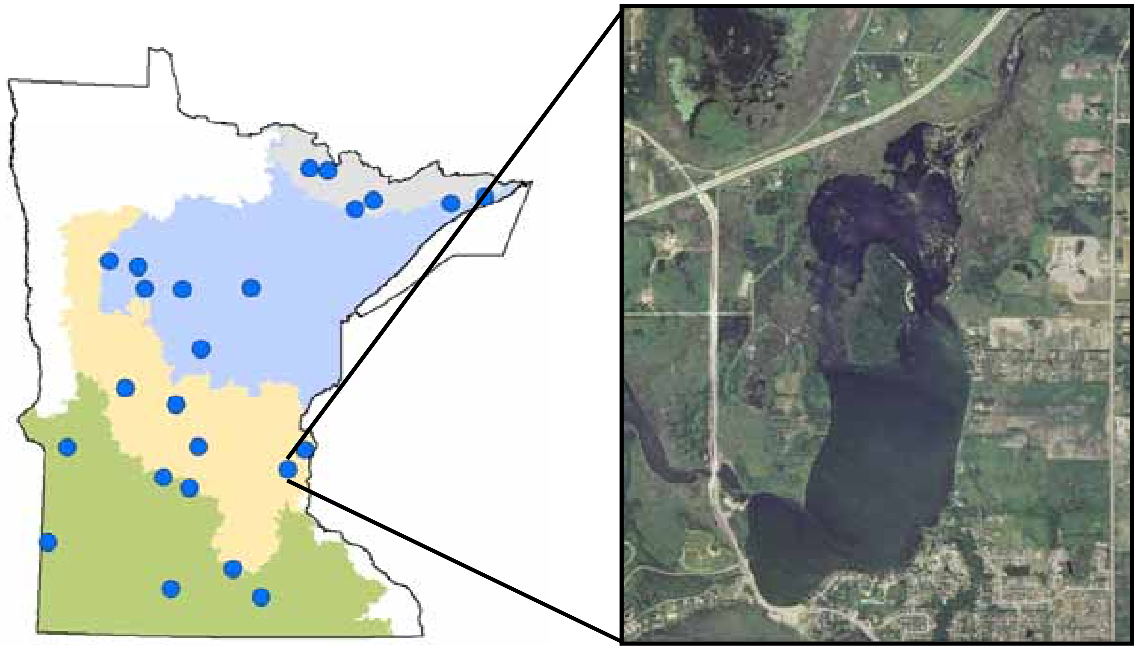
2008 Sentinel Lake Assessment Report for Peltier Lake (02-0004) Anoka County, Minnesota



Minnesota Pollution Control Agency
Water Monitoring Section
Lakes and Streams Monitoring Unit
&
Minnesota Department of Natural Resources
Section of Fisheries
October 2009

Contributing Authors

Matt Lindon and Steve Heiskary, Minnesota Pollution Control Agency

David Gilbraith and Ray Valley, Minnesota Department of Natural Resources

Editing

Dana Vanderbosch, Minnesota Pollution Control Agency

Don Pereira and Peter Jacobson, Minnesota Department of Natural Resources

Other Contributors

Matt Kocian, Rice Creek Watershed District

Chris Zadak Minnesota Pollution Control Agency

Sampling

Matt Lindon, Minnesota Pollution Control Agency, Water Quality Monitoring

Matt Kocian Rice Creek Watershed District, Water Quality Monitoring

Minnesota Department of Natural Resources, Fish and Vegetation Surveys:
David Gilbraith, Gerald Johnson, Dave McCormack, James Stone, Joel Stiras, T.J. DeBates,
Rick Walsh, Ray Valley, Sean Sisler, Donna Dustin, Cindy Tomcko, Tim Ohmann,
Neil Vanderbosch, and Jim Levitt

Volunteer Monitoring

Wayne Leblanc Master Naturalist Program, Lake Water Quality, Vegetation and Ice Out Monitoring

Glennie Gilleen Master Naturalist Program, Vegetation

2008 Lake Assessment of Peltier Lake (02-0004) Anoka County, Minnesota

Minnesota Pollution Control Agency

Water Monitoring Section
Lakes and Streams Monitoring Unit
&
Minnesota Department of Natural Resources
Section of Fisheries

wq-slice02-0004a

The MPCA is reducing printing and mailing costs by using the Internet to distribute reports and information to wider audience. For additional information, see the Web site:

www.pca.state.mn.us/water/lakereport.html

This report was printed on recycled paper manufactured without the use of elemental chlorine (cover: 100% post-consumer; body: 100% post-consumer)

Table of Contents

Table of Contents, continued

List of Tables

Table of Contents, continued

List of Figures

Executive Summary

The Minnesota Pollution Control Agency (MPCA) is working in partnership with the Minnesota Department of Natural Resources (MDNR) on the Sustaining Lakes in a Changing Environment (SLICE) Sentinel Lakes Program. The focus of this interdisciplinary effort is to improve understanding of how major drivers of change such as development, agriculture, climate change, and invasive species can affect lake habitats and fish populations, and to develop a long-term strategy to collect the necessary information to detect undesirable changes in Minnesota Lakes (Valley 2009). To increase our ability to predict the consequences of land cover and climate change on lake habitats, SLICE utilizes intensive lake monitoring strategies on a wide range of representative Minnesota lakes. This includes analyzing relevant land cover and land use, identifying climate stressors, and monitoring the effects on the lake's habitat and biological communities.

The Sentinel Lakes Program has selected 24 lakes for long-term intensive lake monitoring (Figure 1). Peltier Lake was one of the lakes and represents an example of a shallow eutrophic lake in the North Central Hardwood Forests ecoregion. Peltier Lake is 233 hectares (577 acres) of open water and has a maximum depth of 4.9 meters (16 feet) (MDNR GIS Data Deli 2009). It is located partially in the city of Lino Lakes and partially in the city of Centerville. The lake has a relatively large watershed (part of the Rice Creek watershed), spanning 13 municipalities and three counties (Anoka, Ramsey, and Washington). There is extensive water quality data on the lake as a result of monitoring by Rice Creek Watershed District, Metropolitan Council Environmental Service, citizen volunteers, and MPCA. In addition there have been various studies on Peltier's fish and wildlife conducted by MDNR and other parties concerned with the overall ecology of the lake. This data and previous reports were used to develop this assessment of Peltier Lake.

Peltier is an important local resource and a vital component in Anoka County's "Chain of Lakes Park Reserve." It is a popular fishery, particularly in the winter. It also supports other forms of aquatic recreation including waterskiing and swimming; however, water quality and dense stands of invasive curly-leaf pondweed limit usage during portions of the summer. It has historically been a major breeding site for great blue herons and at one time supported a substantial rookery. In recent years the number of herons using the rookery has dwindled and studies were conducted to determine causes. Various problems were identified, but findings indicate waterskiing and raccoon predation are significant factors affecting the rookery. Competing uses for the lake and riparian wetlands present an all too common challenge on this, as well as other, developed and highly used lakes in lakes in a metropolitan area.

The modern-day water quality record indicates Peltier has been hypereutrophic since the mid-1970s with summer average total phosphorus (TP) on the order of 150-350 micrograms per liter (µg/L), chlorophyll-a (Chl-a) of 50-100 µg/L and Secchi of 0.5-1.0 m in most summers. Severe nuisance blooms of blue-green algae are a common occurrence in most summers with individual Chl-a measurements of 100-200 µg/L common in recent years. Sediment diatom reconstruction indicates the lake has been highly eutrophic since the 1930s. Based on a 2007 core study, pre-European diatom-inferred TP was estimated at 60-80 µg/L and the data further indicate that a dramatic increase in TP occurred following the installation of a dam at the outlet in c1910. Landuse changes since that time have led to additional TP loading to the lake. Excessive external (watershed) and internal (recycled P from sediments) both contribute to the modern-day water quality conditions.

Over Peltier's history, there have been significant changes to the macrophyte community as well, which has had an effect on the ecology and water quality of the lake. Native plants were presumably much more abundant prior to European settlement and subsequent land clearance and introduction of carp. Invasive curly-leaf pondweed was first reported in 1982. The population increased to levels deemed a nuisance for recreation by the late 1980's. Curly-leaf pondweed is a self-sustaining, internal driver of poor water quality conditions in nutrient-rich lakes like Peltier due to its mid-summer senescence and subsequent release of nutrients into the water column. Nevertheless, in the absence of other native plants, it does provide important habitat for vegetation-dwelling fish species, especially largemouth bass and bluegill.

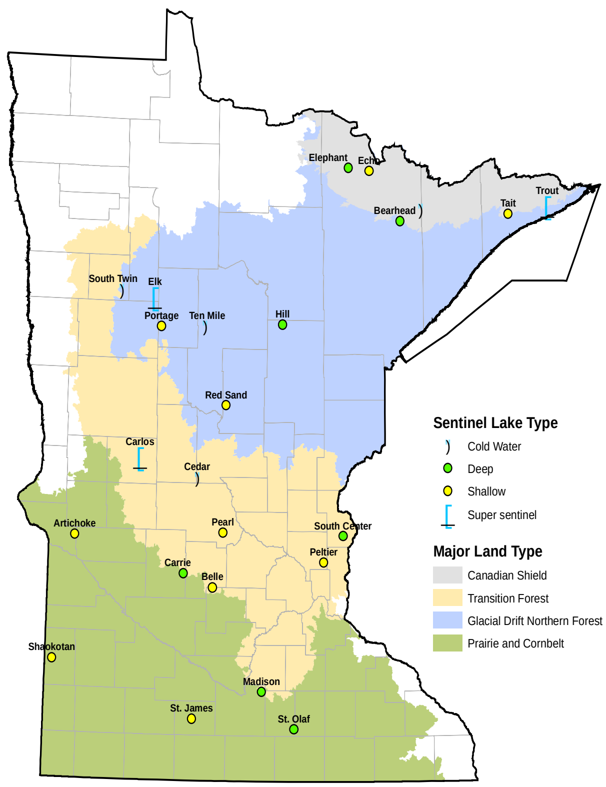
Another invasive species, Eurasian watermilfoil, was first documented in Peltier in 2000; however, Eurasian watermilfoil has not reached nuisance levels of abundance, presumably because the algal productivity of Peltier exceeds that which is optimal for Eurasian watermilfoil growth. Eurasian watermilfoil biomass and cover may increase if nutrient reductions are sufficient to affect a reduction in algal biomass and an improvement in transparency. While extensive milfoil beds can impair recreation this situation may be preferable to the frequent and intense blue-green algal blooms that now characterize the lake during much of the summer.

Peltier's fishery has historically experienced many winterkills, and common carp is a major member of the fish community in terms of biomass. Carp benefit from poor water quality conditions and create additional water quality problems in shallow eutrophic lakes with their feeding and spawning activities that uproot aquatic plants and re-suspend sediments. Nevertheless, Peltier's fishery has improved in recent decades. Evidence of winterkills have been absent since 1988 when an aeration system was installed, carp numbers have dramatically decreased over the same time period, and more recently, black bullhead have also declined. Today, Peltier is a popular fishery for black crappie and bluegill.

Lakes not supporting aquatic recreational use are termed 'impaired' and are placed on a list biennially. This list is formally termed the 303(d) list (referencing the section within the federal Clean Water Act that requires us to assess for condition); it is also commonly called the "Impaired Waters List". A lake placed on the Impaired Waters List is required to be intensively researched through a Total Maximum Daily Load (TMDL) study to determine the source and extent of the pollution problem. The study also requires the development of a restoration plan. Peltier was included on Minnesota's Impaired Waterslist in 2002 because its TP, Chl-a and Secchi transparency values were far in excess of eutrophication standards for lakes in the North Central Hardwood Forests ecoregion.

This has resulted in a detailed TMDL study that is intended to identify sources of excess TP and then create an "allocation" (nutrient budget) that would allow the lake to meet water quality standards. That study is well underway and a draft TMDL report has been developed. To no surprise, both the external and internal loads were deemed to be excessive and both need be addressed if lake water quality is to be improved.

Figure 1. Sentinel lakes locations and designations.



Introduction

This report provides a relatively comprehensive analysis of physical, water quality and ecological characteristics of Peltier Lake in Anoka County, Minnesota (MN). This report will provide a detailed analysis of recent water quality and fishery assessments on the lake. While Minnesota Pollution Control Agency (MPCA) and Minnesota Department of Natural Resources (MDNR) studies from 2008 are emphasized, previous data and studies from monitoring by Rice Creek Watershed District (RCWD), Metropolitan Council Environmental Service (MCES), citizen volunteers, and others will be referred to as well. Water quality data analyzed will include all available data in STORET, the national repository for water quality data. Further detail on water quality and limnological concepts and terms in this report can be found in the Guide to Lake Protection and Management: (http://www.pca.state.mn.us/water/lakeprotection.html).

History

1902	Semi-permanent (wooden) dam installed at Peltier Lake outlet by St. Paul Board of Water Commissioners. Water is drawn from adjacent Centerville Lake for municipal use.
1910	Permanent dam (concrete) replaces wooden structure. Water levels are raised approximately 4.5 feet. Water level management becomes a chronic controversy in the Rice Creek Watershed that continues to this day.
1925-early 1980's	Hundreds of thousands of pounds of "rough" fish removed from the lake by MDNR Fisheries. Rough fish included bowfin, buffalo, carp, bullheads, suckers, and undesirable-sized game fish
1953-1976	Northern pike, largemouth bass, sunfish, and crappies stocked at various sizes and rates.
1950	High carp densities speculated as cause of limited aquatic plant growth
1956	Fish winterkill
1959	Fish winterkill
1960	Fish winterkill
1962	First MDNR Fisheries fish survey
1962	Wastewater effluent cited as major upstream pollutant
1965	Fish winterkill
1970	Fish winterkill
1972	No submerged plants found during July surveys
1975	Fish winterkill
1977	Fish winterkill
1978	Fish winterkill
1979	Fish winterkill
1982	First documented occurrence of curly-leaf pondweed
1982	Summer kill observed below dam
1986	Commercial harvest of 4,500 ponds (lbs)of bullheads
1988	Peltier Lake Association established
1988	Commercial harvest of 8,680 lbs of buffalo, 300 lbs of bullhead, 21,200 lbs of carp
1988	Curly-leaf pondweed first noted by the Peltier Lake Association as being a nuisance
1988-present	Pump and baffle system installed to aerate lake and prevent winterkill
1988-present	Biennial walleye fry stocking
1996	Summer kill observed below dam
1996	Over 1,000 great blue heron nests observed on the island on the north end of the basin. Other heron species observed at this time were great egret and black-crowned night heron
1997	Dam reconstructed water levels are temporarily lowered by 5-6 feet for construction

1998	Winter commercial harvest of 27,800 lbs of buffalo, 1,200 lbs of bullheads, 80,000 lbs of carp, 75 lbs of suckers, 25 lbs of bowfin.
1998	Fall commercial harvest of 2,000 lbs of bullhead, 250 lbs of carp, 10 lbs suckers.
1998	Last documented observance of black-crowned night heron.
1998-2004	Sharp decline in active nests and chick production by great blue heron on the north island. Complete colony desertion was noted in 2000-2004. Human noise disturbance near the island and predation speculated as the cause of the decline.
2000	Eurasian watermilfoil first discovered
2002	Temporary no wake zone near the heron rookery established by the cities of Centerville and Lino Lakes to limit disturbance by boats
2004	No wake ordinance made permanent
2003	Winter creel report published – Peltier supports high harvests of crappie and northern pike.
2004-present	Annual yearling channel catfish stocking
2005	Winter commercial harvest of 2,000 lbs of buffalo, 14,000 lbs of carp, 500 lbs of suckers, and 300 lbs of bowfin.
2005-2008	Heron recruitment slowly recovering from 2004 lows
2006-2009	TMDL study underway
2006	Von Duyke report water-ski recreation effects on the lake
2007	Pump and baffle winter aeration system replaced with 2 pontoon-mounted aspirators.
2007	Edlund and Ramstack (Science Museum of Minnesota) report on “Historical Water Quality and Biological Change in Peltier Lake”
2008	Emmons and Olivier Technical Memo “Request for Natural Background Condition for Peltier Lake”
2008	Peltier is designated as a sentinel lake and established as a site of comprehensive long-term monitoring

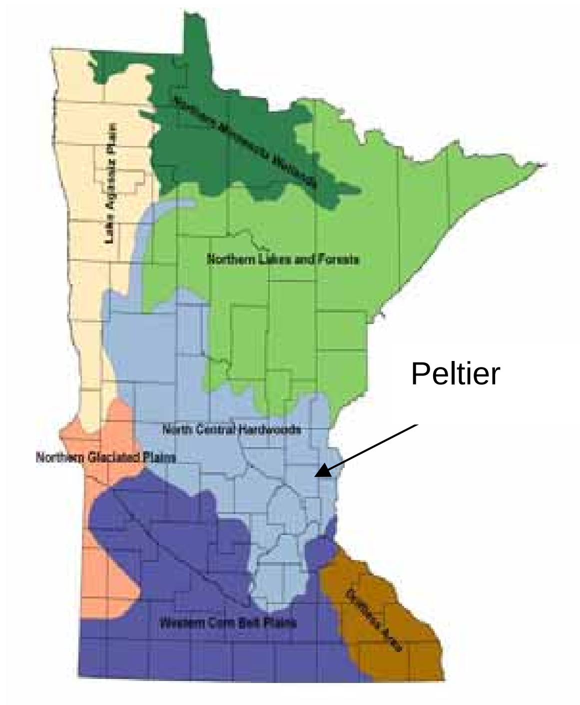
Background

Peltier Lake is a moderately-sized shallow lake in southern Anoka County. Peltier Lake is located partially in the city of Lino Lakes and partially in the city of Centerville. The lake has a relatively large watershed (part of Rice Creek watershed), spanning 13 municipalities and three counties (Anoka, Ramsey, and Washington). There is extensive data on the lake as a result of monitoring by RCWD, MCES and citizen volunteers.

Peltier was assessed for aquatic recreational use as a part of the 2002 assessment process. Because of excessive nutrient and algal concentrations, the lake was found to be impaired for aquatic recreational use and placed on the 2002 303(d) (or Impaired Waters) List. In addition to eutrophication, Peltier has other concerns including: water level control, bird nesting areas, curly-leaf pondweed, and periodic fish kills. To date, numerous studies and improvement efforts have been done and many more are anticipated for the future. The following summary of historical events (assembled from MDNR area fishery records, MPCA files, and Rice Creek watershed records) captures many of the important issues and management efforts on the lake.

Ecoregions

Figure 2. Minnesota ecoregions as delineated by USEPA.



Minnesota is divided into seven somewhat distinct ecoregions that are based on the overlay of soils, potential natural vegetation, land forms, and land use as mapped by U.S. Environmental Protection Agency (USEPA) (Omernik, 1987). Lake water quality, morphometry, and watershed land use has been characterized for each of the four ecoregions that contain 98 percent of Minnesota's lakes: Northern Lakes and Forests, North Central Hardwoods Forests (NCHF), Western Corn Belt Plains and Northern Glaciated Plains based on extensive sampling (1985-1988) of several reference lakes in each of the ecoregions. These "reference" lakes are not necessarily the most pristine lakes in each ecoregion; rather, these lakes are "representative" of the ecoregion and are minimally impacted by man. The typical range of summer mean water quality and other characteristics (e.g. watershed land use) from the reference lakes provides a basis for evaluating the quality of other lakes in the ecoregion. Also, more recently, ecoregion-based eutrophication standards (also referred to as nutrient standards) have been developed. These standards provide the basis for assessing the aquatic recreational use (also referred to as nutrient impairment) for Minnesota's lakes. Details on the development of the standards and further background on ecoregions and reference lakes may be found in Heiskary and Wilson (2005 & 2008). Peltier is located in the North Central Hardwood Forest Ecoregion (Figure 2).

Lake Morphometry

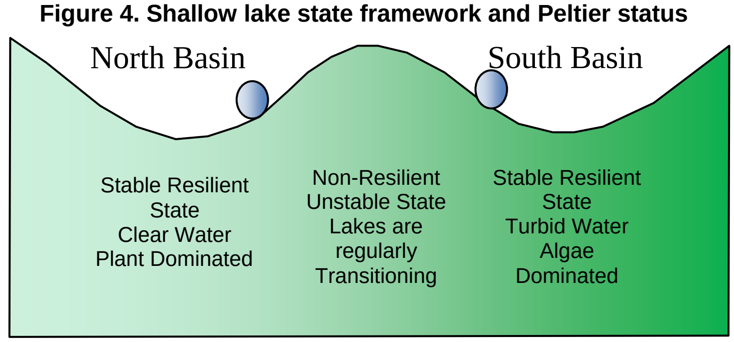
Peltier Lake is approximately 3.2 kilometers (two miles) long and 1.6 kilometers (one mile) wide, and has an open water surface area of 233.5 hectares (577 acres). The public water inventory lists Peltier as 375 hectares (927 acres); however, the lake is part of a large cattail wetland complex and that area is included in the total area. The lake has a mean depth of 2.1 meters (7 feet) and a maximum depth of 4.9 meters or 16 feet (Figure 3). Approximately 89% of the surface area of the lake is littoral (less than 4.6 meters (15 feet) depth). The northern basin of the lake (around and north of the island) is 100% littoral. Peltier meets the MPCA definition of a shallow lake, where littoral area covers at least 80% of the lake's surface area has a maximum depth of less than 4.6 meters (15 feet) depth.

Figure 3. Peltier Lake morphometry map.

The relationship between nutrients, algal density and transparency is somewhat different in shallow lakes as compared to deeper lakes. In shallow, well-mixed lakes rooted plants, zooplankton, and fish play a more pronounced role in nutrient cycling and algal production as compared to deeper thermally-stratified lakes. In shallow lakes these biological interactions can strongly influence the "trophic status" of the lake. Because they have less volume, are well-mixed with respect to temperature and DO, and sunlight can penetrate over much of the bottom area of the lake they are often more productive than deeper lakes. Shallow lakes often exhibit alternative lake "regimes" that may either be stable or unstable (Figure 4) depending on their nutrient loads and other disturbances (Scheffer and Carpenter 2003; Genkai-Kato and Carpenter 2005; Scheffer and van Ness 2007). Shallow lakes with stable regimes are typically resilient to changes. Undisturbed shallow lakes with clear water and abundant native aquatic plants are typically stable and resilient to natural disturbances because of diverse and healthy zooplankton and fish communities and low ambient levels of nutrients. Undisturbed lakes are common in forested watersheds in northern Minnesota. Disturbed lakes, which are common in agricultural or urban areas, are often turbid with little native aquatic plant growth. These lakes are often resilient to changes in Secchi transparency or chlorophyll-a by simply reducing watershed nutrient loading (Genkai-Kato and Carpenter 2005). This is because of self-sustaining feedbacks from benthivorous fish and invasive curly-leaf pondweed. In between these two distinctly different "stable states" : plant-dominated vs. algal-dominated are lakes that are highly unstable, with frequently changing water quality conditions and aquatic plant abundance and patchiness (Genkai-Kato and Carpenter 2005; Valley and Drake 2007). Individual basins within a lake may exhibit different states. The deeper southern portion of Peltier is currently in a more algal-dominated unstable state and has several of the negative feedback mechanisms that serve to keep it in this state: abundant roughfish, limited native vegetation, extensive growth of the exotic curly-leaf and excessively high external nutrient loading. Trends described in this report document improvements to the southern portion of the lake during the past decade that may be moving the lake away from algal dominance. The shallow plant-dominated northern basin of the lake is stable with clear water and a dense emergent and submergent plant community. The clear state is the most preferred, since phytoplankton communities (composed mostly of algae) are held in check by the aquatic plant community.

This complexity in the relationships among the biological communities in shallow lakes leads to less certainty in predicting the in-lake water quality of a shallow lake based on the phosphorus load to the lake. Despite many theoretical and simulation models quantifying these critical thresholds, lake food-web and basin complexity makes precise prediction of the level of phosphorus loading that will lead to a regime shift difficult.

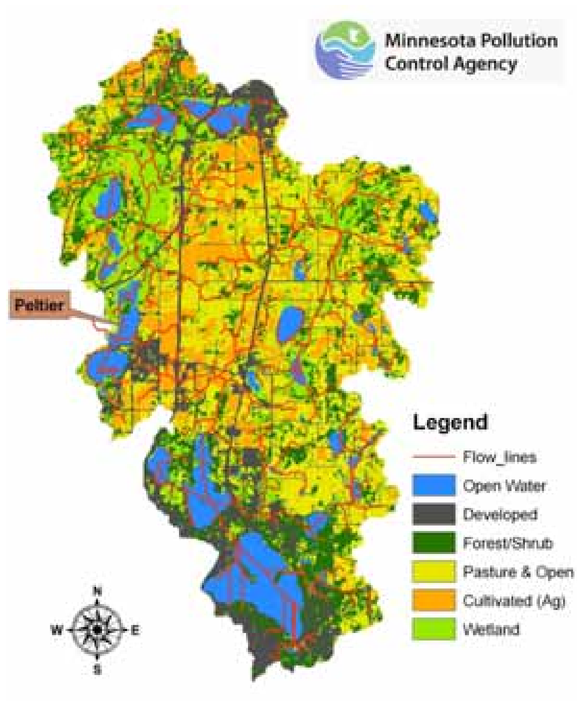
Figure 4. Shallow lake state framework and Peltier status



Watershed Characteristics

The lake's watershed is the central portion of the Rice Creek watershed in the upper Mississippi River basin. The watershed area is 27,937.11 hectares (69,034 acres) resulting in an extremely high watershed area to lake area ratio of119:1 (MDNR Data Deli 2009; Figure 5). In general, as the watershed-to-lake area ratio increases, water and phosphorus loads often increase and water residence time decreases. The main tributaries to Peltier Lake are Upper Rice Creek, which enters the lake from the north, Hardwood Creek, which also enters the lake from the north, and Clearwater Creek, which enters the lake from the southeast.

Figure 5. Lake watershed and land use



Landuse and Cover

Although Peltier's watershed has a large amount of open and undeveloped land, developed and agricultural land uses together comprise the other dominant land use. Developed land (residential use) is likely to increase in the near future according to Metropolitan Council 2020 land use projection; whereby agricultural and idle grass land will give way to increased urbanized uses and higher percentages of impervious cover (Emmons and Oliver Resources 2009). Comparisons between three historic land use records show cultivated land have decreased, while open water and wetlands, and developed areas have increased in the watershed since 1969 (Table 1).

Table 1. Land use composition. Typical range based on interquartile range for North Central Hardwoods Forests ecoregion reference lakes.Land use	**% Land Use NLCD 2001[1]**	**% Land Use GAP 1991[2]**	**% Land Use LU 1969[3]**	**NCHF typical land use percentage**
Developed	14	11	10	2 – 9
Cultivated (Ag)	14	29	34	22 – 50
Undeveloped – Open	31	30	26	11 – 25
Forest	15	10	14	6 – 25
Water & Wetland	26	20	16	14 – 30
Feedlots (#)	7			

[1]National Land Cover Database www.mrlc.gov/index.php
[2]Minnesota Land Cover 1991-1992:MAP www.lmic.state.mn.us/chouse/land_use_DNRmap.html

[3]Minnesota Land Management Information Center www.lmic.state.mn.us/chouse/metadata/luse69.html

Discharge Sources
The city of Forest Lake's drinking water treatment plant discharges to an adjacent wetland, then through Clear, Mud, and Howard Lakes before flowing into Rice Creek. The discharge is approximately 13 km (eight miles upstream from the northern end of Peltier Lake. There are 16 separate municipal storm water permits in the Peltier watershed (Emmons and Olivier Resources 2009). Seven feedlots exist in the watershed all of which are located within the Hardwood Creek watershed.

Groundwater
A groundwater assessment was a part of the TMDL study on Peltier. The groundwater investigation concluded that Peltier Lake functions as groundwater flow-through, groundwater discharge and groundwater recharge point (Emmons and Olivier 2009). The study also concluded groundwater and surface water interaction is an important component to consider for development of an accurate water and nutrient budget.

Precipitation and Climate Summary
Precipitation and runoff can affect water quality. Excessive runoff from the watershed often occurs in response to extreme rain events. This often results in high loading of nutrients and suspended solids to a lake. Daily precipitation data from 1970-2008 taken at the Centerville weather station #211420 show average annual precipitation around 30 inches (Figure 6). Annual precipitation totaled only 19 inches in 2008 making it a particularly dry year. Daily rainfall events of one inch or greater are often associated with runoff contribution. A slight increase in annual and summer precipitation is evident for this site and period of record (Figure 6). On average, the Centerville area has seven one-inch or more events per year, with most occurring in June – September (the growing season) (Figure 7). Two inch or greater rain events occurred on average 1.3 times per year. There is no apparent trend in the frequency or magnitude of "significant" rain events – based on this dataset. Ice on and off records on Peltier Lake are limited, but show ice off is typically early April (Figure 8). The ice records show that the typical days of open water per year are around 235 days. Other studies with longer datasets have documented a long-term trend of earlier ice-out dates (Johnson and Stefan 2006)

This information was obtained through the State Climatology Office and can be found at http://climate.umn.edu/climatology.htm.

Figure 6. Annual precipitation trend based on Centerville weather station #211420. Data for total annual and total summer precipitation and simple linear regressions for each noted.

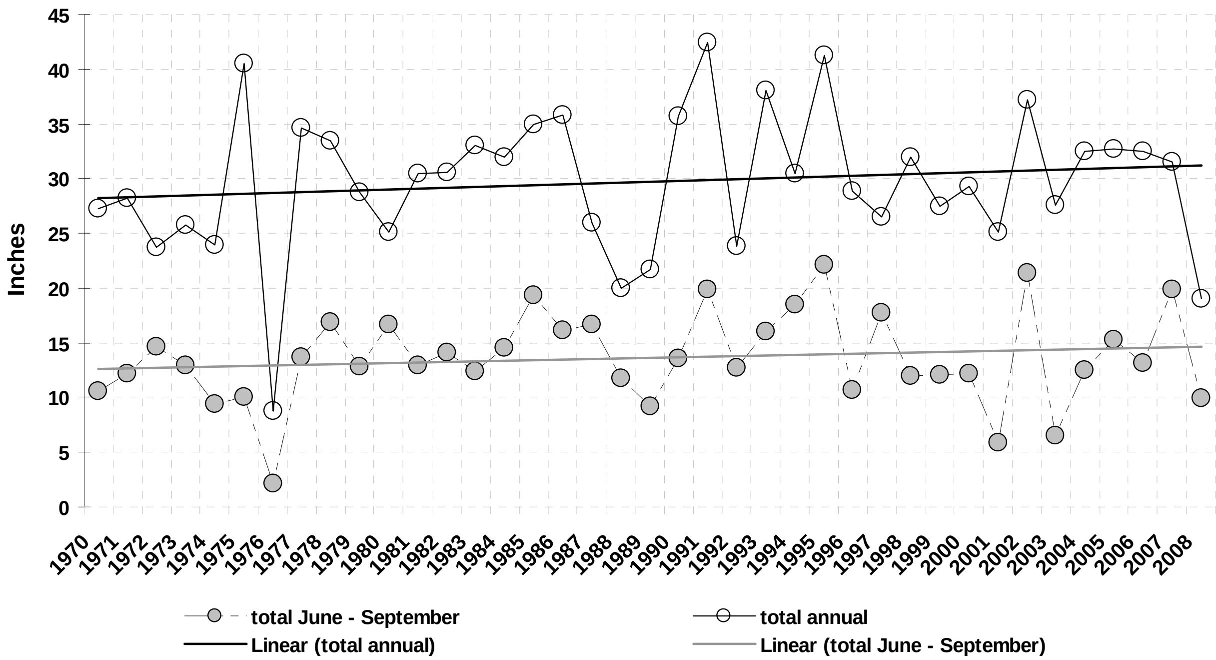

Inches
45
40
35
30
25
20
15
10
5
0
1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008
total June - September
total annual
Linear (total annual)
Linear (total June - September)

Figure 7. Count of significant (one inch or greater) rain events based on Centerville weather station #211420

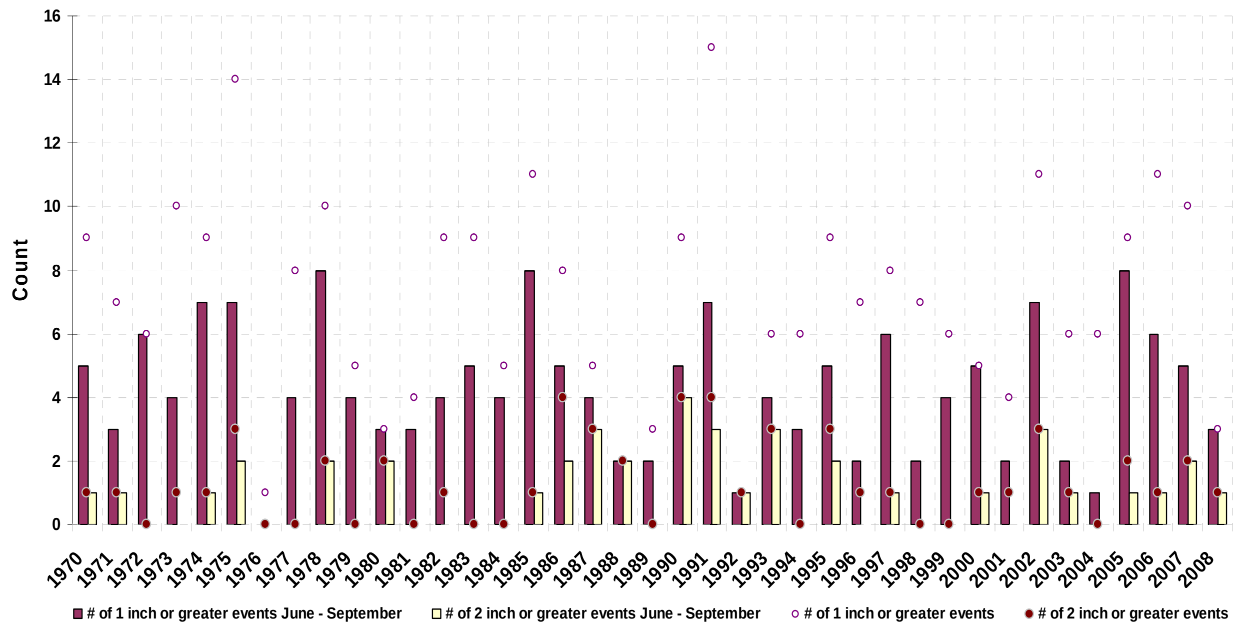
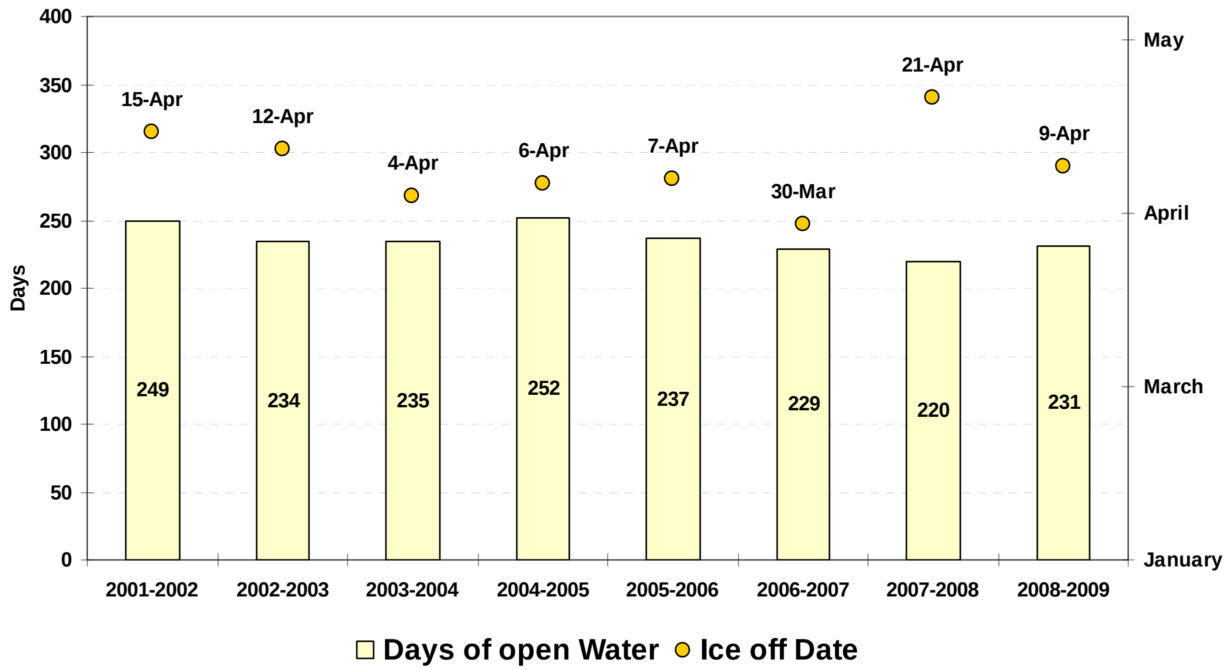


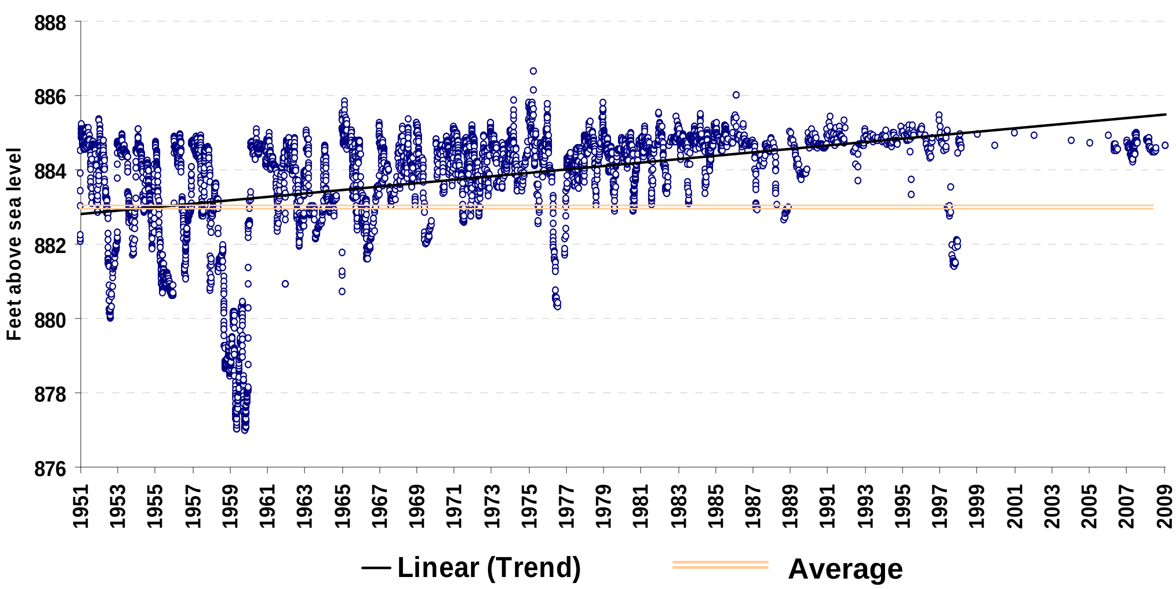
Figure 8. Ice on and ice off record summary for Peltier (source MPCA Citizen Lake Monitoring Program)



Lake Level Trends

Lake level information was drawn from the MDNR web site. Lake level data have been collected on Peltier from 1951 to September 2008. The highest recorded level was 886.6 feet on July 3rd 1975 the lowest record was 876.9 taken on February 2nd 1960. Lake level has ranged (9.7 feet) since 1951 based on this record. This is an extremely large range given the shallowness of the lake and is driven largely by the very low levels in the 1959 and 1960 timeframe. Absent these extremes most lake level reading range between ~881-885 feet. Low water levels observed in 1997/1998 correspond to lake draw-down associated with dam reconstruction. The hydrograph of the most recent ten years (1989-2009) reveals fairly stable lake level conditions as compared to earlier decades (Figure 9). The overall record suggests an increase in lake level over time. Several factors could contribute to the observed variability and trend in lake level including: an increase in precipitation over time (Figure 9), increased urbanization and amount of impervious area in the watershed over time, and changes in the management of the dam at the outlet of the lake.

Figure 9. Peltier Lake level data as derived from MDNR web site. Long-term mean and simple linear regression of lake levels.



Methods

Aquatic Plants

Frequency of occurrence of aquatic plant species were assessed using the point-intercept method (Madsen 1999). This entailed visiting sampling points on a grid within the vegetated zone of the lake, throwing a two-sided rake over one side of the boat at each point, raking the bottom approximately 1 m, then retrieving the rake and identifying all species present, and recording the depth. Survey points were spaced approximately 80-m (0.7 points per littoral acre). Hydroacoustics were used to survey vegetation biovolume (percent of water column occupied by vegetation) along 40-m transects using methods and equipment described by Valley et al. (2005). Local kriging with VESPER 1.6 was used to create 15-m raster grids of biovolume (Walter et al. 2001; Minasny et al. 2002).

Fishery Survey

Most recent Fisheries surveys follow guidelines outlined by MDNR Special Publication 147 (1993; Manual of Instructions for Lake Survey). Fish community integrity surveys were also completed on each Sentinel lake following methods described by Drake and Pereira (2002).

Water Quality

Water quality monitoring has been conducted on Peltier over a long period of time and several organizations have participated: J. M. Montgomery Consulting Engineers, MCES, RCWD and the MPCA.

In 2008, water quality samples and observations were taken from May through October, via a collaborative effort from RCWD, Wayne LeBlanc and the MPCA. Lake surface samples were collected with an integrated sampler, which is a PVC tube 2 meters (6.6 feet) in length with an inside diameter of 1.24 inches (3.2 centimeters). Phytoplankton (algae) samples were also taken with an integrated sampler. Lake profile data (temperature, depth, conductivity, pH, Oxygen Reduction Potential (ORP) was collected with a calibrated probe. Zooplankton samples were collected with an 80 µm mesh Wisconsin zooplankton net. Phytoplankton (algae) samples were taken with an integrated sampler. Depth total phosphorous (TP) samples were collected with a Kemmerer sampler. Depth (hypolimnetic) samples were collected about one meter above the lake bottom at the sampling point. Temperature and dissolved oxygen (DO) profiles and Secchi disk transparency measurements were also taken. Sampling procedures were employed as described in the MPCA Standard Operating Procedure for Lake Water Quality document, which can be found here: http://www.pca.state.mn.us/publications/wq-s1-16.pdf. Seasonal averages were calculated using June through September data. Chl-a samples were filtered on the day of collection; filters were placed in Petri dishes and wrapped in foil. Samples were chilled on ice or frozen prior to shipment to the Minnesota Department of Health (MDH) for analysis.

Plankton

Phytoplankton samples were collected using a two meter integrated sampler. Algal samples were preserved with Lugol's solution. The dominant forms of algae were identified and estimates of biovolume were made using the Minnesota Rapid Algal Assessment Technique. This method consists of scanning samples using an inverted microscope and identify genera (and species, where easily identified) of algae present in sample. Under lower power, enough area of the sample is scanned estimate percent abundance by volume for each genera identified. Estimates should consider size and density of algal types.

Zooplankton samples were collected monthly from ice-out (April/May) through October 2009. Two replicate vertical tows were taken at each sampling event. The net was lowered to within 0.5 meter of the bottom and withdrawn at a rate of approximately 0.5 meters per second. Contents were rinsed into sample bottles and preserved with 100% reagent alcohol. Analysis was conducted by MDNR personnel.

Each zooplankton sample was adjusted to a known volume by filtering through 80 µg/L mesh netting and rinsing specimens into a graduated beaker. Water was added to the beaker to a volume that provided at least 150 organisms per 5-milliliter aliquot. A 5-milliliter aliquot was withdrawn from each sample using a bulb pipette and transferred to a counting wheel. Specimens from each aliquot were counted, identified to the lowest taxonomic level possible (most to species level), and measured to the nearest .01 millimeter using a dissecting microscope and an image analysis system. Densities (#/liter), biomass (µg/L), percent composition by number and weight, mean length (millimeter), mean weight (µg) and total counts for each taxonomic group identified were calculated with the zooplankton counting program ZCOUNT (Charpentier and Jamnick 1994 in Hirsch 2009).

Laboratory Analysis

All 2008 water quality samples, with the exception of phytoplankton, were analyzed by the MDH lab in St. Paul, MN. Method numbers and associated quality assurance information is noted for several of the parameters (Table 2). These samples were later identified to family or genus in most cases using the Minnesota Rapid Algal Analysis Procedure. This technique provides a semi-quantitative estimate of the relative biomass of the phytoplankton community and focuses on the dominant forms in the sample

All water quality data for the Sentinel Lakes Program is stored in STORET, USEPA's national water quality data bank. These data are also available at the MPCA's Environmental Data Access system that is accessible via the web at http://www.pca.state.mn.us/data/eda/. This site has all the water quality data used in this analysis including the historic data noted above, citizen volunteer data and MPCA collected data.

Table 2. Laboratory methods and precision

Parameter	Reporting Limit & Units	Method number	Precision: [1] mean difference	Difference as Percent of observed
Total Phosphorus	3.0 µg/L	EPA365.1	4.8 µg/L	2.7 %
Total Kjeldahl N	0.1 mg/L	EPA351.2	0.05 mg/L	2.8 %
$NO_2 + NO_3$	0.05 mg/L	EPA353.2		
Total Suspended Solids	1.0 mg/L	SM2540D	2.8 mg/L	9.6 %
Total Suspended Volatile Solids	1.0 mg/L	SM2540E	--	--
Alkalinity	10 mg/L CaCO3	SM 2320 B	--	--
Chloride	1.0 mg/L	EPA 325.2		
Color	5 CU	EPA 110.2		
Chlorophyll-a		SM10200H	1.7 µg/L	7.4 %
Pheophytin		SM10200H	--	--

1. Mean difference between observed and duplicate sample

Other organization sampling procedures are likely not substantially different for the MPCA's.

Results and Discussion

Aquatic Plant Assessment

Based on pre-European settlement reconstructions of water quality conditions, Peltier Lake was eutrophic (TP = 60-80 ppb) with potentially much higher cover of aquatic plants and less planktonic algae compared with post-WWII conditions (Edlund and Ramstack 2007). High sedimentation rates associated with land clearance in Peltier's watershed during the 1940's, discharge of sewage upstream, infestation by carp (date of introduction is unknown), and more recent infestation by curly-leaf pondweed are likely all contributing factors in today's hypereutrophic water quality conditions and depauperate aquatic plant community (Table 3). As early as 1950, carp were implicated as a potential cause of poor aquatic plant growth.

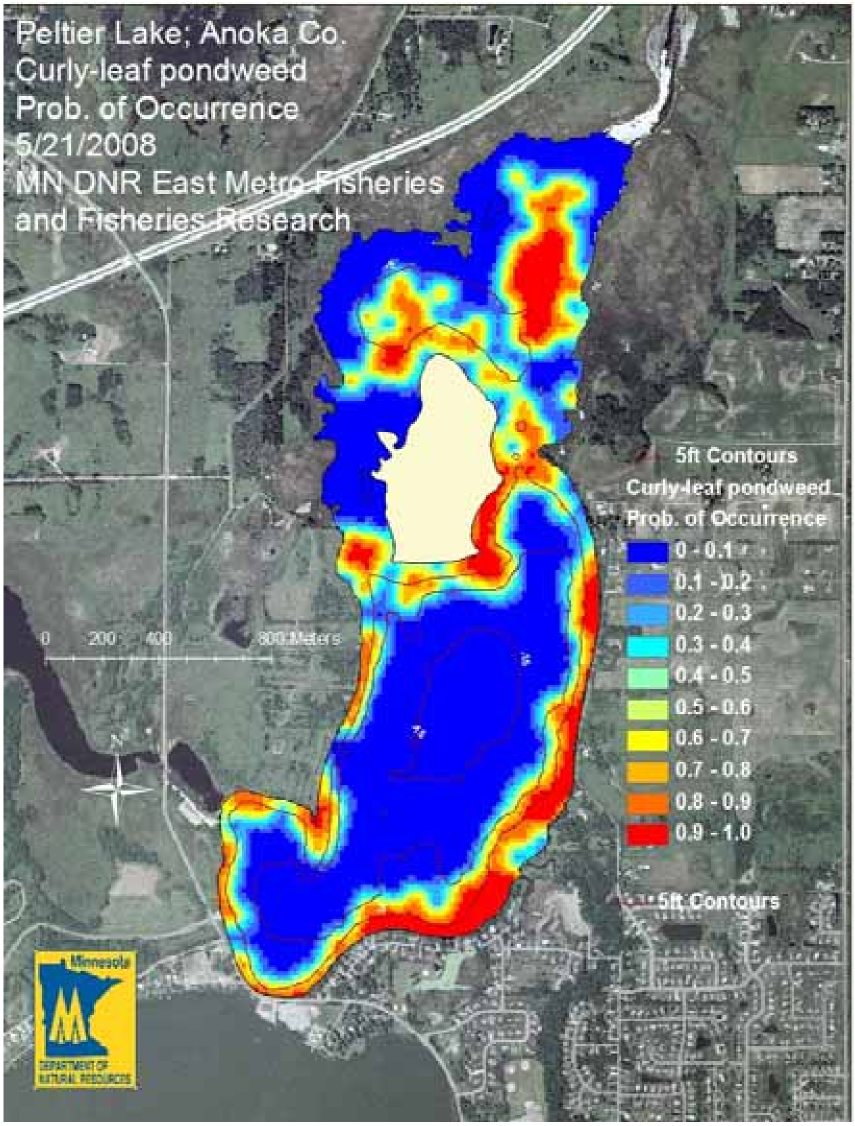
Curly-leaf pondweed infestation

Curly-leaf pondweed is a non-native invasive submerged aquatic plant that is widespread throughout the southern part of the state. The exact date of introduction into Minnesota is unknown, but it is believed to have been present in Minnesota lakes since the early 1900's when carp were brought into the state. Curly-leaf pondweed was first observed in Peltier Lake in 1982. It is unclear if curly-leaf pondweed was present in Peltier prior to 1982, since the plant senesces in late June and can often go undetected in late summer surveys. Nevertheless, through investigation of historical vegetation surveys in Peltier and nearby lakes (Centerville and Rondeau), the actual date of curly-leaf pondweed invasion may have occurred sometime between 1962-1982. Curly-leaf pondweed wasn't reported growing in nuisance conditions until 1988.

The unique, opportunistic life-history of curly-leaf pondweed has a reinforcing negative effect on water quality. Specifically, curly-leaf pondweed photosynthesizes and remains green under ice-cover (Bolduan et al. 1994). In early spring, after ice-off, curly-leaf pondweed can grow rapidly, form dense mats at the lake surface, and crowd-out native aquatic plants. In mid to late June, curly-leaf pondweed senesces, and decomposition during the warmest period of the summer, promotes algal blooms that further suppress aquatic plant growth (Bolduan et al. 1994). Anecdotal evidence from lakes across Minnesota suggests that this "boom-bust" response of curly-leaf pondweed is most typical of eutrophic to hypereutrophic lakes. Curly-leaf pondweed does not seem to negatively affect water quality or native aquatic plants in mesotrophic lakes. At some threshold of nutrient enrichment, curly-leaf pondweed can become a self-sustaining internal driver of poor water conditions. Once lakes cross this threshold, they become highly resilient in the impaired state and it can be quite difficult to reverse the trend (Scheffer 1998; Carpenter et al. 1999). Unfortunately, Peltier occupies an unstable state and curly-leaf pondweed appears to contribute significant internal loads of phosphorous to the lake during summer. Furthermore, anecdotal evidence from across the state during the last two decades (1990's – present) suggests shorter winters and lower snow cover on lake ice has, over time, increased the viability of over-wintering curly-leaf pondweed plants and facilitated more rapid spring growth. Thus, climate change has the potential to exacerbate harmful ecosystem and recreation effects of curly-leaf pondweed infestations.

During spring curly-leaf pondweed surveys on May 21, 2008, curly-leaf pondweed occurred over 20% of the lake's surface (Figure 10); however, for depths less than three meters (10 feet), cover was much higher (Figures 10). Furthermore, hydroacoustic surveys of vegetation biovolume (percent of water column occupied by vegetation) indicated vegetation growth close to the surface over most areas less than 10 ft. Although hydroacoustics cannot differentiate between species, comparisons between Figures 10 and 11, and personal observations, suggest most vegetation biomass in May was curly-leaf pondweed.

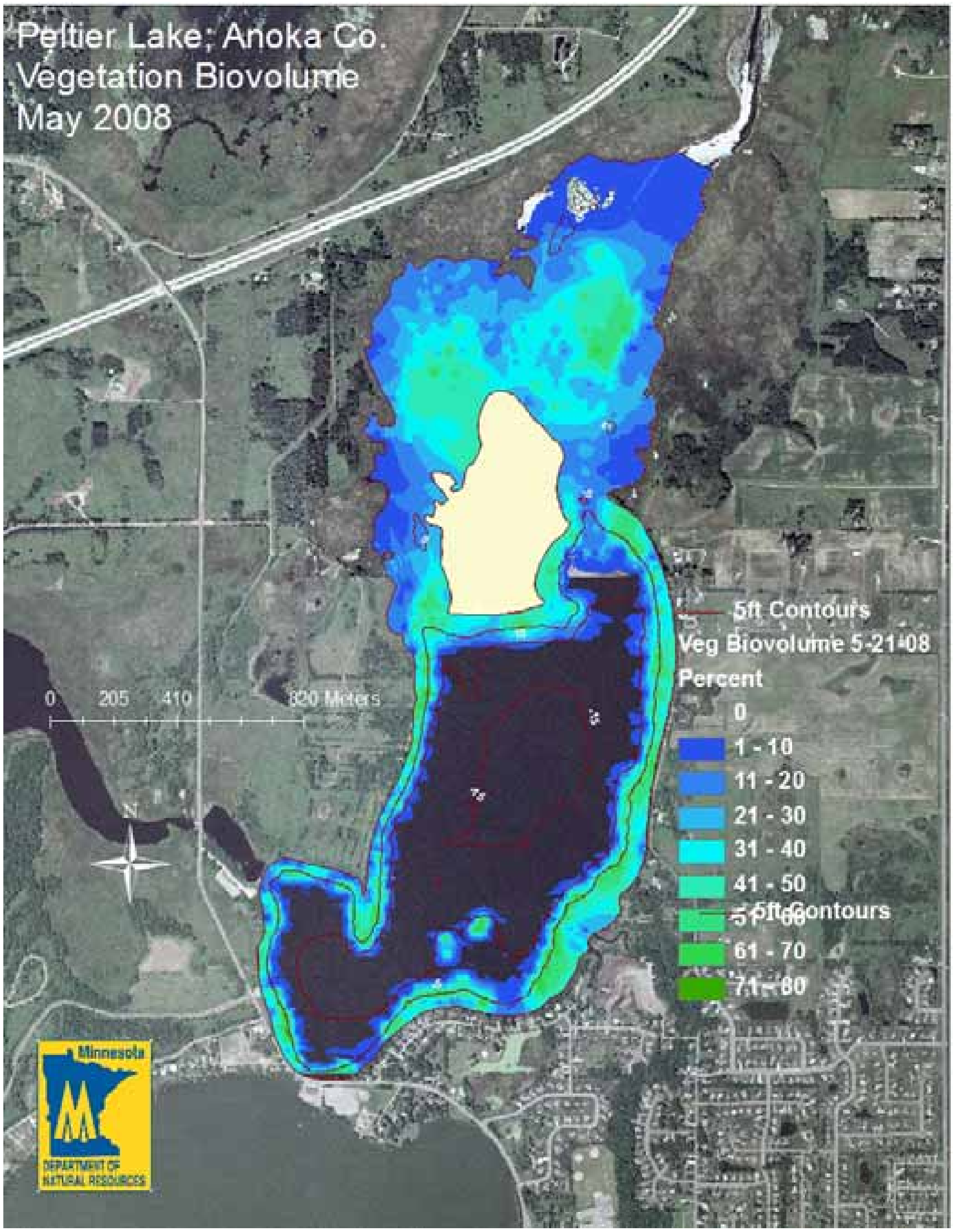
Figure 10. Maps of probability of occurrence of curly-leaf pondweed based on point-intercept surveys conducted in May 2008



The grid was created using indicator kriging on presence/absence point data of curly-leaf pondweed. All grid cells with a probability of ≥ 0.75 were considered highly-likely that curly-leaf pondweed occurred in that location and were counted as "present."

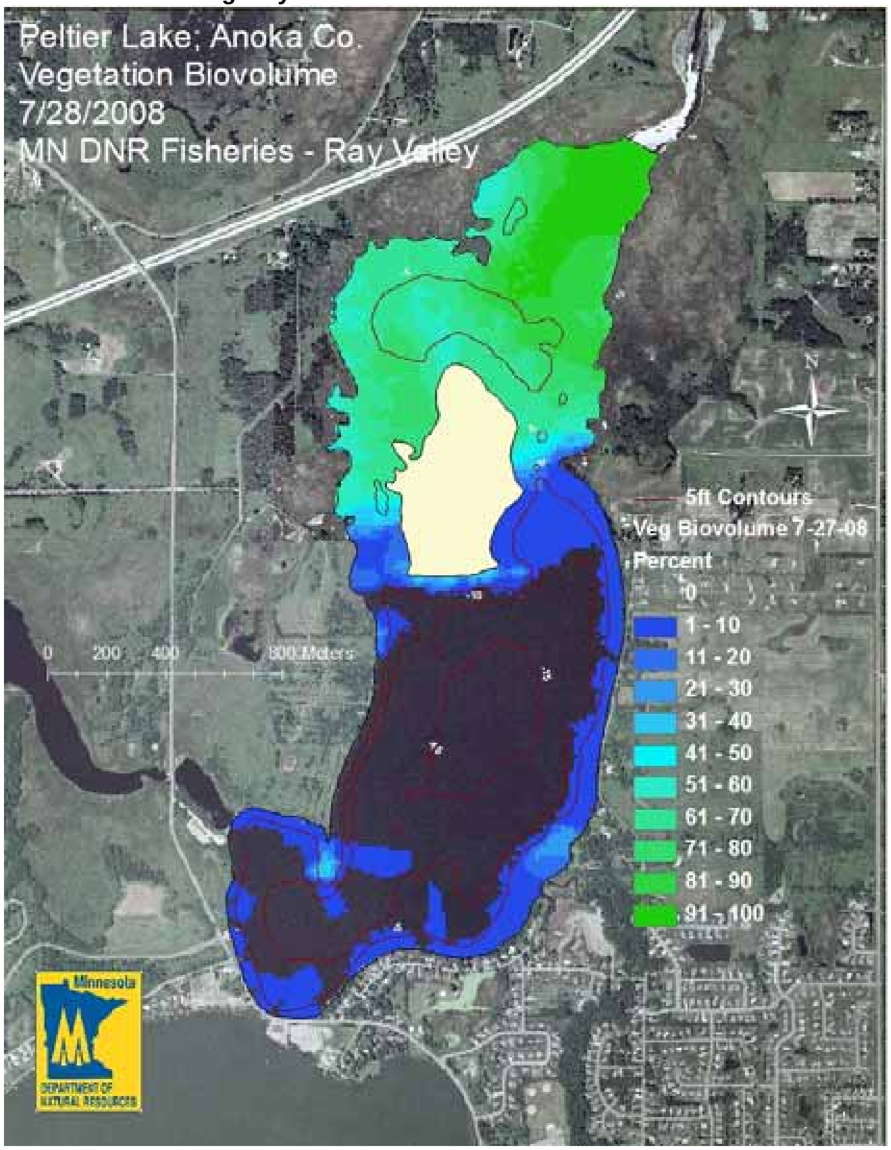
During July surveys in 2008, most curly-leaf pondweed was senesced and vegetation growth was sparse to non-existent in the southern basin (Figure 12). In contrast, in the shallow north basin, submersed vegetation abundance, primarily coontail, was very dense. Surveys over Peltier's history suggest submersed vegetation has been highly variable from season to season. Repeated curly-leaf pondweed and summer surveys will be repeated during 2009-2011 to better document this variability.

Figure 11. Maps of vegetation biovolume (percent of water column occupied by vegetation) collected with a scientific-grade echosounder during May 2008



.

Figure 12. Maps of vegetation biovolume (percent of water column occupied by vegetation) collected with a scientific-grade echosounder during July 2008



Eurasian watermilfoil infestation

Myriophyllum spicatum (Eurasian watermilfoil), a non-native invasive plant that has been present in Minnesota since 1987, was first documented and confirmed by MDNR invasive species program in fall 2000 in Peltier Lake. As of summer 2008, Eurasian watermilfoil has spread to 219 water bodies (see http://www.dnr.state.mn.us/invasives/aquaticplants/milfoil/index.html; cited 3/10/09) with the greatest cluster of infested waters within the Twin Cities metropolitan area. Eurasian watermilfoil grows quickly and can displace native plants (Boylen et al. 1999); however, Eurasian watermilfoil's "aggressiveness" greatly depends on lake productivity, with the highest potential to and dominate plant communities in mesotrophic to eutrophic waters (Madsen 1998). Eurasian watermilfoil typically does not grow to nuisance conditions in waters as productive and turbid as Peltier. Indeed, the two surveys since Eurasian watermilfoil's infestation in 2000 documented only spotty occurrences of the plant in depths typically less than five feet. Improvements to Peltier's transparency would likely lead to more abundant and deeper growth of Eurasian watermilfoil. Unfortunately, whole-lake herbicide treatments will not eradicate Eurasian watermilfoil and may do more harm than good to water quality and habitat in eutrophic lakes (Valley et al. 2004, Valley et al. 2006). If forced to choose the lesser of two evils, abundant Eurasian watermilfoil is the preferred alternative to barren sediments and algae blooms for waterfowl, fish, and human health.

Trends in macrophyte composition for the lake

Table 3. Common species sampled during past lake vegetation surveys

Species were deemed common if they were either noted as "common" or "abundant" or if they were encountered greater than 10% of the sample stations or transects surveyed

Date	Common Name	Species Name	Growth Form
7/9/1962[a]	Lesser duckweed	*Lemna minor*	Free-floating
	Bushy pondweed	*Najas flexilis*	Submersed
	Canada waterweed	*Elodea canadensis*	Submersed
	Claspingleaf pondweed	*Potamogeton richardsonii*	Submersed
	Coontail	*Ceratophyllum dermersum*	Submersed
	Flatstem pondweed	*Potamogeton zosteriformis*	Submersed
	Fries' pondweed	*Potamogeton friesii*	Submersed
	Sago pondweed	*Stuckenia pectinata*	Submersed
7/28/1972[b]	Cattail	*Typha spp.*	Emergent
8/4/1982[c]	Cattail	*Typha spp.*	Emergent
	Duckweed	*Lemna sp.*	Free-floating
	Canada waterweed	*Elodea canadensis*	Submersed
	Coontail	*Ceratophyllum dermersum*	Submersed
	Sago pondweed	*Stuckenia pectinata*	Submersed
8/11/1992	Cattail	*Typha spp.*	Emergent
	Smartweed	*Polygonum sp.*	Emergent
	Coontail	*Ceratophyllum dermersum*	Submersed
	Sago pondweed	*Stuckenia pectinata*	Submersed
8/5/2003	Cattail	*Typha spp.*	Emergent
	Smartweed	*Polygonum sp.*	Emergent
	Lesser duckweed	*Lemna minor*	Free-floating
	Watermeal	*Wolffia sp.*	Free-floating
	Canada waterweed	*Elodea canadensis*	Submersed
	Coontail	*Ceratophyllum dermersum*	Submersed
	Curly-leaf pondweed	*Potamogeton crispus*	Submersed
	Eurasian watermilfoil	*Myriophyllum spicatum*	Submersed
	Sago pondweed	*Stuckenia pectinata*	Submersed
8/4/2008[d]	Lesser duckweed	*Lemna minor*	Free-floating
	Star duckweed	*Lemna trisulca*	Free-floating
	Coontail	*Ceratophyllum dermersum*	Submersed
	Flat-stem pondweed	*Potamogeton zosteriformis*	Submersed

[a]Emergent vegetation was surveyed but cover was not assessed.
[b]No submerged vegetation growth noted on Fisheries lake survey.
[c]First documented presence of curly-leaf pondweed (occasional).
[d]Emergent vegetation was not surveyed

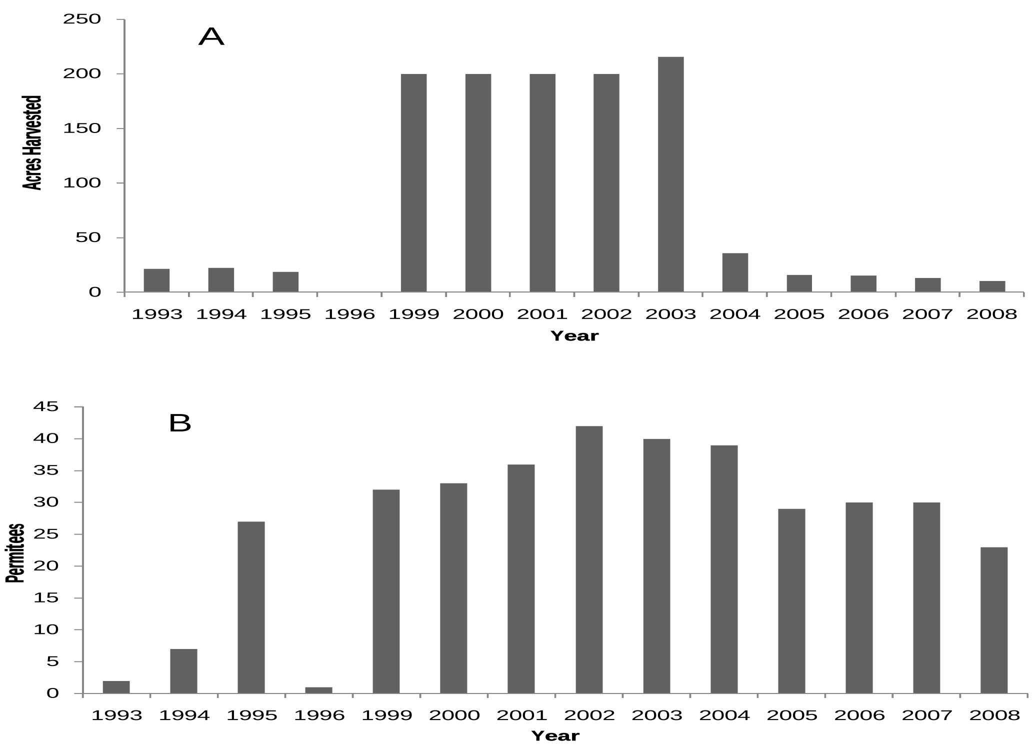
Aquatic plant management activities

Peltier Lake has a MDNR shoreland classification as a Natural Environment lake. Chemical herbicide control is not authorized in Natural Environment lakes per MN Rule 6280.0250 subp. 4 and MN Rule 6120.300. Only control for plankton algae and swimmers' itch is allowed with chemical algaecides and molluscides in Natural Environment lakes. Peltier Lake has been permitted for large area plankton control 4 times in the years 1993,1994,1995,1996 by the St. Paul Water Commission. They were permitted to treat 140 hectares (348 acres) and were not to apply more than 1740 lbs of copper sulfate per year for each of those years.

As of 2003, there were approximately 36 separate properties on the lakeshore of Peltier Lake. To allow for recreational access, lakeshore owners are allowed to clear a 232 m (2,500 square ft) area of submerged plants and a 4.6 m (15 ft) wide boat lane to open water without a permit. Activities resulting in the removal of larger beds of submerged plants, floating-leaf plants or emergent plants require a permit from MDNR. There have been a total of 22 permits issued and 371 permitees requesting the removal of aquatic plants in Peltier Lake since 1993. Mechanical control (cutting and pulling) has been permitted on Peltier Lake in the past and in some years 80.9 Hectors (200 acres)were permitted (Figure 13) which is near the limit allowed by MDNR. Since that time, the area permitted for mechanical control has decreased substantially to around 4-12 hectares (10-30 acres) (Figure 13).

Water-ski recreation on the lake has also been implicated as a significant disturbance to fish and wildlife habitat, aquatic plants and water quality (Von Duyke 2009). Water ski activities during the past decade have led to scoured lake bottoms, resuspended sediments, destruction of native aquatic plants, and local declines in water clarity (Von Duyke 2009).

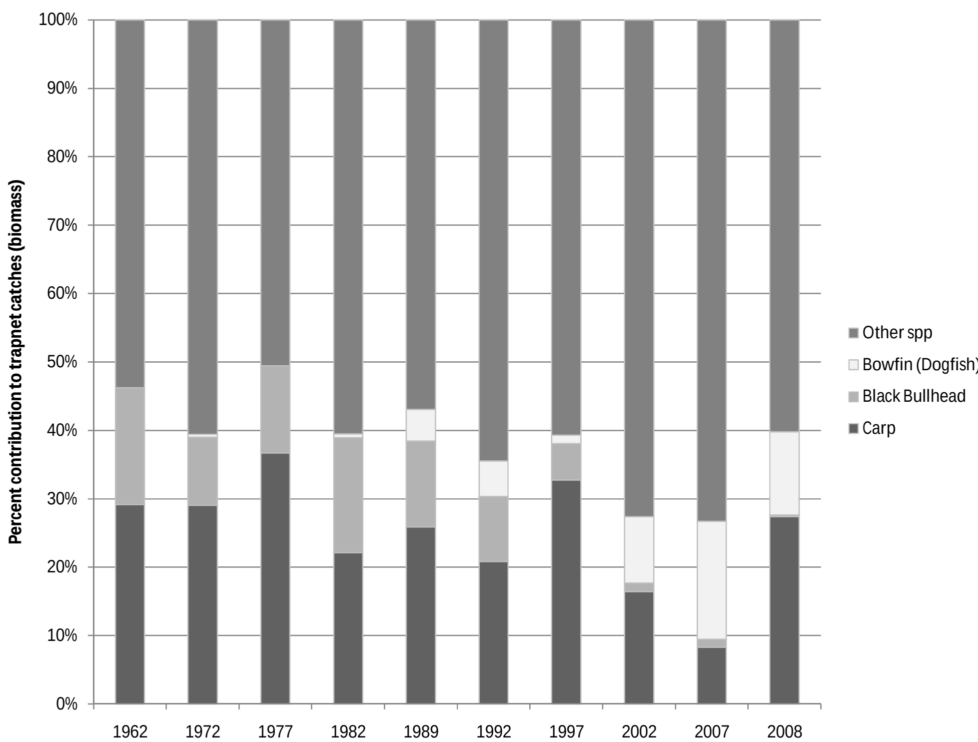
Figure 13. Trends in acres of aquatic plants permitted for removal (A) and number of permittees (B) in Peltier Lake.



Fisheries Assessment

In terms of fish biomass, Peltier Lake is one of the most productive (in terms of nutrients and fish biomass) of the 24 sentinel lakes. Common carp often dominate fish communities in hyperproductive lakes (Egertson and Downing 2004), and this has been the case with Peltier Lake. "Rough" fish removal programs and commercial fishing have been in operation on Peltier periodically since 1925 to remove primarily carp. These programs have had little impact on the biomass of carp and the contribution of carp to trapnet catches has averaged 25% of the total fish biomass (range 8% - 37%; Figure 14). MDNR rough fish removal programs across the state ceased in the early 1980's. The last commercial fishing operation on Peltier that targeted carp occurred during winter 2005.

Figure 14. Percent contribution of bowfin (dogfish), black bullhead, and common carp biomass (pounds per net) to total trapnet catches in fisheries lake surveys of Peltier Lake.



Peltier also has a history of winterkills due to depletion of DO under winter ice; however, significant winterkills have not been documented since the 1979. A pump and baffle aeration system was installed during winter 1988 to provide an oxygenated, open water refuge for fish during winter. Aeration systems have been maintained on the lake ever since. In 2007, the pump and baffle system was replaced by two 2-horsepower surface aspirating aerators. Due to adequate ambient DO levels winter 2007 and 2008, the new aeration system was not operated and has yet to be tested.

Drake and Pereira (2002) developed a fish-based index of biotic integrity (IBI) for small Minnesota lakes. Indices of biotic integrity have been used for decades across North America to assess status of aquatic communities and to classify biotic impairments (Angermeier and Karr 1994). Although formal criteria have yet to be developed for classifying biotic impairments in Minnesota lakes, IBI surveys from over 250 lakes across the state provide a good assessment of the range of conditions we might expect in lakes of differing productivity.

The fish community of Peltier, in terms of biomass, is dominated by relatively few species with a high abundance of disturbance-tolerant species such as common carp (Figure 14; Table 4). The fish IBI score in 2008 was 34, which is average compared to lakes with similar levels of hypereutrophic productivity. Despite the large contribution of carp to Peltier's fish production, populations of bluegill and black crappie are of modest quality and support a popular recreational fishery during most times of the year (Gorton 2003).

Fishery overview

Nine gill-net surveys and 10 trap-net surveys have been conducted by MDNR fisheries staff over the last 47 years. The following assessments by species and gear type contain graphical representations of historical net catches in the form of catch per unit effort (CPUE) or fish/net (Figure 15); however, data from surveys 10 years apart may have missed additional changes in species relative abundance and size structural indices, underestimating variability. Also represented graphically are Relative Stock Density (RSD) values (Figure 16). RSD is the total number of fish greater than or equal to a harvestable size (Gorton 2003) divided by the number of fish in the sample greater than or equal to a stock size and multiplied by 100 (Anderson and Neumann 1996). The 2008 Fisheries Lake Management Plan lists walleye and channel catfish as species of primary management importance and bluegill, black crappie, and northern pike as species of secondary management importance.

Prior to the implementation of winter aeration in 1988, there were 9 documented cases of fish winterkill in Peltier Lake. The fishery in the lake is best characterized by boom and bust cycles. Boom/bust fisheries are common in highly disturbed lakes where conditions for recruitment are highly variable from one year to the next (Lathrop et al. 1992). These highly variable conditions make it difficult to manage a consistent high-quality fishery. Lowering nutrient concentrations in the lake may reduce some variability in game fish recruitment.

Table 4. Fish species sampled during past fisheries assessments.

Common Name	Species Name	Trophic Guild	Environmental Tolerance	First Documented
Black crappie	*Pomoxis nigromaculatus*	Predator	Neutral	1962
White crappie	*Pomoxis annularis*	Predator	Neutral	1962
Bowfin	*Amia calva*	Predator	Neutral	1948
Largemouth bass	*Micropterus salmoides*	Predator	Neutral	1948
Northern pike	*Esox lucius*	Predator	Neutral	1948
Walleye	*Sander vitreus*	Predator	Neutral	1948
Black bullhead	*Ameiurus melas*	Omnivore	Tolerant	1962
Tadpole madtom	*Noturus gyrinus*	Insectivore	Neutral	1982
Brown bullhead	*Ameiurus nebulosus*	Omnivore	Neutral	1962
Carp	*Cyprinus carpio*	Omnivore	Tolerant	1947
White sucker	*Catostomus commersonii*	Omnivore	Tolerant	1948
Yellow bullhead	*Ameiurus natalis*	Omnivore	Neutral	1992
Buffalo	*Ictiobus spp.*	Insectivore	Neutral	1948
Fathead minnow	*Pimephales promelas*	Omnivore	Tolerant	1962
Brook silverside	*Labidesthes sicculus*	Insectivore	Neutral	1982
Bluegill sunfish	*Lepomis macrochirus*	Insectivore	Neutral	1962
Muskellunge	*Esox masquinongy*	Predator	Intolerant	1992
Central mudminnow	*Umbra limi*	Insectivore	Neutral	2008
Common shiner	*Notropis cornutus*	Insectivore	Neutral	1977
Golden shiner	*Notemigonus crysoleucas*	Insectivore	Neutral	1962
Green sunfish	*Lepomis cyanellus*	Insectivore	Neutral	1989
Johnny darter	*Etheostoma nigrum*	Insectivore	Neutral	1962
Pumpkinseed sunfish	*Lepomis gibbosus*	Insectivore	Neutral	1962
Spottail shiner	*Notropis hudsonius*	Insectivore	Neutral	1962
Yellow perch	*Perca flavescens*	Insectivore	Neutral	1962

Yellow perch

Yellow perch abundance has been highly variable, with the peak years in the 1980's offset with peak years in Walleye abundance (Figure 15). Yellow perch abundance during the last several surveys in Peltier has been modest to low. In Minnesota, yellow perch are an important prey for northern pike, largemouth bass, and walleye, and abundance is often closely tied to changes in the abundance of these predators (Pierce et al. 2006).

Walleye

Walleye fry have been stocked since 1988, at numbers between 285,000 and 1,236,000. The current lake management plan calls for 2,500 walleye fry/littoral acre (1,030,000 fry) every other year in odd-numbered years. Survival of fry stocked in the spring is probably more variable than survival of fingerlings stocked in the fall; however, fry are less expensive and are more successful in systems with low bluegill and crappie predator abundance (Parsons and Pereira 2001). The start of regular walleye fry stocking in 1988 coincides with a decline in yellow perch relative abundance from 83 fish/net in 1982 to 1 fish/net in 1997. Walleye abundance has only exceeded the 75% quartile once, in 1997, and declined to 0 fish/net in the 2007 survey (Figure 15). Walleye were relatively large in 1992 and size, along with abundance has been in decline ever since (Figure 15). The Sentinel lakes pilot project will be important for evaluating whether walleye fry stocking will provide a viable walleye fishery. Alternative stocking regimes may need to be evaluated if walleye abundance remains low.

Northern pike

Northern pike density is an important predictor of growth rate and population size structure (Pierce and Tomcko 2003). In general, as northern pike density increases, size decreases. High abundance of small northern pike (i.e., 'hammer handles') is a problem throughout Minnesota due primarily to over exploitation of large individuals. Indeed this pattern of increasing abundance and decreasing size is evident in Peltier (Figures

15 and 16). Unfortunately, poor size structure of northern pike is quite difficult to reverse, but cannot occur without reduced harvest of large pike.

Largemouth bass

Because largemouth bass are not a primary management species and are difficult to sample with standard gears, there are few historical data on their population status. MDNR fisheries crews first surveyed largemouth bass in spring 2008 with night electrofishing. They captured 23 per hour with an RSD15 of 26. Female largemouth bass were represented to Age IV while males were represented to Age VI. Peltier's hypereutrophic productivity is near the edge of habitat suitability for largemouth bass. Reductions to nutrient loads may benefit largemouth bass size and abundance.

Black crappie

About one third of the total annual harvest of black crappies in Minnesota lakes occurs during winter (McInerny and Cross 2005). Peltier Lake supports a popular winter crappie fishery in Anoka County (Gorton 2003). According to Gorton (2003), 97% of the fish caught in the winter were panfish. Mean size of crappie measured exceeded 9 inches for both ice anglers and open water anglers. Crappie recruitment is often cyclic, with strong year-classes being produced every 2-5 years (Boxrucker and Irwin 2002). Unfortunately, it is often difficult to assess status of crappie populations with standard gears set during summer. Nevertheless, three times in 47 years, black crappie CPUE exceeded the 75% quartile value, only to be barely detectable in subsequent survey years (Figure 15). Patterns in angling pressure and harvest likely follow these boom-bust cycles.

Bluegill

Bluegill in Peltier are relatively large considering its hypereutrophic productivity and high angling pressure; two stressors that typically impair bluegill fisheries. Gorton (2003) indicated the average bluegill harvested was >7 inches for both ice and open water anglers on Peltier, with an estimated fishing pressure of 100 angler-hours per acre in 2001-2002. Historical bluegill trap-net CPUE ranged from 0.2-58.11 fish/net and was within the middle quartiles (avg. 14.4/net; Figure 15). Bluegill populations in Peltier stand to benefit from reduced nutrient loads and lower angler harvest.

Channel catfish

Channel catfish were first stocked in 2001 and have been stocked annually since 2004 (with an exception in 2008). Yearling channel catfish stocked during 2005-2007 averaged 17 fish/lb and over 2000 fish annually. Only two fish were sampled by gill nets during the 2002 survey; however, Gorton (2003) reported anglers caught 276 catfish from the 2001 stocking. No channel catfish were surveyed during gillnet assessments in 2007. Gillnet surveys planned in 2009 and a proposed creel survey will help identify whether catfish stocking provides a viable fishery in Peltier

White sucker

White sucker are a widespread, unexploited coolwater fish that might serve as a valuable indicator of climate change. In Peltier, white sucker CPUE exceeded the 75% quartile value of 2.25 twice historically, but was within normal ranges during the last survey (Figure 15). Length of the 12 fish captured during the 2008 lake survey with trapnets ranged from 14.6 to 20.2 inches. Fish ranged from age IV to IX. Recruitment appears variable over the lake's surveyed history with no obvious trend.

Black bullhead

High black bullhead abundance is often characteristic of productive lakes; however, black bullhead has declined during the recent decade (Figures 14 and 15). A pre-aeration natural reproduction check in 1960 by shoreline seining yielded more black bullhead than the biologists could count (estimate ~ 1,000,000). A subsequent natural reproduction check in 2002 by shoreline seining yielded 0 fish. Recently, black bullhead abundance in trapnets and gillnets has been quite low (Figures 15 and 16). Channel catfish and walleye are known to feed on black bullhead (Schultz 2008), yet recent evidence suggests these predators are not abundant in Peltier. Rather, another predator bowfin, commonly referred to dogfish, has increased over the same time period. Bowfin, among other predators, may be exerting increased predation pressure on black bullhead. Low bullhead abundance is common in aerated lakes, perhaps as a result of sustained predator survival overwinter.

Carp

In terms of relative biomass, invasive common carp have been a major member of Peltier's fish community throughout its surveyed history (Figure 14). Numbers and size of carp have varied with high numbers of small individuals present in early surveys and few, large individuals present in more recent surveys. Historical CPUE of common carp peaked at 41.4 fish/net in 1972, well above the 75% quartile value of 2.38. Since winter aeration was implemented in 1988, CPUE has been much lower - between 0.38 and 2.38 fish/net (Figure 15). Our knowledge of the population dynamics of this species remains somewhat limited, but status and trends of carp should become more clear with additional sampling.

Commercial fishermen harvested 15,000 pounds of common carp in 1988, 85,000 pounds in 1998, and 14,000 pounds in 2005. The commercial operator in 2005 noted that carp were very large. Furthermore, commercial fisherman noted a recent trend of low carp recruitment across harvested lakes. Recent research at the University of Minnesota is demonstrating that carp reproduce successfully after disturbances such as winterkill have removed most other fish from the system (Bajer and Sorensen 2009). Indeed, recruitment of new carp to the system has been low since the aerator was installed in 1988. Lower winterkill, whether through aeration or climate change, may reduce carp recruitment. Furthermore, reductions to nutrient loading may also help limit their abundance.

Bowfin

Bowfin are a primitive, often underappreciated native fish. They are an effective predator and important for maintaining balanced fish populations. The 2008 trap-net CPUE of 1.89 exceeded the 75% quartile level as did the mean weight of 2.85 pounds. Bowfin represent a relic form of a fish group that was dominant in early geological history. The bowfin is an opportunistic rather than a selective predator. Becker (1983) found many species of minnows, bluegills, pumpkinseed, largemouth and smallmouth bass, and perch in bowfin stomachs. Bowfin seem to be quite active during the winter, and many are caught by commercial fishermen while seining under the ice (Eddy and Underhill 1974). Commercial fishermen reported taking 136 kg from Peltier (MDNR Commercial Fish Report 2005). Until recently, the bowfin has not been of high value to commercial fishermen. It was discovered that bowfin roe can be substituted for sturgeon eggs to make caviar and it is possible the fish will be targeted commercially. Becker (1983) highlighted the bowfin's role as a predator in lacustrine systems. He stated, "Since it inhabits waters likely to be populated by panfish or nongame fishes, the bowfin is often an asset. It may be quite effective in preventing stunting in sport fish populations. In fact, the quality of such waters may be attributable in part to the presence of this species."

Pflieger (1975) found that the bowfin occurs in a variety of habitats, but tends to avoid those with excessively turbid waters. This makes sense ecologically, as bowfin are sight feeders like northern pike; however, it may be functioning as the primary predator in a system where the prey species of yellow perch, bluegills, and black crappies constitute a substantial part of the biomass in gill net catch. Bowfin began contributing to net catch biomass in 1989 and they have accounted for 5-13% of total biomass through 2008. Based on trapnet catches, bowfin has increased appreciably in the recent decade (Figure 14). Above historical average number of northern pike, together with a possible expanding bowfin population maybe contributing to the good growth of bluegills. Continued monitoring will be necessary to determine whether we are seeing a temporary large year class move through the fish community or whether population levels will remain relatively high.

Pumpkinseed

Pumpkinseed are a common sunfish species statewide, but are generally less abundant than bluegill. Pumpkinseeds are relatively rare in Peltier.

Figure 15. Trends in catch per unit effort (CPUE), quartiles from other class 38 lakes, and historical averages of major fish species in Peltier Lake.

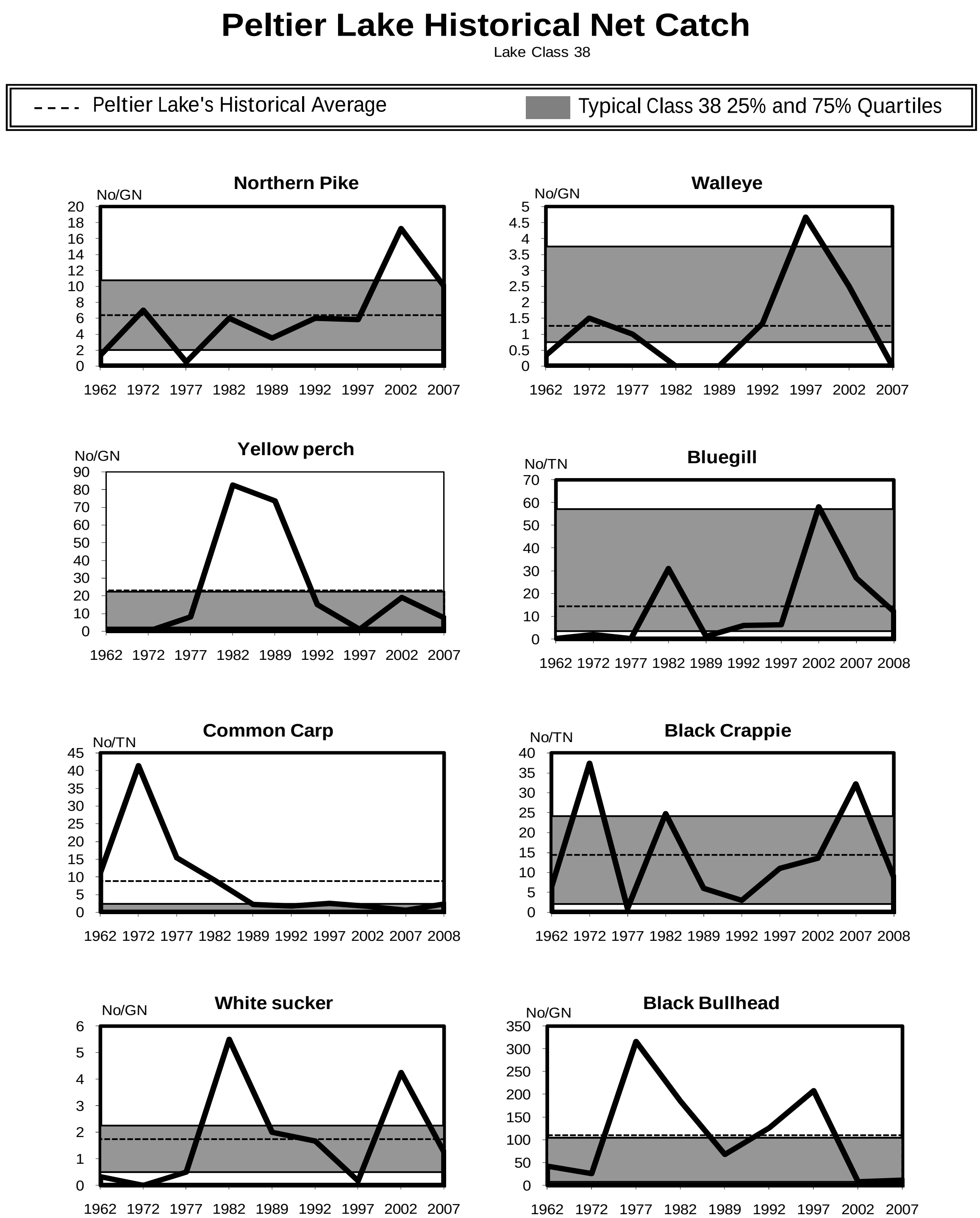
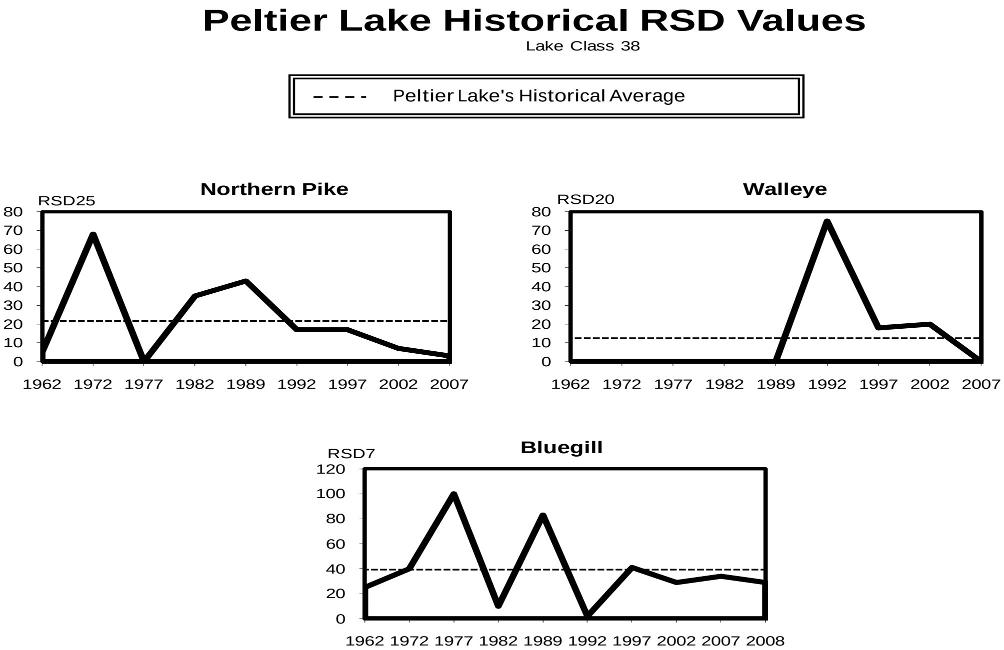


Figure 16. Trends in relative stock density (RSD) for desirable-sized fish captured in gillnets (walleye and northern pike) and trapnets (bluegill) in Peltier Lake



Wildlife Assessment

Waterfowl

The shallow north basin is a popular waterfowl hunting destination for local hunters (Tim Bremicker, MDNR Central Region Wildlife Manager, personal communication). Peltier is south of the wetland-rich 64 km (25,900 acre) Carlos Avery Wildlife Management Area and is a stopover spot for migrating waterfowl during spring and fall. Due to poor water quality, Peltier is generally not considered productive waterfowl habitat for resident waterfowl (Bryan Lueth, Area Wildlife Manager, personal communication).

Colonial waterbirds

Since first documented in 1945, the north island on Peltier Lake has supported a large colonial waterbird nesting colony (MDNR Natural Heritage Information System 2009). At its peak in 1996, this island supported 1,149 active nests with three heron species: great blue herons (*Ardea Herodias)*, great egret (*Ardea alba),*and black-crowned night heron (*Nicticorax nicticorax)* (Von Duyke 2009). Beginning in 1998, the colony experienced sharp declines in nesting and complete abandonment by 2000. The last black-crowned night herons were observed in 1997. The colony remained largely deserted until 2005 (Von Duyke 2009). Since 2005, great blue heron have been nesting with slowly increasing success (source Wayne LeBlanc, lake citizen observer; MDNR Natural Heritage Information System 2009).

The sharp decline in waterbird nesting raised alarm and controversy over its cause. Strong circumstantial evidence presented by Von Duyke (2009) suggests, human noise disturbance (e.g., waterski recreation, aircraft operations, pedestrian traffic, and road construction) was the primary cause of the decline. Several mitigation measures have since been implemented by MDNR and local governments including a "no-wake" zone near the island. The effectiveness of these mitigation measures and recovery of the colony will continue to be monitored into the future.

Water Quality Assessment

Monitoring locations

Over the lake's history, several locations have been monitored for water quality (Figure 17). The majority of the water transparency (Secchi) monitoring done through the MPCA's Citizen Lake Monitoring Program (CLMP) has occurred at sites 451 and 203 (Figure 18). No apparent differences are noted in the transparency among the different sampling sites (Figure 18). Based on this site comparison, additional water quality analysis in this report did not take site location into account.

Figure 17. Established sampling sites on Peltier Lake

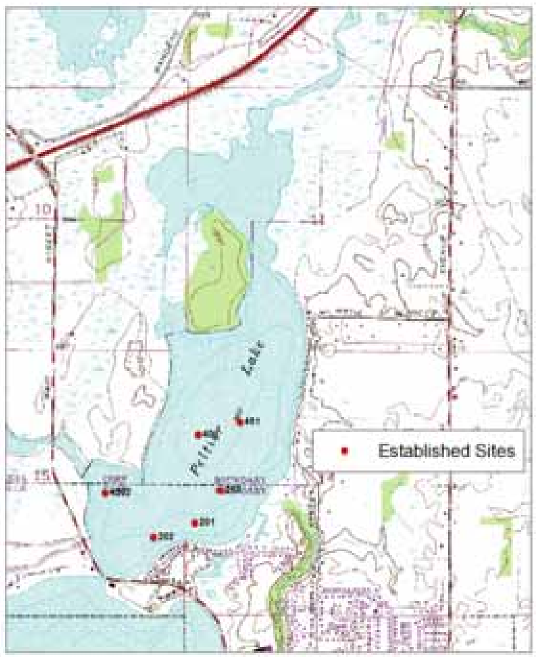
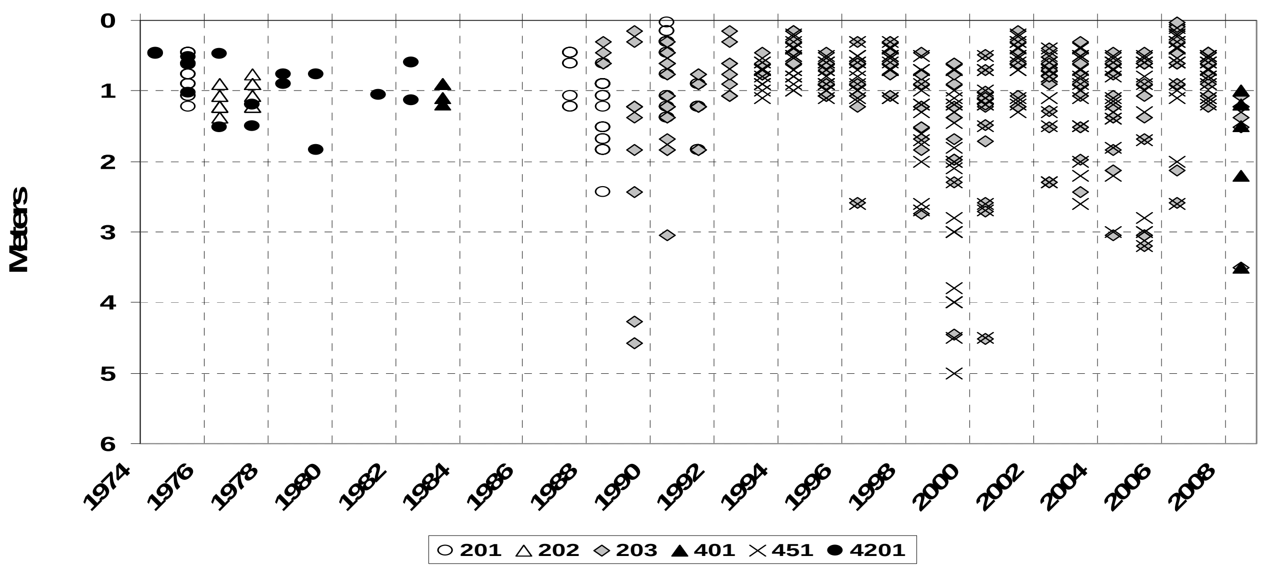


Figure 18. Peltier Secchi transparency comparison among sites. Includes data from entire period of record.



Peltier water quality records

Peltier has an extensive water quality data record. This entire record, based on data available through STORET (via MPCA's EDA), is used in this analysis. Results and discussion proceed from the most current data collected in 2008, with comparisons to previous years when appropriate. The general approach is to examine stratification patterns over the course of one or two years, examine seasonal trends in basic trophic status indicators and water chemistry, and make comparisons to typical concentrations for NCHF ecoregion lakes. This basic characterization then allows for a more detailed examination of trends over time using the entire data record. In addition, major cations, anions, and total organic carbon were analyzed on three sample dates, and those values and typical ranges as derived from the National Lakes Assessment (NLA) database for Minnesota are summarized in Table 6. The NLA was a statistically-based survey of the nations lakes administered by the USEPA in 2007.

Lake stratification

Surface to near bottom profiles of temperature and DO are collected routinely with most water quality sampling visits. For Peltier ,in 2008 the combined sampling effort of MPCA staff and volunteer, Wayne LeBlanc, provided a good series of measurements from April through October (Figure 19 and 20). On most sample dates, there was minimal difference in water temperature from the surface to the bottom of the lake and the lake would have been considered well-mixed. On two sample dates, June 2 and July 28, a minimal temperature gradient was evident. Temperatures were quite warm (above 20°C) from surface to bottom from the end of June through August. Elevated temperatures can serve to reduce DO solubility and in the bottom waters may increase the likelihood of internal P release as a result of increased bacterial decomposition.

2008 summer temperature and DO profiles

Surface DO measurements were quite variable in 2008 and are a direct reflection of temperature (DO solubility) and algal photosynthesis and respiration and aquatic plant condition on the lake. DO was supersaturated near the surface on July 28, but declined rapidly with increasing depth. Mild thermal stratification, low transparency (minimizes DO production fro algae) and high oxygen demand in sediments and water all contribute to the low DO. Hypoxic (<2.0 milligrams per liter - mg/L) conditions were evident in the bottom waters from June through August (Figure 20). This combination of low DO and high temperature in the water that overlies the sediments can contribute to sediment P release that will be discussed in greater detail later in the report.

Yearly temperature and DO profile trends

While the frequency of sampling in 2008 was good, closer interval sampling can provide more insight into temperature and DO dynamics and frequency of mixing in a shallow lake like Peltier. For this purpose, data from 1990 and 1991 were used to create isopleth diagrams for the period from April 1990-April 1991 (Figures 21 and 22). Based on these profiles the lake was isothermal from late September through mid-May. Peak surface temperature was measured at the end of June and surface temperatures remained above 21 C from mid June to mid September. Bottom waters overlying the sediments were quite warm as well and remained above 21 C from the end of June to early September.

Surface DO was high throughout most of the open water season; however, near-bottom DO was quite low (Figure 21). Though the lake was relatively well-mixed, from a thermal standpoint (Figure 20), DO stratification was evident over much of the year. Near-bottom waters were hypoxic from the end of May through the end of March based on these data and as noted previously this promotes internal P release.

Figure 19. Peltier Lake 2008 temperature profiles

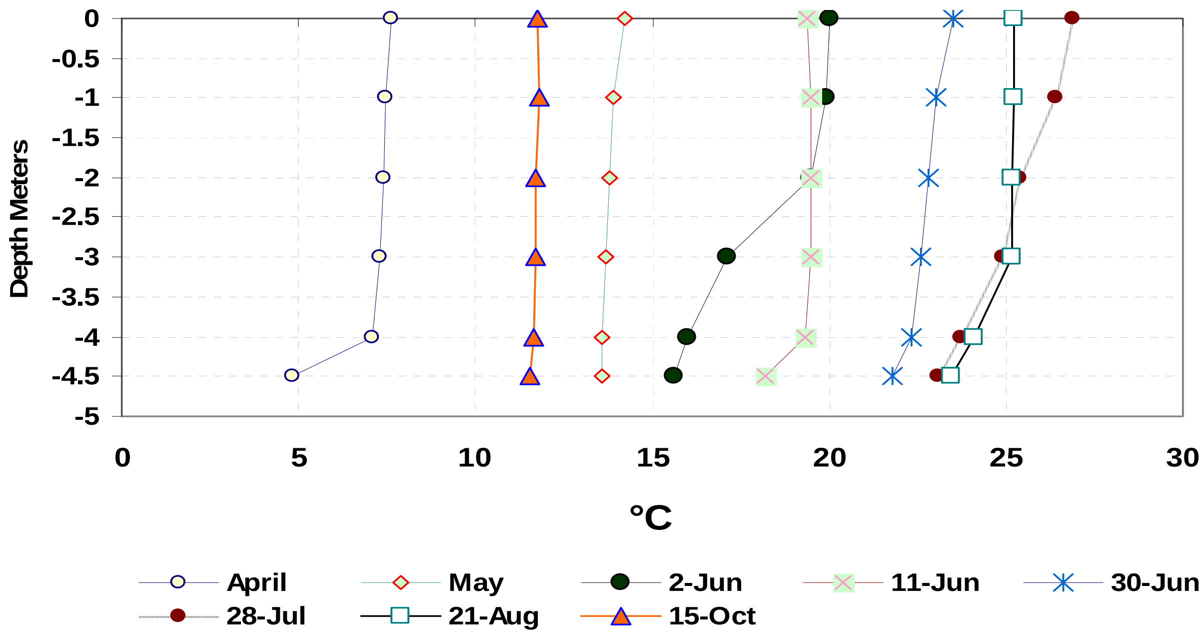


Figure 20. Peltier Lake 2008 dissolved oxygen profiles

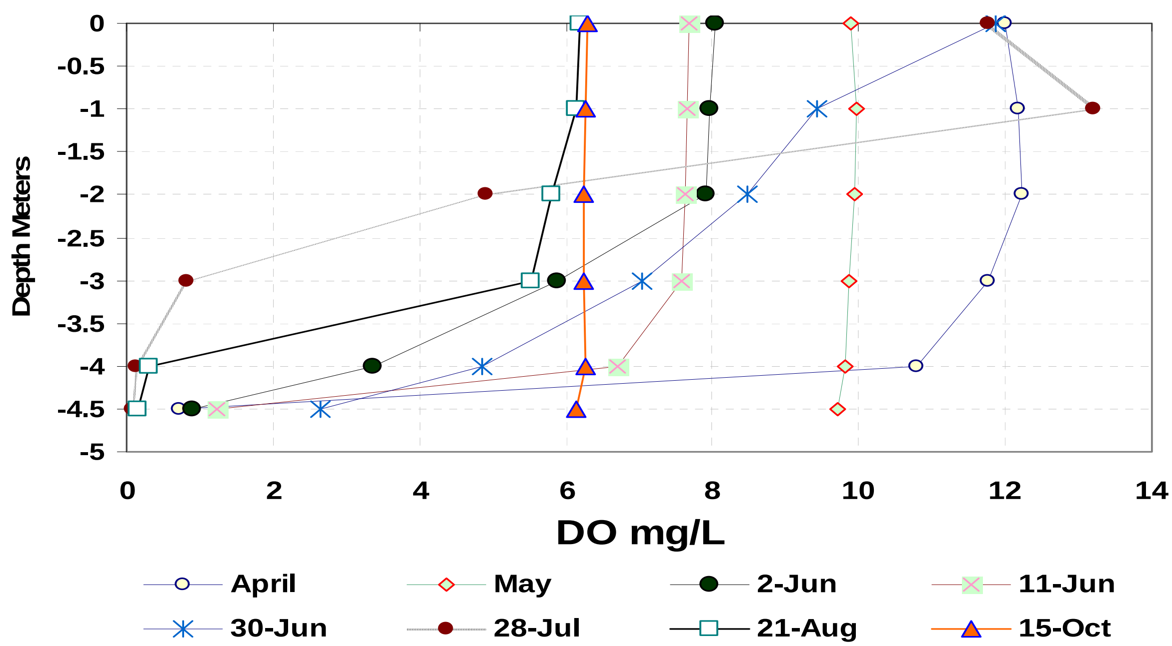


Figure 21. Peltier Lake 1990 – 1991 temperature profile

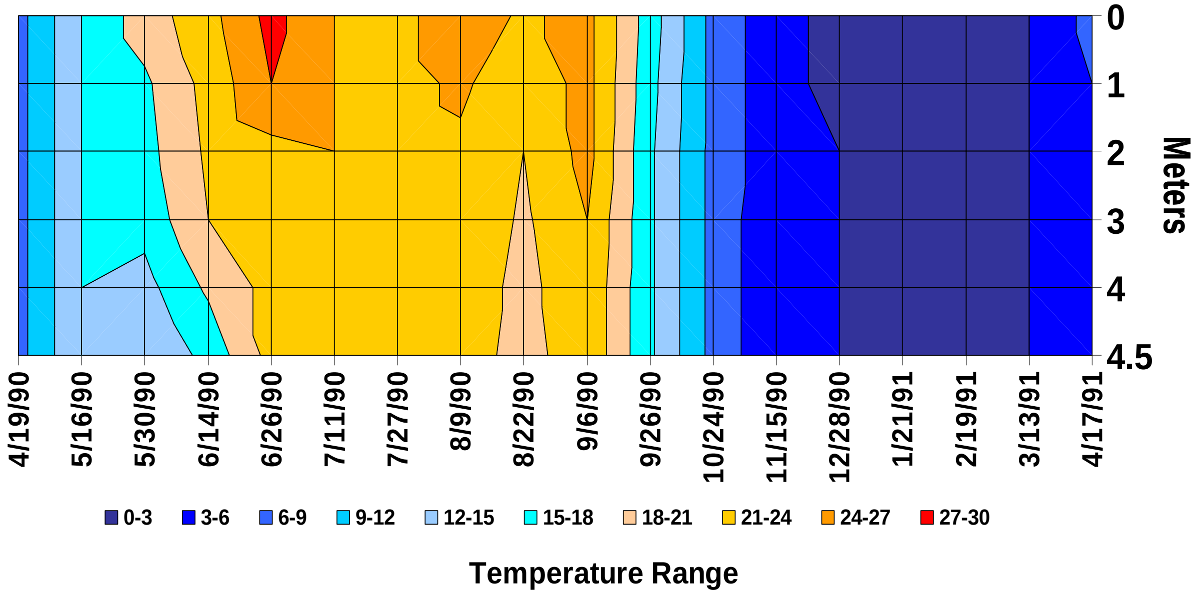
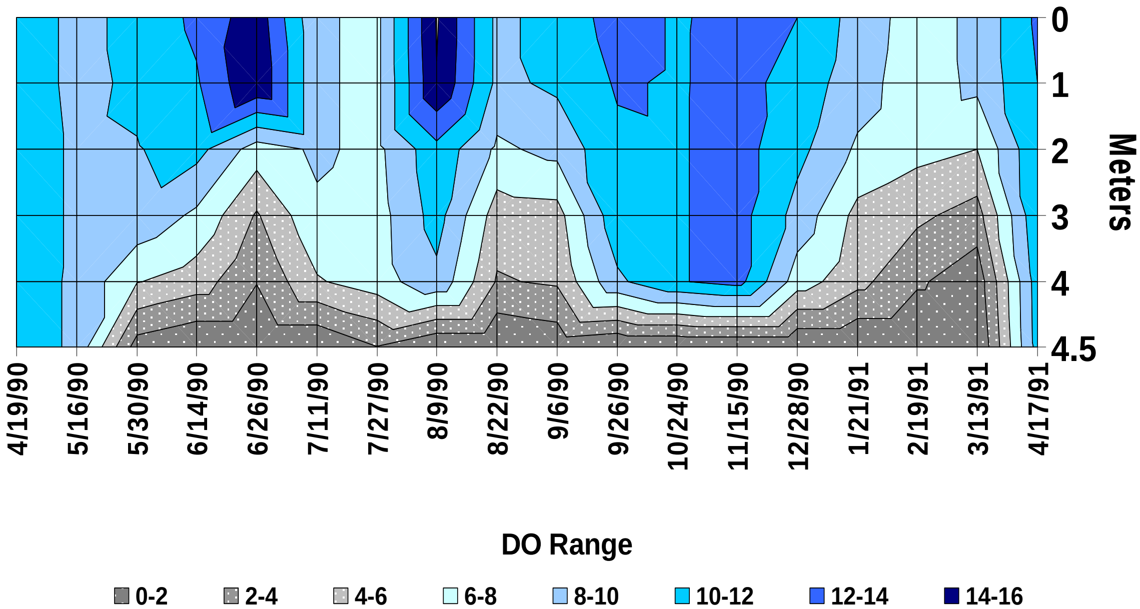


Figure 22. Peltier Lake 1990-1991 dissolved oxygen profiles



Water quality results for 2008

The 2008 lake monitoring was a collaborative effort between the MPCA, RCWD and volunteer monitor, Wayne LeBlanc. This resulted in a fairly comprehensive data record for 2008 that included standard lake water quality monthly measurements, such as total suspended solids (TSS), alkalinity, conductivity and color (Table 5). While several of these parameters have "typical" ecoregion-based concentrations, some do not (Table 5). Summer average for most parameters with the exception of alkalinity, Secchi and total suspended inorganic solids were above the NCHF Ecoregion. The high color value indicates the water is turbid and has high dissolved organic carbon. As such, the total organic carbon (TOC) levels were also high. Much of the TOC in water is due to incompletely dissolved organic material. Lakes with high amounts of forest and wetlands in their watershed often have correspondingly higher color and TOC values. In addition to the parameters that are typically monitored in a standard MPCA lake assessment, some additional parameters were added to enhance the database for this Sentinel lake.

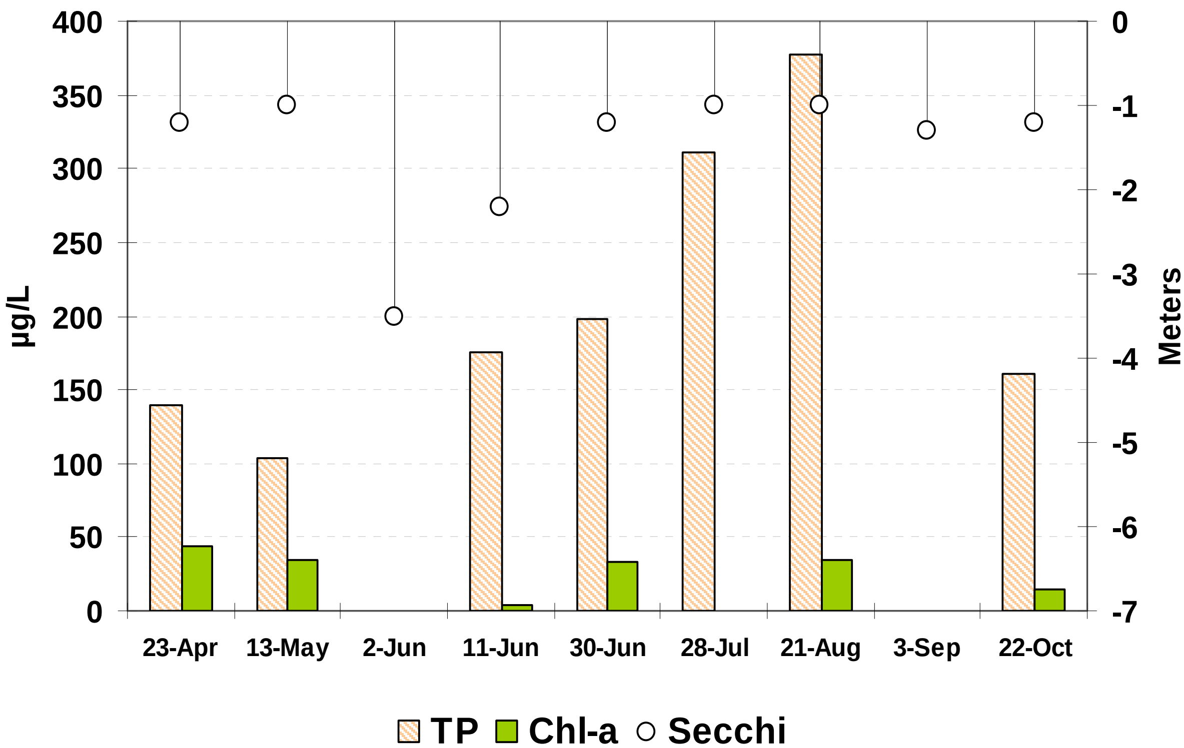
Table 5. Lake Peltier 2008 water quality results and NCHF ecoregion reference lake typical (IQ) range.

Parameter	April 23	April 30	May 13	June 2	June 11	June 30	July 28	Aug. 12	Sept. 8	Oct. 21	Mean	SE	NCHF Ecoregion Reference Lake Range
Alkalinity (mg/L)	140						150			150	146	3.3	75 – 150
Carbon, organic + inorganic (mg/L)	12						17			14	14.3	1.5	
Chloride (mg/L)	52						114			47.2	71.1	21.5	4 - 10
Chlorophyll mean (µg/L)	43.2				3.78		33.6	34.1		15.1	24.5	8.9	5 – 22
Color (Pt-Co U)	60						60			40	53	6.7	10 – 20
Secchi Depth (M)	1.2	1.2	1.0	3.5	2.2	1.2	1.0	1.5	1.4		1.6	0.3	1.5 – 3.2
Dissolved oxygen (DO)	12.0		9.9	8.1	7.7	11.9	11.8	6.2		6.3	9.2	0.9	
Total Kjeldahl Nitrogen (mg/L)	1.7						3.3	2.6		2.2	2.4	0.3	<0.6 – 1.2
Nitrogen, (NO2 +NO3)	0.25							ND		0.21	0.23	0.0	
Oxidation reduction potential (ORP)	467							286			376	90.5	
pH (SU)	7.5							8.8		8.2	8.2	0.7	
Pheophytin-a µg/L	5.4				0.44			6.8		ND	4.2	1.9	
Phosphorus µg/L	140				174		349	378		161	204	0.1	23 – 50
TSS (mg/L)	5.6						16.0			2.4	8.0	4.1	4 - 6
TSIS (mg/L)	2						1			1	1	0.6	1 - 2
Specific Conductivity (umhos/cm)	459							448		421	443	5.5	300-400
Temperature, water (Deg. C)	7.6		14.2	20	19.4	23.5	26.9	25.2			19.6	2.5	
Solids, Volatile	3.6						15			2.6	7.1	4.0	2 - 6

Trophic indicators

Monitoring in 2008 showed lower transparency in the spring followed by an increase in transparency in June (Figure 23). Transparency declined from June – July and then remained fairly stable from July through October. Fluctuations in Secchi transparency were in direct response to increases or decreases in Chl-a. With the exception of low Chl-a on June 11, Chl-a levels were fairly stable in 2008 and extreme nuisance conditions, which have been prevalent in most previous summers, were not as common in 2008. TP increased significantly during mid-summer and peaked at 378 µg/L in late August. This pattern of a mid-summer increase in TP is consistent with other shallow lakes in Minnesota and is likely a response to curly-leaf pondweed senescence and internal P release from the sediments.

Figure 23. Peltier Lake 2008 trophic status indicators



Dissolved Minerals and Carbon

Among the parameters added to the 2008 monitoring were cations and anions. Since Minnesota has no ecoregion reference values for most ions, comparison were made with data from the 2007 NLA. The 2007 NLA study was used to provide perspective on reported concentrations. Since the NLA lakes were selected randomly, they provide a reasonable basis for describing typical ranges and distributions at the statewide level. With the exception chlorides (Cl) and sulfates (SO^4) ions were relatively stable (Table 6). The field replicate sample, taken in July, shows good quality assurance with the sampling and analysis. Comparison with 2007 NLAP results show Ca, Mg, Cl and Na levels in Peltier were over the 90th percentile (Table 7). The elevated ions are most likely attributed to application of road salt on roads in the watershed. While these numbers may high, compared to the state wide random NLA study, it is not uncommon for urban lakes to have elevated levels of these ions. Overall, cations and anions balanced with a relative percent difference of about 10 %.

Table 6. Peltier Ion and carbon concentration

Date	Cations				Anions			Total Organic Carbon mg/L
	mg/L Ca	mg/L Mg	mg/L Na	mg/L K	Alkalinity As $CaCO_3$	mg/L Cl	mg/L SO_4	
4/23/2008	48	14.3	25	4	140	52	11.7	12
7/28/2008	44	14.6	24	2.5	150	114	21.7	17
7/28/2008 field replicate	44	14.6	24	2.5	150	114	21.8	17
10/28/2008	48	14.6	25	2.4	140	47.2	5.7	14

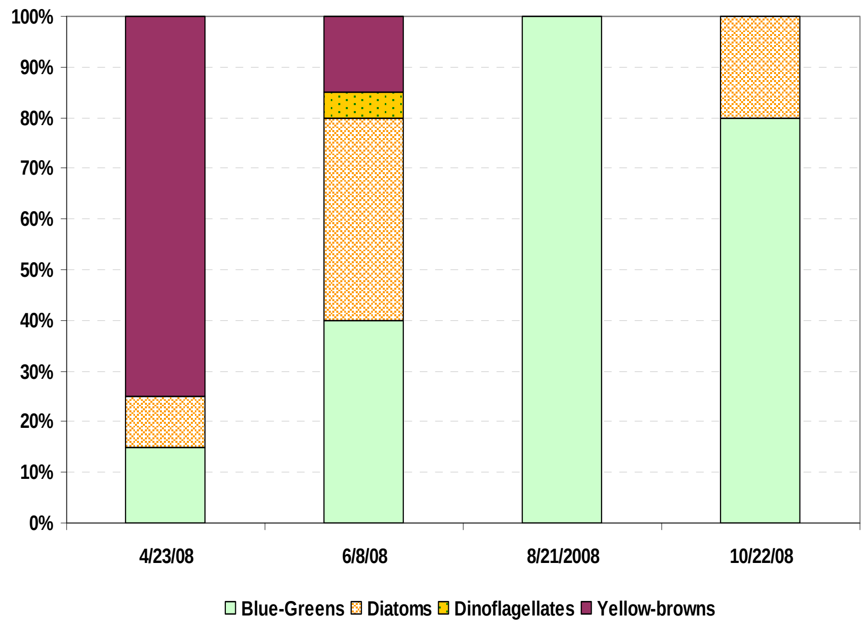
Table 7. Peltier Lake ion balance. Interquartile range (referred to as typical range) based on 64 lakes from the 2007 NLA study provided for perspective.

Parameter[1]	Peltier	NLA IQ Range	µeq/L
	2008	**2007**	**2008**
Ca (mg/L)	47.0	19.1 - 33.7	2345
Mg (mg/L)	14.5	6.7 - 26.9	1193
K (mg/L)	2.9	0.9 - 4.8	74
Na (mg/L)	24.0	2.2 - 9.0	1066
Cation sum			**4678**
Alk (mg/L	146.7		2920
SO_4 (mg/L)	13.0	2.2 - 14.1	271
Cl (mg/L)	71.1	1.5 - 18.4	2003
Anion Sum			**5194**

Phytoplankton (algae)

A seasonal transition in algal types from diatoms to greens to blue-green is rather typical for mesotrophic and eutrophic lakes in Minnesota. In 2008, phytoplankton (algae) samples were collected from Peltier in April, June, August, and October. Samples were analyzed via MPCA's Rapid Assessment Method. The April phytoplankton community was predominately yellow-brown varieties. By June, diatoms and blue-greens became more prominent. By August, the algal community was dominated (100%) by blue-green algae, with *Aphanizomenon* the most common genera (Figure 24). In October, the algae community was still dominated by blue-greens, but diatoms were once again observed. The transitions in the phytoplankton community in Peltier seems not only tied to nutrient concentrations, but also the macrophyte and zooplankton community. Based on Chl-a (Table 5) concentrations and the level of blue-greens in the southern portion of the lake, nuisance blooms were present throughout most of the summer. This summer trend to Mid-summer blue-green dominance is common in unstable shallow lakes.

Figure 24. Phytoplankton summary



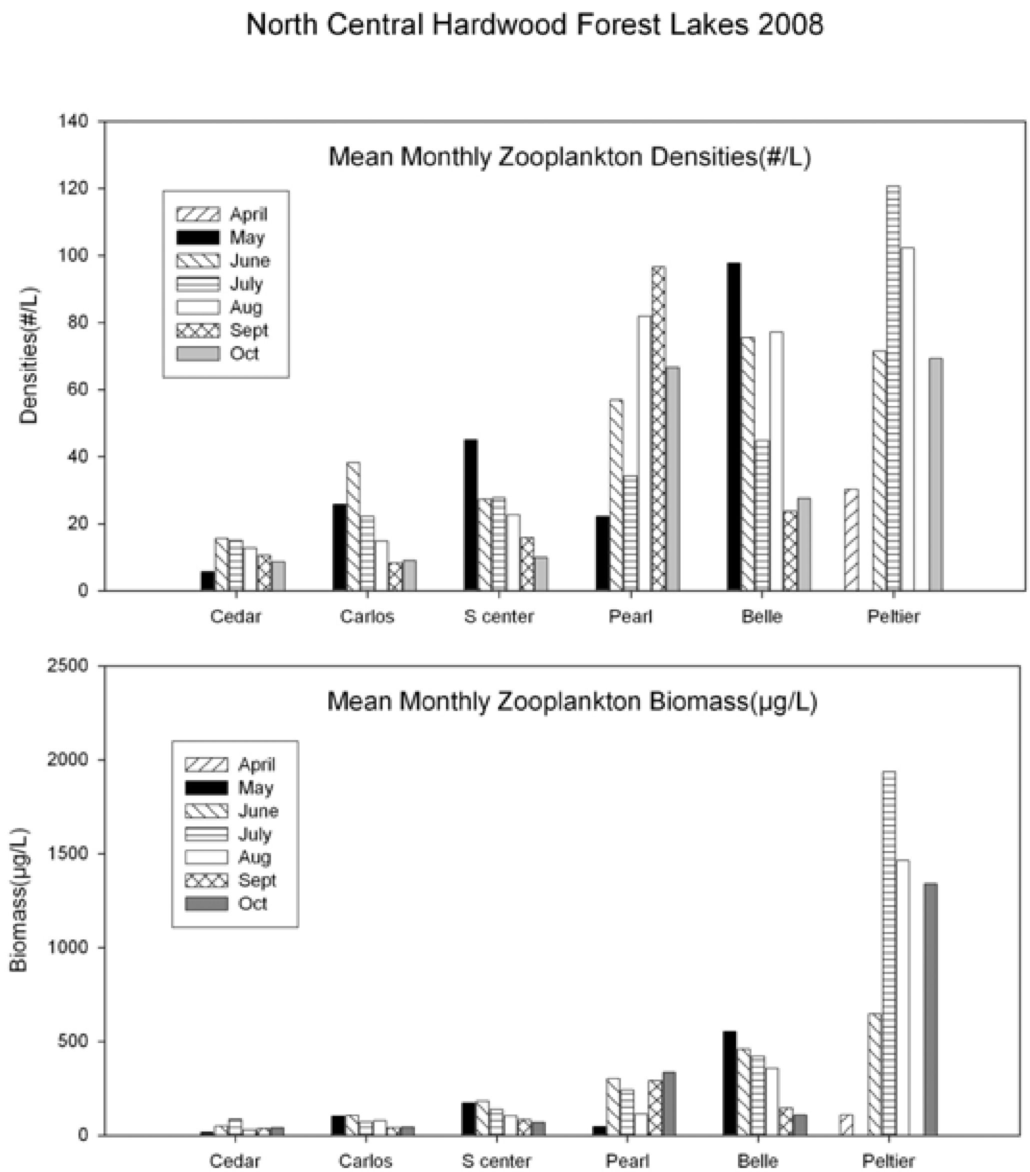
Zooplankton

Peltier Lake was sampled for zooplankton monthly from ice-out (April or May) through October 2008. A total of 12 different taxa (most to species level) were identified on (Hirsch 2009). Mean annual biomass of zooplankton takes size as well as the abundance in to account. Of the 24 Sentinel lakes samples in 2008, Peltier Lake had the highest mean annual biomass at 1098 µg/L (Table 8). Zooplankton biomass peaked in July, corresponding to the passing of the curly-leaf on the lake (Figure 25). The high concentration of zooplankton is likely a factor in the lower relative Chl-a and Secchi to TP.

Table 8. Mean annual zooplankton densities (#/L), biomass (µg/L) and total number of taxa for each of the sentinel lakes sampled in 2008. Lakes are arranged by ecoregion (Sentinel lake groupings).

Sentinel Lakes Zooplankton 2008	Mean Annual Densities (#/L)	Mean Annual Biomass (µg/L)	Total# Taxa
Western Cornbelt Plains (WCBP & NGP)			
Artichoke	139.64	724.05	12
Shaokotan	107.55	1070.97	11
St. James	62.73	108.56	10
St.Olaf	60.23	336.20	15
Carrie	56.41	254.21	13
Madison	52.78	310.93	14
North Central Hardwood Forest (NCHF)			
Peltier	78.75	1098.39	12
Pearl	59.68	221.13	14
Belle	57.67	340.06	12
South Center	24.72	123.71	18
Carlos	19.66	73.49	16
Cedar	11.31	41.85	11
Northern Lakes and Forests (NLF)			
Portage	100.10	277.38	10
Red Sand	79.31	127.96	18
South Twin	25.83	54.93	12
Hill	17.73	147.29	11
Elk	16.95	47.10	12
Ten Mile	14.94	44.89	14
Border Lakes (NLF)			
Echo	37.03	89.68	12
Elephant	13.26	75.50	12
White Iron	10.00	38.64	14
Trout	6.28	29.52	13
Bearhead	5.15	38.37	14
Northern Light	1.03	4.16	13

Figure 25. Mean monthly zooplankton densities (#/L) and biomass (µg/L) in the Sentinel lakes of the Northern Central Hardwood 2008. (Lakes are arranged on graph from left to right, with increasing total phosphorous levels.



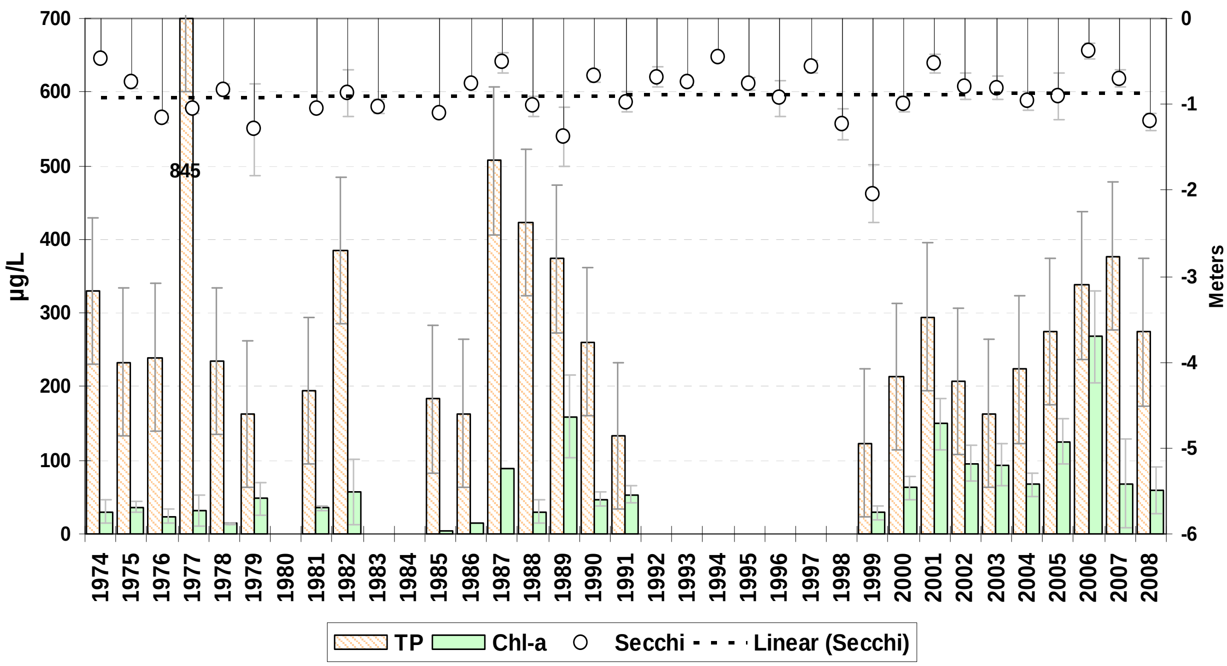
Long-Term Water Quality Trends

Peltier Lake has one of the longest and most extensive water quality records of any of the Sentinel lakes. This allows for a more comprehensive assessment of trends in the primary trophic status variables, TP, Chl-a and Secchi, as well as other parameters such as nitrogen, CL, and surface water temperature. In addition, sediment cores were collected as a part of the recent TMDL study and results from this work allow for a description of trends in P over time as inferred from fossil diatoms in the cores.

Summer mean trophic indicators

Summer mean trophic indicators show the lake has been eutrophic to hypereutrophic since the beginning of the modern-day water quality records in 1974 (Figure 26). TP concentrations have varied over the years, with annual means ranging from approximately 100 to >800 µg/L. TP in recent years (1999-2008) has averaged slightly less than previous years; however, high variability is also evident in the most recent records with summer-means that range from about 125-375 µg/L. While TP may be slightly lower in the recent record, Chl-a appears to be higher with summer averages that range from about 50 µg/L to over 200 µg/L. Overall, transparency is rather low throughout the entire record, averaging about 0.8 m and ranging between about 0.5-1.0 m in most summers.

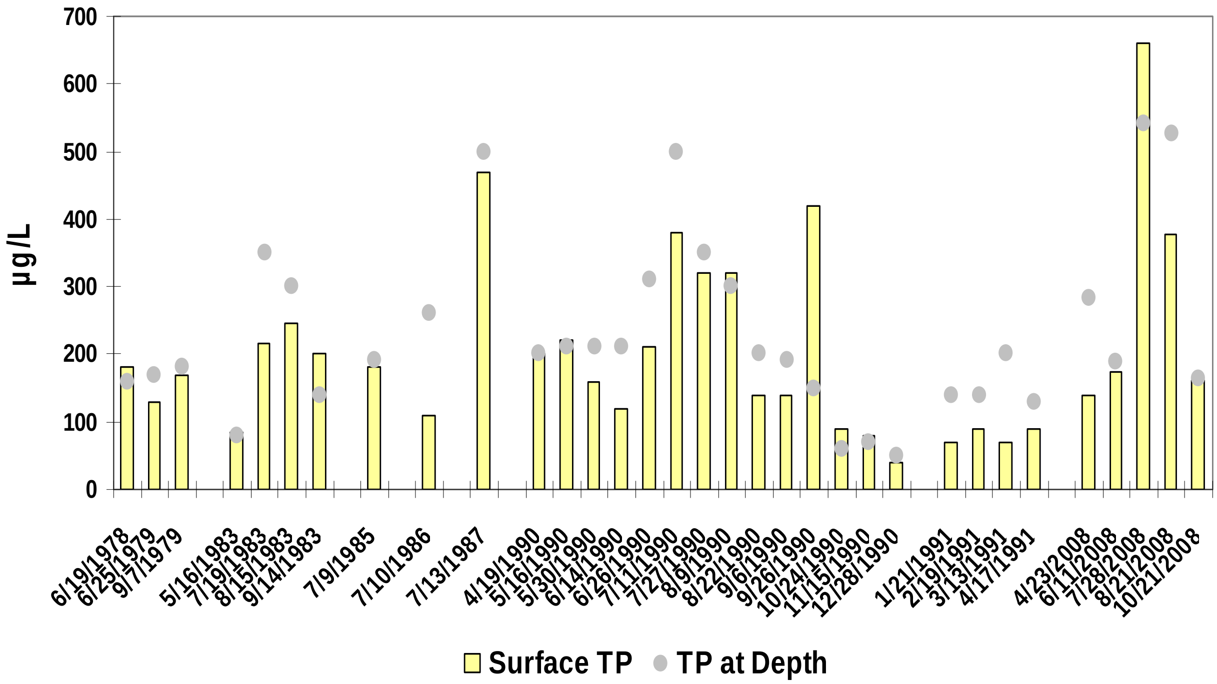
Figure 26. Summer mean trophic indicators for Peltier Lake



TP: surface and depth comparison

Though Peltier is very shallow there is a fairly extensive record of surface and hypolimnetic TP samples. Hypolimnetic samples are generally collected about 1.0 m above the sediment, which for Peltier would be at a depth of approximately 3.5 m. This comparison provides insight into internal P release and degree of wind mixing in the lake. Based on these comparisons (Figure 27) there was often minimal difference between the surface and deep TP concentrations. The detailed record from 1990 provides a good seasonal picture of changes in surface and deep TP. Based on 1990 mid-summer (July and August), peaks in both surface and deep TP are evident. July measures in 1987 and 2008 show similar midsummer peaks (Figure 27). The 1990 midsummer peak corresponded to very warm temperatures (21-24°C) and low DO near the sediments (Figures 22), both of which promote internal recycling.

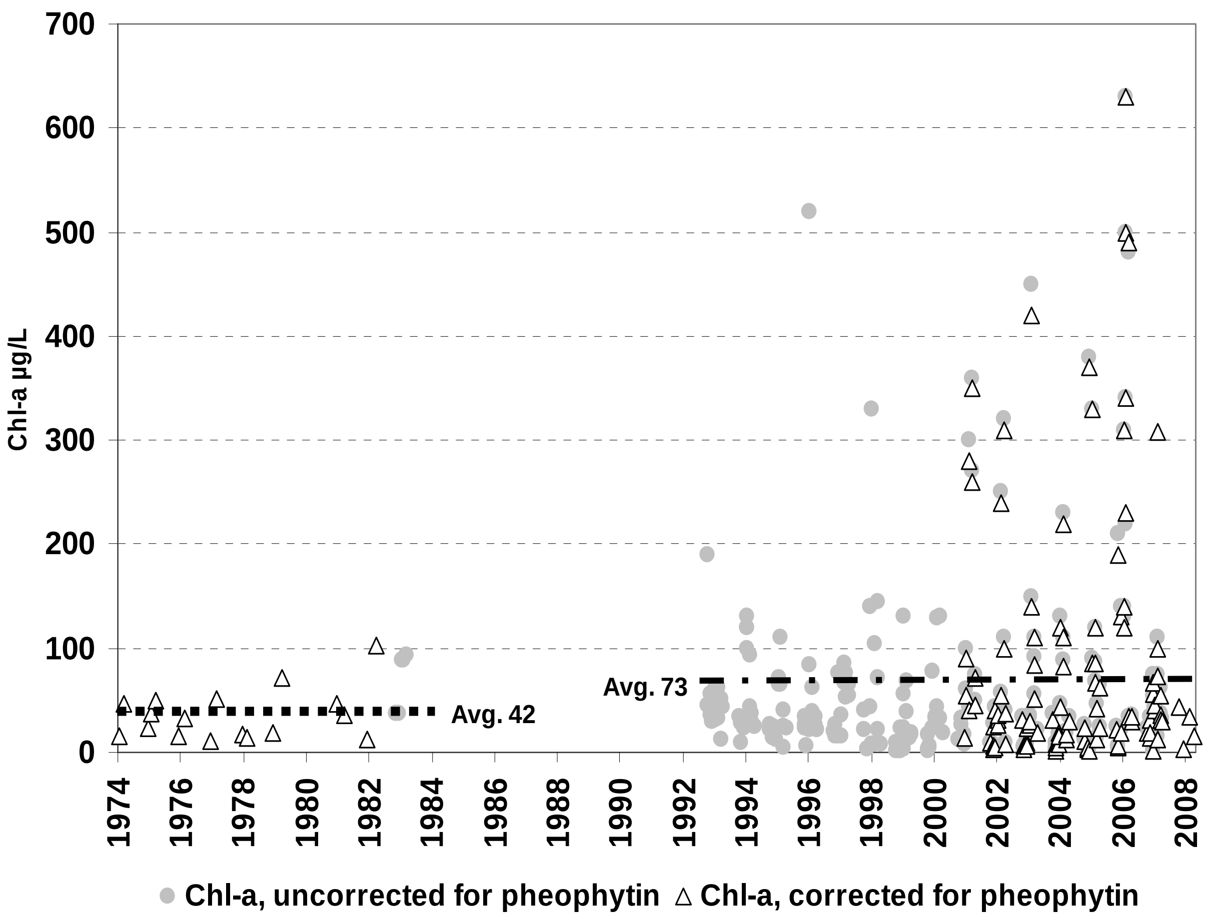
Figure 27. Peltier Lake surface (0-2 m integrated) vs. near-bottom TP



Chlorophyll-a and nuisance bloom trends

Long-term summer-mean Chl-a indicate higher algae levels in recent years (Figure 28). This increase in summer-mean is driven to some extent by an increase in extreme values. This is quite evident in a comparison of the recent record with an average of 73 µg/L, as compared to 42 µg/L for the earlier record. It is also evident from this record that extreme values in excess of 100 µg/L are fairly common in the recent record. These values are extremely high given that very severe nuisance blooms are often equated with Chl-a >60 µg/L for lakes in the NCHF ecoregion (Heiskary and Walker 1988). This analysis also allowed for a comparison between Chl-a value corrected for pheophytin (a degradation pigment that may interfere with Chl-a analysis) and measures that are not corrected – since the long-term database was comprised of both measurements. This comparison suggests there was minimal difference between these two measurements based on paired samples for Peltier Lake.

Figure 28. Peltier Chl-a trends over time based on individual samples. Includes both corrected and uncorrected Chl-a.

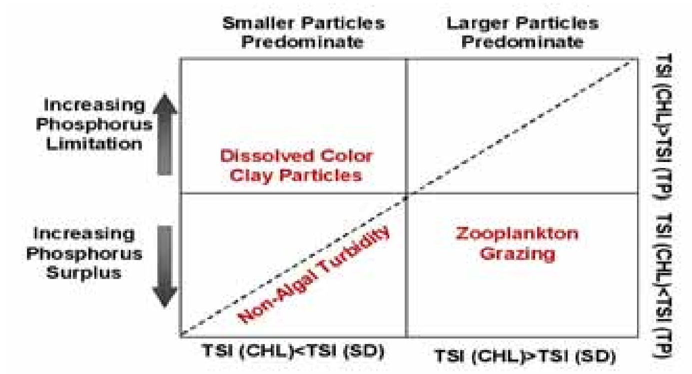


Trophic status trends .....

TP, Chl-a and Secchi transparency are closely interrelated and are collectively used to characterize the “trophic status” of lakes. One means to evaluate the trophic status of a lake and to interpret the relationship between TP, Chl-a and Secchi transparency is Carlson's Trophic State Index (TSI) (Carlson 1977). This index was developed from the interrelationships of summer Secchi transparency and the concentrations of surface water Chl-a and total phosphorus. TSI values are calculated as follows:

Total phosphorus TSI (TSIP) = 14.42 1n (TP) + 4.15
Chlorophyll a TSI (TSIC) = 9.91 1n (chl *a*) + 30.6
Secchi disk TSI (TSIS) = 60 - 14.41 1n (Secchi)

Figure 29. Possible explanations for deviations of the TSI



Source Carlson, R.E and K.E. Havens. 2005.

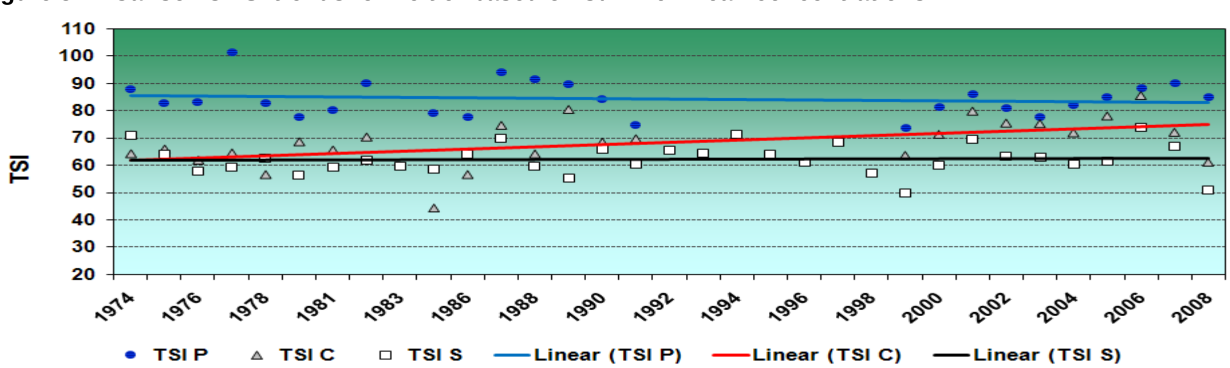
TSI values generally range from 0 (oligotrophic) to 100 (hypereutrophic) (Figure 30). In this index, each increase of 10 units represents a doubling of algal biomass. This index is based on the interrelationship of the three variables and allows one to predict any variable based on a result of any one indicator. Typical deviations in TSI comparisons are explained in figure 29. When combined with Figure 30 interpretations of the relationships among TP, Chl-a and Secchi may be made.

Figure 30. TSI range and eutrophication categories

Productivity Category	*Oligotrophic*			*Mesotrophic*		*Eutrophic*		*Hypereutrophic*			
TSI Value	0	10	20	30	40	50	60	70	80	90	100

TSIP for Peltier exceeds TSIC and TSIS over the majority of the record (Figure 32). Zooplankton grazing (as noted earlier) can play a role as well to keep Chl-a lower than anticipated based on TP. In general, TSIC is greater than TSIS. Again zooplankton grazing can play a role via cropping of small algal forms – leaving large colonial forms like *Aphanizomenon* to dominate. These colonies in turn allow for higher transparency (lower TSIS). In recent years (1999-2008), the three TSI variables show very consistent correspondence to one another (Figure 31); whereby as TP increases, Chl-a increases and Secchi declines. Potential explanations can include: a) the aeration system put into effect in the late 1980’s has helped to sustain predator gamefish, which along with roughfish harvest may serve to keep bullheads low and b) the expansion of curly-leaf and Eurasian milfoil can provide refuge for zooplankton and act as nursery areas for juvenile fish. Whatever the case, the system appears to be more “stable” than it was previously (Figure 31).

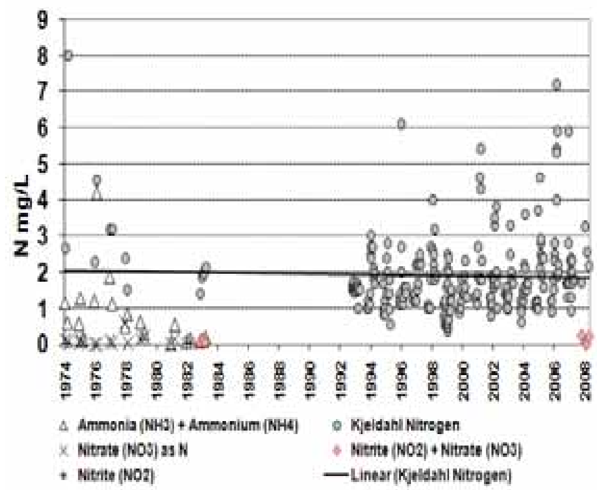
Figure 31. Carlson’s TSI trends for Peltier based on summer-mean concentrations



Nitrogen

Nitrogen is an essential for plant and algal growth and in some instances (e.g. when TP is very high) nitrogen may limit the growth of algae. There are several forms of N, but the most commonly measured are Total Kjeldahl Nitrogen (TKN) and nitrite+nitrate as nitrogen. The sum of these two measures is referred to as total nitrogen (TN). If the TN: TP ratio is greater than 10:1, TP tends to be the limiting nutrient, and if the TN:TP ratio is less than 5:1, nitrogen may be limiting (Chiaudani et al. 1974) . The long-term TN: TP ratio averaged 10.2: 1 and based on 250 comparisons of TP and TN. TKN, which includes organic nitrogen (algae) and ammonia-nitrogen is quite high (Figure 32) and well above the typical range for NCHF lakes (Table 5). Based on data from the 1970s ammonia-nitrogen may periodically be quite high in the lake.

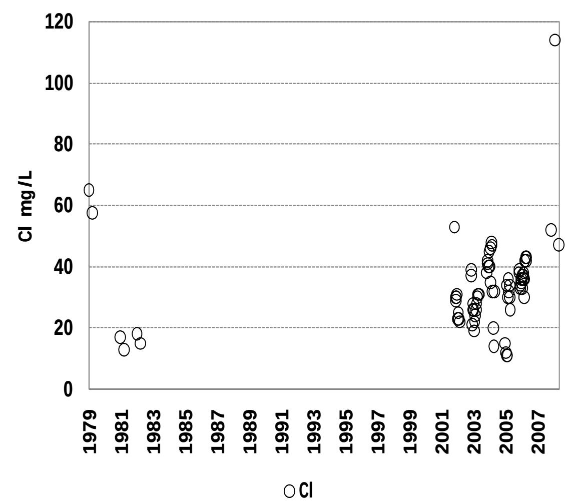
Figure 32. Nitrogen trends for Lake Peltier



Chloride

Chloride is considered a good indicator of anthropogenic impact on a lake. Road salt is often a large contributor to elevated Cl in lakes. For example, Northern Lakes and Forests ecoregion lakes with limited road networks and road salting in their watersheds often exhibit Cl on the order of 1-2 mg/L and NCHF reference lakes (outside of major metropolitan areas) are often in the 4-10 mg/L range. Cl in Peltier routinely ranges between about 20-40 mg/L, much higher than the typical range for NCHF ecoregion reference lakes (Table 5). Cl measures are rather variable and data from 2002-2008 suggest Cl may be increasing (Figure 33).

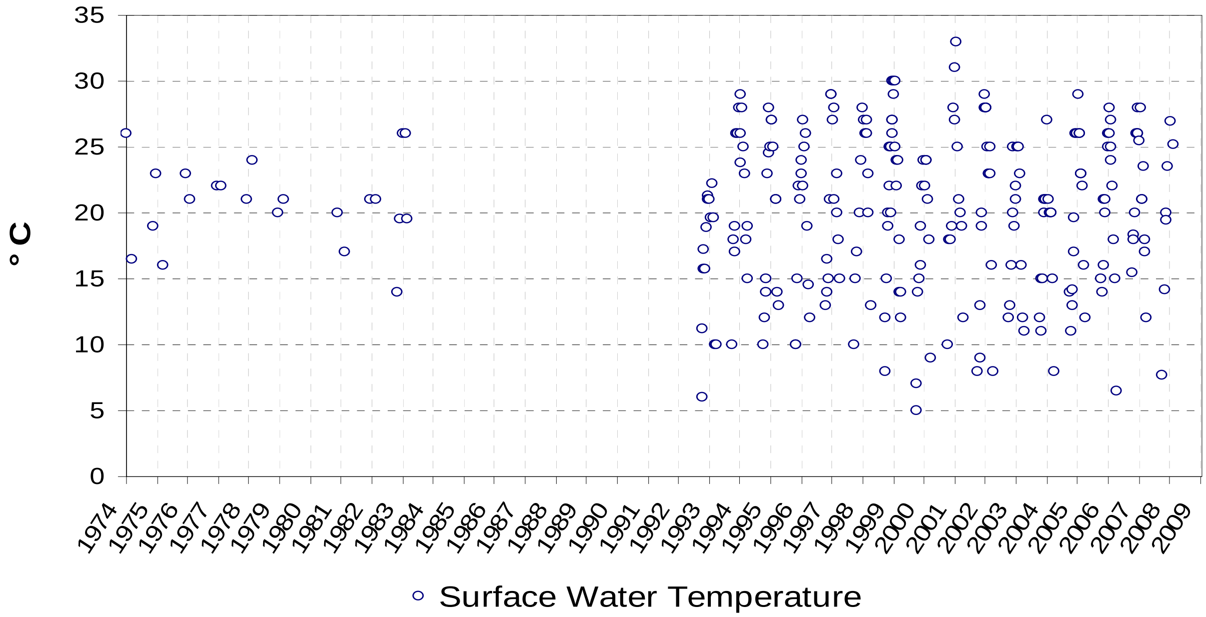
Figure 33. Chloride trends for Lake Peltier



Surface water temperatures

Given the shallowness of the lake, surface water temperature can have a major impact on water quality and ecology of the lake. For example, temperatures in excess of 20-21ºC help promote internal P recycling. Given the shallowness of Peltier and its lack of thermal stratification, these very warm temperatures often extend to the bottom of the lake (Figure 19 and 21). While temperature records for Peltier are rather scarce prior to 1993, the recent record suggests a high frequency of very warm temperatures (25°C or greater) as compared to the earlier data (Figure 35); however, given the paucity of historical data and the current analysis we are unable to discern whether there is any temporal trend in these data. Further analysis of this record for a specific time period (e.g. early June, late August, etc.) combined with air temperature data for a nearby weather station could be informative.

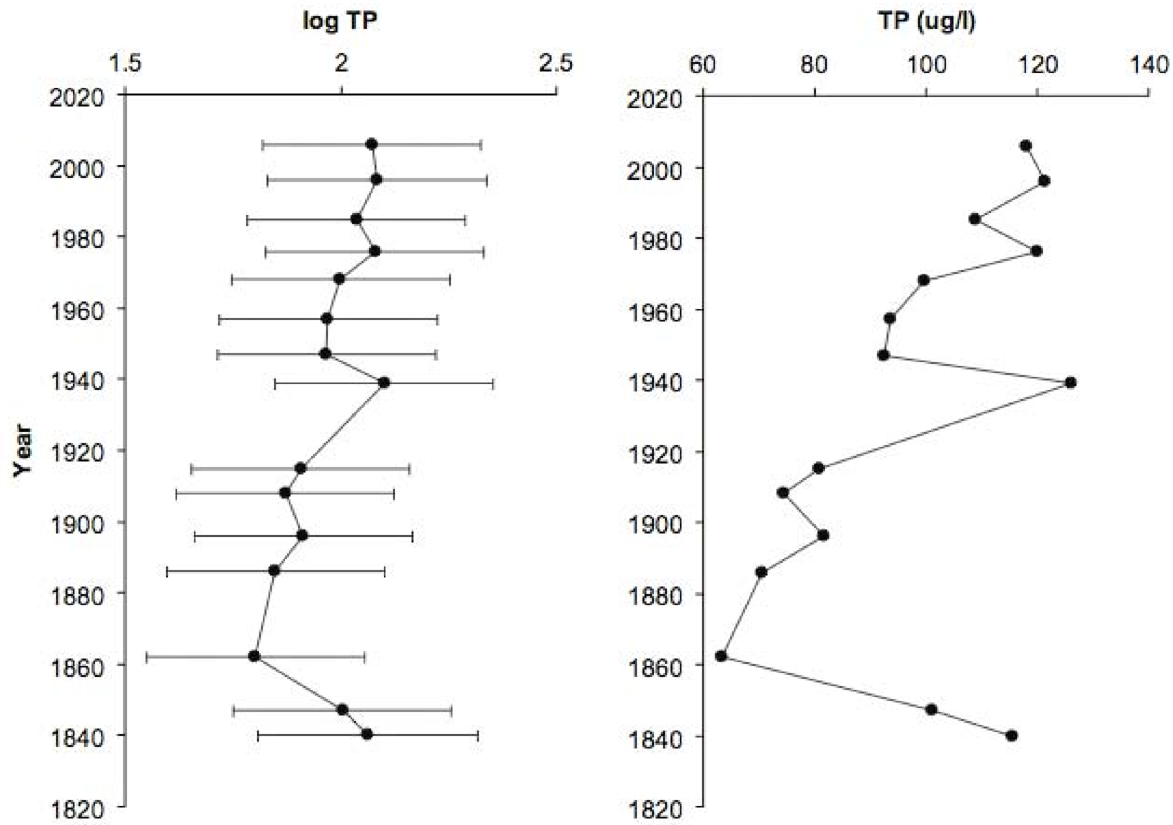
Figure 34. Peltier Lake surface water temperature trends



Sediment diatom reconstruction

In 2006, lake sediment cores were collected on Peltier Lake. These cores were later dated and analyzed for diatom- inferred phosphorus by the St. Croix Watershed Research Station (Figure 35). Analysis of fossilized diatoms showed Peltier Lake was a "eutrophic system during pre-European settlement, post-European settlement, pre-damming, and immediate post-damming with diatom-inferred" (Edlund and Ramstack 2007). Based on diatom reconstruction estimates of background TP in Peltier appears to be in the range of 60-80 µg/L.

Figure 35. Diatom-inferred historic phosphorus



Water Quality Modeling

As a part of the TMDL and other work on Peltier several response model were used to estimate water quality in Peltier Lake, including BATHTUB, P8 and Minnesota Lake Eutrophication Analysis Procedure (MINLEAP). MINLEAP is a simple model 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). The MINLEAP model predicted in-lake TP to be 82 µg/L, which is significantly lower than the 2009 summer mean of 204 µg/L. The model predicted Chl-a to be almost twice the observed concentration at 4 µg/L. Secchi depth was estimated at 0.9 m, which is less than observed.

The BATHTUB response model estimates in lake water quality based on lake characteristics and external loading. It estimated combined watershed load to Peltier Lake accounts for approximately 37% of the total load to the lake, while internal loading accounts for about 62% (Table 9). Atmospheric deposition (both wet and dry fall) on the surface of the lake is a relatively minor source based on the BATHTUB default rate of 0.27 ponds/acre-year (30 kg/km^2-year). This rate falls within the range of rates reported by Heiskary and Wilson (1994), 0.2 to 0.4 ponds/acre-year. Plugging phosphorus loading values (2.46 gram/m^2/year) into Janse's (1997) regime shift lake model, we see that Peltier is precariously close to a resilient turbid lake regime The TMDL implementation plan will describe steps for reducing both the excess external and internal loading as needed to achieve the TMDL.

Internal loading in lakes refers to the phosphorus load that originates in the bottom sediments and is released back into the water column. It can occur through various mechanisms several of which are common to Peltier:

- Anoxic or hypoxic DO in the overlying waters;
- High temperatures (>20-21 C) and/or elevated pH in the overlying water;
- Physical disturbance by bottom-feeding fish such as carp and bullhead. This is exacerbated in shallow lakes since bottom-feeding fish inhabit a greater portion of the lake bottom than in deeper lakes.
- Physical disturbance due to wind mixing. This is more common in shallow lakes than in deeper lakes. In shallower depths, wind energy can vertically mix the lake at numerous instances throughout the growing season.
- Decaying curlyleaf pondweed (*Potamogeton crispus*) can yield P and N as the plant decomposes. This is more common in shallow lakes since shallow lakes are more likely to have nuisance levels of curlyleaf pondweed.

More detail on modeling results as well as internal loading can be found in the 2009 TMDL report (Emmons and Olivier 2009)

Table 9. Phosphorus loading summary

Source	Phosphorus Load (lbs/growing season)	Percent Total
Watershed runoff (2001 modeled)	4,727	37%
Point sources	1	<1%
Internal loading	7,875	62%
Groundwater discharge (middle of range)	1	<1%
Atmospheric deposition	43	<1%
Total	*12,647*	

(Source Emmons and Olivier 2009*)*

Impairment Status

Peltier Lake was listed as an impaired water by the MPCA on the 2002 Impaired Waters List. The impaired use is aquatic recreation, with the stressor identified as nutrient/ eutrophication biological indicators.

MPCA lake TMDL protocol allows for setting site-specific standards and standards based on natural background conditions (Lake nutrient TMDL protocols and submittal requirements, MPCA March 2007). A natural background condition standard of 80 µg/L TP was requested for Peltier Lake based on a study that reconstructed historical environmental change in Peltier Lake using paleolimnological analysis (Table 10). The TMDL study and plan is scheduled to be completed in 2009 where improvement goals and plans well be specified. Based on the aforementioned analysis, large reductions in the external and internal load will be required for the lake to meet lake eutrophication water quality standards.

Table 10. Minnesota lake eutrophication standards, Peltier's current observed condition and estimated natural background.

Parameter	Eutrophication Standard. Deep	Eutrophication Standard, Shallow Lakes	Peltier Lake 1999-2008 Yearly Average	Proposed TP Natural Background Condition (µg/L)
TP (µg/L)	TP < 40	TP < 60	240	80
Chlorophyll-*a* (µg/L)	chl < 14	chl < 20	114	27
Secchi depth (m)	SD > 1.4	SD > 1.0	1.8	0.8

Summary and Recommendations

Peltier Island October 2008

Peltier is a disturbed shallow lake with very large watershed. Water quality and lake habitats are unstable and precariously close to a highly resilient impaired regime. Peltier has a long history of concerns including, rising water levels, excessive nutrient loading from the watershed, internal recycling of nutrients, high abundance of carp biomass, a history of winterkill, nuisance conditions of curly-leaf pondweed, and human disturbance of wildlife habitats. A recent sediment diatom-reconstruction study indicates it is much more eutrophic today than it was prior to the 1920s. Peltier's impaired water quality conditions will be difficult and expensive to reverse given current technologies, lake restoration practices, and other socio-economic pressures. Reducing both external and internal sources of nutrients will likely be an important focus of TMDL implementation plan. Successful reductions in nutrients and algal biomass that result in improved transparency should result in improvement to the lake's water quality and fishery, but could possibly exacerbate aquatic plant problems.

Climate change, in the form of shorter winters, longer growing seasons, and more variable precipitation is likely to decrease fish winterkill frequencies. This may benefit most fish populations and limit carp recruitment. However, climate change will also likely favor denser growth of curly-leaf pondweed that could further exacerbate water quality problems. These outcomes could have negative impacts on fish communities. Further, climate change will likely exacerbate the negative impacts of high nutrient loading from Peltier's watershed and other in-lake problems such as aquatic plant removal and bottom scouring from watercraft (Emmons and Olivier, 2009).

The most significant gains to the lake are likely to come from reduced watershed and internal nutrient loading. The TMDL implementation plan will address both sources. Continued monitoring efforts will be increasing critical to assess the effectives of lake improvement efforts that result from TMDL implementation.

References

Anderson, R.O., and R.M. Neumann 1996. Length, weight, and associated structural indices. Pages 447-482 in Fisheries Techniques, 2nd Edition. B.R. Murphy and D. W. Willis, Editors. American Fisheries Society, Bethesda, Maryland, USA.

Angermeier P.L. and J.R. Karr 1994, Biological integrity versus biological diversity as policy directives: protecting biotic resources. Bioscience, 44: 690-697.

Bajer, P. G., and P. W. Sorensen. 2009. Recruitment and abundance of an invasive fish, the common carp, is driven by its propensity to invade and reproduce in basins that experience winter-time hypoxia in interconnected lakes. Biological Invasions DOI 10.1007/s10530-009-9528-y (online – not yet in print)

Becker, G.C. 1983. Fishes of Wisconsin. The University of Wisconsin Press, Madison, Wisconsin.

Boxrucker, J., and E. Irwin. 2002. Challenges of crappie management continuing into the 21st century. North American Journal of Fisheries Management 22:1334-1339.

Bolduan, B.R., G.C. Van Eeckhout, H.W. Quade, and J.E. Gannon. 1994. Potamogeton crispus-the other invader. Lake and Reservoir Management 10:113-125.

Boylen, C. W., L. W. Eichler, and J. D. Madsen. 1999. Loss of native aquatic plant species in a community dominated by Eurasian watermilfoil. Hydrobiologia 415:207-211.

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

Carlson, R.E and K.E. Havens. 2005. Graphical methods fro the interpretation of relationships between trophic sate variables. Lake and Reserv. Manage. 21(1):107-118

Carpenter, S. R., D. Ludwig, and W. A. Brock. 1999. Management of eutrophication for lakes subject to potentially irreversible change. Ecological Applications 9:751-771.

Chiaudani, G. and M. Vighi, "The N:P Ratio and Tests with Selanastrum to Predict Eutrophication in Lakes", Water Research, Vol. 8, pp 1063-1069. 1974

Department of Natural Resources (MDNR) Natural Heritage Information System 2009. http://www.dnr.state.mn.us/eco/nhnrp/nhis.html (cited 15 Apr 2009).

Drake, M. T., and D. L. Pereira. 2002. Development of a fish-based index of biotic integrity for small inland lakes in central Minnesota. North American Journal of Fisheries Management 22:1105-1123.

Eddy, S. and J.C. Underhill 1974. Northern Fishes. The University of Minnesota Press, Minneapolis, MN.

Edlund, M. and J. Ramstack. 2007. Historical water quality and biological change in Peltier Lake, Anoka Co., MN. Science Museum of Minnesota Final Report submitted to the Rice Creek Watershed District. 19pp.

Egertson, C. J., and J. A. Downing. 2004. Relationship of fish catch and composition to water quality in a suite of agriculturally eutrophic lakes. Canadian Journal of Fisheries and Aquatic Sciences 61(9):1784-1796.

Emmons and Olivier Resources, Inc. 2009. Peltier Lake and Centerville Lake TMDL Report,. Prepared for the Minnesota Pollution Control Agency

Genkai-Kato, M., and S. R. Carpenter. 2005. Eutrophication due to phosphorus recycling in relation to lake morphometry, temperature, and macrophytes. Ecology 86(1):210-219.

Gorton, J.M. 2003. A creel survey of four Anoka county lakes managed for walleye. Minnesota Department of Natural Resources, Division of Fisheries. Completion Report, F-29-R(P)-22.

Gilbraith, D.M., M.J. Schwalbach, and C.R. Berry. 1988. Prelimanary Report on the Status of the Pallid Sturgeon, Scaphirhynchus albus, a candidate endangered species. Cooperative Fish and Wildlife Research Unit, U.S. Fish and Wildlife Service, Dept. of Wildlife and Fisheries Sciences, South Dakota State University, Brookings, South Dakota.

Hirsch J. 2009 Sentinel Lake Zooplankton Assessment, Minnesota Department of Natural Resources

Isaaks, E. H., and R. M. Srivastava. 1989. An introduction to applied geostatistics. Oxford University Press, New York.

Janse, J. H. 1997. A model of nutrient dynamics in shallow lakes in relation to multiple stable states. Hydrobiologia 342/343:1-8.

Johnson, S. L., and H. Stefan. 2006. Indicators of climate warming in Minnesota: lake ice covers and snow melt runoff. Climate Change 75:421-453.

Lathrop, R.C., S.B. Nehls, C.L. Brynildson, and K.R. Plass. 1992. The fishery of the Yahara lakes. Wisconsin Department of Natural Resources Technical Bulletin No. 181. 214pp.

Land use Projection Metropolitan Council's 2030 Regional Development Framework - Revised Forecasts, January 3, 2007

Madsen, J. D. 1998. Predicting invasion success of Eurasian watermilfoil. Journal of Aquatic Plant Management 36:28-32.

Madsen, J. D. 1999. Point intercept and line intercept methods for aquatic plant management. Army Corps of Engineers Waterways Experiment Station, MI-02, Vicksburg, MS.

McInerny, M.C., and T.K. Cross. 2005. An evaluation of mark-recapture estimates of black crappie population size determined by trap-netting during fall and spring in Minnesota lakes. North American Journal of Fisheries Management 25:475-490.

Minasny, B., McBratney, A.B., and Whelan, B.M. 2002. VESPER version 1.6. Australian Centre for Precision Agriculture, McMillan Building A05, The University of Sydney, NSW 2006.

Nürnberg, G.K. 2005. Quantification of internal phosphorus loading in polymictic lakes. *Verhandlungen Internationalen Vereinigung Limnologie (SIL)* 29: 623-626.

Omernik, J.M., 1987, Ecoregions of the conterminous United States (map supplement): Annals of the Association of American Geographers, v. 77, no. 1, p. 118-125, scale 1:7,500,000.

Parsons, B.G., and D.L. Pereira. 2001. Relationship between walleye stocking and year-class strength in three Minnesota lakes. Journal of Fisheries Management 21:801-808.

Pflieger, W.L. 1975. The Fishes of Missouri. Missouri Department of Conservation, Jefferson City, Missouri.

Pierce, R.B., C.M. Tomcko, and M.T. Negus. 2006. Interactions between stocked walleyes and native yellow perch in Lake Thirteen, Minnesota: a case history of percid community dynamics. North American Journal of Fisheries Management 26:97-107.

Scheffer, M., 1998. Ecology of Shallow Lakes. Chapman and Hall, London.

Scheffer, M., and S. R. Carpenter. 2003. Catastrophic regime shifts in ecosystems: linking theory to observation. Trends in Ecology and Evolution 18(12):648-656.

Scheffer, M., and E. H. van Nes. 2007. Shallow lakes theory revisited: various alternative regimes driven by climate, nutrients, depth and lake size. Hydrobiologia 584:455-466.

Schultz, B.E. 2008. A history of channel catfish stocking and effects of channel catfish stocking on black bullhead populations in southern Minnesota lakes. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries, Completion Report. F-29-R(P)-27, Study IV, Job 800.

Valley, R. D., M. T. Drake, and C. S. Anderson. 2005. Evaluation of alternative interpolation techniques for the mapping of remotely-sensed submersed vegetation abundance. Aquatic Botany 81(1):13-25.

Valley, R. D., T. K. Cross, and P. Radomski. 2004. The role of submersed aquatic vegetation as habitat for fish in Minnesota lakes, including the implications of non-native plant invasions and their management. Minnesota Department of Natural Resources, 160, St. Paul.

Valley, R. D., W. Crowell, C. H. Welling, and N. Proulx. 2006. Effects of a low-dose fluridone treatment on submersed aquatic vegetation in a eutrophic Minnesota lake dominated by Eurasian watermilfoil and coontail. Journal of Aquatic Plant Management 44:19-25.

Valley, R. D., and M. T. Drake. 2007. What does resilience of a clear-water state in lakes mean for the spatial heterogeneity of submersed macrophyte biovolume? Aquatic Botany 87:307-319.

Van Duyke, A. 2006. Conservation and restoration of a Great Blue Heron breeding colony in east central Minnesota. Master's Thesis. University of Minnesota, St. Paul. 125 pp.

Van Horssen, P. W., P. P. Shot, and A. Barendregt. 1999. A GIS-based plant prediction model for wetland ecosystems. Landscape Ecology 14:253-265.

Walter, C., McBratney, A.B., Douaoui, A., Minasny, B., 2001. Spatial prediction of topsoil salinity in the Chelif Valley, Algeria, using local ordinary kriging with local variograms versus whole-area variogram. Aust. J. Soil Res. 39, 259–272.