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Abbreviations

CAMP	Citizen-Assisted Monitoring Program
Chl-*a*	Chlorophyll-*a*
CMSCWD	Carnelian-Marine-St. Croix Watershed District
CWP	Clean Water Partnership
D. mendotae	*Daphnia mendotae*
D. pulicaria	*Daphnia pulicaria*
DNR	Minnesota Department of Natural Resources
EMWREP	East Metro Water Resource Education Program
EOR	Emmons & Olivier Resources, Inc
EQuIS	Environmental Quality Information System
LCCMR	Legislative-Citizen Commission on Minnesota Resources
MLCCS	Minnesota Land Cover Classification System
MPCA	Minnesota Pollution Control Agency
MWMO	Marine on St. Croix Watershed Management Organization
QA/QC	Quality Assurance/ Quality Control
QAPP	Quality Assurance Project Plan
SRP	Soluble Reactive Phosphorus
SWCD	Soil and Water Conservation District
TKN	Total Kjeldahl Nitrogen
TP	Total Phosphorus
QWTA	Quaternary Water Table Wells
WCD	Washington Conservation District

EXECUTIVE SUMMARY

1.1 Diagnostic Study

Square Lake (DNR Public Water #82-0046), located in May Township, is ranked in the top 1% for water clarity in the north central hardwood forest ecoregion of Minnesota and is located in the St. Croix River Basin within the Carnelian-Marine-St. Croix Watershed District (CMSCWD). Square Lake is of regional significance due to its very high water quality and unique recreational opportunities including trout fishing and scuba diving.

From the 1970s through approximately the early 1990s, water clarity in Square Lake averaged 7 meters (Figure 1). In the years since then, water clarity has been consistently declining and reached a low of 4.9 meters in 2008. Whereas water clarity declines in many MN lakes are linked to increasing amounts of phosphorus inputs from the landscape or from lake sediments, the water clarity trend in Square Lake does not fit this pattern. In-lake phosphorus concentrations have remained surprisingly consistent over the time period in which water transparency has declined (Figure 2).

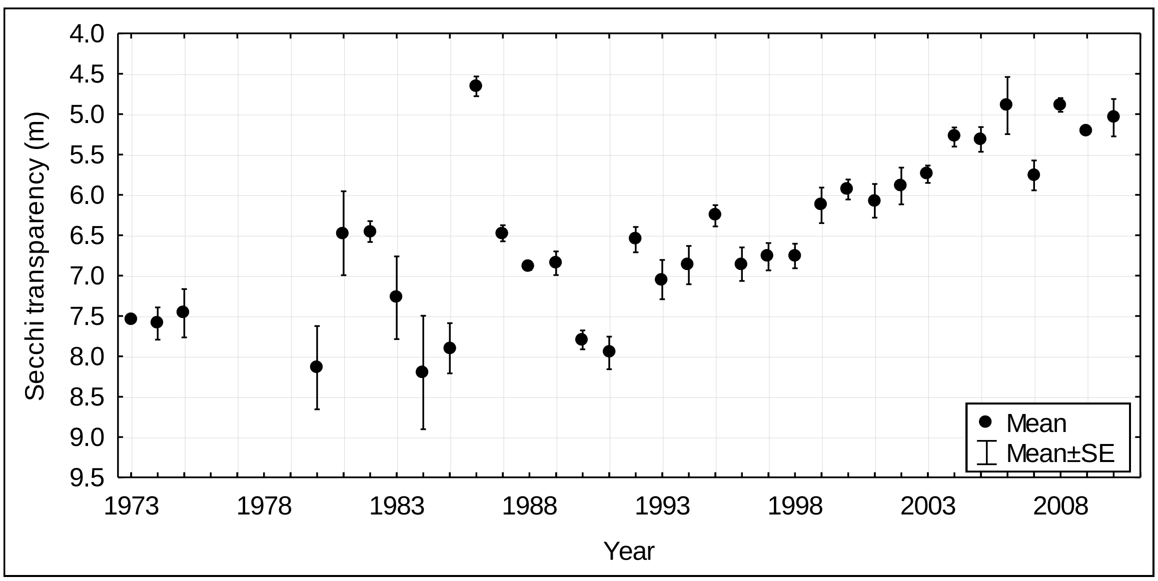


Figure 1. Water transparency in Square Lake, Jun-Sep means

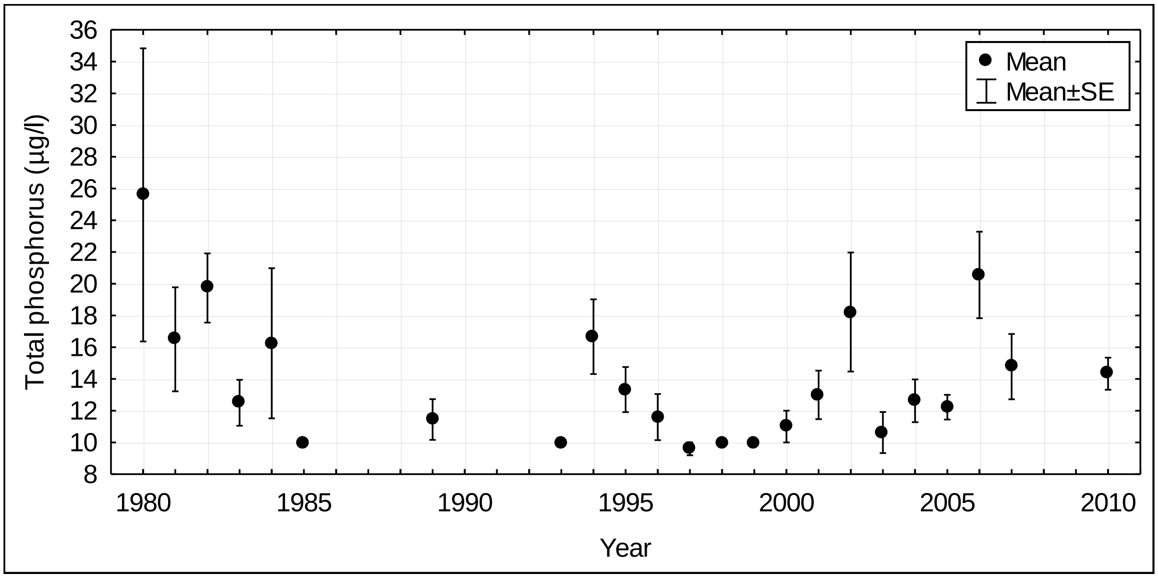


Figure 2. Phosphorus concentrations in Square Lake, Jun-Sep means

A 2002 Washington Conservation District (WCD) study funded by the Minnesota Pollution Control Agency's Clean Water Partnership (MPCA CWP) linked the water quality decline to the size of the *Daphnia pulicaria* population. *D. pulicaria* are large-bodied, algae-eating zooplankton that can substantially decrease algae concentrations and increase water clarity when they are abundant. *D. pulicaria* in 1998-1999 were smaller and less abundant than in 1982, and the CWP study suggested that the stocking of rainbow trout, which are known to be size-selective predators on *Daphnia*, may be responsible for the lower numbers of large-bodied *Daphnia*, increased levels of phytoplankton, and decreased clarity of Square Lake.

A study funded by the Environment and Natural Resources Trust Fund under recommendation by the Legislative-Citizen Commission on Minnesota Resources (LCCMR) was conducted during 2004-2005 (Hembre, 2006). Consistent with the findings of the 2002 CWP study, the LCCMR study also showed that surface water algae concentrations (measured as chlorophyll a) were lower and water clarity was greater when *D. pulicaria* were more abundant. In addition, it was found that rainbow trout preferentially feed on large-bodied *Daphnia*. However, trout predation could not account for the majority of *D. pulicaria* mortality.

The CMSCWD initiated a study in 2010, with funding again from the MPCA CWP program, to further investigate the link between *D. pulicaria*, its predators, and Square Lake's water clarity, and to investigate sources of phosphorus from the watershed and groundwater. The following are findings from this study:

Phosphorus loads

- Changes in the watershed have led to small increases in watershed phosphorus loading to Square Lake since the time of the 2002 diagnostic study.
- The phosphorus load from the Wilder wetland may not be as big a component of the overall phosphorus budget to Square Lake as previously thought. Based on the observation that the

wetland has not been negatively impacted by humans, phosphorus loads have likely not increased in recent years.

- Phosphorus concentrations in the groundwatershed of Square Lake are typical for the region and do not appear to be contributing to the decline in water quality in Square Lake.

In-lake ecological interactions

- Rainbow trout consume the most *D. pulicaria* per capita of any of the fish species examined in this study.
- Only relatively large (> 15 cm) bluegill sunfish consume *Daphnia*, and most of the *Daphnia* they consume are smaller-bodied species.
- None of the species of small fish (minnows, shiners, killifish) were found to consume *Daphnia*.
- *D. pulicaria* abundances declined to very low levels (< 0.5 per liter) by late July and they were less abundant in 2010 than in 2004-2005.
- Low oxygen levels in the deeper waters began to restrict the habitat space for *D. pulicaria* in early June and severely limited their 'refuge zone' later in the summer (Figure 3).

Based on these findings, it is hypothesized that an interaction between the earlier onset of summer stratification (due to climate change; see DNR (2011) for a discussion about projected impacts of climate change on lake stratification) and predation on *D. pulicaria* by rainbow trout during winter-early summer is responsible for the marked decline in the water clarity of Square Lake (Figure 3).

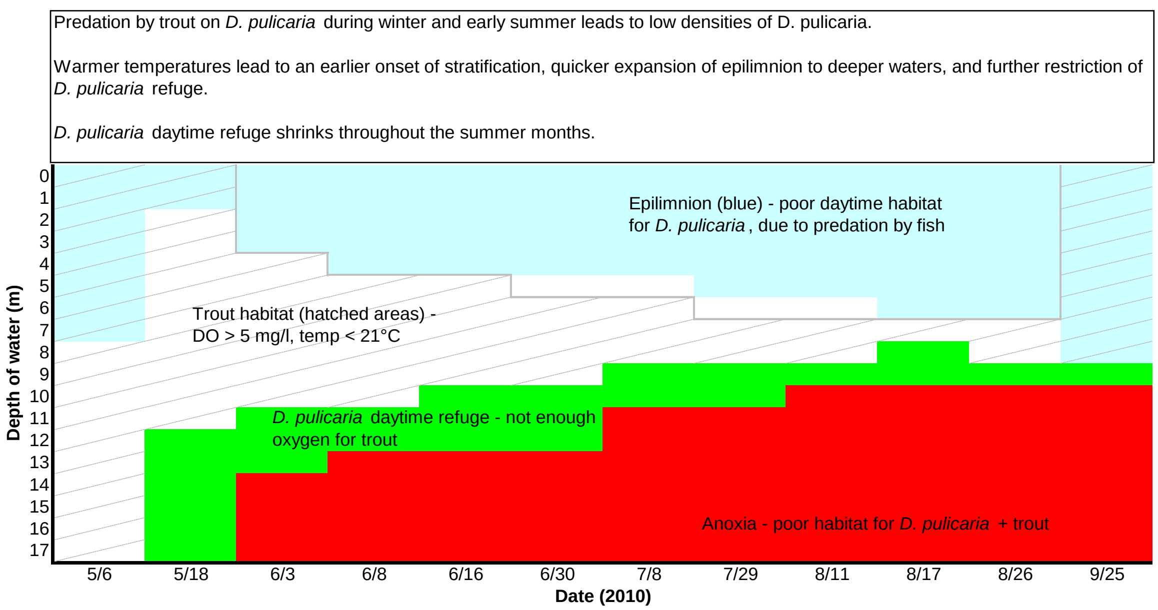


Figure 3. Representation of shrinking *D. pulicaria* daytime refuge

1.2 Implementation Plan

To meet the resource water quality goal of improving long term Secchi transparency in Square Lake to an average of 7 meters (23 feet), the following strategies will be used:

1. Increase *Daphnia pulicaria* densities through either decreasing predation pressure and/or improving habitat.
2. Maintain or decrease existing phosphorus loads to buffer the lake against potential eutrophication.

The highest priority implementation activities identified in this implementation plan are a three-year stocking suspension of rainbow trout in Square Lake to evaluate whether stocking suspension results in an increase in *Daphnia pulicaria* density and water clarity of the lake, and continued in-lake water quality monitoring. Additional priority implementation activities that maintain or decrease the total phosphorus load to Square Lake include septic system pumping and upgrades to reduce phosphorus loading from groundwater; and shoreline buffers, rain gardens, and lawn management activities to reduce phosphorus loading from surface water runoff.

2 INTRODUCTION AND PROJECT BACKGROUND

2.1 History of the Lake and Project Area

The Carnelian-Marine-St Croix Watershed District (CMSCWD) is located in northern Washington County (Figure 4). The majority of the watershed ultimately drains to the St. Croix River. The portion of the watershed that does not drain to the St. Croix River is landlocked. The overall watershed is approximately 81.4 square miles (52,100 acres) in size. The watershed landscape is characterized generally from west to east by hilly topography associated with the St. Croix Moraine and till deposits, a large outwash plain with very sandy soils, and bluffs and terraces associated with the historic St. Croix River.

Square Lake (DNR Public Water #82-0046), located in May Township, is ranked in the top 1% for water clarity in the north central hardwood forest ecoregion of Minnesota and is located in the St. Croix River Basin within the CMSCWD. Square Lake provides regional recreation opportunities as a place for swimming (public beach at the east end of the lake), fishing (including fishing for rainbow trout that are stocked by the MN Department of Natural Resources [DNR]), scuba diving, and canoeing. The lake is of regional significance due to its very high water quality and unique recreational opportunities including trout fishing and scuba diving.

Square Lake and its subwatersheds are shown in Figure 4. Land cover within the Square Lake watershed is divided relatively evenly among forest and woodland (36%), planted or cultivated vegetation (30%), and artificial surfaces and associated areas (31%, see Figure 7). Square Lake Regional Park, a popular Washington County park, is located along the east side of the lake. In addition, the Wilder Forest is located on the western side of lake. These properties account for most of the late-successional vegetation (forest) throughout the watershed. A natural resource inventory was conducted in 2001 by the watershed organization and identified an extensive area of high quality oak forest, high quality shrub swamp, and four documented rare features within the lake's landscape unit. The landscape unit including Square Lake received a high ranking for all categories including ecological, wildlife habitat, and rare features potential.

2.1.1 Known and Potential Water Quality Problems

Square Lake, one of the clearest metropolitan area lakes, is currently meeting its beneficial use of aquatic recreation. While water quality is overall excellent in the lake, mean Secchi transparency dropped from an average of 7 meters in 1993 to 5 meters in 2008. An increase in chlorophyll-*a* concentrations generally corresponding with decreased clarity has been observed, whereas total phosphorus concentrations have remained essentially unchanged in the data record.

2.1.2 History of fisheries management

Before 1974, the lake was managed to support warm-water gamefish and various species (sunfish, crappie, smallmouth bass, lake trout, walleye, and northern pike) were stocked. In 1974 management was switched to a two-story strategy, with both trout and warm-water gamefish being managed. The non-native rainbow trout are now the primary species managed, with 3,000 yearlings stocked every spring and 2,000 yearlings stocked every fall. Surplus brood fish had been stocked prior to 1998, but stocking was suspended due to concerns about water clarity degradation caused by the presence of trout.

Efforts in the 1980s were conducted to reduce the population of northern pike, presumably due to concerns regarding predation by northern pike on rainbow trout.

Starting in 1990, the release of all trout and salmon from mid-May to early June was required, in an effort to spread out the rainbow trout harvest, with harvest limited to two trout for the remainder of the year. Beginning in 1998, the regulation with respect to salmon was removed, and trout harvest was closed during October. Catch and release angling is allowed in October.

2.1.3 Related Plans and Studies

Square Lake Clean Water Partnership Project: Diagnostic Feasibility Study and Implementation Plan, 2002

A Clean Water Partnership (CWP) Diagnostic Study (MWMO, 2002; hereafter referred to as the “2002 diagnostic study”) investigated potential causes for the trend in declining water clarity. The study estimated the phosphorus budget of watershed load to Square Lake as 12% originating from the atmosphere, 18% from surface water, and 70% from groundwater. The study did not find strong evidence that nutrient loading was responsible for the increased levels of phytoplankton (measured as Chl-*a*) and decreased water clarity in Square Lake. Instead, the size of the lake's *Daphnia pulicaria* population was identified as the main predictor of algal abundance and water clarity. *Daphnia pulicaria* are large-bodied, herbivorous (algae-eating) zooplankton that can substantially decrease algae concentrations and increase water clarity when they are abundant (e.g., Shapiro and Wright, 1984; Carpenter et al., 1987; Hembre and Megard, 2005). Compared to data from 1982 (Osgood, 1982), *D. pulicaria* in 1998-1999 were markedly less abundant and had a smaller body size (MWMO, 2002). This 2002 diagnostic study suggested that the stocking of rainbow trout, which are known to be size-selective predators on *Daphnia* (Geist et al., 1993; Wang et al., 1996; Hembre and Megard, 2005), may be responsible for the decreased levels of large-bodied *Daphnia*, increased levels of phytoplankton, and decreased clarity of Square Lake.

Maintaining zooplankton (*Daphnia*) for water quality: Square Lake; Final report of 2003-2005 study funded by the Environment and Natural Resources Trust Fund

To investigate the impact of rainbow trout predation on *D. pulicaria* population dynamics and the water quality of Square Lake, a study funded by the Legislative-Citizen Commission on Minnesota Resources (LCCMR) was conducted during 2004-2005 (Hembre, 2006). Consistent with the findings of the 2002 CWP study, the LCCMR study also showed that Chl-*a* concentrations were lower and water clarity was greater when *D. pulicaria* were more abundant. In addition, stomach content analyses done for that study showed that rainbow trout preferentially feed on large-bodied *Daphnia*. However, a demographic analysis of the *D. pulicaria* population indicated that trout predation could not account for the majority of *D. pulicaria* mortality. The study results did not identify the other sources of mortality, but listed possibilities such as predation by other fish species (e.g., sunfish), predation by invertebrates (e.g., the phantom midge larva *Chaoborus*), or disease.

The study also identified dense populations of *Chaoborus*, common predators of *Daphnia*, through the use of high frequency sonar. Similar to *Daphnia* and other planktonic invertebrates, *Chaoborus* (commonly referred to as the "phantom midge") also migrate vertically to surface waters at night, using the deeper waters during the day as a refuge from zooplanktivorous fish.

A recommendation of that report was that future research should be done to more holistically quantify predation on *Daphnia* by rainbow trout and other potential predators (such as other zooplanktivorous fish and *Chaoborus* larvae).

DNR Lake Management Plan

The Department of Natural Resources (DNR) Lake Management Plan for Square Lake contains the following goals and plans:

- Long Range Goal: Maintain a two-story management program that provides a put-grow-take rainbow trout fishery and a bluegill PSD (proportional stock density) of 40-50 and RSD7 (relative stock density at the 7-inch category) of 20-30.
- Operational Plan:
  1) Stock 2,400 yearling rainbow trout annually in the spring.
  2) Stock 1,600 yearling rainbow trout annually in the fall.
  3) Protect and enhance water through the environmental review, DOW review and Watershed District Project input processes.
  4) Population assessment in 2014, resurvey in 2020.
- Mid-Range Goal: Maintain a two-story management program that provides a put-grow-take rainbow trout fishery and bluegill trap net catch per unit effort at or above 50% quartiles for lake class 23.
- Potential Plan:
  1) Reconsider stocking surplus adult rainbow trout brood fish
  2) Creel or recreational use survey
  3) Install an additional fishing pier
  4) Implement special regulation to reduce harvest of large bluegill

The lake management plan discusses the history of declining water transparency in Square Lake and the likelihood that the declines are related to imbalances in the lake's food web, most probably from the decline of *Daphnia pulicaria*, the primary algae-consuming zooplankton in Square Lake. Declines in *D. pulicaria* could be due to 1) a reduction in habitat, 2) predation by fish such as bluegill or rainbow trout, or 3) predation by zooplankton such as *Chaoborus* spp.
DNR fisheries managers have disputed the suggestion that rainbow trout have caused the decline in *D. pulicaria* densities, considering that rainbow trout are in the lake for a short period of time and that fish stomach contents show a preference toward aquatic macroinvertebrates[1]. The plan

[1] The LCCMR study (Hembre, 2006) found macroinvertebrates (*Chaoborus* and Chironomid midges) in rainbow trout stomachs in moderate amounts, but did not find that rainbow trout consume macroinvertebrates preferentially to *Daphnia*.

states that fisheries managers will continue to review studies and adjust fish management strategies if rainbow trout are found to negatively impact water clarity in Square Lake.

Biotic integrity of Square Lake

In 1997, the biotic integrity of the fish community in Square Lake was scored at 87 (Drake and Pereira, 2002). This is high relative to other Twin Cities metropolitan area lakes, but lower than average for other lakes with similar productivity as Square Lake.

Movement patterns and habitat use of three declining littoral fish species in a north-temperate mesotrophic lake

A study by Valley et al. (2010) investigated movement patterns of the blackchin shiner (*Notropis Heterodon*), blacknose shiner (*Notropis heterolepis*), and banded killifish (*Fundulus diaphanus*). These three species are intolerant to eutrophication and were found to inhabit shallow zones of Square Lake with macrophyte biovolume greater than 20% and with a high probability of occurrence of *Chara*. The macrophytes and *Chara* serve as habitat for the fish and their prey. The authors conclude that protection of macrophytes and *Chara* in lake littoral zones may be needed to conserve the blackchin shiner, blacknose shiner, and banded killifish

What does resilience of a clear-water state in lakes mean for the spatial heterogeneity of submersed macrophyte biovolume

A study by Valley and Drake (2007) investigated variability in spatial heterogeneity of submersed aquatic macrophtyes in four MN lakes. Square Lake was one of the lakes studied and had the highest water transparency of the four. In Square Lake, macrophytes grew over a large range of depths, and the spatial pattern of macrophyte growth in the littoral zone was similar in the six surveys completed for the study. Depth of macrophyte growth and spatial patterns in the more turbid lakes in the study varied greatly among the surveys. The authors conclude that factors that increase a lake's productivity and weaken its resilience may lead to unstable spatial patterns of macrophyte biovolume.

Largemouth bass assessment

A nighttime electrofishing survey indicated a high abundance of small largemouth bass in Square Lake. The density of these fish was above the third quartile for other lakes in Square Lake's class, and the median length of the fish was below the third quartile.

Carnelian-Marine-St. Croix Watershed District 2010 Watershed Management Plan

The CMSCWD 2010 Watershed Management Plan (CMSCWD 2010) was developed to guide management of the District's water resources through the year 2020. The document includes assessment of the lakes, streams, and wetlands of the District and an implementation program based on objectives, policies, and resource management plans. An individual watershed management plan was developed for the Square Lake Watershed.

Integrating Groundwater and Surface Water Management – Northern Washington County

The Stewardship Plan is a companion to *Integrating Groundwater and Surface Water Management in Northern Washington County* (EOR, 2003), which evaluated groundwater-surface water interaction and prescribed management recommendations for groundwater resources. The plan assesses twenty of the major creeks that flow into the St. Croix River from the north boundary of the City of Stillwater to the northern boundary of Washington County along the Minnesota side of the river. Each of the twenty streams was evaluated seasonally for two years. Parameters assessed include: hydrology, geomorphology, water quality and chemistry, macroinvertebrates, fisheries and riparian plant communities. Groundwater discharge areas supporting ground-water dependent plant communities were identified, evaluated, and mapped. Using this data, streams were classified into one of four Stream Comparison Domains:

1. Surface water-fed streams
2. Groundwater-fed streams with large watersheds
3. Groundwater-fed streams with small watersheds
4. Groundwater-fed streams, urban land uses

Results of two years of monitoring and data collection show that the spring creeks and associated groundwater-dependent natural resources are among the most diverse and unique ecosystems in the Twin Cities region. Over half the streams evaluated contain self-sustaining populations of brook trout and several contain new or undocumented (for Minnesota) taxa of macroinvertebrates.

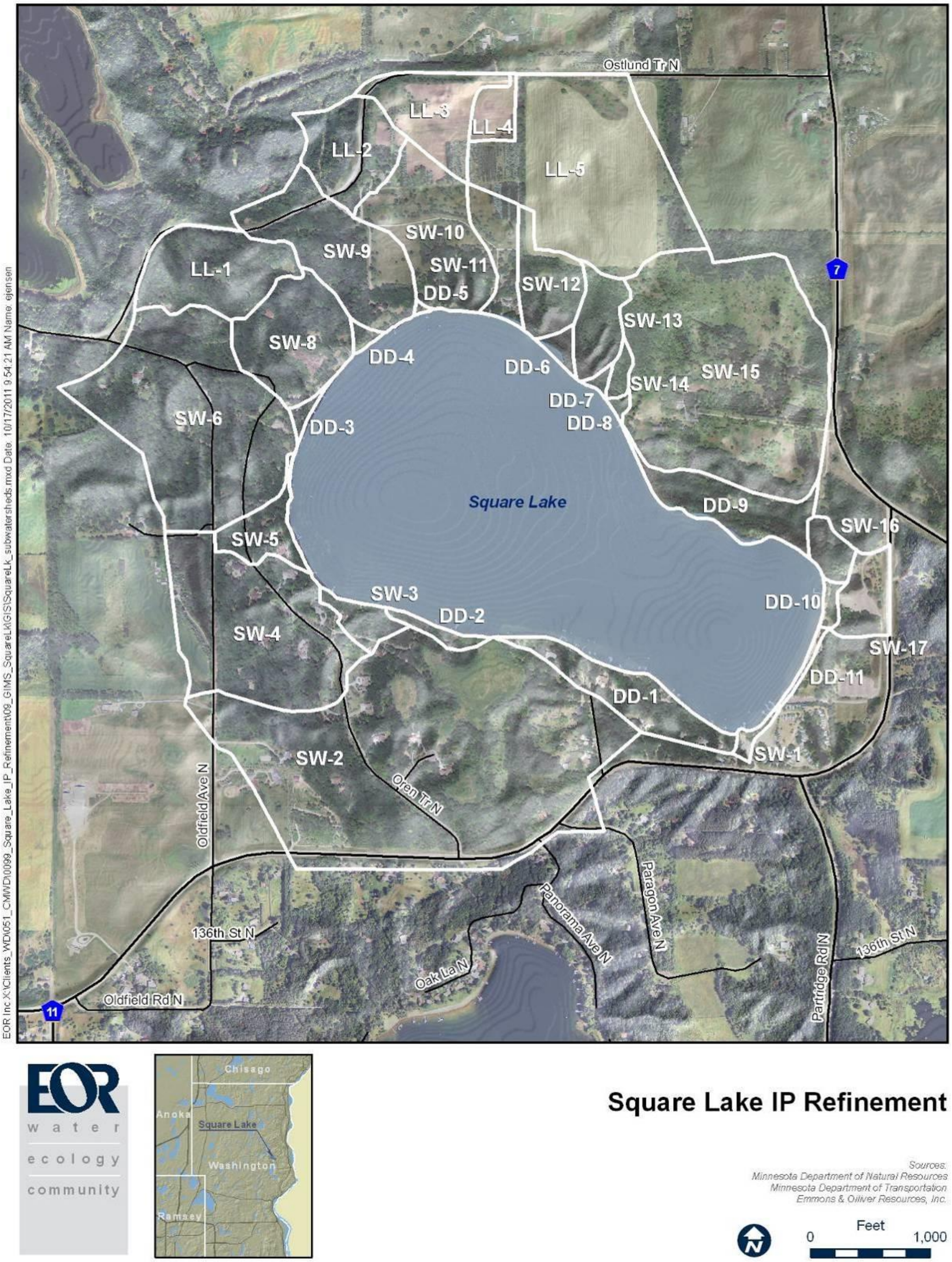


Figure 4. Square Lake Watershed and subwatershed boundaries.

2.2 Project Purpose

Prior to the 2002 diagnostic study and since it was completed, the clarity in Square Lake has steadily decreased. Many of the implementation activities identified in the 2002 diagnostic study have the potential to protect Square Lake; however, additional information and further study is required to determine which specific actions are necessary.

The CMSCWD recently completed their 2010 Overall Watershed Management Plan, which identifies short and long term goals for water quality. The plan identifies Square Lake as needing "Focused Watershed Management" due to its declining water quality, which is the highest priority focus of the watershed. The "Focused Watershed Management" designation will be used to effectively allocate watershed funding and activities to the Square Lake watershed. This project begins to identify specifically where that funding should go.

In addition, this project updates the results of the 2002 diagnostic study, identifies changes in the lake since 2002, and turns the implementation ideas previously developed into site-specific and action-specific activities to protect the water quality of Square Lake. The outcomes of this project serve as an example of monitoring and evaluation needed to determine protection measures for a high quality lake influenced heavily by groundwater inputs and in-lake dynamics among algae, zooplankton, and fish.

The following are the specific goals of the diagnostic study:

1) Evaluate the watershed of Square Lake to determine if substantial changes in watershed phosphorus loading have occurred since the 2002 diagnostic study.
2) Evaluate the groundwatershed of Square Lake to determine if phosphorus loads from groundwater are a cause of the decline in transparency in Square Lake.
3) Gather environmental and water quality data to compare with historical data from Square Lake and evaluate trends in the lake's water quality.
4) Evaluate the diets of an array of predators to determine which are the most significant consumers of large-bodied *Daphnia* (*D. pulicaria*).
5) Assess the structure of the zooplankton community using conventional (plankton net) and high-frequency sonar sampling to compare to previous studies of Square Lake.

2.3 Project Partners

As the project sponsor, the CMSCWD used their staff and consultants [Emmons & Olivier Resources, Inc. (EOR), Washington Conservation District (WCD), Leif Hembre of the Biology Department at Hamline University, East Metro Water Resource Education Program (EMWREP)] to conduct data analysis, coordination of public input and goal setting, diagnostic study and implementation plan development, and project administration. EOR conducted data analysis and diagnostic study and implementation plan development. Leif Hembre oversaw the in-lake biology component for the diagnostic study. Staff from the WCD conducted monitoring. Staff from EMWREP facilitated the stakeholder involvement process.

2.4 Public Participation

An initial stakeholder meeting for this diagnostic study and implementation plan was held on August 18, 2010. This meeting served to introduce the project to residents, review Square Lake data, and discuss the community's concerns. Meeting attendees included lakeshore residents, lake association members, and project team staff from the WCD, Hamline University, EOR, and CMSCWD. The meeting included a summary of the diagnostic study and implementation process, discussion on the water quality in the lake, and discussion on the issues and goals for each lake. Thirteen stakeholders attended the meeting.

A second stakeholder meeting was held on March 26, 2012 to present the results of the diagnostic study and the approach to restoration, and to solicit input from the public regarding their support of a temporary suspension of trout stocking in the lake (see Section 4: Implementation Plan).

2.5 Project Costs

Table 1. Project costs broken down by program element

Program Element	Description	Grant	Cash	In-Kind	Total
1	Project Work Plan	$3,507	$3,510	--	$7,017
2	Data Collection	$17,358	$18,129	--	$35,487
3	Analysis of Data	$6,350	$7,356	--	$13,706
4	Stakeholder Input and Goal Setting	$5,344	$2,027	$1,336	$8,707
5	Evaluate Management & Protection Options	$3,454	$3,008	--	$6,462
6	Diagnostic Study Final Report Sections	$5,229	$6,300	--	$11,529
7	Update Implementation Plan	$6,228	$4,952	--	$11,180
8	Final Report Preparation	$3,492	$4,280	--	$7,772
9	Project Administration	$2,184	$3,571	$675	$6,180
Total Costs:		**$53,145**	**$53,132**	**$2,011**	**$108,288**

2.6 Project Milestones

Table 2. Table of project milestones, organized by program element and task

Program Element & Task	2010										2011												2012												2013					
	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J
1 - Project Work Plan	→	→																																						
2 - Data Collection																																								
a. In-lake data collection			→	→	→	→	→	→																→	→	→	→	→	→	→	→									
b. Watershed data collection			→	→	→	→	→	→																																
c. Groundwater monitoring			→	→	→	→	→	→	→	→	→	→	→	→	→																									
3 - Analysis of Data																																								
a. Evaluate water quality and biological data														→	→	→	→	→	→	→	→	→																		
b. Watershed evaluation				→	→	→	→	→	→	→	→	→																												
c. Groundwater data analysis														→	→	→																								
4 - Stakeholder Input and Goal Setting (meetings indicated)						X																			X							X								
5 - Evaluate management and protection options																																								
a. Identify implementation and management options																→	→	→	→	→	→	→	→	→	→	→	→	→												
b. Meetings with DNR and agencies																		→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→						
c. Prioritize implementation options																								→	→	→	→	→												
6 - Diagnostic Study Final Report Sections																																								
a. Methods and results												→	→	→	→	→	→	→	→	→	→	→																		
b. Methods and results review																							→	→																
c. Discussion and conclusions																						→	→	→																
7 - Update Implementation Plan																																								
a. Implementation alternatives analysis and selection																			→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→						
b. Implementation program development																											→	→	→	→	→	→	→	→	→					
c. Final report - implementation plan																														→	→	→	→	→	→	→	→	→	→	→
8 - Final Report Preparation																															→	→	→	→	→	→	→	→	→	→
9 - Project Administration	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→

3 DIAGNOSTIC STUDY

3.1 Methods

3.1.1 Data Collection

In-lake monitoring included chemistry, macrophytes, plankton, fish, and an evaluation of the lakeshore environment. Groundwater and wetland monitoring was also conducted. Data collection methods are organized by the project goals (see Section 2.2).

Goal 1: Evaluate the watershed of Square Lake to determine if substantial changes in watershed phosphorus loading have occurred since the 2002 diagnostic study.

Watershed assessment

The 2002 Square Lake Diagnostic Feasibility Study entailed a complete watershed assessment to inform implementation planning for management of watershed phosphorus loading to Square Lake. The study identified land use, land cover, septic system data (where available), soil erosivity, gully erosion, and animal operations in the watershed. Climatic data (precipitation, evaporation, atmospheric phosphorus loading) were also assessed. A complete description of methods and results can be found in the study (MWMO et al., 2002).

A watershed evaluation was conducted for this study in order to update, as necessary, findings from the 2002 watershed evaluation. Those data assessed include land use, land cover, septic systems (housing types and quantities), animal operations, gully erosion, and stormwater ponds. A field visit also informed this update to the watershed evaluation.

2005 land use data were obtained from the Metropolitan Council. Land cover data consisted of 2008 Minnesota Land Cover Classification System (MLCCS) data. Septic system data were collected based on an analysis of new homes and home types (based on parcel data) since the 2002 diagnostic study. Animal operations data were provided by the WCD and from a MPCA feedlot database. The field visit served to corroborate findings from these sources. The field visit was also conducted to identify the status of completed gully erosion projects, any new gully erosion problem areas, and stormwater ponding areas. Where changes in the watershed dictated updated phosphorus loading calculations, methodologies used in the 2002 diagnostic study were followed (MWMO et al., 2002).

Wetland

To evaluate the flow and phosphorus concentrations from the Wilder wetland (located in SW-8, see Figure 44) to Square Lake, discharge and phosphorus concentrations were monitored.

Surface flow leaving the wetland was quantified using a Global Water WL-16 continuous recording level pressure transducer and a Rickly Hydrological Company collapsible cutthroat flume. The flume was installed per the manufacturer’s recommendations and was verified to be level during monthly downloading events. The monitoring station was situated in an ice ridge, approximately twenty feet west of Square Lake, where the wetland run out is channelized. The ice ridges appeared to consist predominantly of coarse granular materials such as sand and gravel. It is likely that a portion of the discharge impounded by the flume structure circumvented the flume structure through the coarse grained substrate in the surrounding ice ridges. Sodium bentonite clay was poured underneath the flume and where the flume wings tied into the channel to help prevent water undermining or circumventing the flume.

Monitoring occurred from May 28 to November 15, 2010 (172 days). Flume level was recorded with a 15 minute frequency. Volumetric flow was determined using a rating curve developed from the manufacturers level/discharge table developed for the flume. Level accuracy and data downloading occurred at minimum monthly.

Phosphorus concentrations discharging to Square Lake from the Wilder Forest wetland complex were monitored. Wetland surface water grab samples were collected in the run out channel west of the lake's shoreline. A synchronous site specific groundwater investigation in the Wilder Forest wetland consisted of collecting pore water samples from a static sampling point within the wetland. Samples were extracted using a bailer following extracting a minimum of three volumes of pore water. In total, twelve paired pore water samples and wetland surface water run out samples were collected throughout the growing season in the Wilder Forest wetland to characterize the impact of the wetland on the water quality of Square Lake. Three additional samples were collected for QA/QC. Samples were timed to capture different flow conditions.

All pore water samples were analyzed for total phosphorus (TP), soluble reactive phosphorus (SRP), and nitrate plus nitrite; with total dissolved phosphorus added to a small subset of Wilder Forest pore water samples. Surface water "run-out" samples were analyzed for TP, SRP, total Kjeldahl nitrogen (TKN), and nitrate plus nitrite. Laboratory analyses were completed by RMB Environmental Laboratories, Inc. Sample results from the wetland run out were submitted to EQuIS.

Lakeshore environment

The shoreline was evaluated to identify erosion and sedimentation issues and any activities that may be contributing to pollutant loadings to the lake or decreased clarity.

A qualitative shoreline survey was conducted using two steps. The first step was a remote analysis of shoreline buffer vegetation. Data were viewed and analyzed using spatial tools in ArcGIS. Recent aerial photography was viewed to determine the width and delineation of shoreline vegetation or lack thereof. Using ArcGIS, a boundary around the entire shoreline was then created. Within this shoreline buffer, vegetation was delineated according to type and width. These spatial data were then used in the field to further verify vegetation type and width.

The entire shoreline was surveyed from the water using a boat and a GeoXT handheld GPS. The buffer shapefile was loaded into the GPS and was used to locate buffer boundaries along the shoreline. Any discrepancies between the actual buffer and the buffer shapefile were marked on an aerial photo that contained the original buffer boundaries. Any erosion locations were surveyed with the handheld GPS and were photographed.

Goal 2: Evaluate the groundwatershed of Square Lake to determine if phosphorus loads from groundwater are a cause of the decline in transparency in Square Lake.

Groundwater

Groundwater phosphorus concentrations were investigated through sampling of two private residential wells set in the Quaternary Water Table Aquifer upgradient of Square Lake and through site specific investigations in the vicinity of the Wilder Forest wetland. Groundwater sampling of the upgradient private wells was planned to take place quarterly; however, difficulty with receiving permission from landowners resulted in a less robust sampling frequency. One private residential well, unique well # 199502, was sampled in July 2010 and again in May 2011. The other private residential well, unique well # 142303 was only sampled once in July 2010. Groundwater collection at unique well # 199502 consisted of collecting samples from an unconditioned outdoor spigot. Samples were collected following stabilization of parameters monitored through a flow through cell. Groundwater collection at unique well # 142303 consisted of filling the sample bottles in an unconditioned indoor sink. Due to the occupant's uneasiness with allowing strangers to enter the home, parameters were not monitored through the flow through cell prior to sample collection. Samples were analyzed for total phosphorus (TP), soluble reactive phosphorus (SRP), and nitrate plus nitrite. Laboratory analyses were completed by RMB Environmental Laboratories, Inc. One additional groundwater sample was collected for QA/QC.

Goal 3: Gather environmental and water quality data to compare with historical data from Square Lake and evaluate trends in the lake's water quality.

Lake water quality

Square Lake continued to undergo routine in-lake water quality monitoring through the Metropolitan Council's citizen-assisted monitoring program (CAMP) administered by the WCD. Water quality sampling was conducted for two growing seasons to supplement the available water quality data. Parameters included TP, TKN, chlorophyll-*a*, and Secchi depth. Fourteen samples were collected during each of the 2010 and 2011 field seasons (two samples per month, April through October). Data were entered into EQuIS following appropriate quality control procedures.

In addition to the CAMP monitoring, Secchi transparency and vertical profiles of temperature and oxygen were collected at the central sampling site (Figure 5) on each of the nine zooplankton sampling dates. Temperature and dissolved oxygen were measured at 1-m intervals with a YSI© 55 dissolved oxygen meter. Supplemental Secchi depth data were collected on several other dates by research assistants (Dan Carlson and Tim Olson) from Hamline University when they were angling to collect zooplanktivorous fish for diet analyses.

Macrophytes

An aquatic vegetation survey was conducted to survey the species and density of aquatic plants within Square Lake. The survey was conducted using the point intercept method (Madsen, 1999) where the plant species and density were recorded at each site. The survey data were summarized by dominant aquatic vegetation communities.

Goal 4: Evaluate the diets of an array of predators to determine which are the most significant consumers of large-bodied *Daphnia* (*D. pulicaria*).

Two types of zooplankton predators were examined: 1) zooplanktivorous fish (e.g., trout, bluegill sunfish, yellow perch, minnows) and 2) larvae of the phantom midge (*Chaoborus*).

Fish

Zooplanktivorous fish diets were assessed through gut content analysis. Samples were obtained in two ways:

1) Larger zooplanktivorous fish (e.g., rainbow trout, bluegill sunfish, crappie, and yellow perch) were obtained by angling on several days per week from late May to mid-August 2010 (see Table 18 in *Appendix A: Monitoring Results: Biology* for specific dates). The stomach contents of these fish were collected by gastric lavage (Hartleb and Moring, 1995) and analyzed in the lab to determine what proportion of their diet is made up of large-bodied *Daphnia*. To perform the gastric lavage technique, water from a syringe fitted with flexible plastic tubing is forced into the upper digestive tract of the fish, prompting the fish to regurgitate its stomach contents. The stomach contents are then collected in a tray and washed into a specimen jar. All fish sampled in this manner were released after the gastric lavage sample was collected. Samples were preserved in 70% ethanol in the field and were later examined under a stereo-microscope in the lab (at Hamline University).

2) Smaller fish (not able to be captured by angling) were collected monthly (May through August) from near-shore areas by seining. These fish surveys were performed by Dr. Philip Cochran of St. Mary’s University. Preserved samples of these fish were provided for gut content analysis (via dissection). The following describes the seining approach:

   Square Lake was seined for fish once a month in 2010 (May 18, June 8, July 6, and August 19) for a total of four months and all permits for sampling and seining were secured prior to the start of the project. Seining was performed by manually pulling a bag seine (26.5 m by 1.7 m; seine bar mesh: 7 mm; bag bar mesh: 5 mm by 3 mm; with one person at each end of the seine) along the wadeable limits of the littoral zone. The distance from the shore was marked in each case on a nearby dock, measured, and recorded. The seine was pulled up to the shoreline in a swooping fashion to capture any fish caught between the seine poles. To aid in the number of fish caught in the seine, one additional person chased fish into the net by walking within the wadeable zone toward the two people pulling the seine, funneling any fleeing fish into the seine. The number of seining attempts was dependant on the number of fish caught per sampling run; it is possible that one attempt produced enough fish for sufficient analysis. At least one sample was collected on all dates from Square Lake Regional Park along the eastern shoreline, specifically in the vicinity of the scuba dock north of the swimming beach proper. At least one sample was collected on the final three dates from a private property along the southern shoreline. All fish collected were stored in a live well or aerated tank until they could be identified and counted. On the later dates, very small young-of-the-year cyprinids that could get through the mesh were not counted. Cyprinids that were not easily identified in the field (e.g., blacknose and blackchin shiners, small bluntnose minnows) were preserved and sorted in the lab. A subsample of the smaller, potentially planktivorous fish were provided for gut analysis (via dissection), since these smaller fish were unlikely to be captured through angling. All other fish were released.

Fish gut contents were analyzed in the lab (at Hamline University) to determine the diets of the various fish species. Fish collected by seining were dissected and the stomach contents of each fish were washed into separate specimen jars. Stomach contents from the specimen jars (either from the dissected fish or the gastric lavage samples) were gently rinsed over a sieve (230 µm mesh) with distilled water. Larger invertebrates (e.g., insect larvae and pupae) retained on the sieve were individually picked from the samples, identified (using Bouchard, 2004), and counted. When zooplankton (e.g., *Daphnia*, copepods, etc.) were numerous (>100 individuals) in the samples, abundances were calculated by subsampling by identifying and counting zooplankton in five 5-ml subsamples under a stereo-microscope.

Chaoborus

Plankton net and sediment samples (using an Ekman dredge) were obtained twice a month from May through August and once in September to obtain *Chaoborus* for evaluation of their diet. In addition, to obtain more samples for diet analysis of *Chaoborus*, samples were collected from the water column just after sundown on June 10 and July 12 and from sediments on June 18. Crop contents of *Chaoborus* were examined using the methods of Swift and Fedorenko (1973) to determine whether or not *Daphnia pulicaria* were a main part of their diet. This process involves using fine forceps to extrude the crop from the body of the animal and then using dissecting needles to tease out the contents of the crop for identification under a microscope.

Goal 5: Assess the structure of the zooplankton community using conventional (plankton net) and high-frequency sonar sampling to compare to previous studies of Square Lake.

Zooplankton surveys

A high-frequency sonar system (Hembre and Megard, 2003) was employed to estimate the size of the *Daphnia pulicaria* population. Sonar data were collected on six dates in 2010 (30 June, 8 July, 29 July, 11 August, 26 August, and 25 September) while traveling slowly (~ 5 km h^{-1}) along a transect of the lake's long axis from the northwest to the southeast end of the lake (Figure 5). The sonar system (described in detail in Megard et al., 1997) consists of a Lowrance X- 16 high-frequency (192 kHz) single-beam echosounder connected to an IBM personal computer. An analog converter digitizes voltage variation due to backscattered sound from zooplankton aggregations and other sound-scatterers. The system software uses the sonar equations (e.g. Urick, 1983) to transform the digitized echo strengths to volume scattering strengths, which are displayed instantaneously on the computer monitor as echograms. Echograms were used to locate zooplankton aggregations and to select depth increments for net sampling. In addition to providing instantaneous information to guide sampling with plankton nets, sonar data were saved on the computer's hard disk and later analyzed to estimate total *Daphnia* abundance in the lake. *Daphnia pulicaria* are considerably larger than other zooplankton in Square Lake and they are the dominant contributor to volume backscattering at depths where they occur. A previous study (Hembre and Megard, 2003) found the target strength of *D. pulicaria* to be -120 dB, and this value was used to estimate densities of *D. pulicaria* in terms of "*Daphnia* equivalents" by dividing mean volume backscattering strengths in depth increments inhabited by *D. pulicaria* by the target strength. Whole lake population densities were estimated by multiplying *Daphnia* equivalent concentrations by the water volumes of the relevant depth intervals, summing those products, and dividing by the lake volume.

Zooplankton surveys were performed twice per month from May through August, and once in September of 2010. On dates when sonar sampling was done, net samples of zooplankton were collected from depth increments at one sampling site in the center of the lake (Figure 5) using a closing plankton net. On dates when sonar sampling was not done, plankton net samples were taken at incremental depths at three different locations in the lake (NW, C, and SE in Figure 5).

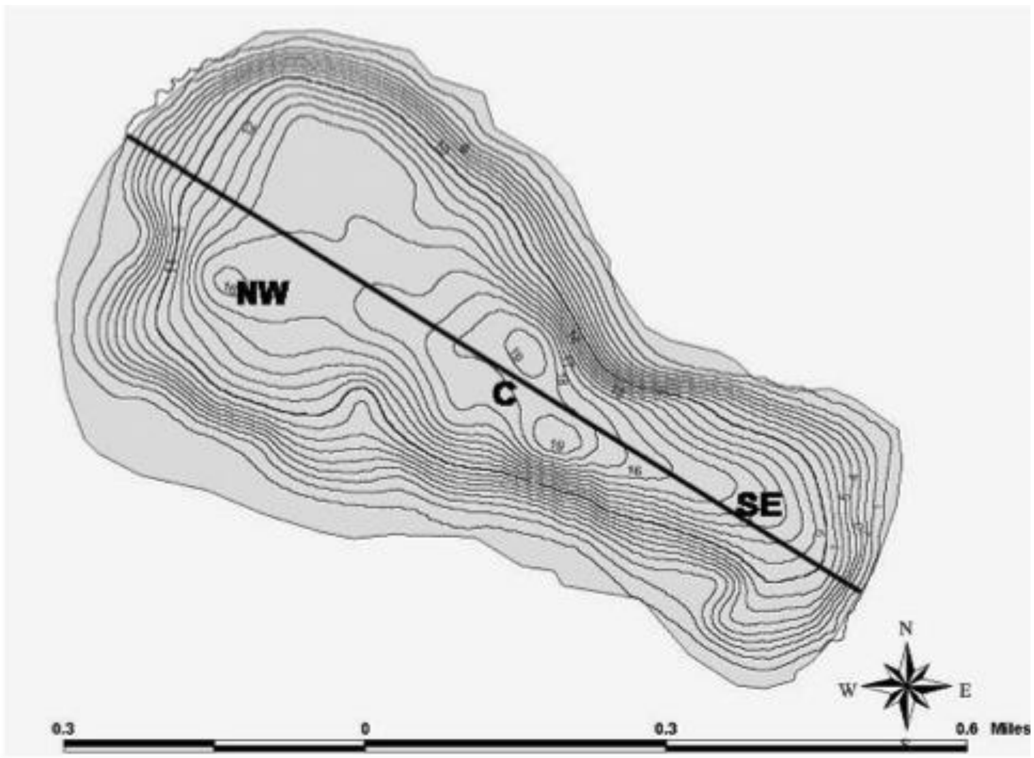


Figure 5. Map of Square Lake (courtesy of Ray Valley, MDNR Fisheries) showing the locations of the sonar transect (solid black line) and the locations where zooplankton samples were collected.

Zooplankton enumeration

For each plankton net sample, the animals in five 5-ml subsamples were identified and counted under a stereo-microscope. Table 20 in *Appendix A: Monitoring Results: Biology* contains data on zooplankton densities and the specific depths sampled. For whole water column samples, body lengths of a subset of individuals (25 when possible) of each taxon were measured to the nearest 0.024 mm with an ocular micrometer.

3.1.2 Data Management and Statistics

Water quality monitoring data (chemistry and biological) were managed according to Section B10 of the *Square Lake Implementation Plan Refinement CWP Project Quality Assurance Project Plan* (QAPP) prepared by MPCA.

3.1.3 Quality Assurance

The main work environments encountered by the project team are the field, the laboratory, and the office. The Quality Assurance Project Plan (QAPP) addresses both monitoring and office activities and was prepared as part of the work plan for this project In brief, the following description is provided.

Laboratory and field activities

RMB Environmental Laboratories, Inc. (MN Department of Health certification #027-005-336) completed the laboratory analyses for the groundwater and wetland investigation. Metropolitan Council Analytical Services Lab (MN Department of Health certification #027-123-172) completed the laboratory analyses for the in-lake water chemistry monitoring. Table 3 identifies the methods that were used.

Table 3. Laboratory Methods

Laboratory	Chemical Parameter	Method	Reporting Limit
RMB Laboratories, Inc.	Nitrogen, nitrite + nitrate	EPA 353.2 Rev. 2.0	0.03 mg/L
RMB Laboratories, Inc.	Nitrogen, total Kjeldahl	EPA 351.2 Rev 2.0	0.5 mg/L
RMB Laboratories, Inc.	Phosphorus, soluble reactive	EPA 365.3	0.005 mg/L
RMB Laboratories, Inc.	Phosphorus, total dissolved	EPA 365.3	0.005
RMB Laboratories, Inc.	Phosphorus, total	EPA 365.3	0.005-0.05 mg/L
Metropolitan Council Analytical Services Lab	Nitrogen, total Kjeldahl	EPA 351.2 Rev. 2.0	0.03 mg/L
Metropolitan Council Analytical Services Lab	Phosphorus, total	MNPBMS 014 (365.4)	0.01 mg/L
Metropolitan Council Analytical Services Lab	Chlorophyll-*a*	SM 10200H	Depends on Volume filtered

Office activities

Data received from lab analyses were delivered in spreadsheet format and as pdf files. Originals remained unchanged and on record. Data analysis was conducted with the supervision of project managers. In addition, the organizational chart in *Section 3 Project Organization and Responsibility* of the work plan created a framework for checks and balances throughout the data analysis, interpretation, and report development process.

3.1.4 Watershed Modeling Techniques

The 2002 diagnostic study estimated watershed phosphorus loading based on surface outflow and water quality sampling. The calculation is based on strategically located field measurements and extrapolation to all subwatersheds. Based on these data, total phosphorus loading from the Square Lake watershed is 30 lb/year. A complete description of methods and results can be found in the 2002 diagnostic study (MWMO et al., 2002).

No additional watershed modeling was conducted for this study.

3.2 Results and Discussion

3.2.1 Goal 1: Evaluate the watershed of Square Lake to determine if substantial changes in watershed phosphorus loading have occurred since the 2002 diagnostic study.

Land use and land cover

Some changes in land use and land cover in the Square Lake Watershed have changed since the 2002 diagnostic study, leading to small changes in phosphorus loading to the lake. The most significant change in the watershed is property development (10 residential lots in total; 3 are lakeshore residences) mostly in and adjacent to the Maywood South Development and affecting phosphorus loading from subwatersheds SW-2 through SW-6 (Figure 4). Lot development in subwatersheds SW-2 through SW-4 represents 6% (29 ac) of the entire 509-acre Square Lake watershed (Table 4). The areas actually altered by home building (a fraction of the parcel area) represent approximately 1% (5 ac) of the total watershed area. In addition, two of the new lots in the Maywood South Development have traditional turf-grass lawns (close to one acre in total area) in contrast to the neighborhood's generally unaltered, natural landscaping. Land cover from the 2008 Minnesota Land Cover Classification System (MLCCS) database is illustrated in Figure 7.

Table 4. Lot development in select Square Lake subwatersheds between 2000 and 2010.
(Development acreages include the entire parcel, whereas typically only a fraction of the total parcel was altered)

Subwatershed	Subwatershed Area (acres)	Lot Development, 2000 to 2010 (acres)	Lot Development, 2000 to 2010 (percent)
SW-2	114	13.7	12%
SW-3	3.8	2.2	58%
SW-4	39	12.6	32%
SW-5	6.3	0.1	2%
SW-6	50	0.8	1.6%

In the 2002 diagnostic study, monitoring data from subwatershed SW-4 were used to calculate phosphorus loading from all subwatersheds (except SW-8, Wilder Forest) on an area-weighted basis under the assumption that subwatershed SW-4 is fairly representative of the land uses in the Square Lake watershed. Since the 2002 diagnostic study was completed, subwatersheds SW-5 and SW-6 changed very little due to residential lot development, but subwatersheds SW-2 through SW-4 may exhibit higher phosphorus loading than previously estimated. The change in phosphorus loading is expected to be within the range of the uncertainty that is already inherent in the existing watershed phosphorus loading estimate. No changes are recommended to the 2002 estimated surface water load (30 lbs) to Square Lake as a result of this update to the watershed assessment. However, implementation of best management practices in response to watershed changes identified in the updated watershed assessment (including residential lot development) can reduce phosphorus loading to Square Lake.

Septic systems

The ten residential homes built between 2000 and 2010 in the Square Lake Watershed were evaluated to estimate increased phosphorus loading since the 2002 diagnostic study. Using the same methodology (MWMO et al., 2002), these ten homes (residential and year-round, located in groundwater inflow areas, with septic systems assumed to be permitted), contribute 6.2 lb/year of phosphorus to Square Lake. This represents a 10% increase above the modeled estimate from septic systems in the 2002 diagnostic study, which was 62 lb/year. The 2002 estimate was not directly used in the phosphorus budget calculations in the 2002 diagnostic study; the phosphorus budget calculations were based on measured groundwater inputs.

Animal operations

The 1995 Washington SWCD feedlot inventory used for the 2002 diagnostic study remains the most up to date information on feedlots. A site visit and review of 2009 aerial photography indicated that no additional animal operations are occurring in the Square Lake Watershed apart from those already indicated in the 2002 diagnostic study.

Gully erosion

Two gully erosion control projects were identified in the 2002 diagnostic study and were subsequently visited in the field for this study (Figure 8). One is located on the north end of the lake and flows south to the lake through subwatershed SW-12. The other is located on the south end of the lake and flows north to a large wetland complex from County Road 7, east of Oren Trail North.

The gully project on the north end of the lake (completed in 1999) appears to collect and slowly release agricultural runoff upstream of a steep grade down to Square Lake. The gully is fully vegetated and appears stable.

The gully project on the south end of the lake receives drainage from County Road 7. The gully discharges to the large wetland complex adjacent to Square Lake in subwatershed SW-2. The project is located at the upstream end of the gully and provides energy dissipation to drainage from County Road 7. The project site is stable and operating properly. However, the gully remains channelized and devoid of vegetation in the main channel. It appears that while energy dissipation may have been achieved, volume control has likely not.

Several other potential gully problem areas (based on topography) were visited in the field. Ultimately, no additional gully erosion control problems were found.

Stormwater ponds

Stormwater ponds were not discussed in the 2002 diagnostic study. During the site visit, three existing stormwater ponds were identified in the Square Lake Watershed (Figure 8). Each has significant storage capacity for its respective drainage area. Two of the three ponds provide skimming of floatables (e.g. debris, oil and grease) prior to discharge to the large wetland complex in SW-2. The third (in SW-4) discharges along a wide, gently sloped swale prior to discharge to Square Lake. No data are available from the outflow of these stormwater ponds. However, based on a field visit alone, there do not appear to be functional problems associated with these stormwater ponds.

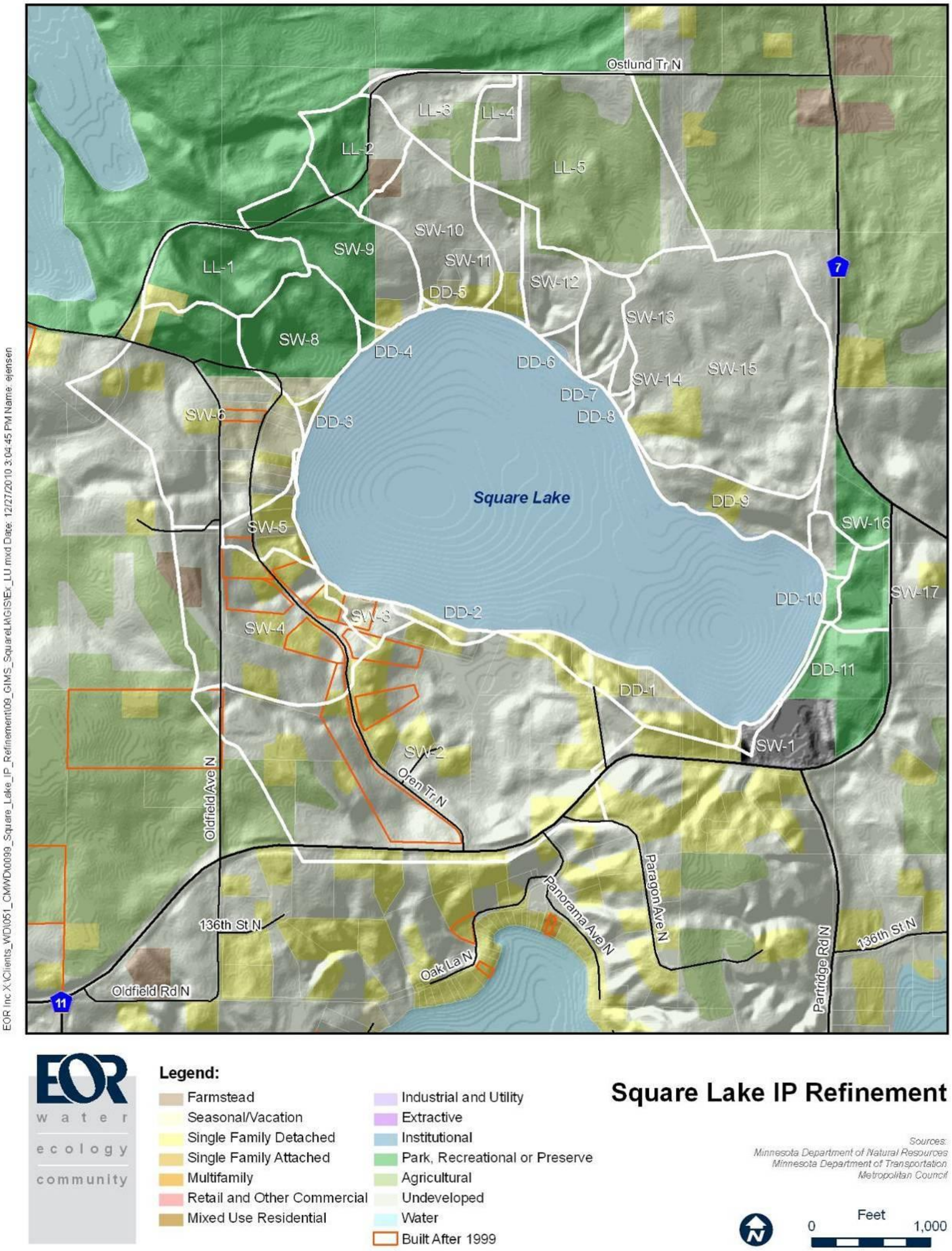


Figure 6. Square Lake Watershed 2005 land use, and parcels constructed after 1999.
(2005 Generalized Land Use for the Twin Cities Metropolitan Area)

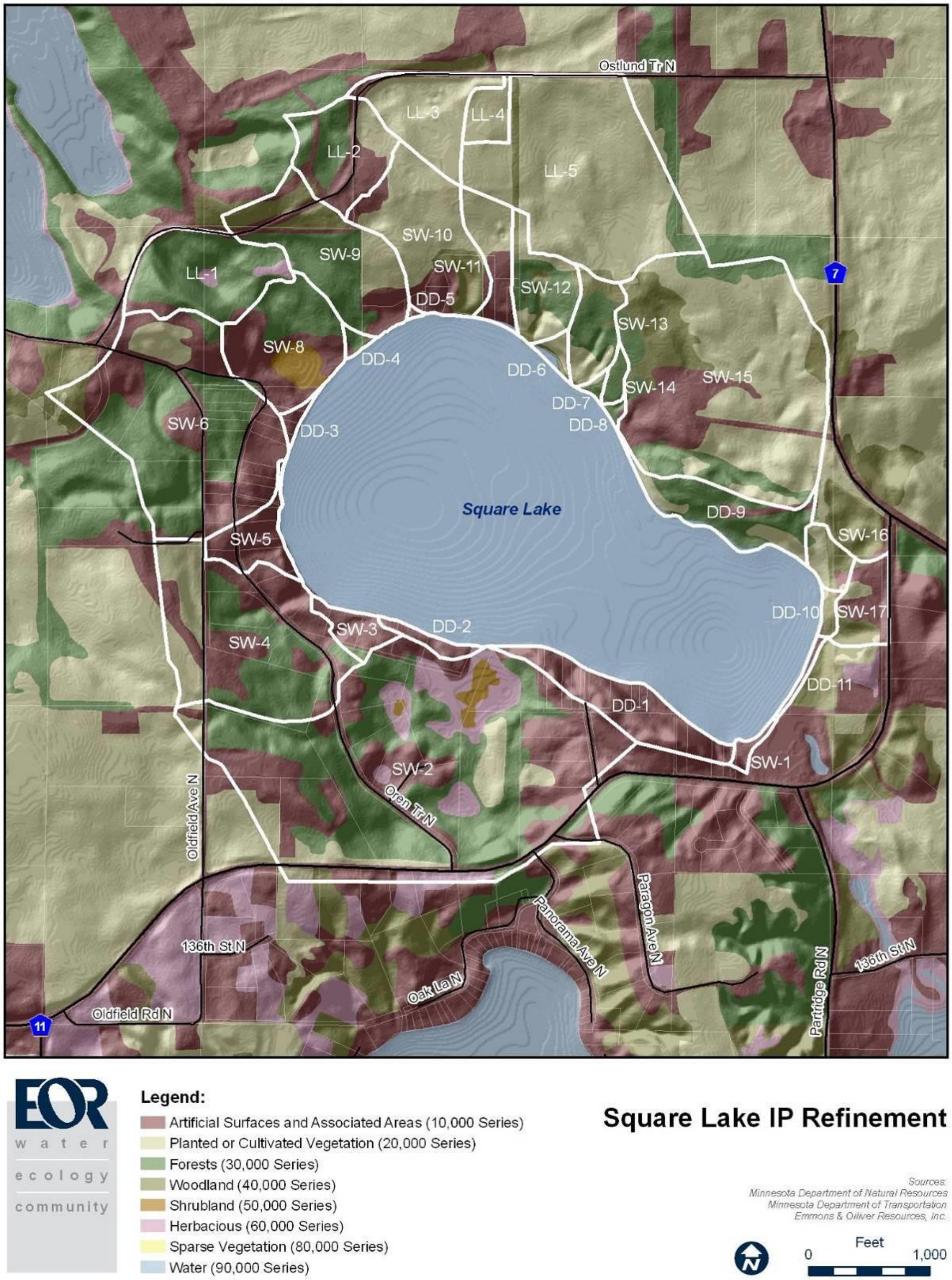


Figure 7. Square Lake Watershed land cover, 2008.
(2008 Minnesota Land Cover Classification System)

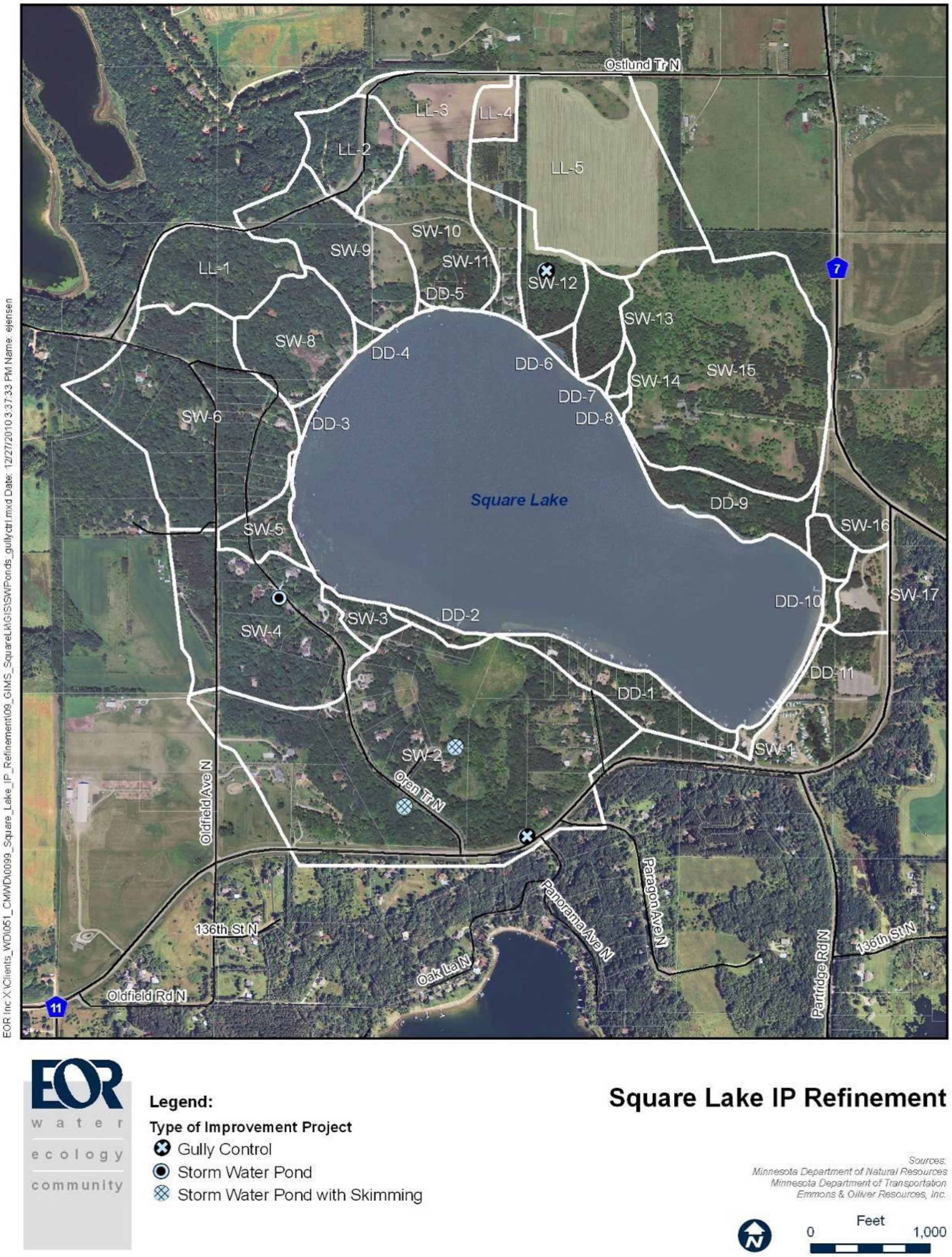


Figure 8. Square Lake Watershed gully erosion control projects and stormwater ponds.

Wetland

The following section describes an evaluation of flow and phosphorus concentrations of the Wilder wetland (located in SW-8, see Figure 44) discharge to Square Lake based on monitoring data collected in 2010.

Discharge

Figure 9 depicts the hydrograph of the Wilder wetland surface water outflow. During the time period monitored (May 28-November 15, or 172 days), the Wilder wetland discharged 608,164 cubic feet (hydraulic export of 9.3 inches).

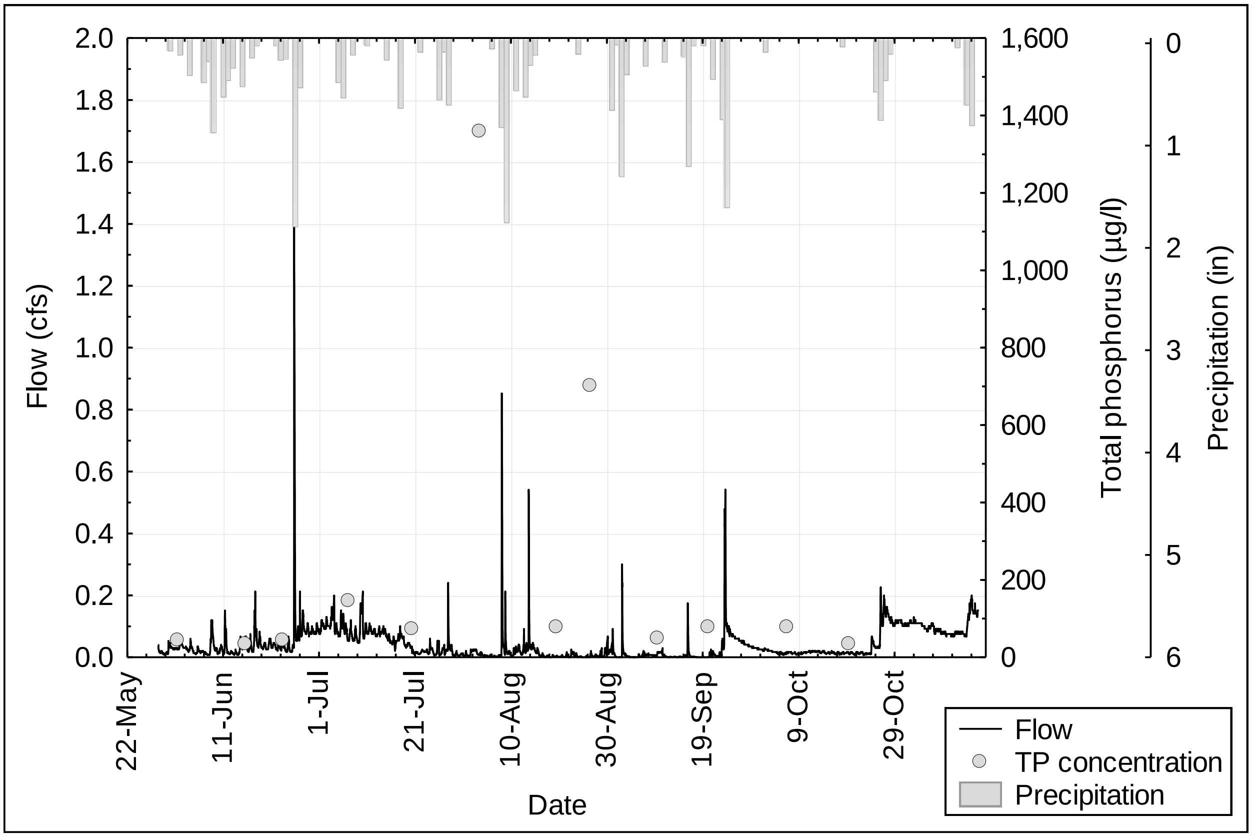


Figure 9. Wilder Wetland flow, precipitation, and phosphorus concentrations

Water quality – nutrient concentrations

Water quality was evaluated in wetland pore water samples and surface water run out samples. The pore water was sampled from within the Wilder wetland in an organic region where diffuse groundwater discharge and iron flocculent was visible at the wetland ground surface, confirming the presence of groundwater discharge. Total phosphorus (TP) concentrations in the pore water samples collected at the Wilder wetland ranged from 98 µg/l to 1,570 µg/l, with the highest concentration observed in October (Table 5, Figure 10).

High phosphorus concentrations can occur when groundwater that flows through organic substances in peat bogs and wetlands interacts with oxygen demanding organic matter. When the rate of decomposition in the naturally decaying peat is increased by warm temperatures, biological activity is accelerated, which consumes dissolved oxygen. This resultant highly reduced pore water affects the association of phosphorus with iron, manganese, and other metals, resulting in higher concentrations of phosphorus and the presence of precipitated metals (i.e. floc). The relatively high total Kjeldahl nitrogen (TKN) concentration in all of the pore water samples additionally confirms the presence of decaying organic matter. The pore water samples also indicated the presence of nitrate plus nitrite early in the growing season, but by August concentrations fell below the reporting level of 30 µg/l. It is possible that plant uptake by deeper active root systems lowered the concentration of nitrate plus nitrite over the course of the growing season.

Total phosphorus (TP) concentrations in the surface water run out samples collected at the Wilder wetland ranged from 33 µg/l to 1,360 µg/l (Table 5, Figure 10). There was no strong seasonal pattern. The samples with the three highest TP concentrations recorded also had very high TKN concentrations. This suggests that organic matter mixed in the sample solution may have caused the high TP concentrations. One of the highest TP concentrations, 700 µg/l, occurred on August 26. On that day, total dissolved phosphorus (TDP) was 28 µg/l and soluble reactive phosphorus (SRP) was 32 µg/l. The TDP and SRP values were very close in concentration, indicating that the majority of the dissolved phosphorus was inorganic. The majority of the total phosphorus was in the particulate fraction (the difference between TP and TDP, or approximately 670 µg/l). The same sample also had a very high TKN concentration (8810 µg/l), suggesting the presence of organic matter.

Surface water run out SRP concentrations ranged from 11 µg/l to 64 µg/l. Surface water run out nitrate plus nitrite concentrations were all found to be below the laboratory reporting limit of 30 µg/l. Surface water run out TKN samples ranged from less than 300 µg/l to 8,810 µg/l, with high TKN concentrations attributable to organic debris in the run out channel. Nitrate plus nitrite concentrations were all below the reporting limit of 30 µg/l.

Table 5. Wetland nutrient concentrations

Date	Total Phosphorus (µg/L)	Total Dissolved Phosphorus (µg/L)	Soluble Reactive (µg/l)	Total Kjeldahl Nitrogen (µg/L)	Nitrate+Nitrite-Nitrogen (µg/L)
Pore water					
6/1/2010	98		< 5	563	240
6/15/2010	1,270		11	4,650	50
6/23/2010	265		9	949	50
7/7/2010	609		25	2,330	90
7/20/2010	1,120		8	2,920	70
8/3/2010	67	41	46	552	< 30
8/19/2010	1,570		22	3,270	< 30
8/26/2010	978	13	20	3,210	< 30
9/9/2010	1,460		15	3,760	< 30
9/20/2010	950		12	2,920	< 30
10/6/2010	3,400		16	3,650	< 30
10/19/2010	501		17	1,650	< 30
Surface water					
6/1/2010	43		24	319	< 30
6/15/2010	33		28	419	< 30
6/23/2010	43		36	417	< 30
7/7/2010	146		64	1,280	< 30
7/20/2010	73		34	603	< 30
8/3/2010	1,360		11	3,180	< 30
8/19/2010	78		44	471	< 30
8/26/2010	700	28	32	8,810	< 30
9/9/2010	48		23	644	< 30
9/20/2010	77		31	737	< 30
10/6/2010	78		24	711	< 30
10/19/2010	34		14	< 300	< 30

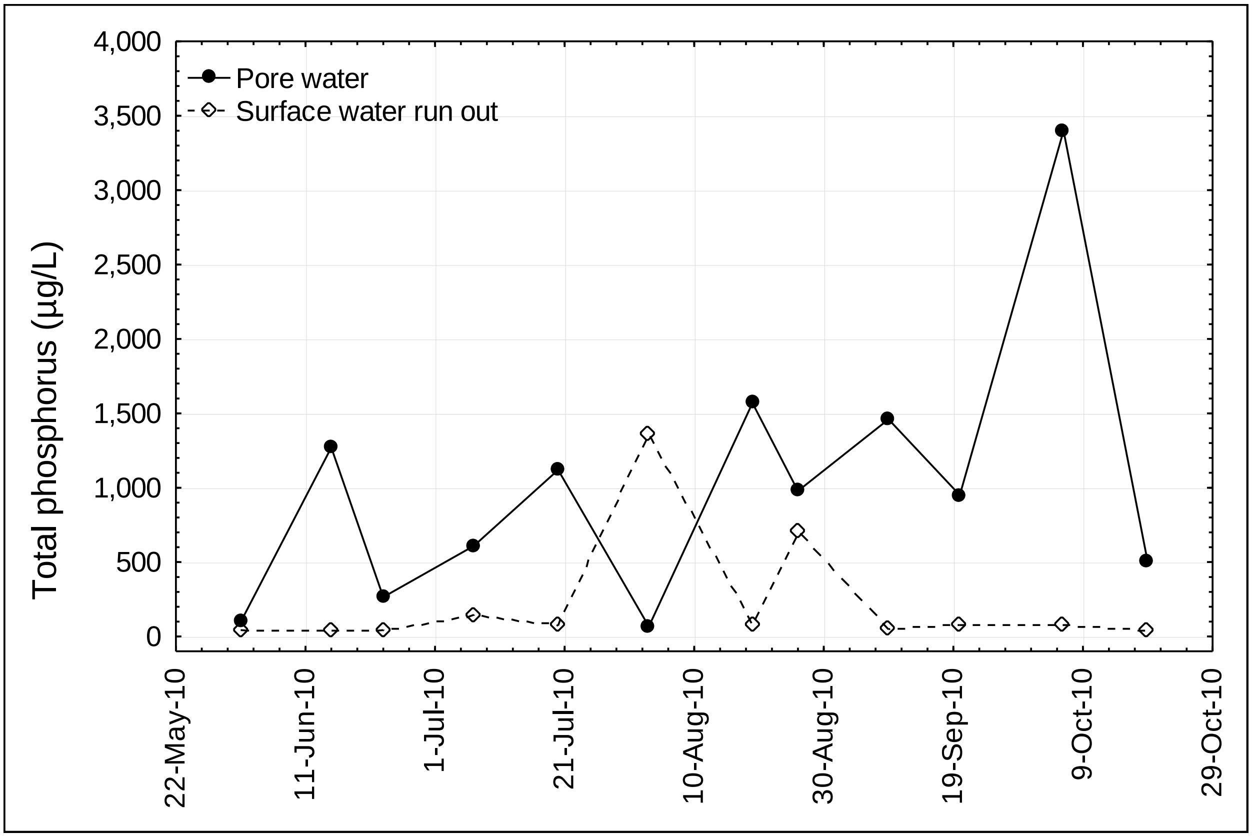


Figure 10. Total phosphorus concentrations in Wilder wetland, 2010

Regional groundwater discharging to the surface at the Wilder wetland (the monitored pore water in this study) has average nutrient concentrations that are higher than nutrients that leave the wetland and enter Square Lake through the run out channel (Figure 10). Plant uptake, microbiological activity, and change in redox across the Wilder wetland contribute to the decrease in nutrient concentrations. Except for two high values, total phosphorus concentrations were similar in the 1999 and 2010 monitoring (Figure 11). The two high values in 2010 were not associated with precipitation events (Figure 9) and may have been due to particulate organic matter in the sample.

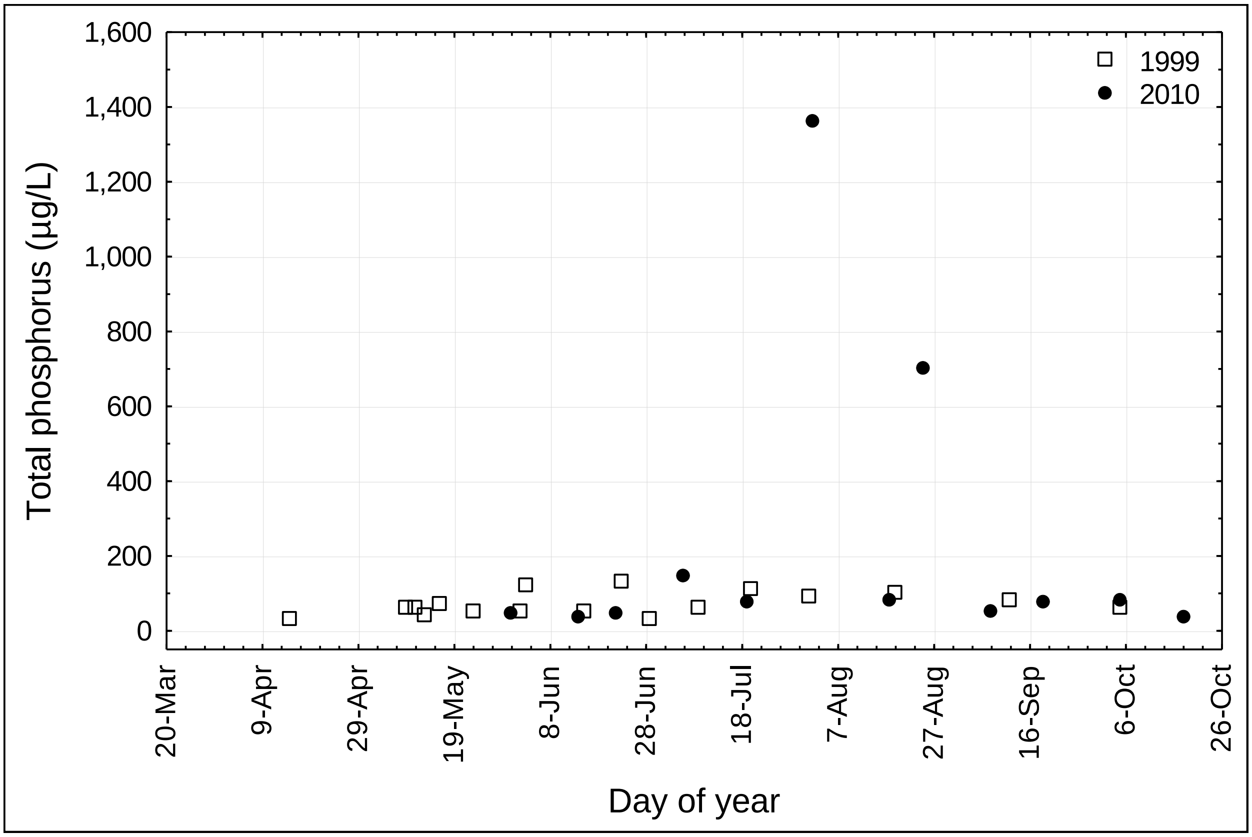


Figure 11. Total phosphorus concentrations in Wilder wetland outflow (surface water runout), 1999 and 2010

Water quality – phosphorus loads

Phosphorus loads at the surface runout location were estimated from the monitored flows and total phosphorus concentrations, using the U.S. Army Corps of Engineers's FLUX *Mass Discharge Computations for Streams*. The computations can be done in multiple ways, resulting in a range of loading estimates. Over the 172 days monitored, 0.7 to 2.3 kg phosphorus (0.096-0.32 kg/ha) were discharged into Square Lake from the Wilder wetland.

The estimated load from the Wilder wetland to Square Lake in the 2002 diagnostic study (6.2 kg, based on 1999 data) was 1.7 to 7.9 times higher than the 2010 estimated phosphorus load (0.7-2.3 kg) in 2010. The discrepancy in loading was mostly due to the higher volumes estimated in 1999: the estimated volume discharged from the wetland in 1999 (2,755,710 ft^3, with a hydraulic export of 41.7 inches) was 3.5 times the estimated volume discharged from the wetland in 2010 (608,164 ft^3, with a hydraulic export of 9.3 inches). This discrepancy could be due to any of the following:

- Length of monitoring: Discharge was monitored for a 30% longer period of time in the 2002 diagnostic study (April 1 through November 9, or 223 days) than in the 2010 monitored period (May 28 through November 15, or 172 days).
- Precipitation patterns and amounts: Whereas the 2010 monitoring season, based on Stillwater National Weather Service data, had approximately 1.2 more inches of precipitation than the 1999 monitoring season, the timing of the precipitation can influence runoff volumes.

- A data logger and rating curve were used to estimate discharge in 1999, whereas a data logger and flume were used to estimate discharge in 2010. Because flumes have a well-defined geometry, the rating curve is also well-defined, whereas rating curves developed for natural open channels have more error.
- Depending on exactly where the monitoring site was located, 1999 water levels could have been influenced by backwater from the lake, leading to higher flow estimates than what was experienced.

Combining the Wilder wetland runoff and load estimates from the 2010 data with the loads estimated in the 2002 diagnostic study, the load from the Wilder wetland represents approximately 24% of the surface water runoff load to Square Lake (compared to 46% estimated in the 2002 diagnostic study), and approximately 4% of the total load to Square Lake (compared to 8% estimated in the 2002 diagnostic study), which includes the high contribution from groundwater.

These results suggest that the load from the Wilder wetland may not be as big a component of the overall phosphorus budget to Square Lake as previously thought, and phosphorus loads have likely not increased in recent years.

Lakeshore Environment

The lakeshore environment is a mix of forest, homes, lawns, sand beach, wetlands, and impervious surfaces (Figure 12). No sites with excessive erosion problems were noted.

Figure 12. Shoreline vegetation and land cover

3.2.2 Goal 2: Evaluate the groundwatershed of Square Lake to determine if phosphorus loads from groundwater are a cause of the decline in transparency in Square Lake.

Phosphorus concentrations in groundwater

Total phosphorus concentrations in the residential Quaternary Water Table Wells (QWTA) monitored in 2010 ranged from 35 to 60 µg/l. Total phosphorus concentrations in unique well # 199502 changed slightly from 35 µg/l in July 2010 to 44 µg/l in May 2011. Total phosphorus concentration in unique well # 142303 was found to be 60 µg/l in July 2010. Due to poor access to the wells, not enough data were collected to determine seasonality.

Soluble reactive phosphorus showed little variation in concentration with values ranging from less than 5 µg/l to 9 µg/l. Nitrate plus nitrite samples collected from the private residential wells were all found to be below the laboratory reporting limit of 30 µg/l.

Table 6. Well water nutrient concentrations

Date	Well #	Nitrate+Nitrite-Nitrogen (µg/l)	Soluble Reactive Phosphorus (µg/l)	Total Phosphorus (µg/l)
7/20/2010	142303	< 30	8	60
7/20/2010	199502	< 30	9	35
5/26/2011	199502	< 30	< 5	44

The median total phosphorus concentration for QWTA wells (N=119) was found to be 56 µg/l in the MPCA's statewide *1998 Baseline Water Quality of Minnesota's Principal Aquifers*. Total phosphorus concentrations for QWTA aquifers ranged from less than 15 µg/l to a maximum concentration of 488 µg/l. Total phosphorus concentrations determined through the Square Lake 2010 investigation, which ranged from 35-60 µg/l (Table 6), are very similar to the statewide average determined in the MPCA study.

In-lake total phosphorus groundwater concentrations collected in 2000 as part of the 2002 diagnostic study ranged from 15 to 460 µg/l (N=26). All in-lake groundwater samples had concentrations of 30 µg/l or less except at three locations. The three greatest concentrations measured were 460 µg/l, 140 µg/l, and 40 µg/l. The two highest phosphorus concentrations may have been caused by increased organic matter in the lake bed at these sampling locations. None of these locations exhibited high Cl:Br ratios (used to indicate anthropogenic influence), suggesting that the increased phosphorus concentrations are likely not due to anthropogenic reasons.

In conclusion, the phosphorus concentrations in the groundwatershed of Square Lake are typical for the region and do not appear to be contributing to the decline in water quality in Square Lake.

Groundwatershed

To assist in the watershed evaluation, an approximate groundwatershed to Square Lake was delineated using groundwater 10 foot Quaternary Aquifer contours developed for the Northern Washington County Groundwater Study (EOR 2003). The groundwatershed was delineated using an approach similar to delineating a surface watershed using the kriged contours. Groundwatersheds are actually three-dimensional bodies that depict the aquifer that discharges to a resource. The groundwatershed developed as part of this investigation represents a plan view of the groundwatershed, and does not depict leakage from the upper aquifer to the lower aquifer units. The delineated groundwatershed is an approximation, as the groundwater potentiometric surface is not static. The groundwater potentiometric surface is a dynamic “surface” that changes seasonally and year to year with changes in recharge and withdrawal. Extended periods of abnormally high (or low) precipitation or increases in groundwater appropriations and/or evapotranspiration would alter the potentiometric surface and size and shape of the groundwatershed.

Square Lake’s approximate groundwatershed extends to the northwest of the lake and is 8,146 acres (Figure 13).

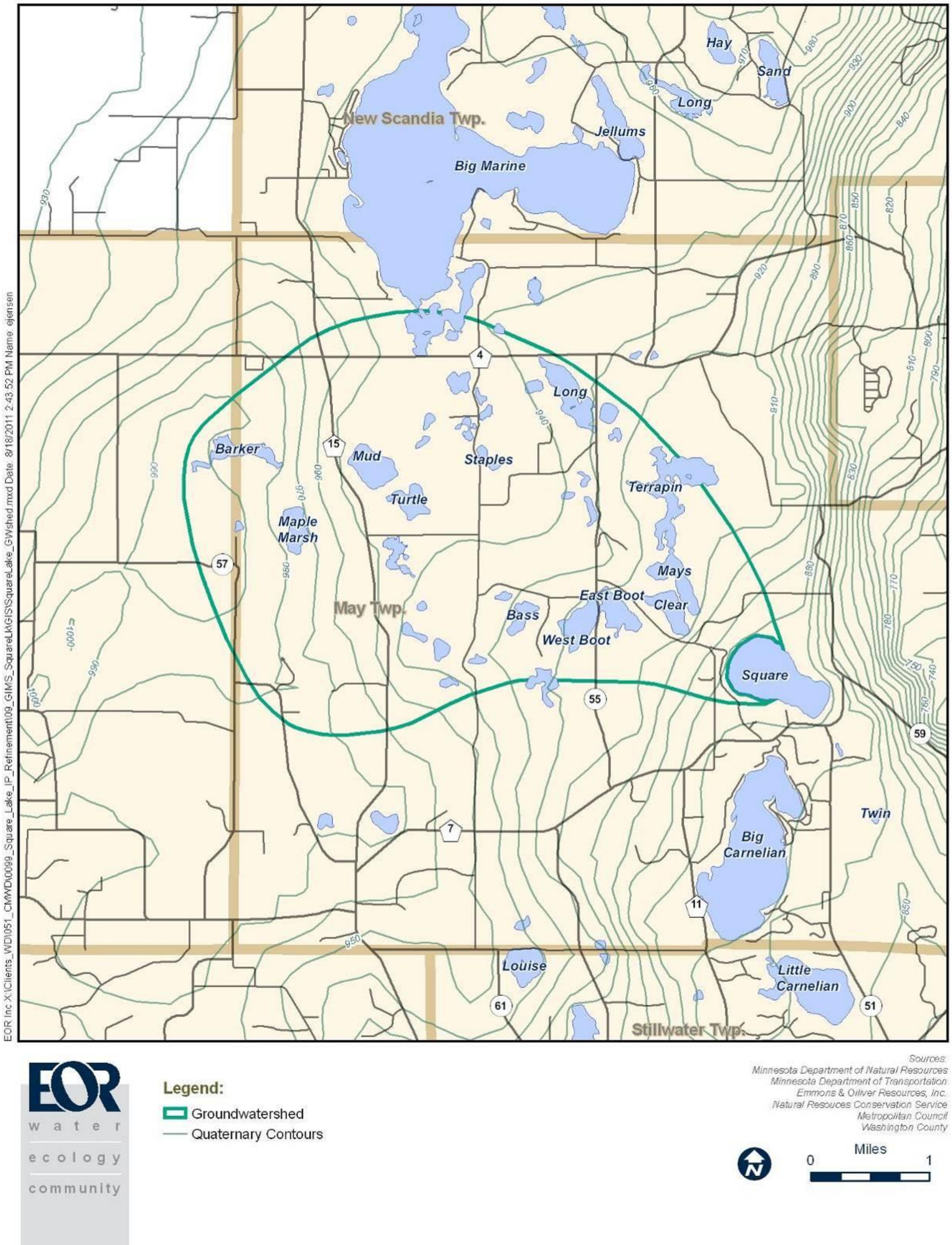


Figure 13. Square Lake approximate groundwatershed

3.2.3 Goal 3: Gather environmental and water quality data to compare with historical data from Square Lake and evaluate trends in the lake's water quality.

Lake Characteristics

Square Lake is 203 acres in size, with a maximum depth of 68 feet (Table 7, Figure 14). The total watershed draining to the lake is 509 acres.

Table 7. Square Lake characteristics.

Data from MWMO et al., 2002

Characteristic	Value
Lake total surface area (ac)	203
Maximum depth (ft)	68
Drainage area (acres)	509
Watershed area : lake area	2.5

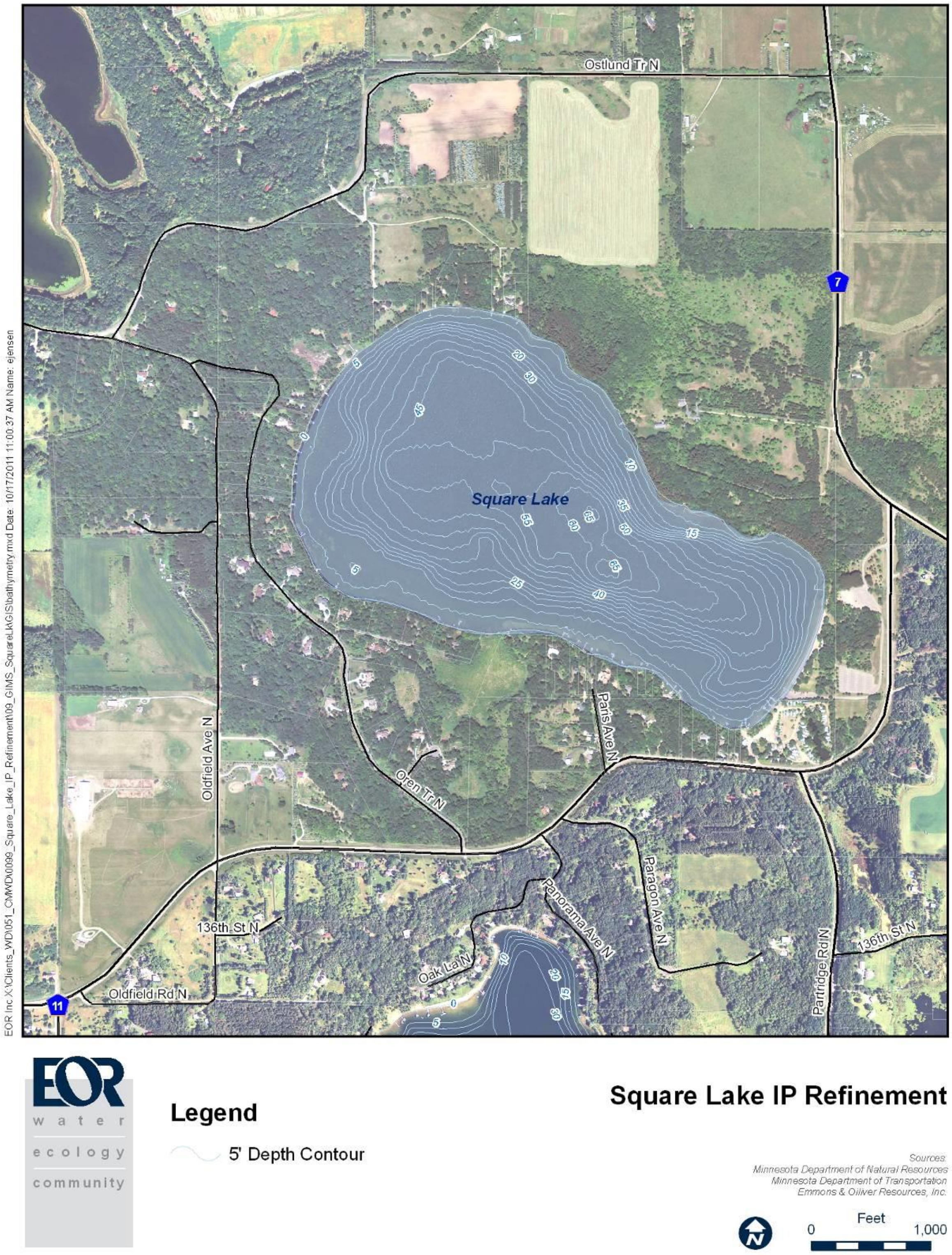


Figure 14. Square Lake bathymetry

Data source: MN DNR, digitized from existing lake contour maps produced by the DNR Ecological Services Lake Mapping Unit

Lake Water Quality

2010 Water Quality results

Total phosphorus concentrations in 2010 fluctuated between 8 and 21 µg/l (Figure 15). Concentrations were lowest in May and peaked at the end of July, with overall higher concentrations as the season progressed. Chlorophyll-*a* concentrations cycled from May through July, after which they increased to a peak of 5 µg/l in September (Figure 16). Transparency also cycled, although the pattern was not necessarily tied to the changes in chlorophyll concentration. The mean total phosphorus concentration in 2010 was 14 µg/l, which is similar to the annual means from the last ten years (see Figure 20). The mean chlorophyll concentration, 3.2 µg/l, is the highest ever observed in Square Lake (Figure 18). The mean transparency, 5.4 m, was slightly better than the last two years, although when viewed over the long term it continues the trend of decreasing transparency in the lake (Figure 17). Clumps of algae were observed in the lake in 2010; clumped algae does not affect transparency as negatively as single-celled algae do. Therefore transparency readings may be better than expected given the chlorophyll concentrations that were measured.

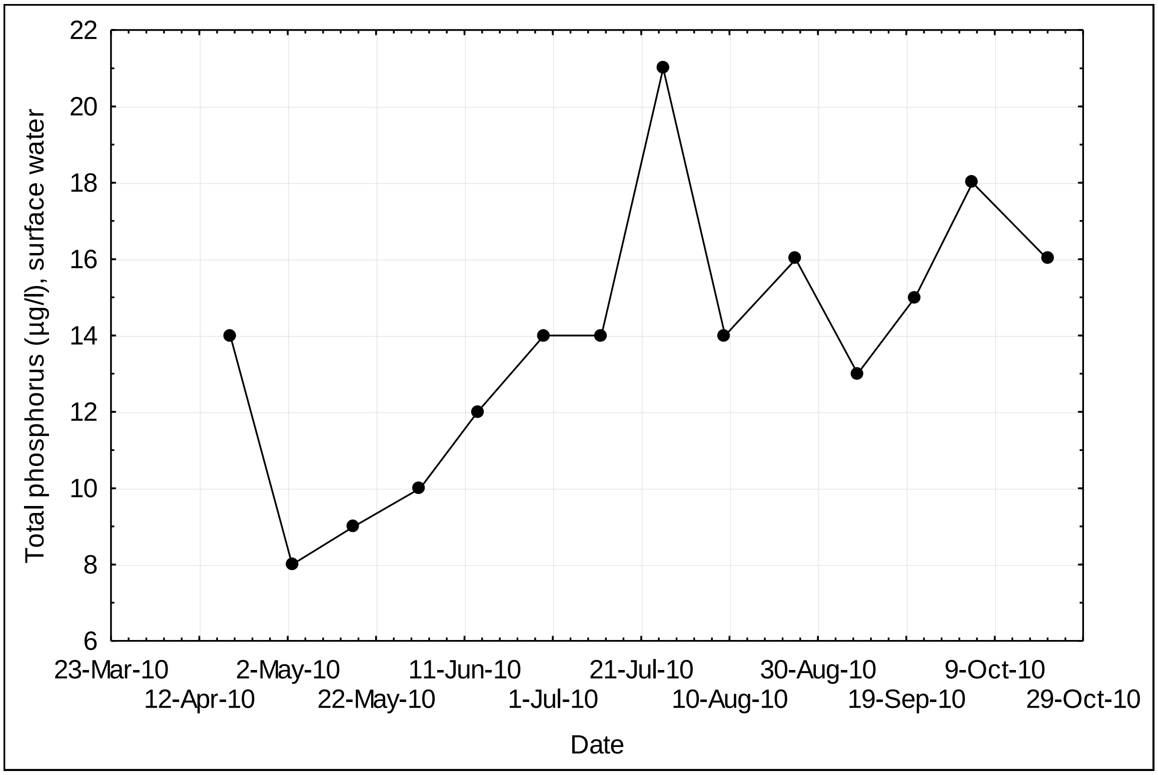


Figure 15. Surface water total phosphorus concentrations in Square Lake, 2010

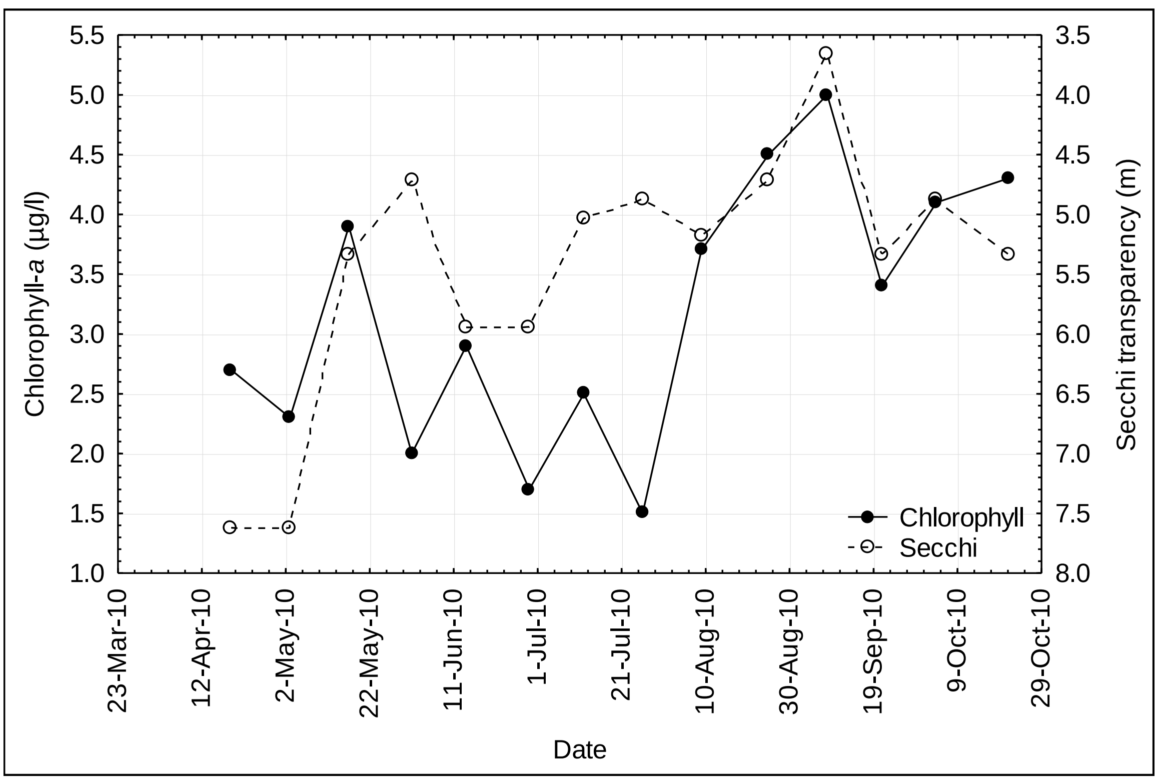


Figure 16. Chlorophyll-*a* concentrations and Secchi transparency in Square Lake, 2010

Historical Water Quality trends for Square Lake

Square Lake has historically been categorized as an oligotrophic lake (Table 8) on the basis of its clear water (Secchi depth) and low levels of phosphorus and phytoplankton biomass (Chl-*a*). However, over the past 20 years it has been transitioning into more of a mesotrophic lake with respect to its water clarity and levels of phytoplankton biomass.

Table 8. Water quality parameters for lakes of different trophic state.
Table adapted from Carlson R.E. and J. Simpson (1996).

Chl-*a* (µg/L)	Total Phosphorus (µg/L)	Secchi depth (m)	Trophic state
0-2.6	0-12	> 4	Oligotrophic
2.6-20	12-24	2-4	Mesotrophic
20-56	24-96	0.5-2	Eutrophic
>56	>96	< 0.5	Hypereutrophic

From the 1970s through the early 1990s the water clarity of Square Lake averaged about 7 m. Since the early 1990s, though, water clarity has steadily declined to about 5 m (Figure 17) likely as a result of increased levels of phytoplankton biomass (Chl-*a*) in surface water (Figure 18). In lakes where Chl-*a* levels are low (< 5 µg/L), relatively small changes in Chl-*a* concentration result in large changes in water clarity (Figure 19). So, if the trend of increased algal biomass in Square Lake continues into the future, steep declines in water clarity are to be expected.

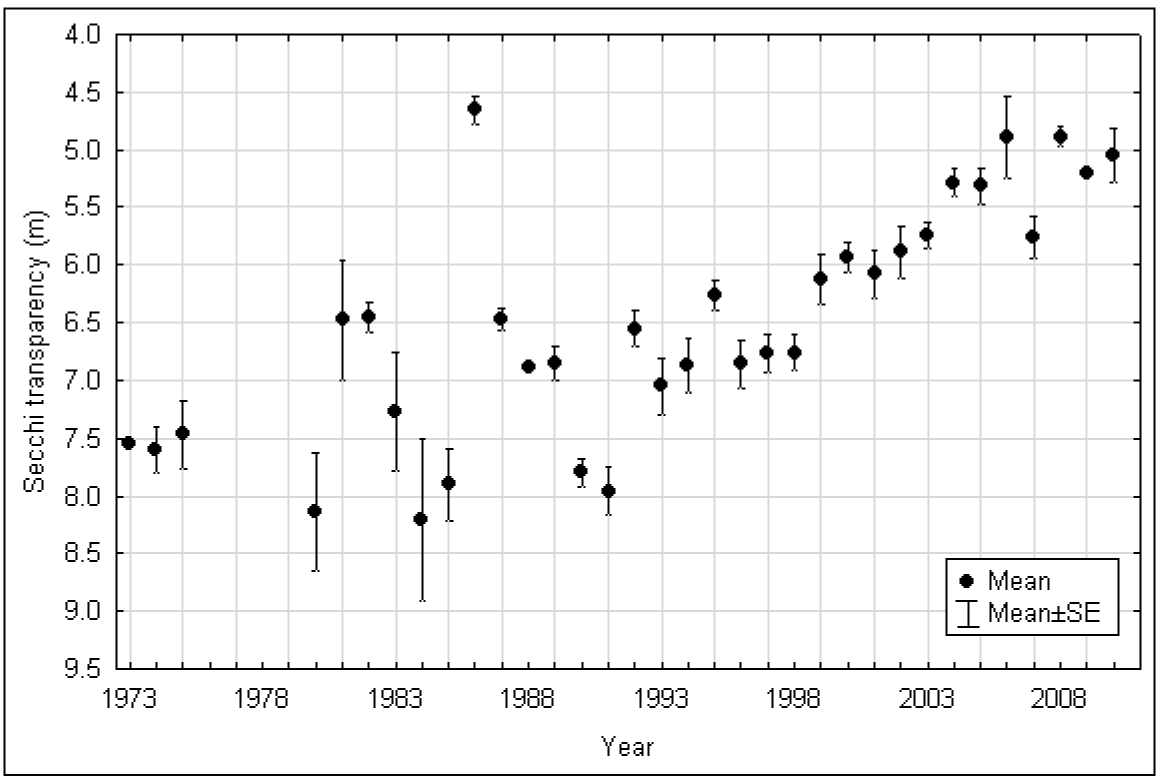


Figure 17. Mean growing season (Jun-Sep) Secchi transparency in Square Lake, 1973-2010

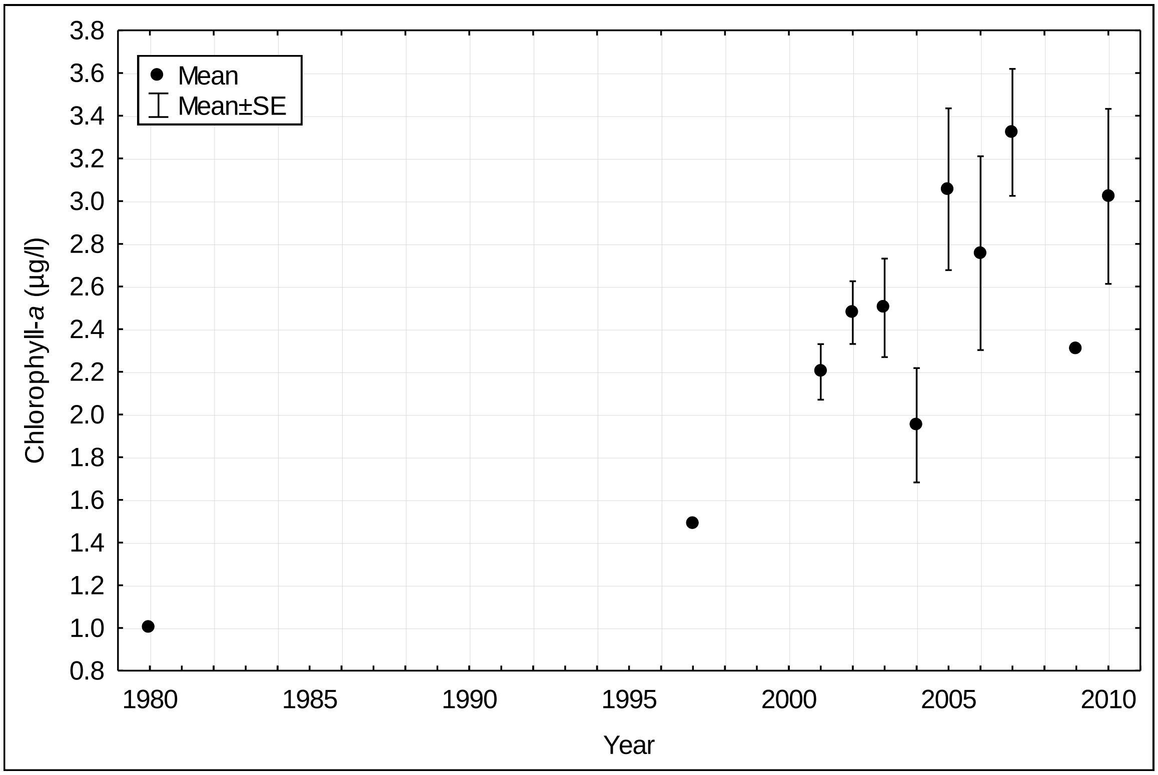


Figure 18. Mean growing season (Jun-Sep) chlorophyll-*a* concentrations in Square Lake, 2001-2010.

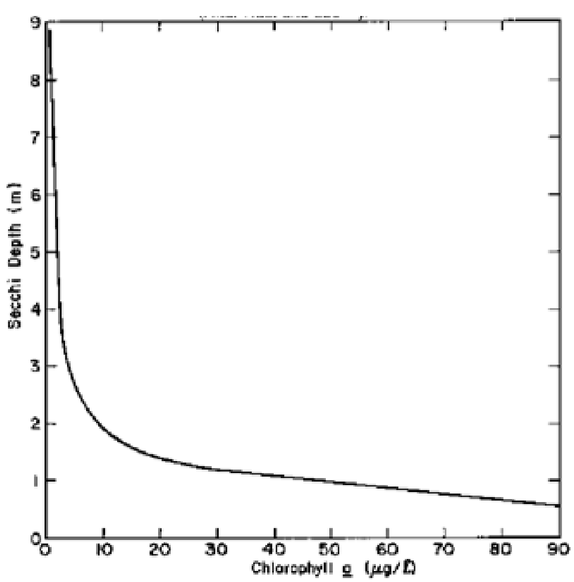


Figure 19. Relationship between Secchi depth and Chl-*a* concentration (µg/L) (hypothetical lake). Note the large changes in water clarity at the low range of Chl-*a* concentration. Figure from Rast & Lee (1978).

While diminished water clarity in many Minnesota lakes is linked to increased loading of phosphorus from the landscape or from lake sediments, the trend of decreased water clarity in Square Lake does not fit this pattern. Total phosphorus concentrations in the lake have remained quite consistent (Figure 20) over the time period (since the early 1990s) when the lake's water transparency has declined. The disconnection between the phosphorus levels and the declining water clarity of the lake implies that other factors are responsible for the eutrophication trend that has been observed. A hypothesis for the decline in water clarity is proposed in section 3.5 of this report.

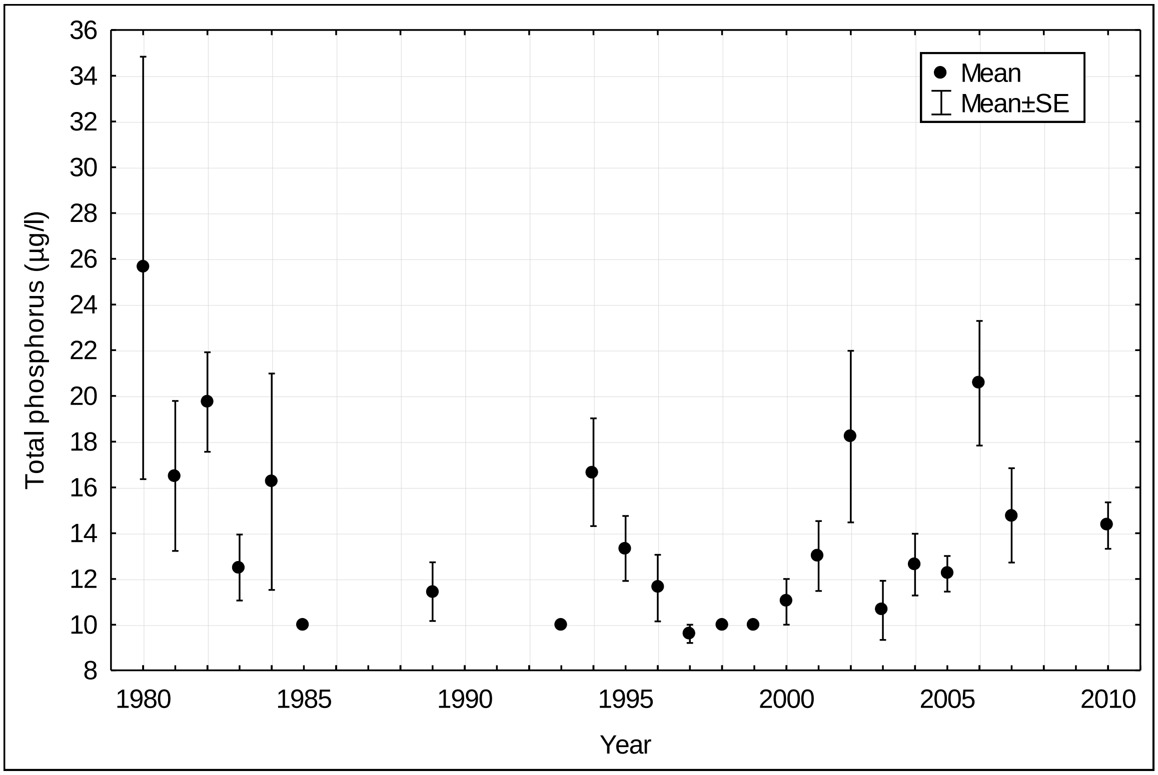


Figure 20. Mean growing season (Jun-Sep) total phosphorus concentrations in Square Lake, 1980-2010

To evaluate whether or not these long-term water quality trends are observed in other nearby lakes, water quality trends from a nearby mesotrophic lake of similar size, Big Carnelian Lake, were compared to the water quality trends in Square Lake. In Big Carnelian Lake, like in Square Lake, there has not been a long-term trend in growing season mean phosphorus concentrations (Figure 21). However, unlike in Square Lake, chlorophyll-*a* concentrations and Secchi transparency have improved over the last ten years (Figure 21). This suggests that the water quality trends observed in Square Lake are not regional and are likely not solely due to regional climate patterns.

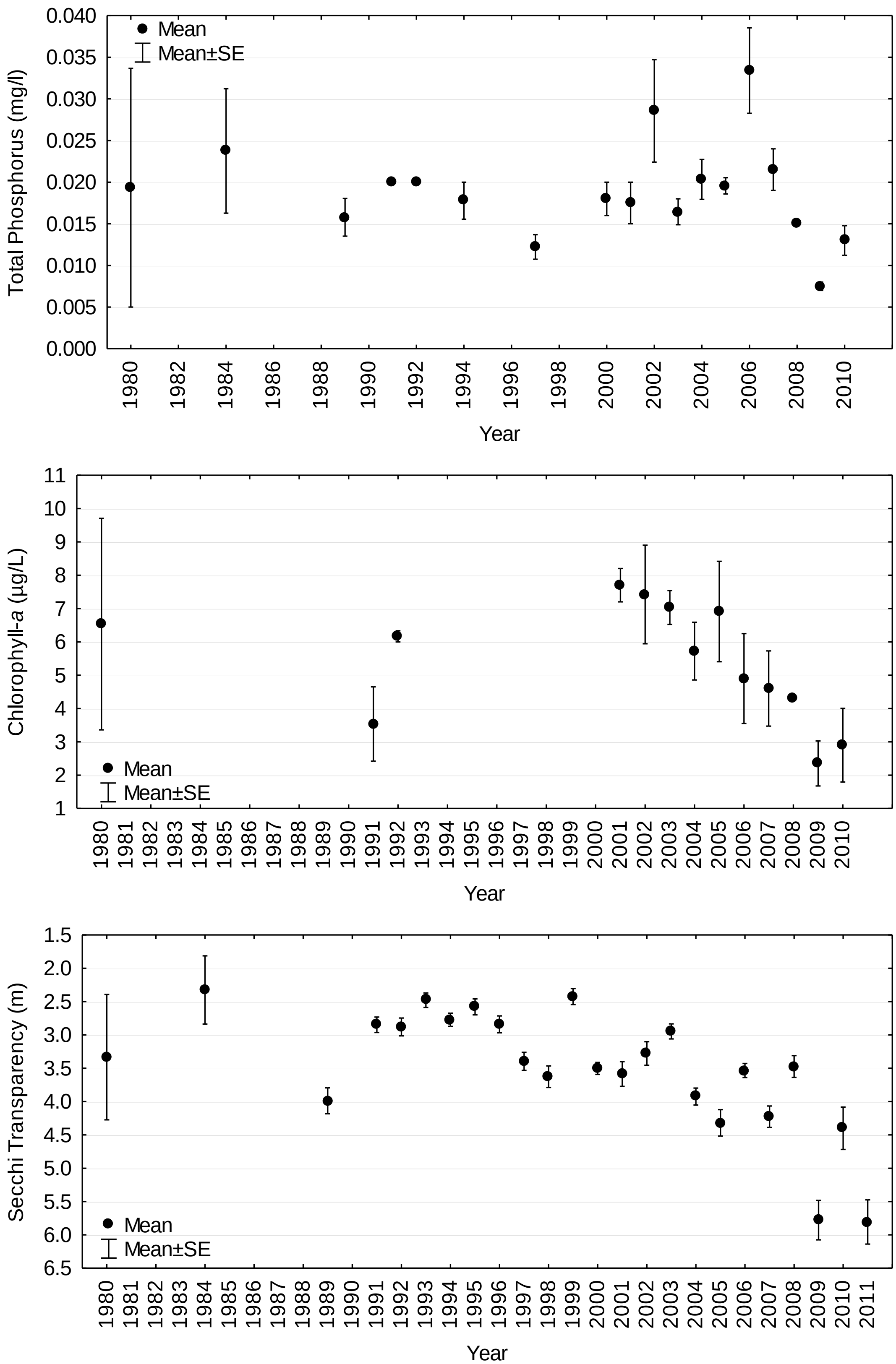


Figure 21. Water quality of Big Carnelian Lake, growing season (Jun-Sep) means

Temperature and oxygen data from 2010 (Figure 22 and Figure 23) show that the lake was strongly thermally stratified by early June. The epilimnion extended from the surface to approximately a depth of four meters, and the metalimnion extended to approximately 12 meters. Dissolved oxygen concentration began to decline in the hypolimnion in the spring, and by June the hypolimnion was hypoxic (DO < 2 mg/l; Figure 23).

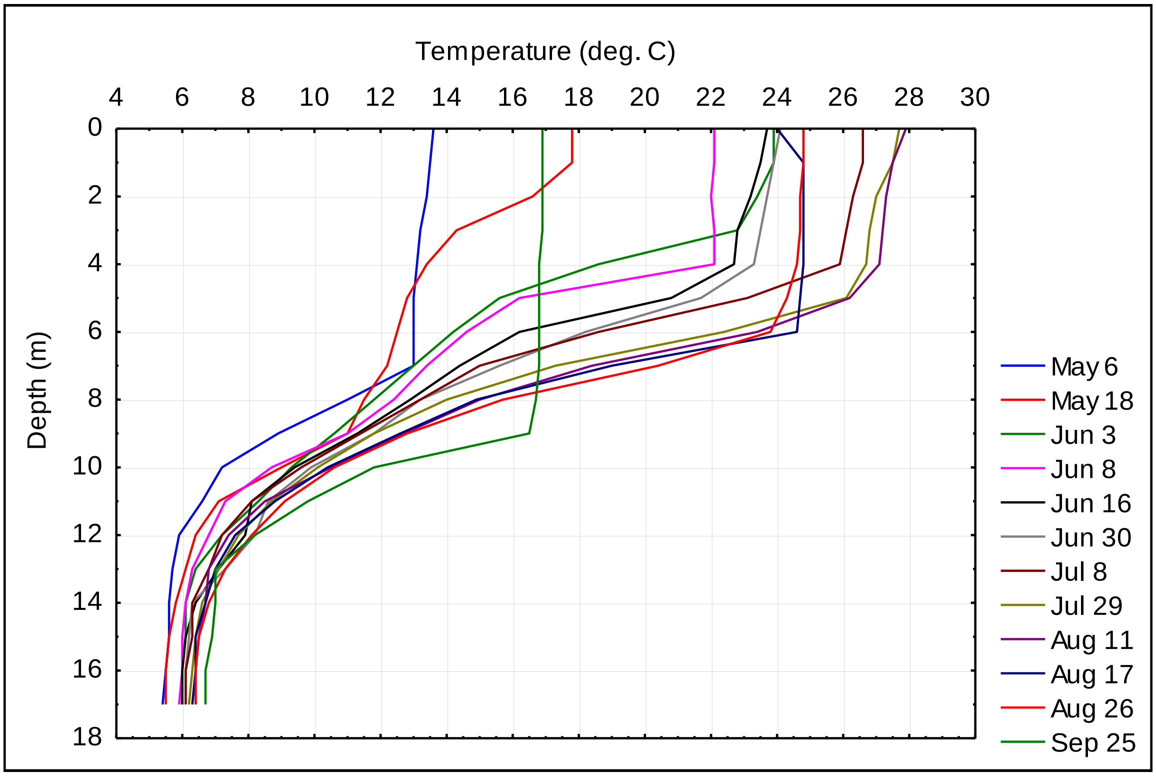


Figure 22. Temperature depth profile in Square Lake, 2010

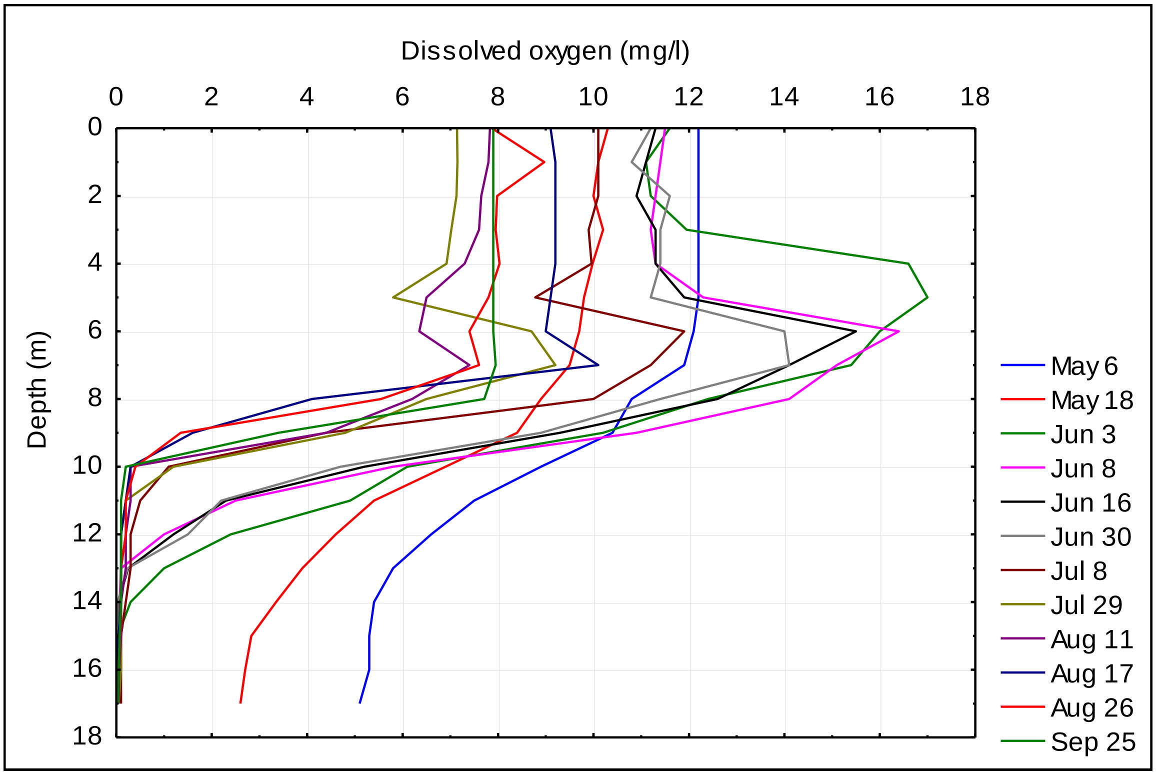


Figure 23. DO depth profile in Square Lake, 2010

Macrophytes

A macrophyte survey was completed for Square Lake on August 17, 2010. The survey was conducted using the point intercept method (Madsen, 1999) where the plant species and density are recorded at each site.

Submergent macrophytes were observed at most locations with a depth of 25-30 feet. Emergent and/or floating leaf macrophytes were present at multiple locations along the shoreline (Figure 24). On the day of survey, the lake had a very high density and diversity of macrophyte plants throughout the entire littoral zone, with the exception of a few small spots on the south end of the lake where landowners had raked the lake bottom or had applied herbicides near their shore.

The macrophyte species observed were the following:

Table 9. Macrophyte species observed in Square Lake, August 17, 2010

Scientific Name	Common Name
Ceratophyllum demersum	Coontail
Chara vulgaris	Muskgrass
Elodea canadensis	Elodea
Myriophyllum exalbescens	Northern water milfoil
Najas guadalupensis	Southern waternymph
Nitella sp.	Stonewart species
Nuphar lutea	Yellow water-lily

Potamogeton amplifolius	Large-leaved pondweed
Potamogeton foliosus	Leafy pondweed
Potamogeton gramineus	Variable-Leaved Pondweed
Potamogeton natans	Floating-leaved pondweed
Potamogeton pectinatus	Sago pondweed
Potamogeton richardsonii	Claspingleaf pondweed
Potamogeton sp.	Pondweed species
Potamogeton zosteriformis	Flat-stemmed pondweed
Scirpus acutus	Hardstem bulrush
Vallisneria americana	Wild Celery

Appendix B: *Aquatic Macrophyte Survey Results* (Table 22 and Figure 45) contains the raw data.

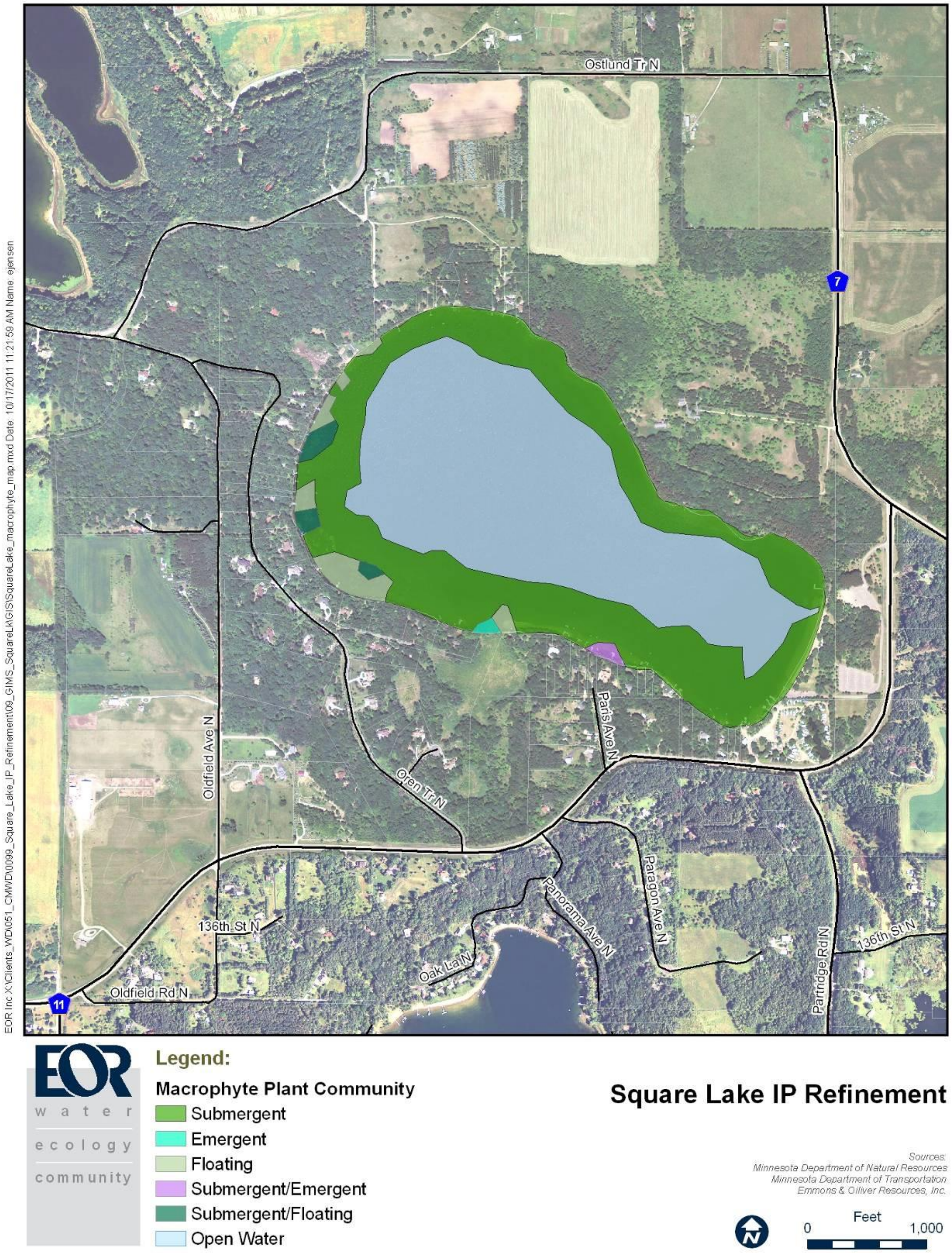


Figure 24. Distribution of macrophyte communities in Square Lake, August 17, 2010

3.2.4 Goal 4: Evaluate the diets of an array of predators to determine which are the most significant consumers of large-bodied Daphnia (D. pulicaria).

Fish Diets

A total of 197 stomach samples of various species of fishes (Table 10) were examined to evaluate which species consume *Daphnia*. Seventy-four of the samples were gastric lavage samples from fish collected by angling and 123 were stomach samples dissected from fish that were collected by seining. See Table 17 and Table 18 in *Appendix A: Monitoring Results: Biology* for stomach content data.

Table 10. Number of samples analyzed for each fish species and the method by which samples were obtained.

Species	Sample size	
	Gastric lavage	Seine
Rainbow trout (RBT)	20	0
Bluegill sunfish (BLG)	49	62
Black crappie (CRP)	3	0
Yellow perch (YP)	2	0
Spotfin shiner (SPS)	0	20
Bluntnose minnow (BNM)	0	15
Banded killifish (BKF)	0	16
Blacknose shiner (BNS)	0	10
Total	**74**	**123**

No *Daphnia* of any type were found in any of the minnow, shiner, or killifish stomachs. The diets of these species were composed of a variety of littoral zone aquatic invertebrates.

The two fish species for which *Daphnia* were important prey items were rainbow trout and bluegill sunfish. Rainbow trout were the zooplanktivorous predator that consumed the most large-bodied *Daphnia (D. pulicaria)* per capita (Figure 25) and they consumed significantly more per capita than did bluegills (T=9.91, df=129, p <0.0001). Bluegill sunfish consumed relatively few *D. pulicaria* (Figure 26), but were the species that consumed the most *D. mendotae*.

Notes:

- *Daphnia mendotae* is a smaller-bodied *Daphnia* species (see Figure 33) and was more common in shallower water than was *D. pulicaria* (see Figure 29).
- Angling success for rainbow trout in July and August was poor. The majority of the gastric lavage samples from rainbow trout were collected in June (see Table 18 in *Appendix A: Monitoring Results: Biology*). The poor angling success for rainbow trout in July and August in 2010 is consistent with the findings of the creels surveys performed as part of the 2004-2005 LCCMR study (Hembre, 2006).

There were striking differences in the diet of bluegill greater than 15 cm in length compared to those shorter than 15 cm (Figure 27). Those shorter than 15 cm consumed no *D. pulicaria* and very few *D. mendotae*. This implies that small bluegill restrict their foraging to the littoral (near-shore) zone. However, bluegill sunfish larger than 15 cm consumed some *D. pulicaria* and many of the smaller-bodied *D. mendotae*. This suggests that larger bluegill forage in the shallower depths of the open water (pelagic zone) as well as near-shore. While the diet of bluegill varied considerably with body size, no systematic effect of body size on rainbow trout diet was observed (Figure 27).

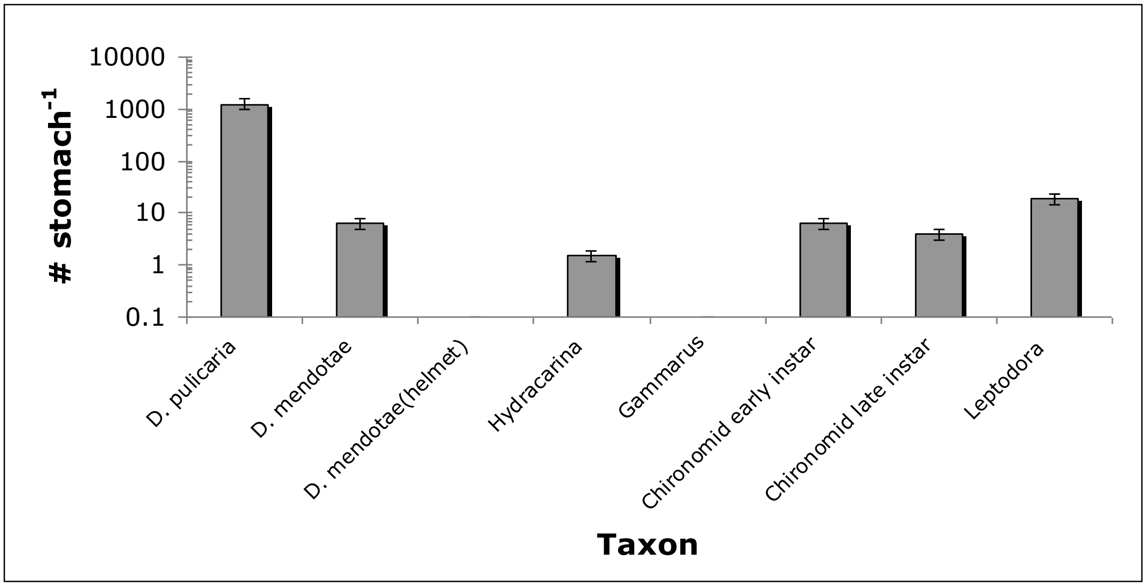


Figure 25. Diet of rainbow trout in Square Lake in 2010 (n=20).
Mean number of various types of prey in stomach samples analyzed. Error bars represent +/- 1 s.e.

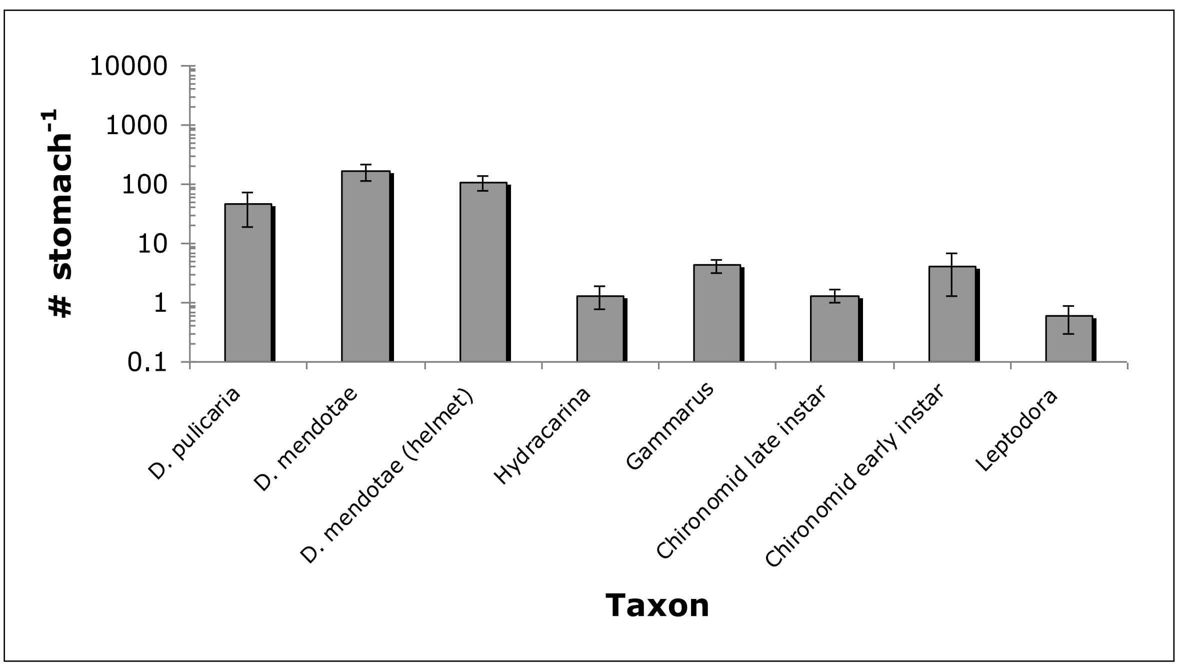


Figure 26. Diet of bluegill sunfish in Square Lake in 2010 (n=111).
Mean number of various types of prey in stomach samples analyzed. Error bars represent +/- 1 s.e.

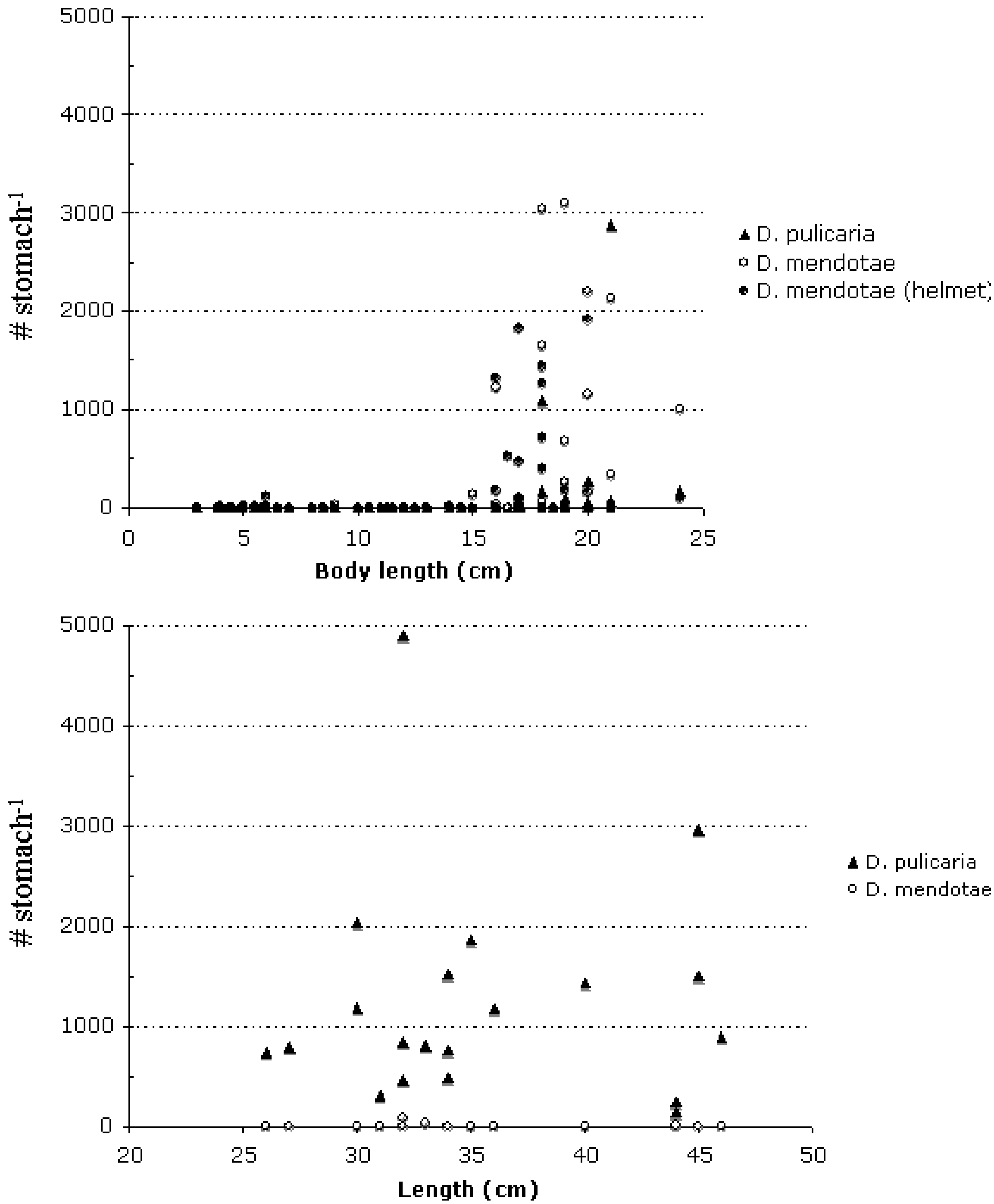


Figure 27. Daphnia consumed by bluegill (BLG) sunfish (top) and rainbow trout (RBT) (bottom) of different lengths.

Note that only bluegill larger than 15 cm consume *Daphnia* and that the smaller-bodied *D. mendotae* is their preferred prey. Rainbow trout of all lengths collected prefer *D. pulicaria*.

***Chaoborus* abundance and diet**

Chaoborus were very scarce in Square Lake in 2010 (Figure 28), which was unlike in 2004-2005 when they were often abundant (Hembre, 2006). Only 32 *Chaoborus* samples were obtained for diet analysis from a combination of net sampling and sediment sampling on 11 dates in 2010. Eleven of the 32 crops examined were found to be empty upon dissection. The prey most commonly found in the crops were copepod nauplii, *Kelicottia* (a rotifer), and *D. mendotae* (see Table 19 in *Appendix A: Monitoring Results: Biology*). No *D. pulicaria* were found in any of the 21 *Chaoborus* that had prey in their crops. The scarcity of *Chaoborus* and the fact that none of the individuals examined showed evidence of having consumed *D. pulicaria* indicates that *Chaoborus* are not a significant cause of *D. pulicaria* mortality in Square Lake.

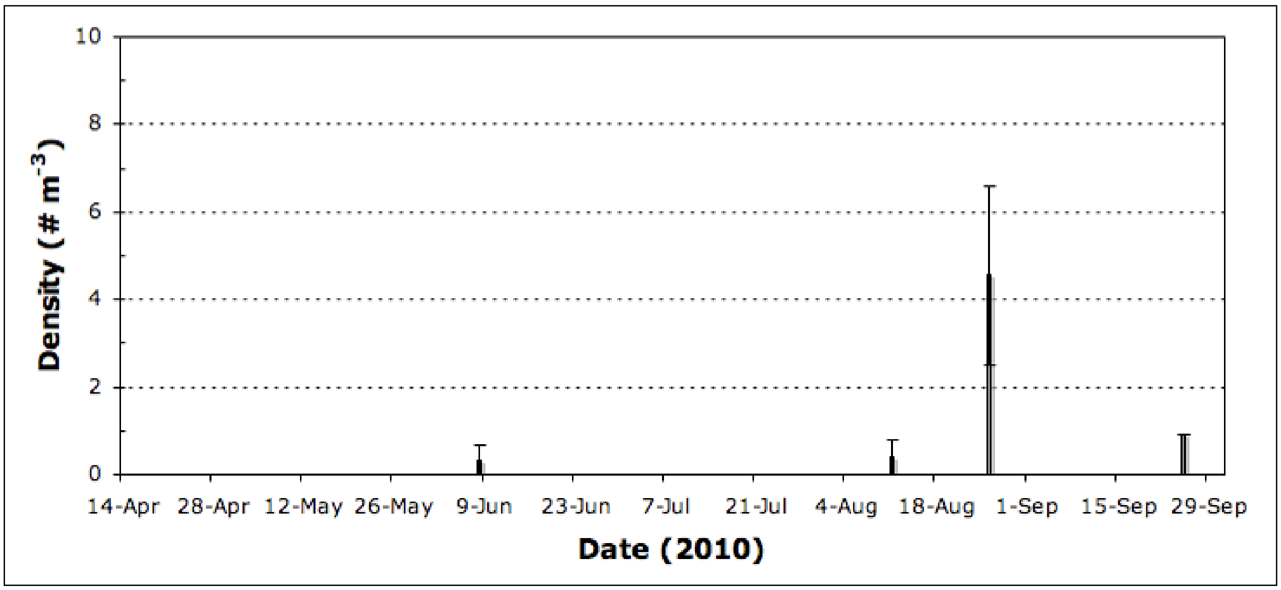


Figure 28. Densities of Chaoborus from whole water column net samples in 2010.
Error bars represent +/- s.d.

3.2.5 Goal 5: Assess the structure of the zooplankton community using conventional (plankton net) and high-frequency sonar sampling to compare to previous studies of Square Lake.

The biomass of the zooplankton community of Square Lake was dominated by two species of *Daphnia* (the large-bodied *D. pulicaria* and the smaller-bodied *D. mendotae*) and calanoid and cyclopoid copepods. In addition to these dominant taxa, there were a variety of other, less common types that included small cladocerans (e.g., *Bosmina*, *Chydorus*), rotifers (*Kelicottia* and *Asplanchna*), and several invertebrate predators. The invertebrate predators sampled were the cladoceran *Leptodora*, *Chaoborus* (the phantom midge), and Hydracarina (a water mite). It is also notable that large (~ 0.6 mm diameter) spherical clumps of an unidentified algae species were found at relatively high densities in zooplankton net samples collected from shallow water in July and August (see Table 20 in *Appendix A: Monitoring Results: Biology* for complete zooplankton net sample data set).

Data from net samples show that the smaller-bodied *D. mendotae* was more abundant than larger-bodied *D. pulicaria* throughout the 2010 study (Figure 29 and Figure 30). This is a change from previous years when *D. pulicaria* was the most abundant species of *Daphnia* in Square Lake (MWMO 2002; Hembre 2006). *Daphnia mendotae* was found in net samples from all depths, but was usually most abundant in samples from shallower (epilimnetic and metalimnetic) depths (Figure 30). In addition, a helmeted morph of *D. mendotae* was common in samples from July and August. The induction of structures such as helmets and spines in *Daphnia* often occurs in response to presence of invertebrate predators such as *Chaoborus* or *Leptodora* (e.g., LaForsch and Beccara, 2006). The increased abundance of the helmeted *D. mendotae* morph may have been caused by the increased levels of *Leptodora* that were observed in July and August (see Table 19 in *Appendix A: Monitoring Results: Biology*).

Daphnia pulicaria concentrations were highest from May through early July (between 1.6-2.8/L), and decreased to low levels (< 0.5/L) from late July through September (Figure 29). From June onward, *D. pulicaria* was almost entirely absent in net samples from epilimnetic depths (Figure 30). The population density of *D. pulicaria* was lower in 2010 (Figure 31) than it was in 2004-2005 (Figure 32 – from Hembre, 2006). Mean body size of *D. pulicaria* was greatest in late-June and July (Figure 33).

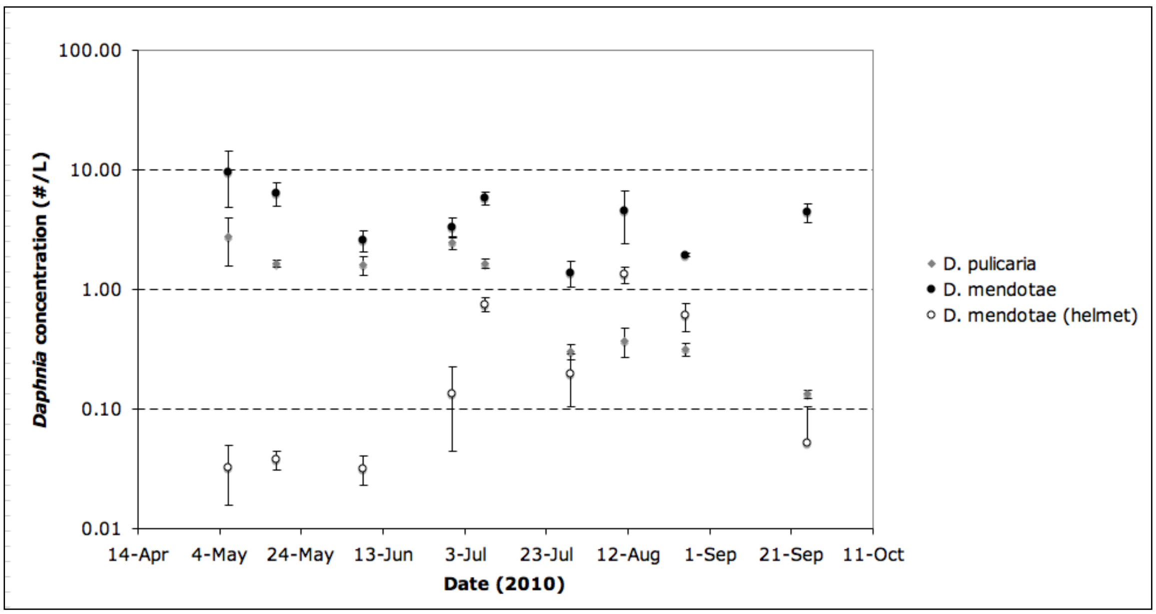
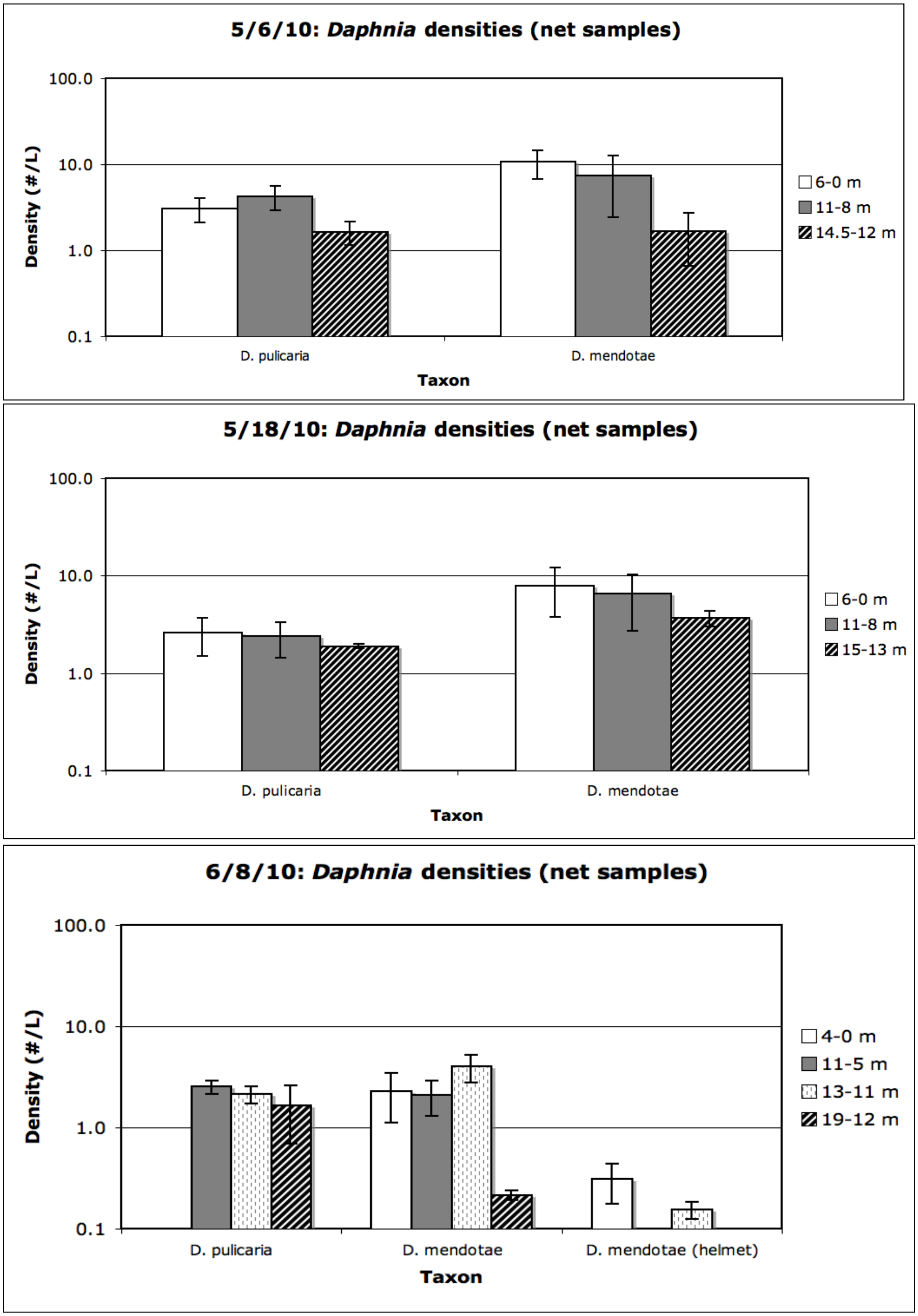
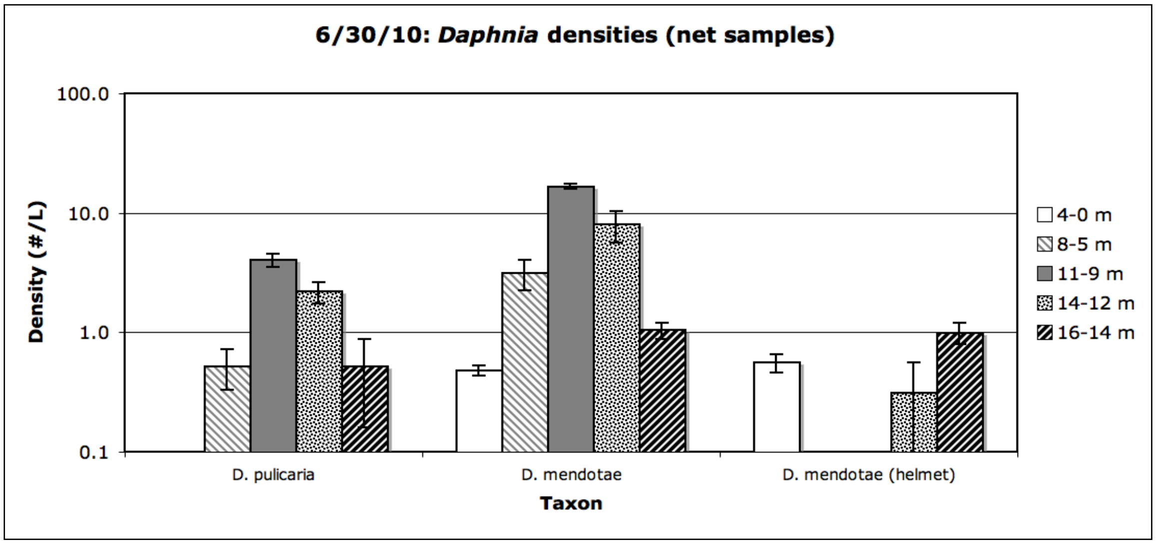
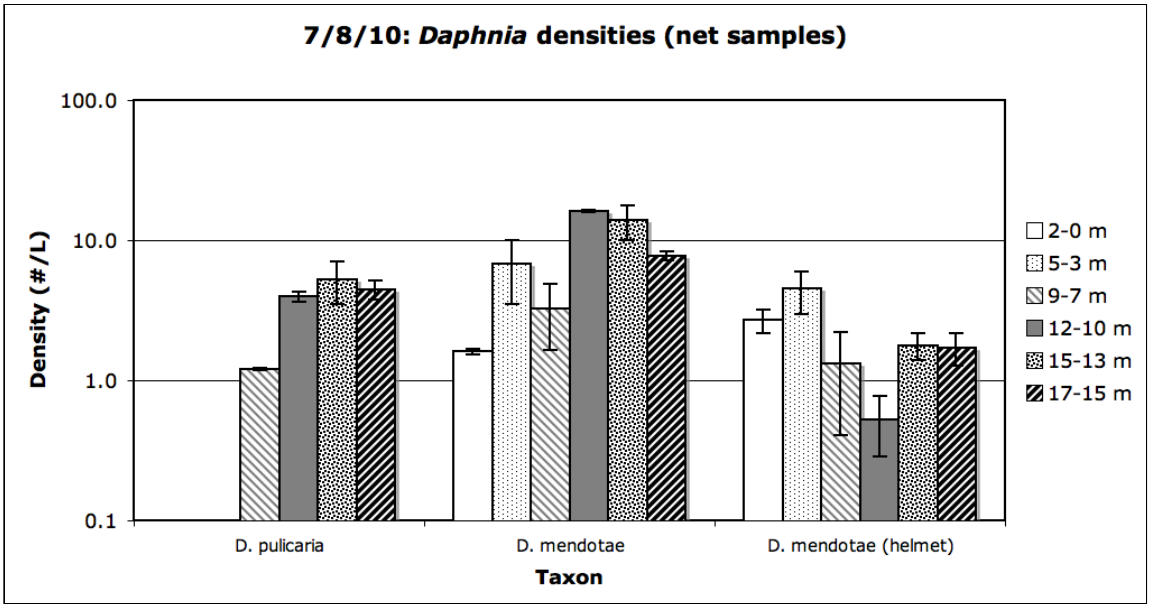


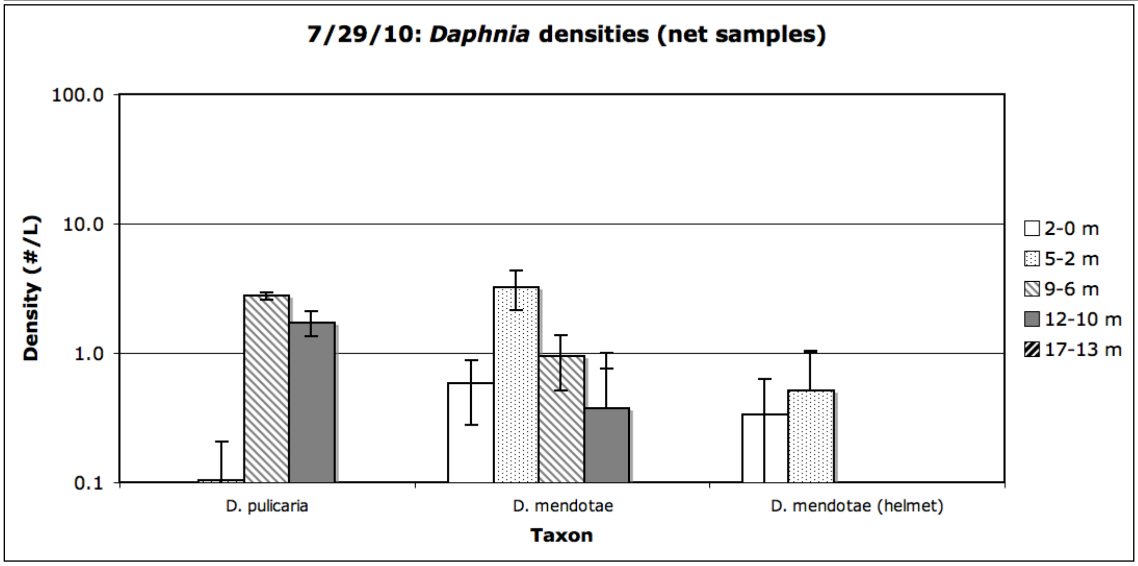
Figure 29. Densities of *Daphnia pulicaria* and *D. mendotae* (normal and helmeted morph) from whole water column net samples in 2010. Error bars represent +/- s.d.

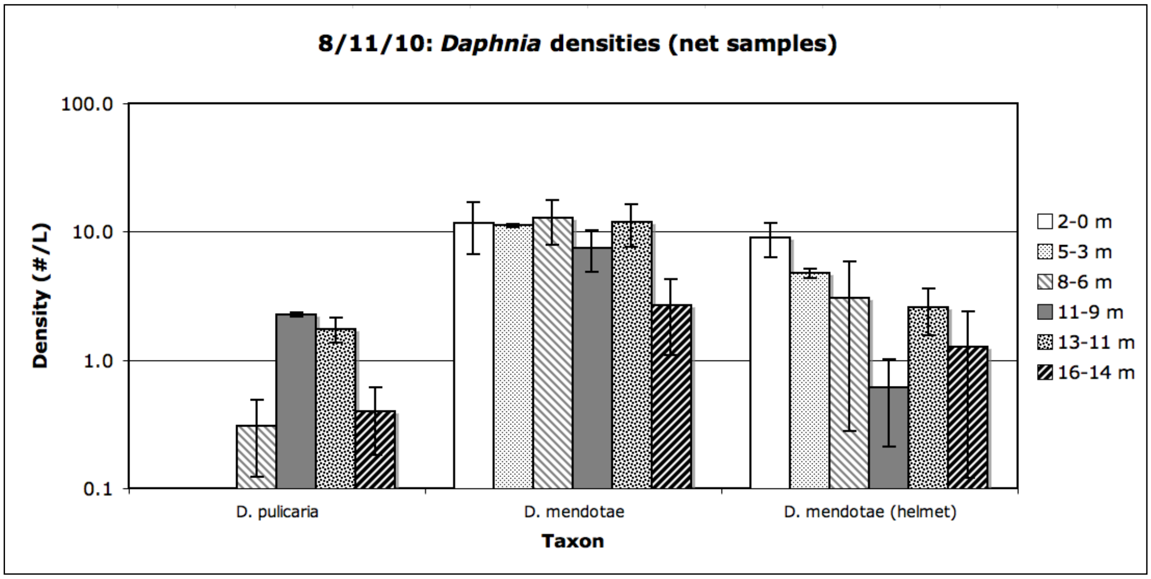
Figure 30. Densities of *D. pulicaria* and *D. mendotae* collected in net tows from different depths in the water column in 2010 (multi-panel figure). Error bars represent +/- s.d.

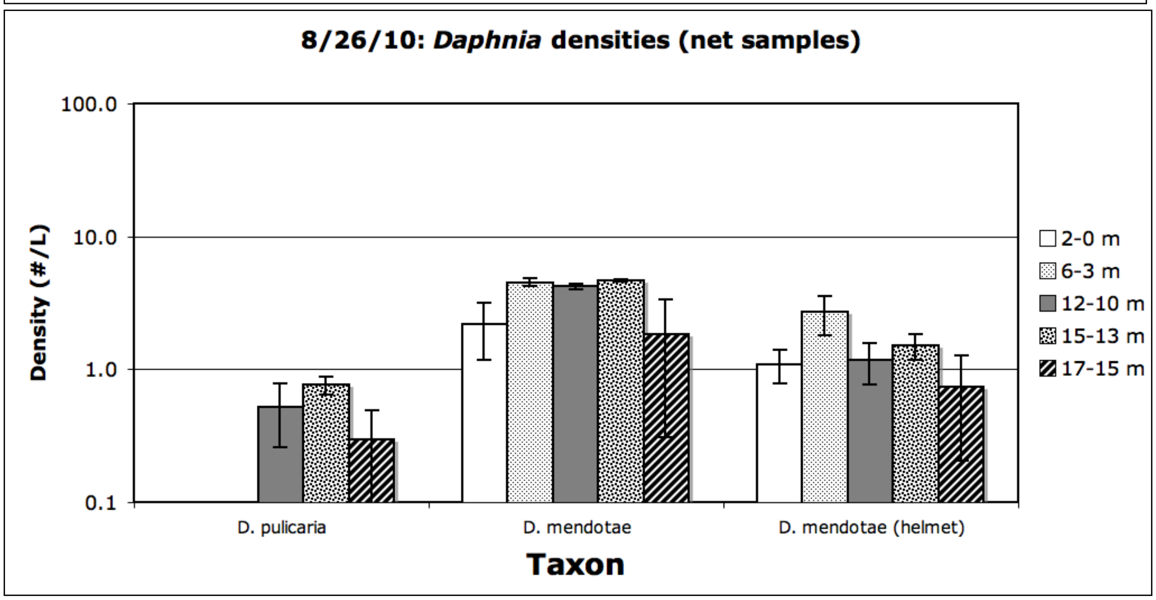


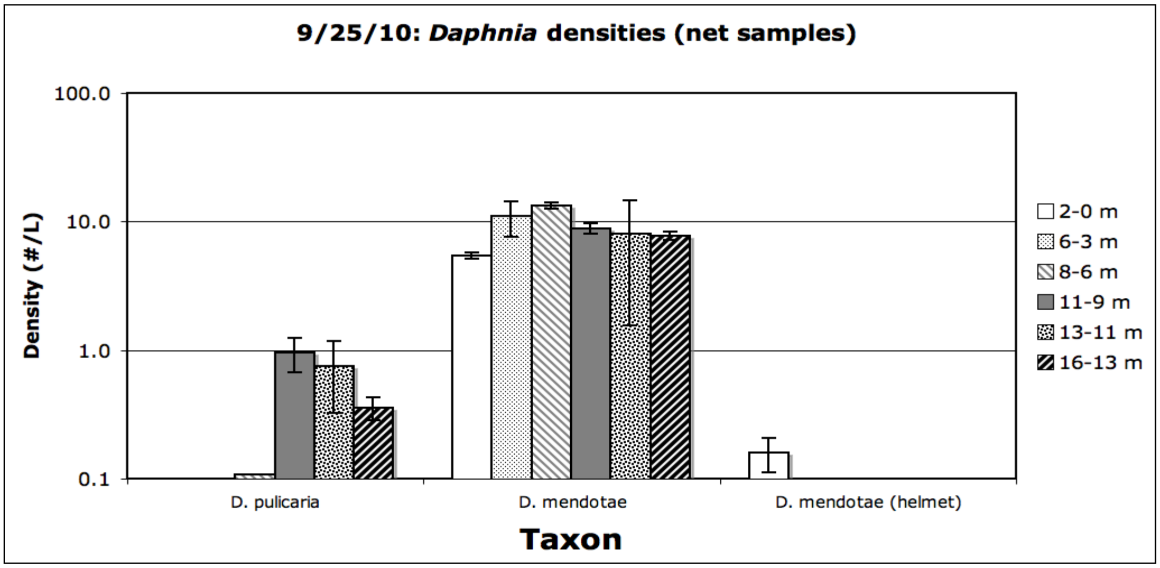

6/30/10: Daphnia densities (net samples)
Density (#/L)
100.0
10.0
1.0
0.1
D. pulicaria
D. mendotae
D. mendotae (helmet)
Taxon
4-0 m
8-5 m
11-9 m
14-12 m
16-14 m


7/8/10: Daphnia densities (net samples)
Density (#/L)
100.0
10.0
1.0
0.1
D. pulicaria
D. mendotae
D. mendotae (helmet)
Taxon
2-0 m
5-3 m
9-7 m
12-10 m
15-13 m
17-15 m


7/29/10: Daphnia densities (net samples)
Density (#/L)
100.0
10.0
1.0
0.1
D. pulicaria
D. mendotae
D. mendotae (helmet)
Taxon
2-0 m
5-2 m
9-6 m
12-10 m
17-13 m


8/11/10: Daphnia densities (net samples)
100.0
10.0
1.0
0.1
Density (#/L)
D. pulicaria
D. mendotae
D. mendotae (helmet)
Taxon
2-0 m
5-3 m
8-6 m
11-9 m
13-11 m
16-14 m


8/26/10: Daphnia densities (net samples)
100.0
10.0
1.0
0.1
Density (#/L)
D. pulicaria
D. mendotae
D. mendotae (helmet)
Taxon
2-0 m
6-3 m
12-10 m
15-13 m
17-15 m



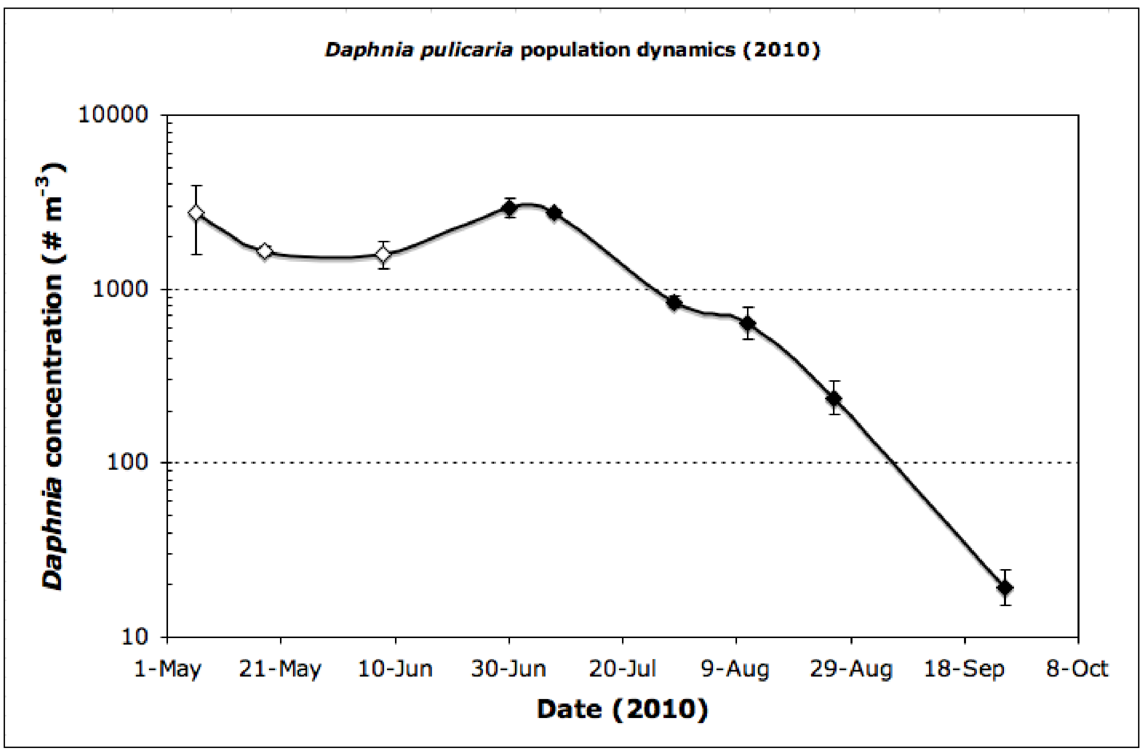


Figure 31. Population density of D. pulicaria during 2010.

Open symbols represent dates when population size was assessed from net samples from three locations. Closed symbols are population size estimates from sonar data. Error bars represent +/- s.e.

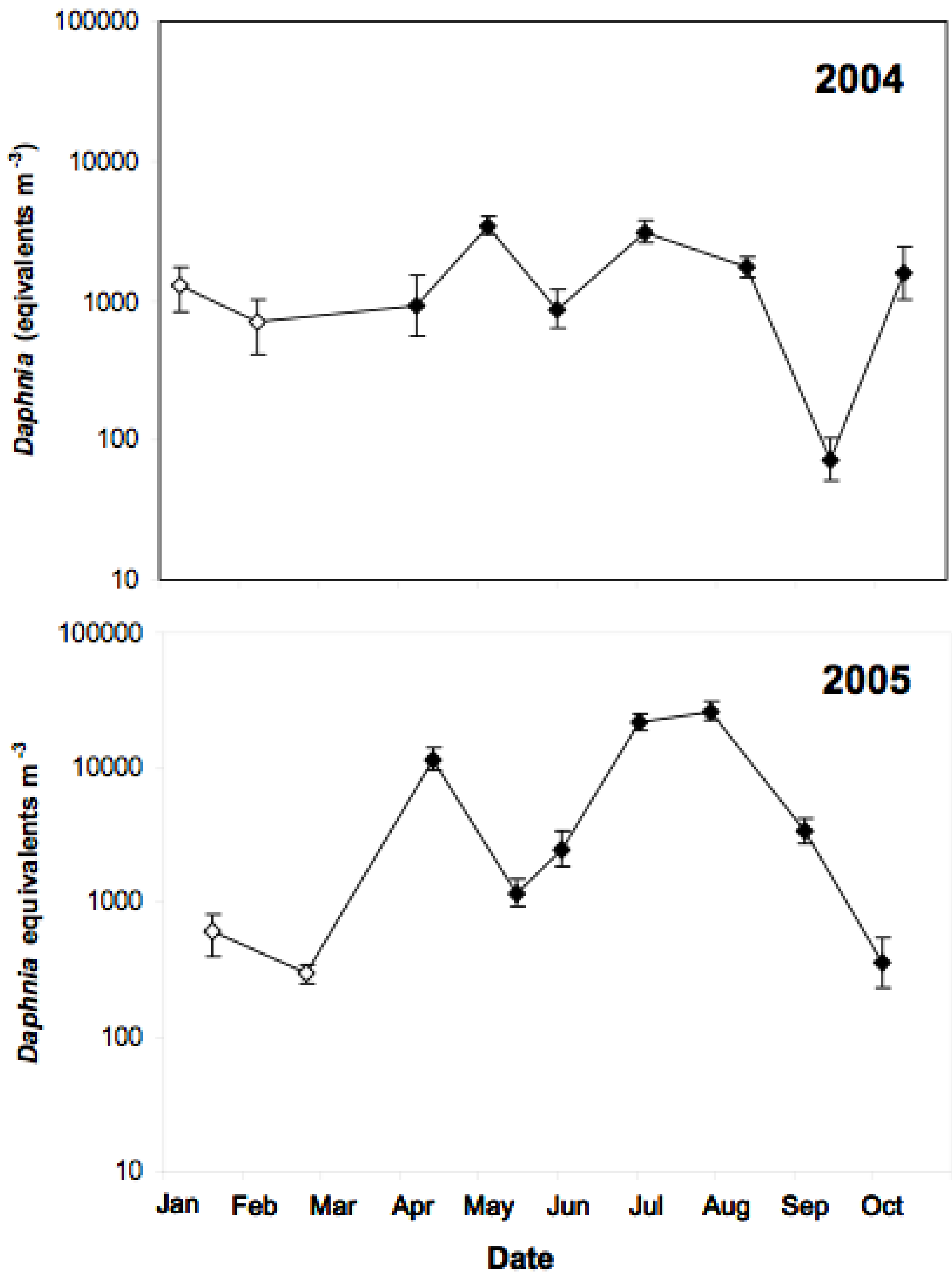


Figure 5. Population dynamics of *D. pulicaria* for 2004-2005. Sonar data were used to estimate population density (*Daphnia* equivalents m^{-3}) on all but the four winter dates (open symbols). On those dates, population density was estimated from conventional net sampling. Error bars represent ± s.e.

Figure 32. Daphnia pulicaria population density during 2004-2005

Excerpted from Fig. 5 of LCCMR study report (Hembre, 2006); compare to 2010 data in Figure 31.

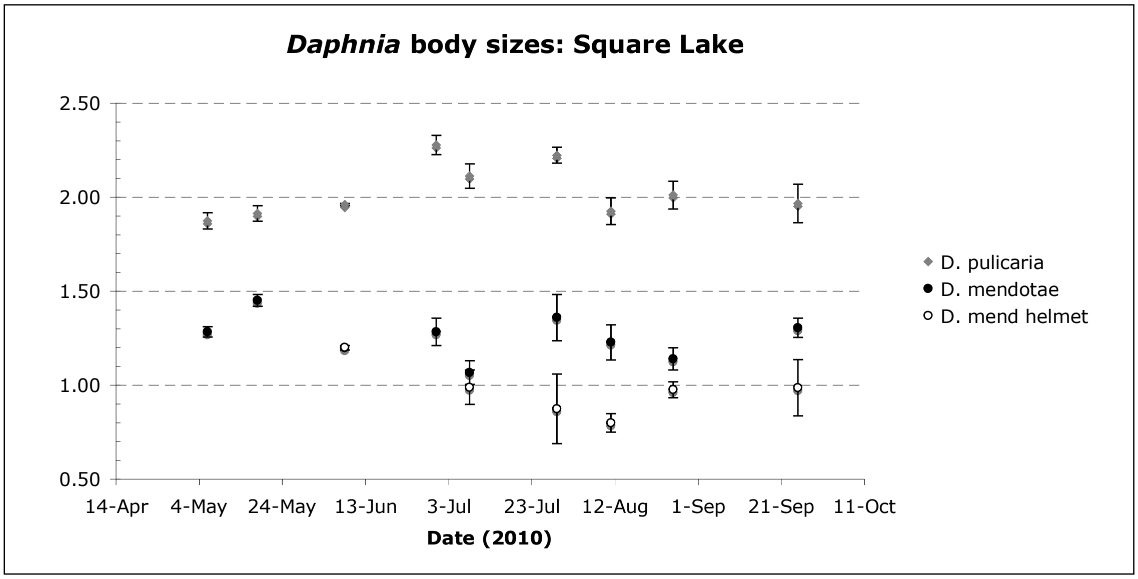


Figure 33. Mean body sizes of *D. pulicaria* and *D. mendotae* from whole water column net tows collected in 2010.

D. pulicaria is markedly larger than *D. mendotae*. Error bars represent +/- s.e.

3.3 Major Findings and Hypothesis for the Water Quality Decline

3.3.1 Summary of findings

The following summarizes the diet analysis, zooplankton community structure, and environmental and water quality data as they relate to the in-lake ecological interactions.

- Diet analysis of potential predators of large-bodied *Daphnia* (*D. pulicaria*)
    - Rainbow trout consume the most *D. pulicaria* (per capita) of any of the fish species examined in this study.
    - Only relatively large (> 15 cm) bluegill sunfish consume *Daphnia*, and most of the *Daphnia* they consume are the smaller-bodied *D. mendotae* species.
    - Whereas the per capita consumption of *D. pulicaria* by trout was higher than the per capita rate by bluegill, the bluegill population size is likely larger than the population of rainbow trout in Square Lake.
    - None of the species of small fishes (minnows, shiners, killifish) were found to consume *Daphnia*.
    - *Chaoborus* were not abundant in Square Lake in 2010 and those examined were not found to have consumed *D. pulicaria*.

- Zooplankton community structure
    - *D. pulicaria* were less abundant than *D. mendotae* throughout the 2010 study.
    - *D. pulicaria* abundances declined to very low levels (< 0.5/L) by late July and they were less abundant in 2010 than in 2004-2005 (Hembre, 2006).

- Environmental and water quality data
  - Summer water quality (water transparency and algal biomass levels) was similar to that of the past decade and substantially worse than historical water quality (before 1990).
  - The hypolimnion became hypoxic (< 2 mg/L) by early June 2010. The low levels of oxygen in the deep water restricted the habitat space (see explanation below) for *D. pulicaria* and likely contributed to the decline in their population density over the summer.

3.3.2 Daphnia pulicaria refuge

Low densities of large-bodied zooplankton such as *D. pulicaria* limit the grazing capacity in the lake and may be a factor leading to the declining lake transparency. The decline in *D. pulicaria* population likely involves an interaction between direct predation on *D. pulicaria* and a loss of *D. pulicaria* refuge as oxygen becomes depleted in deep water. Temperature and oxygen data from 2010 show that the lake was strongly thermally stratified by early June and that low oxygen levels in the deep water caused the refuge zone available to *D. pulicaria* (Hembre and Megard, 2003) to be quite restricted from early June onward (Table 11). *Daphnia pulicaria* migrate out of surface waters during the daytime and typically require oxygen levels greater than 1 mg/L. An important predator of *D. pulicaria* in Square Lake, rainbow trout, requires cold (< 21 ^{o}C) and well-oxygenated (> 5 mg/L) water and can potentially inhabit depths where those conditions are met (Wang et al., 1996). Therefore the daytime refuge for *D. pulicaria* is where oxygen levels are between 1 and 5 mg/L. The thickness of this daytime refuge decreases throughout the growing season, becoming extremely restricted in late August and September.

Table 11. Temperature and oxygen data, 2010 with respect to Daphnia pulicaria habitat & refugia. The top half of this table shows temperature data with color coding for epilimnion (orange), metalimnion (yellow), and hypolimnion (blue). The bottom half of the table contains dissolved oxygen data and is coded to illustrate the daytime habitat and refuge zones for *Daphnia pulicaria*. The orange border marks the bottom of the epilimnion. *D. pulicaria* descend out of the epilimnion during the daytime. Rainbow trout require cold (< 21 °C) and well-oxygenated (> 5 mg/L) water and can potentially inhabit depths where those conditions are met. Red shading indicates the anoxic zone (< 1 mg/L), green shading indicates the depth zone that would be a daytime refuge for *D. pulicaria* (oxygen > 1 mg/L and < 5 mg/L). From June onward in 2010, the daytime refuge zone for *D. pulicaria* in Square Lake was only 1-3 m thick.

2010 temp		orange = epilimnion			yellow = metalimnion			blue = hypolimnion				
Depth	5/6	5/18	6/3	6/8	6/16	6/30	7/8	7/29	8/11	8/17	8/26	9/25
0	13.6	17.8	23.9	22.1	23.7	24.1	26.6	27.7	27.9	24	24.8	16.9
1	13.5	17.8	23.9	22.1	23.5	23.9	26.6	27.5	27.5	24.8	24.8	16.9
2	13.4	16.6	23.4	22	23.2	23.7	26.3	27	27.3	24.8	24.7	16.9
3	13.2	14.3	22.8	22.1	22.8	23.5	26.1	26.8	27.2	24.8	24.7	16.9
4	13.1	13.4	18.6	22.1	22.7	23.3	25.9	26.7	27.1	24.8	24.6	16.8
5	13	12.8	15.6	16.2	20.8	21.7	23.1	26.1	26.2	24.7	24.3	16.8
6	13	12.5	14.2	14.6	16.2	18.2	18.6	22.4	23.4	24.6	23.8	16.8
7	13	12.2	13	13.4	14.4	15.6	15	17.3	18.4	19	20.4	16.8
8	11	11.5	11.8	12.4	12.9	13.2	13.2	14	15	14.9	15.7	16.7
9	8.9	11	10.6	11	11.3	11.8	11.4	11.8	12.7	12.6	12.8	16.5
10	7.2	9	9.3	8.7	9.4	9.9	9.6	10.1	10.5	10.4	10.6	11.8
11	6.6	7.1	8.3	7.3	8.1	8.6	8.1	8.7	8.5	8.8	9.1	9.8
12	5.9	6.4	7.2	6.8	7.9	8.2	7.2	7.7	7.4	7.6	8.1	8.2
13	5.7	6.1	6.4	6.3	7.1	7.3	6.8	7.1	6.8	7	7.3	7
14	5.6	5.8	6.1	6.1	6.4	6.3	6.3	6.6	6.7	6.7	6.8	7
15	5.6	5.6	6.1	6	6.1	6.2	6.3	6.4	6.5	6.4	6.5	6.9
16	5.5	5.5	6	6	6	6.1	6.1	6.3	6.4	6.4	6.4	6.7
17	5.4	5.5	6	5.9	6	6.1	6.1	6.2	6.4	6.3	6.4	6.7

2010 oxygen	red = anoxia zone		green = *D. pulicaria* refuge (<5 mg/L & > 1 mg/L)				daytime habitat: below orange line (excluding red shaded area)					
Depth	5/6	5/18	6/3	6/8	6/16	6/30	7/8	7/29	8/11	8/17	8/26	9/25
0	12.2	10.3	11.6	11.5	11.3	11.2	10.1	7.14	7.83	9.1	7.87	7.9
1	12.2	10.1	11.1	11.4	11.1	10.8	10.1	7.15	7.8	9.2	8.97	7.9
2	12.2	**10**	11.2	11.3	10.9	11.6	10.1	7.13	7.65	9.2	7.98	7.9
3	12.2	**10.2**	11.95	11.2	11.3	11.4	9.9	7.02	7.6	9.2	7.95	7.9
4	12.2	**9.98**	**16.6**	11.3	11.3	11.4	9.96	6.92	7.3	9.2	8.03	7.9
5	12.2	**9.8**	**17**	**12.3**	**11.9**	**11.2**	**8.78**	5.8	6.5	9.1	7.8	7.9
6	12.1	**9.7**	**16**	**16.4**	**15.5**	**14**	**11.9**	**8.7**	**6.35**	9	7.4	7.9
7	11.9	**9.5**	**15.4**	**15.1**	**14.1**	**14.1**	**11.2**	**9.2**	**7.4**	**10.1**	**7.6**	7.95
8	**10.8**	**8.9**	**12.4**	**14.1**	**12.6**	**11.4**	**10**	**6.5**	**6.2**	**4.1**	**5.55**	7.71
9	**10.4**	**8.4**	**10.2**	**10.9**	**9.3**	**8.9**	**4.4**	**4.8**	**4.4**	**1.6**	**1.35**	**3.4**
10	**8.9**	**6.9**	**6.1**	**5.8**	**5.2**	**4.7**	**1.1**	**1.2**	0.3	0.3	0.4	0.2
11	**7.5**	**5.4**	**4.9**	**2.5**	**2.3**	**2.2**	0.5	0.2	0.3	0.2	0.2	0.1
12	**6.6**	**4.6**	**2.4**	**1**	**1.2**	**1.5**	0.3	0.1	0.2	0.1	0.2	0.1
13	**5.8**	**3.9**	**1**	0.1	0.25	0.24	0.3	0.1	0.2	0.1	0.1	0.1
14	**5.4**	**3.35**	0.3	0.07	0.04	0.03	0.2	0.1	0.1	0.1	0.1	0.1
15	**5.3**	**2.83**	0.03	0.05	0.03	0.02	0.1	0.1	0.1	0.05	0.08	0.07
16	**5.3**	**2.7**	0.02	0.04	0.02	0.02	0.1	0.1	0.06	0.04	0.05	0.05
17	**5.1**	**2.6**	0.02	0.04	0.02	0.02	0.1	0.05	0.05	0.03	0.03	0.04

3.3.3 Hypothesis for the decline in the water clarity of Square Lake:

The following section presents logic for the hypothesis that an interaction between the earlier onset of summer stratification (due to climate change) and predation on *D. pulicaria* by rainbow trout during winter-early summer is responsible for the marked decline in the water clarity of Square Lake over the past 30 years. It is important to note that previous research on Square Lake (MWMO, 2002; Hembre, 2006) has shown that the population density of *Daphnia pulicaria* significantly affects the levels of algal biomass in the lake (e.g., Figure 34) and the lake's water clarity.

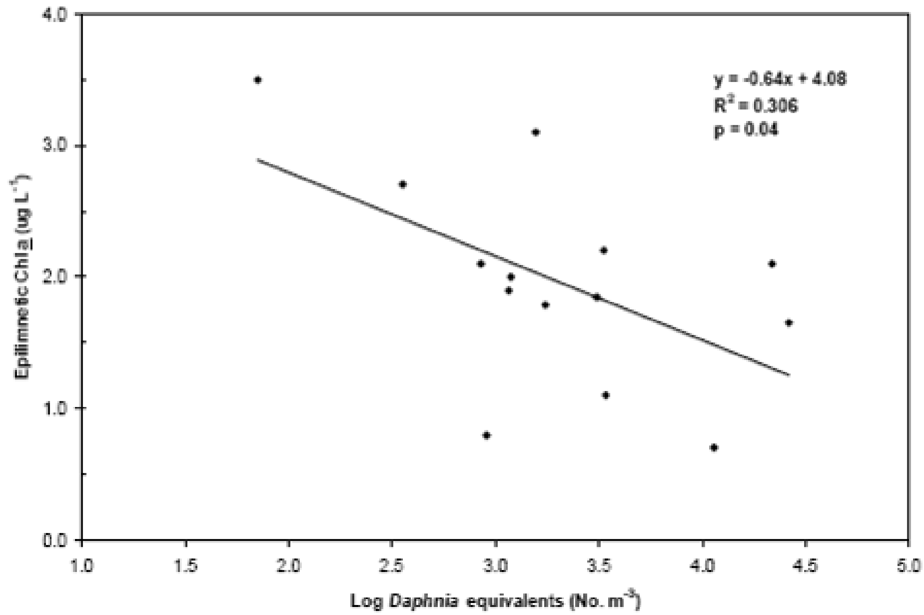


Figure 12. Simple linear regression of epilimnetic chlorophyll a (Chl a) concentration versus Log *Daphnia* concentration determined from acoustic analyses in 2004 and 2005.

Figure 34. Significant (p=0.04) negative relationship between *Daphnia* population density and algal biomass in Square Lake (excerpted from Hembre, 2006).

Effects of predation by rainbow trout over winter and into early summer:

- Predation on *D. pulicaria* by rainbow trout over winter and in the spring prevents the *Daphnia* population from attaining an adequate 'seed' population that can proliferate in response to the spring phytoplankton bloom (Hembre and Megard, 2005).
- Smaller populations of large-bodied *Daphnia* in the spring enables higher levels of algal biomass to accumulate and less of the algae is consumed than when the *D. pulicaria* population is able to reach its maximum. This inhibits the 'spring clear-water phase' that occurs in many lakes with levels of productivity near the oligo-mesotrophic border.
- As a result, there is more organic deposition (sinking algae) from the photic to the aphotic zone of the lake. As that organic material decomposes in the aphotic zone it depletes the oxygen from the deep water. Examination of available historical data for Square Lake from the EQuIS database shows the expected positive relationship between deep water (12 m) oxygen concentrations in August versus average May-June Secchi depths (Figure 35).

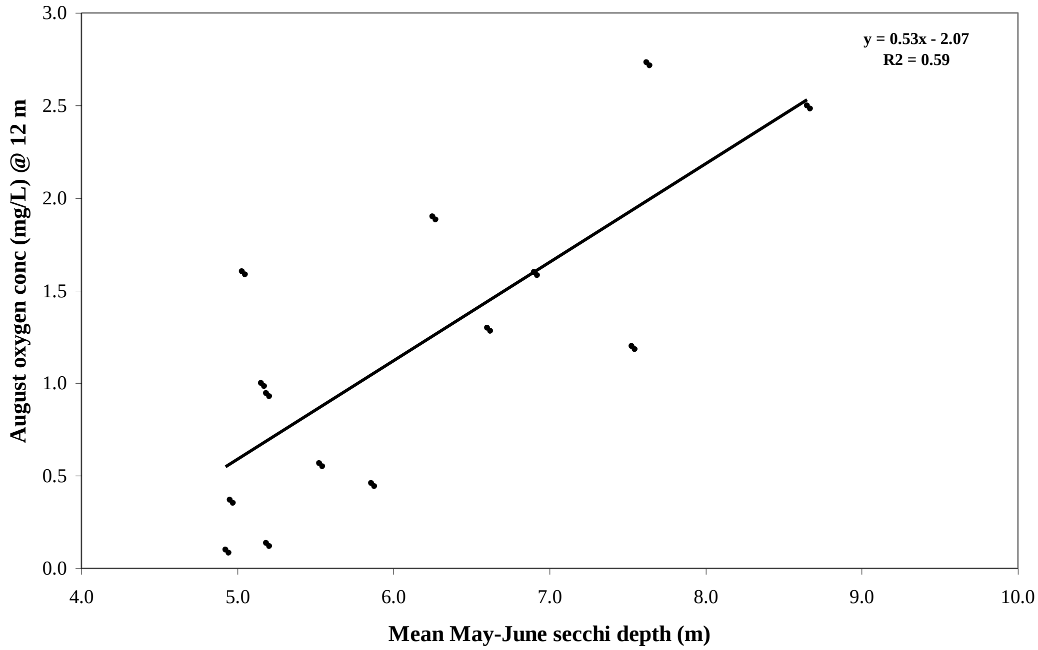


Figure 35. Dissolved oxygen concentration in the deep water (12 m) of Square Lake versus the mean Secchi depth during May-June (based on available data from the EQuIS database).
The 12 m depth is typically near the top of the hypolimnion.

- Oxygen depletion in the deep water has two relevant consequences:
  - It decreases the daytime 'refuge zone' for the large-bodied *Daphnia* by squeezing them into shallower depths where they are more susceptible to predation by rainbow trout.
  - It eventually diminishes the volume of habitat suitable for rainbow trout (i.e., water <21 deg. C and oxygen > 5 mg/l).

    * Data from 2010 fit this pattern in that *D. pulicaria* densities decreased to low levels when their refuge zone became very small.

    ** The low abundances of rainbow trout observed from July onward in 2004 and 2005 (Hembre, 2006) are also consistent with this mechanism.

Effect of earlier onset of stratification and interaction with food chain dynamics:

- The trophic scenario described above would logically be exacerbated by an earlier onset of summer stratification (due to climate warming). It has been documented (by the Minnesota State Climatology Office and the Department of Natural Resources) that the climate in Minnesota has warmed significantly over the past 30 years and that the average date of ice-out is significantly earlier now than in the past (DNR 2011). Earlier and stronger stratification decreases the dissolved oxygen flux (via mixing) into the deeper water and effectively 'puts a cap' on the deeper water of the lake earlier in the year. The high thermal stability of the water column promotes greater hypolimnetic oxygen depletion (Jankowski et al., 2006) and constrains the volume of the habitat spaces available to rainbow trout and *D. pulicaria*.

If the trend in increased algal abundance and decreasing water transparency continues, Square Lake is likely to continue its shift from a historically oligotrophic system to a mesotrophic system (Figure 36).

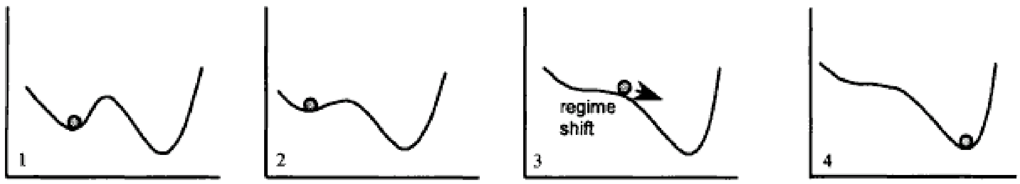


Figure 36. Conceptual visualization (adapted from Folke et al., 2004) of a regime shift that may be occurring in Square Lake.

The left-hand panel represents the resilient oligotrophic, clear-water regime that predominated in the past. The middle two panels represent the erosion of resilience in the ecosystem and the movement toward a new equilibrium condition (right-hand panel). The new equilibrium would likely be a mesotrophic state given the nutrient status of the lake.

3.4 Resource Water Quality Goals

The goal of the Square Lake Implementation Plan is to improve the long term Secchi transparency to an average of 7 meters (23 feet). This was also the Secchi transparency goal from the 2002 diagnostic study and represents the water clarity observed in Square Lake in the mid-1990s before the water clarity began to degrade.

In order to meet the transparency goal, *Daphnia pulicaria* densities need to be increased in Square Lake through either decreasing predation pressure and/or improving habitat.

In order to buffer the lake against potential eutrophication, phosphorus loads to the lake should at a minimum not be allowed to increase. Where possible, recent increases in phosphorus loading to the lake should be mitigated.

3.5 Conclusions

3.5.1 Phosphorus loads

- Changes in the watershed have led to small increases in watershed phosphorus loading to Square Lake since the time of the 2002 diagnostic study.
- The phosphorus load from the Wilder wetland may not be as big a component of the overall phosphorus budget to Square Lake as previously thought. Based on the observation that the wetland has not been negatively impacted by humans, phosphorus loads have likely not increased in recent years.
- Phosphorus concentrations in the groundwatershed of Square Lake are typical for the region and do not appear to be contributing to the decline in water quality in Square Lake.

3.5.2 In-lake ecological interactions

- Rainbow trout consume the most *D. pulicaria* per capita of any of the fish species examined in this study.

- Only relatively large (> 15 cm) bluegill sunfish consume *Daphnia*, and most of the *Daphnia* they consume are the smaller-bodied species.
- None of the species of small fish (minnows, shiners, killifish) were found to consume *Daphnia*.
- *D. pulicaria* abundances declined to very low levels (< 0.5 per liter) by late July and they were less abundant in 2010 than in 2004-2005.
- Low oxygen levels in the deeper waters began to restrict the habitat space for *D. pulicaria* in early June and severely limited their 'refuge zone' later in the summer (Table 11, Figure 37).

3.5.3 Hypothesis for the decline in the water clarity of Square Lake:

It is hypothesized that an interaction between the earlier onset of summer stratification (due to climate change; see DNR (2011) for a discussion about projected impacts of climate change on lake stratification) and predation on *D. pulicaria* by rainbow trout during winter-early summer is responsible for the marked decline in the water clarity of Square Lake (Figure 37).

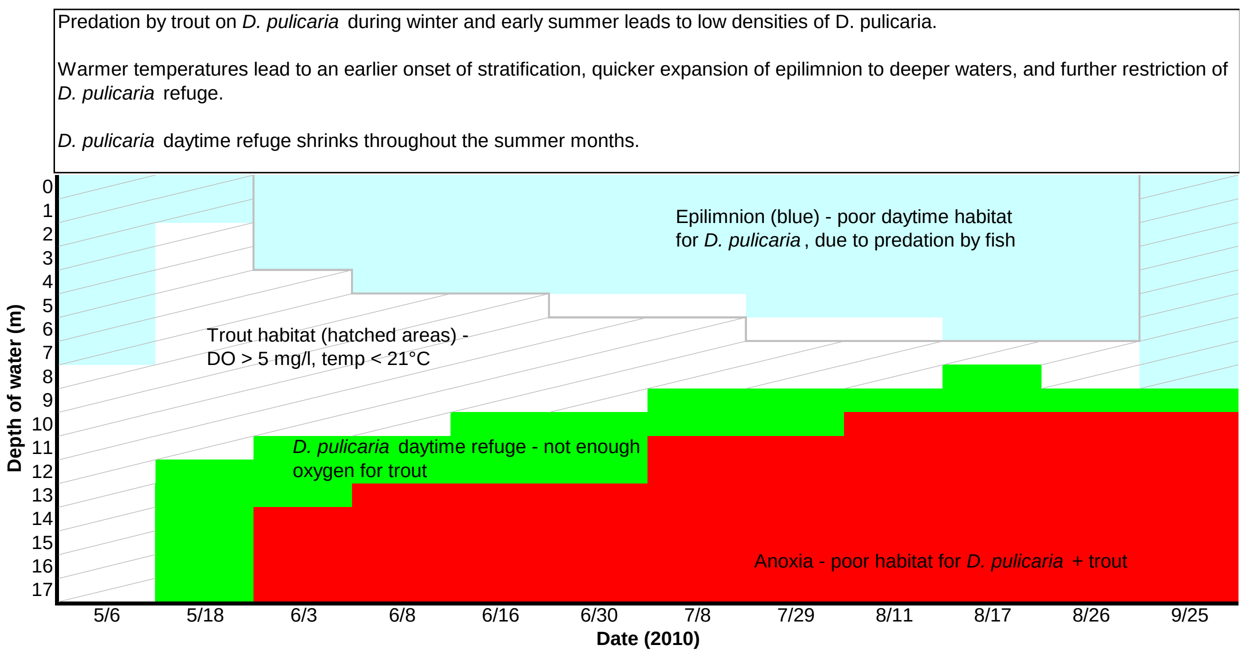


Figure 37. Representation of the shrinking *D. pulicaria* daytime refuge during summer stratification in 2010.

4 IMPLEMENTATION PLAN

4.1 Objectives

The objective of this project was to turn the implementation ideas developed in the 2002 Diagnostic Feasibility Study and Implementation Plan ("2002 Implementation Plan") into site-specific and action-specific activities to meet the resource water quality goal of improving long term Secchi transparency to an average of 7 meters (23 feet). This was accomplished by further investigating the implementation ideas identified in the 2002 Implementation Plan, gathering additional relevant information to identify changes in the lake from 2002 to present, and developing specific actionable projects for implementation.

Based on the findings from the Diagnostic Study (Section 3), the following priority management areas were identified for implementation and will be referred to throughout this implementation plan:

1. ***Primary: In-Lake Food Web Interactions***
   In-lake food web interactions were predicted to have the strongest effect on improving water quality and are the primary focus of this implementation plan.
2. ***Secondary: Groundwater***
   Phosphorus loads from groundwater account for 70% of the total phosphorus load to Square Lake and are a secondary focus of this implementation plan.
3. ***Secondary: Surface Water Runoff***
   Phosphorus loads from surface water runoff account for 18% of the total phosphorus load to Square Lake and are a secondary focus of this implementation plan.

Table 12 summarizes all implementation activities that were assessed in the 2002 Implementation Plan and as a part of this study. The numbering system used in the original 2002 Implementation Plan is used in this study. In order to distinguish between original and new projects, completed and priority projects, the implementation activities have been categorized with the following symbols:

- ***Completed*** (✓): Implementation activities from the 2002 Implementation Plan that have been completed, or partially completed, at the time this report was finished.
- ***New*** (**NEW**): New implementation activities recommended as a part of this study.
- ***Updated*** (ⓘ): Updates to implementation activities originally recommended in the 2002 Implementation Plan.
- ***Priority*** (★ or ★★)**:** Implementation activities with one star (★) address a secondary management area and are a priority; recommendations with two stars (★★) address a primary management area and are a high priority.

These implementation activities fit within two main strategies to meet the transparency goal:

1. Increase *Daphnia pulicaria* densities by decreasing predation and/or improving habitat.
2. Maintain or decrease existing watershed phosphorus loads to buffer the lake against potential eutrophication.

Table 12. Summary of completed 2002 Implementation Plan activities, new activities with updates and prioritization recommendations

Implementation Plan Activities	Completed	New	Priority	Updated (See report page)
1. Water Quality—Groundwater				
a. Informational kiosk at the Washington County Square Lake Park	✓			
b. In-lake groundwater monitoring				ⓘ (32-35)
c. Groundwater monitoring network				
d. Distribution of septic management materials to homeowners in Square Lake Watershed	✓		★	
e. Septic pumping program	✓		★	
f. Septic system upgrades			★	ⓘ
2. Water Quality—Surface Water				
a. Informational kiosk at the Washington County Square Lake Park	✓			
b. Distribute home lawn care information	✓			
c. Stormwater runoff regulations to provide no net increase in phosphorus			★	
d. Soil testing program				
e. In-lake bio-monitoring				ⓘ (47-58)
f. In-lake water quality monitoring			★★	ⓘ (37-44)
g. Wilder road stabilization				
h. Gully erosion control project				ⓘ
i. Maywood stormwater pond retrofit/enhancement				ⓘ
~~j. Wilder wetland rehabilitation~~ ‡				
k. Landowner education programs		**NEW**	★	
3. Fisheries Management Plan				
a. Evaluate predation of Daphnia	✓			ⓘ (47-58)
b. Suspend trout stocking		**NEW**	★★	

Implementation Plan Activities	Completed	New	Priority	Updated (See report page)
4. Aquatic Vegetation				
a. Develop and distribute information to encourage riparian landowners to protect and/or restore aquatic vegetation	✓			
b. Distribute MN DNR rules to riparian landowners	✓			
c. Aquatic plant survey	✓			ⓘ (44-46)
d. Develop an aquatic plant management plan				
5. Wildlife				
a. Work with landowners to place remaining undeveloped shoreline into conservation easement			★	ⓘ
6. Exotic Species				
a. Conduct boat inspections for Eurasian milfoil and zebra mussels	✓			
b. Conduct aquatic plant survey	✓			
7. Land Use/Zoning				
a. Distribute current shore land zoning regulations	✓		★	
b. Develop regulations regarding the alteration of ice/beach ridges	✓		★	
c. Stormwater runoff regulations to provide no net increase in phosphorus			★	
d. Work with landowners to place remaining undeveloped shoreline into conservation easement			★	ⓘ
8. Surface Water Use				
a. Distribute Square Lake boating regulations at boat launches	✓			
b. Conduct a study to determine appropriate peak and off-peak surface water use				
9. Public Water Access				
a. Distribute Square Lake boating regulations at boat launches	✓			
b. Develop an access policy consistent with surface water use study				
c. Work with private campground/marina (Golden Acres) to distribute educational materials and provide exotics inspections concurrent with efforts at public boat launch				

‡ Removed based on findings from this study, see Section 4.3

4.2 Implementation Activity Alternatives and Analysis

The following discussion is organized by priority management area and describes new, updated, and priority implementation activities (refer to Table 12). Activities from Table 12 that are already described in *Section 3: Diagnostic Study* or are unchanged from the original 2002 Implementation Plan are not discussed here. Table 12 includes reference page numbers for items previously discussed in Section 3 of this report. Information on priority recommendations carried over from the 2002 Implementation Plan was taken from the 2002 Implementation Plan and modified with updated project partners and costs. New information on implementation activities from this study is outlined with a box.

In-Lake Food Web Interactions

In-lake food web interactions were predicted to have the strongest effect on improving water quality and are the primary focus of this implementation plan. The two highest priority activities are to suspend trout stocking and to continue in-lake water quality monitoring.

★★ NEW Suspend trout stocking

The CMSCWD and the Minnesota Department of Natural Resources (MDNR) Central Region Fisheries signed a Memorandum of Understanding on November 16, 2012 to suspend trout stocking in Square Lake for three years, beginning in the fall of 2012, to evaluate whether stocking suspension results in significant changes to *Daphnia pulicaria* densities and water clarity of the lake (see Appendix C). The effects of the stocking suspension on zooplankton abundance and community composition, surface water algal biomass (chlorophyll-a), and water clarity will be evaluated with respect to whether or not the suspension leads to an increase in the abundance of *Daphnia pulicaria* in Square Lake and an increase in the lake's water clarity. The outcomes of this project are:

1. Zooplankton species abundance data during trout stocking suspension;
2. Water quality (nutrients, chlorophyll, transparency, dissolved oxygen, and temperature) data during trout stocking suspension;
3. Evaluation of the impact of the three-year suspension of rainbow trout stocking on the water quality of Square Lake; and
4. A recommendation of whether or not to permanently extend the trout stocking suspension for the benefit of the water quality in Square Lake.

See Section 4.4: Implementation Monitoring and Evaluation and Appendix C for trout stocking suspension and monitoring plan details. This project is funded by the CMSCWD and Hamline University and will cost $44,506.

★★ In-lake water quality monitoring

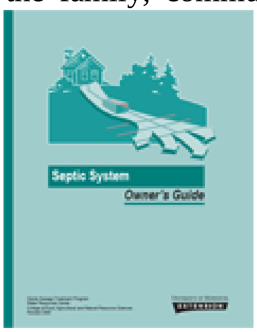
In-lake monitoring conducted by the Washington CD and the Metropolitan Council to look at Secchi disk transparency, temperature and dissolved oxygen depth profile, surface chlorophyll *a*, surface total phosphorus, and lake elevation, as well as qualitative characteristics such as recreational suitability, should continue 14 times per year (April through October) at the deepest location in Square Lake. This data will give the data necessary to ensure that Square Lake is maintaining its goal Secchi disk transparency of 22.9 ft (7 m) and give early warning signs of trends in decreased water quality. This program will continue to be funded through the CMSCWD and would cost approximately $2,100 per year.

Groundwater

Phosphorus loads from groundwater account for 70% of the total phosphorus load to Square Lake and are a secondary focus of this implementation plan. Septic system improvements can greatly reduce phosphorus loading to lakes and can be achieved through distribution of septic management materials to homeowners, septic pumping programs, septic system upgrades, and reducing the total number of septic systems.

★ Distribution of septic management materials to homeowners

CMSCWD or Washington County should distribute septic management materials to residents in the Square Lake watershed in even years. Septic systems, when properly designed, installed, operated, and maintained, will treat sewage cost-effectively to protect the family, community, and water supply from contamination and diseases for many years (Figure 38). A number of publications are available from the Minnesota Pollution Control Agency and the University of Minnesota Extension Service, including a prepared information packet from the Extension Service entitled, "A Septic System Owner's Guide"*. This document includes a worksheet for determining cleaning frequency based on specific septic system designs and on the amount of usage of the system, as well as information on how to minimize water use in the household. Assuming distribution to the owners of approximately 63 individual septic treatment systems located near Square Lake, these publications may cost $126 per distribution, plus staff time.



*Available online at: www.extension.umn.edu/distribution/naturalresources/dd6583.html.

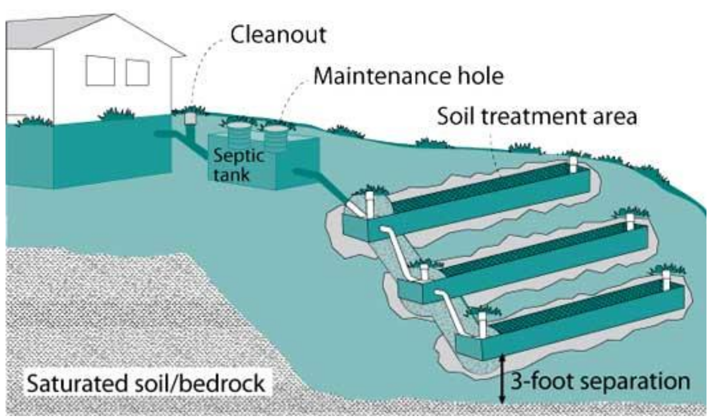


Figure 38. Schematic of a healthy septic system

From: www.pca.state.mn.us/index.php/living-green/living-green-citizen/yard-and-garden/healthy-septic-systems.html

★ Septic pumping program

Washington County Individual Sewage Treatment System Regulations (Ordinance 128) states: "The owner of an individual sewage treatment system or the owner's agent shall regularly, but in no case less frequently than every three years, have the tank or tanks pumped ..." A septic system that fails to treat sewage can also allow excess nutrients to reach nearby lakes and streams promoting algae and weed growth.

Washington County should send out notification every three years to remind homeowners to have their septic tanks pumped. If the county does not receive verification from the septic pumper that the septic has been pumped, a follow-up letter should be sent to the homeowner. In addition, the CMSCWD and the Square Lake Association can publish articles in their newsletters to remind homeowners to pump their septic systems. See Figure 39 for approximate locations of individual septic systems and their relation to the ground and surface watersheds of Square Lake.

★ Septic system upgrades

A septic system that fails to treat sewage can allow excess nutrients to reach nearby lakes and streams promoting algae and weed growth. Even systems that appear to be working well or that are in compliance with local design and installation codes may allow nutrients or bacteria to reach the ground or surface water. Washington County can seek funding assistance from the Board of Water and Soil Resources (BWSR) to conduct a county wide inspection of septic systems to reveal poorly functioning septic systems or systems that do not meet current standards. Only septic systems identified as imminent threats to public health would require mandatory upgrades. Other failing septic systems would be upgraded on a voluntary basis. An imminent threat to public health septic system is identified by:

- Sewage backing up into the home,
- Sewage discharging to the ground surface, and/or
- Sewage discharging to surface water bodies such as ditches, streams or lakes

The cost of the upgrade will depend on the individual septic system. The septic system upgrades would be paid by the individual landowner, but the CMSCWD can help landowners seek funding assistance from MPCA and BWSR.

> ⓘ A 2004 study by the MPCA estimated that approximately 11.4% of septic systems are failing (nonconforming) in the St. Croix Basin of Minnesota where Square Lake is located (MPCA 2004). Upgrading all failing septic systems (~7) to conforming systems in the Square Lake watershed would reduce the groundwater phosphorus load by 7 lb per year, or 4% of the total phosphorus load to Square Lake.

★ **Work with landowners to place remaining undeveloped shoreline into conservation easement(s)**

As part of the CMSCWD 2010 Watershed Management Plan Implementation Program - Administrative Projects and Initiatives (Section IV.H.3d), the CMSCWD can work with lakeshore landowners, May Township, Washington County, and nonprofit conservation organizations to place remaining undeveloped shoreline into conservation easements, a legally recorded agreement by which landowners may voluntarily restrict the use of their land. The landowner retains title to the property, the right to sell it, the right to restrict public access, and the right to deed it to whomever they choose. However, most or all of the rights to develop are restricted or eliminated. The terms of a conservation easement are individually tailored to reflect each landowner's particular needs, situation and property. Although the duration of a conservation easement can vary depending on the desires of the landowner, tax benefits generally are available only for perpetual easements. The cost of the program depends on the value of the property being placed into a conservation easement. The CMSCWD and Square Lake Association can work annually with individual landowners to place undeveloped shoreline into conservation easements.

ⓘ The northern shoreline of Square Lake remains largely undeveloped (Figure 39). If this land were subdivided into ten lots with permanent shoreline residences, approximately 11 lb P per year (or 6.5%) may be added to the total phosphorus load to Square Lake. Working with landowners to place the remaining undeveloped shoreline into conservation easement(s) would prevent future increases in septic system phosphorus loading to Square Lake.

Figure 39. Implementation activities targeted at reducing phosphorus in groundwater

Surface Water Runoff

Phosphorus loads from surface water runoff account for 18% of the total phosphorus load to Square Lake and are a secondary focus of this implementation plan. Surface watershed phosphorus loads can be reduced through regulations, landowner education, and best management practices. Since the 2002 Implementation Plan, an additional 12.6 and 13.7 acres of land were developed within subwatersheds SW-2 and SW-4. Implementation of best management practices in response to these watershed changes can reduce phosphorus loading to Square Lake.

The following implementation activities are discussed in this section:

- Distribute current shoreland ordinances
- Stormwater runoff regulations to provide no net increase in phosphorus
- Landowner education programs
- Gully erosion control projects
- Maywood stormwater ponds retrofits/enhancements
- Wilder Wetland rehabilitation

Figure 44 illustrates the location of the gully erosion control projects, Maywood stormwater ponds, and Wilder Wetland.

★ Distribute current shoreland ordinances

The CMSCWD can distribute current shoreland ordinances to residents in the Square Lake watershed annually. Educating landowners of shoreland ordinances can decrease the amount of sediment, fertilizers, or pesticides from surface runoff. It may also positively affect the shoreline habitat for wildlife. These distributions may cost $126 per distribution and may be funded by the CMSCWD.

★ Stormwater runoff regulations to provide no net increase in phosphorus

The CMSCWD can develop stormwater runoff regulations that provide no net increase in phosphorus loading into Square Lake. This regulation can be added to existing rules during the next rule update and may cost $5,000, which includes modeling justification support, the public comment process, and revisions.

★ NEW Landowner education programs

Landowner education programs are vital for increasing awareness of how human activities in the Square Lake watershed contribute to watershed phosphorus loading and affect lake water quality. Blue Thumb workshops can be used to educate landowners on the benefits and installation of shoreline buffers and rain gardens, but can be expanded to include the proper management of lawns (see descriptions below).

1. **Shoreline buffers** provide native vegetation with deep roots along lakeshores to reduce phosphorus loads through reduced runoff velocities, increased settling of particles, enhanced infiltration of water into the soil, and vegetative adsorption of phosphorus in runoff. Buffers should be at least 15 feet wide and on average 25 feet wide. In addition to phosphorus load reductions, shoreline buffers provide many additional benefits, including: filtering out other pollutants (besides nutrients) and sediments from runoff, protecting shoreline from erosion, providing food and habitat for wildlife, protecting property values, and providing aesthetic value.
2. **Rain gardens** are small, vegetated depressions that store and infiltrate runoff to reduce phosphorus loads through reduced runoff velocities, increased settling of particles, enhanced infiltration of water into the soil, and vegetative adsorption of phosphorus in runoff.
3. **Proper management of lawns** involves maintaining a healthy dense stand of turfgrass to reduce transport of phosphorus to lakes through erosion of bare soils and physical transport of grass and leaves. Proper lawn management recommendations include: leaving grass clippings on the lawn as fertilizer, mowing at a slightly higher height (2 ½ to 3 ½ inches) to shade out weeds, mowing often and not cutting off more than one-third of the grass blade so clippings will filter into grass and quickly decompose, and keeping stockpiles of yard waste (leaves and clippings) out of contact with watershed runoff.

Landowners with disturbed shorelines (wooded lawn, lawn, or impervious surfaces; Figure 44) should be specifically targeted for Blue Thumb workshops. These workshops may be funded through the CMSCWD and would cost approximately $1,500 per workshop of 20 attending landowners. One workshop should be held every year. Cost-sharing for landowners to construct shoreline buffers and rain gardens is available through the CMSCWD.

www.bluethumb.org

Gully erosion control projects

Two existing gullies in SW-2 and SW-12 of the Square Lake watershed have recently received treatment by Washington SWCD (Figure 44). In 1999, a gully erosion control project was completed on the north side of the lake in SW-12. While there are several other gullies on this property, they appeared stable at the time of this study and no further action is required other than periodic monitoring for future problems. Another active gully was treated on the south side of the lake in SW-2. This gully received drainage from CR 7 and was causing sediment to accumulate into the wetland complex within SW-2. No other active gullies exist within the watershed at this time.

The SW-2 gully was treated via installation of pipe and riprap from the County Road 7 right-of-way swales down to the toe of the slope. This treatment measure effectively eliminated the gully as an acute source of sediment, which is important for reducing soil erosion and transport of soil bound phosphorus. However, the project was not designed to reduce peak rates or channel velocities downstream of the gully stabilization project. As a result, the downstream drainage way continues to erode. Lack of managing peak runoff rates and volumes is further exacerbated by full tree canopy and near zero ground cover (Figure 40). Increasing the infiltration capacity of the road right of way swales can provide rate and volume reduction to this point discharge. In concept, this retrofit can be accomplished by over excavating the swales and backfilling with a rock storage layer below an engineered soil filtration layer with drain tile (Figure 41). While further feasibility would be required, a preliminary estimate of probable cost is approximately $75,000. Alternatively, stabilization of the downstream channel with erosion control blanket, native grasses, and judiciously placed rock can be explored in conjunction with tree canopy thinning. While this project would not provide upstream watershed treatment, preliminary estimated costs would be significantly less (<$25,000) than retrofitting the road right of way swales.

If watershed loading to Square Lake needs to be reduced in the future, the SW-12 gully pond can be retrofitted to reduce dissolved phosphorus loading from agricultural runoff. This can be accomplished by retrofitting the existing dry detention pond with filter media, such as iron enhanced sand. This project would be funded by the CMSCWD and would cost approximately $35,000, which includes design and construction.

Figure 40. County Road 7 swales drainage pipe (left) and SW-2 gully (right)

Figure 41. Potential retrofit areas of the road right of way swales discharging to the SW-2 gully. The shading denotes areas to be excavated and backfilled. The arrows show general flow direction.

Maywood stormwater pond retrofits/enhancements

Three stormwater ponds were constructed in the Maywood development on the south side of Square Lake (Figure 44). Aerial views of the three stormwater ponds are shown in Figure 42 and Figure 43.

Updated information from this study indicates that the Maywood stormwater pond in SW-4 (Figure 42) has significant storage capacity for its drainage area, but there is currently no skimmer on this stormwater pond to remove floatables. This pond discharges along a wide, gently sloped swale prior to discharging to Square Lake. A future enhancement to this stormwater pond can be the addition of a skimmer at the pond outlet to remove floatables and debris. This project would be funded by the CMSCWD and would cost approximately $5,000.

If watershed loading to Square Lake needs to be reduced in the future, all three stormwater ponds can be retrofitted to increase dissolved phosphorus removal. This can be accomplished by incorporating a pond bench with an iron enhanced sand filter and drain tile to the primary outlet. Existing outlet hydraulic modifications can also be explored to further enhance pond filtration capacity. This project may be funded by the CMSCWD and would cost approximately $28,000 per pond, which includes design and construction.

Figure 42. Aerial photograph of the SW-4 Maywood stormwater pond (circled in yellow)

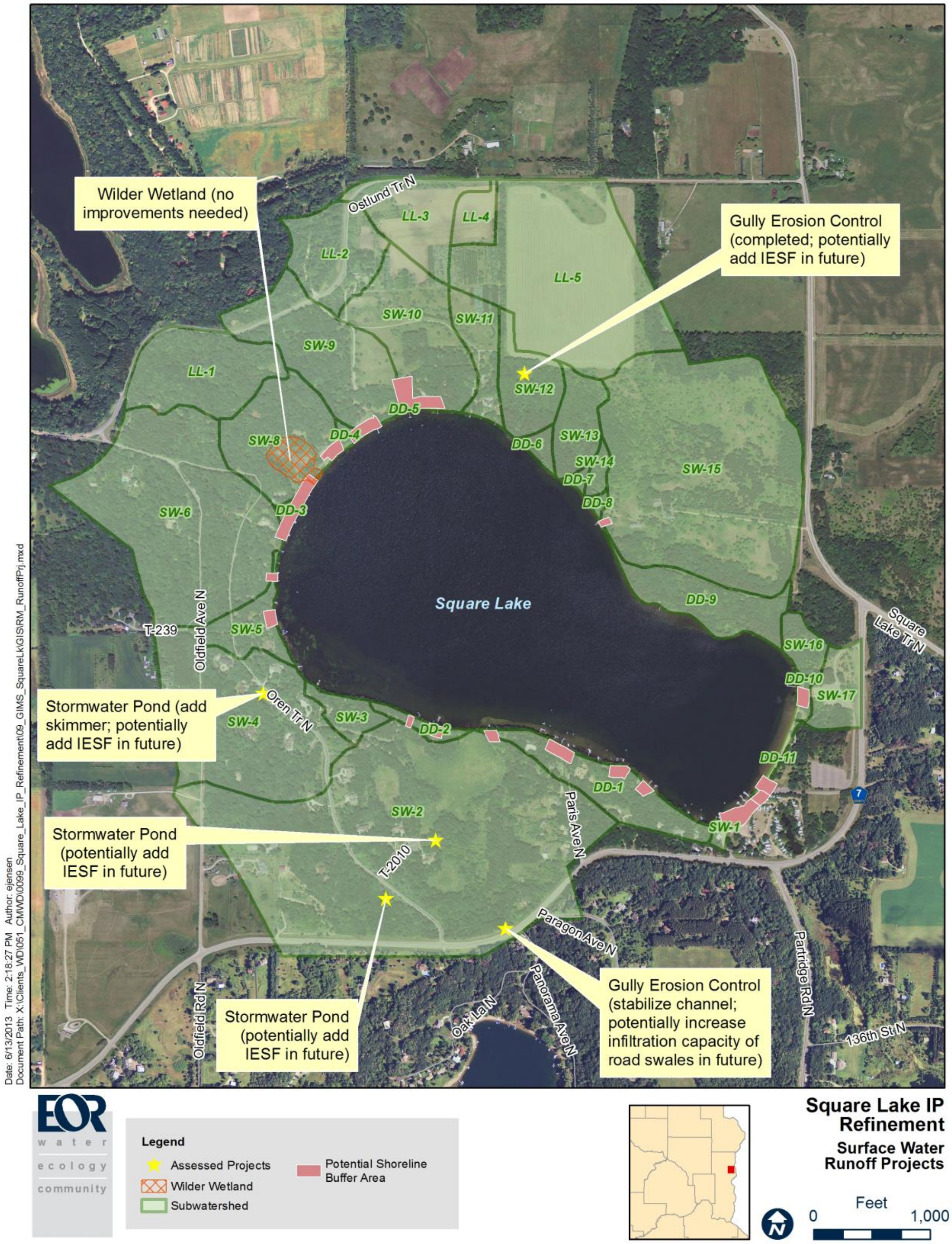
Figure 43. Aerial photograph of the SW-2 Maywood stormwater ponds (circled in yellow)

Wilder Wetland rehabilitation

The 2002 Implementation Plan recommended an evaluation of the effects or benefits to restoring or rehabilitating the Wilder Forest wetland. Updated information from this study indicates that the phosphorus load from the Wilder wetland may not be as big a component of the overall phosphorus budget to Square Lake as previously thought, and phosphorus loads have likely not increased in recent years. The estimated load from the Wilder wetland to Square Lake in the 2002 diagnostic study (6.2 kg, based on 1999 data) was 1.7 to 7.9 times higher than the 2010 estimated phosphorus load (0.7-2.3 kg) in 2010. Combining the Wilder wetland runoff and load estimates from the 2010 data with the loads estimated in the 2002 diagnostic study, the load from the Wilder wetland represents approximately 24% of the surface water runoff load to Square Lake (compared to 46% estimated in the 2002 diagnostic study), and approximately 4% of the total load to Square Lake (compared to 8% estimated in the 2002 diagnostic study), which includes the high contribution from groundwater.

Findings from this study do not support rehabilitation of the Wilder Wetland at this time.

Figure 44. Watershed implementation projects and potential shoreline buffer locations
(IESF = iron enhanced sand filter)



4.3 Implementation Activity Selection and Justification

Implementation activities were ranked based on their relevance to the priority management areas (Table 13). The highest priority implementation activities identified in this implementation plan are a three-year stocking suspension of rainbow trout in Square Lake to evaluate whether stocking suspension results in an increase in *Daphnia pulicaria* density and water clarity of the lake, and continued in-lake water quality monitoring. Additional priority implementation activities that maintain or decrease the total phosphorus load to Square Lake include septic system pumping and upgrades to reduce phosphorus loading from groundwater; and shoreline buffers, rain gardens, and lawn management activities to reduce phosphorus loading from surface water runoff. Several potential BMP improvements were also identified in the watershed. Due to low surface watershed TP loads, these BMP improvements are not priority at this time.

Implementation of priority activities began in fall of 2012 with the commencement of a three-year trout stocking suspension. Only activities which maintain existing watershed phosphorus loads to the lake should be implemented during the three-year trout stocking suspension so that any observed changes in in-lake water quality can be clearly linked to the trout stocking suspension. Following the trout stocking suspension, all remaining activities should be implemented according to the schedule from Table 15 in Section 4.6 of this report.

Table 13. Priority ranking of selected implementation activities

Implementation Activity	Priority Rank	Mechanism	Capital/Annual Costs[¥]	TP Reduction
Suspend trout stocking	**	Direct effect on water clarity	$44,506	N/A
In-lake water quality monitoring	**	Prevention	$2,100	N/A
Distribution of septic management materials to homeowners	*	Reduce groundwater P load	$126 annually	Variable
Septic pumping program	*		N/A	Variable
Septic system upgrades	*		N/A	7 lb/yr
Conservation easement(s)	*		Variable	11 lb/yr of potential future load
Landowner education programs	*	Prevention	$3,000 annually	Variable
Distribute current shoreland ordinances	*		$126 annually	Variable
Stormwater runoff regulations to provide no net increase in phosphorus	*		$5,000	Variable
SW-2 gully project		Reduce surface watershed P load	$25,000-75,000	TBD
SW-12 gully project			$35,000	TBD
SW-4 pond skimmer			$5,000	TBD
Stormwater pond retrofits			$28,000	TBD

* = priority, ** = high priority; N/A = not applicable; TBD = to be determined
¥ - Does not include 30-year operation and maintenance costs

4.4 Implementation Monitoring and Evaluation

In-lake monitoring will be undertaken to track the progress of implementation. During the time that Square Lake is not stocked with rainbow trout, the effects of the stocking suspension on zooplankton abundance and community composition, surface water algal biomass (chlorophyll-*a*), and water clarity will be evaluated with respect to whether or not the suspension leads to an increase in the abundance of *Daphnia pulicaria* in Square Lake and an increase in the lake's water clarity. Trout suspension monitoring and evaluation, schedule, and budget can be found in a copy of the Memorandum of Understanding and Square Lake Monitoring Plan submitted by the CMSCWD to the MDNR in Appendix C. In addition, on-going monitoring of lake water quality will be conducted as an implementation activity to ensure that Square Lake is maintaining its goal Secchi disk transparency of 22.9 ft (7m) and give early warning signs of trends in decreased water quality.

4.5 Roles and Responsibilities of Project Participants

A list of project participants and their individual roles and responsibilities for each priority implementation activity, organized by priority management area, is included in Table 14 below.

4.6 Information and Education Program

The CMSCWD participates in the East Metro Water Resource Education Program (EMWREP). EMWREP is a collaborative group of multiple watershed organizations, municipalities, WCD, and Washington County, which conducts education to support implementation efforts and promote participation in cost-share programs. EMWREP activities include Blue Thumb workshops, articles in the media, and Stormwater U trainings.

Outreach has already been initiated as a part of this project in coordination with EMWREP through stakeholder meetings. Future outreach will include homeowner education programs on the benefits and installation of shoreline buffers and rain gardens, and proper management of lawns.

4.7 Permits Required

Permitting does not appear to be a feasibility constraint for any of the priority implementation activities identified in this implementation plan.

Table 14. Project participants, and roles and responsibilities for priority implementation activities

	Priority Implementation Activity	Project Participants	Roles and Responsibilities
In-lake Food Web	Suspend trout stocking	CMSCWD	Oversee monitoring and submit annual summary memos and final report to MDNR
		MDNR	Suspend all stocking of rainbow trout in Square Lake for the remainder of 2012 through the end of 2015.
		Consultants	Collect and evaluate monitoring data during stocking suspension.
	In-lake water quality monitoring	CMSCWD	Oversee and fund annual in-lake monitoring
		Washington CD, Metropolitan Council	Collect monitoring data 14 times per year
Groundwater	Distribution of septic management materials to homeowners	CMSCWD	Distribute septic management materials to residents in the Square Lake watershed
	Septic pumping program	Washington County	Notify homeowners to pump their septic systems and keep track of completions
		CMSCWD, SLA	Publish reminder articles in newsletter
		Homeowners	Schedule and fund septic system pumping
	Septic system upgrades	Washington County	Inspect septic systems
		CMSCWD	Support homeowners seeking funding assistance
		Homeowners	Schedule and partially fund septic system upgrades
	Work with landowners to place remaining undeveloped shoreline into conservation easement(s)	May Township, Washington County, CMSCWD, Nonprofit conservation organizations	Coordinate with landowners to place undeveloped shoreline into conservation easements
Surface Water Runoff	Landowner education programs	CMSCWD, SLA	Coordinate, advertise, and fund education programs for landowners
		EMWREP	Lead education programs for landowners
	Distribute current shoreland ordinances	CMSCWD	Compile and distribute packets to residents in the Square Lake watershed
	Stormwater runoff regulations to provide no net increase in phosphorus	CMSCWD	Develop regulations concurrent with other rule changes
	Watershed BMPs	CMSCWD	Seek funding and manage projects
		Consultants	Oversee design and construction

CMSCWD – Carnelian-Marine-St. Croix Watershed District
SLA – Square Lake Association
Washington CD – Washington Conservation District

4.8 Implementation Program Elements, Milestone Schedule, and Budget

A 10-year (2013-2022) implementation schedule and budget for priority implementation activities in Square Lake and its watershed, organized by priority management area, are summarized in Table 15 and Table 16 below. Implementation activities are recommended to begin with the trout stocking suspension and monitoring, which will result in a final recommendation in 2016 on whether to permanently extend the trout stocking suspension by the MDNR in Square Lake.

Priority implementation activities that will not confound the results of the trout stocking suspension can be implemented beginning in 2013, including:

- Distributing septic management materials to homeowners (even years),
- Septic pumping programs (annually),
- Septic system upgrades (ongoing),
- Working with landowners to place remaining undeveloped shoreline into conservation easements (ongoing),
- Distributing current shoreland ordinances (odd years), and
- Developing stormwater runoff regulations to provide no net increase in phosphorus (2014 or the next regular rule update).

Other priority implementation activities that can result in reductions in watershed TP loading are recommended for implementation if the trout stocking suspension alone does not result in improved water clarity of Square Lake. These should be implemented in the following order:

- 2017: Stabilize the downstream channel of the SW-2 gully with an erosion control blanket, native grasses, and/or judiciously placed rock in conjunction with tree canopy thinning. Add a skimmer to the SW-4 stormwater pond.
- 2022: In 5 years, reassess the water quality of Square Lake. If watershed phosphorus loading needs to be further reduced, retrofit the existing dry detention pond in the SW-12 gully erosion control project with filter media, such as iron enhanced sand, to reduce dissolved phosphorus loading from agricultural runoff.
- Future: In 10 years, reassess the water quality of Square Lake. If watershed phosphorus loading needs to be even further reduced, iron enhanced sand filter media can be added to the Maywood stormwater ponds.

Table 15. 10-year schedule (2013-2022) for priority implementation activities in Square Lake.

	Priority Implementation Activity	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Future
In-lake Food Web	Suspend trout stocking	■	■	■								
	In-lake water quality monitoring	■	■	■	■	■	■	■	■	■	■	
Groundwater	Distribution of septic management materials to homeowners		■		■		■		■		■	
	Septic pumping program	■	■	■	■	■	■	■	■	■	■	
	Septic system upgrades	■	■	■	■	■	■	■	■	■	■	
	Work with landowners to place remaining undeveloped shoreline into conservation easement(s)	■	■	■	■	■	■	■	■	■	■	
Surface Water Runoff	Landowner education programs	■		■		■		■		■		
	Distribute current shore land zoning regulations	■	■	■	■	■	■	■	■	■	■	
	Stormwater runoff regulations to provide no net increase in phosphorus		■									
	Gully erosion control projects					■					■	
	Stormwater pond enhancements					■						■

Table 16. Estimated costs for priority implementation activities in Square Lake, including optional watershed BMPs

Priority Implementation Activity		Annual project costs ($)										
		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Future
In-lake	Suspend trout stocking	14,005	14,005	14,005								
In-lake	In-lake water quality monitoring	i	i	i	2,092	2,092	2,092	2,092	2,092	2,092	2,092	
Groundwater	Distribution of septic management materials to homeowners		126		126		126		126		126	
Groundwater	Septic pumping program	A	A	A	A	A	A	A	A	A	A	
Groundwater	Septic system upgrades	V	V	V	V	V	V	V	V	V	V	
Groundwater	Work with landowners to place remaining undeveloped shoreline into conservation easement(s)	V	V	V	V	V	V	V	V	V	V	
Surface Water Runoff	Landowner education programs	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	
Surface Water Runoff	Distribute current shore land zoning regulations	126		126		126		126		126		
Surface Water Runoff	Stormwater runoff regulations to provide no net increase in phosphorus		5,000									
Surface Water Runoff	Gully erosion control projects					25,000					35,000	
Surface Water Runoff	Stormwater pond enhancements					5,000						84,000
Total = $226,919		**$15,631**	**$20,631**	**$15,631**	**$3,718**	**$33,718**	**$3,718**	**$3,718**	**$3,718**	**$3,718**	**$38,718**	**$84,000**

i = included in trout stocking suspension costs; A = Already funded; V = Variable/ funded by landowner

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6 APPENDIX A: MONITORING RESULTS: BIOLOGY

Table 17. Stomach contents of fish collected by seining in 2010.

See information for abbreviations below the table.

Date	Sp	Lng (cm)	Stat	DP	DM	DMh	LP	GM	HY	CHI	CHp	oDI	oDp	ODn	TRI	aDP	aCP	aOD	PH	GA	NM	FL
5/18	BKF	5	NE	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0
6/8	BKF	5.3	NE	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0
6/8	BKF	4.5	NE	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
6/8	BKF	4	NE	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
6/8	BKF	5.5	E																			
6/8	BKF	5	E																			
7/6	BKF	4	NE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
7/6	BKF	4	NE	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
7/6	BKF	4.5	NE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0
7/6	BKF	3	NE	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
7/6	BKF	3.5	NE	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
5/18	BLG	4.5	NE	0	1	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0
5/18	BLG	5.8	NE	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	1	0
5/18	BLG	4.4	NE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/18	BLG	4.9	NE	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
5/18	BLG	3.9	NE	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6/8	BLG	7	NE	0	0	0	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0
6/8	BLG	6	NE	0	0	0	0	0	35	0	0	0	0	1	0	0	0	0	0	0	0	1
6/8	BLG	5	NE	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1
6/8	BLG	9	NE	0	36	0	0	19	0	0	0	0	0	1	0	0	0	0	0	0	0	1
6/8	BLG	6	NE	0	12	0	0	8	15	0	0	0	0	0	0	0	0	0	0	0	0	0
6/8	BLG	11.3	NE	0	0	0	0	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6/8	BLG	10.5	NE	0	0	0	0	3	0	0	0	0	0	1	7	0	0	0	0	0	0	1
6/8	BLG	6.5	NE	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0
6/8	BLG	8.5	NE	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	0	0	0	0
6/8	BLG	4.5	NE	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7/6	BLG	9	NE	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
7/6	BLG	7	NE	0	0	0	0	2	0	6	0	0	0	0	0	0	0	0	0	0	0	0

Date	Sp	Lng (cm)	Stat	DP	DM	DMh	LP	GM	HY	CHI	CHp	oDI	oDp	ODn	TRI	aDP	aCP	aOD	PH	GA	NM	FL
7/6	BLG	6	NE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
7/6	BLG	5.5	NE	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
7/6	BLG	5	NE	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7/6	BLG	13	NE	0	0	0	0	4	0	0	0	0	0	1	3	0	0	0	0	0	0	0
7/6	BLG	12	NE	0	0	0	0	10	0	0	2	0	0	1	0	0	0	0	0	0	0	0
7/6	BLG	11.5	NE	0	0	0	0	0	0	13	0	0	0	0	0	0	1	0	0	0	0	0
7/6	BLG	12.5	NE	0	0	0	0	18	0	8	0	0	0	0	0	0	1	0	0	0	0	0
7/6	BLG	14	NE	0	0	0	0	31	0	0	0	0	0	1	0	0	0	0	0	0	0	0
8/19	BLG	5	NE	0	3	0	0	3	2	0	0	0	0	1	0	0	0	0	0	0	0	0
8/19	BLG	5	NE	0	1	24	0	5	0	1	0	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	4.5	NE	0	0	0	0	19	3	0	0	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	5	NE	0	1	0	0	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	6.5	NE	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	7	NE	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
8/19	BLG	6	NE	0	19	119	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	5.5	NE	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	6	NE	0	15	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	5	NE	0	12	0	0	13	0	0	0	0	0	2	0	0	0	0	0	0	0	0
8/19	BLG	5	NE	0	0	11	0	1	3	3	0	0	0	2	0	0	0	0	0	0	0	0
8/19	BLG	6	NE	0	7	24	0	5	0	1	0	0	0	0	0	0	0	0	0	4	0	0
8/19	BLG	5.5	NE	0	0	0	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	5.5	NE	0	0	15	1	29	0	1	0	0	0	1	0	0	0	0	0	0	0	0
8/19	BLG	5	NE	0	4	0	0	17	0	3	0	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	5	NE	0	0	0	0	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	5	NE	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	4.5	NE	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	4	NE	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	11	NE	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	10	NE	0	1	0	2	27	0	3	0	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	8	NE	0	0	0	0	3	0	14	0	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	4	NE	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0

Date	Sp	Lng (cm)	Stat	DP	DM	DMh	LP	GM	HY	CHI	CHp	oDI	oDp	ODn	TRI	aDP	aCP	aOD	PH	GA	NM	FL
8/19	BLG	5.5	NE	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	4	NE	0	25	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	3	NE	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	4.5	NE	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	4.5	NE	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	4	NE	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	5	NE	0	0	0	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	4	NE	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
5/18	BNS	5.5	NE	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
5/18	BNS	5.5	NE	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
5/18	BNS	5	E																			
5/18	BNS	4.5	E																			
5/18	BNS	5	E																			
5/18	BNM	7	NE	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
5/18	BNM	7	E																			
5/18	BNM	6.5	E																			
5/18	BNM	7.5	E																			
5/18	BNM	6	E																			
6/8	BNM	6.5	NE	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
6/8	BNM	7	E																			
6/8	BNM	6.5	E																			
6/8	BNM	7	E																			
6/8	BNM	7	E																			
5/18	SFS	6.5	NE	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
5/18	SFS	6	NE	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
5/18	SFS	7	NE	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
5/18	SFS	7.5	NE	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
5/18	SFS	6	E																			
6/8	SFS	7	NE	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
6/8	SFS	7.5	NE	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	3	0	0
6/8	SFS	7	NE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0

Date	Sp	Lng (cm)	Stat	DP	DM	DMh	LP	GM	HY	CHI	CHp	oDI	oDp	ODn	TRI	aDP	aCP	aOD	PH	GA	NM	FL
6/8	SFS	6.5	NE	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
6/8	SFS	8	E																			
7/6	SFS	6.5	NE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7/6	SFS	6	NE	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
7/6	SFS	5.5	E																			
7/6	SFS	5.5	E																			

Codes:
Sp = fish species
- BKF = banded killifish
- BLG = bluegill sunfish
- BNS = blacknose shiner
- BNM = bluntnose minnow
- SFS = spotfin shiner

Lng = length
Stat = status (E = empty; NE = not empty)

DP = *Daphnia pulicaria*
DM = *Daphnia mendotae*
DMh = *Daphnia mendotae* (helmeted morph)
LP = *Leptodora*
GM = *Gammarus*
HY = *Hydracarina*
CHI = Chironomid larvae
CHp = Chironomid pupae
oDI = other Diptera larvae

oDp = other Diptera pupae
ODn = Odonata nymphs
TRI = Trichoptera larvae
aDP = adult Diptera
aCP = adult Coleoptera
aOD = adult Odonata
PH = Physidae (fingernail clam)
GA = Gastropod (snail)
NM = nematode (round worm)
FL = fish larvae

Table 18. Stomach contents of gastric lavage samples obtained from fish sampled by angling in 2010. See information for abbreviations below the table.

Date	Sp	Lng (cm)	Status	DP	DM	DMh	CAL	CHB	LP	HY	GM	CHI	CHe	CHp	oDI	oDp	ODn	GA	aDP	PLn
5/26	BLG	16	NE	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
5/26	BLG	14.5	NE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
5/26	BLG	15	NE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	0	0
5/26	BLG	10.5	NE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
5/30	BLG	14	NE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0
5/30	BLG	20	E																	
5/31	BLG	14	NE	0	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5/31	BLG	12	NE	0	0	0	0	0	0	0	0	32	0	0	0	0	1	1	0	0
5/31	BLG	16	NE	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
5/31	BLG	15	NE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0
5/31	BLG	21	NE	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
6/3	BLG	10	NE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
6/4	BLG	19	NE	8	41	184	0	0	0	0	0	4	0	0	0	0	0	0	0	0
6/4	BLG	17	NE	0	0	0	0	0	0	40	0	0	0	0	0	0	0	3	0	0
6/4	BLG	18	NE	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6/4	BLG	17	NE	0	0	100	0	0	0	0	0	6	0	0	0	0	0	0	0	0
6/4	BLG	16	NE	0	40	0	0	0	0	0	0	12	173	0	0	0	0	0	0	0
6/4	BLG	17	NE	20	80	473	0	0	0	0	0	7	247	1	0	0	0	0	0	0
6/23	BLG	21	NE	70	2135	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6/24	BLG	18	NE	0	0	400	0	0	0	0	0	5	0	0	0	0	0	0	0	0
6/24	BLG	18	NE	0	0	1442	0	0	0	0	0	6	0	0	0	0	0	0	0	0
6/25	BLG	18	NE	1092	59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7/2	BLG	17	NE	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7/2	BLG	17	NE	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7/2	BLG	17	NE	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7/2	BLG	15	NE	0	140	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7/2	BLG	16	NE	0	0	1325	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7/2	BLG	16	NE	0	0	175	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Date	Sp	Lng (cm)	Status	DP	DM	DMh	CAL	CHB	LP	HY	GM	CHI	CHe	CHp	oDI	oDp	ODn	GA	aDP	PLn
7/2	BLG	16.5	NE	0	0	530	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7/6	BLG	16	NE	0	1225	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7/7	BLG	17	NE	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
7/7	BLG	18	E																	
7/7	BLG	17	E																	
7/13	BLG	19	NE	93	3107	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
7/13	BLG	18	NE	0	1650	717	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7/13	BLG	17	NE	0	33	1827	0	0	0	0	0	0	0	0	0	0	0	0	0	1
7/13	BLG	18	NE	0	0	1270	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7/13	BLG	19	NE	0	264	0	0	0	2	0	0	0	0	0	0	0	0	0	1	0
7/15	BLG	18	NE	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7/15	BLG	20	NE	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0
7/15	BLG	17	E																	
7/15	BLG	19	E																	
7/15	BLG	18.5	E																	
7/17	BLG	18	NE	0	2	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
7/17	BLG	14	NE	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0
7/17	BLG	17	NE	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7/17	BLG	20	NE	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
8/5	BLG	16	NE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
8/5	BLG	19	NE	30	680	30	0	0	10	0	0	0	0	0	0	0	0	0	0	0
8/5	BLG	20	E																	
8/12	BLG	20	NE	270	1159	160	0	0	1	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	24	NE	173	1013	100	0	0	1	27	0	0	0	0	0	0	0	0	0	0
8/19	BLG	21	NE	2880	340	30	0	0	10	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	18	NE	170	3041	401	0	0	30	0	0	0	0	0	0	0	0	0	0	0
8/19	BLG	20	NE	47	2207	1927	0	0	0	0	93	0	0	0	0	0	0	0	0	0
5/26	CRP	25	NE	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
5/26	CRP	25.5	E																	
6/3	CRP	18	NE	0	0	0	0	0	8	0	0	3	0	22	0	0	0	0	0	0
6/3	RBT	27	NE	784	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Date	Sp	Lng (cm)	Status	DP	DM	DMh	CAL	CHB	LP	HY	GM	CHl	CHe	CHp	oDl	oDp	ODn	GA	aDP	PLn
6/5	RBT	32	NE	4900	82	0	0	4	3	23	0	0	0	0	2	0	0	0	0	0
6/5	RBT	45	NE	1500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6/5	RBT	44	NE	140	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6/5	RBT	34	NE	1517	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
6/5	RBT	34	NE	484	0	0	0	6	33	0	0	0	0	0	42	0	0	0	0	0
6/6	RBT	30	NE	1180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6/6	RBT	35	NE	1867	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
6/7	RBT	32	NE	840	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
6/10	RBT	26	NE	733	0	0	0	5	0	0	0	53	0	0	0	7	0	0	0	0
6/13	RBT	30	NE	2033	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6/15	RBT	40	NE	1433	0	0	0	5	0	0	0	32	0	0	0	8	0	0	0	0
6/23	RBT	45	NE	2960	0	0	13.3	6	0	0	0	13	0	0	0	3	0	0	0	0
6/25	RBT	44	NE	242	8.3	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0
6/25	RBT	46	NE	890	0	0	0	3	0	0	0	28	79.5	0	0	0	0	0	0	0
6/28	RBT	34	NE	760	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6/28	RBT	31	NE	307	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7/10	RBT	32	NE	459	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0
7/10	RBT	36	NE	1175	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0
8/12	RBT	33	NE	800	33	0	0	0	320	0	0	0	0	0	0	0	0	0	0	0
5/26	YOP	21.5	NE	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
6/3	YOP	21	E																	

Codes:
Sp = fish species
BLG = bluegill sunfish
CRP = black crappie
RBT = rainbow trout
YOP = yellow perch)
Lng = length
Stat = status (E=empty; NE = not empty)

DP = *Daphnia pulicaria*
DM = *Daphnia mendotae*
DMh = *Daphnia mendotae* (helmeted morph)
CAL = calanoid copepod
CHN = *Chaoborus*
LP = *Leptodora*
HY = *Hydracarina*
GM = *Gammarus*

CHl = Chironomid larvae
CHe = Chironomid larvae (early instar)
CHp = Chironomid pupae
oDl = other Diptera larvae
oDp = other Diptera pupae
ODn = Odonata nymphs
GA = Gastropod (snail)
aDP = adult Diptera
PLn = Plecoptera nymph

Table 19. *Chaoborus* crop contents

Date (2010)	Source	Status	*D. mendotae*	*Chydorus*	Calanoid	Cyclopoid	Nauplii	*Kellicottia*
5/6	Sediment	Not empty	0	0	0	0	1	1
5/6	Sediment	Not empty	0	0	0	0	1	1
5/6	Sediment	Not empty	0	1	0	0	1	0
5/18	Sediment	Not empty	1	0	0	0	0	0
5/18	Sediment	Not empty	0	1	0	0	0	2
5/18	Sediment	Not empty	0	0	1	0	1	0
5/18	Sediment	Not empty	1	0	0	1	0	0
5/18	Sediment	Empty	0	0	0	0	0	0
6/8	Sediment	Empty	0	0	0	0	0	0
6/10	Net	Not empty	0	1	0	0	0	0
6/10	Net	Empty	0	0	0	0	0	0
6/10	Net	Not empty	0	0	0	1	1	0
6/18	Sediment	Empty	0	0	0	0	0	0
6/18	Sediment	Empty	0	0	0	0	0	0
6/18	Sediment	Not empty	0	1	0	0	0	0
6/18	Sediment	Not empty	0	0	1	0	0	0
6/25	RBT stomach	Empty	0	0	0	0	0	0
6/25	RBT stomach	Empty	0	0	0	0	0	0
6/25	RBT stomach	Not empty	0	2	0	0	0	0
6/30	Sediment	Not empty	1	0	0	0	0	0
6/30	Sediment	Empty	0	0	0	0	0	0
8/26	Net	Not empty	0	0	0	0	0	1
8/26	Net	Not empty	0	0	0	0	1	0
8/26	Net	Not empty	1	0	1	0	0	0
8/26	Net	Empty	0	0	0	0	0	0
8/26	Net	Empty	0	0	0	0	0	0
8/26	Net	Not empty	0	0	0	0	1	0
8/26	Net	Not empty	0	0	1	0	0	0
8/26	Net	Not empty	0	1	0	0	0	0
8/26	Net	Empty	0	0	0	0	0	0
8/26	Net	Not empty	1	0	0	0	0	1
9/25	Net	Not empty	0	0	0	1	0	0

Table 20. Zooplankton densities (#/liter) from net samples in 2010. See information for abbreviations below the table.

Date	Loc	Depth (m)	Rep	DP	DM	DMh	Cal	Cyc	Nau	Chy	Bos	Lp	Hy	Chb	Kel	Asp	AC
5/6	C	17.5-0	A	3.50	3.34	0.08	5.26	6.92	3.92	0	0	0	0	0	0.17	0	0
5/6	C	17.5-0	B	2.75	6.36	0	8.42	7.05	2.32	0	0	0	0	0	0.09	0	0
5/6	NW	14.5-0	A	9.15	37.8	0.11	37.0	21.1	0	0	0	0	0	0	0.11	0	0
5/6	NW	14.5-0	B	0.15	0.30	0	1.09	0.93	0.34	0	0	0	0	0	0	0	0
5/6	SE	14.5-0	A	0.37	3.36	0	9.70	7.50	1.71	0.06	0	0	0	0	0.18	0	0
5/6	SE	14.5-0	B	0.73	6.46	0	3.34	3.36	0	0.02	0	0	0	0	0	0	0
5/6	C	6-0		2.00	18.1	0.04	6.49	4.19	0	0	0	0	0	0	0	0	0
5/6	NW	6-0		2.18	5.40	0.14	7.05	2.21	0.81	0	0	0	0	0	0	0	0
5/6	SE	6-0		5.05	8.35	0	10.4	1.22	0.35	0	0	0	0	0	0.07	0	0
5/6	C	11-8		5.61	17.5	0	9.94	8.68	0	0	0	0	0	0	0	0	0
5/6	NW	11-8		5.56	3.10	0	13.1	6.91	0.56	0	0	0	0	0	0.24	0	0
5/6	SE	11-8		1.63	1.74	0	9.31	2.52	0.73	0	0	0	0	0	0	0	0
5/6	C	17.5-12		1.40	2.62	0	2.59	2.71	0.30	0	0	0	0	0	0.03	0	0
5/6	NW	14.5-12		2.21	1.80	0	6.37	3.74	0.14	0	0.07	0	0	0	0	0	0
5/6	SE	14.5-12		1.32	0.60	0	5.03	3.47	0.42	0	0.12	0	0	0	0.12	0	0
5/18	C	16-0	A	2.24	4.07	0	3.39	3.71	0	0.03	0	0	0	0	0	0	0
5/18	C	16-0	B	0.75	5.35	0.08	4.29	4.98	0	0.02	0	0	0.02	0	0.06	0	0
5/18	SE	15-0	A	1.51	5.60	0	3.59	1.54	0.02	0.03	0	0	0	0	0.02	0	0
5/18	SE	15-0	B	2.20	4.96	0.10	3.97	3.77	0	0	0	0	0	0	0	0	0
5/18	NW	13-0	A	2.57	7.15	0.04	4.02	3.97	0	0.04	0	0	0.04	0	0.04	0	0
5/18	NW	13-0	B	0.68	11.0	0.02	3.86	1.90	0.02	0.02	0	0	0	0	0.07	0	0
5/18	C	6-0		1.42	2.71	0.07	9.90	0.95	0.07	0	0	0	0	0	0.10	0	0
5/18	SE	6-0		4.84	4.92	0.08	11.2	0.67	0.17	0.04	0	0	0	0	0.08	0	0
5/18	NW	6-0		1.56	16.2	0	6.01	1.56	0	0.13	0	0	0	0	0	0	0
5/18	C	11-8		0.55	2.42	0.04	2.92	2.57	0.16	0.08	0	0	0	0	0	0	0
5/18	SE	11-8		3.66	3.02	0.16	5.64	2.86	0.24	0.08	0	0	0	0	0.32	0	0
5/18	NW	10-8		2.95	14.1	0	8.54	4.81	0.20	0.39	0	0	0	0	0	0	0

Date	Loc	Depth (m)	Rep	DP	DM	DMh	Cal	Cyc	Nau	Chy	Bos	Lp	Hy	Chb	Kel	Asp	AC
5/18	C	16-13		1.88	3.00	0	1.93	8.55	0.24	0	0	0	0	0	0	0	0
5/18	SE	15-13		1.89	4.35	0	3.58	13.2	0.07	0	0	0	0	0	0	0	0
6/8	C	17-0	A	0.94	1.78	0.02	1.24	2.07	0	0	0	0	0	0	0	0	0
6/8	C	17-0	B	1.21	1.33	0.07	4.49	1.63	0.08	0	0	0	0	0	0	0	0
6/8	SE	13-0	A	1.07	1.56	0.05	2.87	1.85	0.04	0	0	0	0	0	0	0	0
6/8	SE	13-0	B	0.14	0.22	0.02	1.63	0.22	0.04	0	0	0	0	0	0	0	0
6/8	NW	13-0	A	2.38	3.19	0.03	3.06	1.76	0	0	0	0	0	0	0	0.016	0
6/8	NW	13-0	B	1.65	3.35	0	2.28	2.11	0	0	0	0	0	0	0	0	0
6/8	C	4-0	A	0.07	4.35	0.18	0.80	0.04	0.07	0	0	0	0	0	0	0	0
6/8	C	4-0	B	0	2.30	0.70	0.95	0.32	0.21	0	0	0	0	0	0.70	0	0
6/8	NW	4-0	A	0	0.70	0.21	0.33	0.03	0	0	0	0.03	0	0	0	0.06	0
6/8	NW	4-0	B	0.29	6.30	0	0.37	0.16	0	0	0	0	0	0	0	0	0
6/8	SE	4-0	A	0.14	3.50	0.11	0.35	0.10	0	0	0	0.02	0	0	0	0.03	0
6/8	SE	4-0	B	0.14	2.80	0.11	0.02	0.07	0	0	0	0.02	0	0	0	0.03	0
6/8	C	11-5		1.77	1.20	0.02	7.49	2.46	0	0	0	0	0.04	0	0	0	0
6/8	NW	11-5		3.00	1.42	0	4.44	2.57	0.04	0.02	0	0	0	0	0	0	0
6/8	SE	11-5		2.85	3.65	0	2.34	2.29	0.02	0.02	0	0	0	0	0	0	0
6/8	C	13-11		2.20	4.23	0.21	3.22	10.1	0.65	0	0	0	0	0	0.11	0	0
6/8	SE	12-11		2.81	6.06	0.11	3.70	14.5	0	0	0	0	0	0	0.11	0	0
6/8	NW	13-11		1.40	1.75	0.14	3.09	7.57	0	0	0	0	0	0.01	0	0	0
6/8	C	19-12	A	0.69	0.24	0.01	0.65	1.57	0.04	0	0	0	0	0	0	0	0
6/8	C	19-12	B	2.60	0.19	0.01	0.97	1.3	0.34	0	0	0	0	0	0	0	0
6/30	C	16-0	A	2.76	3.93	0.22	2.82	1.41	0.02	0	0	0	0	0	0	0	0
6/30	C	16-0	B	2.14	2.72	0.04	3.07	1.58	0	0	0	0	0	0	0.22	0	0
6/30	C	4-0	A	0.06	0.56	0.48	1.01	0.03	0.11	0	0	0	0	0	0	0	0
6/30	C	4-0	B	0	0.48	0.45	0.39	0.03	0.03	0	0	0	0	0	0.03	0	0
6/30	C	8-5	A	0.72	4.04	0.04	10.9	0.51	0.08	0	0	0	0	0	0	0	0
6/30	C	8-5	B	0.33	2.24	0	7.57	0.19	0.14	0	0	0	0	0	0	0	0
6/30	C	11-9	A	0.52	3.14	0.02	9.23	0.35	0.11	0	0	0	0	0	0	0	0

Date	Loc	Depth (m)	Rep	DP	DM	DMh	Cal	Cyc	Nau	Chy	Bos	Lp	Hy	Chb	Kel	Asp	AC
6/30	C	11-9	B	0.19	0.90	0.02	1.66	0.16	0.03	0	0	0	0	0	0	0	0
6/30	C	14-12	A	3.51	15.9	0	2.66	5.82	0.63	0	0	0	0	0	0	0	0
6/30	C	14-12	B	4.56	17.4	0.15	8.91	5.29	0.07	0	0	0	0	0	0	0	0
6/30	C	16-14	A	4.04	16.6	0.07	5.79	5.56	0.35	0	0	0	0	0	0	0	0
6/30	C	16-14	B	0.52	0.77	0.07	3.13	0.27	0.28	0	0	0	0	0	0	0	0
7/8	C	17-0	A	1.78	5.07	0.85	2.61	1.13	0	0	0	0	0.01	0	0	0	0
7/8	C	17-0	B	1.50	6.53	0.65	3.16	1.8	0	0	0	0.03	0.03	0	0	0	0
7/8	C	2-0	A	1.64	5.80	0.75	2.89	1.47	0	0	0	0.01	0.02	0	0	0	0
7/8	C	2-0	B	0.14	0.73	0.10	0.28	0.34	0	0	0	0.01	0.01	0	0	0	0
7/8	C	5-3	A	0	1.68	3.20	0.06	0.11	0.06	0	0	0	0	0	0	0	0.22
7/8	C	5-3	B	0	1.54	2.16	0.47	0.11	0.11	0	0	0	0	0	0	0	0
7/8	C	9-7	A	0	1.61	2.68	0.26	0.11	0.08	0	0	0	0	0	0	0	0.11
7/8	C	9-7	B	0	0.07	0.52	0.21	0	0.02	0	0	0	0	0	0	0	0.11
7/8	C	12-10	A	0	3.48	2.97	1.38	0	0.22	0	0	0	0	0	0	0	0
7/8	C	12-10	B	0	10	6.02	3.28	0.06	0	0	0	0	0	0	0	0	0
7/8	C	15-13	A	0	6.74	4.50	2.33	0.03	0.11	0	0	0	0	0	0	0	0
7/8	C	15-13	B	0	3.26	1.53	0.95	0.03	0.11	0	0	0	0	0	0	0	0
7/8	C	17-13	A	1.17	1.64	0.41	4.32	4.44	0.06	0	0	0.06	0	0	0	0	0.06
7/8	C	17-13	B	1.23	4.91	2.22	4.15	1.4	0.06	0	0	0	0	0	0	0	0.29
7/29	C	17-0	A	0.26	1.04	0.10	1.04	3.28	1.41	0	0	0	0	0	0.10	0	0
7/29	C	17-0	B	0.35	1.72	0.29	1.26	2.35	1.09	0	0	0	0	0	0	0	0
7/29	C	2-0	A	0.30	1.38	0.20	1.15	2.82	1.25	0	0	0	0	0	0	0	0
7/29	C	2-0	B	0.04	0.34	0.09	0.11	0.47	0.16	0	0	0	0	0	0	0	0
7/29	C	5-2	A	0	0.89	0.66	1.11	0.89	1.11	0	0	0	0	0	0	0	0
7/29	C	5-2	B	0	0.28	0	0	0.56	0.28	0	0	0	0	0	4.20	0	0
7/29	C	9-6	A	0	0.58	0.33	0.56	0.72	0.70	0	0	0	0	0	2.10	0	0
7/29	C	9-6	B	0	0.30	0.33	0.56	0.16	0.42	0	0	0	0	0	2.10	0	0
7/29	C	12-10	A	0	2.16	0	1.08	0.43	1.73	0	0	0	0	0	0	1.08	0.43
7/29	C	12-10	B	0.21	4.34	1.03	2.27	0.62	0.83	0	0	0	0	0	0	2.27	0

Date	Loc	Depth (m)	Rep	DP	DM	DMh	Cal	Cyc	Nau	Chy	Bos	Lp	Hy	Chb	Kel	Asp	AC
7/29	C	17-13	A	0.10	3.25	0.52	1.68	0.53	1.28	0	0	0	0	0	0	1.68	0.22
7/29	C	17-13	B	0.10	1.09	0.52	0.60	0.09	0.45	0	0	0	0	0	0	0.60	0.22
8/11	C	16-0	A	0.47	2.43	1.13	1.37	0.75	0.03	0	0	0.01	0	0.01	0	0	0.05
8/11	C	16-0	B	0.27	6.73	1.55	1.91	1.4	0.03	0	0	0.06	0	0	0	0	0
8/11	C	2-0	A	0.37	4.58	1.34	1.64	1.07	0.03	0	0	0.04	0	0	0	0	0.03
8/11	C	2-0	B	0.10	2.15	0.21	0.27	0.33	0.00	0	0	0.02	0	0	0	0	0.03
8/11	C	5-3	A	0	16.9	11.6	0.45	0.22	0.17	0	0	0	0	0	0	0	1.57
8/11	C	5-3	B	0	6.68	6.34	0.73	0.06	0.06	0	0	0	0	0	0	0	3.03
8/11	C	8-6	A	0	11.8	8.97	0.59	0.14	0.11	0	0	0	0	0	0	0	2.30
8/11	C	8-6	B	0	5.11	2.63	0.14	0.08	0.06	0	0	0	0	0	0	0	0.73
8/11	C	11-9	A	0	10.9	5.16	1.34	0.05	0.11	0	0.05	0	0	0	0	0	1.51
8/11	C	11-9	B	0	11.5	4.37	1.44	0	0.31	0	0	0.10	0	0	0.05	0	0.67
8/11	C	13-11	A	0	11.2	4.77	1.39	0.03	0.21	0	0.03	0.05	0	0	0.03	0	1.09
8/11	C	13-11	B	0	0.30	0.39	0.05	0.03	0.10	0	0.03	0.05	0	0	0.03	0	0.42
8/11	C	16-14	A	0.49	7.85	0.28	5.82	1.54	0.07	0	0	0.14	0	0	0	0	0.70
8/11	C	16-14	B	0.12	17.7	5.83	4.68	1.70	0.06	0	0	0	0	0	0	0	0.55
8/26	C	17-0	A	0.36	2	0.76	1.65	1.15	0	0	0	0	0	0.01	0	0	0.32
8/26	C	17-0	B	0.27	1.88	0.45	1.62	1.82	0.01	0	0	0.01	0	0.01	0	0	0.38
8/26	C	2-0	A	0.31	1.94	0.61	1.64	1.49	0.01	0	0	0.01	0	0	0	0	0.35
8/26	C	2-0	B	0.04	0.06	0.16	0.01	0.34	0.01	0	0	0.01	0	0	0	0	0.03
8/26	C	6-3	A	0	1.18	0.79	2.08	0.112	0.06	0	0	0	0	0	0	0	2.86
8/26	C	6-3	B	0	3.19	1.39	1.13	0.206	0.10	0	0	0.10	0	0	0	0	1.85
8/26	C	12-10	A	0	2.19	1.09	1.61	0.16	0.08	0	0	0.05	0	0	0	0	2.36
8/26	C	12-10	B	0	1.01	0.30	0.48	0.05	0.02	0	0	0.05	0	0	0	0	0.51
8/26	C	15-13	A	0	4.22	1.80	3.96	0.08	0.15	0	0	0	0	0	0	0	0.41
8/26	C	15-13	B	0	4.83	3.57	4.05	0.03	0.07	0	0	0.03	0	0	0	0	0.21
8/26	C	17-15	A	0	4.53	2.69	4.01	0.05	0.11	0	0	0.02	0	0	0	0	0.31
8/26	C	17-15	B	0	0.30	0.89	0.04	0.02	0.04	0	0	0.02	0	0	0	0	0.10
9/25	C	16-0	A	0.15	5.25	0.11	3.58	2.22	0	0	0	0	0	0.01	0	0	0.03

Date	Loc	Depth (m)	Rep	DP	DM	DMh	Cal	Cyc	Nau	Chy	Bos	Lp	Hy	Chb	Kel	Asp	AC
9/25	C	16-0	B	0.12	3.61	0	3.47	4.13	0.02	0	0	0.04	0	0.01	0	0	0
9/25	C	2-0	A	0.13	4.43	0.05	3.53	3.18	0.01	0	0	0.02	0	0	0	0	0.01
9/25	C	2-0	B	0.01	0.82	0.05	0.05	0.96	0.01	0	0	0.02	0	0	0	0	0.01
9/25	C	6-3	A	0	5.76	0.21	12.0	0.21	0.26	0	0	0	0	0	0	0	0
9/25	C	6-3	B	0	5.11	0.11	11.8	0.28	0.11	0	0	0	0	0	0	0	0
9/25	C	8-6	A	0	5.44	0.16	11.9	0.24	0.18	0	0	0	0	0	0	0	0
9/25	C	8-6	B	0	0.32	0.05	0.10	0.04	0.07	0	0	0	0	0	0	0	0
9/25	C	11-9	A	0.11	7.66	0.08	7.69	0.20	0.28	0	0	0	0	0	0	0	0
9/25	C	11-9	B	0	14.3	0	10.4	0.30	0.22	0	0	0.08	0	0	0	0	0
9/25	C	13-11	A	0.06	11.0	0.04	9.05	0.25	0.25	0	0	0.04	0	0	0	0	0
9/25	C	13-11	B	0.06	3.32	0.04	1.36	0.05	0.03	0	0	0.04	0	0	0	0	0
9/25	C	16-13	A	0.11	12.5	0	3.66	0.65	0.32	0	0	0	0	0	0	0	0
9/25	C	16-13	B	0.11	14.2	0.16	2.58	0.59	0.16	0	0	0	0	0	0	0	0

Codes:
Loc = sampling location (see Fig. 2)
Rep = replicate
DP = *Daphnia pulicaria*
DM = *Daphnia mendotae*
DMh = *Daphnia mendotae* (helmeted morph)

Cal = calanoid copepod
Cyc = cyclopoid copepod
Nau = copepod nauplii
Chy = *Chydorus*
Bos = *Bosmina*
LP = *Leptodora*
Hy = *Hydracarina*

Chb= *Chaoborus*
Kel = *Kelicottia* (rotifer)
Asp = *Asplanchna* (rotifer)
AC = algae clumps

Table 21. Fish survey results, 2010

Parameter	05/18/10	05/18/10	06/08/10	06/08/10	06/08/10	07/06/10	07/06/10	07/06/10	08/19/10	08/19/10	08/19/10	08/19/10
	Survey general information											
Site[1]	E	E	E	E	S	E	E	S	E	E	E	S
Haul	1	2				1	2	1	1	2	3	1
Haul length (m)	16	16	16	16	23	16	15	21	16	16	16	17
Haul area (m^2) (X 26.5 m)[2]	421	421	421	421	607	429	387	546	419	411	413	448
Comment			bag twisted			partly rolled		algae				algae
Fish species: common name (Latin name)	# fish / haul											
rainbow trout (*Oncorhynchus mykiss*)	1	0	0	0	0	0	0	0	0	0	0	0
northern pike (*Esox lucius*)	0	0	0	0	0	0	1	0	1	0	0	1
bluntnose minnow (*Pimephales notatus*)	205	119	3	14	12	2	19	12	0	0	7	33
spotfin shiner (*Cyprinella spiloptera*)	38	83	9	34	5	5	39	7	4	0	7	141
blacknose shiner (*Notropis heterolepis*)	31	53	0	45	24	7	21	74	0	0	1	18
blackchin shiner (*Notropis heterodon*)	2	16	0	3	11	0	0	21	0	0	0	2
banded killifish (*Fundulus diaphanus*)	31	76	0	1	11	1	3	0	0	0	0	8
bluegill juvenile (*Lepomis macrochirus*)	6	0	2	12	5	7	0	5	12	0	0	81
bluegill adult (*Lepomis macrochirus*)	1	0	2	1	12	3	0	9	10	2	9	1
bluegill/greensunfish hybrid (*Lepomis macrochirus / L. Cyanellus*)	0	0	0	0	0	0	0	0	0	0	0	1
pumpkinseed (*Lepomis gibbosus*)	0	0	0	0	0	0	0	0	1	0	0	0
largemouth bass juvenile/subadult (*Micropterus salmoides*)	6	2	2	1	1	8	0	6	3	5	2	3
largemouth bass young of year (*Micropterus salmoides*)	0	0	0	0	0	0	1	2	0	0	0	0
johnny darter (*Etheostoma nigrum*)	0	0	0	4	0	0	1	0	0	0	0	1
Iowa darter (*Etheostoma exile*)	0	0	0	0	0	0	0	5	0	0	0	3
Fish species	# fish / m^2											
rainbow trout (*Oncorhynchus mykiss*)	0.0024	0	0	0	0	0	0	0	0	0	0	0
northern pike (*Esox lucius*)	0	0	0	0	0	0	0.0026	0	0.0024	0	0	0.0022
bluntnose minnow (*Pimephales notatus*)	0.49	0.28	0.0071	0.033	0.020	0.0047	0.049	0.022	0	0	0.017	0.074
spotfin shiner (*Cyprinella spiloptera*)	0.090	0.20	0.021	0.081	0.0082	0.012	0.10	0.013	0.0096	0	0.017	0.31
blacknose shiner (*Notropis heterolepis*)	0.074	0.13	0	0.11	0.040	0.016	0.054	0.14	0	0	0.0024	0.040
blackchin shiner (*Notropis heterodon*)	0.0047	0.038	0	0.0071	0.018	0	0	0.038	0	0	0	0.0045
banded killifish (*Fundulus diaphanus*)	0.074	0.18	0	0.0024	0.018	0.0023	0.0078	0	0	0	0	0.018
bluegill juvenile (*Lepomis macrochirus*)	0.014	0	0.0047	0.028	0.0082	0.016	0	0.0092	0.029	0	0	0.18
bluegill adult (*Lepomis macrochirus*)	0.0024	0	0.0047	0.0024	0.020	0.0070	0	0.016	0.024	0.0049	0.022	0.0022
bluegill/greensunfish hybrid (*Lepomis macrochirus / L. Cyanellus*)	0	0	0	0	0	0	0	0	0	0	0	0.0022
pumpkinseed (*Lepomis gibbosus*)	0	0	0	0	0	0	0	0	0.0024	0	0	0
largemouth bass juvenile/subadult (*Micropterus salmoides*)	0.014	0.0047	0.0047	0.0024	0.0016	0.019	0	0.011	0.0072	0.012	0.0048	0.0067
largemouth bass young of year (*Micropterus salmoides*)	0	0	0	0	0	0	0.0026	0.0037	0	0	0	0
johnny darter (*Etheostoma nigrum*)	0	0	0	0.0095	0	0	0.0026	0	0	0	0	0.0022
Iowa darter (*Etheostoma exile*)	0	0	0	0	0	0	0	0.0092	0	0	0	0.0067

[1]Sites: E = Square Lake Regional Park along east shoreline, S = private residence along south shoreline.

[2]Haul area is a maximum estimate because the seine bows when pulled. This will lead to an underestimate of density, as will any escapes under or over the seine.

7 APPENDIX B: AQUATIC MACROPHYTE SURVEY RESULTS

Table 22. Aquatic macrophyte survey results. See Figure 45 for survey locations.

Species Density (1-very sparce, barely any in rake tines; 4-very dense, covering all of rake tines), By species: scientific name / common name

Point #	*Ceratophyllum demersum* **Coontail**	*Chara vulgaris* **Muskgrass**	*Elodea canadensis* **Elodea**	*Myriophyllum exalbescens* **Northern water milfoil**	*Najas guadalupensis* **Southern waternymph**	*Nitella* sp. **Stonewart species**	*Nuphar lutea* **Yellow water-lily**	*Potamogeton amplifolius* **Large-leaved pondweed**	*Potamogeton foliosus* **Leafy pondweed**	*Potamogeton gramineus* **Variable-leaved pondweed**	*Potamogeton natans* **Floating-leaved pondweed**	*Potamogeton pectinatus* **Sago pondweed**	*Potamogeton richardsonii* **Claspingleaf pondweed**	*Potamogeton* sp. **Pondweed species**	*Potamogeton zosteriformis* **Flat-stemmed pondweed**	*Scirpus acutus* **Hardstem bulrush**	*Vallisneria americana* **Wild celery**	***No vegetation***
1					1	3												
2						1												
3	1						4							1				
4						3												
5						4												X
6																		X
7																		X
8						1												
9	1	1	1	1		1							1					
10																		X
11																		X
12		2				2												
13		4						1										
14																		X
15	1	2			2			1					1	1				
16	1	1	1	2		1						1						
17	4					2												
18						1												
19		4		1														
20		2						1										
21							4											
22		2					1											

23	1					2												
24																		X
25																		X
26		2																
27		3																
28		2			1			1					1					
29																		X
30						4												
31																		X
32		4																
33		4						1			1		1				1	
34																		X
35		3		1														
36																		X
37		3			1							1		1				
38		4						1										
39						3												
40																		X
41												1	1		1		3	
42		3			1			1									1	
43																		X
44		2			1										1			
45		1		1				3				1	1					
46																		X
47		4						1					1					
48	1					1												
49		4						3										
50		4						1					1					
51						2												
52																		X
53		4						1					1					
54	1					1												
55																		X
56																		X
57		4						2										

58							4											
59							4											
60						4												
61																		X
62		4					4						1				1	
63							4											
64						1												
65						3												
66																		X
67	3					2												
68																		X
69	2		1		1							1						
70							4											
71							4											
72		4						1			1		1					
73	1	2		1								1						
74																		X
75	3					2												
76		3												1				
77		4					4	1										
78		4						1			1		1					
79	1	2	1										1	1			1	
80		1			3				1			1						
81	2	2	1		1		4								1			
82																		X
83		4						1					1					
84	1	1		1				1				1						
85										1								
86		4						1					1					
87		3			1			1					1	1				
88																		X
89																		X
90							4											
91		3						1				1	1					
92		1			2			1				1	1					

93					1			1				1	2				1	
94																		X
95		1			3								1		1		1	
96		1						2										
97		3						1						1			1	
98		2				4												
99	2	1		1									1		1			
100						2												
101																		X
102		1		1									1					
103							4											
104	1												1	2			1	
105																		X
106																		X
107	2	1		1	1		1				1				1			
108		2		1														
109																1		
110							4											
111		1																
112		4																
113																		X
114		4											1					
115	3	1	1															
116																		X
117																		X
118		2						1					1					
119		1																
120		1														1		
121		4						1										
122						2												
123																		X
124																		X
125		4																
126		1																
127		3						1					1					

128						1												
129	4	2										1	1					
130						2												
131																		X
132																		X
133		3																
134		4						1										
135		4						1										
136		4						1										
137						4												
138		4						2										
139		4											1					

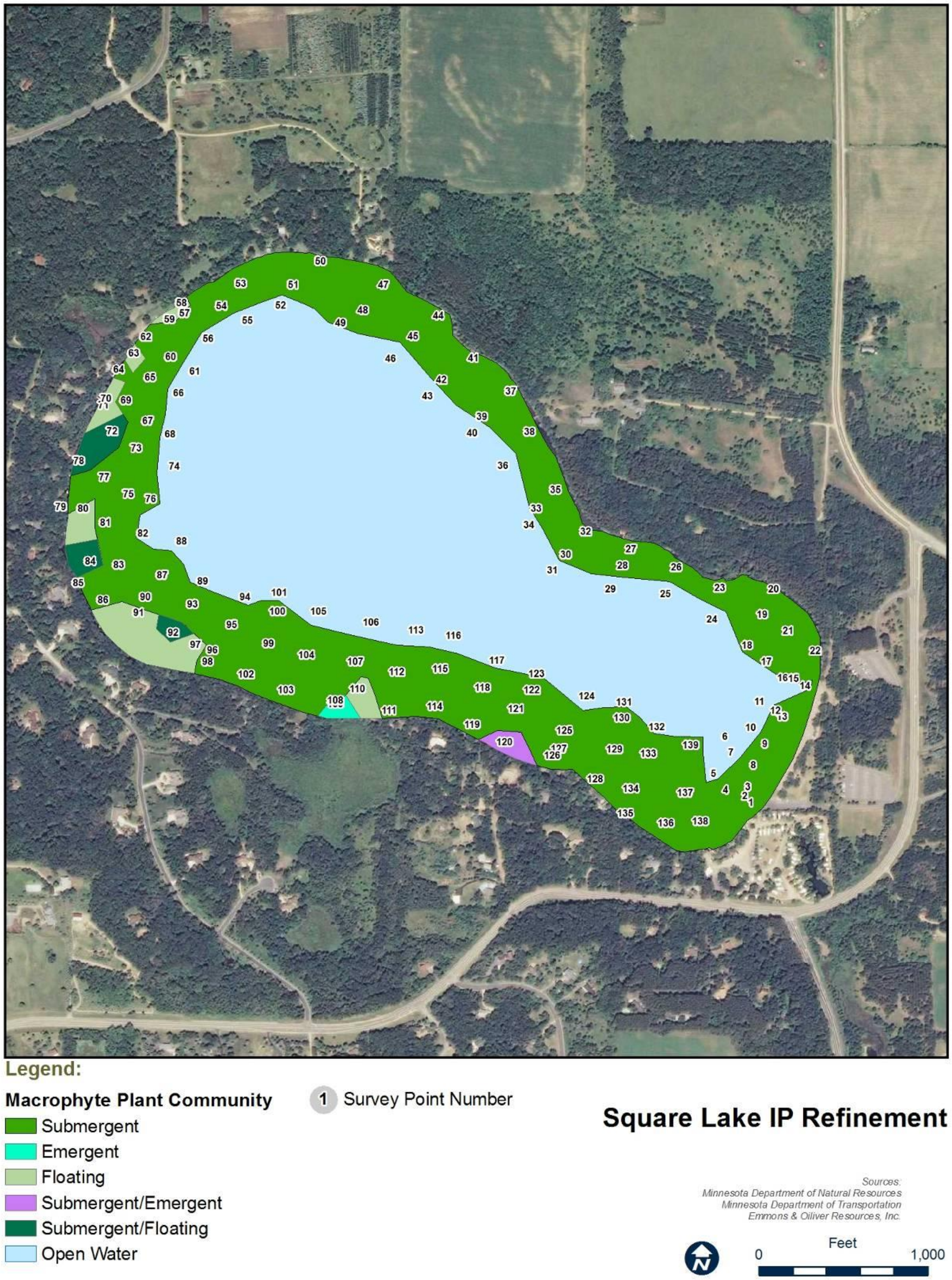

Figure 45. Survey point locations, aquatic macrophyte survey

8 APPENDIX C: MEMORANDUM OF UNDERSTANDING

Memorandum of Understanding between the
Minnesota Department of Natural Resources, Central Region Fisheries
and the Carnelian-Marine-St. Croix Watershed District
Regarding the Temporary Suspension of Trout Stocking in Square Lake

November 16, 2012

1. BACKGROUND AND INTRODUCTION

This Memorandum of Understanding (MOU) is between the Minnesota Department of Natural Resources (MDNR) Central Regions Fisheries and the Carnelian-Marine-St. Croix Watershed District (CMSCWD).

2. TERM OF MOU AND CANCELATION

This is effective upon execution by the parties and will remain in effect until canceled by either party. A thirty-day notice shall be given by the party wishing to cancel this agreement, and that party shall be responsible for any implementation, monitoring, and data evaluation expenses of the three-year stocking suspension, including reimbursing the other party for those expenses incurred.

3. AMENDMENTS

Any amendments or modifications to this MOU must be in writing and will not be effective until executed by the parties.

4. ENTIRE AGREEMENT

This MOU contains the entire agreement between the parties.

Minnesota Department of Natural Resources, Central Region Fisheries

Regional Fisheries Manager Brad Parsons
Date:

Carnelian-Marine-St. Croix Watershed District

Board President Steven Kronmiller
Date:

The following discussion addresses two areas of agreement listed by topic. Additional issues may be amended onto this agreement as they are completed and approved by both parties.

Contents:

Attachment: Square Lake Monitoring Plan, 2013-2015

PART I. Fisheries Stocking in Square Lake

The MDNR will suspend all stocking of rainbow trout in Square Lake, for the remainder of 2012 through the end of 2015. During this time period, the MDNR will not stock Square Lake with any other fish.

PART II. Monitoring Data Collection and Evaluation

During the time that Square Lake is not stocked with fish, the effects of the stocking suspension on zooplankton abundance and community composition, surface water algal biomass (chlorophyll-*a*), and water clarity will be evaluated with respect to whether or not the suspension leads to an increase in the abundance of *Daphnia pulicaria* in Square Lake and an increase in the lake's water clarity.

A. Expectations for changes in *Daphnia* abundance and water clarity

If the hypothesis that trout stocking is one of the main causes of the decline in transparency in Square Lake is correct, the following is expected:

Zooplankton

3) Greater population density of the large-bodied *Daphnia* (*Daphnia pulicaria,* or *D. pulicaria*) compared to recent years (data available from 2010 and 2012) when rainbow trout (hereafter, RBT) were stocked in the lake. Expect larger populations over the winter through mid-summer (before oxygen depletion diminishes the volume of *D. pulicaria* habitat).
4) Larger mean body size of *D. pulicaria* compared to pre-moratorium data.

Water quality

5) Greater water transparency (Secchi depth) than in years when RBT were stocked.
6) Lower levels of epilimnetic algal biomass (measured as chlorophyll-*a*) than in years when RBT were stocked.
7) More prominent spring clear-water phase than in years when RBT were stocked.
8) Total phosphorus concentrations similar to pre-moratorium.
9) Less hypolimnetic oxygen depletion compared to years when RBT were stocked. This would result in a greater volume of *D. pulicaria* habitat (metalimnetic and hypolimnetic water with dissolved oxygen concentrations > 1 mg/L) during summer stratification. However, summer stratification and hypolimnetic oxygen depletion are also affected by climate conditions (e.g., ice-out date, extent of spring mixing, timing of onset of stratification) and therefore no change (or an increase) in hypolimnetic oxygen depletion does not necessarily disprove the hypothesis.

Zooplankton densities and sizes are likely to respond more quickly to a suspension of trout stocking than would summer averages of water transparency and algae concentrations (measured as chlorophyll-*a*).

B. Monitoring

The following data will be collected and analyzed to determine if the above patterns are observed. The CMSCWD will coordinate the data collection and evaluation. See attached work plan and budget for more details.

Zooplankton

- Monthly water column sampling of zooplankton during winter (January, February, and March) from the three locations sampled in previous (2004, 2010, 2012) studies.
- Twice monthly sampling of zooplankton from April through September: incremental depth sampling (4 depths) from the deepest location and water column sampling at all three sites.

Water Quality

- Twice monthly monitoring of water quality parameters (Secchi depth, chlorophyll-*a*, total phosphorus, and depth profiles of temperature and dissolved oxygen).

C. Data Evaluation

Monitoring data from pre-moratorium years (2010 and 2012) will be compared to post-moratorium years (2013-2015) to assess whether *Daphnia pulicaria* abundance, biomass, and body size; water clarity; total phosphorus; algal biomass; and hypolimnetic dissolved oxygen are significantly different ($p < 0.05$) using ANOVA statistical tests. ANOVA was chosen because it can differentiate seasonal changes in zooplankton and water quality by accounting for both months and years. We expect the strongest, most immediate response to the stocking moratorium in *Daphnia pulicaria* abundance and mean body size, but a weight of evidence approach will be used to account for other changes observed in water clarity, total phosphorus, chlorophyll-*a*, and hypolimnetic dissolved oxygen. In addition, these effects should be most pronounced during the spring clear-water phase from April to June (a period of reduced algal biomass due to seasonally high levels of zooplankton grazing). However, a strong response to the stocking moratorium may result in significant changes to be observed later in the season (June to September) as well.

Any or all of the following changes, measured from April to June or from June to September, would provide support to continue the rainbow trout stocking moratorium:

1. Any or all of the following changes in *Daphnia pulicaria* abundance or body size:
    a. Significantly greater *Daphnia pulicaria* densities (#/liter) in post-moratorium years than pre-moratorium years
    b. Significantly greater large (> 1.3 mm in length) *Daphnia pulicaria* densities (#/liter) in post-moratorium years than pre-moratorium years
    c. Significantly greater total *Daphnia pulicaria* biomass (µg/liter) in post-moratorium years than pre-moratorium years
    d. Significantly greater *Daphnia pulicaria* average length (mm) in post-moratorium years than pre-moratorium years
2. No significant change (leveling off) or a significant increase in Secchi transparency depth (m) in post-moratorium years than pre-moratorium years. A statistical trend analysis will be used to identify if and when the Secchi transparency depth begins to change over the entire period of record (1980-2015).
3. Significantly less algal biomass (µg chlorophyll-*a*/liter) in post-moratorium years than pre-moratorium years

4. Significantly less hypolimnetic oxygen depletion during the summer in post-moratorium than pre-moratorium years, evidenced by:
    a. Significantly greater mean depth where dissolved oxygen concentration is greater than 1 mg/liter in post-moratorium than pre-moratorium years
    OR
    b. Significantly shorter annual time period when hypolimnetic dissolved oxygen concentrations are less than 1 mg/liter in post-moratorium than pre-moratorium years.

No significant changes in the criteria listed above would suggest that RBT stocking is not a significant driver for the eutrophication trend in Square Lake, and it would be reasonable for the MDNR to resume the RBT stocking program should they so desire. Additionally, there should be no significant change in growing season (June-September) mean surface water total phosphorus concentration (µg P/liter) in post-moratorium years than pre-moratorium years. Significant changes in total phosphorus may confound the effects of the stocking moratorium on monitoring data. In this case, additional years of the moratorium may be warranted to provide three years of post-moratorium data without significantly different total phosphorus concentrations from pre-moratorium years.

The following deliverables will be produced in accordance with this MOU:

1. Monitoring data will be evaluated on an annual basis by the CMSCWD, and an annual summary memo of the monitoring data will be provided to the MDNR by the CMSCWD.
2. A final report, including a preliminary recommendation of whether to continue the trout stocking suspension for the benefit of the water quality in Square Lake, will be completed by the CMSCWD by June 2016.
3. The final report will be reviewed by an impartial, scientific expert in limnology from a local institution of higher education and research to provide a third party recommendation to the MDNR Central Region Fisheries by December 1, 2016.
4. A decision will be made by the MDNR Central Region Fisheries by January 1, 2017 as to whether to continue the trout stocking suspension in Square Lake.
5. An amendment to this agreement will be developed by the MDNR and the CMSCWD after January 1, 2017 to define further actions required by the parties according to the outcome of Deliverable 4.

memo

651 Hale Avenue North Oakdale, Minnesota 55128 telephone: 651.770.8448 facsimile: 651.770.2552 www.eorinc.com

Date | August 13, 2012

To | CMSCWD Board of Managers

cc | Jim Shaver, District Administrator

From | Meghan Jacobson

Regarding | Square Lake Monitoring Plan, 2013-2015

Background

The Carnelian-Marine-St. Croix Watershed District (CMSCWD) is in discussions with the Department of Natural Resources regarding a three-year suspension of trout stocking in Square Lake to evaluate whether there are significant changes to food web structure and water clarity of the lake. Monitoring data collected during the stocking suspension period will be evaluated with respect to monitoring data taken during the years when trout were stocked in the lake.

Zooplankton were monitored in 2004 and 2010 as part of previous studies on Square Lake. Zooplankton data are being collected during 2012, which will add one more year of data taken during a year when trout *were* stocked in the lake. Monitoring is being conducted by Dr. Leif Hembre of Hamline University and is being funded by the Watershed District and the MPCA's Clean Water Partnership program.

During the time that Square Lake is not stocked with fish (2013-2015), the following monitoring is recommended to evaluate whether or not the suspension leads to an increase in the abundance of *Daphnia pulicaria* in Square Lake and an increase in the lake's water clarity.

Scope of Work

Leif Hembre from the Biology Department at Hamline University will conduct the zooplankton monitoring and will collect the samples for water quality analysis, and EOR will manage and coordinate the effort. Water quality samples will be analyzed through the Metropolitan Council's CAMP program, administered by the Washington Conservation District.

Task 1. Zooplankton and water quality monitoring

Zooplankton

- Monthly water column sampling of zooplankton during winter (January, February, and March) from the three locations sampled in previous (2004, 2010, 2012) studies. Duplicates will be taken of all samples.
- Twice monthly sampling of zooplankton from April through September: incremental depth sampling (4 depths) from the deepest location and water column sampling at all three sites. Duplicates will be taken of all samples.
- Zooplankton will be measured and taxonomically identified.

Water Quality

- Twice monthly monitoring of water quality parameters (Secchi depth, chlorophyll-*a*, total phosphorus, total Kjeldahl nitrogen, and depth profiles of temperature and dissolved oxygen), from April through October.
- Data will be annually submitted to the MPCA's database.

Task 2. Data analysis and reporting

- A summary memorandum will be prepared annually for the first two years of monitoring.
- A final report, including a preliminary recommendation of whether or not to permanently extend the trout stocking suspension for the benefit of the water quality in Square Lake, will be completed by June 2016.

Budget

The total cost of this monitoring effort is $44,506. A portion of the costs will be covered in-kind from the Hamline University's Department of Biology through its funding of an undergraduate research assistant. $36,586 is requested from the Watershed District (Table 1), to be spread out over three years: $11,365 in 2013; $11,365 in 2014; and $13,586 in 2015.

Typical annual costs to the District for Square Lake water quality monitoring in Square Lake are $2,090. The budget presented in Table 1 *includes* the Square Lake water quality monitoring for three years. The cost to the District for the monitoring program presented here, above what it typically pays for monitoring Square Lake, is $30,310.

Table 1. Project costs

Task		Cost provided by Hamline University	Ongoing Square Lake Water Quality Monitoring Cost budgeted by CMSCWD	Additional Cost requested from CMSCWD	Total Cost
2013	Monitoring	$2,640	$2,092	$8,222	$12,954
	Data analysis & reporting	$0	$0	$1,051	$1,051
2014	Monitoring	$2,640	$2,092	$8,222	$12,954
	Data analysis & reporting	$0	$0	$1,051	$1,051
2015	Monitoring	$2,640	$2,092	$8,222	$12,954
	Data analysis & reporting	$0	$0	$3,542	$3,542
Total:		**$7,920**	**$6,276**	**$30,310**	**$44,506**