.88573		680.1	75	48.47466
	778.1	79	51.05998		680.12	102.4	66.18407
	778.1	79	51.05998		680.12	102.4	66.18407
	778.1	79	51.05998		680.12	102.4	66.18407
	778.1	79	51.05998		680.14	129.8	83.89349
	778.1	79	51.05998		680.14	129.8	83.89349
	778.15	118	76.2668		680.16	157.2	101.6029
	778.15	118	76.2668		680.16	157.2	101.6029

EUCHA				**SPAVINAW**			
DATE	**STAGE>778**	**Q(cfs)**	**Q(MGD)**	**DATE**	**STAGE>680**	**Q(cfs)**	**Q(MGD)**
	778.15	118	76.2668		680.18	184.6	119.3123
	778.2	279	180.3257		680.2	212	137.0217
	778.2	279	180.3257		TOTAL	2537.8	1640.253
	778.2	279	180.3257				
	778.2	279	180.3257	Jan-99	680.02	15	9.694933
	778.2	279	180.3257		680.02	15	9.694933
	778.2	279	180.3257		680.05	37.5	24.23733
	778.2	279	180.3257		680.05	37.5	24.23733
	778.3	133.4	86.22027		680.05	37.5	24.23733
	778.3	519	335.4447		680.1	75	48.47466
	778.4	889	574.5863		680.1	75	48.47466
	778.4	889	574.5863		680.1	75	48.47466
	778.4	889	574.5863		680.1	75	48.47466
	778.42	939.6	607.2906		680.1	75	48.47466
	778.45	1015.5	656.3469		680.1	75	48.47466
	778.45	1015.5	656.3469		680.1	75	48.47466
	778.6	1512	977.2492		680.1	75	48.47466
	778.6	1512	977.2492		680.1	75	48.47466
	778.6	1512	977.2492		680.1	75	48.47466
	778.6	1512	977.2492		680.1	75	48.47466
	778.65	1716	1109.1		680.1	75	48.47466
	778.7	1920	1240.951		680.1	75	48.47466
	TOTAL	18792.4	12146.07		680.11	88.7	57.32937
					TOTAL	1206.2	779.6019
1-Apr-99	778.1	79	51.05998				
	778.1	79	51.05998	Feb-99	680.1	75	48.47466
	778.15	118	76.2668		680.1	75	48.47466
	778.15	118	76.2668		680.1	75	48.47466
	778.15	118	76.2668		680.1	75	48.47466
	778.18	242.6	156.7994		680.1	75	48.47466
	778.18	242.6	156.7994		680.1	75	48.47466
	778.2	279	180.3257		680.1	75	48.47466

EUCHA				SPAVINAW			
DATE	STAGE>778	Q(cfs)	Q(MGD)	DATE	STAGE>680	Q(cfs)	Q(MGD)
	778.2	279	180.3257		680.1	75	48.47466
	778.2	279	180.3257		680.1	75	48.47466
	778.2	279	180.3257		680.12	102.4	66.18407
	778.2	279	180.3257		680.13	116.1	75.03878
	778.2	279	180.3257		680.18	184.6	119.3123
	778.2	279	180.3257		680.2	212	137.0217
	778.2	279	180.3257		680.2	212	137.0217
	778.2	279	180.3257		680.2	212	137.0217
	778.2	279	180.3257		680.22	248	160.2896
	778.2	279	180.3257		680.22	248	160.2896
	778.2	279	180.3257		680.25	302	195.1913
	778.2	279	180.3257		680.3	392	253.3609
	778.2	279	180.3257		680.3	392	253.3609
	778.2	279	180.3257		680.4	608	392.9679
	778.2	279	180.3257		680.46	756.2	488.7539
	778.23	351	226.8614		680.52	904.4	584.5398
	778.27	447	288.909		680.7	1423	919.726
	778.35	704	455.0155		680.9	2084	1346.949
	778.45	1015.5	656.3469		681.13	2950.9	1907.252
	778.5	1142	738.1075		681.4	4094	2646.07
	778.7	1920	1240.951		TOTAL	16116.6	10416.62
	779.2	4363	2819.933				
	TOTAL	15403.7	9955.856	Mar-99	680.06	45	29.0848
					680.1	75	48.47466
1-May-99	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.1	79	51.05998		680.1	75	48.47466
	778.12	133.4	86.22027		680.2	212	137.0217
	778.12	133.4	86.22027		680.2	212	137.0217
	778.15	118	76.2668		680.2	212	137.0217
	778.15	118	76.2668		680.2	212	137.0217
	778.15	118	76.2668		680.26	320	206.8252

EUCHA				**SPAVINAW**			
DATE	**STAGE>778**	**Q(cfs)**	**Q(MGD)**	**DATE**	**STAGE>680**	**Q(cfs)**	**Q(MGD)**
	778.18	242.6	156.7994		680.3	392	253.3609
	778.18	242.6	156.7994		680.3	392	253.3609
	778.2	279	180.3257		680.3	392	253.3609
	778.2	279	180.3257		680.4	608	392.9679
	778.2	279	180.3257		680.4	608	392.9679
	778.2	279	180.3257		680.44	706.8	456.8252
	778.2	279	180.3257		680.5	855	552.6112
	778.2	279	180.3257		680.5	855	552.6112
	778.2	279	180.3257		680.6	1126	727.7663
	778.2	279	180.3257		680.6	1126	727.7663
	778.2	279	180.3257		680.6	1126	727.7663
	778.25	399	257.8852		680.6	1126	727.7663
	778.25	399	257.8852		680.68	1363.6	881.334
	778.27	447	288.909		680.7	1423	919.726
	778.27	447	288.909		680.85	1913.5	1236.75
	778.3	133.4	86.22027		680.9	2084	1346.949
	778.35	704	455.0155		680.9	2084	1346.949
	778.45	1015.5	656.3469		680.94	2229.2	1440.796
	778.45	1015.5	656.3469		TOTAL	21923.1	14169.53
	778.5	1142	738.1075				
	778.6	1512	977.2492	1-Apr-99	680.2	212	137.0217
	778.7	1920	1240.951		680.2	212	137.0217
	779.15	4108.5	2655.442		680.2	212	137.0217
	TOTAL	17096.9	11050.22		680.2	212	137.0217
					680.2	212	137.0217
1-Jun-99	778.01	9.7	6.26939		680.2	212	137.0217
	778.05	48.5	31.34695		680.2	212	137.0217
	778.15	118	76.2668		680.2	212	137.0217
	778.15	118	76.2668		680.2	212	137.0217
	778.15	118	76.2668		680.22	248	160.2896
	778.2	279	180.3257		680.23	266	171.9235
	778.2	279	180.3257		680.25	302	195.1913

EUCHA

DATE	STAGE>778	Q(cfs)	Q(MGD)
	778.2	279	180.3257
	778.2	279	180.3257
	778.22	327	211.3495
	778.25	399	257.8852
	778.25	399	257.8852
	778.3	519	335.4447
	778.3	519	335.4447
	778.3	519	335.4447
	778.3	519	335.4447
	778.37	778	502.8438
	778.62	1593.6	1029.99
	778.8	2360	1525.336
	TOTAL	9460.8	6114.788
1-Jul-99	778.12	133.4	86.22027
	778.12	133.4	86.22027
	778.12	133.4	86.22027
	778.17	224.4	145.0362
	778.2	279	180.3257
	778.2	279	180.3257
	778.25	399	257.8852
	778.3	519	335.4447
	778.32	593	383.273
	778.4	889	574.5863
	778.42	939.6	607.2906
	778.6	1512	977.2492
	778.7	1920	1240.951
	TOTAL	7954.2	5141.029
1-Aug-99	0	0	0
	TOTAL	0	0

SPAVINAW

DATE	STAGE>680	Q(cfs)	Q(MGD)
	680.26	320	206.8252
	680.28	356	230.0931
	680.28	356	230.0931
	680.3	392	253.3609
	680.3	392	253.3609
	680.3	392	253.3609
	680.3	392	253.3609
	680.3	392	253.3609
	680.3	392	253.3609
	680.3	392	253.3609
	680.3	392	253.3609
	680.3	392	253.3609
	680.3	392	253.3609
	680.6	1126	727.7663
	680.8	1743	1126.551
	680.8	1743	1126.551
	681.2	3233	2089.581
	681.6	5032	3252.327
	TOTAL	20553	13284
1-May-99	680.3	392	253.3609
	680.3	392	253.3609
	680.3	392	253.3609
	680.3	392	253.3609
	680.32	435.2	281.2823
	680.35	500	323.1644
	680.36	521.6	337.1251
	680.36	521.6	337.1251
	680.38	564.8	365.0465
	680.4	608	392.9679
	680.4	608	392.9679
	680.4	608	392.9679

EUCHA DATE	STAGE>778	Q(cfs)	Q(MGD)	SPAVINAW DATE	STAGE>680	Q(cfs)	Q(MGD)
					680.4	608	392.9679
1-Sep-99	0	0	0		680.4	608	392.9679
	TOTAL	0	0		680.4	608	392.9679
					680.42	657.4	424.8966
1-Oct-99	0	0	0		680.42	657.4	424.8966
	TOTAL	0	0		680.46	756.2	488.7539
					680.5	855	552.6112
1-Nov-99	0	0	0		680.5	855	552.6112
	TOTAL	0	0		680.5	855	552.6112
					680.5	855	552.6112
1-Dec-99	0	0	0		680.54	953.8	616.4685
	TOTAL	0	0		680.6	1126	727.7663
					680.6	1126	727.7663
1-Jan-00	0	0	0		680.66	1304.2	842.9421
	TOTAL	0	0		680.75	1583	1023.139
					680.8	1743	1126.551
1-Feb-00	0	0	0		680.82	1811.2	1170.631
	TOTAL	0	0		681.14	2991.2	1933.299
					681.5	4551	2941.443
1-Mar-00	0	0	0		TOTAL	30439.6	19673.99
	TOTAL	0	0				
				1-Jun-99	680.12	102.4	66.18407
					680.12	102.4	66.18407
					680.13	116.1	75.03878
					680.18	184.6	119.3123
					680.2	212	137.0217
					680.2	212	137.0217
					680.2	212	137.0217
					680.2	212	137.0217
					680.22	248	160.2896
					680.23	266	171.9235
					680.24	284	183.5574

EUCHA				SPAVINAW			
DATE	STAGE>778	Q(cfs)	Q(MGD)	DATE	STAGE>680	Q(cfs)	Q(MGD)
					680.26	320	206.8252
					680.26	320	206.8252
					680.3	392	253.3609
					680.32	435.2	281.2823
					680.33	456.8	295.243
					680.36	521.6	337.1251
					680.4	608	392.9679
					680.43	682.1	440.8609
					680.44	706.8	456.8252
					680.44	706.8	456.8252
					680.45	731.5	472.7896
					680.5	855	552.6112
					680.5	855	552.6112
					680.52	904.4	584.5398
					680.53	929.1	600.5041
					680.62	1185.4	766.1582
					680.7	1423	919.726
					680.98	2374.4	1534.643
					TOTAL	16558.6	10702.3
				1-Jul-99	680.02	15	9.694933
					680.02	15	9.694933
					680.08	60	38.77973
					680.1	75	48.47466
					680.18	184.6	119.3123
					680.2	212	137.0217
					680.2	212	137.0217
					680.2	212	137.0217
					680.2	212	137.0217
					680.28	356	230.0931
					680.29	374	241.727
					680.3	392	253.3609
					680.3	392	253.3609

EUCHA				SPAVINAW			
DATE	STAGE>778	Q(cfs)	Q(MGD)	DATE	STAGE>680	Q(cfs)	Q(MGD)
					680.3	392	253.3609
					680.3	392	253.3609
					680.31	413.6	267.3216
					680.31	413.6	267.3216
					680.32	435.2	281.2823
					680.36	521.6	337.1251
					680.4	608	392.9679
					680.5	855	552.6112
					680.6	1126	727.7663
					680.7	1423	919.726
					680.84	1879.4	1214.71
					681.6	5032	3252.327
					682.48	9953.8	6433.428
					TOTAL	26156.8	16905.89
				1-Aug-99	0	0	0
					TOTAL	0	0
				1-Sep-99	0	0	
					TOTAL	0	0
				1-Oct-99	0	0	
					TOTAL	0	0
				1-Nov-99	680.01	7.5	4.847466
					680.03	22.5	14.5424
					680.05	37.5	24.23733
					680.05	37.5	24.23733
					TOTAL	105	67.86453
				1-Dec-99	680.05	37.5	24.23733

EUCHA				SPAVINAW			
DATE	STAGE>778	Q(cfs)	Q(MGD)	DATE	STAGE>680	Q(cfs)	Q(MGD)
					680.05	37.5	24.23733
					680.06	45	29.0848
					680.06	45	29.0848
					680.06	45	29.0848
					680.06	45	29.0848
					680.06	45	29.0848
					680.06	45	29.0848
					680.08	60	38.77973
					680.08	60	38.77973
					680.08	60	38.77973
					680.1	75	48.47466
					680.1	75	48.47466
					680.1	75	48.47466
					680.11	88.7	57.32937
					680.14	129.8	83.89349
					680.16	157.2	101.6029
					680.2	212	137.0217
					680.2	212	137.0217
					680.22	248	160.2896
					680.25	302	195.1913
					680.26	320	206.8252
					680.3	392	253.3609
					680.39	586.4	379.0072
					680.39	586.4	379.0072
					680.4	608	392.9679
					680.41	632.7	408.9323
					680.54	953.8	616.4685
					TOTAL	6179	3993.666
				1-Jan-00	680.06	45	29.0848
					680.08	60	38.77973
					680.1	75	48.47466
					680.1	75	48.47466

EUCHA				SPAVINAW			
DATE	STAGE>778	Q(cfs)	Q(MGD)	DATE	STAGE>680	Q(cfs)	Q(MGD)
					TOTAL	255	164.8139
				1-Feb-00	0	0	0
					TOTAL	0	0
				1-Mar-00	680.08	60	38.77973
					680.11	88.7	57.32937
					680.11	88.7	57.32937
					680.12	102.4	66.18407
					680.12	102.4	66.18407
					680.13	116.1	75.03878
					680.16	157.2	101.6029
					680.18	184.6	119.3123
					680.18	184.6	119.3123
					680.19	198.3	128.167
					680.2	212	137.0217
					680.2	212	137.0217
					680.2	212	137.0217
					680.21	230	148.6556
					680.22	248	160.2896
					680.22	248	160.2896
					680.23	266	171.9235
					680.25	302	195.1913
					680.25	302	195.1913
					680.25	302	195.1913
					680.26	320	206.8252
					680.27	338	218.4592
					680.27	338	218.4592
					680.27	338	218.4592
					680.28	356	230.0931
					680.28	356	230.0931
				31-Mar-00	680.28	356	230.0931

EUCHA				**SPAVINAW**			
DATE	**STAGE>778**	**Q(cfs)**	**Q(MGD)**	**DATE**	**STAGE>680**	**Q(cfs)**	**Q(MGD)**
					TOTAL	6219	4019.519

Bibliography

Thomann R. V., J. A. Mueller, 1987. *Principles of Surface Water Quality Modeling and Control,* Harper Collins Pub. Inc., New York, NY, pp. 173-218.

Osborn N. I., R. H. Hardy, L. R. Penderson, R. S. Fabian, *2000, Groundwater Investigation,* Oklahoma Water Resources Board, Oklahoma City, OK., pp. 4-15

Appendix D: Groundwater

Eucha and Spavinaw Clean Lakes Project: Groundwater Investigation

By Noel I. Osborn, Ray H. Hardy, Lisa R. Penderson, and Robert S. Fabian

Oklahoma Water Resources Board

Prepared in cooperation with the City of Tulsa for the

Tulsa Metropolitan Utility Authority

June 2000

Introduction

In response to concerns about nutrient loading in Lake Eucha and Spavinaw Lake, the Oklahoma Water Resource Board (OWRB), in cooperation with the City of Tulsa, conducted a groundwater investigation of the lakes' watershed. To date, most of the research on the lakes has been focused on the surface water component. However, to fully understand the water budget and water quality of the lakes, the groundwater component should also be considered. The purpose of this investigation was to provide a reconnaissance examination of the groundwater component. The study had three objectives:

1. delineate the groundwater recharge area contributing to the lakes,
2. determine the rate of groundwater discharge to the lakes, and
3. describe the general water quality of the groundwater with specific attention to nutrients.

Information gained from this study can then be used to determine the total lake water budget and the lake nutrient budget. If groundwater is determined to be a significant contributor of nutrients to the lake, then further investigation may be necessary.

The study area encompassed two miles beyond the boundary of the surface watershed of the lakes, and was confined to Oklahoma. Although 37% of the surface watershed is in Arkansas, the Oklahoma portion of the watershed was considered adequate for the purposes of this study.

Hydrogeology

PHYSIOGRAPHY

The study area lies within the Springfield Plateau section of the Ozark Plateaus Province, where Mississippian age rocks crop out (Fenneman, 1946). The Ozark Plateaus Province (commonly referred to as the Ozarks) is a geologic uplift that rises above surrounding lowlands. Erosion has cut the limestones and cherty limestones, forming a rugged topography with deep, V-shaped valleys separated by narrow, flat-topped ridges (Marcher and Bingham, 1971).

STRATIGRAPHY

To understand the groundwater flow system, it is necessary to define the geologic framework through which the water moves. This section of the report describes the rock units and aquifers underlying the study area.

The study area overlies rocks ranging from Precambrian to Mississippian age. Figure 1 shows the surface geology of the study area (from Marcher and Bingham, 1971; Marcher, 1969; and Cederstrand, 1996a,b). The Mississippian-age Boone Formation crops out over most of the watershed. Downcutting by Spavinaw Creek has exposed rocks of Devonian and Ordovician age along parts of Spavinaw Creek and along the shores of Lake Eucha/Spavinaw. The oldest exposed rock in the study area is the Spavinaw Granite of Precambrian age that crops out in five

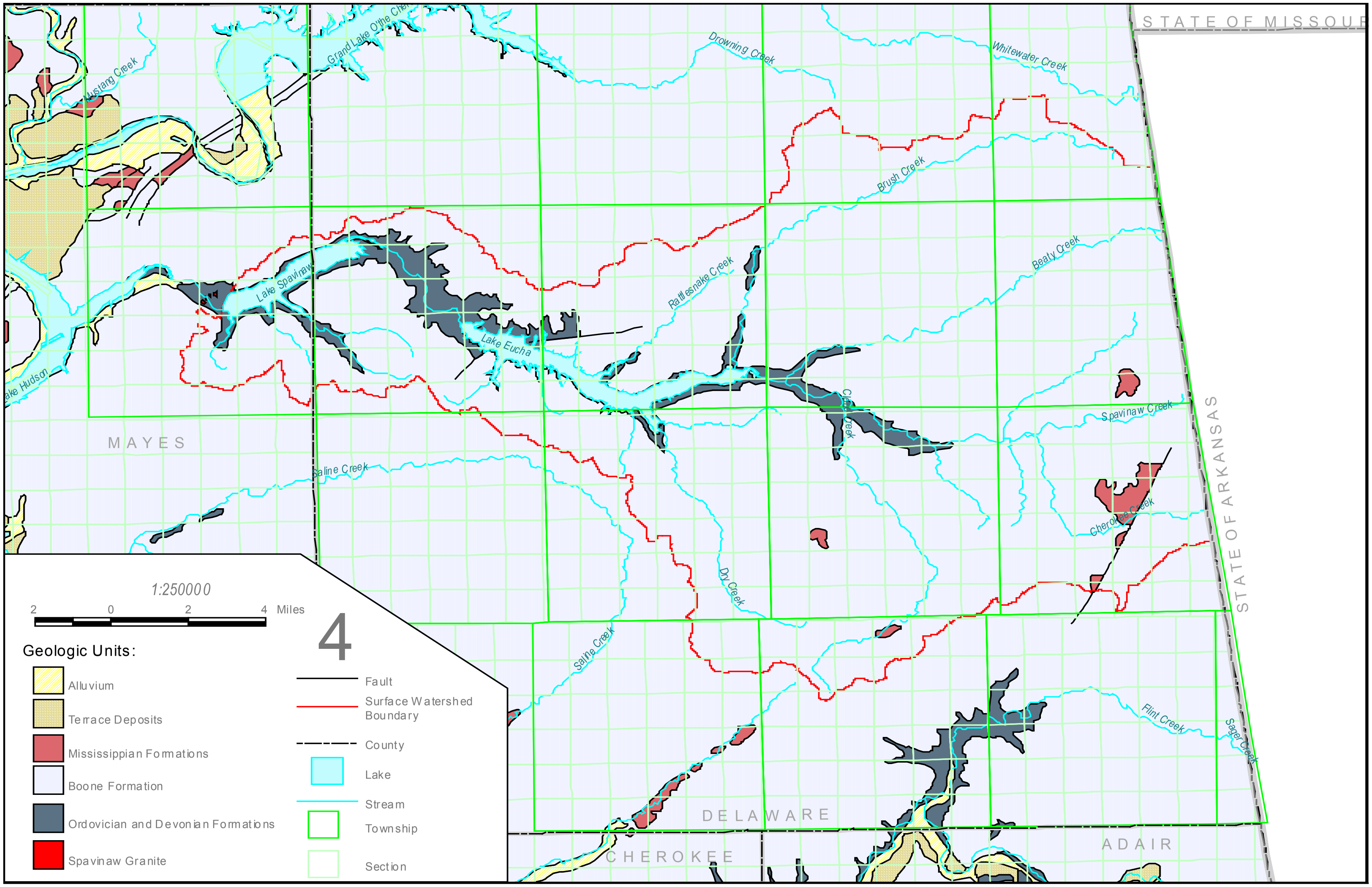


Figure 1. Surface geology of the Lake Eucha/Spavinaw study area.

small hills in the Town of Spavinaw. A stratigraphic column is displayed in Table 1. Below is a brief description of the geologic units.

Table 1. Stratigraphic Column of the Lake Eucha/Spavinaw Study Area

Age (million years ago)	Period	Geologic Unit
0-1.6	Quaternary	Alluvium
1.6-65	Tertiary	Terrace Deposits
325-355	Mississippian	Pitkin Limestone Fayetteville Shale Batesville Sandstone Hindsville Limestone Moorefield Formation
		“Boone Formation”: Keokuk Formation Reeds Spring Formation St. Joe Group
355-410	Devonian	Chattanooga Shale
438-510	Ordovician	Burgen Sandstone Cotter Dolomite Jefferson City Dolomite Roubidoux Formation Gasconade Dolomite
510-570	Cambrian	Eminence Dolomite Potosi Dolomite Doe Run Dolomite Reagan Sandstone Lamotte Sandstone
570-4,500	Precambrian	Precambrian basement rocks, Spavinaw Granite

The basement material underlying the watershed consists of granitic rocks of Precambrian age. The Precambrian surface is very irregular; depth to bedrock ranges from zero, where it outcrops in Spavinaw, to as deep as 3,000 ft (Christenson and others, 1994; Imes and Emmett, 1994).

Overlying the Precambrian surface is a thick sequence of water-bearing dolomite, limestone, and sandstone formations ranging in age from Late Cambrian to Middle Devonian. The primary water-bearing formations are the Gasconade Dolomite, Roubidoux Formation, Jefferson City Dolomite, Cotter Dolomite, and Burgen Sandstone. Because the highest yielding wells are completed in the Roubidoux Formation, the water-bearing units are collectively called the Roubidoux aquifer (Christenson and others, 1994).

The Cotter Dolomite and Burgen Sandstone are exposed along Spavinaw Creek. The Cotter Dolomite consists of dolomite with minor amounts of sandstone, shale, and chert. The Burgen Sandstone rests unconformably upon the irregular Cotter Dolomite surface, and consists of white to light brown, fine-grained, even-bedded sandstone (Reese, 1963).

The Chattanooga Shale overlies the formations comprising the Roubidoux aquifer. The Chattanooga Shale is a black, carbonaceous, fissile shale, 0-80 ft thick. It contains pyrite, phosphate, glauconite, and minor amounts of uranium. This low-permeability shale is a confining layer for the Roubidoux aquifer (Adamski and others, 1995; Christenson and others, 1994).

Overlying the Chattanooga Shale are the Mississippian Keokuk and Reeds Spring formations and the St. Joe Group. These geologic units are commonly called the *Boone Formation*. The rocks consist of highly fractured, fine-grained limestone and massive gray chert, and comprise the Boone aquifer. Secondary mineralization is extensive in the limestones. The Boone Formation is the host rock for the lead and zinc sulfide ores, principally galena and sphalerite, that were mined in Ottawa County.

In a few small areas, the Boone Formation is overlain by younger Mississippian rocks. Geologic units include the Moorefield Formation, Hindsville Limestone, Batesville Sandstone, Fayetteville Shale, and Pitkin Limestone. These rocks consist of alternating sequences of low-permeability shale and low-permeability to permeable limestone, sandstone, and coal (Imes and Emmett, 1994).

Quaternary-age alluvium and terrace deposits occur locally along the rivers and larger streams. These deposits consist of unconsolidated gravel, sand, silt, and clay, and yield small to moderate amounts of water (Marcher and Bingham, 1971).

HYDROLOGY

The study area is underlain by two aquifers: the shallower Boone aquifer and the deeper Roubidoux aquifer. The Boone aquifer discharges to Lake Eucha/Spavinaw and is the primary focus of this investigation.

The Boone aquifer is part of a large groundwater system that encompasses parts of southern Missouri, southeastern Kansas, northeastern Oklahoma, and northern Arkansas. Water in the Boone aquifer is obtained from fractures in the chert and from cavities and solution channels in the limestone. Where the Boone Formation crops out at the surface, the aquifer is unconfined.

Due to its cavernous and fractured nature, the Boone aquifer is considered a karst aquifer. Karst features, such as caves, sinkholes, disappearing streams, and springs, occur where the Boone Formation crops out. These features provide direct conduits for precipitation and runoff to transport contaminants to the water table, making the aquifer highly vulnerable to contamination from surface sources (Osborn and Hardy, 1999). Other characteristics common to karst aquifers are the rapid recharge rate and groundwater flow rate. Water levels in wells and discharge from springs can increase rapidly after a rainstorm.

The water table surface of the Boone aquifer generally reflects the surface topography. Groundwater flows laterally from topographic highs to streams, where it discharges to springs and seeps. Locally, groundwater flow can cross topographic divides, making determination of the groundwater watersheds for lakes and springs difficult (Adamski and others, 1995). The regional flow is westward toward the Grand River.

Recharge to the Boone aquifer is almost entirely from infiltration of precipitation in areas where the Boone Formation crops out. Precipitation may infiltrate the unsaturated zone quickly because soil and subsoil in the Ozarks is thin, near-surface faults and fracture systems are common, and dissolution of the carbonate rocks is widespread. Although slopes are often steep, the trees, grass, and other vegetation hold the water, reducing the loss through runoff. Sinkholes can take large amounts of water from disappearing streams (Reed and others, 1955).

Dugan and Peckenpaugh (1986) estimated the amount of recharge to the water table based on climate, soil type, slope, land use, and consumptive water use by crops and vegetation. They estimated the mean annual groundwater recharge in the Oklahoma portion of the Ozarks to be about 10 inches. Imes and Emmett (1994) used a regional groundwater flow model of the Ozark Plateaus aquifer system to determine that 25% of the mean annual precipitation recharges the Boone aquifer. The average annual precipitation in Delaware County ranges from 44 to 46 inches (Oklahoma Climatological Survey, 1997). Assuming an average annual precipitation of 45 inches, groundwater recharge in the study area is about 11 inches per year (in/yr).

Most of the aquifer's porosity and permeability result from fracturing of the chert and dissolution of the limestone. The distribution of porosity and permeability is very heterogeneous, and varies widely. Using a regional groundwater flow model of the Ozark Plateaus aquifer system, Imes and Emmett (1994) estimated an average hydraulic conductivity of the Boone aquifer of about 22 ft/day, and a specific yield of 0.07. Within the study area, the thickness of the aquifer ranges from zero, where it is absent from erosion, to about 200 ft.

WATER QUALITY

In areas where the Boone Formation crops out, water type in the aquifer is calcium bicarbonate, resulting from dissolution of carbonate rocks. Dissolved solids concentrations are generally within the range of 100-300 milligrams per liter (mg/L). Chloride and sulfate concentrations are generally less than 10 mg/L (Imes and Davis, 1991; Imes and Emmett, 1994).

Calcium bicarbonate is also the most common water type in the Roubidoux aquifer. The dissolved solids content is least (<200-300 mg/L) along the regional groundwater divides and is greatest (>400 mg/L) toward the discharge areas. Regional water quality maps of the Roubidoux aquifer indicate that in the Lake Eucha/Spavinaw watershed dissolved solids concentrations range from less than 200 to about 300 mg/L. Chloride concentrations generally are less than 10 mg/L. Sulfate concentrations generally are less than 20 mg/L, and in the Lake Eucha/Spavinaw watershed, they are less than 10 mg/L (Imes and Davis, 1991).

The U.S. Geological Survey (USGS) conducted a water-quality study of the Ozark Plateaus aquifer system as part of the National Water Quality Assessment (NAWQA) Program. The study unit encompasses parts of Oklahoma, Arkansas, Kansas, and Missouri and includes the Springfield Plateau (Boone) and Ozark (Roubidoux) aquifers. A total of 229 groundwater samples were collected from 215 springs and wells from 1993 through 1995. Samples were collected from the unconfined portions of the Boone and Roubidoux aquifers (Adamski, 1997; Peterson and others, 1998).

Results from the study indicate that the water quality of the Boone aquifer is susceptible to surface contamination and is being affected by increased concentrations of nitrate and the presence of pesticides. Elevated concentrations of nitrate in groundwater of the Boone aquifer are widespread, particularly in areas where land use is predominantly agricultural. However, very few samples exceeded EPA's drinking-water standard of 10 mg/L. Pesticides were detected in 18 of 36 (50 percent) samples from the Boone aquifer (Peterson and others, 1998).

Adamski (1977) determined background concentrations of nutrients in the Boone and Roubidoux aquifers in samples collected from 25 relatively pristine sites. Background concentrations were determined to be as follows: nitrite plus nitrate was 0.98 mg/L; nitrite was less than 0.01 mg/L; ammonia was 0.02 mg/L; and phosphorus was 0.02 mg/L. The median nitrate concentration from samples collected from wells in the Boone aquifer was 1.0 mg/L, and the median phosphorus concentration was 0.01 mg/L (Adamski, 1997).

Samples from 61 springs and 50 wells in the Boone aquifer were analyzed for tritium (^3H) concentrations to determine the age of recharge. Samples from all springs and from 36 wells had detectable concentrations of tritium, indicting that some portion of the water was recharged to the groundwater system in the past 40 years. Fifty-eight of the samples appear to represent water that recharged 2 to 6 years prior to sample collection (Adamski, 2000).

Adamski (2000) concluded that the young age for most groundwater samples is consistent with other geochemical findings from the NAWQA study. The relatively high dissolved oxygen concentrations of most groundwater samples (median of 7.1 mg/L) indicate rapid recharge or short residence time. Groundwater samples generally had low calcite saturation indices ($\leq$ -0.1) and high partial pressure of carbon dioxide ($\geq 10^{-2}$ atm), indicating rapid flow through large conduits and/or having short flow paths.

GROUNDWATER PRODUCTION

Wells in the Boone and Roubidoux aquifers typically have an open-borehole construction; they have surface casing, and are then left open. Well screens or perforations are not required because the geologic units are competent enough that the well bore stays open without casing. Wells that are not cased through the Boone, and that are drilled into the underlying Roubidoux aquifer produce water that is a mixture of Boone and Roubidoux waters.

Most of the wells in the Boone aquifer are used for domestic purposes, although some are used for agriculture (such as poultry operations), commercial, and public supply purposes. Water wells yield between 0.3 and 100 gallons per minute (gpm), with most wells yielding less than 25 gpm. At the time of this study, the Oklahoma Water Resources Board had drillers' logs for 390 water wells located within the Lake Eucha/Spavinaw watershed. Of these 390 wells, about 140 appear to be completed in the Boone aquifer; the remainder are completed in the deeper Roubidoux aquifer, or a combination of the two aquifers.

GROUNDWATER-SURFACE WATER INTERACTION

The groundwater contribution to streams and lakes is variable. Some systems are dominated by groundwater flow and others by runoff from precipitation; most are a combination of groundwater and precipitation. The primary factors affecting the interaction of groundwater with surface water are the physiography of the land surface, climate, and permeability of the geologic materials (Winter, personal communication).

The USGS estimated the groundwater component of streamflow for 54 streams using hydrograph separation methods. The selected streams represented 24 regions in the United States, delineated on the basis of physiography and climate. Daily streamflow values for the 30-year period, 1961-1990, were used for the analysis of each stream. Groundwater contributions ranged from 14-90 percent of the streamflow, and the median was 55 percent (Winter and others, 1999). Analysis of two streams in the Ozark region indicated that groundwater contributed about 50 percent of the streamflow (Winter, personal communication).

Groundwater Flow

ASSUMPTIONS

In conducting this study, the following assumptions of groundwater-surface water interaction in the Lake Eucha/Spavinaw watershed were made:

1. Groundwater discharges directly to the lake and to streams, springs, and seeps that flow into the lakes, resulting in gaining streams.
2. Seepage from the lakes into the underlying aquifers is negligible.
3. Most of the groundwater contribution is from the shallower Boone aquifer.

Streams in the watershed gain water from groundwater runoff, and are referred to as gaining streams. Although some stream reaches lose water to the underlying aquifers, causing them to disappear, the lost water resurfaces downstream (Chichester, personal communication).

Seepage from the lake into the underlying aquifer may occur. However, this is assumed to be negligible because of the steep hydraulic gradient toward the lakes, and because the underlying pinnacle of Precambrian granite below the Spavinaw dam would limit flow into the aquifer from the downslope side of the lakes.

At least some groundwater from the underlying Cotter Dolomite discharges to the lakes and streams where the Boone and Chattanooga Shale have been removed by erosion. It is assumed that this groundwater is in communication with the shallower Boone aquifer, and follows shallow, local flow paths. Little is known about the hydrologic heads of the deeper Roubidoux aquifer. It is possible that groundwater from the deeper, more regional system, also discharges to the lakes and streams.

WATER-LEVEL MAP

Water depth was measured in 34 water wells January 25-28, 1999. Twenty-eight of the wells were completed in the Boone aquifer, and the remaining six were completed in the Roubidoux aquifer. The locations and surface elevations of the wells and five springs were determined using a Trimble Pathfinder Pro-XR Global Positioning Survey (GPS) unit. Table 2 lists the site information of the springs that were measured, and Table 3 lists the site information and water-level elevations of measured wells. Well and spring locations are shown in Figure 2.

Table 2. Site Information on Measured Srings

Site ID	Spring Name	Legal Location			Latitude	Longitude	Aquifer	Surface Elevation (ft)
		Section	Township	Range				
SP02	Mason Spring	35	23N	22EI	36.424786	-94.924644	Boone	907.26
SP03	Bowles Spring	11	22N	24EI	36.398582	-94.707451	Boone	997.28
SP11	Spavinaw Roadside Park	15	22N	21EI	36.387981	-95.048241	Roubidoux	665.44
SP12	Buzzard Spring	4	22N	23EI	36.419613	-94.859116	Boone	961.86
SP13	Sycamore Spring	12	22N	24EI	36.401485	-94.688774	Boone	999.80
SP21	Blevins Spring	10	21N	23EI	36.316807	-94.836296	Boone	816.70
SP22	Colcord Spring	27	21N	24EI	36.264023	-94.725197	Boone	1117.25

Water-level elevations from 28 wells completed in the Boone aquifer and from springs and streams that discharge water from the aquifer were used to construct a water-level map. To supplement the water-level measurements from wells and springs collected in the field, water-level elevations were derived from 17 drillers' logs and from streams that discharge water from the aquifer. Surface elevations were determined from the Digital Elevation Model (DEM). Also used were the elevations of about 50 springs that were obtained from the USGS database.

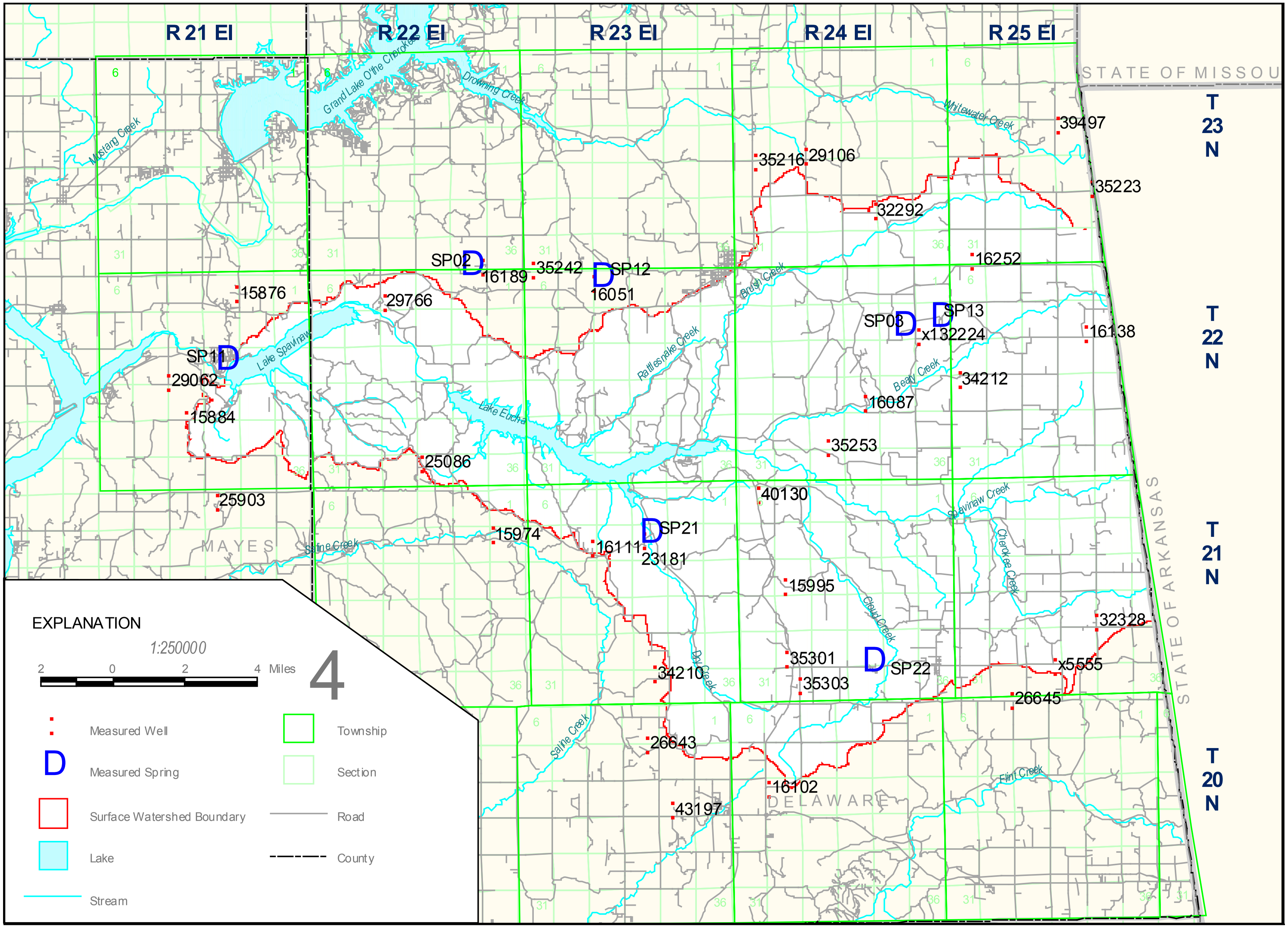
A water-level elevation contour map of the Boone aquifer was generated with ARC/INFO Geographic Information Systems (GIS) software, and is shown in Figure 3. Groundwater flows perpendicular to the water-level contours, from high to low elevations. As illustrated in Figure 3, groundwater in the Lake Eucha/Spavinaw watershed flows toward the streams and lakes, where it discharges.

As determined from the water-level map, the hydraulic gradient (slope of the water table) varies across the study area, from about 21 ft/mi (0.004) along the flat-topped ridges to about 105 ft/mi (0.02) in the steep valleys. The regional hydraulic gradient of the study area was calculated to be about 26 ft/mi, or 0.005.

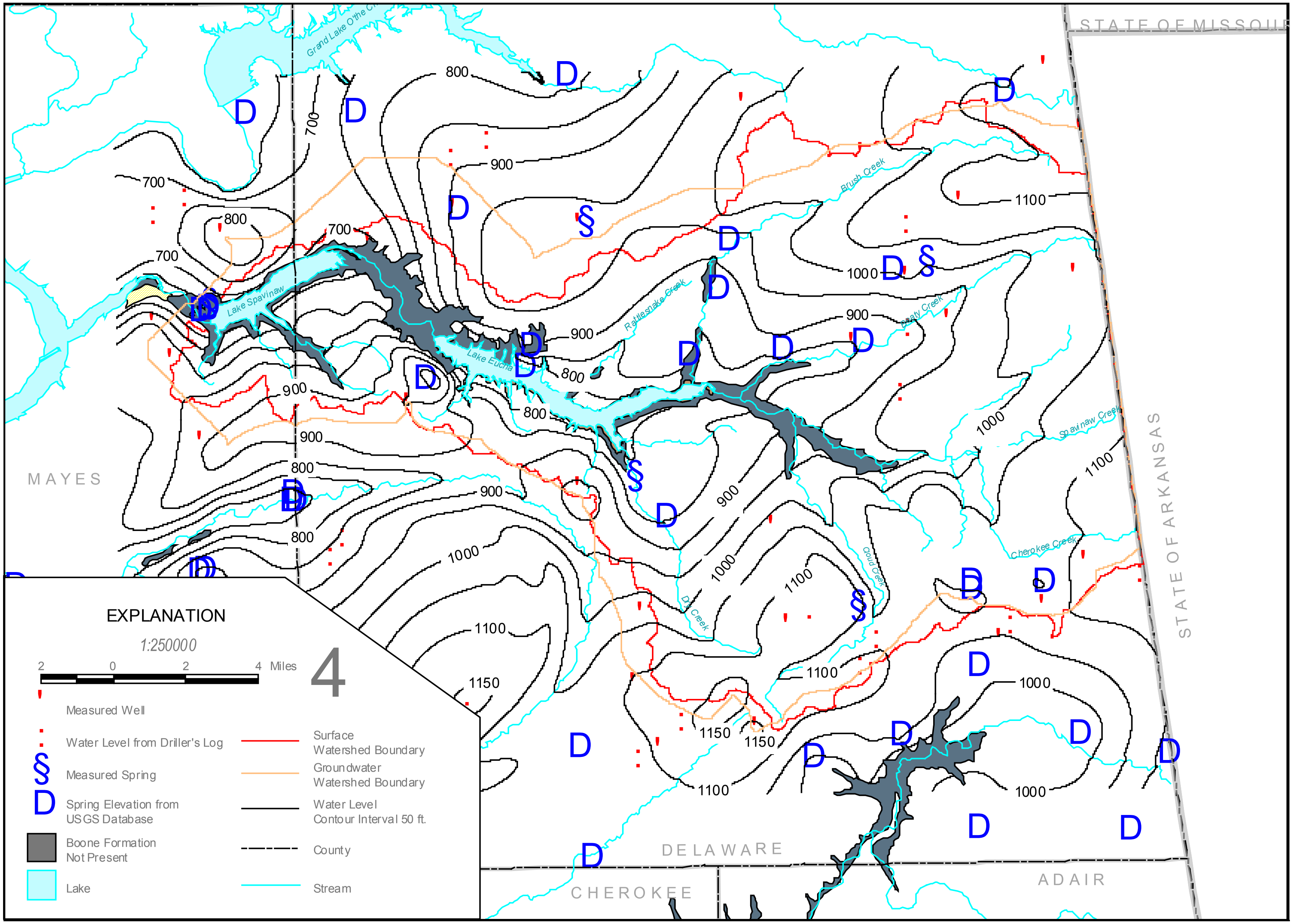
Groundwater velocity can be calculated by multiplying the hydraulic gradient by the hydraulic conductivity, and dividing by the average porosity (Driscoll, 1986). Assuming a regional hydraulic gradient of 0.005, an average hydraulic conductivity of 22 ft/day, and an average

Table 3. Site Information and Water Level Measurements for Measured Wells

Site ID	Well Owner	Legal Location Section	Township	Range	Latitude	Longitude	Aquifer	Date Measured	Well Depth (ft)	Surface Elevation (ft)	Depth to Water (ft)	Water Level Elevation (ft)
15876	Ellis Q.Summers	3	22N	21EI	36.414268	-95.042046	Boone	01/25/1999	179	861.32	29.70	832
15884	RC Owen	28	22N	21EI	36.364681	-95.067978	Boone	01/25/1999	143	923.01	88.85	834
15974	Annie Loy	12	21N	22EI	36.316826	-94.914497	Roubidoux	01/27/1999	244	882.93	92.58	790
15995	Andy Foreman	17	21N	24EI	36.294838	-94.767754	Boone	01/26/1999	125	1101.53	66.13	1035
16051	Glenda Gibe	4	22N	23EI	36.416939	-94.862389	Boone	01/27/1999	143	1065.99	94.11	972
16087	Piney Baptist Church	22	22N	24EI	36.367661	-94.726616	Boone	01/26/1999	118	871.70	29.29	842
16102	Velda Partain	17	20N	24EI	36.214249	-94.777428	Boone	01/27/1999	80	1207.91	48.38	1160
16111	Elizabeth Tagg	8	21N	23EI	36.311150	-94.864525	Boone	01/27/1999	143	1046.14	54.24	992
16138	Justin Chastain	15	22N	25EI	36.394463	-94.614815	Boone	01/26/1999	148	1071.02	42.22	1029
16188	Wilber Mason	35	23N	22EI	36.423420	-94.924988	Boone	01/25/1999	148	972.48	51.78	921
16252	Duane Cearley	31	23N	25EI	36.423969	-94.671967	Boone	01/26/1999	138	1141.80	45.65	1096
23181	Howard Mouse	10	21N	23EI	36.313751	-94.838501	Roubidoux	01/27/1999	208	859.64	59.09	801
25086	Deloris Gilley	34	22N	22EI	36.345787	-94.949585	Boone	01/27/1999	163	976.97	31.06	946
25903	Mary Boney	3	21N	21EI	36.331177	-95.052841	Boone	01/25/1999	203	941.76	42.03	900
26643	Gregory Carnell	10	20N	23EI	36.232292	-94.837845	Boone	01/27/1999	106	1185.38	82.24	1103
26645	Preston Osbourn	4	20N	25EI	36.248402	-94.654861	Boone	01/26/1999	103	1061.35	28.19	1033
29062	Kenneth Eagles	21	22N	21EI	36.379433	-95.076408	Boone	01/25/1999	100	852.85	40.68	813
29106	Mike Honewell	21	23N	24EI	36.466728	-94.754852	Roubidoux	01/27/1999	423	1089.56	105.49	984
29766	Bob Mooney	4	22N	22EI	36.410366	-94.967606	Roubidoux	01/25/1999	150	733.79	46.98	687
32292	Coleman Blevins	27	23N	24EI	36.444347	-94.720299	Boone	01/27/1999	183	1086.16	55.49	1031
32328	Renda Harrison	23	21N	25EI	36.279194	-94.611565	Boone	01/28/1999	123	1164.98	39.25	1126
34210	Lula Sixkiller	34	21N	23EI	36.260456	-94.833885	Boone	01/27/1999	123	1075.85	33.28	1043
34212	Rusty DeMoss	19	22N	25EI	36.376617	-94.678856	Boone	01/26/1999	155	954.24	9.42	945
35216	Andrew Warren	19	23N	24EI	36.464920	-94.779671	Boone	01/27/1999	100	1029.90	31.13	999
35223	Gary Chastain	26	23N	25EI	36.452263	-94.610649	Boone	01/26/1999	111	1145.70	21.22	1124
35242	Danniel Wiese	6	22N	23EI	36.422756	-94.892616	Roubidoux	01/25/1999	395	1038.27	96.01	942
35253	Alfred Hutchison	33	22N	24EI	36.350540	-94.745087	Roubidoux	01/26/1999	387	1098.46	188.40	910
35301	Ken Lessard	29	21N	24EI	36.265850	-94.767532	Boone	01/27/1999	150	1209.87	47.39	1162
35303	Dale Jackson	32	21N	24EI	36.255169	-94.761032	Boone	01/26/1999	227	1168.56	41.25	1127
39497	Julie Michels	15	23N	25EI	36.477921	-94.627937	Boone	01/27/1999	100	1157.77	44.16	1114
40130	Larry O'Leary	7	21N	24EI	36.331497	-94.780785	Boone	01/26/1999	210	1041.29	32.68	1009
43197	VFW Post 10596	14	20N	23EI	36.205971	-94.825630	Boone	01/26/1999	52	1147.96	34.22	1114
x132224	Carl Palm	13	22N	24EI	36.394348	-94.698868	Boone	01/26/1999	90	1024.42	31.05	993
x5555	Shawn Kustanborter	33	21N	25EI	36.261543	-94.632721	Boone	01/28/1999	103	1122.09	26.95	1095



A Figure 2. Map showing locations of measured wells and springs.



A Figure 3. Water level map of the Boone aquifer from wells measured in January 1999.

porosity of 0.07 (specific yield), average groundwater velocity over the study area was calculated to be about 1.6 ft/day.

GROUNDWATER WATERSHED

Just as the surface watershed is the area throughout which surface water drains into Lake Eucha and Spavinaw Lake, the groundwater recharge area, or watershed, is the area throughout which groundwater drains into the lakes. In karst aquifers the groundwater watershed might or might not coincide with the surface watershed. The boundary of the groundwater watershed was determined from the water-level elevation map in the same manner as the boundary of the surface watershed was determined from a topographic map. ARC/INFO Grid software was used to determine the up-gradient area that contributes groundwater runoff to the Spavinaw Dam. (For more information on delineating watershed boundaries, refer to Sanders, 1998.)

As illustrated in Figure 3, the groundwater watershed (shown in orange) closely corresponds to the surface watershed (shown in red). The largest deviation is north of Spavinaw Lake, where the groundwater watershed extends about two miles beyond the surface watershed. However, there are an insufficient number of measurement points in this area to determine whether the deviation is real.

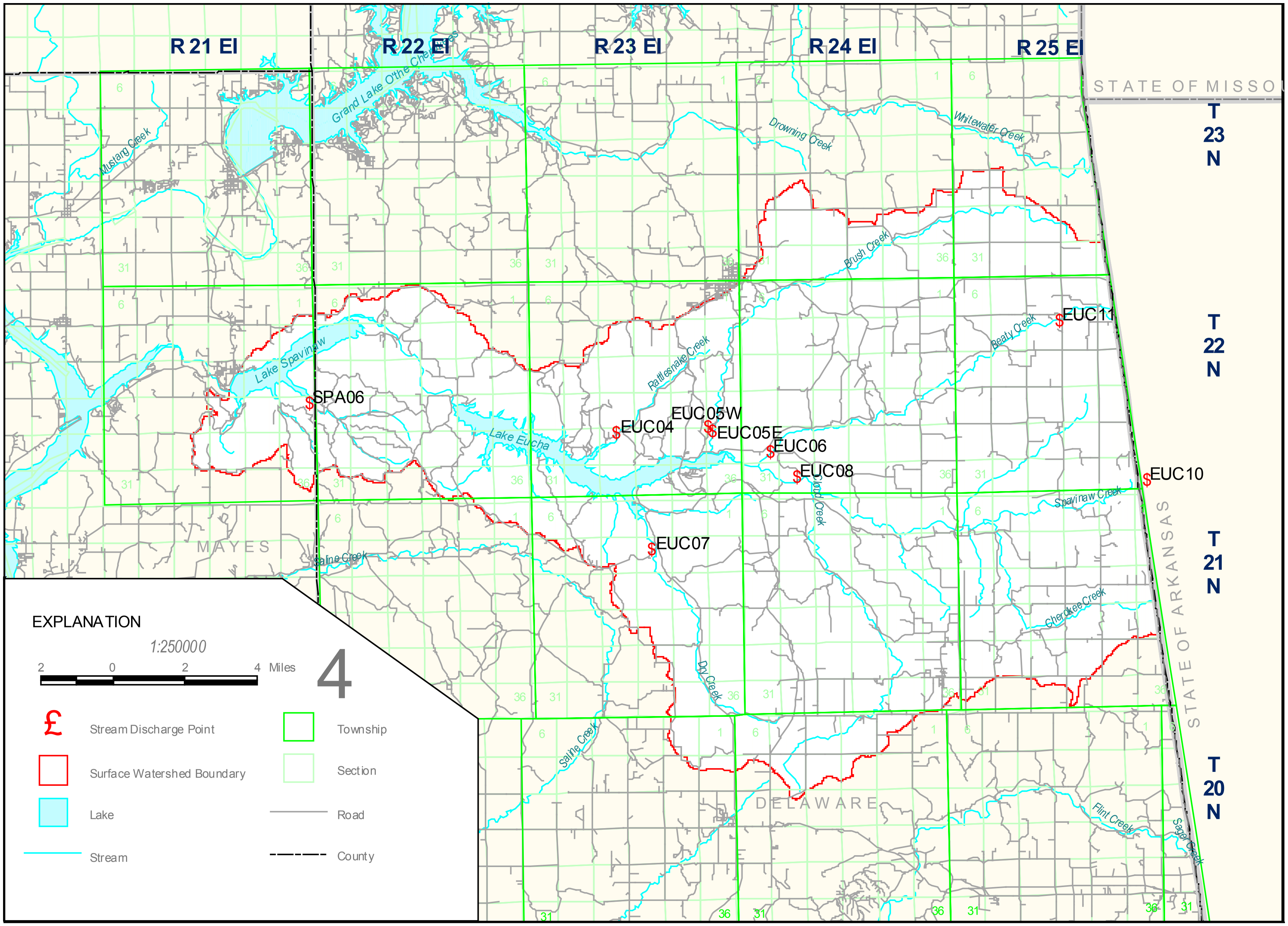
The area of the Oklahoma portion of the groundwater watershed is 272 mi^2. A water-level map from which the groundwater watershed could be determined was not created for the Arkansas portion. However, assuming the groundwater watershed approximates the surface watershed, as is the case in the Oklahoma portion, the groundwater watershed in Arkansas is about 143 mi^2. The total groundwater watershed area for Lake Eucha/Spavinaw is estimated to be about 415 mi^2.

GROUNDWATER DISCHARGE

Base flow is the flow supplied by groundwater to the lakes and streams. To determine base flow, discharge is measured at discrete points along perennial streams during low flow conditions, when surface runoff is minimal. Stream discharge was measured at nine sites along six perennial streams with a portable flow meter. The measurements were taken in February, when evapotranspiration and well pumpage were at a minimum, and during low flow conditions. Table 4 lists the measurement sites, location information, and the discharge measurements. Site locations are shown in Figure 4.

Table 4. Site Information and Flow Rates for Stream Discharge Measurements

Site ID	Location Description	Date	Flow (cfs)
EUC11	Beaty Creek near Arkansas border	02/25/1999	13.84
EUC06	Beaty Creek near confluence with Spavinaw Creek	02/24/1999	35.35
EUC08	Spavinaw Creek near confluence with Beaty Creek	02/25/1999	114.31
EUC10	Spavinaw Creek near Arkansas border	02/25/1999	55.62
EUC05E	Brush Creek near Lake Eucha, east branch	02/24/1999	6.00
EUC05W	Brush Creek near Lake Eucha, west branch	02/24/1999	4.40
EUC07	Dry Creek near Lake Eucha	02/24/1999	8.65
EUC04	Rattlesnake Creek near Lake Eucha	02/25/1999	0.95
SPA06	Black Hollow near Spavinaw Lake	02/25/1999	2.92



A Figure 4. Map showing locations of stream discharge measurement sites.

The discharge at Beaty Creek near the confluence of Spavinaw Creek (35.35 cubic feet per second, or cfs, at site EUC06) was greater than the discharge at Beaty Creek near the Arkansas border (13.84 cfs at site EUC11). This indicates that Beaty Creek was gaining groundwater runoff from the aquifer at a rate of 21.51 cfs in the Oklahoma portion of the groundwater watershed.

Similarly, the discharge at Spavinaw Creek near the confluence with Beaty Creek (114.31 at site EUC08) was greater than the discharge at Spavinaw Creek near the Arkansas border (55.62 at siteEUC10), indicating that Spavinaw Creek gained 58.69 cfs in the Oklahoma portion of the groundwater watershed. Cherokee Creek, which originates in Arkansas, flows into Spavinaw Creek between the two measurement sites. The discharge at Cherokee Creek near the Arkansas border was not measured, so an unknown portion of this gain was contributed from Cherokee Creek in Arkansas.

The discharge at Brush Creek near Lake Eucha (sites EUC05E and EUC05W) was 10.40 cfs. Because Brush Creek originates within the Oklahoma portion of the groundwater watershed, this represents the total groundwater contribution to Brush Creek. Discharge at the other sites (0.95 cfs at EUC04, 8.65 cfs at EUC07, and 2.92 cfs at SPA06) derives from groundwater flow within the Oklahoma portion of the groundwater watershed. The total groundwater contribution to the measured streams in the Oklahoma portion of the groundwater watershed was 102.12 cfs.

Streamflow from Arkansas into the groundwater watershed is primarily from Beaty, Spavinaw, and Cherokee Creeks. The discharge at Beaty Creek near the Arkansas border was 13.84 cfs, and represents the groundwater contribution to Beaty Creek from the Arkansas portion of the groundwater watershed. The discharge at Spavinaw Creek near the Arkansas border was 55.62 cfs. This includes the groundwater contribution to Spavinaw Creek from the Arkansas portion of the groundwater watershed plus some municipal wastewater discharged from the cities of Decatur and Gravette. In February 1999, Decatur discharged 1.3-2.2 million gallons per day (MGD) of wastewater and Gravette discharged 0.32-0.38 MGD (AEDS, 1999). The maximum discharge rate in February from the two cities was no greater than 2.58 MGD, or 4 cfs. The wastewater component (4 cfs) was subtracted from the discharge measurement (55.62 cfs), resulting in 51.62 cfs groundwater contribution to Spavinaw Creek from Arkansas.

The total groundwater contribution to Beaty and Spavinaw Creeks from Arkansas was 65.46 cfs. The discharge from Cherokee Creek near the Arkansas border was not measured, so the total groundwater contribution from streams flowing from Arkansas is slightly larger.

The groundwater watersheds of the measured streams were determined from the water-level map. The area of the watersheds of the measured streams in Oklahoma was calculated to be 182 mi^2. In addition to discharging to the streams that were measured, groundwater discharges to seeps, springs, and small streams within the groundwater watershed that were not measured. Within the 272-mi2 watershed in Oklahoma, an additional 90 mi^2 contributes groundwater to the lakes that was not accounted for by discharge measurements.

By linear extrapolation, the groundwater discharge from 272 mi^2 of the groundwater watershed in Oklahoma was calculated to be 152.62 cfs. Added to the 65.46 cfs groundwater discharged from the estimated 143 mi^2 in the Arkansas portion, the total groundwater discharged to Lake Eucha/Spavinaw from the 415-mi^2 groundwater watershed was calculated to be 218.08 cfs, or about 433 acre-feet per day.

Under equilibrium conditions, water should discharge to streams at about the same rate as the aquifer receives recharge from precipitation. Because the discharge measurements were taken in February, when discharge to wells and evapotranspiration was at a minimum, the aquifer was assumed to be in equilibrium. The recharge rate was estimated by dividing the base-flow (218.08 cfs) by the drainage area (415 mi^2), resulting in a recharge rate of 7.13 in/yr. This recharge rate is about 16 percent of the 45-in/yr average annual precipitation for the study area, which is less than the 25 percent for the Ozark region determined by Imes and Emmett (1994).

Base flow varies annually and seasonally. Base flow increases with rises in groundwater levels and decreases with declines in groundwater levels. The highest groundwater levels generally occur during the spring, when recharge is high, and during the winter, when evapotranspiration and well pumpage are low. Conversely, groundwater levels are lowest in the summer when evapotranspiration and well pumpage are high. Thus, the calculated discharge rates represent the winter groundwater conditions during 1999. The groundwater discharge rate may vary somewhat from year to year, and may be significantly lower during the summer months.

The calculated discharge rate is based on the assumptions of groundwater flow discussed above. Potential errors may have been introduced during collection of discharge measurements and in determination of the groundwater watershed.

Water Quality

WATER QUALITY SAMPLES

Water samples were collected August 16-18 from a sampling network of 11 domestic wells and 5 springs within the study area. Sites were selected and sampled in accordance with the Quality Assurance Project Plan and the OWRB Standard Operating Procedures. The locations and surface elevations of all sampling sites were determined with a Trimble Pathfinder Pro-XR GPS unit. Site information on the sampled wells and springs are listed in Table 5, and site locations are shown in Figure 5. Spring sites are distinguished by their site identifier, which begins with "SP".

All of the wells sampled were completed in the Boone aquifer. One well (X5555) did not have a well driller's log. However, this well replaced an adjacent well that did have a driller's log, and was assumed to have similar construction and lithology. Four of the sampled springs discharge from the Boone aquifer, and the Spavinaw Roadside Spring (SP11) discharges from the underlying Cotter Dolomite. There were no known potential sources of contamination within 100 feet of the sampling sites.

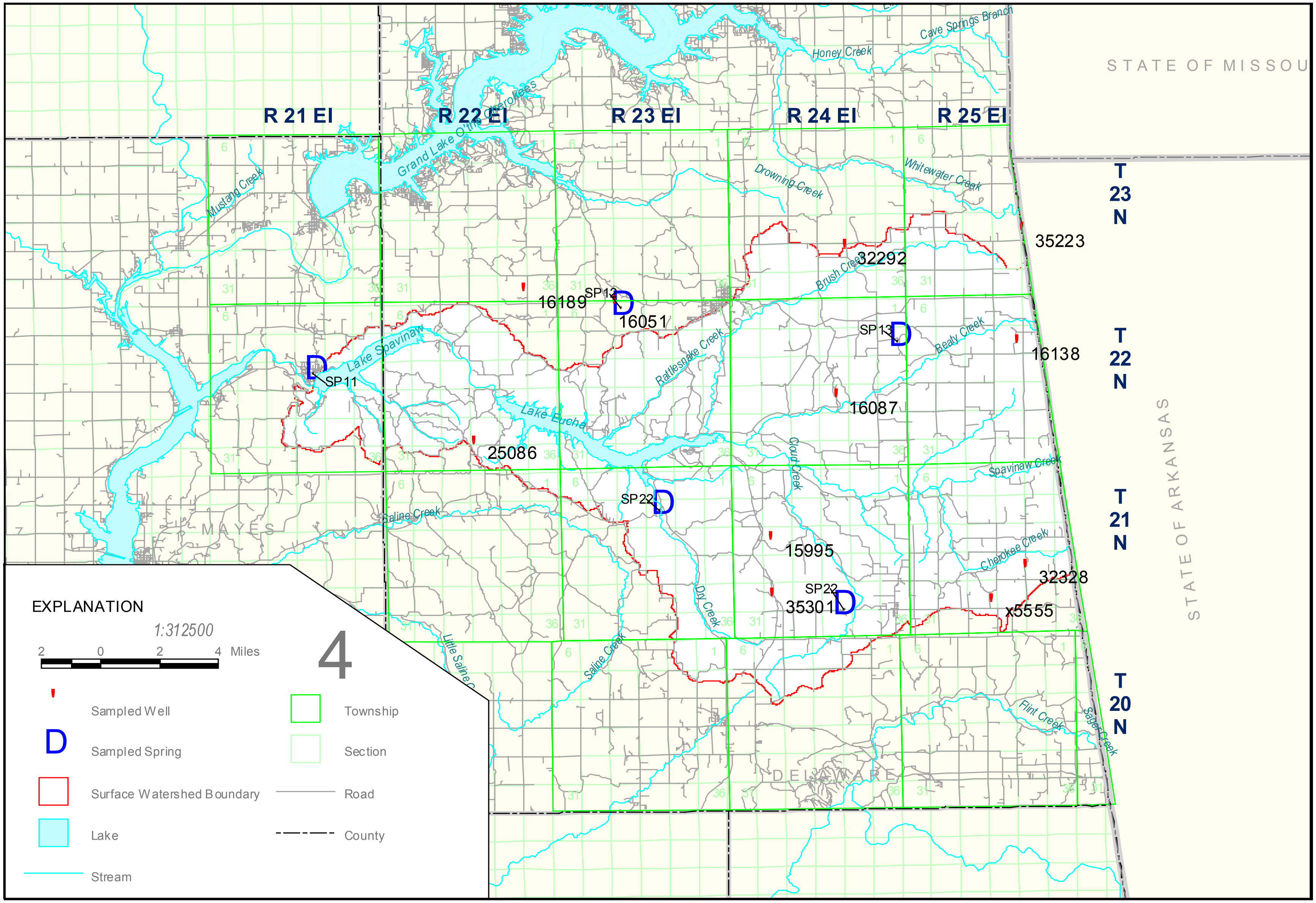


Figure 5. Map showing locations of sampled wells and springs.

AI

Wells and springs were selected to obtain a statistical representation of the water quality of the groundwater contributing to Lake Eucha/Spavinaw. However, because the network consists of existing wells and springs, it is impossible to remove all sampling biases. Samples may be biased because wells and springs were not equally distributed throughout the study area. Land use and well construction can also bias the data. Although sites near possible sources of contamination were avoided, land use was not used as a criterion for site selection.

Table 5. Site Location of Sampled Wells and Springs

Site ID	Well Owner or Spring Name	Legal Location			Latitude	Longitude	Well Depth (ft)
		Section	Township	Range			
15995	Andy Foreman	17	21N	24EI	36.294838	-94.767754	125
16051	Glenda Gibe	04	22N	23EI	36.416939	-94.862389	143
16087	Piney Baptist Church	22	22N	24EI	36.367661	-94.726616	118
16138	Justin Chastain	15	22N	25EI	36.394463	-94.614815	148
16189	Andy Evans	35	23N	22EI	36.424175	-94.917641	118
25086	Deloris Gilley	34	22N	22EI	36.345787	-94.949585	163
32292	Coleman Blevins	27	23N	24EI	36.444347	-94.720299	183
32328	Renda Harrison	23	21N	25EI	36.279194	-94.611565	123
35223	Gustabo Hernandez	26	23N	25EI	36.452263	-94.610649	111
35301	Ken Lessard	29	21N	24EI	36.265850	-94.767532	150
X5555	Shawn Kustanboro	33	21N	25EI	36.261543	-94.632721	103
SP11	Spavinaw Roadside Park	15	22N	21EI	36.387981	-95.048241	---
SP12	Buzzard Spring	04	22N	23EI	36.419613	-94.859116	---
SP13	Sycamore Spring	12	22N	24EI	36.401485	-94.688774	---
SP21	Blevins Spring	10	21N	23EI	36.316807	-94.836296	---
SP22	Colcord Spring	27	21N	24EI	36.264023	-94.725197	---

Water samples were collected from domestic wells using existing submersible pumps. Specific conductance, pH, dissolved oxygen, and water temperature were measured continuously during the pumping process with a Hydrolab H-twenty Multiparameter Data Recording Sonde. The well was considered purged when a minimum of one well volume had been pumped and the field parameters had stabilized. Samples were placed on ice immediately after collection. Within 24 hours of collection, the samples were filtered through a 0.45 μm-filter to remove suspended sediments. The filtered samples were tested for alkalinity with a sulfuric acid titration. Appropriate preservatives were then added to the remaining samples.

Water samples were analyzed at the Oklahoma City/County laboratory for common ions (calcium, chloride, magnesium, potassium, sodium, and sulfate), total dissolved solids, dissolved silica, trace elements (barium, iron, manganese, and zinc), and nutrients (total phosphorus, nitrate as N, nitrite as N, and ammonia as N). Table 6 lists the physical properties and concentrations chemical constituents in water samples from the wells and springs.

Table 6. Measurements of Physical Properties and Concentrations of Chemical Constituents in Water Samples from Wells and Springs

Site ID	Date Sampled	pH (units)	Temperature (°C)	Specific Conductance (uS/cm)	Dissolved Oxygen (mg/L)	Alkalinity (mg/L)	TDS (mg/L)	Total Phosphorus (mg/L)	Nitrate as N (mg/L)	Nitrite as N (mg/L)	Ammonia as N (mg/L)	Calcium (mg/L)	Magnesium (mg/L)
15995	08/17/1999	9.03	16.82	754	5.91	46	564	0.005	0.15	<0.005	<0.030	53.0	3.56
16051	08/17/1999	6.61	15.97	83	5.00	104	140	0.022	0.77	<0.005	<0.030	38.5	0.64
16051B	08/17/1999	6.61	15.97	83	5.00	103	137	0.023	0.77	<0.005	<0.030	39.7	0.50
16087	08/17/1999	7.08	16.95	272	1.36	121	177	0.034	2.59	0.064	<0.030	47.5	1.79
16138	08/16/1999	7.28	16.14	352	0.03	177	203	0.007	0.10	0.096	<0.030	62.0	1.40
16189	08/16/1999	6.40	15.80	141	5.04	61	90	0.013	0.45	<0.005	<0.030	29.9	0.66
25086	08/17/1999	5.75	17.99	375	6.23	174	222	0.044	0.21	<0.005	<0.030	62.7	0.84
32292	08/16/1999	7.04	16.47	441	2.26	221	274	0.023	2.09	<0.005	<0.030	61.8	7.00
32328	08/16/1999	6.30	15.29	363	0.99	56	279	0.005	3.63	0.012	<0.030	32.3	1.81
35223	08/17/1999	7.14	16.50	606	0.24	245	459	0.005	1.78	0.006	<0.030	66.7	1.40
35301	08/16/1999	5.92	16.09	68	4.71	9	50	0.005	1.13	<0.005	<0.030	3.7	0.27
X5555	08/18/1999	6.19	16.77	150	2.69	46	114	0.006	3.09	<0.005	<0.030	19.4	0.66
SP11	08/16/1999	8.90	17.61	343	3.45	139	204	0.014	0.28	<0.005	0.040	47.5	5.05
SP12	08/16/1999	6.80	16.90	243	4.67	112	151	0.016	0.84	<0.005	<0.030	41.4	0.59
SP13	08/16/1999	6.63	15.50	247	4.70	100	157	0.036	2.66	<0.005	<0.030	39.9	0.94
SP21	08/17/1999	6.45	18.69	239	4.87	100	148	0.009	0.60	<0.005	<0.030	34.6	0.86
SP21B	08/17/1999	6.45	18.69	239	4.87	105	143	0.010	0.60	<0.005	<0.030	33.8	0.86
SP22	08/18/1999	6.29	15.33	147	6.05	41	102	0.018	2.46	<0.005	<0.030	18.6	1.16

Table 6. Measurements of Physical Properties and Concentrations of Chemical Constituents in Water Samples from Wells and Springs (Continued)

Site ID	Sodium (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Dissolved Silica (mg/L)	Potasium (mg/L)	Manganese (mg/L)	Zinc (mg/L)	Iron (mg/L)	Barium (mg/L)
15995	62.5	200.0	10.50	2.86	2.50	<0.100	<0.010	0.790	<0.100
16051	2.7	5.0	1.74	3.03	<1.00	<0.100	<0.010	<0.100	<0.100
16051B	2.7	5.0	1.74	3.01	<1.00	<0.100	<0.010	<0.100	<0.100
16087	5.7	8.0	6.81	3.54	2.57	<0.100	<0.010	0.144	<0.100
16138	4.2	3.0	6.19	2.33	<1.00	<0.100	<0.010	0.206	<0.100
16189	3.0	4.0	<1.00	3.31	1.00	<0.100	<0.010	<0.100	<0.100
25086	3.5	4.0	6.59	2.46	4.00	<0.100	<0.010	<0.100	<0.100
32292	16.8	7.0	5.10	3.18	2.20	1.410	0.040	0.102	<0.100
32328	24.5	67.0	<1.00	3.76	<1.00	<0.100	<0.010	<0.100	<0.100
35223	72.5	20.0	98.50	3.31	<1.00	<0.100	<0.010	<0.100	<0.100
35301	5.0	7.0	3.53	2.78	<1.00	<0.100	0.190	0.308	<0.100
X5555	3.4	5.5	<1.00	2.98	<1.00	<0.100	0.070	<0.100	<0.100
SP11	6.5	11.0	10.30	3.49	1.32	0.760	<0.010	0.275	<0.100
SP12	3.5	5.0	3.32	3.07	1.04	<0.100	<0.010	<0.100	<0.100
SP13	3.9	8.8	<1.00	3.10	1.50	<0.100	<0.010	0.175	<0.100
SP21	5.2	12.0	5.32	3.33	<1.00	<0.100	<0.010	0.121	<0.100
SP21B	4.4	12.0	5.35	3.32	4.00	<0.100	<0.010	<0.100	<0.100
SP22	5.4	10.0	2.63	2.42	1.04	<0.100	<0.010	<0.100	<0.100

QUALITY ASSURANCE

To determine the precision of the sampling and analytical procedures, environmental and duplicate samples were collected from one well (16051 and 16051B) and one spring (SP21 and SP21B). The duplicate samples were collected from the same source immediately following the environmental sample, and analyzed in the same manner.

For each duplicate sample, the relative percent difference between the duplicate and the environmental sample was calculated, as follows:

$$RPD = \frac{|C_1 - C_2|}{\frac{(C_1 + C_2)}{2}} \times 100$$

where RPD is the relative percent difference, C_1 is the concentration of the environmental sample, and C_2 is the concentration of the duplicate sample. The results of the calculations of relative percent difference are shown in Table 7. Relative percent difference could not be calculated for analyses of ammonia, nitrite, barium, iron, manganese, zinc, or potassium because at least one of the samples had censored data (concentrations below the laboratory minimum reporting level).

Table 7. Relative Percent Difference (RPD) Between Environmental and Duplicate Samples

	Well Samples			Spring Samples		
Parameter	**16051**	**16051B**	**RPD**	**SP21**	**SP21B**	**RPD**
Alkalinity	104	103	**1.0**	100	105	**4.9**
Total Dissolved Solids	140	137	**2.2**	148	143	**3.4**
Total Phosphorus	0.022	0.023	**4.4**	0.009	0.01	**10.5**
Nitrate	0.77	0.77	**0.0**	0.6	0.6	**0.0**
Nitrite	<0.005	<0.005	**---**	<0.005	<0.005	**---**
Ammonia	<0.03	<0.03	**---**	<0.03	<0.03	**---**
Calcium	38.5	39.7	**3.1**	34.6	33.8	**2.3**
Magnesium	0.64	0.5	**24.6**	0.86	0.86	**0.0**
Sodium	2.7	2.7	**0.0**	5.2	4.4	**16.7**
Chloride	5	5	**0.0**	12	12	**0.0**
Sulfate	1.74	1.74	**0.0**	5.32	5.35	**0.6**
Dissolved Silica	3.03	3.01	**0.7**	3.33	3.32	**0.3**
Potassium	<1	<1	**---**	<1	4	**---**
Manganese	<0.1	<0.1	**---**	<0.1	<0.1	**---**
Zinc	<0.01	<0.01	**---**	<0.01	<0.01	**---**
Iron	<0.1	<0.1	**---**	0.121	<0.1	**---**
Barium	<0.1	<0.1	**---**	<0.1	<0.1	**---**

The relative percent difference between environmental and duplicate samples in the well sample set were equal to or less than 4.4% for alkalinity, total dissolved solids (TDS), total phosphorus, calcium, chloride, nitrate, sulfate, and silica. The greatest relative percent differences for the well set was for magnesium (24.6%). The magnesium concentrations in the environmental and duplicate samples were 0.64 and 0.5 mg/L, respectively. The large difference is associated with the low concentrations of this constituent.

The relative percent difference between environmental and duplicate samples in the spring sample set were equal to or less than 4.9% for alkalinity, TDS, calcium, magnesium, chloride, nitrate, sulfate, and silica. The largest relative percent differences for the spring set were for sodium (16.7%) and total phosphorus (10.5%). These large differences are associated with low concentrations of these constituents. The sodium concentration was 5.2 mg/L in the environmental sample, and 4.4 mg/L in the duplicate. The total phosphorus concentration was 0.009 mg/L in the environmental sample, and 0.010 mg/L in the duplicate.

The concentration of potassium in the environmental spring sample was below the laboratory minimum reporting level (<1 mg/L) while the concentration in the duplicate was 4 mg/L. Although the relative percent difference was not calculated for potassium, the difference between the environmental and duplicate samples is at least 120 percent. The reason for this discrepancy is unknown. Neither of the duplicate samples was used in the statistical analysis.

Statistical Analysis

COMPARISON OF SPRINGS AND WELLS

Before calculating the summary statistics, it was necessary to determine if the samples from the springs and wells represented the same population. Quality of the spring and well water was compared using the Mann-Whitney test, a non-parametric rank-sum test that works on the ranks of the data instead of the actual constituent concentrations (Helsel and Hirsch, 1992). Parameters with near 50% or more-censored data were not tested because the Mann-Whitney test has little power for detecting differences when censoring is severe.

The null hypothesis was that the concentrations of chemical constituents in groundwater samples were the same in the spring samples and well samples. The alternative hypothesis was that the concentrations were different in the spring and well samples. The null hypothesis was rejected if the p-value of the test was less than or equal to 0.100. The results of the Mann-Whitney tests for each tested parameter are shown in Table 8.

The p-values for all tested parameters are greater than 0.100, and the null hypothesis was accepted. It was concluded that the samples from springs and wells located in the study area were not significantly different and could be treated as the same population.

DESCRIPTIVE STATISTICS

Because samples from springs and wells were not significantly different, they were combined for the statistical analysis. Descriptive statistics were calculated for physical properties and chemical constituents of the combined well and spring water samples, and are presented in Table 9. For those constituents with censored data, only the minimum and maximum concentrations are listed. Boxplots showing the median and upper and lower quartile of each constituent are shown in Appendix A.

Table 8. P-Values from the Mann-Whitney Test Comparing Water Samples from Springs and Wells

Parameter	p-value
pH	0.777
Temperature	0.610
Specific Conductance	0.396
Dissolved Oxygen	0.396
Alkalinity	0.691
Total Dissolved Solids	0.396
Total Phosphorus	0.278
Nitrate	0.865
Calcium	0.427
Magnesium	0.865
Sodium	0.910
Chloride	0.364
Sulfate	0.732
Dissolved Silica	0.692

Table 9. Descriptive Statistics for Physical Properties and Chemical Constituents of Water Samples from Wells and Springs

Parameter	Minimum	25th Percentile	50th Percentile Median	75th Percentile	Maximum
pH (standard units)	5.75	6.30	6.62	7.11	9.03
Temperature (°C)	15.29	15.89	16.49	16.93	18.69
Specific Conductance (µS/ cm)	68	148.5	259.5	369	754
Dissolved Oxygen	0.03	1.81	4.69	5.02	6.23
Alkalinity	9	51.00	102.00	156.00	245.00
Total Dissolved Solids	50	127.00	167.00	248.00	564.00
Total Phosphorus	<0.005	0.005	0.010	0.023	0.044
Nitrate as N	0.10	0.37	0.99	2.53	3.63
Nitrite as N	<0.005	---	---	---	0.096
Ammonia as N	<0.030	---	---	---	0.040
Calcium	3.7	31.10	40.65	57.40	66.70
Magnesium	0.27	0.66	1.05	1.80	7.00
Sodium	2.7	3.50	5.10	11.65	72.50
Chloride	3.0	5.00	7.50	11.50	200.00
Sulfate	<1.00	---	---	---	98.50
Dissolved Silica	2.33	2.820	3.085	3.320	3.760
Potassium	<1.00	---	---	---	4.000
Manganese	<0.100	---	---	---	1.410
Zinc	<0.010	---	---	---	0.190
Iron	<0.100	---	---	---	0.790
Barium	<0.100	---	---	---	<0.10

GENERAL CHEMISTRY

Several geochemical processes affect water quality. These processes include, but are not limited to, mineral dissolution, ion exchange, and oxidation-reduction reactions. In the Boone aquifer, the most important of these is dissolution of limestone, which causes the predominant water type of the aquifer to be calcium bicarbonate. Alkalinity and specific conductance are related to ionic concentrations resulting from dissolution of the rock. Ion exchange along a groundwater flow path can cause the dominant cation to change from calcium to sodium. Oxidation and dissolution of sulfide minerals, such as pyrite (FeS_2), sphalerite (ZnS), and galena (PbS), increases the trace element and sulfate concentrations in the water. Dissolved oxygen is supplied by recharge.

As expected in a limestone aquifer, the predominate water type is calcium bicarbonate. A trilinear plot of the well samples is shown in Figure 6, and a plot of the spring samples is shown in Figure 7. As illustrated in the plots, all but four of the samples are calcium bicarbonate water. Well samples 35223 and 35301 are calcium sodium bicarbonate water, sample 15995 is calcium sodium chloride water, and sample 32328 is calcium sodium bicarbonate chloride water.

The ionic concentrations of well 35301 are anomalous. Extremely low pH and alkalinity, low concentrations of TDS, calcium, magnesium, and silica, and high dissolved oxygen suggest water that has not been in contact with the aquifer long enough for the aquifer to become mineralized. It is likely that the well is receiving localized recharge from precipitation through conduits such as fractures or solution openings in the Boone Formation. The ionic concentrations of Colcord Spring (SP22), located 2.5 miles from well 35301, also suggest a shallow source or short flowpath for the water; the concentrations of pH, alkalinity, TDS, calcium, magnesium, and silica are all relatively low.

Another anomalous well is 15995, located 2 miles north of well 35301. The low concentrations of alkalinity and silica and the high dissolved oxygen suggest a shallow source or short flowpath for the water. The sulfate and iron concentrations could be increased by oxidation of sulfide minerals such as pyrite. The very high pH (9.03) may indicate a poor cement seal in the well, which would provide a direct conduit for surface runoff to enter the aquifer.

NUTRIENTS

The dominant form of nitrogen was nitrate. Nitrate was detected in all 16 samples, with concentrations ranging from 0.10-3.63 mg/L. Eight samples had concentrations greater than background level. The median concentration was 0.99 mg/L, which is similar to the median of 1.0 mg/L for the Ozark region determined by Adamski (1997). Although greater than the background concentration of 0.98 mg/L, all concentrations were well below the drinking water standard of 10 mg/L. Probable sources of nitrate include chemical fertilizer, animal manure, and septic tanks.

Nitrite and ammonia concentrations were low. In 12 of the 16 samples, nitrite concentrations were less than the detection limit of 0.005 mg/L. Four samples, all from wells, had nitrite concentrations greater than the detection limit. The samples with nitrite had low dissolved oxygen (between 0.24 and 1.36 mg/L). Because nitrite is unstable in aerated water, nitrite in groundwater tends to oxidize to nitrate. Ammonia concentrations were greater than the detection limit of 0.03 mg/L in only one sample; sample SP11, from the Spavinaw Roadside Park Spring, had an ammonia concentration of 0.04 mg/L.

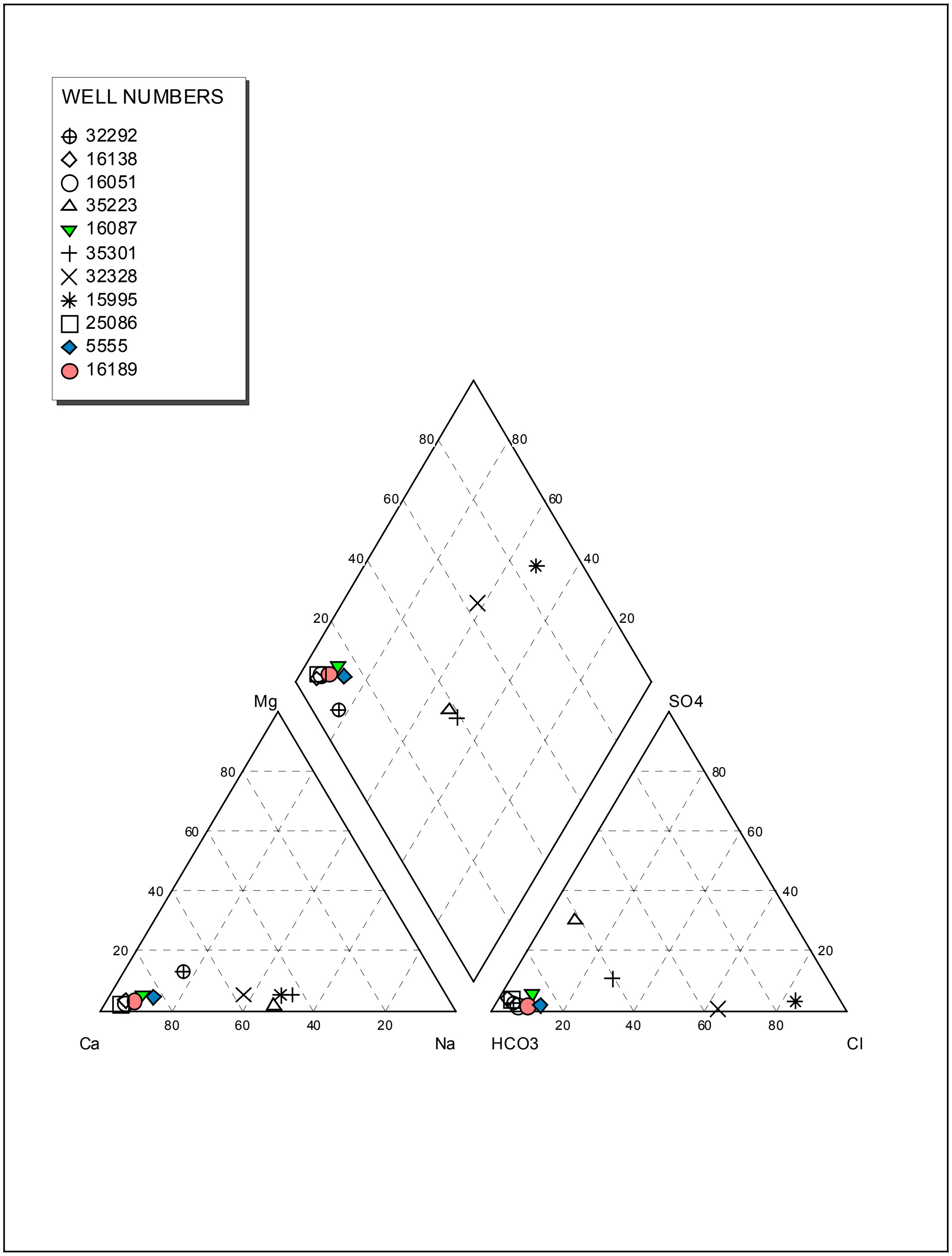


Figure 6. Trilinear diagram showing major component composition of sampled wells.

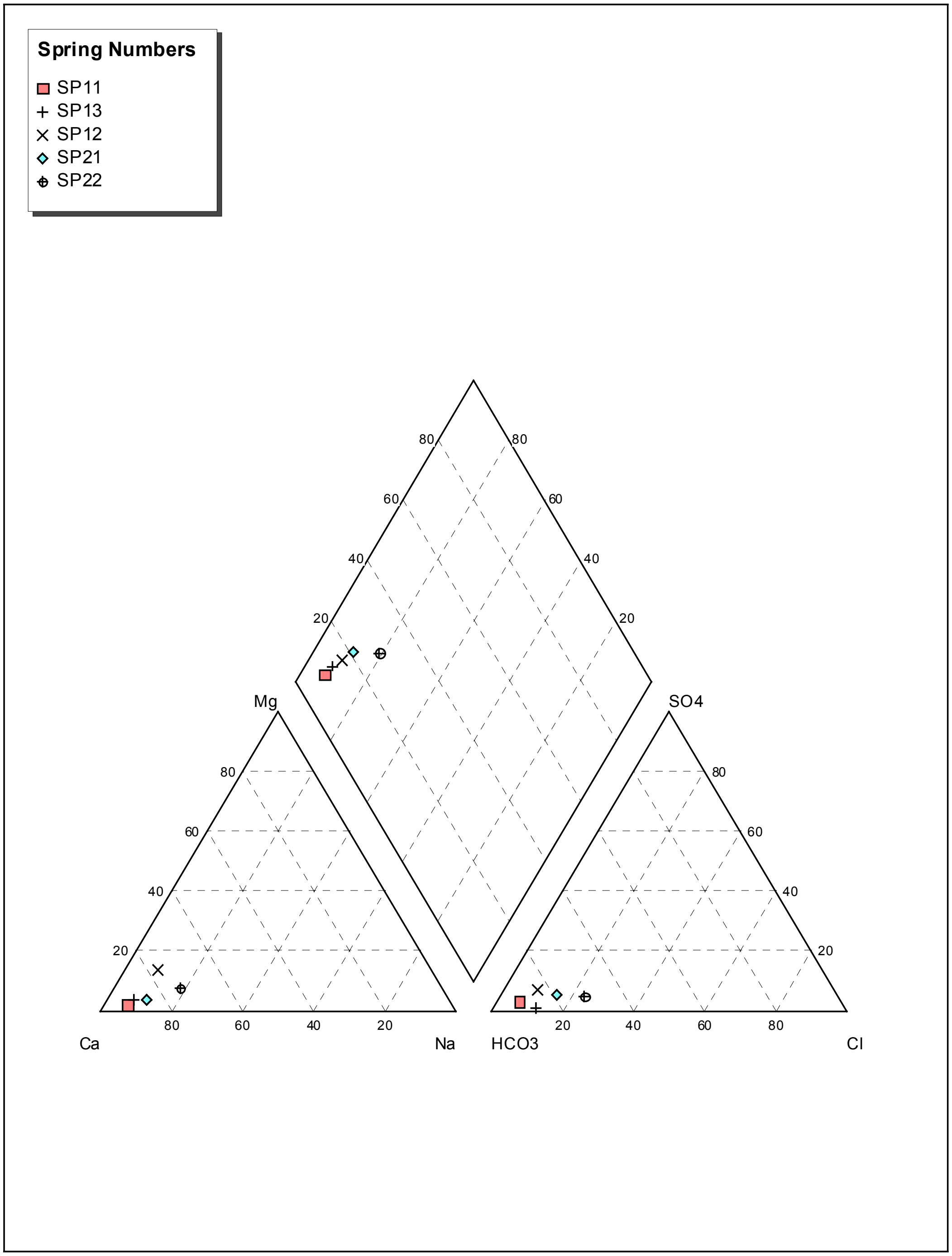


Figure 7. Trilinear diagram showing major component composition of sampled springs.

Concentrations of total phosphorus were low, ranging from <0.005-0.044 mg/L. In four of the 16 samples, phosphorus was less than the detection limit of 0.005 mg/L. Phosphorus was greater than the background concentration of 0.02 mg/L in four samples. The median was 0.01 mg/L, the same as determined by the USGS for wells sampled in the Boone aquifer.

Phosphorus is a common element in igneous rocks and is abundant in sediments. However, concentrations in natural groundwater are generally low (no more than a few tenths of a milligram per liter) because it remains attached to soil particles and has a low solubility (Hem, 1985). Other sources of phosphorus include fertilizer, animal manure, and septic tanks.

DRINKING-WATER QUALITY

Groundwater quality in the study area is good for drinking water. Drinking water standards established by the U.S. Environmental Protection Agency (EPA) for the parameters that were tested are listed in Table 10. Primary drinking water standards, or maximum contaminant levels (MCLs), are established for chemical constituents that may have an adverse effect upon human health when present at excessive levels. Two of the tested parameters have MCLs: nitrate has an MCL of 10 mg/L, and barium has an MCL of 1.0 mg/L. Neither of these levels was exceeded in any of the samples.

Secondary maximum contaminant levels (SMCLS), present no health hazard, but affect the taste, smell, and appearance of the water, or can damage components of the water system. A few of the SMCLS were exceeded. Of the 16 samples, five had a pH <6.5 and two had a pH >8.5. Water with low pH is acidic and will corrode copper and iron pipes, and water with a high pH is alkaline and may cause lime deposits to build up and clog fixtures and pipes. Water from two samples exceeded the SMCL of 0.3 mg/L for iron, which could cause stains on laundry and plumbing fixtures. The water from one sample exceeded the SMCL of 500 mg/L for TDS, which could affect the taste. Two samples exceeded the SMCL for manganese.

Table 10. Drinking Water Standards for Tested Parameters

Parameter	Drinking Water Standard (mg/L)	Standard Type
Nitrate	10	primary
Barium	1.0	primary
pH (standard units)	6.5-8.5	secondary
Total Dissolved Solids	500	secondary
Chloride	250	secondary
Sulfate	250	secondary
Iron	0.3	secondary
Manganese	0.05	secondary
Zinc	5	secondary

Discussion and Recommendations for Further Study

Information gained from this study can be used to determine the total lake water budget and the lake nutrient budget. If groundwater is determined to be a significant contributor of nutrients to the lake, then further investigation may be necessary.

Although the Arkansas portion of the watershed was not included in this investigation, we believe that analysis of the Oklahoma portion sufficiently characterized the groundwater component of the system. Inflow from Arkansas was considered in the calculation of groundwater discharge, but was not considered in describing the water quality. Because it appears that groundwater in the Boone aquifer generally flows short distances, the amount of inflow from Arkansas is probably small. Land use and the hydrogeology of the Arkansas portion are similar to the Oklahoma portion, and it is assumed that the water quality is similar. However, this assumption may need to be verified in future investigations.

To determine seasonal variation in discharge, base flow should be measured at various times throughout the year. Future measurements should include Cherokee Creek near the Arkansas border.

The discharge estimates were based on several assumptions of the groundwater-surface water interaction. More wells would be necessary to better define the flow system. Wells that are open to different depths within the two aquifers could be used to determine various flow paths, and to determine if the deeper Roubidoux water discharges to the streams and lakes. Unfortunately, most existing wells are not adequate for this level of analysis. Most wells have only a surface casing and are open to the remaining rock formations. Thus, wells in the Roubidoux aquifer also produce water from the Boone, and measured water levels reflect a combination of hydrologic heads.

Water tracing with isotopes, ions, spores and yeast, and dyes can assist in delineating groundwater watersheds and estimating groundwater flow velocities. Tracing with fluorescent dyes is the principal and most successful tracer in karst aquifers (Ford and Williams, 1989; Mull and others, 1988).

It is assumed that most of the groundwater contribution to the lakes is from the Boone aquifer, and that the component from the underlying Cotter Dolomite is in communication with the Boone aquifer, and follows shallow, local flow paths. If this is the case, then it is reasonable to assume that water quality of groundwater in the Cotter Dolomite is similar to that of the Boone aquifer. If it is determined that deeper Roubidoux water discharges to the lakes, then water quality sampling of the Roubidoux aquifer may be warranted.

Concentrations of phosphorus appear to be low, and of little concern. However, the moderate concentrations of nitrate may warrant further investigation. Increased sample frequency throughout the year may determine if nitrate concentrations vary seasonally.

Determining the source of nitrate in groundwater can be difficult. One approach would be to design a sampling network based on land use. Statistical analysis of the sampled water can then be used to determine the effects of land use on nutrient concentrations. Nitrogen isotope ratios can be used to determine whether fertilizers or animal wastes are the source of nitrate. To distinguish between septic tank waste and livestock waste, analyzing for household tracers (such as pharmaceuticals, caffeine, and solvents) or agricultural tracers (hormones and fecal indicators) may be necessary.

A relatively inexpensive method of assessing septic field contamination is to examine groundwater samples for optical brighteners. Optical brighteners are fluorescent whitening agents used in laundry soaps and detergents. Unbleached cotton wool hanks can be suspended in the flow of a well or spring, then examined under light from an ultra-violet lamp. Studies by the Ozark Underground Laboratory have demonstrated a direct correlation between the presence of optical brighteners in groundwater and the presence of other sewage contaminants (Aley, 1984).

Age dating the samples with chlorofluorocarbons (CFCs) or tritium (^3H) is helpful in evaluating land use data. For example, water that was introduced to the subsurface more than 35 years ago could not have originated from a poultry farm that has been in operation less than 5 years. Information about the age of groundwater can also be used to define recharge rates and refine hydrologic models of groundwater systems (Plummer and Friedman, 1999).

Summary

The Lake Eucha/Spavinaw watershed is underlain by two aquifers: the shallower Boone aquifer and the deeper Roubidoux aquifer. The Boone aquifer discharges to Lake Eucha/Spavinaw and was the primary focus of this investigation.

Water-level elevations from 28 wells completed in the Boone aquifer and from springs and streams that discharge water from the aquifer were used to construct a water-level elevation map. The map illustrates that the water table surface of the Boone aquifer generally reflects the surface topography. Groundwater appears to flow relatively short distances, from where it receives recharge from precipitation on topographically high areas, to where it discharges along streams by way of springs and seeps.

As determined from the water-level map, the hydraulic gradient varies across the study area, from about 21 ft/mi (0.004) along the flat-topped ridges to about 105 ft/mi (0.02) in the steep valleys. The regional hydraulic gradient is about 26 ft/mi, or 0.005. Average groundwater velocity over the study area is estimated to be 1.6 ft/day.

The boundary of the groundwater watershed was determined from the water-level elevation map in the same manner as the boundary of the surface watershed was determined from a topographic map. Examination of the groundwater and surface watersheds indicates the two watersheds correspond closely. The total groundwater watershed area for Lake Eucha/Spavinaw in Oklahoma and Arkansas is estimated to be 415 mi^2.
Discharge measurements taken on major perennial streams in February 1999 were used to estimate the rate of groundwater discharge to the lakes. Spavinaw and Beaty Creeks provided a substantial contribution of base flow to the lakes. Spavinaw Creek gained 110.31 cfs of groundwater in Arkansas and Oklahoma, and Beaty Creek gained 35.35 cfs. Groundwater discharged to Lake Eucha/Spavinaw from the 415-mi^2 groundwater watershed at an estimated rate of 218.08 cfs, or about 433 acre-feet per day.

Water samples from 11 domestic wells and five springs were analyzed to describe the general water quality of the study area. The predominate water type is calcium bicarbonate, reflecting dissolution of limestone. Four of the 16 samples were mixed water of calcium sodium bicarbonate, calcium sodium chloride, and calcium sodium bicarbonate chloride water.

Concentrations of nutrients were generally low. Concentrations of total phosphorus ranged from <0.005-0.044 mg/L, and the median was 0.01 mg/L. Nitrite is unstable in aerated water, and tends to oxidize to nitrate. In 12 of the 16 samples, nitrite concentrations were less than the detection limit of 0.005 mg/L. Ammonia concentrations were greater than the detection limit of 0.03 mg/L in only one sample; sample SP11, from the Spavinaw Roadside Park Spring, had an ammonia concentration of 0.04 mg/L.

Nitrate was detected in all 16 samples. Concentrations ranged from 0.10-3.63 mg/L, and the median concentration was 0.99 mg/L. Eight samples had concentrations greater than the regional background level of 0.98, as determined by Adamski, 1997. Although greater than background levels, nitrate concentrations are well below the drinking water standard of 10 mg/L. Probable sources of nitrate include chemical fertilizer, animal manure, and septic tanks.

In conclusion, it is hoped that the results of this study will contribute to the understanding of the groundwater and surface waters of the Lake Eucha/Spavinaw watershed. Information gained from this study can be used to determine the total lake water budget and the lake nutrient budget. If groundwater is determined to be a significant contributor of nutrients to the lake, then further investigation may be necessary.

References

AEDS, 1999, Eucha/Spavinaw NPDES Release Data: (http//www.tulsawater.com/ tmuadata.html).

Adamski, J.C., 1997, Nutrients and Pesticides in Ground Water of Ozark Plateaus in Arkansas, Kansas, Missouri, and Oklahoma: U.S. Geological Survey Water-Resources Investigations Report 96-4313, 28 p.

Adamski, J.C., 2000, Geochemistry of the Springfield Plateau Aquifer of the Ozark Plateaus Province in Arkansas, Kansas, Missouri and Oklahoma, USA: Hydrological Processes, vol. 14, p. 849-866.

Adamski, J.C., Petersen, J.C., Freiwald, D.A., and Davis, J.V., 1995, Environmental and Hydrogeologic Setting of the Ozark Plateaus Study Unit, Arkansas, Kansas, Missouri, and Oklahoma: U.S. Geological Survey Water-Resources Investigations Report 94-4022, 69 p.

Aley, T., 1984, Septic Fields and the Protection of Groundwater Quality in Greene County, Missouri, unpublished report for the City of Springfield, Missouri, 18 p.

Cederstrand, J.R., 1996a, Digital Geologic Map of Fort Smith Quadrangle, East-Central Oklahoma: U.S. Geological survey Open-File Report 96-375, based on a scale of 1:250,000.

---- 1996b, Digital Geologic Map of Tulsa Quadrangle, Northeastern Oklahoma: U.S. Geological survey Open-File Report 96-381, based on a scale of 1:250,000.

Chichester, H., (Tulsa Metropolitan Utility Authority) personal communication, May 2, 2000.

Christenson, S.C., Parkhurst, D.L., and Fairchild, R.W., 1994, Geohydrology and Water Quality of the Roubidoux Aquifer, Northeastern Oklahoma: Oklahoma Geological Survey Circular 96, 70 p.

Driscoll, F.G., 1986, Groundwater and Wells (second edition): Johnson Filtration Systems, Inc., St. Paul, Minnesota, 1089 p.

Dugan, J.T., and Peckenpaugh, J.M., 1986, The Effects of Climate on Consumptive Water Use and Ground-Water Recharge in Parts of Arkansas, Colorado, Kansas, Missouri, Nebraska, Oklahoma, South Dakota, and Texas: U.S. Geological Survey Water-Resources Investigations Report 85-4326, 78 p.

Fenneman, N.M., 1946, Physical Divisions of the United States: U.S. Geological Survey, 1 map.

Ford, D.C., and Williams, P.W., 1989, Karst Geomorphology and Hydrology: Unwin Hyman Ltd., Winchester, Massachusetts, 601 p.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical Methods in Water Resources: Elsevier Science Publishers B.V., Amsterdam, The Netherlands, 529 p.

Hem, J.D., 1985, Study and Interpretation of the Chemical Characteristics of Natural Water: U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Imes, J.L., and Davis, J.V., 1990, Water Type and Concentration of Dissolved Solids, Chloride, and Sulfate in Water from the Ozark Aquifer in Missouri, Arkansas, Kansas, and Oklahoma: U.S. Geological Survey Hydrologic Investigations Atlas HA-711-K, 4 sheets.

Imes, J.L., and Emmett, L.F., 1994, Geohydrology of the Ozarks Plateaus Aquifer System in Parts of Missouri, Arkansas, Oklahoma, and Kansas: U.S. Geological Survey Professional Paper 1414-D, 127 p.

Marcher, M.V., 1969, Reconnaissance of the Water Resources of the Fort Smith Quadrangle, East-Central Oklahoma: Oklahoma Geological Survey Hydrologic Atlas 1, 4 sheets, scale 1:250,000.

Marcher, M.V., and Bingham, R.H., 1971, Reconnaissance of the Water Resources of the Tulsa Quadrangle, Northeastern Oklahoma: Oklahoma Geological Survey Hydrologic Atlas 2, 4 sheets, scale 1:250,000.

Mull, S.D., Liebermann, T.D., Smoot, J.L., and Woosley, L.H., Jr., 1988, Application of Dye-Tracing Techniques for Determining Solute-Transport Characteristics of Ground Water in Karst Terranes: U.S. Environmental Protection Agency, EPA 904/6-88-001, 103 p.

Oklahoma Climatological Survey, 1997, Data and Products: http://climate.ocs.ou.edu/.

Osborn, N.I., and Hardy, R.H., 1999, Statewide Groundwater Vulnerability Map of Oklahoma: OWRB Technical Report 99-1, 34 p.

Plummer, L.N. and Friedman, L.C., 1999, Tracing and Dating Young Ground Water: U.S. Geological Survey Fact Sheet 134-99.

Reed, E.W., Schoff, S.L., and Branson, C.C., 1955, Groundwater Resources of Ottawa County, Oklahoma: Oklahoma Geological Survey Bulletin 72, 203 p.

Reese, D.L., 1963, Areal Geology of the Spavinaw Lakes Area, Delaware County, Oklahoma: unpublished thesis, University of Oklahoma, 67 p.

Sanders, L.L., 1998, A Manual of Field Hydrogeology: Prentice Hall, Upper Saddle River, New Jersey, 381 p.

Winter, T.C., (U.S. Geological Survey) personal communication April 27, 2000.

Winter, T.C., Harvey, J.W., Franke, O.L., and Alley, W.M., 1999, Ground Water and Surface Water A Single Resource: U.S. Geological Survey Circular 1139, 79 p.

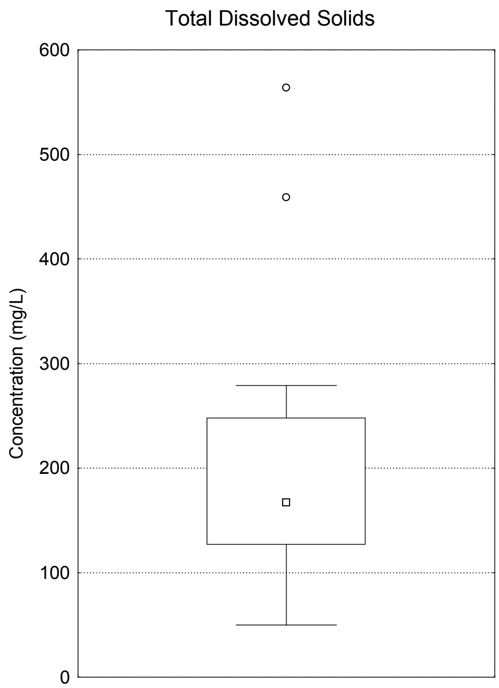
APPENDIX A

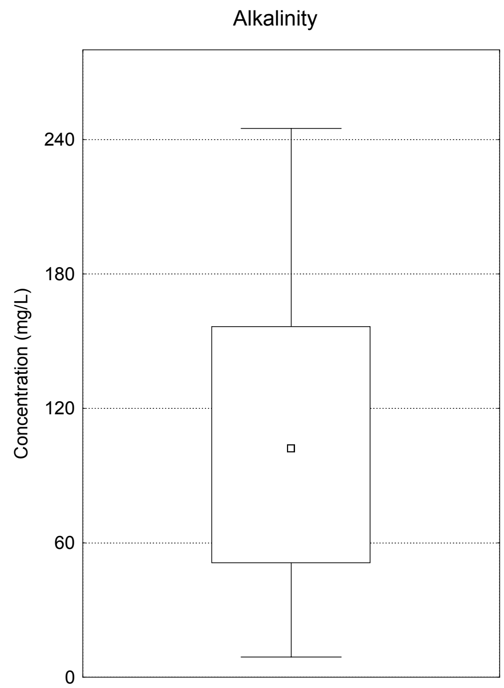
Boxplots of Physical Properties and Chemical Constituents in Groundwater Samples from Wells and Springs in the Lake Eucha/Spavinaw Study Area

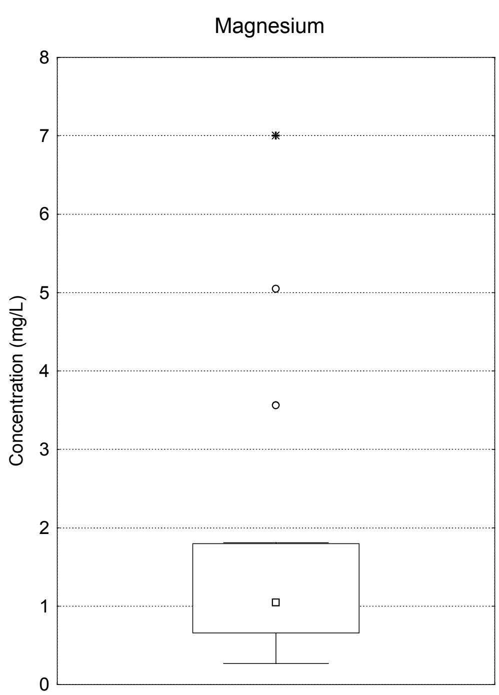
Legend for Boxplots

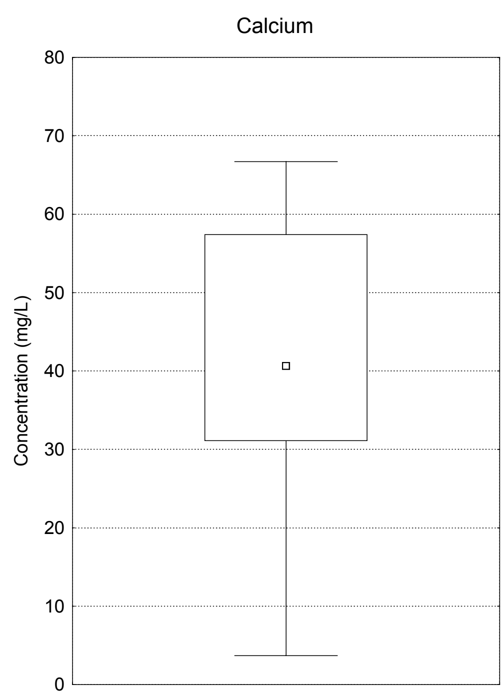
- Non-Outlier Max / Non-Outlier Min
- 75% / 25%
- □ Median
- ○ Outliers
- ✳ Extremes

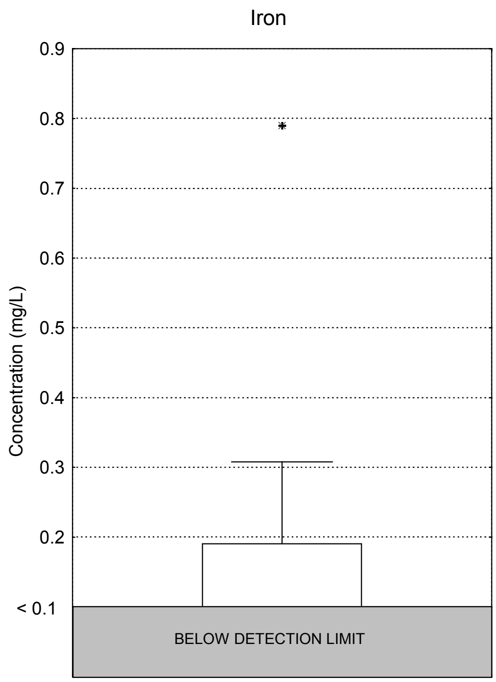
Note: The data for boxplots with gray shading labeled “Below Detection Limit” included censored data.

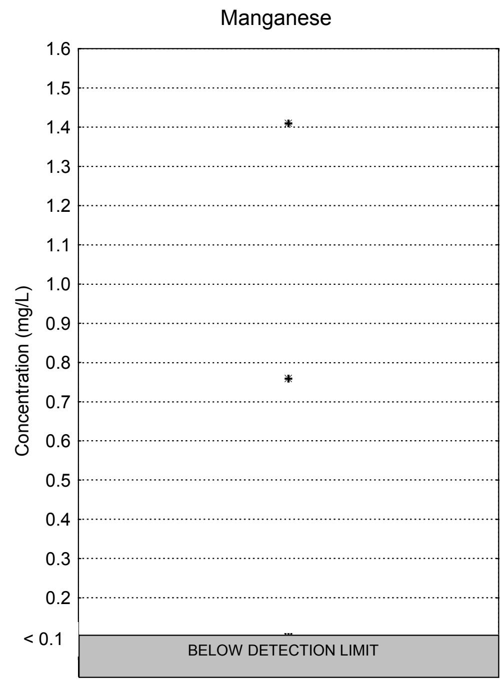

Total Dissolved Solids
Concentration (mg/L)
600
500
400
300
200
100
0

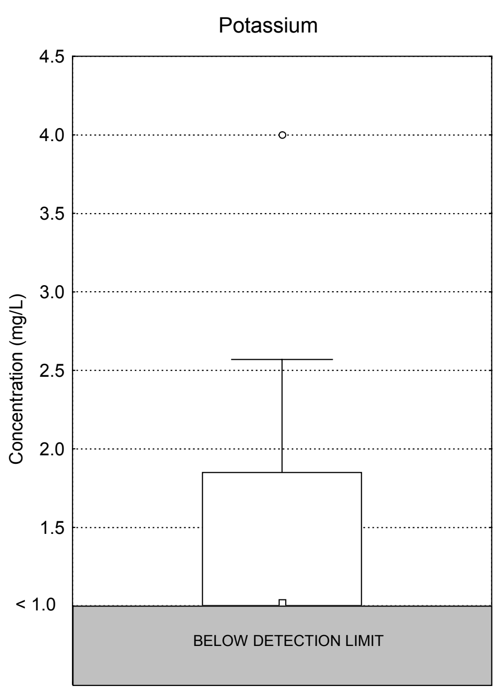

Alkalinity
Concentration (mg/L)
240
180
120
60
0

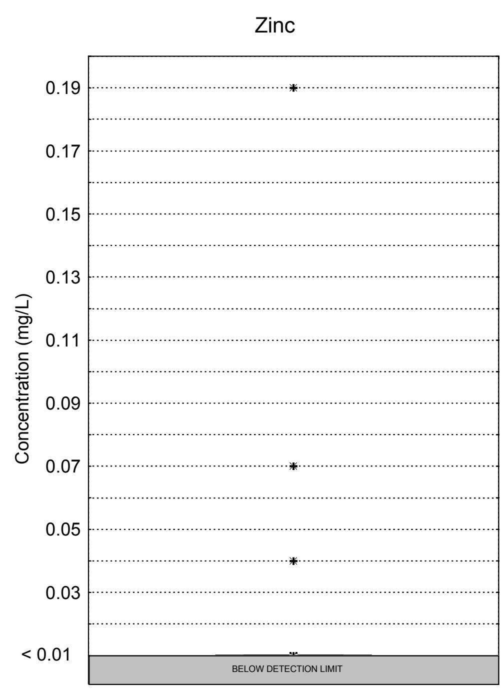

Magnesium
Concentration (mg/L)
8
7
6
5
4
3
2
1
0

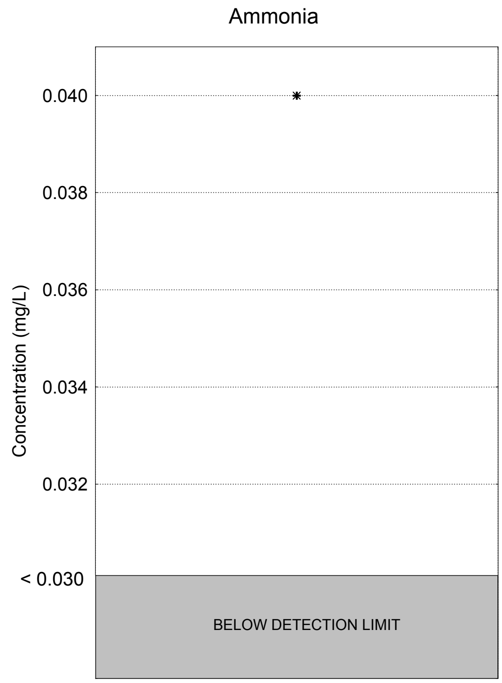

Calcium
Concentration (mg/L)
80
70
60
50
40
30
20
10
0

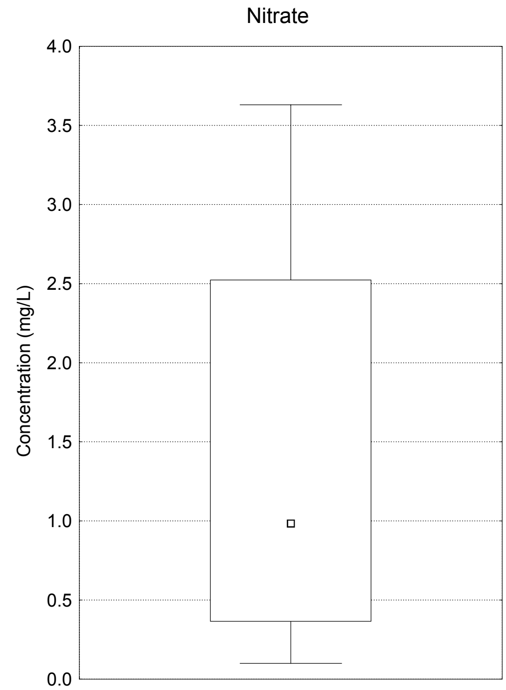

Iron
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
< 0.1
Concentration (mg/L)
BELOW DETECTION LIMIT

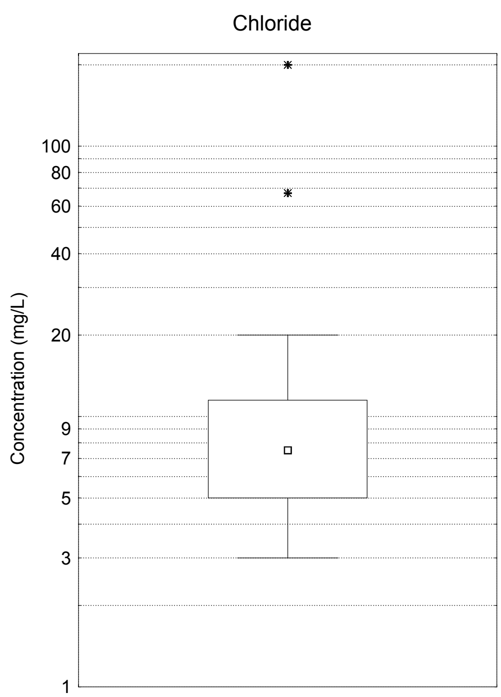

Manganese
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
< 0.1
Concentration (mg/L)
BELOW DETECTION LIMIT

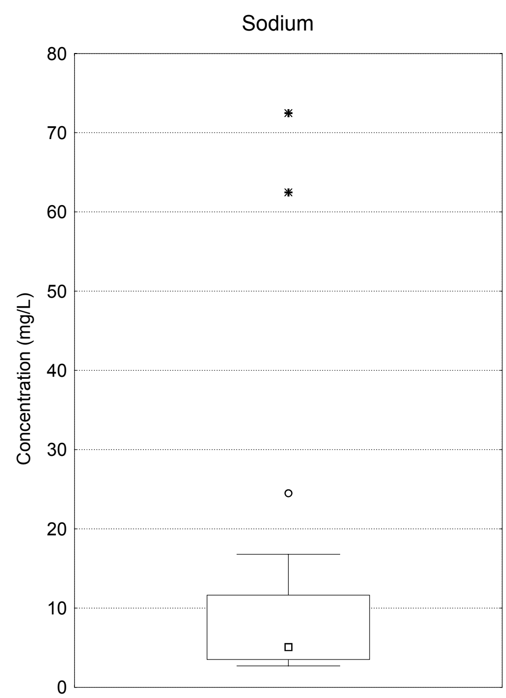

Potassium
4.5
4.0
3.5
3.0
2.5
2.0
1.5
< 1.0
Concentration (mg/L)
BELOW DETECTION LIMIT

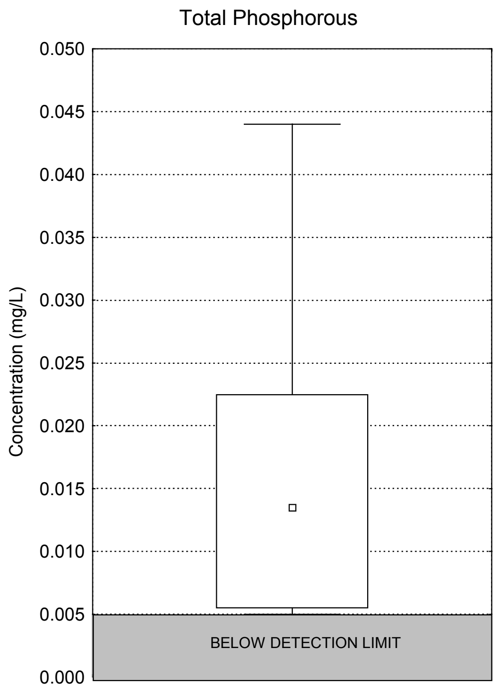

Zinc
0.19
0.17
0.15
0.13
0.11
0.09
0.07
0.05
0.03
< 0.01
Concentration (mg/L)
BELOW DETECTION LIMIT

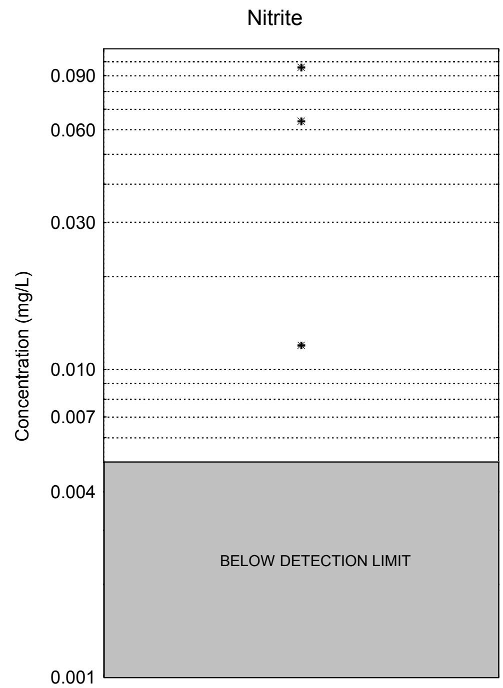

Ammonia
Concentration (mg/L)
0.040
0.038
0.036
0.034
0.032
< 0.030
BELOW DETECTION LIMIT

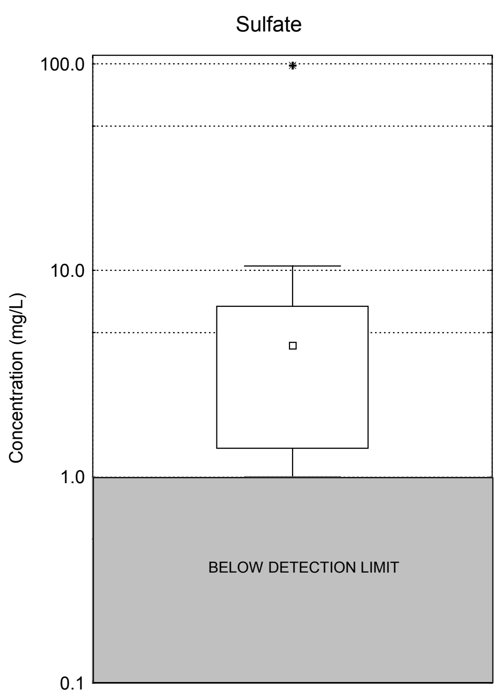

Nitrate
Concentration (mg/L)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0

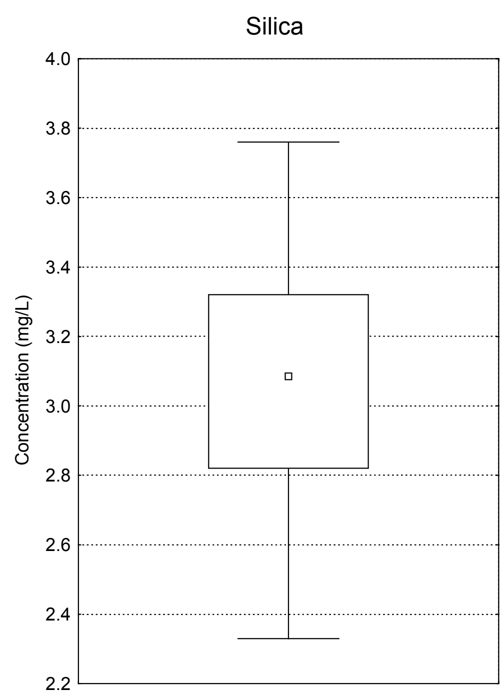

Chloride
Concentration (mg/L)
100
80
60
40
20
9
7
5
3
1

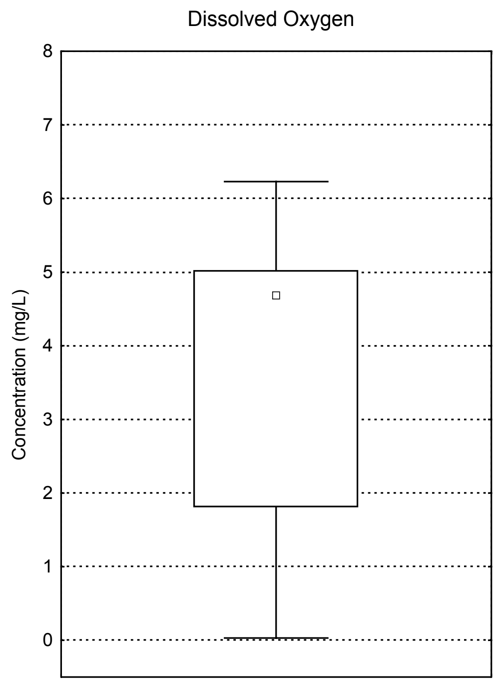

Sodium
Concentration (mg/L)
80
70
60
50
40
30
20
10
0

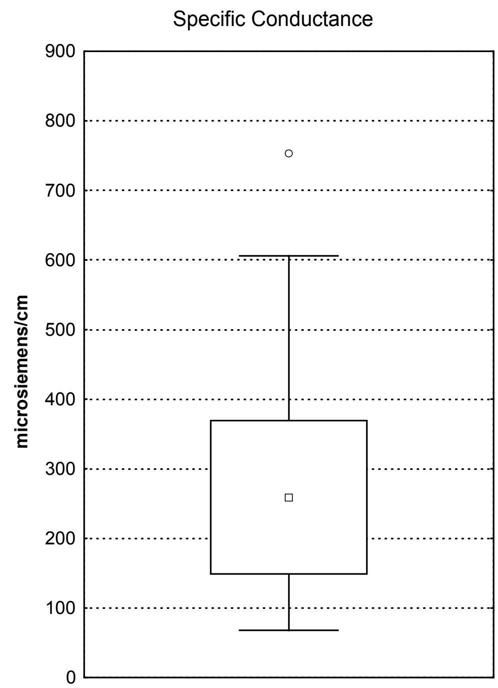

Total Phosphorous
Concentration (mg/L)
0.050
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
BELOW DETECTION LIMIT

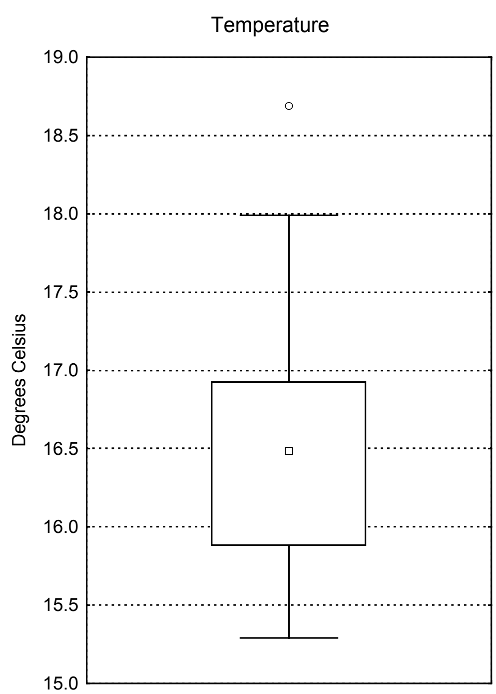

Nitrite
Concentration (mg/L)
0.090
0.060
0.030
0.010
0.007
0.004
0.001
BELOW DETECTION LIMIT

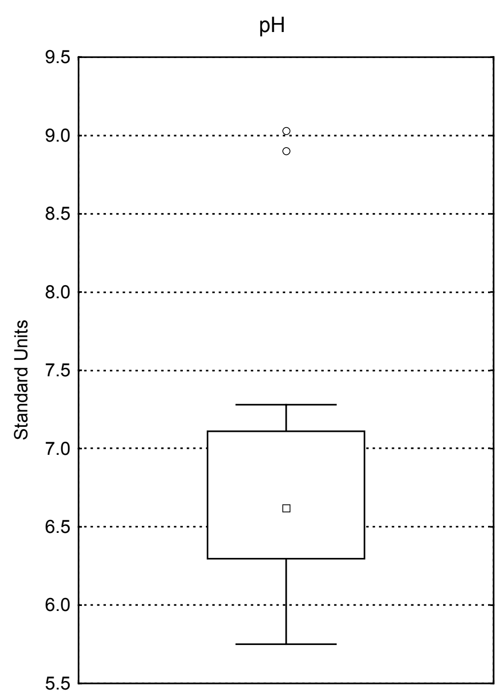

Sulfate
Concentration (mg/L)
100.0
10.0
1.0
0.1
BELOW DETECTION LIMIT


Silica
Concentration (mg/L)
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2


Dissolved Oxygen
Concentration (mg/L)
0
1
2
3
4
5
6
7
8


Specific Conductance
microsiemens/cm
0
100
200
300
400
500
600
700
800
900


Temperature
Degrees Celsius
15.0
15.5
16.0
16.5
17.0
17.5
18.0
18.5
19.0


pH
Standard Units
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5

Appendix E: Sediment Phosphorus Load

Sediment Phosphorus Load Estimation for Lake Eucha and Lake Spavinaw

The first step determining the importance of sediment phosphorus load to Eucha and Spavinaw Lake is to check the chemical data for indicators of internal load. One important indicator is the iron-phosphorus ratio. Literature reports that low iron-phosphorous ratios (less than 3) in the sediment interstitial waters or anaerobic bottom waters permit the migration of phosphorus into aerobic zones without iron-phosphate precipitation (Walker 1996).

Iron-phosphorous ratios did show periods when phosphorus migration would be expected from anaerobic, hypolimnetic waters into the epilimnetic surface waters. However, definitive extrapolations were not possible because the data were not available for evaluation during the entire anaerobic period. Because of this uncertainty and the potential for phosphorus load, internal loads were estimated to assess their impact on the phosphorus nutrient budget.

Total iron and total phosphorus values were compiled into tables to report these values during anoxic hypolimnetic conditions and the iron/phosphorus ratio calculated. It is important to note that sampling for iron was not as frequent as that for total phosphorus. For example analysis for iron did not occur on every sample when anaerobic conditions were noted. For this reason data was examined for a trend of low ratios and guidance for pursuing internal load calculations.

Total iron and total phosphorous data were available for Lake Eucha in September, October and November of 1999. Four out of nine samples had a ratio below three (Table 1). One of three samples in early September had a low ratio while none of the samples (3 of 3) in late September had a low ratio. All samples (3 of 3) in October and November had low ratios. Examination of iron-phosphorus ratios for Eucha Lake indicates there were chemical conditions conducive to phosphorus migration.

Total iron and total phosphorous data were available for Lake Spavinaw in July 1998 and September 1999. Four out of eight samples had a ratio below three (Table 2). One of three samples in July had a low ratio, one of the three in July had a high ratio and one was just above the threshold. None of the samples (2 of 2) in early September had a low ratio. All samples (3 of 3) in late September had low ratios. Examination of iron-phosphorus ratios for Spavinaw Lake indicates there were chemical conditions conducive to phosphorus migration.

Table 1. Available total iron and total phosphorous values using anaerobic bottom samples, Eucha Lake.

Date	Site	Depth (meters)	Total Iron (mg/L)	Total Phosphorous (mg/L)	Iron-Phosphorous Ratio
September 15, 1999	1	22	1.228	0.486	2.53
September 15, 1999	2	14	2.594	0.694	3.74
September 15, 1999	16	10	1.052	0.235	4.48
September 30, 1999	1	22	0.85	0.018	47.22
September 30, 1999	2	14	1.221	0.017	71.82
September 30, 1999	16	10	0.056	0.018	3.11
October 13, 1999	1	22	0.13	0.161	0.81
October 13, 1999	2	14	0.272	0.139	1.96
November 3, 1999	1	22	0.039	0.054	0.72

Table 2. Available total iron and total phosphorous values for anaerobic bottom samples, Spavinaw Lake.

Date	Site	Depth (meters)	Total Iron (mg/L)	Total Phosphorous (mg/L)	Iron-Phosphorous Ratio
July 30, 1998	5	4	0.035	0.024	1.46
July 30, 1998	2	9	0.691	0.116	5.96
July 30, 1998	1	14	0.77	0.251	3.07
September 16, 1999	2	9	0.495	0.015	33.00
September 16, 1999	1	14	1.59	0.015	106.00
September 29, 1999	2	9	0.045	0.029	1.55
September 29, 1999	1	11	0.021	0.041	0.51
September 29, 1999	1	14	0.305	0.217	1.41

Estimation of the sediment phosphorous load was accomplished by using ortho-phosphorous concentration data, temperature data, and morphometric data for both lakes. Three components were calculated using the data:

- sediment phosphorous release rate.
- diffusive rate of phosphorous from the hypolimnion up to the epilimnion.
- phosphorous mass release through entrainment.

Snow and DiGiano's (1976) equation for estimating phosphorous mass from lake sediments assumes a constant release rate from the sediment. In brief, this equation takes into account:

- ΔP is the change in phosphorous concentration (mg/L).
- Δt is the change in time (days).
- M_s is phosphorous mass released per unit sediment area (mg/m^2-day).
- A is the area of the lake (acres).
- V is the volume of the lake (acre-feet).

$$(\Delta P/\Delta t) = (M_s)(A)/V$$

Phosphorous release rates were calculated using hypolimnetic values of ortho-phosphorous for sites 1, 2, and 16 in Lake Eucha and sites 1, 2, and 5 for Lake Spavinaw. Ortho-phosphorous was chosen because it would be the formed phosphorus to be desorbed from the sediment. Isopleth plots of ortho-phosphorous concentration in Lake Eucha and Lake Spavinaw indicate that increases in ortho-phosphorous concentration correspond with periods of stratification in the lake. Ortho-phosphorous values were transformed into one-half the median detection limit when reported values were below the detection limit. The median detection limit value for both lakes was 0.005 mg/L.

Periods of lake stratification for both Lake Eucha and Lake Spavinaw were determined using dissolved oxygen/temperature profiles. Slope changes were calculated for both parameters and were used as the basis for determining stratification layers. Hypolimnetic depth is listed in tables 1 and 2 for Lake Eucha and Lake Spavinaw respectively. The area and volume of each lake were then calculated based off this hypolimnetic depth using morphometric data that was prepared in December 1999 for Lake Eucha and in August 1999 for Lake Spavinaw (Tables 3 and 4). Lake levels for Lake Eucha were taken into account for area and volume determinations and appropriate adjustments to both area and volume values were made when lake levels were below the normal 778 mean sea level feet elevation (Table 3). The criteria for lake level determination was simply rounding down for values of 0.1-0.4 and rounding up for values of 0.6-0.9. Lake level values of 0.5 were kept as 0.5. The change in phosphorous between 2 sampling times of the month was determined by taking the average of transformed ortho-phosphorous concentration data. The period in between the two sampling dates was generally two weeks.

Table 3—Lake Eucha hypolimnetic depths, area, and volume for 1998-1999 stratification season. Area and volume discrepancies with hypolimnetic depth can be explained by lake levels changes between sample dates.

Lake Eucha Hypolimnetic Depth, Area, and Volume						
Date	Lake Level (in feet at mean sea level)	Hypolimnion (feet)	Area (acres)	Area (m^2)	Volume (acre-feet)	Volume (m^3)
April 14, 1998	778	62	80.6	326,178	390.3	481,431
April 30, 1998	778	46	461.3	1,866,821	4,510.3	5,563,410
May 13, 1998	778	26	1,346.2	5,447,896	22,431.4	27,668,908
May 28, 1998	778	26	1,346.2	5,447,896	22,431.4	27,668,908
June 10, 1998	778	23	1,537.1	6,220,444	27,461.5	33,873,486
June 23, 1998	778	23	1,537.1	6,220,444	27,461.5	33,873,486
July 14, 1998	777	23	1,346.2	5,447,896	22,431.4	27,668,908
July 28, 1998	776	23	1,219.7	4,935,967	18,437.1	22,741,978
August 12, 1998	774	30	604.5	2,446,333	6,474.7	7,986,,478
August 25, 1998	773	30	461.3	1,866,821	4,510.3	5,563,004
September 9, 1998	772	33	300.1	1,214,466	2,031.0	2,505,218
September 23, 1998	772	36	218.9	885,860	1,329.9	1,640,418
October 14, 1998	778	46	461.3	1,866,821	4,510.3	5,563,410
October 27, 1998	778	49	380.7	1,540,643	6,474.7	7,986,478
November 12, 1998	778	66	23.5	95,101	151.8	187,244
April 13, 1999	778	43	604.5	2,446,333	6,474.7	7,986,478
April 28, 1999	778	39	747.6	3,025,440	8,439.1	10,409,545
May 13, 1999	778	49	380.7	1,540643	3,270.7	4,034,376
May 25, 1999	778	46	461.3	1,866,821	4,510.3	5,563,410
June 9, 1999	778	20	1,728.1	6,993,396	32,491.6	40,078,064
June 28, 1999	778	23	1,537.1	6,220,444	27,461.5	33,873,486
July 13, 1999	778	20	1,728.1	6993,396	32,491.6	40,078,064
July 27, 1999	776	23	1,219.7	4,935,967	18,437.1	22,741,978
August 10, 1999	776	30	920.4	3,724,739	11,440.9	14,112,236
August 24, 1999	775	26	920.4	3,724,739	11,440.9	14,112,236
September 15, 1999	775	36	461.3	1,866,821	4,510.3	5,563,410
September 30, 1999	775	43	300.1	1,214,466	3,270.7	4,034,376
October 13, 1999	774	46	137.7	557,254	628.7	775,495

Table 4—Lake Spavinaw hypolimnetic depths, area, and volume for 1998-1999 stratification season.

Lake Spavinaw Hypolimnetic Depths, Area, and Volume					
Date	Hypolimnion (feet)	Area (acres)	Area (m^2)	Volume (acre-feet)	Volume (m^3)
April 16 ,1998	39	27.1	109,670	53.9	66,485
April 29, 1998	43	4.8	19,425	6.5	8,018
May 12, 1998	23	528.0	2,136,747	3,617.5	4,462,150
May 27, 1998	26	363.8	1,472,251	2,162.8	2,667,792
June 11, 1998	26	363.8	1,472,251	2,162.8	2,667,792
June 25, 1998	26	363.8	1,472,251	2,162.8	2667,792
July 15, 1998	20	647.9	2,621,967	5,543.1	6,837,358
July 30, 1998	26	363.8	1,472,251	2,162.8	2,667,792
August 13, 1998	33	153.5	621,195	604.0	745,028
August 26, 1998	30	220.4	891,930	1,214.2	1,497,704
September 8, 1998	33	153.5	621,195	604.0	745,028
September 21, 1998	26	81.7	330,629	224.3	276,672
October 13, 1998	43	4.8	19,425	6.5	8,018
April 20, 1999	39	27.1	109,670	53.9	66,485
April 29, 1999	30	220.4	891,930	1,214.2	1,497,704
May 12, 1999	30	220.4	891,930	1,214.2	1,497,704
May 26, 1999	20	647.9	2,621,967	5,543.1	6,837,358
June 10, 1999	20	647.9	2,621,967	5,543.1	6,837,358
June 24, 1999	26	363.8	1,472,251	2,162.8	2,667,792
July 15, 1999	26	363.8	1,472,251	2,162.8	2,667,792
July 29, 1999	20	647.9	2,621,967	5,543.1	6,837,358
August 11, 1999	20	647.9	2,621,967	5,543.1	6,837,358
August 26, 1999	26	363.8	1,472,251	2,162.8	2,667,792
September 16, 1999	36	81.7	330,629	224.3	276,672
September 29, 1999	39	27.1	109,670	53.9	66,485
October 12, 1999	39	27.1	109,670	53.9	66,485

Calculations indicate an average constant release rate of 2.4 mg of phosphorous per m^2-day during the stratification period of April 14 through November 12 in Lake Eucha for the 1998 season (Table 5). In 1999, there was an average constant rate of 2.9 mg of phosphorous per m^2-day during the months of stratification for Lake Eucha (Table 5). This value is reflective of a time period from April 13 through October 13.

Table 5—Lake Eucha average constant phosphorous release rates for 1998 and 1999.

Lake Eucha Average Constant Phosphorous Release Rate (mg/m^2-day)		
	1998 Season	1999 Season
Average Rate	2.4	2.9
Standard Deviation	5.2	16.7
Coefficient of Variation	2.2	5.8

Lake Spavinaw underwent lake stratification from April 16 to October 13 in 1998 during which there was an average constant release rate 2.4 mg of phosphorous per m^2-day (Table 6). In 1999, Lake Spavinaw underwent stratification from April 20 to October 12. Phosphorous release for Lake Spavinaw during 1999 stratification was 1.8 mg of phosphorous per m^2-day (Table 6).

Table 6—Lake Spavinaw average constant phosphorous release rates for 1998 and 1999.

Lake Spavinaw Average Constant Phosphorous Release Rate (mg/m^2-day)		
	1998 Season	1999 Season
Average Rate	2.5	1.8
Standard Deviation	7.8	8.1
Coefficient of Variation	3.1	4.5

In 1998 2,027.4 kg of phosphorous was released in Lake Eucha during 1998 (Table 7). In 1999, 3,337.2 kg of phosphorous was released into Lake Eucha during the stratification period. In comparison, Lake Spavinaw released 938.4 kg of phosphorous during 1998 stratification. In 1999, 339.6 kg of phosphorous accounted for the release in Lake Spavinaw during the stratification months.

Table 7—Average phosphorous mass released during stratification for Lake Eucha and Lake Spavinaw.

Lake	Year	Duration (Day)	Total released Phosphorus (kg)
Eucha	1998	212	2,027.4
	1999	183	3,337.2
Spavinaw	1998	180	938.4
	1999	175	339.6

As stated earlier, phosphorous is a limiting nutrient that can have profound effects on algae growth when excess phosphorous is present. Sediment release of phosphorous was determined earlier and results discussed in the previous section. The next step is to estimate the amount of hypolimnetic phosphorus reaching the epilimnion as an internal phosphorus load. To do this, a rate of diffusion ($W_{diffusion}$) across the metalimnion was calculated using temperature data (Chapra and Reckhow, 1983). This equation takes into account:

- hypolimnetic volume (V_h).
- average epilimnetic temperature (T_e).
- area of thermocline (A_t).
- duration of the stratification period (t_s).
- average dissolved ortho-phosphorous concentrations of the hypolimnion ($P_{s,h}$).
- average dissolved ortho-phosphorous concentrations of the epilimnion ($P_{s,e}$).
- hypolimnetic temperature for the beginning ($T_{h,i}$) of the stratification period.
- hypolimnetic temperature for the end ($T_{h,s}$) of the stratification period.

$$V_t = \frac{V_h}{A_t t_s} \ln\left[\frac{T_{h,i} - T_e}{T_{h,s} - T_e}\right]$$

$$W_{diffusion} = V_t A_t (P_{s,h} - P_{s,e})$$

Thermal diffusion rate calculations encompassed time periods when hypolimnetic phosphorus accumulation was observed (Table 7). Therefore the same dates of April 14, 1998 through November 12, 1998 for sediment phosphorous release calculations estimates that 7.5 kg is being incorporated into the epilimnion (Table 8). In 1999, $W_{diffusion}$ calculations estimate that 197.4 kg is being mixed into the epilimnion during the 183 day time period of April 13 through October 13.

Chapra and Reckhow's thermal diffusion equation estimated that 1.7 kg of phosphorous from the sediment release was being incorporated into the upper parts of the lake during the 180 day time period in Lake Spavinaw for the 1998 season (Table 8). However, during a 175 day time period of April 20 through October 12 in 1999, thermal diffusion calculations estimate that 1.2 kg of phosphorous released by the sediment was being taken up into the epilimnion.

Table 8—Internal phosphorus load estimates for Lake Eucha and Lake Spavinaw.

Lake	Year	Thermal Diffusion Coefficient (V_t) (m/day)	Duration (Day)	Phosphorus Load (kg)
Eucha	1998	0.0012	212	7.4
	1999	0.0058	183	197.4
Spavinaw	1998	0.0003	180	1.7
	1999	0.0008	175	1.2

Entrainment calculations involved the use of average transformed ortho-phosphorous values and the change in lake volume at the hypolimnetic depth using the equation $E = (P)(\Delta V)$ where P is the average of transformed ortho-phosphorous values for one time period and ΔV is the change in volume between the one sampling period and the next sampling period. Entrainment was calculated during stratification when a graphical trend was apparent in the decrease of the hypolimnion as evidenced by a pattern in decreasing epnilimnetic water temperature. Generally speaking, this pattern was observed in the later months of the stratification season as lake waters approached being isothermal. Volumes were adjusted once again for Lake Eucha when lake elevations were below normal.

For Lake Eucha in 1998, entrainment dates of July 28 to November 12, indicated 1,984.2 kg of phosphorous was present (Table 9). In 1999, 2,840 kg of phosphorous of was calculated by entrainment data for the dates of July 27 through October 13. These dates correspond to a pattern where the lake was beginning to cool in water temperature and hence therefore begin the break down of the stratification layers apparent during the earlier, warmer time periods observed at the onset of stratification.

For the time period of July 30 through October 13, entrainment calculations indicate a total of 635.1 kg of phosphorous in Lake Spavinaw during the 1998 season (Table 9). During the 1999 season, 455.4 kg of phosphorous was calculated from entrainment data from August 11 through October 12. As in Lake Eucha, the dates observed in entrainment calculations relate to a time period where waters in Lake Spavinaw were beginning to cool as a result of the lake beginning the early stages of becoming isothermal.

Table 9—Entrainment of phosphorous mass for Lake Eucha and Lake Spavinaw.

Phosphorous Release (kg) by Entrainment			
Eucha 1998	Eucha 1999	Spavinaw 1998	Spavinaw 1999
1,984.2	2,840	635.1	455.4

Tables 10 and 11 are summaries for sediment phosphorous load estimations to the epilimnion of Lake Eucha and Lake Spavinaw. The total annual load that is listed in the table is a summation of the phosphorous mass that was calculated by thermal release and by entrainment calculations. The total annual load for both Lake Eucha and Lake Spavinaw are less than the values calculated by phosphorous sediment release except for Lake Spavinaw in the 1999 season where it was found that total annual load of phosphorous was greater than the phosphorous load calculated by sediment release.

Table 10—Sediment derived phosphorous load estimation for Lake Eucha during 1998-1999 stratification season. Total annual load is a summation of thermal diffusion release and entrainment release.

Lake Eucha			
Time Period	Sediment Release (kg)	Thermal Diffusion Release (kg)	Entrainment Release (kg)
April 14, 1998	2,027.4	7.5	
April 30, 1998			
May 13, 1998			
May 28, 1998			
June 10, 1998			
June 23, 1998			
July 14, 1998			
July 28, 1998			824.5
August 12, 1998			146.3
August 25, 1998			382.3
September 9, 1998			121.4
September 23, 1998			0
October 14, 1998			143.2
October 27, 1998			344.3
November 12, 1998			22.3
Total Annual Load	1,991.7		
April 13, 1999	3,337.2	197.4	
April 28, 1999			
May 13, 1999			
May 25, 1999			
June 9, 1999			
June 28, 1999			
July 13, 1999			
July 27, 1999			919.1
August 10, 1999			0
August 24, 1999			1,134.9
September 15, 1999			700.3
September 30, 1999			4.3
October 13, 1999			81.4
Total Annual Load	3,037.3		

Table 11—Sediment derived phosphorous load estimation for Lake Spavinaw during 1998-1999 stratification season. Total annual load is a summation of thermal diffusion release and entrainment release.

Lake Spavinaw			
Time Period	Sediment Release (kg)	Thermal Diffusion Release (kg)	Entrainment Release (kg)
April 16 ,1998			
April 29, 1998			
May 12, 1998			
May 27, 1998			
June 11, 1998			
June 25, 1998			
July 15, 1998	938.4	1.7	
July 30, 1998			250.6
August 13, 1998			0
August 26, 1998			179.4
September 8, 1998			110.5
September 21, 1998			94.3
October 13, 1998			0.3
Total Annual Load		636.8	
April 20, 1999			
April 29, 1999			
May 12, 1999			
May 26, 1999			
June 10, 1999			
June 24, 1999			
July 15, 1999	339.6	1.2	
July 29, 1999			
August 11, 1999			442.5
August 26, 1999			12.0
September 16, 1999			0.5
September 29, 1999			0
October 12, 1999			0.415
Total Annual Load		456.6	

Bibliography

Chapra, S.C. and K.H. Reckhow. 1983. Engineering approaches for lake management, volume 2: mechanistic modeling. Butterworth publishers, Stoneham, MA.

Snow, P.D. and F.A. DiGiano. 1976. “Mathematical modeling of phosphorous exchange between sediments and overlying water in shallow eutrophic lakes,” Environmental engineering, department of civil engineering, University of Massachusetts, Amherst, Report No. E. 54-76-3.

Appendix F: BATHTUB

Eucha Lake Annual

File name euchan1.bin

```
 MODEL OPTIONS:
  1 CONSERVATIVE SUBSTANCE           0 NOT COMPUTED
  2 PHOSPHORUS BALANCE               1 2ND ORDER, AVAIL P
  3 NITROGEN BALANCE                 0 NOT COMPUTED
  4 CHLOROPHYLL-A                    5 P, JONES & BACHMAN
  5 SECCHI DEPTH                     1 VS. CHLA & TURBIDITY
  6 DISPERSION                       1 FISCHER-NUMERIC
  7 PHOSPHORUS CALIBRATION           1 DECAY RATES
  8 NITROGEN CALIBRATION             2 CONCENTRATIONS
  9 ERROR ANALYSIS                   1 MODEL & DATA
 10 AVAILABILITY FACTORS             1 USE FOR MODEL 1 ONLY
 11 MASS-BALANCE TABLES              0 USE OBSERVED CONCS

 ATMOSPHERIC LOADS & AVAILABILITY FACTORS:
             ATMOSPHERIC-LOADS   AVAILABILITY
 VARIABLE     KG/KM2-YR      CV      FACTOR
  1 CONSERV         .00     .00         .00
  2 TOTAL P         .00     .50        1.00
  3 TOTAL N         .00     .50        1.00
  4 ORTHO P         .00     .50         .00
  5 INORG N         .00     .50         .00

 GLOBAL INPUT VALUES:
 PARAMETER                      MEAN     CV
 PERIOD LENGTH     YRS         1.000   .000
 PRECIPITATION M                .000   .000
 EVAPORATION   M                .140   .450
 INCREASE IN STORAGE M         -.390  1.410

 TRIBUTARY DRAINAGE AREAS AND FLOWS:
 ID TYPE SEG NAME            DRAINAGE AREA    MEAN FLOW  CV OF MEAN
FLOW
                                       KM2       HM3/YR
  1   1    3 External Loads        825.000      284.300        .054
  2   5    1 Internal Load            .000         .000        .000
  3   4    0 Outflow                  .000      261.000        .192

 TRIBUTARY CONCENTRATIONS (PPB): MEAN/CV
 ID        CONSERV       TOTAL P      TOTAL N      ORTHO P      INORG N
  1      .0/ .00   121.0/ .05      .0/ .00   119.0/ .05  2139.0/ .39
  2      .0/ .00     1.6/ .29    16.0/ .22      .0/ .00      .0/ .00
  3      .0/ .00    28.5/ .09  1441.0/ .02      .0/ .00      .0/ .00

 MODEL SEGMENTS & CALIBRATION FACTORS:
                                    ----------- CALIBRATION FACTORS --
---------
 SEG OUTFLOW GROUP SEGMENT NAME      P SED  N SED  CHL-A SECCHI    HOD
DISP
  1       0     1  Lacustrine         1.00   1.00   1.00   1.00   1.00
1.000
```

```
                                CV:    .000   .000   .000   .000   .000
.000
  2       1     1  Transition          1.00   1.00   1.00   1.00   1.00
1.000
                                CV:    .000   .000   .000   .000   .000
.000
  3       2     1  Riverine            1.00   1.00   1.00   1.00   1.00
1.000
                                CV:    .000   .000   .000   .000   .000
.000

 SEGMENT MORPHOMETRY: MEAN/CV
                     LENGTH      AREA  ZMEAN      ZMIX       ZHYP
 ID LABEL                KM       KM2      M         M          M
  1 Lacustrine         3.50    4.4200  15.00  10.30/ .43   9.70/ .31
  2 Transition         2.04    2.5700   7.00   7.82/ .44   8.20/ .17
  3 Riverine           3.46    4.3700   2.00   5.40/ .23    .00/ .00

 SEGMENT OBSERVED WATER QUALITY:
 SEG    TURBID CONSER TOTALP TOTALN  CHL-A SECCHI  ORG-N  TP-OP   HODV
MODV
          1/M    ---   MG/M3  MG/M3  MG/M3      M  MG/M3  MG/M3 MG/M3-D
MG/M3-D
  1 MN:    .18     .0   30.0 1330.0   17.9    2.1  314.0   21.0   80.5
118.2
    CV:   1.61    .00    .96    .45    .88    .56    .95    .87    .69
.71
  2 MN:    .28     .0   42.2 1527.0   18.9    1.6  332.0   32.2  170.8
133.1
    CV:    .77    .00   1.04    .41    .60    .42    .81   1.11   1.03
.38
  3 MN:    .48     .0   39.3 2046.0   17.9    1.3  324.0   28.2     .0
.0
    CV:    .72    .00    .45    .43    .77    .49    .89    .55    .00
.00

 MODEL COEFFICIENTS:
 COEFFICIENT           MEAN      CV
 DISPERSION FACTO     1.000     .70
 P DECAY RATE         2.204     .45
 N DECAY RATE         1.000     .55
 CHL-A MODEL          1.000     .26
 SECCHI MODEL         1.000     .10
 ORGANIC N MODEL      1.000     .12
 TP-OP MODEL          1.000     .15
 HODV MODEL           1.000     .15
 MODV MODEL           1.000     .22
 BETA  M2/MG           .025     .00
 MINIMUM QS           4.000     .00
 FLUSHING EFFECT      1.000     .00
 CHLOROPHYLL-A CV      .620     .00

 CASE NOTES:
 trib 1 - external load
  trib 2 - outflow
  trib 3 - internal load
  seg 3 - riverine zone
```

```
  seg 2 - transition zone
  seg 1 - lacustrine zone


 GROSS WATER BALANCE:
                              DRAINAGE AREA      ---- FLOW (HM3/YR) ----
RUNOFF
 ID  T LOCATION                         KM2          MEAN  VARIANCE    CV
M/YR
 ----------------------------------------------------------------------
------
  1  1 External Loads         825.000      284.300  .236E+03  .054
.345
  3  4 Outflow                   .000      261.000  .251E+04  .192
.000
 ----------------------------------------------------------------------
------
 TRIBUTARY INFLOW             825.000      284.300  .236E+03  .054
.345
 ***TOTAL INFLOW              836.360      284.300  .236E+03  .054
.340
 ADVECTIVE OUTFLOW            836.360      287.140  .275E+03  .058
.343
 ***TOTAL OUTFLOW             836.360      287.140  .275E+03  .058
.343
 ***EVAPORATION                  .000        1.590  .512E+00  .450
.000
 ***STORAGE INCREASE             .000       -4.430  .390E+02 1.410
.000
 ----------------------------------------------------------------------
------

 GROSS MASS BALANCE BASED UPON  OBSERVED CONCENTRATIONS
 COMPONENT: TOTAL P
                              ----- LOADING ---- --- VARIANCE ---
CONC  EXPORT
 ID T LOCATION                      KG/YR   %(I)  KG/YR**2   %(I)    CV
MG/M3  KG/KM2
 ----------------------------------------------------------------------
---------
  1 1 External Loads        34400.3   93.2  .703E+07   92.8  .077
121.0    41.7
 ----------------------------------------------------------------------
---------
 INTERNAL LOAD               2515.2    6.8  .547E+06    7.2  .294
.0      .0
 TRIBUTARY INFLOW           34400.3   93.2  .703E+07   92.8  .077
121.0    41.7
 ***TOTAL INFLOW            36915.5  100.0  .758E+07  100.0  .075
129.8    44.1
 ADVECTIVE OUTFLOW           8614.2   23.3  .686E+08  905.8  .962
30.0    10.3
 ***TOTAL OUTFLOW            8614.2   23.3  .686E+08  905.8  .962
30.0    10.3
 ***STORAGE INCREASE         -162.3    -.4  .533E+05     .7 1.422
36.6      .0
```

***RETENTION 28463.7 77.1 .745E+08 983.1 .303 .0 .0

	HYDRAULIC	-----	----- TOTAL P	-----	-----
OVERFLOW	RESIDENCE	POOL	RESIDENCE	TURNOVER	RETENTION
RATE	TIME	CONC	TIME	RATIO	COEF
M/YR	YRS	MG/M3	YRS	-	-
24.89	.3291	36.3	.0916	10.9202	.7710

T STATISTICS COMPARE OBSERVED AND PREDICTED MEANS
USING THE FOLLOWING ERROR TERMS:

1 = OBSERVED WATER QUALITY ERROR ONLY
2 = ERROR TYPICAL OF MODEL DEVELOPMENT DATA SET
3 = OBSERVED AND PREDICTED ERROR

SEGMENT: 4 AREA-WTD MEAN

		OBSERVED		ESTIMATED			T STATISTICS		
VARIABLE		MEAN	CV	MEAN	CV	RATIO	1	2	3
TOTAL P	MG/M3	36.3	.77	36.6	.18	.99	-.01	-.03	-.01
TOTAL N	MG/M3	1650.0	.43	1650.0	.26	1.00	.00	.00	.00
C.NUTRIENT	MG/M3	34.8	.68	35.1	.17	.99	-.01	-.04	-.01
CHL-A	MG/M3	18.1	.77	15.6	.37	1.16	.20	.44	.18
SECCHI	M	1.7	.51	1.5	.39	1.13	.23	.43	.19
ORGANIC N	MG/M3	321.9	.89	536.6	.27	.60	-.57	-2.04	-.55
TP-ORTHO-P	MG/M3	26.3	.80	31.3	.39	.84	-.21	-.47	-.19
HOD-V	MG/M3-DAY	113.7	.88	104.3	.30	1.09	.10	.43	.09
MOD-V	MG/M3-DAY	123.7	.58	96.4	.35	1.28	.43	.76	.37

OBSERVED AND PREDICTED DIAGNOSTIC VARIABLES
RANKED AGAINST CE MODEL DEVELOPMENT DATA SET

SEGMENT: 4 AREA-WTD MEAN

		----- VALUES -----		--- RANKS (%) ----	
VARIABLE		OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P	MG/M3	36.34	36.64	37.9	38.3
TOTAL N	MG/M3	1650.00	1650.00	78.2	78.2
C.NUTRIENT	MG/M3	34.80	35.09	48.7	49.1

CHL-A MG/M3	18.13	15.59	80.4	74.5
SECCHI M	1.68	1.50	72.1	66.6
ORGANIC N MG/M3	321.92	536.56	22.4	59.6
TP-ORTHO-P MG/M3	26.30	31.26	44.5	51.7
HOD-V MG/M3-DAY	113.70	104.25	70.0	65.8
MOD-V MG/M3-DAY	123.68	96.39	80.0	68.8
ANTILOG PC-1	244.75	287.54	50.0	54.9
ANTILOG PC-2	12.89	11.62	90.7	87.0
(N - 150) / P	41.28	40.93	90.4	90.2
INORGANIC N / P	132.36	206.67	93.4	97.5
TURBIDITY 1/M	.32	.32	23.4	23.4
ZMIX * TURBIDITY	2.52	2.52	38.7	38.7
ZMIX / SECCHI	4.66	5.25	48.4	56.6
CHL-A * SECCHI	30.54	23.31	93.9	87.8
CHL-A / TOTAL P	.50	.43	92.9	88.8
FREQ(CHL-a>10) %	74.20	65.76	.0	.0
FREQ(CHL-a>20) %	31.96	23.82	.0	.0
FREQ(CHL-a>30) %	13.08	8.59	.0	.0
FREQ(CHL-a>40) %	5.63	3.36	.0	.0
FREQ(CHL-a>50) %	2.58	1.43	.0	.0
FREQ(CHL-a>60) %	1.25	.65	.0	.0
CARLSON TSI-P	55.96	56.08	.0	.0
CARLSON TSI-CHLA	59.02	57.54	.0	.0
CARLSON TSI-SEC	52.48	54.20	.0	.0

Eucha Lake Summer

File name: sueucha.bin

Eucha Lake Summer

MODEL OPTIONS:

1	CONSERVATIVE SUBSTANCE	0 NOT COMPUTED
2	PHOSPHORUS BALANCE	1 2ND ORDER, AVAIL P
3	NITROGEN BALANCE	0 NOT COMPUTED
4	CHLOROPHYLL-A	5 P, JONES & BACHMAN
5	SECCHI DEPTH	1 VS. CHLA & TURBIDITY
6	DISPERSION	1 FISCHER-NUMERIC
7	PHOSPHORUS CALIBRATION	1 DECAY RATES
8	NITROGEN CALIBRATION	2 CONCENTRATIONS
9	ERROR ANALYSIS	1 MODEL & DATA
10	AVAILABILITY FACTORS	1 USE FOR MODEL 1 ONLY
11	MASS-BALANCE TABLES	0 USE OBSERVED CONCS

ATMOSPHERIC LOADS & AVAILABILITY FACTORS:

VARIABLE	ATMOSPHERIC-LOADS KG/KM2-YR	CV	AVAILABILITY FACTOR
1 CONSERV	.00	.00	.00
2 TOTAL P	.00	.00	1.00
3 TOTAL N	.00	.00	1.00
4 ORTHO P	.00	.00	.00
5 INORG N	.00	.00	.00

GLOBAL INPUT VALUES:

```
 PARAMETER                       MEAN     CV
 PERIOD LENGTH     YRS           .500   .100
 PRECIPITATION M                 .000   .000
 EVAPORATION   M                 .190   .210
 INCREASE IN STORAGE M         -1.530   .410

 TRIBUTARY DRAINAGE AREAS AND FLOWS:
 ID TYPE SEG NAME            DRAINAGE AREA    MEAN FLOW  CV OF MEAN
FLOW
                                       KM2       HM3/YR
  1   1    3 External Loads        825.000      283.000         .641
  2   5    1 Internal Load            .000         .000         .000
  3   4    0 Outflow                  .000      303.000         .686

 TRIBUTARY CONCENTRATIONS (PPB): MEAN/CV
 ID        CONSERV      TOTAL P      TOTAL N      ORTHO P      INORG N
  1      .0/ .00   122.0/ .29      .0/ .00   120.0/ .28  1000.0/ .26
  2      .0/ .00     1.6/ .29    16.0/ .22      .0/ .00       .0/ .00
  3      .0/ .00    26.7/ .44  1481.0/ .31      .0/ .00       .0/ .00

 MODEL SEGMENTS & CALIBRATION FACTORS:
                                     ----------- CALIBRATION FACTORS --
---------
 SEG OUTFLOW GROUP SEGMENT NAME      P SED  N SED  CHL-A SECCHI    HOD
DISP
  1       0     1  Lacustrine         1.00   1.00   1.00   1.00   1.00
1.000
                               CV:    .000   .000   .000   .000   .000
.000
  2       1     1  Transition         1.00   1.00   1.00   1.00   1.00
1.000
                               CV:    .000   .000   .000   .000   .000
.000
  3       2     1  Riverine           1.00   1.00   1.00   1.00   1.00
1.000
                               CV:    .000   .000   .000   .000   .000
.000

 SEGMENT MORPHOMETRY: MEAN/CV
                     LENGTH      AREA  ZMEAN       ZMIX       ZHYP
 ID LABEL                KM       KM2      M          M          M
  1 Lacustrine         3.50    4.4200  14.00   6.50/ .50   9.70/ .31
  2 Transition         2.04    2.5700   8.00   4.69/ .36   8.20/ .17
  3 Riverine           3.46    4.3700   2.50   4.60/ .29    .00/ .00

 SEGMENT OBSERVED WATER QUALITY:
 SEG    TURBID CONSER TOTALP TOTALN  CHL-A SECCHI  ORG-N  TP-OP   HODV
MODV
          1/M    ---   MG/M3  MG/M3  MG/M3      M  MG/M3  MG/M3 MG/M3-D
MG/M3-D
  1 MN:    .18     .0   21.0 1080.0   19.6    2.1  390.0   17.0   80.5
118.2
    CV:   1.13    .00    .56    .60    .94    .63   1.01    .62    .69
.71
  2 MN:    .28     .0   39.6 1182.0   18.7    1.7  494.0   36.8  170.8
133.1
```

```
    CV:     .48    .00   1.49    .56    .65    .55    .60   1.60   1.03
.38
  3 MN:     .34     .0   36.0 1657.0   26.5    1.2  528.0   31.3     .0
.0
    CV:     .94    .00    .42    .50    .51    .45    .64    .47    .00
.00

 MODEL COEFFICIENTS:
 COEFFICIENT            MEAN      CV
 DISPERSION FACTO      1.000     .70
 P DECAY RATE          3.442     .45
 N DECAY RATE          1.000     .55
 CHL-A MODEL           1.581     .26
 SECCHI MODEL          1.000     .10
 ORGANIC N MODEL       1.000     .12
 TP-OP MODEL           1.000     .15
 HODV MODEL            1.000     .15
 MODV MODEL            1.000     .22
 BETA  M2/MG            .025     .00
 MINIMUM QS            4.000     .00
 FLUSHING EFFECT       1.000     .00
 CHLOROPHYLL-A CV       .620     .00

 CASE NOTES:
 trib 1 - external load
  trib 2 - outflow
  trib 3 - internal load
  seg 3 - riverine zone
  seg 2 - transition zone
  seg 1 - lacustrine zone
  Short residence time suggests
  using summer values only


 CASE: Eucha Lake Summer
 GROSS WATER BALANCE:
                      DRAINAGE AREA      ---- FLOW (HM3/YR) ----
RUNOFF
 ID  T LOCATION                 KM2         MEAN  VARIANCE    CV
M/YR
 ----------------------------------------------------------------------
------
  1  1 External Loads       825.000      283.000  .329E+05  .641
.343
  3  4 Outflow                 .000      303.000  .432E+05  .686
.000
 ----------------------------------------------------------------------
------
 TRIBUTARY INFLOW           825.000      283.000  .329E+05  .641
.343
 ***TOTAL INFLOW            836.360      283.000  .329E+05  .641
.338
 ADVECTIVE OUTFLOW          836.360      313.445  .331E+05  .581
.375
 ***TOTAL OUTFLOW           836.360      313.445  .331E+05  .581
.375
```

```
 ***EVAPORATION                  .000        4.317  .997E+00  .231
.000
 ***STORAGE INCREASE             .000      -34.762  .215E+03  .421
.000
 ----------------------------------------------------------------------
------

 GROSS MASS BALANCE BASED UPON  OBSERVED CONCENTRATIONS
 COMPONENT: TOTAL P
                       ----- LOADING ---- --- VARIANCE ---
CONC  EXPORT
 ID T LOCATION               KG/YR   %(I)  KG/YR**2   %(I)    CV
MG/M3  KG/KM2
 ----------------------------------------------------------------------
---------
  1 1 External Loads       34526.0   93.2  .588E+09   99.9  .702
122.0    41.8
 ----------------------------------------------------------------------
---------
 INTERNAL LOAD              2515.2    6.8  .547E+06     .1  .294
.0      .0
 TRIBUTARY INFLOW          34526.0   93.2  .588E+09   99.9  .702
122.0    41.8
 ***TOTAL INFLOW           37041.2  100.0  .589E+09  100.0  .655
130.9    44.3
 ADVECTIVE OUTFLOW          6582.3   17.8  .282E+08    4.8  .807
21.0     7.9
 ***TOTAL OUTFLOW           6582.3   17.8  .282E+08    4.8  .807
21.0     7.9
 ***STORAGE INCREASE       -1066.9   -2.9  .294E+06     .1  .509
30.7      .0
 ***RETENTION              31525.8   85.1  .457E+09   77.7  .678
.0      .0
 ----------------------------------------------------------------------
---------

           HYDRAULIC    -------------- TOTAL P  --------------
  OVERFLOW RESIDENCE      POOL RESIDENCE  TURNOVER RETENTION
      RATE      TIME      CONC      TIME     RATIO      COEF
      M/YR       YRS     MG/M3       YRS       -          -
     24.53     .3350      31.0     .0781    6.4035     .8511
 CASE: Eucha Lake Summer

 T STATISTICS COMPARE OBSERVED AND PREDICTED MEANS
 USING THE FOLLOWING ERROR TERMS:
  1 = OBSERVED WATER QUALITY ERROR ONLY
  2 = ERROR TYPICAL OF MODEL DEVELOPMENT DATA SET
  3 = OBSERVED AND PREDICTED ERROR

 SEGMENT:  4 AREA-WTD MEAN
                       OBSERVED     ESTIMATED              T
STATISTICS
 VARIABLE            MEAN    CV    MEAN    CV   RATIO      1      2
3
 ----------------------------------------------------------------------
---
```

TOTAL P	MG/M3	31.0	.77	30.7	.28	1.01	.01	.03	.01
TOTAL N	MG/M3	1325.0	.54	1325.0	.33	1.00	.00	.00	.00
C.NUTRIENT	MG/M3	29.3	.68	29.2	.26	1.00	.01	.02	.01
CHL-A	MG/M3	22.0	.69	19.0	.49	1.16	.21	.42	.17
SECCHI	M	1.7	.56	1.4	.39	1.20	.33	.65	.27
ORGANIC N	MG/M3	466.6	.75	611.3	.37	.76	-.36	-1.08	-.32
TP-ORTHO-P	MG/M3	27.0	.86	36.1	.49	.75	-.34	-.80	-.29
HOD-V	MG/M3-DAY	113.7	.88	115.2	.34	.99	-.02	-.07	-.01
MOD-V	MG/M3-DAY	123.7	.58	106.6	.38	1.16	.26	.46	.21

CASE: Eucha Lake Summer

OBSERVED AND PREDICTED DIAGNOSTIC VARIABLES
RANKED AGAINST CE MODEL DEVELOPMENT DATA SET

SEGMENT: 4 AREA-WTD MEAN

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	30.98	30.69	31.4	31.0
TOTAL N MG/M3	1325.04	1325.04	66.9	66.9
C.NUTRIENT MG/M3	29.34	29.23	40.3	40.1
CHL-A MG/M3	22.04	19.05	86.6	82.1
SECCHI M	1.68	1.40	71.9	63.3
ORGANIC N MG/M3	466.61	611.28	48.8	69.1
TP-ORTHO-P MG/M3	26.98	36.10	45.6	57.7
HOD-V MG/M3-DAY	113.70	115.24	70.0	70.6
MOD-V MG/M3-DAY	123.68	106.55	80.0	73.7
ANTILOG PC-1	282.64	312.59	54.3	57.4
ANTILOG PC-2	16.18	13.52	96.0	92.1
(N - 150) / P	37.93	38.29	88.1	88.3
INORGANIC N / P	214.72	713.76	97.7	99.9
TURBIDITY 1/M	.27	.27	17.3	17.3
ZMIX * TURBIDITY	1.43	1.43	15.3	15.3
ZMIX / SECCHI	3.19	3.84	24.5	35.4
CHL-A * SECCHI	36.99	26.61	96.6	91.2
CHL-A / TOTAL P	.71	.62	97.9	96.5
FREQ(CHL-a>10) %	83.27	76.71	.0	.0
FREQ(CHL-a>20) %	43.90	34.87	.0	.0
FREQ(CHL-a>30) %	20.97	14.85	.0	.0
FREQ(CHL-a>40) %	10.18	6.59	.0	.0
FREQ(CHL-a>50) %	5.14	3.10	.0	.0
FREQ(CHL-a>60) %	2.71	1.54	.0	.0
CARLSON TSI-P	53.66	53.52	.0	.0
CARLSON TSI-CHLA	60.94	59.51	.0	.0
CARLSON TSI-SEC	52.54	55.18	.0	.0

Spavinaw Lake Annual

```
 File name: anspav.bin

 Spavinaw Lake Annual

 MODEL OPTIONS:
  1 CONSERVATIVE SUBSTANCE            0 NOT COMPUTED
  2 PHOSPHORUS BALANCE                1 2ND ORDER, AVAIL P
  3 NITROGEN BALANCE                  0 NOT COMPUTED
  4 CHLOROPHYLL-A                     5 P, JONES & BACHMAN
  5 SECCHI DEPTH                      1 VS. CHLA & TURBIDITY
  6 DISPERSION                        1 FISCHER-NUMERIC
  7 PHOSPHORUS CALIBRATION            1 DECAY RATES
  8 NITROGEN CALIBRATION              2 CONCENTRATIONS
  9 ERROR ANALYSIS                    1 MODEL & DATA
 10 AVAILABILITY FACTORS              1 USE FOR MODEL 1 ONLY
 11 MASS-BALANCE TABLES               0 USE OBSERVED CONCS

 ATMOSPHERIC LOADS & AVAILABILITY FACTORS:
             ATMOSPHERIC-LOADS   AVAILABILITY
 VARIABLE     KG/KM2-YR      CV      FACTOR
  1 CONSERV         .00     .00         .00
  2 TOTAL P         .00     .00        1.00
  3 TOTAL N         .00     .00        1.00
  4 ORTHO P         .00     .00         .00
  5 INORG N         .00     .00         .00

 GLOBAL INPUT VALUES:
 PARAMETER                       MEAN     CV
 PERIOD LENGTH     YRS          1.000   .000
 PRECIPITATION M                 .000   .000
 EVAPORATION   M                 .140   .450
 INCREASE IN STORAGE M          -.040   .370

 TRIBUTARY DRAINAGE AREAS AND FLOWS:
 ID TYPE SEG NAME            DRAINAGE AREA    MEAN FLOW  CV OF MEAN
FLOW
                                       KM2       HM3/YR
  1   1    2 Eucha dam             825.000      261.000         .192
  2   4    0 Outflow                  .000      297.000         .239
  3   5    1 Internal                 .000         .000         .000
  4   1    2 Lake basin            191.000       19.000         .454

 TRIBUTARY CONCENTRATIONS (PPB): MEAN/CV
 ID        CONSERV       TOTAL P      TOTAL N      ORTHO P      INORG N
  1       .0/ .00    28.5/ .09  1441.0/ .02      .0/ .00      .0/ .00
  2       .0/ .00    20.3/ .16  1042.1/ .03      .0/ .00      .0/ .00
  3       .0/ .00      .4/ .23     5.6/ .45      .0/ .00      .0/ .00
  4       .0/ .00    33.0/ .35      .0/ .00     7.0/ .98   465.0/ .88

 MODEL SEGMENTS & CALIBRATION FACTORS:
                                     ----------- CALIBRATION FACTORS --
---------
 SEG OUTFLOW GROUP SEGMENT NAME      P SED  N SED  CHL-A SECCHI    HOD
DISP
```

```
  1       0     1  Lacustrine         1.00   1.00   1.00   1.00   1.00
1.000
                                CV:   .000   .000   .000   .000   .000
.000
  2       1     1  Transition         1.00   1.00   1.00   1.00   1.00
1.000
                                CV:   .000   .000   .000   .000   .000
.000

 SEGMENT MORPHOMETRY: MEAN/CV
                     LENGTH      AREA  ZMEAN      ZMIX       ZHYP
 ID LABEL                KM       KM2      M         M          M
  1 Lacustrine         4.16    3.8700   7.00   7.30/ .32   7.80/ .23
  2 Transition         2.68    2.5000   2.20   4.00/ .04    .00/ .00

 SEGMENT OBSERVED WATER QUALITY:
 SEG    TURBID CONSER TOTALP TOTALN  CHL-A SECCHI  ORG-N  TP-OP   HODV
MODV
          1/M    ---   MG/M3  MG/M3  MG/M3      M  MG/M3  MG/M3 MG/M3-D
MG/M3-D
  1 MN:    .29     .0   24.0  794.0   14.6    1.7  337.0   20.0  248.0
193.0
    CV:    .63    .00    .85    .52    .48    .35    .75   1.02    .37
.48
  2 MN:    .52     .0   26.0 1062.0   15.0    1.3  534.0   25.0     .0
.0
    CV:    .97    .00    .54    .67    .47    .34   1.15   1.41    .00
.00

 MODEL COEFFICIENTS:
 COEFFICIENT            MEAN      CV
 DISPERSION FACTO      1.000     .70
 P DECAY RATE          1.000     .45
 N DECAY RATE          1.000     .55
 CHL-A MODEL           1.875     .26
 SECCHI MODEL          1.000     .10
 ORGANIC N MODEL       1.000     .12
 TP-OP MODEL           1.000     .15
 HODV MODEL            1.000     .15
 MODV MODEL            1.000     .22
 BETA  M2/MG            .025     .00
 MINIMUM QS            4.000     .00
 FLUSHING EFFECT       1.000     .00
 CHLOROPHYLL-A CV       .620     .00

 CASE NOTES:
 Trib #1 - Eucha dam release
 Trib #2 - Internal load
 trib #3 - outflow
 trib #4 - Lake basin inflow


 CASE: Spavinaw Lake Annual
 GROSS WATER BALANCE:
                       DRAINAGE AREA      ---- FLOW (HM3/YR) ----
RUNOFF
```

```
 ID  T LOCATION                   KM2         MEAN  VARIANCE    CV
M/YR
 --------------------------------------------------------------------
------
  1  1 Eucha dam              825.000      261.000  .251E+04  .192
.316
  2  4 Outflow                   .000      297.000  .504E+04  .239
.000
  4  1 Lake basin             191.000       19.000  .744E+02  .454
.099
 --------------------------------------------------------------------
------
 TRIBUTARY INFLOW            1016.000      280.000  .259E+04  .182
.276
 ***TOTAL INFLOW             1022.370      280.000  .259E+04  .182
.274
 ADVECTIVE OUTFLOW           1022.370      279.363  .259E+04  .182
.273
 ***TOTAL OUTFLOW            1022.370      279.363  .259E+04  .182
.273
 ***EVAPORATION                  .000         .892  .161E+00  .450
.000
 ***STORAGE INCREASE             .000        -.255  .889E-02  .370
.000
 --------------------------------------------------------------------
------

 GROSS MASS BALANCE BASED UPON  OBSERVED CONCENTRATIONS
 COMPONENT: TOTAL P
                       ----- LOADING ---- --- VARIANCE ---
CONC  EXPORT
 ID T LOCATION               KG/YR   %(I)  KG/YR**2   %(I)    CV
MG/M3  KG/KM2
 --------------------------------------------------------------------
---------
  1 1 Eucha dam             7448.9   86.4  .253E+07   94.5  .213
28.5     9.0
  4 1 Lake basin             627.0    7.3  .130E+06    4.9  .575
33.0     3.3
 --------------------------------------------------------------------
---------
 INTERNAL LOAD               546.5    6.3  .162E+05     .6  .233
.0      .0
 TRIBUTARY INFLOW           8075.9   93.7  .266E+07   99.4  .202
28.8     7.9
 ***TOTAL INFLOW            8622.4  100.0  .267E+07  100.0  .190
30.8     8.4
 ADVECTIVE OUTFLOW          6704.7   77.8  .340E+08 1271.5  .869
24.0     6.6
 ***TOTAL OUTFLOW           6704.7   77.8  .340E+08 1271.5  .869
24.0     6.6
 ***STORAGE INCREASE          -5.9    -.1  .515E+01     .0  .387
23.0      .0
 ***RETENTION               1923.6   22.3  .331E+08 1238.3 2.990
.0      .0
 --------------------------------------------------------------------
---------
```

OVERFLOW RATE M/YR	HYDRAULIC RESIDENCE TIME YRS	TOTAL P POOL CONC MG/M3	TOTAL P RESIDENCE TIME YRS	TOTAL P TURNOVER RATIO -	TOTAL P RETENTION COEF -
43.82	.1168	24.8	.0937	10.6747	.2231

CASE: Spavinaw Lake Annual

T STATISTICS COMPARE OBSERVED AND PREDICTED MEANS
USING THE FOLLOWING ERROR TERMS:
1 = OBSERVED WATER QUALITY ERROR ONLY
2 = ERROR TYPICAL OF MODEL DEVELOPMENT DATA SET
3 = OBSERVED AND PREDICTED ERROR

SEGMENT: 3 AREA-WTD MEAN

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	24.8	.72	23.0	.11	1.08	.10	.28	.10
TOTAL N	MG/M3	899.2	.59	899.2	.42	1.00	.00	.00	.00
C.NUTRIENT	MG/M3	23.0	.67	21.5	.12	1.07	.10	.33	.10
CHL-A	MG/M3	14.8	.48	14.8	.31	1.00	.00	.00	.00
SECCHI	M	1.5	.35	1.4	.32	1.12	.33	.41	.24
ORGANIC N	MG/M3	414.3	.95	522.5	.23	.79	-.24	-.93	-.24
TP-ORTHO-P	MG/M3	22.0	1.19	31.2	.35	.70	-.29	-.96	-.28
HOD-V	MG/M3-DAY	248.0	.37	118.2	.31	2.10	2.00	3.67	1.53
MOD-V	MG/M3-DAY	193.0	.48	103.2	.34	1.87	1.30	1.91	1.07

CASE: Spavinaw Lake Annual

OBSERVED AND PREDICTED DIAGNOSTIC VARIABLES
RANKED AGAINST CE MODEL DEVELOPMENT DATA SET

SEGMENT: 3 AREA-WTD MEAN

VARIABLE		VALUES OBSERVED	VALUES ESTIMATED	RANKS (%) OBSERVED	RANKS (%) ESTIMATED
TOTAL P	MG/M3	24.78	22.99	23.2	20.7
TOTAL N	MG/M3	899.18	899.18	43.3	43.3
C.NUTRIENT	MG/M3	22.97	21.48	29.1	26.3
CHL-A	MG/M3	14.76	14.77	72.1	72.2
SECCHI	M	1.52	1.36	67.5	62.0
ORGANIC N	MG/M3	414.32	522.48	39.6	57.6

TP-ORTHO-P MG/M3	21.96	31.23	37.1	51.7
HOD-V MG/M3-DAY	248.00	118.25	94.2	71.8
MOD-V MG/M3-DAY	193.00	103.24	92.9	72.2
ANTILOG PC-1	196.75	217.16	43.3	46.3
ANTILOG PC-2	11.87	11.57	87.8	86.8
(N - 150) / P	30.23	32.59	80.1	83.0
INORGANIC N / P	171.78	376.70	96.1	99.5
TURBIDITY 1/M	.38	.38	29.8	29.8
ZMIX * TURBIDITY	2.29	2.29	34.1	34.1
ZMIX / SECCHI	3.94	4.41	37.1	44.7
CHL-A * SECCHI	22.50	20.10	86.8	83.1
CHL-A / TOTAL P	.60	.64	96.0	96.9
FREQ(CHL-a>10) %	62.47	62.52	.0	.0
FREQ(CHL-a>20) %	21.17	21.21	.0	.0
FREQ(CHL-a>30) %	7.29	7.31	.0	.0
FREQ(CHL-a>40) %	2.75	2.76	.0	.0
FREQ(CHL-a>50) %	1.14	1.14	.0	.0
FREQ(CHL-a>60) %	.51	.51	.0	.0
CARLSON TSI-P	50.44	49.36	.0	.0
CARLSON TSI-CHLA	57.01	57.01	.0	.0
CARLSON TSI-SEC	53.92	55.56	.0	.0

Spavinaw Lake Summer

File name: suspav.bin

MODEL OPTIONS:

1	CONSERVATIVE SUBSTANCE	0 NOT COMPUTED
2	PHOSPHORUS BALANCE	1 2ND ORDER, AVAIL P
3	NITROGEN BALANCE	0 NOT COMPUTED
4	CHLOROPHYLL-A	5 P, JONES & BACHMAN
5	SECCHI DEPTH	1 VS. CHLA & TURBIDITY
6	DISPERSION	1 FISCHER-NUMERIC
7	PHOSPHORUS CALIBRATION	1 DECAY RATES
8	NITROGEN CALIBRATION	0 NONE
9	ERROR ANALYSIS	1 MODEL & DATA
10	AVAILABILITY FACTORS	1 USE FOR MODEL 1 ONLY
11	MASS-BALANCE TABLES	0 USE OBSERVED CONCS

ATMOSPHERIC LOADS & AVAILABILITY FACTORS:

VARIABLE	ATMOSPHERIC-LOADS KG/KM2-YR	CV	AVAILABILITY FACTOR
1 CONSERV	.00	.00	.00
2 TOTAL P	.00	.00	1.00
3 TOTAL N	.00	.00	1.00
4 ORTHO P	.00	.00	.00
5 INORG N	.00	.00	.00

GLOBAL INPUT VALUES:

PARAMETER		MEAN	CV
PERIOD LENGTH	YRS	.500	.100
PRECIPITATION	M	.000	.000
EVAPORATION	M	.190	.210
INCREASE IN STORAGE	M	-.150	.020

TRIBUTARY DRAINAGE AREAS AND FLOWS:

ID	TYPE	SEG	NAME	DRAINAGE AREA KM2	MEAN FLOW HM3/YR	CV OF MEAN FLOW
1	1	2	Eucha dam releas	825.000	303.000	.686
2	4	0	Outflow	.000	365.000	1.083
3	5	1	Internal	.000	.000	.000
4	1	2	lake basin	191.000	22.000	.876

TRIBUTARY CONCENTRATIONS (PPB): MEAN/CV

ID	CONSERV	TOTAL P	TOTAL N	ORTHO P	INORG N
1	.0/ .00	26.7/ .44	1481.0/ .31	.0/ .00	.0/ .00
2	.0/ .00	15.7/ .64	905.6/ .66	.0/ .00	.0/ .00
3	.0/ .00	.4/ .23	5.6/ .45	.0/ .00	.0/ .00
4	.0/ .00	35.0/ .18	.0/ .00	6.0/ .65	282.0/ .25

MODEL SEGMENTS & CALIBRATION FACTORS:

SEG	OUTFLOW	GROUP	SEGMENT NAME	P SED	N SED	CHL-A	SECCHI	HOD	DISP
				----------- CALIBRATION FACTORS -----------					
1	0	1	Lacustrine	1.00	1.00	1.00	1.00	1.00	1.000

```
                                            CV:    .000    .000    .000    .000    .000
.000
  2       1      1  Transition                    1.00    1.00    1.00    1.00    1.00
1.000
                                            CV:    .000    .000    .000    .000    .000
.000

 SEGMENT MORPHOMETRY: MEAN/CV
                     LENGTH      AREA  ZMEAN      ZMIX       ZHYP
 ID LABEL                KM       KM2      M         M          M
  1 Lacustrine         4.16    3.8700   7.00   5.50/ .32   7.80/ .23
  2 Transition         2.68    2.5000   2.20   4.00/ .05    .00/ .00

 SEGMENT OBSERVED WATER QUALITY:
 SEG    TURBID CONSER TOTALP TOTALN  CHL-A SECCHI  ORG-N  TP-OP   HODV
MODV
          1/M   ---   MG/M3  MG/M3  MG/M3      M  MG/M3  MG/M3 MG/M3-D
MG/M3-D
  1 MN:    .28     .0   17.0  883.0   16.0    1.6  362.0   14.0  248.0
193.0
    CV:    .51    .00    .40    .60    .52    .38    .80    .46    .37
.48
  2 MN:    .46     .0   25.0 1027.0   18.8    1.2  469.0   29.0     .0
.0
    CV:    .51    .00    .46    .51    .41    .31    .74   1.59    .00
.00

 MODEL COEFFICIENTS:
 COEFFICIENT            MEAN      CV
 DISPERSION FACTO      1.000     .70
 P DECAY RATE          1.000     .45
 N DECAY RATE          1.000     .55
 CHL-A MODEL           2.275     .26
 SECCHI MODEL          1.000     .10
 ORGANIC N MODEL       1.000     .12
 TP-OP MODEL           1.000     .15
 HODV MODEL            1.000     .15
 MODV MODEL            1.000     .22
 BETA  M2/MG            .025     .00
 MINIMUM QS            4.000     .00
 FLUSHING EFFECT       1.000     .00
 CHLOROPHYLL-A CV       .620     .00

 CASE NOTES:
 Trib #1 - Eucha Dam Release
 Trib #2 - Internal load
 trib #3 - outflow
 Low residence time suggests
 using summer values only
  Trib #4 - Lake basin inflow
```

GROSS WATER BALANCE:

```
                       DRAINAGE AREA      ---- FLOW (HM3/YR) ----
RUNOFF
 ID  T LOCATION                  KM2          MEAN  VARIANCE    CV
M/YR
```

```
 ----------------------------------------------------------------------
------
  1  1 Eucha dam releas      825.000      303.000  .432E+05  .686
.367
  2  4 Outflow                  .000      365.000  .156E+06 1.083
.000
  4  1 lake basin            191.000       22.000  .371E+03  .876
.115
 ----------------------------------------------------------------------
------
 TRIBUTARY INFLOW           1016.000      325.000  .436E+05  .642
.320
 ***TOTAL INFLOW            1022.370      325.000  .436E+05  .642
.318
 ADVECTIVE OUTFLOW          1022.370      324.490  .436E+05  .643
.317
 ***TOTAL OUTFLOW           1022.370      324.490  .436E+05  .643
.317
 ***EVAPORATION                 .000        2.421  .314E+00  .231
.000
 ***STORAGE INCREASE            .000       -1.911  .359E-01  .099
.000
 ----------------------------------------------------------------------
------

 GROSS MASS BALANCE BASED UPON  OBSERVED CONCENTRATIONS
 COMPONENT: TOTAL P
                       ----- LOADING ---- --- VARIANCE ---
CONC  EXPORT
 ID T LOCATION               KG/YR   %(I)  KG/YR**2   %(I)    CV
MG/M3  KG/KM2
 ----------------------------------------------------------------------
---------
  1 1 Eucha dam releas      8102.2   86.0  .435E+08   98.9  .814
26.7     9.8
  4 1 lake basin             770.0    8.2  .474E+06    1.1  .894
35.0     4.0
 ----------------------------------------------------------------------
---------
 INTERNAL LOAD               546.5    5.8  .162E+05     .0  .233
.0      .0
 TRIBUTARY INFLOW           8872.2   94.2  .440E+08  100.0  .748
27.3     8.7
 ***TOTAL INFLOW            9418.7  100.0  .440E+08  100.0  .705
29.0     9.2
 ADVECTIVE OUTFLOW          5516.3   58.6  .175E+08   39.7  .758
17.0     5.4
 ***TOTAL OUTFLOW           5516.3   58.6  .175E+08   39.7  .758
17.0     5.4
 ***STORAGE INCREASE         -42.9    -.5  .210E+03     .0  .338
22.5      .0
 ***RETENTION               3945.3   41.9  .219E+08   49.7 1.186
.0      .0
 ----------------------------------------------------------------------
---------

           HYDRAULIC    -------------- TOTAL P  --------------
```

OVERFLOW RATE	RESIDENCE TIME	POOL CONC	RESIDENCE TIME	TURNOVER RATIO	RETENTION COEF
M/YR	YRS	MG/M3	YRS	-	-
50.64	.1010	20.1	.0697	7.1750	.4189

T STATISTICS COMPARE OBSERVED AND PREDICTED MEANS
USING THE FOLLOWING ERROR TERMS:

1 = OBSERVED WATER QUALITY ERROR ONLY
2 = ERROR TYPICAL OF MODEL DEVELOPMENT DATA SET
3 = OBSERVED AND PREDICTED ERROR

SEGMENT: 3 AREA-WTD MEAN

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	20.1	.43	22.5	.32	.90	-.25	-.40	-.20
TOTAL N	MG/M3	939.5	.56	939.5	.41	1.00	.00	.00	.00
C.NUTRIENT	MG/M3	19.2	.46	21.2	.29	.91	-.22	-.49	-.18
CHL-A	MG/M3	17.1	.47	17.3	.54	.99	-.03	-.04	-.02
SECCHI	M	1.5	.36	1.3	.35	1.13	.34	.44	.24
ORGANIC N	MG/M3	404.0	.77	578.0	.39	.70	-.46	-1.43	-.41
TP-ORTHO-P	MG/M3	19.9	1.11	34.9	.51	.57	-.51	-1.54	-.46
HOD-V	MG/M3-DAY	248.0	.37	128.0	.38	1.94	1.79	3.27	1.25
MOD-V	MG/M3-DAY	193.0	.48	111.8	.40	1.73	1.14	1.67	.87

OBSERVED AND PREDICTED DIAGNOSTIC VARIABLES
RANKED AGAINST CE MODEL DEVELOPMENT DATA SET

SEGMENT: 3 AREA-WTD MEAN

VARIABLE		VALUES OBSERVED	VALUES ESTIMATED	RANKS (%) OBSERVED	RANKS (%) ESTIMATED
TOTAL P	MG/M3	20.14	22.46	16.8	20.0
TOTAL N	MG/M3	939.51	939.51	46.0	46.0
C.NUTRIENT	MG/M3	19.23	21.23	22.0	25.8
CHL-A	MG/M3	17.10	17.32	78.2	78.7
SECCHI	M	1.47	1.30	65.7	59.6
ORGANIC N	MG/M3	403.99	577.96	37.7	65.1
TP-ORTHO-P	MG/M3	19.89	34.95	33.3	56.4
HOD-V	MG/M3-DAY	248.00	128.04	94.2	75.3
MOD-V	MG/M3-DAY	193.00	111.79	92.9	75.8
ANTILOG PC-1		194.28	249.75	43.0	50.6

ANTILOG PC-2	13.22	12.75	91.5	90.3
(N - 150) / P	39.20	35.16	89.0	85.7
INORGANIC N / P	535.52	361.55	99.8	99.4
TURBIDITY 1/M	.35	.35	26.1	26.1
ZMIX * TURBIDITY	1.70	1.70	21.4	21.4
ZMIX / SECCHI	3.35	3.78	27.1	34.5
CHL-A * SECCHI	25.09	22.49	89.8	86.8
CHL-A / TOTAL P	.85	.77	98.9	98.4
FREQ(CHL-a>10) %	71.07	71.76	.0	.0
FREQ(CHL-a>20) %	28.68	29.38	.0	.0
FREQ(CHL-a>30) %	11.18	11.58	.0	.0
FREQ(CHL-a>40) %	4.64	4.84	.0	.0
FREQ(CHL-a>50) %	2.06	2.17	.0	.0
FREQ(CHL-a>60) %	.98	1.03	.0	.0
CARLSON TSI-P	47.45	49.02	.0	.0
CARLSON TSI-CHLA	58.45	58.58	.0	.0
CARLSON TSI-SEC	54.47	56.24	.0	.0

Eucha Lake Non-segmented Model; Variable nutrient scenarios

CASE: Enrichment Scenario; w/internal
File name: euchanut.bin

MODEL OPTIONS:

1	CONSERVATIVE SUBSTANCE	0 NOT COMPUTED
2	PHOSPHORUS BALANCE	1 2ND ORDER, AVAIL P
3	NITROGEN BALANCE	0 NOT COMPUTED
4	CHLOROPHYLL-A	5 P, JONES & BACHMAN
5	SECCHI DEPTH	1 VS. CHLA & TURBIDITY
6	DISPERSION	1 FISCHER-NUMERIC
7	PHOSPHORUS CALIBRATION	1 DECAY RATES
8	NITROGEN CALIBRATION	2 CONCENTRATIONS
9	ERROR ANALYSIS	1 MODEL & DATA
10	AVAILABILITY FACTORS	1 USE FOR MODEL 1 ONLY
11	MASS-BALANCE TABLES	1 USE ESTIMATED CONCS

ATMOSPHERIC LOADS & AVAILABILITY FACTORS:

	ATMOSPHERIC-LOADS		AVAILABILITY
VARIABLE	KG/KM2-YR	CV	FACTOR
1 CONSERV	.00	.00	.00
2 TOTAL P	.00	.00	1.00
3 TOTAL N	.00	.00	1.00
4 ORTHO P	.00	.00	.00
5 INORG N	.00	.00	.00

GLOBAL INPUT VALUES:

PARAMETER		MEAN	CV
PERIOD LENGTH	YRS	1.000	.000
PRECIPITATION	M	.000	.000
EVAPORATION	M	.140	.450
INCREASE IN STORAGE	M	-.390	1.410

TRIBUTARY DRAINAGE AREAS AND FLOWS:

ID	TYPE	SEG	NAME	DRAINAGE AREA KM2	MEAN FLOW HM3/YR	CV OF MEAN FLOW
1	1	1	125% external	825.000	284.300	.054
2	1	2	115% External	825.000	284.300	.054
3	1	3	105% External	825.000	284.300	.054
4	1	4	100% external	825.000	284.300	.054
5	1	5	95% external	825.000	284.300	.054
6	1	6	85% External	825.000	284.300	.054
7	1	7	75% external	825.000	284.300	.054
8	1	8	50% external	825.000	284.300	.054
9	1	9	25% external	825.000	284.300	.054
10	1	10	17% external	825.000	284.300	.054
11	5	1	int	.000	.000	.000
12	5	2	int	.000	.000	.000
13	5	3	int	.000	.000	.000
14	5	4	int	.000	.000	.000
15	5	5	int	.000	.000	.000
16	5	6	int	.000	.000	.000
17	5	7	int	.000	.000	.000
18	5	8	int	.000	.000	.000
19	5	9	int	.000	.000	.000
20	5	10	int	.000	.000	.000
21	1	12	150%	825.000	284.300	.054
22	1	11	135%	825.000	284.300	.054
23	1	14	65%	825.000	284.300	.054
24	1	13	35%	825.000	284.300	.054
25	5	12	Int	.000	.000	.000
26	5	11	int	.000	.000	.000
27	5	13	int	.000	.000	.000
28	5	14	int	.000	.000	.000
29	1	15	SWAT	825.000	284.300	.054
30	5	15	int	.000	.000	.000

TRIBUTARY CONCENTRATIONS (PPB): MEAN/CV

ID	CONSERV	TOTAL P	TOTAL N	ORTHO P	INORG N
1	.0/ .00	151.3/ .05	.0/ .00	.0/ .00	.0/ .00
2	.0/ .00	139.2/ .05	.0/ .00	.0/ .00	.0/ .00
3	.0/ .00	127.1/ .05	.0/ .00	.0/ .00	.0/ .00
4	.0/ .00	121.0/ .05	.0/ .00	.0/ .00	.0/ .00
5	.0/ .00	115.0/ .05	.0/ .00	.0/ .00	.0/ .00
6	.0/ .00	102.9/ .05	.0/ .00	.0/ .00	.0/ .00
7	.0/ .00	90.8/ .05	.0/ .00	.0/ .00	.0/ .00
8	.0/ .00	60.5/ .05	.0/ .00	.0/ .00	.0/ .00
9	.0/ .00	30.3/ .05	.0/ .00	.0/ .00	.0/ .00
10	.0/ .00	20.6/ .05	.0/ .00	.0/ .00	.0/ .00
11	.0/ .00	.6/ .29	.0/ .00	.0/ .00	.0/ .00
12	.0/ .00	.6/ .29	.0/ .00	.0/ .00	.0/ .00
13	.0/ .00	.6/ .29	.0/ .00	.0/ .00	.0/ .00
14	.0/ .00	.6/ .29	1.7/ .22	.0/ .00	.0/ .00
15	.0/ .00	.6/ .29	.0/ .00	.0/ .00	.0/ .00
16	.0/ .00	.6/ .29	.0/ .00	.0/ .00	.0/ .00
17	.0/ .00	.6/ .29	.0/ .00	.0/ .00	.0/ .00
18	.0/ .00	.6/ .29	.0/ .00	.0/ .00	.0/ .00
19	.0/ .00	.6/ .29	.0/ .00	.0/ .00	.0/ .00
20	.0/ .00	.6/ .29	.0/ .00	.0/ .00	.0/ .00

```
 21      .0/ .00   190.6/ .05      .0/ .00      .0/ .00      .0/ .00
 22      .0/ .00   171.5/ .05      .0/ .00      .0/ .00      .0/ .00
 23      .0/ .00    78.7/ .05      .0/ .00      .0/ .00      .0/ .00
 24      .0/ .00    42.4/ .05      .0/ .00      .0/ .00      .0/ .00
 25      .0/ .00      .6/ .29      .0/ .00      .0/ .00      .0/ .00
 26      .0/ .00      .6/ .29      .0/ .00      .0/ .00      .0/ .00
 27      .0/ .00      .6/ .29      .0/ .00      .0/ .00      .0/ .00
 28      .0/ .00      .6/ .29      .0/ .00      .0/ .00      .0/ .00
 29      .0/ .00     6.6/1.10      .0/ .00      .0/ .00      .0/ .00
 30      .0/ .00      .6/ .29      .0/ .00      .0/ .00      .0/ .00

 MODEL SEGMENTS & CALIBRATION FACTORS:
                                             ----------- CALIBRATION FACTORS --
---------
 SEG OUTFLOW GROUP SEGMENT NAME       P SED  N SED  CHL-A SECCHI    HOD
DISP
  1      0     1  125%                 1.00   1.00   1.00   1.00   1.00
1.000
                                  CV:   .000   .000   .000   .000   .000
.000
  2      0     1  115%                 1.00   1.00   1.00   1.00   1.00
1.000
                                  CV:   .000   .000   .000   .000   .000
.000
  3      0     1  105                  1.00   1.00   1.00   1.00   1.00
1.000
                                  CV:   .000   .000   .000   .000   .000
.000
  4      0     1  100%                 1.00   1.00   1.00   1.00   1.00
1.000
                                  CV:   .000   .000   .000   .000   .000
.000
  5      0     1  95%                  1.00   1.00   1.00   1.00   1.00
1.000
                                  CV:   .000   .000   .000   .000   .000
.000
  6      0     1  85%                  1.00   1.00   1.00   1.00   1.00
1.000
                                  CV:   .000   .000   .000   .000   .000
.000
  7      0     1  75%                  1.00   1.00   1.00   1.00   1.00
1.000
                                  CV:   .000   .000   .000   .000   .000
.000
  8      0     1  50%                  1.00   1.00   1.00   1.00   1.00
1.000
                                  CV:   .000   .000   .000   .000   .000
.000
  9      0     1  25%                  1.00   1.00   1.00   1.00   1.00
1.000
                                  CV:   .000   .000   .000   .000   .000
.000
 10      0     1  17%                  1.00   1.00   1.00   1.00   1.00
1.000
                                  CV:   .000   .000   .000   .000   .000
.000
```

```
 11        0     1  135%                1.00   1.00   1.00   1.00   1.00
1.000
                                CV:    .000   .000   .000   .000   .000
.000
 12        0     1  150%                1.00   1.00   1.00   1.00   1.00
1.000
                                CV:    .000   .000   .000   .000   .000
.000
 13        0     1  35%                 1.00   1.00   1.00   1.00   1.00
1.000
                                CV:    .000   .000   .000   .000   .000
.000
 14        0     1  65%                 1.00   1.00   1.00   1.00   1.00
1.000
                                CV:    .000   .000   .000   .000   .000
.000
 15        0     1  SWAT Background     1.00   1.00   1.00   1.00   1.00
1.000
                                CV:    .000   .000   .000   .000   .000
.000

 SEGMENT MORPHOMETRY: MEAN/CV
                     LENGTH      AREA  ZMEAN      ZMIX       ZHYP
 ID LABEL                KM       KM2      M         M          M
  1 125%               9.00   11.3600   8.20   6.50/ .50   8.85/ .24
  2 115%               9.00   11.3600   8.20   6.50/ .50   8.85/ .24
  3 105                9.00   11.3600   8.20   6.50/ .50   8.85/ .24
  4 100%               9.00   11.3600   8.20   6.50/ .50   8.85/ .24
  5 95%                9.00   11.3600   8.20   6.50/ .50   8.85/ .24
  6 85%                9.00   11.3600   8.20   6.50/ .50   8.85/ .24
  7 75%                9.00   11.3600   8.20   6.50/ .50   8.85/ .24
  8 50%                9.00   11.3600   8.20   6.50/ .50   8.85/ .24
  9 25%                9.00   11.3600   8.20   6.50/ .50   8.85/ .24
 10 17%                9.00   11.3600   8.20   6.50/ .50   8.85/ .24
 11 135%               9.00   11.3600   8.20   6.50/ .50   8.85/ .24
 12 150%               9.00   11.3600   8.20   6.50/ .50   8.85/ .24
 13 35%                9.00   11.3600   8.20   6.50/ .50   8.85/ .24
 14 65%                9.00   11.3600   8.20   6.50/ .50   8.85/ .24
 15 SWAT Background    9.00   11.3600   8.20   6.50/ .50   8.85/ .24

 SEGMENT OBSERVED WATER QUALITY:
 SEG    TURBID CONSER TOTALP TOTALN  CHL-A SECCHI  ORG-N  TP-OP   HODV
MODV
          1/M    ---   MG/M3  MG/M3  MG/M3      M  MG/M3  MG/M3 MG/M3-D
MG/M3-D
  1 MN:    .00     .0     .0     .0     .0     .0     .0     .0     .0
.0
    CV:    .00    .00    .00    .00    .00    .00    .00    .00    .00
.00
  2 MN:    .00     .0     .0     .0     .0     .0     .0     .0     .0
.0
    CV:    .00    .00    .00    .00    .00    .00    .00    .00    .00
.00
  3 MN:    .00     .0     .0     .0     .0     .0     .0     .0     .0
.0
    CV:    .00    .00    .00    .00    .00    .00    .00    .00    .00
.00
```

4	MN:	.32	.0	36.3	1650.0	18.1	1.7	321.9	26.3	113.7	123.7
	CV:	.25	.00	.77	.43	.77	1.40	.89	.80	.88	.58
5	MN:	.00	.0	.0	.0	.0	.0	.0	.0	.0	.0
	CV:	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
6	MN:	.00	.0	.0	.0	.0	.0	.0	.0	.0	.0
	CV:	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
7	MN:	.00	.0	.0	.0	.0	.0	.0	.0	.0	.0
	CV:	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
8	MN:	.00	.0	.0	.0	.0	.0	.0	.0	.0	.0
	CV:	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
9	MN:	.00	.0	.0	.0	.0	.0	.0	.0	.0	.0
	CV:	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
10	MN:	.00	.0	.0	.0	.0	.0	.0	.0	.0	.0
	CV:	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
11	MN:	.00	.0	.0	.0	.0	.0	.0	.0	.0	.0
	CV:	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
12	MN:	.00	.0	.0	.0	.0	.0	.0	.0	.0	.0
	CV:	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
13	MN:	.00	.0	.0	.0	.0	.0	.0	.0	.0	.0
	CV:	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
14	MN:	.00	.0	.0	.0	.0	.0	.0	.0	.0	.0
	CV:	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
15	MN:	.00	.0	.0	.0	.0	.0	.0	.0	.0	.0
	CV:	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

MODEL COEFFICIENTS:

COEFFICIENT	MEAN	CV
DISPERSION FACTO	1.000	.70
P DECAY RATE	2.204	.45
N DECAY RATE	1.000	.55
CHL-A MODEL	1.000	.26
SECCHI MODEL	1.000	.10
ORGANIC N MODEL	1.000	.12

```
 TP-OP MODEL          1.000     .15
 HODV MODEL           1.000     .15
 MODV MODEL           1.000     .22
 BETA  M2/MG           .025     .00
 MINIMUM QS           4.000     .00
 FLUSHING EFFECT      1.000     .00
 CHLOROPHYLL-A CV      .620     .00

 CASE NOTES:
 125,115,105,100,95,85,75,50
 25 & 17% changes in influent
 concentration
 internal Load included
 135, 150, 65 & 35% added
 SWAT background conc too
```

```
 CASE: Enrichment Scenario; w/internal

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                        SEGMENT:  1 125%
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
  1  1 125% external         284.30  100.0     43014.6   94.5
151.3
 ----------------------------------------------------------------------
--
 INTERNAL LOAD                  .00     .0      2513.6    5.5
.0
 TRIBUTARY INFLOW            284.30  100.0     43014.6   94.5
151.3
 ***TOTAL INFLOW             284.30  100.0     45528.2  100.0
160.1
 ADVECTIVE OUTFLOW           287.14  101.0     11185.3   24.6
39.0
 ***TOTAL OUTFLOW            287.14  101.0     11185.3   24.6
39.0
 ***EVAPORATION                1.59     .6          .0     .0
.0
 ***STORAGE INCREASE          -4.43   -1.6      -172.6    -.4
39.0
 ***RETENTION                   .00     .0     34515.5   75.8
.0
 ----------------------------------------------------------------------
--
```

```
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                           SEGMENT:  2 115%
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
  2  1 115% External         284.30  100.0     39574.6   94.0
139.2
 ----------------------------------------------------------------------
--
 INTERNAL LOAD                  .00     .0      2513.6    6.0
.0
 TRIBUTARY INFLOW            284.30  100.0     39574.6   94.0
139.2
 ***TOTAL INFLOW             284.30  100.0     42088.2  100.0
148.0
 ADVECTIVE OUTFLOW           287.14  101.0     10695.3   25.4
37.2
 ***TOTAL OUTFLOW            287.14  101.0     10695.3   25.4
37.2
 ***EVAPORATION                1.59     .6          .0     .0
.0
 ***STORAGE INCREASE          -4.43   -1.6      -165.0    -.4
37.2
 ***RETENTION                   .00     .0     31557.9   75.0
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                           SEGMENT:  3 105
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
  3  1 105% External         284.30  100.0     36134.5   93.5
127.1
 ----------------------------------------------------------------------
--
 INTERNAL LOAD                  .00     .0      2513.6    6.5
.0
 TRIBUTARY INFLOW            284.30  100.0     36134.5   93.5
127.1
 ***TOTAL INFLOW             284.30  100.0     38648.1  100.0
135.9
 ADVECTIVE OUTFLOW           287.14  101.0     10185.3   26.4
35.5
```

```
 ***TOTAL OUTFLOW            287.14  101.0     10185.3   26.4
35.5
 ***EVAPORATION                1.59     .6          .0     .0
.0
 ***STORAGE INCREASE          -4.43   -1.6      -157.2    -.4
35.5
 ***RETENTION                  .00      .0     28620.0   74.1
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                         SEGMENT:  4 100%
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
  4  1 100% external         284.30  100.0     34400.3   93.2
121.0
 ----------------------------------------------------------------------
--
 INTERNAL LOAD                 .00      .0      2513.6    6.8
.0
 TRIBUTARY INFLOW            284.30  100.0     34400.3   93.2
121.0
 ***TOTAL INFLOW             284.30  100.0     36913.9  100.0
129.8
 ADVECTIVE OUTFLOW           287.14  101.0      9919.8   26.9
34.5
 ***TOTAL OUTFLOW            287.14  101.0      9919.8   26.9
34.5
 ***EVAPORATION                1.59     .6          .0     .0
.0
 ***STORAGE INCREASE          -4.43   -1.6      -153.1    -.4
34.5
 ***RETENTION                  .00      .0     27147.2   73.5
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                         SEGMENT:  5 95%
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
  5  1 95% external          284.30  100.0     32694.5   92.9
115.0
```

```
 -----------------------------------------------------------------------
--
 INTERNAL LOAD                     .00     .0      2513.6    7.1
.0
 TRIBUTARY INFLOW               284.30  100.0     32694.5   92.9
115.0
 ***TOTAL INFLOW                284.30  100.0     35208.1  100.0
123.8
 ADVECTIVE OUTFLOW              287.14  101.0      9652.6   27.4
33.6
 ***TOTAL OUTFLOW               287.14  101.0      9652.6   27.4
33.6
 ***EVAPORATION                   1.59     .6          .0     .0
.0
 ***STORAGE INCREASE             -4.43   -1.6      -148.9    -.4
33.6
 ***RETENTION                      .00     .0     25704.4   73.0
.0
 -----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                         SEGMENT:  6 85%
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION                 HM3/YR      %       KG/YR      %
MG/M3
 -----------------------------------------------------------------------
--
  6  1 85% External             284.30  100.0     29254.5   92.1
102.9
 -----------------------------------------------------------------------
--
 INTERNAL LOAD                     .00     .0      2513.6    7.9
.0
 TRIBUTARY INFLOW               284.30  100.0     29254.5   92.1
102.9
 ***TOTAL INFLOW                284.30  100.0     31768.1  100.0
111.7
 ADVECTIVE OUTFLOW              287.14  101.0      9093.8   28.6
31.7
 ***TOTAL OUTFLOW               287.14  101.0      9093.8   28.6
31.7
 ***EVAPORATION                   1.59     .6          .0     .0
.0
 ***STORAGE INCREASE             -4.43   -1.6      -140.3    -.4
31.7
 ***RETENTION                      .00     .0     22814.6   71.8
.0
 -----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
```

COMPONENT: TOTAL P SEGMENT: 7 75%

ID	T	LOCATION	FLOW HM3/YR	FLOW %	LOAD KG/YR	LOAD %	CONC MG/M3
7	1	75% external	284.30	100.0	25814.4	91.1	90.8
		INTERNAL LOAD	.00	.0	2513.6	8.9	.0
		TRIBUTARY INFLOW	284.30	100.0	25814.4	91.1	90.8
		***TOTAL INFLOW	284.30	100.0	28328.0	100.0	99.6
		ADVECTIVE OUTFLOW	287.14	101.0	8504.7	30.0	29.6
		***TOTAL OUTFLOW	287.14	101.0	8504.7	30.0	29.6
		***EVAPORATION	1.59	.6	.0	.0	.0
		***STORAGE INCREASE	-4.43	-1.6	-131.2	-.5	29.6
		***RETENTION	.00	.0	19954.5	70.4	.0

RESID. TIME = .329 YRS, OVERFLOW RATE = 24.9 M/YR, DEPTH = 8.2 M

SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
COMPONENT: TOTAL P SEGMENT: 8 50%

ID	T	LOCATION	FLOW HM3/YR	FLOW %	LOAD KG/YR	LOAD %	CONC MG/M3
8	1	50% external	284.30	100.0	17200.1	87.2	60.5
		INTERNAL LOAD	.00	.0	2513.6	12.8	.0
		TRIBUTARY INFLOW	284.30	100.0	17200.1	87.2	60.5
		***TOTAL INFLOW	284.30	100.0	19713.8	100.0	69.3
		ADVECTIVE OUTFLOW	287.14	101.0	6855.1	34.8	23.9
		***TOTAL OUTFLOW	287.14	101.0	6855.1	34.8	23.9
		***EVAPORATION	1.59	.6	.0	.0	.0

```
 ***STORAGE INCREASE          -4.43   -1.6      -105.8    -.5
23.9
 ***RETENTION                   .00     .0     12964.4   65.8
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                         SEGMENT:  9 25%
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
  9  1 25% external          284.30  100.0      8614.3   77.4
30.3
 ----------------------------------------------------------------------
--
 INTERNAL LOAD                  .00     .0      2513.6   22.6
.0
 TRIBUTARY INFLOW            284.30  100.0      8614.3   77.4
30.3
 ***TOTAL INFLOW             284.30  100.0     11127.9  100.0
39.1
 ADVECTIVE OUTFLOW           287.14  101.0      4812.6   43.2
16.8
 ***TOTAL OUTFLOW            287.14  101.0      4812.6   43.2
16.8
 ***EVAPORATION                1.59     .6          .0     .0
.0
 ***STORAGE INCREASE          -4.43   -1.6       -74.3    -.7
16.8
 ***RETENTION                   .00     .0      6389.6   57.4
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                         SEGMENT: 10 17%
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
 10  1 17% external          284.30  100.0      5856.6   70.0
20.6
 ----------------------------------------------------------------------
--
 INTERNAL LOAD                  .00     .0      2513.6   30.0
.0
```

```
 TRIBUTARY INFLOW             284.30  100.0      5856.6   70.0
20.6
 ***TOTAL INFLOW              284.30  100.0      8370.2  100.0
29.4
 ADVECTIVE OUTFLOW            287.14  101.0      4005.6   47.9
13.9
 ***TOTAL OUTFLOW             287.14  101.0      4005.6   47.9
13.9
 ***EVAPORATION                 1.59     .6          .0     .0
.0
 ***STORAGE INCREASE           -4.43   -1.6       -61.8    -.7
13.9
 ***RETENTION                    .00     .0      4426.4   52.9
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                         SEGMENT: 11 135%
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
 22  1 135%                   284.30  100.0     48757.4   95.1
171.5
 ----------------------------------------------------------------------
--
 INTERNAL LOAD                   .00     .0      2513.6    4.9
.0
 TRIBUTARY INFLOW             284.30  100.0     48757.4   95.1
171.5
 ***TOTAL INFLOW              284.30  100.0     51271.1  100.0
180.3
 ADVECTIVE OUTFLOW            287.14  101.0     11964.4   23.3
41.7
 ***TOTAL OUTFLOW             287.14  101.0     11964.4   23.3
41.7
 ***EVAPORATION                 1.59     .6          .0     .0
.0
 ***STORAGE INCREASE           -4.43   -1.6      -184.6    -.4
41.7
 ***RETENTION                    .00     .0     39491.3   77.0
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                         SEGMENT: 12 150%
                             --- FLOW ---       --- LOAD ---
CONC
```

```
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
 21  1 150%                  284.30  100.0     54187.6   95.6
190.6
 ----------------------------------------------------------------------
--
 INTERNAL LOAD                  .00     .0      2513.6    4.4
.0
 TRIBUTARY INFLOW            284.30  100.0     54187.6   95.6
190.6
 ***TOTAL INFLOW             284.30  100.0     56701.2  100.0
199.4
 ADVECTIVE OUTFLOW           287.14  101.0     12662.5   22.3
44.1
 ***TOTAL OUTFLOW            287.14  101.0     12662.5   22.3
44.1
 ***EVAPORATION                1.59     .6          .0     .0
.0
 ***STORAGE INCREASE          -4.43   -1.6      -195.4    -.3
44.1
 ***RETENTION                   .00     .0     44234.1   78.0
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                         SEGMENT: 13 35%
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
 24  1 35%                   284.30  100.0     12054.3   82.7
42.4
 ----------------------------------------------------------------------
--
 INTERNAL LOAD                  .00     .0      2513.6   17.3
.0
 TRIBUTARY INFLOW            284.30  100.0     12054.3   82.7
42.4
 ***TOTAL INFLOW             284.30  100.0     14567.9  100.0
51.2
 ADVECTIVE OUTFLOW           287.14  101.0      5698.2   39.1
19.8
 ***TOTAL OUTFLOW            287.14  101.0      5698.2   39.1
19.8
 ***EVAPORATION                1.59     .6          .0     .0
.0
 ***STORAGE INCREASE          -4.43   -1.6       -87.9    -.6
19.8
 ***RETENTION                   .00     .0      8957.6   61.5
.0
```

```
 ----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                         SEGMENT: 14 65%
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
 23  1 65%                   284.30  100.0     22374.4   89.9
78.7
 ----------------------------------------------------------------------
--
 INTERNAL LOAD                  .00     .0      2513.6   10.1
.0
 TRIBUTARY INFLOW            284.30  100.0     22374.4   89.9
78.7
 ***TOTAL INFLOW             284.30  100.0     24888.0  100.0
87.5
 ADVECTIVE OUTFLOW           287.14  101.0      7879.8   31.7
27.4
 ***TOTAL OUTFLOW            287.14  101.0      7879.8   31.7
27.4
 ***EVAPORATION                1.59     .6          .0     .0
.0
 ***STORAGE INCREASE          -4.43   -1.6      -121.6    -.5
27.4
 ***RETENTION                   .00     .0     17129.8   68.8
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                         SEGMENT: 15 SWAT Background
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
 29  1 SWAT                  284.30  100.0      1876.4   42.7
6.6
 ----------------------------------------------------------------------
--
 INTERNAL LOAD                  .00     .0      2513.6   57.3
.0
 TRIBUTARY INFLOW            284.30  100.0      1876.4   42.7
6.6
 ***TOTAL INFLOW             284.30  100.0      4390.0  100.0
15.4
```

```
 ADVECTIVE OUTFLOW           287.14  101.0      2585.6   58.9
9.0
 ***TOTAL OUTFLOW            287.14  101.0      2585.6   58.9
9.0
 ***EVAPORATION                1.59     .6          .0     .0
.0
 ***STORAGE INCREASE          -4.43   -1.6       -39.9    -.9
9.0
 ***RETENTION                   .00     .0      1844.3   42.0
.0
 -----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M
 CASE: Enrichment Scenario; w/internal

 T STATISTICS COMPARE OBSERVED AND PREDICTED MEANS
 USING THE FOLLOWING ERROR TERMS:
  1 = OBSERVED WATER QUALITY ERROR ONLY
  2 = ERROR TYPICAL OF MODEL DEVELOPMENT DATA SET
  3 = OBSERVED AND PREDICTED ERROR

 SEGMENT:  1 125%
                      OBSERVED     ESTIMATED              T
STATISTICS
 VARIABLE           MEAN    CV    MEAN    CV   RATIO      1      2
3
 -----------------------------------------------------------------------
---
 TOTAL P    MG/M3      .0   .00    39.0   .19     .00    .00    .00
.00
 CHL-A      MG/M3      .0   .00    17.0   .38     .00    .00    .00
.00
 HOD-V  MG/M3-DAY      .0   .00    92.5   .33     .00    .00    .00
.00
 MOD-V  MG/M3-DAY      .0   .00    84.7   .36     .00    .00    .00
.00
 -----------------------------------------------------------------------
---

 SEGMENT:  2 115%
                      OBSERVED     ESTIMATED              T
STATISTICS
 VARIABLE           MEAN    CV    MEAN    CV   RATIO      1      2
3
 -----------------------------------------------------------------------
---
 TOTAL P    MG/M3      .0   .00    37.2   .19     .00    .00    .00
.00
 CHL-A      MG/M3      .0   .00    15.9   .38     .00    .00    .00
.00
 HOD-V  MG/M3-DAY      .0   .00    92.5   .33     .00    .00    .00
.00
 MOD-V  MG/M3-DAY      .0   .00    84.7   .36     .00    .00    .00
.00
 -----------------------------------------------------------------------
---
```

SEGMENT: 3 105

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	.0	.00	35.5	.19	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	14.8	.38	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	92.5	.33	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	84.7	.36	.00	.00	.00	.00

SEGMENT: 4 100%

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	36.3	.77	34.5	.19	1.05	.06	.18	.06
TOTAL N	MG/M3	1650.0	.43	1650.0	.43	1.00	.00	.00	.00
C.NUTRIENT	MG/M3	34.9	.69	33.3	.18	1.05	.07	.23	.06
CHL-A	MG/M3	18.1	.77	14.3	.38	1.27	.31	.69	.28
SECCHI	M	1.7	1.40	1.5	.25	1.15	.10	.50	.10
ORGANIC N	MG/M3	321.9	.89	506.6	.27	.64	-.51	-1.81	-.49
TP-ORTHO-P	MG/M3	26.3	.80	28.9	.37	.91	-.12	-.26	-.11
HOD-V	MG/M3-DAY	113.7	.88	92.5	.33	1.23	.23	1.02	.22
MOD-V	MG/M3-DAY	123.7	.58	84.7	.36	1.46	.65	1.16	.56

SEGMENT: 5 95%

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	.0	.00	33.6	.19	.00	.00	.00	.00

```
 CHL-A      MG/M3        .0   .00    13.7   .38     .00    .00    .00
.00
 HOD-V  MG/M3-DAY        .0   .00    92.5   .33     .00    .00    .00
.00
 MOD-V  MG/M3-DAY        .0   .00    84.7   .36     .00    .00    .00
.00
 ----------------------------------------------------------------------
---

 SEGMENT:  6 85%
                       OBSERVED     ESTIMATED                T
STATISTICS
 VARIABLE             MEAN     CV    MEAN     CV   RATIO      1      2
3
 ----------------------------------------------------------------------
---
 TOTAL P    MG/M3        .0   .00    31.7   .19     .00    .00    .00
.00
 CHL-A      MG/M3        .0   .00    12.6   .38     .00    .00    .00
.00
 HOD-V  MG/M3-DAY        .0   .00    92.5   .33     .00    .00    .00
.00
 MOD-V  MG/M3-DAY        .0   .00    84.7   .36     .00    .00    .00
.00
 ----------------------------------------------------------------------
---

 SEGMENT:  7 75%
                       OBSERVED     ESTIMATED                T
STATISTICS
 VARIABLE             MEAN     CV    MEAN     CV   RATIO      1      2
3
 ----------------------------------------------------------------------
---
 TOTAL P    MG/M3        .0   .00    29.6   .19     .00    .00    .00
.00
 CHL-A      MG/M3        .0   .00    11.4   .38     .00    .00    .00
.00
 HOD-V  MG/M3-DAY        .0   .00    92.5   .33     .00    .00    .00
.00
 MOD-V  MG/M3-DAY        .0   .00    84.7   .36     .00    .00    .00
.00
 ----------------------------------------------------------------------
---

 SEGMENT:  8 50%
                       OBSERVED     ESTIMATED                T
STATISTICS
 VARIABLE             MEAN     CV    MEAN     CV   RATIO      1      2
3
 ----------------------------------------------------------------------
---
 TOTAL P    MG/M3        .0   .00    23.9   .18     .00    .00    .00
.00
 CHL-A      MG/M3        .0   .00     8.3   .37     .00    .00    .00
.00
```

HOD-V	MG/M3-DAY	.0	.00	92.5	.33	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	84.7	.36	.00	.00	.00	.00

SEGMENT: 9 25%

VARIABLE		OBSERVED MEAN	CV	ESTIMATED MEAN	CV	RATIO	T STATISTICS 1	2	3
TOTAL P	MG/M3	.0	.00	16.8	.17	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	5.0	.36	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	92.5	.33	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	84.7	.36	.00	.00	.00	.00

SEGMENT: 10 17%

VARIABLE		OBSERVED MEAN	CV	ESTIMATED MEAN	CV	RATIO	T STATISTICS 1	2	3
TOTAL P	MG/M3	.0	.00	13.9	.17	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	3.8	.35	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	92.5	.33	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	84.7	.36	.00	.00	.00	.00

SEGMENT: 11 135%

VARIABLE		OBSERVED MEAN	CV	ESTIMATED MEAN	CV	RATIO	T STATISTICS 1	2	3
TOTAL P	MG/M3	.0	.00	41.7	.20	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	18.8	.39	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	92.5	.33	.00	.00	.00	.00

```
 MOD-V  MG/M3-DAY       .0    .00     84.7    .36      .00     .00     .00
.00
 -----------------------------------------------------------------------
---

 SEGMENT: 12 150%
                         OBSERVED     ESTIMATED                  T
STATISTICS
 VARIABLE              MEAN     CV     MEAN     CV   RATIO       1       2
3
 -----------------------------------------------------------------------
---
 TOTAL P    MG/M3       .0    .00     44.1    .20      .00     .00     .00
.00
 CHL-A      MG/M3       .0    .00     20.4    .39      .00     .00     .00
.00
 HOD-V  MG/M3-DAY       .0    .00     92.5    .33      .00     .00     .00
.00
 MOD-V  MG/M3-DAY       .0    .00     84.7    .36      .00     .00     .00
.00
 -----------------------------------------------------------------------
---

 SEGMENT: 13 35%
                         OBSERVED     ESTIMATED                  T
STATISTICS
 VARIABLE              MEAN     CV     MEAN     CV   RATIO       1       2
3
 -----------------------------------------------------------------------
---
 TOTAL P    MG/M3       .0    .00     19.8    .17      .00     .00     .00
.00
 CHL-A      MG/M3       .0    .00      6.4    .36      .00     .00     .00
.00
 HOD-V  MG/M3-DAY       .0    .00     92.5    .33      .00     .00     .00
.00
 MOD-V  MG/M3-DAY       .0    .00     84.7    .36      .00     .00     .00
.00
 -----------------------------------------------------------------------
---

 SEGMENT: 14 65%
                         OBSERVED     ESTIMATED                  T
STATISTICS
 VARIABLE              MEAN     CV     MEAN     CV   RATIO       1       2
3
 -----------------------------------------------------------------------
---
 TOTAL P    MG/M3       .0    .00     27.4    .18      .00     .00     .00
.00
 CHL-A      MG/M3       .0    .00     10.2    .37      .00     .00     .00
.00
 HOD-V  MG/M3-DAY       .0    .00     92.5    .33      .00     .00     .00
.00
 MOD-V  MG/M3-DAY       .0    .00     84.7    .36      .00     .00     .00
.00
```

SEGMENT: 15 SWAT Background

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	.0	.00	9.0	.37	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	2.0	.61	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	92.5	.33	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	84.7	.36	.00	.00	.00	.00

SEGMENT: 16 AREA-WTD MEAN

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	36.3	.77	29.2	.18	1.24	.28	.81	.28
TOTAL N	MG/M3	1650.0	.43	1650.0	.43	1.00	.00	.00	.00
C.NUTRIENT	MG/M3	34.9	.69	33.3	.18	1.05	.07	.23	.06
CHL-A	MG/M3	18.1	.77	11.6	.37	1.56	.57	1.28	.52
SECCHI	M	1.7	1.40	1.5	.25	1.15	.10	.50	.10
ORGANIC N	MG/M3	321.9	.89	506.6	.27	.64	-.51	-1.81	-.49
TP-ORTHO-P	MG/M3	26.3	.80	28.9	.37	.91	-.12	-.26	-.11
HOD-V	MG/M3-DAY	113.7	.88	92.5	.25	1.23	.23	1.02	.23
MOD-V	MG/M3-DAY	123.7	.58	84.7	.33	1.46	.65	1.16	.57

CASE: Enrichment Scenario; w/internal

OBSERVED AND PREDICTED DIAGNOSTIC VARIABLES
RANKED AGAINST CE MODEL DEVELOPMENT DATA SET

SEGMENT: 1 125%

VARIABLE	----- VALUES ----- OBSERVED	ESTIMATED	--- RANKS (%) ---- OBSERVED	ESTIMATED

TOTAL P MG/M3	.00	38.95	.0	40.9
CHL-A MG/M3	.00	17.01	.0	78.0
HOD-V MG/M3-DAY	.00	92.51	.0	59.7
MOD-V MG/M3-DAY	.00	84.74	.0	62.2
CHL-A / TOTAL P	.00	.44	.0	89.6
FREQ(CHL-a>10) %	.00	70.78	.0	.0
FREQ(CHL-a>20) %	.00	28.39	.0	.0
FREQ(CHL-a>30) %	.00	11.02	.0	.0
FREQ(CHL-a>40) %	.00	4.56	.0	.0
FREQ(CHL-a>50) %	.00	2.02	.0	.0
FREQ(CHL-a>60) %	.00	.96	.0	.0
CARLSON TSI-P	.00	56.96	.0	.0
CARLSON TSI-CHLA	.00	58.40	.0	.0

SEGMENT: 2 115%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	37.25	.0	39.0
CHL-A MG/M3	.00	15.93	.0	75.4
HOD-V MG/M3-DAY	.00	92.51	.0	59.7
MOD-V MG/M3-DAY	.00	84.74	.0	62.2
CHL-A / TOTAL P	.00	.43	.0	89.0
FREQ(CHL-a>10) %	.00	67.05	.0	.0
FREQ(CHL-a>20) %	.00	24.93	.0	.0
FREQ(CHL-a>30) %	.00	9.16	.0	.0
FREQ(CHL-a>40) %	.00	3.64	.0	.0
FREQ(CHL-a>50) %	.00	1.56	.0	.0
FREQ(CHL-a>60) %	.00	.72	.0	.0
CARLSON TSI-P	.00	56.32	.0	.0
CARLSON TSI-CHLA	.00	57.76	.0	.0

SEGMENT: 3 105

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	35.47	.0	36.9
CHL-A MG/M3	.00	14.84	.0	72.4
HOD-V MG/M3-DAY	.00	92.51	.0	59.7
MOD-V MG/M3-DAY	.00	84.74	.0	62.2
CHL-A / TOTAL P	.00	.42	.0	88.3
FREQ(CHL-a>10) %	.00	62.79	.0	.0
FREQ(CHL-a>20) %	.00	21.42	.0	.0
FREQ(CHL-a>30) %	.00	7.41	.0	.0
FREQ(CHL-a>40) %	.00	2.81	.0	.0
FREQ(CHL-a>50) %	.00	1.16	.0	.0
FREQ(CHL-a>60) %	.00	.52	.0	.0
CARLSON TSI-P	.00	55.61	.0	.0
CARLSON TSI-CHLA	.00	57.06	.0	.0

SEGMENT: 4 100%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED

TOTAL P MG/M3	36.30	34.55	37.9	35.8
TOTAL N MG/M3	1650.00	1650.00	78.2	78.2
C.NUTRIENT MG/M3	34.86	33.30	48.8	46.5
CHL-A MG/M3	18.10	14.27	80.3	70.7
SECCHI M	1.70	1.48	72.5	66.0
ORGANIC N MG/M3	321.90	506.56	22.4	55.2
TP-ORTHO-P MG/M3	26.30	28.89	44.5	48.4
HOD-V MG/M3-DAY	113.70	92.51	70.0	59.7
MOD-V MG/M3-DAY	123.70	84.74	80.0	62.2
ANTILOG PC-1	243.76	261.71	49.8	52.0
ANTILOG PC-2	12.95	10.87	90.9	84.1
(N - 150) / P	41.32	43.42	90.4	91.6
INORGANIC N / P	132.81	202.23	93.4	97.3
TURBIDITY 1/M	.32	.32	23.2	23.2
ZMIX * TURBIDITY	2.08	2.08	29.6	29.6
ZMIX / SECCHI	3.82	4.40	35.2	44.5
CHL-A * SECCHI	30.77	21.09	94.1	84.8
CHL-A / TOTAL P	.50	.41	92.9	88.0
FREQ(CHL-a>10) %	74.12	60.42	.0	.0
FREQ(CHL-a>20) %	31.88	19.65	.0	.0
FREQ(CHL-a>30) %	13.03	6.58	.0	.0
FREQ(CHL-a>40) %	5.60	2.43	.0	.0
FREQ(CHL-a>50) %	2.57	.99	.0	.0
FREQ(CHL-a>60) %	1.25	.43	.0	.0
CARLSON TSI-P	55.94	55.23	.0	.0
CARLSON TSI-CHLA	59.01	56.68	.0	.0
CARLSON TSI-SEC	52.35	54.38	.0	.0

SEGMENT: 5 95%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	33.62	.0	34.7
CHL-A MG/M3	.00	13.72	.0	68.9
HOD-V MG/M3-DAY	.00	92.51	.0	59.7
MOD-V MG/M3-DAY	.00	84.74	.0	62.2
CHL-A / TOTAL P	.00	.41	.0	87.6
FREQ(CHL-a>10) %	.00	57.92	.0	.0
FREQ(CHL-a>20) %	.00	17.92	.0	.0
FREQ(CHL-a>30) %	.00	5.79	.0	.0
FREQ(CHL-a>40) %	.00	2.09	.0	.0
FREQ(CHL-a>50) %	.00	.83	.0	.0
FREQ(CHL-a>60) %	.00	.36	.0	.0
CARLSON TSI-P	.00	54.84	.0	.0
CARLSON TSI-CHLA	.00	56.29	.0	.0

SEGMENT: 6 85%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	31.67	.0	32.3
CHL-A MG/M3	.00	12.57	.0	64.8
HOD-V MG/M3-DAY	.00	92.51	.0	59.7
MOD-V MG/M3-DAY	.00	84.74	.0	62.2

CHL-A / TOTAL P	.00	.40	.0	86.6
FREQ(CHL-a>10) %	.00	52.37	.0	.0
FREQ(CHL-a>20) %	.00	14.48	.0	.0
FREQ(CHL-a>30) %	.00	4.34	.0	.0
FREQ(CHL-a>40) %	.00	1.48	.0	.0
FREQ(CHL-a>50) %	.00	.56	.0	.0
FREQ(CHL-a>60) %	.00	.23	.0	.0
CARLSON TSI-P	.00	53.98	.0	.0
CARLSON TSI-CHLA	.00	55.43	.0	.0

SEGMENT: 7 75%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	29.62	.0	29.7
CHL-A MG/M3	.00	11.40	.0	60.0
HOD-V MG/M3-DAY	.00	92.51	.0	59.7
MOD-V MG/M3-DAY	.00	84.74	.0	62.2
CHL-A / TOTAL P	.00	.38	.0	85.6
FREQ(CHL-a>10) %	.00	46.07	.0	.0
FREQ(CHL-a>20) %	.00	11.19	.0	.0
FREQ(CHL-a>30) %	.00	3.07	.0	.0
FREQ(CHL-a>40) %	.00	.98	.0	.0
FREQ(CHL-a>50) %	.00	.35	.0	.0
FREQ(CHL-a>60) %	.00	.14	.0	.0
CARLSON TSI-P	.00	53.01	.0	.0
CARLSON TSI-CHLA	.00	54.48	.0	.0

SEGMENT: 8 50%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	23.87	.0	22.0
CHL-A MG/M3	.00	8.32	.0	43.8
HOD-V MG/M3-DAY	.00	92.51	.0	59.7
MOD-V MG/M3-DAY	.00	84.74	.0	62.2
CHL-A / TOTAL P	.00	.35	.0	81.7
FREQ(CHL-a>10) %	.00	27.22	.0	.0
FREQ(CHL-a>20) %	.00	4.23	.0	.0
FREQ(CHL-a>30) %	.00	.87	.0	.0
FREQ(CHL-a>40) %	.00	.22	.0	.0
FREQ(CHL-a>50) %	.00	.07	.0	.0
FREQ(CHL-a>60) %	.00	.02	.0	.0
CARLSON TSI-P	.00	49.90	.0	.0
CARLSON TSI-CHLA	.00	51.39	.0	.0

SEGMENT: 9 25%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	16.76	.0	12.2
CHL-A MG/M3	.00	4.97	.0	20.4
HOD-V MG/M3-DAY	.00	92.51	.0	59.7
MOD-V MG/M3-DAY	.00	84.74	.0	62.2

CHL-A / TOTAL P	.00	.30	.0	74.2
FREQ(CHL-a>10) %	.00	7.50	.0	.0
FREQ(CHL-a>20) %	.00	.53	.0	.0
FREQ(CHL-a>30) %	.00	.07	.0	.0
FREQ(CHL-a>40) %	.00	.01	.0	.0
FREQ(CHL-a>50) %	.00	.00	.0	.0
FREQ(CHL-a>60) %	.00	.00	.0	.0
CARLSON TSI-P	.00	44.80	.0	.0
CARLSON TSI-CHLA	.00	46.32	.0	.0

SEGMENT:10 17%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	13.95	.0	8.5
CHL-A MG/M3	.00	3.80	.0	12.0
HOD-V MG/M3-DAY	.00	92.51	.0	59.7
MOD-V MG/M3-DAY	.00	84.74	.0	62.2
CHL-A / TOTAL P	.00	.27	.0	69.7
FREQ(CHL-a>10) %	.00	3.06	.0	.0
FREQ(CHL-a>20) %	.00	.14	.0	.0
FREQ(CHL-a>30) %	.00	.01	.0	.0
FREQ(CHL-a>40) %	.00	.00	.0	.0
FREQ(CHL-a>50) %	.00	.00	.0	.0
FREQ(CHL-a>60) %	.00	.00	.0	.0
CARLSON TSI-P	.00	42.15	.0	.0
CARLSON TSI-CHLA	.00	43.69	.0	.0

SEGMENT:11 135%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	41.67	.0	43.8
CHL-A MG/M3	.00	18.77	.0	81.6
HOD-V MG/M3-DAY	.00	92.51	.0	59.7
MOD-V MG/M3-DAY	.00	84.74	.0	62.2
CHL-A / TOTAL P	.00	.45	.0	90.5
FREQ(CHL-a>10) %	.00	75.97	.0	.0
FREQ(CHL-a>20) %	.00	33.99	.0	.0
FREQ(CHL-a>30) %	.00	14.30	.0	.0
FREQ(CHL-a>40) %	.00	6.29	.0	.0
FREQ(CHL-a>50) %	.00	2.93	.0	.0
FREQ(CHL-a>60) %	.00	1.45	.0	.0
CARLSON TSI-P	.00	57.93	.0	.0
CARLSON TSI-CHLA	.00	59.36	.0	.0

SEGMENT:12 150%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	44.10	.0	46.3
CHL-A MG/M3	.00	20.39	.0	84.3
HOD-V MG/M3-DAY	.00	92.51	.0	59.7
MOD-V MG/M3-DAY	.00	84.74	.0	62.2

CHL-A / TOTAL P	.00	.46	.0	91.1
FREQ(CHL-a>10) %	.00	79.93	.0	.0
FREQ(CHL-a>20) %	.00	39.00	.0	.0
FREQ(CHL-a>30) %	.00	17.54	.0	.0
FREQ(CHL-a>40) %	.00	8.12	.0	.0
FREQ(CHL-a>50) %	.00	3.95	.0	.0
FREQ(CHL-a>60) %	.00	2.01	.0	.0
CARLSON TSI-P	.00	58.75	.0	.0
CARLSON TSI-CHLA	.00	60.18	.0	.0

SEGMENT:13 35%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	19.84	.0	16.4
CHL-A MG/M3	.00	6.35	.0	30.6
HOD-V MG/M3-DAY	.00	92.51	.0	59.7
MOD-V MG/M3-DAY	.00	84.74	.0	62.2
CHL-A / TOTAL P	.00	.32	.0	78.0
FREQ(CHL-a>10) %	.00	14.88	.0	.0
FREQ(CHL-a>20) %	.00	1.54	.0	.0
FREQ(CHL-a>30) %	.00	.25	.0	.0
FREQ(CHL-a>40) %	.00	.05	.0	.0
FREQ(CHL-a>50) %	.00	.01	.0	.0
FREQ(CHL-a>60) %	.00	.00	.0	.0
CARLSON TSI-P	.00	47.24	.0	.0
CARLSON TSI-CHLA	.00	48.74	.0	.0

SEGMENT:14 65%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	27.44	.0	26.8
CHL-A MG/M3	.00	10.20	.0	54.3
HOD-V MG/M3-DAY	.00	92.51	.0	59.7
MOD-V MG/M3-DAY	.00	84.74	.0	62.2
CHL-A / TOTAL P	.00	.37	.0	84.3
FREQ(CHL-a>10) %	.00	39.04	.0	.0
FREQ(CHL-a>20) %	.00	8.13	.0	.0
FREQ(CHL-a>30) %	.00	2.02	.0	.0
FREQ(CHL-a>40) %	.00	.60	.0	.0
FREQ(CHL-a>50) %	.00	.20	.0	.0
FREQ(CHL-a>60) %	.00	.08	.0	.0
CARLSON TSI-P	.00	51.91	.0	.0
CARLSON TSI-CHLA	.00	53.38	.0	.0

SEGMENT:15 SWAT Background

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	9.00	.0	3.2
CHL-A MG/M3	.00	2.00	.0	2.2
HOD-V MG/M3-DAY	.00	92.51	.0	59.7
MOD-V MG/M3-DAY	.00	84.74	.0	62.2

CHL-A / TOTAL P	.00	.22	.0	57.9
FREQ(CHL-a>10) %	.00	.19	.0	.0
FREQ(CHL-a>20) %	.00	.00	.0	.0
FREQ(CHL-a>30) %	.00	.00	.0	.0
FREQ(CHL-a>40) %	.00	.00	.0	.0
FREQ(CHL-a>50) %	.00	.00	.0	.0
FREQ(CHL-a>60) %	.00	.00	.0	.0
CARLSON TSI-P	.00	35.84	.0	.0
CARLSON TSI-CHLA	.00	37.42	.0	.0

SEGMENT:16 AREA-WTD MEAN

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	36.30	29.18	37.9	29.1
TOTAL N MG/M3	1650.00	1650.00	78.2	78.2
C.NUTRIENT MG/M3	34.86	33.30	48.8	46.5
CHL-A MG/M3	18.10	11.64	80.3	61.0
SECCHI M	1.70	1.48	72.5	66.0
ORGANIC N MG/M3	321.90	506.56	22.4	55.2
TP-ORTHO-P MG/M3	26.30	28.89	44.5	48.4
HOD-V MG/M3-DAY	113.70	92.51	70.0	59.7
MOD-V MG/M3-DAY	123.70	84.74	80.0	62.2
ANTILOG PC-1	243.76	233.70	49.8	48.6
ANTILOG PC-2	12.95	9.44	90.9	76.7
(N - 150) / P	41.32	51.40	90.4	94.8
INORGANIC N / P	132.81	1143.44	93.4	100.0
TURBIDITY 1/M	.02	.02	.0	.0
ZMIX * TURBIDITY	.14	.14	.0	.0
ZMIX / SECCHI	3.82	4.40	35.2	44.5
CHL-A * SECCHI	30.77	17.19	94.1	77.0
CHL-A / TOTAL P	.50	.40	92.9	86.8
FREQ(CHL-a>10) %	74.12	47.38	.0	.0
FREQ(CHL-a>20) %	31.88	11.83	.0	.0
FREQ(CHL-a>30) %	13.03	3.31	.0	.0
FREQ(CHL-a>40) %	5.60	1.07	.0	.0
FREQ(CHL-a>50) %	2.57	.39	.0	.0
FREQ(CHL-a>60) %	1.25	.16	.0	.0
CARLSON TSI-P	55.94	52.80	.0	.0
CARLSON TSI-CHLA	59.01	54.67	.0	.0
CARLSON TSI-SEC	52.35	54.38	.0	.0

CASE: Enrichment Scenario; No internal
File name: nointeuch.bin

Enrichment Scenario; w/internal

MODEL OPTIONS:

1	CONSERVATIVE SUBSTANCE	0 NOT COMPUTED
2	PHOSPHORUS BALANCE	1 2ND ORDER, AVAIL P
3	NITROGEN BALANCE	0 NOT COMPUTED
4	CHLOROPHYLL-A	5 P, JONES & BACHMAN
5	SECCHI DEPTH	1 VS. CHLA & TURBIDITY

6	DISPERSION	1 FISCHER-NUMERIC
7	PHOSPHORUS CALIBRATION	1 DECAY RATES
8	NITROGEN CALIBRATION	2 CONCENTRATIONS
9	ERROR ANALYSIS	1 MODEL & DATA
10	AVAILABILITY FACTORS	1 USE FOR MODEL 1 ONLY
11	MASS-BALANCE TABLES	1 USE ESTIMATED CONCS

ATMOSPHERIC LOADS & AVAILABILITY FACTORS:

VARIABLE	ATMOSPHERIC-LOADS KG/KM2-YR	CV	AVAILABILITY FACTOR
1 CONSERV	.00	.00	.00
2 TOTAL P	.00	.00	1.00
3 TOTAL N	.00	.00	1.00
4 ORTHO P	.00	.00	.00
5 INORG N	.00	.00	.00

GLOBAL INPUT VALUES:

PARAMETER		MEAN	CV
PERIOD LENGTH	YRS	1.000	.000
PRECIPITATION	M	.000	.000
EVAPORATION	M	.140	.450
INCREASE IN STORAGE	M	-.390	1.410

TRIBUTARY DRAINAGE AREAS AND FLOWS:

ID	TYPE	SEG	NAME	DRAINAGE AREA KM2	MEAN FLOW HM3/YR	CV OF MEAN FLOW
1	1	1	125% external	825.000	284.300	.054
2	1	2	115% External	825.000	284.300	.054
3	1	3	105% External	825.000	284.300	.054
4	1	4	100% external	825.000	284.300	.054
5	1	5	95% external	825.000	284.300	.054
6	1	6	85% External	825.000	284.300	.054
7	1	7	75% external	825.000	284.300	.054
8	1	8	50% external	825.000	284.300	.054
9	1	9	25% external	825.000	284.300	.054
10	1	10	17% external	825.000	284.300	.054
11	5	1	int	.000	.000	.000
12	5	2	int	.000	.000	.000
13	5	3	int	.000	.000	.000
14	5	4	int	.000	.000	.000
15	5	5	int	.000	.000	.000
16	5	6	int	.000	.000	.000
17	5	7	int	.000	.000	.000
18	5	8	int	.000	.000	.000
19	5	9	int	.000	.000	.000
20	5	10	int	.000	.000	.000
21	1	12	150%	825.000	284.300	.054
22	1	11	135%	825.000	284.300	.054
23	1	14	65%	825.000	284.300	.054
24	1	13	35%	825.000	284.300	.054
25	5	12	Int	.000	.000	.000
26	5	11	int	.000	.000	.000
27	5	13	int	.000	.000	.000
28	5	14	int	.000	.000	.000
29	1	15	SWAT	825.000	284.300	.054
30	5	15	int	.000	.000	.000

TRIBUTARY CONCENTRATIONS (PPB): MEAN/CV

ID	CONSERV	TOTAL P	TOTAL N	ORTHO P	INORG N
1	.0/ .00	151.3/ .05	.0/ .00	.0/ .00	.0/ .00
2	.0/ .00	139.2/ .05	.0/ .00	.0/ .00	.0/ .00
3	.0/ .00	127.1/ .05	.0/ .00	.0/ .00	.0/ .00
4	.0/ .00	121.0/ .05	.0/ .00	.0/ .00	.0/ .00
5	.0/ .00	115.0/ .05	.0/ .00	.0/ .00	.0/ .00
6	.0/ .00	102.9/ .05	.0/ .00	.0/ .00	.0/ .00
7	.0/ .00	90.8/ .05	.0/ .00	.0/ .00	.0/ .00
8	.0/ .00	60.5/ .05	.0/ .00	.0/ .00	.0/ .00
9	.0/ .00	30.3/ .05	.0/ .00	.0/ .00	.0/ .00
10	.0/ .00	20.6/ .05	.0/ .00	.0/ .00	.0/ .00
11	.0/ .00	.0/ .00	.0/ .00	.0/ .00	.0/ .00
12	.0/ .00	.0/ .00	.0/ .00	.0/ .00	.0/ .00
13	.0/ .00	.0/ .00	.0/ .00	.0/ .00	.0/ .00
14	.0/ .00	.0/ .00	.0/ .00	.0/ .00	.0/ .00
15	.0/ .00	.0/ .00	.0/ .00	.0/ .00	.0/ .00
16	.0/ .00	.0/ .00	.0/ .00	.0/ .00	.0/ .00
17	.0/ .00	.0/ .00	.0/ .00	.0/ .00	.0/ .00
18	.0/ .00	.0/ .00	.0/ .00	.0/ .00	.0/ .00
19	.0/ .00	.0/ .00	.0/ .00	.0/ .00	.0/ .00
20	.0/ .00	.0/ .00	.0/ .00	.0/ .00	.0/ .00
21	.0/ .00	190.6/ .05	.0/ .00	.0/ .00	.0/ .00
22	.0/ .00	171.5/ .05	.0/ .00	.0/ .00	.0/ .00
23	.0/ .00	78.7/ .05	.0/ .00	.0/ .00	.0/ .00
24	.0/ .00	42.4/ .05	.0/ .00	.0/ .00	.0/ .00
25	.0/ .00	.0/ .00	.0/ .00	.0/ .00	.0/ .00
26	.0/ .00	.0/ .00	.0/ .00	.0/ .00	.0/ .00
27	.0/ .00	.0/ .00	.0/ .00	.0/ .00	.0/ .00
28	.0/ .00	.0/ .00	.0/ .00	.0/ .00	.0/ .00
29	.0/ .00	6.6/1.10	.0/ .00	.0/ .00	.0/ .00
30	.0/ .00	.0/ .00	.0/ .00	.0/ .00	.0/ .00

MODEL SEGMENTS & CALIBRATION FACTORS:

					----------- CALIBRATION FACTORS -- ---------					
SEG	OUTFLOW	GROUP	SEGMENT NAME		P SED	N SED	CHL-A	SECCHI	HOD	DISP
1	0	1	125%		1.00	1.00	1.00	1.00	1.00	1.000
				CV:	.000	.000	.000	.000	.000	.000
2	0	1	115%		1.00	1.00	1.00	1.00	1.00	1.000
				CV:	.000	.000	.000	.000	.000	.000
3	0	1	105		1.00	1.00	1.00	1.00	1.00	1.000
				CV:	.000	.000	.000	.000	.000	.000
4	0	1	100%		1.00	1.00	1.00	1.00	1.00	1.000
				CV:	.000	.000	.000	.000	.000	.000
5	0	1	95%		1.00	1.00	1.00	1.00	1.00	1.000

				CV:	.000	.000	.000	.000	.000	.000
6	0	1	85%		1.00	1.00	1.00	1.00	1.00	1.000
				CV:	.000	.000	.000	.000	.000	.000
7	0	1	75%		1.00	1.00	1.00	1.00	1.00	1.000
				CV:	.000	.000	.000	.000	.000	.000
8	0	1	50%		1.00	1.00	1.00	1.00	1.00	1.000
				CV:	.000	.000	.000	.000	.000	.000
9	0	1	25%		1.00	1.00	1.00	1.00	1.00	1.000
				CV:	.000	.000	.000	.000	.000	.000
10	0	1	17%		1.00	1.00	1.00	1.00	1.00	1.000
				CV:	.000	.000	.000	.000	.000	.000
11	0	1	135%		1.00	1.00	1.00	1.00	1.00	1.000
				CV:	.000	.000	.000	.000	.000	.000
12	0	1	150%		1.00	1.00	1.00	1.00	1.00	1.000
				CV:	.000	.000	.000	.000	.000	.000
13	0	1	35%		1.00	1.00	1.00	1.00	1.00	1.000
				CV:	.000	.000	.000	.000	.000	.000
14	0	1	65%		1.00	1.00	1.00	1.00	1.00	1.000
				CV:	.000	.000	.000	.000	.000	.000
15	0	1	SWAT Background		1.00	1.00	1.00	1.00	1.00	1.000
				CV:	.000	.000	.000	.000	.000	.000

SEGMENT MORPHOMETRY: MEAN/CV

ID	LABEL	LENGTH KM	AREA KM2	ZMEAN M	ZMIX M	ZHYP M
1	125%	9.00	11.3600	8.20	6.50/ .50	8.85/ .24
2	115%	9.00	11.3600	8.20	6.50/ .50	8.85/ .24
3	105	9.00	11.3600	8.20	6.50/ .50	8.85/ .24
4	100%	9.00	11.3600	8.20	6.50/ .50	8.85/ .24
5	95%	9.00	11.3600	8.20	6.50/ .50	8.85/ .24
6	85%	9.00	11.3600	8.20	6.50/ .50	8.85/ .24
7	75%	9.00	11.3600	8.20	6.50/ .50	8.85/ .24
8	50%	9.00	11.3600	8.20	6.50/ .50	8.85/ .24
9	25%	9.00	11.3600	8.20	6.50/ .50	8.85/ .24
10	17%	9.00	11.3600	8.20	6.50/ .50	8.85/ .24
11	135%	9.00	11.3600	8.20	6.50/ .50	8.85/ .24

```
 12 150%                9.00   11.3600   8.20   6.50/ .50   8.85/ .24
 13 35%                 9.00   11.3600   8.20   6.50/ .50   8.85/ .24
 14 65%                 9.00   11.3600   8.20   6.50/ .50   8.85/ .24
 15 SWAT Background     9.00   11.3600   8.20   6.50/ .50   8.85/ .24

 SEGMENT OBSERVED WATER QUALITY:
 SEG    TURBID CONSER TOTALP TOTALN  CHL-A SECCHI  ORG-N  TP-OP   HODV
MODV
           1/M    ---   MG/M3  MG/M3  MG/M3      M  MG/M3  MG/M3 MG/M3-D
MG/M3-D
  1 MN:    .00     .0     .0     .0     .0     .0     .0     .0     .0
.0
    CV:    .00    .00    .00    .00    .00    .00    .00    .00    .00
.00
  2 MN:    .00     .0     .0     .0     .0     .0     .0     .0     .0
.0
    CV:    .00    .00    .00    .00    .00    .00    .00    .00    .00
.00
  3 MN:    .00     .0     .0     .0     .0     .0     .0     .0     .0
.0
    CV:    .00    .00    .00    .00    .00    .00    .00    .00    .00
.00
  4 MN:    .32     .0   36.3 1650.0   18.1    1.7  321.9   26.3  113.7
123.7
    CV:    .25    .00    .77    .43    .77   1.40    .89    .80    .88
.58
  5 MN:    .00     .0     .0     .0     .0     .0     .0     .0     .0
.0
    CV:    .00    .00    .00    .00    .00    .00    .00    .00    .00
.00
  6 MN:    .00     .0     .0     .0     .0     .0     .0     .0     .0
.0
    CV:    .00    .00    .00    .00    .00    .00    .00    .00    .00
.00
  7 MN:    .00     .0     .0     .0     .0     .0     .0     .0     .0
.0
    CV:    .00    .00    .00    .00    .00    .00    .00    .00    .00
.00
  8 MN:    .00     .0     .0     .0     .0     .0     .0     .0     .0
.0
    CV:    .00    .00    .00    .00    .00    .00    .00    .00    .00
.00
  9 MN:    .00     .0     .0     .0     .0     .0     .0     .0     .0
.0
    CV:    .00    .00    .00    .00    .00    .00    .00    .00    .00
.00
 10 MN:    .00     .0     .0     .0     .0     .0     .0     .0     .0
.0
    CV:    .00    .00    .00    .00    .00    .00    .00    .00    .00
.00
 11 MN:    .00     .0     .0     .0     .0     .0     .0     .0     .0
.0
    CV:    .00    .00    .00    .00    .00    .00    .00    .00    .00
.00
 12 MN:    .00     .0     .0     .0     .0     .0     .0     .0     .0
.0
```

```
   CV:    .00    .00    .00    .00    .00    .00    .00    .00    .00
.00
 13 MN:    .00     .0     .0     .0     .0     .0     .0     .0     .0
.0
   CV:    .00    .00    .00    .00    .00    .00    .00    .00    .00
.00
 14 MN:    .00     .0     .0     .0     .0     .0     .0     .0     .0
.0
   CV:    .00    .00    .00    .00    .00    .00    .00    .00    .00
.00
 15 MN:    .00     .0     .0     .0     .0     .0     .0     .0     .0
.0
   CV:    .00    .00    .00    .00    .00    .00    .00    .00    .00
.00

 MODEL COEFFICIENTS:
 COEFFICIENT             MEAN      CV
 DISPERSION FACTO       1.000     .70
 P DECAY RATE           2.204     .45
 N DECAY RATE           1.000     .55
 CHL-A MODEL            1.000     .26
 SECCHI MODEL           1.000     .10
 ORGANIC N MODEL        1.000     .12
 TP-OP MODEL            1.000     .15
 HODV MODEL             1.000     .15
 MODV MODEL             1.000     .22
 BETA  M2/MG             .025     .00
 MINIMUM QS             4.000     .00
 FLUSHING EFFECT        1.000     .00
 CHLOROPHYLL-A CV        .620     .00

 CASE NOTES:
 125,115,105,100,95,85,75,50
  25 & 17% changes in influent
  concentration
  internal Load included
  135, 150, 65 & 35% added
  SWAT background conc too


 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                        SEGMENT:  1 125%
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
  1  1 125% external         284.30  100.0     43014.6  100.0
151.3
 ----------------------------------------------------------------------
--
 TRIBUTARY INFLOW            284.30  100.0     43014.6  100.0
151.3
 ***TOTAL INFLOW             284.30  100.0     43014.6  100.0
151.3
```

```
 ADVECTIVE OUTFLOW           287.14  101.0     10829.2   25.2
37.7
 ***TOTAL OUTFLOW            287.14  101.0     10829.2   25.2
37.7
 ***EVAPORATION                1.59     .6          .0     .0
.0
 ***STORAGE INCREASE          -4.43   -1.6      -167.1    -.4
37.7
 ***RETENTION                   .00     .0     32352.5   75.2
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                         SEGMENT:  2 115%
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
  2  1 115% External         284.30  100.0     39574.6  100.0
139.2
 ----------------------------------------------------------------------
--
 TRIBUTARY INFLOW            284.30  100.0     39574.6  100.0
139.2
 ***TOTAL INFLOW             284.30  100.0     39574.6  100.0
139.2
 ADVECTIVE OUTFLOW           287.14  101.0     10324.8   26.1
36.0
 ***TOTAL OUTFLOW            287.14  101.0     10324.8   26.1
36.0
 ***EVAPORATION                1.59     .6          .0     .0
.0
 ***STORAGE INCREASE          -4.43   -1.6      -159.3    -.4
36.0
 ***RETENTION                   .00     .0     29409.1   74.3
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                         SEGMENT:  3 105
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
  3  1 105% External         284.30  100.0     36134.5  100.0
127.1
```

```
 ----------------------------------------------------------------------
--
 TRIBUTARY INFLOW            284.30  100.0     36134.5  100.0
127.1
 ***TOTAL INFLOW             284.30  100.0     36134.5  100.0
127.1
 ADVECTIVE OUTFLOW           287.14  101.0      9798.5   27.1
34.1
 ***TOTAL OUTFLOW            287.14  101.0      9798.5   27.1
34.1
 ***EVAPORATION                1.59     .6          .0     .0
.0
 ***STORAGE INCREASE          -4.43   -1.6      -151.2    -.4
34.1
 ***RETENTION                  .00     .0     26487.2   73.3
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                         SEGMENT:  4 100%
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
  4  1 100% external         284.30  100.0     34400.3  100.0
121.0
 ----------------------------------------------------------------------
--
 TRIBUTARY INFLOW            284.30  100.0     34400.3  100.0
121.0
 ***TOTAL INFLOW             284.30  100.0     34400.3  100.0
121.0
 ADVECTIVE OUTFLOW           287.14  101.0      9523.9   27.7
33.2
 ***TOTAL OUTFLOW            287.14  101.0      9523.9   27.7
33.2
 ***EVAPORATION                1.59     .6          .0     .0
.0
 ***STORAGE INCREASE          -4.43   -1.6      -146.9    -.4
33.2
 ***RETENTION                  .00     .0     25023.4   72.7
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                         SEGMENT:  5 95%
                             --- FLOW ---       --- LOAD ---
CONC
```

```
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
  5  1 95% external          284.30  100.0     32694.5  100.0
115.0
 ----------------------------------------------------------------------
--
 TRIBUTARY INFLOW            284.30  100.0     32694.5  100.0
115.0
 ***TOTAL INFLOW             284.30  100.0     32694.5  100.0
115.0
 ADVECTIVE OUTFLOW           287.14  101.0      9247.1   28.3
32.2
 ***TOTAL OUTFLOW            287.14  101.0      9247.1   28.3
32.2
 ***EVAPORATION                1.59     .6          .0     .0
.0
 ***STORAGE INCREASE          -4.43   -1.6      -142.7    -.4
32.2
 ***RETENTION                   .00     .0     23590.1   72.2
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                             SEGMENT:  6 85%
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
  6  1 85% External          284.30  100.0     29254.5  100.0
102.9
 ----------------------------------------------------------------------
--
 TRIBUTARY INFLOW            284.30  100.0     29254.5  100.0
102.9
 ***TOTAL INFLOW             284.30  100.0     29254.5  100.0
102.9
 ADVECTIVE OUTFLOW           287.14  101.0      8666.7   29.6
30.2
 ***TOTAL OUTFLOW            287.14  101.0      8666.7   29.6
30.2
 ***EVAPORATION                1.59     .6          .0     .0
.0
 ***STORAGE INCREASE          -4.43   -1.6      -133.7    -.5
30.2
 ***RETENTION                   .00     .0     20721.5   70.8
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M
```

SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
COMPONENT: TOTAL P SEGMENT: 7 75%

ID T LOCATION	--- FLOW --- HM3/YR	%	--- LOAD --- KG/YR	%	CONC MG/M3
7 1 75% external	284.30	100.0	25814.4	100.0	90.8
TRIBUTARY INFLOW	284.30	100.0	25814.4	100.0	90.8
***TOTAL INFLOW	284.30	100.0	25814.4	100.0	90.8
ADVECTIVE OUTFLOW	287.14	101.0	8052.0	31.2	28.0
***TOTAL OUTFLOW	287.14	101.0	8052.0	31.2	28.0
***EVAPORATION	1.59	.6	.0	.0	.0
***STORAGE INCREASE	-4.43	-1.6	-124.2	-.5	28.0
***RETENTION	.00	.0	17886.7	69.3	.0

RESID. TIME = .329 YRS, OVERFLOW RATE = 24.9 M/YR, DEPTH = 8.2 M

SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
COMPONENT: TOTAL P SEGMENT: 8 50%

ID T LOCATION	--- FLOW --- HM3/YR	%	--- LOAD --- KG/YR	%	CONC MG/M3
8 1 50% external	284.30	100.0	17200.1	100.0	60.5
TRIBUTARY INFLOW	284.30	100.0	17200.1	100.0	60.5
***TOTAL INFLOW	284.30	100.0	17200.1	100.0	60.5
ADVECTIVE OUTFLOW	287.14	101.0	6310.7	36.7	22.0
***TOTAL OUTFLOW	287.14	101.0	6310.7	36.7	22.0
***EVAPORATION	1.59	.6	.0	.0	.0
***STORAGE INCREASE	-4.43	-1.6	-97.4	-.6	22.0

```
 ***RETENTION                      .00     .0     10986.8   63.9
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                          SEGMENT:  9 25%
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
  9  1 25% external          284.30  100.0      8614.3  100.0
30.3
 ----------------------------------------------------------------------
--
 TRIBUTARY INFLOW            284.30  100.0      8614.3  100.0
30.3
 ***TOTAL INFLOW             284.30  100.0      8614.3  100.0
30.3
 ADVECTIVE OUTFLOW           287.14  101.0      4081.5   47.4
14.2
 ***TOTAL OUTFLOW            287.14  101.0      4081.5   47.4
14.2
 ***EVAPORATION                1.59     .6          .0     .0
.0
 ***STORAGE INCREASE          -4.43   -1.6       -63.0    -.7
14.2
 ***RETENTION                  .00     .0      4595.8   53.4
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                          SEGMENT: 10 17%
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
 10  1 17% external          284.30  100.0      5856.6  100.0
20.6
 ----------------------------------------------------------------------
--
 TRIBUTARY INFLOW            284.30  100.0      5856.6  100.0
20.6
 ***TOTAL INFLOW             284.30  100.0      5856.6  100.0
20.6
 ADVECTIVE OUTFLOW           287.14  101.0      3156.5   53.9
11.0
```

```
 ***TOTAL OUTFLOW             287.14  101.0      3156.5   53.9
11.0
 ***EVAPORATION                 1.59     .6          .0     .0
.0
 ***STORAGE INCREASE           -4.43   -1.6       -48.7    -.8
11.0
 ***RETENTION                    .00     .0      2748.8   46.9
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                           SEGMENT: 11 135%
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
 22  1 135%                  284.30  100.0     48757.4  100.0
171.5
 ----------------------------------------------------------------------
--
 TRIBUTARY INFLOW            284.30  100.0     48757.4  100.0
171.5
 ***TOTAL INFLOW             284.30  100.0     48757.4  100.0
171.5
 ADVECTIVE OUTFLOW           287.14  101.0     11629.0   23.9
40.5
 ***TOTAL OUTFLOW            287.14  101.0     11629.0   23.9
40.5
 ***EVAPORATION                1.59     .6          .0     .0
.0
 ***STORAGE INCREASE          -4.43   -1.6      -179.4    -.4
40.5
 ***RETENTION                   .00     .0     37307.9   76.5
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                           SEGMENT: 12 150%
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
 21  1 150%                  284.30  100.0     54187.6  100.0
190.6
 ----------------------------------------------------------------------
--
```

```
 TRIBUTARY INFLOW             284.30  100.0     54187.6  100.0
190.6
 ***TOTAL INFLOW              284.30  100.0     54187.6  100.0
190.6
 ADVECTIVE OUTFLOW            287.14  101.0     12343.6   22.8
43.0
 ***TOTAL OUTFLOW             287.14  101.0     12343.6   22.8
43.0
 ***EVAPORATION                 1.59     .6          .0     .0
.0
 ***STORAGE INCREASE           -4.43   -1.6      -190.5    -.4
43.0
 ***RETENTION                    .00     .0     42034.4   77.6
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                         SEGMENT: 13 35%
                              --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION               HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
 24  1 35%                    284.30  100.0     12054.3  100.0
42.4
 ----------------------------------------------------------------------
--
 TRIBUTARY INFLOW             284.30  100.0     12054.3  100.0
42.4
 ***TOTAL INFLOW              284.30  100.0     12054.3  100.0
42.4
 ADVECTIVE OUTFLOW            287.14  101.0      5062.4   42.0
17.6
 ***TOTAL OUTFLOW             287.14  101.0      5062.4   42.0
17.6
 ***EVAPORATION                 1.59     .6          .0     .0
.0
 ***STORAGE INCREASE           -4.43   -1.6       -78.1    -.6
17.6
 ***RETENTION                    .00     .0      7070.1   58.7
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                         SEGMENT: 14 65%
                              --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION               HM3/YR      %       KG/YR      %
MG/M3
```

```
 ----------------------------------------------------------------------
--
 23  1 65%                      284.30  100.0     22374.4  100.0
78.7
 ----------------------------------------------------------------------
--
 TRIBUTARY INFLOW               284.30  100.0     22374.4  100.0
78.7
 ***TOTAL INFLOW                284.30  100.0     22374.4  100.0
78.7
 ADVECTIVE OUTFLOW              287.14  101.0      7396.3   33.1
25.8
 ***TOTAL OUTFLOW               287.14  101.0      7396.3   33.1
25.8
 ***EVAPORATION                   1.59     .6          .0     .0
.0
 ***STORAGE INCREASE             -4.43   -1.6      -114.1    -.5
25.8
 ***RETENTION                      .00     .0     15092.2   67.5
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                          SEGMENT: 15 SWAT Background
                                --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION                 HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
 29  1 SWAT                     284.30  100.0      1876.4  100.0
6.6
 ----------------------------------------------------------------------
--
 TRIBUTARY INFLOW               284.30  100.0      1876.4  100.0
6.6
 ***TOTAL INFLOW                284.30  100.0      1876.4  100.0
6.6
 ADVECTIVE OUTFLOW              287.14  101.0      1375.6   73.3
4.8
 ***TOTAL OUTFLOW               287.14  101.0      1375.6   73.3
4.8
 ***EVAPORATION                   1.59     .6          .0     .0
.0
 ***STORAGE INCREASE             -4.43   -1.6       -21.2   -1.1
4.8
 ***RETENTION                      .00     .0       522.0   27.8
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .329 YRS, OVERFLOW RATE =    24.9 M/YR, DEPTH =   8.2
M
```

T STATISTICS COMPARE OBSERVED AND PREDICTED MEANS
USING THE FOLLOWING ERROR TERMS:
1 = OBSERVED WATER QUALITY ERROR ONLY
2 = ERROR TYPICAL OF MODEL DEVELOPMENT DATA SET
3 = OBSERVED AND PREDICTED ERROR

SEGMENT: 1 125%

		OBSERVED		ESTIMATED			T STATISTICS		
VARIABLE		MEAN	CV	MEAN	CV	RATIO	1	2	3
TOTAL P	MG/M3	.0	.00	37.7	.19	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	16.2	.38	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	88.8	.33	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	81.4	.36	.00	.00	.00	.00

SEGMENT: 2 115%

		OBSERVED		ESTIMATED			T STATISTICS		
VARIABLE		MEAN	CV	MEAN	CV	RATIO	1	2	3
TOTAL P	MG/M3	.0	.00	36.0	.19	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	15.1	.38	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	88.8	.33	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	81.4	.36	.00	.00	.00	.00

SEGMENT: 3 105

		OBSERVED		ESTIMATED			T STATISTICS		
VARIABLE		MEAN	CV	MEAN	CV	RATIO	1	2	3
TOTAL P	MG/M3	.0	.00	34.1	.19	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	14.0	.38	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	88.8	.33	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	81.4	.36	.00	.00	.00	.00

SEGMENT: 4 100%

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	36.3	.77	33.2	.19	1.09	.12	.34	.11
TOTAL N	MG/M3	1650.0	.43	1650.0	.43	1.00	.00	.00	.00
C.NUTRIENT	MG/M3	34.9	.69	32.1	.18	1.09	.12	.42	.12
CHL-A	MG/M3	18.1	.77	13.5	.38	1.35	.39	.86	.35
SECCHI	M	1.7	1.40	1.5	.25	1.12	.08	.39	.08
ORGANIC N	MG/M3	321.9	.89	487.8	.27	.66	-.47	-1.66	-.45
TP-ORTHO-P	MG/M3	26.3	.80	27.4	.37	.96	-.05	-.11	-.05
HOD-V	MG/M3-DAY	113.7	.88	88.8	.33	1.28	.28	1.22	.26
MOD-V	MG/M3-DAY	123.7	.58	81.4	.36	1.52	.72	1.28	.62

SEGMENT: 5 95%

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	.0	.00	32.2	.19	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	12.9	.38	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	88.8	.33	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	81.4	.36	.00	.00	.00	.00

SEGMENT: 6 85%

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3

TOTAL P	MG/M3	.0	.00	30.2	.19	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	11.7	.38	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	88.8	.33	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	81.4	.36	.00	.00	.00	.00

SEGMENT: 7 75%

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	.0	.00	28.0	.18	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	10.5	.37	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	88.8	.33	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	81.4	.36	.00	.00	.00	.00

SEGMENT: 8 50%

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	.0	.00	22.0	.18	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	7.4	.37	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	88.8	.33	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	81.4	.36	.00	.00	.00	.00

SEGMENT: 9 25%

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	.0	.00	14.2	.16	.00	.00	.00	.00

CHL-A	MG/M3	.0	.00	3.9	.35	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	88.8	.33	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	81.4	.36	.00	.00	.00	.00

SEGMENT: 10 17%

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	.0	.00	11.0	.15	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	2.7	.34	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	88.8	.33	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	81.4	.36	.00	.00	.00	.00

SEGMENT: 11 135%

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	.0	.00	40.5	.19	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	18.0	.38	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	88.8	.33	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	81.4	.36	.00	.00	.00	.00

SEGMENT: 12 150%

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	.0	.00	43.0	.20	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	19.6	.39	.00	.00	.00	.00

HOD-V	MG/M3-DAY	.0	.00	88.8	.33	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	81.4	.36	.00	.00	.00	.00

SEGMENT: 13 35%

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	.0	.00	17.6	.17	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	5.3	.36	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	88.8	.33	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	81.4	.36	.00	.00	.00	.00

SEGMENT: 14 65%

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	.0	.00	25.8	.18	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	9.3	.37	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	88.8	.33	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	81.4	.36	.00	.00	.00	.00

SEGMENT: 15 SWAT Background

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	.0	.00	4.8	.86	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	.8	1.29	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	88.8	.33	.00	.00	.00	.00

MOD-V	MG/M3-DAY	.0	.00	81.4	.36	.00	.00	.00	.00

SEGMENT: 16 AREA-WTD MEAN

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	36.3	.77	27.3	.18	1.33	.37	1.05	.36
TOTAL N	MG/M3	1650.0	.43	1650.0	.43	1.00	.00	.00	.00
C.NUTRIENT	MG/M3	34.9	.69	32.1	.18	1.09	.12	.42	.12
CHL-A	MG/M3	18.1	.77	10.7	.37	1.69	.68	1.51	.61
SECCHI	M	1.7	1.40	1.5	.25	1.12	.08	.39	.08
ORGANIC N	MG/M3	321.9	.89	487.8	.27	.66	-.47	-1.66	-.45
TP-ORTHO-P	MG/M3	26.3	.80	27.4	.37	.96	-.05	-.11	-.05
HOD-V	MG/M3-DAY	113.7	.88	88.8	.25	1.28	.28	1.22	.27
MOD-V	MG/M3-DAY	123.7	.58	81.4	.33	1.52	.72	1.28	.63

OBSERVED AND PREDICTED DIAGNOSTIC VARIABLES
RANKED AGAINST CE MODEL DEVELOPMENT DATA SET

SEGMENT: 1 125%

VARIABLE		VALUES OBSERVED	VALUES ESTIMATED	RANKS (%) OBSERVED	RANKS (%) ESTIMATED
TOTAL P	MG/M3	.00	37.71	.0	39.5
CHL-A	MG/M3	.00	16.22	.0	76.1
HOD-V	MG/M3-DAY	.00	88.85	.0	57.6
MOD-V	MG/M3-DAY	.00	81.39	.0	60.0
CHL-A / TOTAL P		.00	.43	.0	89.2
FREQ(CHL-a>10) %		.00	68.11	.0	.0
FREQ(CHL-a>20) %		.00	25.86	.0	.0
FREQ(CHL-a>30) %		.00	9.65	.0	.0
FREQ(CHL-a>40) %		.00	3.87	.0	.0
FREQ(CHL-a>50) %		.00	1.68	.0	.0
FREQ(CHL-a>60) %		.00	.78	.0	.0
CARLSON TSI-P		.00	56.49	.0	.0
CARLSON TSI-CHLA		.00	57.94	.0	.0

SEGMENT: 2 115%

	VALUES		RANKS (%)	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	35.96	.0	37.5
CHL-A MG/M3	.00	15.13	.0	73.2
HOD-V MG/M3-DAY	.00	88.85	.0	57.6
MOD-V MG/M3-DAY	.00	81.39	.0	60.0
CHL-A / TOTAL P	.00	.42	.0	88.5
FREQ(CHL-a>10) %	.00	64.00	.0	.0
FREQ(CHL-a>20) %	.00	22.37	.0	.0
FREQ(CHL-a>30) %	.00	7.87	.0	.0
FREQ(CHL-a>40) %	.00	3.02	.0	.0
FREQ(CHL-a>50) %	.00	1.26	.0	.0
FREQ(CHL-a>60) %	.00	.57	.0	.0
CARLSON TSI-P	.00	55.81	.0	.0
CARLSON TSI-CHLA	.00	57.25	.0	.0

SEGMENT: 3 105

	VALUES		RANKS (%)	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	34.12	.0	35.3
CHL-A MG/M3	.00	14.02	.0	69.9
HOD-V MG/M3-DAY	.00	88.85	.0	57.6
MOD-V MG/M3-DAY	.00	81.39	.0	60.0
CHL-A / TOTAL P	.00	.41	.0	87.8
FREQ(CHL-a>10) %	.00	59.30	.0	.0
FREQ(CHL-a>20) %	.00	18.86	.0	.0
FREQ(CHL-a>30) %	.00	6.21	.0	.0
FREQ(CHL-a>40) %	.00	2.27	.0	.0
FREQ(CHL-a>50) %	.00	.91	.0	.0
FREQ(CHL-a>60) %	.00	.40	.0	.0
CARLSON TSI-P	.00	55.05	.0	.0
CARLSON TSI-CHLA	.00	56.50	.0	.0

SEGMENT: 4 100%

	VALUES		RANKS (%)	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	36.30	33.17	37.9	34.1
TOTAL N MG/M3	1650.00	1650.00	78.2	78.2
C.NUTRIENT MG/M3	34.86	32.06	48.8	44.6
CHL-A MG/M3	18.10	13.45	80.3	68.0
SECCHI M	1.70	1.52	72.5	67.5
ORGANIC N MG/M3	321.90	487.77	22.4	52.2
TP-ORTHO-P MG/M3	26.30	27.43	44.5	46.2
HOD-V MG/M3-DAY	113.70	88.85	70.0	57.6
MOD-V MG/M3-DAY	123.70	81.39	80.0	60.0
ANTILOG PC-1	243.76	240.80	49.8	49.5
ANTILOG PC-2	12.95	10.67	90.9	83.2
(N - 150) / P	41.32	45.22	90.4	92.5
INORGANIC N / P	132.81	202.40	93.4	97.3
TURBIDITY 1/M	.32	.32	23.2	23.2
ZMIX * TURBIDITY	2.08	2.08	29.6	29.6
ZMIX / SECCHI	3.82	4.27	35.2	42.4

CHL-A * SECCHI	30.77	20.50	94.1	83.8
CHL-A / TOTAL P	.50	.41	92.9	87.4
FREQ(CHL-a>10) %	74.12	56.68	.0	.0
FREQ(CHL-a>20) %	31.88	17.11	.0	.0
FREQ(CHL-a>30) %	13.03	5.44	.0	.0
FREQ(CHL-a>40) %	5.60	1.93	.0	.0
FREQ(CHL-a>50) %	2.57	.76	.0	.0
FREQ(CHL-a>60) %	1.25	.33	.0	.0
CARLSON TSI-P	55.94	54.64	.0	.0
CARLSON TSI-CHLA	59.01	56.10	.0	.0
CARLSON TSI-SEC	52.35	53.93	.0	.0

SEGMENT: 5 95%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	32.20	.0	33.0
CHL-A MG/M3	.00	12.88	.0	65.9
HOD-V MG/M3-DAY	.00	88.85	.0	57.6
MOD-V MG/M3-DAY	.00	81.39	.0	60.0
CHL-A / TOTAL P	.00	.40	.0	86.9
FREQ(CHL-a>10) %	.00	53.94	.0	.0
FREQ(CHL-a>20) %	.00	15.40	.0	.0
FREQ(CHL-a>30) %	.00	4.71	.0	.0
FREQ(CHL-a>40) %	.00	1.63	.0	.0
FREQ(CHL-a>50) %	.00	.63	.0	.0
FREQ(CHL-a>60) %	.00	.26	.0	.0
CARLSON TSI-P	.00	54.22	.0	.0
CARLSON TSI-CHLA	.00	55.67	.0	.0

SEGMENT: 6 85%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	30.18	.0	30.4
CHL-A MG/M3	.00	11.72	.0	61.3
HOD-V MG/M3-DAY	.00	88.85	.0	57.6
MOD-V MG/M3-DAY	.00	81.39	.0	60.0
CHL-A / TOTAL P	.00	.39	.0	85.9
FREQ(CHL-a>10) %	.00	47.84	.0	.0
FREQ(CHL-a>20) %	.00	12.06	.0	.0
FREQ(CHL-a>30) %	.00	3.39	.0	.0
FREQ(CHL-a>40) %	.00	1.10	.0	.0
FREQ(CHL-a>50) %	.00	.40	.0	.0
FREQ(CHL-a>60) %	.00	.16	.0	.0
CARLSON TSI-P	.00	53.28	.0	.0
CARLSON TSI-CHLA	.00	54.75	.0	.0

SEGMENT: 7 75%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	28.04	.0	27.6
CHL-A MG/M3	.00	10.53	.0	55.9

HOD-V MG/M3-DAY	.00	88.85	.0	57.6
MOD-V MG/M3-DAY	.00	81.39	.0	60.0
CHL-A / TOTAL P	.00	.38	.0	84.7
FREQ(CHL-a>10) %	.00	41.01	.0	.0
FREQ(CHL-a>20) %	.00	8.93	.0	.0
FREQ(CHL-a>30) %	.00	2.28	.0	.0
FREQ(CHL-a>40) %	.00	.69	.0	.0
FREQ(CHL-a>50) %	.00	.24	.0	.0
FREQ(CHL-a>60) %	.00	.09	.0	.0
CARLSON TSI-P	.00	52.22	.0	.0
CARLSON TSI-CHLA	.00	53.69	.0	.0

SEGMENT: 8 50%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	21.98	.0	19.3
CHL-A MG/M3	.00	7.38	.0	37.7
HOD-V MG/M3-DAY	.00	88.85	.0	57.6
MOD-V MG/M3-DAY	.00	81.39	.0	60.0
CHL-A / TOTAL P	.00	.34	.0	80.1
FREQ(CHL-a>10) %	.00	21.15	.0	.0
FREQ(CHL-a>20) %	.00	2.75	.0	.0
FREQ(CHL-a>30) %	.00	.50	.0	.0
FREQ(CHL-a>40) %	.00	.12	.0	.0
FREQ(CHL-a>50) %	.00	.03	.0	.0
FREQ(CHL-a>60) %	.00	.01	.0	.0
CARLSON TSI-P	.00	48.71	.0	.0
CARLSON TSI-CHLA	.00	50.20	.0	.0

SEGMENT: 9 25%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	14.21	.0	8.9
CHL-A MG/M3	.00	3.90	.0	12.7
HOD-V MG/M3-DAY	.00	88.85	.0	57.6
MOD-V MG/M3-DAY	.00	81.39	.0	60.0
CHL-A / TOTAL P	.00	.27	.0	70.2
FREQ(CHL-a>10) %	.00	3.38	.0	.0
FREQ(CHL-a>20) %	.00	.16	.0	.0
FREQ(CHL-a>30) %	.00	.02	.0	.0
FREQ(CHL-a>40) %	.00	.00	.0	.0
FREQ(CHL-a>50) %	.00	.00	.0	.0
FREQ(CHL-a>60) %	.00	.00	.0	.0
CARLSON TSI-P	.00	42.42	.0	.0
CARLSON TSI-CHLA	.00	43.96	.0	.0

SEGMENT:10 17%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	10.99	.0	5.1
CHL-A MG/M3	.00	2.68	.0	5.2

HOD-V MG/M3-DAY	.00	88.85	.0	57.6
MOD-V MG/M3-DAY	.00	81.39	.0	60.0
CHL-A / TOTAL P	.00	.24	.0	63.5
FREQ(CHL-a>10) %	.00	.75	.0	.0
FREQ(CHL-a>20) %	.00	.02	.0	.0
FREQ(CHL-a>30) %	.00	.00	.0	.0
FREQ(CHL-a>40) %	.00	.00	.0	.0
FREQ(CHL-a>50) %	.00	.00	.0	.0
FREQ(CHL-a>60) %	.00	.00	.0	.0
CARLSON TSI-P	.00	38.72	.0	.0
CARLSON TSI-CHLA	.00	40.28	.0	.0

SEGMENT:11 135%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	40.50	.0	42.6
CHL-A MG/M3	.00	18.00	.0	80.1
HOD-V MG/M3-DAY	.00	88.85	.0	57.6
MOD-V MG/M3-DAY	.00	81.39	.0	60.0
CHL-A / TOTAL P	.00	.44	.0	90.1
FREQ(CHL-a>10) %	.00	73.84	.0	.0
FREQ(CHL-a>20) %	.00	31.57	.0	.0
FREQ(CHL-a>30) %	.00	12.85	.0	.0
FREQ(CHL-a>40) %	.00	5.51	.0	.0
FREQ(CHL-a>50) %	.00	2.51	.0	.0
FREQ(CHL-a>60) %	.00	1.22	.0	.0
CARLSON TSI-P	.00	57.52	.0	.0
CARLSON TSI-CHLA	.00	58.96	.0	.0

SEGMENT:12 150%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	42.99	.0	45.2
CHL-A MG/M3	.00	19.64	.0	83.1
HOD-V MG/M3-DAY	.00	88.85	.0	57.6
MOD-V MG/M3-DAY	.00	81.39	.0	60.0
CHL-A / TOTAL P	.00	.46	.0	90.8
FREQ(CHL-a>10) %	.00	78.20	.0	.0
FREQ(CHL-a>20) %	.00	36.72	.0	.0
FREQ(CHL-a>30) %	.00	16.03	.0	.0
FREQ(CHL-a>40) %	.00	7.25	.0	.0
FREQ(CHL-a>50) %	.00	3.46	.0	.0
FREQ(CHL-a>60) %	.00	1.74	.0	.0
CARLSON TSI-P	.00	58.38	.0	.0
CARLSON TSI-CHLA	.00	59.81	.0	.0

SEGMENT:13 35%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	17.63	.0	13.3
CHL-A MG/M3	.00	5.35	.0	23.2

HOD-V MG/M3-DAY	.00	88.85	.0	57.6
MOD-V MG/M3-DAY	.00	81.39	.0	60.0
CHL-A / TOTAL P	.00	.30	.0	75.4
FREQ(CHL-a>10) %	.00	9.34	.0	.0
FREQ(CHL-a>20) %	.00	.74	.0	.0
FREQ(CHL-a>30) %	.00	.10	.0	.0
FREQ(CHL-a>40) %	.00	.02	.0	.0
FREQ(CHL-a>50) %	.00	.00	.0	.0
FREQ(CHL-a>60) %	.00	.00	.0	.0
CARLSON TSI-P	.00	45.53	.0	.0
CARLSON TSI-CHLA	.00	47.04	.0	.0

SEGMENT:14 65%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	25.76	.0	24.5
CHL-A MG/M3	.00	9.30	.0	49.5
HOD-V MG/M3-DAY	.00	88.85	.0	57.6
MOD-V MG/M3-DAY	.00	81.39	.0	60.0
CHL-A / TOTAL P	.00	.36	.0	83.2
FREQ(CHL-a>10) %	.00	33.46	.0	.0
FREQ(CHL-a>20) %	.00	6.11	.0	.0
FREQ(CHL-a>30) %	.00	1.39	.0	.0
FREQ(CHL-a>40) %	.00	.39	.0	.0
FREQ(CHL-a>50) %	.00	.13	.0	.0
FREQ(CHL-a>60) %	.00	.05	.0	.0
CARLSON TSI-P	.00	51.00	.0	.0
CARLSON TSI-CHLA	.00	52.48	.0	.0

SEGMENT:15 SWAT Background

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	4.79	.0	.5
CHL-A MG/M3	.00	.80	.0	.1
HOD-V MG/M3-DAY	.00	88.85	.0	57.6
MOD-V MG/M3-DAY	.00	81.39	.0	60.0
CHL-A / TOTAL P	.00	.17	.0	39.9
FREQ(CHL-a>10) %	.00	.00	.0	.0
FREQ(CHL-a>20) %	.00	.00	.0	.0
FREQ(CHL-a>30) %	.00	.00	.0	.0
FREQ(CHL-a>40) %	.00	.00	.0	.0
FREQ(CHL-a>50) %	.00	.00	.0	.0
FREQ(CHL-a>60) %	.00	.00	.0	.0
CARLSON TSI-P	.00	26.74	.0	.0
CARLSON TSI-CHLA	.00	28.38	.0	.0

SEGMENT:16 AREA-WTD MEAN

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	36.30	27.35	37.9	26.7
TOTAL N MG/M3	1650.00	1650.00	78.2	78.2

C.NUTRIENT MG/M3	34.86	32.06	48.8	44.6
CHL-A MG/M3	18.10	10.73	80.3	56.9
SECCHI M	1.70	1.52	72.5	67.5
ORGANIC N MG/M3	321.90	487.77	22.4	52.2
TP-ORTHO-P MG/M3	26.30	27.43	44.5	46.2
HOD-V MG/M3-DAY	113.70	88.85	70.0	57.6
MOD-V MG/M3-DAY	123.70	81.39	80.0	60.0
ANTILOG PC-1	243.76	212.50	49.8	45.7
ANTILOG PC-2	12.95	9.13	90.9	74.8
(N - 150) / P	41.32	54.85	90.4	95.7
INORGANIC N / P	132.81	1162.23	93.4	100.0
TURBIDITY 1/M	.02	.02	.0	.0
ZMIX * TURBIDITY	.14	.14	.0	.0
ZMIX / SECCHI	3.82	4.27	35.2	42.4
CHL-A * SECCHI	30.77	16.36	94.1	74.8
CHL-A / TOTAL P	.50	.39	92.9	86.3
FREQ(CHL-a>10) %	74.12	42.23	.0	.0
FREQ(CHL-a>20) %	31.88	9.44	.0	.0
FREQ(CHL-a>30) %	13.03	2.46	.0	.0
FREQ(CHL-a>40) %	5.60	.75	.0	.0
FREQ(CHL-a>50) %	2.57	.26	.0	.0
FREQ(CHL-a>60) %	1.25	.10	.0	.0
CARLSON TSI-P	55.94	51.86	.0	.0
CARLSON TSI-CHLA	59.01	53.88	.0	.0
CARLSON TSI-SEC	52.35	53.93	.0	.0

Spavinaw Lake Non-segmented Model; Variable nutrient scenarios

File name: spavmod.bin

MODEL OPTIONS:

1	CONSERVATIVE SUBSTANCE	0 NOT COMPUTED
2	PHOSPHORUS BALANCE	1 2ND ORDER, AVAIL P
3	NITROGEN BALANCE	0 NOT COMPUTED
4	CHLOROPHYLL-A	5 P, JONES & BACHMAN
5	SECCHI DEPTH	1 VS. CHLA & TURBIDITY
6	DISPERSION	1 FISCHER-NUMERIC
7	PHOSPHORUS CALIBRATION	1 DECAY RATES
8	NITROGEN CALIBRATION	2 CONCENTRATIONS
9	ERROR ANALYSIS	1 MODEL & DATA
10	AVAILABILITY FACTORS	1 USE FOR MODEL 1 ONLY
11	MASS-BALANCE TABLES	1 USE ESTIMATED CONCS

ATMOSPHERIC LOADS & AVAILABILITY FACTORS:

VARIABLE	ATMOSPHERIC-LOADS KG/KM2-YR	CV	AVAILABILITY FACTOR
1 CONSERV	.00	.00	.00
2 TOTAL P	.00	.00	1.00
3 TOTAL N	.00	.00	1.00
4 ORTHO P	.00	.00	.00
5 INORG N	.00	.00	.00

GLOBAL INPUT VALUES:

PARAMETER		MEAN	CV
PERIOD LENGTH	YRS	1.000	.000
PRECIPITATION	M	.000	.000
EVAPORATION	M	.140	.450
INCREASE IN STORAGE	M	-.040	.370

TRIBUTARY DRAINAGE AREAS AND FLOWS:

ID	TYPE	SEG	NAME	DRAINAGE AREA KM2	MEAN FLOW HM3/YR	CV OF MEAN FLOW
1	1	1	basin	191.000	19.000	.454
2	1	2	basin 25%	191.000	19.000	.454
3	1	3	basin	191.000	19.000	.454
4	1	4	basin	191.000	19.000	.454
5	1	5	basin	191.000	19.000	.454
6	1	6	basin bckgrnd	191.000	19.000	.454
7	1	1	Eucha Dam	825.000	261.000	.192
8	1	2	Eucha Dam	825.000	261.000	.192
9	1	3	Eucha dam	825.000	261.000	.192
10	1	4	Eucha dam 25%	825.000	261.000	.192
11	1	5	Eucha dam 25%	825.000	261.000	.192
12	1	6	Eucha dam 25%	825.000	261.000	.192
13	5	1	Internal	.000	.000	.000
14	5	2	Internal	.000	.000	.000
15	5	3	Internal 25%	.000	.000	.000
16	5	4	Internal	.000	.000	.000
17	5	5	Internal 25%	.000	.000	.000
18	5	6	Internal 10%	.000	.000	.000

19	1	7	basin 25%	191.000	19.000	.454
20	1	8	basin 25%	191.000	19.000	.454
21	1	7	Eucha dam	825.000	261.000	.192
22	1	8	Eucha Dam 25%	825.000	261.000	.192
23	5	7	Internal 25%	.000	.000	.000
24	5	8	Internal	.000	.000	.000
25	5	9	internal	.000	.000	.000
26	1	9	Eucha dam 150%	825.000	261.000	.192
27	1	9	basin 150%	191.000	19.000	.454
28	5	10	Internal	.000	.000	.000
29	1	10	Eucha dam 135%	825.000	261.000	.192
30	1	10	basin 135%	191.000	19.000	.454
31	5	11	Internal	.000	.000	.000
32	1	11	Eucha dam 125%	825.000	261.000	.192
33	1	11	basin 125%	191.000	19.000	.454
34	5	12	internal	.000	.000	.000
35	1	12	Eucha dam 115%	825.000	261.000	.192
36	1	12	Basin 115%	191.000	19.000	.454
37	5	13	Internal	.000	.000	.000
38	1	13	Eucha dam 105%	825.000	261.000	.192
39	1	13	basin 105%	191.000	19.000	.454

TRIBUTARY CONCENTRATIONS (PPB): MEAN/CV

ID	CONSERV	TOTAL P	TOTAL N	ORTHO P	INORG N
1	.0/ .00	33.0/ .35	.0/ .00	7.0/ .98	465.0/ .88
2	.0/ .00	8.3/ .35	.0/ .00	.0/ .00	.0/ .00
3	.0/ .00	33.0/ .35	.0/ .00	.0/ .00	.0/ .00
4	.0/ .00	33.0/ .35	.0/ .00	.0/ .00	.0/ .00
5	.0/ .00	33.0/ .35	.0/ .00	.0/ .00	.0/ .00
6	.0/ .00	7.9/1.70	.0/ .00	.0/ .00	688.5/1.09
7	.0/ .00	28.5/ .09	1441.0/ .02	.0/ .00	.0/ .00
8	.0/ .00	28.5/ .09	.0/ .00	.0/ .00	.0/ .00
9	.0/ .00	28.5/ .09	.0/ .00	.0/ .00	.0/ .00
10	.0/ .00	7.1/ .09	.0/ .00	.0/ .00	.0/ .00
11	.0/ .00	7.1/ .09	.0/ .00	.0/ .00	.0/ .00
12	.0/ .00	7.1/ .09	.0/ .00	.0/ .00	.0/ .00
13	.0/ .00	.2/ .23	.0/ .00	.0/ .00	.0/ .00
14	.0/ .00	.2/ .23	.0/ .00	.0/ .00	.0/ .00
15	.0/ .00	.1/ .23	.0/ .00	.0/ .00	.0/ .00
16	.0/ .00	.6/ .23	.0/ .00	.0/ .00	.0/ .00
17	.0/ .00	.1/ .23	.0/ .00	.0/ .00	.0/ .00
18	.0/ .00	.0/ .23	.0/ .00	.0/ .00	.0/ .00
19	.0/ .00	8.3/ .35	.0/ .00	.0/ .00	.0/ .00
20	.0/ .00	8.3/ .35	.0/ .00	.0/ .00	.0/ .00
21	.0/ .00	28.5/ .09	.0/ .00	.0/ .00	.0/ .00
22	.0/ .00	7.1/ .09	.0/ .00	.0/ .00	.0/ .00
23	.0/ .00	.1/ .23	.0/ .00	.0/ .00	.0/ .00
24	.0/ .00	.2/ .23	.0/ .00	.0/ .00	.0/ .00
25	.0/ .00	.2/ .23	.0/ .00	.0/ .00	.0/ .00
26	.0/ .00	42.8/ .09	.0/ .00	.0/ .00	.0/ .00
27	.0/ .00	49.5/ .35	.0/ .00	.0/ .00	.0/ .00
28	.0/ .00	.2/ .23	.0/ .00	.0/ .00	.0/ .00
29	.0/ .00	38.5/ .09	.0/ .00	.0/ .00	.0/ .00
30	.0/ .00	44.5/ .35	.0/ .00	.0/ .00	.0/ .00
31	.0/ .00	.2/ .23	.0/ .00	.0/ .00	.0/ .00
32	.0/ .00	35.6/ .09	.0/ .00	.0/ .00	.0/ .00
33	.0/ .00	41.3/ .35	.0/ .00	.0/ .00	.0/ .00

34	.0/ .00	.2/ .23	.0/ .00	.0/ .00	.0/ .00
35	.0/ .00	32.8/ .09	.0/ .00	.0/ .00	.0/ .00
36	.0/ .00	38.0/ .35	.0/ .00	.0/ .00	.0/ .00
37	.0/ .00	.2/ .23	.0/ .00	.0/ .00	.0/ .00
38	.0/ .00	29.9/ .09	.0/ .00	.0/ .00	.0/ .00
39	.0/ .00	34.7/ .35	.0/ .00	.0/ .00	.0/ .00

MODEL SEGMENTS & CALIBRATION FACTORS:

				----------- CALIBRATION FACTORS -----------					
SEG	OUTFLOW	GROUP	SEGMENT NAME	P SED	N SED	CHL-A	SECCHI	HOD	DISP
1	0	1	Current	1.00	1.00	1.00	1.00	1.00	1.000
			CV:	.000	.000	.000	.000	.000	.000
2	0	1	basin 25%	1.00	1.00	1.00	1.00	1.00	1.000
			CV:	.000	.000	.000	.000	.000	.000
3	0	1	Internal 25%	1.00	1.00	1.00	1.00	1.00	1.000
			CV:	.000	.000	.000	.000	.000	.000
4	0	1	Eucha Dam 25%	1.00	1.00	1.00	1.00	1.00	1.000
			CV:	.000	.000	.000	.000	.000	.000
5	0	1	25% int & dam	1.00	1.00	1.00	1.00	1.00	1.000
			CV:	.000	.000	.000	.000	.000	.000
6	0	1	all cleaned up	1.00	1.00	1.00	1.00	1.00	1.000
			CV:	.000	.000	.000	.000	.000	.000
7	0	1	25%Int & basin	1.00	1.00	1.00	1.00	1.00	1.000
			CV:	.000	.000	.000	.000	.000	.000
8	0	1	Basin & dam 25%	1.00	1.00	1.00	1.00	1.00	1.000
			CV:	.000	.000	.000	.000	.000	.000
9	0	1	150% inputs	1.00	1.00	1.00	1.00	1.00	1.000
			CV:	.000	.000	.000	.000	.000	.000
10	0	1	135% inputs	1.00	1.00	1.00	1.00	1.00	1.000
			CV:	.000	.000	.000	.000	.000	.000
11	0	1	125% inputs	1.00	1.00	1.00	1.00	1.00	1.000
			CV:	.000	.000	.000	.000	.000	.000

12	0	1	115% inputs		1.00	1.00	1.00	1.00	1.00	1.000
				CV:	.000	.000	.000	.000	.000	.000
13	0	1	105% Inputs		1.00	1.00	1.00	1.00	1.00	1.000
				CV:	.000	.000	.000	.000	.000	.000

SEGMENT MORPHOMETRY: MEAN/CV

ID	LABEL	LENGTH KM	AREA KM2	ZMEAN M	ZMIX M	ZHYP M
1	Current	6.84	6.3700	5.10	5.50/ .32	7.80/ .23
2	basin 25%	6.84	6.3700	5.10	5.50/ .32	7.80/ .23
3	Internal 25%	6.84	6.3700	5.10	5.50/ .32	7.80/ .23
4	Eucha Dam 25%	6.84	6.3700	5.10	5.50/ .32	7.80/ .23
5	25% int & dam	6.84	6.3700	5.10	5.50/ .32	7.80/ .23
6	all cleaned up	6.84	6.3700	5.10	5.50/ .32	7.80/ .23
7	25%Int & basin	6.84	6.3700	5.10	5.50/ .32	7.80/ .23
8	Basin & dam 25%	6.84	6.3700	5.10	5.50/ .32	7.80/ .23
9	150% inputs	6.84	6.3700	5.10	5.50/ .32	7.80/ .23
10	135% inputs	6.84	6.3700	5.10	5.50/ .32	7.80/ .23
11	125% inputs	6.84	6.3700	5.10	5.50/ .32	7.80/ .23
12	115% inputs	6.84	6.3700	5.10	5.50/ .32	7.80/ .23
13	105% Inputs	6.84	6.3700	5.10	5.50/ .32	7.80/ .23

SEGMENT OBSERVED WATER QUALITY:

SEG		TURBID 1/M	CONSER ---	TOTALP MG/M3	TOTALN MG/M3	CHL-A MG/M3	SECCHI M	ORG-N MG/M3	TP-OP MG/M3	HODV MG/M3-D	MODV MG/M3-D
1	MN:	.00	.0	24.8	899.2	14.8	1.5	414.3	22.0	248.0	193.0
	CV:	.00	.00	.72	.59	.48	.35	.95	1.19	.37	.48
2	MN:	.00	.0	.0	.0	.0	.0	.0	.0	.0	.0
	CV:	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
3	MN:	.00	.0	.0	.0	.0	.0	.0	.0	.0	.0
	CV:	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
4	MN:	.00	.0	.0	.0	.0	.0	.0	.0	.0	.0
	CV:	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
5	MN:	.00	.0	.0	.0	.0	.0	.0	.0	.0	.0
	CV:	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
6	MN:	.00	.0	.0	.0	.0	.0	.0	.0	.0	.0
	CV:	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
7	MN:	.00	.0	.0	.0	.0	.0	.0	.0	.0	.0

```
    CV:    .00    .00    .00    .00    .00    .00    .00    .00    .00
.00
  8 MN:    .00     .0     .0     .0     .0     .0     .0     .0     .0
.0
    CV:    .00    .00    .00    .00    .00    .00    .00    .00    .00
.00
  9 MN:    .00     .0     .0     .0     .0     .0     .0     .0     .0
.0
    CV:    .00    .00    .00    .00    .00    .00    .00    .00    .00
.00
 10 MN:    .00     .0     .0     .0     .0     .0     .0     .0     .0
.0
    CV:    .00    .00    .00    .00    .00    .00    .00    .00    .00
.00
 11 MN:    .00     .0     .0     .0     .0     .0     .0     .0     .0
.0
    CV:    .00    .00    .00    .00    .00    .00    .00    .00    .00
.00
 12 MN:    .00     .0     .0     .0     .0     .0     .0     .0     .0
.0
    CV:    .00    .00    .00    .00    .00    .00    .00    .00    .00
.00
 13 MN:    .00     .0     .0     .0     .0     .0     .0     .0     .0
.0
    CV:    .00    .00    .00    .00    .00    .00    .00    .00    .00
.00

 MODEL COEFFICIENTS:
 COEFFICIENT           MEAN       CV
 DISPERSION FACTO     1.000      .70
 P DECAY RATE         1.000      .45
 N DECAY RATE         1.000      .55
 CHL-A MODEL          1.875      .26
 SECCHI MODEL         1.000      .10
 ORGANIC N MODEL      1.000      .12
 TP-OP MODEL          1.000      .15
 HODV MODEL           1.000      .15
 MODV MODEL           1.000      .22
 BETA  M2/MG           .025      .00
 MINIMUM QS           4.000      .00
 FLUSHING EFFECT      1.000      .00
 CHLOROPHYLL-A CV      .620      .00

 CASE NOTES:
 1st try to vary Spav nut load
 basin to background
 internal load to 25%
 dam conc to 25%
 increasing load too
```

```
 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                          SEGMENT:  1 Current
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
  1  1 basin                  19.00    6.8       627.0    7.3
33.0
  7  1 Eucha Dam             261.00   93.2      7438.5   86.4
28.5
 ----------------------------------------------------------------------
--
 INTERNAL LOAD                  .00     .0       546.8    6.3
.0
 TRIBUTARY INFLOW            280.00  100.0      8065.5   93.7
28.8
 ***TOTAL INFLOW             280.00  100.0      8612.3  100.0
30.8
 ADVECTIVE OUTFLOW           279.36   99.8      6396.8   74.3
22.9
 ***TOTAL OUTFLOW            279.36   99.8      6396.8   74.3
22.9
 ***EVAPORATION                 .89     .3          .0     .0
.0
 ***STORAGE INCREASE           -.25    -.1        -5.8    -.1
22.9
 ***RETENTION                   .00     .0      2221.3   25.8
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .116 YRS, OVERFLOW RATE =    43.8 M/YR, DEPTH =   5.1
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                          SEGMENT:  2 basin 25%
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
  2  1 basin 25%              19.00    6.8       156.8    1.9
8.3
  8  1 Eucha Dam             261.00   93.2      7438.5   91.4
28.5
 ----------------------------------------------------------------------
--
 INTERNAL LOAD                  .00     .0       546.8    6.7
.0
 TRIBUTARY INFLOW            280.00  100.0      7595.3   93.3
27.1
 ***TOTAL INFLOW             280.00  100.0      8142.0  100.0
29.1
```

```
 ADVECTIVE OUTFLOW           279.36   99.8      6116.6   75.1
21.9
 ***TOTAL OUTFLOW            279.36   99.8      6116.6   75.1
21.9
 ***EVAPORATION                 .89     .3          .0     .0
.0
 ***STORAGE INCREASE           -.25    -.1        -5.6    -.1
21.9
 ***RETENTION                   .00     .0      2031.0   24.9
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .116 YRS, OVERFLOW RATE =    43.8 M/YR, DEPTH =   5.1
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                        SEGMENT:  3 Internal 25%
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
  3  1 basin                  19.00    6.8       627.0    7.6
33.0
  9  1 Eucha dam             261.00   93.2      7438.5   90.7
28.5
 ----------------------------------------------------------------------
--
 INTERNAL LOAD                  .00     .0       136.7    1.7
.0
 TRIBUTARY INFLOW            280.00  100.0      8065.5   98.3
28.8
 ***TOTAL INFLOW             280.00  100.0      8202.2  100.0
29.3
 ADVECTIVE OUTFLOW           279.36   99.8      6152.7   75.0
22.0
 ***TOTAL OUTFLOW            279.36   99.8      6152.7   75.0
22.0
 ***EVAPORATION                 .89     .3          .0     .0
.0
 ***STORAGE INCREASE           -.25    -.1        -5.6    -.1
22.0
 ***RETENTION                   .00     .0      2055.1   25.1
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .116 YRS, OVERFLOW RATE =    43.8 M/YR, DEPTH =   5.1
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                        SEGMENT:  4 Eucha Dam 25%
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
```

```
 ----------------------------------------------------------------------
--
  4  1 basin                    19.00    6.8       627.0   16.3
33.0
 10  1 Eucha dam 25%           261.00   93.2      1859.6   48.3
7.1
 ----------------------------------------------------------------------
--
 INTERNAL LOAD                    .00     .0      1366.9   35.5
.0
 TRIBUTARY INFLOW              280.00  100.0      2486.6   64.5
8.9
 ***TOTAL INFLOW               280.00  100.0      3853.5  100.0
13.8
 ADVECTIVE OUTFLOW             279.36   99.8      3274.4   85.0
11.7
 ***TOTAL OUTFLOW              279.36   99.8      3274.4   85.0
11.7
 ***EVAPORATION                   .89     .3          .0     .0
.0
 ***STORAGE INCREASE             -.25    -.1        -3.0    -.1
11.7
 ***RETENTION                     .00     .0       582.1   15.1
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .116 YRS, OVERFLOW RATE =    43.8 M/YR, DEPTH =   5.1
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                       SEGMENT:  5 25% int & dam
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
  5  1 basin                    19.00    6.8       627.0   23.9
33.0
 11  1 Eucha dam 25%           261.00   93.2      1859.6   70.9
7.1
 ----------------------------------------------------------------------
--
 INTERNAL LOAD                    .00     .0       136.7    5.2
.0
 TRIBUTARY INFLOW              280.00  100.0      2486.6   94.8
8.9
 ***TOTAL INFLOW               280.00  100.0      2623.3  100.0
9.4
 ADVECTIVE OUTFLOW             279.36   99.8      2330.6   88.8
8.3
 ***TOTAL OUTFLOW              279.36   99.8      2330.6   88.8
8.3
 ***EVAPORATION                   .89     .3          .0     .0
.0
 ***STORAGE INCREASE             -.25    -.1        -2.1    -.1
8.3
```

```
 ***RETENTION                      .00     .0       294.9   11.2
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .116 YRS, OVERFLOW RATE =    43.8 M/YR, DEPTH =   5.1
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                         SEGMENT:  6 all cleaned up
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
  6  1 basin bckgrnd          19.00    6.8       150.1    7.3
7.9
 12  1 Eucha dam 25%         261.00   93.2      1859.6   90.1
7.1
 ----------------------------------------------------------------------
--
 INTERNAL LOAD                     .00     .0        54.7    2.6
.0
 TRIBUTARY INFLOW            280.00  100.0      2009.7   97.4
7.2
 ***TOTAL INFLOW             280.00  100.0      2064.4  100.0
7.4
 ADVECTIVE OUTFLOW           279.36   99.8      1875.2   90.8
6.7
 ***TOTAL OUTFLOW            279.36   99.8      1875.2   90.8
6.7
 ***EVAPORATION                    .89     .3          .0     .0
.0
 ***STORAGE INCREASE             -.25    -.1        -1.7    -.1
6.7
 ***RETENTION                      .00     .0       190.9    9.2
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .116 YRS, OVERFLOW RATE =    43.8 M/YR, DEPTH =   5.1
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                         SEGMENT:  7 25%Int & basin
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
 19  1 basin 25%              19.00    6.8       156.8    2.0
8.3
 21  1 Eucha dam             261.00   93.2      7438.5   96.2
28.5
 ----------------------------------------------------------------------
--
```

```
 INTERNAL LOAD                    .00     .0       136.7    1.8
.0
 TRIBUTARY INFLOW              280.00  100.0      7595.3   98.2
27.1
 ***TOTAL INFLOW               280.00  100.0      7731.9  100.0
27.6
 ADVECTIVE OUTFLOW             279.36   99.8      5868.0   75.9
21.0
 ***TOTAL OUTFLOW              279.36   99.8      5868.0   75.9
21.0
 ***EVAPORATION                   .89     .3          .0     .0
.0
 ***STORAGE INCREASE             -.25    -.1        -5.4    -.1
21.0
 ***RETENTION                     .00     .0      1869.3   24.2
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .116 YRS, OVERFLOW RATE =    43.8 M/YR, DEPTH =   5.1
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                         SEGMENT:  8 Basin & dam 25%
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
 20  1 basin 25%              19.00    6.8       156.8    6.1
8.3
 22  1 Eucha Dam 25%         261.00   93.2      1859.6   72.6
7.1
 ----------------------------------------------------------------------
--
 INTERNAL LOAD                    .00     .0       546.8   21.3
.0
 TRIBUTARY INFLOW              280.00  100.0      2016.4   78.7
7.2
 ***TOTAL INFLOW               280.00  100.0      2563.1  100.0
9.2
 ADVECTIVE OUTFLOW             279.36   99.8      2282.4   89.0
8.2
 ***TOTAL OUTFLOW              279.36   99.8      2282.4   89.0
8.2
 ***EVAPORATION                   .89     .3          .0     .0
.0
 ***STORAGE INCREASE             -.25    -.1        -2.1    -.1
8.2
 ***RETENTION                     .00     .0       282.8   11.0
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .116 YRS, OVERFLOW RATE =    43.8 M/YR, DEPTH =   5.1
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
```

COMPONENT: TOTAL P SEGMENT: 9 150% inputs

ID	T	LOCATION	FLOW HM3/YR	FLOW %	LOAD KG/YR	LOAD %	CONC MG/M3
26	1	Eucha dam 150%	261.00	93.2	11157.8	88.2	42.8
27	1	basin 150%	19.00	6.8	940.5	7.4	49.5
		INTERNAL LOAD	.00	.0	546.8	4.3	.0
		TRIBUTARY INFLOW	280.00	100.0	12098.3	95.7	43.2
		***TOTAL INFLOW	280.00	100.0	12645.0	100.0	45.2
		ADVECTIVE OUTFLOW	279.36	99.8	8619.5	68.2	30.9
		***TOTAL OUTFLOW	279.36	99.8	8619.5	68.2	30.9
		***EVAPORATION	.89	.3	.0	.0	.0
		***STORAGE INCREASE	-.25	-.1	-7.9	-.1	30.9
		***RETENTION	.00	.0	4033.3	31.9	.0

RESID. TIME = .116 YRS, OVERFLOW RATE = 43.8 M/YR, DEPTH = 5.1 M

SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS

COMPONENT: TOTAL P SEGMENT: 10 135% inputs

ID	T	LOCATION	FLOW HM3/YR	FLOW %	LOAD KG/YR	LOAD %	CONC MG/M3
29	1	Eucha dam 135%	261.00	93.2	10042.0	87.8	38.5
30	1	basin 135%	19.00	6.8	846.5	7.4	44.5
		INTERNAL LOAD	.00	.0	546.8	4.8	.0
		TRIBUTARY INFLOW	280.00	100.0	10888.4	95.2	38.9
		***TOTAL INFLOW	280.00	100.0	11435.2	100.0	40.8
		ADVECTIVE OUTFLOW	279.36	99.8	7982.9	69.8	28.6

```
 ***TOTAL OUTFLOW            279.36   99.8      7982.9   69.8
28.6
 ***EVAPORATION                 .89     .3          .0     .0
.0
 ***STORAGE INCREASE           -.25    -.1        -7.3    -.1
28.6
 ***RETENTION                   .00     .0      3459.5   30.3
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .116 YRS, OVERFLOW RATE =    43.8 M/YR, DEPTH =   5.1
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                         SEGMENT: 11 125% inputs
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
 32  1 Eucha dam 125%        261.00   93.2      9298.1   87.5
35.6
 33  1 basin 125%             19.00    6.8       783.8    7.4
41.3
 ----------------------------------------------------------------------
--
 INTERNAL LOAD                  .00     .0       546.8    5.1
.0
 TRIBUTARY INFLOW            280.00  100.0     10081.9   94.9
36.0
 ***TOTAL INFLOW             280.00  100.0     10628.6  100.0
38.0
 ADVECTIVE OUTFLOW           279.36   99.8      7545.1   71.0
27.0
 ***TOTAL OUTFLOW            279.36   99.8      7545.1   71.0
27.0
 ***EVAPORATION                 .89     .3          .0     .0
.0
 ***STORAGE INCREASE           -.25    -.1        -6.9    -.1
27.0
 ***RETENTION                   .00     .0      3090.5   29.1
.0
 ----------------------------------------------------------------------
--
 RESID. TIME =    .116 YRS, OVERFLOW RATE =    43.8 M/YR, DEPTH =   5.1
M

 SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
 COMPONENT: TOTAL P                         SEGMENT: 12 115% inputs
                             --- FLOW ---       --- LOAD ---
CONC
 ID  T LOCATION              HM3/YR      %       KG/YR      %
MG/M3
 ----------------------------------------------------------------------
--
```

ID	T	LOCATION	HM3/YR	%	KG/YR	%	MG/M3
35	1	Eucha dam 115%	261.00	93.2	8554.3	87.1	32.8
36	1	Basin 115%	19.00	6.8	721.0	7.3	38.0
		INTERNAL LOAD	.00	.0	546.8	5.6	.0
		TRIBUTARY INFLOW	280.00	100.0	9275.3	94.4	33.1
		***TOTAL INFLOW	280.00	100.0	9822.1	100.0	35.1
		ADVECTIVE OUTFLOW	279.36	99.8	7095.5	72.2	25.4
		***TOTAL OUTFLOW	279.36	99.8	7095.5	72.2	25.4
		***EVAPORATION	.89	.3	.0	.0	.0
		***STORAGE INCREASE	-.25	-.1	-6.5	-.1	25.4
		***RETENTION	.00	.0	2733.1	27.8	.0

RESID. TIME = .116 YRS, OVERFLOW RATE = 43.8 M/YR, DEPTH = 5.1 M

SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
COMPONENT: TOTAL P SEGMENT: 13 105% Inputs

			--- FLOW ---		--- LOAD ---		CONC
ID	T	LOCATION	HM3/YR	%	KG/YR	%	MG/M3
38	1	Eucha dam 105%	261.00	93.2	7810.4	86.6	29.9
39	1	basin 105%	19.00	6.8	658.4	7.3	34.7
		INTERNAL LOAD	.00	.0	546.8	6.1	.0
		TRIBUTARY INFLOW	280.00	100.0	8468.8	93.9	30.2
		***TOTAL INFLOW	280.00	100.0	9015.5	100.0	32.2
		ADVECTIVE OUTFLOW	279.36	99.8	6633.1	73.6	23.7
		***TOTAL OUTFLOW	279.36	99.8	6633.1	73.6	23.7
		***EVAPORATION	.89	.3	.0	.0	.0
		***STORAGE INCREASE	-.25	-.1	-6.0	-.1	23.7
		***RETENTION	.00	.0	2388.5	26.5	.0

RESID. TIME = .116 YRS, OVERFLOW RATE = 43.8 M/YR, DEPTH = 5.1 M
CASE: Spav Mod inputs

T STATISTICS COMPARE OBSERVED AND PREDICTED MEANS
USING THE FOLLOWING ERROR TERMS:
1 = OBSERVED WATER QUALITY ERROR ONLY
2 = ERROR TYPICAL OF MODEL DEVELOPMENT DATA SET
3 = OBSERVED AND PREDICTED ERROR

SEGMENT: 1 Current

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	24.8	.72	22.9	.12	1.08	.11	.29	.11
TOTAL N	MG/M3	899.2	.59	899.2	.59	1.00	.00	.00	.00
C.NUTRIENT	MG/M3	23.0	.68	21.5	.13	1.07	.10	.34	.10
CHL-A	MG/M3	14.8	.48	14.7	.31	1.01	.01	.02	.01
SECCHI	M	1.5	.35	1.5	.48	1.00	-.01	-.01	-.01
ORGANIC N	MG/M3	414.3	.95	513.5	.24	.81	-.23	-.86	-.22
TP-ORTHO-P	MG/M3	22.0	1.19	28.9	.40	.76	-.23	-.75	-.22
HOD-V	MG/M3-DAY	248.0	.37	109.3	.31	2.27	2.21	4.06	1.71
MOD-V	MG/M3-DAY	193.0	.48	95.4	.33	2.02	1.47	2.15	1.20

SEGMENT: 2 basin 25%

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	.0	.00	21.9	.12	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	13.8	.31	.00	.00	.00	.00

HOD-V	MG/M3-DAY	.0	.00	109.3	.31	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	95.4	.33	.00	.00	.00	.00

SEGMENT: 3 Internal 25%

VARIABLE		OBSERVED MEAN	CV	ESTIMATED MEAN	CV	RATIO	T STATISTICS 1	2	3
TOTAL P	MG/M3	.0	.00	22.0	.12	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	13.9	.31	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	109.3	.31	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	95.4	.33	.00	.00	.00	.00

SEGMENT: 4 Eucha Dam 25%

VARIABLE		OBSERVED MEAN	CV	ESTIMATED MEAN	CV	RATIO	T STATISTICS 1	2	3
TOTAL P	MG/M3	.0	.00	11.7	.13	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	5.5	.32	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	109.3	.31	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	95.4	.33	.00	.00	.00	.00

SEGMENT: 5 25% int & dam

VARIABLE		OBSERVED MEAN	CV	ESTIMATED MEAN	CV	RATIO	T STATISTICS 1	2	3
TOTAL P	MG/M3	.0	.00	8.3	.13	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	3.4	.32	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	109.3	.31	.00	.00	.00	.00

```
 MOD-V  MG/M3-DAY       .0   .00    95.4   .33     .00    .00    .00
.00
 ----------------------------------------------------------------------
---

 SEGMENT:  6 all cleaned up
                      OBSERVED     ESTIMATED                T
STATISTICS
 VARIABLE             MEAN    CV    MEAN    CV   RATIO      1      2
3
 ----------------------------------------------------------------------
---
 TOTAL P    MG/M3       .0   .00     6.7   .14     .00    .00    .00
.00
 CHL-A      MG/M3       .0   .00     2.4   .33     .00    .00    .00
.00
 HOD-V  MG/M3-DAY       .0   .00   109.3   .31     .00    .00    .00
.00
 MOD-V  MG/M3-DAY       .0   .00    95.4   .33     .00    .00    .00
.00
 ----------------------------------------------------------------------
---

 SEGMENT:  7 25%Int & basin
                      OBSERVED     ESTIMATED                T
STATISTICS
 VARIABLE             MEAN    CV    MEAN    CV   RATIO      1      2
3
 ----------------------------------------------------------------------
---
 TOTAL P    MG/M3       .0   .00    21.0   .12     .00    .00    .00
.00
 CHL-A      MG/M3       .0   .00    12.9   .31     .00    .00    .00
.00
 HOD-V  MG/M3-DAY       .0   .00   109.3   .31     .00    .00    .00
.00
 MOD-V  MG/M3-DAY       .0   .00    95.4   .33     .00    .00    .00
.00
 ----------------------------------------------------------------------
---

 SEGMENT:  8 Basin & dam 25%
                      OBSERVED     ESTIMATED                T
STATISTICS
 VARIABLE             MEAN    CV    MEAN    CV   RATIO      1      2
3
 ----------------------------------------------------------------------
---
 TOTAL P    MG/M3       .0   .00     8.2   .09     .00    .00    .00
.00
 CHL-A      MG/M3       .0   .00     3.3   .29     .00    .00    .00
.00
 HOD-V  MG/M3-DAY       .0   .00   109.3   .31     .00    .00    .00
.00
 MOD-V  MG/M3-DAY       .0   .00    95.4   .33     .00    .00    .00
.00
```

SEGMENT: 9 150% inputs

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	.0	.00	30.9	.13	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	22.7	.32	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	109.3	.31	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	95.4	.33	.00	.00	.00	.00

SEGMENT: 10 135% inputs

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	.0	.00	28.6	.13	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	20.3	.32	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	109.3	.31	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	95.4	.33	.00	.00	.00	.00

SEGMENT: 11 125% inputs

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	.0	.00	27.0	.12	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	18.7	.32	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	109.3	.31	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	95.4	.33	.00	.00	.00	.00

SEGMENT: 12 115% inputs

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	.0	.00	25.4	.12	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	17.1	.31	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	109.3	.31	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	95.4	.33	.00	.00	.00	.00

SEGMENT: 13 105% Inputs

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	.0	.00	23.7	.12	.00	.00	.00	.00
CHL-A	MG/M3	.0	.00	15.5	.31	.00	.00	.00	.00
HOD-V	MG/M3-DAY	.0	.00	109.3	.31	.00	.00	.00	.00
MOD-V	MG/M3-DAY	.0	.00	95.4	.33	.00	.00	.00	.00

SEGMENT: 14 AREA-WTD MEAN

VARIABLE		OBSERVED MEAN	OBSERVED CV	ESTIMATED MEAN	ESTIMATED CV	RATIO	T STATISTICS 1	T STATISTICS 2	T STATISTICS 3
TOTAL P	MG/M3	24.8	.72	19.9	.09	1.25	.31	.82	.30
TOTAL N	MG/M3	899.2	.59	899.2	.59	1.00	.00	.00	.00
C.NUTRIENT	MG/M3	23.0	.68	21.5	.13	1.07	.10	.34	.10
CHL-A	MG/M3	14.8	.48	12.6	.29	1.17	.33	.45	.28
SECCHI	M	1.5	.35	1.5	.48	1.00	-.01	-.01	-.01
ORGANIC N	MG/M3	414.3	.95	513.5	.24	.81	-.23	-.86	-.22
TP-ORTHO-P	MG/M3	22.0	1.19	28.9	.40	.76	-.23	-.75	-.22

```
 HOD-V  MG/M3-DAY   248.0   .37   109.3   .22    2.27   2.21   4.06
1.91
 MOD-V  MG/M3-DAY   193.0   .48    95.4   .31    2.02   1.47   2.15
1.24
 ----------------------------------------------------------------------
---
```

OBSERVED AND PREDICTED DIAGNOSTIC VARIABLES
RANKED AGAINST CE MODEL DEVELOPMENT DATA SET

SEGMENT: 1 Current

VARIABLE	----- VALUES ----- OBSERVED	ESTIMATED	--- RANKS (%) ---- OBSERVED	ESTIMATED
TOTAL P MG/M3	24.78	22.90	23.2	20.6
TOTAL N MG/M3	899.18	899.18	43.3	43.3
C.NUTRIENT MG/M3	23.03	21.50	29.2	26.3
CHL-A MG/M3	14.76	14.68	72.2	71.9
SECCHI M	1.52	1.52	67.4	67.5
ORGANIC N MG/M3	414.32	513.50	39.6	56.2
TP-ORTHO-P MG/M3	21.96	28.88	37.1	48.4
HOD-V MG/M3-DAY	248.00	109.31	94.2	68.1
MOD-V MG/M3-DAY	193.00	95.44	92.9	68.3
ANTILOG PC-1	197.40	203.92	43.4	44.4
ANTILOG PC-2	11.83	12.41	87.7	89.4
(N - 150) / P	30.23	32.72	80.1	83.2
INORGANIC N / P	171.94	385.68	96.1	99.5
TURBIDITY 1/M	.29	.29	19.8	19.8
ZMIX * TURBIDITY	1.59	1.59	18.9	18.9
ZMIX / SECCHI	3.62	3.61	31.7	31.6
CHL-A * SECCHI	22.44	22.38	86.7	86.7
CHL-A / TOTAL P	.60	.64	96.0	96.9
FREQ(CHL-a>10) %	62.48	62.15	.0	.0
FREQ(CHL-a>20) %	21.18	20.93	.0	.0
FREQ(CHL-a>30) %	7.30	7.18	.0	.0
FREQ(CHL-a>40) %	2.76	2.70	.0	.0
FREQ(CHL-a>50) %	1.14	1.11	.0	.0
FREQ(CHL-a>60) %	.51	.49	.0	.0
CARLSON TSI-P	50.44	49.30	.0	.0
CARLSON TSI-CHLA	57.01	56.96	.0	.0
CARLSON TSI-SEC	53.97	53.92	.0	.0

SEGMENT: 2 basin 25%

VARIABLE	----- VALUES ----- OBSERVED	ESTIMATED	--- RANKS (%) ---- OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	21.89	.0	19.2
CHL-A MG/M3	.00	13.75	.0	69.0
HOD-V MG/M3-DAY	.00	109.31	.0	68.1
MOD-V MG/M3-DAY	.00	95.44	.0	68.3
CHL-A / TOTAL P	.00	.63	.0	96.6
FREQ(CHL-a>10) %	.00	58.09	.0	.0
FREQ(CHL-a>20) %	.00	18.03	.0	.0
FREQ(CHL-a>30) %	.00	5.84	.0	.0
FREQ(CHL-a>40) %	.00	2.11	.0	.0

FREQ(CHL-a>50) %	.00	.84	.0	.0
FREQ(CHL-a>60) %	.00	.36	.0	.0
CARLSON TSI-P	.00	48.65	.0	.0
CARLSON TSI-CHLA	.00	56.31	.0	.0

SEGMENT: 3 Internal 25%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	22.02	.0	19.4
CHL-A MG/M3	.00	13.87	.0	69.4
HOD-V MG/M3-DAY	.00	109.31	.0	68.1
MOD-V MG/M3-DAY	.00	95.44	.0	68.3
CHL-A / TOTAL P	.00	.63	.0	96.7
FREQ(CHL-a>10) %	.00	58.63	.0	.0
FREQ(CHL-a>20) %	.00	18.40	.0	.0
FREQ(CHL-a>30) %	.00	6.01	.0	.0
FREQ(CHL-a>40) %	.00	2.18	.0	.0
FREQ(CHL-a>50) %	.00	.87	.0	.0
FREQ(CHL-a>60) %	.00	.38	.0	.0
CARLSON TSI-P	.00	48.74	.0	.0
CARLSON TSI-CHLA	.00	56.40	.0	.0

SEGMENT: 4 Eucha Dam 25%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	11.72	.0	5.9
CHL-A MG/M3	.00	5.52	.0	24.5
HOD-V MG/M3-DAY	.00	109.31	.0	68.1
MOD-V MG/M3-DAY	.00	95.44	.0	68.3
CHL-A / TOTAL P	.00	.47	.0	91.6
FREQ(CHL-a>10) %	.00	10.25	.0	.0
FREQ(CHL-a>20) %	.00	.85	.0	.0
FREQ(CHL-a>30) %	.00	.12	.0	.0
FREQ(CHL-a>40) %	.00	.02	.0	.0
FREQ(CHL-a>50) %	.00	.01	.0	.0
FREQ(CHL-a>60) %	.00	.00	.0	.0
CARLSON TSI-P	.00	39.64	.0	.0
CARLSON TSI-CHLA	.00	47.36	.0	.0

SEGMENT: 5 25% int & dam

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	8.34	.0	2.6
CHL-A MG/M3	.00	3.36	.0	9.1
HOD-V MG/M3-DAY	.00	109.31	.0	68.1
MOD-V MG/M3-DAY	.00	95.44	.0	68.3
CHL-A / TOTAL P	.00	.40	.0	87.1
FREQ(CHL-a>10) %	.00	1.93	.0	.0
FREQ(CHL-a>20) %	.00	.07	.0	.0
FREQ(CHL-a>30) %	.00	.01	.0	.0
FREQ(CHL-a>40) %	.00	.00	.0	.0

FREQ(CHL-a>50) %	.00	.00	.0	.0
FREQ(CHL-a>60) %	.00	.00	.0	.0
CARLSON TSI-P	.00	34.74	.0	.0
CARLSON TSI-CHLA	.00	42.49	.0	.0

SEGMENT: 6 all cleaned up

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	6.71	.0	1.4
CHL-A MG/M3	.00	2.45	.0	4.0
HOD-V MG/M3-DAY	.00	109.31	.0	68.1
MOD-V MG/M3-DAY	.00	95.44	.0	68.3
CHL-A / TOTAL P	.00	.36	.0	83.6
FREQ(CHL-a>10) %	.00	.49	.0	.0
FREQ(CHL-a>20) %	.00	.01	.0	.0
FREQ(CHL-a>30) %	.00	.00	.0	.0
FREQ(CHL-a>40) %	.00	.00	.0	.0
FREQ(CHL-a>50) %	.00	.00	.0	.0
FREQ(CHL-a>60) %	.00	.00	.0	.0
CARLSON TSI-P	.00	31.61	.0	.0
CARLSON TSI-CHLA	.00	39.38	.0	.0

SEGMENT: 7 25%Int & basin

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	21.00	.0	18.0
CHL-A MG/M3	.00	12.94	.0	66.2
HOD-V MG/M3-DAY	.00	109.31	.0	68.1
MOD-V MG/M3-DAY	.00	95.44	.0	68.3
CHL-A / TOTAL P	.00	.62	.0	96.4
FREQ(CHL-a>10) %	.00	54.24	.0	.0
FREQ(CHL-a>20) %	.00	15.58	.0	.0
FREQ(CHL-a>30) %	.00	4.79	.0	.0
FREQ(CHL-a>40) %	.00	1.66	.0	.0
FREQ(CHL-a>50) %	.00	.64	.0	.0
FREQ(CHL-a>60) %	.00	.27	.0	.0
CARLSON TSI-P	.00	48.06	.0	.0
CARLSON TSI-CHLA	.00	55.72	.0	.0

SEGMENT: 8 Basin & dam 25%

	----- VALUES -----		--- RANKS (%) ----	
VARIABLE	OBSERVED	ESTIMATED	OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	8.17	.0	2.5
CHL-A MG/M3	.00	3.26	.0	8.5
HOD-V MG/M3-DAY	.00	109.31	.0	68.1
MOD-V MG/M3-DAY	.00	95.44	.0	68.3
CHL-A / TOTAL P	.00	.40	.0	86.8
FREQ(CHL-a>10) %	.00	1.71	.0	.0
FREQ(CHL-a>20) %	.00	.06	.0	.0
FREQ(CHL-a>30) %	.00	.01	.0	.0
FREQ(CHL-a>40) %	.00	.00	.0	.0

FREQ(CHL-a>50) %	.00	.00	.0	.0
FREQ(CHL-a>60) %	.00	.00	.0	.0
CARLSON TSI-P	.00	34.44	.0	.0
CARLSON TSI-CHLA	.00	42.20	.0	.0

SEGMENT: 9 150% inputs

VARIABLE	----- VALUES ----- OBSERVED	ESTIMATED	--- RANKS (%) ---- OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	30.85	.0	31.2
CHL-A MG/M3	.00	22.69	.0	87.4
HOD-V MG/M3-DAY	.00	109.31	.0	68.1
MOD-V MG/M3-DAY	.00	95.44	.0	68.3
CHL-A / TOTAL P	.00	.74	.0	98.1
FREQ(CHL-a>10) %	.00	84.42	.0	.0
FREQ(CHL-a>20) %	.00	45.76	.0	.0
FREQ(CHL-a>30) %	.00	22.35	.0	.0
FREQ(CHL-a>40) %	.00	11.04	.0	.0
FREQ(CHL-a>50) %	.00	5.66	.0	.0
FREQ(CHL-a>60) %	.00	3.02	.0	.0
CARLSON TSI-P	.00	53.60	.0	.0
CARLSON TSI-CHLA	.00	61.23	.0	.0

SEGMENT:10 135% inputs

VARIABLE	----- VALUES ----- OBSERVED	ESTIMATED	--- RANKS (%) ---- OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	28.58	.0	28.3
CHL-A MG/M3	.00	20.29	.0	84.1
HOD-V MG/M3-DAY	.00	109.31	.0	68.1
MOD-V MG/M3-DAY	.00	95.44	.0	68.3
CHL-A / TOTAL P	.00	.71	.0	97.9
FREQ(CHL-a>10) %	.00	79.71	.0	.0
FREQ(CHL-a>20) %	.00	38.70	.0	.0
FREQ(CHL-a>30) %	.00	17.33	.0	.0
FREQ(CHL-a>40) %	.00	8.00	.0	.0
FREQ(CHL-a>50) %	.00	3.88	.0	.0
FREQ(CHL-a>60) %	.00	1.98	.0	.0
CARLSON TSI-P	.00	52.49	.0	.0
CARLSON TSI-CHLA	.00	60.13	.0	.0

SEGMENT:11 125% inputs

VARIABLE	----- VALUES ----- OBSERVED	ESTIMATED	--- RANKS (%) ---- OBSERVED	ESTIMATED
TOTAL P MG/M3	.00	27.01	.0	26.2
CHL-A MG/M3	.00	18.68	.0	81.4
HOD-V MG/M3-DAY	.00	109.31	.0	68.1
MOD-V MG/M3-DAY	.00	95.44	.0	68.3
CHL-A / TOTAL P	.00	.69	.0	97.6
FREQ(CHL-a>10) %	.00	75.75	.0	.0
FREQ(CHL-a>20) %	.00	33.73	.0	.0
FREQ(CHL-a>30) %	.00	14.14	.0	.0
FREQ(CHL-a>40) %	.00	6.20	.0	.0

```
FREQ(CHL-a>50) %       .00      2.89        .0        .0
FREQ(CHL-a>60) %       .00      1.42        .0        .0
CARLSON TSI-P          .00     51.68        .0        .0
CARLSON TSI-CHLA       .00     59.32        .0        .0
----------------------------------------------------------

SEGMENT:12 115% inputs
                  ----- VALUES -----  --- RANKS (%) ----
VARIABLE          OBSERVED ESTIMATED  OBSERVED ESTIMATED
----------------------------------------------------------
TOTAL P    MG/M3       .00     25.40        .0      24.0
CHL-A      MG/M3       .00     17.08        .0      78.1
HOD-V  MG/M3-DAY       .00    109.31        .0      68.1
MOD-V  MG/M3-DAY       .00     95.44        .0      68.3
CHL-A / TOTAL P        .00       .67        .0      97.4
FREQ(CHL-a>10) %       .00     71.01        .0        .0
FREQ(CHL-a>20) %       .00     28.62        .0        .0
FREQ(CHL-a>30) %       .00     11.15        .0        .0
FREQ(CHL-a>40) %       .00      4.62        .0        .0
FREQ(CHL-a>50) %       .00      2.06        .0        .0
FREQ(CHL-a>60) %       .00       .97        .0        .0
CARLSON TSI-P          .00     50.79        .0        .0
CARLSON TSI-CHLA       .00     58.44        .0        .0
----------------------------------------------------------

SEGMENT:13 105% Inputs
                  ----- VALUES -----  --- RANKS (%) ----
VARIABLE          OBSERVED ESTIMATED  OBSERVED ESTIMATED
----------------------------------------------------------
TOTAL P    MG/M3       .00     23.74        .0      21.8
CHL-A      MG/M3       .00     15.48        .0      74.2
HOD-V  MG/M3-DAY       .00    109.31        .0      68.1
MOD-V  MG/M3-DAY       .00     95.44        .0      68.3
CHL-A / TOTAL P        .00       .65        .0      97.1
FREQ(CHL-a>10) %       .00     65.36        .0        .0
FREQ(CHL-a>20) %       .00     23.48        .0        .0
FREQ(CHL-a>30) %       .00      8.42        .0        .0
FREQ(CHL-a>40) %       .00      3.28        .0        .0
FREQ(CHL-a>50) %       .00      1.39        .0        .0
FREQ(CHL-a>60) %       .00       .63        .0        .0
CARLSON TSI-P          .00     49.82        .0        .0
CARLSON TSI-CHLA       .00     57.48        .0        .0
----------------------------------------------------------

SEGMENT:14 AREA-WTD MEAN
                  ----- VALUES -----  --- RANKS (%) ----
VARIABLE          OBSERVED ESTIMATED  OBSERVED ESTIMATED
----------------------------------------------------------
TOTAL P    MG/M3     24.78     19.87      23.2      16.4
TOTAL N    MG/M3    899.18    899.18      43.3      43.3
C.NUTRIENT MG/M3     23.03     21.50      29.2      26.3
CHL-A      MG/M3     14.76     12.62      72.2      65.0
SECCHI         M      1.52      1.52      67.4      67.5
ORGANIC N  MG/M3    414.32    513.50      39.6      56.2
TP-ORTHO-P MG/M3     21.96     28.88      37.1      48.4
HOD-V  MG/M3-DAY    248.00    109.31      94.2      68.1
MOD-V  MG/M3-DAY    193.00     95.44      92.9      68.3
```

ANTILOG PC-1	197.40	187.52	43.4	41.9
ANTILOG PC-2	11.83	11.18	87.7	85.4
(N - 150) / P	30.23	37.70	80.1	87.9
INORGANIC N / P	171.94	385.68	96.1	99.5
TURBIDITY 1/M	.02	.02	.0	.0
ZMIX * TURBIDITY	.12	.12	.0	.0
ZMIX / SECCHI	3.62	3.61	31.7	31.6
CHL-A * SECCHI	22.44	19.24	86.7	81.5
CHL-A / TOTAL P	.60	.64	96.0	96.8
FREQ(CHL-a>10) %	62.48	52.62	.0	.0
FREQ(CHL-a>20) %	21.18	14.62	.0	.0
FREQ(CHL-a>30) %	7.30	4.39	.0	.0
FREQ(CHL-a>40) %	2.76	1.50	.0	.0
FREQ(CHL-a>50) %	1.14	.57	.0	.0
FREQ(CHL-a>60) %	.51	.24	.0	.0
CARLSON TSI-P	50.44	47.26	.0	.0
CARLSON TSI-CHLA	57.01	55.47	.0	.0
CARLSON TSI-SEC	53.97	53.92	.0	.0

Appendix G: Algae/Zooplankton

Algae, Zooplankton, and Taste and Odor events of Eucha, Spavinaw and Yahola Lakes

Ann St. Amand, Ph.D.

PhycoTech

620 Broad Street, Suite 100
St. Joseph, MI 49085
Tel: 616-983-3654
Fax: 616-983-3653

21 March, 2001

Introduction

Algal and zooplankton data provide unique and valuable insights into lake water quality and potential increasing or decreasing trends in water quality. In circumstances where the algae are directly affecting taste and odor issues within a potable water supply, species level data is paramount to determining what specific management practices might resolve the problems. Zooplankton data gives insights into what is driving the algal communities to bloom and bust and vice versa, as well as giving information about potential effects on food resources for the fish community.

The following report provides data analysis for the algae and zooplankton communities for Eucha, Spavinaw and Yahola Lakes in Oklahoma. In addition, chemical data for Geosmin and MIB, both taste and odor compounds, and Chlorophyll a were analyzed to determine if specific algal blooms could be linked to specific taste and odor events. A literature search pertaining to taste and odor was completed as well and is appended to the end of this report.

Methodology

Phytoplankton samples were collected on site and sent to PhycoTech for analysis. Zooplankton samples were collected on site and sent to BSA, Inc. for analysis. Oklahoma Water Resources Board forwarded the final zooplankton data files, as well as data files containing chlorophyll a, chemical analysis, customer complaints and data pertaining to limnological information to PhycoTech.

PhycoTech uses a permanent mounting technique for preparing algal samples for counting. The HPMA method for producing algal sample slides provides an optically clear background while permanently infiltrating and preserving the sample for archival purposes (See Crumpton, 1997, St. Amand, 1990). Mounting distortion is minimal and the method provides the advantage of being able to go 100x to 1000x on the same specimen. Wet sample is always maintained in case clarification of identification is necessary.

Algae was counted to a minimum of 400 natural units and 15 fields at 400x (when possible, maximum of 100 fields) on an Olympus BHT compound microscope. In addition, taxa above 20-30 μm in GALD were counted at 200x (minimum of 15 fields). The number of fields counted was spread evenly over the three slides provided for each sample (i.e. 30 total fields, 10 fields per slide). Counting was completed when the standard error of the mean of the total number of natural units per field is less than

10%. This tiered counting method yielded a minimum of 400 natural units per sample (well over 400 cells per sample). Data was then entered into PHYCO, PhycoTech’s custom data management software and proofed by a QA/QC technician. 1998 and part of 1999 data was counted originally at the genus level and then converted to species counts while the rest of 1999 and 2000 were counted to the species level.

Data Analysis

Data was exported from PHYCO into ASCII files and then imported into Systat 9, which was used for data manipulation and for graphing. Data files from the Oklahoma Water Resources Board were provided in either Excel or Access format and then converted to Systat format for graphing and data analysis.

Ecological data was analyzed initially to determine the general pattern of algal growth over the three-year period (1998-2000). Total algal abundance and biovolume patterns were determined first, followed by the general pattern of algal division seasonal succession within each lake. When flow from station to station was analyzed, we generally tried to follow the pattern of flow within the specific lake (i.e. EUC03 to EUC01, SPA05 to SPA01). Eucha data appears first, then Spavinaw data, then Yahola data; this also coincides with flow from one lake to the next. Once it was determined which algal divisions were important and either impacted water quality significantly or were associated with taste and odor events, certain species were targeted for individual analysis. Species were analyzed if they satisfied one of three criteria: they potentially could impact water quality or were important ecologically, they were potentially associated with a taste and odor event, or they were a documented taste and odor chemical producer.

Chlorophyll a and TSI (Trophic State Index) analysis appears after the algal data analysis. The data was analyzed first in Eucha, then Spavinaw and lastly Yahola.

Zooplankton data analysis followed the same general progression as algal data analysis. Total zooplankton abundance and percent biomass of important groups was analyzed for each lake, going from the upper station to the terminal station in the lake. Species were chosen for individual analysis based on potential ecological importance and high enough densities for seasonal analysis.

Taste and odor chemical data (Geosmin and MIB) were analyzed following all ecological data. Data was provided for several stations within each lake, isolated distribution points and raw and finished water at the Mohawk Water Treatment Plant. Species data was then analyzed in light of the taste and odor data, where several taxa have been implicated in likely causing or contributing substantially to taste and odor events within the lakes and at the Mohawk Water Treatment Plant.

Total Algal Abundances and Biovolume

Eucha:

Total abundances were highest at EUC03 and EUC16, the first and second stations in the reservoir (see Figures 1 and 2). Total abundances peaked at both EUC03 and EUC16 in July 1999, exceeding $1.5x10^6$ natural units/ml. Generally, EUC03 and EUC16 showed the highest abundances of the year during the summer months from late May to mid October. Although stations EUC02 and EUC01 did not experience the high peaks in abundance during July 1999, there were still significant algal communities blooming during the summer months of both 1998 and 1999 (See Figures 3 and 4). At all four stations (EUC03, EUC16, EUC02, EUC01), abundances during the summer months in both 1998 and 1999 exceeded numbers associated with eutrophic conditions (15,000 cells/ml). Replicate samples were taken consistently following August 1998 at the depth of the Chlorophyll a maximum. These samples were referred to as peak samples and are indicated as Replicate 2 in the date set (hatched bar on Figures 1-4). Abundances at the Chlorophyll a maximum were often, but not always, higher than at the surface. This reflects the presence of detrital Chlorophyll at depth and is the result of decaying cells and pigment filtering down through the water column.

Total Biovolume most closely tracked abundance at EUC03 (see Figure 1), with the highest biovolume observed during the summer months in 1998 and 1999. Although there is also some decrease in standing biovolume during the late fall and early winter at EUC16, EUC02 and EUC01, the pattern is not as well defined as for EUC03. Therefore, for EUC16, EUC02, and EUC01, the biovolume is more consistent throughout the year, weighted by fewer, larger individuals during the fall and winter. The highest biovolume was observed in EUC02 and EUC01 in June, 1999 exceeding 5×10^7 μm^3 /ml (see Figures 3 and 4, respectively). Biovolume in EUC02 and EUC01 also tended to be higher during the summer months of 1999. Part of the late summer bloom at EUC02 and EUC02 was fueled by algae blooming upstream and then flowing toward the dam at EUC01. The biovolume at the Chlorophyll a maximum followed the same pattern as abundance, but was even more pronounced. Biovolume at the maximum often lagged well behind the biovolume at the surface. Again, this reflects the presence of detrital Chlorophyll at depth and is the result of decaying cells and pigment filtering down through the water column, although there is a resident “metalimnetic” community most commonly dominated by Merismopedia tenuissima and other taxa blooming at the surface.

Algal data generally agree with Chlorophyll a data. Chlorophyll a more closely tracks biovolume than abundance. Chlorophyll a peaks often coincided with biovolume peaks as on 6/9/99 at EUC01, where a Chlorophyll a concentration of 88.49 ug/l was observed. There were several missing dates for pigment data, so exact correlations with biovolume and abundance data are not possible. Sometimes Chlorophyll a data will not coincide well with algal data because of the mix of different pigments in different algal divisions (e.g. Phycoerythrin and Alloxanthin, present in large concentrations in Blue-green and Cryptophyte algae, respective). As in the Chlorophyll a data, although there were specific date differences, the stations are not significantly different for total abundance or biovolume. As indicated by the Chlorophyll a data, the algal data also shows significantly greater standing abundance and biovolume in 1999 versus 1998 for Eucha (See Figure 5).

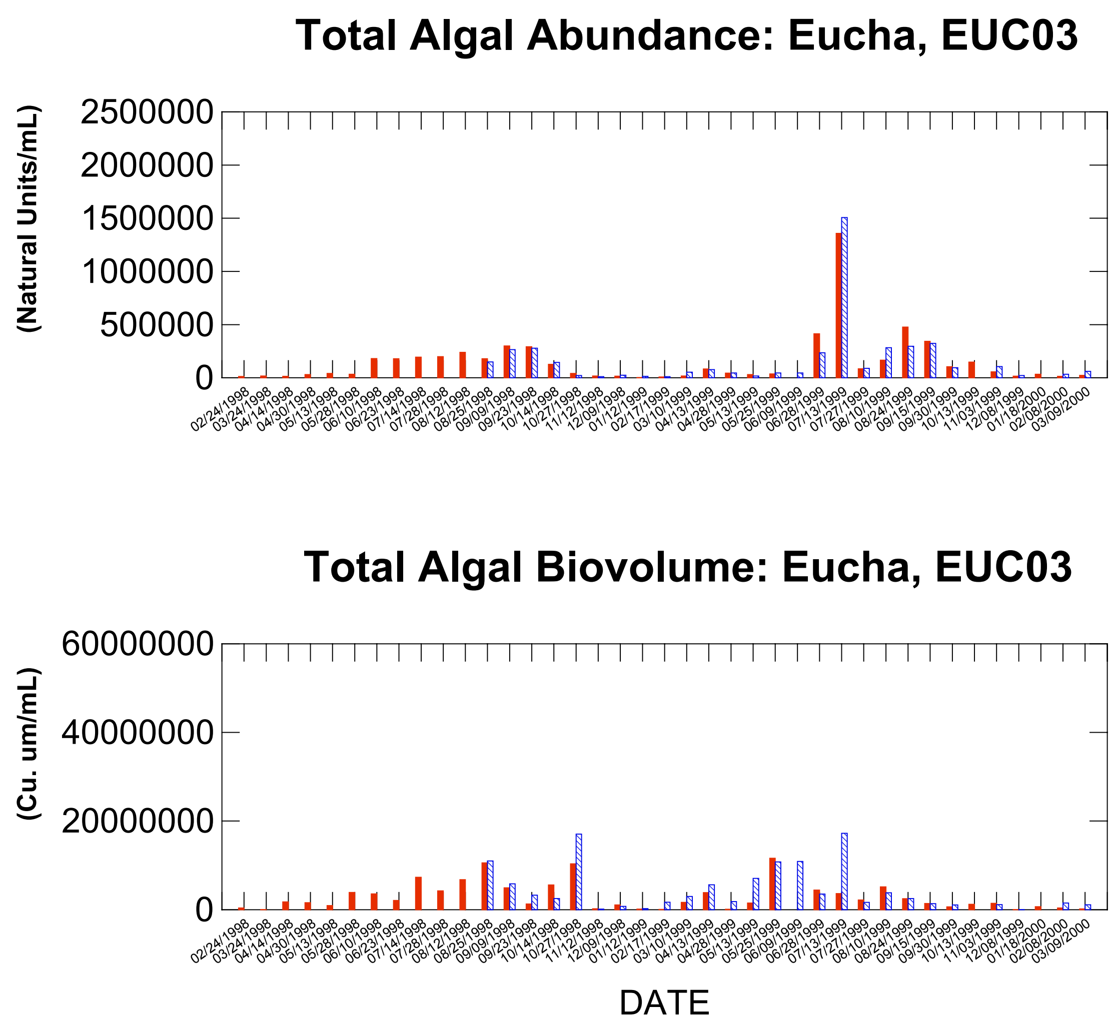


Figure 3: Total Algal Abundance and Biovolume for Lake Eucha, Station 03.
Solid red surface and hatched blue is peak chlorophyll a.

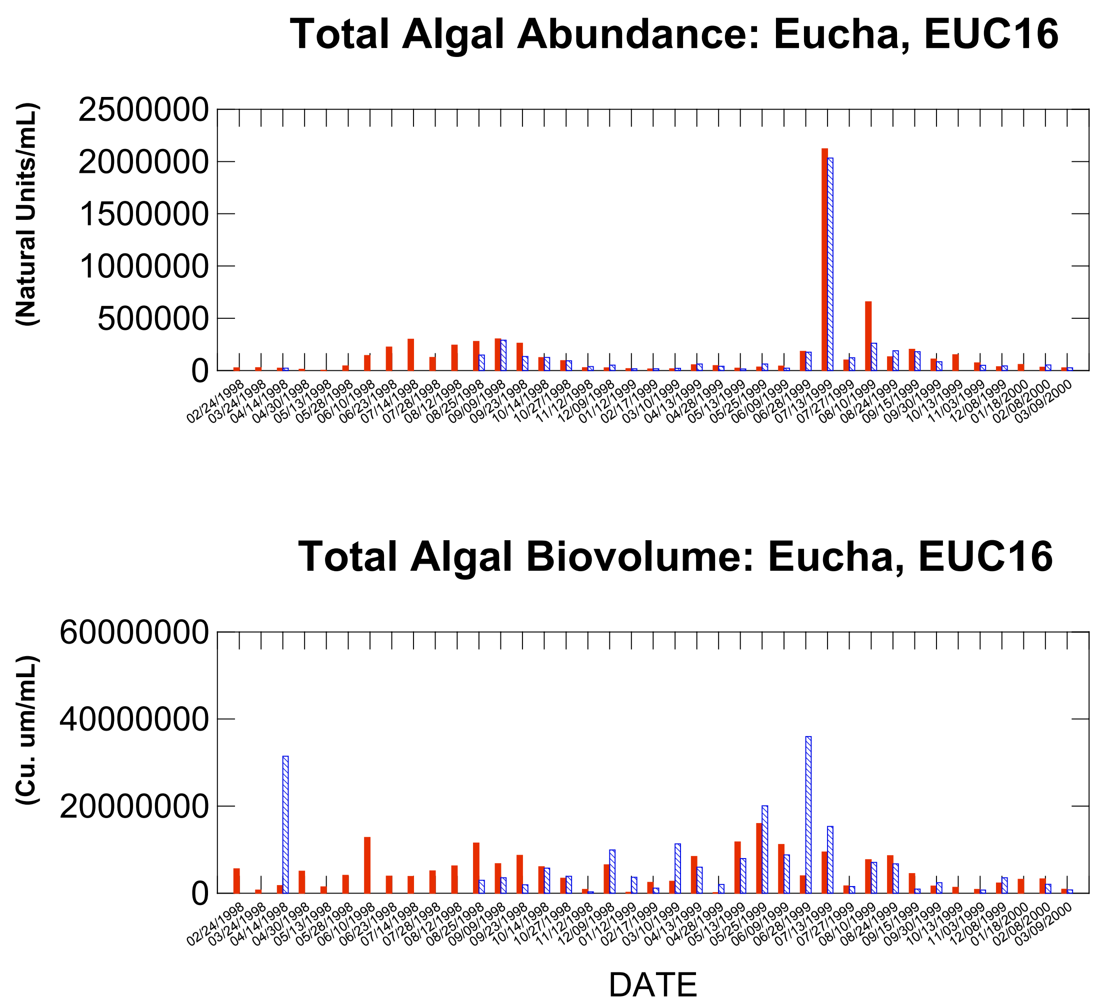
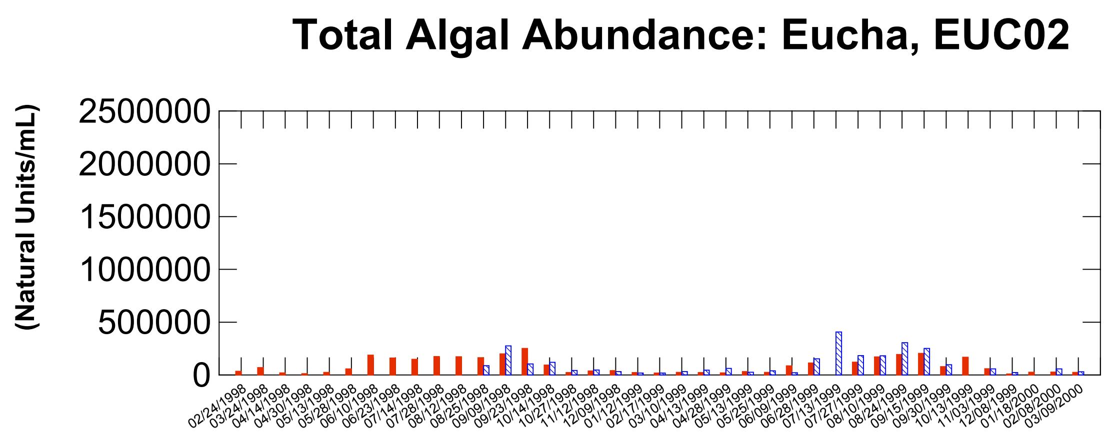


Figure 4: Total Algal Abundance and Biovolume for Lake Eucha, Station 16.
Solid red is surface and hatched blue is peak chlorophyll a



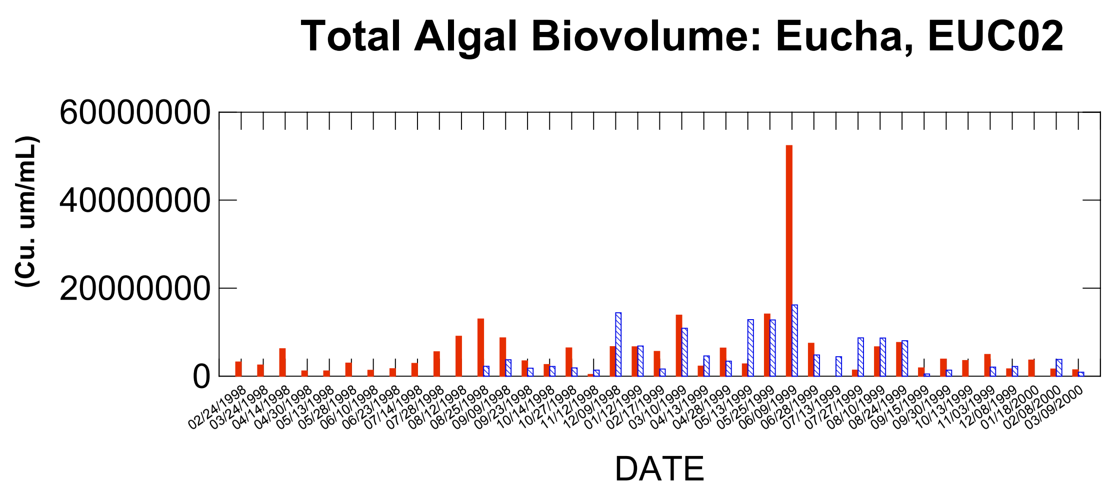
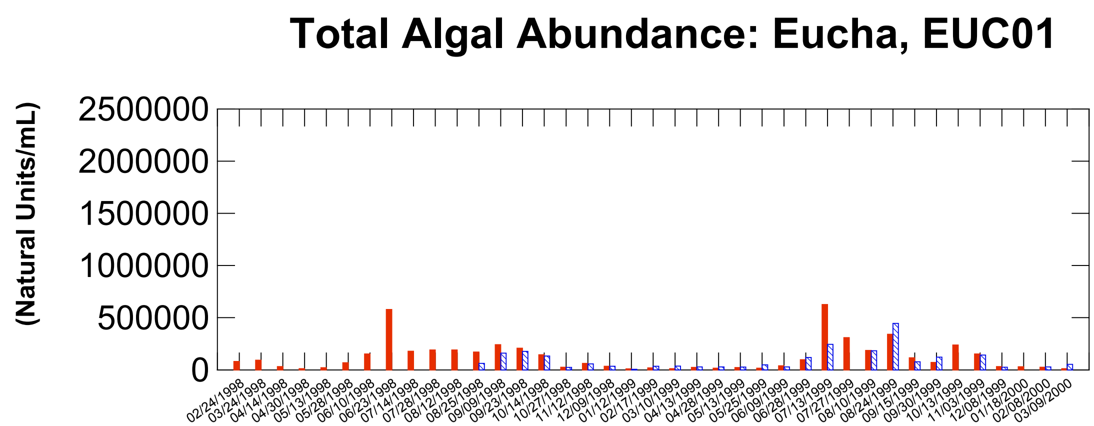


Figure 5: Total Algal Abundance and Biovolume for Lake Eucha, Station 02.
Solid red is surface and hatched blue is peak chlorophyll a.



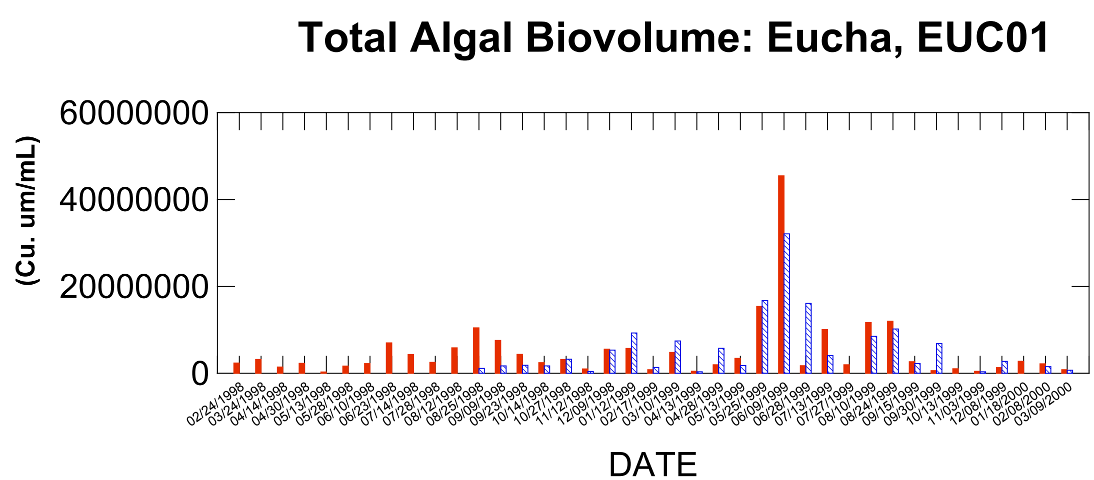


Figure 6: Total Algal Abundance and Biovolume for Lake Eucha, Station 01.
Solid red is surface and hatched blue is peak chlorophyll a.

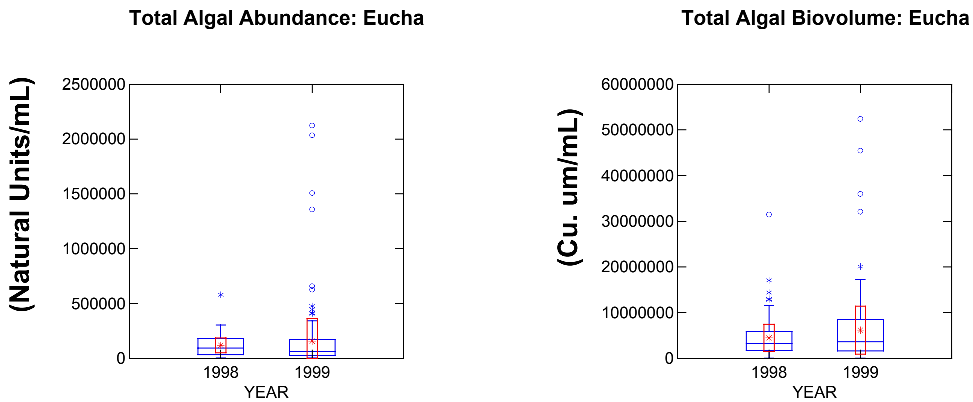


Figure 7: Box plot for Eucha Lake indicating the median totals for abundance and biovolume by year.

Asterisks are out of range points and open circles are significantly out of range of median.
Red box shows standard error about the mean (red asterisk).

Spavinaw:

Spavinaw Lake receives most of its water via the dam outlet of Eucha Lake which then flows into Spavinaw Lake via the Spavinaw creek. Despite the constant supply of algae from Eucha, Spavinaw total abundance was significantly lower than in Eucha., sometimes exceeding only $2x10^5$ natural units/ml, while algal communities in Eucha often exceeded $5x10^5$ natural units/ml (See Figures 6, 7, 8 for SPA05, SPA02, and SPA01, respectively). Abundances, while lower than in Eucha, are still considered eutrophic, exceeding the $1.5x10^4$ cell/ml threshold during the summer and often into fall and winter. Abundances at SPA01 did not peak as high as at SPA05 and SPA02, but remained high for a longer period of time, especially in 1999. Abundances in 1999 were generally higher than in 1998. The pattern of the chlorophyll a maximum samples was the same as in Eucha, often, but not always higher than at the surface. Abundance patterns were well pronounced over the year, highest in the summer months and lower during late fall and winter.

The total biovolume pattern was somewhat similar to Eucha. Consistent with abundance, biovolume was not as high in Spavinaw as in Eucha. There were not the pronounced peaks occasionally during the summer months as in Eucha, however the biomass was more consistent throughout the year. This pattern was apparent at SP05, SPA02 and SPA 01. The primary difference, in addition to lower biovolume peaks, was the increase in total biovolume in early 2000 at all three Spavinaw stations. This small, but obvious increase was not present in early 2000 in Eucha. Also, the three Spavinaw stations were more consistent than the four Eucha stations.

Algal data generally agree with Chlorophyll a data. Chlorophyll a more closely tracks biovolume than abundance. Chlorophyll a peaks often coincided with biovolume peaks in June and July 1999 at SPA01, where Chlorophyll a rarely exceeded 30 ug/l. There were several missing dates for pigment data, so exact correlations with biovolume and abundance data are not possible. Sometimes Chlorophyll a data will not coincide well with algal data because of the mix of different pigments in different algal divisions (e.g. Phycoerythrin and Alloxanthin, present in large concentrations in Blue-green and Cryptophyte algae, respectively). As in the Chlorophyll a data, although there were specific date differences, the stations were not significantly different for total abundance or biovolume. As indicated by the Chlorophyll a data, the algal data also showed significantly greater abundance and standing biovolume in 1999 versus 1998 for Spavinaw (See Figure 9).

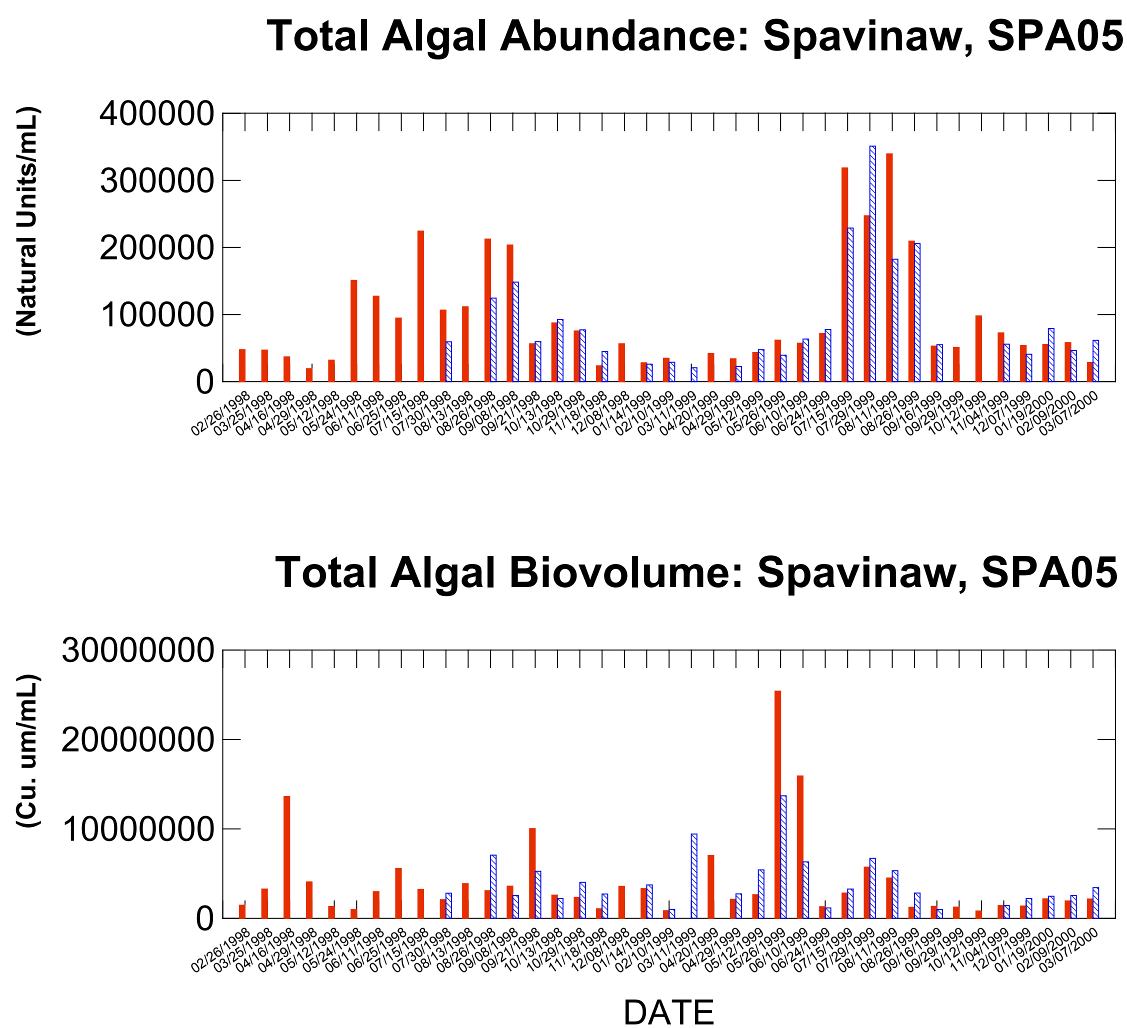


Figure 8: Total Algal Abundance and Biovolume for Spavinaw Lake, Station 05.
Solid red is surface and hatched blue is peak chlorophyll a.

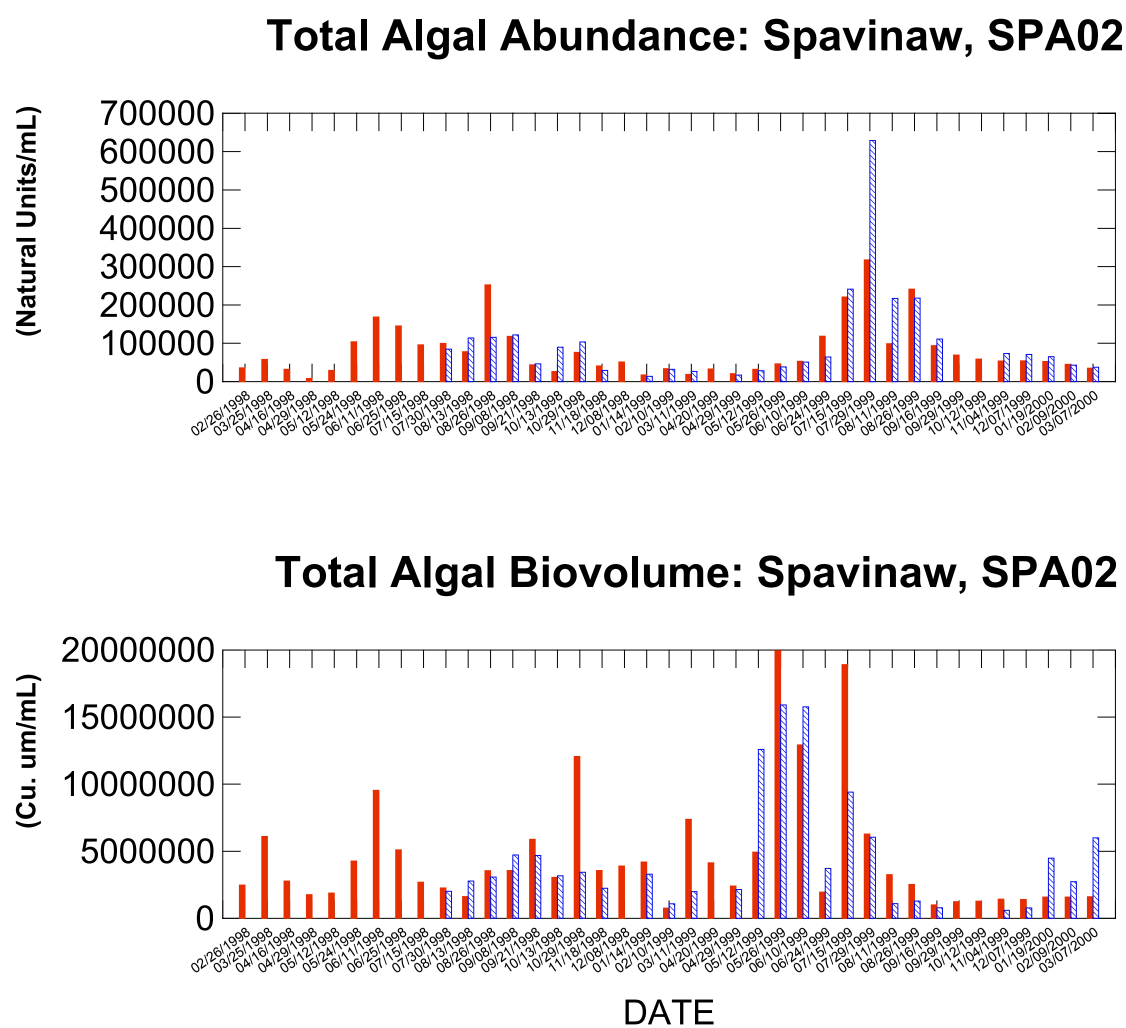


Figure 9: Total Algal Abundance and Biovolume for Spavinaw Lake, Station 02.
Solid red is surface and hatched blue is peak chlorophyll a.

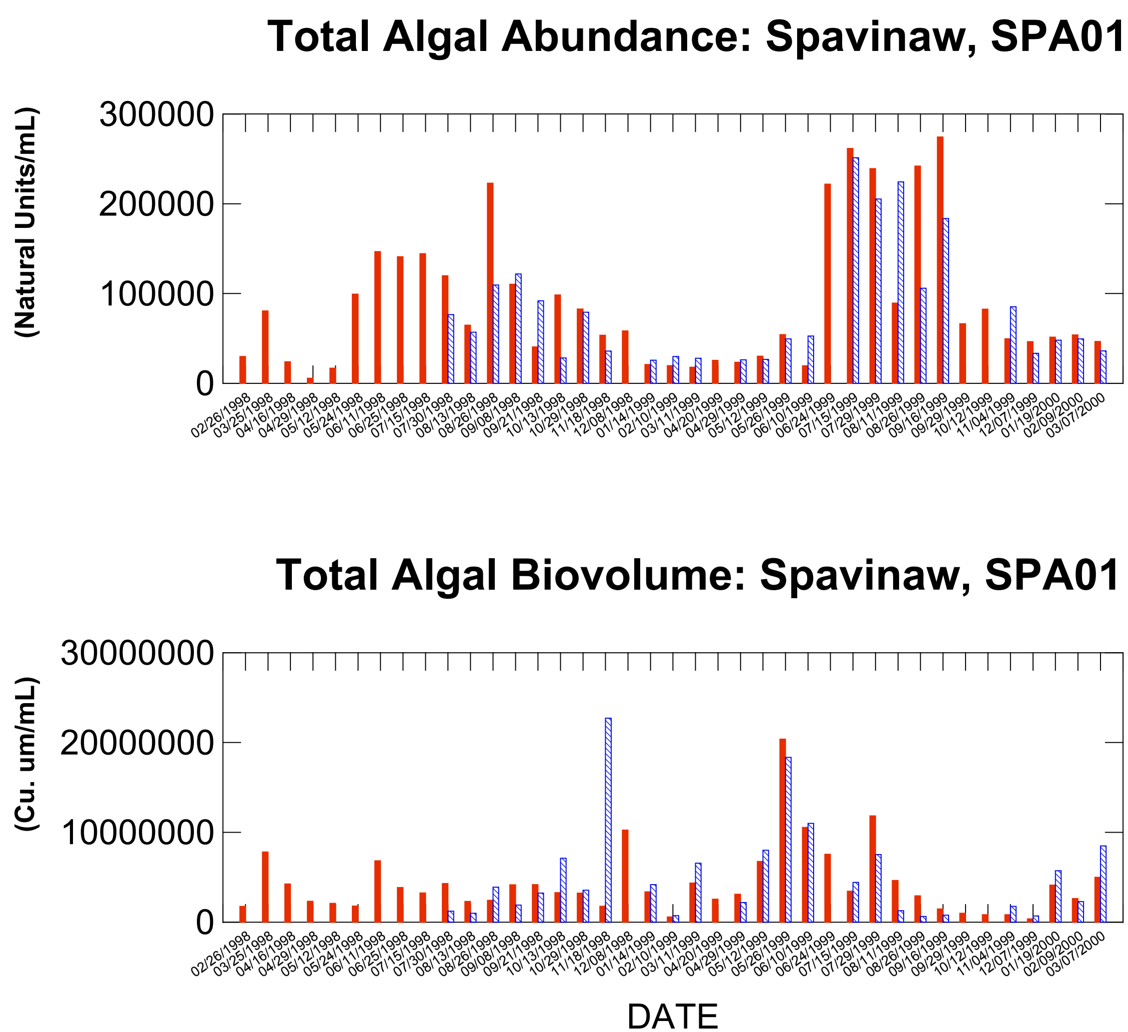


Figure 10: Total Algal Abundance and Biovolume for Spavinaw Lake, Station 01.
Solid red is surface and hatched blue is peak chlorophyll a.

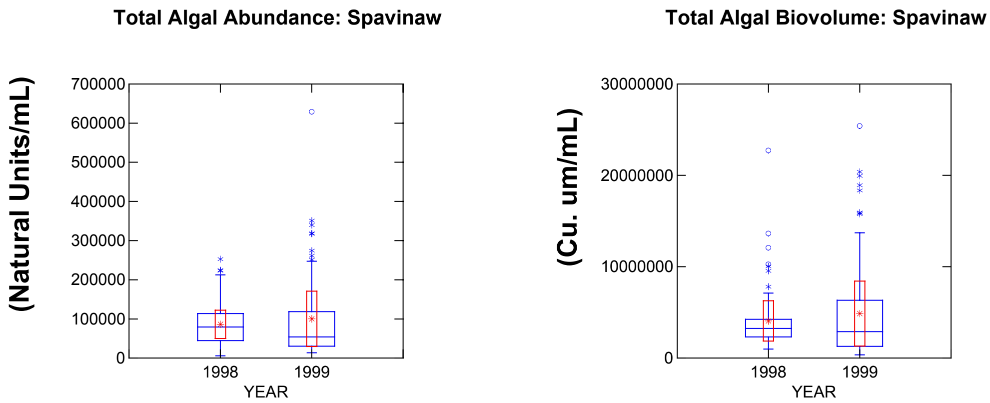


Figure 11: Box plot for Spavinaw Lake indicating median totals for abundance and biovolume by year. Asterisks are out of range data points and open circles are significantly out of range of median.The red box shows standard error about the mean (red asterisk)

Yahola:

Data for Lake Yahola, the terminal reservoir for Spavinaw Lake flow, is much sparser than that for Eucha and Spavinaw. There was only one station (1-1), no sampling at the Chlorophyll a peak, and data only spanned 1999 and 2000. Abundance and data indicate a similar seasonal pattern to the other two reservoirs, higher in the summer, lower in late fall and winter (See Figure 10). Biovolume indicated a more prolonged summer bloom, into September 1999, with winter biomass at its lowest in March, 2000. Again, as in the other two reservoirs, abundances are above the threshold for a eutrophic system.

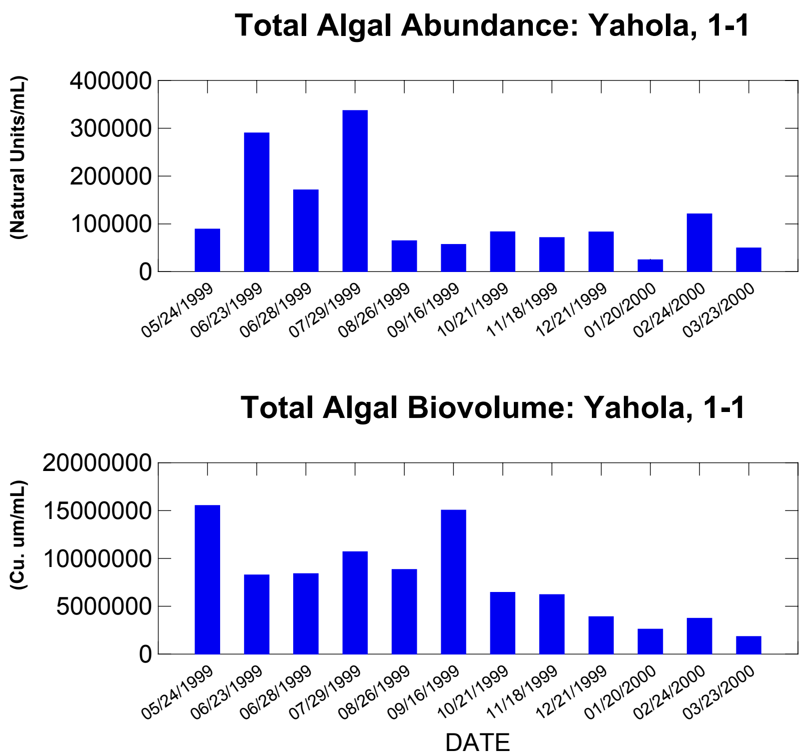


Figure 12: Total Algal Abundance and Biovolume for Yahola Lake, Station 1-1.
Solid red is surface.

Algal Division Abundances and Biovolumes

Eucha-Abundance:

Generally, most dates were dominated numerically by blue-green algae (Cyanophytes) in the surface samples, especially in summer 1998 and 1999 (see Figures 11-14, upper panels). Exceptions are winter, where other groups such a Diatoms (up to 70%) and to a lesser extent, Chrysophytes and Cryptophytes comprised from 10-20% of the assemblage. In early summer in 1999, green algae (Chlorophytes) dominated on one date, 6/28/99.

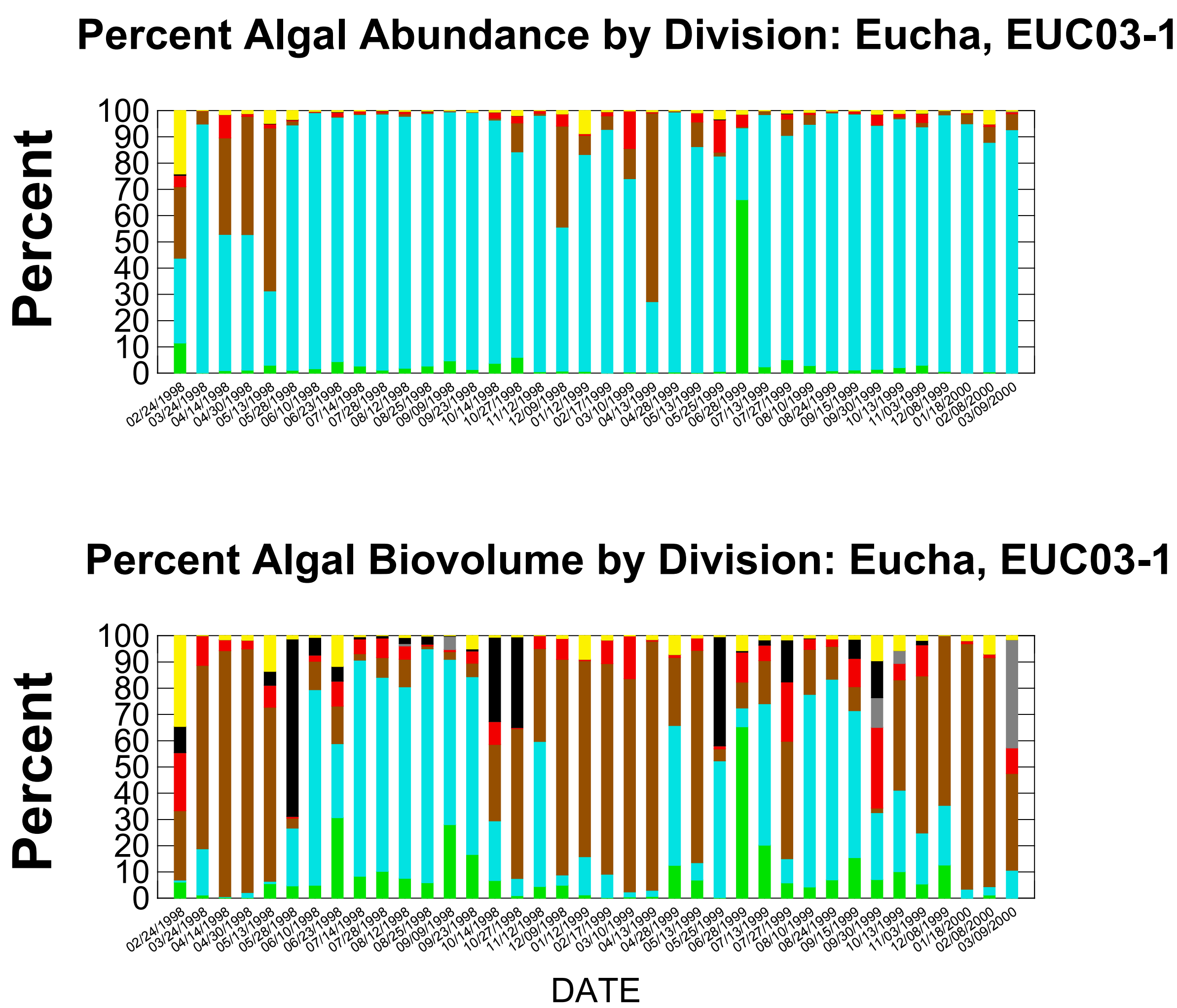


Figure 13: Percent Algal Abundance and Biovolume by Division for Eucha Lake, EUC03, Replicate 1 (surface sample). Colors are as follows: Chlorophytes-green, Cyanophytes-blue, Diatoms-brown, Cryptophytes-red, Euglenophytes-gray,Dinoflagellates-black, and Chrysophytes-yellow.

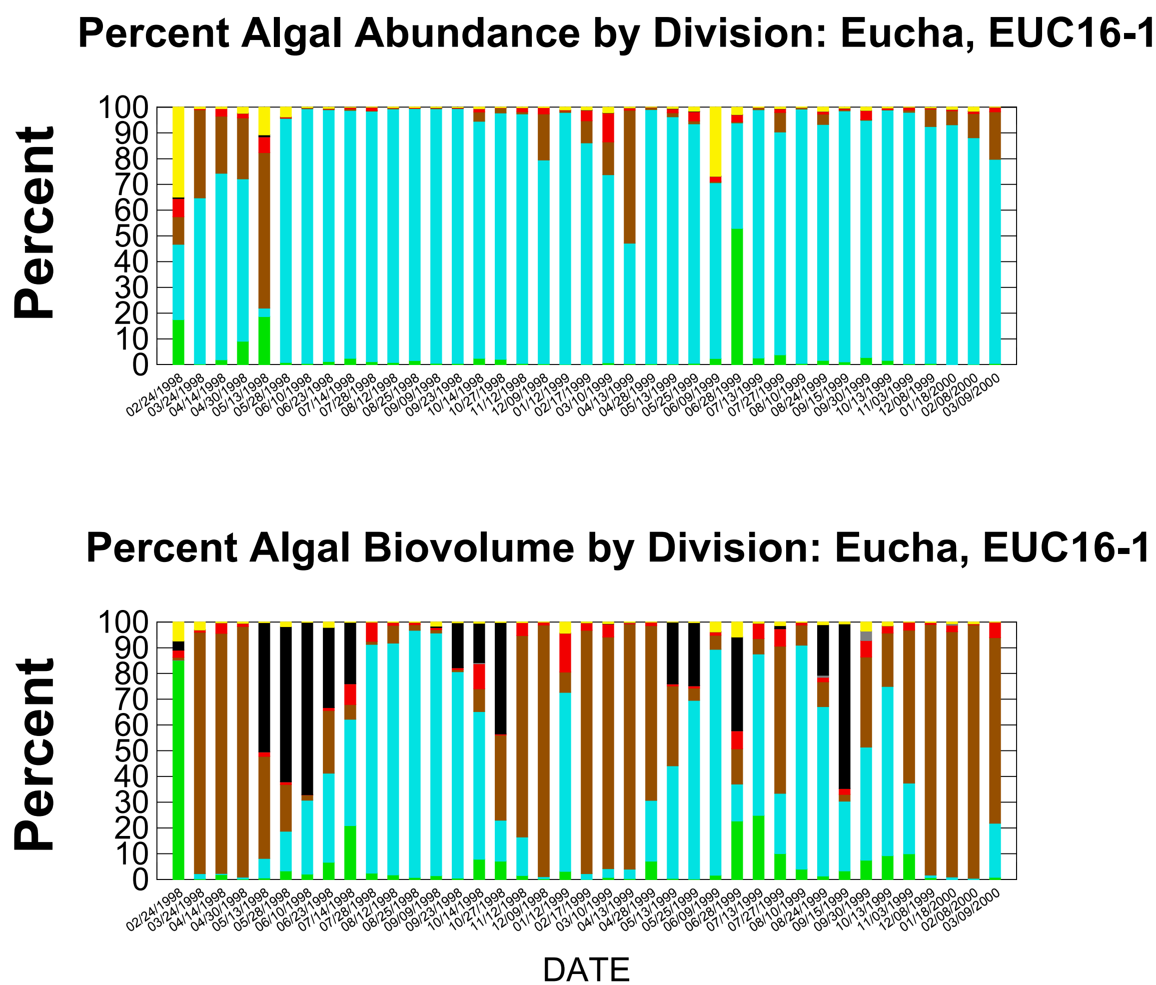
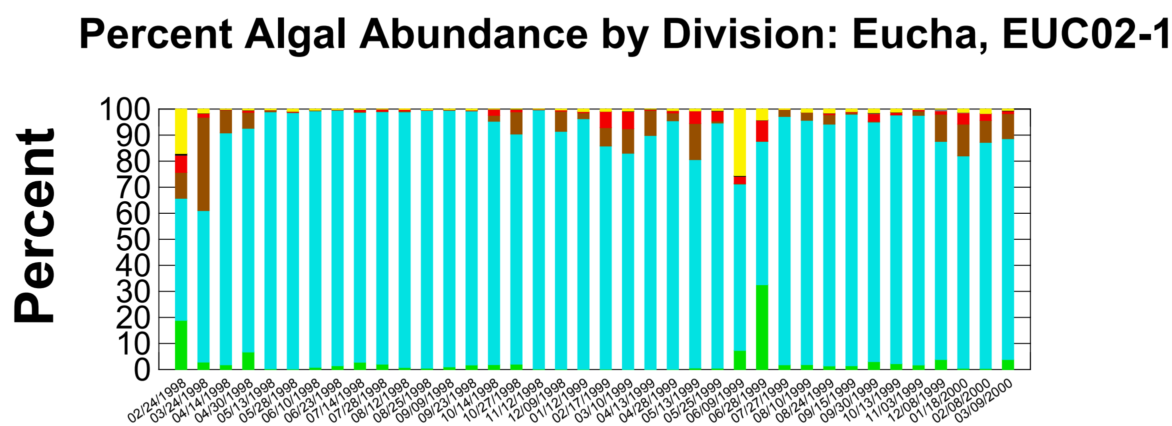


Figure 14: Percent Algal Abundance and Biovolume by Division for Eucha Lake, EUC16, Replicate 1 (surface sample). Colors are as follows: Chlorophytes-green, Cyanophytes-blue, Diatoms-brown, Cryptophytes-red, Euglenophytes-gray,Dinoflagellates-black, and Chrysophytes-yellow



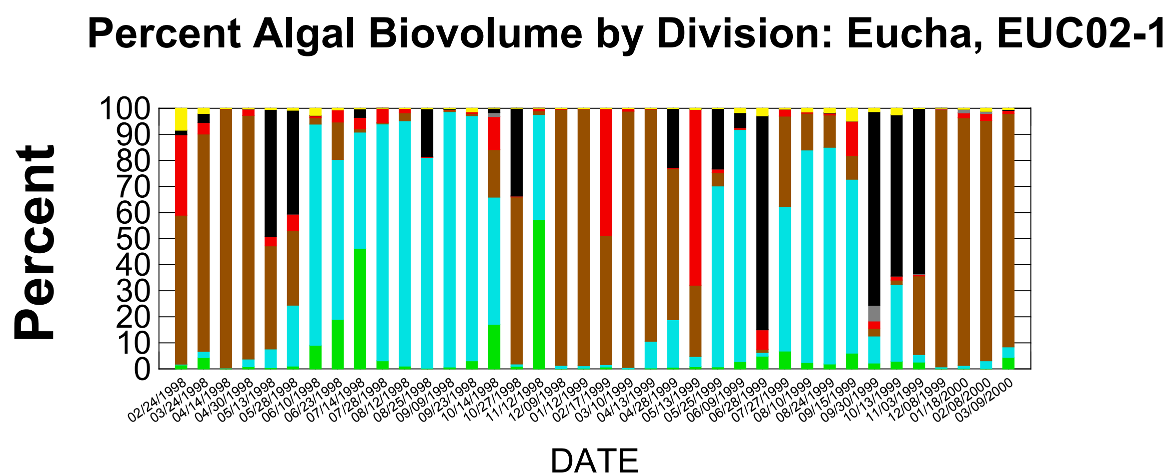
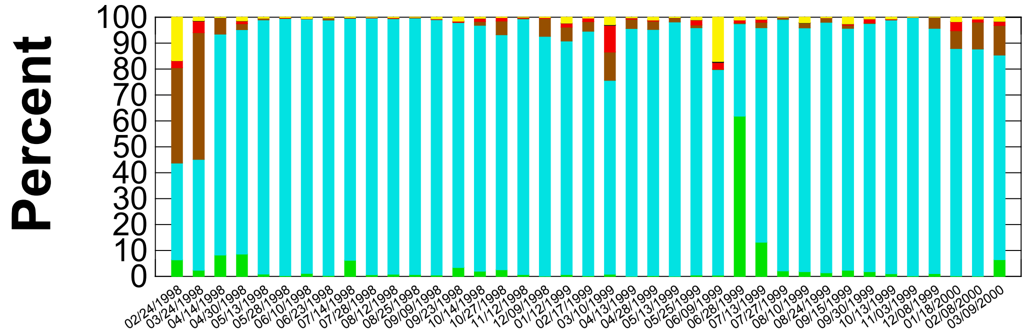


Figure 15: Percent Algal Abundance and Biovolume by Division for Eucha Lake, EUC02, Replicate 1 (surface sample). Colors are as follows: Chlorophytes-green, Cyanophytes-blue, Diatoms-brown, Cryptophytes-red, Euglenophytes-gray, Dinoflagellates-black, and Chrysophytes-yellow

Percent Algal Abundance by Division: Eucha, EUC01-1



Percent Algal Biovolume by Division: Eucha, EUC01-1

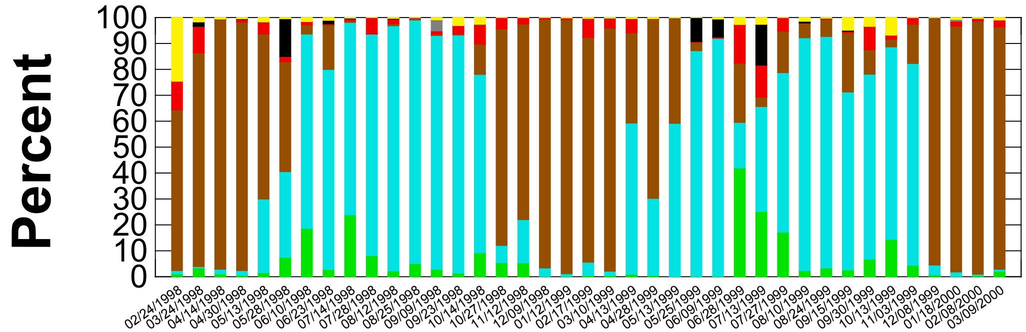
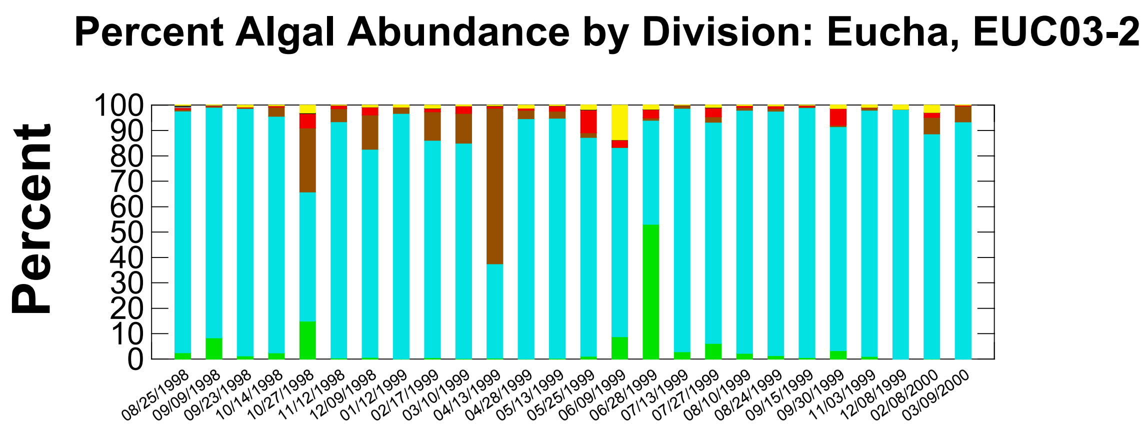


Figure 16: Percent Algal Abundance and Biovolume by Division for Eucha Lake, EUC01, Replicate 1 (surface sample). Colors are as follows: Chlorophytes-green, Cyanophytes-blue, Diatoms-brown, Cryptophytes-red, Euglenophytes-gray, Dinoflagellates-black, and Chrysophytes-yellow

More data is available for the surface samples, than for the Chlorophyll a peak depths; however, the patterns for depth samples tended more towards numerical dominance by blue-greens than at the surface (see Figures 15-18, upper panels). Diatoms were still important numerically, but less than at the surface. Cryptophytes and Chrysophytes were significantly less important than at the surface, comprising less than 10% of the assemblage at depth. Particulates were more concentrated at depth as well.



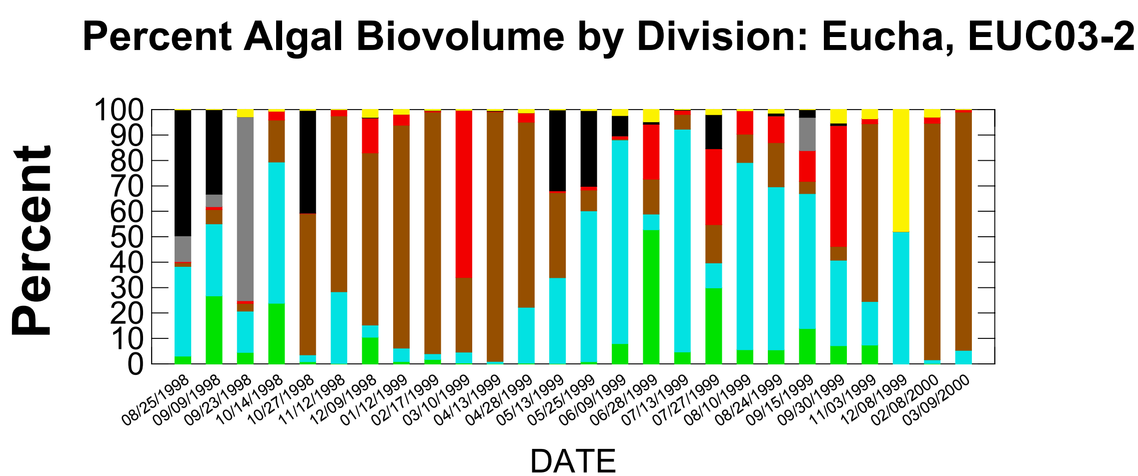


Figure 17: Percent Algal Abundance and Biovolume by Division for Eucha Lake, EUC03, Replicate 2 (surface sample). Colors are as follows: Chlorophytes-green, Cyanophytes-blue, Diatoms-brown, Cryptophytes-red, Euglenophytes-gray, Dinoflagellates-black, and Chrysophytes-yellow

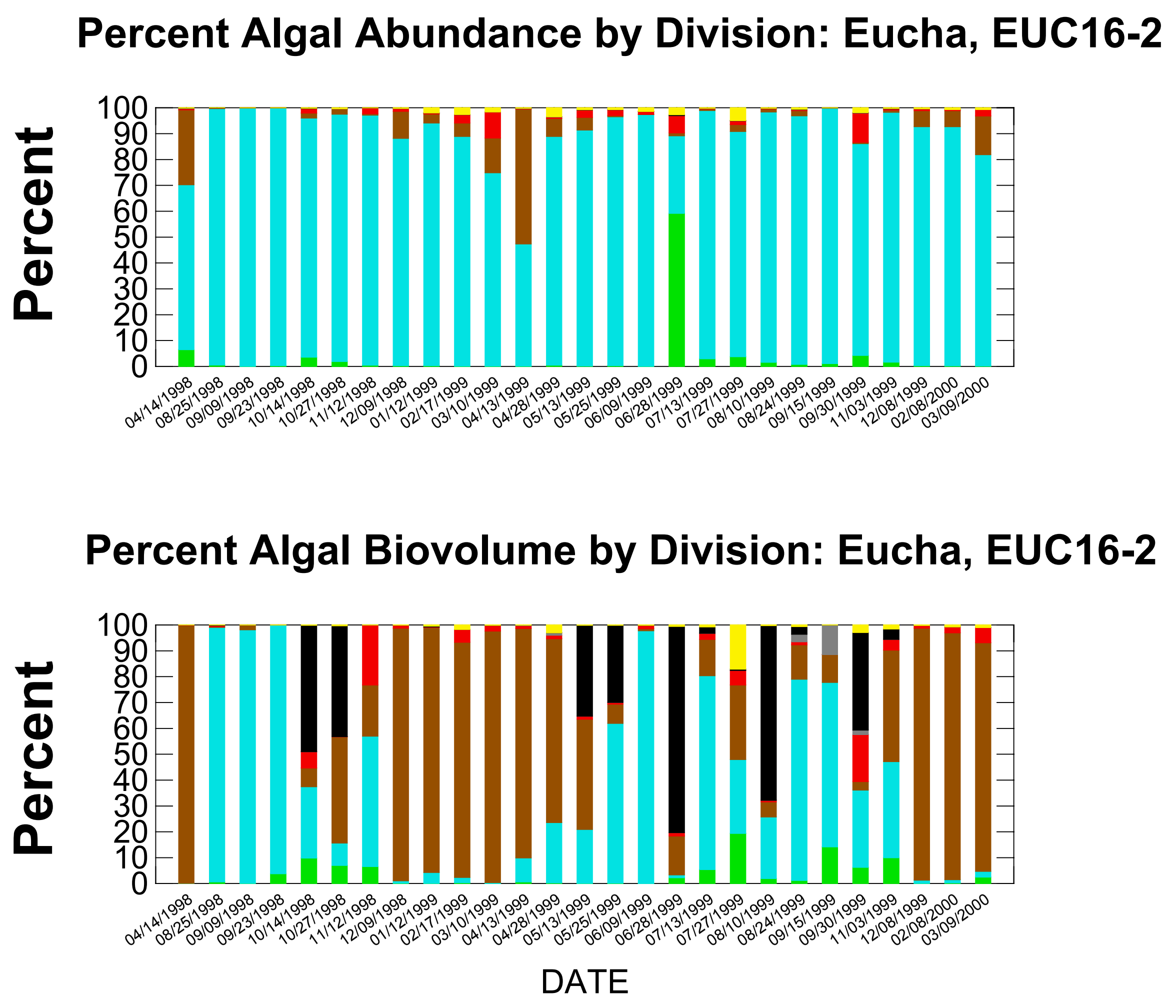
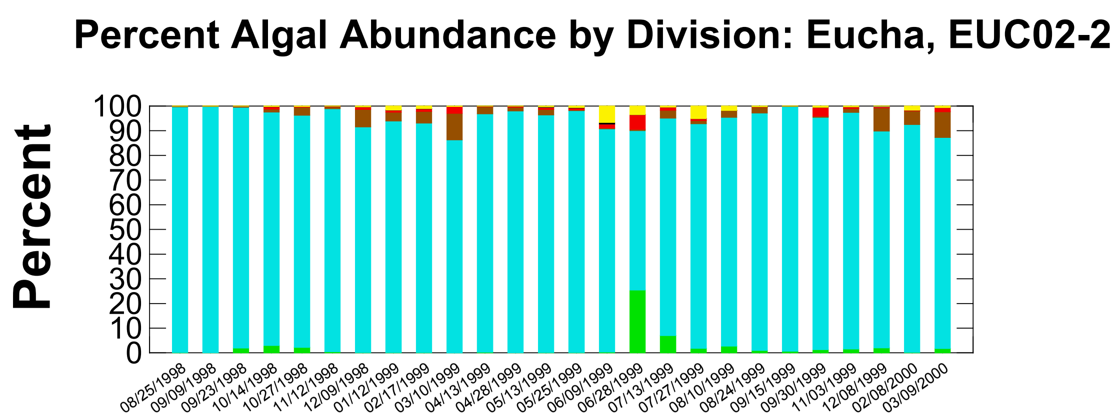


Figure 18: Percent Algal Abundance and Biovolume by Division for Eucha Lake, EUC16, Replicate 2 (surface sample). Colors are as follows: Chlorophytes-green, Cyanophytes-blue, Diatoms-brown, Cryptophytes-red, Euglenophytes-gray, Dinoflagellates-black, and Chrysophytes-yellow



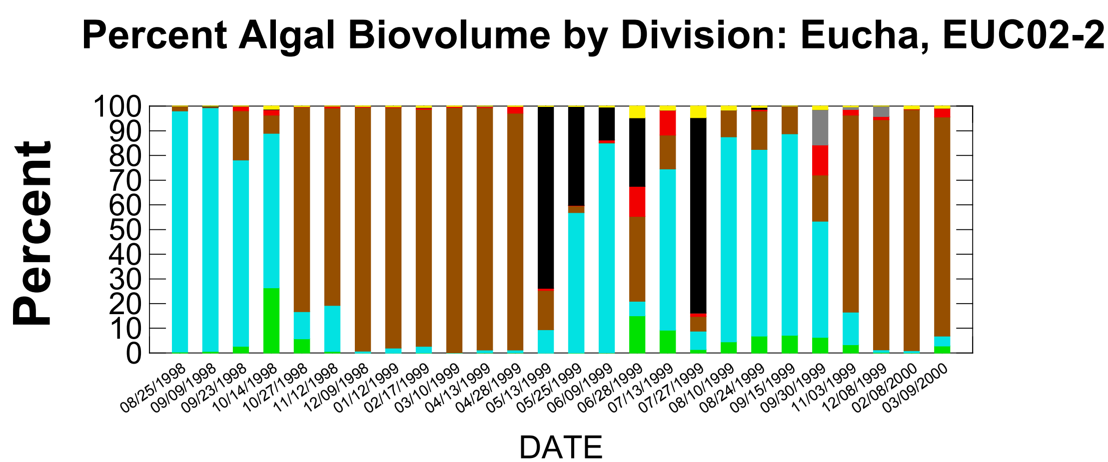
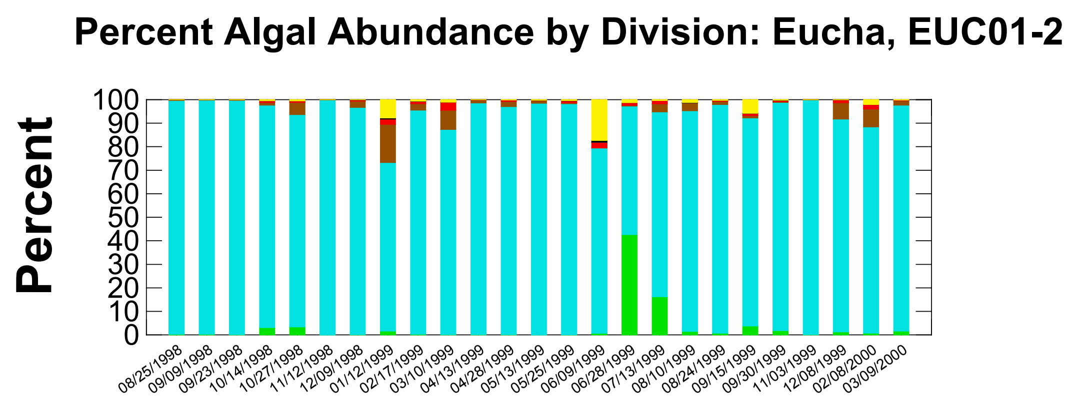


Figure 19: Percent Algal Abundance and Biovolume by Division for Eucha Lake, EUC02, Replicate 2 (surface sample).Colors are as follows: Chlorophytes-green, Cyanophytes-blue, Diatoms-brown, Cryptophytes-red, Euglenophytes-gray, Dinoflagellates-black, and Chrysophytes-yellow



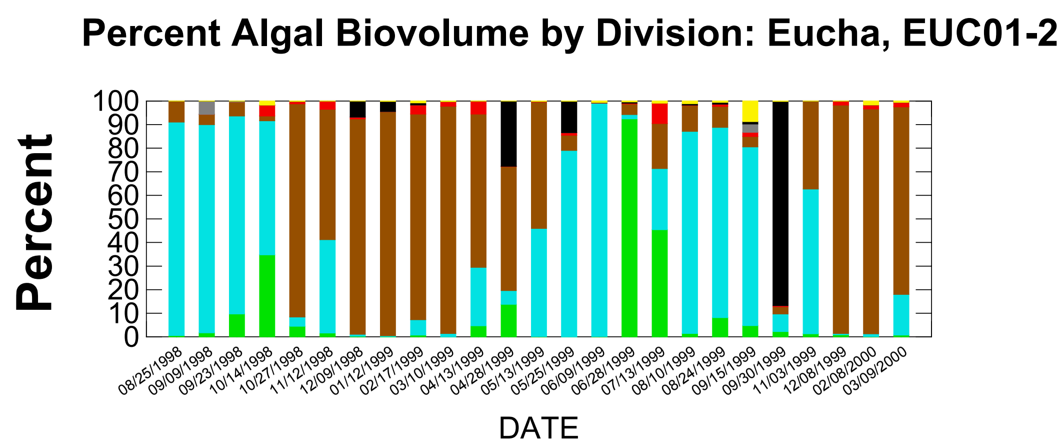


Figure 20: Percent Algal Abundance and Biovolume by Division for Eucha Lake, EUC01, Replicate 2 (surface sample).Colors are as follows: Chlorophytes-green, Cyanophytes-blue, Diatoms-brown, Cryptophytes-red, Euglenophytes-gray, Dinoflagellates-black, and Chrysophytes-yellow

As the stations progressed downstream (EUC03 ºEUC16 ºEUC02 ºEUC01), blue-green algae became even more important numerically, often comprising 90%= of the assemblage, even during the majority of the Winter months. Exceptions were 2/24/98, 3/24/98 and 6/24/99, where the Green algae were 50%+ of the assemblage.

Eucha-Biovolume:

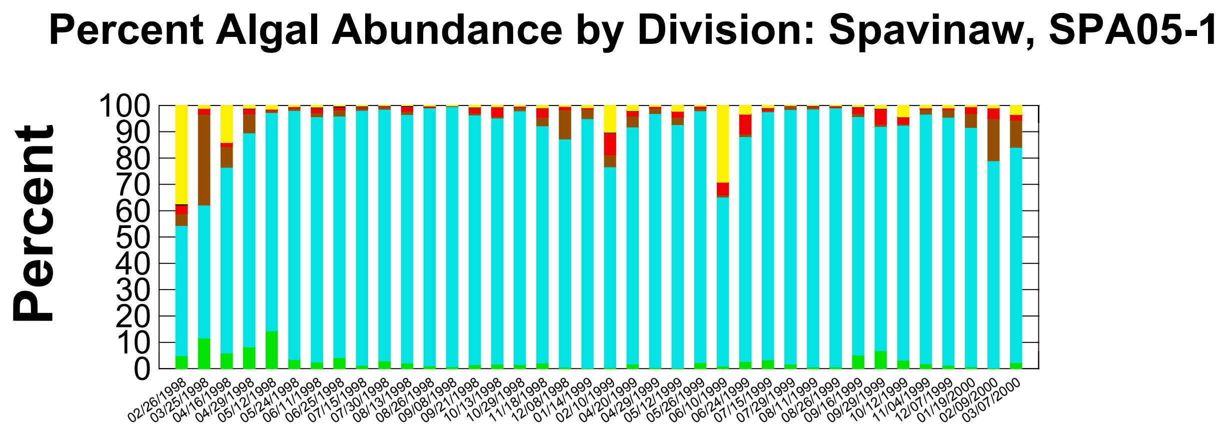
Biovolume indicated significantly greater diversity at the division level. In the surface samples (Figures 11-14, lower panels), Diatoms were much more dominant, especially during the late Fall-Winter and early Spring, as well as occasionally in the Summer of both years. Cryptophytes were often present in varying percentages from 2-20%. Dinoflagellates became an important part of the assemblage in early spring and early Fall (10-60%). Green algae were most important during early-mid summer (June in 1998 and 1999) accounting for up to 70% of the biovolume.

As in the abundance data, Blue-green algae were more important at depth (Figures 15-18, lower panels). Cryptophytes, Dinoflagellates and Euglenophytes became more dominant, but diversity on any given date was less. Cryptophytes and Dinoflagellates at depth may have represented migrating populations in search of refuge from grazing or higher nutrient concentrations. Peak samples tended to be dominated by one or two divisions. Particulates were also present in greater concentrations in the peak samples.

As flow progressed downstream toward the dam, diversity dropped, leaving Blue-green algae and Diatoms the most prevalent taxa at the surface. Dinoflagellates increased from EUC03 to EUC02, but almost dropped from the assemblage at EUC01. Chrysophytes accounted for up to 35% of the biovolume at EUC03, but rarely accounted for more than 2-3% on most dates at EUC01 with few exceptions (2/24/98).

Spavinaw-Abundance:

Abundance patterns in Spavinaw surface samples differed somewhat from Eucha (see Figures 19-21, upper panels). Flow progressed from SPA05 ºSPA02 ºSPA01. Blue-green algae dominated almost all dates, usually accounting for over 80% of the assemblage. Diatoms were less important numerically, rarely accounting for more than 10% of the assemblage. Chrysophytes were more prevalent, increasing in density from SPA05 to SPA01 and comprising as much as 50% of the assemblage at times. Cryptophytes were generally present in low, but consistent numbers, especially during winter and spring months.



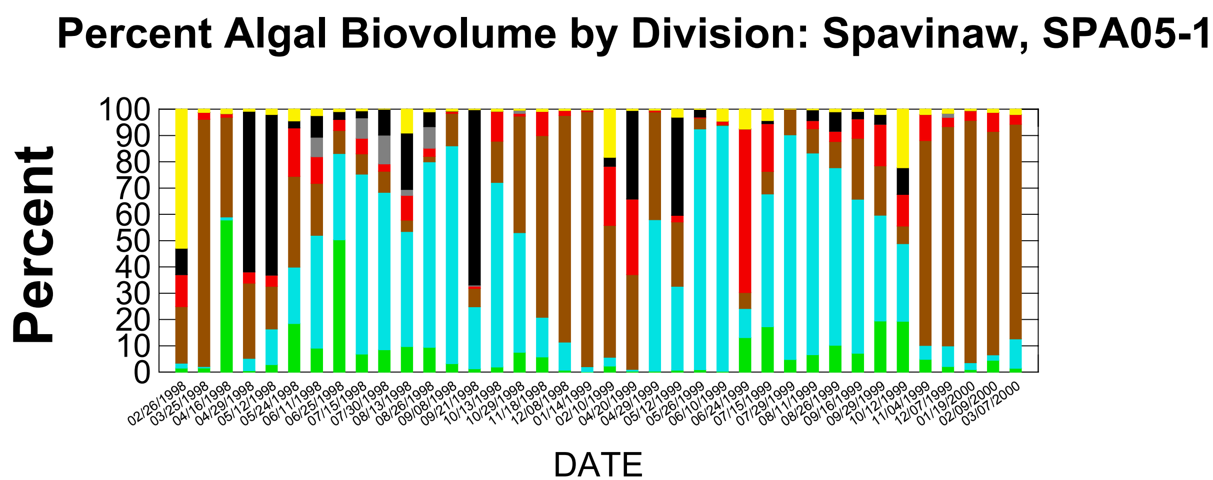
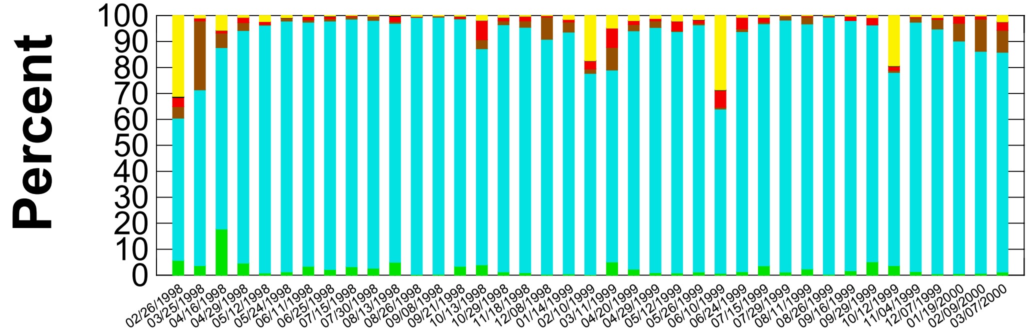


Figure 21: Percent Algal Abundance and Biovolume by Division for Spavinaw Lake, SPA05, Replicate 1 (surface sample).Colors are as follows: Chlorophytes-green, Cyanophytes-blue, Diatoms-brown, Cryptophytes-red, Euglenophytes-gray, Dinoflagellates-black, and Chrysophytes-yellow

Percent Algal Abundance by Division: Spavinaw, SPA02-1



Percent Algal Biovolume by Division: Spavinaw, SPA02-1

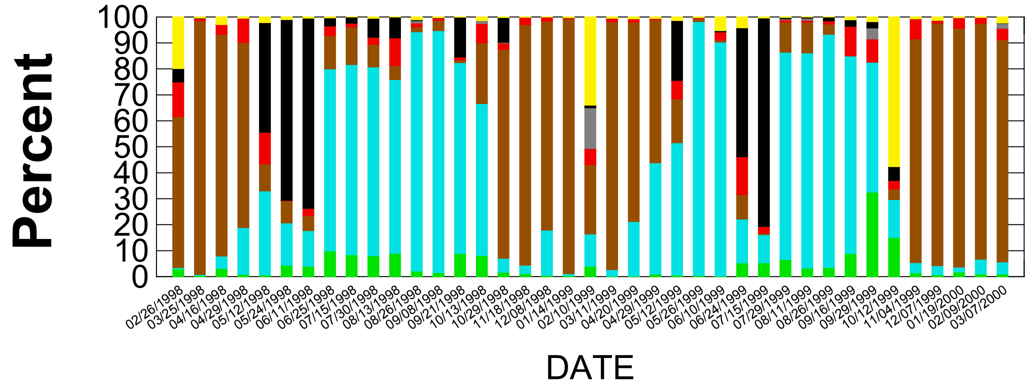
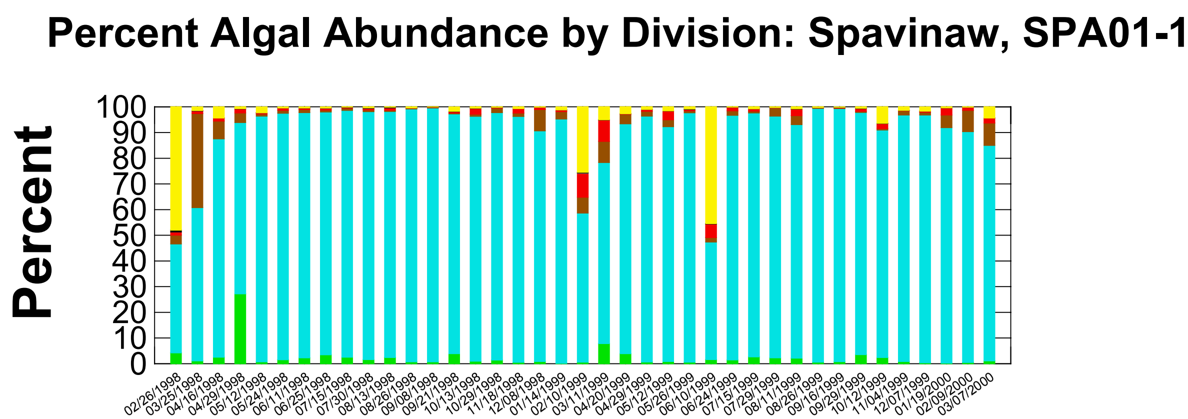


Figure 22: Percent Algal Abundance and Biovolume by Division for Spavinaw Lake, SPA02, Replicate 1 (surface sample).Colors are as follows: Chlorophytes-green, Cyanophytes-blue, Diatoms-brown, Cryptophytes-red, Euglenophytes-gray, Dinoflagellates-black, and Chrysophytes-yellow



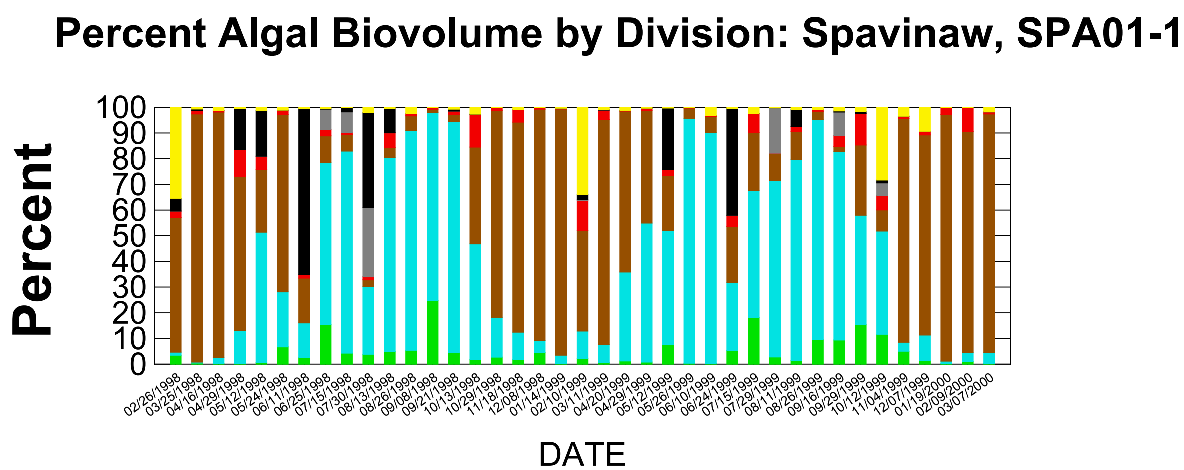
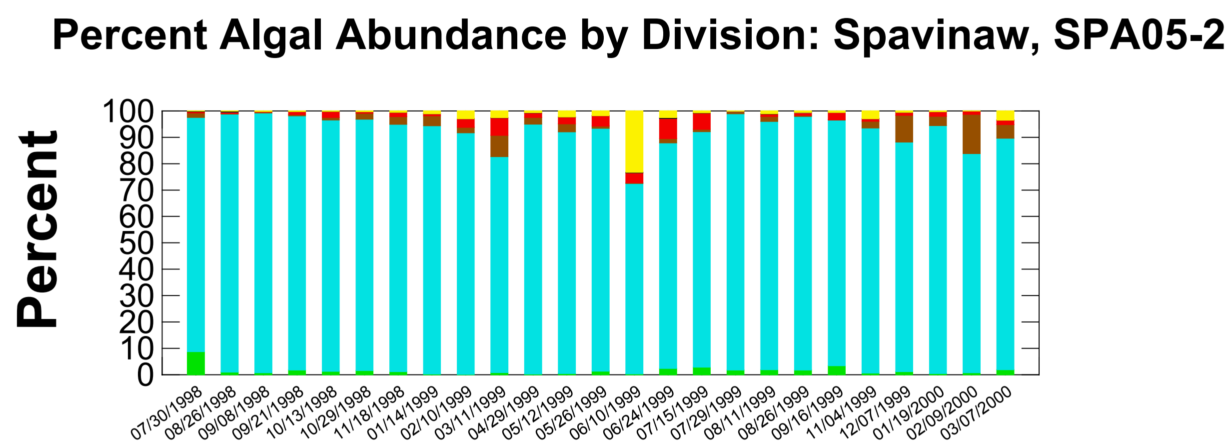


Figure 23: Percent Algal Abundance and Biovolume by Division for Spavinaw Lake, SPA01, Replicate 1 (surface sample).Colors are as follows: Chlorophytes-green, Cyanophytes-blue, Diatoms-brown, Cryptophytes-red, Euglenophytes-gray, Dinoflagellates-black, and Chrysophytes-yellow

Peak Chlorophyll a samples (see Figures 22-24, upper panels) indicated less diversity at depth than the surface samples, consistent with Eucha. The samples at depth contained more Blue-green algae by percent, and fewer Chrysophytes, Green algae and Diatoms. Cryptophytes were present sporadically, accounting for up to 10% of the assemblage on several occasions, usually in late fall or during the winter.



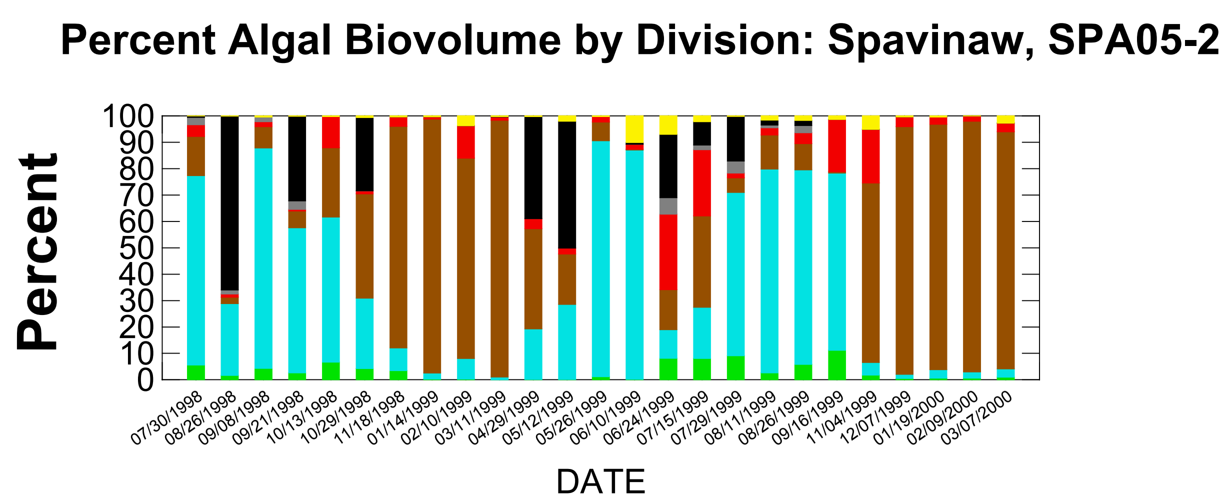
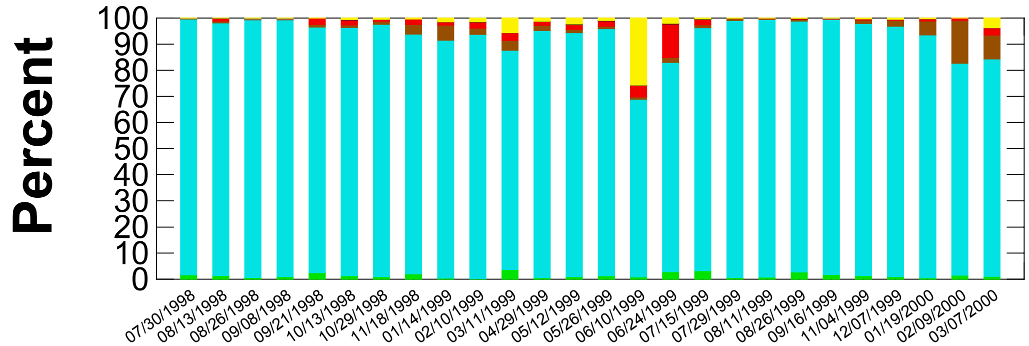


Figure 24: Percent Algal Abundance and Biovolume by Division for Spavinaw Lake, SPA05, Replicate 2 (surface sample).Colors are as follows: Chlorophytes-green, Cyanophytes-blue, Diatoms-brown, Cryptophytes-red, Euglenophytes-gray, Dinoflagellates-black, and Chrysophytes-yellow

Percent Algal Abundance by Division: Spavinaw, SPA02-2



Percent Algal Biovolume by Division: Spavinaw, SPA02-2

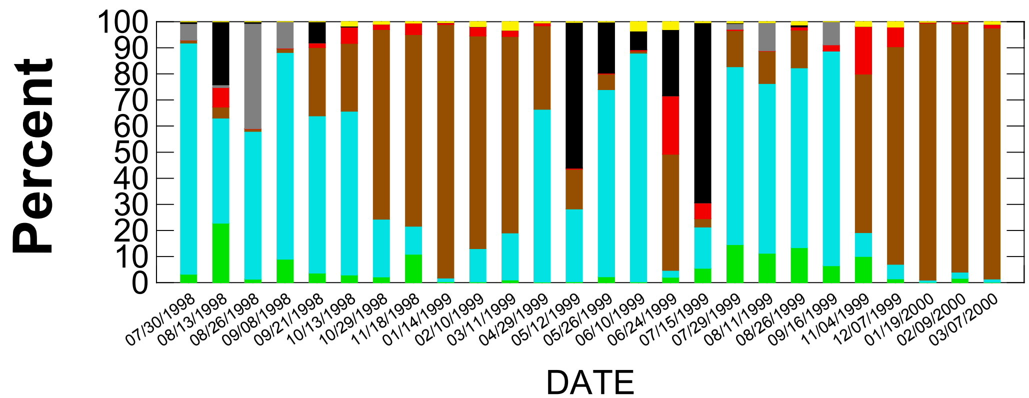
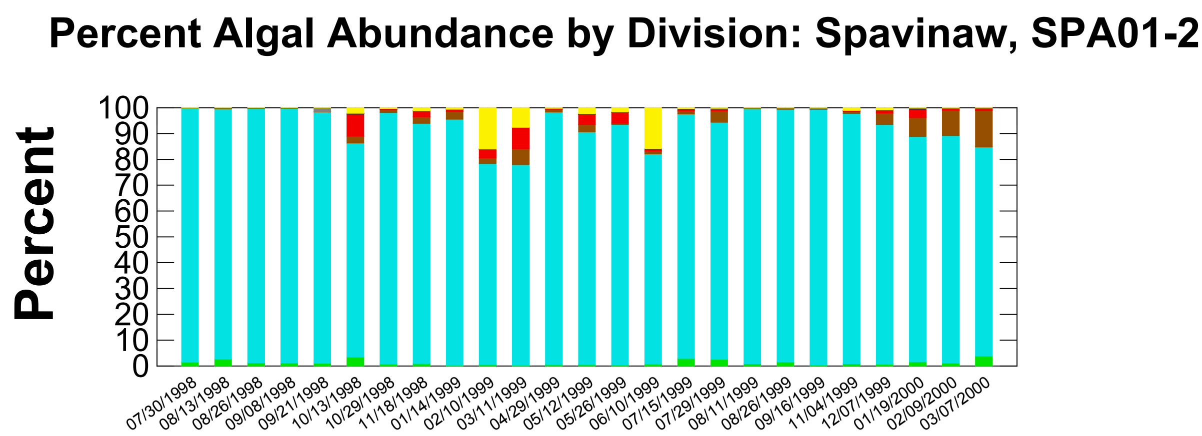


Figure 25: Percent Algal Abundance and Biovolume by Division for Spavinaw Lake, SPA02, Replicate 2 (surface sample).Colors are as follows: Chlorophytes-green, Cyanophytes-blue, Diatoms-brown, Cryptophytes-red, Euglenophytes-gray, Dinoflagellates-black, and Chrysophytes-yellow



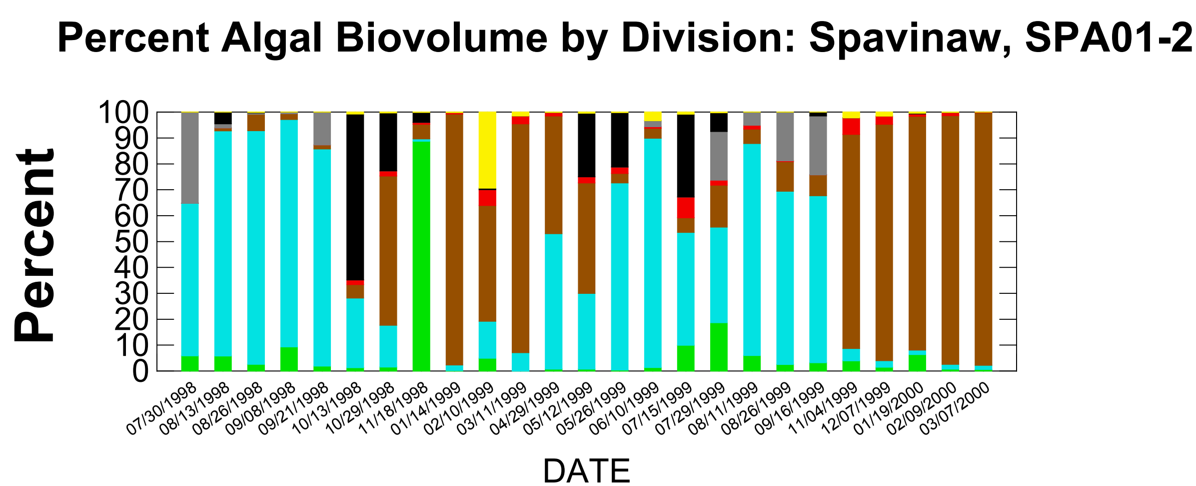


Figure 26: Percent Algal Abundance and Biovolume by Division for Spavinaw Lake, SPA01, Replicate 2 (surface sample).Colors are as follows: Chlorophytes-green, Cyanophytes-blue, Diatoms-brown, Cryptophytes-red, **Euglenophytes-gray, Dinoflagellates-black, and Chrysophytes-yellow**

As flow progressed toward the dam at SPA01, there was not the decrease in diversity that was seen in Eucha in the surface samples. The assemblage varied somewhat as the Chrysophytes increased or decreased slightly, but overall, the assemblage was remarkably consistent. Peak samples were also very consistent from the upper stations to the lower stations numerically.

Spavinaw-Biovolume

Biovolume indicated higher diversity at the surface, in all three Spavinaw stations compared with Eucha. Dinoflagellates, Cryptophytes and Euglenophytes were all more important contributors to the biovolume, especially in mid-Summer in 1998 and late summer in 1999. Diversity did not drop substantially at SPA01 as it did at EUC01, although mid-Summer dates were still dominated by Blue-green algae. Diatoms dominated from winter into early spring.

Peak samples, consistent with Eucha, were less diverse than surface samples. AT SPA05, Cryptophytes and Dinoflagellates were significant contributors to the biovolume. SPA01, in contrast, rarely had significant Cryptophyte populations. The Dinoflagellates were still present and occasionally accounted for 30-60% of the assemblage. Euglenophytes were important later in the summer, accounting for 20-30% of the biovolume. Blue-green algae and Diatoms still dominated on most dates, often to the exclusion of the other divisions.

Yahola-Abundance:

Lake Yahola was dominated numerically by Blue-green algae on all dates (May 1999 through March, 2000, see Figure 25, upper panel). There were only surface samples taken in Yahola at one station, 1-1. Diatoms were important in March 2000, as were the Cryptophytes in January 2000. Green algae were significant in early August 1999.

Yahola-Biovolume:

Biovolume indicates an assemblage most often dominated by Diatoms (See Figure 25, lower panel). Blue-green algae account for over 50% of the biovolume on only three dates: May 1999, July 1999 and August 1999. Diatoms dominated the biovolume on most dates, especially early summer 1999, early fall 1999 and winter 2000. Dinoflagellates were important in spring 1999, while Cryptophytes contributed to the biovolume mildly in winter 2000.

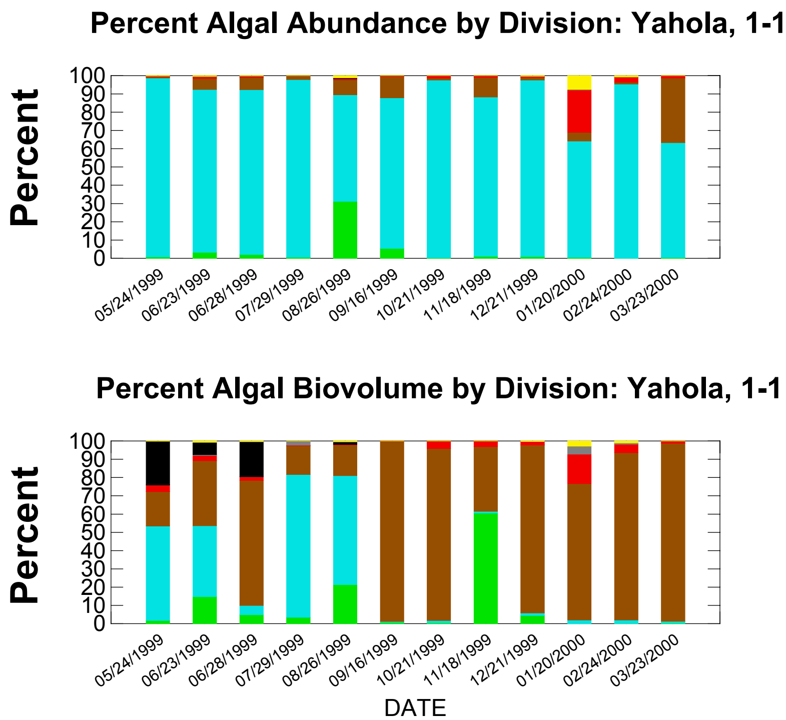


Figure 27: Percent Algal Abundance and Biovolume by Division for Lake Yahola, Replicate 1 (surface sample).Colors are as follows: Chlorophytes-green, Cyanophytes-blue, Diatoms-brown, Cryptophytes-red, Euglenophytes-gray, Dinoflagellates-black, and Chrysophytes-yellow

Algal Species Responses

Eucha:

There are several notable species within several divisions that were present during the study period. The Picoplankton (small, non-motile Blue-green algae in the less than 1 um range) were an important constituent of the algal community in the Summer and early Fall months (June-October) of both years (See Figure 26). The taxa involved are most likely several species in the genera Synechococcus, Synechocystis and Aphanothece. Picoplankton often dominate numerically, but comprise only a few percent of the assemblage biovolume. Although they do not dominate the biovolume, the Picoplankton are extremely important in rapid nutrient cycling because of their high abundance, fast reproduction rate and as an important food resource for zooplankton and phagotrophic algae.

Cylindrospermopsis raciborski bloomed in both 1998 and 1999 (see Figure 27). This Blue-green is considered an exotic invader from Tropical or Sub-tropical habitats (Desichakary, 1959) and was first documented in the United States in the 1980's. *C. raciborski* can easily dominate a system, causing severe water quality problems. *C. raciborski* was present at all four stations in Eucha Lake. It became more important as the flow progressed downstream, reaching the highest concentrations at the dam station, EUC01. The 1999 bloom was more considerably pronounced in terms of total biovolume. Interestingly, the average GALD (Greatest Axial Linear Dimension) was, on average, less in

1999 (See Figure 28), making the species more potentially susceptible to grazing. *Cylindrospermopsis raciborski* produces several toxins (most notably Cylindrospermopsin) and unlike some other Blue-green toxin producers, it seems to produce toxin anytime it is present (Andrew Chapman, SFWMD, personal communication). There is some evidence that these taxa also produce small amounts of Geosmin as well (Chris Williams, SFWMD, personal communication).

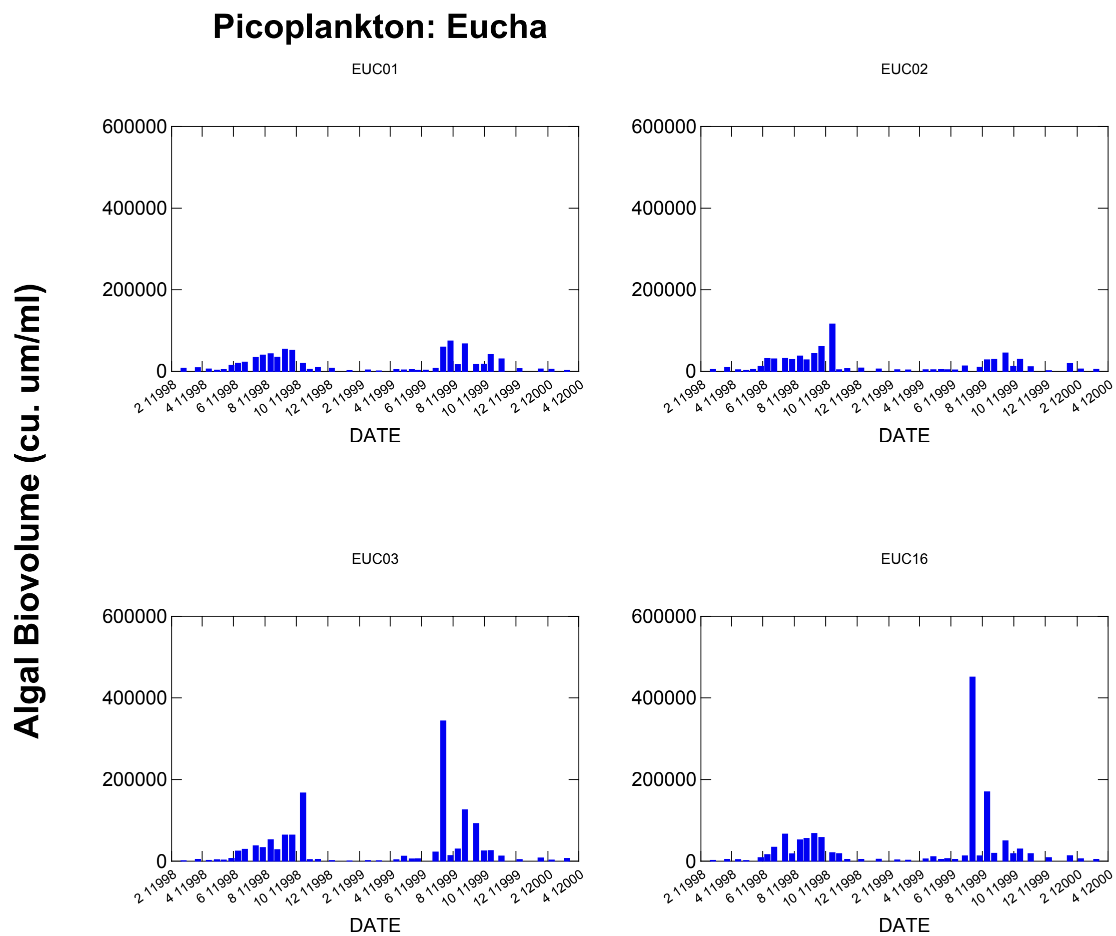


Figure 28: Algal Biovolume for Picoplankton for Eucha Lake at EUC01, EUC02, EUC03 and EUC16 (surface samples)

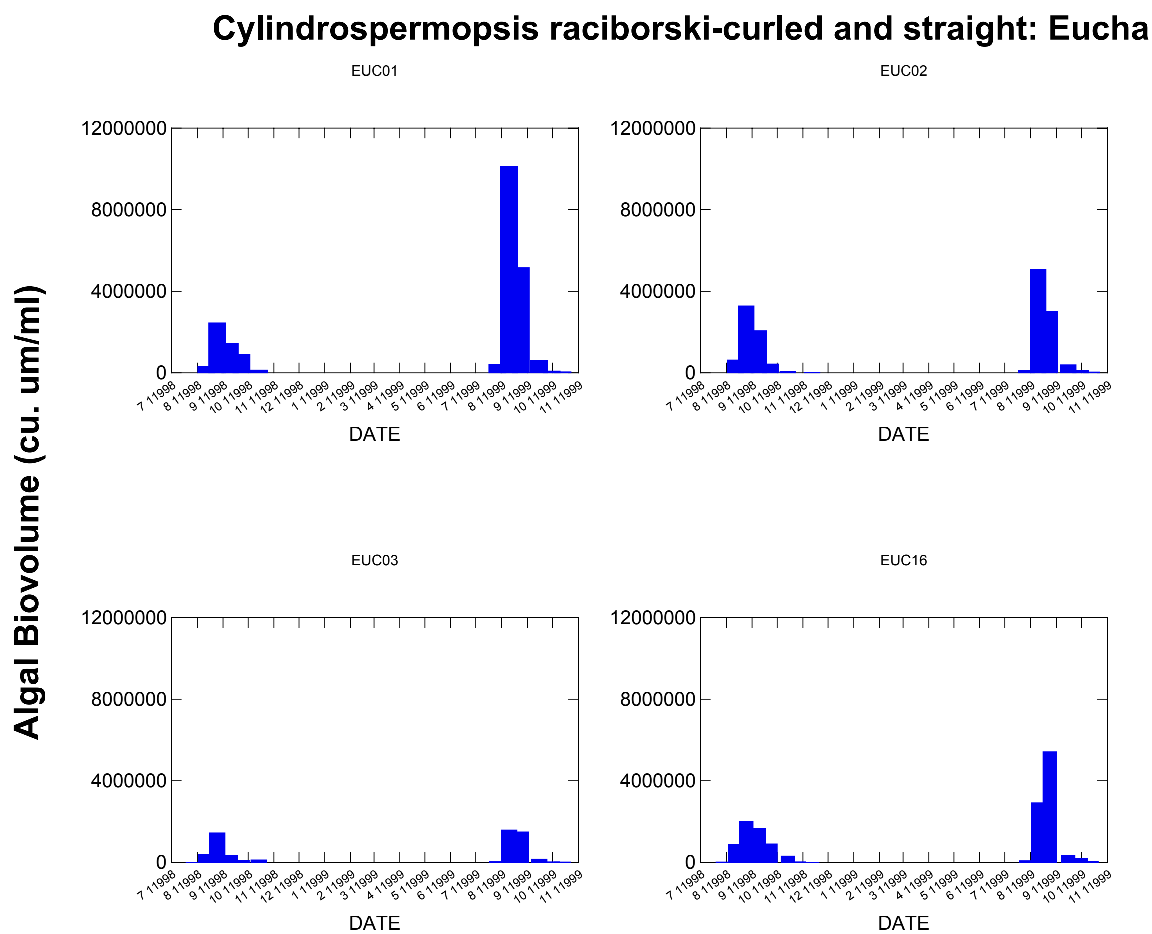


Figure 29: Algal Biovolume for *Cylindrospermopsis raciborski* for Eucha Lake at Euc01, EUC02, EUC03 and EUC16 (surface samples)

-

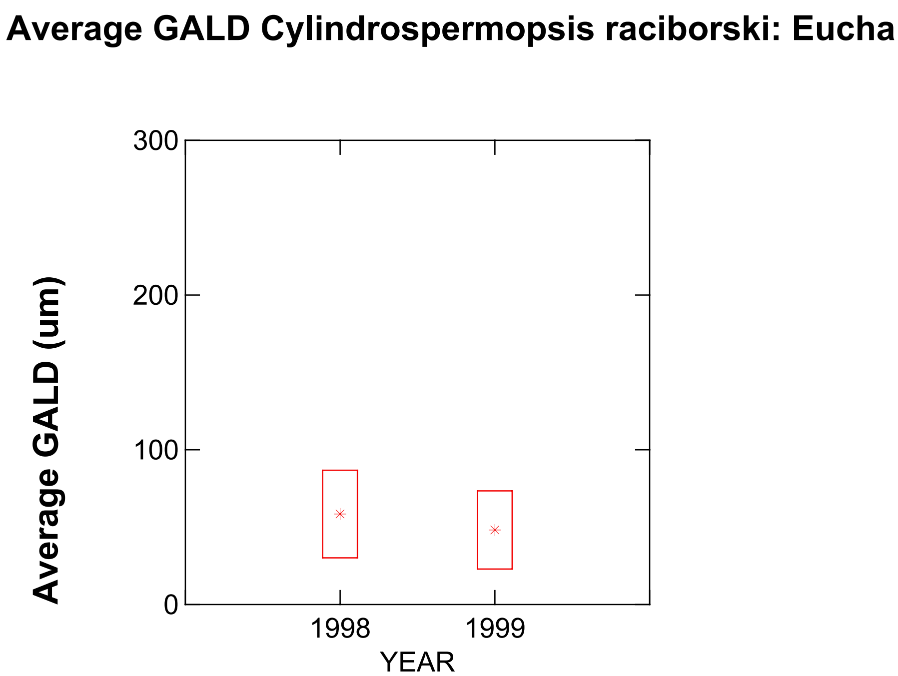


Figure 30: Average GALD for *Cylindrospermopsis raciborski* at Lake Eucha

Other potential taste and odor producers include several Anabaena species. I have combined *Anabaena flos-aquae* and *Anabaena circinalis* data because of potential taxonomic overlap (See Figure 29). *Anabaena macrospora* followed a similar pattern (See Figure 30). Although these three species of Anabaena were present in 1998, there was not a significant bloom until mid summer 1999. Anabaena macrospora accounted for significantly more of the assemblage than the other two species. *Anabaena* bloomed earlier in the summer and then was replaced by *Cylindrospermopsis* later in the season. None of the nitrogen-fixing Blue-green taxa produced heterocysts in significant numbers, indicating nitrogen was not limiting.

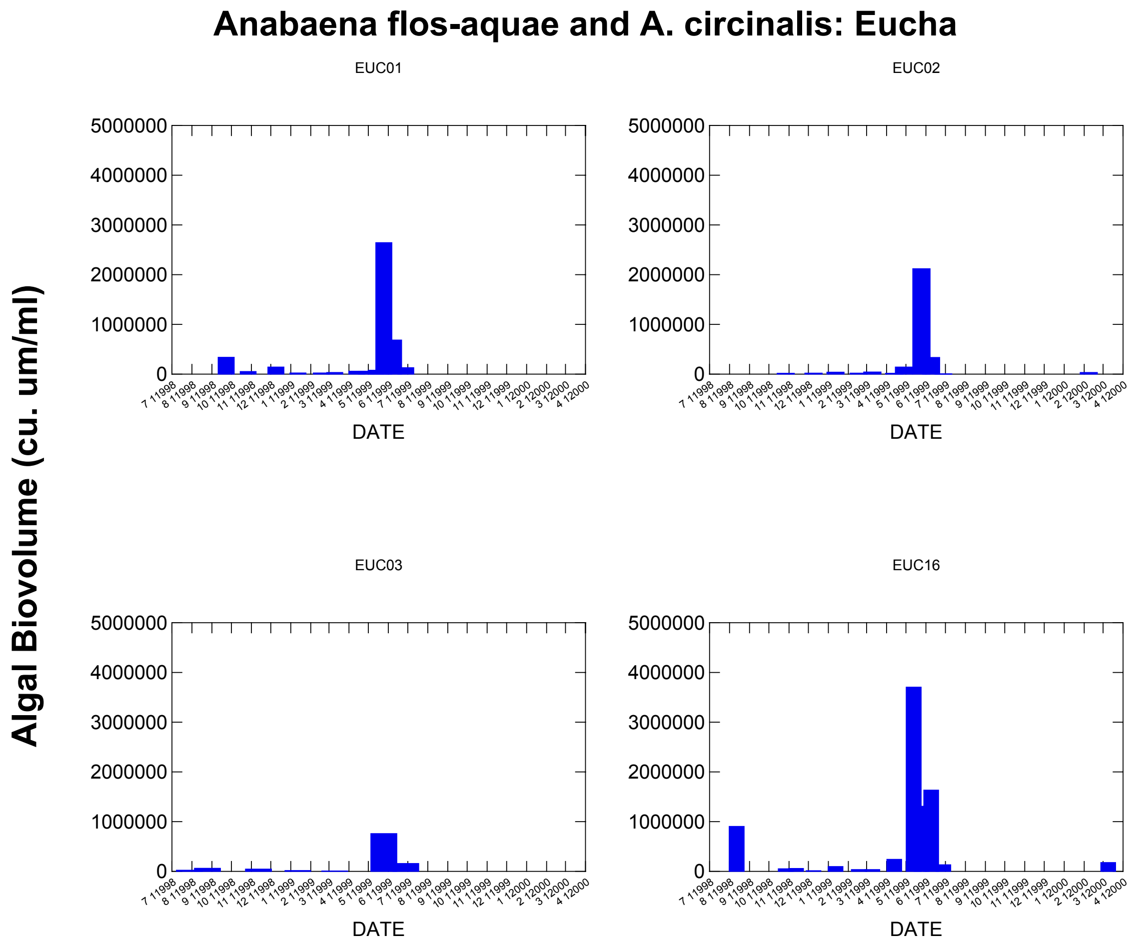


Figure 31: Algal Biovolume for *Anabaena flos-aquae* and *Anabaena circinalis* for Eucha Lake at EUC01, EUC02, CUE03 and EUC16 (surface samples)

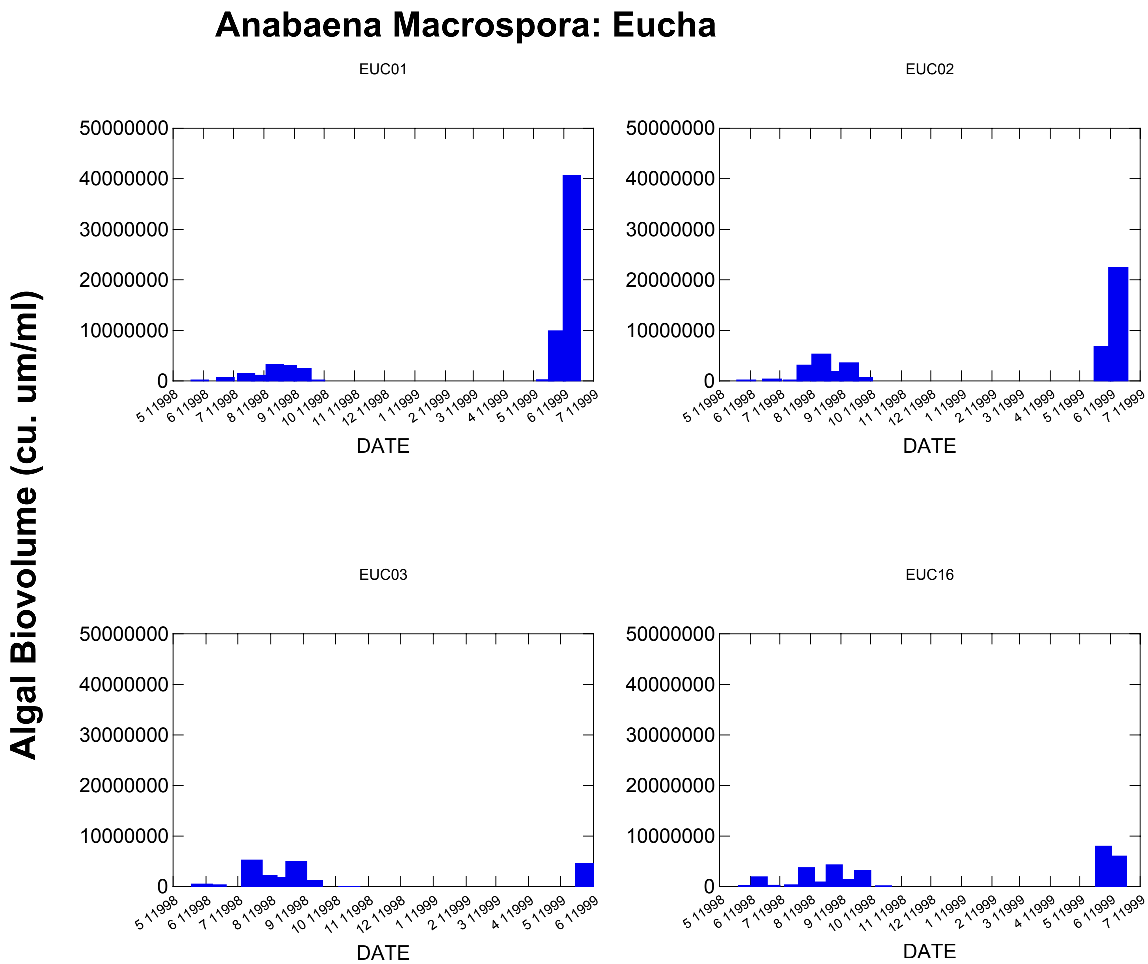


Figure 32: Algal Biovolume for *Anabaena macrospora* for Eucha Lake at EUC01, EUC02, EUC03 and EUC16 (surface samples)

Oscillatoria limnetica has been a documented taste and odor producer as well. It was present in late summer, early fall in both 1998 and 1999 (See figure 31). However, consistent with the other Blue-green taxa, the 1999 bloom of *Oscillatoria* was much larger than in 1998. Its overall biomass was significantly less than either *Cylindrospermopsis raciborski* or the Anabaena species. *Oscillatoria limnetica* also tended to bloom concomitant with *Cylindrospermopsis*.

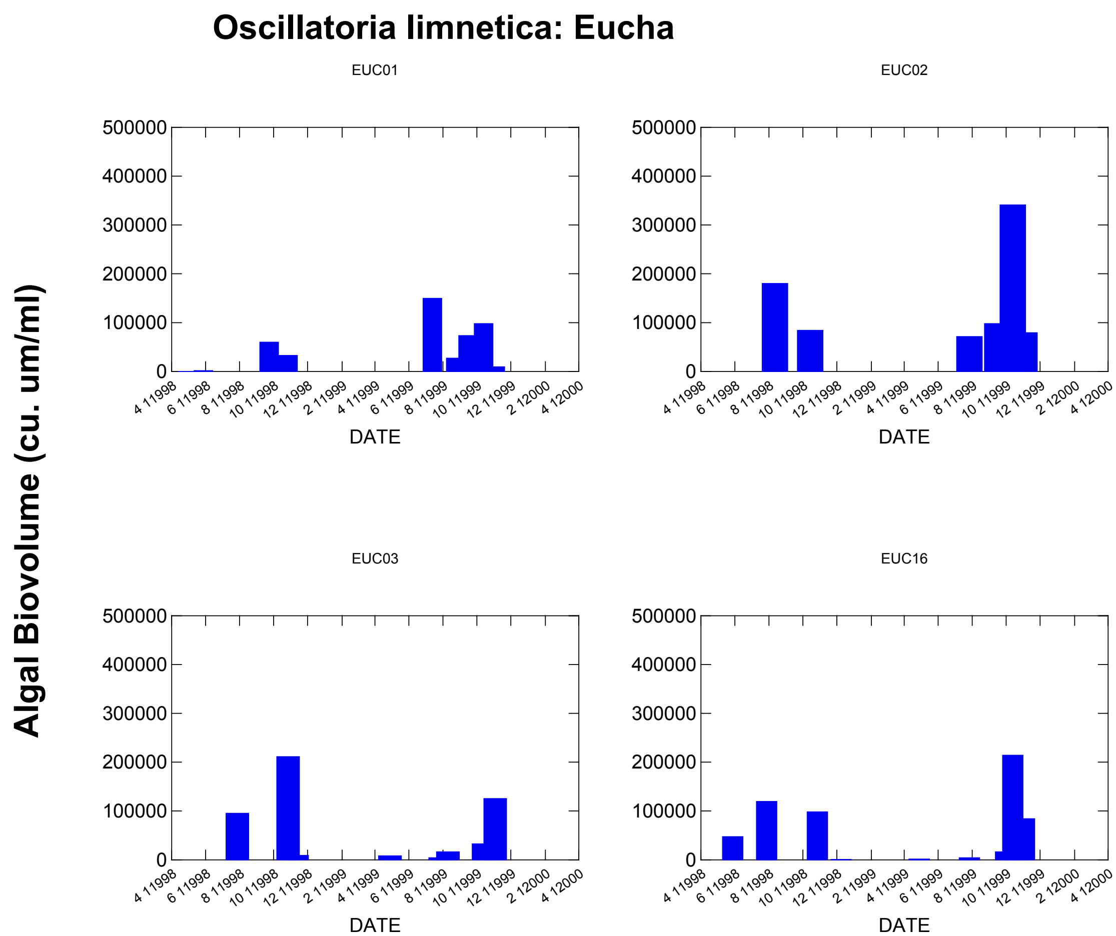


Figure 33: Algal Biovolume for *Oscillatoria limnetica* for Eucha Lake at EUC01, EUC02, EUC03 and EUC16 (surface samples)

Diatoms were the other dominant division during 1998-2000. Among the abundant Diatoms was Stephanodiscus niagare. A large centric diatom with a GALD in 20-40 um range, S. niagare had small blooms in late spring 1998 and late Fall 1999, but bloomed considerably in the late fall and winter of 1999 into the early spring (12/98-4/99, See Figure 32). It was most abundant at EUC02 during the winter 1999 bloom and like *Cylindrospermopsis*, exhibited a decreased average lake-wide GALD in 1999 (See Figure 33).

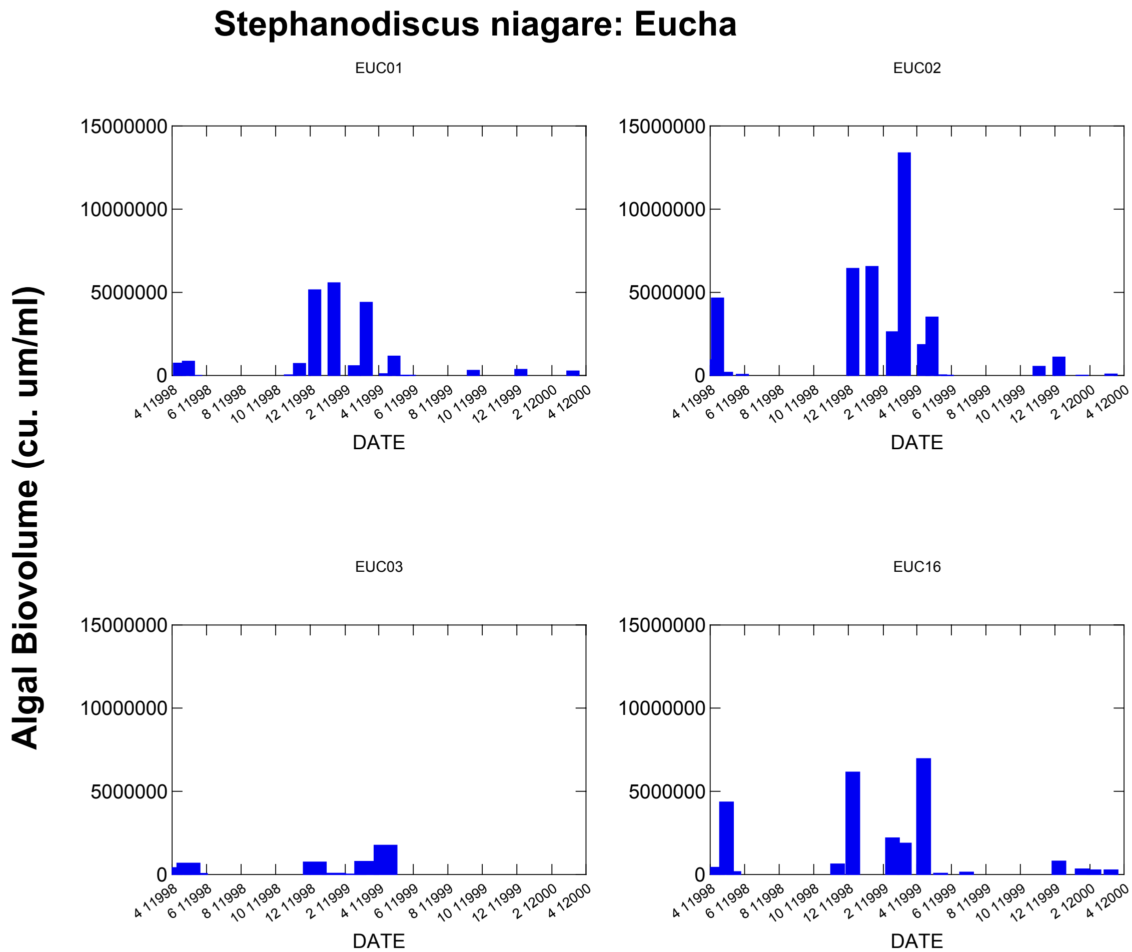


Figure 34: Algal Biovolume for *Stephanodiscus niagare* for Eucha Lake at EUC01, EUC02, EUC03 and EUC16 (surface samples)

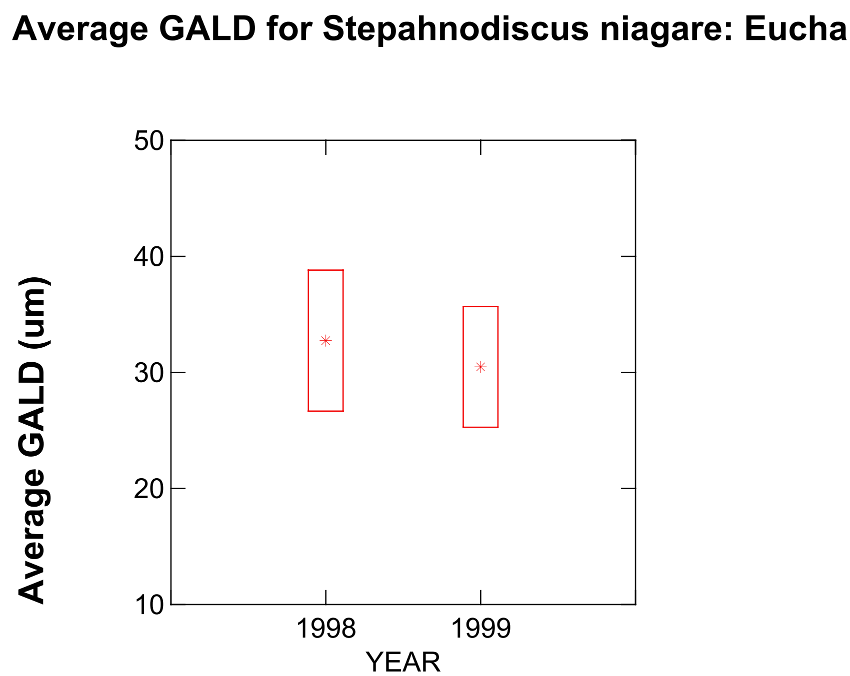


Figure 35: Average GALD for *Stephanodiscus niaga*re for Eucha Lake (surface samples)

Melosira is another Diatom genus that bloomed throughout the study period and has been linked to taste and odor problems. There were two important species, *M. italica* and *M. granulata*. *M. italica* was by far the more abundant species of the two (see Figure 34), although its also useful to look at both species combined (See Figure 35). *M. italica* bloomed in the late fall in 1998, briefly in early summer 1999 and then exhibited an extended bloom in the late fall of 1999 into winter 2000. Both species combined show essentially the same pattern, blooming in late winter, early spring of 1998, transient blooms in the late fall of 1998, and an extended late fall 1999, winter 2000 bloom. With the exception of one date, the total biovolume was lowest at EUC03, higher at EUC16, but more sustained at EUC02 and EUC01. Of the two species, *M. italica* is more lightly silicified, which may help explain its higher densities compared to *M. granulata* (silica limitation).

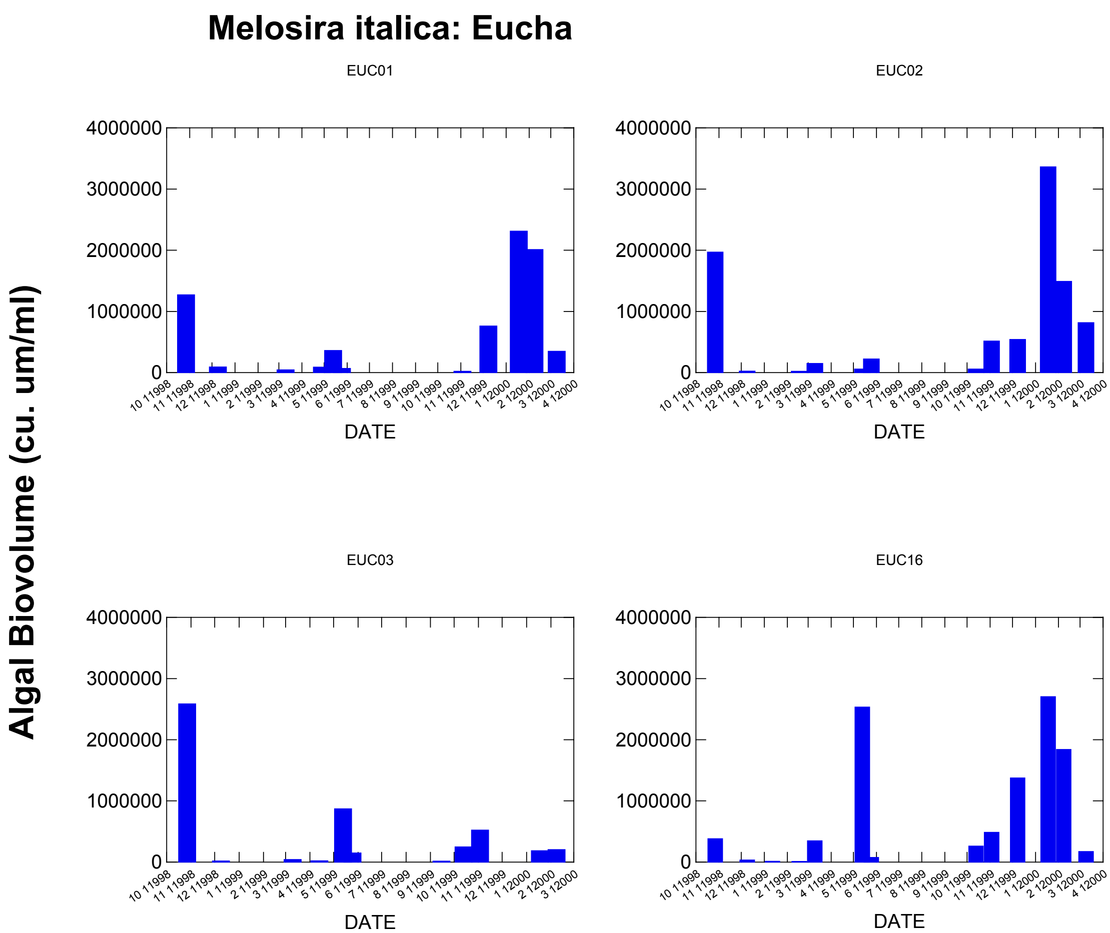


Figure 36: Algal Biovolume for *Melosira italica* for Eucha Lake at EUC01, EUC02, EUC03 and EUC16 (surface samples)

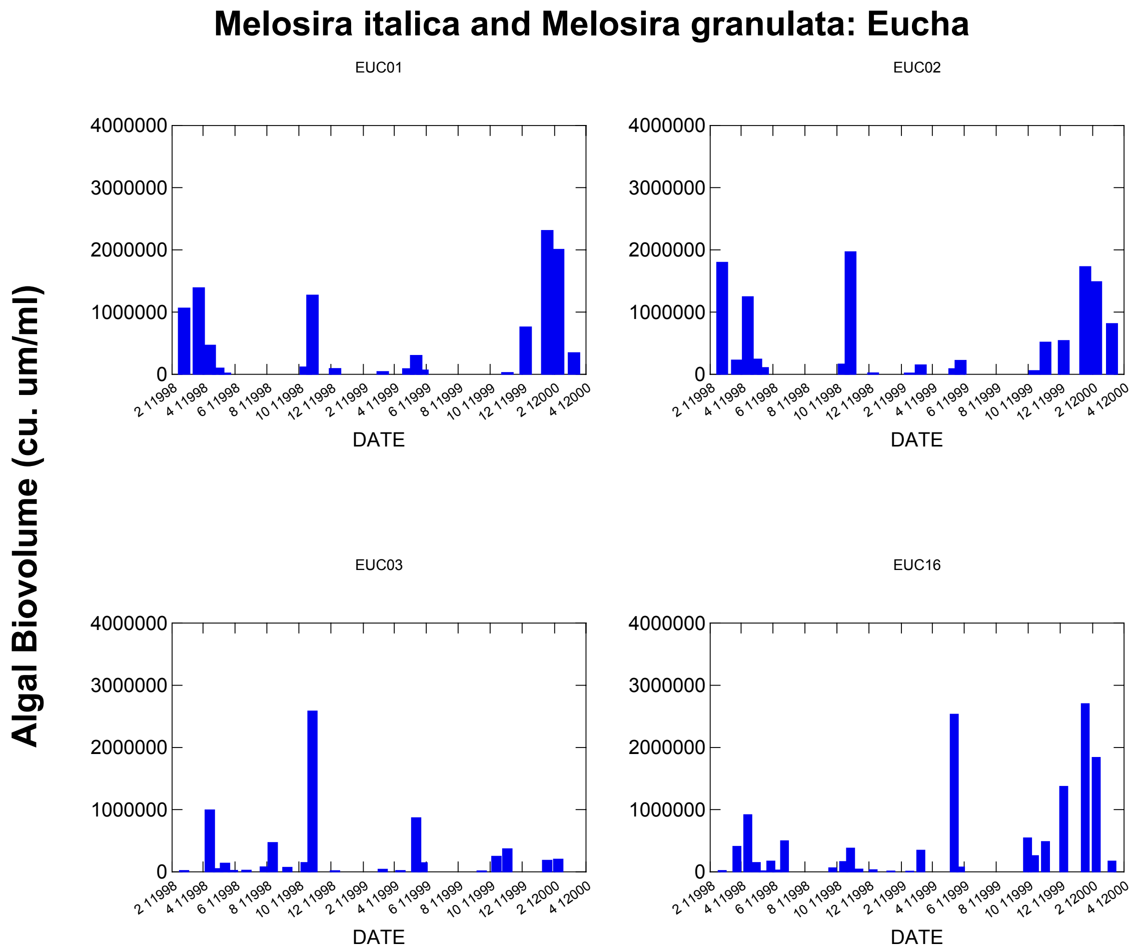


Figure 37: Algal Biovolume for *Melosira italica & Melosira granulata* for Eucha Lake at EUC01, EUC02, EUC03 and EUC16 (surface samples)

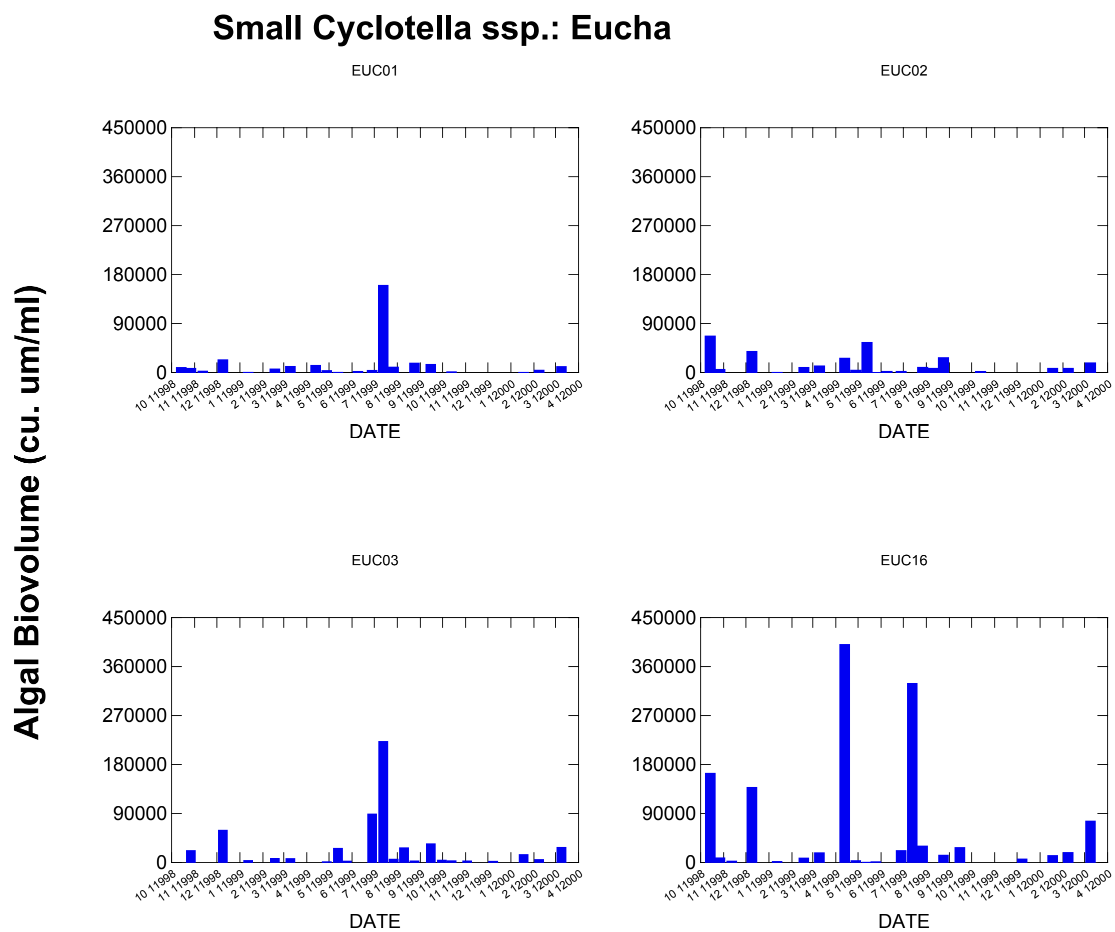


Figure 38: Algal Biovolume for Small Cyclotella species for Eucha Lake at EUC01, EUC02, EUC03 and EUC16 (surface samples)

Other important Diatoms included Small Cyclotella ssp. These taxa are generally 6um or below (often 2-3um) and are difficult to speciate without Electron microscopy. They are relatively abundant at certain time of the year (see Figure 36), and due to their size and abundance can significantly affect nutrient cycles and food resources for micro zooplankton.

Spavinaw:

There are several notable species within several divisions that were present during the study period. The Picoplankton (small, non-motile Blue-green algae in the less than 1 um range) were an important constituent of the algal community in the summer and early fall months (June-October) of both years (See Figure 37). The taxa involved are most likely several species in the genera *Synechococcus*, *Synechocystis* and *Aphanothece*. Picoplankton often dominate numerically, but comprise only a few percent of the assemblage biovolume. Although they do not dominate the biovolume, the Picoplankton are extremely important in rapid nutrient cycling because of their high abundance, fast reproduction rate and as an important food resource for zooplankton and phagotrophic algae. The Picoplankton populations in Spavinaw Lake did not achieve the high peaks as they did in Eucha, otherwise the pattern of total biovolume and abundance was very similar between the two lakes.

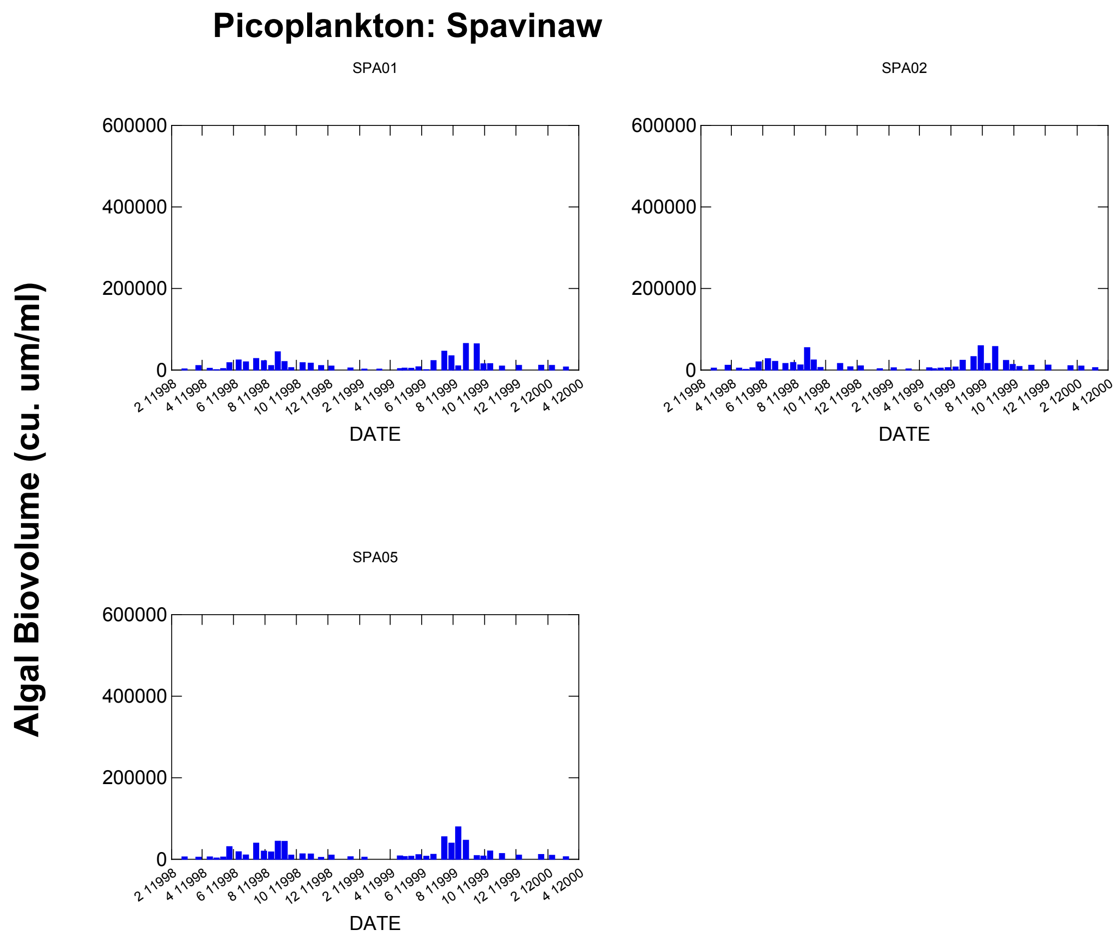


Figure 39: Algal Biovolume for Picoplankton for Spavinaw Lake at SPA01, SPA02 and SPA05 (surface samples)

Cylindrospermopsis raciborski bloomed in both 1998 and 1999 (see Figure 38). This Blue-green is considered an exotic invader from Tropical or Sub-tropical habitats (Desichakary, 1959) and was first documented in the United States in the 1980's. *C. raciborski* can easily dominate a system, causing severe water quality problems. *C. raciborski* was present at all three stations in Spavinaw Lake; however, its total biovolume during the study period was generally less than in Eucha. It became more important as the flow progressed downstream, reaching the highest concentrations at the dam station, SPA01, a similar pattern in Eucha. The 1999 bloom was more considerably pronounced in terms of total biovolume. Also consistent with Eucha, the GALD (Greatest Axial Linear Dimension) was, on average, less in 1999 (See Figure 39), making the species more potentially susceptible to grazing. *Cylindrospermopsis raciborski* produces several toxins (most notably Cylindrospermopsin) and unlike some other Blue-green toxin producers, it seems to produce toxin anytime it is present (Andrew Chapman, SFWMD, personal communication). There is some evidence that this taxa also produces small amounts of geosmin as well (Chris Williams, SFWMD, personal communication).

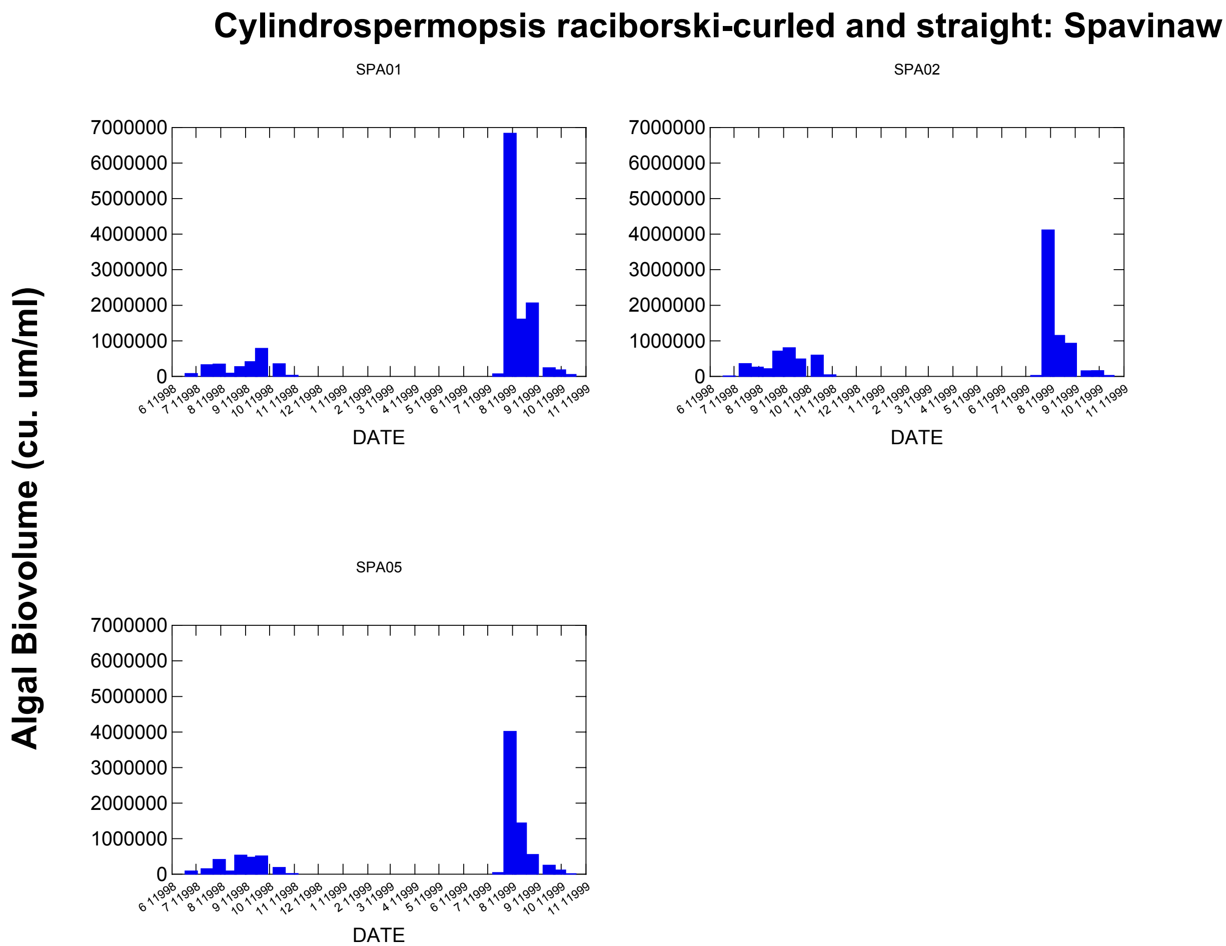


Figure 40: Algal Biovolume for *Cylindrospermopsis raciborski* for Spavinaw Lake at SPA01, SPA02 and SPA05 (surface samples)

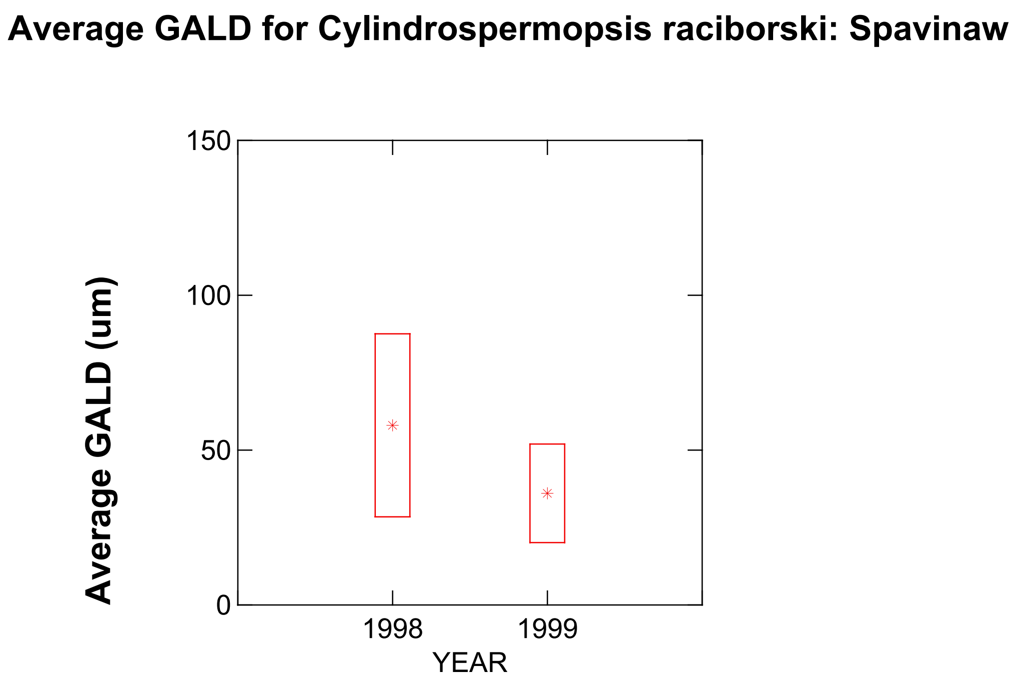


Figure 41: Average GALD for *Cylindrospermopsis raciborski* for Spavinaw Lake (surface sample)

Other potential taste and odor producers include several Anabaena species. I have combined *Anabaena flos-aquae* and *Anabaena circinalis* data because of potential taxonomic overlap (See Figure 40). *Anabaena macrospora* followed a similar pattern (See Figure 41). Although these three species of Anabaena were present in 1998, there was not a significant bloom until mid summer 1999. *Anabaena macrospora* accounted for significantly more of the assemblage than the other two species. *Anabaena* bloomed earlier in the summer and then was replaced by *Cylindrospermopsis* later in the season. *Anabaena* was far more prevalent in Eucha than in Spavinaw. Although the pattern of distribution is similar in both lakes, all three taxa were less abundant in Spavinaw Lake. As in Eucha, none of the nitrogen-fixing Blue-green taxa produced heterocysts in significant numbers, indicating nitrogen was not limiting in Spavinaw. Also, there is no lag in when the taxa appear and bloom in Spavinaw Lake versus Eucha Lake, as is seen with some other taxa (e.g. *Oscillatoria* and to some extent *Cylindrospermopsis*).

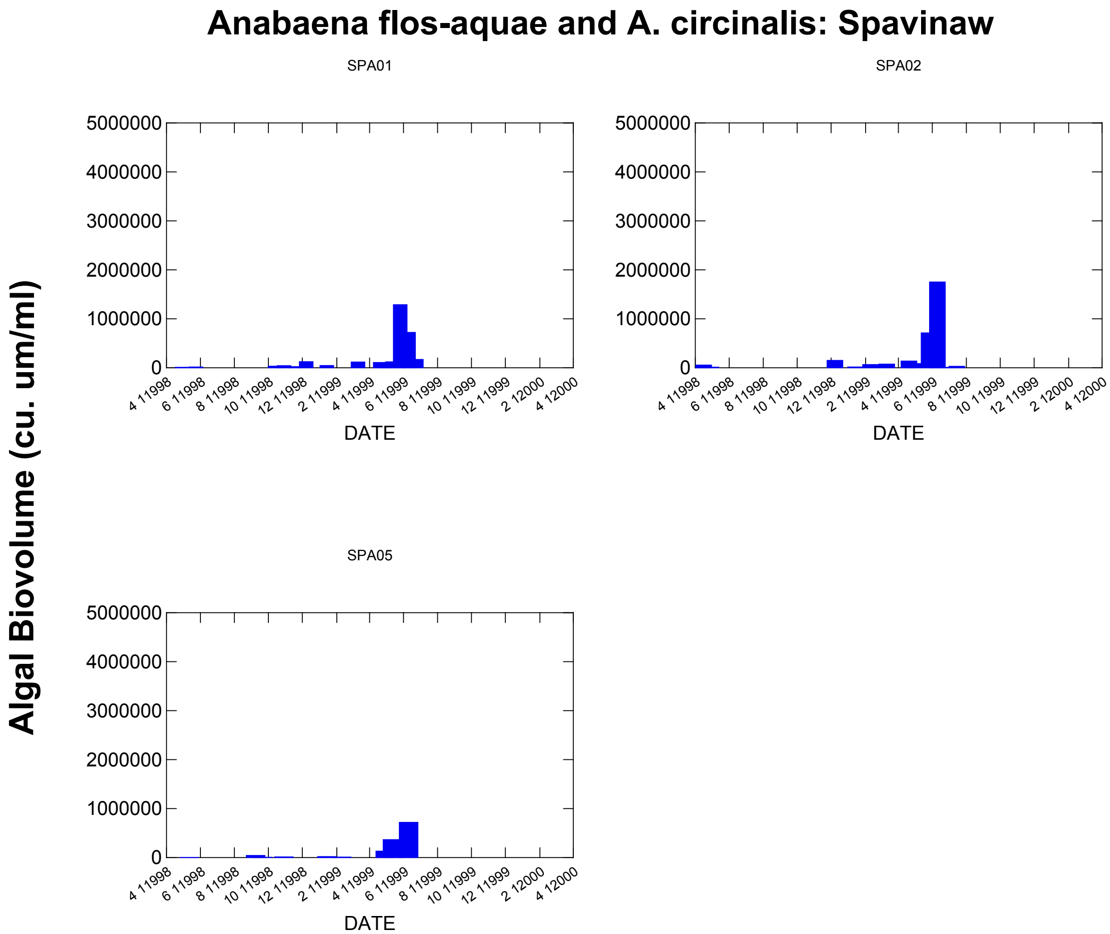


Figure 42: Algal Biovolume for *Anabaena flos-aquae* and *Anabaena circinalis* for Spavinaw Lake at SPA01, SPA02 and SPA05 (surface samples)

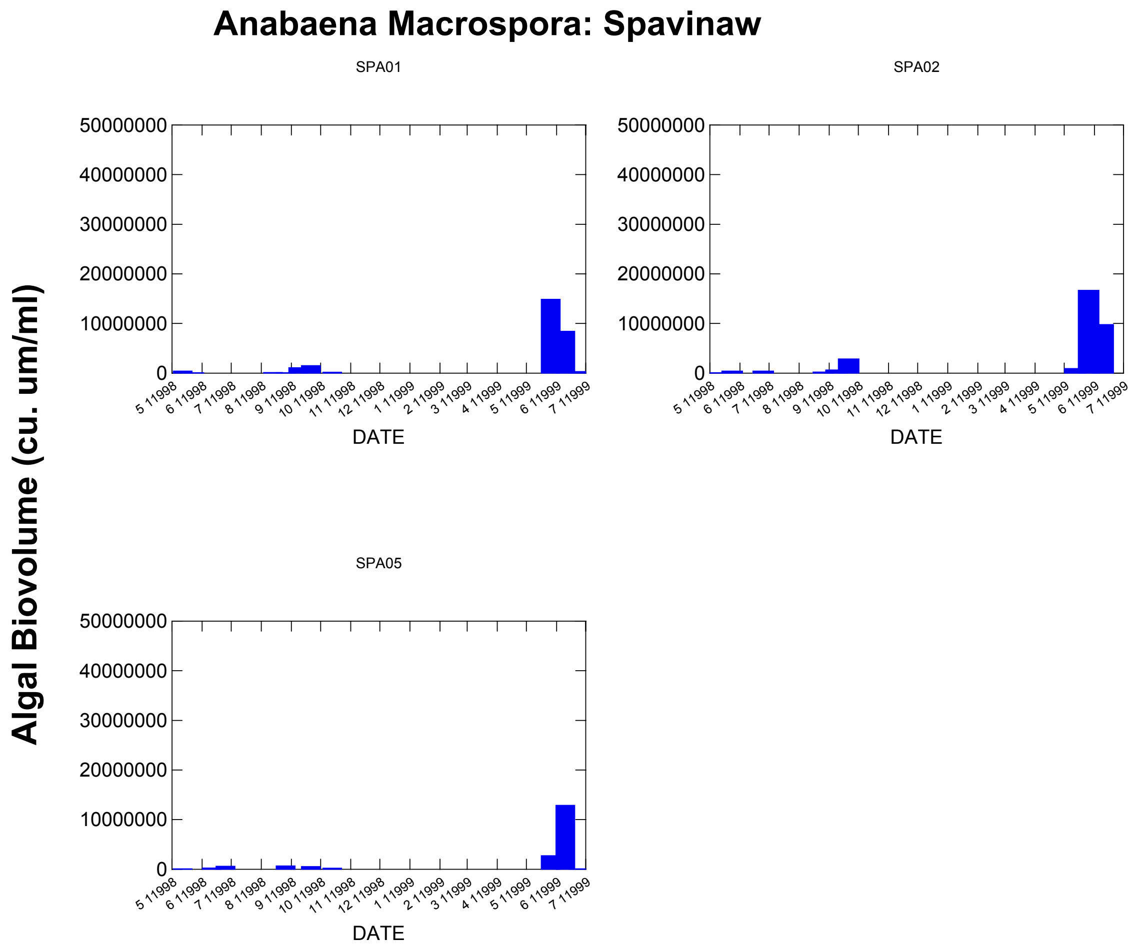


Figure 43: Algal Biovolume for *Anabaena macrospora* for Spavinaw Lake at SPA01, SPA02 and SPA05 (surface samples)

Oscillatoria limnetica has been a documented taste and odor producer as well. It was present in late summer, early fall in both 1998 and 1999 (See Figure 42). However, in Spavinaw Lake, it was not consistent with the other Blue-green taxa, the 1999 bloom of *Oscillatoria* was approximately on the same order as in 1998. *Oscillatoria* also exhibited larger blooms at SPA01 than at EUC01, an unusual circumstance for these two lakes. Its overall biomass was significantly less than either *Cylindrospermopsis raciborski* or the *Anabaena* species. *Oscillatoria limnetica* also tended to bloom concomitant with *Cylindrospermopsis*.

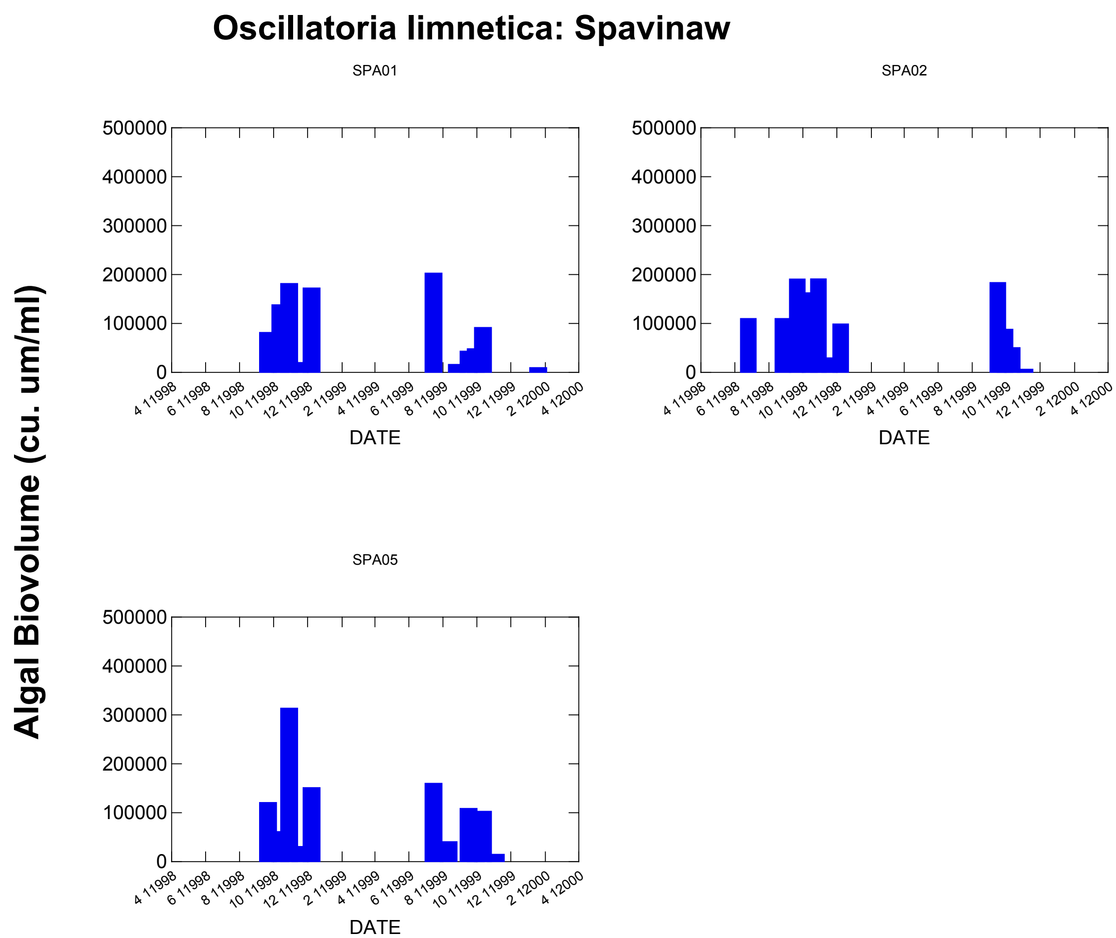


Figure 44: Algal Biovolume for *Oscillatoria limnetica* for Spavinaw Lake at SPA01, SPA02 and SPA05 (surface samples)

Diatoms were the other very dominant division during 1998-2000. Among the abundant Diatoms was *Stephanodiscus niagare*. A large centric diatom with a GALD in 20-40 um range, S. niagare had smaller blooms in late spring 1998 and late fall 1999, and a larger bloom in the late fall and winter of 1999 into the early spring (12/98-4/99, See Figure 43). It was most abundant at SPA01 during the winter 1999 bloom and was generally a more important contributor to biovolume than in Eucha Lake. Unlike Cylindrospermopsis in both lakes and Stephanodiscus in Eucha Lake, Stephanodiscus in Spavinaw Lake did not exhibit a decreased average lake-wide GALD in 1999 (See Figure 44).

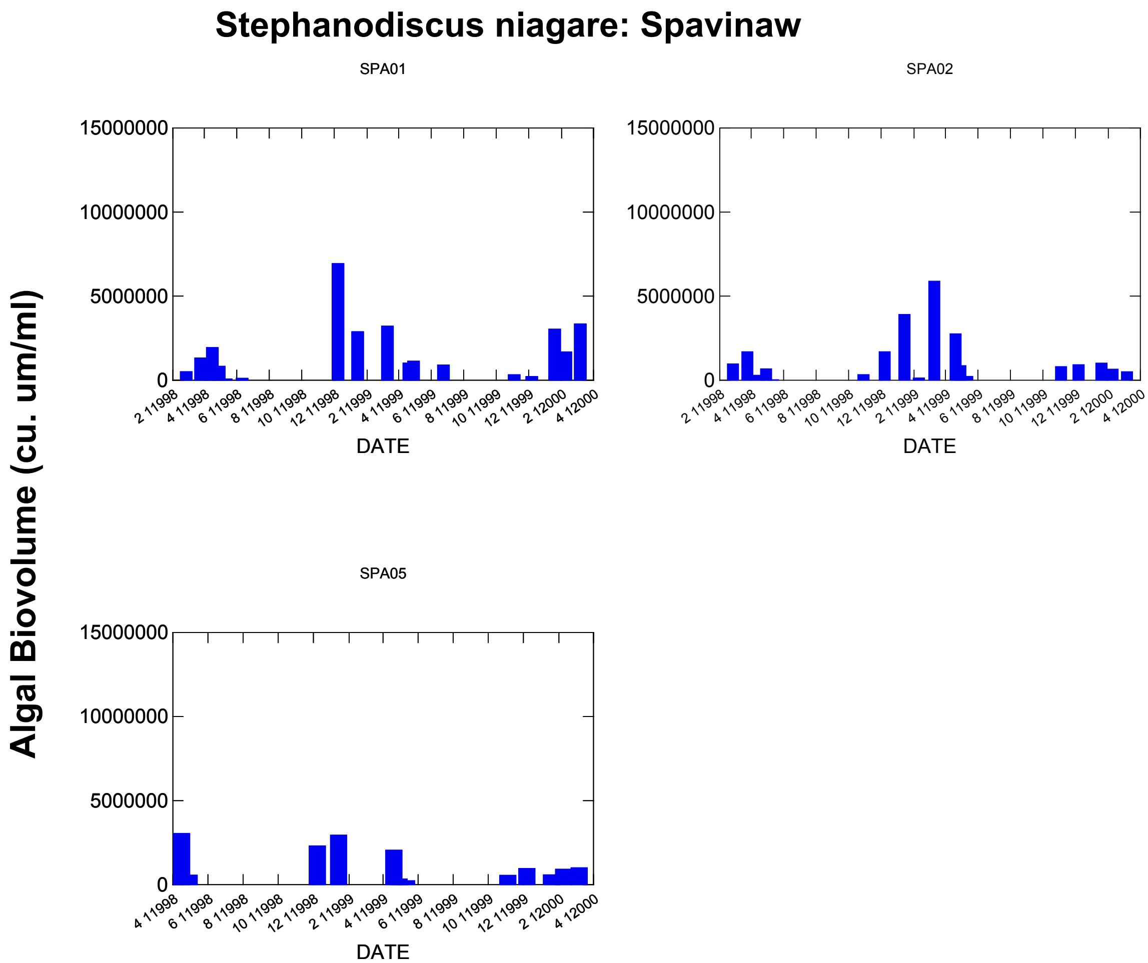


Figure 45: Algal Biovolume for *Stephanodiscus niagare* for Spavinaw Lake at SPA01, SPA02 and SPA05 (surface samples)

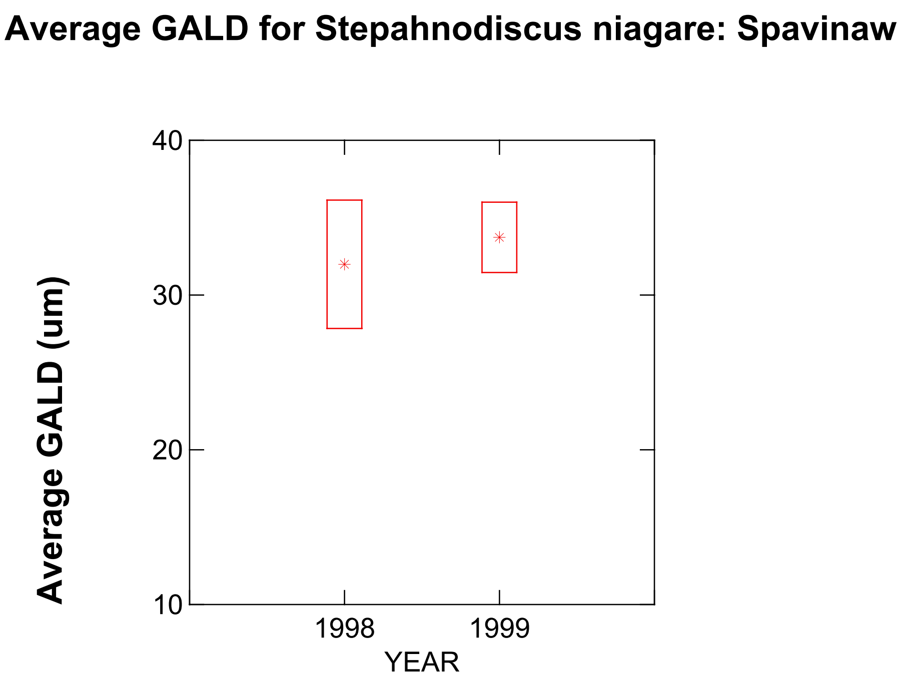


Figure 46: Average GALD for *Stephanodiscus niagare* for Spavinaw Lake (surface samples)

Melosira is another Diatom genus that bloomed throughout the study period and has been linked to taste and odor problems. There were two important species, *M. italica* and *M. granulata*. *M. italica* was by far the more abundant species of the two (see Figure 45), although its also useful to look at both species combined (See Figure 46). *M. italica* bloomed in the late fall in 1998, in early summer 1999 and then again bloomed in the late fall of 1999 into winter 2000. Both species combined show essentially the same pattern, blooming in late winter, early spring of 1998, blooms in the late fall of 1998, and an extended late fall 1999, winter 2000 bloom. With the exception of one date, the total biovolume was lowest at SPA05, and highest at SPA01. Of the two species, M. italica is more lightly silicified, which may help explain its higher densities compared to *M. granulata* (*silica limitation*). Although the peaks were not as high, it was more consistently present throughout the year in Spavinaw as compared to Eucha.

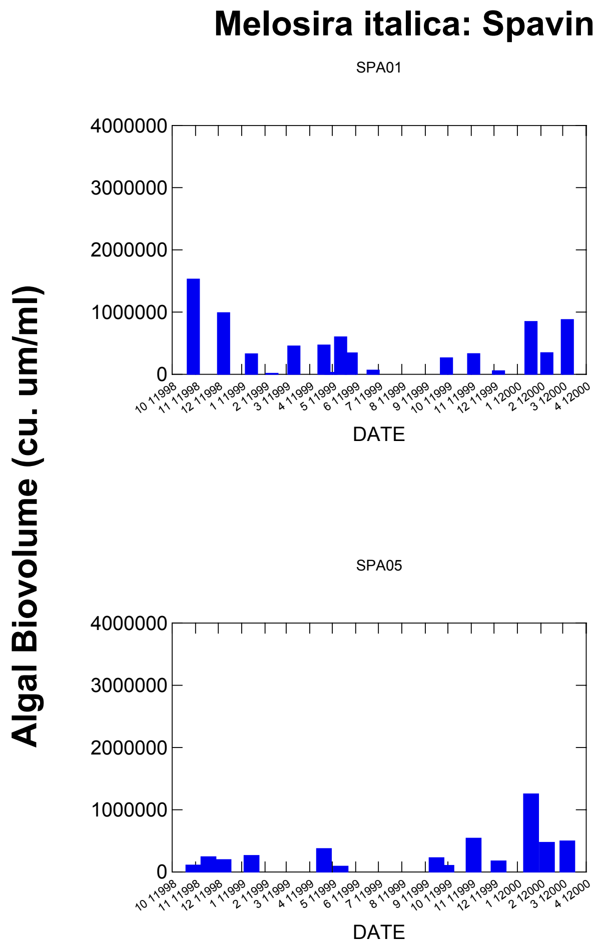


Figure 47: Algal Biovolume for *Melosira italica* for Spavinaw Lake at SPA01, SPA02 and SPA05 (surface samples)

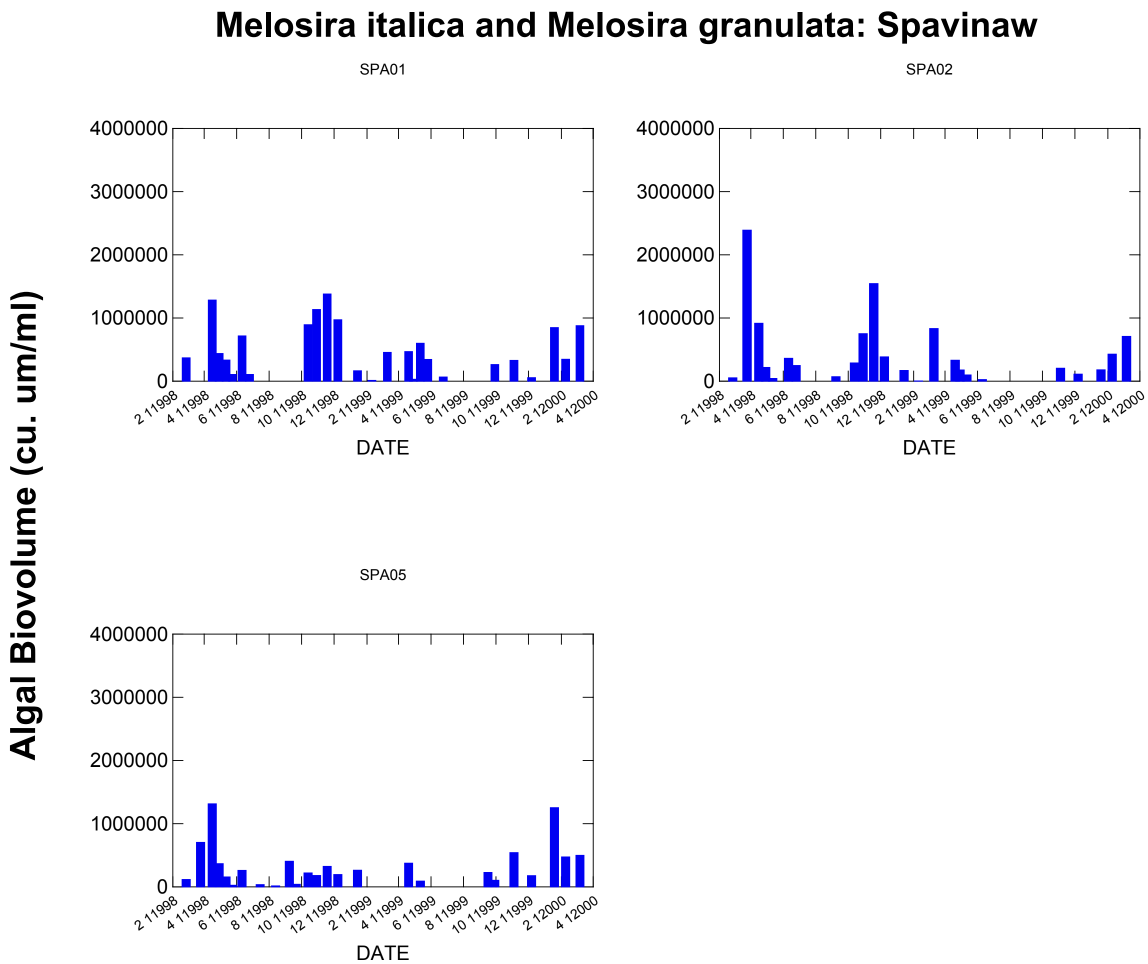


Figure 48: Algal Biovolume for *Melosira italica* and *Melosira granulata* for Spavinaw Lake at SPA01, SPA02 and SPA05 (surface samples)

Other important Diatoms included Small *Cyclotella ssp*. These taxa are generally 6 um or below (often 2-3 um) and are difficult to speciate without Electron microscopy. They are consistently present, relatively abundant at certain times of the year (see Figure 47), and due to their size and abundance can significantly affect nutrient cycles and food resources for micro zooplankton.

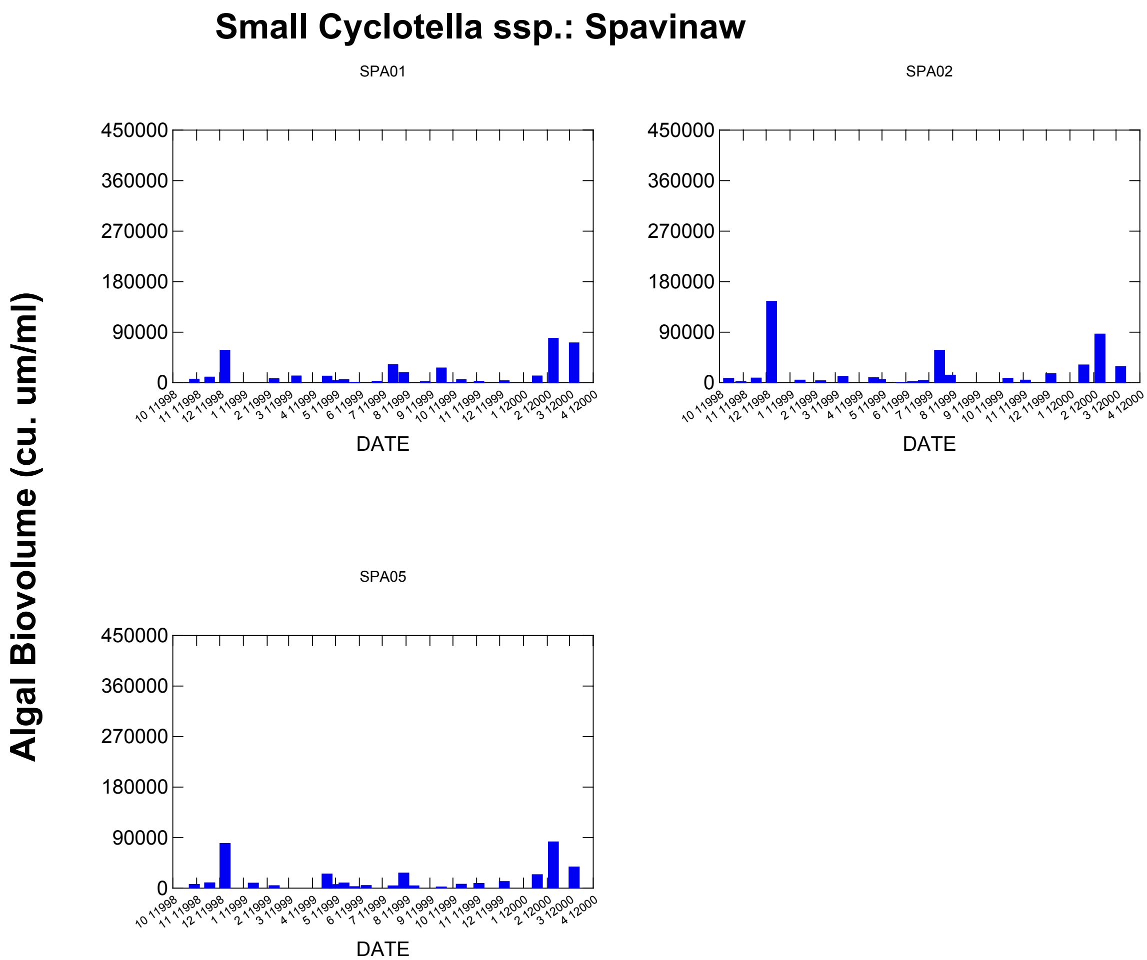


Figure 49: Algal Biovolume for *Small Cyclotella* species for Spavinaw Lake at SPA01, SPA02 and SPA05 (surface samples)

Yahola:

There is significantly less data for Lake Yahola; sampling did not begin until summer 1999. Also, there is only 1 station, 1-1. Yahola had the lowest biovolume of the three lakes and the species data support the total data. Picoplankton were consistently present, and were most abundant over the summer 1999 (see Figure 48).

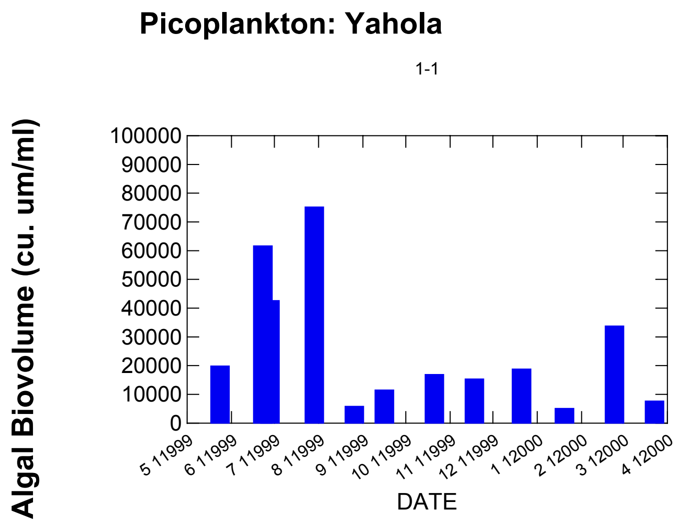


Figure 50: Algal Biovolume for Picoplankton for Lake Yahola (surface samples)

Cylindrospermopsis raciborski was present on only two dates, June 1999 and July 1999 (See Figure 49). This level was lower than both Eucha and Spavinaw. None of the Anabaena species were present in any considerable numbers in Lake Yahola. *Anabaena circinalis* was completely absent during the study period.

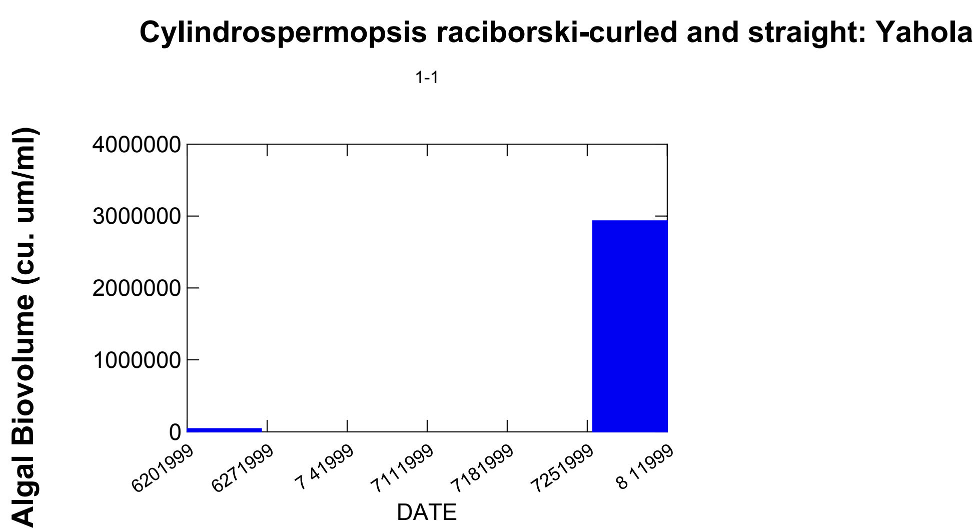


Figure 51: Algal Biovolume for *Cylindrospermopsis raciborski* curled and straight for Lake Yahola (surface samples)

Oscialltoria limnetica was present in Lake Yahola in late summer 1999 (See Figure 50). Its biovolume was consistent with that in Eucha and Spavinaw Lakes.

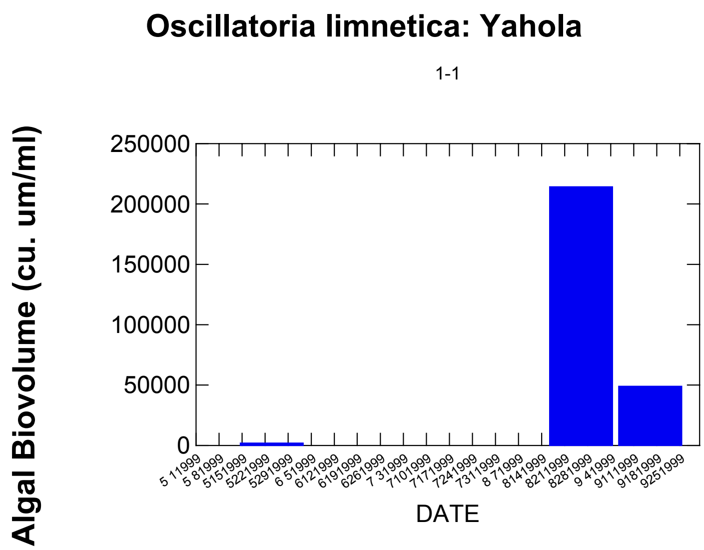


Figure 52: Algal Biovolume for *Oscillatoria limnetica* for Lake Yahola (surface samples)

Stephanodiscus niagare was present during many of the sampling dates for Yahola. Total biovolume was often as high as in Eucha and Spavinaw Lakes, but due to the lack of data, there was no specific pattern (See Figure 51).

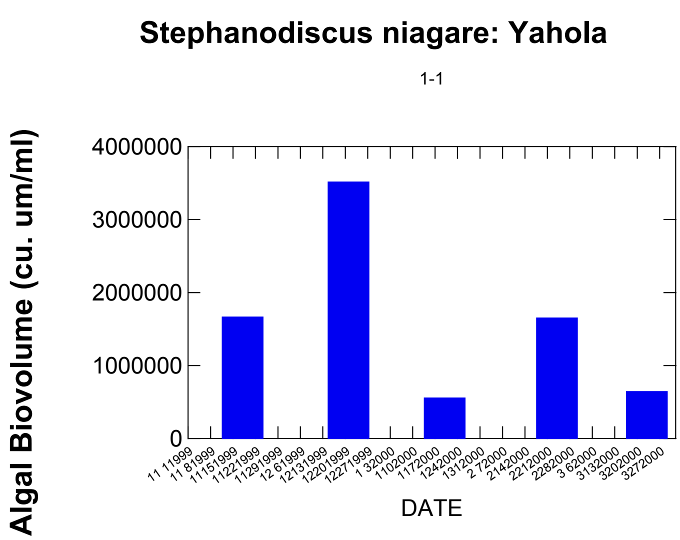


Figure 53: Algal Biovolume for Staphanodiscus niagare for Lake Yahola (surface samples)

Melosira italica and *M. granulata* were present in mid-summer 1999 and then again bloomed in the fall of 1999 into winter 2000. Both species combined show essentially the same pattern. In contrast to Eucha and Spavinaw Lakes, the early fall 1999 bloom exceeded the biovolume (over 5 x 10^6 μm^3 /mL) in those two lakes (See Figure 52).

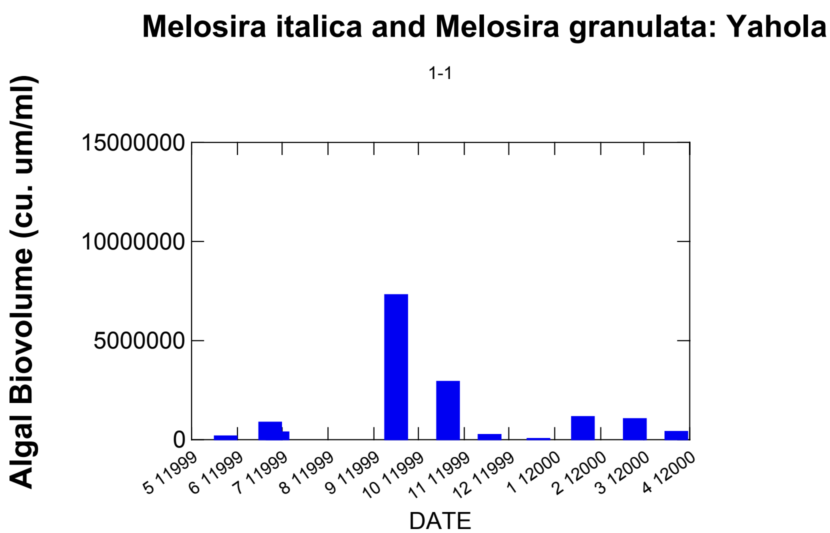


Figure 54: Algal Biovolume for *Melosira italica* and *Melosira granulata* for Lake Yahola (surface samples)

Cyclotella ssp. was also present in Lake Yahola. The total biovolume was higher on two occasions than in Eucha and Spavinaw Lakes: July 1999 and March 2000 (See Figure 53).

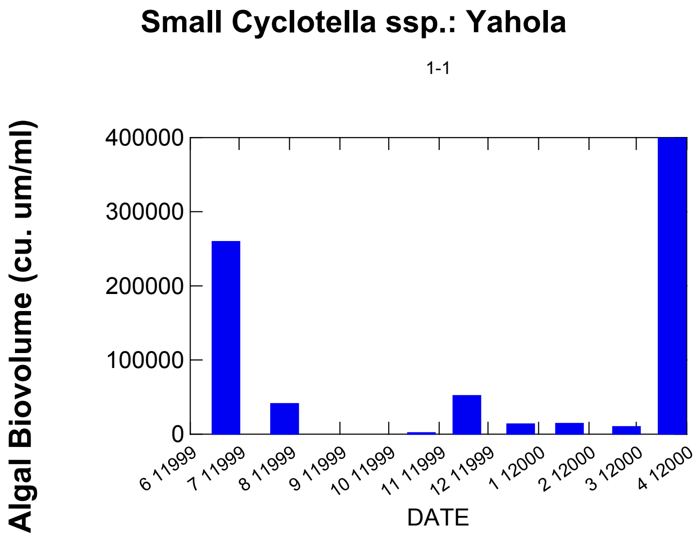


Figure 55: Algal Biovolume for Small Cyclotella species for Lake Yahola (surface samples)

Chlorophyll a and TSI

Eucha:

Chlorophyll a data indicate similar patterns to Algal Abundance and Biovolume, with more noise (See Figure 54). Chlorophyll a was lowest in Eucha during the winter months, although there was substantial missing data during those time periods. Trends in the Chlorophyll a data indicate significantly higher biomass in 1999, consistent with Algal and Biovolume data as well. Overall Chlorophyll a was lowest at EUC01 on most dates, the exception being in early June 1999 when there was a substantial peak in the high 80's. The TSI was consistently above 50, indicating an eutrophic system (See Figure 55).

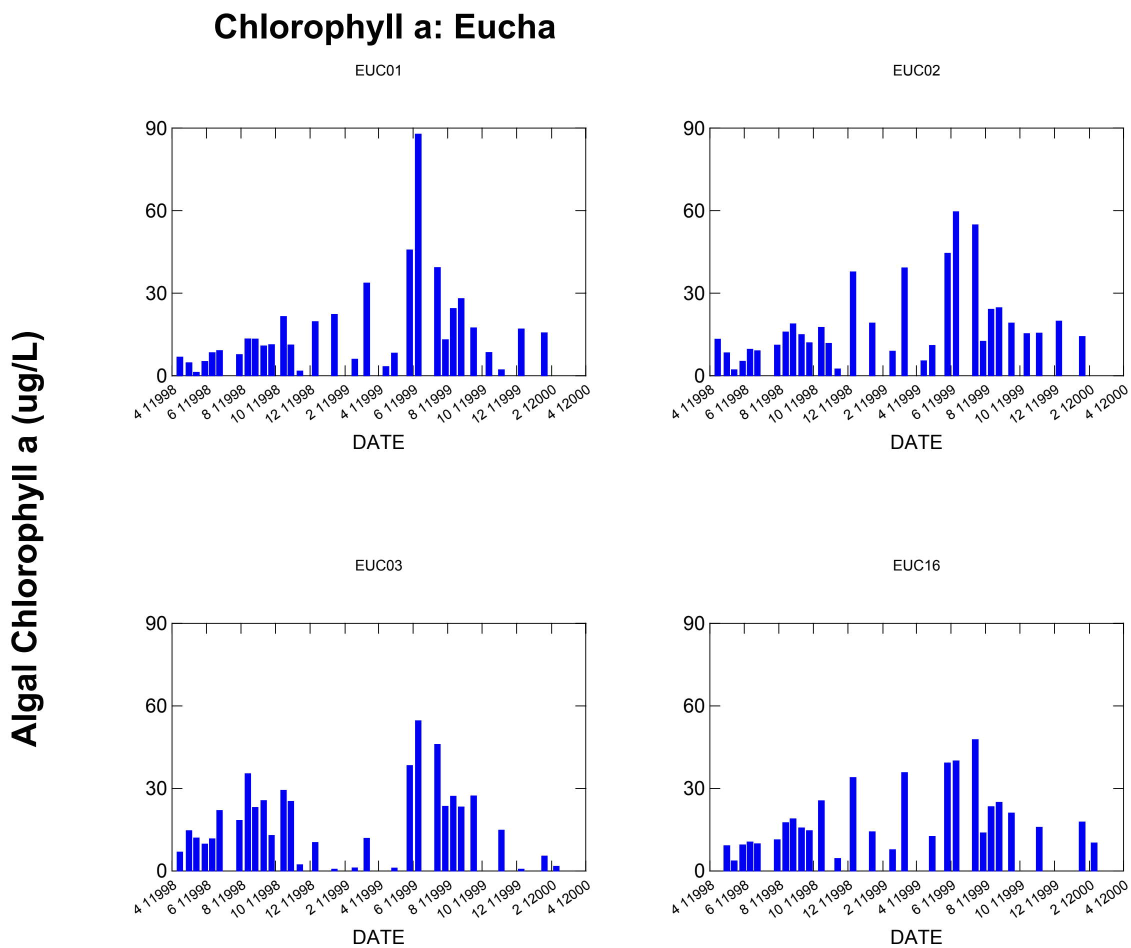


Figure 56: Chlorophyll a: Eucha Lake

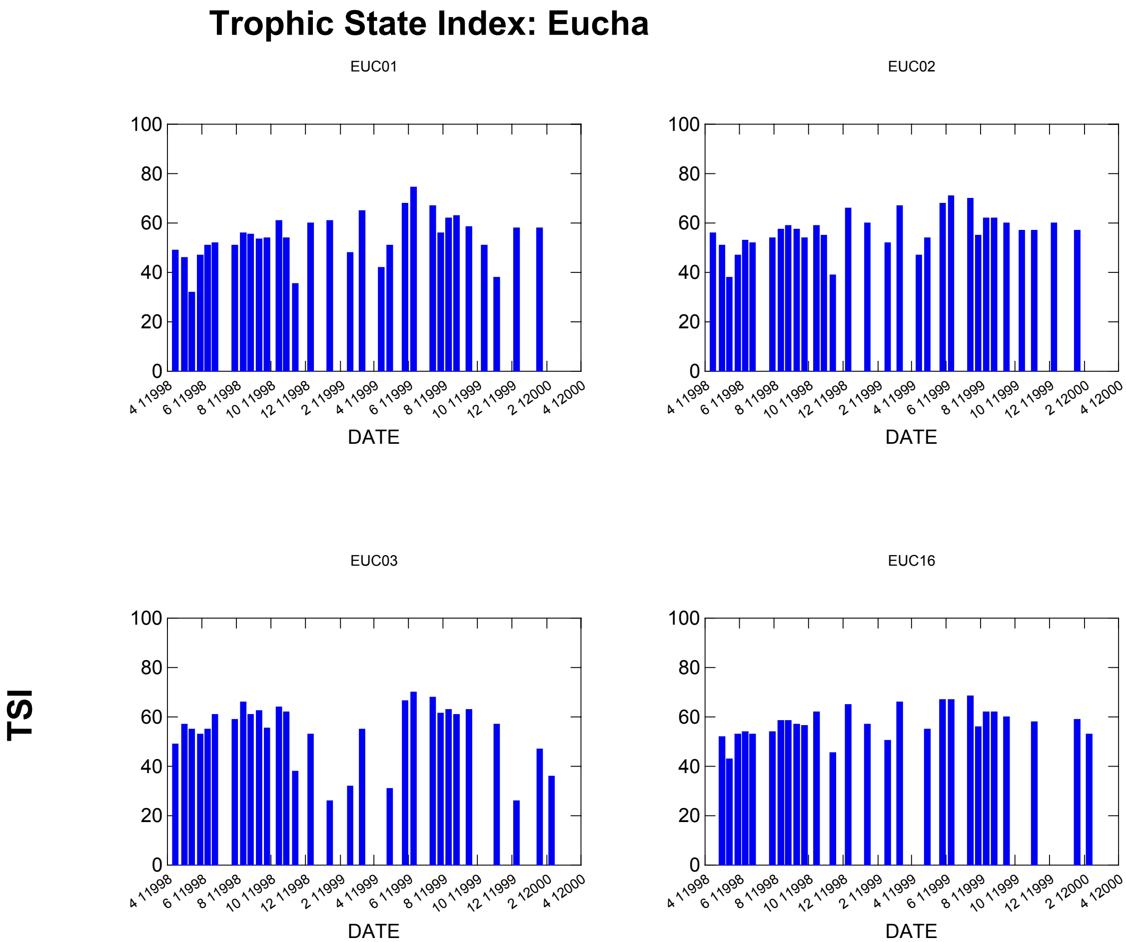


Figure 57: Trophic State Index, Eucha Lake

Spavinaw:

Chlorophyll a data indicate similar patterns to Algal Abundance and Biovolume, with more noise (See Figure 56). Chlorophyll a was lowest in Spavinaw during the winter months, although there was substantial missing data during those time periods. Trends in the Chlorophyll a data indicate significantly higher biomass in 1999, consistent with Algal and Biovolume data as well. Overall Chlorophyll a was remarkably consistent on most dates at the three stations. Although overall Chlorophyll a was lower in Spavinaw than in Eucha, it was also more consistent throughout the year, maintaining higher pigment levels in winter and early spring. The TSI was often above 50, even more so than Eucha, indicating an eutrophic system (See Figure 57). Interestingly the TSI was higher in Spavinaw when Chlorophyll a levels are lower, as well as algal indicators of biomass.

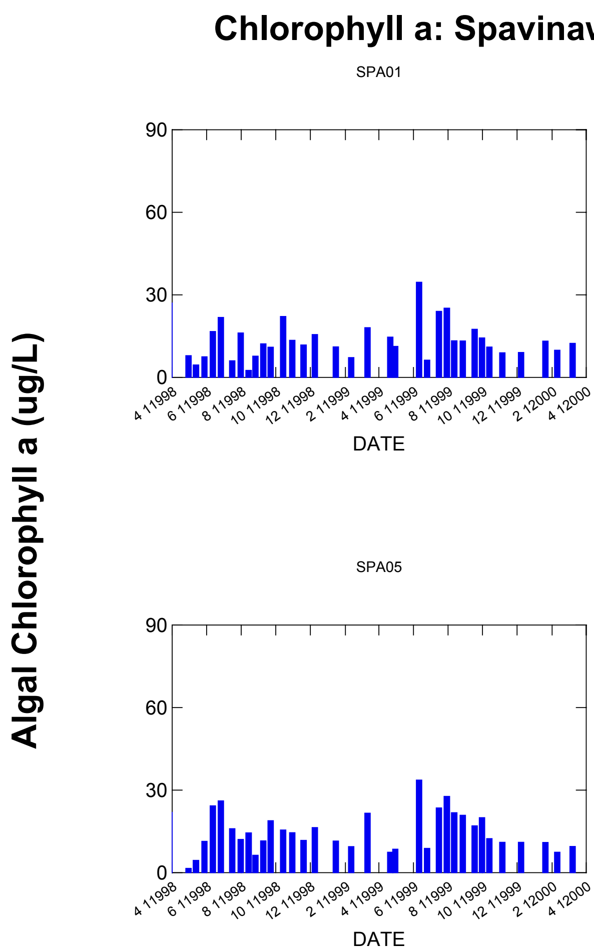


Figure 58: Chlorophyll a, Spavinaw Lake

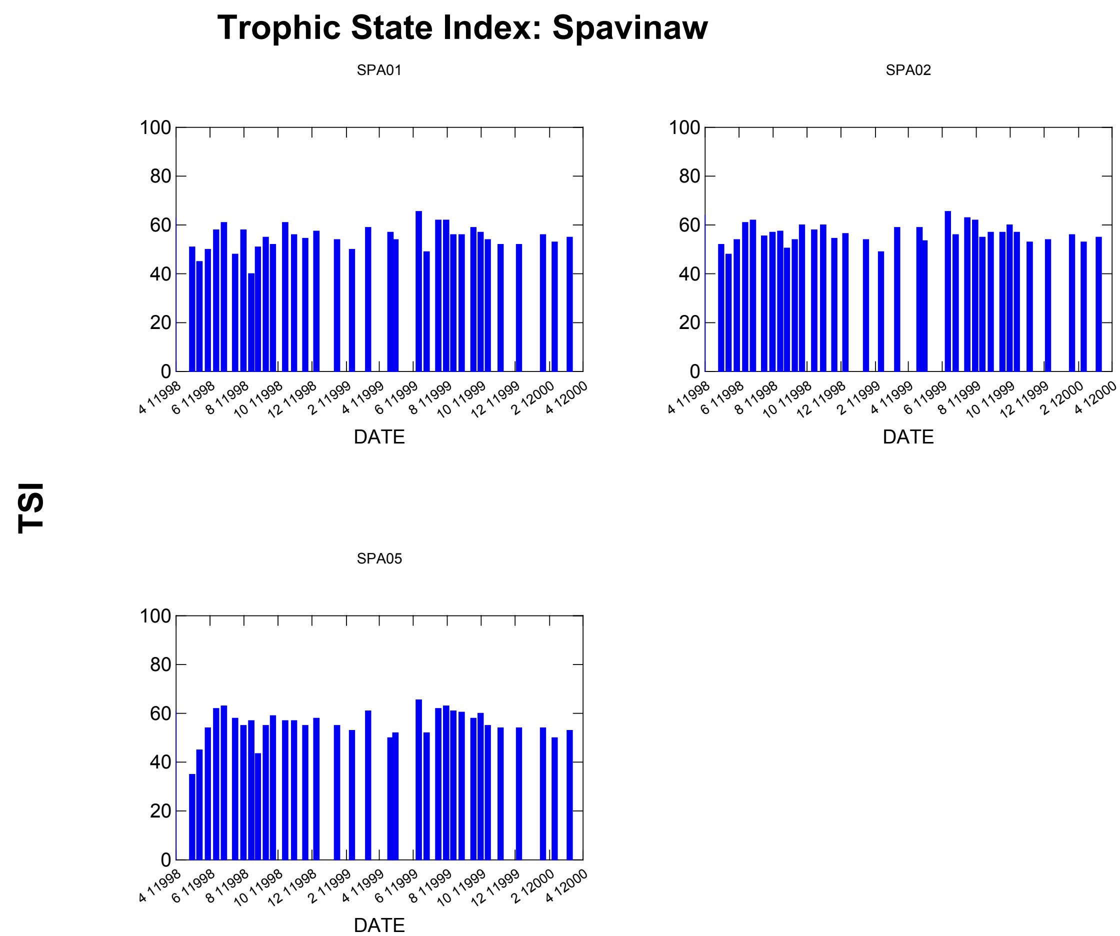


Figure 59: Trophic State Index, Spavinaw Lake

Yahola:

Chlorophyll a data indicate similar patterns to Algal Abundance and Biovolume, with more noise and significant missing data in late 1998 and early 1999 (See Figure 58). Chlorophyll a was lowest in Yahola during the winter months, although there was substantial missing data during those time periods. Trends in the Chlorophyll a data cannot be assessed to be significantly higher biomass in 1999 due to missing data. The TSI was often almost always above 50, even more so than Eucha and Spavinaw, indicating an eutrophic system.

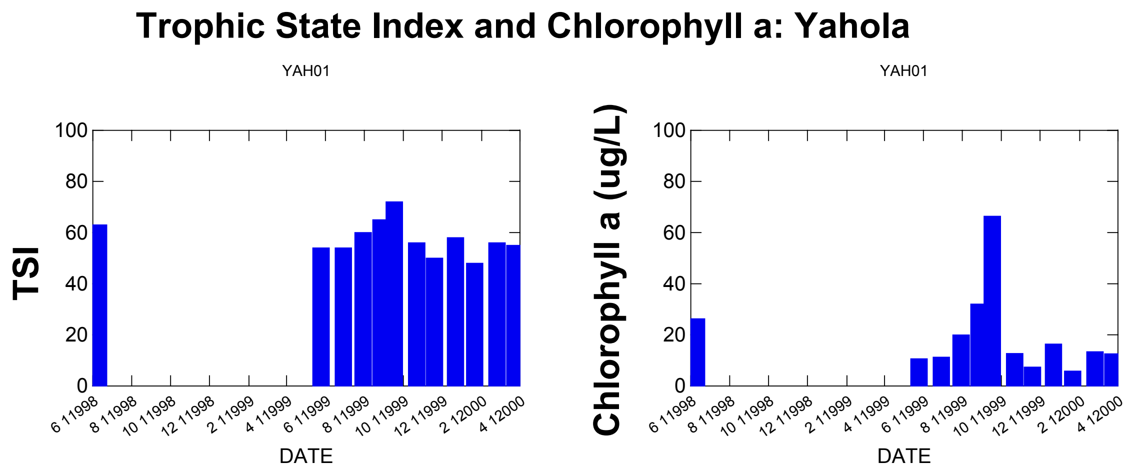


Figure 60: Trophic State Index and Chlorophyll a, Yahola Lake

Total Zooplankton Abundances and Biomass

Eucha:

Total zooplankton abundance was somewhat erratic among the stations and dates (See Figure 59). Station 3 exhibited both the highest and lowest abundances. The other stations more closely tracked each other. There were significant numbers of animals present in May 1998, with moderate peaks again in late winter, early spring 1999 and winter 2000. The largest peak, aside from high abundance at station 3 only during the summer 1998, was in November 1999, when all 4 stations were at their highest abundance. There were several times during the three-year period when zooplankton biomass was zero at station 3. This situation happened several times. Abundance at Station 1 was often the lowest of the four stations, but never reached zero.

Biomass trends were not as erratic as abundance over the years and stations (See Figure 60). High biomass was present at all 4 stations in May 1998. There were small peaks in biomass again in late winter 1999 and in October 1999. Station 2 exhibited a large peak in biomass in December 1999, while the other stations experienced low micro zooplankton biomass. Consistent with abundance, biomass often was lowest at station 1, although again, Station 3, the first in the reservoir, was erratic with several peaks and Station 3 hit zero several times during the year.

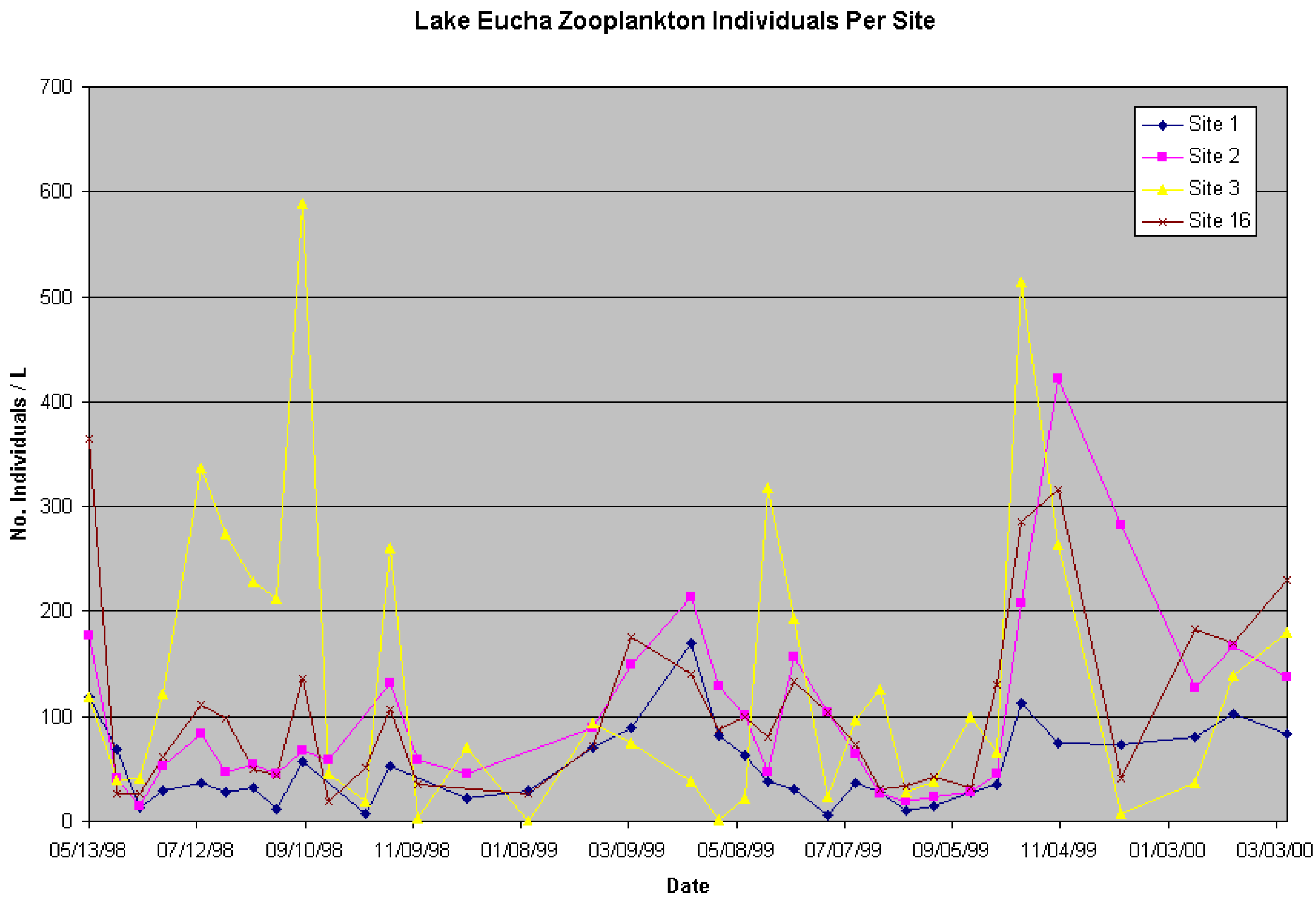


Figure 61: Zooplankton Abundance per site, Lake Eucha

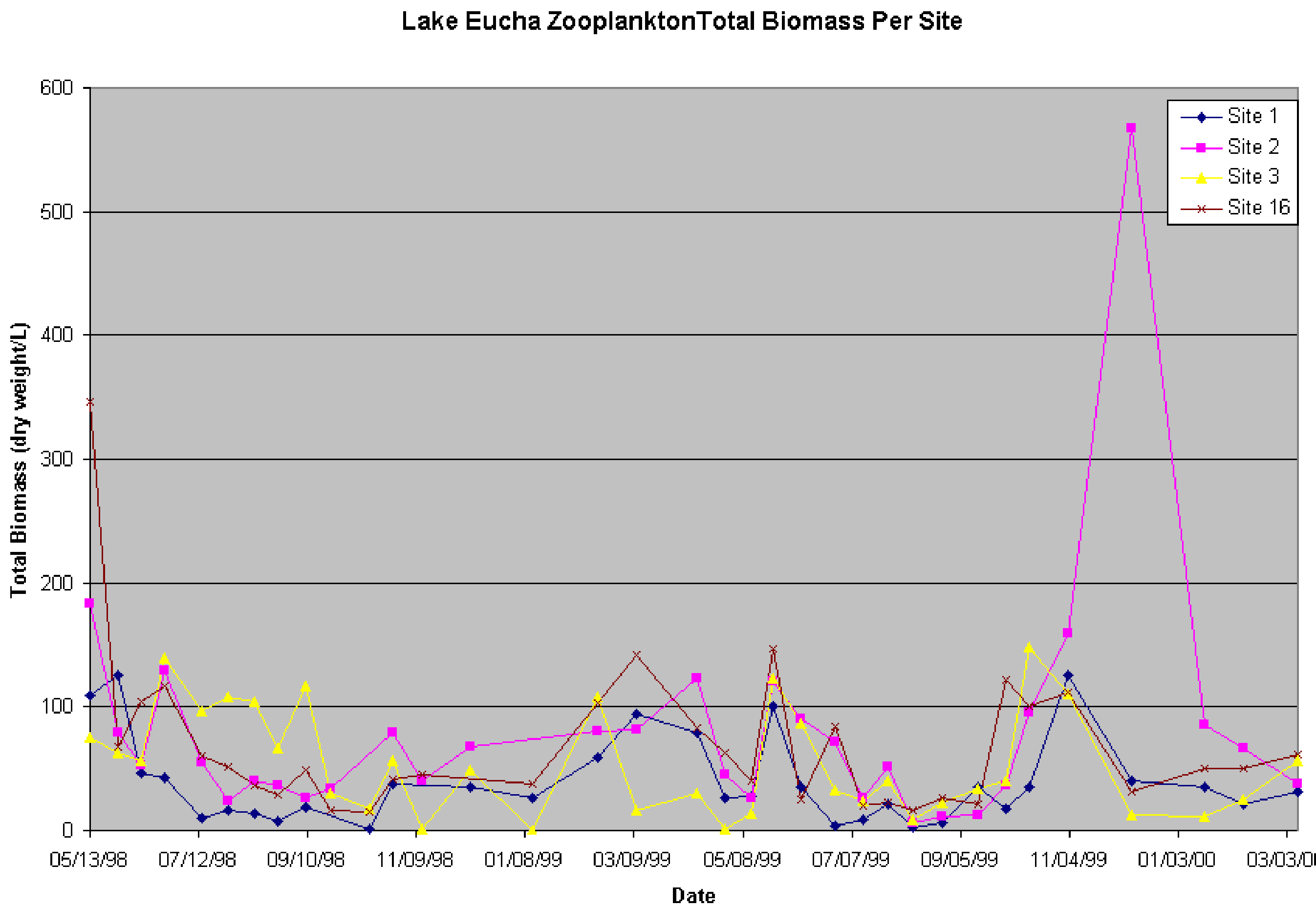


Figure 62: Zooplankton Total Biomass per site, Lake Eucha

Spavinaw:

Spavinaw lake stations exhibited less high peaks in micro zooplankton abundance, but there was more consistent abundance throughout the year (See Figure 61). There were abundance peaks in May 1998. Mid-summer 1998, late winter 1999 and late winter 2000. At other times during the year, abundance was up and down, sometimes reaching zero. As was the case with Eucha, the most erratic station was Station 5, the first station in the system. Micro zooplankton populations in Spavinaw Lake were often higher at all three stations, than Eucha during the same time period. This effect was most obvious in winter 1999 and winter 2000.

Total zooplankton biomass was consistent with abundance measurements (See Figure 62). Biomass peaked in May 1998, November 1999 and in winter 2000. There was also a biomass peak at 2 of the 3 stations in late June 1999. There were fewer instances of any of the stations experiencing zero zooplankton biomass, and the stations more closely tracked each other over the course of the sampling study. Notable exceptions were in late June 1999, and during several dates in mid-summer 1998.

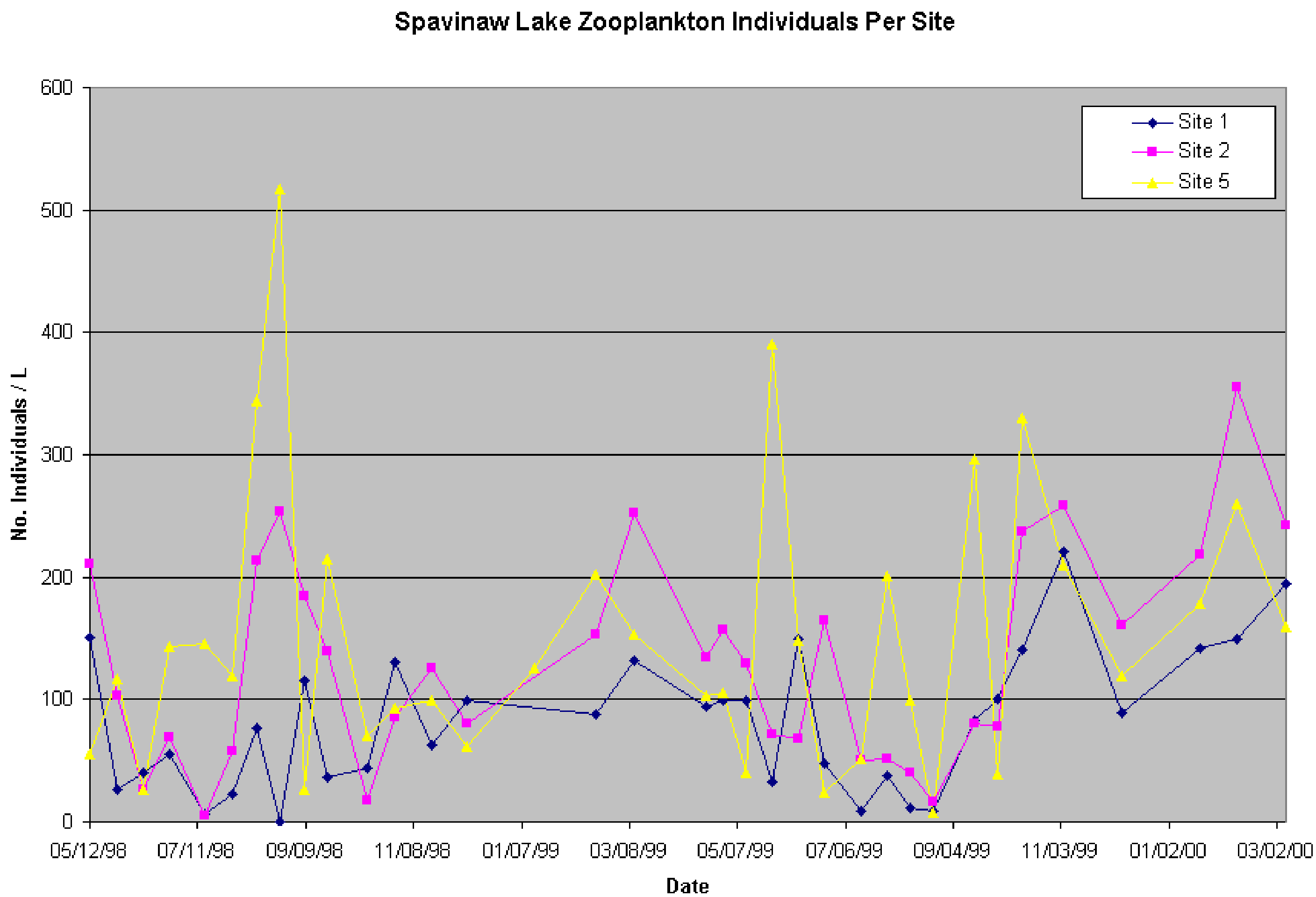


Figure 63: Zooplankton Abundance per site, Spavinaw Lake

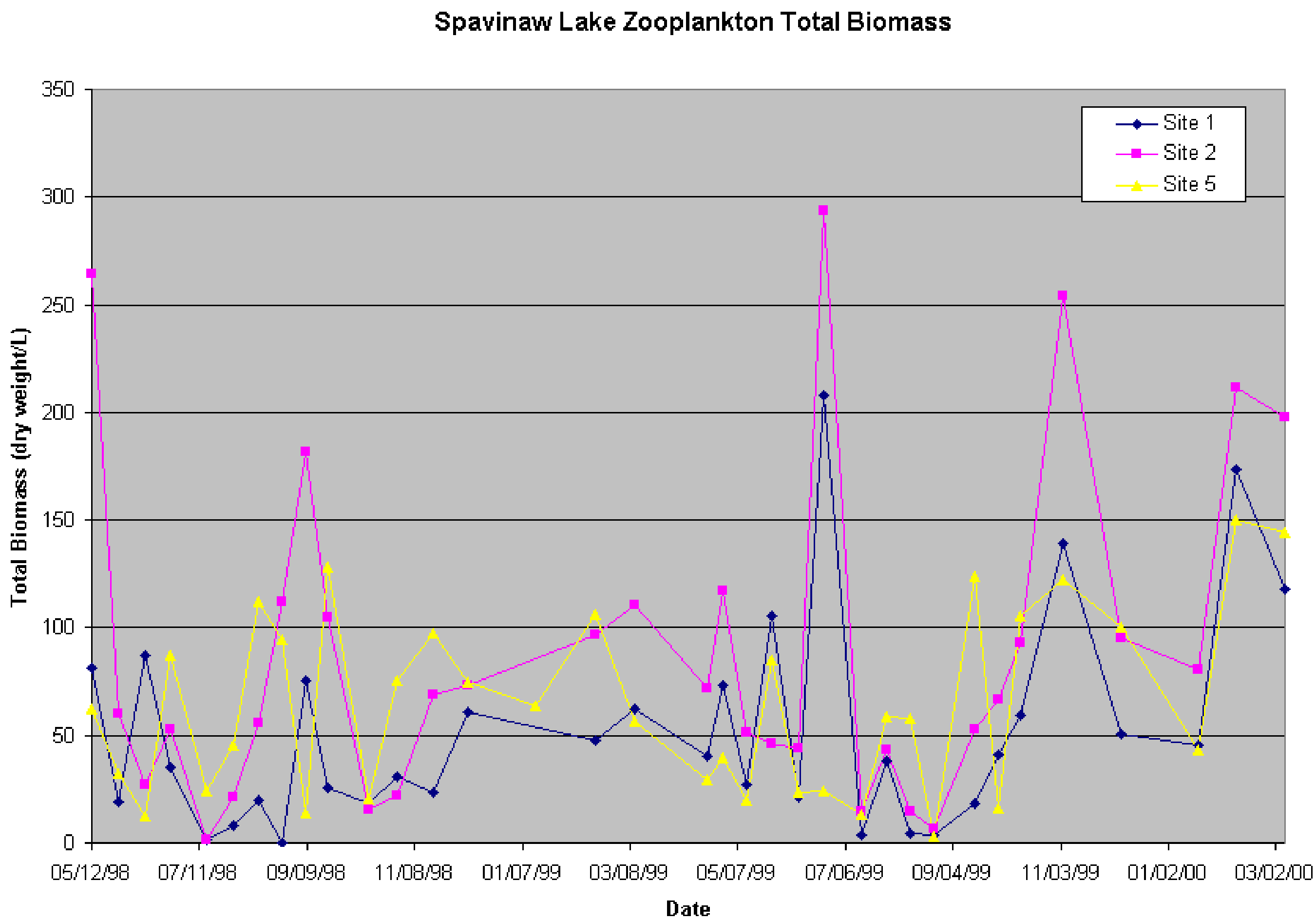


Figure 64: Zooplankton Total Biomass per site, Spavinaw Lake

Zooplankton Group Abundance and Biomass Totals

Eucha -Abundance

Individual group totals for all stations indicate rotifers dominate numerically most of the dates (See Figures 63-66). Especially summer 1998, winter 1999 and after a small summer 1999 peak again in winter 2000. Nauplii follow a similar pattern to Rotifers, with more consistent abundance throughout the year and lower peaks. There were several occasions on which Nauplii were not present at all, generally in mid-late summer. Ostracods are not numerically important on any date, at any stations. Copepods were relatively abundant during the summer 1998; with a peak at all stations except EUC03 in late winter 1999 with a similar pattern the following year. At Station EUC03 Cladocerans were never very abundant, compared with other groups. At the other three stations, Cladocerans were relatively more abundant, reaching the highest abundance at station EUC02. Cladoceran abundance was lower again at the last station, EUC01.

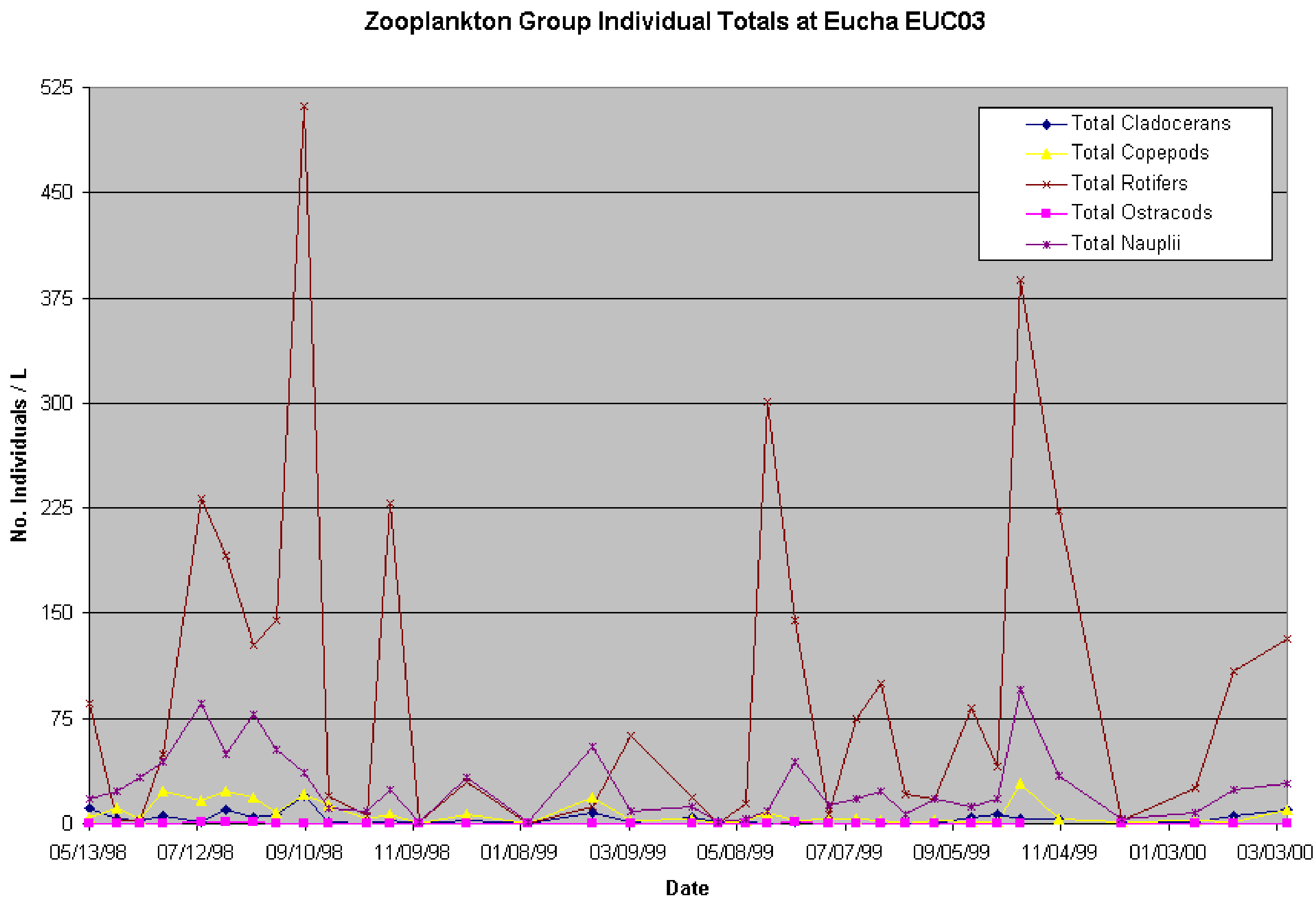


Figure 65: Zooplankton Abundance by Group for Eucha-03

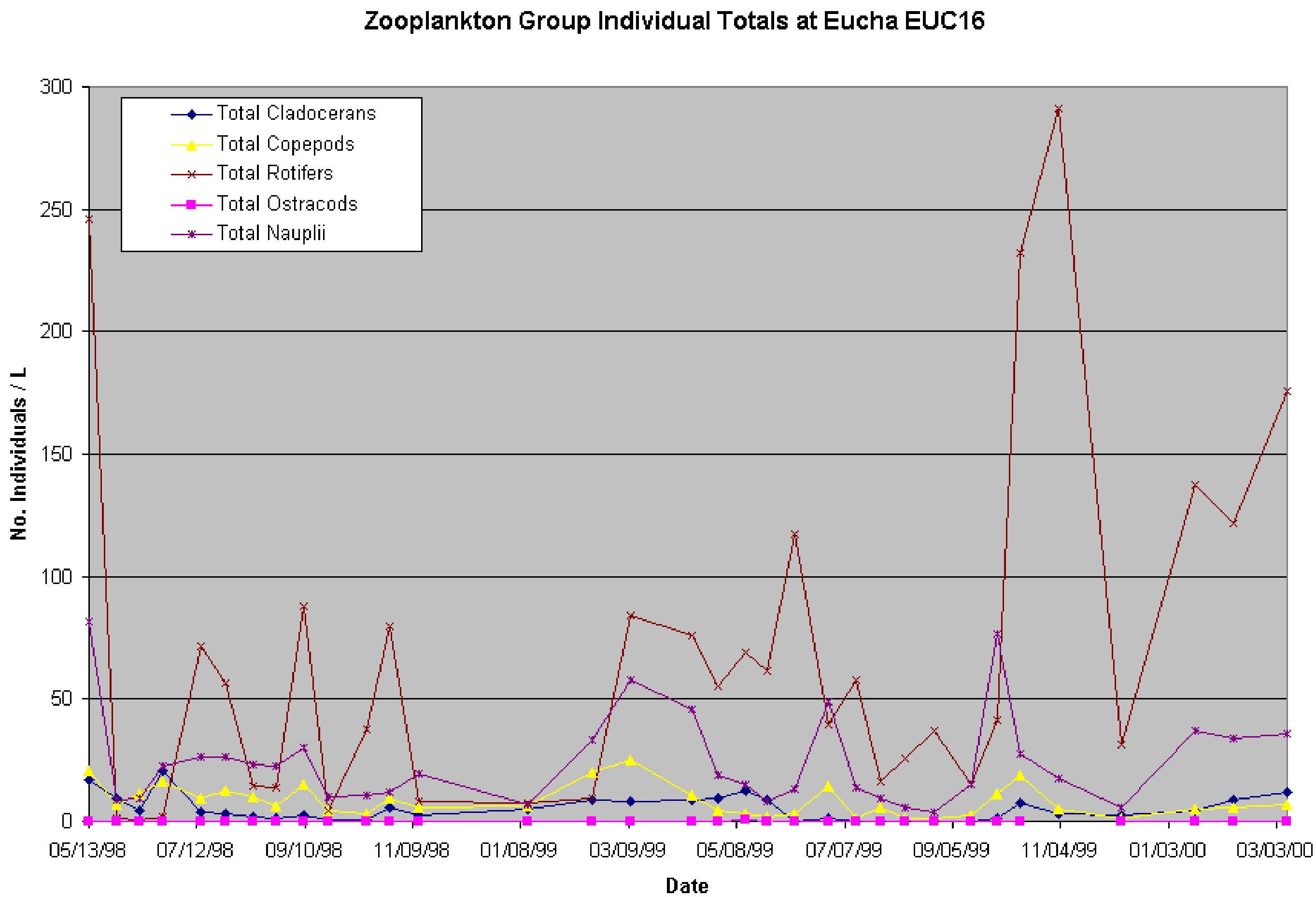


Figure 66: Zooplankton Abundance by Group for Eucha-16

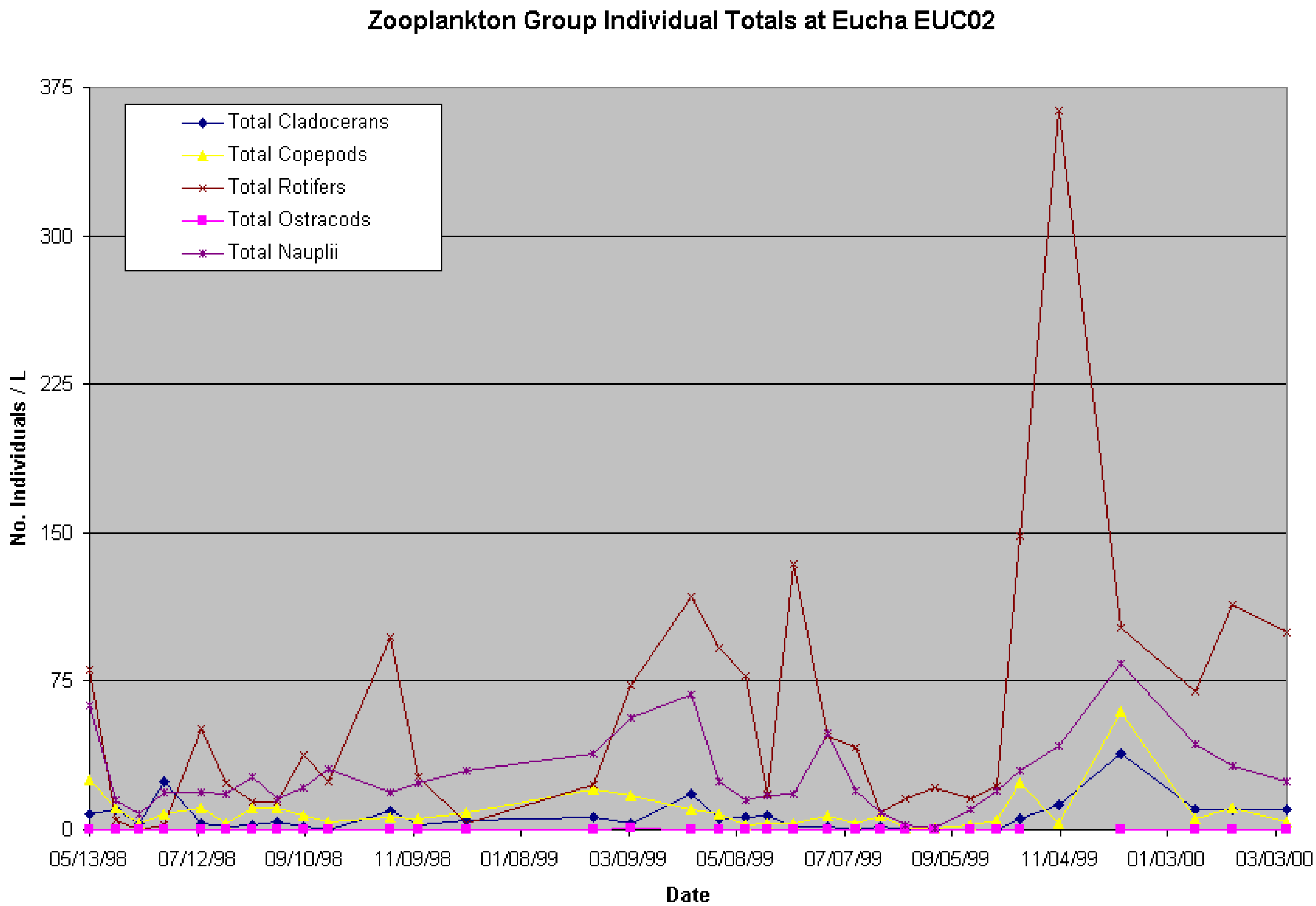


Figure 67: Zooplankton Abundance by Group for Eucha-02

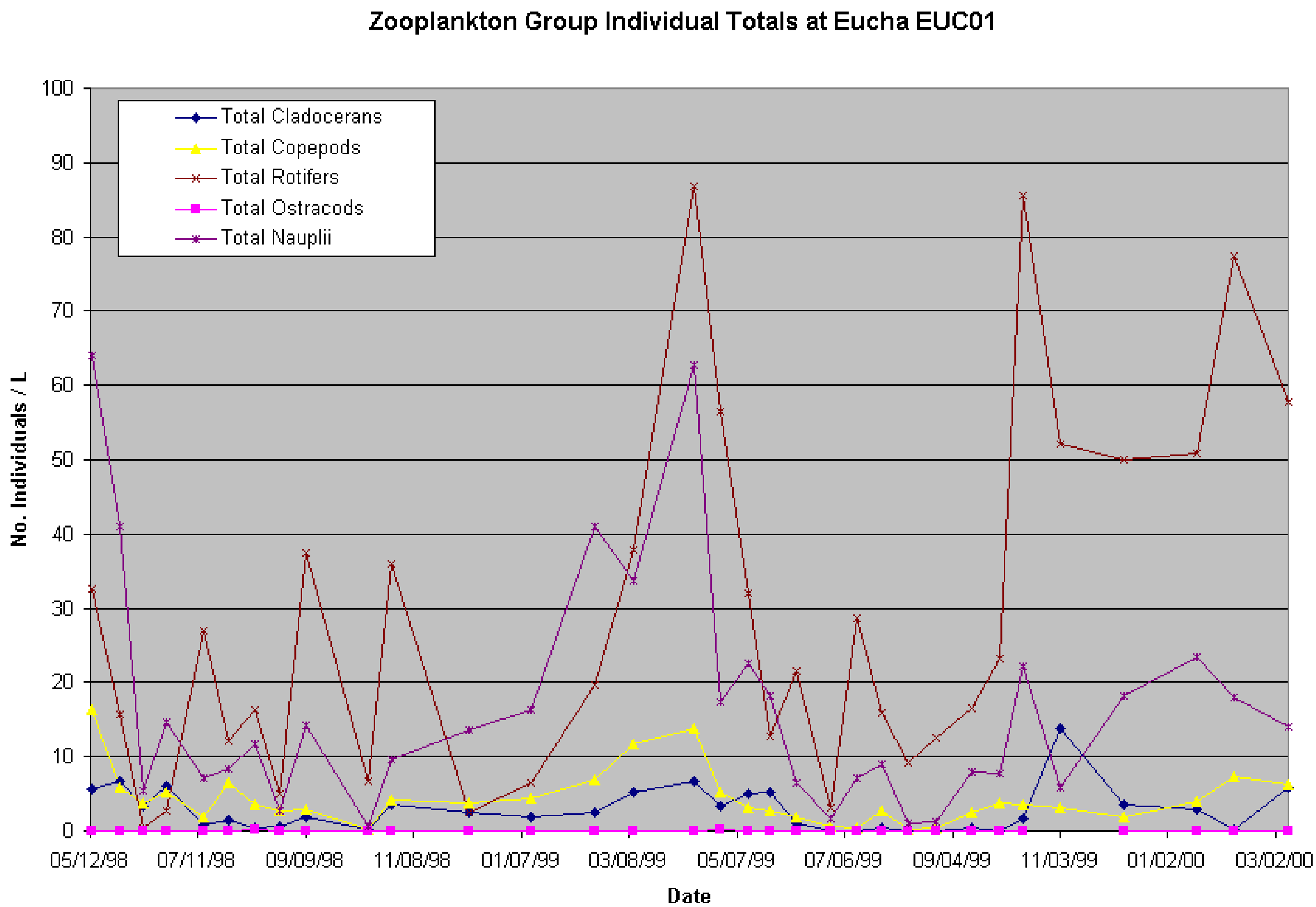


Figure 68: Zooplankton Abundance by Group for Eucha-01

Relative Biomass:

Although Rotifers dominate Eucha numerically, due to their small size, they rarely account for more than 20% of the assemblage at any of the stations (See figures 67-70). Exceptions are at EUC03, where a mid summer peak in 1998 accounted for over 30% of the zooplankton biomass. Rotifers became less dense as flow progressed from station EUC03 to EUC01 at the dam. Rotifer biomass generally peaked in early-mid summer and again in late fall, although the trend is strongest at station EUC03.

Copepods and Cladocerans are the most important contributors in terms of biomass. Copepods often peak when Cladocerans are present in low biomass (late summer 1998 and 1999), but also are equally important during several dates during winter months. Copepods dominate consistently over 80% of the assemblage at station EUC03, and account for over 90% of the biomass during summer 1998 and summer 1999. Cladocerans rarely account for more biomass than Copepods at EUC03, but are more important at other stations going downstream (e.g. early summer 1998 and late fall 1999). Ostracods never represented significant biomass at any of the stations.

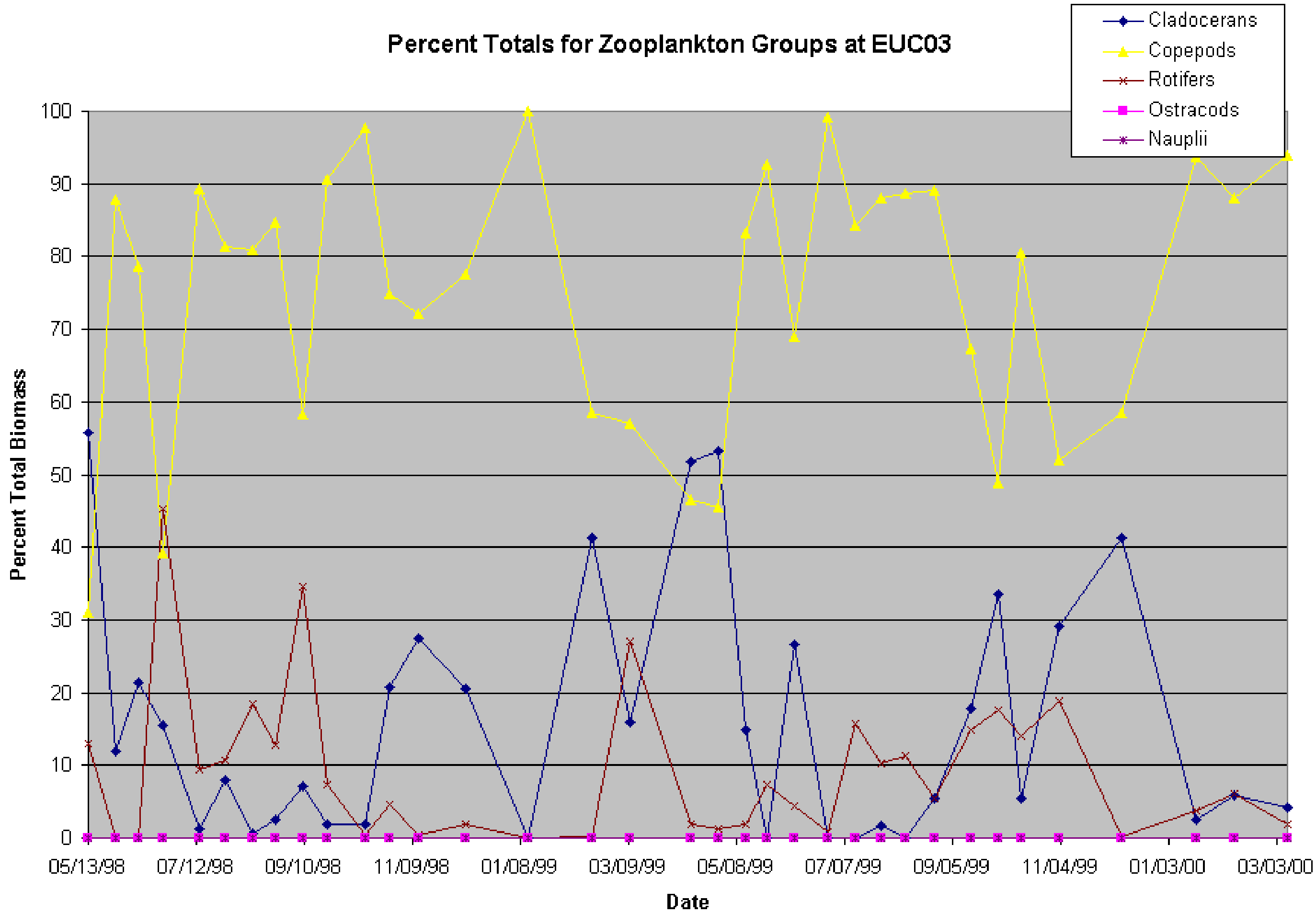


Figure 69: Percent Totals for Zooplankton Groups at Eucha-03

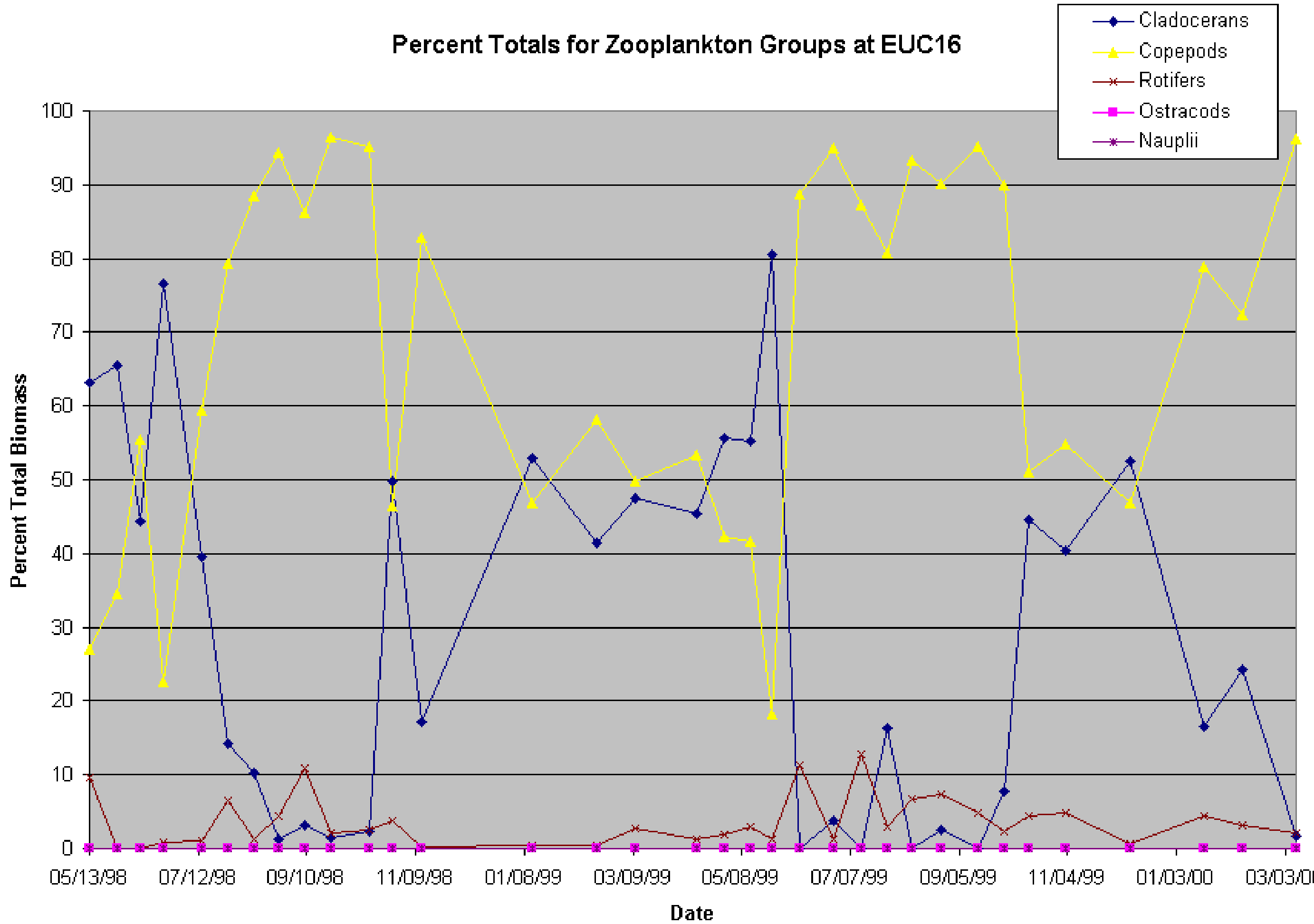


Figure 70: Percent Totals for Zooplankton Groups at Eucha-16

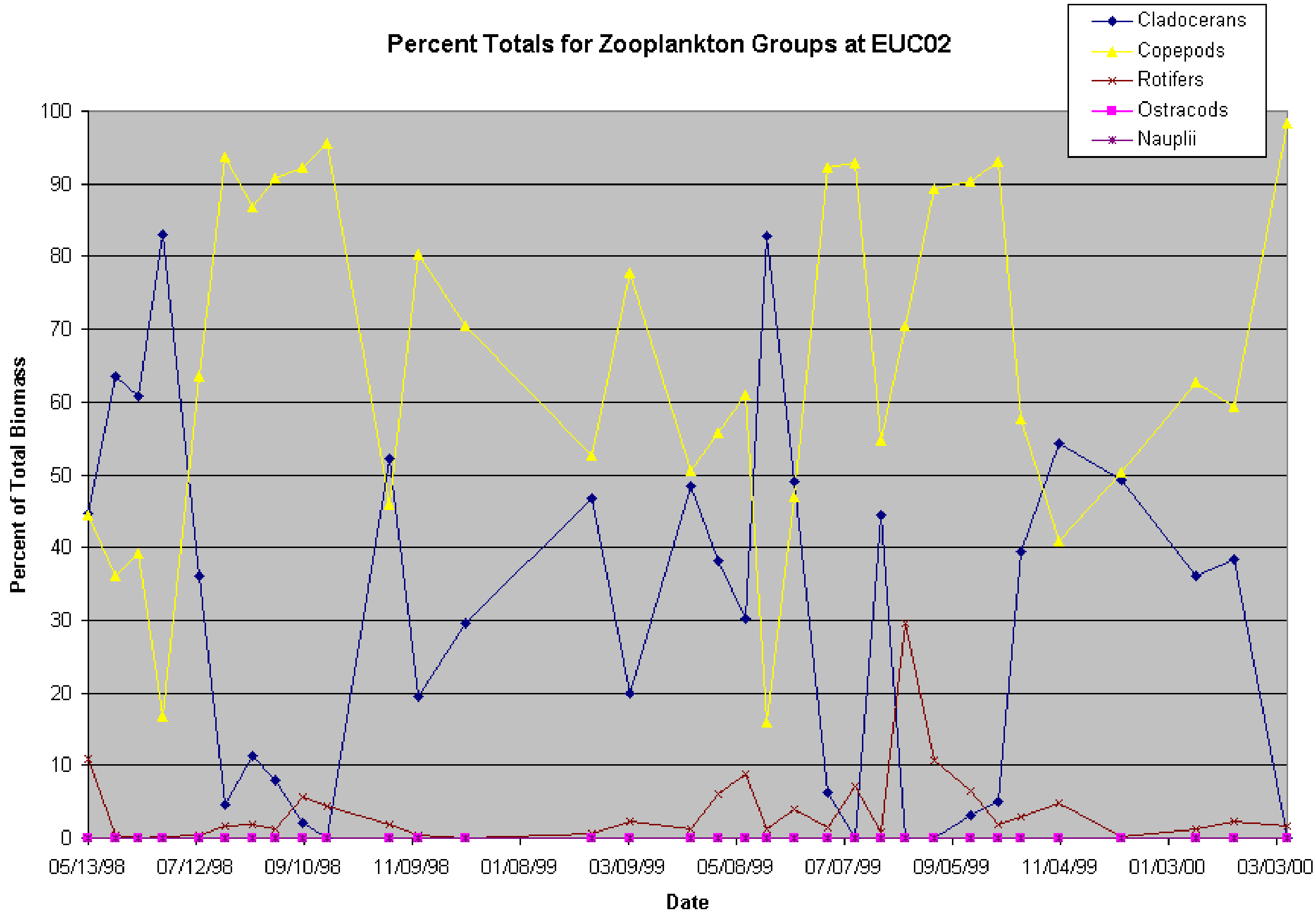


Figure 71: Percent Totals for Zooplankton Groups at Eucha-02

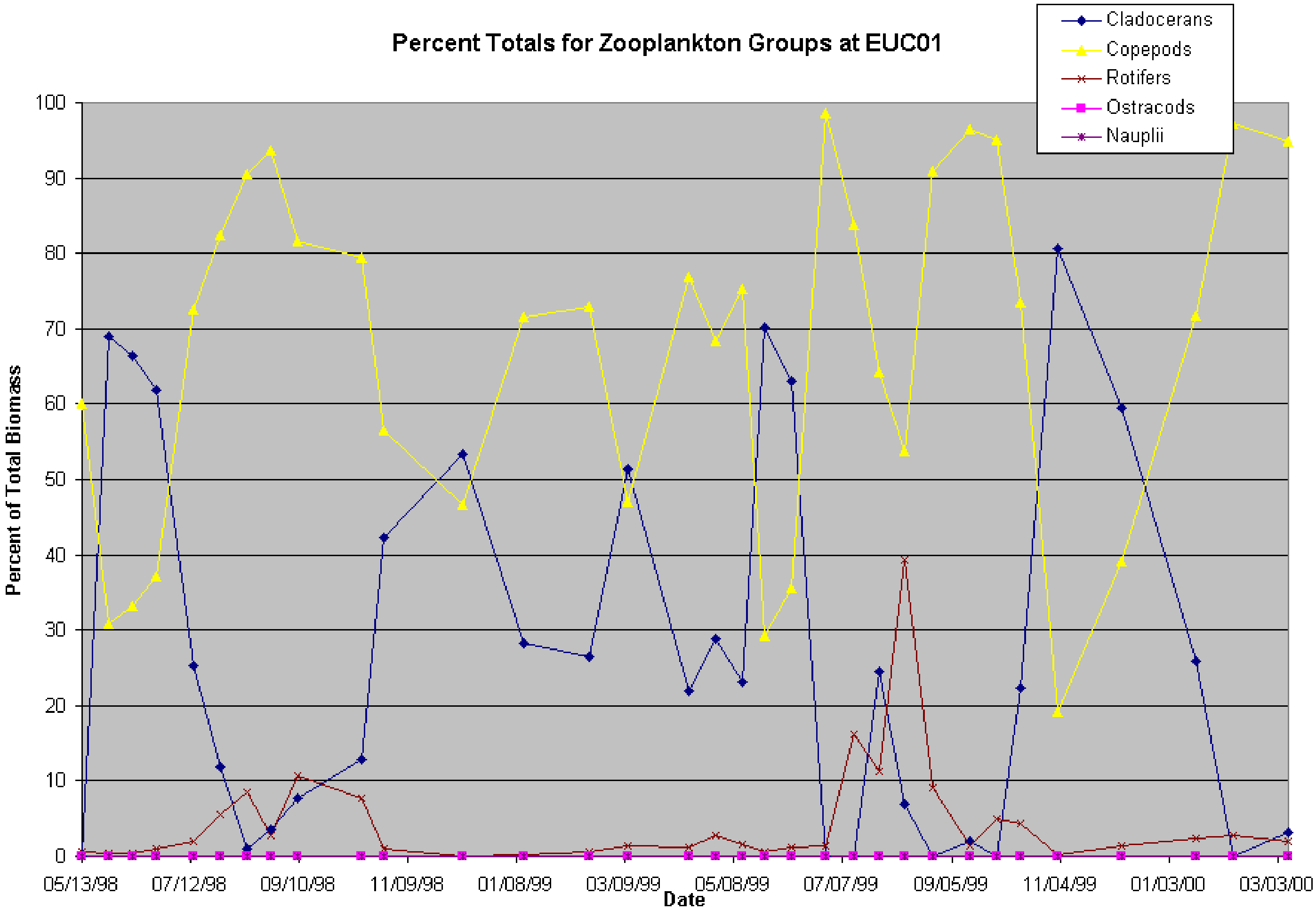


Figure 72: Percent Totals for Zooplankton Groups at Eucha-01

Spavinaw -Abundance:

Individual group totals for all stations indicate rotifers dominate numerically most of the dates (See Figures 71-73). Especially summer 1998, winter 1999 and after a small summer 1999 peak again in winter 2000. Rotifer abundance is more erratic, peaking and dropping markedly, especially at EUC03. Zooplankton biomass, in general, was not as high as in Eucha, but followed a similar pattern of decreasing abundance in total abundance as the flow progressed downstream. Nauplii followed a similar pattern to Rotifers, with more consistent abundance throughout the year and lower peaks. Ostracods were not numerically important on any date, at any stations. Copepods were relatively abundant during the summer 1998, with a small peak at all stations, with a similar pattern the following year. There were also small peaks during the late winter months. Cladocerans were never very abundant, compared with other groups. Cladoceran abundance peaked in early summer lagged and then peaked again in late summer into fall.

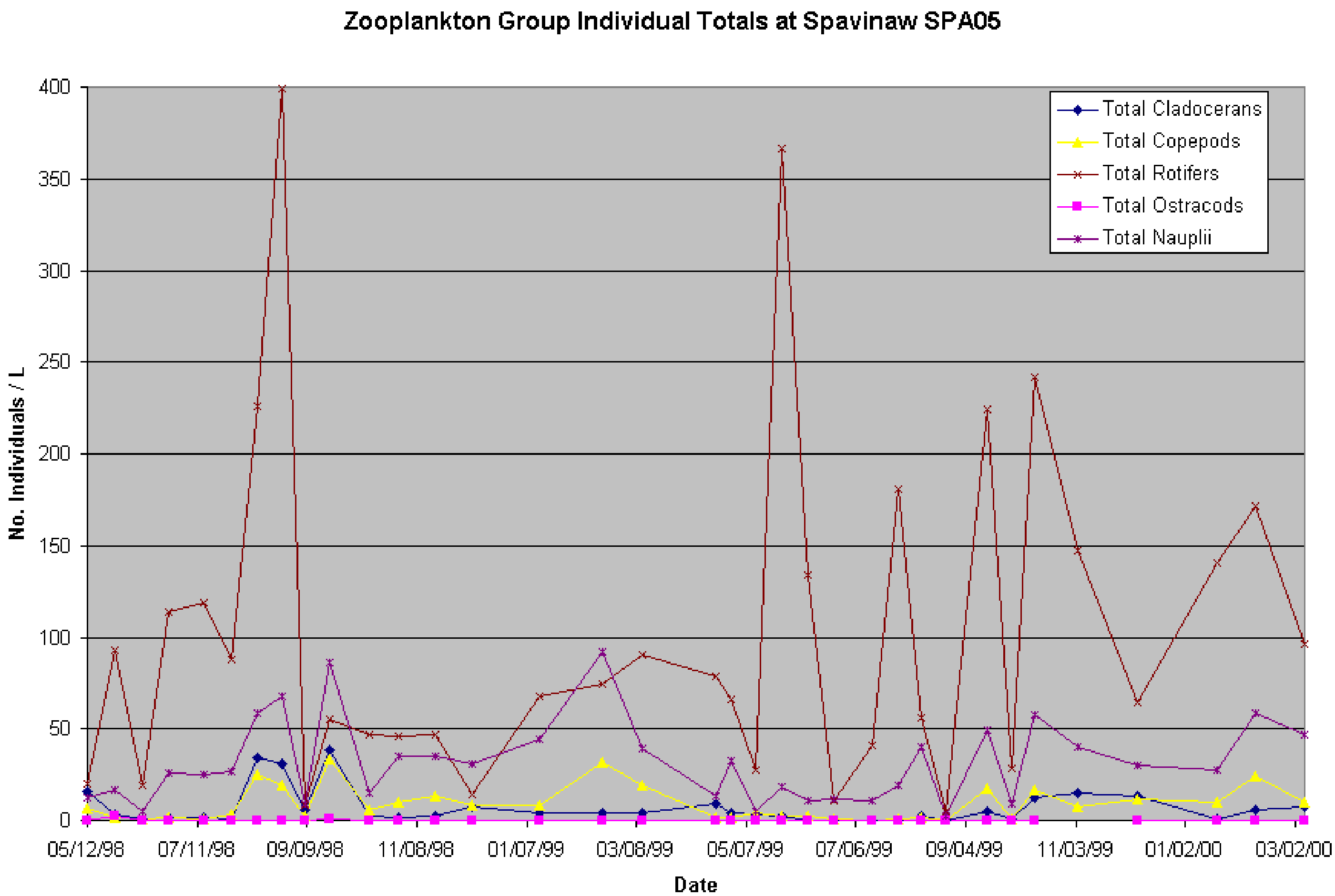


Figure 73: Zooplankton Abundance by Group for Spavinaw-05

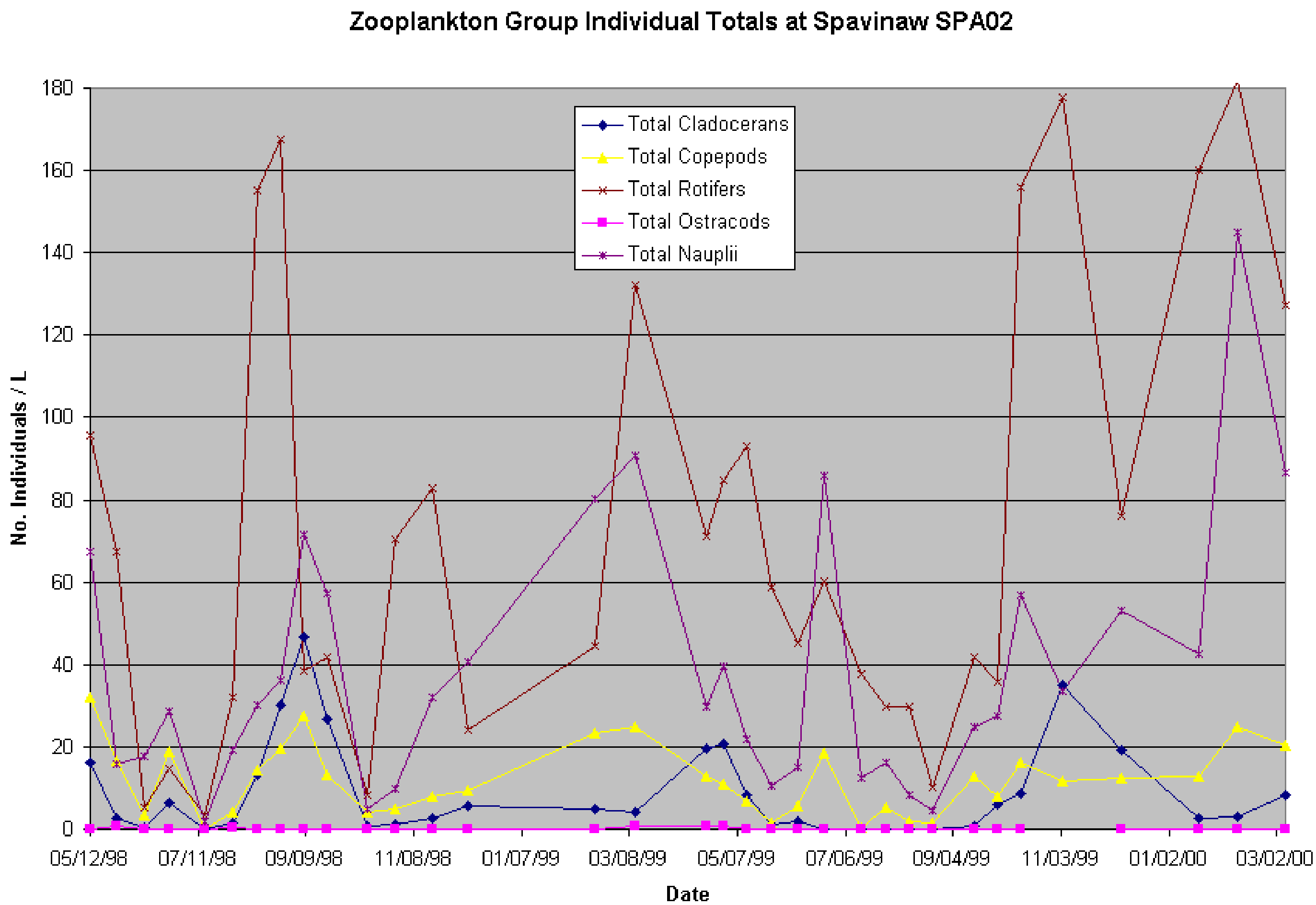


Figure 74: Zooplankton Abundance by Group for Spavinaw-02

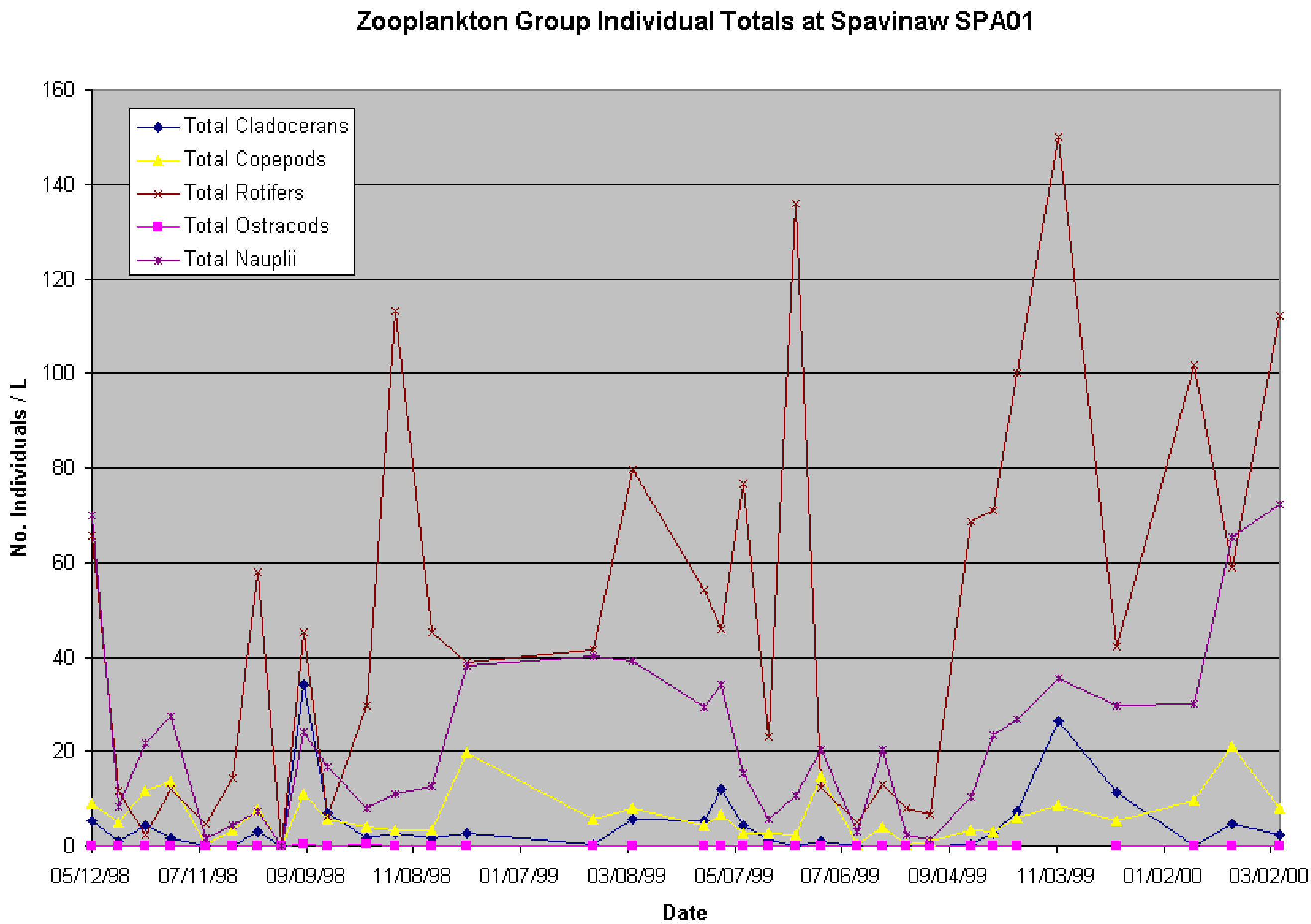


Figure 75: Zooplankton Abundance by Group for Spavinaw-01

Relative Biomass:

Although Rotifers dominate Spavinaw numerically (as in Eucha), due to their small size, they rarely account for more than 10% of the assemblage at any of the stations (See figures 74-76). Exceptions are at SPA)% in the late summer 1998, where biomass percent peaked at 70%. There was also a lake-wide bloom of Rotifers at all three stations in August, 19999, with biomass at SPA05 being the most substantial (60%). Rotifers became less dense as flow progressed from station SPA05 to SPA01 at the dam. Rotifer biomass generally peaked in early-mid summer in 1998 and late summer in 1999. In late Fall, there was also another small Rotifer peak at all three stations.

Copepods and Cladocerans are the most important contributors in terms of biomass, consistent with Eucha. Copepods often peak when Cladocerans are present in low biomass (late Summer 1998 and 1999), but also are more equally important during several dates during winter months. Copepods dominate consistently over 60% of the assemblage at most stations and dates, often accounting for >90% of the biomass in late summer. Cladocerans rarely account for more biomass than Copepods at any of the stations, the exception being June 1999, May 1998 at SPA05 only, and November 1999 at SPA01. Cladocerans generally comprise 20-30% fo the assemblage on most dates. The Cladocerans population did crash in July 1999, but rebounded in late fall at all three stations and again in winter 2000. Ostracods never represented significant biomass at any of the stations.

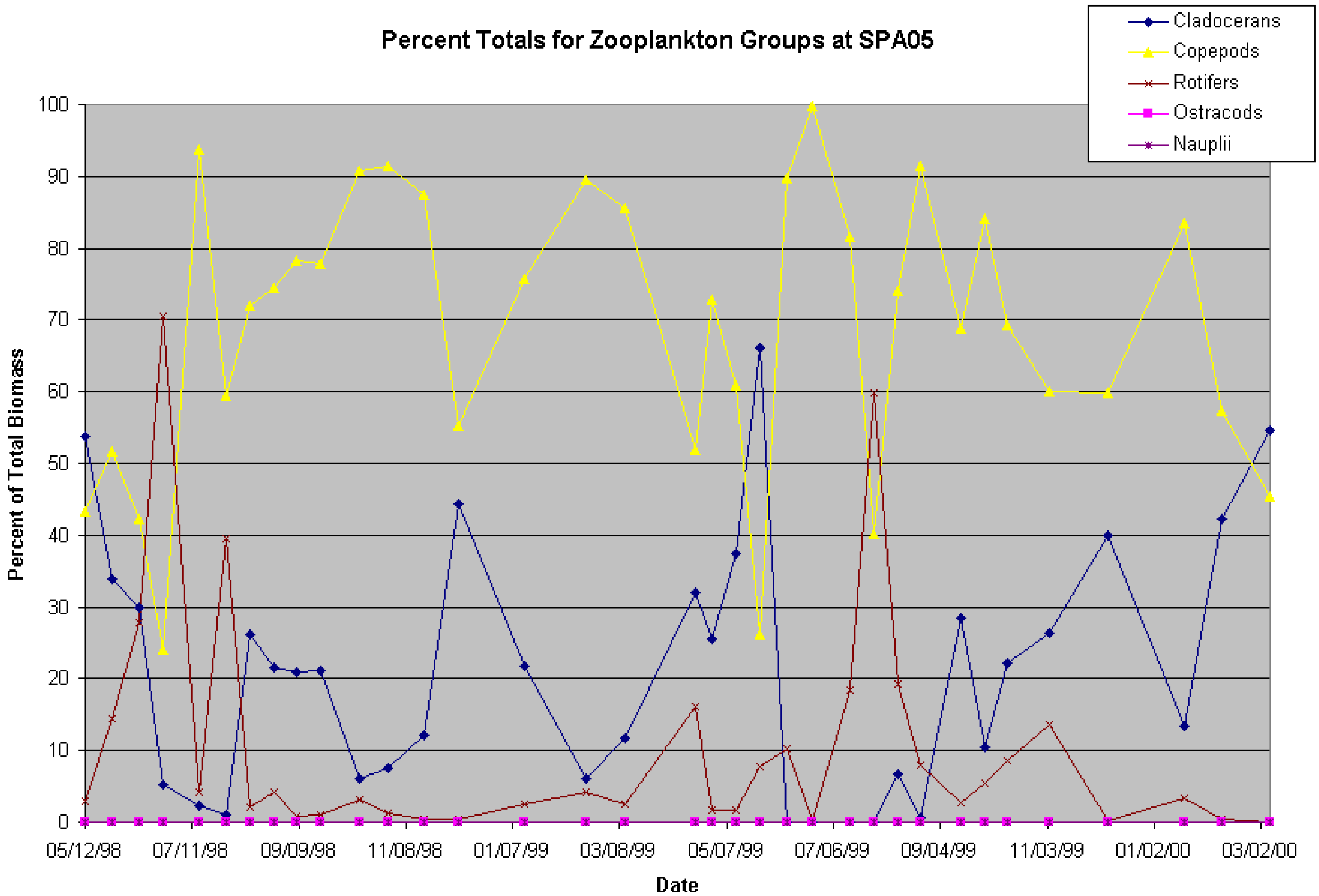


Figure 76: Zooplankton Relative Biovolume by Group for Spavinaw-05

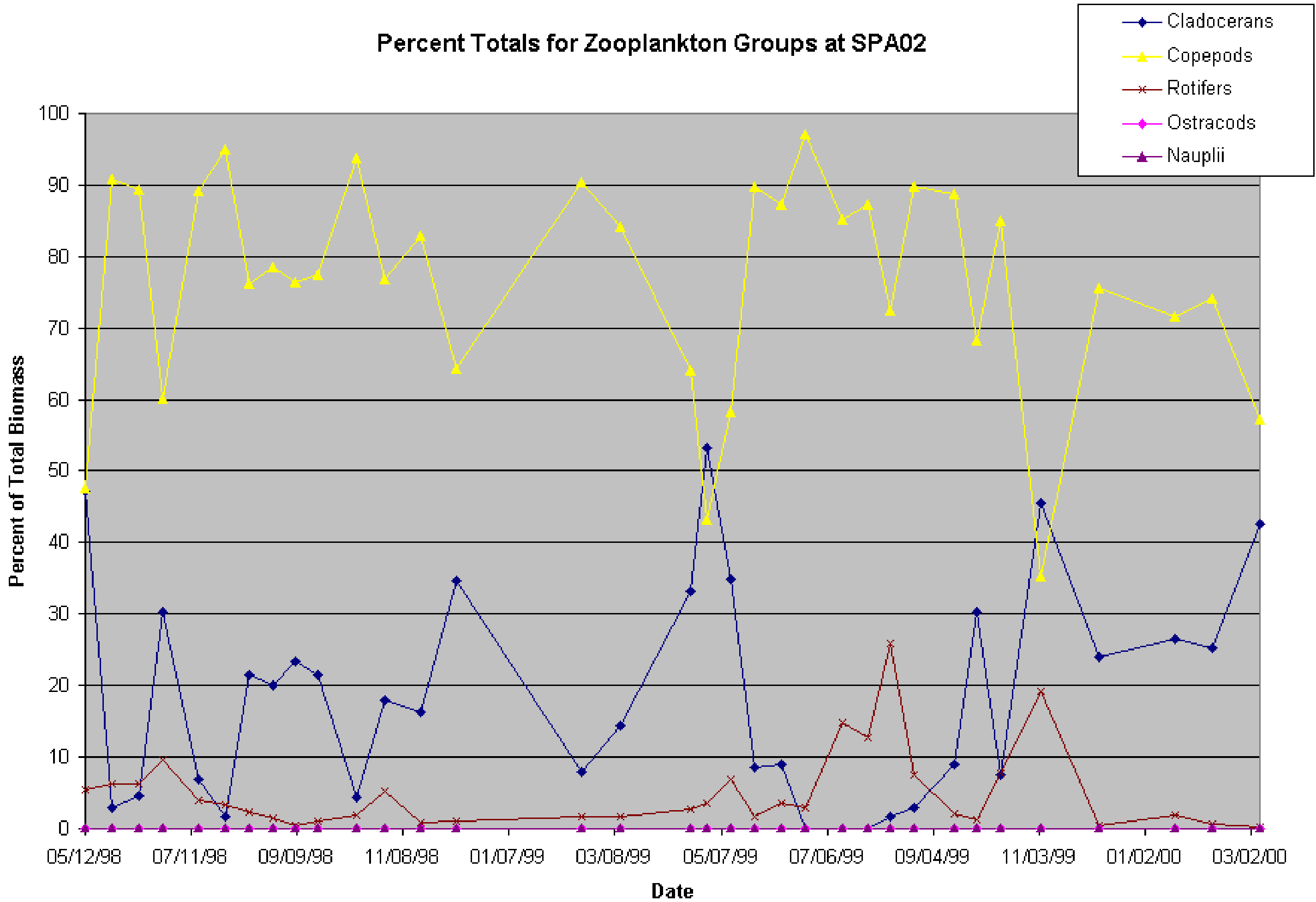


Figure 77: Zooplankton Relative Biovolume by Group for Spavinaw-02

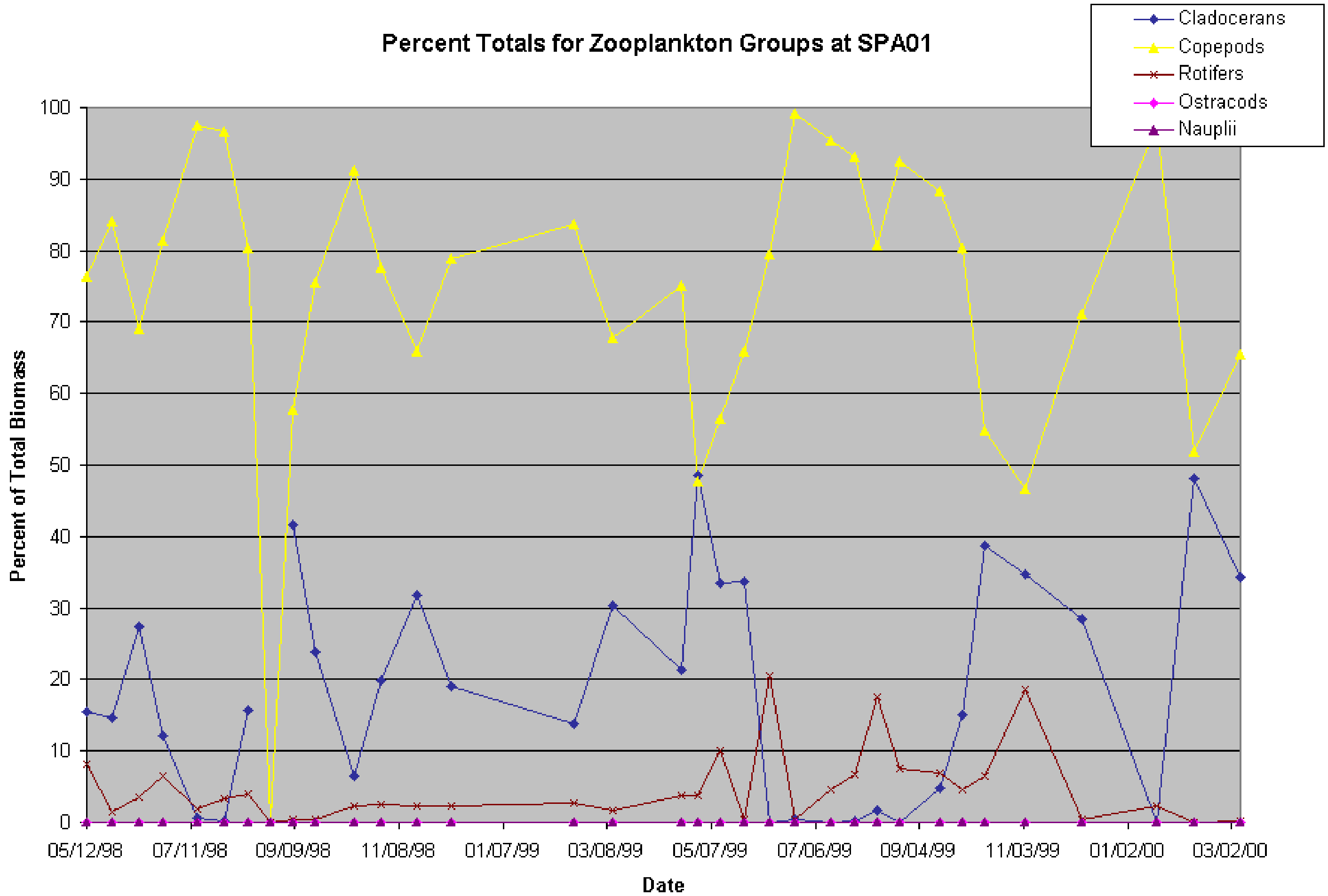


Figure 78: Zooplankton Relative Biovolume by Group for Spavinaw-01

Zooplankton Species Abundances

Eucha:

Bosmina longirostis, a small Cladoceran, was most abundant in mid-summer at all four stations, decreasing in abundance as flow progressed from station EUC03 towards EUC01 (See Figure 77). *Bosmina* was never very abundant. There were several species of Daphnia in Eucha, *Daphnia retrocurva*, *D. laevis*, *D. pulex* and *D. lumholtzi*. In contrast to the other *Daphnia* species, *D. retrocurva* was present most of the year (See Figure 78). *D. retrocurva* was the most abundant in late summer 1998, and late fall 1998 through summer 1999 and was more abundant in winter of 1998 versus 2000. *D. retrocurva* is the smallest of the *Daphnia* species in Eucha Lake. *D. leavis* was abundant only in mid-Summer 1998 and in Winter 2000 (See Figure 79). *D. pulex*, the most efficient Cladoceran grazer in Eucha, was present in late winter 1999 and winter 2000 to a greater extent (See Figure 80). *D. lumholtzi* is not very abundant and only was detected on 1-2 dates in late fall 1999 (See Figure 81). It could be a new invasion, but data is limited. As the total abundance data indicated, the Cladocerans decrease in abundance from EUC03 downstream to EUC01.

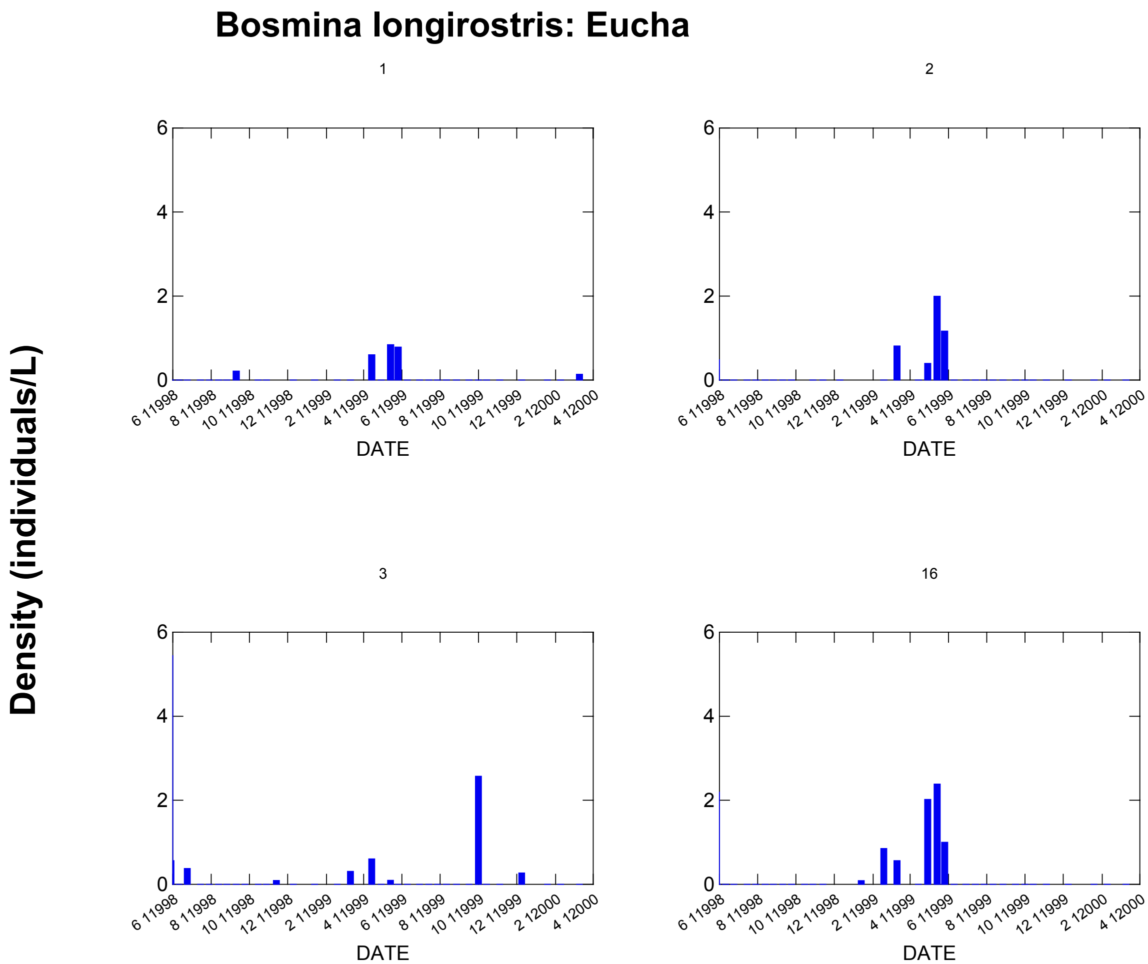


Figure 79: Abundance of *Bosmina longirostris* in Eucha Lake

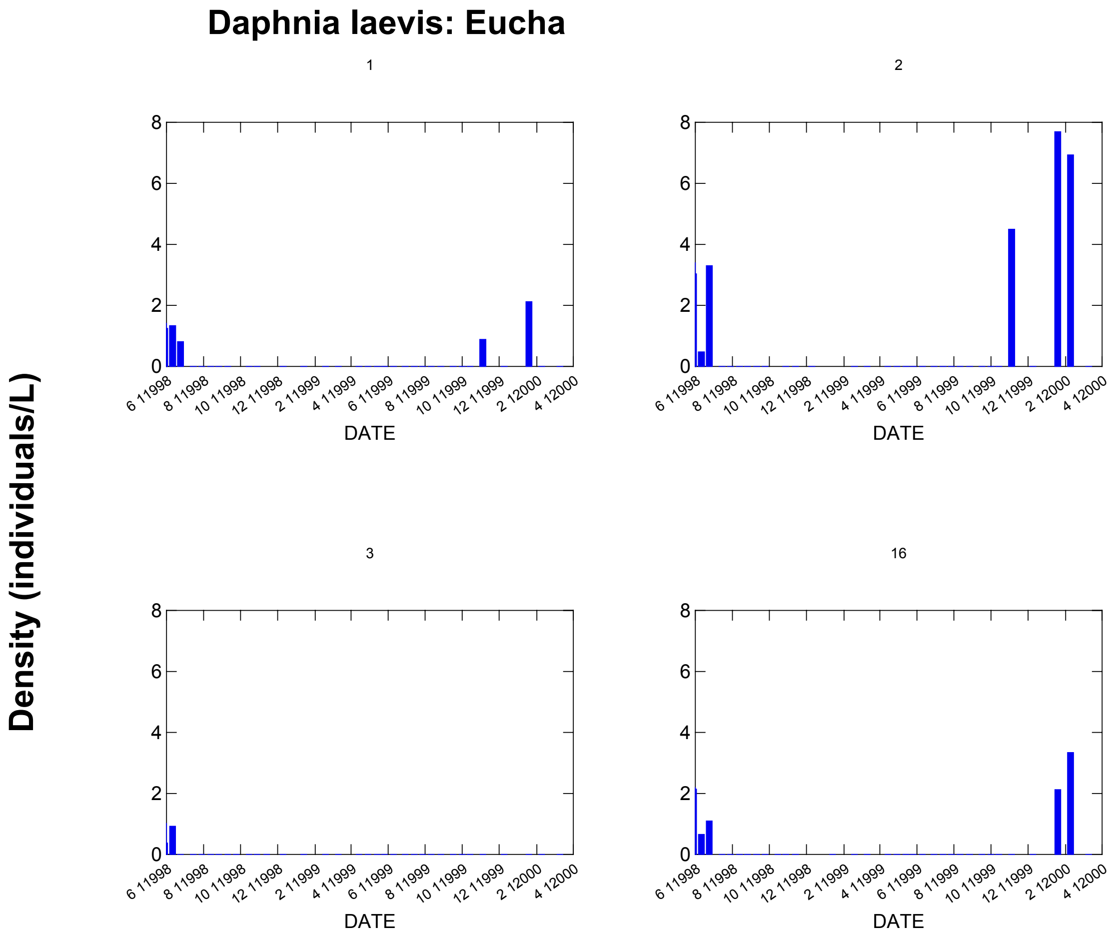


Figure 80: Abundance of *Daphnia retrocurva* in Eucha Lake

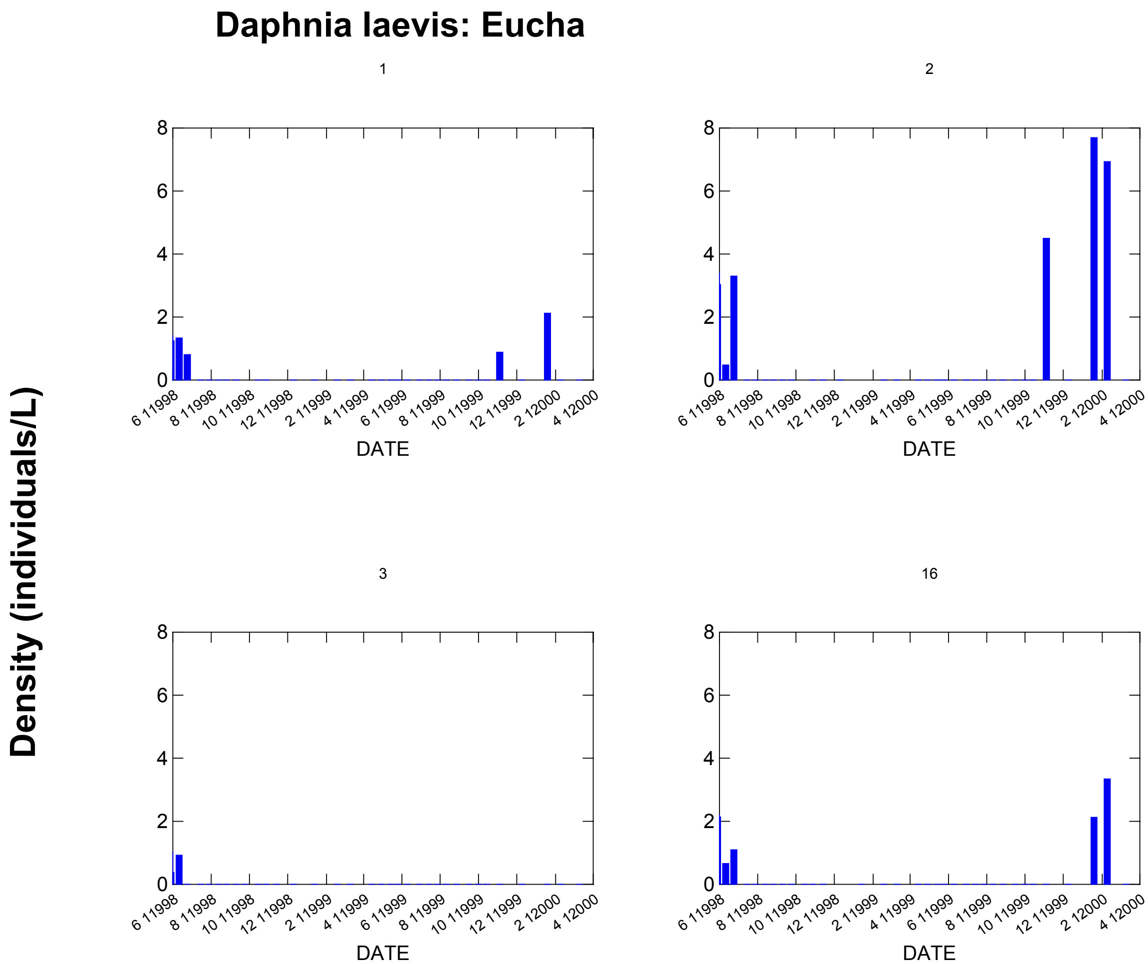


Figure 81: Abundance of *Daphnia laevis* in Eucha Lake

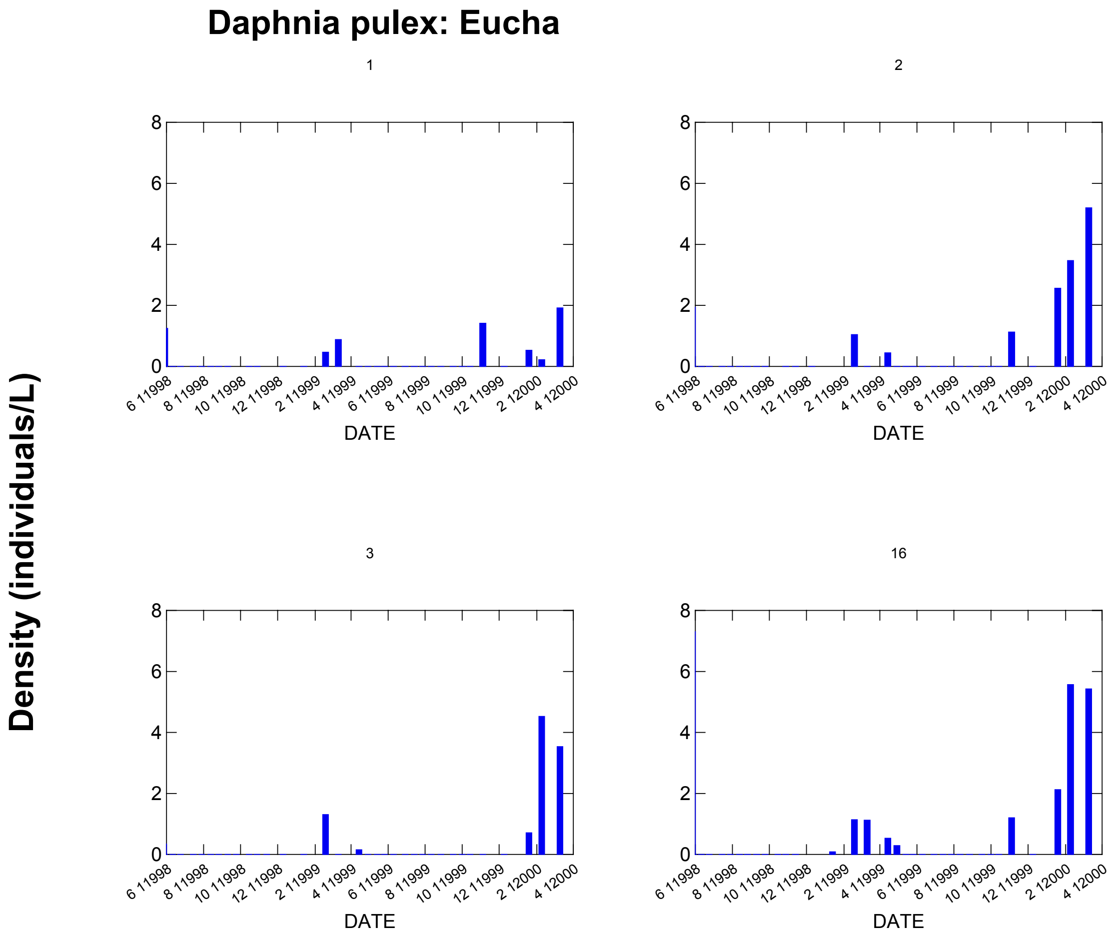


Figure 82: Abundance of *Daphnia pulex* in Eucha Lake

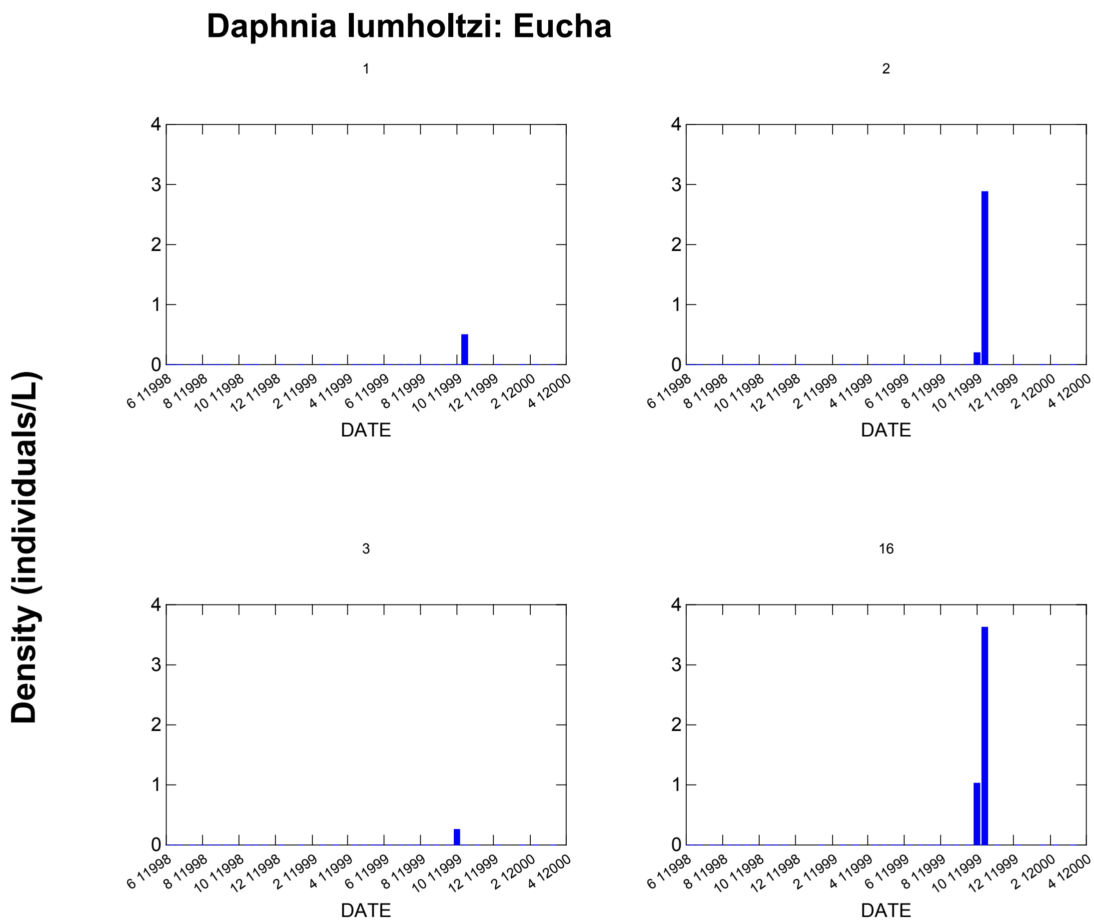


Figure 83: Abundance of *Daphnia lumholtzi* in Eucha Lake

The most dominant Copepods included *Skistodiaptomus mississippiensis* (Calanoid), *Diacyclops bicuspitadus* (Cyclopoid), and *Mesocyclops edax* (Cyclopoid). *S. mississippiensis* was most dominant at stations EUC03 and EUC16, with the exception of a peak of 25+ individuals/L in December 1999 (See Figure 82). Abundances were very low at EUC01. *S. mississippiensis* was abundant in the summer 1998 and 1999, with a smaller peak in the late fall/early winter. Abundances were greatest in the summer 1998 at stations EUC03 and EUC16, but greatest in late fall 1999 at station EUC02. *D. bicuspitadus* (See Figure 83) and M. edax (See Figure 84) were dominant at different times, although neither was as abundant as S. mississippiensis. *M. edax* was abundant in summer through late fall 1998 and 1999, again with the lowest overall abundance at EUC01. *M. edax* was often not even present at EUC03, being most abundant at EUC16 and EUC02. *D. bicuspitadus* was more abundant, but also more sparsely abundant throughout the year than *M. edax*.

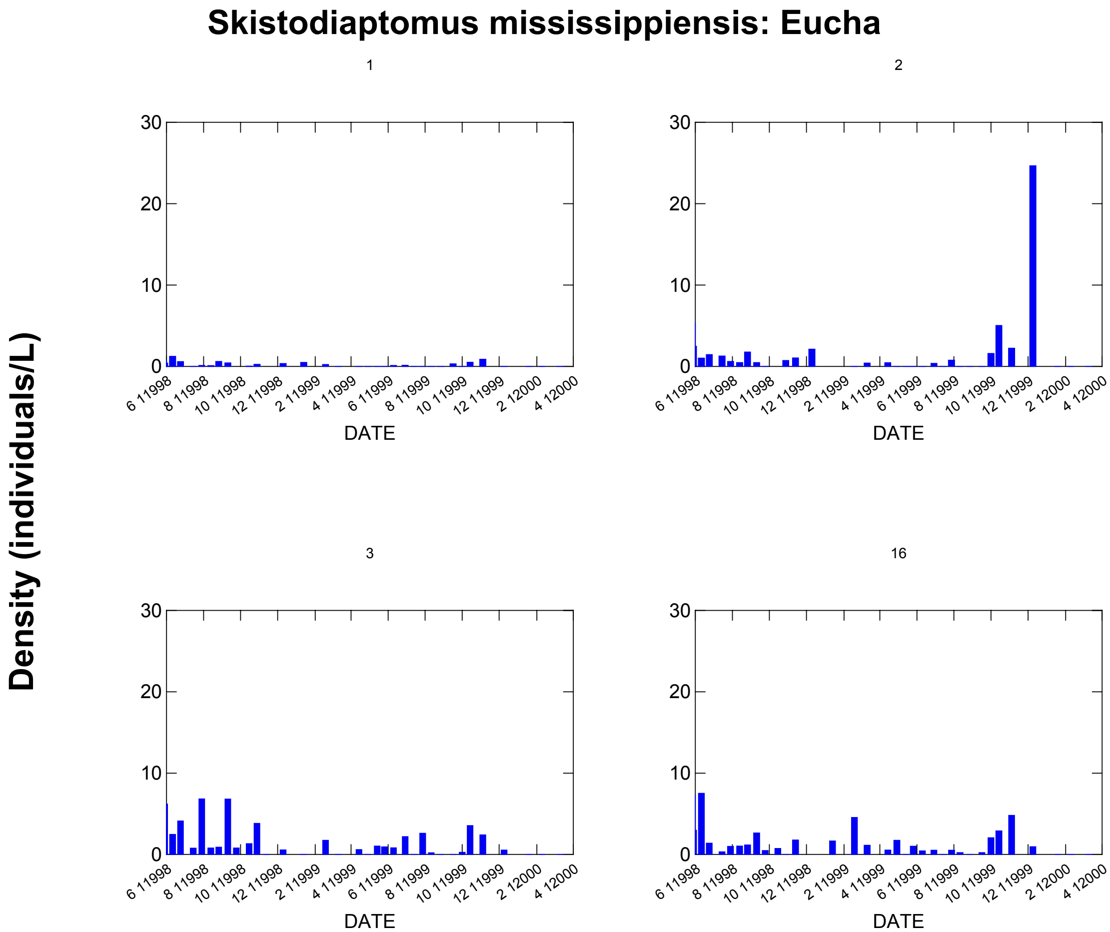


Figure 84: Abundance of *Skistodiaptomus mississippiensis* in Eucha Lake

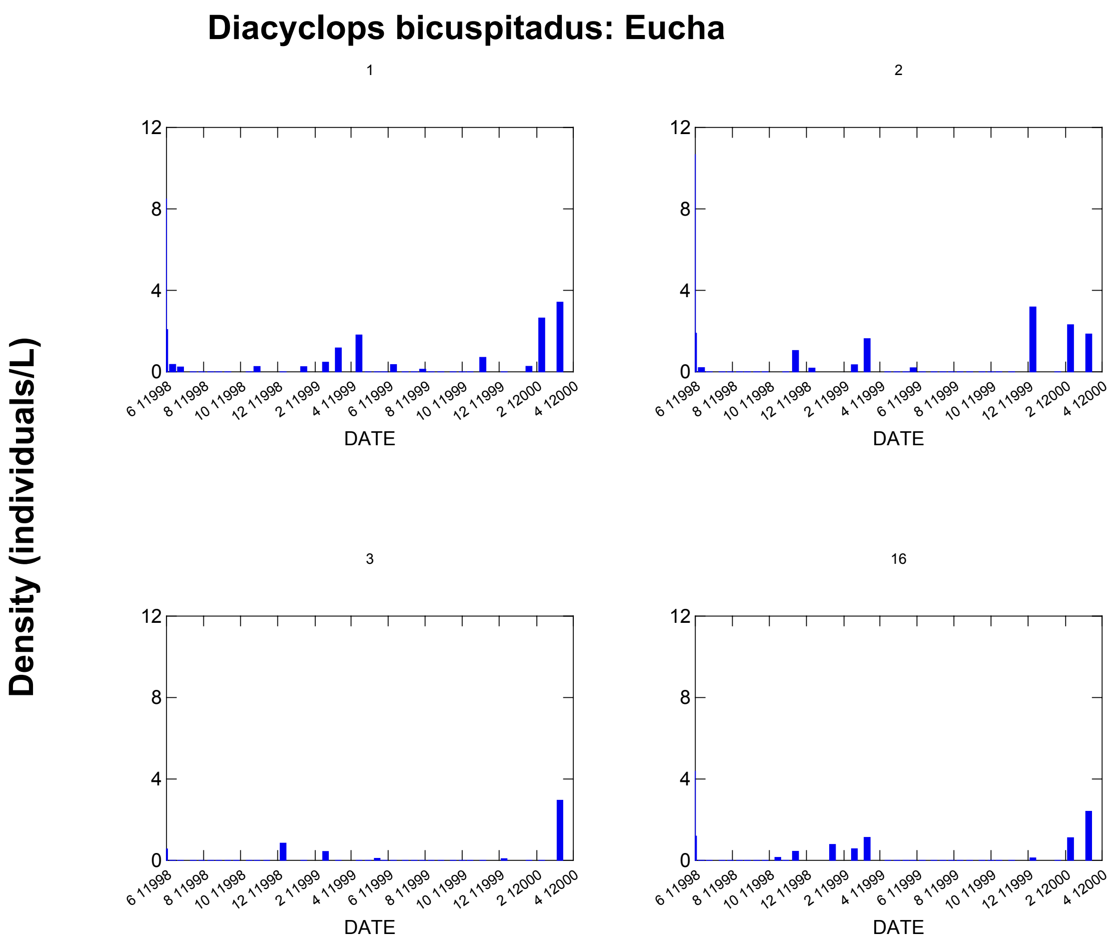


Figure 85: Abundance of *Diacyclops bicuspitadus* in Eucha Lake

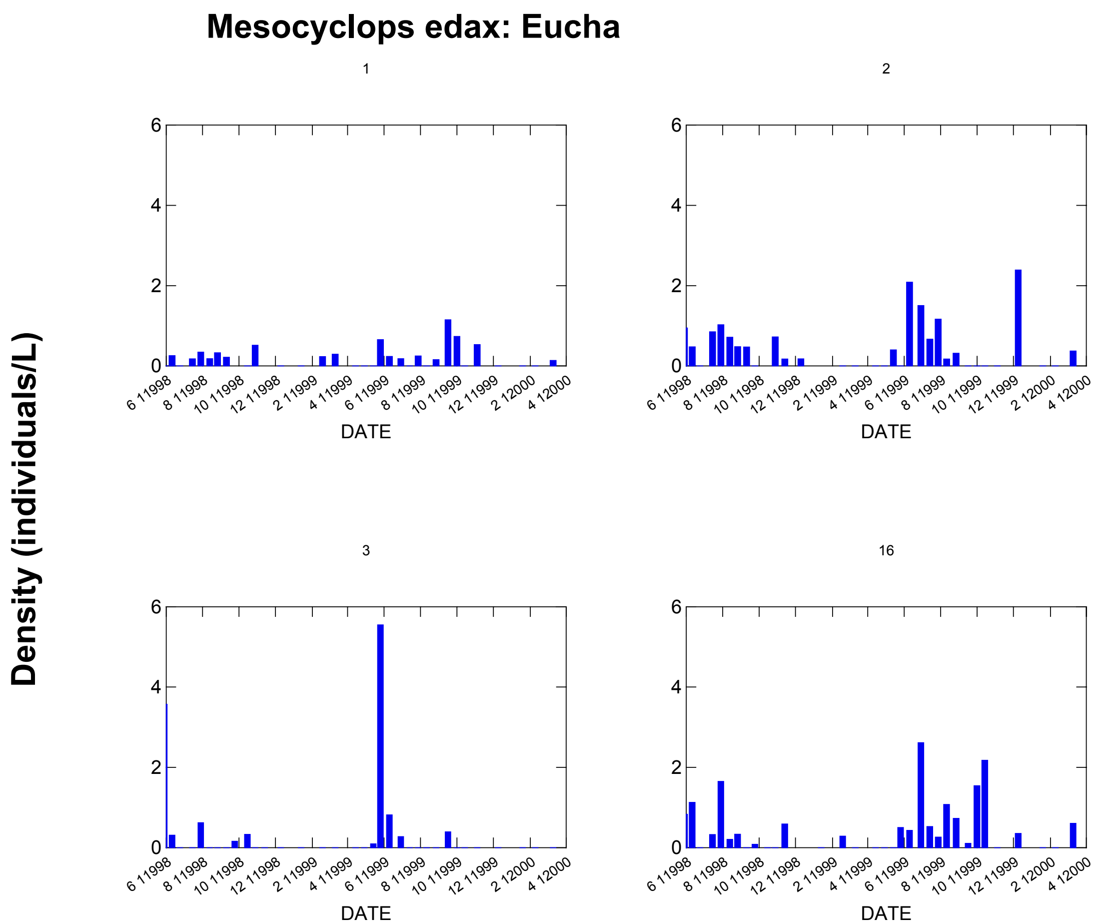


Figure 86: Abundance of *Mesocyclops edax* in Eucha Lake

There were several Rotifers which were abundant during the study period. Most notable were: *Polyarthra vulgaris*, *Keratella cochlearis*, *Brachinus caudatus*, *Synchaeta pectinata* and *Conochilus unicornis*. *P. vulgaris* was abundant throughout the year, reaching peaks at the upper stations of 50+ individuals/L (See Figure 85). Abundance was greatest in the summer of both years and during the Winter 2000. There was a late fall, mid-winter peak at all stations, being the highest at EUC16 and EUC02. *K. cochlearis* was often abundant during the same period as *P. vulgaris* (See Figure 86). *K. cochlearis* was the most abundant of the single celled micro zooplankton tallied, reaching abundances of several hundred animals per litre. *Brachinus caudat*us, a predatory rotifer, was abundant in late summer 1998 only (See figure 87). It was most abundant at Station EUC03, reaching nearly 400 individuals/L, an order of magnitude higher than the other three stations. *Synchaeta pectinata*, another predatory rotifer, was not very abundant in 1998, late summer 1998, but become quite abundant in 1999 at all of the stations (See Figure 88). It was considerably more abundant at the upstream stations, reaching over 200 individuals/L at EUC03, and was over 30 individuals/l at EUC16. Other than a peak of approximately 100 animals/L in June 1999, abundances were under 20 individuals/L at EUC02 and EUC01. The other interesting Rotifer, Conochilus unicornis, is a colonial rotifer with sometimes up to hundreds of animals per colony (See Figure 89). *C. unicornis* was most abundant, again, at EUC03 and EUC16. There were generally three periods of primary abundance at EUC16, EUC02 and EUC01 in late summer 1998, late spring/early summer 1999 and late Fall 1999. Although each occurrence was composed of more animals, the peaks in late summer 1998 and late fall 1999 were not as long lasting as at the other stations and there was only a very small population in the late spring/early summer period of 1999.

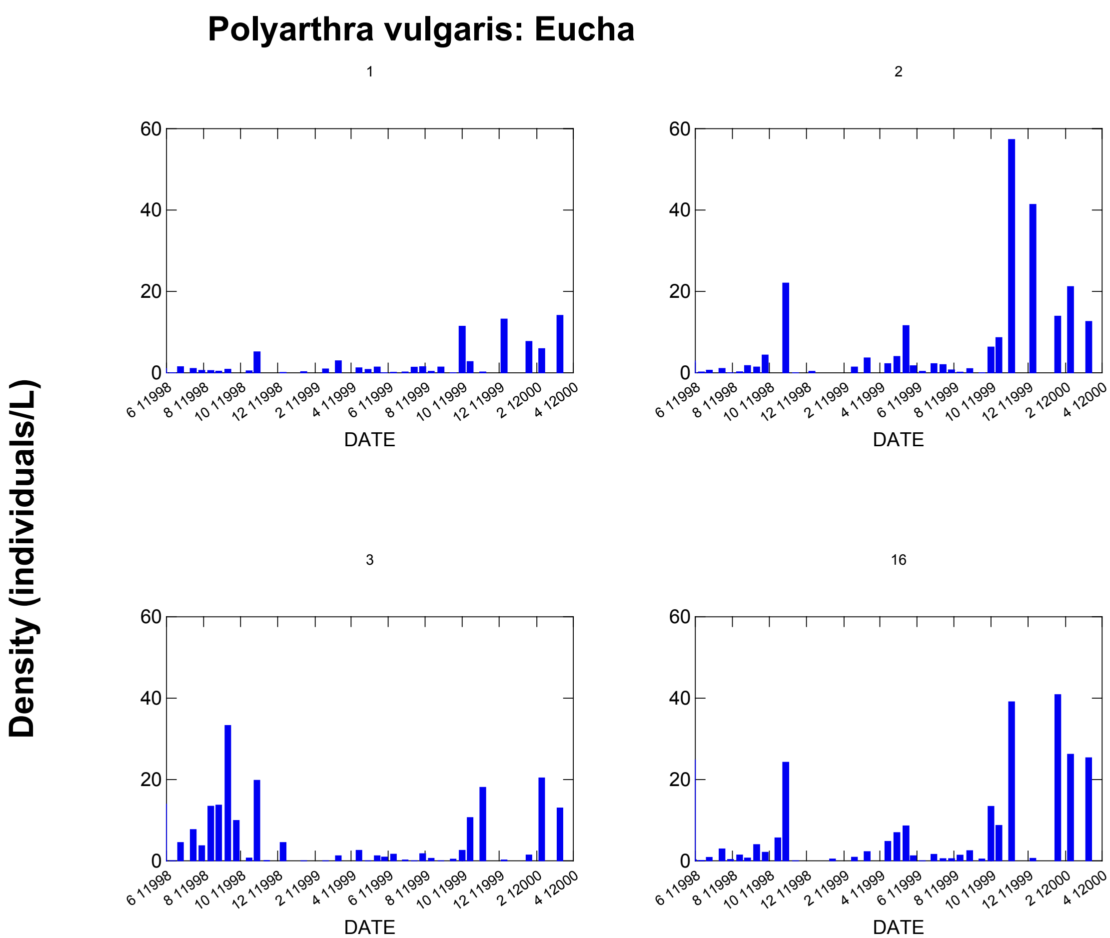


Figure 87: Abundance of *Polyarthra vulgaris* in Eucha Lake

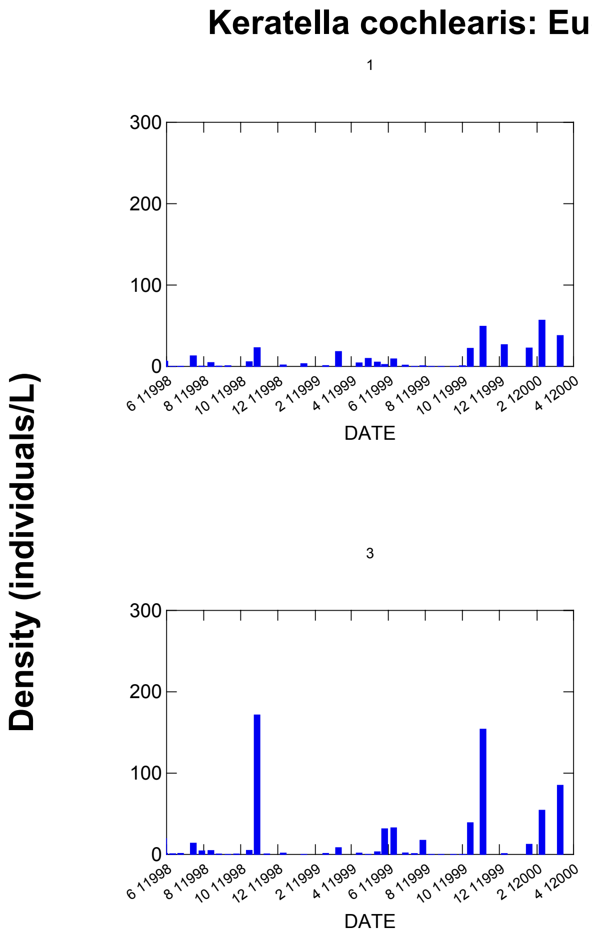


Figure 88: Abundance of *Keratella cochlearis* in Eucha Lake

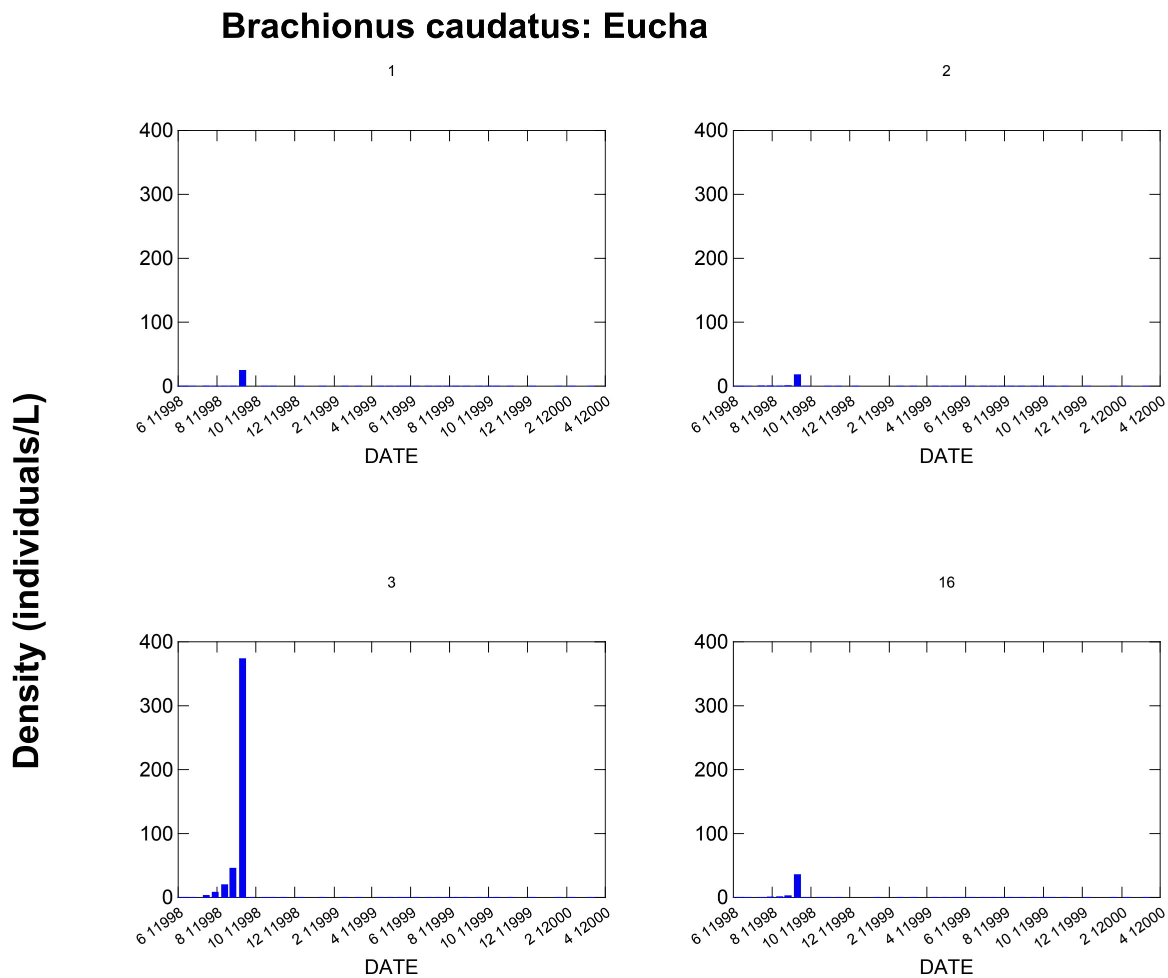


Figure 89: Abundance of *Brachionus caudatus* in Eucha Lake

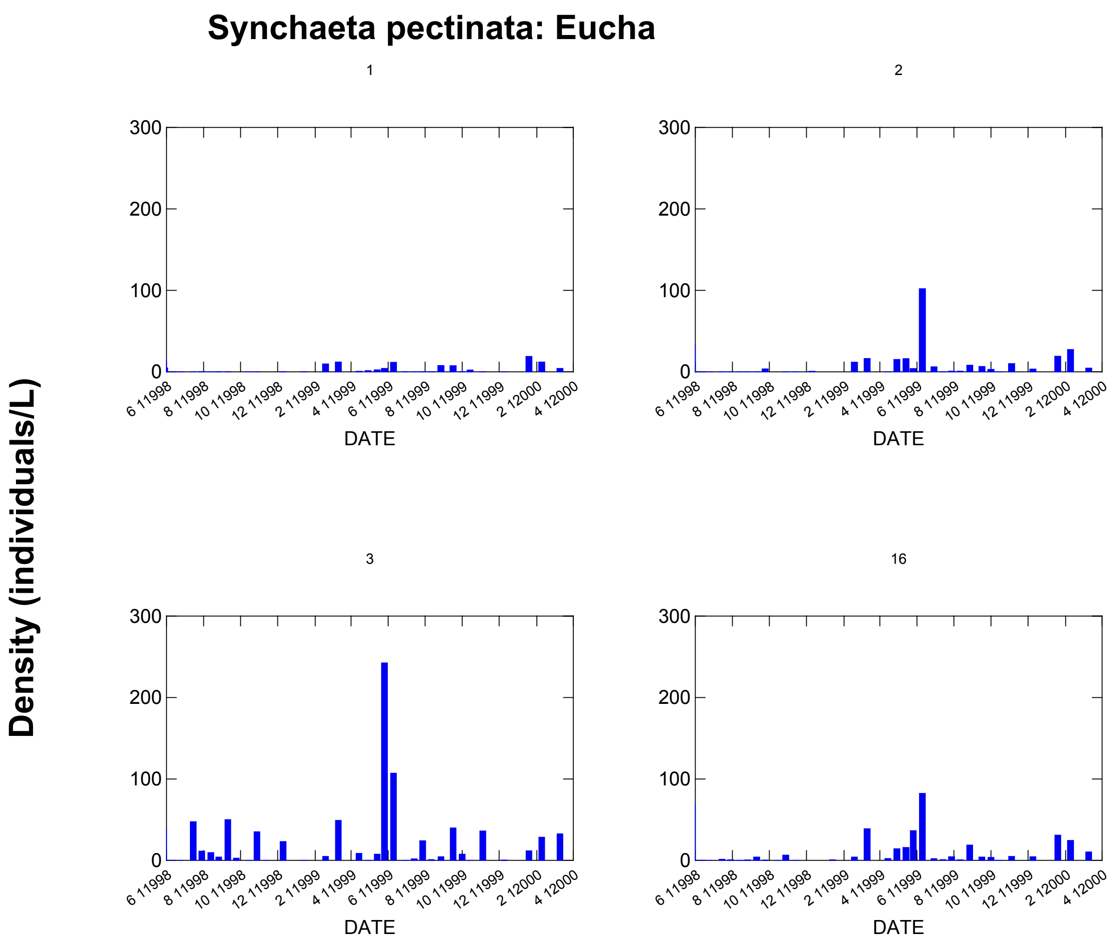


Figure 90: Abundance of *Synchaeta pectinata* in Eucha Lake

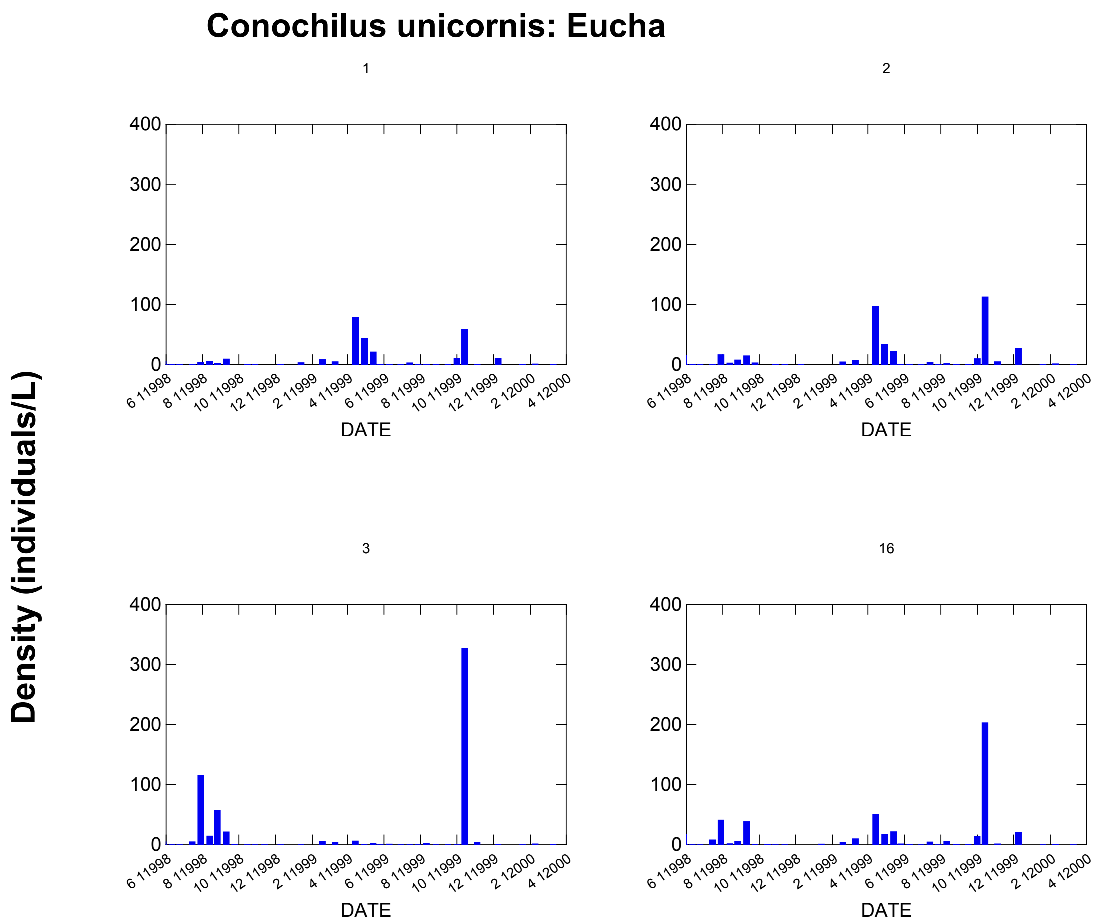


Figure 91: Abundance of *Conochilus unicornis* in Eucha Lake

Spavinaw:

Bosmina longirostis, a small Cladoceran, was most abundant in late-summer 1998 and late fall 1999 at all three stations, decreasing in abundance as flow progressed from station EUC03 towards EUC01 in 1998, but not in 1999 (See Figure 90). Bosmina was considerably more abundant than in Eucha Lake and followed a completely different abundance pattern. There were several species of Daphnia in Spavinaw, *Daphnia retrocurva* , *D. laevis*, *D. pulex* and *D. lumholtzi*. In contrast to the other Daphnia species, *D. retrocurva* was present most of the year (See Figure 91), but was not as dominant as in Eucha. *D. retrocurva* was the most abundant in late summer 1998, late fall through summer 1999 and was more abundant in summer of 1999. *D. retrocurva* is the smallest of the Daphnia species in Spavinaw Lake. *D. leavis* was never abundant in Spavinaw Lake, and was only detected in mid summer 1998 and in winter 2000 (See Figure 92). *D. pulex*, the most efficient Cladoceran grazer in Spavinaw, was present in late winter 1999 and winter 2000 to a greater extent (See Figure 93). *D. pulex* was slightly more abundant in Spavinaw than in Eucha. *D. lumholtzi* was not very abundant and only was detected on 1-2 dates in late summer 1998 and in late fall 1999 (See Figure 94). It could be a new invasion, but data is limited. As the total abundance data indicated, the Cladocerans decrease in abundance from SPA05 downstream to SPA01, but the trend is not as strong as in Eucha.

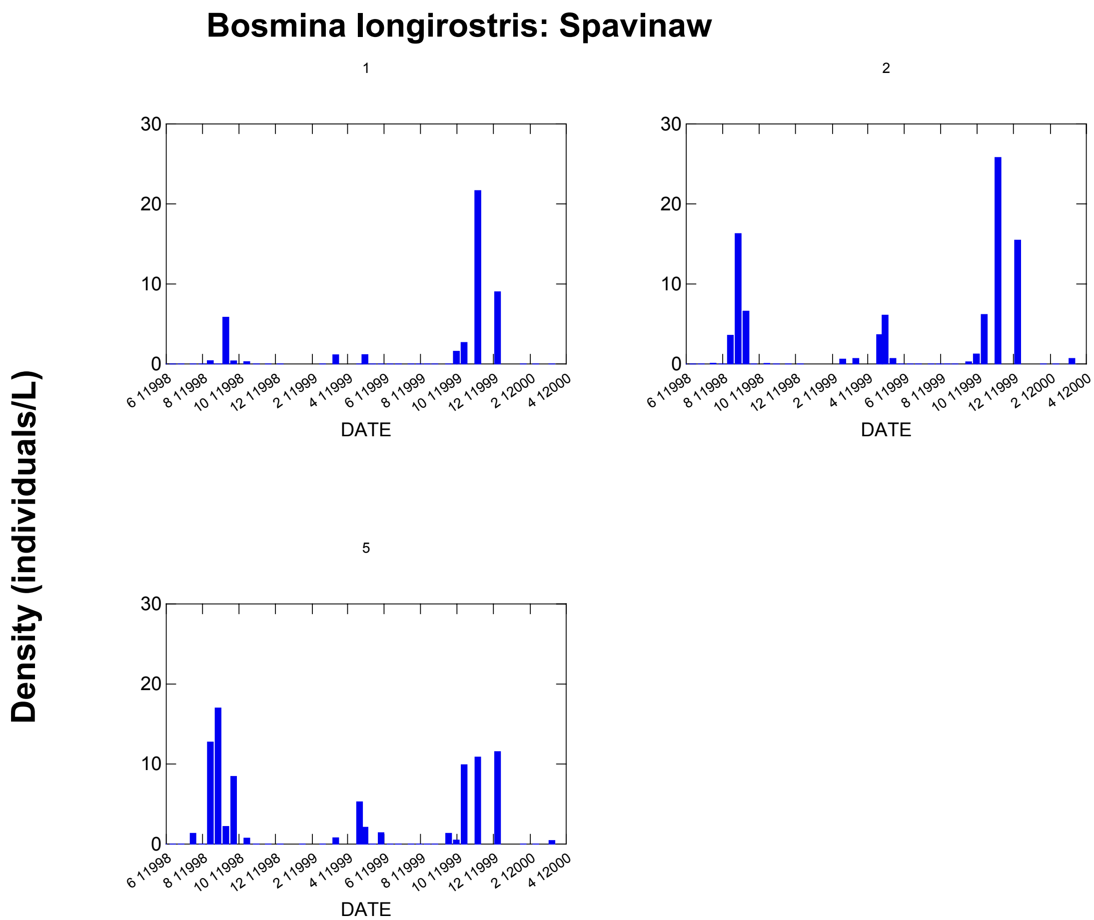


Figure 92: Abundance of *Bosmina longirostris* in Spavinaw Lake

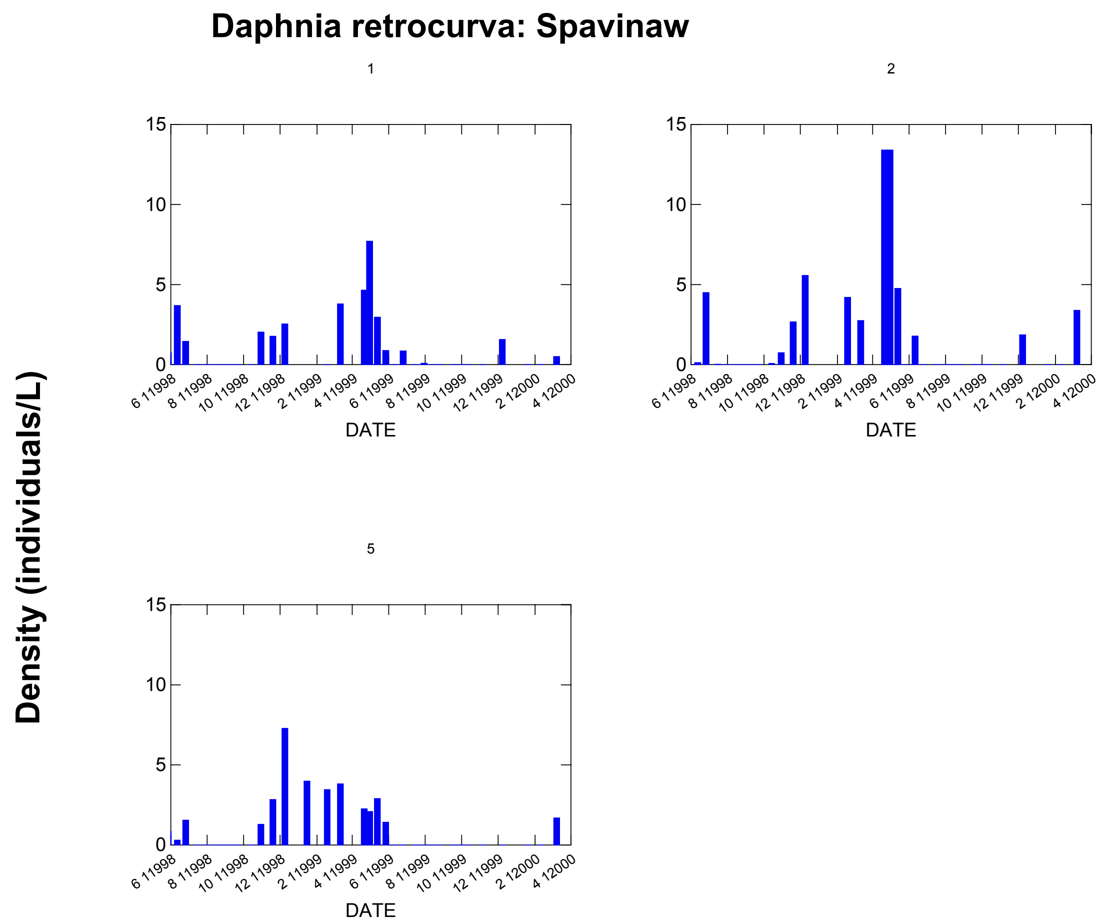


Figure 93: Abundance of *Daphnia retrocurva* in Spavinaw Lake

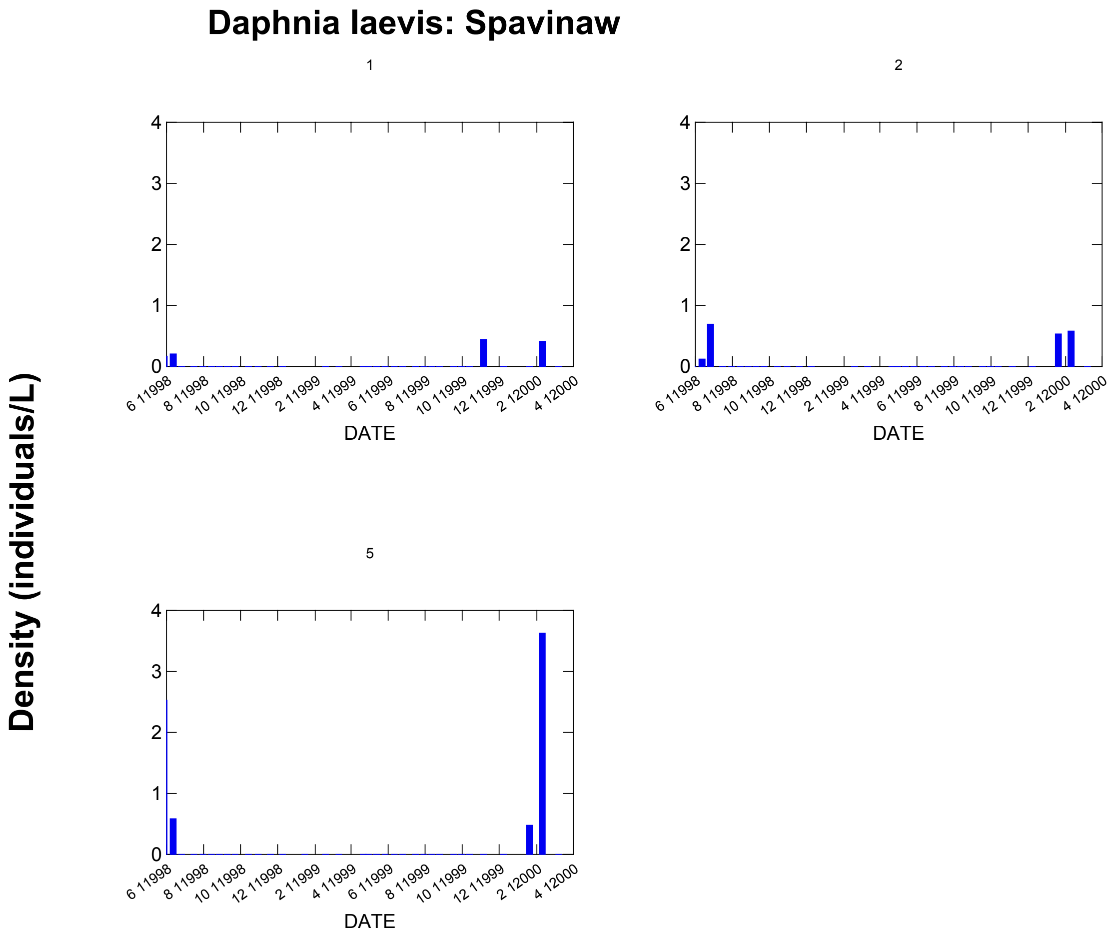


Figure 94: Abundance of *Daphnia laevis* in Spavinaw Lake

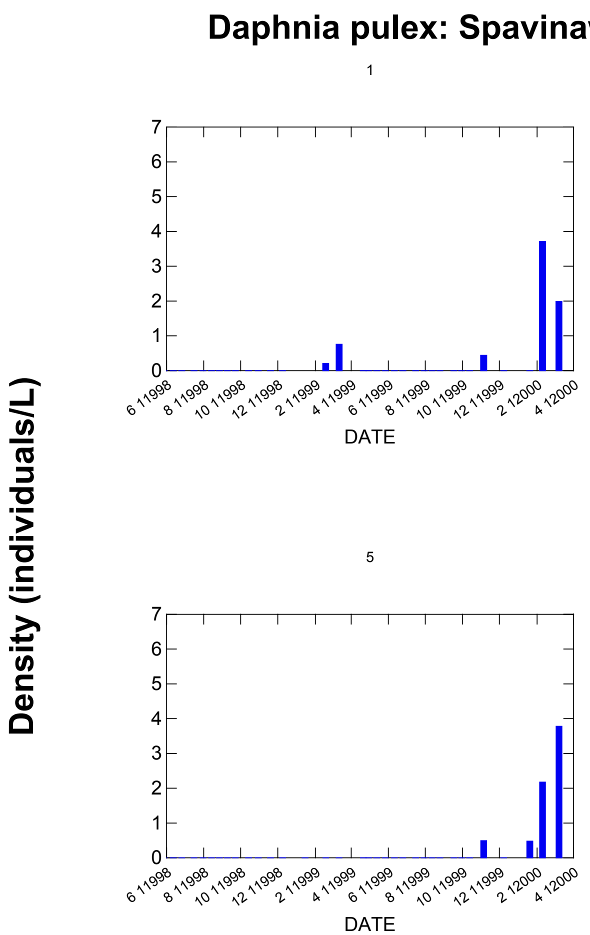


Figure 95: Abundance of *Daphnia pulex* in Spavinaw Lake

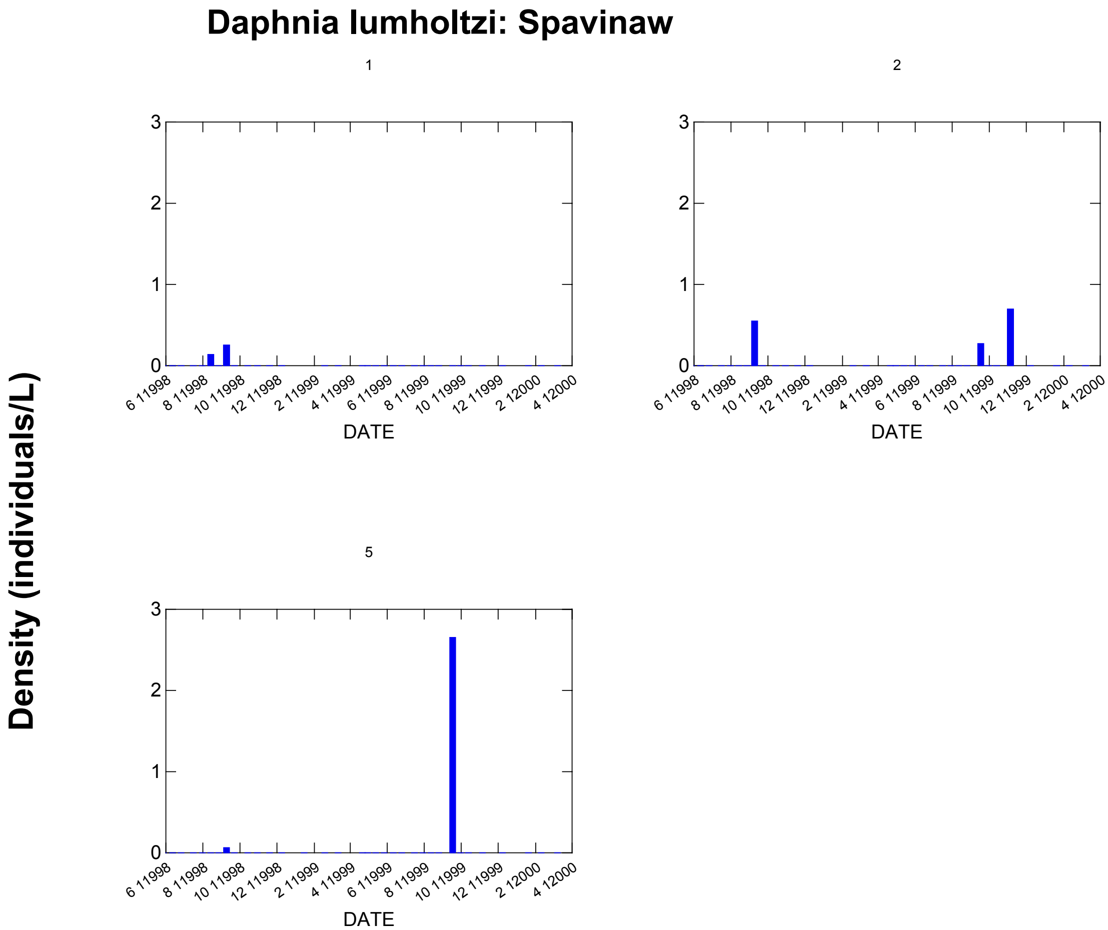


Figure 96: Abundance of *Daphnia lumholtzi* in Spavinaw Lake

The most dominant Copepods included *Skistodiaptomus mississippiensis* (Calanoid), *Diacyclops bicuspitadus* (Cyclopoid), and *Mesocyclops edax* (Cyclopoid). *S. mississippiensis* was most dominant at stations SPA05 and SPA02 (See Figure 95). Abundances were low at SPA01. S. mississippiensis was abundant in the summer 1998 and 1999, with a smaller peak in the late fall/early winter. *D. bicuspitadus* (See Figure 96) and *M. edax* (See Figure 97) were dominant at different times, although neither was as abundant as *S. mississippiensis*. However, both were more abundant in Spavinaw than in Eucha. *M. edax* was abundant in summer through late fall 1998 and 1999. Station SPA01 was not considerably lower than the other two stations. *M. edax* was often not even present at SPA05, being most abundant at SPA02 and SPA01. *D. bicuspitadus* was not more *abundant, as in Eucha, but more sparsely abundant throughout the year than M*. edax.

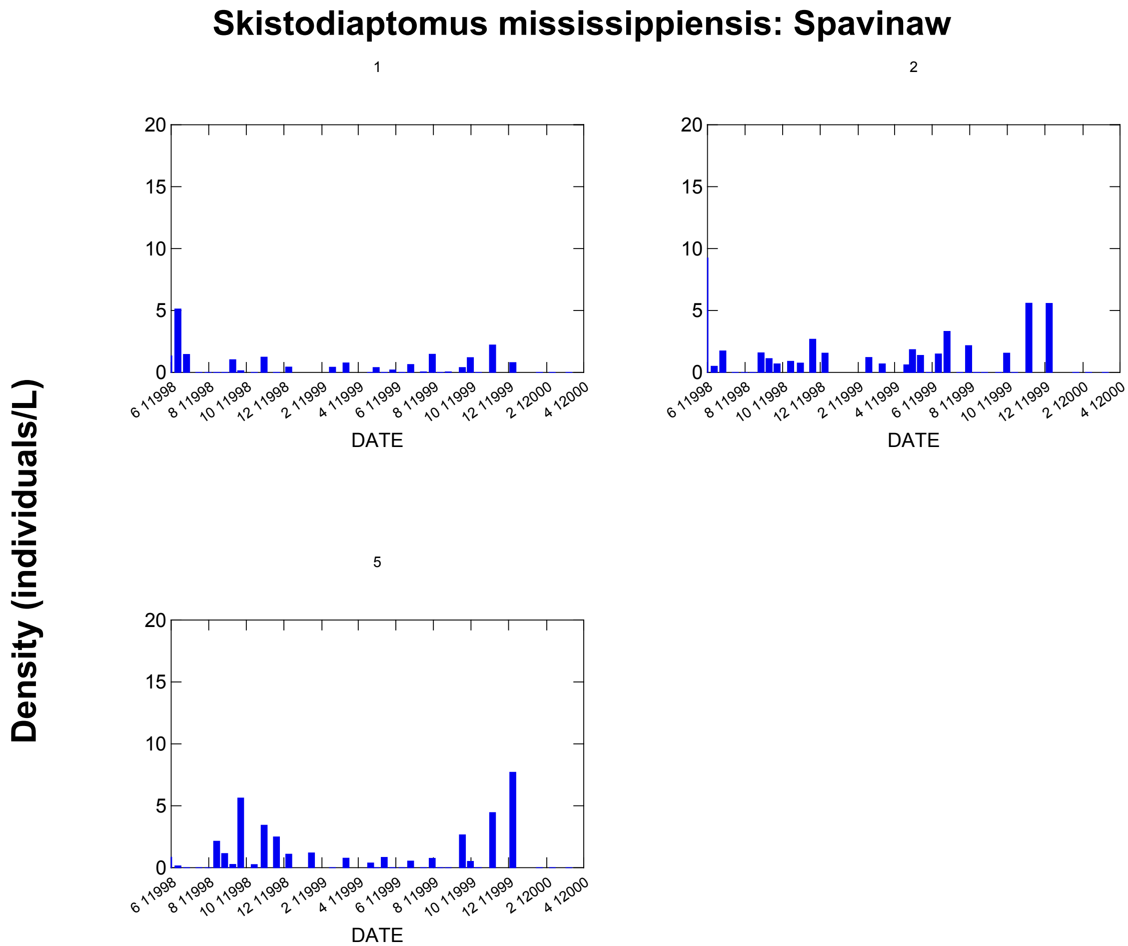


Figure 97: Abundance of *Skistodiaptomus mississippiensis* in Spavinaw Lake

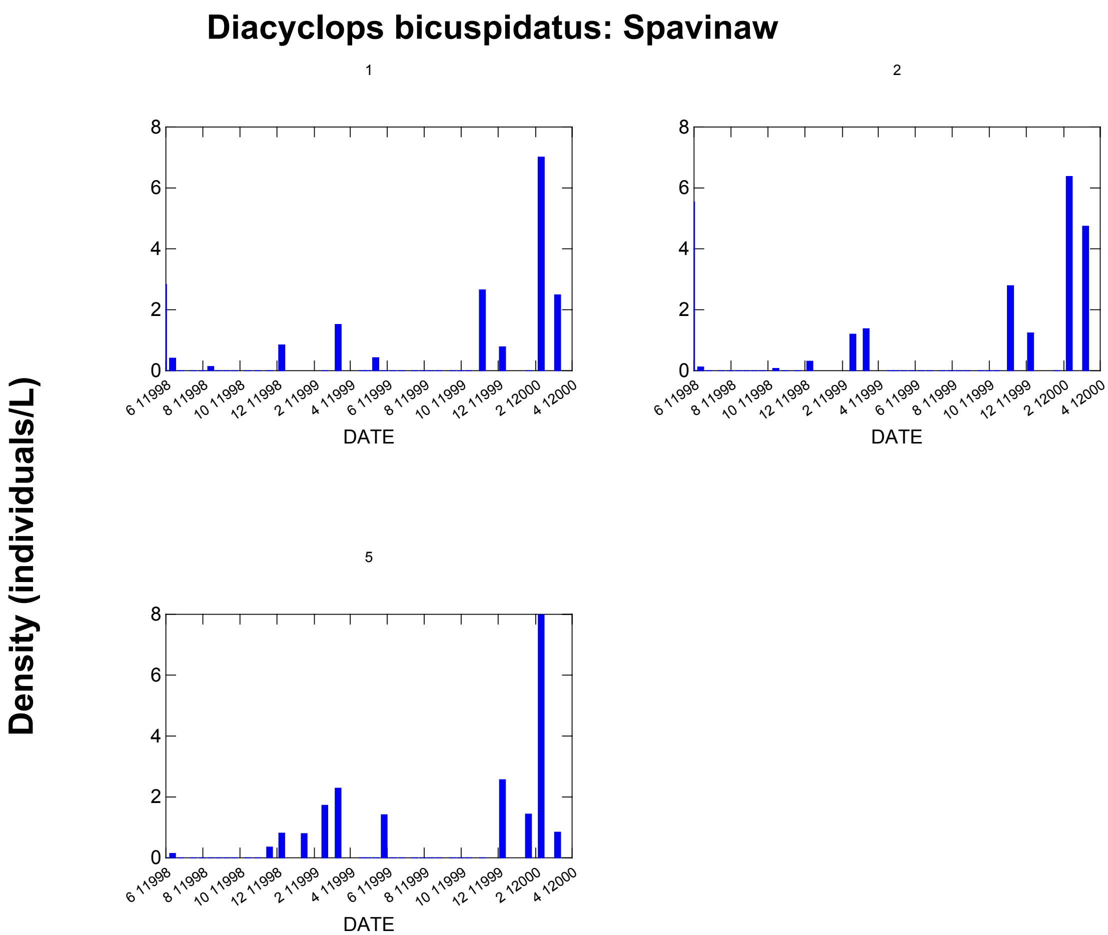


Figure 98: Abundance of *Diacyclops bicuspidatus* in Spavinaw Lake

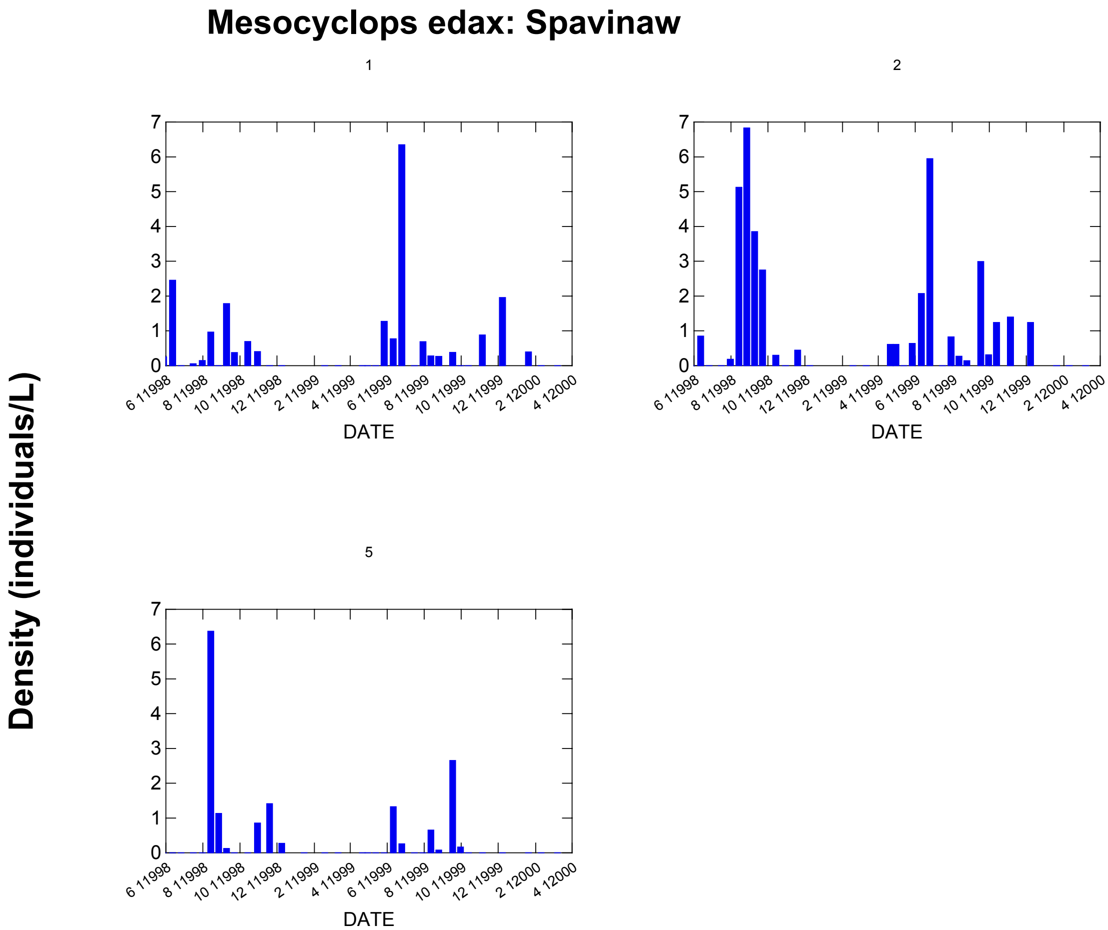


Figure 99: Abundance of *Mesocyclops edax* in Spavinaw Lake

There were several Rotifers which were abundant during the study period. Most notable were: *Polyarthra vulgaris*, *Keratella cochlearis*, *Brachinus caudatus*, *Synchaeta pectinata* and *Conochilus unicornis*. *P. vulgaris* was abundant throughout the year, reaching peaks at the upper stations of 60+ individuals/L (See Figure 98). Abundance was greatest in the late Fall of both years and during the summer in 1998 and 1999. A lessor winter peak followed in 2000. *P. vulgaris* was generally more abundant in Spavinaw than in Eucha, especially at station SPA01. *K. cochlearis* was often abundant during the same period as *P. vulgaris* (See Figure 99). *K. cochlearis* was the most abundant of the single celled micro-zooplankton tallied, reaching abundances of over a hundred animals per litre. *Brachinus caudatus*, a predatory rotifer, was abundant in late summer 1998 only (See figure 100). It was most abundant at Station SPA05, reaching only approximately 9 individuals/L, an order of magnitude higher than the other two stations. *B. caudatus* was significantly less dominant in Spavinaw than in Eucha. *Synchaeta pectinata*, another predatory rotifer, not very abundant in 1998, but become quite abundant in 1999 at all of the stations (See Figure 101). It was considerably more abundant at the upstream stations, reaching over 200 individuals/L at SPA05, and was over 90 individuals/l at SPA01. The other interesting Rotifer, *Conochilus* *unicornis*, is a colonial rotifer with sometimes up to hundreds of animals per colony (See Figure 102). *C. unicornis* was most abundant, again, at SPA05 and SPA02, a similar pattern to Eucha. In contrast to Eucha, C. unicornis was more abundant in 1998 than in 1999, except at station SPA01, where there were slightly higher abundances in the late Fall periods of both years. The early summer bloom of *C. unicornis* was much smaller than abundances in late fall of either year, a pattern opposite of Eucha.

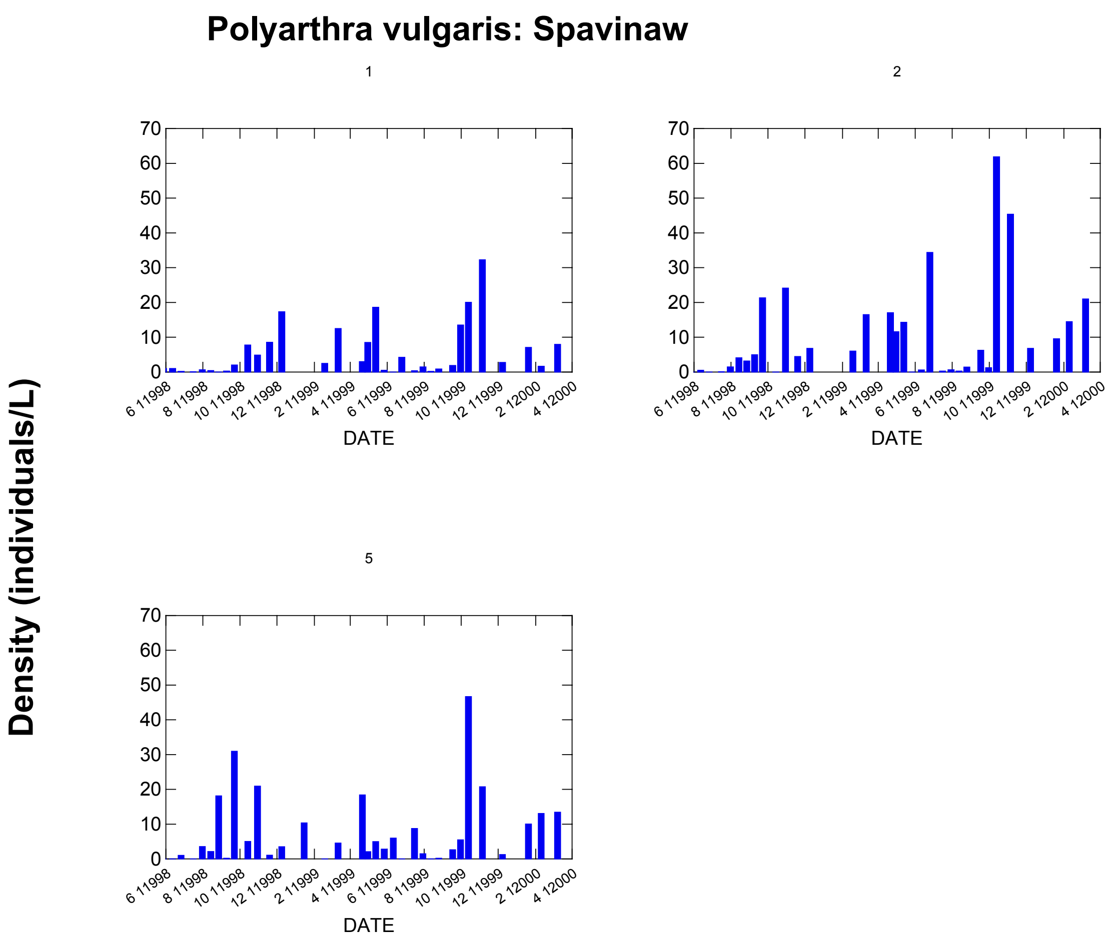


Figure 100: Abundance of *Polyarthra vulgaris* in Spavinaw Lake

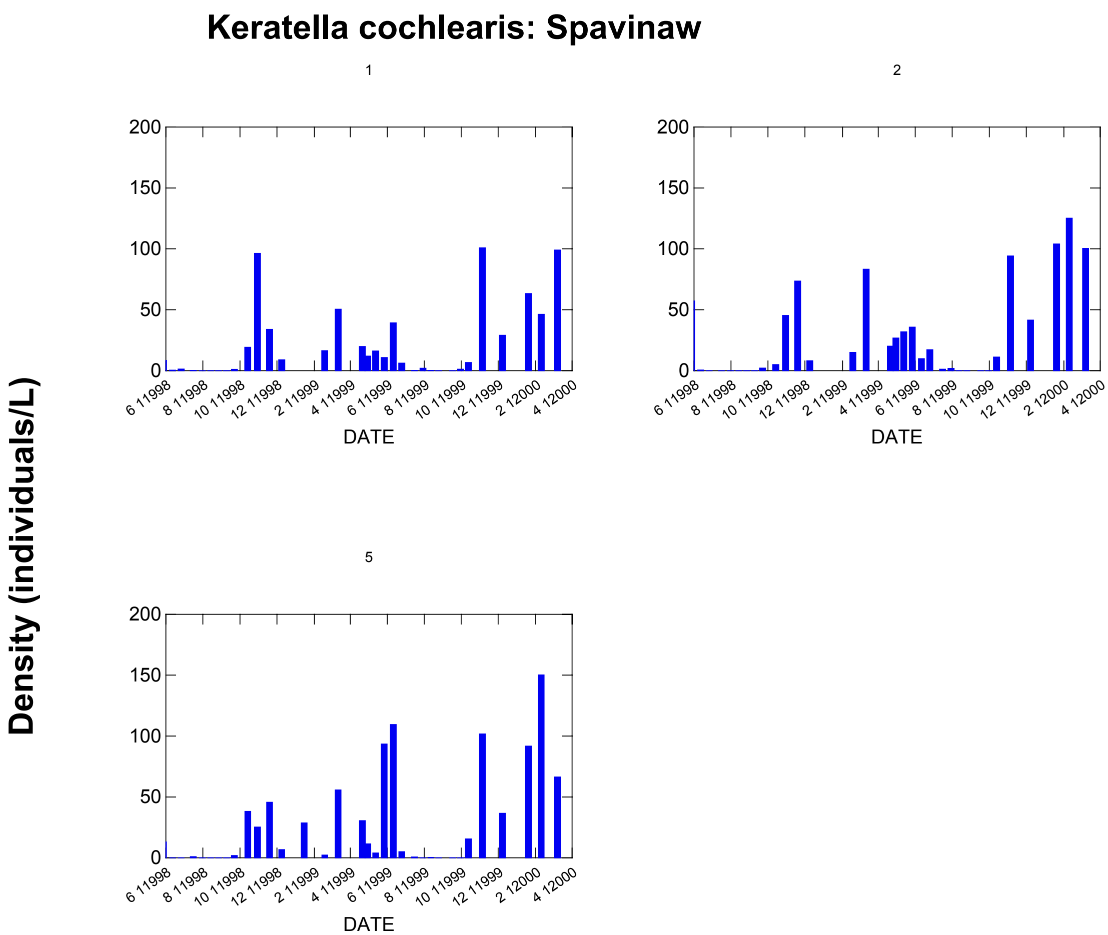


Figure 101: Abundance of *Keratella cochlearis* in Spavinaw Lake

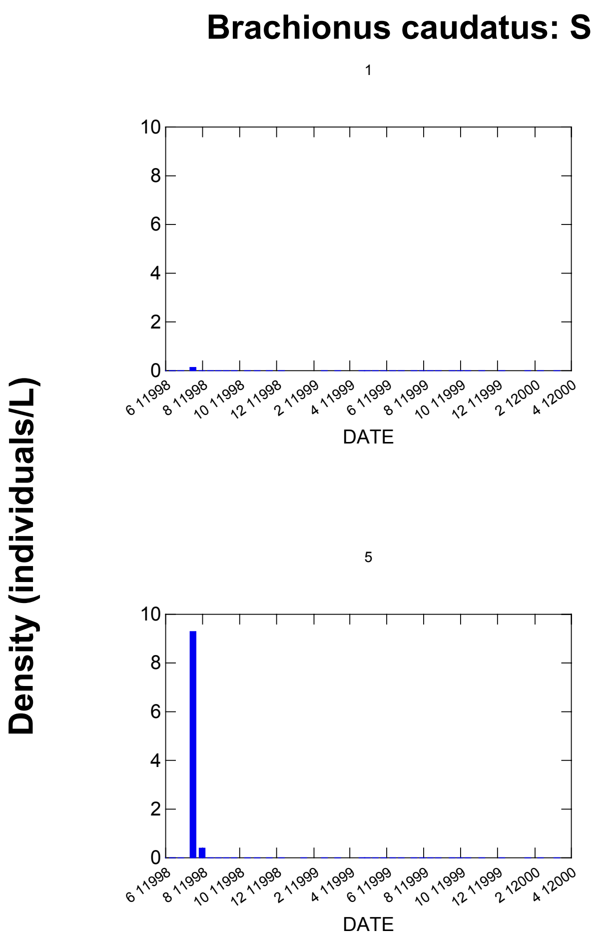


Figure 102: Abundance of *Brachionus caudatus* in Spavinaw Lake

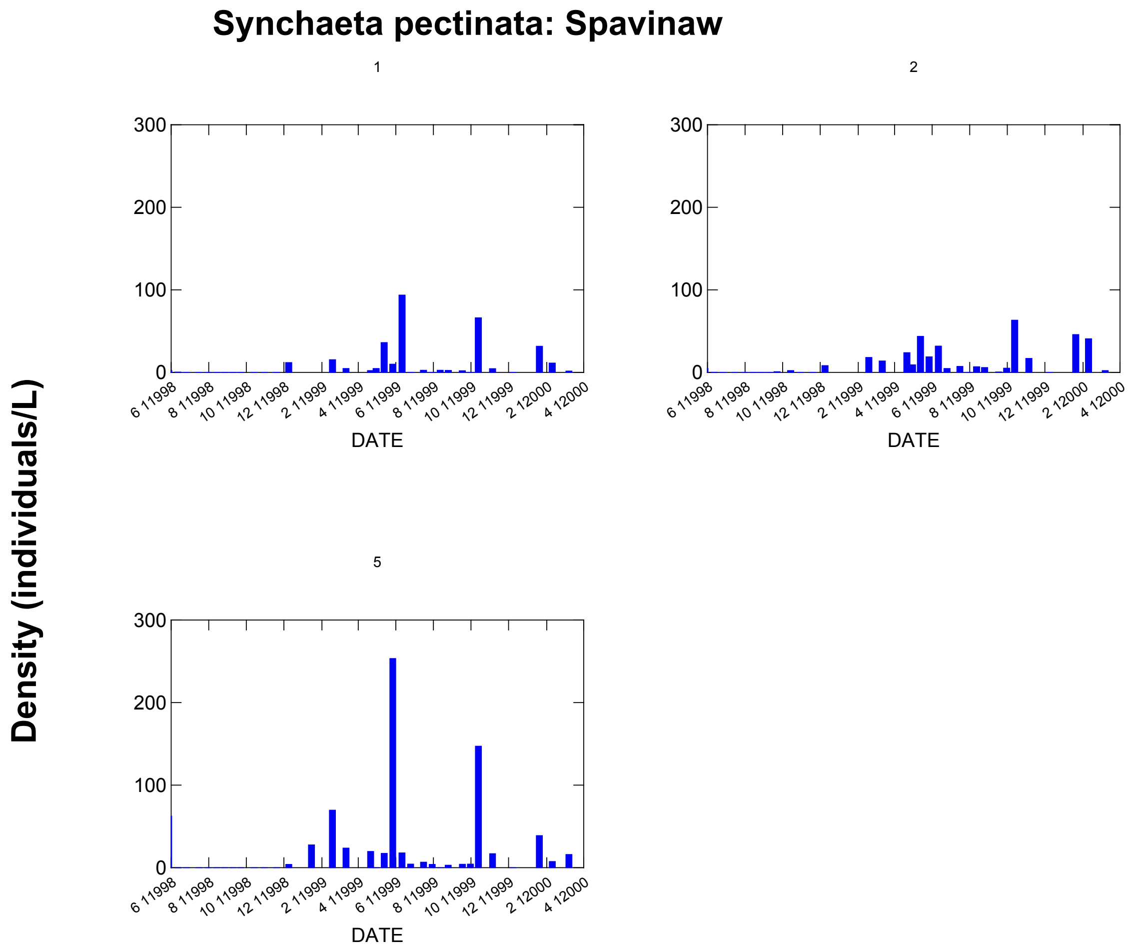


Figure 103: Abundance of *Synchaeta pectinata* in Spavinaw Lake

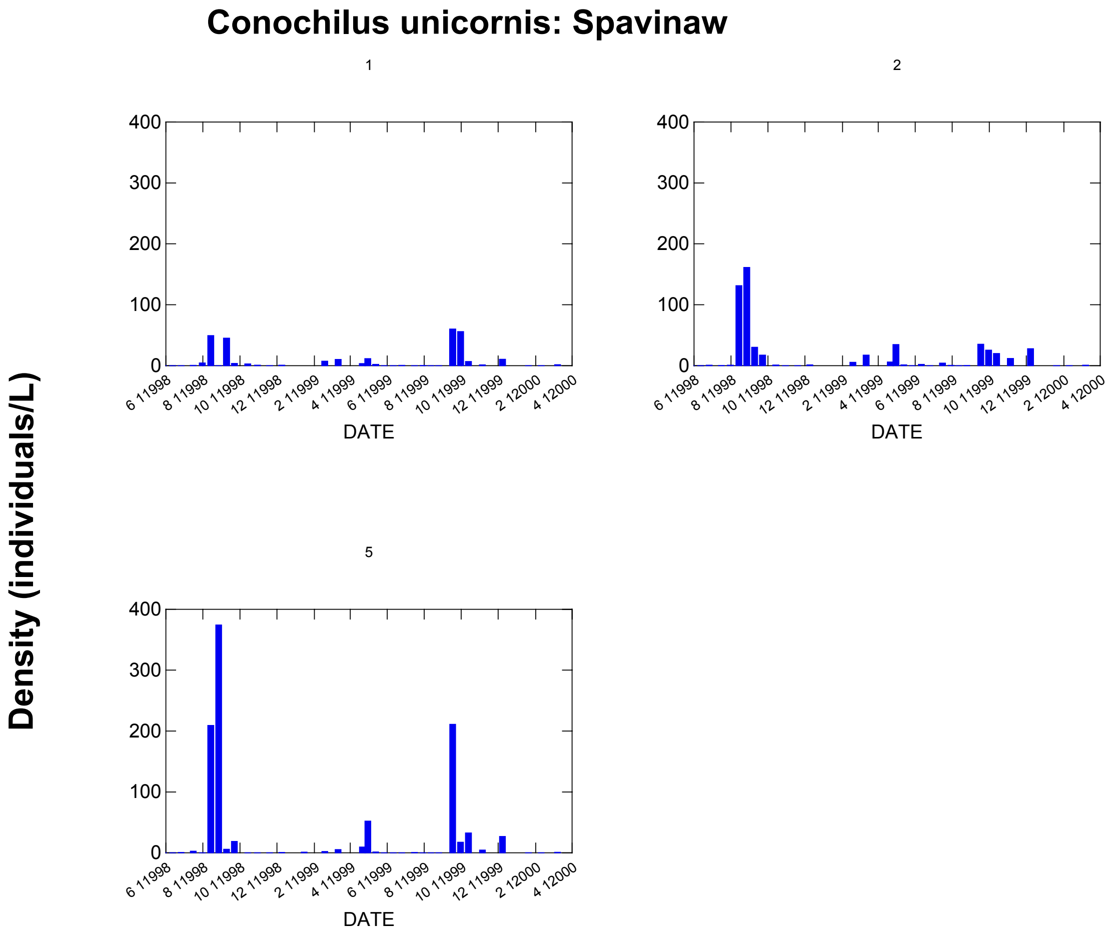


Figure 104: Abundance of *Conochilus unicornis* in Spavinaw Lake

Geosmin and MIB Analysis:

OWRB provided Geosmin and MIB data taken from Eucha, Spavinaw, Yahola and at the Mohawk Water Treatment Plant during periods in 1999 and 2000. However, not all stations were sampled in each lake on each date, therefore, absence of Geosmin or MIB at any one station is not indicative of a lack of taste and odor chemicals in the lake as a whole. In addition, we have customer complaint data from the Mohawk Water Treatment Plant dating back to 1997. Geosmin and MIB testing was conducted in Eucha Lake beginning in March 1999 (See Figures 103 and 104) at four stations: Eucha Dam at the surface and at 6m and at the intake for Eucha Lake at the surface and at 1.5m. A fifth station, Dam, 10 m, was sampled one time on March 17, 1999 with a Geosmin level of 170.00 ng/l. There is no measurement for Dam at 6m on that date, so it appears that the 10m sample replaced the 6m sample. Geosmin and MIB testing was conducted in Spavinaw Lake at the Dam at the surface and 6m and at the Flowline (Bird Creek Pump Station) during the same period (See Figures 105 and 106). Geosmin and MIB were measured at the Mohawk Water Treatment Plant in the raw water and in the finished water as well (See Figures 107 and 108). Measurements were taken in

Lake Yahola from March 1999. Results are shown in Figures 109 and 110 for Geosmin and MIB, respectively.

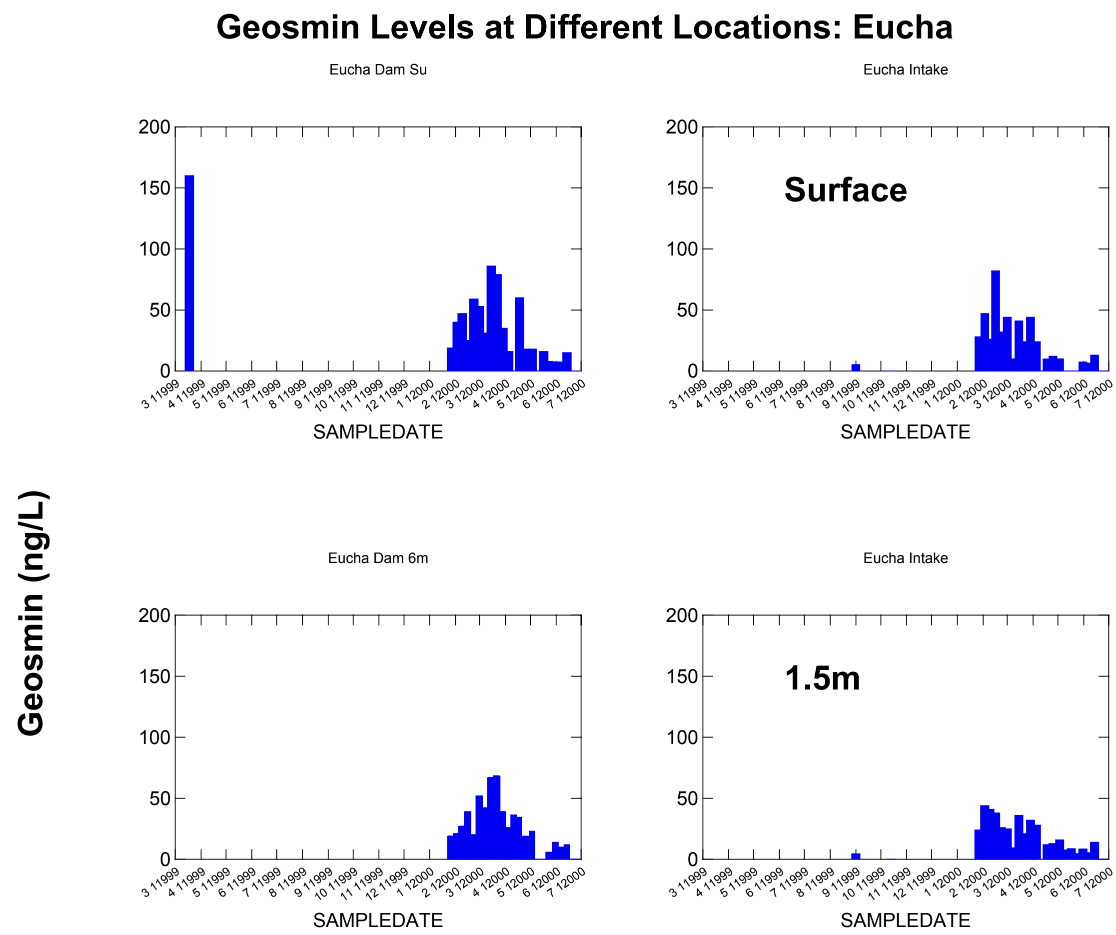


Figure 105: Geosmin Levels, Eucha Lake

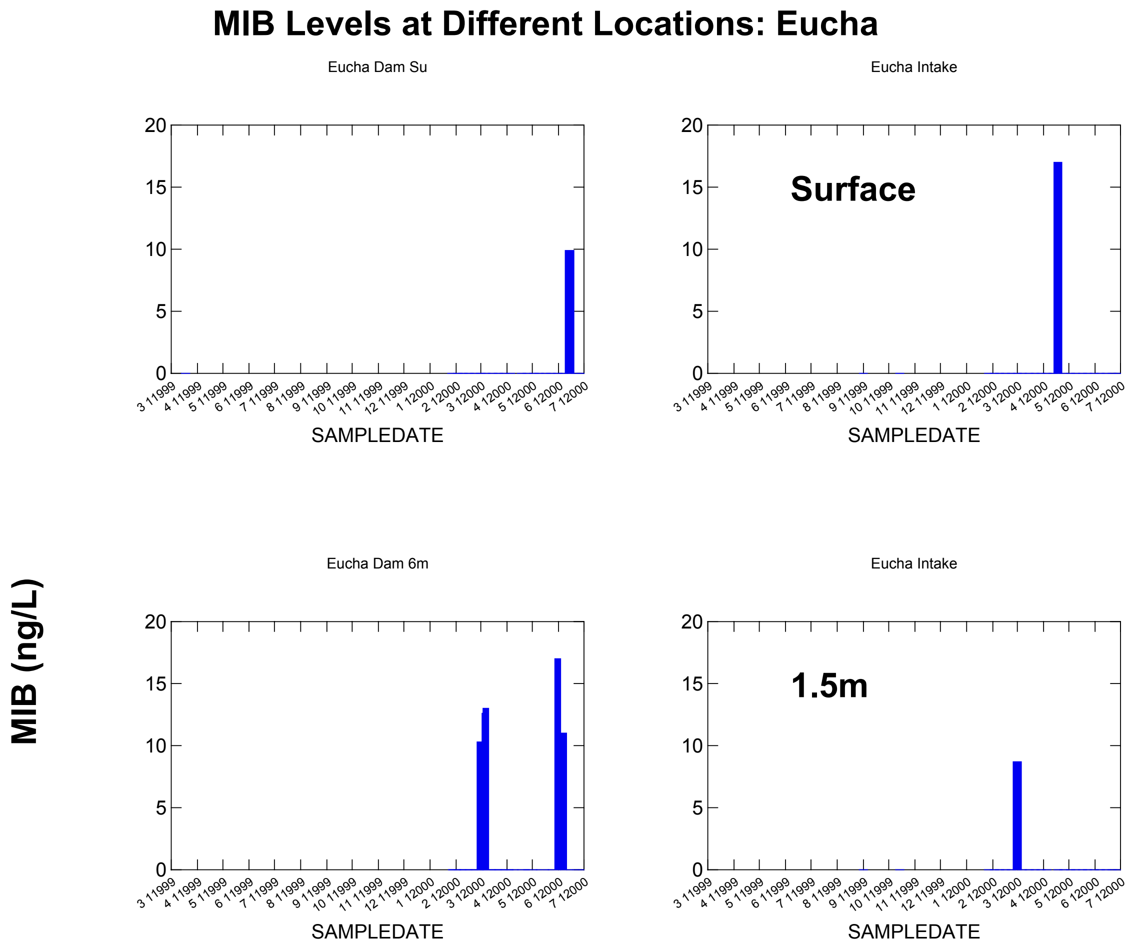


Figure 106: MIB Levels, Eucha Lake

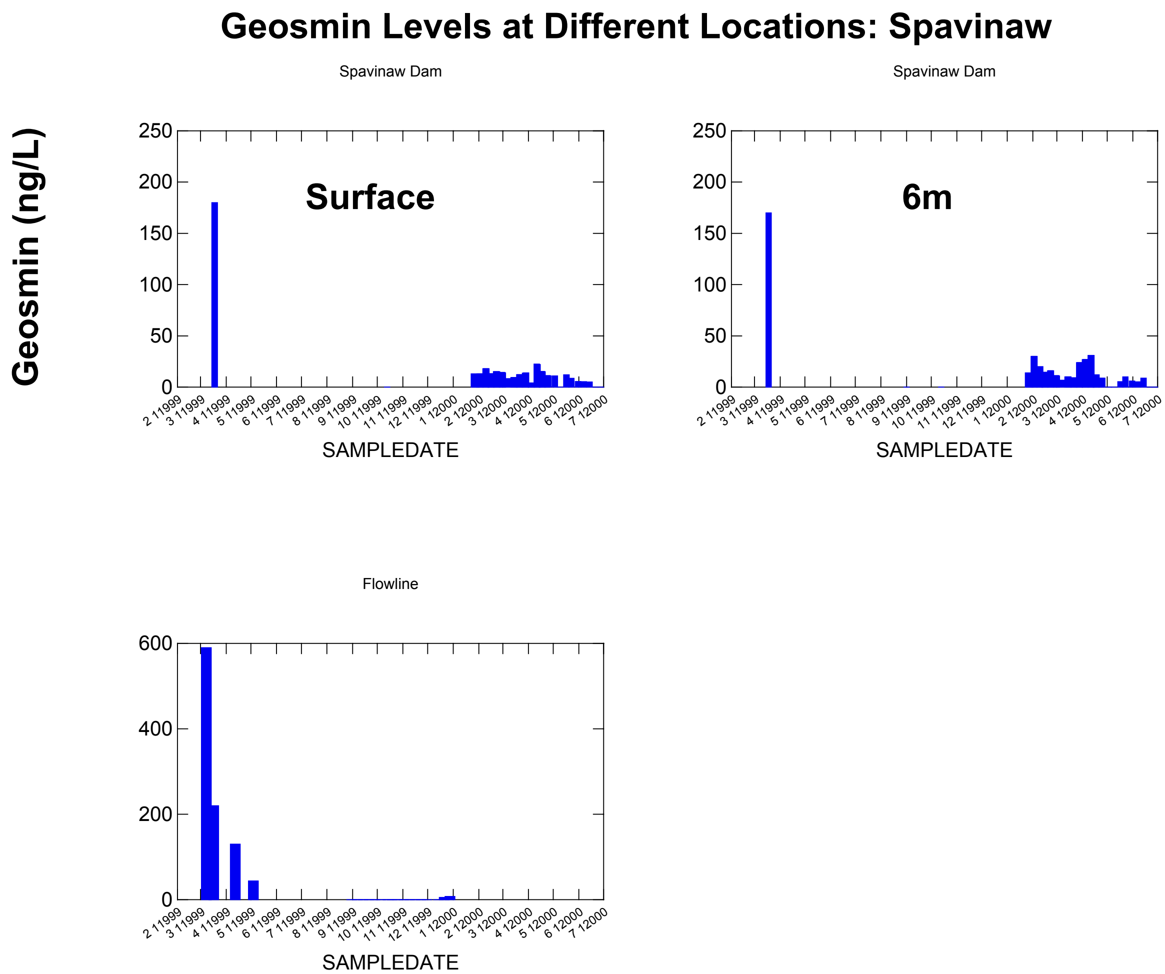


Figure 107: Geosmin Levels, Spavinaw Lake

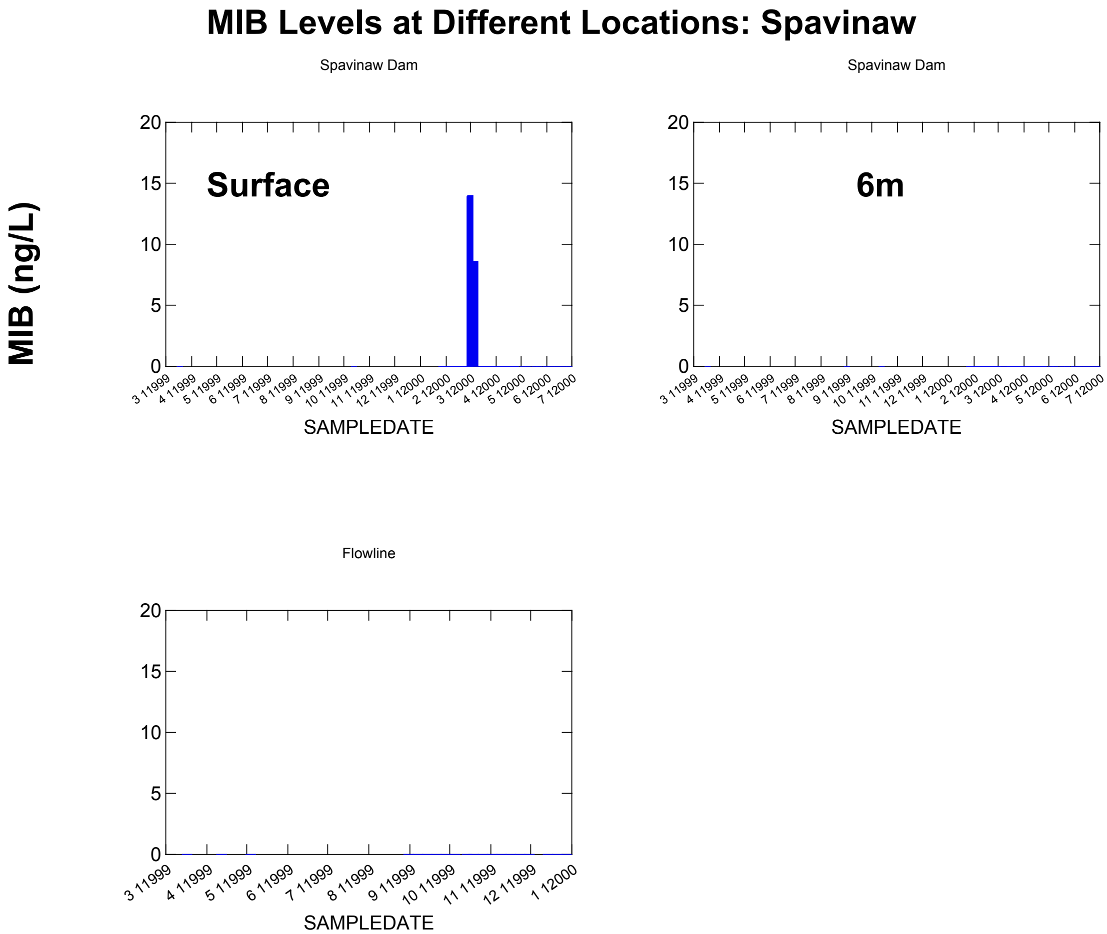


Figure 108: MIB Levels, Spavinaw Lake

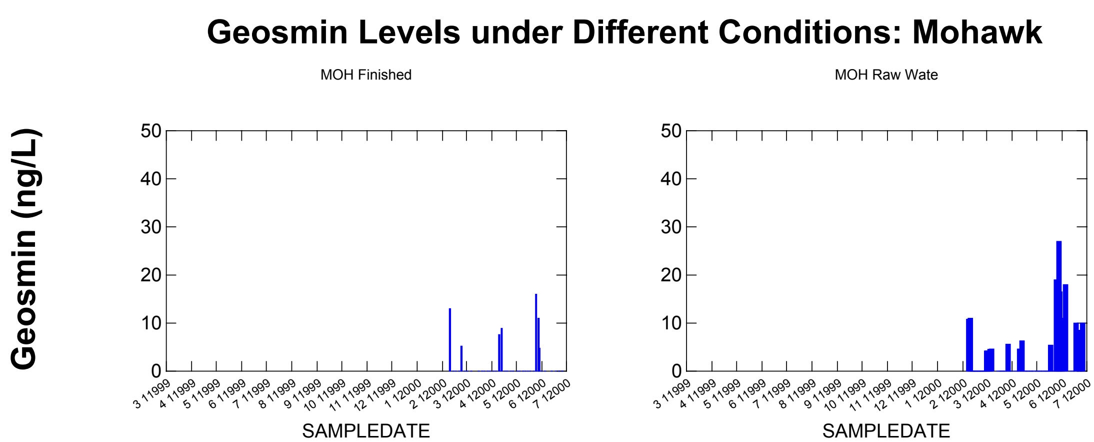


Figure 109: Geosmin Levels under different conditions, Mohawk

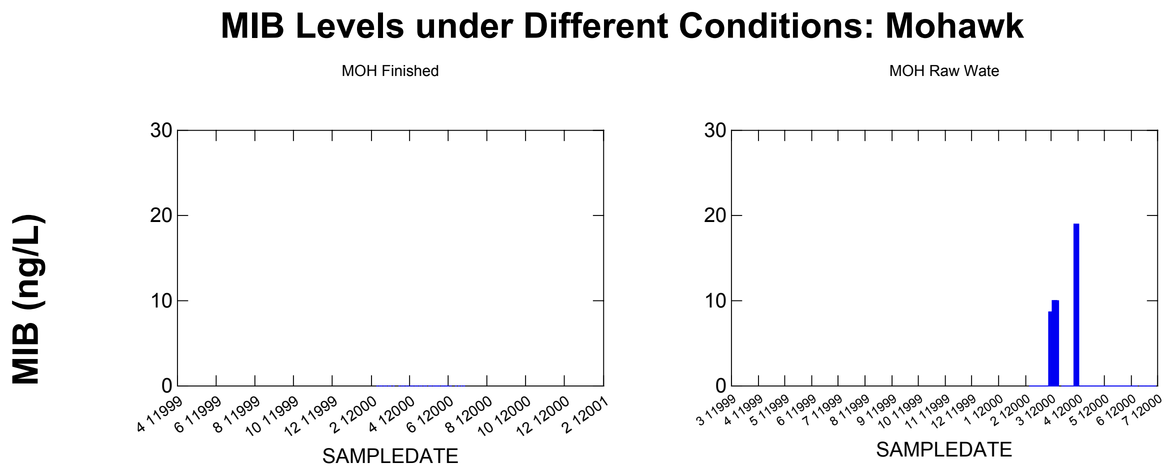


Figure 110: MIB Levels under different conditons, Mohawk

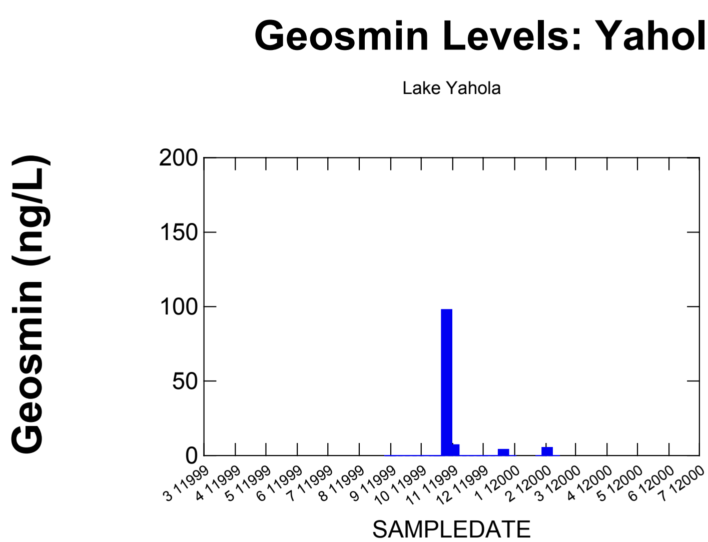


Figure 111: Geosmin Levels, Yahola

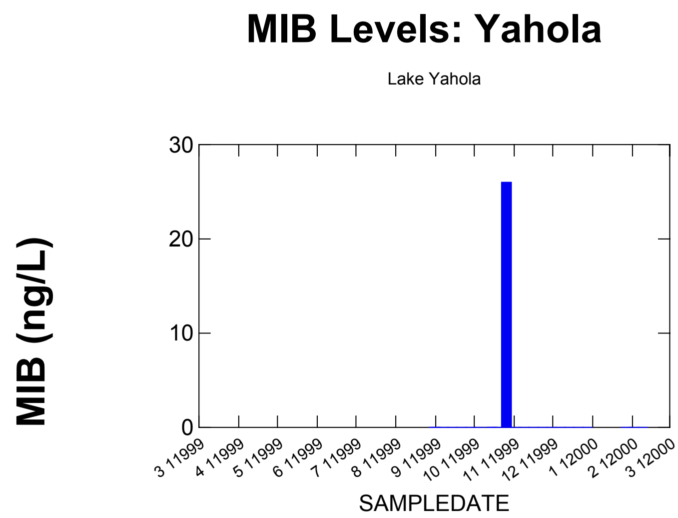


Figure 112: MIB Levels, Yahola

Geosmin levels were high in the late winter 1999 (March 8 and 9, 1999) with another peak in winter 2000 in both Eucha and Spavinaw, although Spavinaw had higher readings. The first peak was the most intense event with Geosmin levels up to 200 ng/L in-lake and almost 600 ng/L in the Flowline. There was no measurable MIB present at any of the sampling stations at this time. The secondary event was an extended period in 2000 starting in February and continuing past the study period in March. These peaks were not as high as in 1999; generally producing Geosmin levels less than 100 ng/L. MIB was detectable in this event, though, at less than 20 ng/L. Geosmin and MIB were high in Lake Yahola in the late fall 1999 as well, reaching over 100 ng/L for Geosmin and nearly 30 ng/L for MIB. Geosmin and MIB were detectable at low levels in the Winter 2000 as well. Geosmin and MIB levels in raw Mohawk water agree with the peaks seen in the lakes. Finished water has substantially less Geosmin and no MIB.

Looking at the species plots for the algae and at the division level data generated by the Mohawk water plant, it appears that Diatoms are the most likely source of Geosmin and MIB (See Figures 111 and 112). It's also possible that there is a contributing population of *Anabaena flos-aquae* and A. circinalis during the same period as well. The Blue-greens, though, are present at much lower biomass than the Diatoms and are likely secondary contributors, at best. Lake Yahola had a large Diatom bloom during its highest documented Geosmin/MIB peak event as well. Also interesting is the customer complaint data (See Figure 113) for the Mohawk finished water. Complaints increased dramatically during the late fall 1998 and winter1999 and in late fall 1999. Although data does not extend back to 1998 for Geosmin and MIB, the algal data confirm that the late fall 1998 period was experiencing a bloom of the same Diatom species (*Stephanodiscus niagare*) that dominated during the March event in 1999 in both Eucha and Spavinaw, and the October/November 1999 event in Yahola. None of the Blue-greens that produce Geosmin and MIB were dominant, either numerically or by biovolume during any of the time periods (1999 and 2000) when Geosmin and MIB were detected. Two Melosira species were present during the late fall/ winter blooms as well, but only contributed a fraction of the biomass compared to *S. niagare*, in Eucha and Spavinaw, especially during the two earlier periods in late 1998 and early 1999. In

Eucha and Spavinaw, when S. niagare dominated in March 1999, Geosmin was the primary chemical detected. Melosira was more important in Winter 2000, in Eucha and Spavinaw, when MIB was also more prevalent during the bloom. In Lake Yahola both Geosmin and MIB were high in the late fall 1999 bloom which was dominated by *M. italica* and *M. granulata*, with *Stephanodiscus niagare* as a secondary contributor. It appears from the species data of all three lakes that MIB is more likely produced when *Melosira* (Geosmin and MIB) is present and dominating, than if *Stephanodiscus* (primarily Geosmin) is present and dominating. Both Diatom genera are likely contributing to the production of Geosmin and MIB, though.

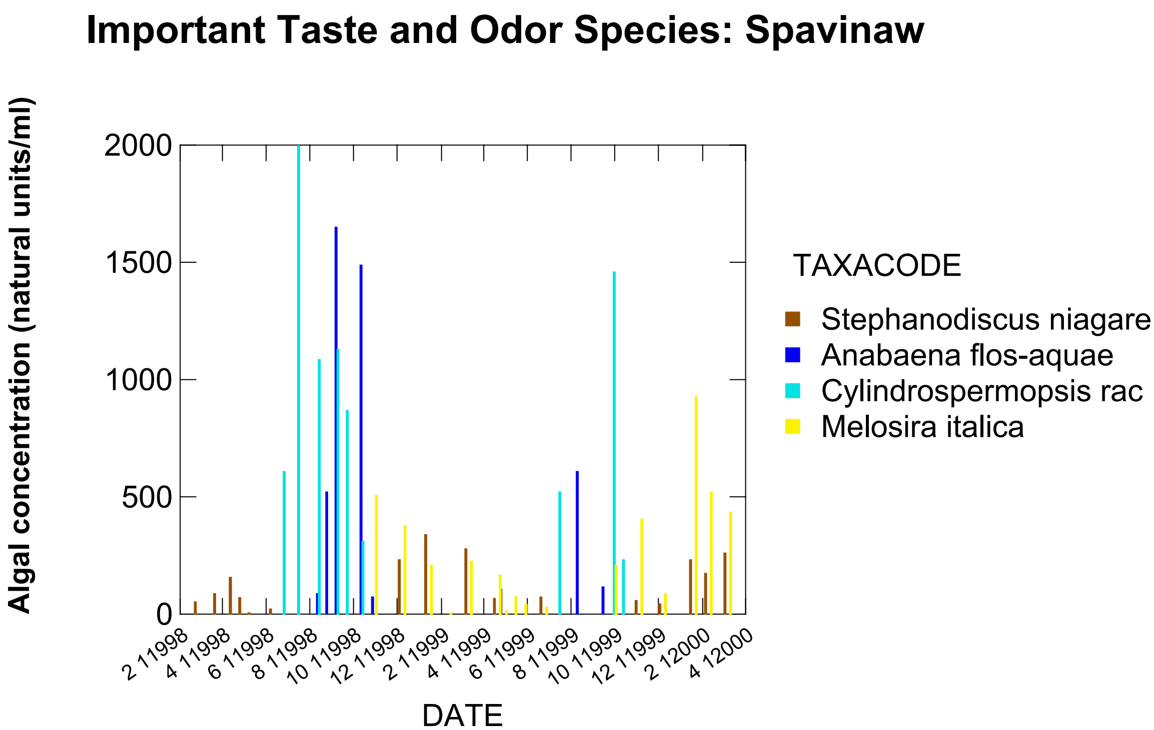


Figure 113: Taste and Odor Species, Spavinaw Lake

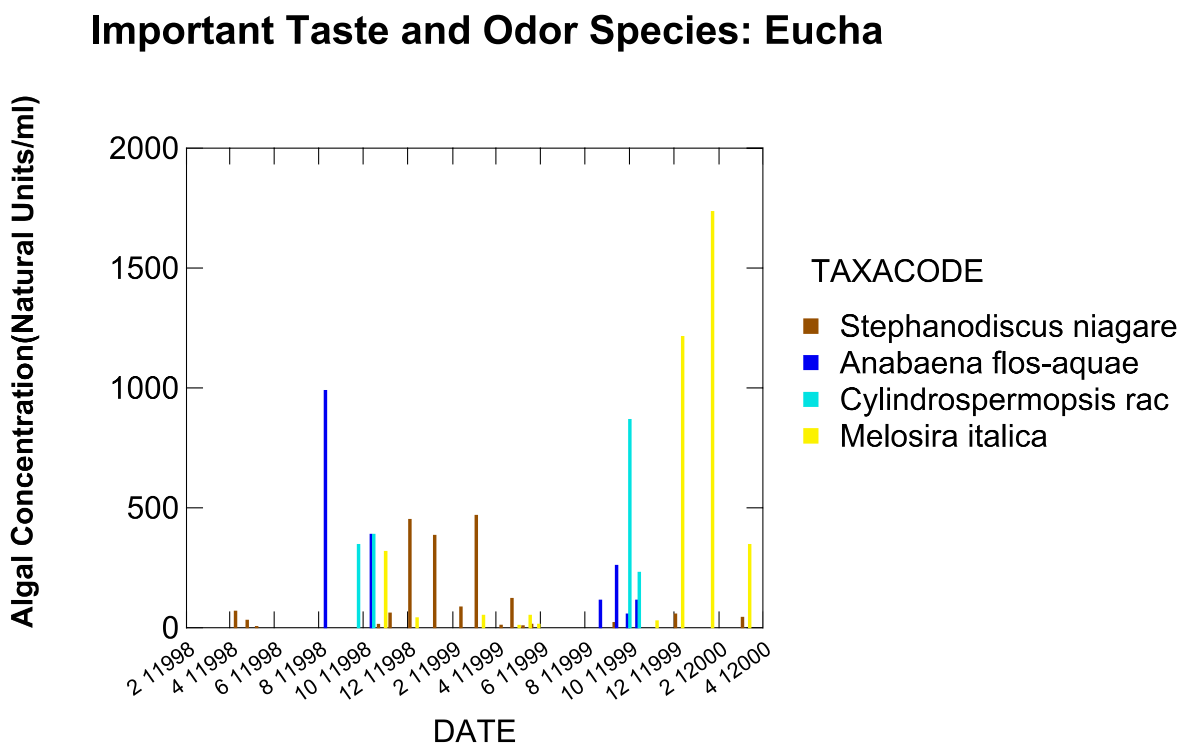


Figure 114: Taste and Odor Species, Eucha Lake

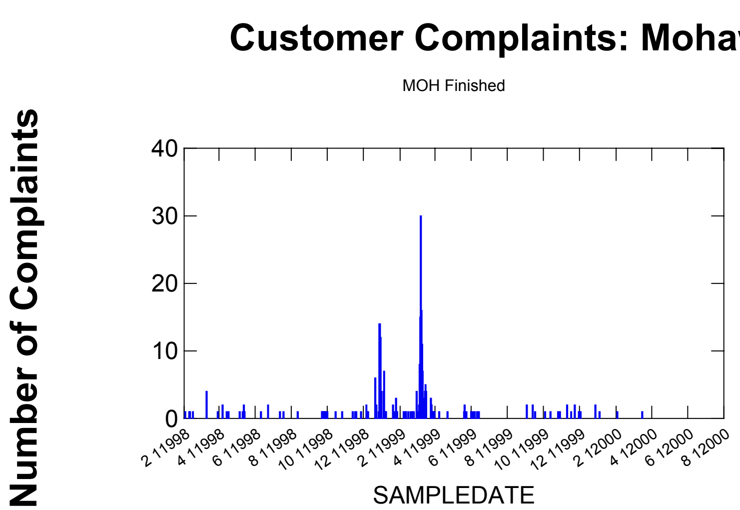


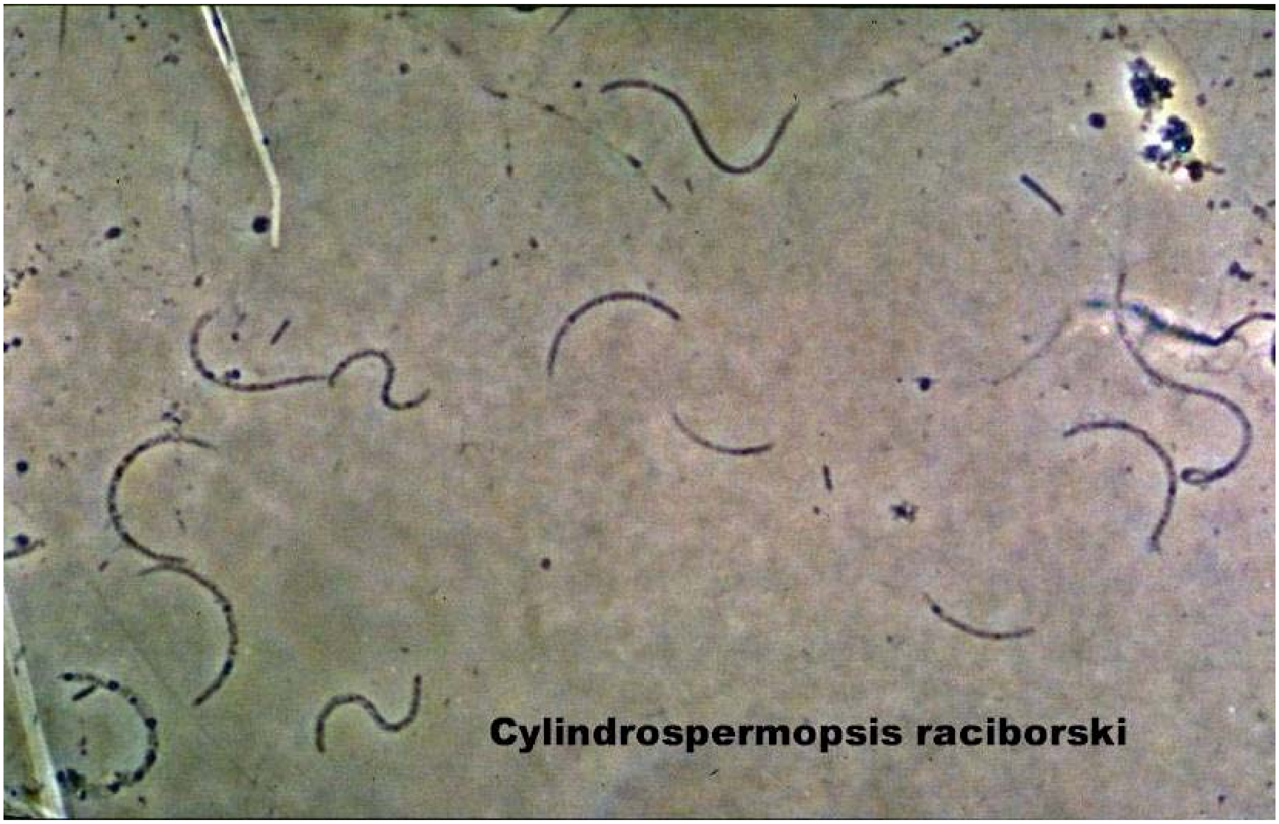
Figure 115: Customer Complaints, Mohawk

Alternative contributors to the production of Geosmin and MIB include attached algae growing in the littoral zone (shallow areas) of all three lakes. Several species of *Oscillatoria* and *Lyngbya*, as well as filamentous bacteria in the Actinomycetes group, have been documented to produce Geosmin and/or MIB. No samples or data was provided on the attached algal or bacterial communities in Eucha, Spavinaw or Yahola Lakes.

Another interesting characteristic of the data is the taste characteristic of the finished water (OWRB, 2000) Often during the Diatom bloom periods there was an Earthy, Musty taste to the water. This is consistent with Geosmin/MIB presence at a detectable level. However, during the late summer periods, there was also a Tingly taste to the water. These were periods when *Cylindrospermopsis raciborski* dominated the assemblage. *Cylindrospermopsis* does not produce large amounts of Geosmin and produces no MIB, but it does produce an algal toxin, Cylindrospermopsin. The tingling could be a reaction to the presence of algal toxin in the finished water. Several Anabaena species were also present which produce toxins as well. The only way to confirm toxin presence would be to specifically test for algal toxins produced by *Cylindrospermopsis* (Cylindrospermopsin) and the three Anabaena species present (*Anatoxin-a, Anatoxin-a*(s), *Microcystin* and *Saxitoxin).*

Discussion and Conclusions

All three reservoirs are considered eutrophic systems based on multiple indicators. Eucha was the more productive Lake; it drains a much larger area and has a larger hypolimnetic phosphorus release rate during the summer months (OWRB, 2000). The algal data from all three lakes indicated very productive systems, both quantitatively (total algal abundances were well above the 15,000 cells/mL threshold considered eutrophic) and qualitatively (a number of species that were associated with troublesome algal blooms were present, e.g. *Cylindrospermopsis, Anabaena, Stephanodiscus, Melosira* (See Figures 114, 115, 116, 117 and 118). Chlorophyll a values were consistently high and peaked to values well over 60 ug/l on occasion. OWRB data indicate significant phosphorus loads to the lakes and in summer, internal recycling has been documented.



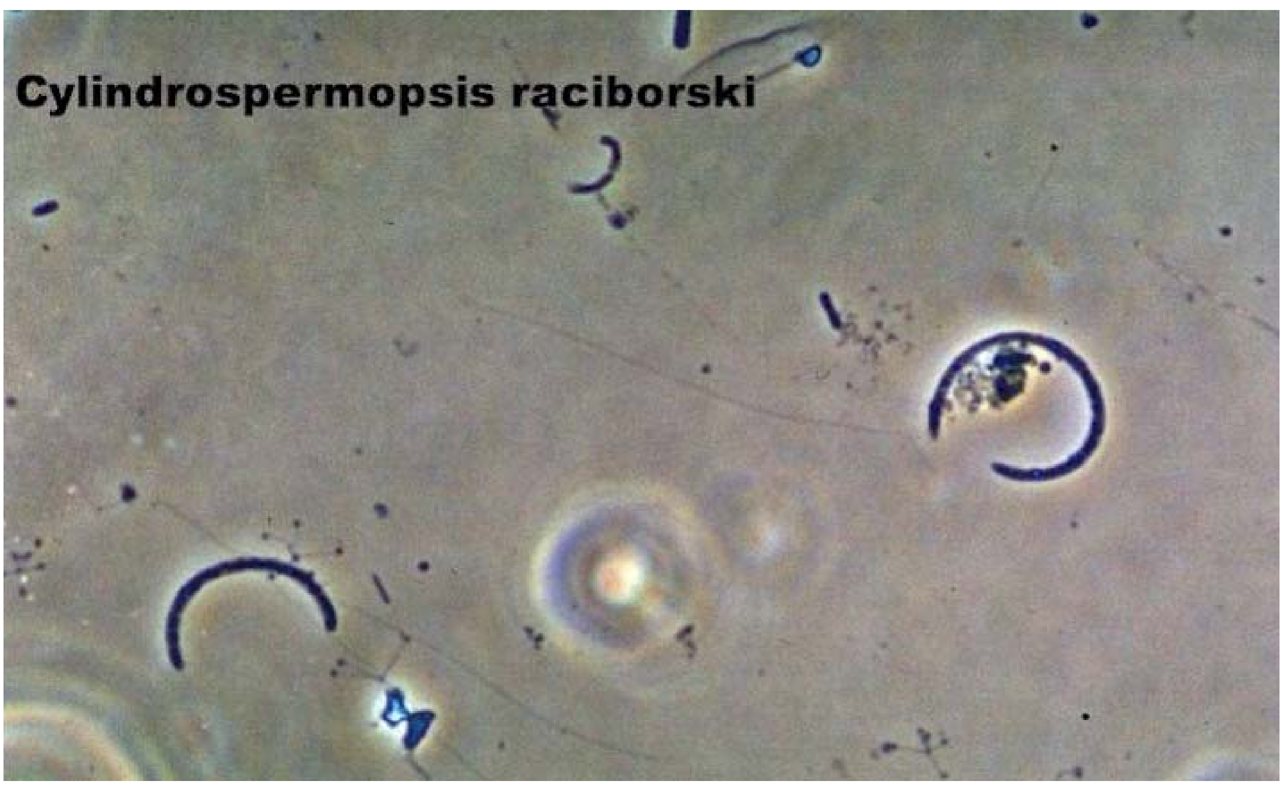


Figure 116: *Cylindrospermopsis raciborski*, photographs taken at 400x, under Phase optics. Notice lack of heterocysts.

Figure 117: *Anabaena flos-aquae*, photograph taken at 200x, under Phase optics

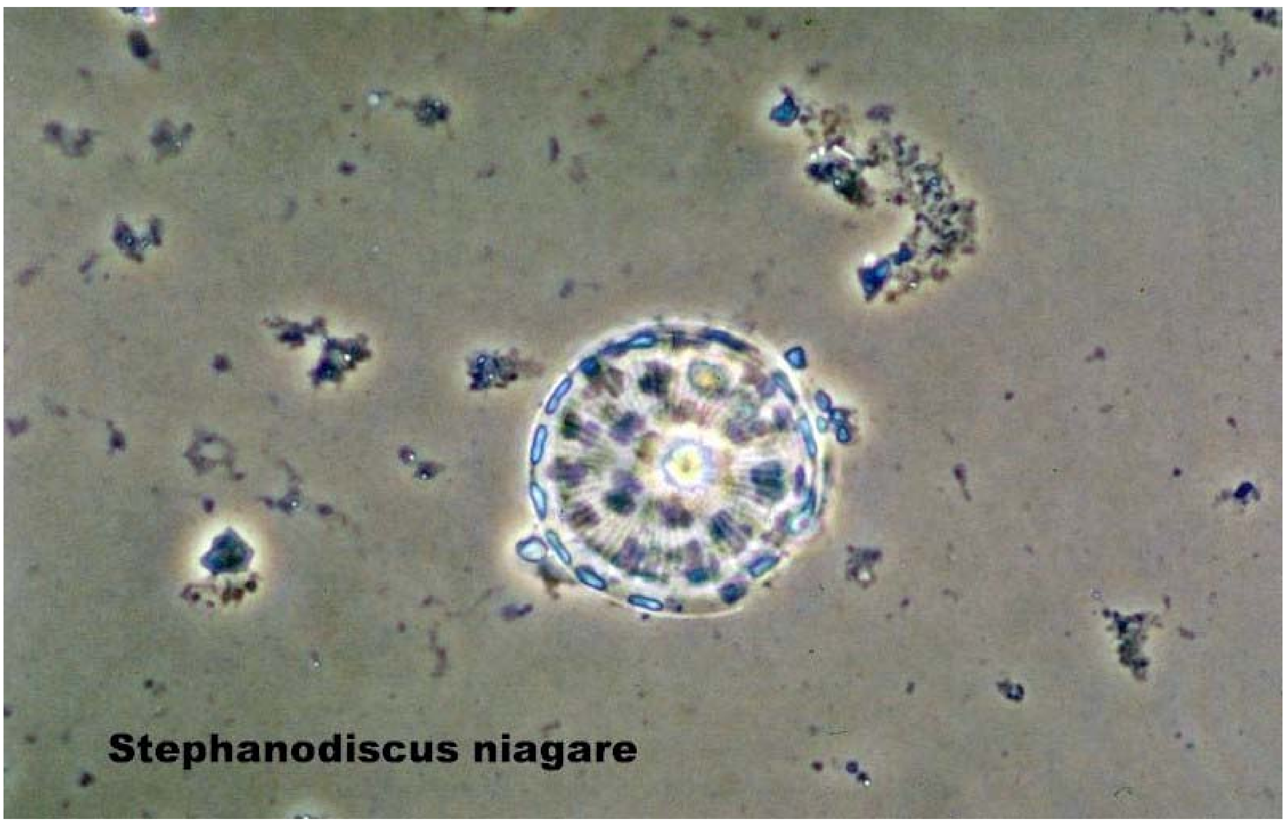


Figure 118: *Stephanodiscus niagare*, photograph taken at 400x, under Phase optics

Figure 119: *Melosira italica*, photograph taken at 400x, under Phase optics

Figure 120: *Melosira granulata*, photograph taken at 400x, under Phase optics

The Blue-green algae dominated numerically much of the year in all three lakes, although the primary taxa to dominate numerically are the Picoplankton, which were not an important contributor to biomass during much of the year and especially during taste and odor events. The Picoplankton are common in large numbers in western reservoirs with reasonably high particulate loads and serve a vital function in recycling nutrients and as a food source for the Rotifers and Calanoid copepods, as well as other small micro-zooplankton (Waterbury, et al. 1986; Gηde. 1989; St. Amand. 1990). Other important Blue-green algae associated with eutrophic conditions include Cylindrospermopsis raciborski (a toxic, invading sub-tropical species) as well as Oscillatoria limnetica (produces taste and odor compounds, See Figure 119) (Matsumoto and Juttner. 1993) and several species of Anabaena including A. flos-aquae, A. macrospora and A. circinalis (also documented to be toxic and to produce taste and odor compounds) (Mohren and Juttner. 1983; Rosen, et al. 1992; Negoro, et al. 1988).

Algae likely replaced significant macrophyte populations in 1999 as the major sink for in-lake nutrients. This often happens in productive systems where algae and macrophytes compete for nutrients and light (Wetzel. 1983). Evidence to support this comes form the decreased nuisance macrophyte beds in 1999 (OWRB, 2000), the heavier year for total algal biomass.

The filamentous, nitrogen-fixing Blue-green algae such as Cylindrospermopsis and Anabaena are not easily available to smaller zooplankton grazers in the lake (above 22 um in length, Sorrano, et al. 1993) . In addition, there were no large Daphnid grazers present during the late summer Early fall periods which could effectively graze the larger filaments. This condition was present in both 1998 and 1999. Lack of large Daphnids could be related to competition from rotifers and copepods for the smaller, more edible algal taxa or could also be a response to algal toxins produced by the Blue-green algae. During the higher biomass 1999 period, Cylindrospermopsis exhibited a decreased GALD, possibly in response to higher nutrients and/or faster growth rates. Cylindrospermopsis and Anabaena did not often exhibit heterocysts, which is common when the N:P ratio is high (OWRB, 2000), indicating a surplus of nitrogen in the system. The N:P ratio was well above 15, the threshold for favoring Blue-green algae (Reynolds. 1984) during much of the study period, the exception being late summer 1999 in Eucha Lake, when the ratio dropped below 10 for a few weeks. Cylindrospermopsis grew best when the lake was stratified and warm, and when phosphorus release from the sediments was at a maximum (OWRB, 2000). Eucha Lake experienced larger Blue-green algal blooms than Spavinaw, and the blooms in Spavinaw generally followed Eucha by 1-2 weeks. Anabaena actually started to grow in very small concentrations in the winter, when the lake was fully de-stratified., but did not bloom until summer, after the lakes had stratified. The Blue-green species in these lakes will be hard to control because they are already well developed during summer periods when the N:P ratio is not favorable for nitrogen fixing Blue-greens (OWRB, 2000).

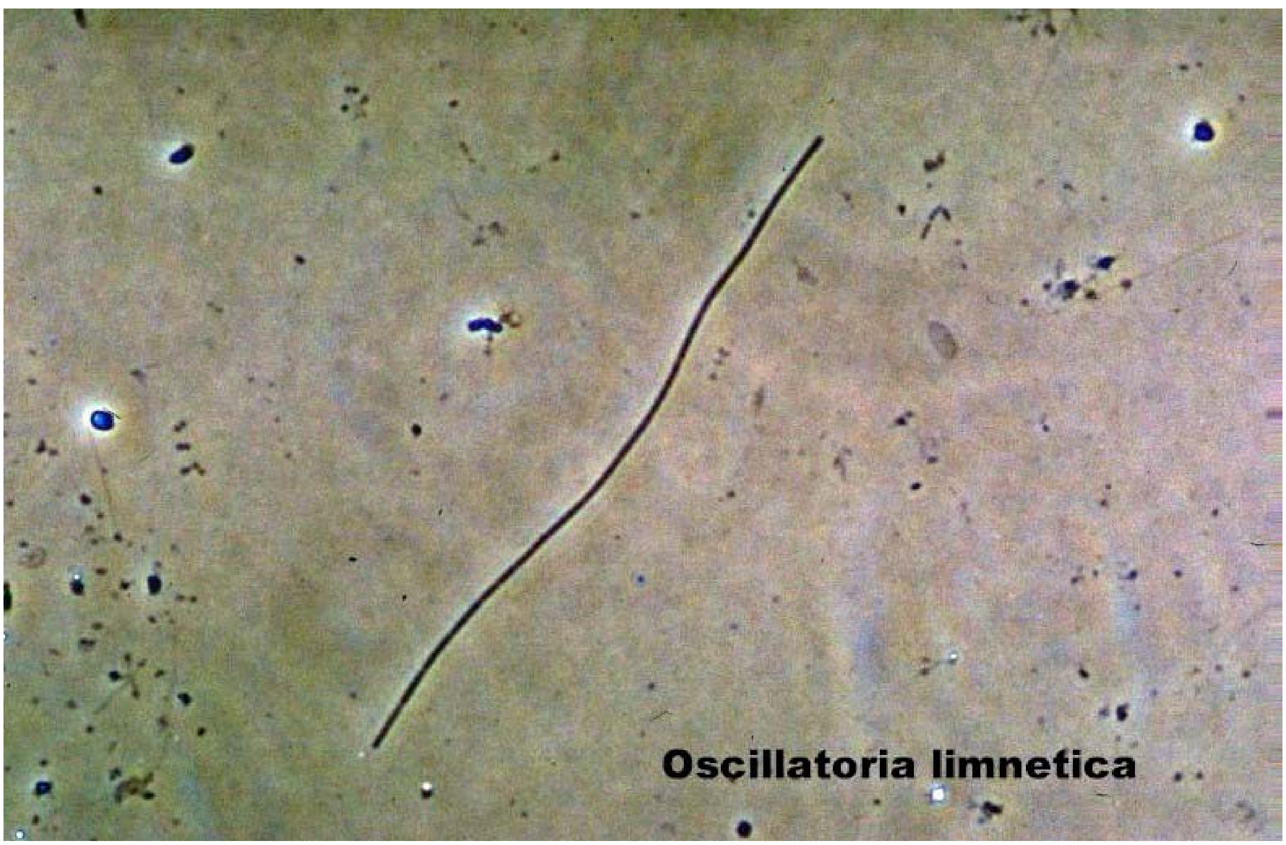


Figure 121: *Oscillatoria limnetica*, photograph taken at 400x, under Phase optics

The Diatoms dominated most dates when the Blue-greens did not, although the other divisions were sporadically important during the year, especially in transition periods such as late Fall and early Spring. The diatoms did not often dominate numerically, due to their large size (often between 20 and 100+ um), but in the late Fall and Winter, they dominated the algal biovolume. Diatom blooms that dominated the biovolume occurred during periods of low dissolved silica in the lakes (OWRB, 2000). This was especially true when Stephanodiscus and Melosira were blooming. There were several small Cyclotella species that also bloomed during the late Fall and Winter, as well as smaller blooms during the Summer, but they did not dominate the biovolume as the larger diatoms did. Stephanodiscus was another species that showed a decreased GALD over the year 1999, compared with the previous year, again, potentially due to a release from competition. For Stephanodiscus, though, the decreased GALD put it into the more edible category. Daphnia pulex, the largest, most effective Daphnid grazer in Eucha and Spavinaw (up to 3 mm, Herbert. 1995), was present in much larger numbers during the late Fall 1999 and Winter 2000 than at any other time in the study period. This situation likely prevented an extreme Stephanodiscus bloom in the lakes in Winter 2000, compared to winter 1999, This effect was especially notable in Eucha where the D. Pulex population was present in higher densities than in Spavinaw. The larger, non-edible, Melosira bloomed in much higher densities in winter 2000 in all three lakes. The situation was reversed in winter 1999, when there was not a population of larger Daphnids available to exert grazing pressure on the Diatom community, allowing Stephanodiscus to bloom more fully.

The Chyrsophytes, Green algae, Euglenophytes and Dinoflagellates occasionally were co-dominant with the Diatoms and Blue-greens during the study period. During Winter months, Uroglena sp., a colonial Chrysophyte, accounted for up to 35% of the biovolume. It sometimes dominated during the same period numerically as well, because the colonies dissociate upon fixation and single cells are generally tallied. The colonies are relatively large and thus exempt from grazing. Like many Chrysophytes, Uroglena does well in lower temperature and light circumstances present in Spring (Sandgren. 1988). Euglenophytes accounted for 10-20% of the assemblage during the late Summer in 1998 and 1999, although the 1998 bloom was earlier than in 1999. Euglena ssp. and Trachelomonas ssp. were the most prevalent Euglenophyte taxa. The Euglenophytes do well in high organic carbon situations (Wetzel. 1983), hence they were generally present in higher numbers at depth rather than at the surface. Cryptophytes were present in small numbers and at times often represented 10+% of the biovolume. The primary contributors were Cryptomonas erosa and Rhodomonas minuta v. nannoplantica, both excellent zooplankton food. Rotifers, Calanoid copepods, and Daphnia ssp. all graze on Cryptomonas and Rhodomonas, either selectively or generally. Dinoflagellates were sporadically important in mid-Summer of both 1998 and 1999. The Green algae were present in small numbers consistently throughout the Summer, often in grazable taxa like Chlamydomonas sp., but were not very important overall.

The zooplankton in Eucha and Spavinaw followed a seasonal pattern generally atypical of temperate lakes (Beaver and Havens. 1996), with biomass abundance the highest in winter months when algal productivity was not at its maximum. The ratio of Calanoid copepods to Cladocerans and Cyclopoid copepods generally increases with decreasing productivity (Johannsson, et al. 1999). Despite the lower productivity in Spavinaw Lake, the ratio of Calanoid copepods to Cladocerans and Cylcopoid copepods combined was not lower than in Eucha Lake. This could reflect a threshold effect, where the productivity is high, even when it is relatively lower than another lake. The ratio was lower in the winter periods when there were fewer zooplankters present overall, and it lagged in Spavinaw Lake compared to Eucha Lake, by a period of several weeks. We would also have expected the ratios of Calanoids to be higher in 1998 as compared to 1999, in both lakes; this was also not the case (see Figure 120). Zooplankton abundance was often at a minimum when algal biomass was at a maximum, this could be due to two different pressures on the zooplankton. First, fish predation could be very important in regulating the presence of large bodied cladocerans (primarily daphnids) and other edible zooplankton during the summer and early Fall (Brooks and Dodson. 1965). Fish data was not available for confirmation about the YOY fish population in the lake.

Ratio of Calanoids to Cladocerans and Cyclopoids

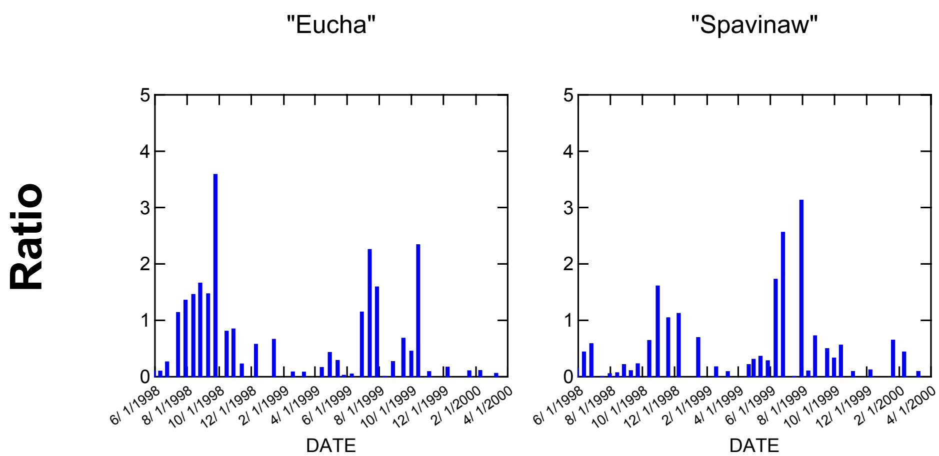


Figure 122: Ratio of Calanoids to Cladocerans and Cyclopoids

Secondly, the periods when the highest biomass of summer algae was present, was dominated by relatively large, toxic, inedible species (e.g. *Cylindrospermopsis raciborski*). There may not have been a suitable food supply to support the expected zooplankton community at higher productivities. Zooplankton did well overall, especially the rotifers and small-medium sized Cladocerans during periods of high numbers of smaller, more edible algal species, such as *Rhodomonas minuta*, *Cryptomonas erosa, Cyclotella* ssp. and small Greens, but not during periods when more inedible algal taxa were present. In both years, picoplankton biomass peaked when the effective grazers, Daphnids, were not present in the lake. At the same time, Rotifers and Copepods did quite well, indicating these groups were benefiting from the higher food supply available in the smaller algal cells. Rotifers generally graze on food particles in the 1-5 um range, while the Calanoid copepods will graze particles up to 10-22 um (Sorrano, et al. 1993). Because there was not significant grazing pressure on the mid to late Summer Blue-greens in either year, the drop in GALD was likely due to higher available nutrients and faster growth rates, rather than from indirect grazing effects.

There was evidence, though, for the drop in *Stephanodiscus* GALD to be related to increased zooplankton grazing pressure. In 1999, there was a significant winter population of *Daphnia pulex*, a large, effective Cladoceran grazer (Herbert. 1995; Mills, et al. 1987). The lower GALD made *Stephanodiscus* more available to *D. pulex*, in contrast to 1998 when no *D. pulex* was present. As a result, the winter *Stephanodiscus* bloom was replaced by *Melosira italica* and *M. granulata,* both too large for *D. pulex* to graze.

Daphnia lumholtzi was found in both Eucha and Spavinaw Lakes during a very short late fall period in both 1998 and 1999. *D. lumholtzi* is an invasive species that is very difficult for YOY fish to eat (Havel, et al, 1995). There is also concern that *D. lumholtzi* might out-compete other native daphnids such as *D. pulex*, *D. laevis* and *D. retrocurva* (Havel, et al. 1995). Although there has been concern since its detection in the early 1990's about potential deleterious effects on other daphnids, there hasn't been substantial evidence to date that it has significantly affected native daphnids (Goulden, et al, 1995). There is still concern over its affect on fish communities and decreased food supply available for YOY larval fish. Because *D. lumholtzi* is present later in the season than in more Eastern Lakes (Hebert, 1995), it is still unclear what permanent effect its presence will have on the fish community and its abundance needs to be watched closely.

Taste and odor data in the three lakes and at the Mohawk Water Treatment Plant were somewhat surprising. The most common cause of taste and odor problems is generally Blue-green algae (AWWA, 1987) and there were several taste and odor producing Blue-green taxa present, in addition to the Picoplankton which have been reported to produce taste and odor compounds in culture (Izaguirre, Hwang, and Krasner, 1983). The data, though, support the Diatoms as the primary cause of the taste and odor problems in Eucha and Spavinaw Lakes. Both times high Geosmin and MIB levels were recorded, there were Diatom blooms in progress. Although data were not available for 1998, there was also a peak in customer complaints (a good predictor of taste and odor compounds, (Nugent, 1998) during an additional Diatom bloom in late Fall 1998. There was data to support a switch between dominant Diatom species, caused a shift in the relative ratio of Geosmin to MIB. *Stephanodiscus* appears to produce primarily Geosmin, while *Melosira* produces both Geosmin and MIB. The presence of large Daphnid grazers limited the Winter 2000 bloom of diatoms significantly, suggesting that one way to decrease the winter bloom would be to encourage the presence of large Daphnids by manipulating the fish community (Mills, et al, 1987), as well as by reducing nutrient loads to the lakes. Using chemicals, such as copper sulfate, to control the algae exclusively may have an undesired effect on productivity. Lower Blue-green blooms in the summer of 1998 were followed by higher Diatom blooms in the winter. Also, the potential for the increase in *Cylindrospermopsis raciborki* could be problematic because of its toxicity. *C. raciborski* consistently produces a toxin when present (Andrew Chapman, SJWMD, personal communication) which can be fatal to fish, reptiles, birds and mammals (Codd, et al, 1989; Izaguirre, et al, 1983). Given the presence and potential toxicity of *C. raciborski*, it would be prudent to determine if the toxins are present in the lakes and if they are at high enough concentrations to cause concern. By reducing other competing taxa and not reducing nutrients, there would likely be an increase in *C. raciborski* and other potentially toxic and taste and odor producing species such as *Anabaena circinalis* and *A. flos-aquae*, which could be substantially more difficult to control. There was some evidence that *Anabaena* was co-dominant (along with *Melosira*) in a taste and odor event in late Fall 2000, decreasing competition for the bloom forming Blue-greens may only exacerbate the problem.

There are two issues which confuse the possibility of the *Stephanodiscus* and *Melosira* causing the taste and odor events observed in December 1998, March, 1999 and Winter 2000. First, although *Melosira* reached or exceeded the concentration threshold for producing detectable taste and odor compounds (250,000cells/100 mL, Seppovaara, 1971 in AWWA, 1987), *Stephanodiscus* was well below the threshold stated for similar diatom species such as *Cyclotella*. *Stephanodiscus* has been documented to produce taste and odor compounds, but was not mentioned specifically as to the threshold required for the population to produce detectable compounds. However, *Stephanodiscus niagare* is an extremely large celled diatom with a GALD often over 30 μm and an average biovolume of approximately 12,000 μm^3/cell during the study period. *Melosira* italica exhibited a biovolume per cell of approximately only 400 μm^3. When the populations are assessed in terms of biovolume, Stephanodiscus biovolume in 1998 and 1999 far exceeded the equivalent biovolume of a taste and odor producing population of *Melosira* in Winter 2000. When determining whether there is a sufficient population of a suspected taste and odor producer, analysis should include relative size as well as concentration.

Secondly, although both *Stephanodiscus* (AWWA, 1987) and *Melosira* (Arruda and From, 1989) are documented taste and odor producers, neither taxa has been documented to produce Geosmin or MIB, instead producing “fishy and musty” taste and odor compounds which have not been fully identified. Culture work on these two genera and the species involved has not been completed, and the discrepancy could be lack of data. However, it’s possible that although the species data corresponds very well, that there was another cause of the taste and odor events.

The most dominant and obvious taxa are not always the ones that are causing the problem (AWWA, 1987).

Picoplankton were present in large numbers during the blooms (likely *Synechococcus* and *Synechocystis*), but did not comprise a significant portion of the biomass, nor were the densities considerably different from the rest of the year. This would indicate that although the Picoplankton were present, they were not likely a significant contributor to the taste and odor events during the study period.

The most likely alternative solution would be a periphytic bloom of taste and odor producing Blue-greens (likely *Oscillatoria* or *Lyngbya* ssp.) at the same time as the phytoplankton Diatom blooms. Attxahed have long been documented to produce large enough attached algal mats capable of producing enough Geosmin and MIB to taint the water (Burlingame, Dann and Brock, 1986 and Zisette, Oppenheimer and Donner, 1994). Also, attached algae would likely be growing well during the Fall and Winter seasons due to the high light (less phytoplankton and macrophytes attenuating the light) and high nutrients available (Reynolds, 1984). Testing was not conducted during the sampling period to confirm or deny possible connections of the taste and odor events to the periphyton. Confirming the connections would involve sampling the periphyton and phytoplankton during a taste and odor event and culturing and testing both communities to determine if Geosmin and MIB were being produced and what species were producing the compounds. Despite the possible role of the periphyton in the taste and odor events that occurred during the study period, the documented Diatom blooms remain a likely explanation (see Table 1).

Season	***Cylindrospermopsis raciborski***	**Oscillatoria *limnetica***	**Stephanodiscus *niagara***	*Melosira* ***italica***	***Anabaena flos-aquae***	**Geosmin MIB**	**Customer Complaints**
Winter 1998	None	None	Dominant	None	None	No data	Moderate customer complaints
Spring 1998	None	None	Dominant	None	None	No data	Moderate customer complaints
Summer 1998	Dominant (S), Subdominant (E)	Minor	None	None	Dominant (E), subdominant (S)	No data	Few to no customer complaints
Fall 1998	Dominant	Subdominant	None	None	Dominant	No data	Few customer complaints
Winter 1999	None	Subdominant early, none late	Dominant	Subdominant	None	High Geosmin, no MIB	High customer complaints
Spring 1999	None	None	Dominant	Subdominant	None	High Geosmin, No MIB	High customer complaints
Summer 199	None (E), dominant (S)	Subdominant	Subdominant early	Subdominant Early	Minor	Low Geosmin (E only), No MIB	Few to no customer complaints
Fall 1999	Dominant	Subdominant	Minor	Minor	Subdominant	No Geosmin, no MIB	Few customer complaints
Winter 2000	none	Minor (S)	Minor (E), subdominant (S)	Dominant	None	Moderate Geosmin, High MIB	Few customer complaints

Table 1: Summary of occurrence by concentration of potential taste and odor producing taxa and taste odor events

(S) = SPAVINAW (E) = EUCHA.

Bibliography

Arruda, J. and C. Fromm. (1989). The relationship between taste and odor problems and lake enrichment from Kansas lakes in agricultural watersheds. Lake Reservoir Management 5 (1) 45-52.

Ashitani, K., Hishida, Y. and K. Fujiwara. (1998). Behavior of musty odorous compounds during the process of water treatment. Wat. Sci. Tech. 20 (8/9), 261-267.

Atasi, K., Chen, T., Huddleston, J., Young, C. and I. Suffet. (1999). Factor screening for ozonating the taste- and odor-causing compounds in source water at Detroit, USA. Wat. Sci. Tech. 40 (6) 115-122.

Bafford, R. A., Seagull, R. W. and D.F. Millie. (1993). Intracellular localization of the taste/odor metabolite 2-methylisoborneol in Oscillatoria limosa (Cyanophyta). J. Phycol. 29 91-95.

Bartels, J. H. M. Burlingame, G. A. and I.H. Suffet. (1986). Flavor profile analysis: taste and odor control of the future. Journal AWWA. 78 50-55.

Bao, M., Barbieri, K. Burrini, D., Griffin, O. and F. Pantani. (1997). Determination of trace levels of taste and odor compunds in water by microextraction and gas chromatography-ion-trap detection-mass spectrometry. Wat. Res. 31 (7) 1719-1727.

Bartels, J., Burlingame, G. and I. Suffett. (1986) Flavor profile analysis: Taste and odor control of the future. J. AWWA 78 (3) 50-55

Beaver, J.R. and K.E. Havens. (1996). Seasonal and spatial variation in zooplankton community structure and their relation to possible controlling variables in Lake Okeechobee. Freshwater Biology 36:45-56.

Berglind, L., Johnsen, I. J., Ormerod, K. and O.M. Skulberg (1983). Oscillatoria brevis (Kutz.) Gom. and some other especially odouriferous benthic cyanophytes in Norwegian inland waters. Wat. Sci. Tech. 15 241-246.

Blevens, W.T., Schrader, K.K.and I. Saadoun. (1995). Comparative physiology of Geosmin production by Streptomyces halstedii and Anabaena sp. WATER SCI. TEHCNOL. 31 (11) 127-133.

Brooks, J.L. and S.I. Dodson. (1965). Predation, body size and composition fo plankton. Science 150: 28-35.

Bruchet, A. (1999). Solved and unsolved cases of taste and odor episodes in the files of inspector cluzeau. Wat. Sci. Tech. 40 (6) 15-21

Bruchet, A., Anselme, C., Jammes, C. and J. Mallevialle. (1995). Development of a taste an odor expert system: Present state, strengths, limitations and possible future evolution. Wat. Sci. Tech. 31 (11) 243-250.

Burlingame, G. A., Dann, R. M. and G.L. Brock. (1986). A case study of geosmin in Philadelphia's water. J. AWWA. 78 56-61.

Carmichael, W. W. (1992). Cyanobacteria secondary metabolites- the cyanotoxins. J of App.Bacteriology. 72 445-459.

Chapman, AD. and C.L. Schelske.(1997). Recent appearance of Cylindrospermopsis (Cyanobacteria) in five hypereutraphic Florida lakes. J. PHYCOL. 33 (2) 191-195.

Codd, G. A., Bell S. G. and W.P. Brooks. (1989) Cyanobacterial toxins in water. Wat. Sci. Tech. 21 (3) 1-13.

Cronberg, G., Annadotter, H. and L. Lawton. (1999). The occurrence of toxic blue-green algae in Lake Ringsjön, southern Sweden, despite nutrient reduction and fish biomanipulation. Hydrobiologia 404 123-129.

Desikachary, T.V., 1959. Cyanophyta. Indian Council of Agricultural Research, New Delhi.

Dionigi, C. P., Millie, D. F., Spanier, A. M. and P.B. Johnsen. (1992). Spore and geosmin production by Streptomyces tendae on several media. J. Agric. Food. Chem. 40 122-125.

Dionigi, C.P., (1994). The effects of copper sulfate on geosmin biosynthesis by Streptomyces tendae, Streptomyces albidoflavus, and Penicillium expansum. WATER SCI.TECHNOL. 31 (11) 135-138.

Dumont, H.J., Van de Velde, I. and S. Dumont. (1975) The dry weight estimate of biomass in a selection of Cladocera, Copepoda and Rotifersa from the plankton, periphyton and benthos of continental waters. Oecologia 19 75-97.

Falconer, IR. (1999). An Overview of problems caused by toxic blue-green algae (cyanobacteria) in drinking and recreational water. Environ. Toxicol. 14 (1) 5-12.

Ferris, M. J. and C.F. Hirsch. (1991). Method for isolation and purification of Cyanobacteria. App. and Env. Microbiol. 57 (5) 1448-1452.

Gerber, N. N. (1983). Volatile substances from actinomycetes: their role in the odor pollution of water. Wat. Sci. Tech. 15 115-125.

Gerber, N. N. and H.A.Lechevalier. (1965). Geosmin, an earthy-smelling substance isolated from actinomycetes. App. Microbiol. 13 (6) 935-938.

Glaze, W. H., Schep, R., Chauncey, W., et al. (1990). Evaluating oxidants for the removal of model taste and odor compounds from a municipal water supply. J. AWWA. 82 (5) 79-84.

Goulden, C.L., Tomljanobich, D., Kreeger D., and E. Corney. The invasion of Daphnia Lumholtzi Sars (Cladocera, Daphniidae) into a North American reservoir. IN:

Hamilton, S.W., White, D.S., Chester, E.W., and A.F. Scott (eds.). 1995. Proceedings of the sixth symposium on the natural history of the lower Tennessee and Cumberland River Valleys. The Center for Field Biology, Austin Peay State University, Clarksville, Tennessee.

Güde, H. (1989). The Role of Grazing on Bacteria in Plankton Succession. In: Plankton Ecology, U. Sommer. [Ed.], pp. 337-364.

Habib, OA., Tippett, R. and K.J Murphy. (1997). Seasonal changes in phytoplankton community structure in relation to physico-chemical factors in Loch Lomond, Scotland. Hydrobiologia. 350 (1-3) 63-79.

Hansen, PS., Phlips, EJ. and F.J. Aldridge. (1997). The effects of sediment resuspension on phosphorus available for algal growth in a shallow subtropical lake, Lake Okeechobee. Lake Reserv. Manage. 13 (2) 154-159.

Hargesheimer, E. E. and S.B Watson. (1996). Drinking water treatment options for taste and odor control. Wat. Res. 30 (6) 1423-1430.

Havel, J.E., Mabee, W.R., and J.R. Jones. (1995). Invasion of the exotic cladoceran Daphnia lumholtzi into North American reservoirs. Can. J. Fish. Aquat. Sci. 52: 151-160.

Hebert, P. (1995). The Daphnia of North America -An Illustrated Fauna. University of Guelph, Guelph, Ontario, CA.

Herzing, D. R., Snoeyink, V. L. and N.F. Wood. (1977). Activated carbon adsoption of the odorous compounds 2-methylisoborneol and geosmin. J. AWWA. 69 (4) 223-229.

Hishida, Y., Ashitani, K. and K. Fujiwara. (1998) Occurrence of musty odor in the Yodo River. Wat. Sci. Tech. 20 (8/9) 193-196.

Hrudey, S. E., Rector, D. and N. Motkosky. (1992) . Characterization of drinking water odour arising from spring thaw for an ice-covered upland river source. Wat. Sci. Tech. 25 (2) 65-72.

Hu, T. L. and P.C. Chiang. (1996). Odorous compounds from a cyanobacterium in a water purification plant in Central Taiwan. Wat. Res. 30 (10) 2522-2525.

Infante, AG. (1997).Primary production of phytoplankton in Lake Valencia (Venezuela). Int. Rev. Gesamt. Hydrobiol. 82 (4) 469-477.

Izaguirre, G., Taylor, W. D. and J. Pasek. (1999). Off-flavor problems in two reservoirs, associated with planktonic Pseudanabaena species. Wat. Sci. Tech. 40 (6) 85-90.

Izaguirre, G. and W.D Taylor. (1998) A Pseudanabaena species from Castaic Lake, California, that produces 2-methylisoborneol. Wat. Res. 32 (5) 1673-1677.

Izaguirre, G. and W.D. Taylor. (1995) Geosmin and 2-methylisoborneol production in a major aqueduct system. WATER SCI. TECHNOL. 31 (11) 41-48.

Izaguirre, G., Hwang, C. J., Krasner, S.W. and M.J. McGuire. (1982) Geosmin and 2-methylisoborneol from cyanobacteria in three water supply systems. App. Env. Microbiol. 43 (3) 708-714.

Jensen, S. E., Anders, C. L., Goatcher, L. J., Perley, T., Kenefick, S. and S.E Hrudey. (1994). Actinomycetes as a factor in odour problems affecting drinking water from the North Saskatchewan River. Wat. Res. 28 (6) 1393-1401.

Juttner, F. (1995) Physiology and biochemistry of odorous compounds from freshwatercyanobacteria and algae. WATER SCI. TECHNOL. 31 (11) 69-78.

Juttner, F. (1984) Dynamics of the volatile organic substances associated with cyanobacteria and algae in a eutrophic shallow lake. App. Env. Microbiol. 47 (4) 814-820.

Kenefick, S. L., Hrudey, S. E., Peterson, H. G. and E.E. Prepas. (1993). Toxin release from Microcystis aeruginosa after chemical treatment. Wat. Sci. Tech. 27 (3-4) 443-440.

Kenefick, S. L., Hrudey, S. E., Prepas, E. E., Motosky, N. and H.G. Peterson. (1992). Odorous substances and cyanobacterial toxins in prairie drinking water sources. Wat. Sci. Tech. 25 (2) 147-154.

Khiari, D., Bruchet, A., Gittelman, et al. (1999). Distribution generated taste and odor phenomena. Wat. Sci. Tech. 40 (6) 129-133.

Kim, Y., Lee, Y., Chai, S. G., and E. Choi. (1997) Treatment of taste and odor causing substances in drinking water. Wat. Sci. Tech. 35 (8) 29-36.

Korth, W., Bowmer, K. and J. Ellis. (1991). New standards for the determination of geosmin and methylisoborneol in water by gas chromotography/mass spectrometry. (1991). Wat. Res. 25 (3) 319-324.

Kotak, B.G., Prepas, E.E. and S.E. Hrudey. (1994). Blue-green algal toxins in drinking water supplies - research in Alberta. LakeLine 14 (1) 37-40.

Kotak, B. G., Lam, A. and E.E Prepas. (1995). Variability of the hepatoxin microcystin-lr in hypereutrophic drinking water lakes. J. Phycol. 31 248-263.

Krasner, S. W., Hwang, C. J. and M.J. McGuire. (1983). A standard method for quantification of earthy-musty odorants in water, sediments, and algal cultures. (1983). Wat. Sci. Tech. 15 127-138.

Kristiansen, S. (1998). Impact of increased river discharge on the phytoplankton community in the outer Oslofjord, Norway. Hydrobiologia. 363 (1-3) 169-177.

Kuritz, T., Bocanera, LV. and N.S. Rivera. (1997). Dechlorination of lindane by the cyanobacterium Anabaena sp. strain PCC7120 depends on the function of the nir operon. J. BACTERIOL. 179 (10) 3368-3370.

Lahti, K. (1997). Cyanobacterial hepatotoxins and drinking water supplies - Aspects of monitoring and potential health risks. Monogr. Boreal Environ. Res. (4) 40.

Lalezary, S., Pirbazari, M. and M. McGuire. (1986). Oxidation of five earthy-musty taste and odor compounds. J. AWWA 78 (3) 62-69

Lalezary, S., Pirbazari, M. and M. McGuire. (1986). Evaluating activated carbons for removing low concentrations of taste-producing and odor-producing organics. J. AWWA 78 (11) 76-82.

Lawrence, S. G., Malley, D.F., Findlay, W.J., et al. (1987). Method for estimating dry weight of freshwater planktonic crustaceans from measures of length and shape. Can .J. Fish Aquat. Sci. 44 264-274.

Levich, A.P. (1996) The role of nitrogen-phosphorus ration in selecting for dominance of phytoplankton by cyanobacteria or green algae and its application to reservoir management. Journal of Aquatic Ecosystem Health 5 (1) 55-61.

Marsalek, B., Dolejs, P. and A. Sladeckova. (1998). Algal toxins in Czech drinking water resources and treatment plants. Water Supply 16 (1-2) 616-619.

Martin, J. F., Izaguirre, G. and P. Waterstrat. (1991). A planktonic Oscillatoria species from Mississippi catfish ponds that produces the off-flavor compound 2-methylisoborneol. Wat. Res. 23 (12) 1447-1451.

Matsumoto, A. and Y. Tsuchiya. (1988). Earthy-musty odor-producing cyanophytes isolated from five water areas in Tokyo. Wat. Sci. Tech. 20 (8/9) 179-183.

McCauley, E. (1984). The estimation of the abundance and biomass of zooplankton in samples. Manual for the Assessment of Secondary Productivity in Fresh Waters. Blackwell. 228-265.

McGuire, J. M., Krasner, S. W., Hwang C. J. and G. Izaguirre. (1981). Closed-loop stripping analysis as a tool for solving taste and odor problems. J. AWWA. 73 (10) 530-537.

Means, E. G. and M.J McGuire. (1986). An early warning system for taste and odor control. J. AWWA. 78 (3) 77-83.

Miwa, M. and K. Morizane. (1988). Effect of chelating agents on the growth of blue-green algae and the release of geosmin. Wat. Sci. Tech. 20 (8/9) 197-203.

Möhren, S. and F. Jüttner. (1983) Odorous compounds of different strains of Anabaena and Nostoc (cyanobacteria). Wat. Sci. Tech. 15 221-228.

Naes, H., Utkilen, H. C. and A.F. Post. (1988). Factors influencing geosmin production by the cyanobacterium Oscillatoria brevis. Wat. Sci. Tech 20 (8/9) 125-131.

Nakajima, M., Ogura, T., Kusama, Y., et al.(1996) Inhibitory effects of odor substances, geosmin and 2-methylisoborneol, on early development of sea urchins. Wat. Res. 30 (10) 2508-2511.

Nakanishi, M., Hoson, T., Inoue, Y. and M. Yagi. (1999). Relationship between the maximum standing crop of musty-odor producing algae and nutrient concentrations in the southern basin water of Lake Biwa. Wat. Sci. Tech. 40 (6) 179-184.

Namkung, E. and B. Rittmann. (1987). Removal of taste- and odor-causing compounds by biofilms grown on humic substances. J. AWWA 79 (7) 107-112.

Negoro, T., Ando, M., and N. Ichikawa. (1988) Blue-green algae in Lake Biwa which produce earthy-musty odors. Wat. Sci. Tech. 20 (8/9) 117-123.

Nicholls, K. and J. Gerrath. (1985) The taxonomy of Synura (Chrysophyceae) in Ontario (Canada) with special reference to taste and odor in water supplies. Can. J. Botany. 63 (8) 1482-1493.

Niemi, R. M., Knuth, S. and K. Lundström. (1982) Actinomycetes and fungi in surface waters and in potable water. App. Env. Microbiol. 43 (2) 378-388.

Nyström, A., Grimvall, A., Krantz-Rülcker, C., Sävenhed, R. and K. Åkerstrand. (1992). Drinking water off-flavor caused by 2,4,6-trichloroanisole. Wat. Sci. Tech. 25 (2) 241-249.

Perlman, D. (1996). Chemical treatment system for producing odor and taste-free potable water. Official Gazette US Patent Trademark Office Patents. 1192 (3) 1960

Persson, P. (1980). On the odor of 2-methylisoborneol. J. Agric. Food. Chem. 28 1344.

Persson, P. (1980) Sensory properties and analysis of two muddy odour compounds, geosmin and 2-methylisoborneol, in water and fish. Wat. Res. 14 1113-1118.

Peterson, H., Hrudey, S., Cantin, I ., Perley, T. and S. Kenefick. (1995). Physiological Toxicity, Cell Membrane Damage and the Release of Dissolved Organic Carbon and Geosmin by

Aphanizomenon Flos-Aquae After Exposure to Water Treatment Chemicals. Wat. Res. 29 (6) 1515-1523.

Preti, G., Gittelman, T. S., Staudte, P. B. and P. Luitweiler. (1993). Letting the nose lead the way, malodorus components in drinking water. Anal. Chem. 65 (15) 699A-702A.

Rashash, D.M.C., Dietrich, A.M., Hoehn, R.C., et al. (1995). The influence of growth conditions on odor-compound production by two chrysophytes and two cyanobacteria. WATER SCI. TECHNOL. 31 (11) 165-172.

Reynolds, C.S. (1984). The Ecology of Freshwater Phytoplankton. Cambridge University Press, Cambridge.

Rosen, B. H., MacLeod, B. W. and M.R. Simpson. (1992). Accumulation and release of Geosmin during the growth phases of Anabaena circinalis (Kutz.) Rabenhorst. Wat. Sci. Tech 25 (2) 185-190.

Sandgren, C. (1988) The Ecology of Chrysophyte Flagellates: Their Growth and Perennation Strategies as Freshwater Phytoplankton. Growth & Reproduction Strategies of Freshwater Phytoplankton [ed] C. Sandgren, Cambridge University Press. 441.

Schrader, K.K., De Regt, M.Q., Tidwell, P.R., et al. (1998). Selective growth inhibition of the musty-ofor producing cyanobacterium Oscillatoria cf. chalybea by natural compounds. Bull. Environm. Contam. Toxicol. 60 (4) 651-658.

Schuler, D. (1994). Lambert Creek/Vadnais Lake diagnostic and feasibility study. LakeLine 14 (1) 43-45.

Schweitzer, L. and I. Suffet. (1999). Exposure assessment of taste and odor standards used in the method of flavor profile analysis. Wat. Sci. Tech. 40 (6) 209-215.

Soranno, P., Carpenter, S.R., and M.M. Elser. (1993). Zooplankton Community Dynamics. In: The Trophic cascade in Lakes [eds] Carpenter, S.R. and Kitchell, J.F. Cambridge University Press. 385.

St. Amand, A. (1990). Mechanisms Controlling Metalimnetic Communities and the Importance of Metalimnetic Phytoplankton to Whole Lake Primary Productivity. Ph.D. dissertation, University of Notre Dame, Notre Dame, Indiana.

Suffet, I. H., Khiari, D. and A. Bruchet. (1999) The drinking water taste and odor wheel for the millennium: beyond geosmin and 2-methylisoborneol. Wat. Sci. Tech. 40 (6) 1-13.

Suffet, I. H., Corado, A., Chou, D. McGuire, M. J. and S. Butterworth. (1996). AWWA taste and odor survey. J. AWWA 88 (4) 168-180.

Tsuchiya, Y. and A. Matsumoto. (1999). Characterization of Oscillatoria F. granulata producing 2-methylisoborneol and Geosmin. J. AWWA 40 (6) 245-250.

Utkilen, H. C. and M. Frøshaug. (1992). Geosmin production and excretion in a planktonic and benthic Oscillatoria. Wat. Sci. Tech. 25 (2) 199-206.

Vaara, T., Vaara, M. and S. Niemelä. (1979). Two improved methods for obtaining axenic cultures of cyanobacteria. App. Env. Micorbiol 38 (5) 1011-1014.

Velzeboer, R., Drikas, M., Donati, C., et al. (1995). Release of geosmin by Anabaena circinalis following treatment with aluminium sulphate. WATER SCI. TECHNOL. 31 (11) 187-194.

Ventura, F., Matia, L., Romero, J., Boleda, M., Marti, I. and J. MartinJ. (1995). Taste and odor events in Barcelona's water supply. Wat. Sci. Tech. 31 (11) 63-68

Vezie, C., Brient, L., Sivonen, K., Bertru, G., et al. (1997). Occurrence of microcystin-containing cyanobacterial blooms in freshwaters of Brittany (France). ARCH. HYDROBIOL.139 (3) 401-413.

Vlaski, A., Van Breemen, AN. and G.J. Alaerts. (1996). The algae problem in the Netherlands from a water treatment perspective. AQUA J. WATER SUPPLY TECHNOL. 45 (4) 184-194.

Waterbury, J.B, Watson, S.W., Balois, F.W., and D.G. Franks. (1986). Biological and Ecological Characterization of the Mrine Unicellular Cyanobacterium Synechococcus. In: Photosynthetic Picoplankton. T. Platt and W. Li [eds.], pp. 71-120, Ottawa, Department of Fisheries and Oceans.

Wee, J., Harris, S., Smith, J., Dionigi, C. and D. Millie. (1994). Production of the taste-odor- causing compounds, trans-2,cis-6-nonadienal, within the Synurophyceae. J. of App. Phycol. 6 (4) 365-369.

Wetzel, R.G. (1983). Limnology. Saunders College Publishing, New York. pp.767.

Wicks, R. J. and P.G. Thiel. (1990). Environmental factors affecting the production of peptide toxins in floating scums of the cyanobacterium Microcystis aeuginosa in a hypertrophic African reservoir. Environ. Sci. Technol. 24 (9) 1413-1418.

Yagi, M., Kajino, M., Matsuo, U. Ashitani, et al. (1983). Musty Odor problems in Lake Biwa. Wat. Sci. Tech. 15 311-321.

Young, W.F., Horth H., Crane R., et al. (1996). Taste and Odour Threshold Concentrations of Potential Potable Water Contaminants. Wat. Res. 30 (2) 331-340.

Zimba, P., Grimm, C., Lloyd, S., et al. (1998). Taste/Odor metabolite-producing cyanobacteria within catfish aquaculture systems: abundance patterns during the Summer-Fall transition. J. of Phycol. 34 (3 suppl) 65-66.

Zimmerman, W.J., Soliman, C.M., and B.H. Rosen. (1995). Growth and 2-methylisoborneol production by the cyanobacterium Phormidium LM689. WATER SCI. TECHNOL. 31 (11) 181-186.

Zisette, R., Oppenheimer, J. and R. Donner. (1994). Sources of taste and odor problems in Lake Youngs, a municipal drinking water reservoir. Lake and Reservoir Management 9 (1) 117-122.