Clearwater River Watershed District

Five Lakes Nutrient TMDL

for:

Lake Caroline
Lake Augusta
Albion Lake
Henshaw Lake
Swartout Lake

Wenck

Prepared for

Clearwater River Watershed District

August 2010

wq-iw8-21e

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Wenck File #. 0002-127

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Acronyms

Agency	Minnesota Pollution Control Agency
BOD	Biochemical Oxygen Demand
CAFO	Confined Animal Feeding Operation
Carlson TSI	Carlson Trophic Status Index
CFR	Code of Federal Regulations
cfs	cubic feet per second
CFU/100 mL	colony forming units per 100 milliliters
COLA	Chain of Lakes Association (for the Clearwater Chain)
CWA	Clear Water Act
CRWD	Clearwater River Watershed District
District	Clearwater River Watershed District
DO	Dissolved Oxygen
EPA	Environmental Protection Agency
Lbs	Pounds
MDNR	Minnesota Department of Natural Resources
µg/L	micrograms per liter
mg/L	milligrams per liter
mi^2	square miles
MOS	Margin of Safety
MPCA	Minnesota Pollution Control Agency
NCHF	North Central Hardwood Forest
NO_2/ NO_3-N	Nitrite/ Nitrate- Nitrogen
NPS	non-point source
QA	Quality Assurance
QC	Quality Control
SOD	Sediment Oxygen Demand
SSTS	Sub-surface Sewage Treatment System
STORET	EPA's "STOrage and RETrevial" System
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
USGS	United States Geological Survey
WWTP	Wastewater Treatment Plant
USDA	United States Department of Agriculture

TMDL Summary Table

TMDL Summary Table		
EPA/MPCA Required Elements	**Summary**	**TMDL Report Section**
Location	The Upper Mississippi St. Cloud area HUC 07010203. More specifically, the downstream portion of the Clearwater River Watershed District, in Stearns, Meeker and Wright Counties, Minnesota.	Section 3: Figures 3.1, 3.2 and 3.3
303(d) Listing Information	Lake Caroline 86-0281 Lake Augusta 86-0284 Albion Lake 86-0212 Swartout Lake 86-0208 Henshaw Lake 86-0213 The five lakes included in this report, Lake Caroline, Lake Augusta, Albion Lake, Swartout Lake and Henshaw Lake, were added to the 303(d) list in 2008. All of the five lakes addressed in this report are included on the 303(d) list due to excess nutrient concentrations impairing aquatic recreation, as set forth in Minnesota Rules 7050.0150. The TMDLs for each of the five lakes were prioritized to start in 2010 and be completed by 2014.	Section 2
Applicable Water Quality Standards/ Numeric Targets	Criteria set forth in Minn. R. 7050.0150 (3) and (5). The numeric target for Lake Caroline and Lake Augusta is a total phosphorus concentration of 40 µg/L or less. The numeric target for Albion Lake, Swartout Lake and Henshaw Lake is a total phosphorus concentration of 60 µg/L.	Section 2
Loading Capacity (expressed as daily load)	The loading capacity is the total maximum daily load for each of these conditions. The critical period for these lakes is the summer growing season. The loading capacity is set forth in Table 7.2. Total maximum daily total phosphorus load (lb/day) Lake Caroline 10.14 (3,705 lb/yr) Lake Augusta 11.36 (4,150 lb/yr) Albion Lake 0.98 (359 lb/yr) Swartout Lake 0.73 (265 lb/yr) Henshaw Lake 2.22 (812 lb/yr)	Section 7
Wasteload Allocation	There are no permitted sources in the watershed allowed to discharge to surface waters. The Wasteload Allocation represents the WWTPs that operate using land application, cluster systems	

TMDL Summary Table

<table>
<tr><th colspan="5">TMDL Summary Table</th></tr>
<tr><th>EPA/MPCA Required Elements</th><th colspan="3">Summary</th><th>TMDL Report Section</th></tr>
<tr><td rowspan="9"></td><td colspan="3">that discharge to drainfields, potential future systems that have been evaluated for the area, and the NPDES Construction Permit. All but the NPDES permit have WLA of 0, as the MPCA has rejected requests to discharge to area lakes in the past.</td><td rowspan="9"></td></tr>
<tr><td>Source</td><td>Permit #</td><td>Gross WLA (lb/day)</td></tr>
<tr><td>NPDES Construction</td><td>MNR100001</td><td>Lake Caroline 0.10
Lake Augusta 0.11
Albion Lake 0.01
Henshaw Lake 0.01
Swartout Lake 0.01</td></tr>
<tr><td>City of Fairhaven- Future</td><td>NA</td><td>0</td></tr>
<tr><td>Clearwater River Watershed District :
❖ Rest-a-While Shores
❖ Wandering Ponds
❖ Lake Louisa Hills
❖ Future Regional System</td><td>

09-17550
09-20199
Pending
NA</td><td>0

0
0
0
0</td></tr>
<tr><td>City of South Haven WWTP</td><td>MN006461</td><td>0</td></tr>
<tr><td>City of Kimball WWTP</td><td>MN005264</td><td>0</td></tr>
<tr><td>City Watkins WWTP</td><td>MN0051365</td><td>0</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="2">Load Allocation</td><td colspan="3">The portion of the loading capacity allocated to existing non-permitted sources.</td><td rowspan="2">Section 7, Tables 7.2 and 7.3</td></tr>
<tr><td>Source</td><td colspan="2">Load Allocation (lb/day)</td></tr>
</table>

TMDL Summary Table

TMDL Summary Table			
EPA/MPCA Required Elements	**Summary**		**TMDL Report Section**
	Atmospheric and Groundwater	Lake Caroline 2.23 Lake Augusta 1.93 Albion Lake 0.16 Henshaw Lake 0.18 Swartout Lake 0.19	
	Source	**Load Allocation (lb/day)**	
	Internal Load	Lake Caroline 0.82 Lake Augusta 1.91 Albion Lake 0.47 Henshaw Lake 0.46 Swartout Lake 0.86	
	Watershed Loads (including upstream lakes)	Lake Caroline 7.0 Lake Augusta 7.41 Albion Lake 0.34 Henshaw Lake 0.08 Swartout Lake 1.05	
	Septic Systems	Lake Caroline 0 Lake Augusta 0 Albion Lake 0 Swartout Lake 0 Henshaw Lake 0	
Margin of Safety	The Margin of Safety is implicit in each TMDL due to the conservative assumptions of the model and the proposed iterative nutrient reduction strategy with monitoring.		Section 7.4
Seasonal Variation	Seasonal variation is accounted for by developing targets for the summer critical period, when the frequency and severity of nuisance algal growth is greatest. Although the critical period is the summer, lakes are not sensitive to short-term changes but rather respond to long-term changes in annual load.		Section 7.3

TMDL Summary Table

TMDL Summary Table		
EPA/MPCA Required Elements	**Summary**	**TMDL Report Section**
Reasonable Assurance	Reasonable assurance is provided by the cooperative efforts of the Clearwater River Watershed District, a watershed-based organization with statutory responsibility to protect and improve water quality in the water resources in the Clearwater River watershed in which these lakes are located.	Section 10
Monitoring	The Clearwater River Watershed District monitors water quality for district lakes on a rotating basis annually through its baseline monitoring program, which it started in 1981. Through this program the CRWD also measures watershed loads and hydrology annually. The CRWD will continue this annual baseline program and add monitoring as recommended in Section 11.	Section 11, Appendix D
Implementation	This TMDL sets forth an implementation framework and load reduction strategies. The final implementation plan is part of a program to address all impaired waters within the Clearwater River Watershed District.	Section 9
Public Participation	Public Comment period: Meeting location: Comments received:	Section 8

Executive Summary

Section 303(d) of the Federal Clean Water Act (CWA) requires the Minnesota Pollution Control Agency (MPCA) to identify water bodies that do not meet water quality standards and to develop total maximum daily pollutant loads for those water bodies. A total maximum daily load (TMDL) is the amount of a pollutant that a water body can assimilate without exceeding the established water quality standard for that pollutant. Through a TMDL, pollutant loads are allocated to point and non-point sources within the watershed that discharge to the water body.

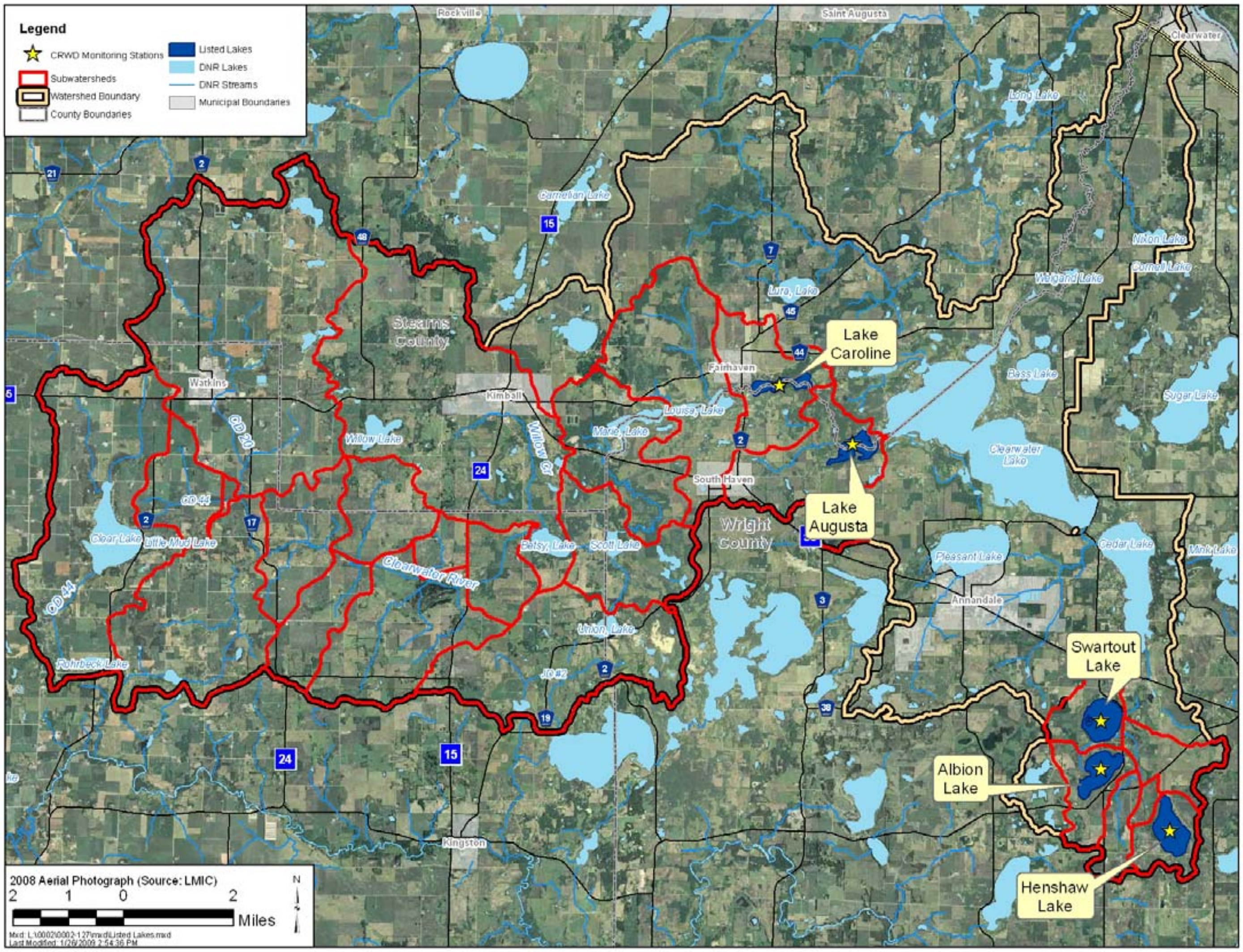
This TMDL study prepared by Wenck Associates, Inc. (Wenck) for the Clearwater River Watershed District (CRWD), addresses nutrient impairments for five lakes in the Clearwater River Watershed District: Lake Caroline (86-0281); Lake Augusta (86-0284); Albion Lake (86-0212); Swartout Lake (86-0208); and Henshaw Lake (86-0213). The goal of this TMDL is to quantify the pollutant reductions needed for these lakes to meet State water quality standards for nutrients.

The Clearwater River and the Clearwater River Chain of Lakes are the predominant water features in the District. The lakes addressed in this report are part of two separate chains of lakes in the District. Lakes Caroline and Augusta are within the downstream portion of a chain of nine lakes located on the main stem of the Clearwater River that drain to the West Basin of Clearwater Lake and ultimately to the Mississippi River. Albion Lake, Henshaw Lake and Swartout Lake are part of a smaller chain of lakes that drain to Cedar Lake, which in turn drains to the southeastern portion of the East Basin of Clearwater Lake. The morphometric characteristics of the impaired lakes are shown in Table E.1; lake location and drainage areas are shown in Figure E.1.

Table E.1 Morphometric Characteristics of Impaired Lakes

Parameter	Lake Caroline	Lake Augusta	Albion Lake	Henshaw Lake	Swartout Lake
Surface Area (ac)	125	169	251	271	296
Average Depth (ft)	15	25	6	4	7
Maximum Depth (ft)	44.5	82	9	8	12
Volume (ac-ft)	1,923	4,269	1,508	1,904	2,105
Average Residence Time (yrs)	0.07	0.15	4.80	4.65	1.26
Littoral Area (ac)	59	55	251	270	293
Watershed (ac)	60,132	62,936	1,094	903	4,768

Figure E.1 Impaired Waters and Drainage Areas



Lake response models were used to set the TMDL for each lake and to calculate the load reductions needed to meet State standards. The lake response models are a numeric description of the relationship between phosphorus loading to a lake, and in lake concentration. The relationship (the model) is based on the size of the lake, drainage area, and settling rate for phosphorus which are all parameters in the model. The model tells us how many pounds of phosphorus the lake can handle and still meet its designated uses, in other words the Assimilative Capacity. The model also assists in calculating the load reductions based on current concentrations.

The models are built and calibrated using GIS-based watershed land use information and the CRWD's existing water quality database which includes 4 to 6 years of data for each lake within the past 10 years. Data are used to quantify phosphorus from land-use based sources and in-lake sources of P (load partitioning). The partitioning of the loads informs the necessary the load reductions and load reduction strategies. These analyses are described in Sections 4, 6 and 7 of the report and model results are included.

The data and modeling indicate that average annual nutrient load reductions for the five lakes from 25% to 95% are required to meet standards under average precipitation conditions. Internal load management and reduction of phosphorus from watershed runoff will both be required to meet load reduction goals for these impaired waters.

1.0 Introduction

1.1 PURPOSE

This TMDL study addresses nutrient impairments in five lakes with in the CRWD: two in the downstream portion of the Clearwater River Chain of Lakes and three that comprise a chain of lakes that drain to Cedar Lake, which drains to the East Basin of Clearwater Lake. Listed from upstream to downstream locations, the lakes addressed in this TMDL are Lake Caroline and Lake Augusta, located on the Clearwater River draining to the West Basin of Clearwater Lake; and Albion Lake, Henshaw Lake and Swartout Lake, located upstream of Cedar Lake, which drains to the East Basin of Clearwater Lake. The goal of this TMDL is to quantify the pollutant reductions needed to meet State water quality standards for nutrients in the five nutrient-impaired lakes. The nutrient TMDLs for these five lakes are being established in accordance with section 303(d) of the Clean Water Act, because the State of Minnesota determined that nutrient concentrations in Lake Caroline, Lake Augusta, Albion Lake, Swartout Lake, and Henshaw Lake exceed the State established standards for nutrients.

This TMDL provides waste load allocations (WLAs) and load allocations (LAs) for Lake Caroline, Lake Augusta, Albion Lake, Swartout Lake, and Henshaw Lake. Based on the current State standard for nutrients, the TMDL establishes a numeric target of 40 µg/L total phosphorus concentration for deep lakes in the Northern Central Hardwood Forests ecoregion and 60 µg/L total phosphorus concentration for shallow lakes in the Northern Lakes and Forests ecoregion. The numeric target for Lake Caroline and Lake Augusta is 40 µg/L as they are deep lakes; the numeric target for Albion Lake, Henshaw Lake, and Swartout Lake is 60 µg/L, as they are shallow lakes.

1.2 PROBLEM IDENTIFICATION

The five lakes addressed in this TMDL are within the CRWD. The 168 square mile CRWD covers parts of eight townships, including Luxemburg, Forest Prairie, Forest City, Maine Prairie, Kingston, Fairhaven, Southside and French Lake across parts of Meeker, Stearns and Wright Counties. The five lakes addressed in this TMDL—Lake Caroline (DNR# 86-0281), Lake Augusta (DNR# 86-0284), Albion Lake (DNR# 86-0212), Swartout Lake (DNR# 86-0208), and Henshaw Lake (DNR# 86-0213)—were placed on the 2008 State of Minnesota's 303(d) list of impaired waters. All of the five lakes addressed in this TMDL were identified for impairment of aquatic recreation (e.g., swimming). Water quality does not meet State standards for nutrient concentrations.

2.0 Target Identification and Determination of Endpoints

2.1 IMPAIRED WATERS

The five lakes—Lake Caroline, Lake Augusta, Albion Lake, Swartout Lake, and Henshaw Lake—were added to the 303(d) impaired water list in 2008. All five lakes are impaired by excess nutrient concentrations, which inhibit aquatic recreation. These lakes comprise the only remaining impaired waters within the CRWD for which a TMDL study has not yet been completed. The MPCA moved forward with this TMDL study because:

- It is appropriate in this case to address all the TMDLs in the basin at once due to the overlap in tributary drainage areas for impaired waters.
- The CRWD, the local government agency that requested the study, will be leading implementation and seeks a uniform implementation plan for their entire Watershed District.
- Ongoing evidence of the CRWD's strong leadership in completing other TMDLs in the District and proactive watershed management and monitoring strategies show a strong likelihood of completing the TMDL and implementation in an expedient manner.
- A strong base of existing data and a high technical capability and willingness locally to assist with the TMDL and follow through with implementation.

2.2 MINNESOTA WATER QUALITY STANDARDS AND ENDPOINTS

2.2.1 State of Minnesota Standards

Minnesota's standards for nutrients limit the quantity of nutrients that may enter waters. Minnesota's standards at the time of listing (Minnesota Rules 7050.0150(3)) stated that in all Class 2 waters of the State (i.e., "…waters…which do or may support fish, other aquatic life, bathing, boating, or other recreational purposes…") "…there shall be no material increase in undesirable slime growths or aquatic plants including algae…." In accordance with Minnesota Rules 7050.0150(5), to evaluate whether a water body is in an impaired condition, the MPCA developed "numeric translators" for the narrative standard for purposes of determining which lakes should be included in the section 303(d) list as being impaired for nutrients. The numeric translators established numeric thresholds for phosphorus, chlorophyll-a, and clarity as measured by Secchi depth. Table 2.1 lists the thresholds for listing lakes on the 303(d) list of impaired waters in Minnesota that were in place when these lakes were listed.

Table 2.1. Trophic status thresholds for determination of use support for lakes

305(b) Designation	Full Support			Partial support to Potential Non-Support			
303(d) Designation	Not Listed			Review	Listed		
Ecoregion	TP Range (ppb)	Chl-a (ppb)	Secchi (m)	TP Range (ppb)	TP (ppb)	Chl-a (ppb)	Secchi (m)
Northern Lakes and Forests	<30	<10	>1.6	30-35	>35	>12	<1.4
(Carlson's TSI)	(<53)	(<53)	(<53)	(53-56)	(>56)	(>56)	(>56)
North Central Hardwood Forests	<40	<14	>1.4	40-45	>45	>18	<1.1
(Carlson's TSI)	(<57)	(<57)	(<57)	(57-59)	(>59)	(>59)	(>59)
Western Cornbelt Plains and Northern Glaciated Plains	<70	<24	>1.0	70-90	>90	>32	<0.7
(Carlson's TSI)	(<66)	(<61)	(<61)	(66-69)	(>69)	(>65)	(>65)

TSI= Carlson trophic state index; Chl-a= chlorophyll-a; ppb= parts per billion or µg/L; m=meters
Source: MPCA

2.2.2 Endpoint Used in this TMDL

The numeric target used to list these lakes was the numeric translator threshold phosphorus standard for Class 2B waters in the North Central Hardwood Forest Ecoregion (40 µg/L) prior to adoption of new standards in 2008 (Table 2.1). Under the new standards, Albion Lake, Swartout Lake and Henshaw Lake are shallow lakes with a numeric target of 60 µg/L. Lake Caroline and Lake Augusta are deep lakes with a numeric target of 40 µg/L. Therefore, this TMDL presents load and wasteload allocations and estimated load reductions assuming an endpoint of 40 µg/L for Lake Caroline and Lake Augusta and an endpoint of 60 µg/L for Albion Lake, Swartout Lake and Henshaw Lake.

The numeric standards for chlorophyll-a and Secchi depth are 14 µg/L and 1.4 meters, respectively, for Lake Caroline and Lake Augusta. The numeric standards for chlorophyll-a and Secchi depth are 20 µg/L and 1.0 meters, respectively, for Albion Lake, Swartout Lake and Henshaw Lake (Table 2.2).

Table 2.2. Numeric targets for Lakes in the North Central Hardwood Forest Ecoregion

Parameters	Ecoregion North Central Hardwood Forest Shallow [1]	 Deep
Phosphorus Concentration (µg/L)	60	40
Chlorophyll-a Concentration (µg/L)	20	14
Secchi Disk Transparency (m)	>1	>1.4

[1] Shallow lakes are defined as lakes with a maximum depth of 15 feet or a less, or with 80% or more of the lake area shallow enough to support emergent and submerged rooted aquatic plants (littoral zone).

2.3 PRE-SETTLEMENT CONDITIONS

Another consideration when evaluating nutrient loads to lakes is the natural background load. Ultimately, the background load represents the load the lake would be expected to receive under natural, undisturbed conditions. This load can be determined using ecoregion pre-settlement nutrient concentrations as determined by diatom fossil reconstruction. Diatom inferred total phosphorus concentrations are presented in Table 2.3.

Table 2.3. Pre-settlement total phosphorus concentrations based on water quality reconstructions from fossil diatoms

Parameters	Ecoregion North Central Hardwood Forest Shallow [1]	 Deep
Phosphorus Concentration (µg/L)	47	26

(MPCA 2002). All are the concentration at the 75th percentile.

1 Shallow lakes are defined as lakes with a maximum depth of 15 feet or a less, or with 80% or more of the lake area shallow enough to support emergent and submerged rooted aquatic plants (littoral zone).

Based on the diatom fossils, pre-settlement concentrations were approximately 26 µg/L for deep lakes in the North Central Hardwood Forests Ecoregion. Another benchmark that may be useful in determining goals and load reductions are expected stream concentrations under natural or undisturbed conditions. Table 2.4 provides data from minimally impacted streams.

Table 2.4. Interquartile range of summer mean concentrations by ecoregion for minimally impacted streams in Minnesota.

Region	Total Phosphorus (µg/L)		
	25th Percentile	50th Percentile	75th Percentile
North Central Hardwood Forest	70	100	170

(McCollor and Heiskary 1993)

Existing flow-weighted mean total phosphorus concentrations in the Clearwater River upstream of Lake Betsy, the closest in-stream monitoring station, have ranged from 130 to 510 µg/L since 1998, with an average of 261 µg/L over that period. Because of the flow-through nature of this lake chain, the concentrations in Lake Marie, upstream of Lake Caroline, is used as a surrogate for upstream concentrations. In-lake concentrations for Lake Marie range from 70 to 87 µg/L TP.

3.0 Watershed and Lake Characterization

3.1 LAKE AND WATERSHED CONDITIONS

The Clearwater River Watershed District is a predominantly agricultural 168-square mile watershed in central Minnesota (Figure 3.1). The Clearwater River and the Clearwater River Chain of Lakes are the predominant water features in the District. The lakes addressed in this report comprise the lower portion of the Clearwater River Chain of Lakes and also a chain of lakes above Cedar Lake. Listed from upstream to downstream locations, the lakes addressed in this TMDL are Lake Caroline and Lake Augusta, which are located on the Clearwater River, which in turn drains to the West Basin of Clearwater Lake; and Albion Lake, Henshaw Lake and Swartout Lake located upstream of Cedar Lake, which drains to the East Basin of Clearwater Lake. A description of watershed and physical lake characteristics is presented for each lake.

3.1.1 Lake Caroline

Lake Caroline is within the lower portion of the Clearwater River Chain of Lakes, located below Lake Marie and above Lake Augusta. The Lake Caroline watershed consists of 60,132 acres of which 2,138 acres is directly contributing watershed and the remaining 57,994 acres is from upstream lakes. Lake Caroline is located on the border of Fairhaven and Southside Townships on the border of Stearns and Wright Counties, Minnesota. The municipalities of Fairhaven and South Haven are located partially within the Lake Caroline watershed. Lake Caroline is a 125 acre basin with an average depth of 15 feet and a maximum depth of 44.5 feet (Table 3.1). The littoral zone covers 59 acres or approximately 47 percent of the basin. The littoral zone is that portion of the lake that is less than 15 feet in depth, and is where the majority of the aquatic plants grow. The Clearwater River flows into the Lake Caroline at the southwest corner of the basin and is also the lake outlet, exiting at the southeast end of the basin. There are no other tributaries that flow directly into Lake Caroline.

3.1.2 Lake Augusta

Lake Augusta is within the lower portion of the Clearwater River Chain of lakes, located below Lake Caroline and above Clearwater Lake. The Lake Augusta watershed consists of 62,936 of which 2,804 acres is directly contributing watershed and the remaining 60,132 acres is from upstream lakes. Lake Augusta is located on the border of Fairhaven and Southside Townships on the border of Stearns and Wright County, Minnesota. The municipalities of Fairhaven and South Haven are located partially within the Lake Augusta watershed. Lake Augusta is a 169 acre basin with an average depth of 25 feet and a maximum depth of 82 feet (Table 3.1). The littoral zone covers 55 acres or approximately 33 percent of the basin. The Clearwater River flows into the Lake Augusta at the northwest corner of the basin and is also the lake outlet, exiting at the east end of the basin. There is one unnamed tributary that flows into Lake Augusta at the point where the Clearwater River enters the basin.

3.1.3 Albion Lake

Albion Lake is not located along the main stem of the Clearwater River, but instead is part of a chain of three lakes that is tributary to Cedar Lake in the southeast-most corner of the Clearwater River watershed. The Albion Lake watershed covers 1,094 acres and is located within Albion Township in Wright County, Minnesota. There are no municipalities located within the Albion Lake watershed. Albion Lake is a 251-acre basin with an average depth of six feet and a maximum depth of nine feet (Table 3.1). The littoral zone covers the entire 251 acres of the basin due to the maximum depth being less than 15 feet. As a result of Albion Lake having a littoral area greater than 80 percent of the basin, the lake meets the MPCA definition of a shallow lake. There are no defined inflow tributaries into Albion Lake. The outlet of Albion Lake is an unnamed perennial stream that exits the north end of the lake and flows north towards Swartout Lake.

3.1.4 Henshaw Lake

Henshaw Lake is not located along the main stem of the Clearwater River, but instead is part of a chain of three lakes that is tributary to Cedar Lake in the southeast-most corner of the Clearwater River watershed. The Henshaw Lake watershed covers 903 acres and is located within Albion Township in Wright County, Minnesota. There are no municipalities located within the Henshaw Lake watershed. Henshaw Lake is a 271 acre basin with an average depth of four feet and a maximum depth of eight feet (Table 3.1). The littoral zone covers the entire 270-acres of the basin due to the maximum depth being less than 15 feet. As a result of Henshaw Lake having a littoral area greater than 80 percent of the basin, the lake meets the MPCA definition of a shallow lake. There are no defined inflow or outlet tributaries for Henshaw Lake. A wetland complex at the northwest corner of the basin serves as the lake outlet as it flows north toward Swartout Lake.

3.1.5 Swartout Lake

Swartout Lake is not located along the main stem of the Clearwater River, but instead is part of a chain of three lakes that is tributary to Cedar Lake in the southeast-most corner of the Clearwater River watershed. Swartout Lake is located downstream of Albion and Henshaw Lakes and upstream of Cedar Lake. The Swartout Lake watershed covers 4,768 acres including approximately 2,771 acres of direct sub-watershed and the upstream watersheds of Albion and Henshaw Lakes. The Swartout Lake watershed is located within Albion Township in Wright County, Minnesota. There are no municipalities located within the Swartout Lake watershed. Swartout Lake is a 296-acre basin with an average depth of seven feet and a maximum depth of 12 feet (Table 3.1). The littoral zone covers the entire 296 acres of the basin due to the maximum depth being less than 15 feet. As a result of Swartout Lake having a littoral area greater than 80 percent of the basin, the lake meets the MPCA definition of a shallow lake. There are two unnamed tributaries that flow into Swartout Lake. One tributary flows from Albion Lake and enters the southwest corner of the basin and the second flows from a wetland complex that is part of the Swartout State Wildlife Management area and enters at the southeast corner of the basin. The outlet of Swartout Lake is a perennial stream that exits the northeast corner of the lake and flows north to Cedar Lake.

Table 3.1 Morphometric characteristics for the six lakes in the Clearwater River Chain of Lakes

Parameter	Lake Caroline	Lake Augusta	Albion Lake	Henshaw Lake	Swartout Lake
Surface Area (ac)	125	169	251	271	296
Average Depth (ft)	15	25	6	4	7
Maximum Depth (ft)	44.5	82	9	8	12
Volume (ac-ft)	1,923	4,269	1,508	1,904	2,105
Average Residence Time (days)	0.07	0.15	4.80	4.65	1.26
Littoral Area (ac)	59	55	251	270	293
Watershed (ac)	60,132	62,936	1,094	903	4,768

3.2 LAND USE

The Clearwater River watershed is composed mainly of agricultural land uses. The National Agriculture Statistics Services (NASS) 2007 cropland data layer was used to determine land use within the sub-watersheds of the five lakes in this TMDL study. This data is an appropriate data set for large agricultural watersheds as the use categories within the data set are more specific in describing agriculture uses, such as separately classifying corn, soybeans and alfalfa. Other categories in the data set are more general, such as urban, wetlands or woodlands. These uses comprise smaller percentages of the total watershed draining to each lake, making the more general categories appropriate when estimating watershed loads. The land use data for each lake watershed is presented in Table 3.2. The potential nutrient load delivered to a lake from each specific land use type can be influenced by a variety of factors including proximity to a lake or contributing tributary, topography, slope and soil type. For example, a frequently disturbed land use on soils with high organic contents located immediate adjacent to tributary to a lake have the potential to deliver a higher nutrient load to a lake than a similar land use on soils with lower organic content (and ultimately nutrients) located a significant distance from the lake.

The five lakes in this study are part of two separate flowages or chains. Lake Caroline and Augusta are within the downstream portion of a chain of nine lakes, located on the main stem of the Clearwater River, which drains to Clearwater Lake. Albion Lake, Henshaw Lake and Swartout Lake are part of a smaller chain of lakes that drains to Cedar Lake. As these lakes are part of two separate chains of lakes in the Clearwater River District, the land use will be described separately for each set of lakes.

Lake Caroline and Lake Augusta are located in the lower watershed of a chain of nine lakes. As a result, the land use in the watersheds of the upstream lakes is a major factor driving the land use totals within the each lake’s watershed. Overall, corn is the most extensive land use, covering 14,628 acres or 23 percent of the 62,935 acres of land contributing to Lake Caroline and Lake Augusta (Figure 3.4). Woodlands and soybeans were the next most widespread land uses, each covering slightly more than 10,000 acres or approximately 18 percent of the total watershed. Grasslands and pasture covered 9,747 acres or 16 percent of the total watershed area. The other major land use categories contributing to Lake Caroline and Lake Augusta include urban (10.8 %), wetlands (8.2 %), open water (3%) and hay (3%). The land use types for each lake watershed are displayed in Table 3.2. In general the land use percentages in the Lake Caroline and Lake Augusta direct subwatersheds are similar to those in the overall contributing watershed that includes the upstream lakes.

The contributing watersheds of Albion, Henshaw and Swartout Lakes are considerably smaller than the watersheds of Lake Caroline and Lake Augusta. Albion and Henshaw Lakes are located in the southeast corner of the Clearwater River Watershed District and each has small direct contributing watersheds and no upstream contributing lakes. Swartout Lake has a slightly larger direct contributing watershed and also is located downstream of both Albion and Henshaw Lakes. Overall, corn is the dominant land use type in the watersheds of these three lakes, accounting for 1,244 acres or 26 percent of the overall watershed (Figure 3.5). Soybeans are the next most widespread land use, covering slightly more than 900 acres or approximately 19 percent of the total watershed. Open water covers approximately 830 acres or 17 percent of the total watershed. The other major land use categories contributing to Albion Lake, Henshaw Lake and Swartout Lake include wetlands (12 %), woodland (10%) and urban (9%). The land use types for each lake watershed are displayed in Table 3.2.

Table 3.2 2007 NASS land use for the watersheds of the Five Lakes TMDL study (acres)

Land Use	Lake Caroline	Lake Augusta	Albion Lake	Henshaw Lake	Swartout Lake
Corn	14,185	14,628	241	150	1,244
Soybeans	10,135	10,657	105	237	923
Grains/Hay	1,711	1,806	39	24	166
Grass/Pasture	9,592	9,747	39	22	138
Woodland	10,794	11,571	155	52	477
Barren	26	26	0	0	1
Urban/Developed	6,476	6,768	102	65	436
Water	1,978	2,175	255	275	828
Wetlands	4,810	5,134	158	76	552
Other	423	423	0	2	3
TOTAL	**60,132**	**62,936**	**1,094**	**903**	**4,768**

** :Other Crops includes spring wheat, winter wheat, peas, oats and rye.

3.3 LAKE DESCRIPTIONS

The five lakes in this TMDL study can be characterized by their recreational uses, fish populations and health, aquatic plants, and shoreline habitat and conditions. A summary of these characteristics for each of the lakes can be found in Table 3.3. A more detailed description of each of the lake characteristics is found in the text that follows.

3.3.1 Recreational Uses

The five lakes in this TMDL study provide a variety of recreational uses, including fishing, hunting and boating. Table 3.3 provides a summary of the lake characteristics for each of the lakes. Overall, compared to other lakes in the District, recreational use in the five lakes in this TMDL study is lower due to the limited public access points. Albion and Swartout Lakes do not have public access. Henshaw Lake can be accessed by the public from a gravel road on the south shore of the lake. Lake Caroline and Lake Augusta do not have public access points on the lake, but both lakes can be accessed by the public via the Clearwater River for Lake Caroline and via Clearwater Lake for Lake Augusta. There are no county or regional parks located on the shores of the five lakes in this TMDL. There is a Boy Scout Camp on the shore of Lake Caroline that receives a moderate amount of use. Lake Caroline and Lake Augusta are managed by the DNR for fishing, while Albion, Henshaw and Swartout Lake are generally wildlife lakes that support a fish population.

Table 3.3 Lake Characterization for the Five TMDL Study Lakes

Lake Name	Lake Caroline	Lake Augusta	Albion Lake	Henshaw Lake	Swartout Lake
Public Boat Access	Via Clearwater River	Via Clearwater Lake	None	From gravel road	None
Most Recent Fish Survey	2005	2005	2006	2006	2005
Primary Managed Fish Species	Northern Pike, Largemouth Bass, Bluegill, Black Crappie	Northern Pike, Largemouth Bass, Panfish, Walleye	NA	NA	NA
Fish Stocking	Bass and Crappies in 1940s	Bass and Sunfish in 1950s	NA	NA	NA
Rough Fish	Black Bullhead; Carp	Black Bullhead; Carp	Carp	Black Bullhead; Carp	Black Bullhead; Carp
Fish Kill Frequency	No Recorded Occurrences	No Recorded Occurrences	Frequent	Frequent; Winter kill occurred 06/07	Frequent
Most Recent Vegetation Survey	2005	2005	NA	2007	2007
Exotic Vegetation	Curly Leaf Pondweed	Curly Leaf Pondweed; Eurasian Water Milfoil	NA	Curly Leaf Pondweed	NA
Shoreline Development	Low Development	Heavily Developed	Low Development	Low Development	Low Development
DNR Lake Classification	RD	RD	NE	NE	NE

Figure 3.1 Location Map

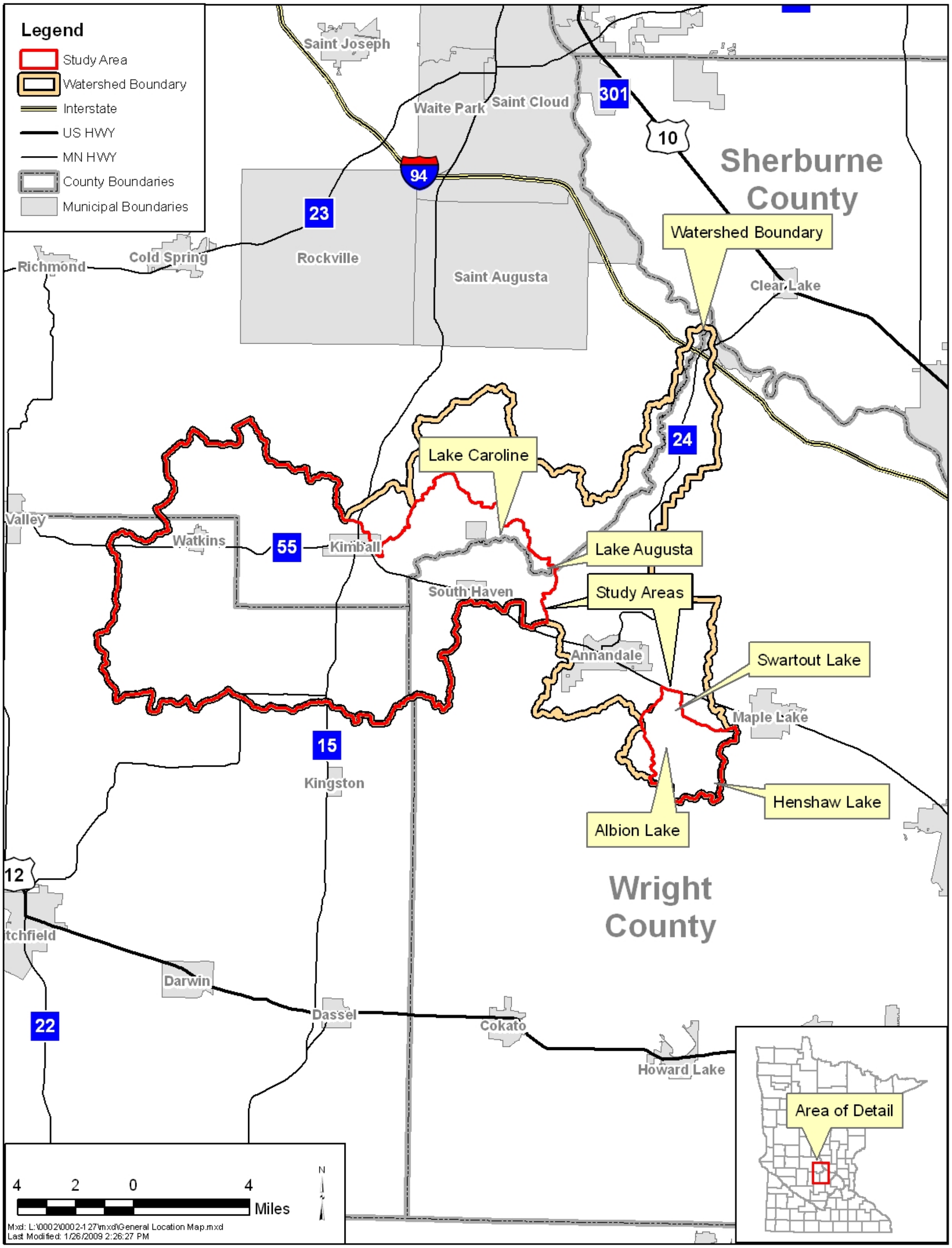


Figure 3.2 Impaired Lakes

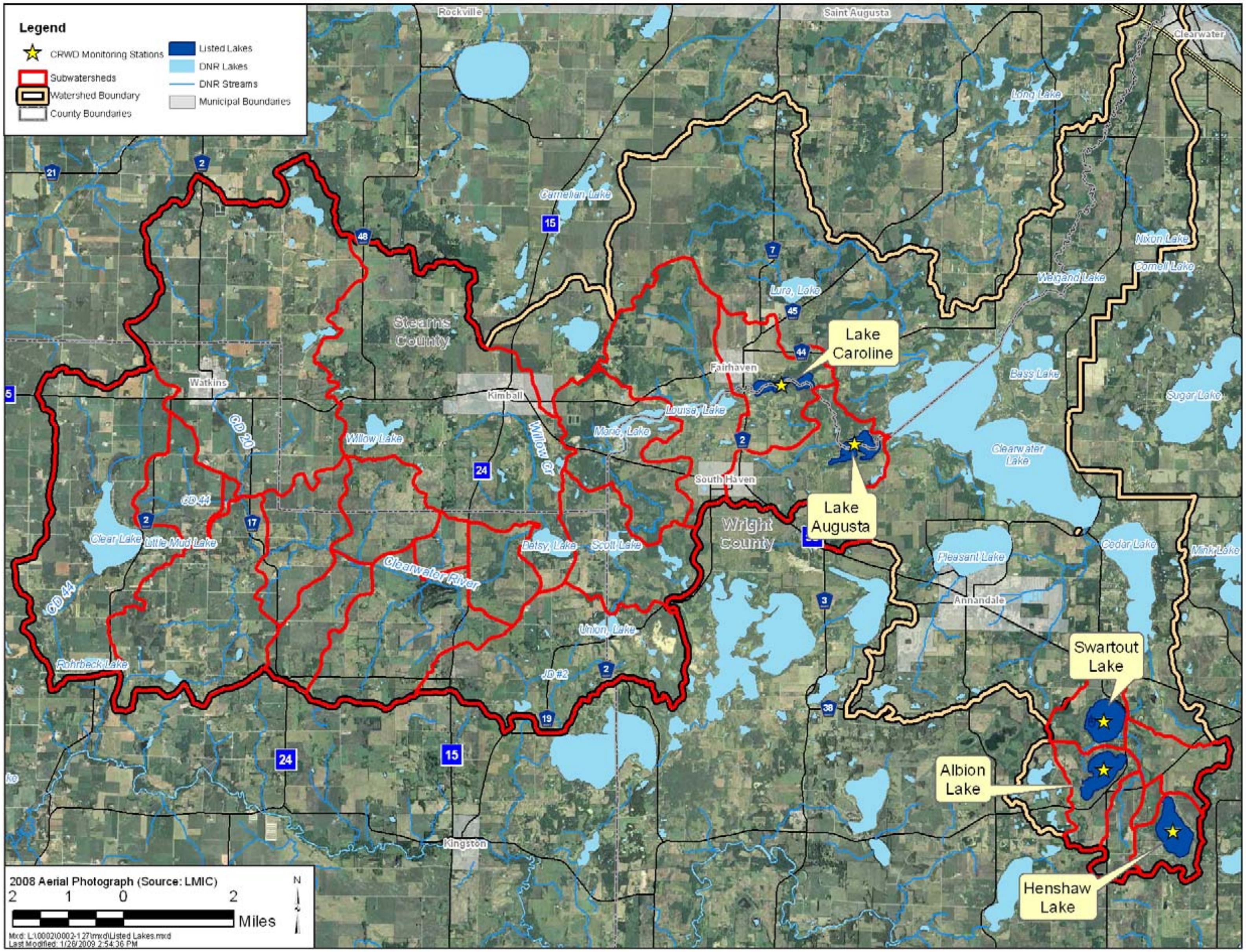


Figure 3.3 General Drainage System

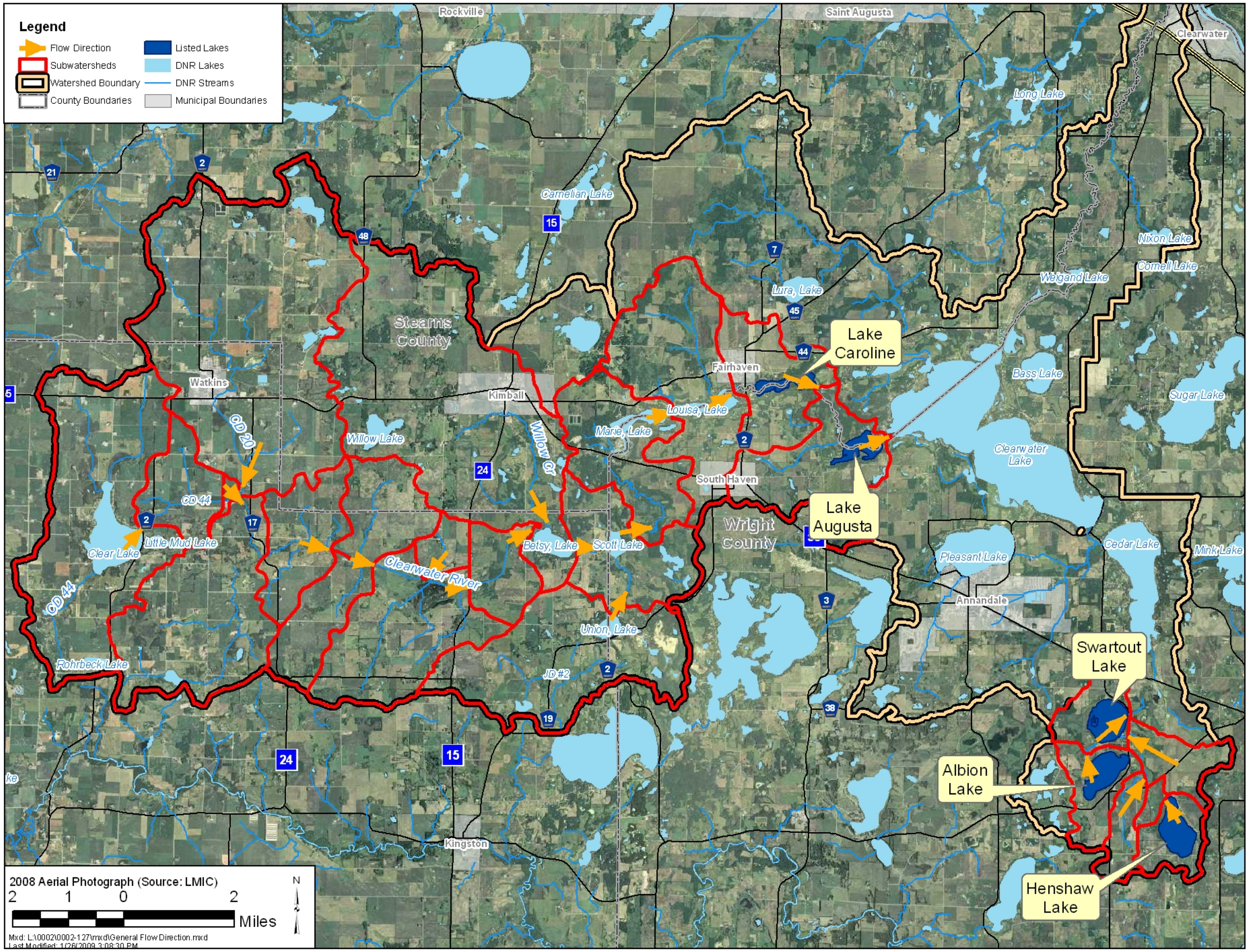


Figure 3.4 Land Use for Lake Caroline and Lake Augusta Subwatersheds

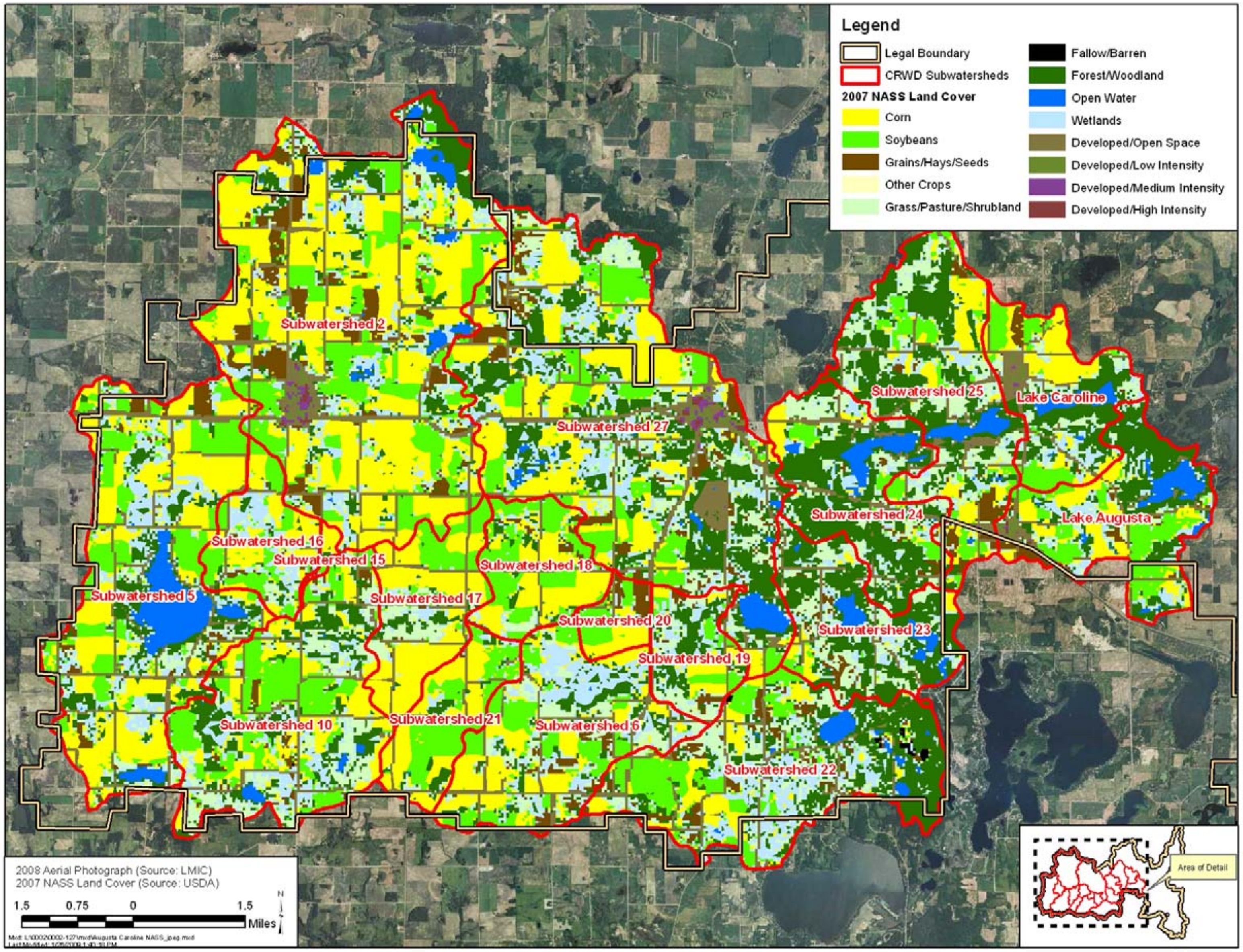
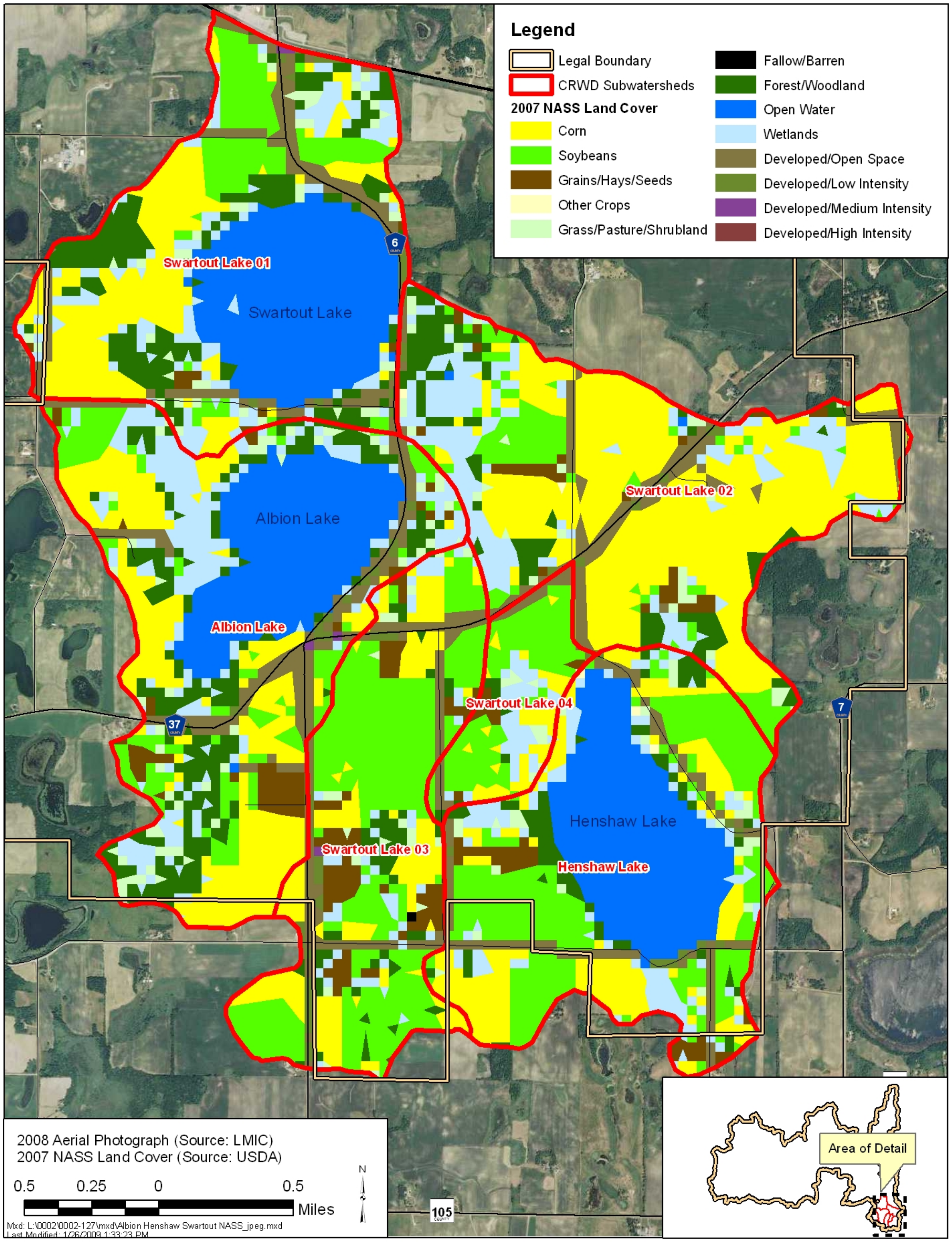


Figure 3.5 Land Use for Albion Lake, Henshaw Lake and Swartout Lake Subwatersheds



3.3.2 Fish Community

Fish surveys have been completed by the Minnesota Department of Natural Resources (DNR) for each of the five lakes in this TMDL study. However, only Lake Caroline and Lake Augusta are managed by the DNR as fish lakes, while Albion Lake, Henshaw Lake and Swartout Lake are generally considered wildlife lakes and are not managed for fishing by the DNR. Fish population surveys were conducted by the DNR in either 2005 or 2006 for all of the five lakes.

The primary management species in Lake Caroline and Lake Augusta are northern pike and largemouth bass, with bluegill, black crappie and walleye identified as secondary management species. The most recent Lake Caroline survey was dominated by bluegill, black crappie and northern pike, while Lake Augusta survey was dominated by bluegill and northern pike. The DNR conducted special fish population assessments of Albion Lake, Henshaw Lake and Swartout Lake in 2005/2006. The catch of Albion Lake was dominated by black crappies and brown bullhead, the catch of Henshaw Lake was dominated by black crappie and bluegill, while the catch of Swartout Lake was dominated by black crappie, common carp and black bullhead. Fish stocking has not occurred recently in the five lakes in this TMDL study. Bass, black crappies and bluegills were stocked in Lake Caroline and Lake Augusta in the 1940s and 1950s. There are no records of fish stocking in Albion Lake, Henshaw Lake or Swartout Lake.

Common carp have both direct and indirect effects on aquatic environments. Carp uproot aquatic macrophytes during feeding and spawning that resuspends bottom sediments and nutrients. These activities can lead to increased nutrients in the water column, ultimately resulting in increased nuisance algal blooms. Common carp are fierce competitors that are long-lived, exhibit fast growth, and produce more than 10 times the offspring of native game fish species. Standard DNR survey methods do not target common carp specifically but there is still evidence of significant common carp populations in the some of the five lakes in this TMDL study. The DNR lake management plans for Lake Caroline and Lake Augusta suggest that common carp populations could be significant due to the connection to the Clearwater River. Surveys of Albion and Henshaw Lakes indicate that black bullhead and common carp are present in the lakes but exact population sizes are not known. Yellow and brown bullheads, which are not directly associated with poor water quality, were removed from Henshaw Lake during the winter of 2009 (black bullheads are the typical target of fish removal).

The population of common carp in Swartout Lake is significant. This is likely due to the connectivity to adjacent wetlands, which provide spawning grounds for common carp. Researchers at the University of Minnesota have determined that common carp populations can thrive in lakes that are connected to wetlands that experience winter kill (Dr. Peter Sorensen, personal communication, 2008). After wetlands experience winterkill they are devoid of small minnows and sunfish that prey on carp eggs and in the absence of this control mechanism common carp can experience population booms due to spawning success in wetlands. The District has been working with local lake residents to actively manage and control the common carp population in Swartout Lake. Carp migration barriers have been added to two inflows to Swartout Lake and at the outflow. Additionally, commercial fisherman have been contracted to remove common carp from the basin. During the winter of 2008, approximately 62,000 pounds of common carp were removed from Swartout Lake over the course of three nettings. These measures have helped to reduce, but not eliminate, common carp populations in Swartout Lake. Continued active management of common carp populations is an important management tool while moving forward towards reaching water quality goals in Swartout Lake, as well as other lakes in the District.

Fish kills occur when dissolved oxygen (DO) levels are so low that fish begin to die from the lack of oxygen. Fish kills can commonly occur during the summer or winter. Summer kills are the result of high productivity (algae and macrophyte) that eventually senesces, and is subsequently broken down by bacteria. The breakdown by bacteria demands oxygen, which depletes DO in the water column. These conditions can result in a summer fish kill. Winter fish kills are the result of snow-covered ice that shades out photosynthesis under the ice. These conditions, coupled with a high sediment oxygen demand, can deplete the DO under the ice and result in a fish kill. The extent of fish kills varies greatly within the five lakes in this TMDL study. There are no documented occurrences of winter or summer fish kills in Lake Caroline or Lake Augusta. This is likely due to the connectivity of the lakes to the Clearwater River, which provides flow and an escape route if low DO conditions occur. Fish kills can be frequent at times in Albion Lake, Henshaw Lake and Swartout Lake due to the shallow nature of the lakes and the high algal productivity. Winter kill occurred as recently as the winter of 2006/2007 in Henshaw Lake.

3.3.3 Aquatic Plants

Aquatic plants are beneficial to lake ecosystems, providing spawning and cover for fish, habitat for macroinvertebrates, refuge for prey, and stabilization of sediments. However, in excess they limit recreation activities such as boating and swimming and reduce aesthetic value. Excess nutrients in lakes can lead to non-native, invasive aquatic plants taking over a lake. Some exotics can lead to special problems in lakes. For example, Eurasian watermilfoil can reduce plant biodiversity in a lake because it grows in great densities and out-competes all the other plants. Ultimately, this can lead to a shift in the fish community because these high densities favor panfish over larger game fish. Species such as curly leaf pondweed can cause very specific problems by changing the dynamics of internal phosphorus loading. All in all, there is a delicate balance within the aquatic plant community in any lake ecosystem.

Plant surveys were conducted recently (from 2005 to 2007) by the DNR in four of the five lakes. In 2005, the Minnesota DNR collected aquatic plant survey data from Lake Louisa and Lake Marie. The DNR also collected aquatic plant survey data from Henshaw Lake and Swartout Lake in 2007. It is not known if an aquatic vegetation survey has been conducted on Albion Lake. Curly leaf pondweed has been observed in Lake Caroline, Lake Augusta and Henshaw Lake during the most recent DNR vegetation surveys. Eurasian water milfoil was observed in Lake Augusta during the most recent DNR vegetation survey.

DNR aquatic plant surveys conducted for Lake Caroline indicate that there are a number of emergent species bordering the lake, identifying approximately 20 species, but the only species labeled as common or abundant was reed canary grass. The submerged species coontail, sago pondweed and filamentous algae were commonly observed during the survey. The survey indicates that while curly leaf pondweed is present in Lake Caroline, it currently is found in only a small percentage (~2%) of the basin. Over 20 emergent species were identified during the vegetation survey of Lake Augusta but all species were labeled as being rare in occurrence. Of the 15 submerged species observed in Lake Augusta, only coontail was observed as being common. The survey indicates that while curly leaf pondweed is present in Augusta, it currently is found in only a small percentage (~11%) of the basin.

The aquatic plant survey conducted by the DNR on Henshaw Lake found submerged vegetation at 59 of the 64 survey points in the basin. However, at each location the only vegetation found was sago pondweed that was listed as being in poor condition. Curly leaf pondweed was also observed but the report does not list what percentage of the lake contained this exotic species. The DNR survey report recommends aggressive shallow lake management (including water level management) for Swartout Lake to aid in controlling rough fish, improving the aquatic plant community, and improving lake water quality.

The vegetation survey in Swartout Lake revealed that the lake is almost entirely devoid of aquatic vegetation. There was no submerged aquatic vegetation observed at any of the 64 sampling points. Cattails were observed along much of the lake's shoreline. The lack of a stable aquatic vegetation community is most certainly impacting the lake's nutrient cycling and water quality. The DNR report recommends aggressive shallow lake management (including water level management) for Swartout Lake to aid in controlling rough fish, establishing an aquatic plant community and improving lake water quality.

3.3.4 Shoreline Habitat Condition

The shoreline areas are defined as the areas adjacent to the lake's edge with hydrophytic vegetation and water up to 1.5 feet deep or a water table within 1.5 feet from the surface. Shoreline areas should not be confused with shoreland areas, which are defined as 1,000 feet upland from the ordinary high water level (OHWL). Natural shorelines provide water quality treatment, wildlife habitat, and increased biodiversity of plants and aquatic organisms. Natural shoreline areas also provide aesthetic values and important habitat to fisheries including spawning areas and refugia.

Vegetated shorelines provide numerous benefits to both lakeshore owners and lake users including improved water quality, increased biodiversity, important habitat for both aquatic and terrestrial animals, and stabilizing erosion resulting in reduced maintenance of the shoreline. Identifying projects where natural shoreline habitats can be restored or protected will enhance the overall lake ecosystem.

The littoral zone is defined as that portion of the lake that is less than 15 feet in depth and is where the majority of the aquatic plants are found. The littoral zone of the lake also provides the essential spawning habitat for most warm water fishes (e.g. bass, walleye, and panfish). The five lakes in this TMDL study range from a low of 33 percent littoral in Lake Augusta to a high of 100 percent littoral in Albion Lake, Henshaw Lake and Swartout Lake. The definition of a shallow lake is any lake that has a maximum depth of 15 feet or less or a lake that is 80 percent or more littoral. Based on these criteria, Albion Lake, Henshaw Lake and Swartout Lake are considered shallow lakes, while Lake Caroline and Lake Augusta are considered deep lakes with littoral areas comprising less than 50 percent of the lake in each instance.

Limited data are available on shoreline conditions, as no shoreline condition surveys have been performed on the five lakes in this TMDL study. Aerial photos and some ground observations indicate that Lake Augusta is the most heavily developed with single family residential homes, cabins and an RV campground, which typically feature turf lawns and little native vegetation. Lake Caroline has less development than Lake Augusta with fewer homes and cabins but does have a Boy Scout Camp on the shores of the lake, which receives a moderate amount of use. Both of these lakes are classified as recreational development (RD) by the DNR. Albion Lake, Henshaw Lake and Swartout Lake have low shoreline development with a mix of single family homes and cabins along with areas of wetlands and undeveloped shorelines. The DNR classifies these three lakes as natural environment (NE) lakes.

4.0 Nutrient Source Assessment

4.1 INTRODUCTION

Understanding the sources of nutrients to a lake is a key component in developing a TMDL for lake nutrients. In this section, we provide a brief description of the potential sources of phosphorus to the lake.

4.2 PERMITTED SOURCES

Permitted sources can range from industrial effluent to municipal wastewater treatment plants. There are no known wastewater treatment plant (WWTP) effluent discharges in the watershed. The Cities of South Haven, Watkins and Kimball operate wastewater treatment plants within the watershed; however, these municipalities use land application to treat their waste water and are not permitted to discharge to surface waters. Additionally, the majority of spray irrigation fields used currently are not within the watersheds tributary to the impaired lakes, and the MPCA has rejected attempts by area WWTPs to discharge to area lakes. As such, these systems are likely not sources of nutrients to impaired waters.

The City of Fairhaven and South Haven are also located within the watersheds tributary to Lakes Caroline and Augusta. This city does not operate a WWTP currently, and homes in the area are believed to be on sub-surface sewage treatment systems (SSTS).

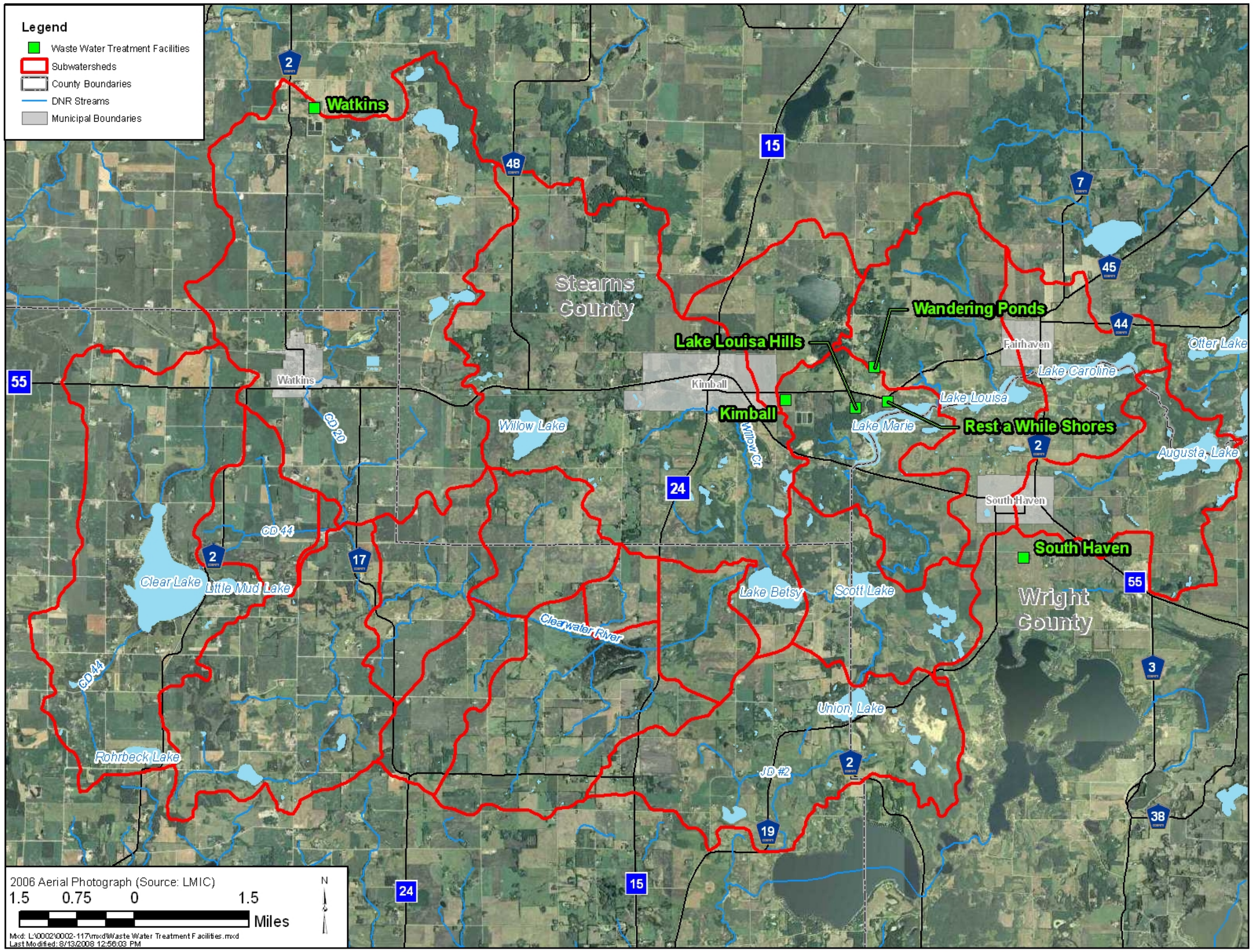
In efforts to improve the water quality of District lakes and streams, the CRWD has issued a report on Master Sanitary Sewer Planning for the area (Wenck 2001), and has installed several cluster wastewater systems, which operate on septic systems that discharge to drain fields. The fact of the study indicates the potential for a future regional system to treat wastewater in the area. Such a regional system would likely serve the chain of lakes between Lake Marie and Clearwater Lake, which includes the areas of Lakes Augusta and Caroline.

All permitted and potential wastewater treatment facilities in the watersheds tributary to the listed waters are listed in Table 4.1; the locations are shown in Figure 4.1.

Table 4.1 Summary of Waste Water Treatment Plants by Municipality

Permit Holder/ System	Waste Water Treatment Method
City of Fairhaven	ISTS (Potential future)
City of Kimball	Land Application (SDS Permit)
City of Watkins	Land Application (SDS Permit)
City of South Haven	Land Application (SDS Permit)
CRWD- Regional	Master System (Potential)
CRWD- Rest-a-While Shores	Cluster System *
CRWD- Wandering Ponds	Cluster System *
CRWD- Lake Louisa Hills	Pending Cluster System *

Figure 4.1 WWTP and Land Application Sites Relative to Impaired Waters



Though the National Pollution Discharge Elimination System (NPDES) Phase II issues permits for small municipal separate storm sewer systems (MS4), none of the four municipalities (Watkins, Kimball, Fairhaven and South Haven) in the watershed tributary to these lakes operates under an NDPES MS4 permit.

No other state-permitted sources are present in the drainage areas tributary to the impaired waters addressed in this study.

4.3 NON-PERMITTED SOURCES

The non-permitted sources of nutrients include:

- In-lake nutrient cycling,
- Clearwater River, Upper Lakes & Wetlands which is comprised of drainage from
    - Agricultural land uses
    - Urban land uses and
    - Residential land uses
- Local (direct) watershed,
- Septic systems,
- Atmospheric loads and
- Ambient groundwater inflows

These sources are assessed in the sections that follow.

4.3.1 In-Lake Nutrient Cycling

In-lake nutrient cycling is an important component of the whole lake nutrient budget. Phosphorus builds up in lake-bottom sediments due to increases in phosphorus load export from the tributary watershed. Phosphorus accumulated in the lake sediments released under specific conditions is called internal loading. Internal loading can be a result of sediment anoxia, where poorly bound phosphorus is released into the water column in a form readily available for phytoplankton production.

Internal loading can also result from sediment resuspension that may result from rough fish activity or prop wash from boat activity. Additionally, curly leaf pondweed can increase internal loading because it senesces and releases phosphorus during the summer growing season (late June to early July).

4.3.2 The Clearwater River/ Upper Lakes and Wetlands

Lake Caroline and Lake Augusta are part of a flow-through chain of Lakes on the Clearwater River. As such, the dominant loading to each lake is often from the upstream water feature. Conversely, where lakes are present in series, the upstream lakes also work to buffer the effects of upstream nutrient loads.

Working upstream to downstream, Lake Marie is the dominant upstream nutrient source to Lake Caroline and Lake Caroline is the dominant upstream nutrient source to Lake Augusta. Nutrient sources that are upstream of Lake Marie and contribute to the overall nutrient loads of Lake Caroline and Lake Augusta include Lake Louisa, the Clearwater River, Scott Lake, Union Lake, Lake Betsy and Clear Lake, each addressed in a previous TMDL study (Wenck 2009).

Albion Lake and Henshaw Lake are located in southeast-most corner of the Clearwater River Watershed and have only direct contributing watersheds with no upstream water bodies. Swartout Lake receives nutrient source contributions from both Albion Lake and Henshaw Lake and from upstream wetlands.

The nutrient loads in the upstream lakes and the Clearwater River typically originate from the dominant land uses within the upstream watersheds. Nutrient loads from upstream lakes are also increasingly the result of internal lake loading within the upstream lakes.

Model boundary conditions were set to reflect the impact of these upstream waters. Boundary conditions were set where upstream monitoring data is available to more accurately represent the system. Understanding this flow-through configuration, the modeled boundary conditions and their impact on model predictions and phosphorus budgets is critical to putting the model in the context of the TMDL. Assumptions are made to incorporate additional Margin of Safety. Boundary condition assumptions for each model are tabulated in Table 4.2.

Table 4.2 Upstream Model Boundary Condition

Lake	Upstream Water Body/ Model Boundary Condition
Lake Caroline	Lake Marie
Lake Augusta	Lake Caroline
Albion Lake	--
Henshaw Lake	--
Swartout Lake	Albion Lake & Henshaw Lake

4.3.3 Local (Direct) Watershed

As described above, Lake Caroline and Lake Augusta are part of a flow-through chain of lakes on the Clearwater River, and as such the upstream water body (and its tributary watershed) is often a dominant source of phosphorus in the nutrient budget for a given lake. Conversely, Albion Lake, Henshaw Lake and Swartout Lake have much smaller contributing watersheds, with only Swartout Lake received nutrient contributions from upstream lakes. As such it is possible that the direct subwatershed could contribute a greater percentage of the total nutrient load to Albion Lake, Henshaw Lake and Swartout Lake. In the context of the TMDL study, the local watershed is the direct drainage area to the lake not also tributary to the upstream boundary condition lake or river station. Dominant nutrient sources in the watershed tend to be dominant land uses, which are summarized in Table 3.2. The load delivered to each lake from the specific land uses within the direct subwatershed can be influenced by a variety of factors including proximity to the lake or tributary streams, the slope of the land, or the underlying soil type. Land uses occurring on steep slopes on soils with high organic or nutrient contents, located immediately adjacent to a lake or tributary stream have the potential to deliver a higher nutrient load than a similar land use located further from the water body on flat terrain or soils with low nutrient content.

4.3.4 Septic Systems

The homes ringing the five lakes addressed in this study are served exclusively by SSTS. The estimated number of homes on septic systems by lake is presented in Table 4.3. For Lake Caroline and Lake Augusta, there are more than 12 residences located on the lake, but based on information from District Managers many of these residences around the lakes use holding tanks, which are pumped out when full and do not have a drain field. Therefore the residences with holding tanks do not contribute to the nutrient load to the lake.

Table 4.3 Number of homes served by SSTS

Lake	Estimated Septic Systems (# of homes)
Lake Caroline	12
Lake Augusta	12
Albion Lake	13
Henshaw Lake	15
Swartout Lake	33

The soils in the CRWD in the vicinity of Lake Caroline and Lake Augusta are sandy. High phosphorus loading from ISTS is possible in sandy soils even when systems are largely compliant. Failure rates were assumed to be 25%. This assumption of 25% failure rates is conservative in the context of the TMDL and protective of lake water quality. Minimizing the potential load reductions to be gained from ISTS maximizes the load reductions required of other areas. In any case, eliminating loads from ISTS is an important element of TMDL implementation, but the load allocation does not overly rely on them to meet standards.

4.3.5 Atmospheric Deposition

The atmosphere delivers phosphorus to water and land surfaces both in precipitation and in so-called “dryfall” (dust particles that are suspended by winds and later deposited). Such atmospheric inputs must be accounted for in development of a nutrient budget, though they are generally very small direct inputs to the lake surface and are impossible to control.

4.3.6 Ambient Groundwater Inflows

Lake Caroline and Lake Augusta lie within the Anoka Sand Plain and are therefore subject to significant groundwater interaction. The hydrologic atlas, “Water Resources of the Mississippi and Sauk Rivers Watershed, Central Minnesota” (Helgesen et al., 1975; U.S Geological Survey HA-534), includes the Clearwater River watershed and contains a water table map indicating that groundwater from the Sand Plain aquifer discharges to Clearwater River generally—as expected for a significant stream—and to the lakes along it. Because groundwater typically contains phosphorus—the statewide median TP concentration for surficial glacial aquifers is 56 μg/L (MPCA, 1999)—it can be a component of the overall nutrient load to a given lake.

Albion Lake, Henshaw Lake and Swartout Lake are not located along the Clearwater River and are shallow basins. Based on review of the hydrologic atlas, the ordinary high water levels of these lakes lie above the reported levels for groundwater in the area. A review of well logs in the Minnesota Department of Health county well database further suggests that the groundwater levels in the vicinity of these lakes is lower than the lake elevations. The logs also show a sequence of clay in the upper portion of the well logs, suggesting these lakes are perched above the local aquifer. It is therefore concluded that these lakes are not interacting with the groundwater to a significant degree. There may be local perched groundwater entering the lakes but it is unquantifiable and likely small.

5.0 Assessment of Water Quality Data

The District first conducted diagnostic monitoring through the 1980 Chain of Lakes Improvement project. Since then, the Clearwater River Watershed District has collected water quality data annually to document trends. Lakes are sampled annually on a rotating basis; data are summarized in the CRWD annual water quality monitoring reports available at the District office (Wenck 1985- 2008). Historical TP, Secchi and chlorophyll- a data for each lake, as well as stream loading data, are presented in Appendix A. Annual average TP concentrations are compared to standards for shallow lakes (Figure 5.1) and deep lakes (Figure 5. 2). Recent typical annual average TP concentrations are compared with lake standards in Table 5.1. Recent generally constitutes the past 10 years.

Figure 5.1 Average In-lake TP Concentrations for Shallow Impaired Lakes

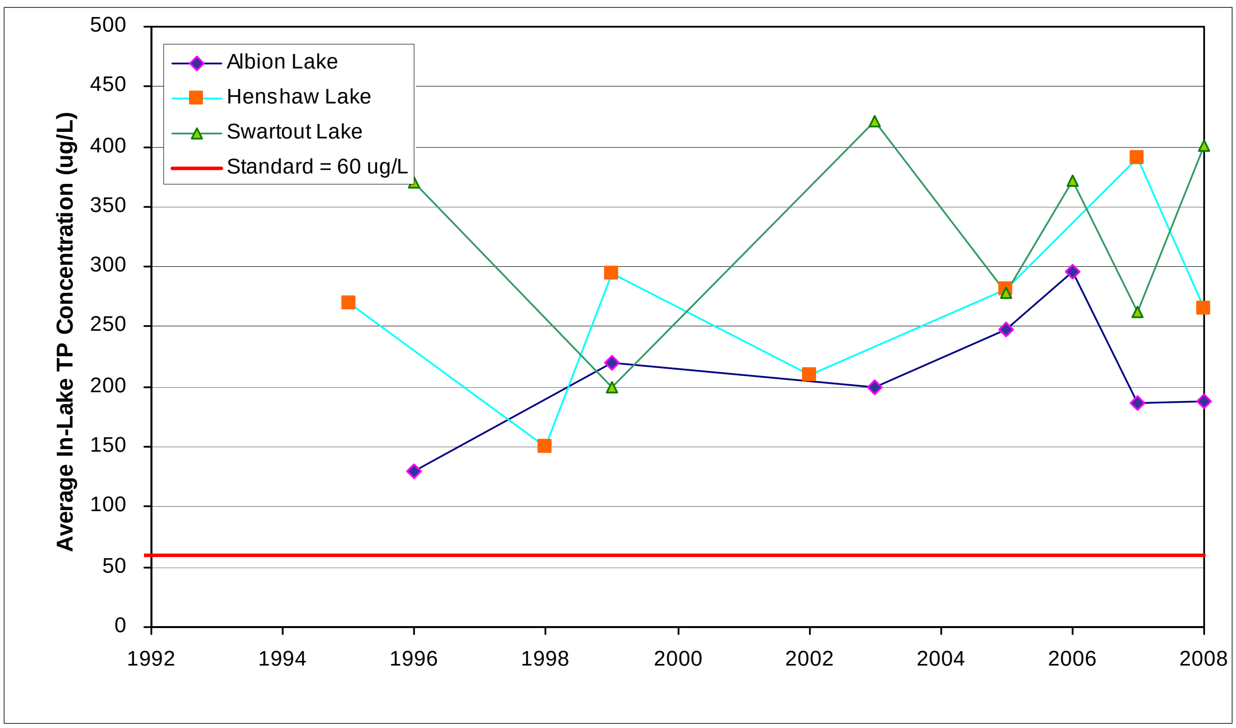


Figure 5.2 Average In-lake TP Concentrations for Deep Impaired Lakes

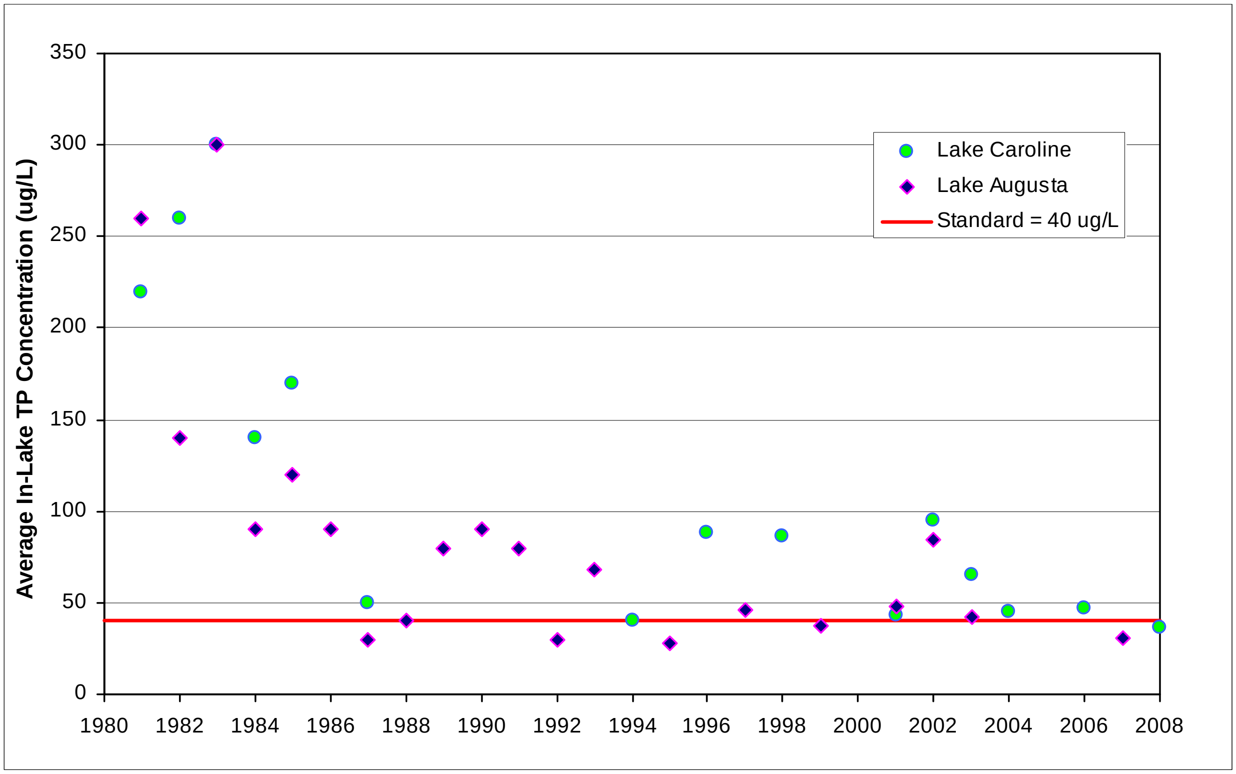


Table 5.1 Recent Typical Annual Average TP Concentrations Compared to Numeric Targets

Lake	TP (µg/L)		Chlorophyll-a (µg/L)		Secchi Depth (ft)	
	Target	**Recent**	**Target**	**Recent**	**Target**	**Recent**
Lake Caroline	**40**	**36 – 95**	**14**	**12 - 55**	**4.6**	**4.2 - 7.2**
Lake Augusta	**40**	**31 - 84**	**14**	**6 – 29**	**4.6**	**5.7 - 7.2**
Albion Lake	**60**	**130 - 296**	**20**	**60 - 204**	**3.3**	**1.6 - 5.2**
Henshaw Lake	**60**	**150 - 390**	**20**	**53 - 278**	**3.3**	**0.7 - 2.9**
Swartout Lake	**60**	**200 - 421**	**20**	**144 - 832**	**3.3**	**0.7 - 3.3**

5.1 LAKE CAROLINE

District monitoring for Lake Caroline began in 1981 with the Clearwater Chain of Lakes Restoration Project. Summer average total phosphorus concentrations in Lake Caroline ranged from 36 in 2008 to 300 µg/L in 1983. With the exception of 2008, average in-lake concentrations exceed the state standard of 40 μg/L during all monitoring years. Since 1998, recent typical in-lake average summer surface TP concentrations have averaged about 60 μg/L.

Summer average chlorophyll-a concentrations ranged from 3 μg/L in 1983 to 55 μg/L in 1998. Since 1998, typical recent chlorophyll-a concentrations have averaged about 32 μg/L. Observed Secchi-depth readings have ranged from just over 2.5 feet in 1994 to greater than 6 feet in 2006. Since 1998 the recent average Secchi depth is approximately 5 feet. In-lake water quality in Lake Caroline has improved significantly relative to monitoring conducted in the early 1980s.

5.2 LAKE AUGUSTA

District water quality monitoring in Lake Augusta began in 1981. Summer average total phosphorus concentrations in Lake Augusta have exhibited a wide range of variation, ranging from 28 μg/L in 1995 to 300 μg/L in 1983. Average in-lake concentrations exceed the state standard of 40 μg/L during 14 of 20 monitoring years. Since 1997, recent typical in-lake average summer surface TP concentrations have averaged about 50 μg/L.

Observed in lake chlorophyll-a concentrations have varied widely in Lake Augusta with some years below the State standard of 14 μg/L and other years greatly exceeding the standard. Summer average chlorophyll-a concentrations ranged from 4 μg/L in 1983 to 73 μg/L in 1990. Since 1997, typical recent chlorophyll-a concentrations have averaged about 16 μg/L. Secchi depth has varied from 3.5 feet in 1991 to a high of 6.2 feet in 2002. Since 1997, recent typical Secchi depth values have averaged about 5.5 feet. In-lake water quality in Lake Augusta has improved significantly relative to monitoring conducted in the early 1980s; however, the lake remains impaired.

5.3 ALBION LAKE

District monitoring in Albion Lake began in 1996. Summer average total phosphorus concentrations in Albion Lake have ranged from 130 to 296 μg/L during that time. Average in-lake concentrations have exceeded the State standard for shallow lakes of 60 μg/L during all monitoring years. Recent typical in-lake P concentrations have average about 230 μg/L. Albion Lake is located in the southeast-most corner of the Clearwater River watershed. It has no contributing upstream lakes and a relatively small contributing watershed. The outlet to Albion Lake is a tributary stream that flows north into Swartout Lake.

Chlorophyll-a values observed in Albion Lake have ranged from 60 μg/L in 2005 to 203 μg/L in 2006, with recent values averaging approximately 120 μg/L. The Secchi depth readings have ranged from 1.6 to 5.2 feet, averaging 3.6 feet. Secchi values have been equal to or better than the State standard during each of the past three monitoring years.

5.4 HENSHAW LAKE

District monitoring for Henshaw Lake began in 1995. Summer average total phosphorus concentrations in Henshaw Lake ranged from 150 µg/L in 1998 to 390 µg/L in 2007. Average in-lake concentrations have exceeded the state standard for shallow lakes of 60 µg/L during all monitoring years. Recent typical in-lake P concentrations have averaged about 270 µg/L.

Henshaw Lake is located in the southeastern corner of the Clearwater River watershed. It has a very small drainage area with a 2.3:1 ratio and no upstream lakes. An outlet structure for Henshaw Lake installed at an unknown time artificially maintains lake elevations compared to native conditions. The native condition of the Henshaw Lake was likely waterfowl habitat instead of its current state as fish habitat. The combination the artificially maintained hydrology in Henshaw Lake and the introduction of carp likely led to the current level of degradation in vegetative habitat and the resulting water quality.

Chlorophyll-a concentrations in Henshaw Lake have varied from a low of 53 µg/L in 1998 to a high of 278 µg/L in 2007. Recent chlorophyll-a concentrations have averaged approximately 150 µg/L. Water clarity is very poor in Henshaw Lake. The Secchi depth readings have ranged from 0.7 to 2.95 feet due primarily to high non-algal turbidity, though algal turbidity is also an issue. Non-algal turbidity is driven by wind suspension and the lack of aquatic macrophytes. The water clarity values have been less than the State standard for shallow lakes (>3.2 ft) during all monitoring years. Recent Secchi values have averaged slightly less than 2 feet.

The CRWD has worked unsuccessfully with Ducks Unlimited and land owners to implement a shallow lakes management plan that includes drawdown of the lake and rough fish management. The lake shore residents have been unreceptive to such plans.

5.5 SWARTOUT LAKE

District monitoring for Swartout Lake began in 1996. Water quality is very poor in Swartout Lake with observed total phosphorus and chlorophyll-a concentrations exceeding State standards during all monitoring years. Summer average total phosphorus concentrations in Swartout Lake ranged from 200 µg/L in 1999 to 421 µg/L in 2003. Recent typical in-lake P concentrations have averaged about 300 µg/L.

Observed chlorophyll-a concentrations have ranged from 144 µg/L in 2005 to 444 µg/L in 2003. Recent typical chlorophyll-a concentrations have averaged about 220 µg/L. Water clarity is very low in Swartout Lake, with Secchi depth values in ranging from 0.7 to 3.2 feet. Recent Secchi values have averaged approximately 2 feet.

Rough fish migration control and removal is an important element of past and current lake management. The District has worked in recent years with the Swartout Lake residents in an attempt to control populations and movements of rough fish, specifically carp, in Swartout Lake. Fish barriers to prevent carp from migrating into wetlands adjacent to Swartout Lake have been installed. Additionally, commercial fishermen were hired during the winter of 2007/2008 and again during the winter to 2008/2009 to net and remove rough fish from Swartout Lake. Table 5.2 shows the pounds of fish removed during recent commercial fishing efforts.

Table 5.2 Rough Fish Removal from Swartout Lake

Year	Rough Fish Removed (lbs)
February 2008	57,000
December 2008	5,000

6.0 Linking Water Quality Target and Sources

A lake nutrient budget can be used to identify and prioritize management strategies to improve water quality. Additionally, lake response models can be developed to understand how lake nutrient concentrations respond to changes in nutrient loads. Through this knowledge, managers can make decisions about how to allocate lake restoration dollars and efforts and quantify the effects of such efforts.

6.1 SELECTION OF MODELS AND TOOLS

The District recently completed TMDL studies addressing bacteria and dissolved oxygen (DO) impairments on the Clearwater River between Clear Lake and Lake Betsy as well as nutrient impairment TMDL studies for six lakes on the chain of lakes, including Clear Lake, Lake Betsy, Union Lake, Scott Lake, Lake Louisa and Lake Marie. Lake Caroline and Lake Augusta are located immediately downstream of Lake Marie and the other lakes on the chain. The data collected to complete that study and calibrate water quality models for those lakes could then easily be used as the upstream starting point for the TMDL studies in Lake Caroline and Lake Augusta.

Albion Lake, Henshaw Lake and Swartout Lake are part of a smaller chain of lakes located upstream of Cedar Lake, which is an important recreational resource in the Clearwater River watershed. The District has been actively working with lake residents to construct projects and implement stewardship practices with the focus of protecting the integrity of the Cedar Lake resource by improving the water quality in upstream watershed and lakes.

There is a large historical data base (runoff, precipitation, in-lake water quality, and watershed loads) available through the CRWD's annual monitoring program that includes data collected for all of the five lakes in this TMDL study.

Available data was the basis for the modeling selections. All lake response modeling was conducted using model equations extracted from BATHTUB. The models are calibrated to available data collected since 1998, focusing on the most recent data available. The partitioned loads from 2001-2007 were averaged to yield the current phosphorus budget for an average year, representing both current watershed conditions relevant to TP export and a range of wet, dry and average years.

Watershed phosphorus loads were calculated using primarily measured water quality and watershed runoff. Runoff volumes across the watershed are based on historical stream flow gauging at long-term monitoring stations for this TMDL study.

6.2 CURRENT PHOSPHORUS BUDGET COMPONENTS

The current phosphorus load contributions from each potential source was developed using the modeling and collected data described above. For each lake the phosphorus load contributions were partitioned into six contributing components:

1. Atmospheric load
2. Septic systems
3. Ambient groundwater
4. Direct watershed runoff
5. The Clearwater River and upstream lakes
6. Internal phosphorus cycling

The Clearwater River is a source of nutrients only for Lake Caroline and Lake Augusta. Albion Lake, Henshaw Lake and Swartout Lake are not located on the chain of lakes on the main stem of the Clearwater River, so the Clearwater River is not a contributing nutrient source in the model for those lakes. Nutrient load inputs from upstream lakes to Swartout Lake included both Albion and Henshaw Lakes. Neither Albion nor Henshaw Lakes have upstream contributing lakes. The following is a brief description of the budget components and how these values were developed.

6.2.1 Atmospheric Load

The atmosphere delivers phosphorus to water and land surfaces both in precipitation and in so-called “dryfall” (dust particles that are suspended by winds and later deposited). A recent statewide study of phosphorus sources commissioned by the MPCA (Barr, 2004 updated in 2007) gives the following atmospheric load data for the upper Mississippi River watershed (Table 6.1):

Table 6.1 Atmospheric Deposition of P

Deposition Component	[kg/ha/yr]	[lb/ac/yr]
Low-Precipitation P Deposition	0.08	0.07
Average-Precipitation P Deposition	0.10	0.09
High-Precipitation P Deposition	0.12	0.11
Dry P Deposition	0.17	0.16
Dry-Year Total P Deposition	0.25	0.23
Average-year Total P Deposition	0.27	0.24
Wet-year Total P Deposition	0.29	0.27

Deposition rates were applied to the area of each lake surface based on annual precipitation for dry (< 25 inches), average, and wet precipitation years (>38 inches). The atmospheric load typically comprises a small percentage of the total load for each lake.

6.2.2 Septic Systems

A review of county parcel information was conducted to determine the amount of lake homes and residents along the shoreline of each lake. Residents comprise both part-time and year-round residents. Local knowledge of the watershed was also applied to determine an accurate number of lake homes utilizing septic systems versus homes utilizing holding tanks. Holding tanks are regularly pumped out and are not connected to a drain field. Therefore, lake homes utilizing holding tanks do not contribute to the nutrient load of a lake.

The total septic load to each lake was calculated by multiplying the number of homes around the lake, assuming four persons per home and a total phosphorus load of 4.2 pounds of phosphorus per system per year. The total phosphorus septic load to the lake was then determined by multiplying the total septic load by an assumed failure rate of 25 percent. For example, for Lake Augusta there are 12 homes on septic systems. Based on the above assumptions, the septic load to the lake would be calculated as follows:

(12 systems)*(4.2 lbs TP/yr per system)*(25% failure rate) = Septic Load to Lake

6.2.3 Ambient Groundwater

Regional studies show that the Clearwater River Chain of Lakes, situated in the Anoka Sand Plain, is subject to groundwater interaction (Helgesen et al., 1975). A water table map indicates that groundwater from the Sand Plain aquifer discharges to Clearwater River generally—as expected for a significant stream—and to the lakes that comprise the Chain of Lakes. Measured base flows in the Clearwater River support this conclusion. Lake Caroline and Lake Augusta are within the lower portion of the Chain of Lakes. The specific rate of groundwater inflow to Lake

Caroline and Lake Augusta was calculated using regional values for hydraulic conductivity for the Anoka Sand Plain, hydraulic gradient from the regional hydraulic atlas and Darcy's Law. Resulting phosphorus loads can then be calculated based on calculated inflow using the statewide median TP concentration for surficial glacial aquifers of 56 µg/L (MPCA, 1999).

Lakes Swartout, Albion, and Henshaw have ordinary high water levels reported in the hydrological atlas higher than those that are part of the chain of lakes on the main stem of the Clearwater River and are either losing water to the aquifer or are perched. These lakes are high in the watershed and lie above lakes Caroline and Augusta. A review of well logs in the Minnesota Department of Health county well database further suggests that the groundwater levels in the vicinity of these lakes is lower than the lake elevations. The logs also show a sequence of clay in the upper portion of the well logs, suggesting these lakes are perched above the local aquifer. It was therefore concluded that Albion Lake, Henshaw Lake and Swartout Lake are not interacting with the groundwater to a significant degree. The nutrient load associated with the groundwater component of the model was set to zero for Albion Lake, Henshaw Lake and Swartout Lake.

6.2.4 Direct Watershed Runoff

The direct sub-watershed is defined as the portion of the upstream load not tributary to another water body. The boundary condition for each lake was the upstream lake or monitoring station for which measured data was available. This reduces the uncertainty of watershed loading by using measured values and takes into account the nutrient removal in upstream lakes. The remaining tributary watershed is considered "direct" watershed runoff.

Phosphorus loads from the direct sub-watershed to each lake were based on direct measurement of water quality and watershed runoff from tributaries themselves or from areas of representative land use around the watershed.

6.2.5 Upstream Lakes

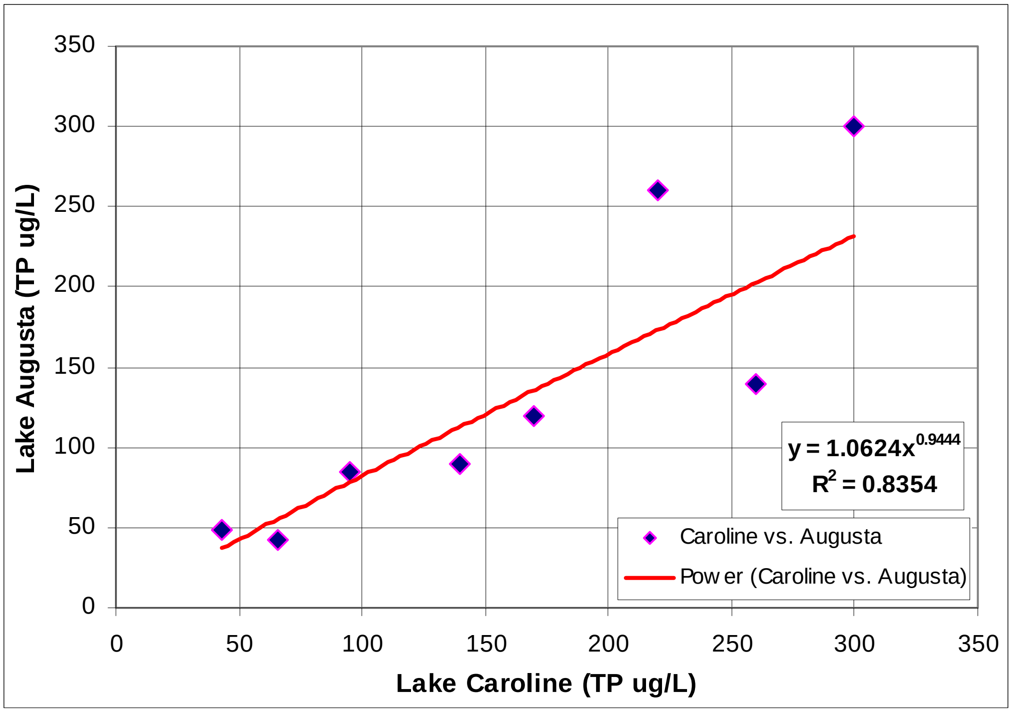
Lake Caroline, Lake Augusta and Swartout Lake receive inflow from upstream lakes. Flow from upstream lakes plays a significant role in the nutrient and water balance for these three lakes. Clear Lake, Lake Betsy, Scott Lake, Lake Louisa, Lake Marie and the Clearwater River all contribute water and therefore nutrients to Lake Caroline and Lake Augusta. Conversely, these lakes also act as a buffer to the downstream lakes by trapping nutrients. Albion Lake and Henshaw Lake do not have upstream contributing lakes or streams but these lakes do contribute water and nutrient loads to Swartout Lake.

Traditional watershed TP export values were not appropriate to characterize watershed export from upstream of these lakes, and water quality data was available for the upstream lake or monitoring station, so the upstream lake or stream station functioned as the boundary condition for each lake model.

Because CRWD measures lake water quality on a rotating basis, in-lake data from the lake directly upstream (paired data) was not available for all years. Paired data sets were available for 2 to 4 years for each lake. Because of the short residence time of the lakes and the dominance of the Clearwater River, paired data sets provided the best quantifications of upstream loads to most lakes, and as such were used for model calibration.

When paired data were not available, the load from upstream lakes was calculated based on data collected farther upstream given the strong relationships between water quality at different locations along the Clearwater River. Strong correlations are not surprising given the relative locations of the lakes and river monitoring stations (Figures 3.2). Examples of these correlations are shown in Figure 6.1.

Figure 6.1 Correlation between Annual Average TP in Lake Caroline and Lake Augusta



6.2.6 Internal Phosphorus Cycling

Internal phosphorus cycling has been shown to be an important element in lake nutrient budgets. In-lake phosphorus concentrations in the five lakes in this TMDL study indicate that internal loading may be significant. Lake Caroline and Lake Augusta are deep lakes that stratify thermally, which leads to anoxic conditions in the hypolimnion that can lead to the release of phosphorus from sediments. Albion Lake, Henshaw Lake and Swartout Lake are shallow, polymictic lakes that rarely stratify. However, internal loading can still be significant in these shallow lakes as wind mixing is continually leading to sediment resuspension and release of internal nutrients. Two methods were used to quantify internal nutrient cycling in CRWD lakes depending on the level of available data for each lake.

The anoxic factor (Nurnberg 1995), which estimates the period when anoxic conditions exist over the sediments, was used to quantify internal loading. The anoxic factor was estimated using two methods for this study. For the deep lakes, Caroline and Augusta, the anoxic factor is calculated from the dissolved oxygen profiles collected in each lake. The anoxic factor is expressed in days but is normalized over the area of the lake. The anoxic factor can then be calculated as the number of anoxic days multiplied by the area of anoxia, divided by the total lake area. The anoxic factor was then used in conjunction with literature values for sediment phosphorus release rates (Nurnberg, 1988) to calculate the internal load for the lake.

For shallow lakes that are polymictic and do not stratify, an anoxic factor can be estimated. An equation for shallow lakes uses long term average in-lake phosphorus concentration with the lake area and average lake depth to predict the anoxic factor (Nurnberg, 2005). This shallow lakes equation was used in conjunction with literature values for sediment phosphorus release rates (Nurnberg, 1988) to calculate the internal load for Albion Lake, Swartout Lake and Henshaw Lake.

6.3 CURRENT PHOSPHORUS BUDGET

A current phosphorus budget quantifying the relative contributions from each of the potential sources was developed using the models and data described above. Data from 2001 to 2007 were used to develop the phosphorus budgets for each lake for an average year because these data represent current relevant watershed conditions that influence TP export, as well as a range of wet and dry conditions. Table 6.2 shows the range of precipitation and runoff measured in Annandale for the averaging period. For comparison, the 20-year average precipitation in Annandale is 28.6 inches.

Table 6.2 Precipitation and Runoff 2001-2007

Year	Annual Precipitation (inches)	Annual Runoff (inches)
2001	31.3	2.8
2002	40.6	7.6
2003	23.0	6.5
2004	33.1	2.8
2005	36.9	7.1
2006	23.4	5.7
2007	27.2	4.7
2008	25.3	2.0
Average	30.8	4.9

The phosphorus budget derived from the water quality modeling is shown in Table 6.3; the modeling summary is included as Appendix B.

Table 6.3 Current Annual Phosphorus Budget (lbs/ yr)

Lake	Total	Direct Watershed	Upstream Lakes	Septic Systems	Atmospheric + Groundwater	Internal
Lake Caroline	5,642	308	4,098	13	822	402
Lake Augusta	5,607	403	3,601	13	710	880
Albion Lake	3,865	342	-	14	60.3	3,449
Henshaw Lake	3,723	256	-	16	65.1	3,386
Swartout Lake	7,982	1,011	533	34	71	6,333

T:\0002\127\Models and Data\Caroline_Augusta LRM\[Average LRModel (Marie-Caroline-Augusta).xls]An Phos Bdgt

For Lake Caroline and Lake Augusta, upstream lakes drive the loading to the lake; for Albion Lake, Henshaw Lake and Swartout Lake, internal sources are by far the dominant load source and must be addressed to meet water quality goals.

6.4 WATER QUALITY RESPONSE MODELING

The BATHTUB model was developed using measured runoff volumes. Measured water quality data was used where available. Measured water quality for subwatersheds with similar land use was used to narrow the predicted export ranges for un-gauged watersheds. In this case ungauged watersheds were limited to very small areas directly tributary to the lakes. No calibration factors were used in the modeling.

6.5 FIT OF THE MODELS

Empirical models can give us an estimate of annual loading. The model fit reasonably well compared to annual average lake water quality data. Differences between observed and predicted average in-lake concentrations were generally within the reported standard deviations for annual average TP for a given year.

Further, after extensive evaluation of load allocations based on the range of watershed and internal loading data, significant differences in the modeled watershed or internal loads or load allocations to different sources do not change the implementation planning discussed in Section 9 of this report. Loads from upstream lakes will require significant reductions to meet standards for Lake Caroline and Lake Augusta and internal loads will require intensive management in Albion Lake, Henshaw Lake and Swartout Lake. Exploration of internal load management in Lake Caroline and Lake Augusta is recommended given that upstream load reduction targets are aggressive and may not be achievable with current available technologies.

6.6 CONCLUSIONS

<u>Lake Caroline:</u>

- Water quality in Lake Caroline is dominated by loads from the Clearwater River and Lake Marie.
- Based on the model results, it appears that water quality goals can be met through a combination of watershed and internal load reductions and management.

<u>Lake Augusta:</u>

- Water quality in Lake Augusta is dominated by loads from the Clearwater River and Lake Caroline. The short residence time of this lake means that water quality in the lake during the early spring and summer months is essentially the same as in the river.
- Based on the model results, it appears that water quality goals can be met through a combination of watershed and internal load reductions and management.

<u>Albion Lake:</u>

- Lake Albion is much closer to a clear state shallow lake than are either Swartout or Henshaw. Management strategies for this lake should be taken very carefully given the lake’s current state of ecological integrity.
- Albion Lake has a small tributary watershed. As a result, while a reduction of watershed loads will be important, reducing watershed loads alone will not be sufficient to achieve water quality targets for the lake.
- Internal loads in Albion Lake are the major nutrient source to the lake. A significant reduction in this internal nutrient source will be required to meet water quality targets; however, care most be taken to maintain high ecological integrity.

<u>Henshaw Lake:</u>

- Henshaw Lake has a small tributary watershed. As a result, while a reduction of watershed loads will be important, reducing watershed loads alone will not be sufficient to achieve water quality targets for the lake.
- The tributary watershed alone is unlikely to have caused the impairment of the lake itself. Artificial maintenance of lake level through installation of an outlet, coupled with the introduction of rough fish, has likely resulted in the turbid water conditions observed on Henshaw Lake. As phosphorus loading alone did not impair the lake, hydrologic and ecological restorations will also be required to return the lake to a more clear state. To date, however, residents have been unwilling to implement recommended strategies outside of watershed load reduction.
- Internal loads in Henshaw Lake are the major nutrient source to the lake. A significant reduction in this internal nutrient source will be required to meet water quality targets

<u>Swartout Lake:</u>

- Internal loads in Swartout Lake are the major nutrient source to the lake. A significant reduction in this internal nutrient source will be required to meet water quality targets

- ❖ Swartout Lake receives significant nutrient loads from both the lake direct subwatershed and the upstream lakes, Albion and Henshaw.
- ❖ Management of both internal and external loads to Swartout Lake will be critical in achieving water quality goals.

7.0 TMDL Allocation

7.1 LOAD AND WASTELOAD ALLOCATION

Nutrient loads in this TMDL are set for phosphorus, since this is typically the limiting nutrient for nuisance aquatic plants. This TMDL is written to solve the TMDL equation for a numeric target of 40 µg/L of total phosphorus in Lakes Caroline and Augusta and a target of 60 µg/L total phosphorus in Albion, Henshaw and Swartout Lakes.

7.1.1 Allocation Approach

There are no known wasteloads in the watersheds tributary to the listed lakes. The permitted WWTPs in the Clearwater River Watershed District listed in Table 7.1 all operate as spray irrigation systems. As such there are no permitted wastewater treatment plant effluent discharges in this portion of the Clearwater River Watershed District. It is unlikely that these WWTPs are a phosphorus source to the impaired waters and therefore they have been included in the TMDL equation with a wasteload allocation of 0. If in the future it is determined that these discharges are a phosphorus source, then this discharger will be assigned a wasteload allocation.

Table 7.1 WWTPs in the Clearwater River Watershed District Tributary to Listed Waters Addressed in this Report.

Permit Holder/ System	Waste Water Treatment Method
City of Fairhaven	ISTS (Potential future)
City of Kimball	Land Application (SDS Permit)
City of Watkins	Land Application (SDS Permit)
City of South Haven	Land Application (SDS Permit)
CRWD- Regional	Master System (Potential)
CRWD- Rest-a-While Shores	Cluster System *
CRWD- Wandering Ponds	Cluster System *
CRWD- Lake Louisa Hills	Pending Cluster System *

The Load allocation must be divided among existing sources, save those that are not permitted under state law. Discharge from septic systems, for example, is not allowed by law and therefore the load allocation for septic systems is zero. Relative proportions allocated to each source are based on reductions that can reasonably be achieved through best management practices as discussed in the implementation section of the report.

7.1.2 Critical Conditions

The critical period for lakes is the summer growing season. Minnesota lakes typically demonstrate the impacts of excessive nutrients during the summer recreation season (June 1 to September 30) including excessive algal blooms and fish kills. Lake goals have focused on summer-mean total phosphorus, Secchi transparency and chlorophyll-a concentrations. These parameters have been linked to user perception (Heiskary and Wilson 2005). Consequently, the lake response models have focused on the summer growing season as the critical condition.

7.1.3 Allocations

The loading capacity is the total maximum daily load. The daily load and wasteload allocations for the average conditions for each lake are shown in Table 7.2

Table 7.2 Total Phosphorus TMDL Allocations Expressed as Daily Loads (1)

Lake	Total Phosphorus TMDL (lbs/day)	Waste Load Allocation (lbs/day)	Load Allocation (lbs/day)	Margin of Safety
Lake Caroline	10.14	0.10	10.04	Implicit
Lake Augusta	11.36	0.11	11.25	Implicit
Albion Lake	0.98	0.01	0.97	Implicit
Henshaw Lake	0.73	0.01	0.72	Implicit
Swartout Lake	2.22	0.02	2.20	Implicit

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(1) : Waste load allocations are limited to stormwater from new construction in the watershed.

Load allocations by source for each lake are provided in Table 7.3. No reduction in atmospheric loading is targeted because this source is impossible to control on a local basis. The remaining load reductions were applied based on our understanding of the lakes and efficacy of proposed implementation strategies, as well as the model fit.

Table 7.3 Total Phosphorus Partitioned Load Allocation Expressed as Daily Load

Lake	Load Allocation (lbs/day)	Direct Watershed	Upstream Lakes	Septic Systems	Atmospheric + Groundwater	Internal
Lake Caroline	10.04	0.59	6.41	0.00	2.23	0.82
Lake Augusta	11.25	0.76	6.65	0.00	1.93	1.91
Albion Lake	0.97	0.34	0.00	0.00	0.16	0.47
Henshaw Lake	0.72	0.08	0.00	0.00	0.18	0.46
Swartout Lake	2.20	0.82	0.33	0.00	0.19	0.86

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Annual total maximum loads are provided in Tables 7.4 and 7.5. The values in Tables 7.2 and 7.3 are calculated from annual loads dividing by 365.25 days per year (to account for leap year). The loading capacity provided in Tables 7.4 and 7.5 are based on average model predicted results for the years in which lake water quality data was available during the recent seven-year period, which represents both wet and dry conditions.

The TMDL is expressed by the following equation:

TMDL= LA+ WLA+ MS+ RC

The TMDL is shown in Table 7.4, the partitioning of the Load Allocation (LA) is summarized in Table 7.5.

Table 7.4 Total Phosphorus TMDL Allocations Expressed as Annual Loads[(1)]

Lake	Total Phosphorus TMDL (lbs/yr)	Waste Load Allocation (lbs/yr)	Load Allocation (lbs/yr)	Margin of Safety
Lake Caroline	3,705	37.05	3,668	Implicit
Lake Augusta	4,150	41.5	4,109	Implicit
Albion Lake	359	3.59	355	Implicit
Henshaw Lake	265	2.65	262	Implicit
Swartout Lake	812	8.12	804	Implicit

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(1) : Waste load allocations are limited to stormwater from new construction in the watershed.

Table 7.5 Total Phosphorus Partitioned Load Allocation Expressed as Annual Load

Lake	Load Allocation (lbs/yr)	Direct Watershed	Upstream Lakes	Septic Systems	Atmospheric + Groundwater	Internal
Lake Caroline	3,668	214	2,342	0	814	298
Lake Augusta	4,109	279	2,429	0	704	697
Albion Lake	355	125	0	0	59	171
Henshaw Lake	262	30.1	0	0	64.8	167.5
Swartout Lake	804	300	120	0	70.5	314

T:\0002\127\models and data\Goal LRM (Marie-Caroline-Augusta).xls – TMDL Tables

7.2 RATIONALE FOR LOAD AND WASTELOAD ALLOCATIONS

The TMDL presented here is developed to be protective of the aquatic recreation beneficial uses in lakes.

7.2.1 Modeled Historic Loads

Using the Canfield-Bachmann equation, historic loads and load reductions were calculated for each of the five impaired lakes. These calculations provide some insight into the assimilative capacity of the lakes under historical conditions as well as over time. Additionally, these results provide a sense for the level of effort necessary to achieve the TMDL and whether that TMDL will be protective of the water quality standard.

7.2.2 Waste Load Allocations

There are no permitted point WWTP discharges within the subwatersheds of the five listed lakes that would be considered waste loads within the framework of the TMDL. However, there is a small amount of land use changes occurring within the District, including the construction of new residential developments on land that was previously in agricultural use. Developments over one acre in size will be required to obtain an NPDES construction permit. These permits regulate erosion control and require that best management practices be employed at a construction site. To account for waste loads associated with NPDES construction permits, an allocation of one percent of the total TMDL load is included. Construction storm water activities are considered in compliance with provisions of the TMDL if they obtain a Construction General Permit under the NPDES program and properly select, install and maintain all BMPs required under the permit, including any applicable additional BMPs required in Appendix A of the Construction General Permit for discharges to impaired waters, or meet local construction stormwater requirements if they are more restrictive than requirements of the State General Permit.

7.3 SEASONAL AND ANNUAL VARIATION

The daily load reduction targets in this TMDL are calculated from the current phosphorus budget for each lake. The budget is an average of several years of monitoring data, 2001-2007, and includes both wet years and dry years to account for annual variation.

The BMPs to address excess loads to the lakes will be designed for average conditions; however, the performance will be protective of all conditions. For example, a stormwater pond designed for average conditions may not perform at design standards for wet years; however, the assimilative capacity of the lake increases in wet years due to increased flushing. Programmatic BMP targets such as areal coverage for buffer strips are finite and can be increased to be protective in all conditions. However, the implementation of this BMP is largely based on willing participation from land owners and will be recommended to the maximum possible extent in any case. Additionally, in dry years the watershed load will be naturally lower, allowing internal loading to compose a larger portion of the overall phosphorus budget. Consequently, averaging across several modeled years addresses annual variability in lake loading.

Seasonal variation is accounted for through the use of annual loads and developing targets for the summer period, when the frequency and severity of nuisance algal growth will be the greatest. Although the critical period is the summer, lakes are not sensitive to short-term changes in water quality; rather, lakes respond to long-term changes such as changes in the annual load. Therefore, the seasonal variation is accounted for in annual loads. Additionally, by setting the TMDL to meet targets established for the most critical period (summer), the TMDL will inherently be protective of water quality during all other seasons.

7.4 MARGIN OF SAFETY

A Margin of Safety has been incorporated into this TMDL by use of conservative modeling approaches to account for an inherently imperfect understanding of the lake system and to ultimately ensure that the nutrient reduction strategy is protective of the water quality standard.

The Canfield Bachman model was used to predict the response of the lakes described herein to phosphorus loads and load reductions. The Canfield-Bachmann model was developed using data collected from 704 natural lakes to best describe the lake phosphorus sedimentation rate which is needed to predict the relationship between in-lake phosphorus concentrations and phosphorus load inputs. The phosphorus sedimentation rate is an estimate of net phosphorus loss from the water column through sedimentation to the lake bottom. The phosphorus sedimentation rate is used in concert with lake-specific characteristics such as annual phosphorus loading, mean depth, and hydraulic flushing rate to predict in-lake concentrations of phosphorus as they relate to phosphorus loading. These model predictions are compared to measured data to evaluate how well the model describes the lake system.

To apply the Canfield-Bachmann model to these lakes watershed specific data were used: measured watershed runoff volumes, concentrations and overall loads were used instead of modeled watershed hydrology and phosphorus load export. Further, no calibration factors were used, only the sediment phosphorus release rates were adjusted within ranges of published values for specific lake types (i.e. eutrophic lakes, Nurnberg 2004).

The models fit reasonably well compared to annual average lake water quality data. Four to six years of data were compared for each lake, and differences between observed and model-predicted average in-lake concentrations were generally within the reported standard deviations for annual average TP for a given year. Given the short residence times of these lakes, on the order of days during spring and early summer high flow, and the shallow nature of the lakes, the models represent a reasonable fit to the available data (Appendix B). The models typically tended towards a slight over-prediction of in-lake TP (an under-prediction in sedimentation rates), which translates into a conservative load reduction in terms of setting the TMDL. That is to say, the model over-prediction resulted in calculation of a conservative (larger) load reduction.
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7.5 RESERVE CAPACITY/ FUTURE GROWTH

Comprehensive plans for the portions of Stearns, Wright and Meeker Counties within Clearwater River Watershed District show that highest projected growth rates will center in existing urban areas, along lake shores and along highway corridors. Significant development is not anticipated, but many of the areas in which growth is projected are tributary to impaired waters in the CRWD and to the lakes addressed in this study specifically.

Load reduction targets to meet water quality goals are already aggressive, and so reserve capacity is not available given the current phosphorus budgets and required load reductions. As a result, planned developments must be undertaken to avoid increasing phosphorus loads to lakes over existing conditions, and to decrease phosphorus loads where possible. The phosphorus load reductions required to meet water quality goals make stormwater BMPs and low impact development in these growth areas necessary. They will be the most cost effective methods to limit watershed phosphorus loads. Further, there are no planned WWTP expansions in the area at this time, and it is unlikely given current MPCA policy and citizen sentiment that any WWTP would be permitted for an expansion of that expansion meant discharges to area lakes. The 1981 Chain of Lakes Restoration Project was specifically designed to eliminate WWTP discharges from area lakes.

This means that reserve capacity for growth is essentially zero with respect to phosphorus, in that nutrient export will need to decline with development instead of increasing. This does not mean no growth, it simply means growth must be accomplished without increasing phosphorus loads to impaired waters. We have the design tools to accomplish this; what is needed is the regulatory framework and intergovernmental coordination in terms of development review and design standards. Recommendations to that end are incorporated in the implementation plan.

This is in line with, and no more stringent than, existing state statutes prohibiting the degradation of Minnesota waters.

8.0 Public Participation

The CRWD sees public participation as critical to the process of implementing the TMDL to meet water quality standards. The public participation efforts for this TMDL study are summarized below. The work described below is collective for all the ongoing TMDL studies in the CRWD, including those previously completed on upstream water bodies.

8.1 STAKEHOLDER MEETINGS

Since the beginning of the TMDL process in 2003, District Administrator Merle Anderson has actively sought engagement from and communication with city, county, township and lake association officials and individuals alike. His efforts took the form of attendance at the regular meetings of these groups, calls to group leaders, organization of special meetings of these groups for the purpose of making presentations, and preparation of materials for distribution.

Administrator Anderson updated the members of these groups on the status of the TMDL and provided information on the cause of the impairments and on their roles in the conceptual implementation plan. The goal of these efforts was to leverage existing regulatory framework and relationships to generate support for TMDL implementation efforts. Using existing governmental programs and services for TMDL implementation should provide a significant cost savings and efficiency.

This work on the part of Administrator Anderson is part of the ongoing tradition of the CRWD to work with other government agencies and provide them with the support they need to protect water resources. Specific examples of this work in the recent past are listed:

- CRWD funded municipal stormwater studies for the Cities of Annandale, Kimball and Watkins, wherein several opportunities for stormwater improvements were identified.
- CRWD funded design of a road pavement project in Maine Prairie Township to ensure protection of the nearby School Section Lake.
- CRWD provides development review and comment for major cities and counties.
- CRWD offers additional incentives for riparian buffers, rain gardens and CRP on top of what is offered by other government agencies.

8.2 PUBLIC MEETINGS

Several public meetings have been held to date. At each stakeholder meeting, the District Administrator and project consultant updated the stakeholders on the status of the TMDL and provided information on the cause of the impairment and on conceptual implementation plans.

The initial 303d impairments addressed in the CRWD include the Clearwater River between Clear Lake and Lake Betsy for DO and bacteria and Lake Louisa for nutrients. Later, Clear Lake, Lake Betsy, Scott Lake, Union Lake, and Lake Marie were added. These water bodies are all upstream of Lakes Augusta and Caroline and compose the majority of the loads to these lakes. Since improvement of these waters facilitates improvement of downstream lakes, including Augusta and Caroline, stakeholder groups for Lake Augusta and Lake Caroline have been active and involved in the TMDL process for the previous TMDL study on upstream waters. Therefore, all stakeholder meetings for these upper water bodies are listed here in addition to newer work for downstream waters, and work for Swartout Lake, Albion Lake and Lake Henshaw completed previously.

December 17, 2002 in Annandale
Watershed District Managers, the District Administrator, the MPCA Project Manager, and the Wenck Project Manager presented information about the TMDL process and the Clearwater River and Lake Louisa TMDL Project specifically. A question-and-answer session followed the presentation. County Soil and Water Conservation District Representatives from Wright, Meeker and Stearns Counties were invited, along with representatives from the Cities of Kimball and Watkins. Citizen advisory group members were also invited. Wright and Meeker County representatives attended.

February 18, 2003 in Annandale
The Wenck Project Manager presented information about the TMDL process and the Clearwater River and Lake Louisa TMDL Project specifically. An analysis of existing data was presented. A question-and-answer session followed the presentation. County Soil and Water Conservation District Representatives from Wright, Meeker and Stearns Counties were invited, along with representatives from the Cities of Kimball and Watkins. Citizen advisory group members and lake associations were also invited. A Meeker County representative attended along with members of the Citizen Advisory Group and Clearwater Lake Association.

March 16, 2004 in Watkins
An additional meeting was held to solicit further stakeholder involvement. The Wenck Project Manager presented information about the TMDL process and the Clearwater River and Lake Louisa TMDL Project specifically. An analysis of existing data was presented. A question-and-answer session followed the presentation.

Meeting invitations and a letter describing the TMDL Project were sent to residents' homes. County Soil and Water Conservation District Representatives from Wright, Meeker and Stearns Counties, as well as representatives from the Cities of Kimball and Watkins, were invited. Citizen advisory group members and lake associations were invited. The goal of the meeting was to establish a representative stakeholder group. These representative stakeholders met two more times.

July 15, 2007 Clearwater Chain of Lakes Association, Lake Louisa Working Group
District Administrator Merle Anderson met with members of the Clearwater Chain of Lakes Association (CCOLA) to spark interest in a Lake Louisa working group. This group of citizens heard a summary of the TMDL process and progress and agreed to discuss the Lake Louisa TMDL with residents to encourage interest and participation.

August 6, 2007, Clearwater Chain of Lakes Association, Lake Louisa Working Group
District Administrator Merle Anderson and Project Engineer Rebecca Kluckhohn met with 16 members of the Clearwater Chain of Lakes Association (CCOLA). This group is composed of Lake Louisa and Lake Marie residents concerned with upstream water quality. Each resident expressed concern about the perceived deterioration of water quality in the entire Chain of Lakes. Most residents had moved to the area since the major improvements in water quality in the 1980s as the result of the Clearwater Chain of Lakes Improvement Project. Residents speculated that many septic systems around the lakes needed replacement, but that costs would be prohibitive for several residents. Residents also expressed concerns about livestock allowed to graze in and near the lakes and the Clearwater River.

August 10, 2007, Clear Lake Citizenship Dinner
The CRWD's 6th Annual Citizenship Dinner was held at the Sportsman's Center at Clear Lake. Residents in the area of Clear Lake, the upstream boundary of the listed reach of the Clearwater River addressed in this report were the main meeting attendees. District Administrator Anderson and District Engineer Norm Wenck listened to residents and answered questions about water quality in Clear Lake.

October 3, 2007, Meeting with the Chain of Lakes Association
This meeting with the Chain of Lakes Association was held to go over the Phase II TMDL Report and answer questions. The CRWD Engineer and Administrator provided discussion topics for their next meeting.

April 16, 2008, Public Meeting
A public meeting to present the findings of the TMDL studies was held April 16, 2008 at Annandale Middle School. Representatives from all areas impacted by the TMDLs attended, including a representative of residents of Lake Betsy, Union Lake and Scott Lake; two members of the Clear Lake Association; and members of the Chain of Lakes Association representing Lakes Louisa and Marie. The CRWD District Administrator, project consultant, MPCA project manager and communication coordinator were also present to answer questions about the TMDL process and outcome.

August 2, 2008, CRWD Summer Tour
CRWD hosted a tour for 81 watershed residents to view watershed projects including rain gardens, buffers, sedimentation basins and fish migration barriers. Implementation of TMDLs was discussed.

February 25, 2009, CRWD Board Work Session I on Implementation
The CRWD's monthly work session for February was used to compile stakeholder input and discuss load reduction scenarios for TMDLs and rank implementation strategies.

March 25, 2009, CRWD Board Work Session II on Implementation
The CRWD's monthly work session for March was used to continue the process of compiling stakeholder input and discussing load reduction scenarios for TMDLs and ranking implementation strategies.

Swartout Lake, Albion Lake, and Henshaw Lake, CRWD Project 06.01
In 2003, concerned citizens petitioned the CRWD to conduct a project to improve water quality in Cedar Lake. The outcome of that study called for load reductions in the three shallow upstream lakes—Swartout Lake, Albion Lake, and Henshaw Lake. Stakeholder meetings for these groups were held to inform stakeholders, gather input and evaluate load reduction scenarios in the context of this project. A public hearing to implement the project was also held, resulting in a subset of load reductions for these three impaired lakes. More recent stakeholder involvement with citizens of Cedar Lake (downstream of Swartout Lake, Albion Lake, and Henshaw Lake) and of the lake shore residents of Swartout Lake, Albion Lake, and Henshaw Lake have been limited to one-on-one communication between Administrator Anderson and residents and have yielded implementation of watershed BMPs to reduce P loads to the lakes and internal loading within the lakes. Some initiatives, such as shallow lakes management plans for each lake, have met with intense resistance of watershed residents.

9.0 Implementation

9.1 IMPLEMENTATION FRAMEWORK

Implementing TMDLs within the CRWD will be a collaborative effort between state and local government, and individuals led by the CRWD. To meet water quality standards, CRWD will leverage existing regulatory framework, and relationships to generate support for TMDL implementation efforts, providing technical support, funding, coordination and facilitation when needed. Efficiency and cost savings are realized by using existing governmental programs and services for TMDL implementation to the maximum extent possible.

9.1.1 Clearwater River Watershed District

The mission of the Clearwater River Watershed District is to promote, preserve and protect water resources within the boundaries of the District in order to maintain property values and quality of life as authorized by MS103D. To this end, the District's Comprehensive Plan approved July 23, 2003, documents the District's goals, existing policies and proposed actions. One of the District's stated goals is to bring all of CRWD surface water into compliance with state water quality standards through the TMDL process.

Because the primary goal and mission of the CRWD is in line with the goal of TMDL implementation, many of the implementation strategies are extensions of existing CRWD programs and projects and can be funded using existing CRWD budgets. However, funding will be necessary. The recommended implementation plan to meet lake water quality goals and associated cost is described in the following section.

9.1.2 Counties, Cities, Townships, Lake Associations

Partnerships with counties, cities, townships and lake associations are one mechanism through which the CRWD protects and improves water quality. The CRWD will continue its strong tradition of partnering with state and local government to protect and improve water resources and to bring waters within the CRWD into compliance with State standards.

9.1.3 Board of Water and Soil Resources

The CRWD recognizes that public funding to set and implement TMDLs is limited, and therefore understands that leveraging matching funds as well as utilizing existing programs will be the most cost efficient and effective way to implement TMDLs within the CRWD. The CRWD does project a potential need for about 50% cost-share support from the Board of Water and Soil Resources, MPCA or other sources in the implementation phase of the TMDL process.

9.2 REDUCTION STRATEGIES

9.2.1 Annual Load Reductions

The focus in implementation will be on reducing the annual phosphorus loads to the lake through structural and non-structural Best Management Practices. The TMDL established for each lake is shown in Section 7 of this report (Table 7.2, and allocated among sources in Table 7.3). Table 9.1 shows load reductions by source for each lake.

Table 9.1 Load Reductions by Source

Lake	Total	Direct Watershed	Upstream Lakes	Septic Systems	Atmospheric + Groundwater	Internal
Lake Caroline	35%	31%	43%	100%	0%	26%
Lake Augusta	27%	31%	33%	100%	0%	21%
Albion Lake	91%	63%	NA	100%	0%	95%
Henshaw Lake	93%	88%	NA	100%	0%	95%
Swartout Lake	90%	70%	77%	100%	0%	95%

No reductions in atmospheric or groundwater loading are targeted because these sources are not readily controllable. The remaining load reductions were applied based on our understanding of the lakes and surrounding watersheds as well as output from the model.

9.2.2 Actions

A conceptual implementation plan for reducing phosphorus loads to the six impaired lakes is presented below (Table 9.2). Strategies are recommended based on their relative cost and effectiveness given the current level of understanding of the sources and in-lake processes. Recommendations take into account findings from stakeholder participation. Cost share breakdown is expected to be 50% from the state and federal funds, 25% from the individual, and 25% from watershed budgets.

The implementation plan pulls from existing CRWD studies and project proposals to reduce watershed phosphorus loads.

Table 9.2 Conceptual Implementation Plan and Costs

Practice	TMDL	Unit Cost	Units	Note	Qty	Cost
Promote Ag BMPs (P Testing and fertilizer application)	Nutrient, DO	$50,000	ls		1	$75,000
Replace Tile Intakes w/ Filters	Nutrient, DO, Bacteria	$500	per intake	*evaluate limestone/steel wool filter intakes to increase P removal	400	$200,000
Tile Intake Buffers	Nutrient, DO, Bacteria	$100	per intake		300	$30,000
Buffer Tributaries	Nutrient, DO, Bacteria	$350	ac		300	$105,000
Buffer Stream Banks	Nutrient, DO, Bacteria	$350	ac		200	$70,000
DO Augmentation for Clearwater River	DO		lf	*design and construct, operation		$500,000
Tile Discharge Management	Nutrient, DO, Bacteria	$130,000	ls	* Inventory, FS, design construct	1	$130,000
Riparian Pasture/ Grazing Management Grants	Nutrient, DO, Bacteria	$10,000	ea	*keep livestock out of stream	10	$100,000
Street Sweeping: Kimball, Southaven, Fairhaven & Watkins	Nutrient, DO, Bacteria	$40	per curb mile	* high efficiency, 55 curb miles for 15 years		1,125,000
Lakeshore Septic Upgrade Grants	Nutrient	$7,500	ea	All Impaired Lakes	130	$975,000
Lake shore restoration grants (Shore land Erosion)	Nutrient	$300	ea	*grants	300	$90,000
Shallow Lakes Management Plans for Marie, Clear, Swartout, Albion & Henshaw Lakes	Nutrient	$15,000	ea		5	$75,000
Carp Control	Nutrient	$25,000	average per year per lake	*Fish trap already installed at Louisa, harvesting under way in several impaired lakes (5 lakes, 6 yrs)	30	$750,000
Curly Leaf Pondweed Control	Nutrient			*Lake association cost, some cost share		$100,000
Lake Aeration	Nutrient			2 Existing aerators re-installed		$600,000
Alum dosing of Cleawater River upstream of Kingston	Nutrient, DO					$600,000
Hypolimnetic withdrawl (Betsy)	Nutrient					$350,000
Kingston Wetland Maintenance / Enhancement	Nutrient, DO					$250,000
South Haven Stormwater Enhancement	Nutrient, DO, Bacteria					$75,000
City of Kimball Stormwater Enhancement Per 2004 Kimball Area Stormwater Management Study	Nutrient, DO, Bacteria					$500,000
City of Watkins Stormwater Enhancement per 2006 Watkins Area Stormwater Management Study	Nutrient, DO, Bacteria					$800,000
Public Outreach	Nutrient, DO, Bacteria	$10,000	per year		10	$100,000
Implementation Project Management and Administration	Nutrient, DO, Bacteria	$30,000	per year		10	$300,000
Implementation Performance Monitoring, Recommendations for Adaptive Management	Nutrient, DO, Bacteria	$25,000	per year		10	$250,000
Implementation Engineering	Nutrient, DO, Bacteria	$15,000	per year		10	$150,000
T:\0002\127\[TMDL Implementation_FINAL.xls]August 08					**TOTAL:**	**$8,300,000**

10.0 Reasonable Assurance

When establishing a TMDL, reasonable assurances must be provided by demonstrating the ability to reach and maintain water quality endpoints. Several factors control reasonable assurance, including a thorough knowledge of the ability to implement BMPs as well as the overall effectiveness of the selected BMPs. This TMDL establishes load reduction goals in the Clearwater River Watershed District to reduce nutrient loads to the impaired lakes.

TMDL implementation will be implemented on an iterative basis so that implementation course corrections based on annual monitoring and reevaluation can adjust the strategies to meet the standards.

11.0 Monitoring

The CRWD measures lake water quality annually on a rotating basis. Precipitation, stream flow, stream water quality, and nutrient and sediment loads at three long-term monitoring stations are also measured and reported annually in the District's Annual Monitoring Reports. This monitoring program, described in detail in Appendix C, will continue, and is generally sufficient to track significant water quality trends, assess progress towards goals and make adjustments towards adaptive management.

In addition to the Annual Monitoring Program, the CRWD sometimes implements special monitoring to track success of individual projects or to investigate specific water quality concerns. Supplemental monitoring of this nature is expected throughout the course of TMDL implementation. The following recommendations are made to supplement the annual monitoring plan (note that some of these items are in reference to other TMDL studies ongoing in the CRWD and that several of the recommendations have been implemented already through the District's Annual Monitoring Program. This further demonstrates the District's willingness to implement the TMDLs):

- Assess special monitoring needs annually based on implementation projects, report findings in the Annual Monitoring Report.
- Consider adding two sampling stations along the impaired reach of the Clearwater River between Clear Lake and Lake Betsy. This will require close coordination by the District sampling technician to ensure holding times are met.
- Install a continuous pressure transducer at the watershed outlet and midpoint to measure flows and annual runoff.
- Increase sampling frequency for CR 28.2 and upper watershed lakes (Betsy, Scott, Union, Louisa, Marie, Caroline & Augusta). Add 3-5 more events per year during high flows to better characterize the lake response to TP loads from the Clearwater River. Weekly stream sampling and bi-weekly lake monitoring for these lakes are recommended.
- At the start of the TMDL implementation, and every 5 years thereafter, sample all lakes in the Clearwater River Chain of Lakes in one year on a bi-weekly basis to provide a District-wide look at lake water quality. This is not imperative for large scale trend tracking, but it provides model calibration data to further evaluate the impact of upstream lakes on downstream lakes and may provide additional insight into implementation strategies.
- Increase frequency of lake DO and temperature profiles to better characterize anoxic factor. Sediment samples to quantify P release rates are recommended for Clear Lake, Scott and Betsy.

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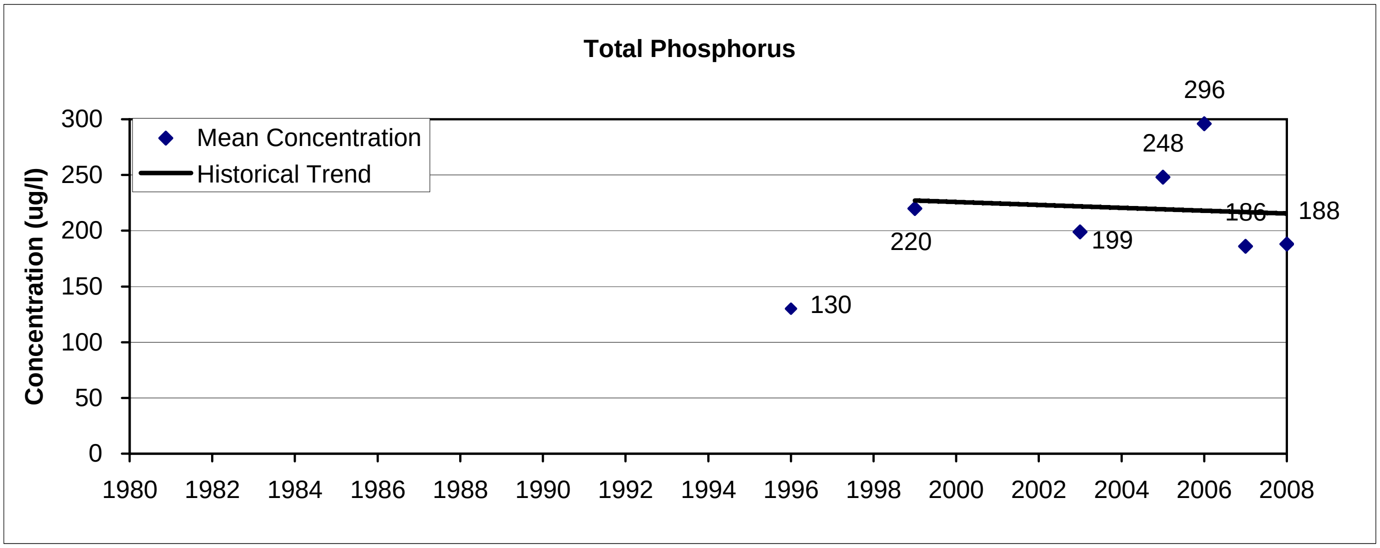
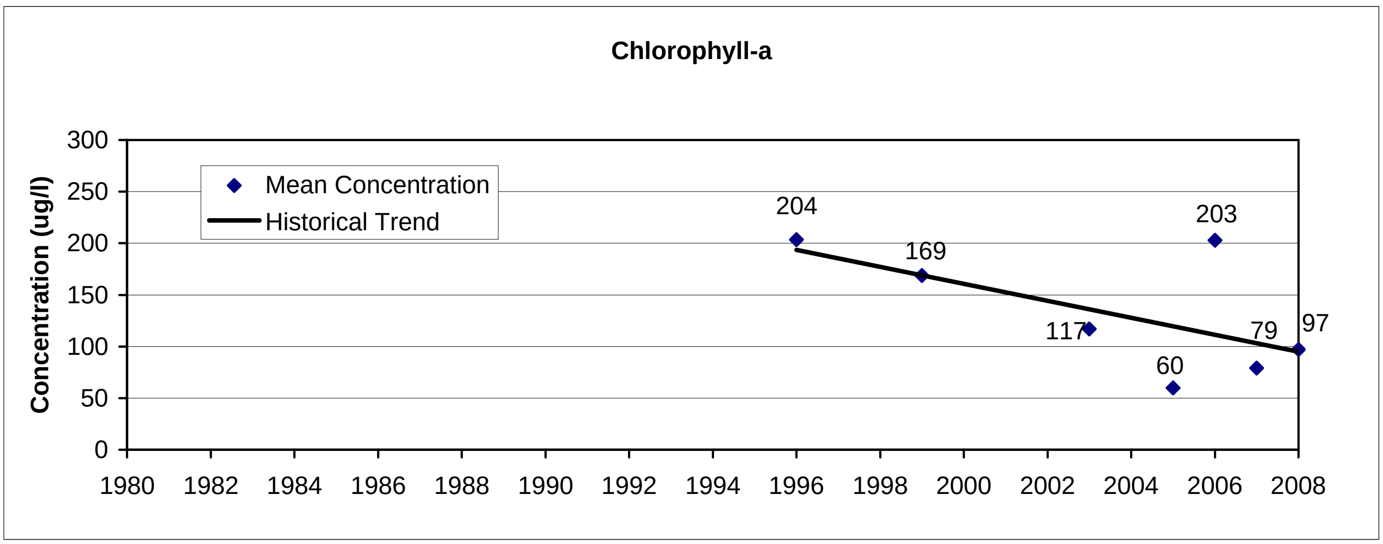
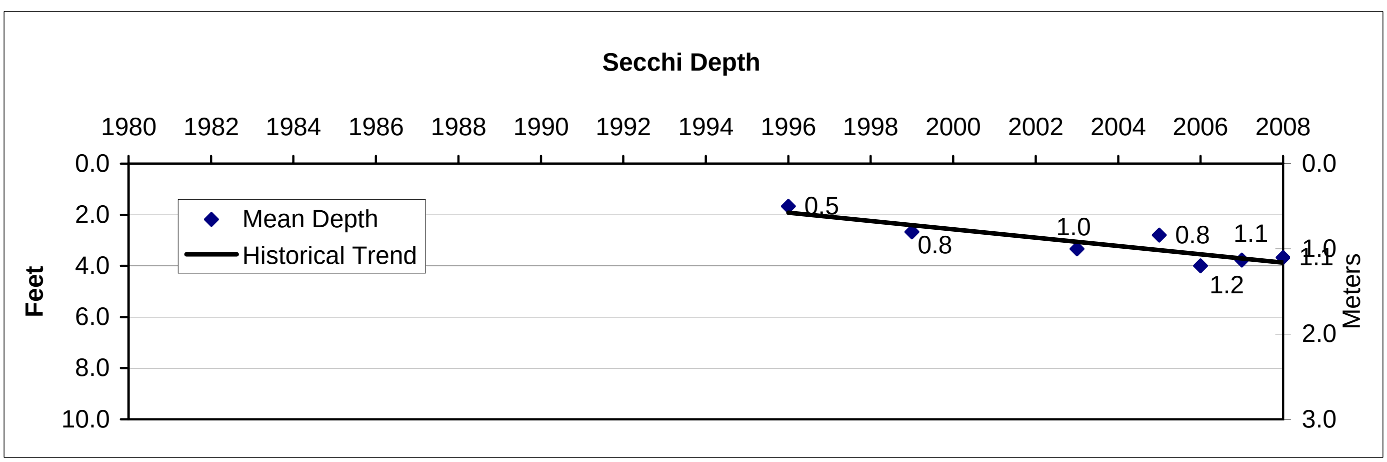
Wenck Associates, Inc. (2008) "Clearwater River Chain of Lakes Nutrient TMDL: Clear Lake, Lake Betsy, Union Lake, Scott Lake, Lake Louisa and Lake Marie" Prepared by Wenck on Behalf of the Clearwater River Watershed District for the MPCA

Appendix A

Historical Lake Water Quality Data







Clearwater River Watershed District

Lake Albion Historical Data

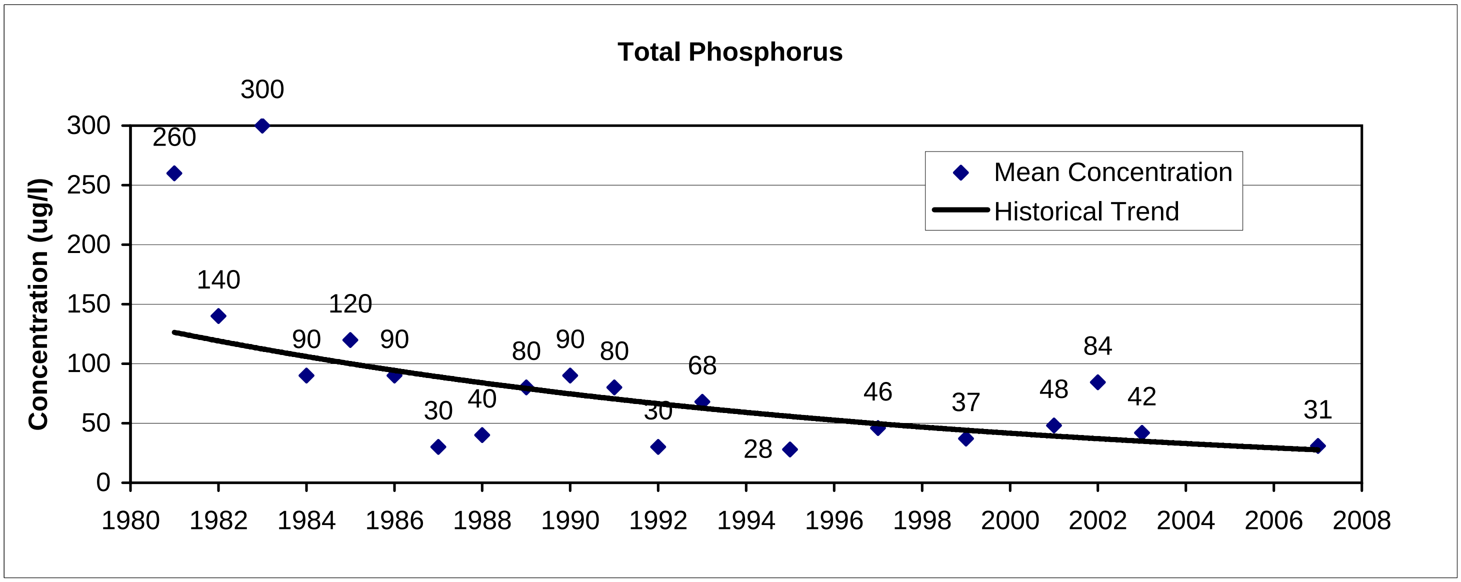
Wenck

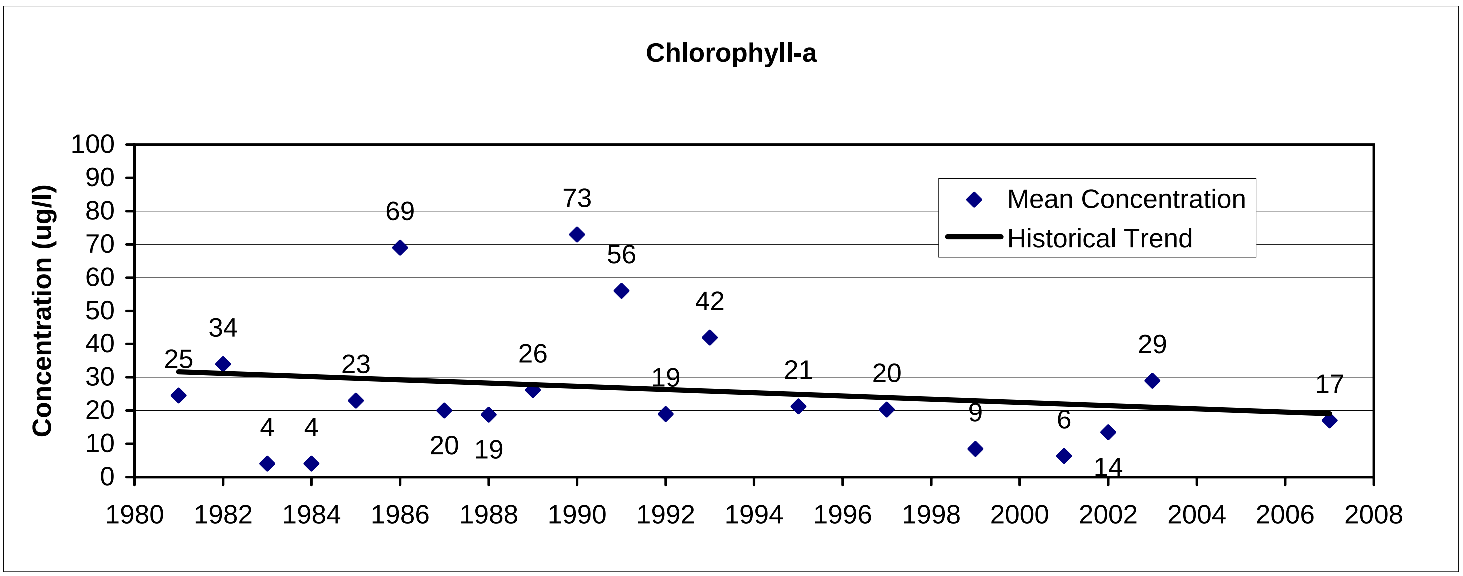
Wenck Associates, Inc.
Environmental Engineers

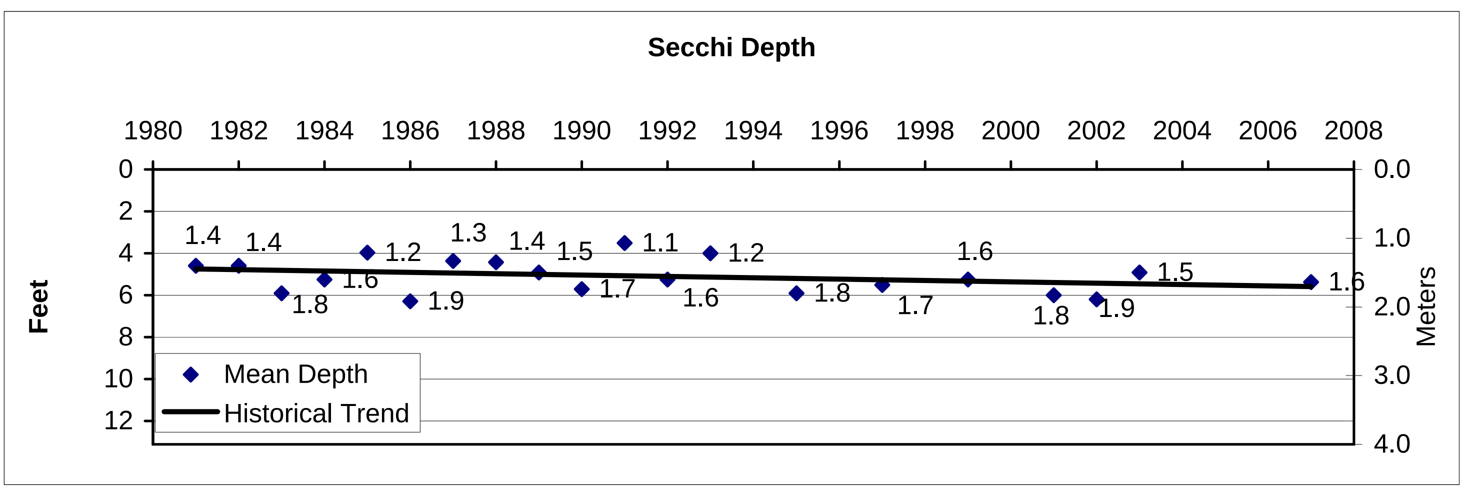
1800 Pioneer Creek Center
Maple Plain, MN 55359

Apr 2009

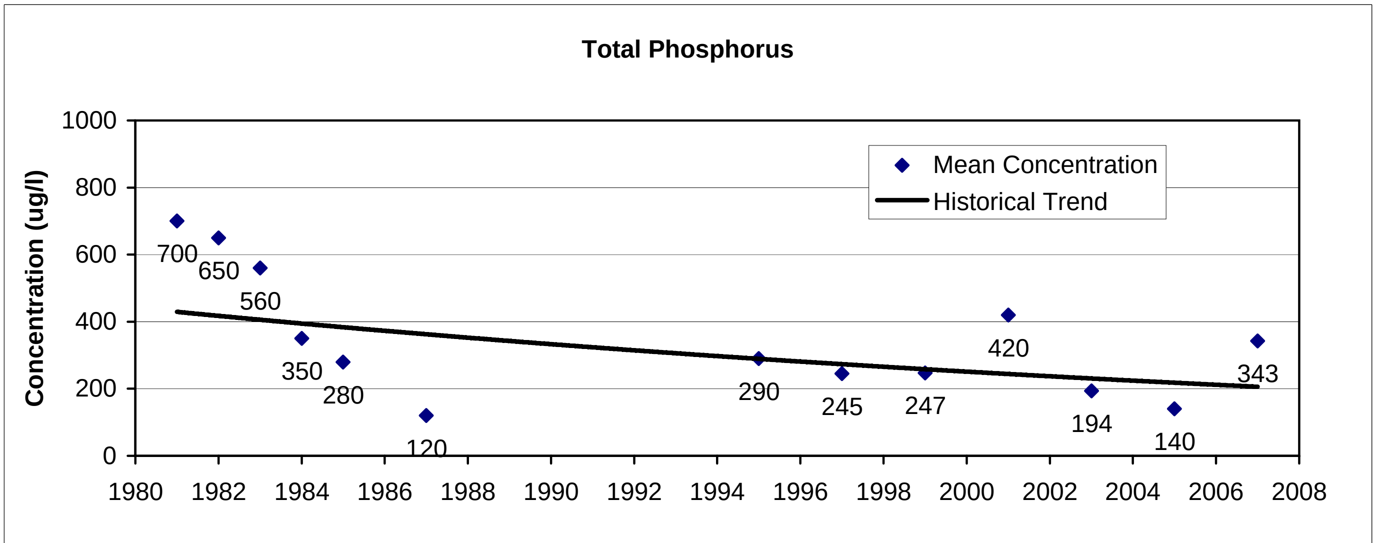
Appendix A

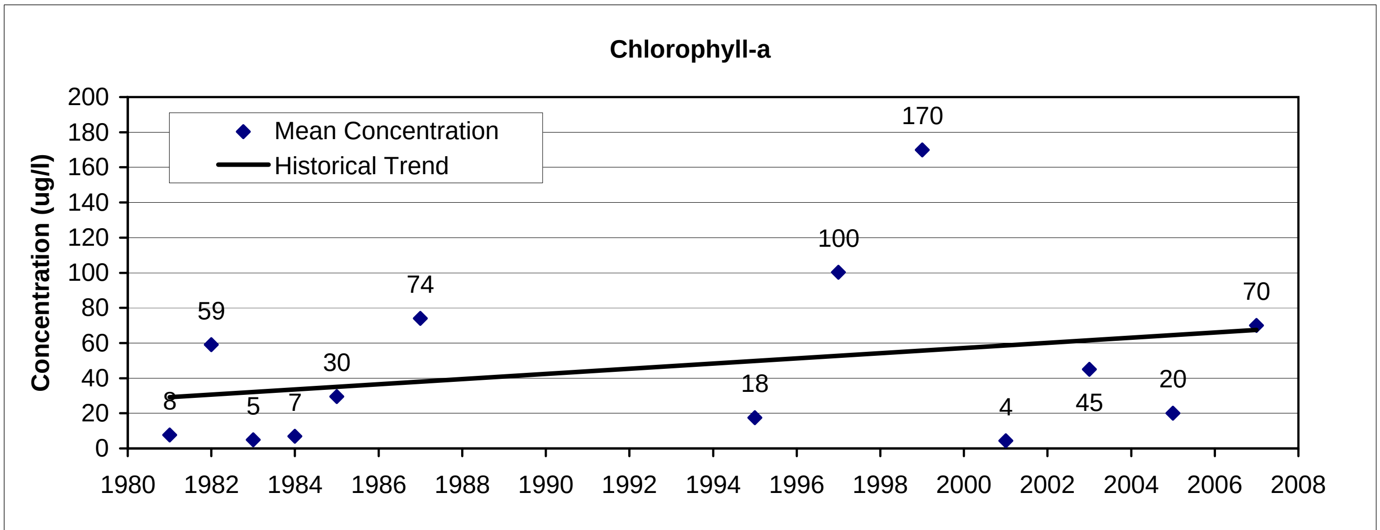


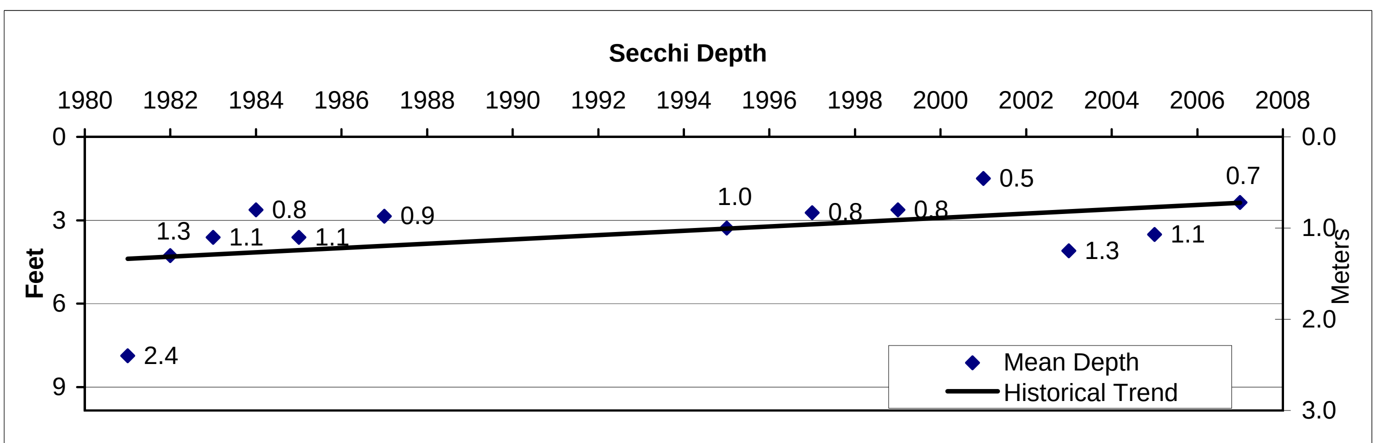




Clearwater River Watershed District	Wenck Associates, Inc. Environmental Engineers 1800 Pioneer Creek Center Maple Plain, MN 55359	Apr 2009
Lake Augusta Historical Data		Appendix A

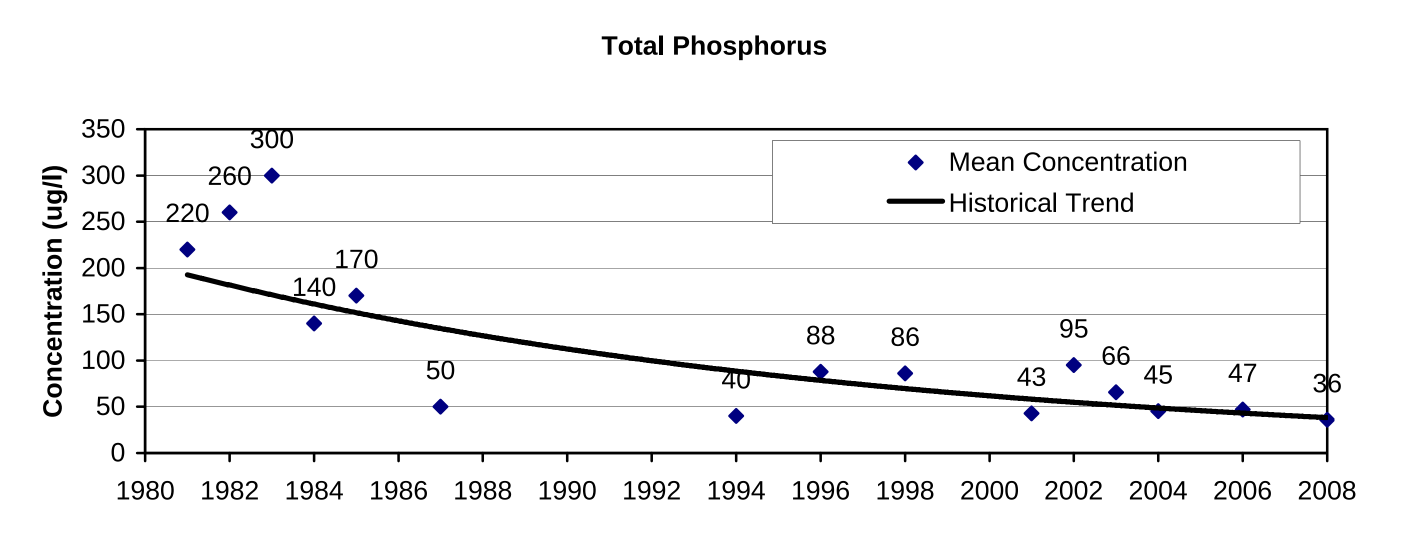


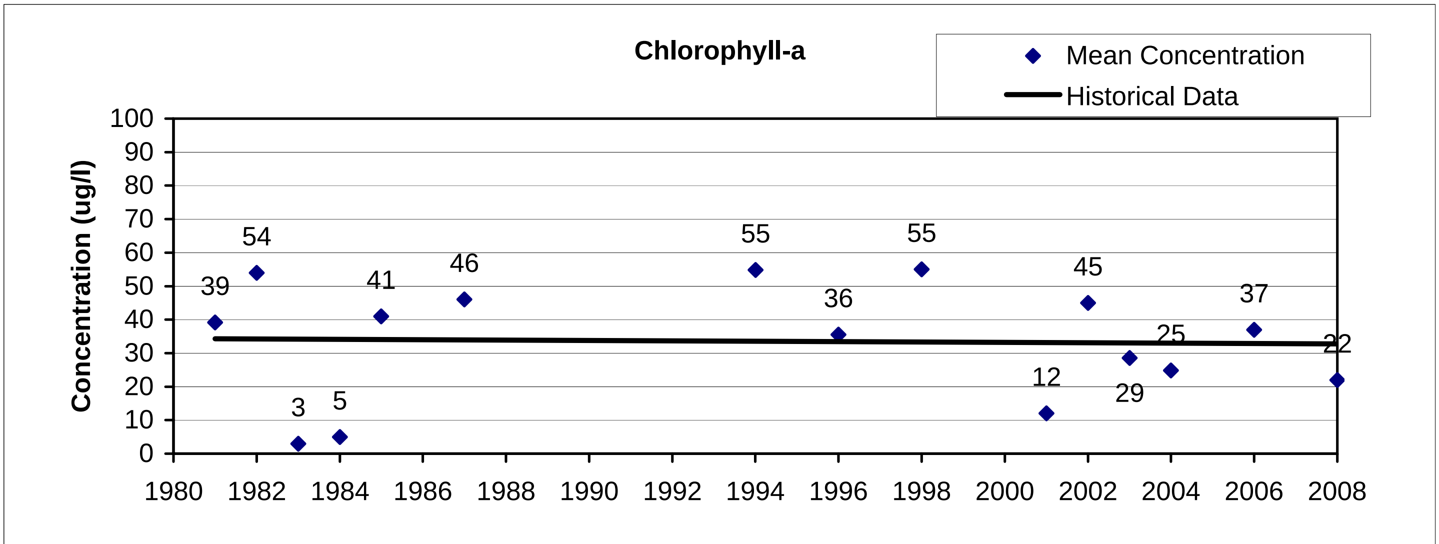


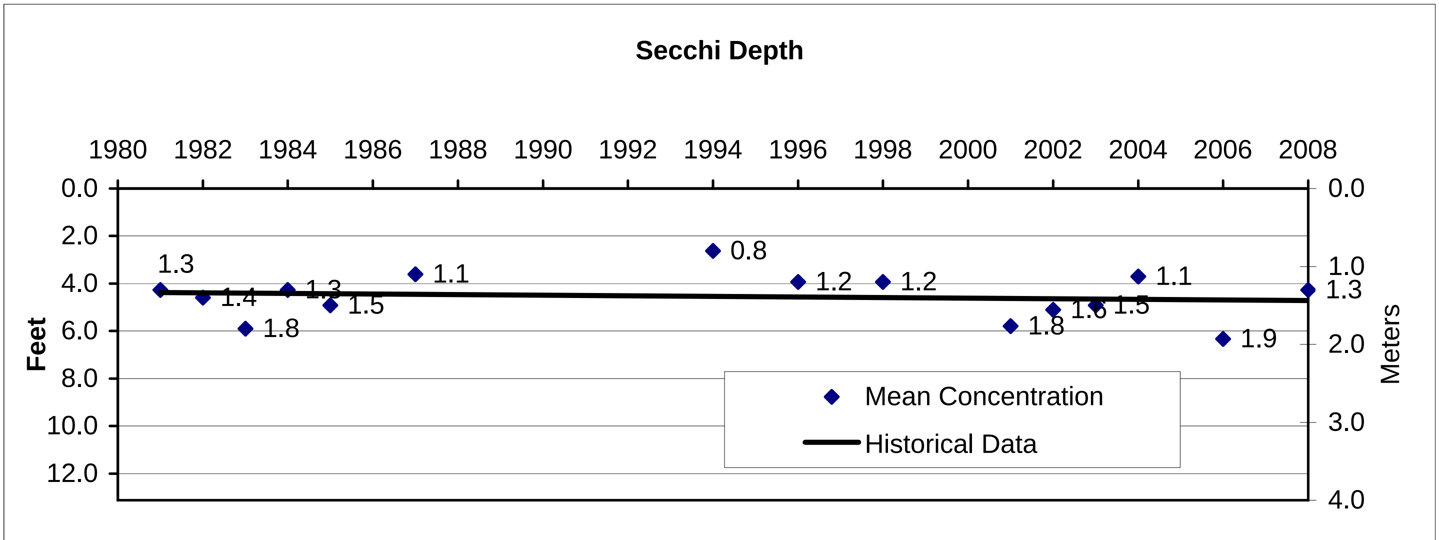


Clearwater River Watershed District	Wenck Associates, Inc. Environmental Engineers 1800 Pioneer Creek Center Maple Plain, MN 55359	Apr 2009
Lake Betsy Historical Data		Appendix A

T:\0002\115\LAKE_WQ_08Lake Betsy



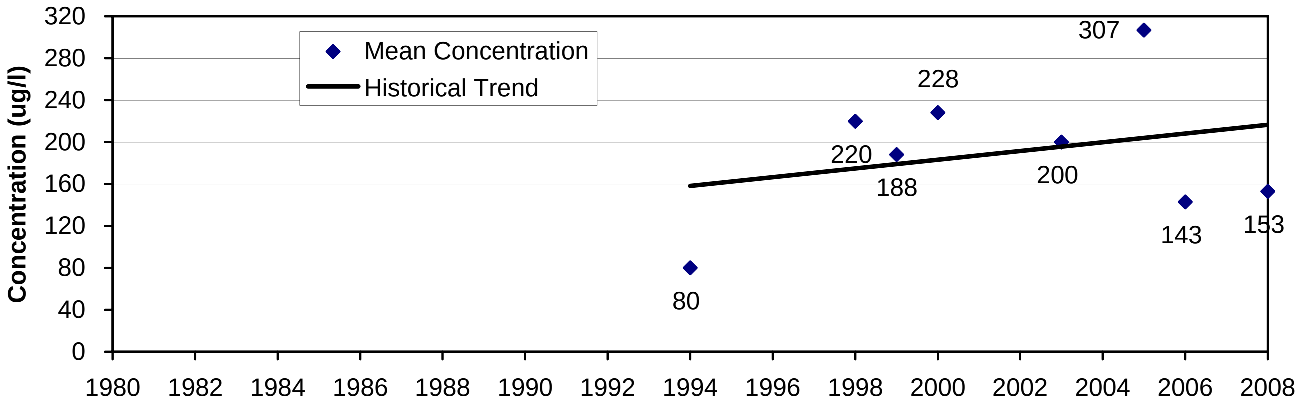




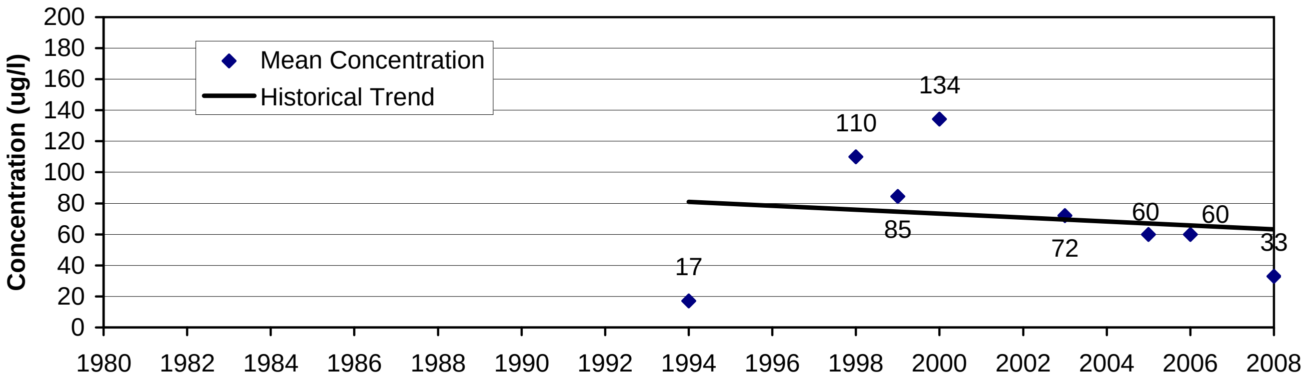
Clearwater River Watershed District	Wenck Associates, Inc. Environmental Engineers 1800 Pioneer Creek Center Maple Plain, MN 55359	Apr 2009
Lake Caroline Historical Data		Appendix A

T:\0002\115\LAKE_WQ_08Lake Caroline

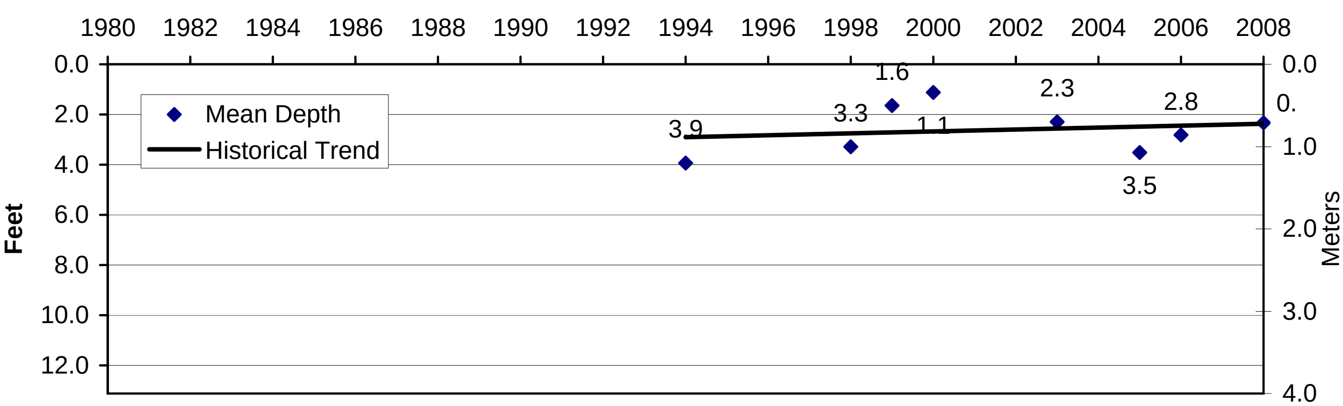
Total Phosphorus



Chlorophyll-a

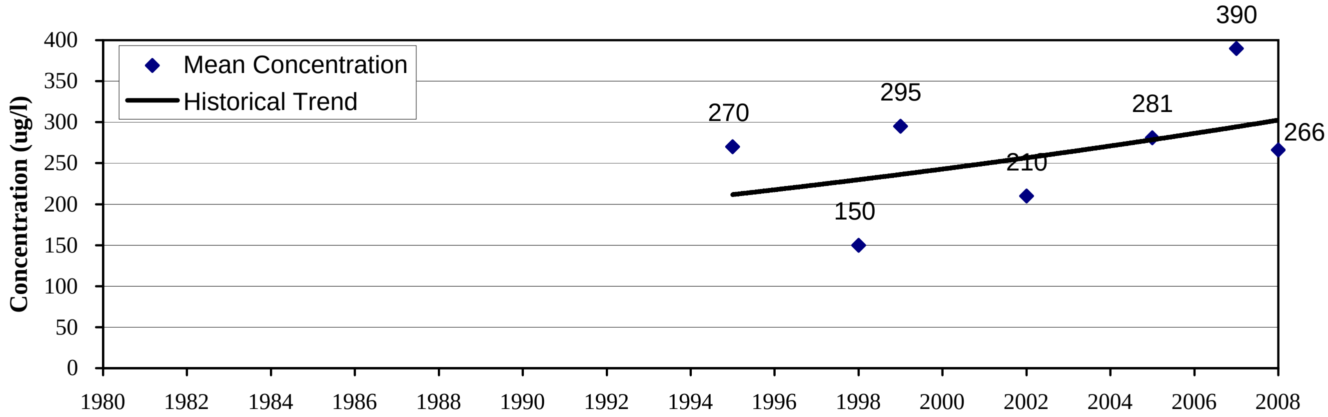


Secchi Depth

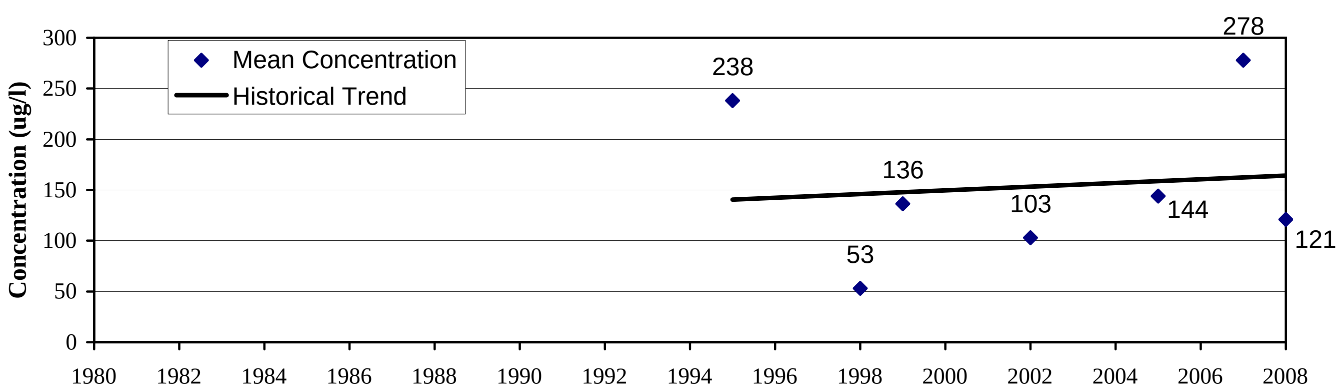


Clearwater River Watershed District	Wenck Wenck Associates, Inc. Environmental Engineers 1800 Pioneer Creek Center Maple Plain, MN 55359	Apr 2009
Clear Lake Historical Data		Appendix A

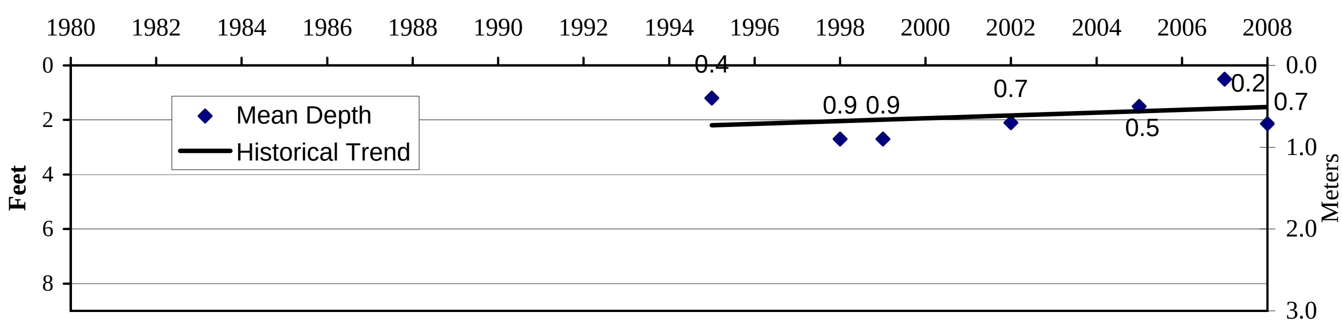
Total Phosphorus



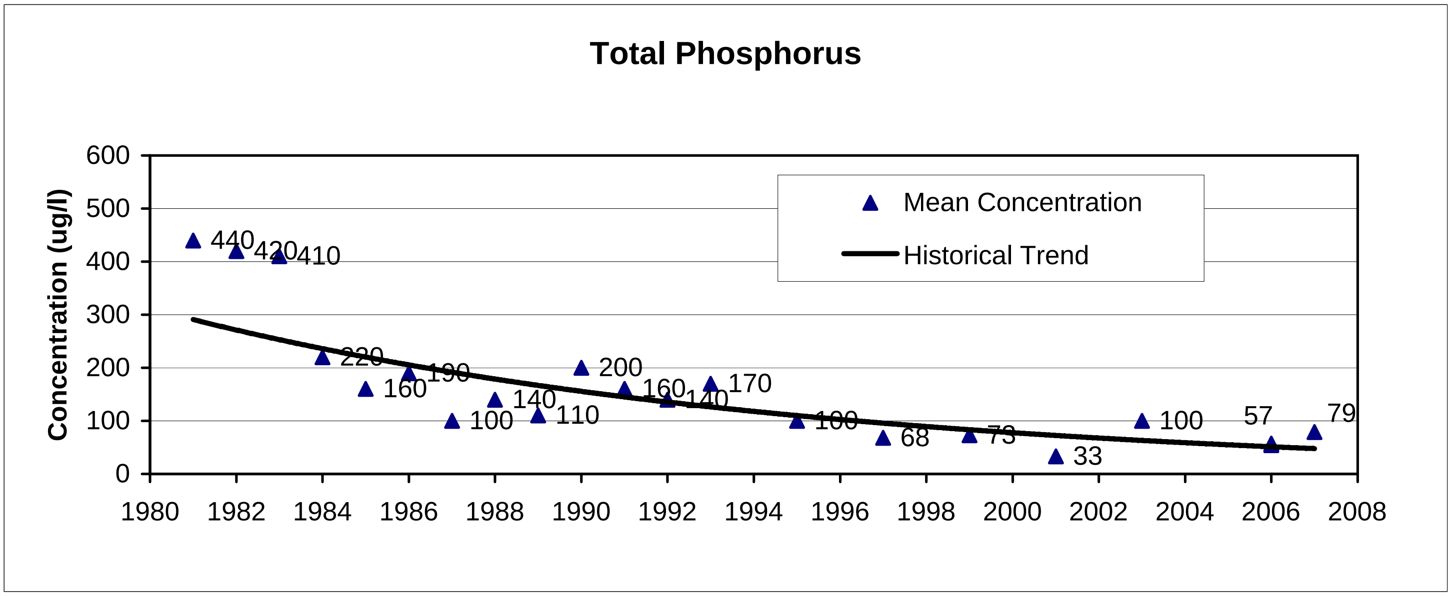
Chlorophyll-*a*

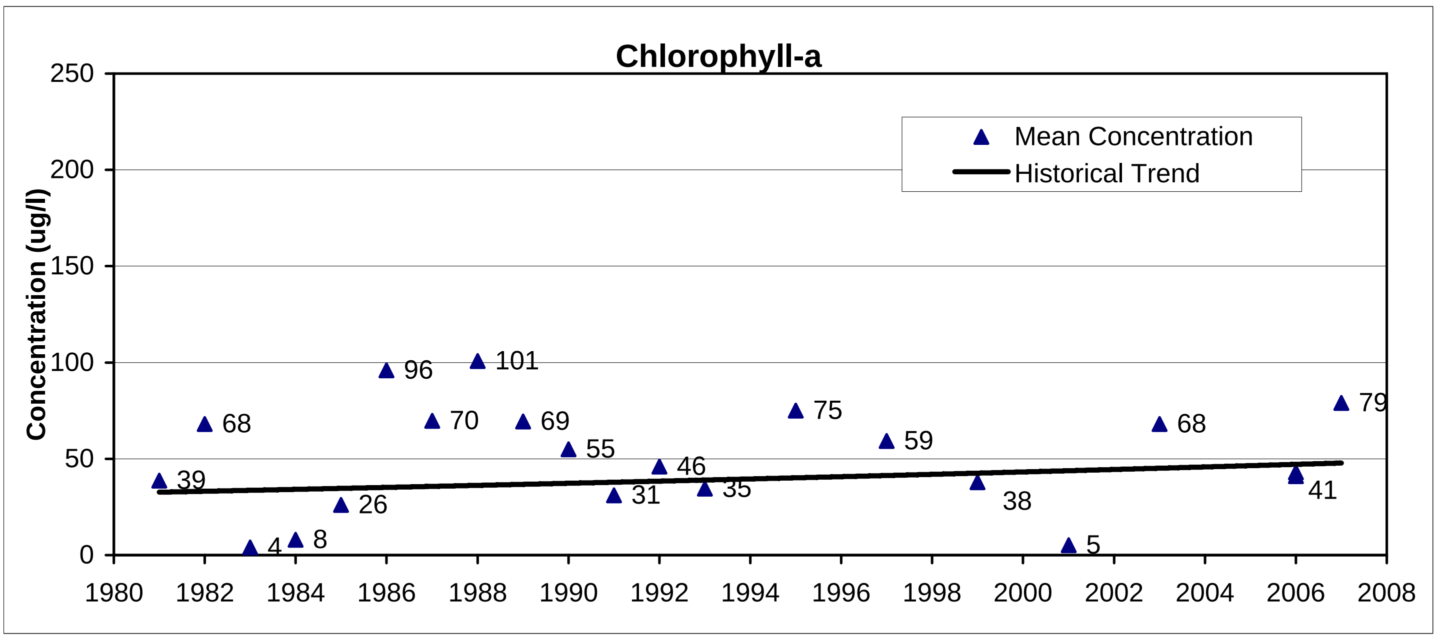


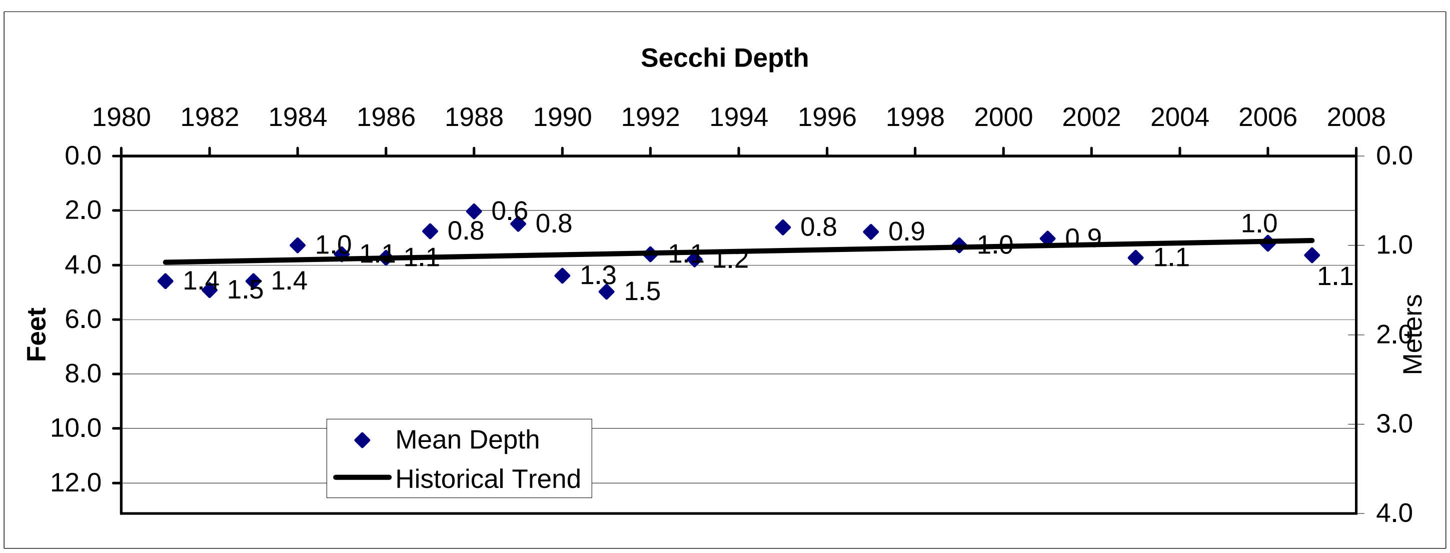
Secchi Depth



Clearwater River Watershed District	Wenck	Apr 2009
Henshaw Lake Historical Data	Wenck Associates, Inc. Environmental Engineers 1800 Pioneer Creek Center Maple Plain, MN 55359	Appendix A

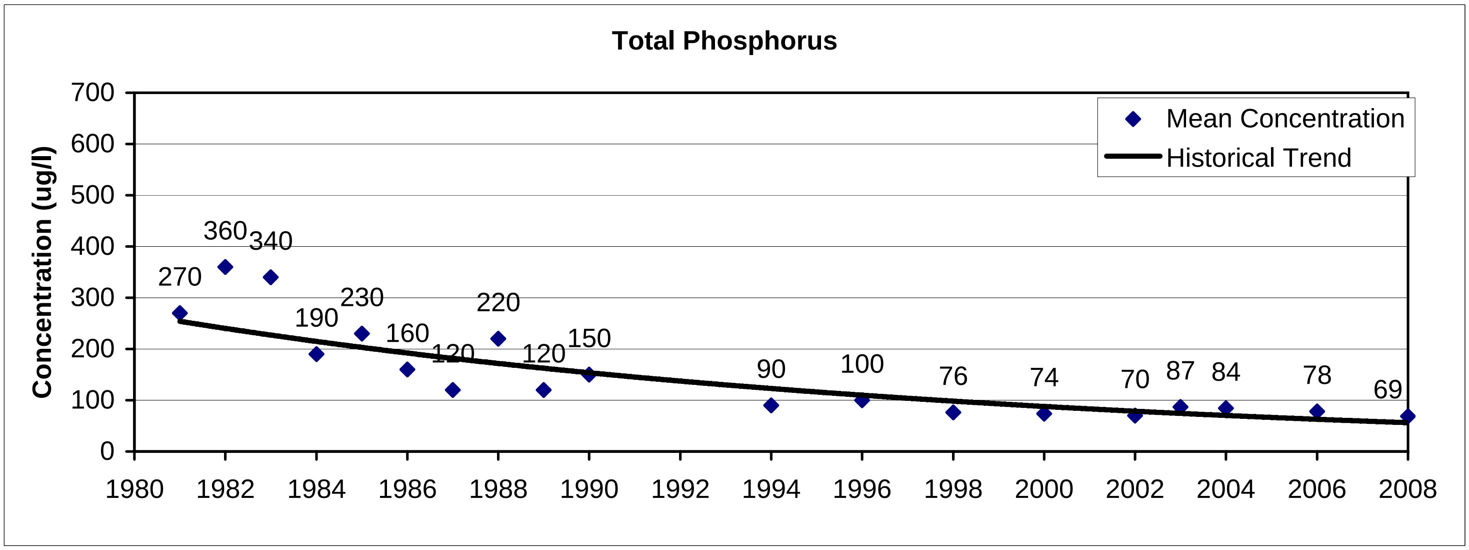


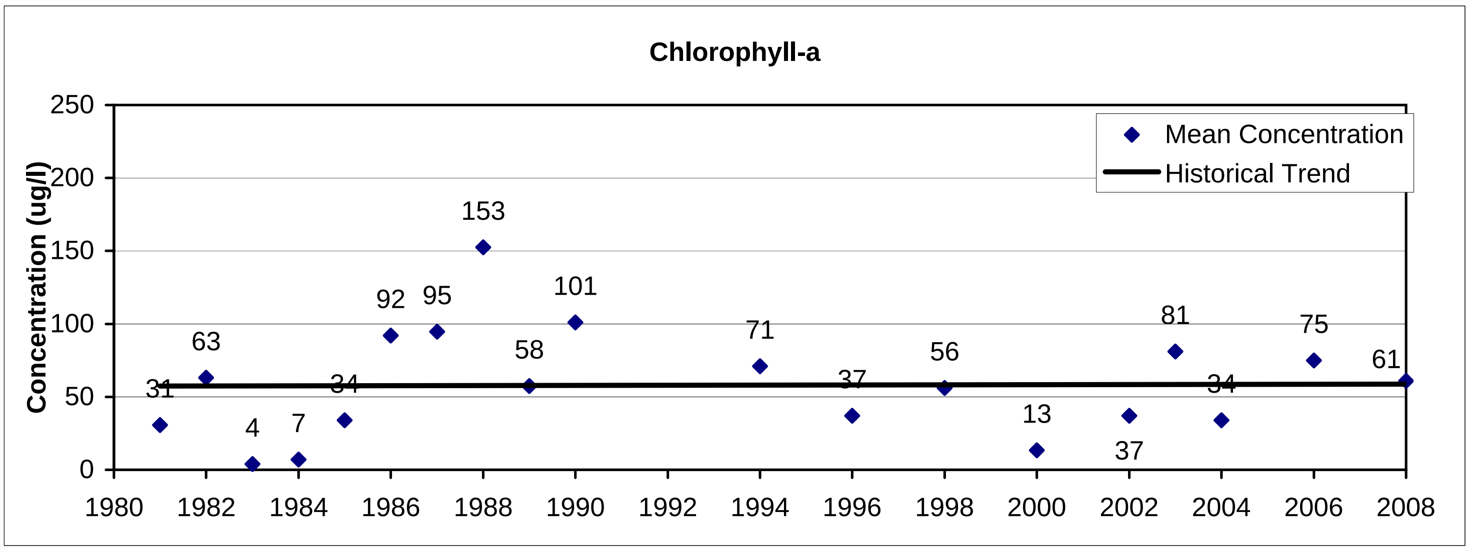


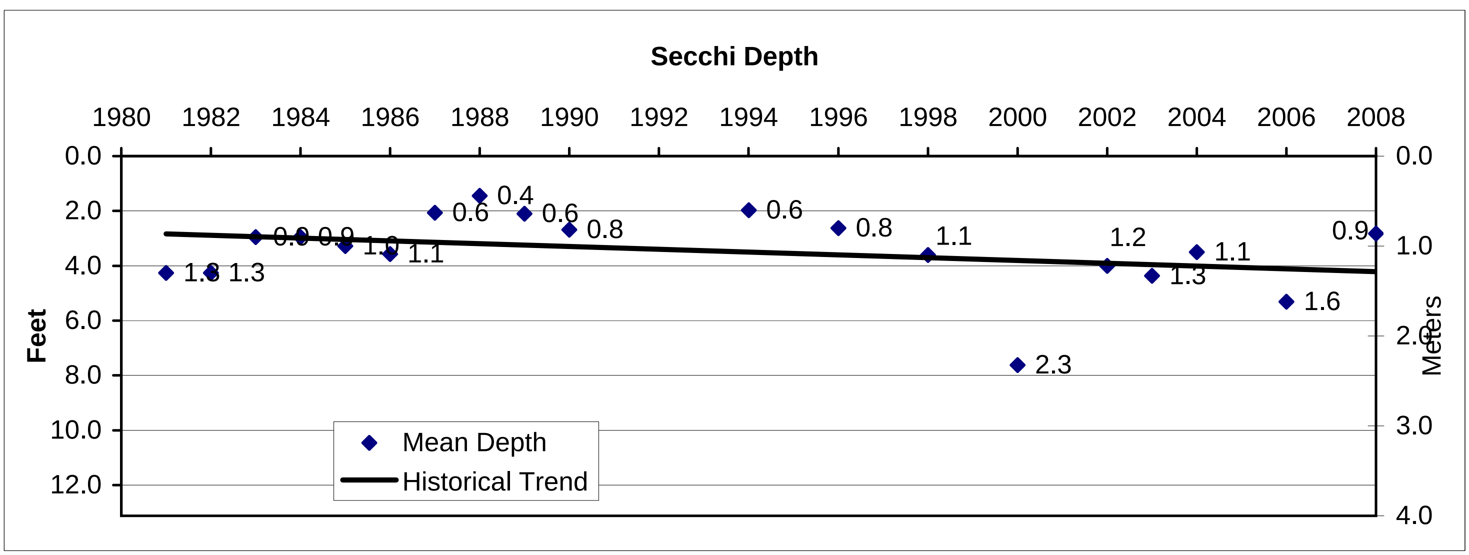


Clearwater River Watershed District	Wenck Associates, Inc. Environmental Engineers 1800 Pioneer Creek Center Maple Plain, MN 55359	Apr 2009
Lake Louisa Historical Data		Appendix A

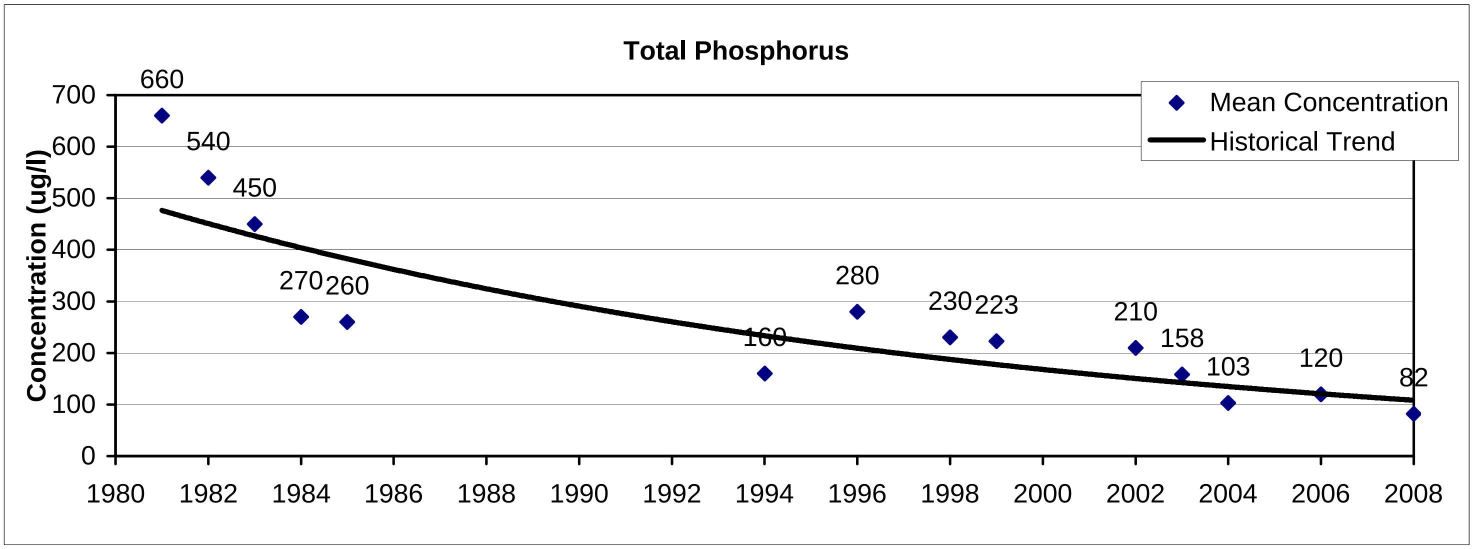
T:\0002\115\LAKE_WQ_08Lake Louisa _Print

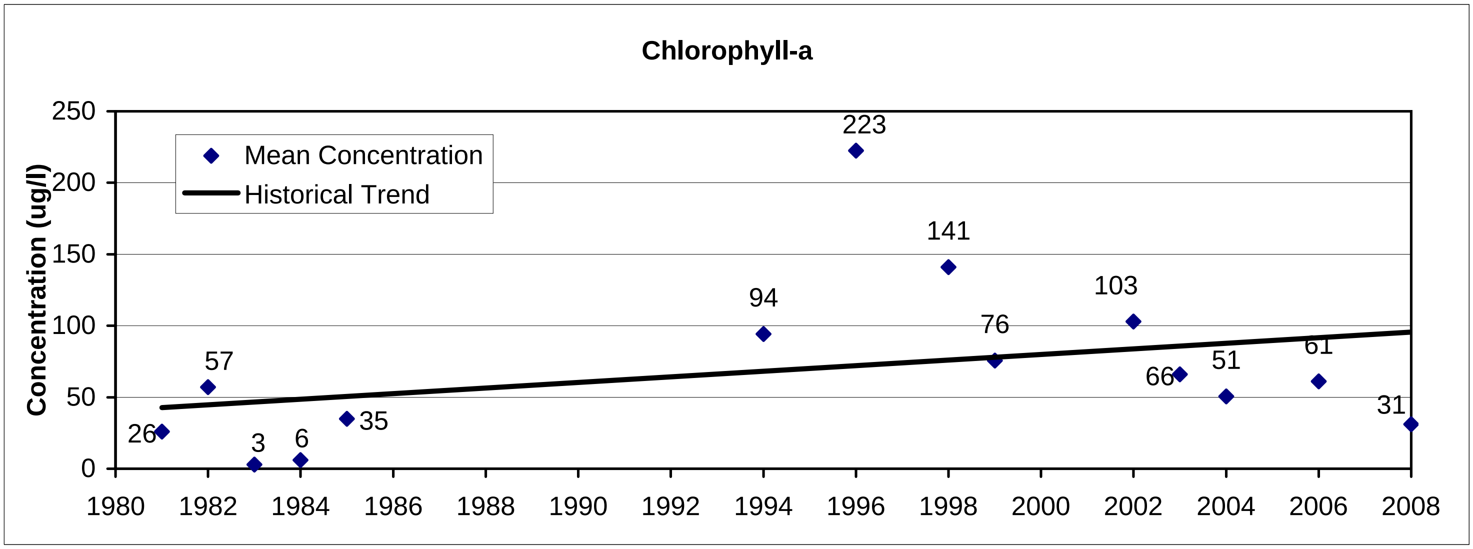


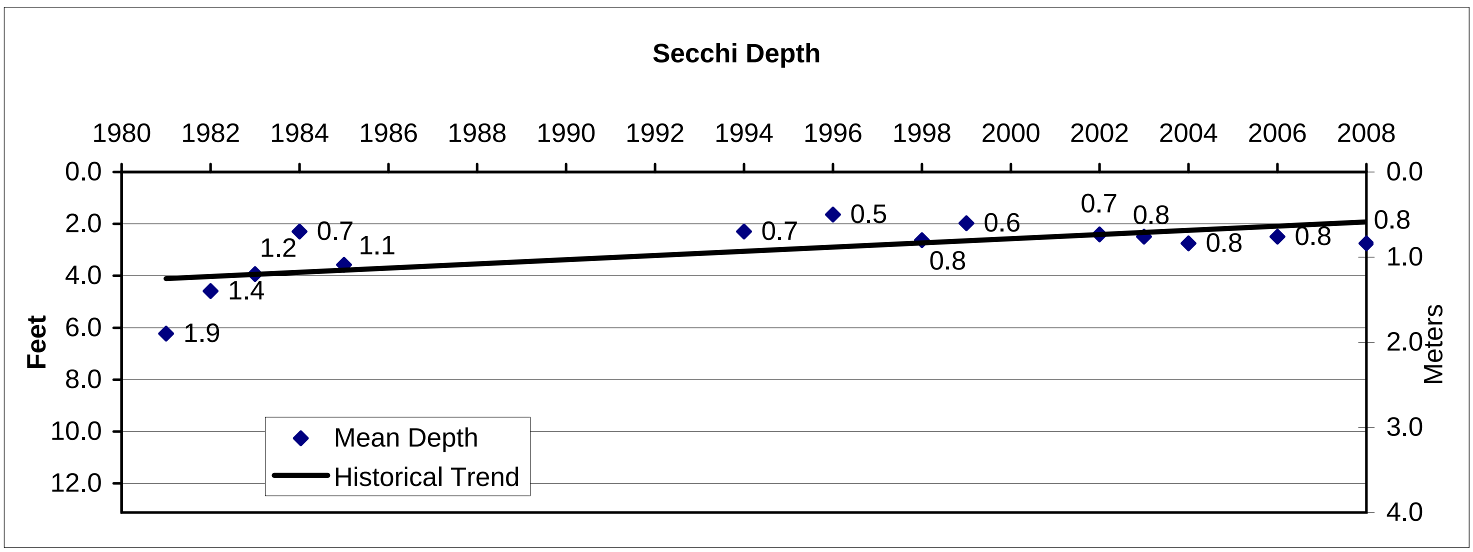


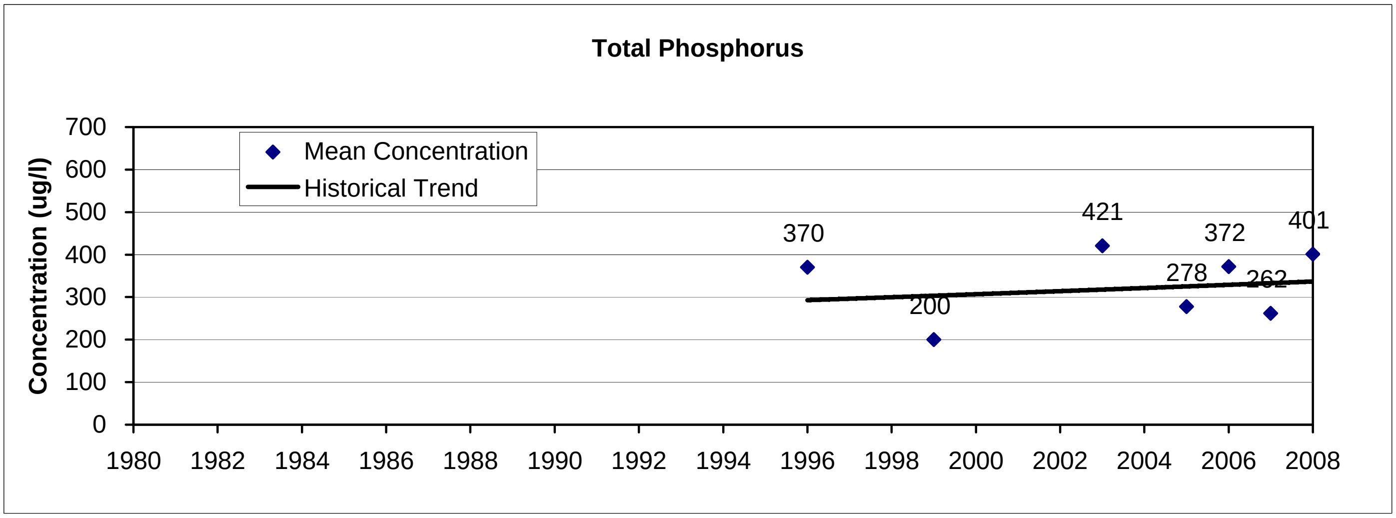


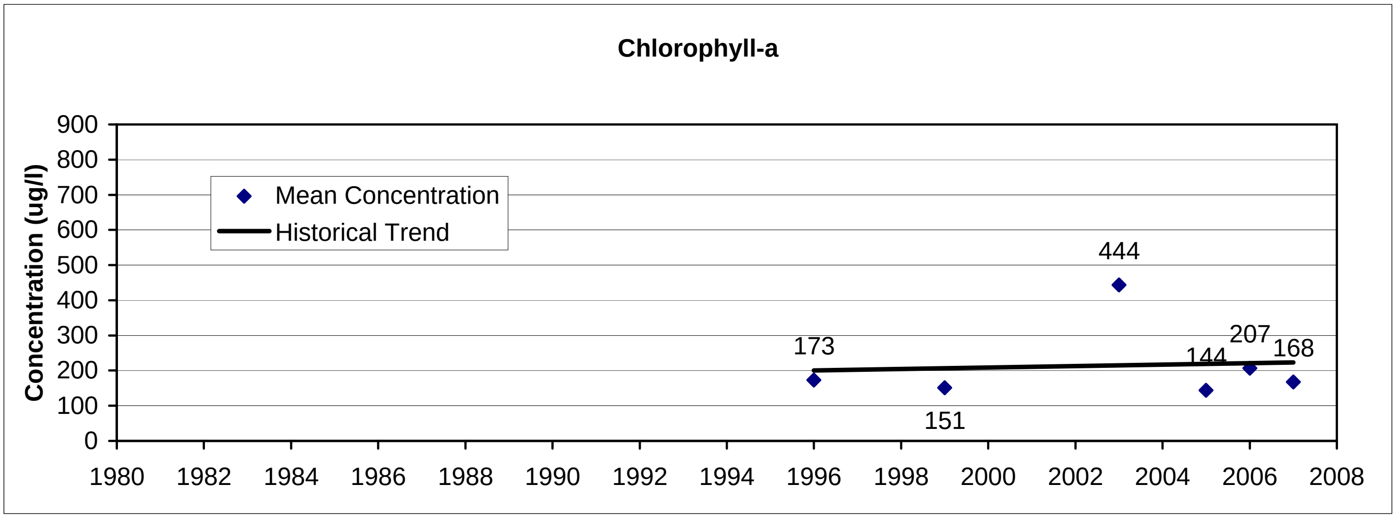
Clearwater River Watershed District	Wenck Associates, Inc. Environmental Engineers 1800 Pioneer Creek Center Maple Plain, MN 55359	Apr 2009
Lake Marie Historical Data		Appendix A

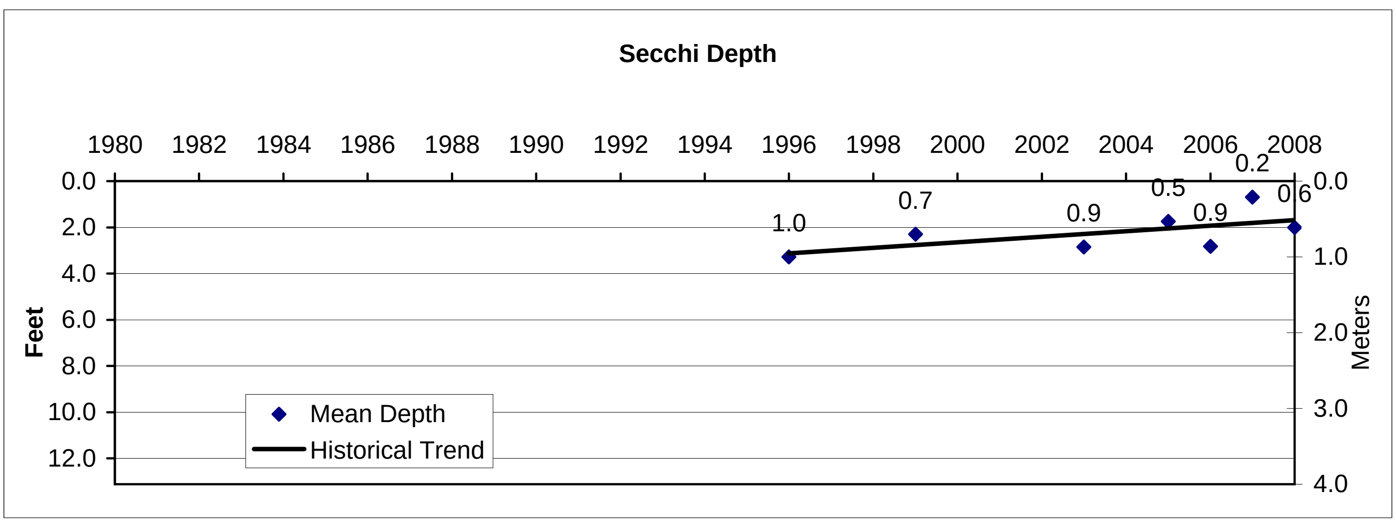

Total Phosphorus
Concentration (ug/l)
Mean Concentration
Historical Trend
660
540
450
270
260
160
280
230
223
210
158
103
120
82


Chlorophyll-a
Concentration (ug/l)
Mean Concentration
Historical Trend
26
57
3
6
35
94
223
141
76
103
66
51
61
31

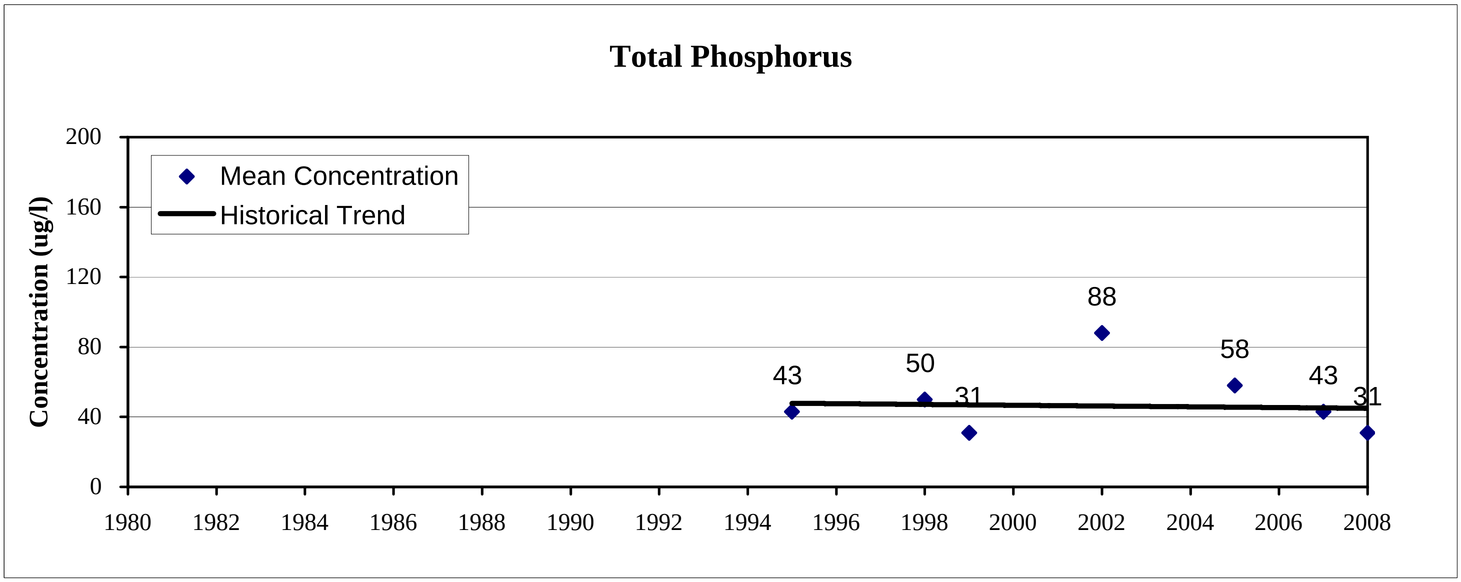

Secchi Depth
Feet
Meters
Mean Depth
Historical Trend
1.9
1.4
1.2
0.7
1.1
0.7
0.5
0.8
0.6
0.7
0.8
0.8
0.8
0.8

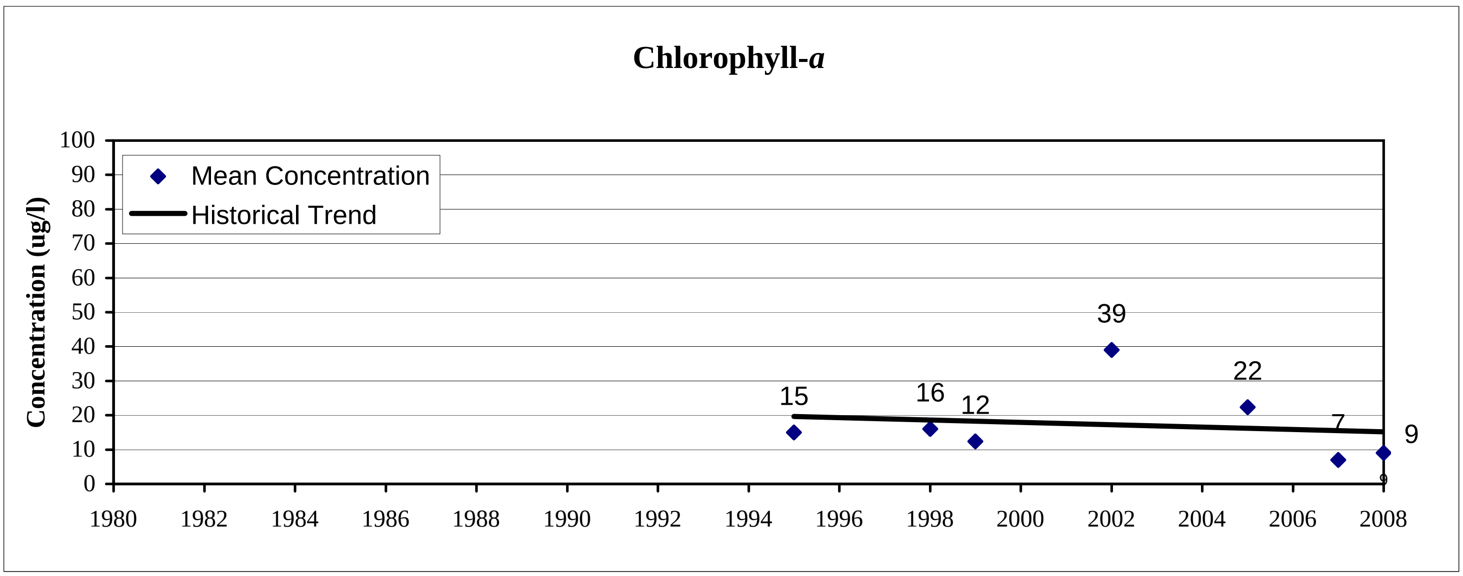


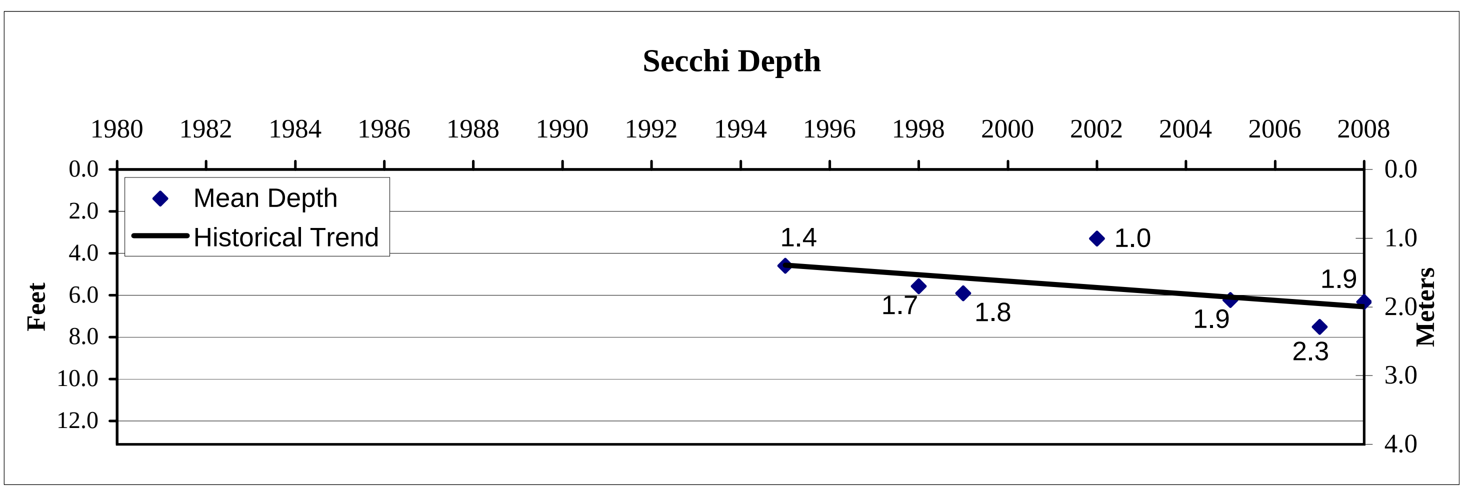




Clearwater River Watershed District	Wenck Associates, Inc. Environmental Engineers 1800 Pioneer Creek Center Maple Plain, MN 55359	Apr 2009
Swartout Lake Historical Data		Appendix A







Clearwater River Watershed District	Wenck Associates, Inc. Environmental Engineers 1800 Pioneer Creek Center Maple Plain, MN 55359	Apr 2009
Union Lake Historical Data		Appendix A

T:\0002\115\LAKE_WQ_08Union Lake

Appendix B

Lake Model Results

Average Loading Summary for Lake Augusta

Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas						
	Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1 Watershed	2,635	**4.5**	988	150.0	1.0	403
2					1.0	
3					1.0	
4					1.0	
5					1.0	
Summation	*2,635*	*5*	*988*	*150.0*		*403.1*
Failing Septic Systems						
Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1 Watershed	2,635	12	25%	4.2	0.0	12.6
2						
3						
4						
5						
Summation	*2,635*	*12*	*25%*		*0.0*	*12.6*
Inflow from Upstream Lakes						
Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1 Lake Caroline	60,132	4.5	22,549.5	58.7	1.0	3,601
2				-	1.0	
3				-	1.0	
Summation			*22,549*	*58.7*		*3,601*
Atmosphere						
Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
169	**28.6**	28.6	0.00	0.24	1.0	40.4
			Dry-year total P deposition =	0.230		
			Average-year total P deposition =	0.240		
			Wet-year total P deposition =	0.268		
			(Barr Engineering 2007)			
Groundwater						
Lake Area [acre]	Groundwater Flux [m/yr]	Net Inflow cfs	Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
169	8.0	6.1	4,400	56	1.0	670
Internal						
Lake Area [acre]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
169	65.0			9.00	1.0	880
			Net Discharge [ac-ft/yr] = 27,938		**Net Load [lb/yr] =**	**5,607**

NOTES

1 Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

Average Lake Response Modeling for Lake Augusta

Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
	$P = P_i \Big/ \left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)$	as f(W,Q,V) from Canfield & Bachmann (1981)	
		C_P =	1.00 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	5,606 [lb/yr]
		Q (lake outflow) =	27,937 [ac-ft/yr]
		V (modeled lake volume) =	4,269 [ac-ft]
		T = V/Q =	0.15 [yr]
		P_i = W/Q =	74 [ug/l]
Model Predicted In-Lake [TP]			**52.0 [ug/l]**
Observed In-Lake [TP]			**42.0 [ug/l]**
CHLOROPHYLL-A CONCENTRATION			
	$[\text{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4	
		CB (Calibration factor) =	1.00 [--]
Model Predicted In-Lake [Chl-a]			**14.6 [ug/l]**
	$[\text{Chl}a] = \frac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})]}$	as f(TP, N, Flushing), Walker 1999, Model 1	
		CB (Calibration factor) =	1.00
	$B_x = \frac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	52 [ug/l]
	$X_{pn} = \left[P^{-2} + \left(\frac{N-150}{12}\right)^{-2}\right]^{-0.5}$	N (Total Nitrogen) =	1332 [ug/l]
	$G = Z_{mix}(0.14 + 0.0039 F_s)$	B_x (Nutrient-Potential Chl-a conc.) =	37.7 [ug/l]
	$F_s = \frac{Q}{V}$	X_{pn} (Composite nutrient conc.)=	46.0 [ug/l]
	$a = \frac{1}{SD} - 0.015 \times [\text{Chl}a]$	G (Kinematic factor) =	0.17 [--]
		F_s (Flushing Rate) =	6.54 [year^{-1}]
		Z_{mix} (Mixing Depth) =	3.28 [ft]
		a (Non algal turbidity) =	0.25 [m^{-1}]
		S (Secchi Depth) =	3.18 [ft]
		Maximum lake depth =	81.99 [ft]
Model Predicted In-Lake [Chl-a]			**31.4 [ug/l]**
Observed In-Lake [Chl-a]			**29.0 [ug/l]**
SECCHI DEPTH			
	$SD = \frac{CS}{(\text{a} + 0.015 \times [\text{Chl}a])}$	as f(Chla), Walker (1999)	
		CS (Calibration factor) =	1.00 [--]
		a (Non algal turbidity) =	0.25 [m^{-1}]
Model Predicted In-Lake SD			**0.97 [m]**
Observed In-Lake SD			**1.50 [m]**
PHOSPHORUS SEDIMENTATION RATE			
	$P_{sed} = C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times [TP] \times V$		
		P_{sed} (phosphorus sedimentation) =	**1,657 [lb/yr]**
PHOSPHORUS OUTFLOW LOAD			
W-P_{sed} =			**3,949 [lb/yr]**

Average Load Reduction Table for Lake Augusta

LOAD		MODELED IN-LAKE WATER QUALITY PARAMETERS					TROPHIC STATE INDICES (Carlson, 1980) FOR MODELED PARAMETERS			
REDUC-TION [%]	NET LOAD [lb]	[TP] [ug/L]	[Chla] [ug/L]	SD [ft]	P SEDIMEN-TATION [lb]	TP OUT-FLOW [lb]	TSI [TP] [--]	TSI [Chla] [--]	TSI SD [--]	TSI Avg. [--]
0%	**5,606**	52	30	4.72	1657	**3949**	61.1	63.9	54.7	**59.9**
5%	**5,326**	50	29	4.85	1548	**3778**	60.5	63.5	54.4	**59.5**
10%	**5,046**	47	27	4.98	1441	**3604**	59.8	63.1	54.0	**59.0**
15%	**4,765**	45	26	5.13	1336	**3429**	59.1	62.6	53.5	**58.4**
20%	**4,485**	43	25	5.30	1232	**3253**	58.3	62.1	53.1	**57.8**
25%	**4,205**	40	23	5.48	1131	**3074**	57.5	61.6	52.6	**57.2**
30%	**3,924**	38	22	5.68	1031	**2893**	56.6	60.9	52.1	**56.6**
35%	**3,644**	36	21	5.91	934	**2710**	55.7	60.3	51.5	**55.8**
40%	**3,364**	33	19	6.16	839	**2525**	54.7	59.5	50.9	**55.0**
45%	**3,084**	31	18	6.44	746	**2338**	53.6	58.7	50.3	**54.2**
50%	**2,803**	28	16	6.76	656	**2147**	52.3	57.7	49.6	**53.2**
55%	**2,523**	26	14	7.12	569	**1954**	51.0	56.7	48.8	**52.2**
60%	**2,243**	23	13	7.53	485	**1758**	49.4	55.5	48.0	**51.0**
65%	**1,962**	21	11	8.00	404	**1558**	47.7	54.0	47.2	**49.6**
70%	**1,682**	18	9	8.54	327	**1354**	45.7	52.4	46.2	**48.1**
75%	**1,402**	15	7	9.15	255	**1147**	43.3	50.3	45.2	**46.3**
80%	**1,121**	12	6	9.86	188	**934**	40.3	47.8	44.1	**44.1**
85%	**841**	9	4	10.66	126	**715**	36.5	44.4	43.0	**41.3**
90%	**561**	6	2	11.56	72	**489**	31.0	39.6	41.9	**37.5**
95%	**280**	3	1	12.52	27	**253**	21.5	31.1	40.7	**31.1**

Goal Loading Summary for Lake Augusta

Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas						
Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1 Watershed	2,635	4.5	988	150.0	**0.70**	282
2					1.0	
3					1.0	
4					1.0	
5					1.0	
Summation	*2,635*	*5*	*988*	*150.0*		*282.2*
Failing Septic Systems						
Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1 Watershed	2,635	12	**0%**	4.2	0.0	0.0
2						
3						
4						
5						
Summation	*2,635*	*12*	*0%*		*0.0*	*0.0*
Inflow from Upstream Lakes						
Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1 Lake Caroline	60,132	4.5	22,549.5	**40.0**	1.0	2,453
2				-	1.0	
3				-	1.0	
Summation			*22,549*	*40.0*		*2,453*
Atmosphere						
Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
169	28.6	28.6	0.00	0.24	1.0	40.4
			Dry-year total P deposition =	0.230		
			Average-year total P deposition =	0.240		
			Wet-year total P deposition =	0.268		
			(Barr Engineering 2007)			
Groundwater						
Lake Area [acre]	Groundwater Flux [m/yr]	Net Inflow cfs	Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
169	8.0	6.1	4,400	56	1.0	670
Internal						
Lake Area [acre]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
169	65.0			9.00	**0.8**	704
			Net Discharge [ac-ft/yr] = 27,938		**Net Load [lb/yr] =**	**4,150**

NOTES

[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

Goal Lake Response Modeling for Lake Augusta

Modeled Parameter	Equation	Parameters	Value [Units]

TOTAL IN-LAKE PHOSPHORUS CONCENTRATION

$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$

Parameters	Value [Units]
as f(W,Q,V) from Canfield & Bachmann (1981)	
C_P =	1.00 [--]
C_{CB} =	0.162 [--]
b =	0.458 [--]
W (total P load = inflow + atm.) =	4,149 [lb/yr]
Q (lake outflow) =	27,937 [ac-ft/yr]
V (modeled lake volume) =	4,269 [ac-ft]
T = V/Q =	0.15 [yr]
P_i = W/Q =	55 [ug/l]
Model Predicted In-Lake [TP]	**40.0 [ug/l]**
Observed In-Lake [TP]	**42.0 [ug/l]**

CHLOROPHYLL-A CONCENTRATION

$$[\text{Chl}a] = CB \times 0.28 \times [TP]$$

Parameters	Value [Units]
as f(TP), Walker 1999, Model 4	
CB (Calibration factor) =	1.00 [--]
Model Predicted In-Lake [Chl-a]	**11.2 [ug/l]**

$$[\text{Chl}a] = \frac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})]}$$

$$B_x = \frac{X_{pn}^{1.33}}{4.31}$$

$$X_{pn} = \left[P^{-2} + \left(\frac{N - 150}{12}\right)^{-2}\right]^{-0.5}$$

$$G = Z_{mix}(0.14 + 0.0039 F_s)$$

$$F_s = \frac{Q}{V}$$

$$a = \frac{1}{SD} - 0.015 \times [\text{Chl}a]$$

Parameters	Value [Units]
as f(TP, N, Flushing), Walker 1999, Model 1	
CB (Calibration factor) =	1.00
P (Total Phosphorus) =	40 [ug/l]
N (Total Nitrogen) =	1332 [ug/l]
B_x (Nutrient-Potential Chl-a conc.) =	28.3 [ug/l]
X_{pn} (Composite nutrient conc.)=	37.1 [ug/l]
G (Kinematic factor) =	0.17 [--]
F_s (Flushing Rate) =	6.54 [year^{-1}]
Z_{mix} (Mixing Depth) =	3.28 [ft]
a (Non algal turbidity) =	0.25 [m^{-1}]
S (Secchi Depth) =	3.84 [ft]
Maximum lake depth =	81.99 [ft]
Model Predicted In-Lake [Chl-a]	**24.4 [ug/l]**
Observed In-Lake [Chl-a]	**29.0 [ug/l]**

SECCHI DEPTH

$$SD = \frac{CS}{(\text{a} + 0.015 \times [\text{Chl}a])}$$

Parameters	Value [Units]
as f(Chla), Walker (1999)	
CS (Calibration factor) =	1.00 [--]
a (Non algal turbidity) =	0.25 [m^{-1}]
Model Predicted In-Lake SD	**1.17 [m]**
Observed In-Lake SD	**1.50 [m]**

PHOSPHORUS SEDIMENTATION RATE

$$P_{sed} = C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times [TP] \times V$$

P_{sed} (phosphorus sedimentation) = 1,111 [lb/yr]

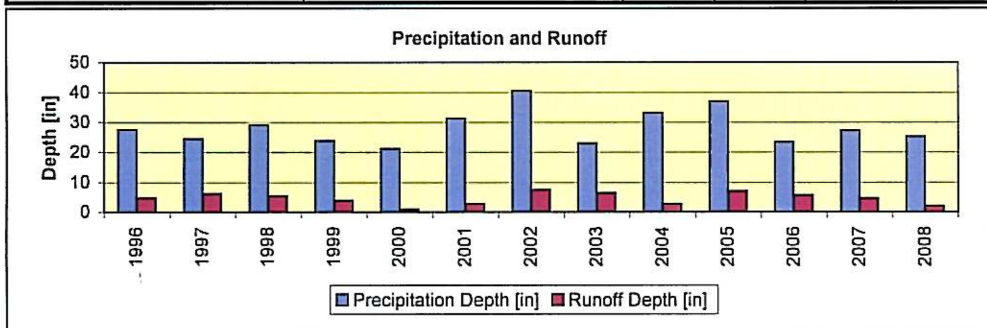
PHOSPHORUS OUTFLOW LOAD

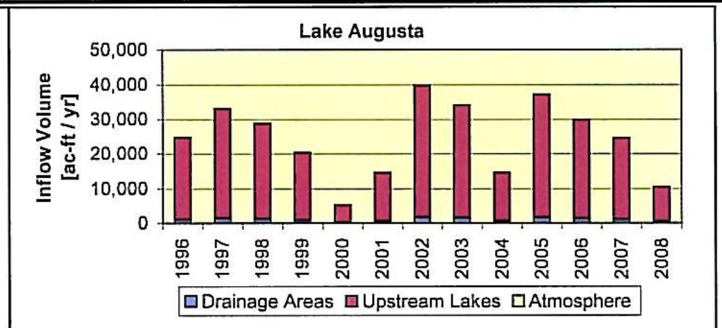
W-P_{sed} = **3,038 [lb/yr]**

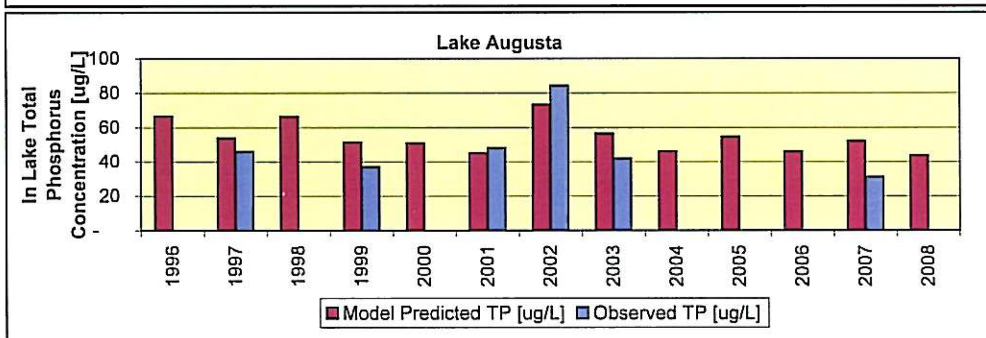
Goal Load Reduction Table for Lake Augusta

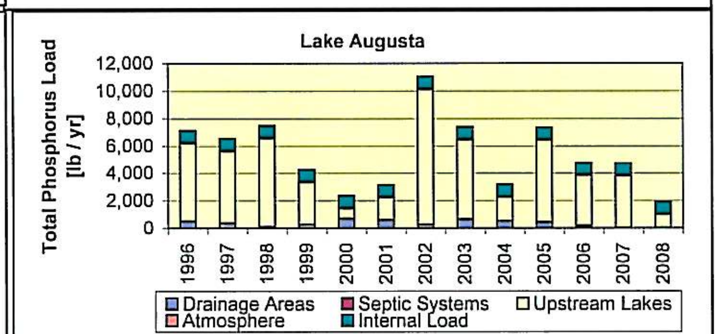
LOAD		MODELED IN-LAKE WATER QUALITY PARAMETERS					TROPHIC STATE INDICES (Carlson, 1980) FOR MODELED PARAMETERS			
REDUCTION [%]	NET LOAD [lb]	[TP] [ug/L]	[Chla] [ug/L]	SD [ft]	P SEDIMENTATION [lb]	TP OUTFLOW [lb]	TSI [TP] [--]	TSI [Chla] [--]	TSI SD [--]	TSI Avg. [--]
0%	**4,149**	40	23	5.49	1111	**3038**	57.3	61.5	52.6	**57.2**
5%	**3,942**	38	22	5.64	1037	**2905**	56.7	61.1	52.2	**56.7**
10%	**3,734**	36	21	5.80	965	**2770**	56.0	60.6	51.8	**56.1**
15%	**3,527**	35	20	5.98	894	**2633**	55.3	60.1	51.4	**55.6**
20%	**3,319**	33	19	6.17	824	**2496**	54.5	59.5	50.9	**55.0**
25%	**3,112**	31	18	6.38	755	**2357**	53.7	58.9	50.4	**54.3**
30%	**2,905**	29	17	6.61	688	**2216**	52.8	58.2	49.9	**53.6**
35%	**2,697**	27	15	6.86	623	**2074**	51.8	57.5	49.4	**52.9**
40%	**2,490**	25	14	7.13	559	**1931**	50.8	56.7	48.8	**52.1**
45%	**2,282**	24	13	7.44	496	**1786**	49.7	55.7	48.2	**51.2**
50%	**2,075**	22	12	7.77	436	**1639**	48.4	54.7	47.6	**50.2**
55%	**1,867**	20	10	8.14	378	**1489**	47.1	53.6	46.9	**49.2**
60%	**1,660**	18	9	8.55	322	**1338**	45.5	52.3	46.2	**48.0**
65%	**1,452**	16	8	9.00	268	**1185**	43.8	50.8	45.5	**46.7**
70%	**1,245**	14	7	9.51	217	**1028**	41.7	49.1	44.7	**45.2**
75%	**1,037**	11	5	10.06	168	**869**	39.3	47.0	43.9	**43.4**
80%	**830**	9	4	10.67	124	**706**	36.3	44.4	43.0	**41.2**
85%	**622**	7	3	11.34	83	**540**	32.4	40.9	42.1	**38.5**
90%	**415**	5	2	12.04	47	**368**	26.9	36.0	41.3	**34.7**
95%	**207**	2	1	12.75	18	**190**	17.4	27.4	40.4	**28.4**

Lake Augusta	Source	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Precipitation Depth [in]		27.6	24.4	29.1	23.8	21.2	31.3	40.6	23.0	33.1	36.9	23.4	27.2	25.3
Runoff Depth [in]		4.8	6.3	5.5	3.9	1.0	2.8	7.6	6.5	2.8	7.1	5.7	4.7	2.0
	Residence Time [yr]	0.15	0.11	0.13	0.17	0.44	0.22	0.10	0.11	0.22	0.10	0.12	0.15	0.29
Inflow Volume [ac-ft / yr]	Drainage Areas	1,043	1,388	1,208	856	220	615	1,669	1,427	615	1,559	1,252	1,032	439
	Upstream Lakes	23,802	31,669	27,560	19,543	5,011	14,031	38,084	32,571	14,031	35,578	28,563	23,552	10,022
	Atmosphere	-	-	-	-	-	-	-	-	-	-	-	-	-
	TOTAL =	**24,845**	**33,057**	**28,768**	**20,399**	**5,231**	**14,646**	**39,752**	**33,999**	**14,646**	**37,137**	**29,814**	**24,584**	**10,461**
Total Phosphorus Load [lb / yr]	Drainage Areas	426	566	493	349	90	251	681	582	251	636	511	421	179
	Septic Systems	13	13	13	13	13	13	13	13	13	13	13	13	13
	Upstream Lakes	5,697	5,261	6,446	3,069	748	1,641	9,840	5,811	1,727	5,994	3,651	3,780	981
	Atmosphere	40	39	40	39	39	40	45	39	40	40	39	40	40
	Internal Load	880	880	880	880	880	880	880	880	880	880	880	880	880
	TOTAL =	**7,055**	**6,758**	**7,871**	**4,349**	**1,769**	**2,824**	**11,458**	**7,324**	**2,910**	**7,563**	**5,093**	**5,133**	**2,093**
Model Results	Model Predicted TP [ug/L]	66	54	66	51	51	45	73	56	46	55	46	52	44
	Observed TP [ug/L]	-	46	-	37	-	48	84	42	-	-	-	31	-
	Phosphorus Sedimentation [lb]	2,449	1,950	2,563	1,556	1,107	1,158	3,327	2,113	1,195	2,073	1,485	1,690	1,004
	TOTAL OUTFLOW [lb] =	***5,275***	***5,478***	***5,979***	***3,463***	***1,332***	***2,336***	***8,800***	***5,882***	***2,385***	***6,159***	***4,278***	***4,113***	***1,759***
Load Factors:	*Drainage Area [-]*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*
	Release Rate [mg/m2-day]	*9*	*9*	*9*	*9*	*9*	*9*	*9*	*9*	*9*	*9*	*9*	*9*	*9*
	Anoxic factor [day]	*65*	*65*	*65*	*65*	*65*	*65*	*65*	*65*	*65*	*65*	*65*	*65*	*65*









Average Loading Summary for Lake Caroline

	Water Budgets			Phosphorus Loading		
Inflow from Drainage Areas						
	Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1 Watershed	2,013	**4.5**	755	150.0	1.0	308
2					1.0	
3					1.0	
4					1.0	
5					1.0	
Summation	*2,013*	*5*	*755*	*150.0*		*308.0*
Failing Septic Systems						
Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1 Watershed	2,013	12	25%	4.2	0.0	12.6
2						
3						
4						
5						
Summation	*2,013*	*12*	*25%*		*0.0*	*12.6*
Inflow from Upstream Lakes						
	Drainage Area	Runoff Depth	Discharge	Estimated P Concentration	Calibration Factor	Load
Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1 Lake Marie	57,994	4.5	21,747.7	69.3	1.0	4,098
2				-	1.0	
3				-	1.0	
Summation			*21,748*	*69.3*		*4,098*
Atmosphere						
Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load
[acre]	[in/yr]	[in/yr]	[ac-ft/yr]	[lb/ac-yr]	[--]	[lb/yr]
125	**28.6**	28.6	0.00	0.24	1.0	30.0
			Dry-year total P deposition =	0.230		
			Average-year total P deposition =	0.240		
			Wet-year total P deposition =	0.268		
			(Barr Engineering 2007)			
Groundwater						
Lake Area	Groundwater Flux	Net Inflow	Net Inflow	Phosphorus Concentration	Calibration Factor	Load
[acre]	[m/yr]	cfs	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
125	12.7	7.2	5,200	56	1.0	792
Internal						
Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
[acre]	[days]			[mg/m^2-day]	[--]	[lb/yr]
125	40.0			9.00	1.0	402
		Net Discharge [ac-ft/yr] =	**27,703**		**Net Load [lb/yr] =**	**5,642**

NOTES

[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

Average Lake Response Modeling for Lake Caroline

Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)	
		C_P =	1.00 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	5,642 [lb/yr]
		Q (lake outflow) =	27,702 [ac-ft/yr]
		V (modeled lake volume) =	1,925 [ac-ft]
		T = V/Q =	0.07 [yr]
		P_i = W/Q =	75 [ug/l]
Model Predicted In-Lake [TP]			**58.7 [ug/l]**
Observed In-Lake [TP]			**65.6 [ug/l]**
CHLOROPHYLL-A CONCENTRATION			
	$[\mathrm{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4	
		CB (Calibration factor) =	1.00 [--]
Model Predicted In-Lake [Chl-a]			**16.4 [ug/l]**
	$[\mathrm{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \mathrm{a})]}$	as f(TP, N, Flushing), Walker 1999, Model 1	
		CB (Calibration factor) =	1.00
	$B_x = \dfrac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	59 [ug/l]
		N (Total Nitrogen) =	1707 [ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	46.1 [ug/l]
	$X_{pn} = \left[P^{-2} + \left(\dfrac{N - 150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	53.5 [ug/l]
		G (Kinematic factor) =	0.20 [--]
		F_s (Flushing Rate) =	14.39 [year^{-1}]
	$G = Z_{mix}(0.14 + 0.0039F_s)$	Z_{mix} (Mixing Depth) =	3.28 [ft]
	$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - 0.015 \times [\mathrm{Chl}a]$	a (Non algal turbidity) =	0.22 [m^{-1}]
		S (Secchi Depth) =	2.93 [ft]
		Maximum lake depth =	146.00 [ft]
Model Predicted In-Lake [Chl-a]			**36.1 [ug/l]**
Observed In-Lake [Chl-a]			**28.6 [ug/l]**
SECCHI DEPTH			
	$SD = \dfrac{CS}{(\mathrm{a} + 0.015 \times [\mathrm{Chl}a])}$	as f(Chla), Walker (1999)	
		CS (Calibration factor) =	1.00 [--]
		a (Non algal turbidity) =	0.22 [m^{-1}]
Model Predicted In-Lake SD			**0.89 [m]**
Observed In-Lake SD			**1.50 [m]**
PHOSPHORUS SEDIMENTATION RATE			
	$P_{sed} = C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times [TP] \times V$		
		P_{sed} (phosphorus sedimentation) =	**1,219 [lb/yr]**
PHOSPHORUS OUTFLOW LOAD			
	W-P_{sed} =		**4,423 [lb/yr]**

Average Load Reduction Table for Lake Caroline

LOAD		MODELED IN-LAKE WATER QUALITY PARAMETERS					TROPHIC STATE INDICES (Carlson, 1980) FOR MODELED PARAMETERS			
REDUC-TION [%]	NET LOAD [lb]	[TP] [ug/L]	[Chla] [ug/L]	SD [ft]	P SEDIMEN-TATION [lb]	TP OUT-FLOW [lb]	TSI [TP] [--]	TSI [Chla] [--]	TSI SD [--]	TSI Avg. [--]
0%	**5,642**	59	34	4.52	1219	**4423**	62.9	65.1	55.4	**61.1**
5%	**5,360**	56	32	4.65	1137	**4223**	62.2	64.7	55.0	**60.6**
10%	**5,078**	53	31	4.80	1056	**4022**	61.5	64.3	54.5	**60.1**
15%	**4,796**	51	29	4.97	977	**3819**	60.8	63.8	54.0	**59.5**
20%	**4,514**	48	28	5.15	900	**3614**	60.0	63.3	53.5	**58.9**
25%	**4,232**	45	26	5.35	824	**3408**	59.1	62.7	53.0	**58.3**
30%	**3,950**	42	25	5.57	749	**3200**	58.2	62.0	52.4	**57.5**
35%	**3,667**	40	23	5.82	677	**2991**	57.2	61.3	51.7	**56.8**
40%	**3,385**	37	21	6.11	606	**2779**	56.2	60.6	51.0	**55.9**
45%	**3,103**	34	19	6.43	538	**2565**	55.0	59.7	50.3	**55.0**
50%	**2,821**	31	18	6.79	472	**2350**	53.8	58.7	49.5	**54.0**
55%	**2,539**	28	16	7.21	408	**2131**	52.4	57.6	48.7	**52.9**
60%	**2,257**	25	14	7.69	346	**1911**	50.8	56.4	47.7	**51.6**
65%	**1,975**	22	12	8.25	288	**1687**	49.0	54.9	46.7	**50.2**
70%	**1,693**	19	10	8.89	232	**1461**	46.9	53.2	45.6	**48.6**
75%	**1,411**	16	8	9.64	180	**1231**	44.4	51.1	44.5	**46.7**
80%	**1,128**	13	6	10.52	132	**997**	41.4	48.5	43.2	**44.4**
85%	**846**	10	4	11.53	88	**759**	37.5	45.1	41.9	**41.5**
90%	**564**	7	3	12.69	49	**515**	31.9	40.1	40.5	**37.5**
95%	**282**	4	1	13.94	18	**264**	22.2	31.5	39.2	**31.0**

Goal Loading Summary for Lake Caroline

Water Budgets				Phosphorus Loading		

Inflow from Drainage Areas

Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1 Watershed	2,013	4.5	755	150.0	**0.70**	216
2					1.0	
3					1.0	
4					1.0	
5					1.0	
Summation	*2,013*	*5*	*755*	*150.0*		*215.6*

Failing Septic Systems

Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1 Watershed	2,013	12	**0%**	4.2	0.0	0.0
2						
3						
4						
5						
Summation	*2,013*	*12*	*0%*		*0.0*	*0.0*

Inflow from Upstream Lakes

Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1 Lake Marie	57,994	4.5	21,747.7	**40.0**	1.0	2,366
2				-	1.0	
3				-	1.0	
Summation			*21,748*	*40.0*		*2,366*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
125	28.6	28.6	0.00	0.24	1.0	30.0
			Dry-year total P deposition =	0.230		
			Average-year total P deposition =	0.240		
			Wet-year total P deposition =	0.268		
			(Barr Engineering 2007)			

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]	Net Inflow cfs	Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
125	12.7	7.2	5,200	56	1.0	792

Internal

Lake Area [acre]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
125	40.0			9.00	**0.75**	301
			Net Discharge [ac-ft/yr] = 27,703			**Net Load [lb/yr] = 3,705**

NOTES

[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

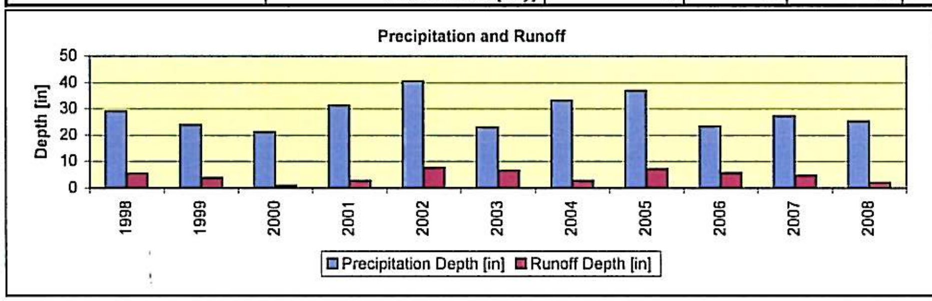
Goal Lake Response Modeling for Lake Caroline

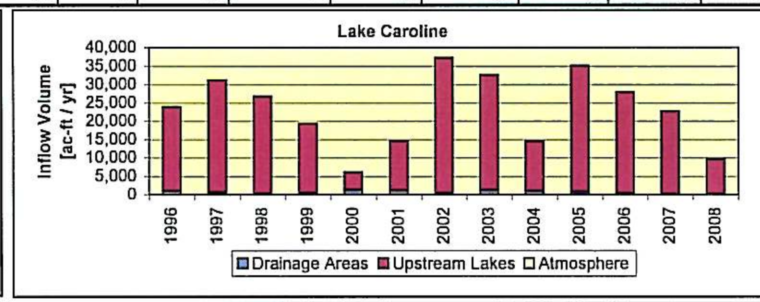
Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)	
		C_P =	1.00 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	3,704 [lb/yr]
		Q (lake outflow) =	27,702 [ac-ft/yr]
		V (modeled lake volume) =	1,925 [ac-ft]
		T = V/Q =	0.07 [yr]
		P_i = W/Q =	49 [ug/l]
Model Predicted In-Lake [TP]			**40.1 [ug/l]**
Observed In-Lake [TP]			**65.6 [ug/l]**
CHLOROPHYLL-A CONCENTRATION			
	$[\text{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4	
		CB (Calibration factor) =	1.00 [--]
Model Predicted In-Lake [Chl-a]			**11.2 [ug/l]**
	$[\text{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})]}$	as f(TP, N, Flushing), Walker 1999, Model 1	
		CB (Calibration factor) =	1.00
	$B_x = \dfrac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	40 [ug/l]
		N (Total Nitrogen) =	1707 [ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	29.6 [ug/l]
	$X_{pn} = \left[P^{-2} + \left(\frac{N - 150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	38.3 [ug/l]
		G (Kinematic factor) =	0.20 [--]
		F_s (Flushing Rate) =	14.39 [year^{-1}]
	$G = Z_{mix}(0.14 + 0.0039F_s)$	Z_{mix} (Mixing Depth) =	3.28 [ft]
	$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - 0.015 \times [\text{Chl}a]$	a (Non algal turbidity) =	0.22 [m^{-1}]
		S (Secchi Depth) =	3.91 [ft]
		Maximum lake depth =	146.00 [ft]
Model Predicted In-Lake [Chl-a]			**24.8 [ug/l]**
Observed In-Lake [Chl-a]			**28.6 [ug/l]**
SECCHI DEPTH			
	$SD = \dfrac{CS}{(\text{a} + 0.015 \times [\text{Chl}a])}$	as f(Chla), Walker (1999)	
		CS (Calibration factor) =	1.00 [--]
		a (Non algal turbidity) =	0.22 [m^{-1}]
Model Predicted In-Lake SD			**1.19 [m]**
Observed In-Lake SD			**1.50 [m]**
PHOSPHORUS SEDIMENTATION RATE			
	$P_{sed} = C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times [TP] \times V$		
		P_{sed} (phosphorus sedimentation) =	**686 [lb/yr]**
PHOSPHORUS OUTFLOW LOAD			
	W-P_{sed} =		**3,018 [lb/yr]**

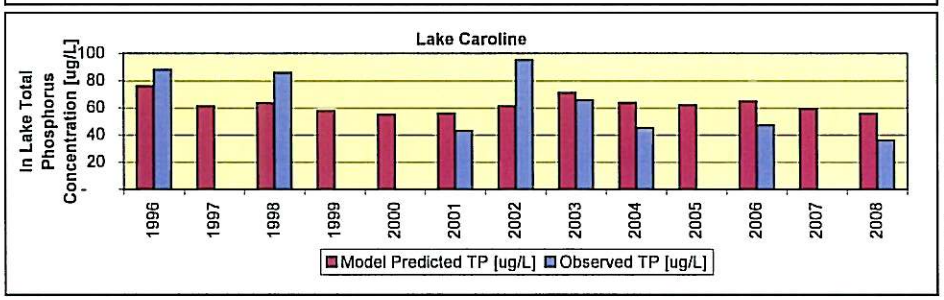
Goal Load Reduction Table for Lake Caroline

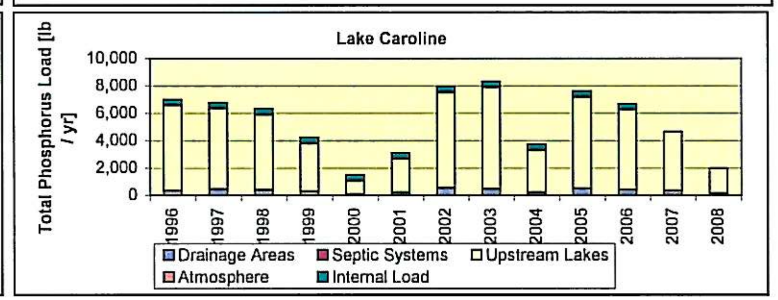
LOAD		MODELED IN-LAKE WATER QUALITY PARAMETERS					TROPHIC STATE INDICES (Carlson, 1980) FOR MODELED PARAMETERS			
REDUCTION [%]	NET LOAD [lb]	[TP] [ug/L]	[Chla] [ug/L]	SD [ft]	P SEDIMENTATION [lb]	TP OUTFLOW [lb]	TSI [TP] [--]	TSI [Chla] [--]	TSI SD [--]	TSI Avg. [--]
0%	**3,704**	40	24	5.72	686	**3018**	57.4	61.6	52.0	**57.0**
5%	**3,519**	38	23	5.90	640	**2880**	56.7	61.1	51.6	**56.5**
10%	**3,334**	36	21	6.09	594	**2740**	56.0	60.6	51.1	**55.9**
15%	**3,149**	35	20	6.30	549	**2600**	55.2	60.1	50.6	**55.3**
20%	**2,964**	33	19	6.53	505	**2459**	54.4	59.4	50.1	**54.6**
25%	**2,778**	31	18	6.78	462	**2317**	53.6	58.8	49.5	**54.0**
30%	**2,593**	29	16	7.05	420	**2173**	52.6	58.1	49.0	**53.2**
35%	**2,408**	27	15	7.35	379	**2029**	51.6	57.3	48.4	**52.4**
40%	**2,223**	25	14	7.68	339	**1884**	50.6	56.4	47.7	**51.6**
45%	**2,037**	23	13	8.04	300	**1737**	49.4	55.5	47.1	**50.6**
50%	**1,852**	21	11	8.44	263	**1589**	48.1	54.4	46.4	**49.6**
55%	**1,667**	19	10	8.88	227	**1440**	46.7	53.2	45.7	**48.5**
60%	**1,482**	17	9	9.37	193	**1289**	45.1	51.9	44.9	**47.3**
65%	**1,297**	15	7	9.91	160	**1137**	43.3	50.3	44.1	**45.9**
70%	**1,111**	13	6	10.51	129	**983**	41.2	48.5	43.2	**44.3**
75%	**926**	11	5	11.17	100	**827**	38.7	46.4	42.3	**42.5**
80%	**741**	9	4	11.90	73	**668**	35.6	43.7	41.4	**40.2**
85%	**556**	7	3	12.69	48	**507**	31.7	40.1	40.5	**37.4**
90%	**370**	5	2	13.52	27	**343**	26.0	35.1	39.6	**33.6**
95%	**185**	2	1	14.35	10	**175**	16.3	26.4	38.7	**27.1**

Lake Caroline	Source	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Precipitation Depth [in]		27.6	24.4	29.1	23.8	21.2	31.3	40.6	23.0	33.1	36.9	23.4	27.2	25.3
Runoff Depth [in]		4.8	6.3	5.5	3.9	1.0	2.8	7.6	6.5	2.8	7.1	5.7	4.7	2.0
	Residence Time [yr]	0.1	0.1	0.1	0.1	0.2	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.1
Inflow Volume [ac-ft / yr]	Drainage Areas	797	1,060	923	654	168	470	1,275	1,090	470	1,191	956	788	336
	Upstream Lakes	22,956	30,543	26,581	18,848	4,833	13,532	36,729	31,413	13,532	34,313	27,547	22,714	9,666
	Atmosphere	-	-	-	-	-	-	-	-	-	-	-	-	-
	TOTAL =	**23,753**	**31,604**	**27,503**	**19,502**	**5,001**	**14,002**	**38,004**	**32,504**	**14,002**	**35,504**	**28,503**	**23,503**	**10,001**
Total Phosphorus Load [lb / yr]	Drainage Areas	325	433	376	267	68	192	520	445	192	486	390	322	137
	Septic Systems	13	13	13	13	13	13	13	13	13	13	13	13	13
	Upstream Lakes	6,243	5,897	5,494	3,513	973	2,460	6,992	7,433	3,091	6,678	5,844	4,294	1,814
	Atmosphere	30	29	30	29	29	30	34	29	30	30	29	30	30
	Internal Load	402	402	402	402	402	402	402	402	402	402	402	402	402
	TOTAL =	**7,013**	**6,772**	**6,315**	**4,223**	**1,484**	**3,096**	**7,960**	**8,321**	**3,727**	**7,608**	**6,677**	**5,060**	**2,395**
Model Results	Model Predicted TP [ug/L]	76	61	63	58	55	56	61	71	64	62	65	59	56
	Observed TP [ug/L]	88	-	86	-	-	43	95	66	45	-	47	-	36
	Phosphorus Sedimentation [lb]	1,829	1,451	1,464	1,136	752	976	1,555	1,836	1,194	1,544	1,530	1,246	889
	TOTAL OUTFLOW [lb] =	***5,976***	***6,113***	***5,642***	***3,879***	***1,523***	***2,912***	***7,197***	***7,277***	***3,325***	***6,857***	***5,938***	***4,606***	***2,298***
Load Factors:	*Drainage Area [-]*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*
	Release Rate [mg/m2-day]	*9*	*9*	*9*	*9*	*9*	*9*	*9*	*9*	*9*	*9*	*9*	*9*	*9*
	Anoxic factor [day]	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*	*40*









Average Loading Summary for Albion Lake

Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas						
Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1 Albion	838	4.5	314	400.0	1.0	342
2					1.0	
3					1.0	
4					1.0	
5					1.0	
Summation	838	4.5	314	400.0		341.7
Failing Septic Systems						
Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1 Albion	838	13	25%	4.2	0.0	13.7
2						
3						
4						
5						
Summation	838	13	25%		0.0	13.7
Inflow from Upstream Lakes						
Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	0	4.5	0.0	0.0	1.0	0
2				-	1.0	
3				-	1.0	
Summation			0	0.0		0
Atmosphere						
Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
251	28.6	28.6	0.00	0.24	1.0	60.3
		Dry-year total P deposition =		0.230		
		Average-year total P deposition =		0.240		
		Wet-year total P deposition =		0.268		
		(Barr Engineering 2007)				
Groundwater						
Lake Area [acre]	Groundwater Flux [m/yr]	Net Inflow cfs	Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
251	0.0	0.0	0	0	1.0	0
Internal						
Lake Area [acre]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
251	70.0			22.00	1.0	3,449
		Net Discharge [ac-ft/yr] =	314		Net Load [lb/yr] =	3,865

NOTES

[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

Average Lake Response Modeling for Albion Lake

Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)	
		C_P =	1.00 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	3,865 [lb/yr]
		Q (lake outflow) =	314 [ac-ft/yr]
		V (modeled lake volume) =	1,508 [ac-ft]
		T = V/Q =	4.80 [yr]
		P_i = W/Q =	4525 [ug/l]
Model Predicted In-Lake [TP]			**239.3 [ug/l]**
Observed In-Lake [TP]			**248.0 [ug/l]**
CHLOROPHYLL-A CONCENTRATION			
	$[\mathrm{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4	
		CB (Calibration factor) =	1.00 [--]
Model Predicted In-Lake [Chl-a]			**67.0 [ug/l]**
	$[\mathrm{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \mathrm{a})]}$	as f(TP, N, Flushing), Walker 1999, Model 1	
		CB (Calibration factor) =	1.00
	$B_x = \dfrac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	239 [ug/l]
		N (Total Nitrogen) =	2 [ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	6.5 [ug/l]
	$X_{pn} = \left[P^{-2} + \left(\frac{N - 150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	12.3 [ug/l]
		G (Kinematic factor) =	0.14 [--]
		F_s (Flushing Rate) =	0.21 [year^{-1}]
	$G = Z_{mix}(0.14 + 0.0039 F_s)$	Z_{mix} (Mixing Depth) =	3.28 [ft]
	$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - 0.015 \times [\mathrm{Chl}a]$	a (Non algal turbidity) =	-0.99 [m^{-1}]
		S (Secchi Depth) =	-4.07 [ft]
		Maximum lake depth =	8.99 [ft]
Model Predicted In-Lake [Chl-a]			**7.4 [ug/l]**
Observed In-Lake [Chl-a]			**60.0 [ug/l]**
SECCHI DEPTH			
	$SD = \dfrac{CS}{(\mathrm{a} + 0.015 \times [\mathrm{Chl}a])}$	as f(Chla), Walker (1999)	
		CS (Calibration factor) =	1.00 [--]
		a (Non algal turbidity) =	-0.99 [m^{-1}]
Model Predicted In-Lake SD			**-1.24 [m]**
Observed In-Lake SD			**0.80 [m]**
PHOSPHORUS SEDIMENTATION RATE			
	$P_{sed} = C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times [TP] \times V$		
		P_{sed} (phosphorus sedimentation) =	**3,661 [lb/yr]**
PHOSPHORUS OUTFLOW LOAD			
	$W - P_{sed}$ =		**204 [lb/yr]**

Average Load Reduction Table for Albion Lake

LOAD		MODELED IN-LAKE WATER QUALITY PARAMETERS					TROPHIC STATE INDICES (Carlson, 1980) FOR MODELED PARAMETERS			
REDUC-TION [%]	NET LOAD [lb]	[TP] [ug/L]	[Chla] [ug/L]	SD [ft]	P SEDIMEN-TATION [lb]	TP OUT-FLOW [lb]	TSI [TP] [--]	TSI [Chla] [--]	TSI SD [--]	TSI Avg. [--]
0%	**3,865**	239	6	-3.67	3661	**204**	83.1	48.8	N/A	**N/A**
5%	**3,672**	232	6	-3.67	3473	**199**	82.7	48.8	N/A	**N/A**
10%	**3,479**	225	6	-3.67	3286	**193**	82.3	48.8	N/A	**N/A**
15%	**3,285**	218	6	-3.67	3099	**186**	81.8	48.8	N/A	**N/A**
20%	**3,092**	211	6	-3.67	2912	**180**	81.3	48.8	N/A	**N/A**
25%	**2,899**	203	6	-3.67	2725	**174**	80.8	48.8	N/A	**N/A**
30%	**2,706**	195	6	-3.67	2539	**167**	80.2	48.8	N/A	**N/A**
35%	**2,512**	187	6	-3.67	2352	**160**	79.6	48.8	N/A	**N/A**
40%	**2,319**	179	6	-3.67	2166	**153**	78.9	48.8	N/A	**N/A**
45%	**2,126**	170	6	-3.67	1980	**145**	78.2	48.8	N/A	**N/A**
50%	**1,933**	161	6	-3.66	1795	**138**	77.4	48.8	N/A	**N/A**
55%	**1,739**	152	6	-3.66	1610	**130**	76.6	48.8	N/A	**N/A**
60%	**1,546**	142	6	-3.66	1425	**121**	75.6	48.7	N/A	**N/A**
65%	**1,353**	131	6	-3.66	1241	**112**	74.5	48.7	N/A	**N/A**
70%	**1,160**	120	6	-3.66	1057	**102**	73.2	48.7	N/A	**N/A**
75%	**966**	108	6	-3.66	874	**92**	71.6	48.7	N/A	**N/A**
80%	**773**	95	6	-3.66	692	**81**	69.8	48.7	N/A	**N/A**
85%	**580**	80	6	-3.66	512	**68**	67.3	48.6	N/A	**N/A**
90%	**387**	63	6	-3.66	333	**53**	63.8	48.6	N/A	**N/A**
95%	**193**	41	6	-3.64	158	**35**	57.6	48.2	N/A	**N/A**

Goal Loading Summary for Albion Lake

	Water Budgets			Phosphorus Loading		

Inflow from Drainage Areas

Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1 Albion	838	**4.5**	314	400.0	**0.37**	126
2					1.0	
3					1.0	
4					1.0	
5					1.0	
Summation	838	4.5	314	400.0		126.4

Failing Septic Systems

Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1 Albion	838	13	**0%**	4.2	0.0	0.0
2						
3						
4						
5						
Summation	838	13	0%		0.0	0.0

Inflow from Upstream Lakes

Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	0	4.5	0.0	0.0	1.0	0
2				-	1.0	
3				-	1.0	
Summation			0	0.0		0

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
251	**28.6**	28.6	0.00	0.24	1.0	60.3
		Dry-year total P deposition =		0.230		
		Average-year total P deposition =		0.240		
		Wet-year total P deposition =		0.268		
		(Barr Engineering 2007)				

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]	Net Inflow cfs	Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
251	0.0	0.0	0	0	1.0	0

Internal

Lake Area [acre]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
251	70.0			22.00	**0.05**	172
		Net Discharge [ac-ft/yr] =	**314**		**Net Load [lb/yr] =**	**359**

NOTES

[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

2005 Lake Response Modeling for Albion Lake

Modeled Parameter	Equation	Parameters	Value [Units]

TOTAL IN-LAKE PHOSPHORUS CONCENTRATION

$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$

as f(W,Q,V) from Canfield & Bachmann (1981)

Parameters	Value [Units]
C_P =	1.00 [--]
C_{CB} =	0.162 [--]
b =	0.458 [--]
W (total P load = inflow + atm.) =	359 [lb/yr]
Q (lake outflow) =	314 [ac-ft/yr]
V (modeled lake volume) =	1,508 [ac-ft]
T = V/Q =	4.80 [yr]
P_i = W/Q =	420 [ug/l]
Model Predicted In-Lake [TP]	**60 [ug/l]**
Observed In-Lake [TP]	**248.0 [ug/l]**

CHLOROPHYLL-A CONCENTRATION

$$[\mathrm{Chl}a] = CB \times 0.28 \times [TP]$$

as f(TP), Walker 1999, Model 4

Parameters	Value [Units]
CB (Calibration factor) =	1.00 [--]
Model Predicted In-Lake [Chl-a]	**16.7 [ug/l]**

$$[\mathrm{Chl}a] = \frac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \mathrm{a})]}$$

$$B_x = \frac{X_{pn}^{1.33}}{4.31}$$

$$X_{pn} = \left[P^{-2} + \left(\frac{N-150}{12}\right)^{-2}\right]^{-0.5}$$

$$G = Z_{mix}(0.14 + 0.0039F_s)$$

$$F_s = \frac{Q}{V}$$

$$a = \frac{1}{SD} - 0.015 \times [\mathrm{Chl}a]$$

as f(TP, N, Flushing), Walker 1999, Model 1

Parameters	Value [Units]
CB (Calibration factor) =	1.00
P (Total Phosphorus) =	60 [ug/l]
N (Total Nitrogen) =	2 [ug/l]
B_x (Nutrient-Potential Chl-a conc.) =	6.4 [ug/l]
X_{pn} (Composite nutrient conc.)=	12.1 [ug/l]
G (Kinematic factor) =	0.14 [--]
F_s (Flushing Rate) =	0.21 [$year^{-1}$]
Z_{mix} (Mixing Depth) =	3.28 [ft]
a (Non algal turbidity) =	-0.99 [m^{-1}]
S (Secchi Depth) =	-4.05 [ft]
Maximum lake depth =	8.99 [ft]
Model Predicted In-Lake [Chl-a]	**7.2 [ug/l]**
Observed In-Lake [Chl-a]	**60.0 [ug/l]**

SECCHI DEPTH

$$SD = \frac{CS}{(\mathrm{a} + 0.015 \times [\mathrm{Chl}a])}$$

as f(Chla), Walker (1999)

Parameters	Value [Units]
CS (Calibration factor) =	1.00 [--]
a (Non algal turbidity) =	-0.99 [m^{-1}]
Model Predicted In-Lake SD	**-1.23 [m]**
Observed In-Lake SD	**0.80 [m]**

PHOSPHORUS SEDIMENTATION RATE

$$P_{sed} = C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times [TP] \times V$$

P_{sed} (phosphorus sedimentation) = 308 [lb/yr]

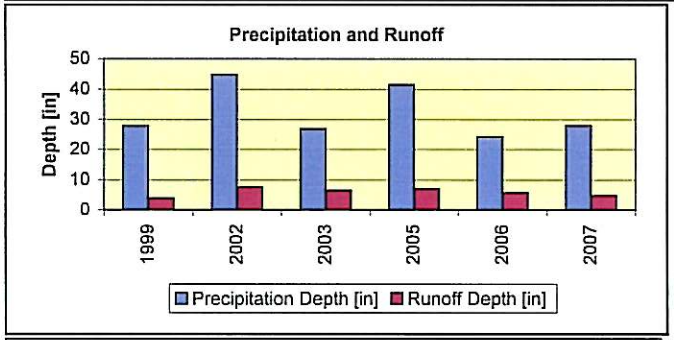
PHOSPHORUS OUTFLOW LOAD

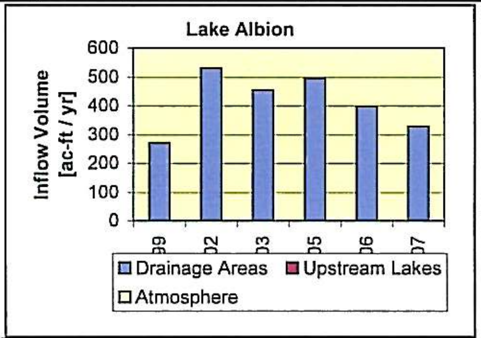
W-P_{sed} = **51 [lb/yr]**

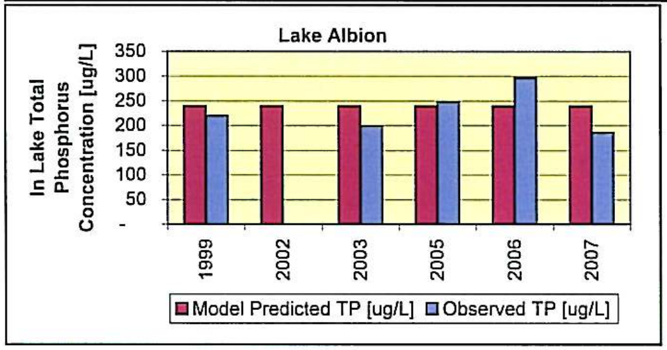
Goal Load Reduction Table for Albion Lake

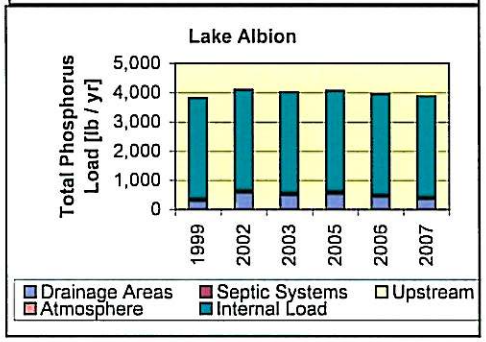
LOAD		MODELED IN-LAKE WATER QUALITY PARAMETERS					TROPHIC STATE INDICES (Carlson, 1980) FOR MODELED PARAMETERS			
REDUCTION [%]	NET LOAD [lb]	[TP] [ug/L]	[Chla] [ug/L]	SD [ft]	P SEDIMENTATION [lb]	TP OUTFLOW [lb]	TSI [TP] [--]	TSI [Chla] [--]	TSI SD [--]	TSI Avg. [--]
0%	**359**	60	6	-3.66	308	**51**	63.1	48.5	N/A	**N/A**
5%	**341**	58	6	-3.66	292	**50**	62.7	48.5	N/A	**N/A**
10%	**323**	56	6	-3.65	275	**48**	62.2	48.5	N/A	**N/A**
15%	**305**	54	6	-3.65	259	**46**	61.7	48.5	N/A	**N/A**
20%	**287**	52	6	-3.65	243	**45**	61.2	48.5	N/A	**N/A**
25%	**269**	50	6	-3.65	227	**43**	60.6	48.4	N/A	**N/A**
30%	**251**	48	6	-3.65	210	**41**	60.0	48.4	N/A	**N/A**
35%	**233**	46	6	-3.65	194	**39**	59.3	48.4	N/A	**N/A**
40%	**216**	44	6	-3.65	178	**37**	58.6	48.3	N/A	**N/A**
45%	**198**	41	6	-3.65	162	**35**	57.8	48.3	N/A	**N/A**
50%	**180**	39	6	-3.64	146	**33**	57.0	48.2	N/A	**N/A**
55%	**162**	36	6	-3.64	130	**31**	56.0	48.1	N/A	**N/A**
60%	**144**	34	6	-3.64	115	**29**	54.9	48.0	N/A	**N/A**
65%	**126**	31	6	-3.63	99	**27**	53.7	47.9	N/A	**N/A**
70%	**108**	28	6	-3.62	84	**24**	52.3	47.7	N/A	**N/A**
75%	**90**	25	6	-3.62	68	**21**	50.6	47.4	N/A	**N/A**
80%	**72**	22	5	-3.60	53	**18**	48.5	47.0	N/A	**N/A**
85%	**54**	18	5	-3.58	39	**15**	45.7	46.3	N/A	**N/A**
90%	**36**	14	4	-3.54	24	**12**	41.7	44.9	N/A	**N/A**
95%	**18**	8	3	-3.47	11	**7**	34.7	41.3	N/A	**N/A**

Lake Albion	Source	*1999*	*2002*	*2003*	*2005*	*2006*	*2007*
Precipitation Depth [in]		27.7	44.7	26.8	41.5	24.2	27.8
Runoff Depth [in]		3.9	7.6	6.5	7.1	5.7	4.7
	Residence Time [yr]	5.54	2.84	3.32	3.04	3.79	4.60
Inflow Volume [ac-ft / yr]	Drainage Areas	272	531	454	496	398	328
	Upstream Lakes	-	-	-	-	-	-
	Atmosphere	-	-	-	-	-	-
	TOTAL =	**272**	**531**	**454**	**496**	**398**	**328**
Total Phosphorus Load [lb / yr]	Drainage Areas	296	577	494	539	433	357
	Septic Systems	14	14	14	14	14	14
	Upstream Lakes	-	-	-	-	-	-
	Atmosphere	60	67	60	67	58	60
	Internal Load	3,449	3,449	3,449	3,449	3,449	3,449
	TOTAL =	**3,820**	**4,108**	**4,017**	**4,070**	**3,954**	**3,880**
Model Results	Model Predicted TP [ug/L]	239	239	239	239	239	239
	Observed TP [ug/L]	220	-	199	248	296	186
	Phosphorus Sedimentation [lb]	3,642	3,762	3,722	3,747	3,695	3,667
	TOTAL OUTFLOW [lb] =	***177***	***345***	***295***	***322***	***259***	***213***
Load Factors:	*Drainage Area [-]*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*
	Release Rate [mg/m2-day]	*22*	*22*	*22*	*22*	*22*	*22*
	Anoxic factor [day]	*70*	*70*	*70*	*70*	*70*	*70*









Average Loading Summary for Henshaw Lake

Water Budgets				Phosphorus Loading		

Inflow from Drainage Areas

Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1 Henshaw	628	4.5	235	400.0	1.0	256
2					1.0	
3					1.0	
4					1.0	
5					1.0	
Summation	628	4.5	235	400.0		256.1

Failing Septic Systems

Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1 Henshaw	628	15	25%	4.2	0.0	15.8
2						
3						
4						
5						
Summation	628	15	25%		0.0	15.8

Inflow from Upstream Lakes

Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	0	4.5	0.0	0.0	1.0	0
2				-	1.0	
3				-	1.0	
Summation			0	0.0		0

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
271	28.6	28.6	0.00	0.24	1.0	65.1
			Dry-year total P deposition =	0.230		
			Average-year total P deposition =	0.240		
			Wet-year total P deposition =	0.268		
			(Barr Engineering 2007)			

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]	Net Inflow cfs	Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
271	0.0	0.0	0	0	1.0	0

Internal

Lake Area [acre]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
271	70.0			20.00	1.0	3,386
		Net Discharge [ac-ft/yr] =	235		Net Load [lb/yr] =	3,723

NOTES

[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

Average Lake Response Modeling for Henshaw Lake

Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)	
		C_P =	1.00 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	3,723 [lb/yr]
		Q (lake outflow) =	235 [ac-ft/yr]
		V (modeled lake volume) =	1,094 [ac-ft]
		T = V/Q =	4.65 [yr]
		P_i = W/Q =	5816 [ug/l]
Model Predicted In-Lake [TP]			**280.5 [ug/l]**
Observed In-Lake [TP]			**281.0 [ug/l]**
CHLOROPHYLL-A CONCENTRATION			
	$[\mathrm{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4	
		CB (Calibration factor) =	1.00 [--]
Model Predicted In-Lake [Chl-a]			**78.5 [ug/l]**
	$[\mathrm{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times a)]}$	as f(TP, N, Flushing), Walker 1999, Model 1	
		CB (Calibration factor) =	1.00
	$B_x = \dfrac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	280 [ug/l]
		N (Total Nitrogen) =	10 [ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	6.1 [ug/l]
	$X_{pn} = \left[P^{-2} + \left(\dfrac{N - 150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	11.7 [ug/l]
		G (Kinematic factor) =	0.14 [--]
		F_s (Flushing Rate) =	0.22 [year^{-1}]
	$G = Z_{mix}(0.14 + 0.0039 F_s)$	Z_{mix} (Mixing Depth) =	3.28 [ft]
	$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - 0.015 \times [\mathrm{Chl}a]$	a (Non algal turbidity) =	-0.67 [m^{-1}]
		S (Secchi Depth) =	-6.47 [ft]
		Maximum lake depth =	8.01 [ft]
Model Predicted In-Lake [Chl-a]			**6.6 [ug/l]**
Observed In-Lake [Chl-a]			**144.0 [ug/l]**
SECCHI DEPTH			
	$SD = \dfrac{CS}{(a + 0.015 \times [\mathrm{Chl}a])}$	as f(Chla), Walker (1999)	
		CS (Calibration factor) =	1.00 [--]
		a (Non algal turbidity) =	-0.67 [m^{-1}]
Model Predicted In-Lake SD			**-1.97 [m]**
Observed In-Lake SD			**0.50 [m]**
PHOSPHORUS SEDIMENTATION RATE			
	$P_{sed} = C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times [TP] \times V$		
		P_{sed} (phosphorus sedimentation) =	**3,543 [lb/yr]**
PHOSPHORUS OUTFLOW LOAD			
	W-P_{sed} =		**180 [lb/yr]**

Average Load Reduction Table for Henshaw Lake

LOAD		MODELED IN-LAKE WATER QUALITY PARAMETERS					TROPHIC STATE INDICES (Carlson, 1980) FOR MODELED PARAMETERS			
REDUCTION [%]	NET LOAD [lb]	[TP] [ug/L]	[Chla] [ug/L]	SD [ft]	P SEDIMENTATION [lb]	TP OUTFLOW [lb]	TSI [TP] [--]	TSI [Chla] [--]	TSI SD [--]	TSI Avg. [--]
0%	**3,723**	280	6	-5.64	3543	**180**	85.4	48.1	N/A	**N/A**
5%	**3,537**	272	6	-5.64	3362	**174**	85.0	48.1	N/A	**N/A**
10%	**3,350**	264	6	-5.64	3181	**169**	84.6	48.1	N/A	**N/A**
15%	**3,164**	256	6	-5.64	3001	**164**	84.1	48.1	N/A	**N/A**
20%	**2,978**	247	6	-5.64	2820	**158**	83.6	48.1	N/A	**N/A**
25%	**2,792**	238	6	-5.64	2639	**153**	83.1	48.1	N/A	**N/A**
30%	**2,606**	229	6	-5.64	2459	**147**	82.5	48.1	N/A	**N/A**
35%	**2,420**	220	6	-5.64	2279	**141**	81.9	48.1	N/A	**N/A**
40%	**2,234**	210	6	-5.64	2099	**134**	81.3	48.1	N/A	**N/A**
45%	**2,048**	200	6	-5.64	1920	**128**	80.5	48.1	N/A	**N/A**
50%	**1,861**	189	6	-5.64	1740	**121**	79.8	48.1	N/A	**N/A**
55%	**1,675**	178	6	-5.64	1561	**114**	78.9	48.1	N/A	**N/A**
60%	**1,489**	166	6	-5.63	1383	**107**	77.9	48.1	N/A	**N/A**
65%	**1,303**	154	6	-5.63	1204	**99**	76.8	48.1	N/A	**N/A**
70%	**1,117**	141	6	-5.63	1027	**90**	75.5	48.1	N/A	**N/A**
75%	**931**	127	6	-5.63	849	**81**	74.0	48.1	N/A	**N/A**
80%	**745**	111	6	-5.63	673	**71**	72.1	48.0	N/A	**N/A**
85%	**558**	94	6	-5.63	498	**60**	69.7	48.0	N/A	**N/A**
90%	**372**	74	6	-5.62	325	**47**	66.2	48.0	N/A	**N/A**
95%	**186**	48	6	-5.61	155	**31**	60.1	47.8	N/A	**N/A**

Goal Loading Summary for Henshaw Lake

Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas						
Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1 Henshaw	628	**4.5**	235	400.0	**0.12**	31
2					1.0	
3					1.0	
4					1.0	
5					1.0	
Summation	628	4.5	235	400.0		30.7
Failing Septic Systems						
Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1 Henshaw	628	15	**0%**	4.2	0.0	0.0
2						
3						
4						
5						
Summation	628	15	0%		0.0	0.0
Inflow from Upstream Lakes						
Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	0	4.5	0.0	0.0	1.0	0
2				-	1.0	
3				-	1.0	
Summation			0	0.0		0
Atmosphere						
Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
271	**28.6**	28.6	0.00	0.24	1.0	65.1
			Dry-year total P deposition =	0.230		
			Average-year total P deposition =	0.240		
			Wet-year total P deposition =	0.268		
			(Barr Engineering 2007)			
Groundwater						
Lake Area [acre]	Groundwater Flux [m/yr]	Net Inflow cfs	Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
271	0.0	0.0	0	0	1.0	0
Internal						
Lake Area [acre]	Anoxic Factor [days]			Release Rate [mg/m²-day]	Calibration Factor [--]	Load [lb/yr]
271	70.0			20.00	**0.05**	169
			Net Discharge [ac-ft/yr] = 235		**Net Load [lb/yr] =**	**265**

NOTES

[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

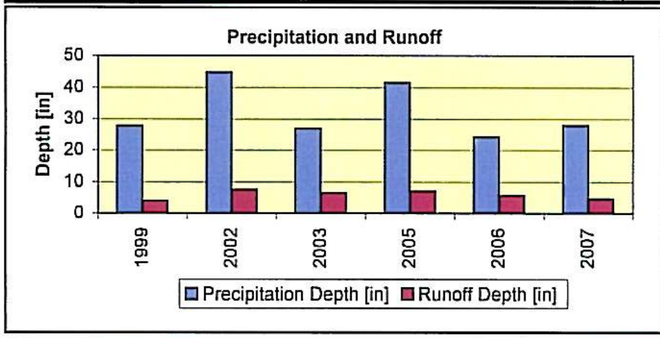
2005 Lake Response Modeling for Henshaw Lake

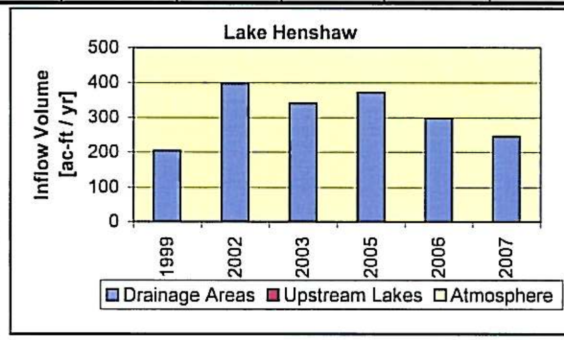
Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)	
		C_P =	1.00 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	265 [lb/yr]
		Q (lake outflow) =	235 [ac-ft/yr]
		V (modeled lake volume) =	1,094 [ac-ft]
		T = V/Q =	4.65 [yr]
		P_i = W/Q =	414 [ug/l]
Model Predicted In-Lake [TP]			**60 [ug/l]**
Observed In-Lake [TP]			**281.0 [ug/l]**
CHLOROPHYLL-A CONCENTRATION			
	$[\mathrm{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4	
		CB (Calibration factor) =	1.00 [--]
Model Predicted In-Lake [Chl-a]			**16.8 [ug/l]**
	$[\mathrm{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times a)]}$	as f(TP, N, Flushing), Walker 1999, Model 1	
		CB (Calibration factor) =	1.00
	$B_x = \dfrac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	60 [ug/l]
		N (Total Nitrogen) =	10 [ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	5.9 [ug/l]
	$X_{pn} = \left[P^{-2} + \left(\frac{N-150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	11.5 [ug/l]
		G (Kinematic factor) =	0.14 [--]
		F_s (Flushing Rate) =	0.22 [year^{-1}]
	$G = Z_{mix}(0.14 + 0.0039F_s)$	Z_{mix} (Mixing Depth) =	3.28 [ft]
	$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - 0.015 \times [\mathrm{Chl}a]$	a (Non algal turbidity) =	-0.67 [m^{-1}]
		S (Secchi Depth) =	-6.42 [ft]
		Maximum lake depth =	8.01 [ft]
Model Predicted In-Lake [Chl-a]			**6.4 [ug/l]**
Observed In-Lake [Chl-a]			**144.0 [ug/l]**
SECCHI DEPTH			
	$SD = \dfrac{CS}{(a + 0.015 \times [\mathrm{Chl}a])}$	as f(Chla), Walker (1999)	
		CS (Calibration factor) =	1.00 [--]
		a (Non algal turbidity) =	-0.67 [m^{-1}]
Model Predicted In-Lake SD			**-1.96 [m]**
Observed In-Lake SD			**0.50 [m]**
PHOSPHORUS SEDIMENTATION RATE			
	$P_{sed} = C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times [TP] \times V$		
		P_{sed} (phosphorus sedimentation) =	**227 [lb/yr]**
PHOSPHORUS OUTFLOW LOAD			
	W-P_{sed} =		**39 [lb/yr]**

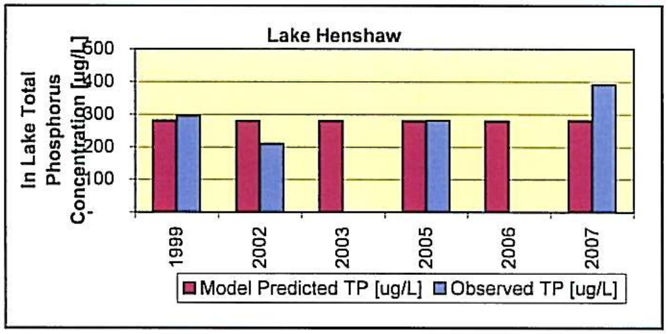
Goal Load Reduction Table for Henshaw Lake

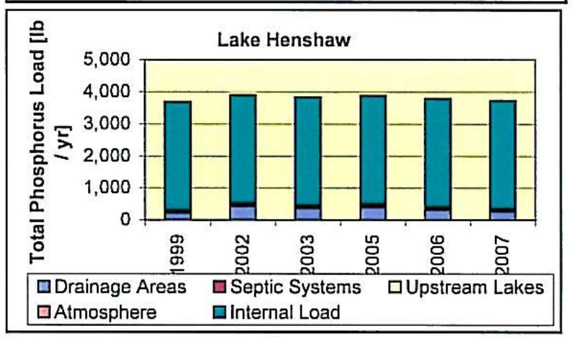
LOAD		MODELED IN-LAKE WATER QUALITY PARAMETERS					TROPHIC STATE INDICES (Carlson, 1980) FOR MODELED PARAMETERS			
REDUCTION [%]	NET LOAD [lb]	[TP] [ug/L]	[Chla] [ug/L]	SD [ft]	P SEDIMENTATION [lb]	TP OUTFLOW [lb]	TSI [TP] [--]	TSI [Chla] [--]	TSI SD [--]	TSI Avg. [--]
0%	**265**	60	6	-5.62	227	**39**	63.2	47.9	N/A	**N/A**
5%	**252**	58	6	-5.62	215	**37**	62.8	47.9	N/A	**N/A**
10%	**239**	56	6	-5.61	202	**36**	62.3	47.8	N/A	**N/A**
15%	**225**	54	6	-5.61	190	**35**	61.8	47.8	N/A	**N/A**
20%	**212**	52	6	-5.61	178	**34**	61.3	47.8	N/A	**N/A**
25%	**199**	50	6	-5.61	167	**32**	60.7	47.8	N/A	**N/A**
30%	**186**	48	6	-5.61	155	**31**	60.1	47.8	N/A	**N/A**
35%	**172**	46	6	-5.60	143	**30**	59.4	47.7	N/A	**N/A**
40%	**159**	44	6	-5.60	131	**28**	58.7	47.7	N/A	**N/A**
45%	**146**	42	6	-5.60	119	**27**	57.9	47.6	N/A	**N/A**
50%	**133**	39	6	-5.59	107	**25**	57.0	47.6	N/A	**N/A**
55%	**119**	37	6	-5.59	96	**23**	56.1	47.5	N/A	**N/A**
60%	**106**	34	6	-5.58	84	**22**	55.0	47.4	N/A	**N/A**
65%	**93**	31	5	-5.57	73	**20**	53.8	47.3	N/A	**N/A**
70%	**80**	28	5	-5.55	61	**18**	52.4	47.1	N/A	**N/A**
75%	**66**	25	5	-5.54	50	**16**	50.6	46.9	N/A	**N/A**
80%	**53**	22	5	-5.51	39	**14**	48.5	46.5	N/A	**N/A**
85%	**40**	18	5	-5.46	28	**11**	45.8	45.9	N/A	**N/A**
90%	**27**	14	4	-5.39	18	**9**	41.8	44.6	N/A	**N/A**
95%	**13**	8	3	-5.23	8	**5**	34.7	41.1	N/A	**N/A**

Lake Henshaw	Source	1999	2002	2003	2005	2006	2007
Precipitation Depth [in]		27.7	44.7	26.8	41.5	24.2	27.8
Runoff Depth [in]		3.9	7.6	6.5	7.1	5.7	4.7
	Residence Time [yr]	5.4	2.8	3.2	2.9	3.7	4.4
Inflow Volume [ac-ft / yr]	Drainage Areas	204	398	340	371	298	246
	Upstream Lakes	-	-	-	-	-	-
	Atmosphere	-	-	-	-	-	-
	TOTAL =	**204**	**398**	**340**	**371**	**298**	**246**
Total Phosphorus Load [lb / yr]	Drainage Areas	222	432	370	404	324	267
	Septic Systems	16	16	16	16	16	16
	Upstream Lakes	-	-	-	-	-	-
	Atmosphere	65	73	65	73	62	65
	Internal Load	3,386	3,386	3,386	3,386	3,386	3,386
	TOTAL =	**3,689**	**3,907**	**3,837**	**3,878**	**3,788**	**3,734**
Model Results	Model Predicted TP [ug/L]	281	279	279	279	280	280
	Observed TP [ug/L]	295	210	-	281	-	390
	Phosphorus Sedimentation [lb]	3,533	3,605	3,578	3,596	3,562	3,547
	TOTAL OUTFLOW [lb] =	***156***	***302***	***258***	***282***	***227***	***187***
Load Factors:	*Drainage Area [-]*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*
	Release Rate [mg/m2-day]	*20*	*20*	*20*	*20*	*20*	*20*
	Anoxic factor [day]	*70*	*70*	*70*	*70*	*70*	*70*









Appendix C

CRWD's Annual Monitoring Program

MEMORANDUM

TO: **Clearwater River Watershed District Board of Managers**

FROM: **Norman C. Wenck**
Engineer for the District

DATE: **February 11, 2009**

RE: **Proposed 2009 Water Quality Monitoring Program**

Introduction

The Clearwater River Watershed District conducts annual water quality monitoring at selected lakes and selected locations on streams. The District's proposed 2009 program is intended to provide data throughout the District.

The 2009 proposed lake monitoring follows the long-term plan as shown in Table 1 and Figure 1. The proposed stream monitoring sites together with laboratory and field parameters are shown in Table 2.

Lake Monitoring

It is recommended that the District's 2009 lake monitoring include all of the lakes in the District as shown on Table 1. The sampling of all of the lakes provides a District-wide look at lake water quality. It is also recommended that bottom water samples be collected at all of the sampled lakes. The proposed stations and the parameters to be monitored are shown on Table 2. Citizens also monitor approximately 10 lakes for secchi depth. The Cedar Lake watershed and its upper watershed lakes will be monitored for the third year under a special three year program as part of the Cedar, Albion, Swartout, Henshaw Improvement Project No 06-1.

Stream Monitoring

The Clearwater River will be monitored twice a month from April-June and once a month from July-September at station CR28.2. A tributary to the Clearwater River will be monitored once a month from April-September at station T B 33.2 near Watkins. Warner Creek will be monitored once a month from April-September at WR 0.2. These stations will be monitored for water quality and flow. Parameters are total phosphorus, total suspended solids, total nitrogen and soluble reactive phosphorus. CR 28.2 and T B33.2 will also be monitored for *E. coli* bacteria.

Estimated Cost

This proposed basic program is estimated to cost $26,700.

Recommended Supplemental Monitoring

In addition to the basic program, it is recommended that supplemental monitoring efforts be considered in 2009. The proposed supplemental monitoring efforts would allow the District to track the success of individual projects or to investigate specific water quality concerns.

Supplemental Monitoring Task 1: Collect additional temperature/dissolved oxygen profiles from selected lakes in the District to better characterize the anoxic factor in lakes.
It is recommended that the District collect profile data twice monthly from May to October in Clear, Betsy, Scott, Union, Louisa, and Marie Lakes. Since the lakes are already being sampled monthly from June to September, this additional task would add eight visits to each lake. The cost of this additional task is approximately $1,200.

Supplemental Monitoring Task 2: Collect lake bottom sediment samples to quantify phosphorus release rates in selected District Lakes.
It is recommended that the District collect lake sediment samples from Clear, Betsy, Scott, Union, Louisa, and Marie Lakes on an one lake per year basis. The cost of this task is approximately $3,500 per lake.

Supplemental Monitoring Task 3: Maintain two continuous flow measurement stations in the District.
It is recommended that the District install pressure transducers at the watershed outlet and midpoint to measure continuous flows and better characterize annual runoff. The approximate cost of this task, including equipment purchase is $4,500.

Equipment Purchase
The current equipment used to collect lake profile data and gauge stream flow is in need of replacement. New equipment would improve the efficiency of data collection and improve the quality of the data. The cost of a new digital temperature/dissolved oxygen meter is approximately $950. The cost of a new digital velocity meter to be used in stream flow gauging is approximately $750.

Summary
The proposed monitoring program continues the program in place since 1981, coordinates with other programs, and reflects input from the Board and citizens. Please feel free to call me at 763-479-4201 or Rebecca Kluckhohn at 763-479-4224 with any questions or comments that you may have.

TABLE 1
PROPOSED LONG-TERM WATER QUALITY MONITORING PLAN FOR CRWD LAKES

LAKE STATIONS[1]	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Clearwater Lake:														
Clearwater East	X	X	X	X	X	X	X	X	DNR		X		X	
Clearwater West	X	X	X	X	X	X	X	X	DNR	X		X	X	X
Main Stem Lakes:														
Augusta	X		X		X		X		DNR		X		X	
Louisa	X		X		X		X		TMDL/ DNR	TMDL	X		X	
Caroline		X				X		X	DNR	X		X	X	X
Scott		X	X			X		X		X		X	X	X
Marie		X		X		X		X	DNR	X		X	X	X
Betsy	X		X		X		X		X		X		X	
Other Lakes:														
Cedar			X		X		X	X	X	X		X(2)	X(2)	X
Pleasant	X		X	X				X	MPCA		X	X(3)	X	X
School Section	X		X	X				X			X		X	X
Nixon	X		X		X			X			X	X	X	X
Otter	X		X		X			X			X		X	X
Bass		X	X		X				MPCA/ DNR	X		X(3)	X	
Clear		X	X	X			X		X			X	X	X
Union		X	X			X			MPCA			X	X	
Henshaw		X	X			X			X		X	X(2)	X(2)	
Little Mud			X			X				X			X	
Wiegand			X			X			X				X	
Swartout			X				X		X	X		X(2)	X(2)	
Albion			X				X		X	X		X(2)	X(2)	
Grass			X				X		DNR			X	X	
Number of Lakes Monitored W/ CRWD Funding	9	9	20	6	9	9	10	10	7	10	9	14	22	10

Note:
(1) Lake selection based on total lake size ranking scores (Lake Priority Ranking, 1990)
(2) Part of Project #06-1
(3) Added to assess trends

TABLE 2
Proposed 2009 CRWD Monitoring Plan Summary

Category	2009Schedule	Station	Parameters
Lakes:	June 1-5, July 6-10, August 3-7, September 7-11	The CRWD will monitor Clearwater (West), Clearwater (East), Augusta, Louisa, Caroline, Scott, Marie, Betsy, Pleasant, School Section, Nixon, Otter, Bass, Clear, Union, Little Mud, Wiegand, Grass	Field: Secchi depth, DO and temperature profiles
		Cedar, Albion, Swartout, and Hensaw Lakes will be monitored under Project No. 06-1	Lab: surface samples for total phosphorus, soluble reactive phosphorus, total nitrogen, chlorophyll-a Bottom samples for total phosphorus, soluble reactive phosphorus, and total iron.
			Citizen Secchi: 10 sites not listed here
Streams:	Twice monthly April-June, monthly July-September	CR 28.2	Field: flows, DO and temperature Lab: total phosphorus, soluble reactive phosphorus, total suspended solids, Total Nitrogen, E. coli
	Monthly April-September	TB 33.2	Field: flows, DO and temperature Lab: total phosphorus, soluble reactive phosphorus, total suspended solids, Total Nitrogen, E. coli
	Monthly April-September	WR0.2	Field: flows, DO and temperature Lab: total phosphorus, soluble reactive phosphorus, total suspended solids, Total Nitrogen
	Bi-weekly	River Stage at CR10.5	
Precipitation:	Daily	Corinna, Kimball, Watkins	
		Cedar, Albion, Swartout, Henshaw, Project #06-1	Tributaries Field: DO, temperature, conductivity, pH profiles; Lab: total phosphorus, soluble reactive phosphorus, TSS, TN Lakes Field: Secchi, DO, temperature profiles Lab: surface: total phosphorus, soluble reactive phosphorus, total nitrogen, chlorophyll-a bottom: total phosphorus, soluble reactive phosphorus, total iron