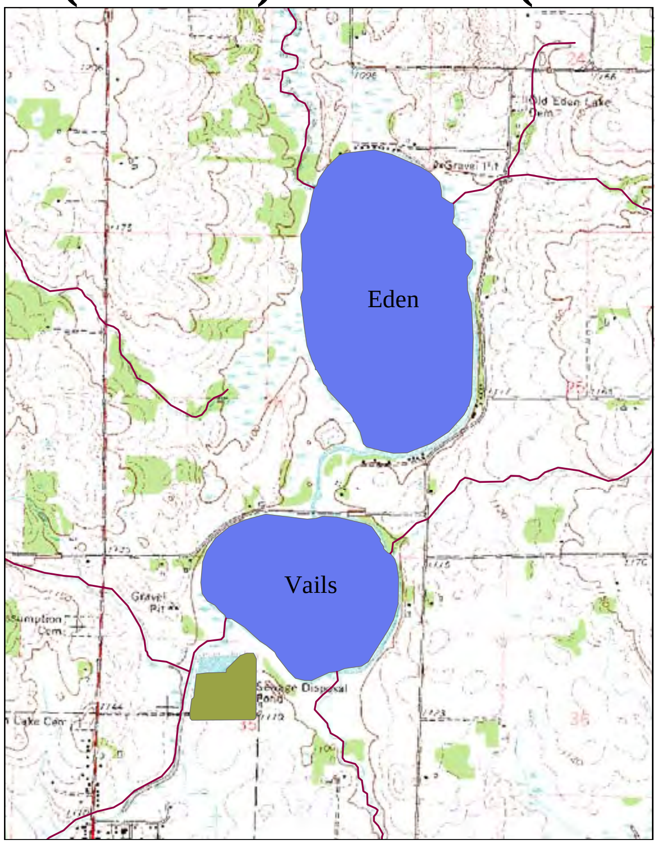
Lake Assessment Program 2004

Eden (73-0150) and Vails (73-0151)



Stearns County

Minnesota Pollution Control Agency

Environmental Analysis and Outcomes Division
Water Assessment and Environmental Information Section

April 2005

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Matt Lindon and Steve Heiskary

In cooperation with

Stearns County

April 2005

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Summary

Eden and Vails were two of three lakes monitored by the Minnesota Pollution Control Agency (MPCA) in Stearns County as part of our Lake Assessment Program (LAP) in 2004. The other lake studied in Stearns County in 2004 was Pelican (73-0118) which is addressed in a separate report. Members of the Eden Lake Association (Association) applied to have both lakes assessed in 2003 with concerns about: algae blooms, winter kill, the city and agriculture runoff. Participants in this overall study effort included Steve Heiskary, Matt Lindon (MPCA), Rolland Stanke, Budd Binsfeld, Mike Linn and Mike and Sandy Weller (Eden Lake Association). Land use and watershed information for Eden and Vails Lake was assembled by Stearns County. Phytoplankton analysis was conducted by Dr. Howard Markus, MPCA. Zooplankton was analyzed by Dr. Bruce Monson, MPCA

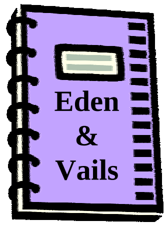
The LAP is designed to assist lake associations or municipalities in the collection and analysis of baseline water quality data, in order to assess the trophic status of their lakes. The general work plan for LAP includes association participation in the Citizen Lake-Monitoring Program (CLMP), cooperative examination of land use and drainage patterns in the watershed of the lake, and an assessment of the data collected by MPCA staff. The report also attempts to introduce and discuss factors that may be affecting water quality on the lakes.

Samples were collected monthly from May through September on both lakes. A summary of data from 2004 and available historical data follows. Summer mean epilimnetic (upper well-mixed layer) concentrations in both lakes were compared to the “typical” range for ecoregion-reference lakes in the North Central Hardwood Forests (CHF) ecoregion. The ecoregion framework provides a basis for placing data from these lakes in perspective to other lakes in the same ecoregion. Water quality parameters sampled, such as total phosphorus, chlorophyll-a (Chl-a) and Secchi transparency, help to characterize the trophic status (will be defined later) of a lake. Models were used to predict water quality of the lakes, based on lake and watershed characteristics, lake shape and other conditions. The models results were than compared to the observed water quality of the lakes. Historical water quality data for each lake was collected and analyzed for trends.

In general, the water quality in Eden and Vails Lakes is poor. While Secchi transparency for both lakes was in the typical range of the CHF ecoregion reference lakes, high total phosphorus (TP) and Chl-a classify the lakes as hypereutrophic (extremely nutrient rich). Several models showed Vails to be higher than predicted in both TP and Chl-a. The water quality for Eden was on with the model predictions with the exception of Chl-a, where the 2004 results were better than predicted. Both lakes TP were much higher than predicted background or inferred pre-European conditions. An analysis of historic Secchi data of Eden and Vails Lakes suggests fairly stable conditions; however over the last six years both lakes show a trend of increased transparency. Continued monitoring through the CLMP will be valuable for assessing future changes in the quality of both lakes. Historical chemistry data is insufficient to determine a trend for either lake.

Some of the more obvious sources of nutrient over enrichment for Eden and Vails lakes’ include: non-point source runoff from a large agriculturally dominated watershed, along with previous and current waste water impacts. Many things can be done to better understand the lakes, as well as help improve them. Included in this report are recommendations and goals to assist with current and future concerns.

Recommendations

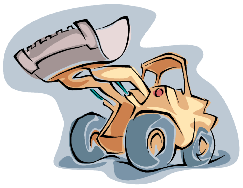


The Association should develop a plan, referred to as a ***Lake Management Plan***; the plan should incorporate a series of activities in a prioritized fashion; which will aid in the long-term protection and improvement of the lake. The plan should be developed cooperatively by a committee consisting of representatives from state agencies (e.g., the Minnesota Department of Natural Resources [MDNR], Minnesota Board of Water and Soil Resources [BWSR], and MPCA), local units of government, and association members. A guide to creating a Lake Management Plan can be found at Minnesota Shoreland Management Resources Guide web site http://www.shorelandmanagement.org/depth/plan.pdf. Following are some activities could be included in the plan:

a) Monitoring

The Association should continue to participate in the CLMP and related monitoring programs. Data from this program provides an excellent basis for assessing long-term and year-to-year variations in algal productivity, i.e., trophic status of the lakes. Long-term Secchi data for both lakes suggests fairly stable summer mean transparency. It is essential that CLMP monitoring is continued on both lakes as a base line for lake monitoring. Ideally, measurements should be taken weekly during the summer at consistent sites on the lakes. Though lake transparency is not a major concern at this time, TP levels indicate a latent (hidden) potential from increased algae abundance and lower transparency.

b) Land Development



Further development or land use change in the watershed should occur in a manner that minimizes water quality impacts on the lakes.

- In the shore land areas, setback provisions should be strictly followed.
- MDNR and county shore land regulations will be important in this regard.
- Stormwater regulations should be adhered to during and following any major construction/development activities in the watershed.
- Limiting the amount of impervious surfaces can have beneficial affects as well, in terms of reduced runoff and P loading.
- Activities in the total watershed that change drainage patterns, such as wetland removal or major alterations in lake usage, should be discouraged unless they are carefully planned and adequately controlled.
- Restoring or improving wetlands in the watershed may also be beneficial for reducing the amount of nutrients or sediments which reach Eden and Vails Lakes. The U.S. Fish and Wildlife Service at Fort Snelling may be able to provide technical and financial assistance for these activities.
- The Association should continue to seek representation on boards or commissions that address land management activities so that their impact can be minimized. The booklet, <u>Protecting Minnesota's Waters, the Land-Use Connection</u>, may be a useful educational tool in this area.

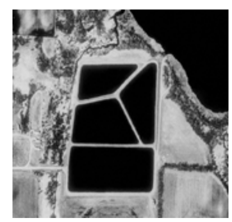
c) Septic Systems

On-site septic systems are a potential source of nutrients to Eden and Vails. Given the relatively high level of phosphorus in both lakes, poorly functioning on-site systems could *potentially* be an important source of nutrient loading.
A recent survey of local property owners by the Eden Lake Association found many older septic systems on both lakes. The survey found that half of the systems on Eden are over 15 years old. The Eden Lake Association and Stearns County should continue to educate homeowners on proper maintenance of their systems and encourage all homeowners with out of code systems to bring their systems up to code. The Association may want to facilitate a lake-wide schedule for pumping systems.

d) Watershed Analysis

An examination of nutrient sources in the watershed would be beneficial for future planning and setting priorities. Areas to focus on include: Animal feedlots, land application of manure, row crop cultivation, lawn fertilizer, Eden Valley's spray irrigation system, ditching and wetland drainage. A better understanding of the relative contributions of these sources will provide a basis for prioritizing efforts to reduce nutrient loading to the lakes.

e) Wastewater



The treatment facility, south of Vails Lake, takes in most of the city of Eden Valley's wastewater. A brief analysis of the location of the spray irrigation area and influent records show that steps could be taken to reduce the nutrient loading to Vails from the waste water treatment facility.

f) Regulations and BMP's

This past year state legislation banning the use of phosphorus in lawn fertilizer was passed. In addition, state feedlot rules (7020) were revised in 2000. The association should work with the county and other regulators to insure compliance with these and other regulation. Considering the watershed's size and, dominated agriculture use Best Management Practices (BMP's) for land use in the watershed could make a significant reduction in the nutrient loading to the lakes. BMP's may include cropping methods, settling ponds, a buffer strip and putting land in to different use.

g) Partnerships and Funding

The Association needs to maintain good relationships with other organizations that have concerns about the lake such as: Stearns County, the Sauk River Watershed, sportsmen's clubs and local officials. These groups have similar concerns and may be able to assist with lake related efforts. Including local land owners and businesses on lake related concerns should beneficial to achieving goals. Another partnership that could prove to be of great benefit would be the local agriculture community. They should be a voice in the association as well as partner in lake protection. The MPCA's Clean Water Partnership Program (CWP) is also an option for assistance with water quality concerns. The CWP funding is designated for dealing with nonpoint sources of nutrients in the watershed. These funds are limited and competition for them can be severe.

Introduction

Eden and Vails Lakes are at the end of a large watershed and have had a history of water quality concerns. This report analyzes existing data and information on the lake is an effort to define the problems and offer recommendations to improve the lake water quality.

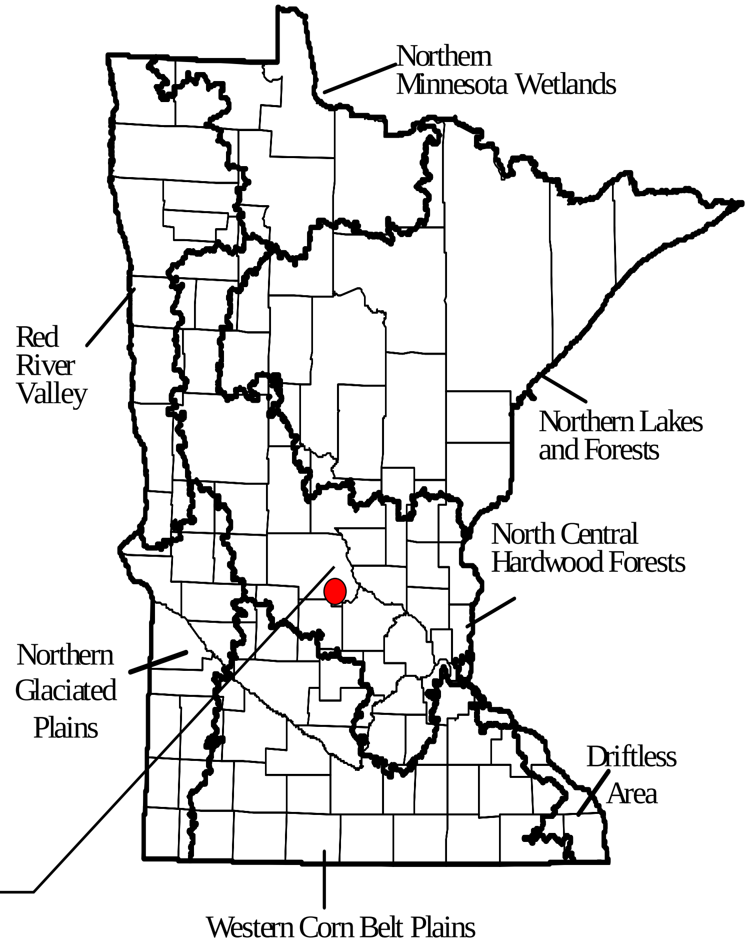
Background

Eden and Vails Lakes are located in Southern Stearns County, just north of the city of Eden Valley (Figure 1). Eden and Vails Lakes were formed when ice blocks separated form a continental glacier retreat (Zumberge, 1952). Both lakes are located in a large watershed that currently consists mainly of cultivated crop land. Soils near the lake consist of the Estherville-Hawick and Koronis-Marcellon series soils (USDA 1984). The major management problems of these soil types include erosion control and drainage (Arneman, 1963). Soils in this association have a hard pan in them that often slows up water infiltration (Arneman, 1963).

Location

Since land use affects water quality, it has proven helpful to divide the state into regions where land use and water resources are similar. Minnesota is divided into seven regions, referred to as ecoregions, as defined by soils, land surface form, natural vegetation and current land use. Data gathered from representative, minimally-impacted (reference) lakes within each ecoregion serve as a basis for comparing the water qualityand characteristics of other lakes. Both Eden and Vails Lakes are located in a region of the state referred to as the Central Hard Wood Forest (CHF) ecoregion.

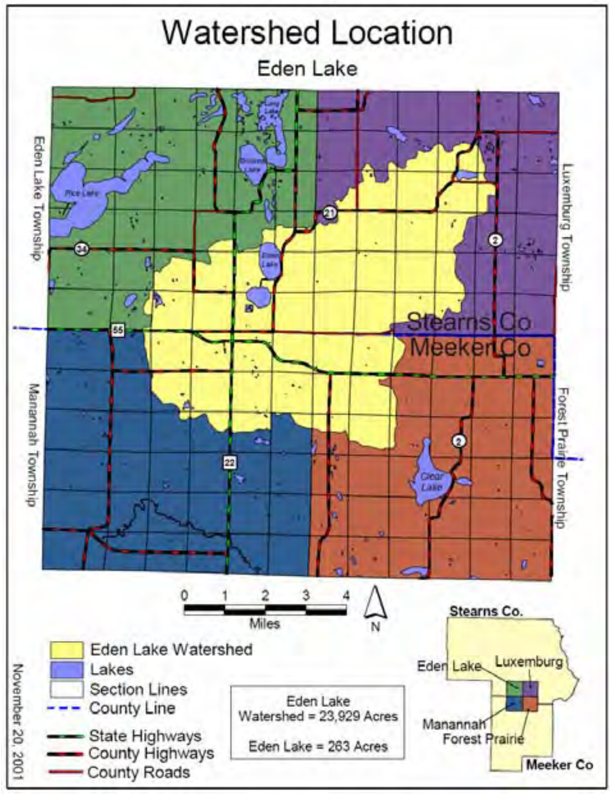
Figure 1. Minnesota's Seven Ecoregions



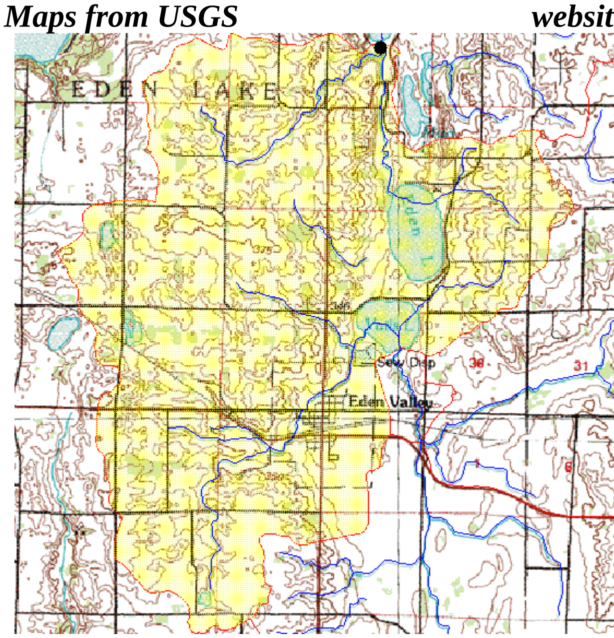
Eden and Vails Watershed

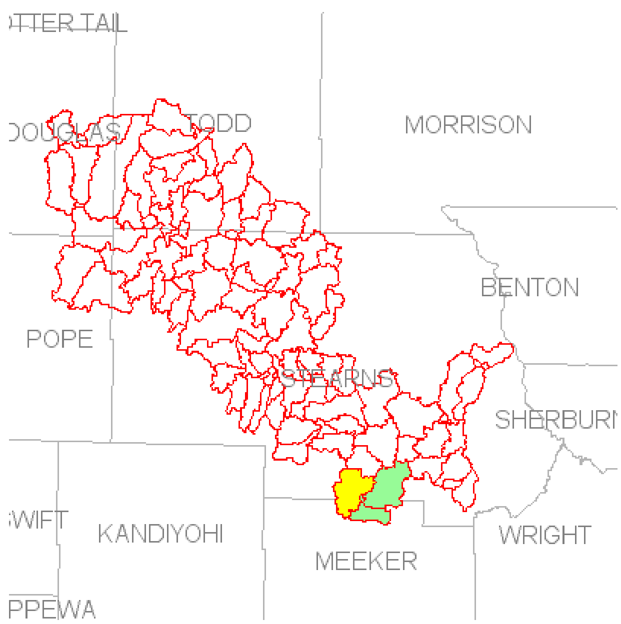
Both lakes are located in the Sauk River Major Watershed. The Sauk River Major Watershed is a part of the Upper Mississippi River Basin and drains to the Mississippi. The lakeshed for both lakes is large in relation to the lakes size and the typical lakesheds of this ecoregion. The lakeshed consists of many streams and ditches, but few lakes and wetlands. Vails Lake drains to Eden Lake, which drains north to Browns Lake, a part of the Sauk River chain of lakes. The total area of the Eden Lakeshed is 23,929 acres (9683 HA), with the vast majority (Table 1) draining through Vails Lake.

Figure 2. Eden and Vails Watershed



Maps from USGS website





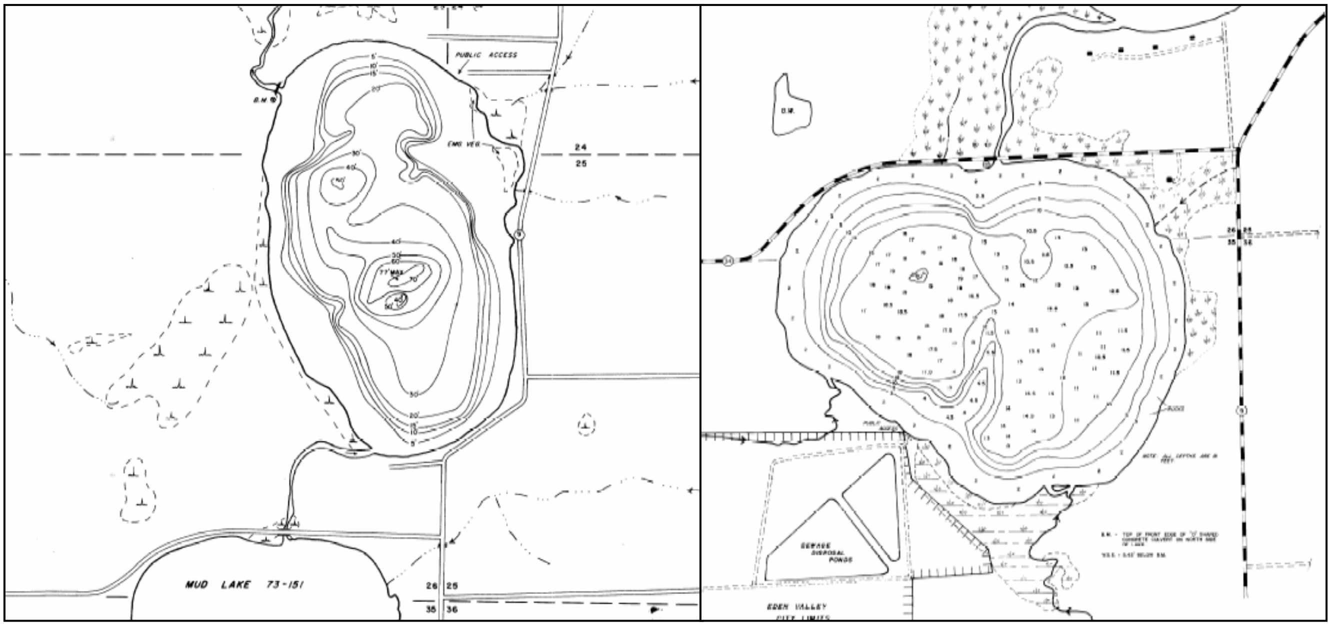
Minor Watershed

Contributing Minor Watershed

Morphometry

Eden and Vails Lakes are fairly regular in shape and underwater relief. Both lakes have a single basin with significant amount of littoral area (depth ≤15 ft.), 47 percent on Eden and 84 percent on Vails. The littoral area is significant for two main reasons: sunlight can reach the lake bottom and it can support rooted plants.

Figure 3. Eden and Vails Bathymetic Maps



Maps are not equal in scale

Table 1. Eden and Vails Lake Morphometry and Watershed Characteristics

	Eden	Vails	CHF Range
Lake Area: acres (hectares)	263 103.4	151 61.1	58- 400
Mean Depth (estimated): feet (meters)	18 5.5	10 3.0	
Maximum Depth: feet (meters)	77 23.5	20 6.1	16-46
Littoral: acres (Percent)	124 47.1%	127 84.1%	
Volume: acre-feet (cubic hectometers)	4,732 5.84	1,503 1.85	
Watershed Area: acres (hectares)	23,929 9,683	*21,536 *8,715	
Watershed: Lake Ratio	91 :1	142 : 1	
Est. Residence Time (years**)**	0.5	0.2	
Public Access	1	1	
Inlets	3	3	
Outlets	1	1	
Permanent Residences*	16	9	
Seasonal Residences*	27	0	

Climatology

State climatology records show precipitation was normal from October 2003 – September 2004 in the Eden and Vails area. Summer temperatures (June – August) averaged 71.5° F in 2004, slightly above the normal. Daily precipitation records from the nearby town of Paynesville were used to compare rain events to sampling dates. Significant rainfall events could cause temporal elevations in TP, due to surface runoff. Daily rainfall records show many rain events prior to sampling dates. May – September 2004 there were six 1 inch or more rain events. It is difficult to determine how much a particular rain fall events have will influence in-lake conditions

Figure. 4. Oct. 2003-Sept. 2004 Precipitation Departure from Normal

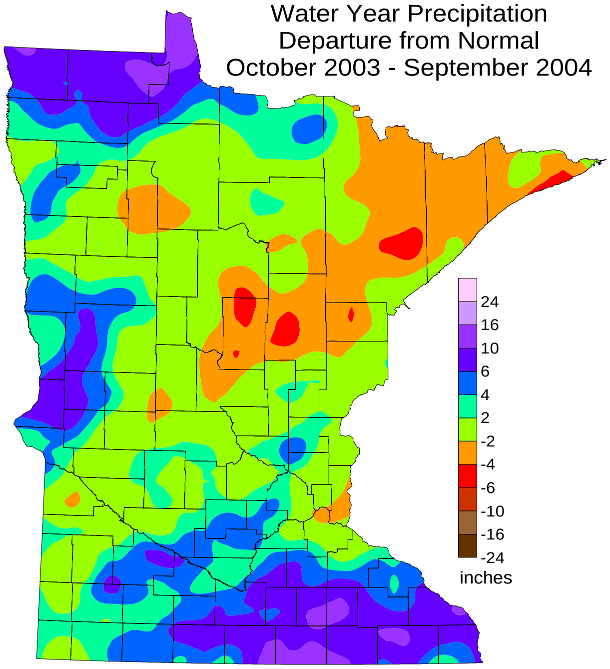
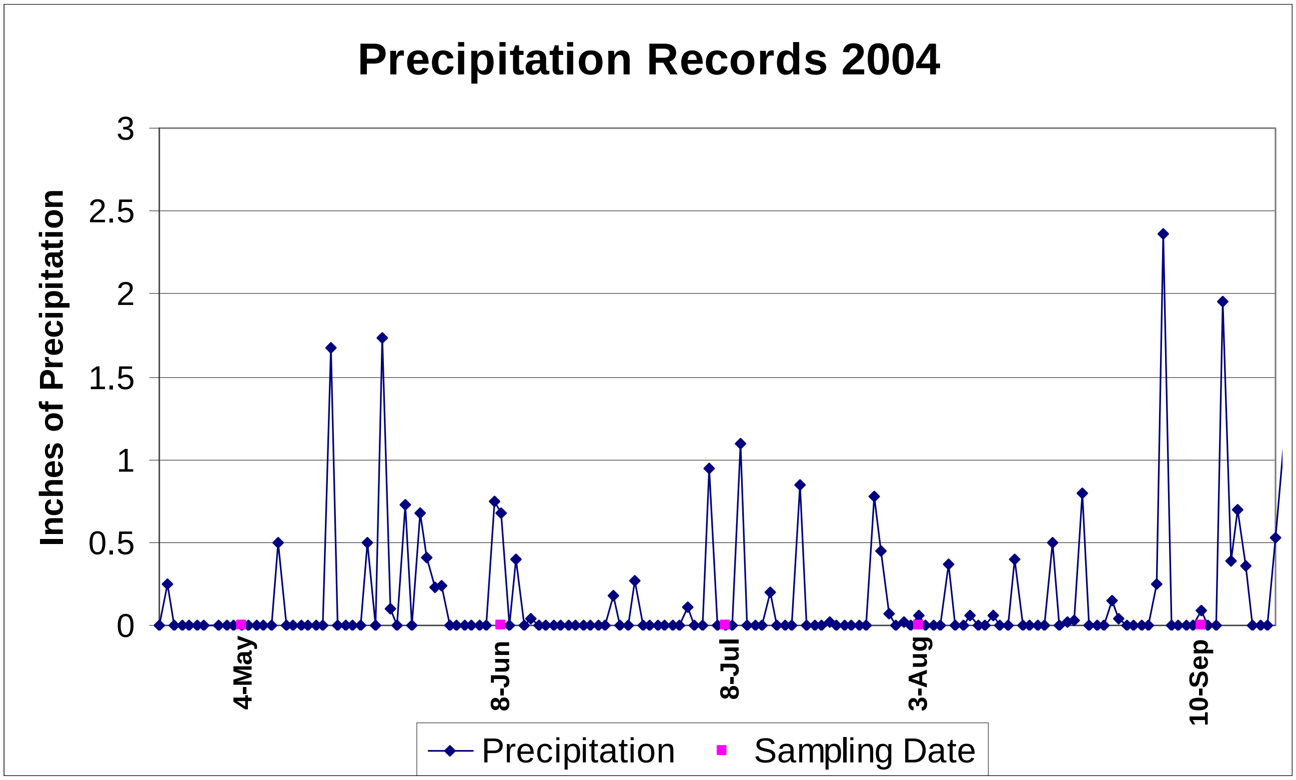


Figure 5. Daily Precipitation

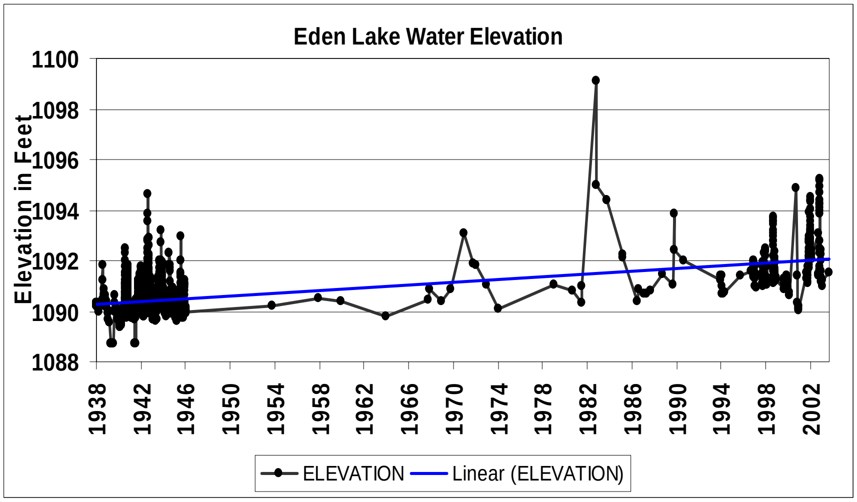


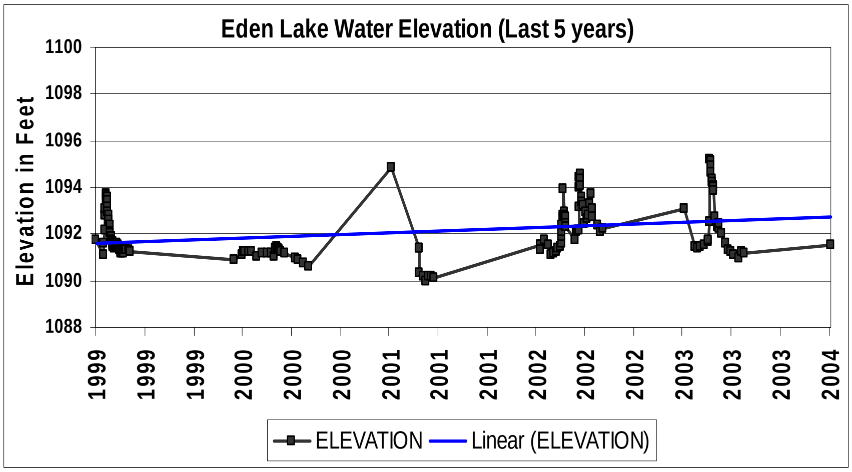
Water Level Reading

Water level readings on Eden Lake go back to 8/21/1938 (Figure 6). There are more than 1,500 records, spanning a range of 10.8 feet with modern-day water levels being about two feet higher then those at the beginning of the record. The long term trend for water level is increasing. The highest recorded water level was 1099.1 feet on 06/22/1983.

Over the most recent five years water levels have ranged 3 to 4 feet (Figure 6). Water levels also show a slight increase, but about half the rate of the long term trend.

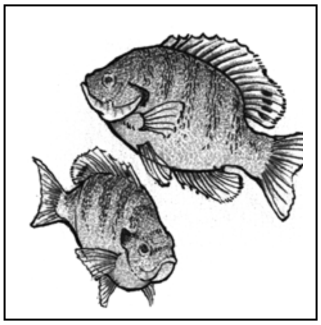
Figure 6. Eden Lake Water Level Data (MDNR)





Fisheries Information

Information from the Minnesota Department of Natural Resources Web site



Eden Lake

Status of the Fishery (as of 06/23/2003)

Eden Lake is located in south central Stearns County, north of Eden Valley. It is the second in a series of lakes that outlet north to join the Sauk River Chain of Lakes. A large, mostly agricultural watershed (over 24,000 acres) drains either directly to Eden Lake, or to nearby Mud Lake and then to Eden. The resulting load of nutrients has resulted in impaired water quality, nuisance algal blooms, and occasional winterkills.

The fishery of Eden Lake is managed primarily for northern pike and walleye. The catch rate of northern pike in 2003 was within the range expected for lakes similar to Eden, and average size of northern pike was favorable (3.2 pounds). The largest fish sampled was over 37 inches.

Eden Lake's walleye population is supported by regular stocking. In 2001 and 2003, fry were stocked rather than fingerlings, which had previously been used. In cases where fry stocking is successful, this strategy can produce higher populations at a lower cost. Nearly all of the walleye sampled in 2003 were from the 2001 year class, and appeared to grow quickly. Evidence of success from the 2003 stocking was also observed during fall electrofishing.

Eden Lake has consistently supported a high population of yellow perch. Perch do not appear to reach a size favored by most anglers, but they provide an abundant source of forage for northern pike and walleye.

Largemouth bass were sampled by electrofishing in mid-May. The population appeared to be lower than average for this area of the state, and most of the fish were less than ten inches. It is typical for lakes like Eden to have lower bass populations than clearer lakes. Also, most of the bass sampled in 2003 were 2 or 3 years old, and the population and average size may increase in coming years.

The catch rate of black crappie in 2003 was relatively high, while average size (0.22 pounds) was in the range expected for lakes like Eden. As with the largemouth bass, most of the fish were ages 2 or 3, so larger fish will likely be available in the next few years. The catch rate of bluegill was in the expected range, as was the average size (0.21 pounds).

Several "rough fish" species were sampled in high numbers, which is typical for hypereutrophic lakes. These included black bullhead, brown bullhead, yellow bullhead, bowfin and white sucker. Carp numbers appeared to be in the normal range, but average weight (8.3 pounds) was high.

Vails Lake

Status of the Fishery (as of 06/16/2003)

Mud Lake, also known as Vails Lake, is located north of Eden Valley, in south central Stearns County. The lake is 151 acres and relatively shallow. It is the first of a series of lakes that outlet northward to join the Sauk River chain of lakes. Nearly 23,000 acres of mostly agricultural land form the watershed of Mud Lake, and this is reflected in the lake's impaired water quality. The lake is prone to partial winterkill, and this occurred most recently in 2001. Fieldwork in 2003 included night electrofishing, gill and trapnetting, shoreline seining, and an aquatic plant survey.

Largemouth bass were sampled by electrofishing in May. Forty-three bass were captured in 1.1 hours (40.7/hr, on-time), somewhat lower than average for lakes in the area. Lakes with low water clarity typically have fewer aquatic plants and fewer largemouth bass than clear lakes. Several bass sampled were greater than 16 inches, and the largest was nearly 19 inches.

The catch rate of northern pike in 2003 was within the range expected for a lake like Mud, but significantly higher than in 1995, and higher than it has been in past surveys. Average size (3.1 pounds) was high, which may be due in part to the ample yellow perch available for forage.
Mud Lake is not stocked with walleye, but a few were sampled during the 2003 survey. It is likely that fish can migrate in from Eden Lake (less than ½ mile away), which is regularly stocked with walleye fry.

The catch rate of black crappie in 2003 was relatively high. Historically, catch rates of black crappie have been high, with the exception of the 1995 survey. Most of the crappie sampled in 2003 were age 2 (6.5 inches) or age 4 (8 inches), with only a few older fish. The catch rate and average size (0.24 pounds) of bluegill were both within the normal range. The average length of bluegills sampled was 6.5 inches, and the largest was 8.3 inches. It appears that any winterkill that occurred in 2001 had only a temporary impact on panfish populations.

Other species sampled in 2003 included black, yellow and brown bullheads, common carp, bowfin, and white sucker.

History of Vails Lake:

(Eden Lake history as recalled by residents)

1939 Dam was built by WPA (Public Works Administration)

1950 There were four resorts on Eden Lake: Heibel, Snell, Haag, and one on the north side of the lake

1960 The creek adjoining Eden Lake and Vails Lake was filled in with lily pads and bull rushes

1965 Eden Lake flooded and a trench had to be dug in the road on the north side of the lake to allow the walleye to swim back into the lake.

1975 Phil Top drowned when his snowmobile went into open water on the lake.

1980's Sportsman's Winter Fishing Contest was held annually for several years.

1980's Wastewater treatment pond was built prior to that wastewater flowed directly into the lake

1983 During Valley Daze in June there was a flood, which produced the highest water levels in history

1988 Drought lowest water levels in memory

1993 Vails / Eden Lake Association were started. First members were Bill Ruhland, Nick Thielen, Dave Thielen and Bud Binsfeld.

1997-2007 Walleye stocking arrangement with the MDNR. The MDNR will stock every other year with the lake association picking up the remaining years

1999-2000 Lake association stocked sunfish both years

2000 Worst winter fish kill in memory

Concerns on the Lake

Eden and Vails residence have stated many concerns including: algae blooms, severe, winter kill and high phosphorus levels.

Shoreland Debris

Sediment buildup on lakeshore is also a noted problem on Eden (Figure 7). A sample was taken of this washed up material on September 10, 2004. After some brief microscope analysis the material was found to be composed of:

- aquatic plants fragments, mainly Ceratophyllum demersum (coon tail)
- wood,
- deciduous leaves,
- snails
- some algae, mostly diatoms

Figure 7. Shoreland Buildup 9/10/2004

These finding were not too surprising as the lake was well-mixed, rooted plants were dying-back and strong winds would tend to tend to cause the accumulation of this material on the down-wind shorelines.

Land Parcels

Neither lake has significant shoreland development. The majority of the lakeshore property around the two lakes is larger agriculture parcels (Figure 8). Large sections of the adjacent lakes property are cropland. The city of Eden Valley is within the watershed of and stormwater runoff from the city maybe a factor with nutrient loading into the lakes as well.

Figure 8. Land Use Parcels of Vails

Septic System Survey

A survey of shoreland septic systems was conducted by the Eden and Vails Lake Association in 2004 (Table 2). Both lakes had a 100 percent response rate. This high response rate shows good septic system awareness and concern for the lake. The survey showed Eden as having almost twice as many seasonal residences as year round residence, while Vails nine residences were all year round. One concern involving the systems on Eden Lake would be, the high percentage of older systems as well that number of unknown system ages. The impact from septic systems on nutrient loading to the lakes is most likely low due to: low residential density on the lakes, the high percentage of seasonal residences, and the types of systems.

Table 2. Septic System Survey

	Eden	Vails
number of surveys distributed	**43**	**9**
number of Surveys returned	**43**	**9**
seasonal residence	**27**	**0**
year round residence	**16**	**9**
Age (years)		
0-5	**7**	**5**
6-10	**2**	**1**
11-15	**8**	**3**
16-20	**8**	**0**
21-25	**9**	**0**
unknown (left blank)	**9**	**0**
System Types		
septic tank and drain field	**29**	**7**
shared septic tank	**13**	**0**
holding tank	**7**	**0**
mound System	**2**	**2**

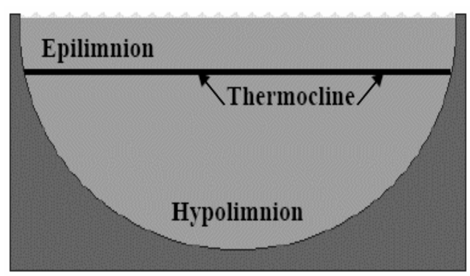
Methods

In 2004, MPCA staff and lake association members cooperated on monthly summer monitoring. Sampling procedures were employed as described in the MPCA Quality Control Manual. Duplicate samples were taken for quality assurance. Laboratory analyses were performed by the Minnesota Department of Health laboratory using U.S. Environmental Protection Agency (EPA) approved methods for the parameters noted in Table 3. In addition, CLMP Secchi measurements were taken by association members throughout this monitoring period. The MPCA monitored one site on each lake surface; samples were collected with an integrated sampler, constructed from a PVC tube 6.6 feet (2 m) long with an inside diameter of 1.24 inches (3.2 cm). Depth samples were taken 2 feet above the lake bottom with a Kemmerer depth sampler. Profiles of dissolved oxygen, temperature, conductivity and pH were taken on each sample date with a Hydro Lab MiniSonde Probe. Zooplankton samples were collected using a Wisconsin plankton net. Field observations were made during each sampling event.

Discussion of Results

In addition to the data from 2004, historic data from the MPCA's CLMP program, of which there is both chemical and transparency data. This historical data was analyzed and will be included in this discussion. All data used in this report is stored in the STORET national water quality data bank and is also available at the MPCA's EDA web site http://www.pca.state.mn.us/data/eda/search.cfm. The following discussion assumes the reader is familiar with basic water quality terminology as used in the Citizens Guide to Lake Protection (http://www.pca.state.mn.us/water/lakeprotection.html). A glossary is included in the appendix of this report to assist the reader with terminology used herein.

Profiles

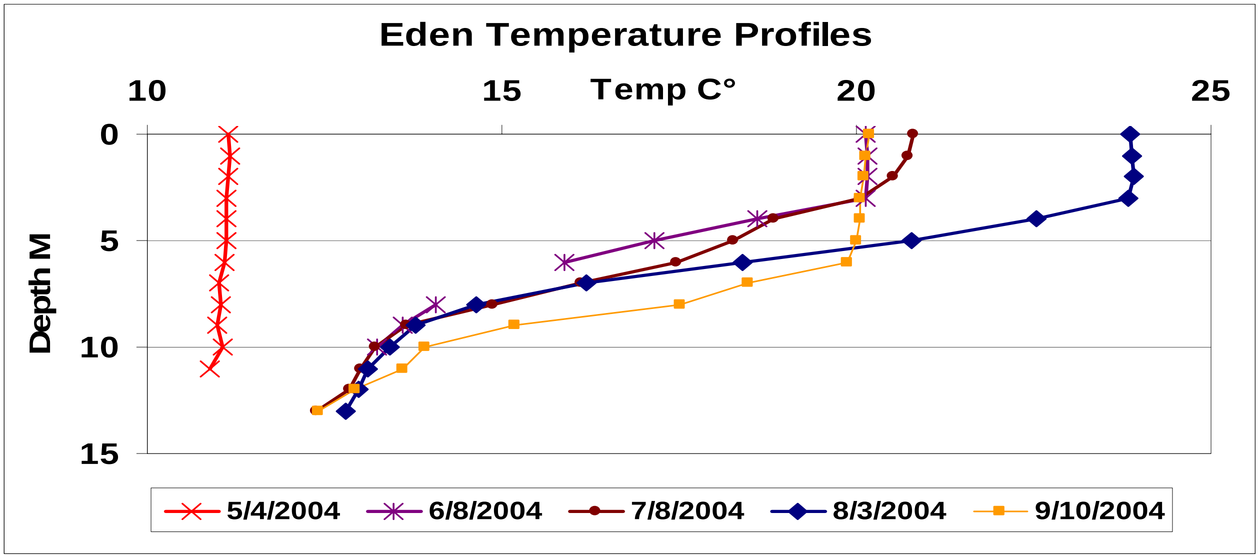


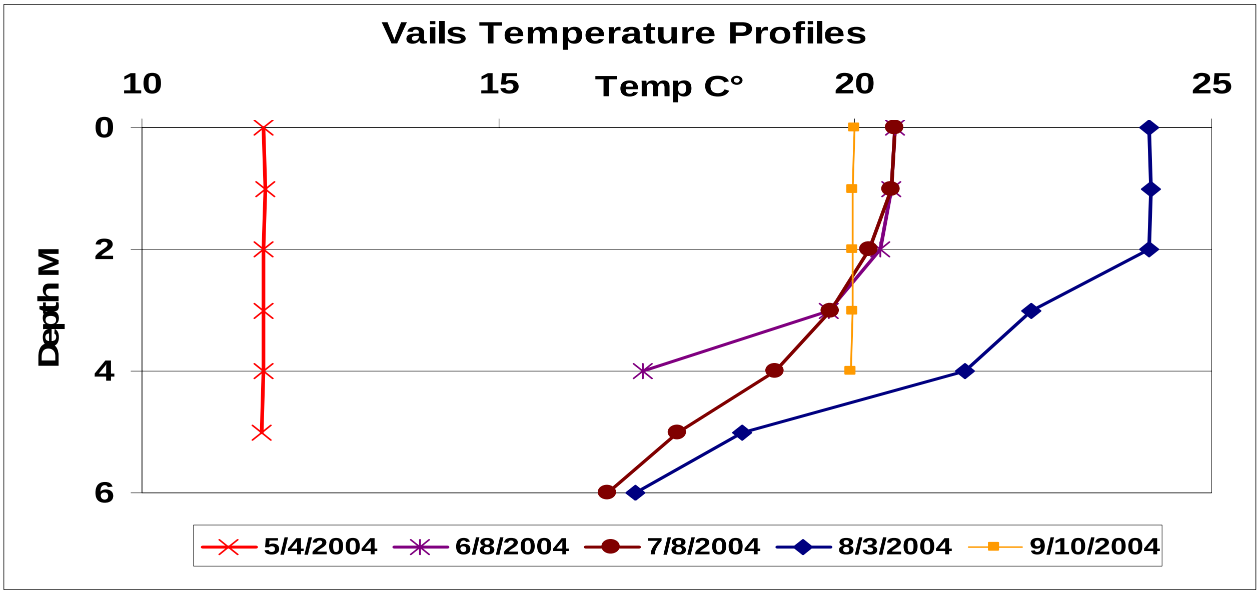
Lake profiles are measurements taken through the water column (surface to bottom). Profile analyses included on Eden and Vails were dissolved oxygen (DO), temperature, conductivity, oxidation reduction potential, and pH. Profile data was collected along with samples during the 2004 monitoring. These profiles provide a basis for describing the oxygen content of the lakes from the surface to the bottom and the degree to which the lakes are thermally (temperature) stratified. In turn, the presence or absence of oxygen in the surface and bottom waters will determine the extent to which fish and other biota are distributed in the lake and along with changes in temperature will influence other biological and chemical processes (e.g. pH) in the lake. Stratified lakes, as was the case in both Eden and Vails (in most observations) exhibit distinct layers. These layers: the epilimnion, warm well-mixed layer with high DO; metalimnion or thermocline, this is the zone of rapid change in temperature over a small depth range; and the hypolimnion, cooler layer separated from the epilimnion and typically has low DO measurements.

Temperature Profiles

Eden Lake was stratified in June and remained so throughout the rest of the summer (Figure 9). The thermocline was present in Eden generally between 3 and 10 meters. The mixed conditions in May correspond to high to the highest TP observed on the lake in 2004. Vails was intermittently stratified in 2004. Temperatures on Vails were stratified from June to August (Figure 9). Since the lake is relatively shallow strong wind may cause Vails to mix, while calm periods will allow it to stratify.

Figure 9. Temperature Profiles

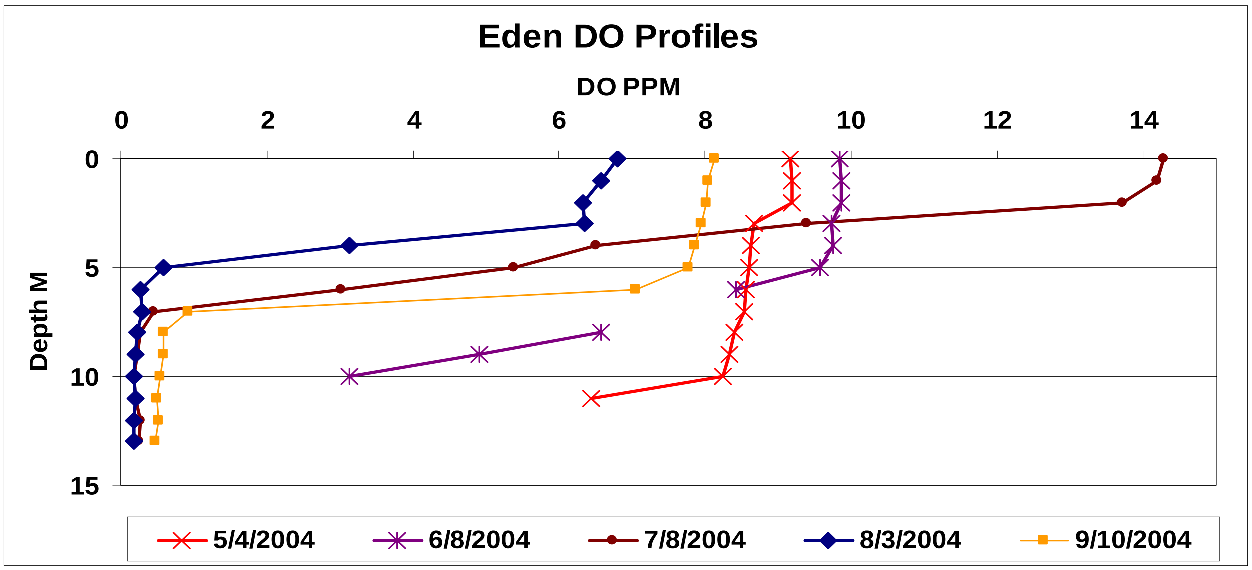


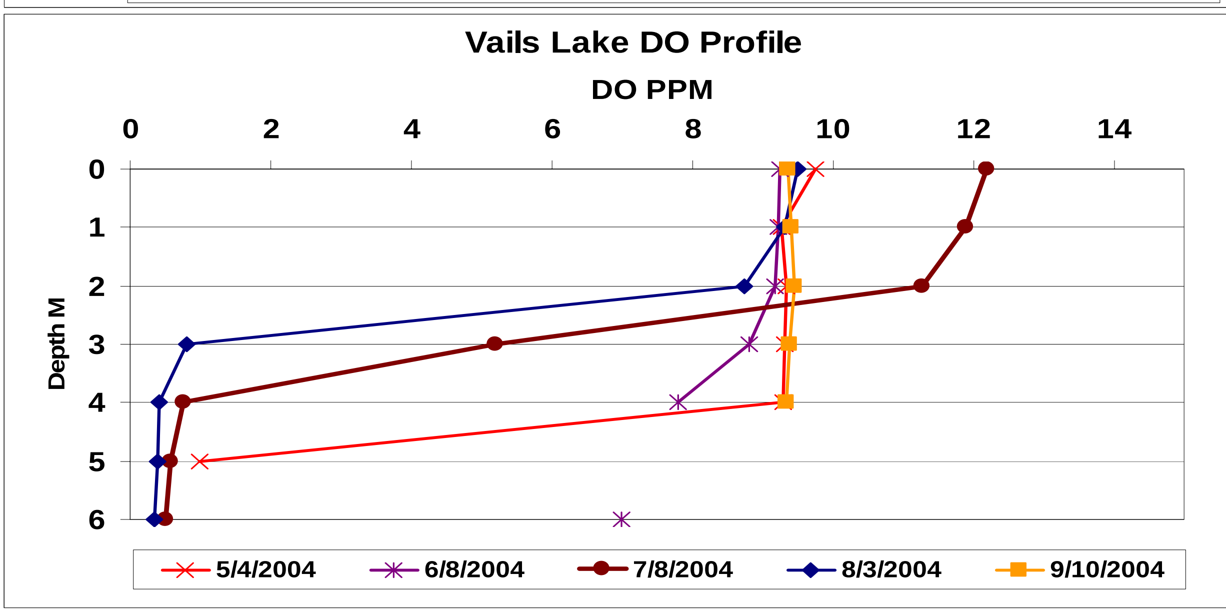


Dissolved Oxygen Profiles

Adequate DO levels are necessary to support fish and other aquatic life. DO concentrations above 5 mg/L will support most fish. When DO levels drop below 2 mg/L (ppm), phosphorus can be released from lake sediments in the overlaying water. DO in Eden Lake generally remained above 5 mg/L in the upper 5-6 meters of the lake and fell below 2 mg/L in the lower 7-13 meters in July-September. Vails Lake DO was above 5 mg/L in the upper 2-3 meters on most dates. The elevated DO on July 8th would be considered "super saturation" which is caused by photosynthesis by algae (producing oxygen).

Figure 10. DO Profiles

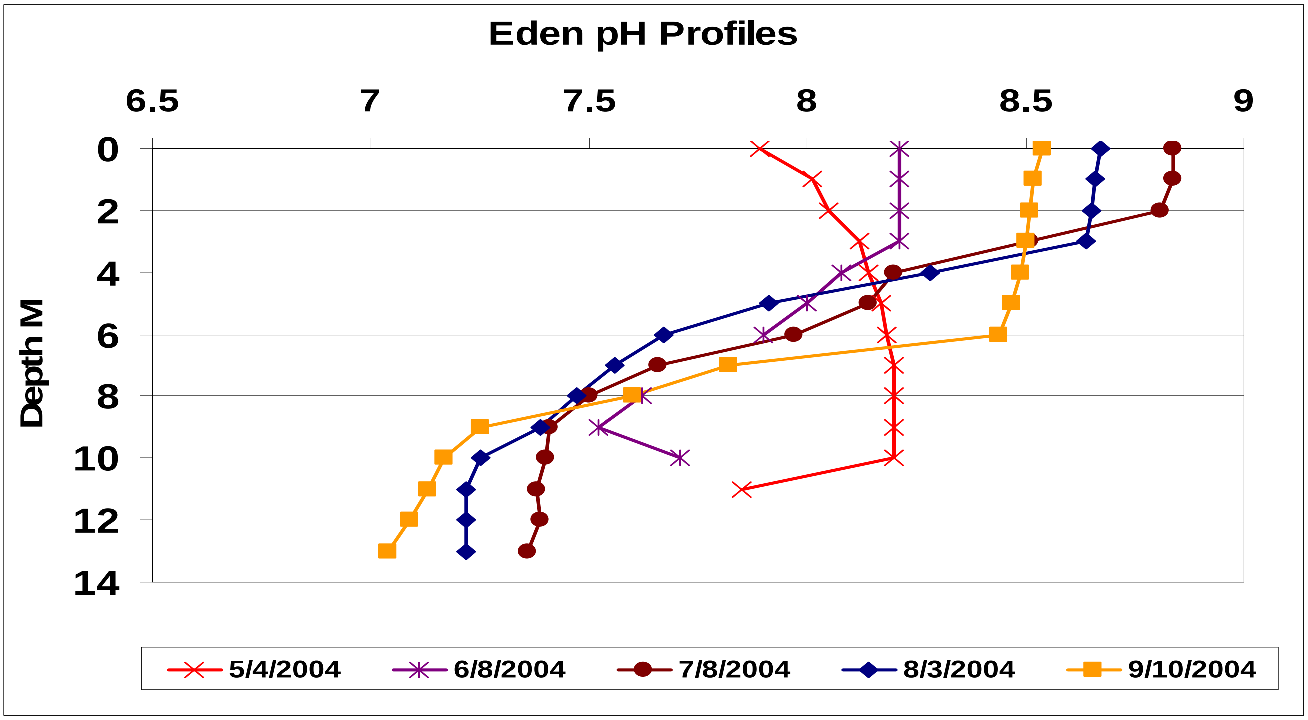


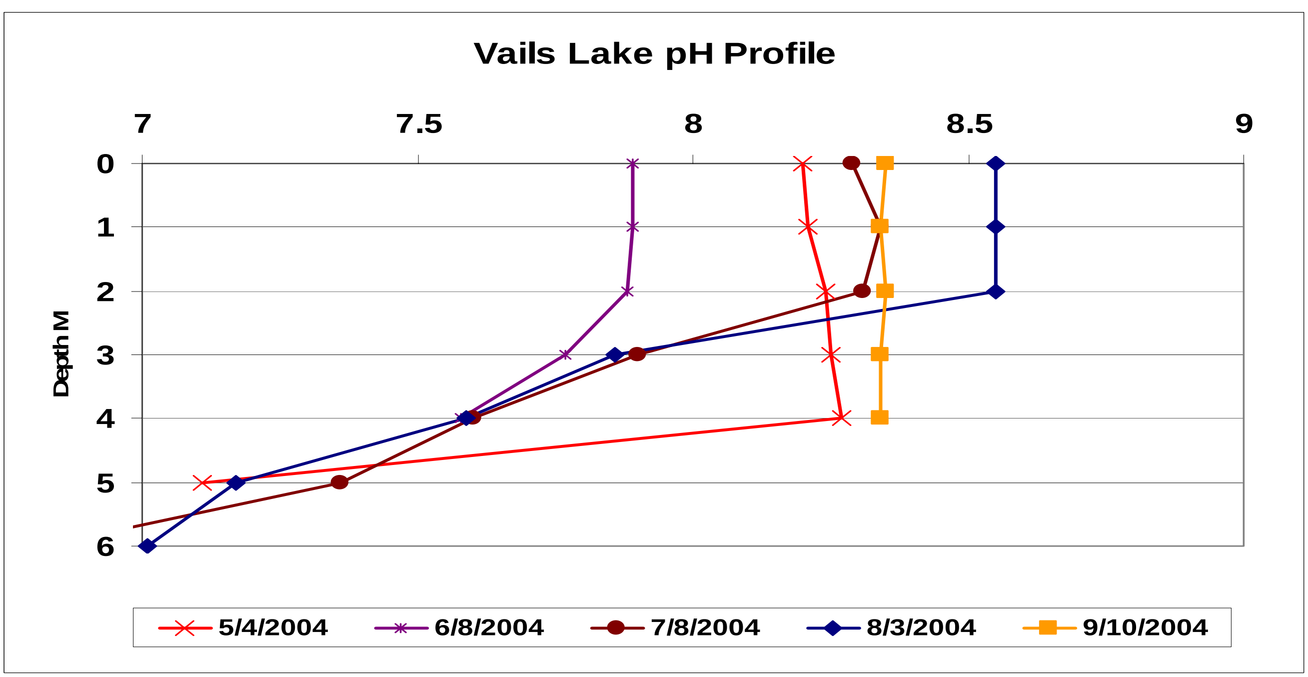


pH Profiles

The pH is a measure of the relative acidity of water. The pH profiles help to determine areas of biological activity. The epilimion is characterized by higher pH values reflective of algal activity (oxygen production and respiration) while lower pH values are noted in the hypolimnion due to decomposition. Eden Lake was stratified for pH during all monitoring events with the exception of May. Vails was pH stratified in June, July and August (Figure 11).

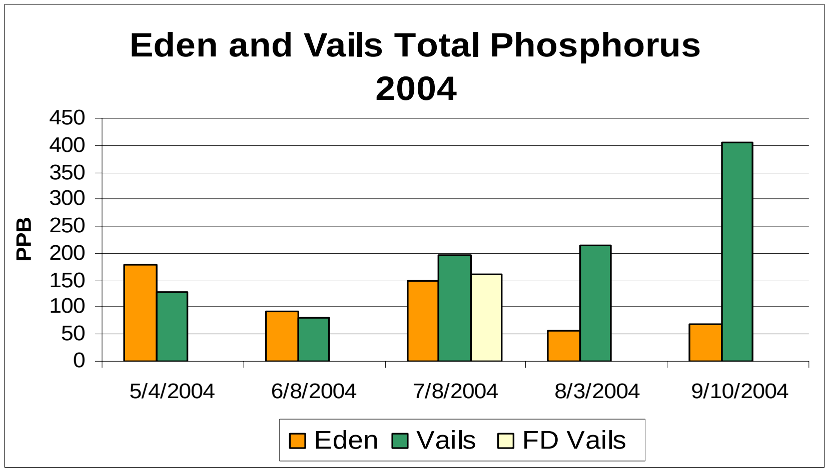
Figure 11. pH Profiles





Total Phosphorus

Figure 12. Total Phosphorus Summer 2003

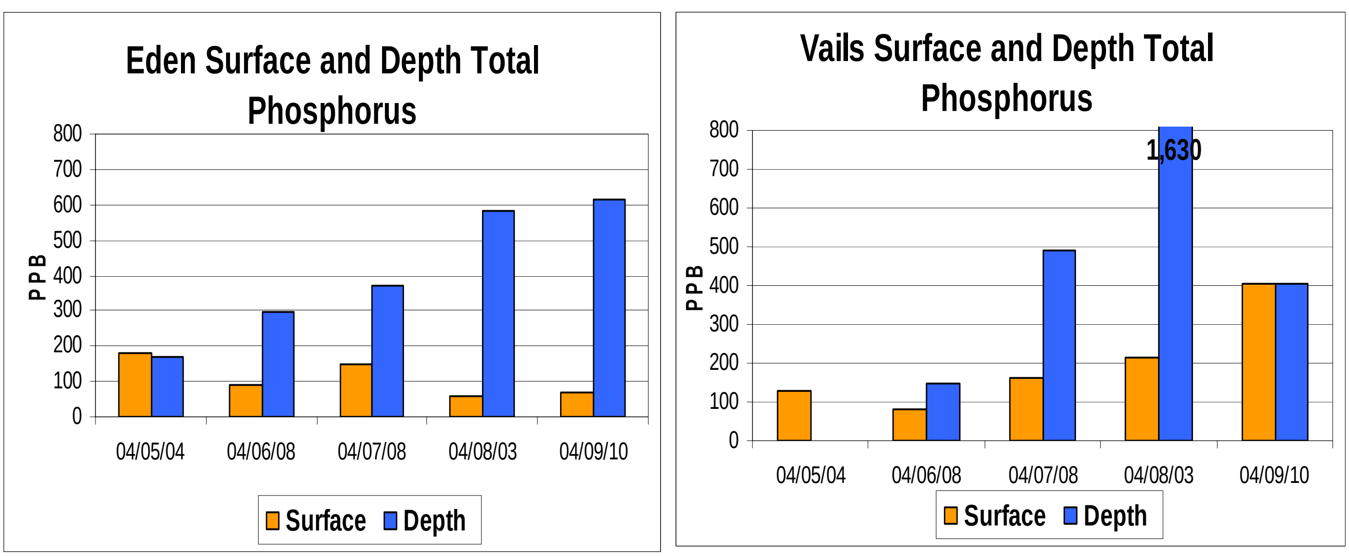


TP is the nutrient that limits algal growth in most Minnesota lakes. The 2004 summer mean TP concentrations for Eden and Vails lakes were 110 and 205 ppb respectively. Both results are well over the typical range for minimally impacted lakes in the CHF ecoregion (Table 3). On July 8, 2004, a field duplicate (FD) sample was taken on Vails during the monthly monitoring for quality assurance. For the CHF ecoregion summer mean TP concentrations, above 45 µg/L (or ppb), are associated with nonsupport of aquatic recreational use. At TP concentrations above about 45 µg/L mild algal blooms occur over 80 percent of the summer, nuisance blooms about 40 percent of the summer, and severe nuisance blooms about 15 percent of the summer

Depth Samples

In addition to surface monitoring, samples were collected one meter above the bottom of both lakes throughout the monitoring period, with the exception of May 4 on Vails. These results help determine, among other things, the effects of thermal stratification and DO concentration on phosphorus levels in the lake. Eden Lake exhibits a distinct increase in hypolimnetic (bottom) TP from May through September, which is consistent with the time the lake was stratified. Vails exhibits similar increase from June – August. In September the hypolimnetic TP declined as the lake underwent fall mixing, which in turn contributed to the increase in the surface TP concentration.

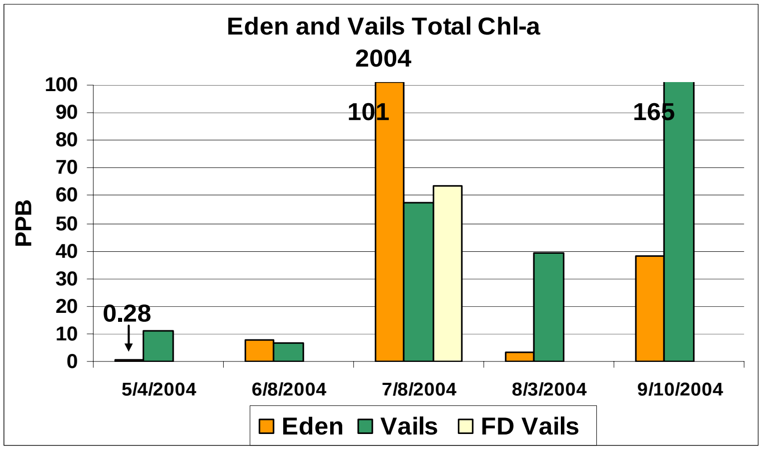
Figure 13. Surface and Depth TP



Chlorophyll-a

Chl-a is a light transforming pigment found in all algae. Concentrations of Chl-a provide an estimate of the amount of algae in a lake. Summer Chl-a for Eden and Vails averaged 30 and 56 µg/L respectively. Both summer means are above the CHF ecoregion minimally impacted lakes range of 5-22 (Table 3). These high mean Chl-a are related to frequent severe algae bloom thorough the summer.

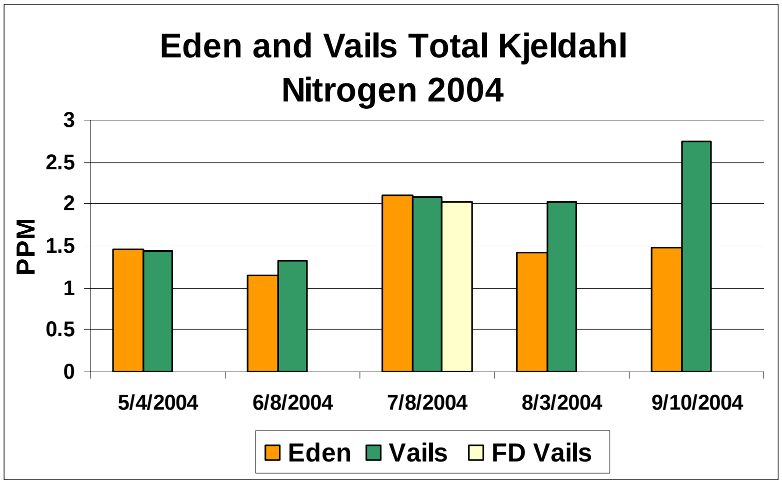
Figure 14. Chl-a



Nitrogen

Nitrogen is an essential nutrient required for plant and algae growth; however it is typically not the "limiting nutrient" in most Minnesota Lakes. Total Kjeldahl Nitrogen (TKN) for Eden and Vails averaged 1.5 and 1.9 ppm respectively. This is above the CHF ecoregion minimally impacted lakes of 0.6-1.2. The total nitrogen (TN) to TP ratio's of Eden and Vails were 73:1 and 107:1 respectively, well above the CHF ecoregion minimally impacted lakes range of 25:1 – 35-1. Lakes are often considered "nitrogen-limited" when TN:TP ratio falls below about 10:1.

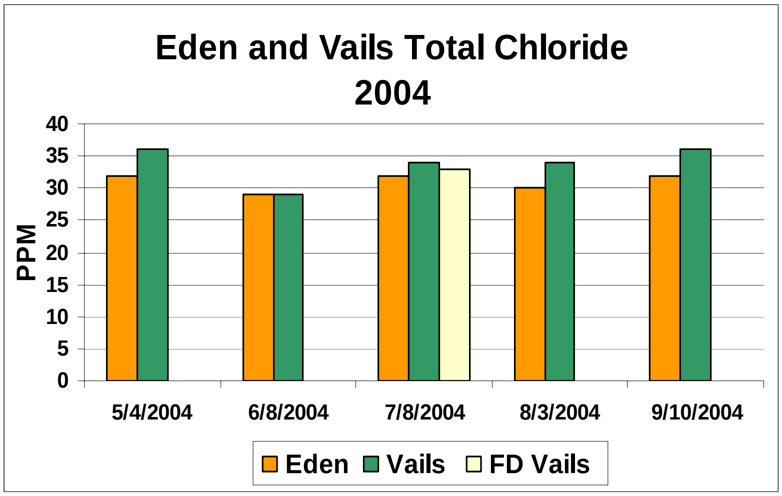
Figure 15. Total Kjeldahl Nitrogen 2004



Chloride

Chloride (Cl) results for both Eden and Vails are higher than the typical range of CHF ecoregion reference lakes of 4-10 ppm (Table 3.). Elevated chloride is often the result of road salt usage within the watershed, however wastewater and feedlot runoff are often high in Cl as well. Though the values are above the "typical" range, they should not cause problems for lake biota. Field duplicate results from Vails on July 8 show good quality assurance.

Figure 16. Chloride 2004



Summer Mean Water Quality Results

Various other water chemistry measurements were taken the lakes including: total suspended solids, conductivity, pH, and chlorides. In general both lakes results were poor compared to the minimally impacted lakes in the in the CHF ecoregion. The 2004 summer mean TP results for Eden Lake place it in the lower 30 percent of all assessed lakes in the CHF ecoregion (Table 4). Vails Lake faired worse than Eden in almost all categories. Summer mean transparency faired uncharacteristically well for both lakes considering the other results.

Table 3. Summer Mean Water Quality Results
Based on 2004 Epilimnetic (Surface Water) Data.

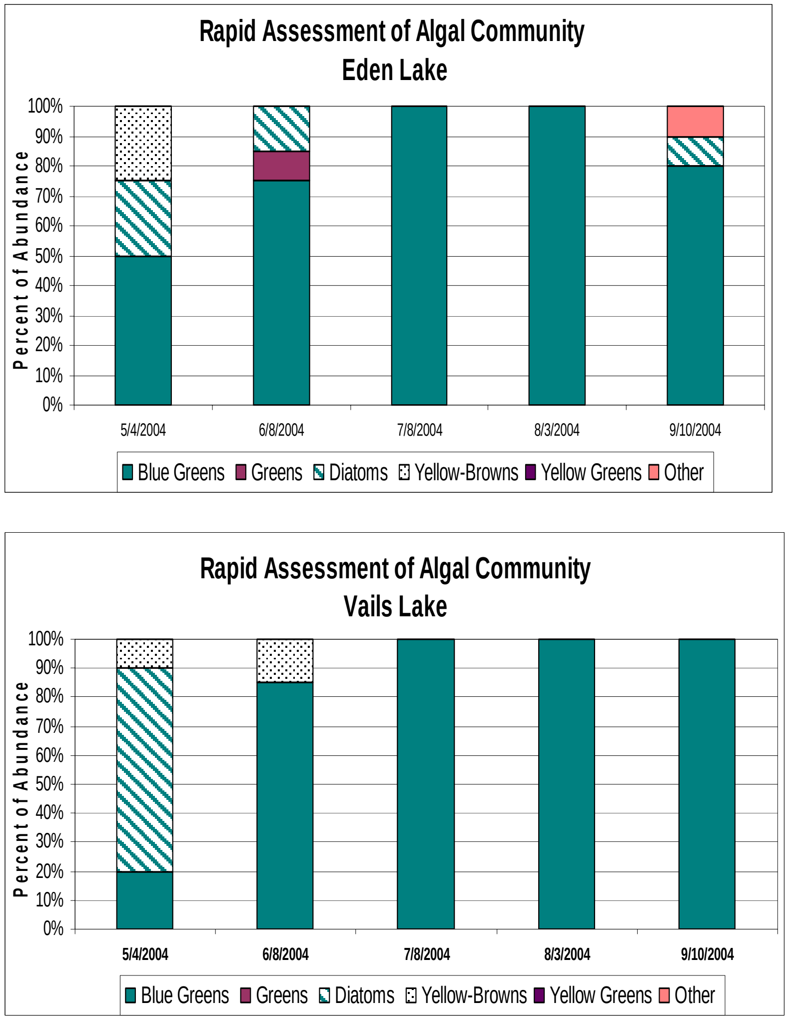
Parameters	Eden	Vails	North Central Hardwood Forests
Total Phosphorus (µg/L)	110 ± 24	205 ± 56	23-50
Chlorophyll a (µg/L)			--
Mean	30 ± 19	56 ± 29	5-22
Maximum	101	165	7-37-
Secchi disk (feet) (meters)	9.1 ± 0.2 2.8 ± 0.6	6.2 ± 1.3 1.9 ± 0.4	4.9-10.5 (1.5-3.2)
Total Kjeldahl Nitrogen (mg/l)	1.5 ± 0.2	1.9 ± 0.3	< 0.6-1.2
Alkalinity (mg/l)	182 ± 10.2	230 ± 9.5	75-150
Color (Pt-Co Units)	28 ± 2	40 ± 0	10-20
pH (SU)	8.4 ± 0.08	8.3 ± 0.05	8.6-8.8
Chloride (mg/l)	31 ± 0.6	34 ± 8	4-10
Total Suspended Solids (mg/l)	5.2 ± 1.7	8.2 ± 2.4	2-6
Total Suspended Volatile Solids (mg/l)	3.5 ± 0.9	5.4 ± 2.4	
Total Suspended Inorganic Solids (mg/l)	1.7	2.8	1-2
Conductivity (µmhos/cm)	472 ± 8	572 ± 5	300-400
TN:TP Ratio	73 : 1	107 : 1	25:1 – 35:1

Table 4. Water Quality Percentile Distribution of Assessed Lake
Based on data base summary (2004) for CHF Lakes

Parameter	5	10	25	50	75	90	95	N
TP ppb	15	18	28	51	112	229	351	691
Chlorophyll-a (ppb)	3	4	8	21	45	89	131	622
Secchi (m)	0.4	0.5	1	1.6	2.6	3.5	4.2	968

Phytoplankton (algae) are an essential part of the "food chain" in Lakes. However, when algae are overly abundant or dominated by certain forms water quality degradation can result. Defining the algae types and their relative abundance helps better understand algae issues on the lakes. As stated previously algae levels, based on Chl-a results, for both lakes were high. Algae composition for Eden and Vails was based on analysis of samples collected during the 2004 monitoring. Data for both lakes is presented in algal type and present abundance (Figure 17). In both lakes blue-greens were dominate from mid-summer through the rest of the monitoring. Blue-green algae are often of the most concern, due to its potential to become a nuisance as well as a hazard. Given the right blend of conditions some blue-green algae can become extremely dense. They are often most abundant during warmer temperatures, in hard, alkaline, and rich in nutrients (primarily phosphorus and nitrogen) waters. Special characteristics of blue-green algae allow them to reach greater abundance than other types of algae.

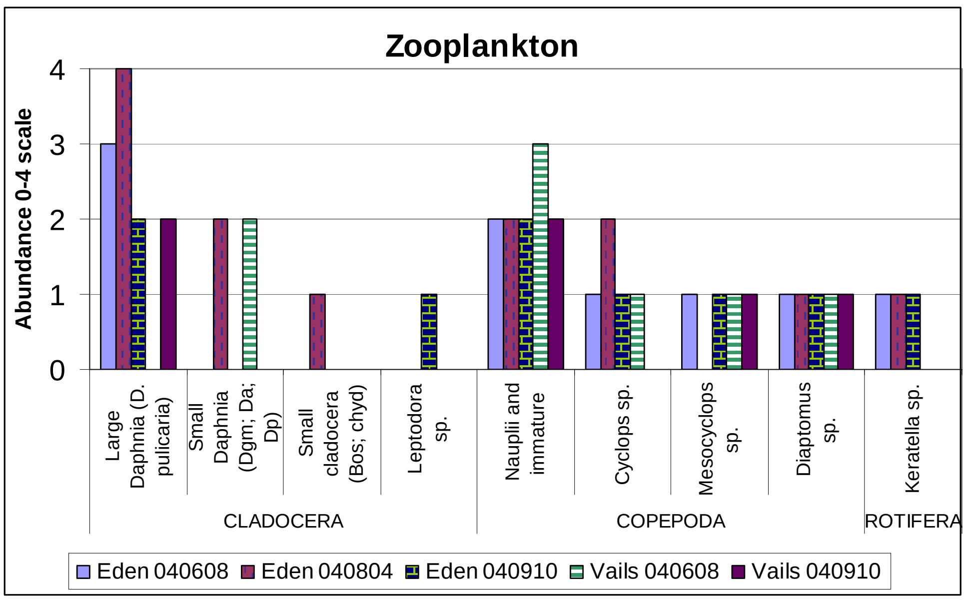
Figure 17. Algal Composition



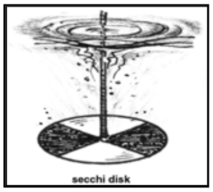
Zooplankton

Unlike phytoplankton, zooplankton cannot produce their own food. Zooplankton must consume phytoplankton, detritus (dead organic matter) or other zooplankton. Lakes abundant with effective filtering zooplankton (mainly large and small daphnids), can exhibit reduced Chl-a because of algal consumption by zooplankton. Zooplankton are an important source food source for small fish, and fish predation determines if large daphnids are present in the lake. Large zooplankton avoid predation by migrating to deep, dark waters during the day. They can only do this if the lake is well oxygenated in the Hypolimnion (deep waters). In 2004, zooplankton samples were collected and analyzed for both lakes. The effective filtering large daphnia (which prefer small algal forms) were found in moderate to high levels Eden during all three sampling. This could be contributing to the discrepancy between TP and transparency.

Figure 18. Zooplankton

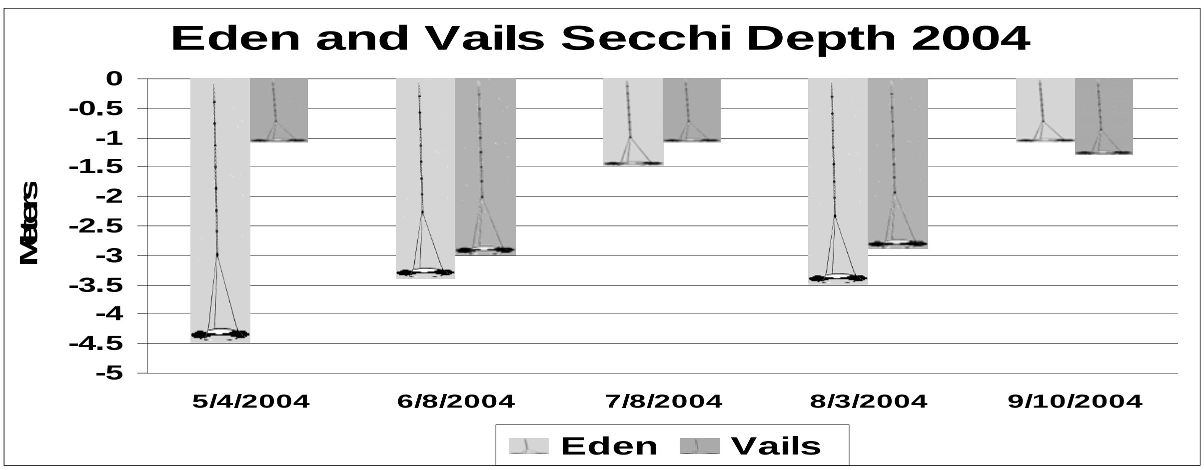


Secchi Disk Transparency



Secchi disk transparency is generally a function of the amount of algae in the water. Suspended sediments or color due to dissolved organic material may also reduce water transparency. Total suspended inorganic solids (TSS; suspended soils or clays) averaged 5.2 and 8.2 on Eden and Vails respectively. Color analysis for 2004 showed Eden and Vails averaged 28 and 40 respectively. These levels of color and TSS would have minimal impact of the water transparency in the lake. During the MPCA lake-monitoring 2004, Secchi observations were made on both lakes during monthly monitoring. Some of the individual Secchi results do not relate well to TP concentration. For example, in May the Secchi results on Eden (Figure 19) show the highest/best transparency observed even though temperatures were mixed (Figure 9) and surface TP was also the highest observed (Figure.12). This can somewhat be explained by May Chl-a results on Eden being very low (Figure 14). Cool water temperature and abundant daphnia likely kept algae levels down and transparency up in May.

Figure 19. Secchi Depth

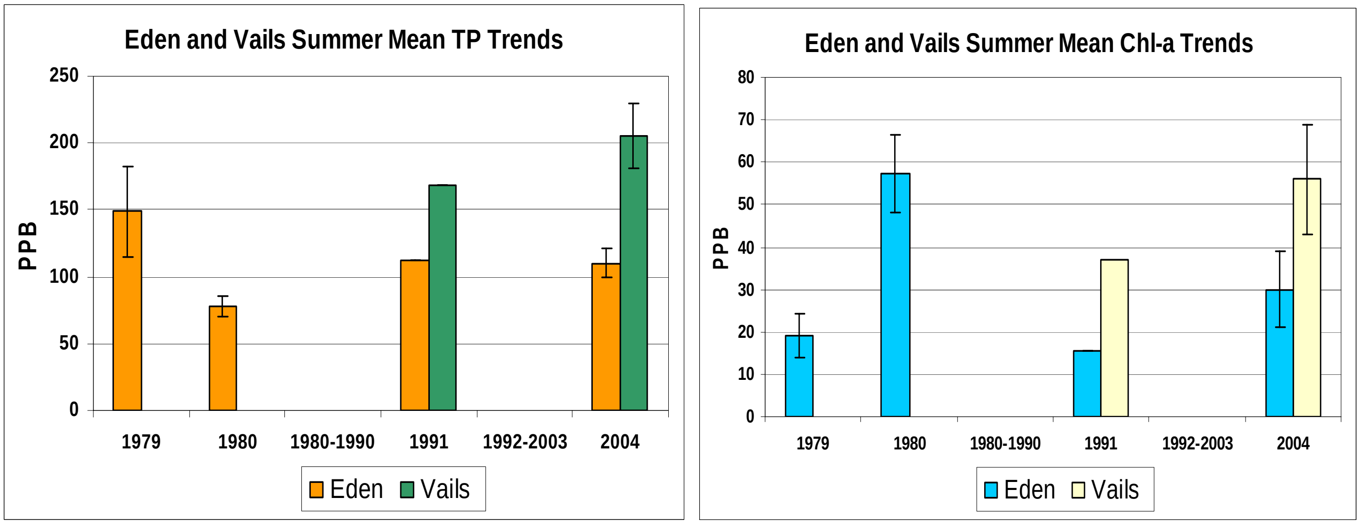


Water Quality Trends

TP and Chl-a Trends

Historic TP and Chl-a data on both lakes is fairly limited. Vails Lake has one additional record from 1991, while Eden has a few more results from 1979, 1980 and 1991. There is not enough data to support a trend for TP or Chl-a on either lake (Figure 20).

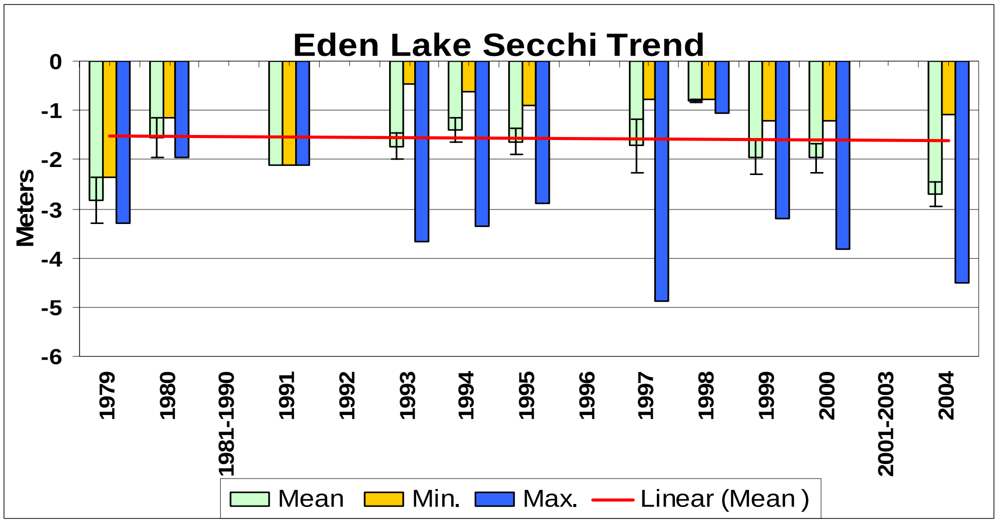
Figure 20. TP and Chl-a Trends

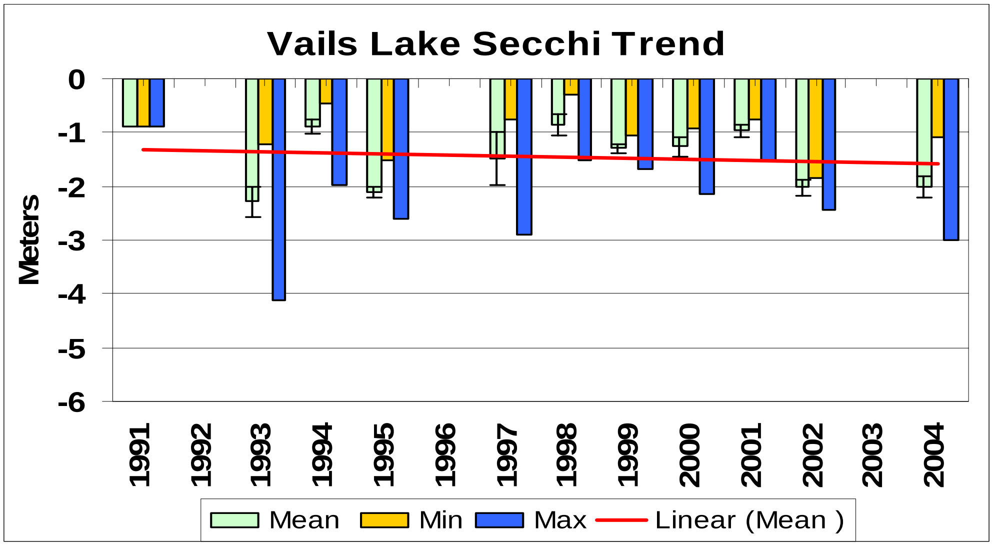


Secchi Trends

Transparency records were analyzed on both lakes to determine if there were any long term trends. Summer-mean transparency ranged from 1.5-2.5 in most summer in Eden Lake. A slight, but not significant increase is evident for the period from 1993 – 2004. Minimum transparency increased from <1.0 in 1993-1995 to 1 meter or greater in 1999-2004. Long term summer mean is 1.4 m.

Figure 21. Summer Mean Secchi Trends

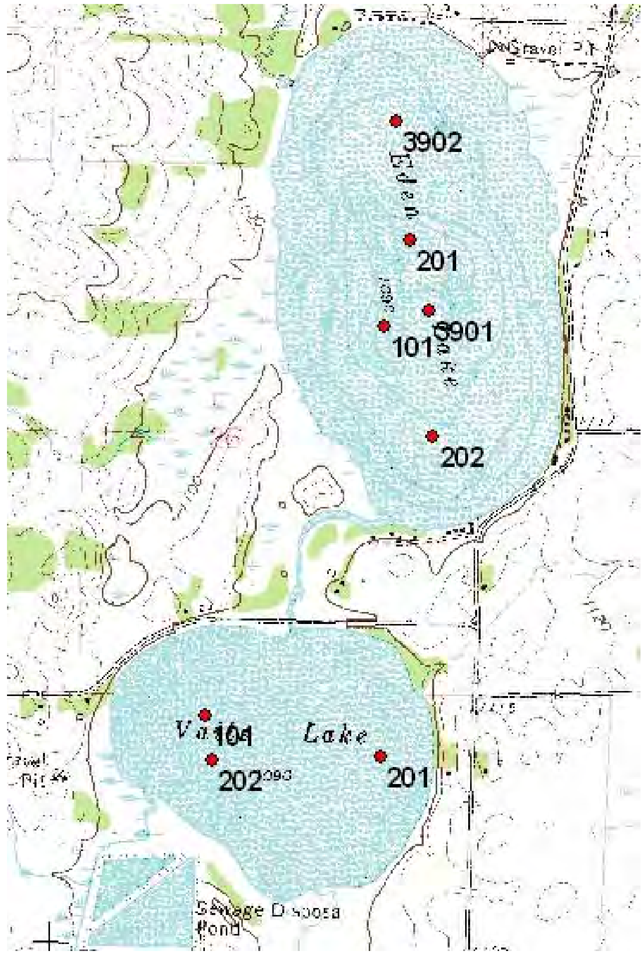




CLMP Monitoring Sites

The vast majority of the Secchi readings on Eden Lake are on Sites 201 and 202. Secchi results are comparable among the two sites. Similar to Eden, the majority of Secchi readings on Vails were on Sites 201 and 202. Comparing the records of the two sites, Site 201 averaged about a half a foot deeper transparency. Being consistent on monitoring sites adds for better data quality. CLMP monitoring has stopped on both lakes of recent years. Secchi monitoring is critical to maintain some form of record on water quality on the lakes.

Figure 22. Monitoring Sites



Eutrophication

Eutrophication is the process by which lakes are enriched with nutrients, increasing the production of rooted aquatic plants and algae. The extent to which this process has occurred is reflected in a lake's trophic classification or state: oligotrophic (nutrient poor), mesotrophic (moderately productive), and eutrophic (very productive and fertile). One way to evaluate the **trophic status** of a lake and to interpret the relationship between total phosphorus, Chl-a and Secchi disk readings is Carlson's Trophic State Index (TSI) (Carlson 1977). This index was developed from the interrelationships of summer Secchi disk transparency and the concentrations of surface water Chl-a and TP. TSI values are calculated as follows:

Total Phosphorus TSI (TSIP) = 14.42 1n (TP) + 4.15
Chlorophyll-a TSI (TSIC) = 9.81 1n (Chl-a) + 30.6
Secchi disk TSI (TSIS) = 60 - 14.41 1n (SD)

$$\text{Tropic State Index (TSI)} = \frac{(\text{TSIP}) + (\text{TSIC}) + (\text{TSIS})}{3}$$

The TSI is a simple mean of the three values TP and Chl-a are in µg/L and Secchi disk transparency is in meters. TSI values range from 0 (ultra-oligotrophic) to 100 (hypereutrophic). In this index, each increase of 10 units represents a doubling of algal biomass.

[1] Derived from Heiskary and Wilson (1990).
[2] Chl-a measurements have been corrected for pheophytin.

Table 5. Trophic Status Indicators

	Eden	Vails
Avg. TSI	61	67
TP TSIP =	72	81
Chl-a TSIC =	64	70
Secchi TSIS =	47	50

Generally TSI values between 50 and 70 are considered eutrophic. Both lakes calculated TSI's were in the eutrophic range. The individual TSIP, TSIC and TSIS show a fair amount of range (Figure 23). Many problems are associated with eutrophic condition such as: nuisance macrophytes (aquatic plants), algal scums, and low transparency and anoxic hypolimnia (low DO). These conditions may discourage swimming and boating and take away the enjoyment of the lake.

Figure 23. Carlson Trophic Sate Index with Eden and Vails Values

Carlson's Trophic State Index
RE Carlson

TSI < 30 Classic Oligotrophy: Clear water, oxygen throughout the year in the hypolimnion, salmonid fisheries in deep lakes.

TSI 30 - 40 Deeper lakes still exhibit classical oligotrophy, but some shallower lakes will become anoxic in the hypolimnion during the summer.

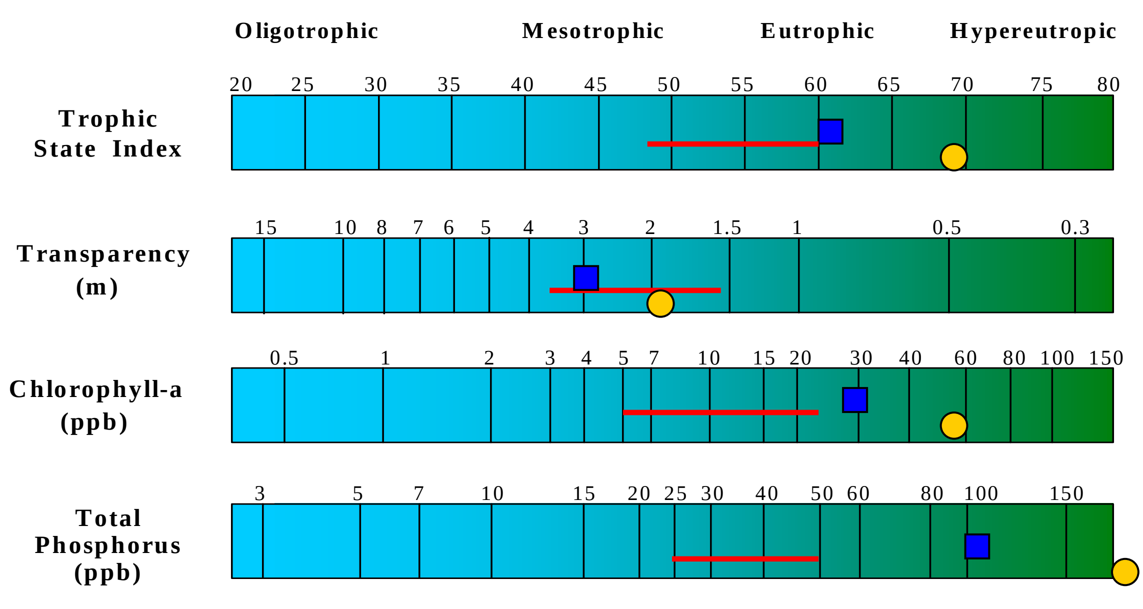
TSI 40 - 50 Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.

TSI 50 - 60 Lower boundary of classical eutrophy: Decreased transparency, anoxic hypolimnia during the summer, macrophyte problems evident, warm-water fisheries only.

TSI 60 - 70 Dominance of blue-green algae, algal scums probable, extensive macrophyte problems.

TSI 70 - 80 Heavy algal blooms possible throughout the summer, dense macrophyte beds, but extent limited by light penetration. Often would be classified as hypereutrophic.

TSI > 80 Algal scums, summer fish kills, few macrophytes, dominance of rough fish.



After Moore, 1. And K. Thornton, [Ed.]1988. Lake and Reservoir Restoration Guidance Manual. USEPA>EPA 440/5-88-002.

Ecoregion Range: —— ■ Eden :● Vails

Modeling and Phosphorus Loading

Numerous complex mathematical models are available for estimating nutrient and water budgets for lakes. These models can be used to relate the flow of water and nutrients from a lake's watershed to observed conditions in the lake. Alternatively, they may be used for estimating changes in the quality of the lake as a result of altering nutrient inputs to the lake (e.g., changing land uses in the watershed) or altering the flow of amount of water that enters the lake. To analyze the in-lake water quality of Eden and Vails Lake, the models **MINLEAP** (Wilson and Walker, 1989), **Reckhow and Simpson** (Reckhow and Simpson, 1980), and **BATHTUB** (Walker, 2004) were used. The "Minnesota Lake Eutrophication Analysis Procedures" (MINLEAP), was developed by MPCA staff based on an analysis of data collected from the ecoregion reference lakes. It is intended to be used as a screening tool for estimating lake conditions with minimal input data and is described in greater detail in Wilson and Walker (1989). Reckhow and Simpson is a spreadsheet model that estimates phosphorus loading to the lake based on phosphorus and runoff coefficients. BATHTUB is an assemblage of models developed by Dr.William Walker in the 1980s for the U.S. Army Corps of Engineers for assessing eutrophication impacts in reservoirs and lakes. The current version (V6.1) is available on the Web from the USACE, which may be accessed via the MPCA web site (http://www.pca.state.mn.us/water/charting.html)

The first model, **MINLEAP,** was used to estimate in-lake TP and related measurements for Vails Lake and a composite of Vails and Eden Lake (treating them as a single lake). Since the majority of the watershed flows through Vails it was not appropriate to model Eden individually as a portion of the watershed loading is trapped in Vails Lake and MINLEAP does not account for this. The observed P for Vails was based on the May-August mean, rather than the typical June through September. This was done to provide a better estimate of the P that would be attributable to external loading rather than internal P loading, which was the primary cause of the elevated P in September. The predicted P for Vails was significantly lower than the observed (Table 6). The P loading rate (flux) associated with the predicted P was 1,695 kg P/yr, which is driven by the estimated stream concentration (149 µg/L) used in MINLEAP for lakes in the CHF ecoregion. Water residence time (time water resides in lake or time it would take to fill the lake if it were empty) is rather short at about 0.2 year (about 2-3 months), as a result of the large watershed relative to the size of Vails Lake. The model also estimates that Vails retains about 40 percent of the P load that enters the lake (hence about 60 percent is transported downstream to Eden Lake). As noted previously there is relatively poor agreement among the TP, Chl-a and Secchi values for both the observed and predicted data.

A similar model run was conducted for a composite of Vails and Eden Lakes (treating them as a single lake). Again, the model predicts a significantly lower TP for the lakes (Table 6). The P loading rate associated with this estimate was 1,912 kg P/yr. The water residence time of the lakes when combined was about 0.6 years. Additional model runs for Vail and for Vails-Eden were conducted in order to estimate the P loading rate and stream concentrations necessary to account for the observed P concentrations. For Vails Lake, a stream P concentration about 100 µg/L higher (250 µg/L) than the MINLEAP default concentration (149 µg/L) was needed to yield an observed concentration of 146 µg/L. The P loading rate was estimated at 2,851 kg P/yr. For the two lakes combined (Vails/Eden) a stream TP concentration of 352 µg/L was needed to yield a TP of 126 µg/L (Table 6). In this case the estimated loading rate was 4,455 kg P/yr. In both cases it is likely that the “calibrated” loading rates are much closer to the actual P loading that reaches these lakes than is the uncalibrated MINLEAP estimate.

Table 6. MINLEAP Modeling Results

Parameter	Vails Observed	Vails Predicted	Vails calibrated to obs-P	Vails-Eden Observed	Vails-Eden Predicted	Vails-Eden Calibrated to Obs. P
TP (µg/L)	146 ± 24	94 ± 22	146 ± 43	130 ± 20	68 ± 20	126 ± 41
Chl-a (µg/L)	56 ± 13	50 ± 25	114 ± 59	40	31	77
% Chl-a >10 µg/L	100	100		95	98	100
% Chl-a >20 µg/L	97	95		74	76	99
% Chl-a >30 µg/L	86	79		52	44	96
Secchi (meters)	1.9 ± 0.2	0.8 ± 0.3	0.5 ± 0.2	2.3	1.0	0.6
P loading (kg P/yr)		1,695	2,851		3,826	4,455
P retention		0.37	0.45		0.55	0.64
P inflow conc.(µg/L)		149	251		151	352
water load (m/yr)		18.6			7.72	
outflow vol. (hm^3/yr)		11.4			12.7	
background P (µg/L)		31			27	
residence time (yrs)		0.2	0.2		0.6	0.6

The **Reckhow-Simpson** model was used to further estimate water quality of these lakes and provide some relative comparisons among potential sources of P. The Reckhow-Simpson model makes estimates based on precipitation, runoff evaporation lake and watershed characteristics. Estimates for P and water loading were made as follows:

1. *P export coefficients* - standard coefficients based on the literature and past experience were used.
2. *Precipitation* - was estimated based on 2004 water year data and runoff was estimated from statewide isopleth maps.
3. *Atmospheric coefficients* – estimated at 15 to 20 kg P/km^2/yr.
4. *Septic Systems* – based on the number of seasonal and annual residences, standard per capita loading rate, and a soil retention coefficient of 70 (low retention) – 90 (high retention) percent.

This model provides a range of predicted concentrations as follows:

	Low	Most Likely	High
Vails	92 ppb	158 ppb	266 ppb
Eden	73 ppb	121 ppb	195 ppb

The “most likely” range of P export coefficients provided the best estimate of in-lake P for Vails and Eden Lakes, since it is predicted in-lake P was closest to the observed (Table 6). By varying the loading from precipitation and septic systems (as noted above) we were able to derive ranges for P loading to the lake from the three source categories: watershed, shoreland septic systems, and precipitation on the lake; however since the watershed is so large (and loading is so high relative to the other two sources) it seems safe to attribute almost 98 percent of the external P loading to Vails Lake to the watershed, and about one percent each to septic and precipitation. The high percent contribution from the watershed is to be expected given the size of the lake and its watershed. Precipitation is relatively insignificant because of the lakes’ small surface area in comparison to the watershed. Much of the watershed is in agriculture uses that tend to have high P export values. The percentage attributed to septic systems is based on several factors as noted above. In instances where the majority of the septic systems are up-to-code, properly maintained, and built on well-drained soils we are inclined to believe that minimal P is transported to the lake (i.e., 90 percent retention by system and soils); in contrast where systems are not up-to-code, not properly maintained, and soils are not well suited for this purpose soil and septic system retention is likely lower and we have used 70 percent retention in our estimate. This model also allows us to make some relative estimates of animal-generated P (e.g. feedlots) on in-lake P concentrations. This aspect will be addressed in more detail in the section on P loading sources.

BATHTUB modeling provides an improved basis for evaluating the water and nutrient budgets for Vails and Eden Lakes as it allows us to "route" water and P loads through Vails Lake and on to Eden Lake. In this fashion the model estimates sedimentation (retention) of P in Vails Lake prior to routing the load downstream to Eden Lake, which results in a more realistic estimate of the downstream loading to Eden. The model framework also allows us to select specific models for prediction of Chl-a and Secchi and make estimates of loadings from the immediate watershed of Eden Lake. Watershed P and water loads were derived based on landuse composition, estimated P concentrations in runoff from the different land uses (similar to P export coefficients), estimated runoff from the watershed, annual precipitation for 2004 water year, and typical evaporation for lakes in this region of the state. A summary of P and water budgets and comparisons of observed and predicted P are presented in Table 7.

Table 7. BATHTUB Predictions for Vails and Eden Lakes

Estimated Water Budget (units=hm^3/yr which =cfs/811)

	Precip. on lake	Watershed runoff	Immediate runoff	Evaporation	Outflow
Vails	0.4 (3%)	11.2 (97%)		0.5 (4%)	11.1 (96%)
Eden	0.7 (5%)	11.1 (85%)	1.3 (10%)	0.8 (6%)	12.2 (94%)

Estimated Phosphorus Budget[1]

	Precip. on lake	Watershed P load	Immediate P load	Retention	Outflow
Vails	12 (0.4%)	2,751 (99%)		1,200 (43%)	1,568 (55%)
Eden	21 (1.0%)	1,568 (85%)	259 (14%)	962 (52%)	899 (48%)

[1]Septic input estimated at less than one percent

In-lake P (ppb), Chl-a (ppb) and Secchi (m): predicted vs. observed

	TP – Pred.	**TP-Obs.[1]**	**Chl-a-Pred.**	**Chl-a-Obs.**	**Secchi-Pred.**	**Secchi-Obs.**
Vails	142	146	58	56	0.4	2.0
Eden	74	120	33	30	0.7	2.5

[1]Mean P for both lakes is for May – August 2004, excludes September fall overturn value.

As noted previously watershed runoff is the primary contributor to the P and water budget of Vails Lake. Based on BATHTUB estimates about 43 percent of the P load is retained in Vails Lake with the remainder transported downstream to Eden Lake. Using standard estimates for stream P for the various land uses in the Vails Lake watershed (Appendix) and a standard runoff coefficient for the watershed a reasonable P and water budget is attained for Vails Lake with observed and predicted P in relatively close agreement. It should be noted that we have intentionally excluded the September in-lake P concentration from Vails Lake, which was strongly influenced by fall turnover (Figure 9 and 13) and mixing of P-rich bottom waters (internal loading) in this comparison as we wanted to emphasize the external P loading. While Vails Lake in-lake observed and predicted P are in close agreement that is not the case for Eden Lake, which exhibits a higher than predicted in-lake P. Various reasons for this could include: 1) downstream transport from Vails Lake is higher than predicted by the model, i.e. retention is less than predicted; 2) there are excessive sources of P in the immediate watershed; and/or 3) internal loading of P in Eden Lake is a significant source. Potential sources of P will be explored in the next section of the report.

Potential Sources of P to Vails and Eden Lakes

The observed data and the three models clearly demonstrate that in-lake P concentrations in Eden and Vails Lake are very high as compared to other lakes in the CHF ecoregion and higher than expected based on the volume of the lakes, size of the watershed and ecoregion they are located in. Following is a discussion of several factors that contribute to the high in-lake P concentrations and high Chl-a which was observed on both lakes:

1. Watershed Size and Land Use - One important factor is the very large watershed that drains to Vails and Eden Lakes. The watershed: lake area ratio is about 143:1 for Vails and is about 59:1 when we consider Vails and Eden as a single lake (Table 6). This means that water and phosphorus loading are very high relative to the size and volume of the lake, which in part contributes to a high predicted in-lake P based on MINLEAP (Table 6). The downstream loading to Eden is diminished somewhat by Vails, which retains about 45 percent of the P that enters the lake. However, the downstream transport of P to Eden remains high as evidenced by the BATHTUB model which predicted an in-lake P of 82 µg/L for Eden and did not fully account for the observed in-lake P (110 µg/L). In addition to being large, the watershed is highly agricultural with over 90 percent of the land in cultivated or other ag-related land uses based on records for Stearns County. Streams draining agricultural lands are typically much more nutrient-rich than streams draining other land uses. For example streams draining predominately forested watersheds in the NLF ecoregion have P concentrations typically in the 30-50 ppb range, while streams draining mixed land uses in the CHF ecoregion often exhibit stream concentrations in the 60-150 ppb range (McCollor and Heiskary, 1993). In highly agricultural watersheds in-stream P concentrations of 210-350 or more are common. Thus it is likely that in-stream concentrations in the Vails-Eden watershed are much higher than the MINLEAP estimate of 150 ppb for the CHF ecoregion.

Figure 24. Feedlots in Watersheds

2. Feedlots – Animal feeding operations can be a large potential source of P in the watershed. Published estimates of P concentrations in runoff from feedlots range from 5,000-85,000 ppb based on data compiled by Reckhow et al. (1980). Whether P generated from animals actually makes it to the lakes is dependant on many factors including: how wastes are stored, methods and timing of land application, proximity of drainage networks (streams, ditches, drain tiles) to feedlots and land application sites, presence of vegetated stream buffers, and various other factors that may either prohibit the movement of this nutrient-rich water or allow for its downstream conveyance to the lakes. In the case of Vails and Eden Lakes the potential P generated from feedlots is quite high considering the large number of feedlots and large number of animals in the watershed (Table 8). Given no current information on manure application sites, such as location, crop type and management, the impact individual sites could vary greatly.

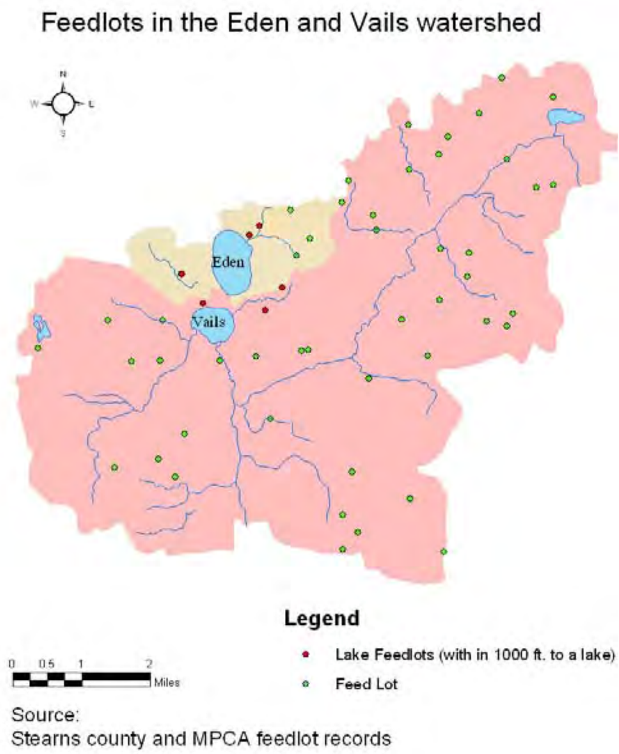


Table 8. Estimated Number of Feedlots and Animals in Vails and Eden Lake Watersheds Based on MPCA and Stearns County Records

	# feedlots	#cattle	#hogs	#sheep	#poultry	#horses
Vails	**45**	**11,600**	**1,600**	**700**	**2,500**	**11**
Eden	**6**	**1,400**	**10**			
Sum	**51**	**13,000**	**1,610**	**700**	**2,500**	**11**

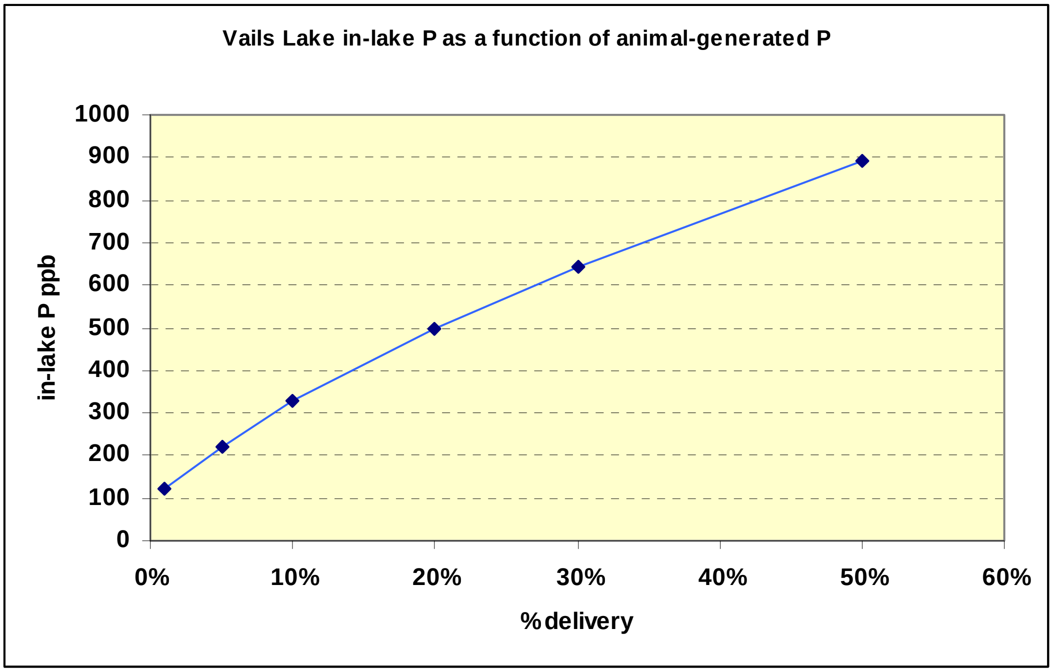
In the Reckhow-Simpson spreadsheet (referred to earlier) we have a basis for estimating the potential contribution from animals in the watershed to downstream lakes. This method takes into account the number and type of animals in the watershed and published estimates of waste generated and estimated mass of P in that waste (e.g. the low, most likely and high range for cattle used here was 3, 6, and 12 kg P/yr). Based on the large number of animals in its watershed (Table 8) the animal p-generation potential is huge, with annually estimated P generation on the order of 37,000 (low), 73,000 (most likely) and 147,000 kg P/yr (high). A sensitivity analysis is used to estimate the affect of the animal-unit P generation potential on in-lake P concentration (Figure 26). In this case we used the MINLEAP-estimated P (low estimate in the Reckhow model run) as a "base" concentration for the lake and then show the affect of varying increments of animal-generated P reaching the lake. For example, in Vails Lake MINLEAP estimated an in-lake P of about 93 ppb. Given the large number of animals in the watershed and high generation potential it would take only a small portion (about 5 percent) of this P to elevate the in-lake concentration to the 160-180 ppb range observed in 2004. For Eden Lake, this may be an important factor as well. Though there are only six feedlots in the immediate watershed, three or four appear to be in either close proximity to the lake or a watercourse (Figure 24). Again using the MINLEAP, low estimate from Reckhow-Simpson, and BATHTUB model prediction we used a base concentration of about 70-80 ppb, which is lower than the observed P of 110 ppb. In this case if 15-20 percent of the animal-generated P in the watershed reached the lake it would account for the concentration observed in 2004. While these methods are not exact, they do provide strong evidence of the potential for excess P loading to the lakes from animal-generated P.

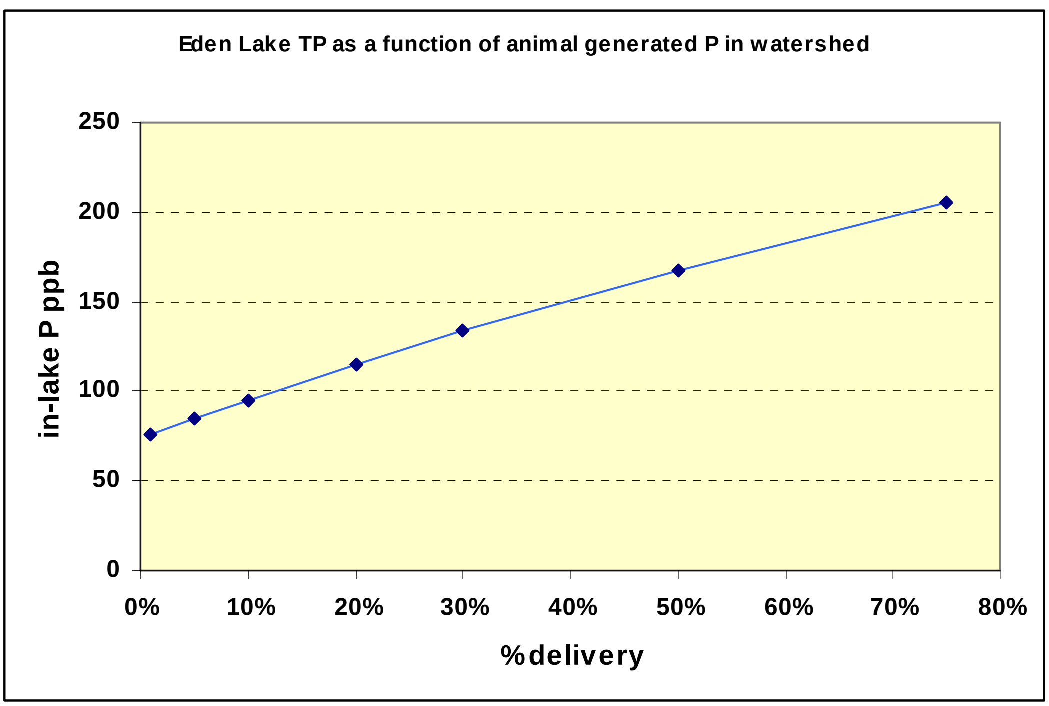
3. Wastewater Spray Field – The City of Eden Valley's wastewater treatment facility at one time discharged treated effluent directly to Vails Lake, which would have been a significant source of P to both Vails and Eden Lake. While it no longer discharges directly to the lake, this discharge likely served to enrich the sediments with P – which may in part account for the high hypolimnetic P concentrations (Figure 13). The treatment facility is a four cell: 2 primaries, 1 secondary and 1 holding, with surface areas of 5.36, 8.66, 3.7 and 5.63 acres respectively. The ponds discharge via spray irrigation on 5 different sites with a total area of 130 acres located on the south side of Eden Lake (Figure 25). A review of the file does not indicate any violations of permit conditions. Given the very close proximity of the spray irritation sites to the lake as well as the tributary there is some potential for runoff from this portion of the watershed to have elevated P concentrations given a significant rainfall event. As long as runoff is prevented at the irrigation fields, there is little risk of wastewater impacting the adjacent surface waters. However, even if some runoff occurs it is most likely not a large source of excess P loading to Vails Lake. It is likely the P enriched sediment in Vails is recycling P in to the water under windy and mixed conditions adding to elevated P.

Figure 25. Eden Valley Treatment Ponds and Irrigation Sites

4. Internal P Loading – Internal recycling of P from lake sediments under anoxic (oxygen poor) conditions occurred in both Vails and Eden Lake (Figure 13). However, based on the DO and temperature profiles (Figures 9 and 10) and the 2004 monthly P data, it appears that much of this P remains in the hypolimnetic waters of the lake until fall turnover, which for Vails Lake occurred in September. While this "source" of P contributes to the annual P budget in both lakes, it does not appear to be too significant during the summer months based on data from 2004.

Figure 26. Vails and Eden Lake In-lake P as a Function of Animal Generated P in Watershed





Estimating Background Phosphorus Concentrations

There are a couple means available to us for estimating background P concentrations, which figures into goal setting for lakes. One method involves a mathematical model, developed by Vighi and Chiaudani (1985), estimated background phosphorus concentration at 25 and 32 µg/L for Eden and Vails (Table 6). The observed P was many times greater than the background estimation for both lakes. This prediction is based on the morphoedaphic index, routinely used in fishery science, and predicts background (i.e. natural) P based on the lake's alkalinity and mean depth. The model assumes that P is delivered to the lake in proportion to other minerals like calcium and magnesium from the watershed. Based on past experience this model provides a reasonable estimate of background P for lakes that were naturally oligotrophic to mesotrophic in nature, however the model may underestimate P for lakes that may have been eutrophic in nature. The model does, however, provide an estimate of the proportion of P in the lake that might be due to natural background loading.

Another way to place lake condition in perspective is to compare modern-day TP concentrations to historic, specifically pre-European conditions, which for most of Minnesota, corresponds to the 1750-1800 time period. One technique for estimating pre-European conditions or changes over time involves the collection of a sediment core (~2 m long) from the bottom of the lake. The sediment core is sectioned and the various sections are "dated" by means of various techniques. Diatom (algae) fossils in the cores can be used to estimate the trophic status since their environmental requirements are well known. A recent study (Heiskary and Swain, 2002) documented pre-European trophic status and trends for 55 Minnesota lakes. While Vails and Eden Lakes were not a part of this study, 30 other CHF ecoregion lakes were (of which two were in Stearns County). Based on the 30 CHF lakes, typical pre-European TP concentrations in CHF lakes averaged 24 ± 2 µg/L. Two nearby lakes in Stearns County, Krieghle and Sagatan, had diatom-inferred pre-European TP of 15 and 17 µg/L respectively.

For more information on diatom-inferred reconstruction of historical water quality:
http://www.pca.state.mn.us/publications/reports/lakes-wqdiatoms.pdf
http://www.pca.state.mn.us/publications/environmentalbulletin/tdr-eb04-04.pdf

Table 9. Modeling Results for TP Compared to Observed

Lake	Observed Mean	Standard MINLEAP	Reckhow-Simpson	BATHTUB	Vighi – P Background	CHF Diatom-inferred P
Eden	120 ± 10	69 ± 20	121	74	24	24
Vails	146 ± 24	93 ± 22	158	142	31	24

Goal Setting

Based on most indications water quality of Eden and Vails is of concern. The 2004 summer mean TP and Chl-a levels are well above the typical range for minimally-impacted CHF ecoregion lakes. According to models that consider lake and watershed characteristics and other factors, Eden and Vails lakes are anticipated to be more nutrient-rich than many lakes in the CHF ecoregion given their large and highly agricultural watershed. However, observed P concentrations appear to be well above MINLEAP and related model estimates. Eden Lake in particular appears to be more nutrient-rich than anticipated given that Vails Lake retains about 40-45 percent of the upstream P loading from the watershed (based on model estimates). It is evident that there are abundant sources of phosphorus in the watershed – many of which relate to cultivated land use and animal agriculture. It is also likely that in-lake P recycling is contributing to elevated phosphorus levels in Vails Lake. Large reductions in P loading will likely be required to yield improved water quality in these lakes.

Lake water quality standards are under development. The current phosphorus criteria value for lakes in the CHF ecoregion is 40 µg/L. Based on this assessment it appears that it may be difficult for Vails and Eden Lake to achieve a concentration this low. However, this does not mean to imply that water quality improvement cannot be attained on these lakes; rather there will be a need for fairly large reductions in the P loading to these lakes. In the case of Eden Lake, if excess P loading is arising from within its immediate (direct) watershed this may not be an insurmountable task. More detailed analysis of the two lakes, including some tributary monitoring, assessment of land use practices in the watersheds (with particular emphasis on feedlots and land application practices), and related efforts may help identify sources where reductions can be realized that will benefit the lakes. This work would also allow for the development of reasonably attainable water quality goals for each lake.

Appendix A. Glossary

Acid Rain: Rain with a higher than normal acid range (low pH). Caused when polluted air mixes with cloud moisture. Can make lakes devoid of fish.

Algal Bloom: An unusual or excessive abundance of algae.

Alkalinity: Capacity of a lake to neutralize acid.

Bioaccumulation: Build-up of toxic substances in fish flesh. Toxic effects may be passed on to humans eating the fish.

Biomanipulation: Adjusting the fish species composition in a lake as a restoration technique.

Dimictic: Lakes which thermally stratify and mix (turnover) once in spring and fall.

Ecoregion: Areas of relative homogeneity. EPA ecoregions have been defined for Minnesota based on land use, soils, landform, and potential natural vegetation.

Ecosystem: A community of interaction among animals, plants, and microorganisms, and the physical and chemical environment in which they live.

Epilimnion: Most lakes from three distinct layers of water during summertime weather. The epilimnion is the upper layer and is characterized by warmer and lighter water.

Eutrophication: The aging process by which lakes are fertilized with nutrients. *Natural eutrophication* will very gradually change the character of a lake. *Cultural eutrophication* is the accelerated aging of a lake as a result of human activities.

Eutrophic Lake: A nutrient-rich lake – usually shallow, "green" and with limited oxygen in the bottom layer of water.

Fall Turnover: Cooling surface waters, activated by wind action, sink to mix with lower levels of water. As in spring turnover, all water is now at the same temperature.

Hypolimnion: The bottom layer of lake water during the summer months. The water in the hypolimnion is denser and much colder than the water in the upper two layers.

Lake Management: A process that involves study, assessment of problems, and decisions on how to maintain a lake as a thriving ecosystem.

Lake Restoration: Actions directed toward improving the quality of a lake.

Lake Stewardship: An attitude that recognizes the vulnerability of lakes and the need for citizens, both individually and collectively, to assume responsibility for their care.

Limnetic Community: The area of open water in a lake providing the habitat for phytoplankton, zooplankton and fish.

Appendix A. Glossary Continued

Littoral Community: The shallow areas around a lake's shoreline, dominated by aquatic plants. The plants produce oxygen and provide food and shelter for animal life.

Mesotrophic Lake: Midway in nutrient levels between the eutrophic and oligotrophic lakes

Nonpoint Source: Polluted runoff – nutrients and pollution sources not discharged from a single point: e.g. runoff from agricultural fields or feedlots.

Oligotrophic Lake: A relatively nutrient-poor lake, it is clear and deep with bottom waters high in dissolved oxygen.

pH Scale: A measure of acidity.

Photosynthesis: The process by which green plants produce oxygen from sunlight, water and carbon dioxide.

Phytoplankton: Algae – the base of the lake's food chain, it also produces oxygen.

Point Sources: Specific sources of nutrient or polluted discharge to a lake: e.g. stormwater outlets.

Polymictic: A lake which does not thermally stratify in the summer. Tends to mix periodically throughout summer via wind and wave action.

Profundal Community: The area below the limnetic zone where light does not penetrate. This area roughly corresponds to the hypolimnion layer of water and is home to organisms that break down or consume organic matter.

Respiration: Oxygen consumption

Secchi Disk: A device measuring the depth of light penetration in water.

Sedimentation: The addition of soils to lakes, a part of the natural aging process, makes lakes shallower. The process can be greatly accelerated by human activities.

Spring Turnover: After ice melts in spring, warming surface water sinks to mix with deeper water. At this time of year, all water is the same temperature.

Thermocline: During summertime, the middle layer of lake water. Lying below the epilimnion, this water rapidly loses warmth.

Trophic Status: The level of growth or productivity of a lake as measured by phosphorus content, algae abundance, and depth of light penetration.

Turbidity: Particles in solution (e.g. soil or algae) which scatter light and reduce transparency.

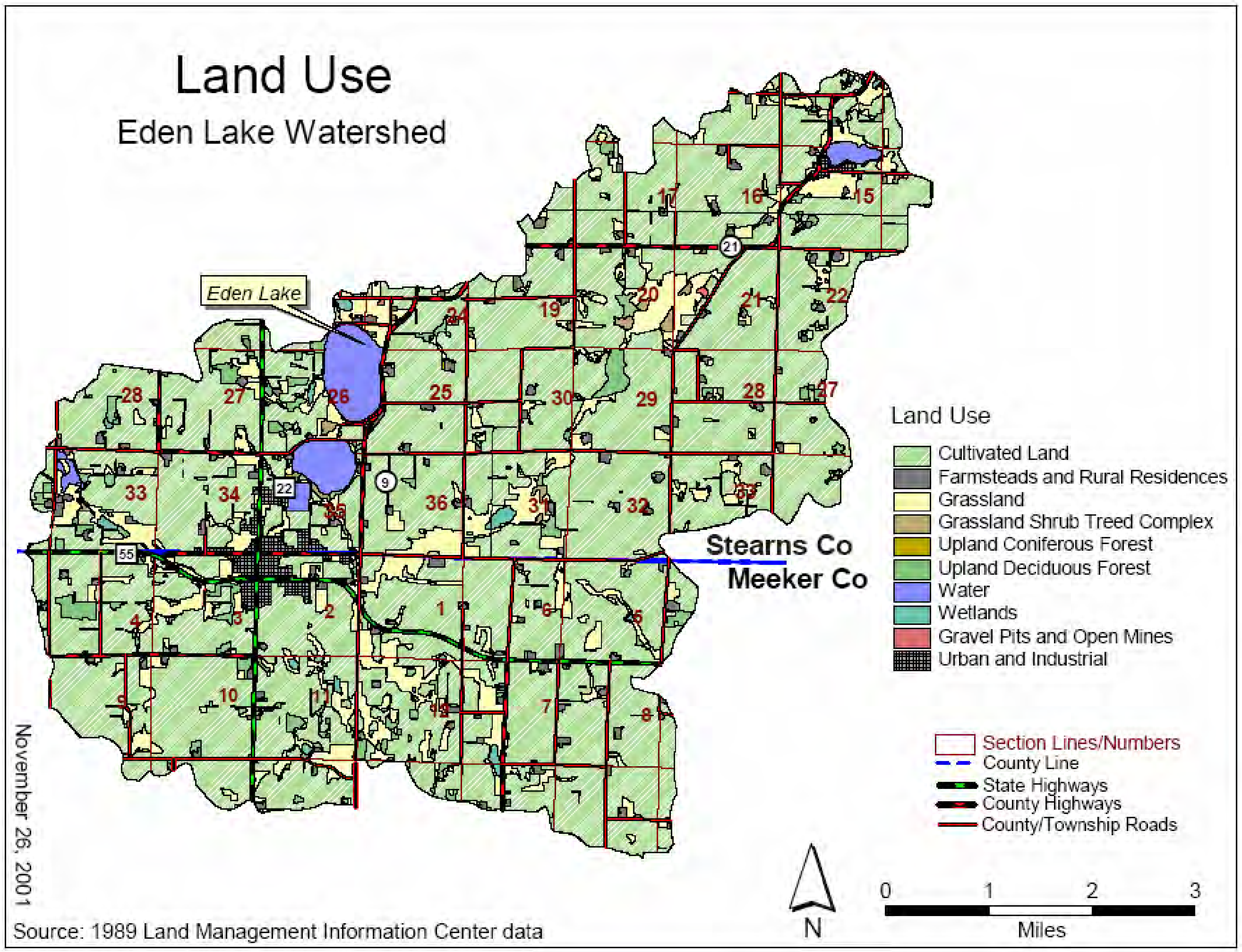
Appendix A. Glossary Continued

Water Density: Water is most dense at 39° F (four degrees Celsius) and expands (becomes less dense) at both higher and lower temperatures.

Watershed: The surrounding land area that drains into a lake, river or river system.

Zooplankton: Microscopic animals

Appendix B. Eden and Vails Watershed Land Use



Appendix C. Field Data

Lake	Lake ID	Site	Date	Depth	Temp	DO	Cond.	pH	ORP	DO	Secchi	Phys.	Rec.	Zooplank abundance
			yymmdd	m	°C	mg/L	µScm		mV	%sat	m	Cond.	Suit	
Mud/Vails	73-0151	101	04/05/04	0	11.7	9.75	532	8.2	351	91.8	1.1	2.0	2.0	4
Mud/Vails	73-0151	101	04/05/04	1	11.72	9.28	532	8.21	350	87.4				
Mud/Vails	73-0151	101	04/05/04	2	11.71	9.33	532	8.24	349	87.9				
Mud/Vails	73-0151	101	04/05/04	3	11.7	9.31	532	8.25	349	87.7				
Mud/Vails	73-0151	101	04/05/04	4	11.7	9.3	532	8.27	349	87.6				
Mud/Vails	73-0151	101	04/05/04	5	11.69	0.98	537	7.11	89	9.2				
Eden	73-0150	101	04/05/04	0	11.15	9.17	500	7.89	314	85.3	4.5			
Eden	73-0150	101	04/05/04	1	11.16	9.19	501	8.01	314	85.5				
Eden	73-0150	101	04/05/04	2	11.14	9.19	501	8.05	314	85.5				
Eden	73-0150	101	04/05/04	3	11.12	8.67	501	8.12	313	80.3				
Eden	73-0150	101	04/05/04	4	11.12	8.63	501	8.14	313	80.2				
Eden	73-0150	101	04/05/04	5	11.12	8.61	501	8.17	313	80				
Eden	73-0150	101	04/05/04	6	11.1	8.56	501	8.18	313	79.5				
Eden	73-0150	101	04/05/04	7	11	8.53	501	8.2	313	79.1				
Eden	73-0150	101	04/05/04	8	11.04	8.41	501	8.2	313	78.1				
Eden	73-0150	101	04/05/04	9	10.99	8.34	501	8.2	313	77.3				
Eden	73-0150	101	04/05/04	10	11.06	8.24	501	8.2	314	76.8				
Eden	73-0150	101	04/05/04	11	10.88	6.44	506	7.85	230	59.5				
Mud/Vails	73-0151	101	04/06/08	0	20.55	9.24	590	7.89	361	107.2	3	3	2	3
Mud/Vails	73-0151	101	04/06/08	1	20.5	9.23	591	7.89	361	106.9				
Mud/Vails	73-0151	101	04/06/08	2	20.35	9.18	592	7.88	361	106.1				
Mud/Vails	73-0151	101	04/06/08	3	19.62	8.83	600	7.77	362	100.5				
Mud/Vails	73-0151	101	04/06/08	4	17.02	7.88	606	7.58	366	85.1				
Eden	73-0150	101	04/06/08	0	20.14	9.84	495	8.21	355	113.1	3.4	3	3	3
Eden	73-0150	101	04/06/08	1	20.15	9.87	495	8.21	355	113.5				
Eden	73-0150	101	04/06/08	2	20.15	9.87	495	8.21	355	113.5				
Eden	73-0150	101	04/06/08	3	20.12	9.73	495	8.21	355	111.9				
Eden	73-0150	101	04/06/08	4	18.6	9.75	501	8.08	357	108.5				
Eden	73-0150	101	04/06/08	5	17.16	9.58	503	8	359	103.7				
Eden	73-0150	101	04/06/08	6	15.88	8.43	502	7.9	359	88.8				
Eden	73-0150	101	04/06/08	8	14.06	6.57	504	7.62	364	66.6				
Eden	73-0150	101	04/06/08	9	13.61	4.92	506	7.52	365	49.3				

Lake	Lake ID	Site	Date	Depth	Temp	DO	Cond.	pH	ORP	DO	Secchi	Phys.	Rec.	Zooplank abundance
Eden	73-0150	101	04/06/08	10	13.23	3.14	507	7.71	367	30.4				
			yymmdd	m	°C	mg/L	µScm		mV	%sat	m	Cond.	Suit	
Mud/Vails	73-0151	101	04/07/08	0	20.57	12.19	588	8.29	406	141.9	1.5	4	4	NA
Mud/Vails	73-0151	101	04/07/08	0										
Mud/Vails	73-0151	101	04/07/08	1	20.51	11.89	588	8.34	407	138.2				
Mud/Vails	73-0151	101	04/07/08	2	20.19	11.28	591	8.31	408	130.2				
Mud/Vails	73-0151	101	04/07/08	3	19.65	5.2	615	7.9	415	59.1				
Mud/Vails	73-0151	101	04/07/08	4	18.87	0.76	649	7.6	383	8.6				
Mud/Vails	73-0151	101	04/07/08	5	17.51	0.57	685	7.36	147	6.2				
Mud/Vails	73-0151	101	04/07/08	5										
Mud/Vails	73-0151	101	04/07/08	6	16.53	0.5	759	6.82	105	5.3				
Eden	73-0150	101	04/07/08	0	20.8	14.29	443	8.84	379	167	1.1	4	3	1
Eden	73-0150	101	04/07/08	1	20.72	14.2	443	8.84	382	165.6				
Eden	73-0150	101	04/07/08	2	20.53	13.71	443	8.81	385	159.3				
Eden	73-0150	101	04/07/08	3	20.04	9.39	454	8.51	391	108				
Eden	73-0150	101	04/07/08	4	18.83	6.5	504	8.2	397	73				
Eden	73-0150	101	04/07/08	5	18.27	5.38	522	8.14	398	59.7				
Eden	73-0150	101	04/07/08	6	17.46	3.01	533	7.97	399	32.9				
Eden	73-0150	101	04/07/08	7	16.11	0.44	541	7.66	400	4.7				
Eden	73-0150	101	04/07/08	8	14.87	0.26	545	7.5	257	2.7				
Eden	73-0150	101	04/07/08	9	13.64	0.22	549	7.41	188	3.2				
Eden	73-0150	101	04/07/08	10	13.21	0.19	550	7.4	139	1.9				
Eden	73-0150	101	04/07/08	11	13.01	0.21	552	7.38	126	2.1				
Eden	73-0150	101	04/07/08	12	12.84	0.26	552	7.39	108	2.6				
Eden	73-0150	101	04/07/08	13	12.38	0.25	555	7.36	97	2.5				
Eden	73-0150	101	04/07/08	15										
Mud/Vails	73-0151	101	04/08/03	0	24.12	9.5	556	8.55	312	116.7	2.9	4	4	2
Mud/Vails	73-0151	101	04/08/03	1	24.14	9.32	556	8.55	312	114.5				
Mud/Vails	73-0151	101	04/08/03	2	24.13	8.74	556	8.55	313	107.4				
Mud/Vails	73-0151	101	04/08/03	3	22.48	0.8	577	7.86	322	9.6				
Mud/Vails	73-0151	101	04/08/03	4	21.55	0.42	603	7.59	85	4.9				
Mud/Vails	73-0151	101	04/08/03	5	18.42	0.38	690	7.17	24	4.2				
Mud/Vails	73-0151	101	04/08/03	6	16.93	0.34	721	7.01	-2	3.6				
Eden	73-0150	101	04/08/03	0	23.87	6.81	439	8.67	256	83.3	3.5	2	2	3
Eden	73-0150	101	04/08/03	1	23.89	6.58	439	8.66	256	80.5				

Eden	73-0150	101	04/08/03	2	23.9	6.34	439	8.65	256	77.6				
Eden	73-0150	101	04/08/03	3	23.84	6.35	439	8.64	257	77.5				
Eden	73-0150	101	04/08/03	4	22.54	3.12	449	8.28	261	37.2				
Lake	**Lake ID**	**Site**	**Date**	**Depth**	**Temp**	**DO**	**Cond.**	**pH**	**ORP**	**DO**	**Secchi**	**Phys.**	**Rec.**	**Zooplank abundance**
			yymmdd	**m**	**°C**	**mg/L**	**µScm**		**mV**	**%sat**	**m**	**Cond.**	**Suit**	
Eden	73-0150	101	04/08/03	5	20.78	0.59	475	7.91	156	6.7				
Eden	73-0150	101	04/08/03	6	18.39	0.26	513	7.67	38	2.8				
Eden	73-0150	101	04/08/03	7	16.2	0.29	529	7.56	6	3.1				
Eden	73-0150	101	04/08/03	8	14.65	0.23	535	7.47	-9	2.3				
Eden	73-0150	101	04/08/03	9	13.79	0.21	539	7.39	-15	2.1				
Eden	73-0150	101	04/08/03	10	13.43	0.18	539	7.25	-20	1.8				
Eden	73-0150	101	04/08/03	11	13.12	0.21	541	7.22	-29	2.1				
Eden	73-0150	101	04/08/03	12	12.97	0.17	541	7.22	-33	1.6				
Eden	73-0150	101	04/08/03	13	12.81	0.17	543	7.22	-37	1.6				
Mud/Vails	73-0150	101	04/09/10	0	19.98	9.36	592	8.35	291	110.8	1.3	4	3	NA
Mud/Vails	73-0150	101	04/09/10	1	19.97	9.41	591	8.34	290	110.5				
Mud/Vails	73-0150	101	04/09/10	2	19.96	9.46	589	8.35	287	111				
Mud/Vails	73-0150	101	04/09/10	3	19.96	9.39	589	8.34	286	110.2				
Mud/Vails	73-0150	101	04/09/10	3.5	19.93	9.33	588	8.34	285	109.4				
Mud/Vails	73-0150	101	04/09/10	4.5										
Eden	73-0150	101	04/09/10	0	20.18	8.12	482	8.54	272	95.6	1.1	3	2	1
Eden	73-0150	101	04/09/10	1	20.14	8.03	481	8.52	270	94.6	1.1	3	2	1
Eden	73-0150	101	04/09/10	2	20.1	8.02	481	8.51	269	94.3				
Eden	73-0150	101	04/09/10	3	20.06	7.95	481	8.5	267	93.4				
Eden	73-0150	101	04/09/10	4	20.04	7.85	481	8.49	267	92.2				
Eden	73-0150	101	04/09/10	5	20.01	7.76	481	8.47	267	90.2				
Eden	73-0150	101	04/09/10	6	19.88	7.05	482	8.44	267	82.6				
Eden	73-0150	101	04/09/10	7	18.48	0.93	512	7.82	64	10.6				
Eden	73-0150	101	04/09/10	8	17.5	0.59	526	7.6	-32	6.5				
Eden	73-0150	101	04/09/10	9	15.17	0.58	568	7.25	-63	5.4				
Eden	73-0150	101	04/09/10	10	13.92	0.55	578	7.17	-68	5.7				
Eden	73-0150	101	04/09/10	11	13.6	0.5	578	7.13	-71	5.1				
Eden	73-0150	101	04/09/10	12	12.92	0.51	581	7.09	-71	5.2				
Eden	73-0150	101	04/09/10	13	12.4	0.48	582	7.04	-71	4.9				

Appendix D. Lab Results

Lake Name	Lake ID	Site	Date yymmdd	Alkalinity mg/L	Color CU	SSV mg/L	TSS mg/L	Chloride	TKN mg	TP mg/L	Chl-a ug/L	Pheophytin ug/L
Mud/Vails	73-0151	101	04/05/04	200	40	2.4	11	36	1.45	0.127	11.1	6.54
Eden	73-0150	101	04/05/04	210	30	1	1	32	1.46	0.180	0.28	0.15
Mud/Vails	73-0151	101	04/06/08	230	40	1.6	2.8	29	1.32	0.081	6.81	0.75
Eden	73-0150	101	04/06/08	200	30	2.8	3.6	29	1.15	0.092	7.5	0.32
Mud/Vails	73-0151	101	04/07/08	230	40	4.8	5.2	33	2.03	0.161	63.4	0.31
Mud/Vails	73-0151	101	04/07/08	230	40	4	4.8	34	2.08	0.198	57.5	0.86
Eden	73-0150	101	04/07/08	160	30	6.6	8.2	32	2.11	0.149	101	2.65
Mud/Vails	73-0151	101	04/08/03	230	40	4.4	6.4	34	2.02	0.216	39.4	2.29
Eden	73-0150	101	04/08/03	160	30	2.8	3.2	30	1.43	0.058	3.52	0.45
Mud/Vails	73-0150	101	04/09/10	260	40	15	16	36	2.75	0.405	165	29.6
Eden	73-0150	101	04/09/10	180	20	4.4	10	32	1.48	0.069	37.9	5.33

Appendix E. References

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Appendix F. Bathtub Modeling

Eden & Vails Lakes (Annual)

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Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: **3** **Area-Wtd Mean**

	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
CONSERVATIVE SUB				9.6	10.00	
TOTAL P MG/M3	99.0	0.28	79.0%	129.7	20.00	86.6%
TOTAL N MG/M3	1648.8	14.29	78.2%	1648.8	20.00	78.2%
C.NUTRIENT MG/M3	76.5	6.04	83.0%	89.9	20.00	87.6%
CHL-A MG/M3	42.1	4.89	97.4%	39.7	20.00	96.9%
SECCHI M	0.6	0.27	20.6%	2.3	30.00	84.2%
ORGANIC N MG/M3	1123.9	4.13	95.5%			
TP-ORTHO-P MG/M3	72.8	4.85	82.5%			
ANTILOG PC-1	1757.8	8.50	93.4%	465.8	23.65	68.8%
ANTILOG PC-2	11.2	2.88	85.3%	30.2	19.18	99.8%
(N - 150) / P	16.1	17.05	46.8%	11.5	21.32	28.4%
INORGANIC N / P	24.8	55.42	42.8%			
TURBIDITY 1/M	0.1	33.91	1.1%	0.1	33.91	1.1%
ZMIX * TURBIDITY	0.3	39.63	0.2%	0.3	39.63	0.2%
ZMIX / SECCHI	7.2	0.25	76.4%	1.8	22.00	4.6%
CHL-A * SECCHI	22.8	4.75	87.3%	88.8	25.54	99.9%
CHL-A / TOTAL P	0.4	4.77	89.3%	0.3	19.73	74.8%
FREQ(CHL-a>10) %	96.4	0.70	97.4%	95.2	2.78	96.9%
FREQ(CHL-a>20) %	77.4	2.94	97.4%	73.8	10.39	96.9%
FREQ(CHL-a>30) %	56.0	4.95	97.4%	51.9	16.30	96.9%
FREQ(CHL-a>40) %	39.4	6.74	97.4%	35.8	21.07	96.9%
FREQ(CHL-a>50) %	27.6	8.50	97.4%	24.8	25.68	96.9%
FREQ(CHL-a>60) %	19.5	10.27	97.4%	17.3	30.41	96.9%
CARLSON TSI-P	69.7	0.06	79.0%	74.2	2.79	86.6%
CARLSON TSI-CHLA	66.9	0.69	97.4%	66.2	2.13	96.9%
CARLSON TSI-SEC	68.3	0.05	79.4%	48.0	6.48	15.8%

Segment: **1** **Vails Lake**

	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
CONSERVATIVE SUB				9.0	10.00	
TOTAL P MG/M3	141.6	0.19	88.6%	146.0	20.00	89.2%
TOTAL N MG/M3	1900.0	20.00	84.1%	1900.0	20.00	84.1%
C.NUTRIENT MG/M3	101.6	10.27	90.4%	103.2	20.00	90.8%
CHL-A MG/M3	58.0	7.56	99.1%	56.0	20.00	99.0%
SECCHI M	0.4	0.18	10.3%	2.0	30.00	79.1%
ORGANIC N MG/M3	1484.8	6.73	98.7%			
TP-ORTHO-P MG/M3	101.0	7.72	89.9%			
ANTILOG PC-1	2934.5	12.63	97.1%	712.1	33.14	79.2%
ANTILOG PC-2	11.4	4.19	86.2%	35.0	26.87	99.9%
(N - 150) / P	12.4	21.72	32.0%	12.0	29.13	30.4%
INORGANIC N / P	10.2	89.26	14.2%			

TURBIDITY 1/M	0.1		1.1%	0.1		1.1%
ZMIX * TURBIDITY	0.2		0.0%	0.2		0.0%
ZMIX / SECCHI	7.3	0.18	76.5%	1.5	29.13	2.3%
CHL-A * SECCHI	23.9	7.56	88.6%	112.0	36.06	100.0%
CHL-A / TOTAL P	0.4	7.56	87.7%	0.4	27.88	85.4%
FREQ(CHL-a>10) %	99.4	0.20	99.1%	99.3	0.57	99.0%
FREQ(CHL-a>20) %	92.0	1.93	99.1%	91.2	5.41	99.0%
FREQ(CHL-a>30) %	77.4	4.67	99.1%	75.7	12.92	99.0%
FREQ(CHL-a>40) %	61.4	7.54	99.1%	59.2	20.71	99.0%
FREQ(CHL-a>50) %	47.1	10.24	99.1%	44.9	28.06	99.0%
FREQ(CHL-a>60) %	35.7	12.70	99.1%	33.7	34.78	99.0%
CARLSON TSI-P	75.6	0.04	88.6%	76.0	3.74	89.2%
CARLSON TSI-CHLA	70.4	1.05	99.1%	70.1	2.76	99.0%
CARLSON TSI-SEC	72.8	0.04	89.7%	50.0	8.52	20.9%

Segment: 2 Eden Lake

	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
CONSERVATIVE SUB				10.0	10.00	
TOTAL P MG/M3	73.7	0.39	68.4%	120.0	20.00	84.6%
TOTAL N MG/M3	1500.0	20.00	73.6%	1500.0	20.00	73.6%
C.NUTRIENT MG/M3	61.7	6.46	75.3%	82.1	20.00	85.1%
CHL-A MG/M3	32.8	6.10	94.8%	30.0	20.00	93.4%
SECCHI M	0.7	0.31	27.0%	2.5	30.00	86.5%
ORGANIC N MG/M3	910.2	4.84	90.0%			
TP-ORTHO-P MG/M3	56.1	5.68	74.5%			
ANTILOG PC-1	1060.9	8.65	86.8%	319.9	33.14	58.1%
ANTILOG PC-2	11.0	3.87	84.7%	27.4	26.87	99.7%
(N - 150) / P	18.3	22.23	54.3%	11.3	29.51	27.2%
INORGANIC N / P	33.5	63.43	54.8%			
TURBIDITY 1/M	0.1	54.00	1.1%	0.1	54.00	1.1%
ZMIX * TURBIDITY	0.4	54.00	0.4%	0.4	54.00	0.4%
ZMIX / SECCHI	7.2	0.31	76.3%	2.0	29.13	6.3%
CHL-A * SECCHI	22.2	6.10	86.4%	75.0	36.06	99.8%
CHL-A / TOTAL P	0.4	6.10	90.1%	0.3	27.88	64.9%
FREQ(CHL-a>10) %	94.6	1.13	94.8%	92.8	4.53	93.4%
FREQ(CHL-a>20) %	68.7	5.05	94.8%	63.5	18.67	93.4%
FREQ(CHL-a>30) %	43.3	8.91	94.8%	37.8	32.17	93.4%
FREQ(CHL-a>40) %	26.4	12.18	94.8%	21.9	43.61	93.4%
FREQ(CHL-a>50) %	16.1	14.96	94.8%	12.8	53.33	93.4%
FREQ(CHL-a>60) %	9.9	17.35	94.8%	7.7	61.73	93.4%
CARLSON TSI-P	66.2	0.08	68.4%	73.2	3.88	84.6%
CARLSON TSI-CHLA	64.8	0.92	94.8%	64.0	3.02	93.4%
CARLSON TSI-SEC	65.6	0.07	73.0%	46.8	9.10	13.5%