Emmons & Olivier Resources, Inc.
for the Minnesota Pollution Control Agency

Peltier Lake and Centerville Lake TMDL

July 2013

water | ecology | community

wq-iw11-02e

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TMDL Summary Table

<table>
<tr><th>EPA/MPCA Required Elements</th><th colspan="3">Summary</th><th>TMDL Page #</th></tr>
<tr><td>Location</td><td colspan="3">Drainage Basin, Part of State, County, etc.</td><td>6</td></tr>
<tr><td>303(d) Listing Information</td><td colspan="3">Describe the waterbody as it is identified on the State/Tribe’s 303(d) list:
• Waterbody name, description and ID# for each river segment, lake or wetland
• Impaired Beneficial Use(s) - List use(s) with source citation(s)
• Impairment/TMDL Pollutant(s) of Concern (e.g., nutrients: phosphorus; biota: sediment)
• Priority ranking of the waterbody (i.e. schedule)
• Original listing year</td><td>6</td></tr>
<tr><td>Applicable Water Quality Standards/ Numeric Targets</td><td colspan="3">List all applicable WQS/Targets with source citations. If the TMDL is based on a target other than a numeric water quality criterion, a description of the process used to derive the target must be included in the submittal.</td><td>26</td></tr>
<tr><td>Loading Capacity (expressed as daily load)</td><td colspan="3">Identify the waterbody’s loading capacity for the applicable pollutant. Identify the critical condition.
For each pollutant: LC = X/day; and Critical Condition Summary</td><td>58, 60</td></tr>
<tr><td rowspan="8">Wasteload Allocation</td><td colspan="3">Portion of the loading capacity allocated to existing and future point sources [40 CFR §130.2(h)].
Total WLA = lbs/day, for each pollutant</td><td></td></tr>
<tr><td>Source</td><td>Permit #</td><td>WLA</td><td></td></tr>
<tr><td>Stormwater (Peltier)</td><td>Various</td><td>4.78</td><td>64</td></tr>
<tr><td>Stormwater-Mn/DOT (Peltier)</td><td>MS400170</td><td>0.03</td><td>63</td></tr>
<tr><td>Forest Lake Water Treatment (Peltier)</td><td>MNG640118</td><td>0.01</td><td>64</td></tr>
<tr><td>St. Croix Forge (Peltier)</td><td>MN0069051</td><td>0.03</td><td>64</td></tr>
<tr><td>Stormwater (Centerville)</td><td>Various</td><td>0.21</td><td>66</td></tr>
<tr><td>Reserve Capacity</td><td>NA</td><td>NA</td><td>68</td></tr>
<tr><td rowspan="5">Load Allocation</td><td colspan="3">Identify the portion of the loading capacity allocated to existing and future nonpoint sources and to natural background if possible [40 CFR §130.2(g)].
Total LA = lbs/day, for each pollutant</td><td></td></tr>
<tr><td>Source</td><td colspan="2">LA</td><td></td></tr>
<tr><td>Watershed runoff (Peltier)</td><td colspan="2">9.9</td><td>67</td></tr>
<tr><td>Internal loading (Peltier)</td><td colspan="2">0</td><td>67</td></tr>
<tr><td>Atmospheric deposition (Peltier)</td><td colspan="2">0.35</td><td>67</td></tr>
</table>

	Lake Centerville outflow (Peltier)	0.090	67
	Peltier Lake outflow (Centerville)	0.12	68
	Atmospheric deposition (Centerville)	0.36	68
Margin of Safety	Include a MOS to account for any lack of knowledge concerning the relationship between load and wasteload allocations and water quality [CWA §303(d)(1)(C), 40 CFR §130.7(c)(1)]. ***Identify <u>and explain</u> the implicit or explicit MOS for each pollutant***		61
Seasonal Variation	Statute and regulations require that a TMDL be established with consideration of seasonal variation. The method chosen for including seasonal variation in the TMDL should be described [CWA §303(d)(1)(C), 40 CFR §130.7(c)(1)] ***Seasonal Variation Summary for each pollutant***		70
Reasonable Assurance	***Summarize Reasonable Assurance*** *Note: In a water impaired by both point and nonpoint sources, where a point source is given a less stringent WLA based on an assumption that NPS load reductions will occur, reasonable assurance that the NPS reductions will happen must be explained.* *In a water impaired solely by NPS, reasonable assurances that load reductions will be achieved are not required (by EPA) in order for a TMDL to be approved.*		85
Monitoring	***Monitoring Plan included?*** *Note: EPA does not approve effectiveness monitoring plans but providing a general plan is helpful to meet reasonable assurance requirements for nonpoint source reductions. A monitoring plan should describe the additional data to be collected to determine if the load reductions provided for in the TMDL are occurring and leading to attainment of water quality standards.*		71
Implementation	***1. Implementation Strategy included?*** The MPCA requires a general implementation strategy/framework in the TMDL. *Note: Projects are required to submit a separate, more detailed implementation plan to MPCA within one year of the TMDL's approval by EPA.* ***2. Cost estimate included?*** The Clean Water Legacy Act requires that a TMDL include an overall approximation ("…a range of estimates") of the cost to implement a TMDL [MN Statutes 2007, section 114D.25]. *Note: EPA is not required to and does not approve TMDL implementation plans.*		72 82

Public Participation	Included Stakeholder Advisory Committee, public meetings and 30-day public comment period *Note: EPA regulations require public review [40 CFR §130.7(c)(1)(ii), 40 CFR §25] consistent with State or Tribe's own continuing planning process and public participation requirements.*	88

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Abbreviations

Atm	Atmospheric
BMP	Best management practice
CALM	Consolidation assessment and listing methodology
CAMP	Citizen Assisted Monitoring Program
Chl	Chlorophyll-*a*
DNR	Minnesota Department of Natural Resources
EPA	United States Environmental Protection Agency
LL RMP	City of Lino Lakes Resource Management Plan
µg/L	Micrograms per liter (equivalent to parts per billion)
Mn/DOT	Minnesota Department of Transportation
MOS	Margin of safety
MPCA	Minnesota Pollution Control Agency
MS4	Municipal separate storm sewer system
NPDES	National Pollutant Discharge Elimination System
RCWD	Rice Creek Watershed District
RMP	Resource management plan
SD	Secchi depth
SPRWS	St. Paul Regional Water Services
SWPPP	Stormwater pollution prevention program
TMDL	Total maximum daily load
TP	Total phosphorus
TSI	Trophic state index
WLA	Wasteload allocation

Executive Summary

Peltier Lake and Centerville Lake were listed as impaired waters by the Minnesota Pollution Control Agency (MPCA) in the 2002 303d list. The impaired use is aquatic recreation, with the stressor identified as "nutrient/ eutrophication biological indicators." The Centerville Lake watershed lies entirely within the Peltier Lake watershed.

The Peltier Lake and Centerville Lake watersheds are located in the central portion of the Rice Creek Watershed District (RCWD), which lies entirely within the North Central Hardwood Forest Ecoregion. Portions of 13 cities/townships and three counties are contained in the Peltier Lake watershed, while the Centerville Lake watershed contains portions of two cities and one county.

Phosphorus was identified as the main pollutant causing the impairment. The Minnesota state eutrophication standards were used to calculate the total maximum daily load (TMDL) for both lakes. (At the outset of this project an alternative water quality endpoint was proposed for Peltier Lake. This endpoint was a natural background condition standard and was based on paleolimnological diatom reconstructions done by the Science Museum of Minnesota for Peltier Lake. At this time, however, a formal natural background condition standard is not being proposed for Peltier Lake. Thus, only the current state eutrophication standards will apply. However, information and results relating to the previously sought natural background condition standard will remain in this TMDL document solely for reference and for possible reconsideration of an alternative endpoint in the future.)

Peltier Lake ranges from eutrophic to hypereutrophic, with relatively higher total phosphorus (TP) and chlorophyll (chl) concentrations compared to transparency. TP concentrations have varied over the years, with annual means ranging from approximately 100 to 300 µg/L. 2001 was the year with the poorest water quality. The same general pattern exists for chlorophyll-*a* and Secchi depth (SD).

Centerville Lake is a eutrophic lake, with relatively higher chlorophyll concentrations compared to TP, and slightly better transparency. Monitoring data from the 1980s suggest that the water quality of the lake was worse then. Water quality has fluctuated since 2000, but seems to be on a declining trend.

The categories of phosphorus loads to Peltier and Centerville Lakes are watershed runoff, point sources, internal loading, Peltier Lake backflow, groundwater discharge, and atmospheric deposition. Phosphorus loads from each of these sources were estimated (Table 1) and used as input into the lake response model.

Table 1. Phosphorus Loading Summary

Source	Peltier Lake		Centerville Lake	
	Phosphorus Load (lbs/growing season)	Percent Total	Phosphorus Load (lbs/growing season)	Percent Total
Watershed runoff (2001 modeled)	4,727	37%	37	25%
Point sources	2	<1%	0	0%
Internal loading	7,875	62%	*	*
Backflow from Peltier	NA	NA	70	46%
Groundwater discharge (middle of range)	1	<1%	0.3	<1%
Atmospheric deposition	43	<1%	44	29%
Total	*12,648*		*151*	

*Not explicitly quantified, see 4C.

The lake response model (Bathtub) was used to estimate the assimilative capacity of the lake. The model was calibrated to 2001 data and validated with 2004 data. The combined watershed load to Peltier Lake represents approximately 37% of the total load to the lake, and internal load represents approximately 62% of the phosphorus load to the lake (Figure 1). Of the phosphorus loads to Centerville Lake, the largest load is from the backflow from Peltier (46%), followed by atmospheric deposition and the watershed load, at 29% and 25% respectively (Figure 2).

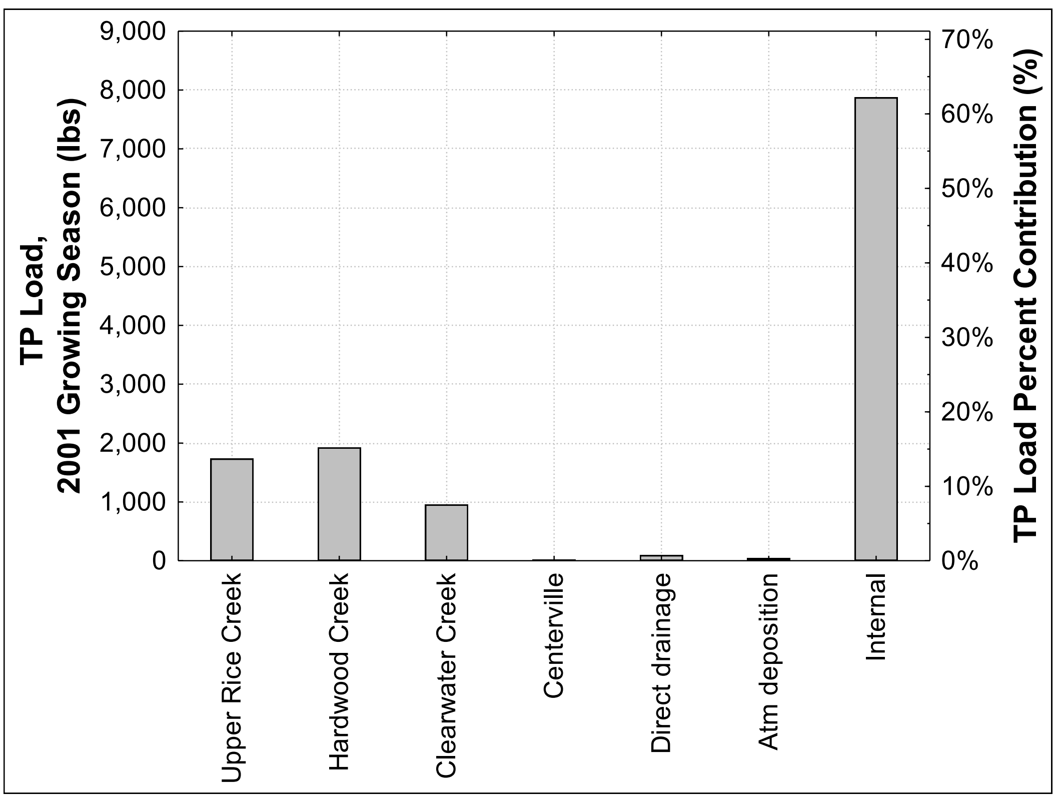

Figure 1. Phosphorus Loads to Peltier Lake, 2001 Growing Season

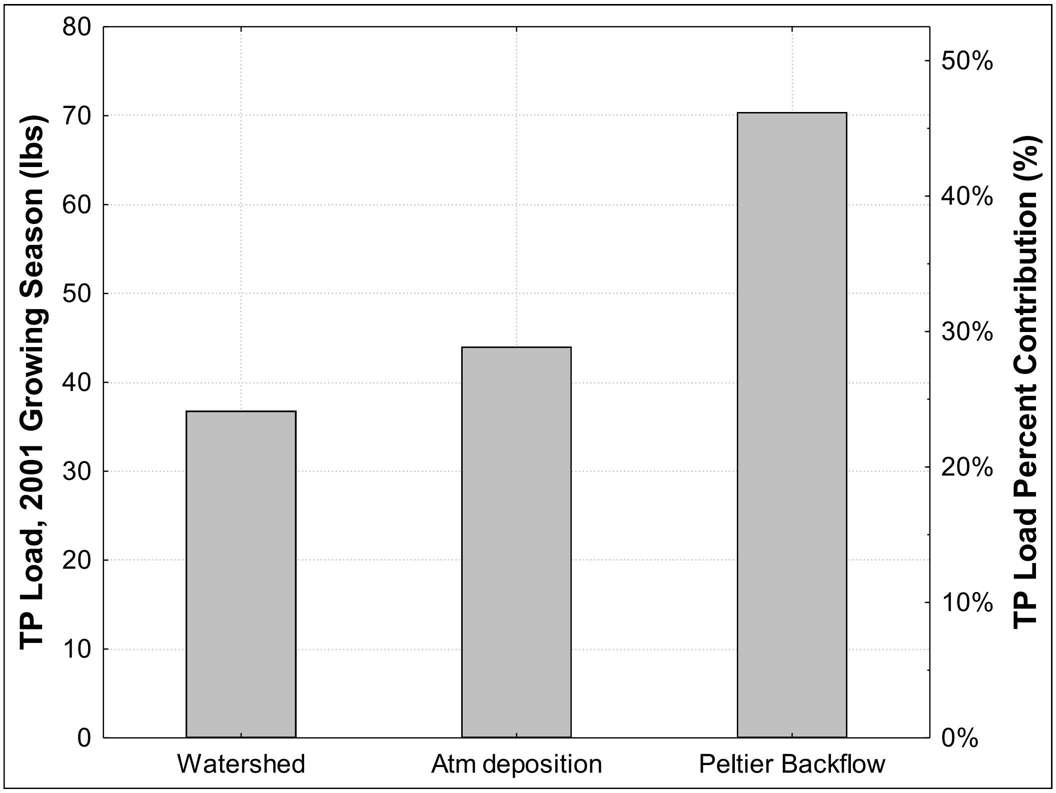

Figure 2. Phosphorus Loads to Centerville Lake, 2001 Growing Season

The assimilative capacity (Table 2) is based on each lake meeting the TP, chlorophyll-*a* and Secchi standards.

Table 2. Existing Loads and Assimilative Capacities

Lake	Model Scenario	Total Load to Lake during Growing Season (lbs)	Total Daily Load to Lake (lbs)	% Reduction Relative to Existing
Peltier	Existing	12,646	104	--
	Assimilative Capacity at Natural Background Condition (80 µg/L)	2,597	21.3	79%
	Assimilative Capacity at Eutrophication Standard (60 µg/L)	1,855	15.2	85%
Centerville	Existing	151	1.2	--
	Assimilative Capacity at Eutrophication Standard (40 µg/L)*	95	0.8	37%

*This loading scenario accounts for Peltier Lake achieving the natural background condition of 80 µg/L. Centerville Lake improves due to the decreased loading from Peltier Lake backflow.

The assimilative capacity was then divided up among the wasteload allocations (WLA) and the load allocations (LA).

The stormwater sources (regulated municipal separate storm sewer systems [MS4s] except for Mn/DOT Metro District, construction stormwater, and industrial stormwater) were given categorical WLAs for both Peltier Lake and Centerville Lake. The categorical WLA covers all stormwater sources indicated above; the load reductions identified by the WLAs will need to be met by this group as a whole. Mn/DOT Metro District received an individual WLA for Peltier Lake, per their request, and does not have any roads in the Centerville watershed. A WLA was given to the Forest Lake Water Treatment Plant and the St. Croix Forge for the Peltier Lake TMDL. There are fifteen MS4s with WLAs in the Peltier Lake TMDL (Table 3), and three MS4s with WLAs in the Centerville Lake TMDL (Table 5). It should be noted that Rice Creek Watershed District is considered a regulated MS4 due to its authority over some public ditches. However, for the drainage area covered by this TMDL it has not been determined if the public ditches here are "waters of the state" or treatment conveyances that treat stormwater. It is not possible to be both. For the purposes of moving forward with this TMDL the RCWD drainages systems will be considered part of the load allocation for this TMDL. Should it later be determined that the ditches are stormwater conveyances a correction will be made to the TMDL to move them to the categorical WLA. It should further be noted that the district has expressed that they are committed to the same level of work to pursue pollutant load reductions regardless of which category they are placed in.

Table 3. National Pollutant Discharge Elimination System (NPDES) Permits with WLAs for Peltier Lake

Permit Type	Permit Name	MS4 ID or Permit Number
MS4 stormwater	Anoka County	MS400066
MS4 stormwater	Birchwood Village	MS400004
MS4 stormwater	Centerville	MS400078
MS4 stormwater	Dellwood	MS400084
MS4 stormwater	Forest Lake	MS400262
MS4 stormwater	Grant	MS400091
MS4 stormwater	Hugo	MS400094
MS4 stormwater	Lino Lakes	MS400100
MS4 stormwater	Mahtomedi	MS400031
MS4 stormwater	Mn/DOT Metro District	MS400170
MS4 stormwater	Ramsey County Public Works	MS400191
MS4 stormwater	Washington County	MS400160
MS4 stormwater	White Bear Lake	MS400060
MS4 stormwater	White Bear Township	MS400163
MS4 stormwater	Willernie	MS400061
Construction stormwater	Various	Various
Industrial stormwater	No current permitted sources	NA
Industrial wastewater Industrial wastewater	Forest Lake Water Treatment Plant St. Croix Forge	MNG640118 MN0069051

Table 4. NPDES Permits with WLAs for Centerville Lake

Permit Type	Permit Name	MS4 ID or Permit Number
MS4 stormwater	Anoka County	MS400066
MS4 stormwater	Centerville	MS400078
MS4 stormwater	Lino Lakes	MS400100
Construction stormwater	Various	Various
Industrial stormwater	No current permitted sources	NA

The load allocations for Peltier Lake consist of non-MS4 stormwater runoff, atmospheric deposition, internal loading, and outflow from Centerville Lake. The load allocations for Centerville Lake consist of backflow from Peltier Lake and atmospheric deposition.

A monitoring plan was outlined that lays out the different types of monitoring that will need to be completed in order to track the progress of implementation activities associated with Peltier Lake and Centerville Lake, and of associated changes in water quality due to the management practices.

The implementation strategy lays out an approach to reduce both the watershed load and the internal load in both Peltier and Centerville Lakes.

Three technical advisory committee meetings and two public meetings were held for this project.

1. Background and Pollutant Sources

1A. 303(D) LISTINGS

Table 5. Impaired Waters Listings

Lake	DNR ID#	Hydrologic Unit Code	Pollutant or Stressor	Affected Use	Year Listed	Target Start/ Completion (reflects the priority ranking)	CALM Category*
Peltier Lake	02-0004-00	7010206	Nutrient/ eutrophication biological indicators	Aquatic recreation	2002	2005/2009	5B
Centerville Lake	02-0006-00	7010206	Nutrient/ eutrophication biological indicators	Aquatic recreation	2002	2005/2009	5C

*CALM (Consolidation Assessment and Listing Methodology):
5B – Impaired by multiple pollutants and at least one TMDL study plan is approved by EPA
5C – Impaired by one pollutant and no TMDL study plan is approved by EPA

1B. BACKGROUND

Watershed

Peltier Lake

The Peltier Lake watershed is located in the central portion of the Rice Creek watershed in southern Anoka County and is a sub-watershed of the Upper Mississippi Watershed. This area lies entirely within the North Central Hardwood Forest Ecoregion. Peltier Lake is located partially in the City of Lino Lakes and partially in the City of Centerville (Figure 3), and the watershed spans 13 municipalities (Table 6, Figure 4) and three counties (Anoka, Ramsey, and Washington).

Peltier Lake is 483 acres in surface area, with a 67,835-acre watershed. This 140:1 ratio of watershed to lake surface area is one of the reasons that the lake has a high external nutrient loading rate relative to its size. The main tributaries to Peltier Lake are Upper Rice Creek, which enters the lake from the north, Hardwood Creek, which also enters the lake from the north, and Clearwater Creek, which enters the lake from the southeast.

Centerville Lake

Centerville Lake is located within the watershed of Peltier Lake and is directly connected to it via a culvert under County Road 14. Like Peltier Lake, Centerville Lake is also located partially in the City of Lino Lakes and partially in the City of Centerville. Its watershed is located in Lino Lakes and Centerville (Table 6, Figure 3), and is completely within Anoka County.

Centerville Lake, with a surface area of 495 acres, is similar in size to Peltier Lake, but has only a 466-acre watershed, for a ratio of watershed to lake area of 0.9:1. There are no other streams or lakes within the Centerville Lake watershed. Anoka County Ditch 25 used to flow into the lake from the south, but it has been diverted away from Centerville Lake and into Reshanau Lake.

Table 6. Municipalities within Peltier Lake and Centerville Lake Watersheds.
Peltier Lake watershed includes the entire Centerville Lake Watershed. Areas include both the watersheds and the lakes themselves.

Peltier Lake Watershed		Centerville Lake Watershed	
City or Township	**Area (ac)**	**City or Township**	**Area (ac)**
Birchwood Village	214	Centerville	407
Centerville	1,428	Lino Lakes	554
Dellwood	1,799		
Grant	5,351		
Hugo	20,094		
Lino Lakes	7,260		
Mahtomedi	2,906		
White Bear Township	4,659		
White Bear Lake	709		
Willernie	82		
Forest Lake	11,130		
May Township	320		
Columbus	12,367		
TOTAL	68,319	TOTAL	961

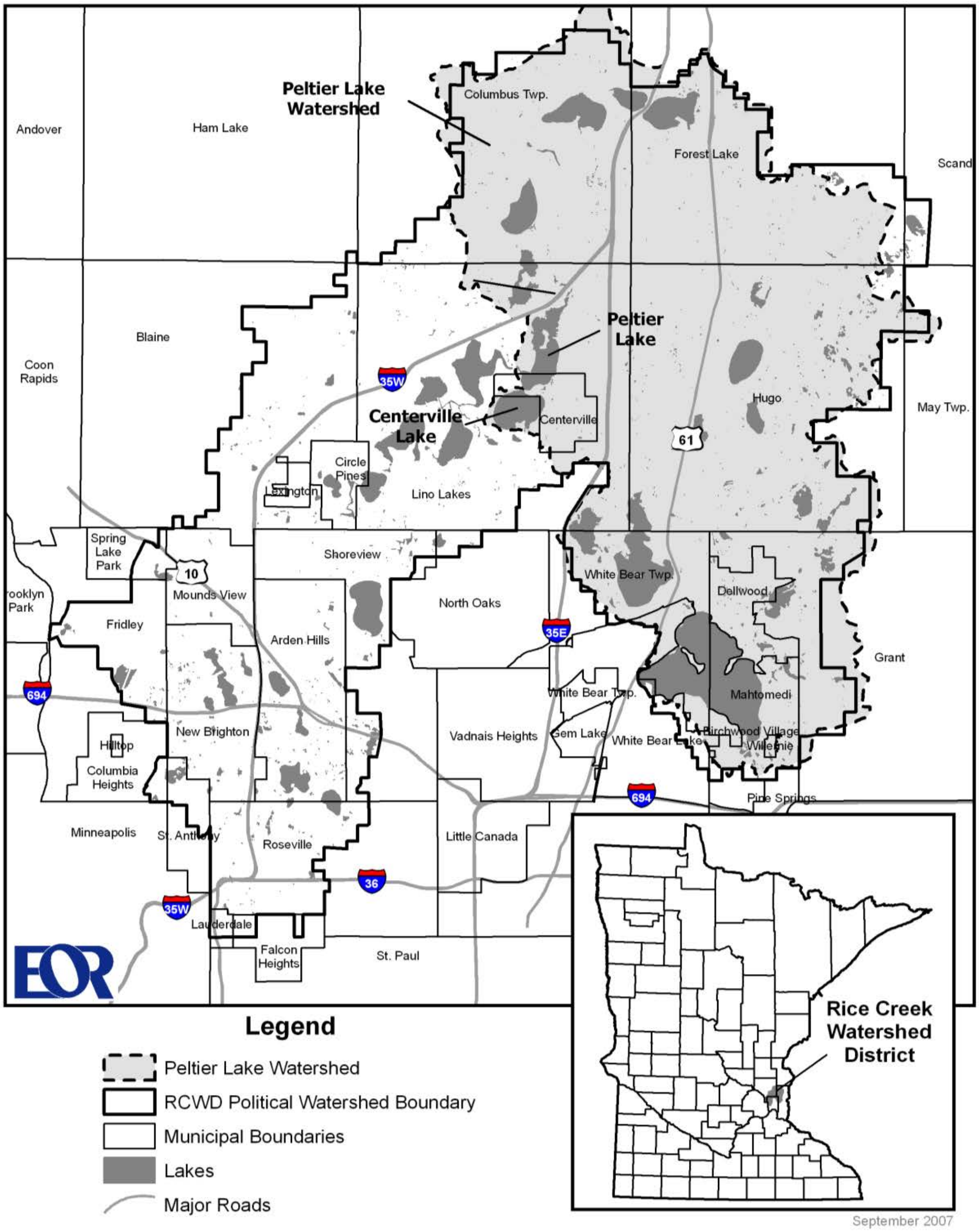

Figure 3. Location of the Peltier and Centerville Lakes Watershed

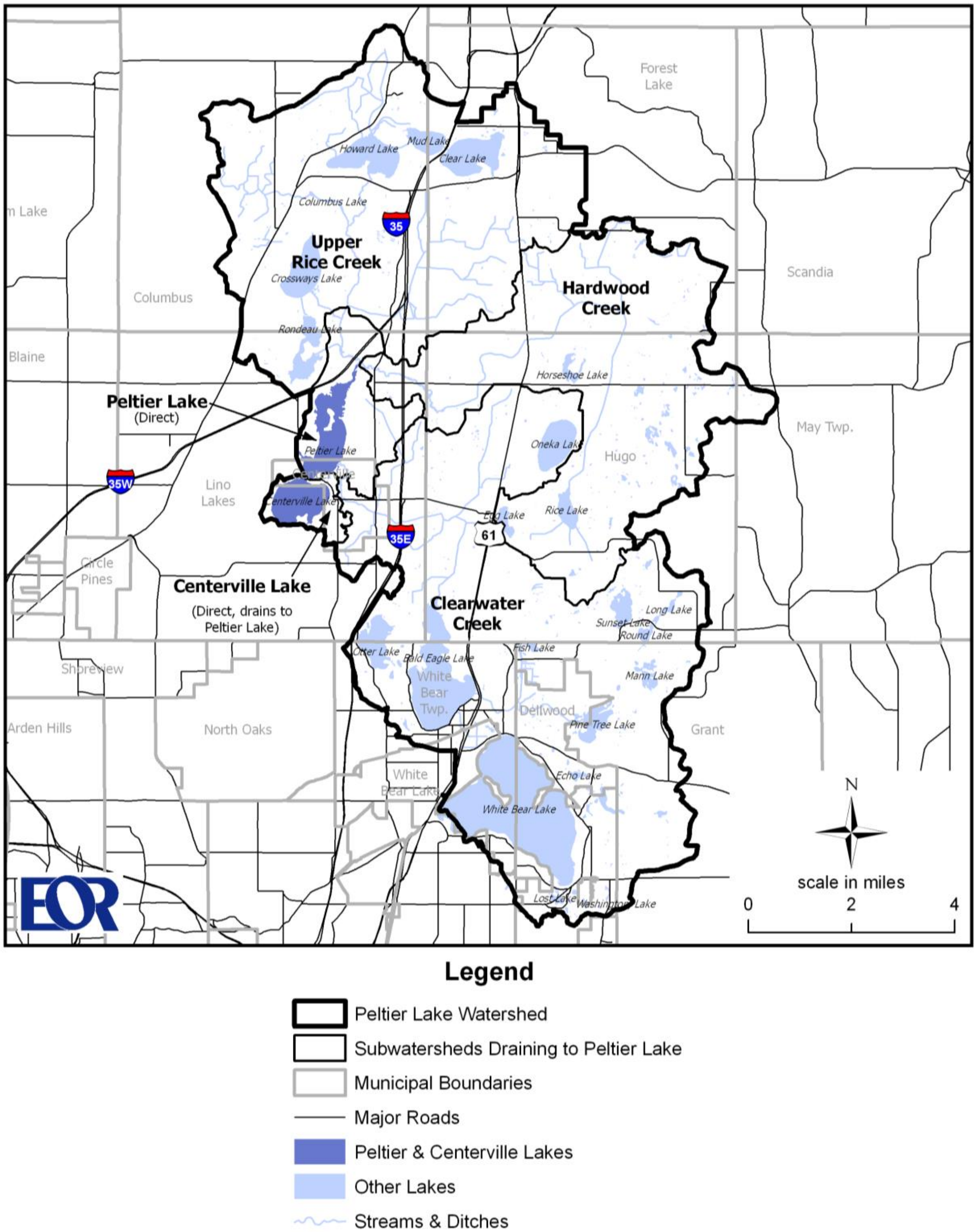

Figure 4. Peltier and Centerville Lakes Watershed

Land Use

The main land uses in the Peltier Lake watershed (Figure 5) are undeveloped (39%), agriculture (19%), single family residential (16%), open water (12%), and parks, recreation, and preserves (8%). The Centerville Lake watershed is composed mostly of single family residential and parks, recreation, and preserves.

Planned land use (Metropolitan Council 2020 Land Use) shows relatively little change in agriculture and single family residential land uses (Figure 6). There is a shift, compared to current conditions, from undeveloped land (39% under current conditions) to rural residential (30% under planned land use).

Seven feedlots exist in the watershed (Figure 7), all of which are located within the Hardwood Creek watershed.

Land Cover

The MLCCS (Minnesota Land Cover Classification System) land cover classifications were combined into five impervious surface area categories and six vegetative cover type categories, for both existing (Generalized Land Use 2005 for the Twin Cities Metropolitan Area) and future (Regional Planned [2020] Land Use - Twin Cities Metropolitan Area) conditions (Figure 8 and Figure 9). The biggest changes in the Peltier Lake watershed include a decrease in the agricultural and natural area categories, and an increase in most of the impervious surface categories (Table 7). Fewer changes are expected in the Centerville Lake watershed, with reductions in agricultural, grasslands, and woodlands, and a large increase in the 11% to 25% impervious cover category (Table 7).

Table 7. Peltier Lake Watershed Land Cover Summary

Land Cover Category	Land Cover Percent Change (from existing to future conditions)	
	Peltier Lake Watershed	Centerville Lake Watershed
0% to 10% impervious cover	209%	0%
11% to 25% impervious cover	51%	297%
26% to 50% impervious cover	0%	0%
51% to 75% impervious cover	211%	5%
76% to 100% impervious cover	2%	0%
Impervious cover (unknown percentage)	103%	0%
Agricultural Land	-65%	-78%
Tree Plantations	-48%	0%
Forests & Woodlands	-50%	-20%
Grasslands	-30%	-28%
Lakes, Rivers & Open Water Wetlands	0%	0%
Maintained Grasslands	-68%	-24%
Shrubland	-73%	0%
Wetlands	0%	0%
Unclassified	-91%	0%

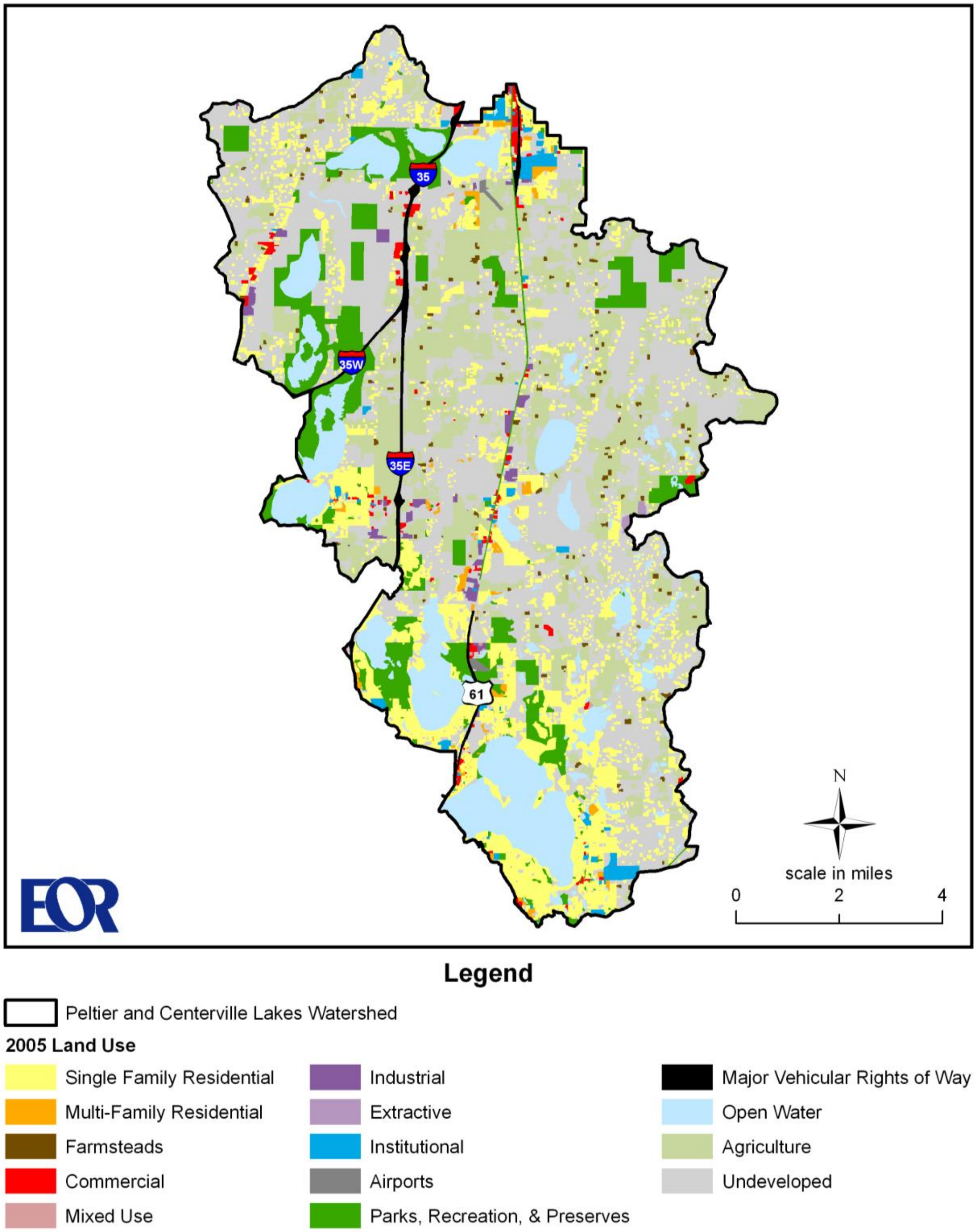

Figure 5. Existing Land Use in the Peltier and Centerville lakes Watershed

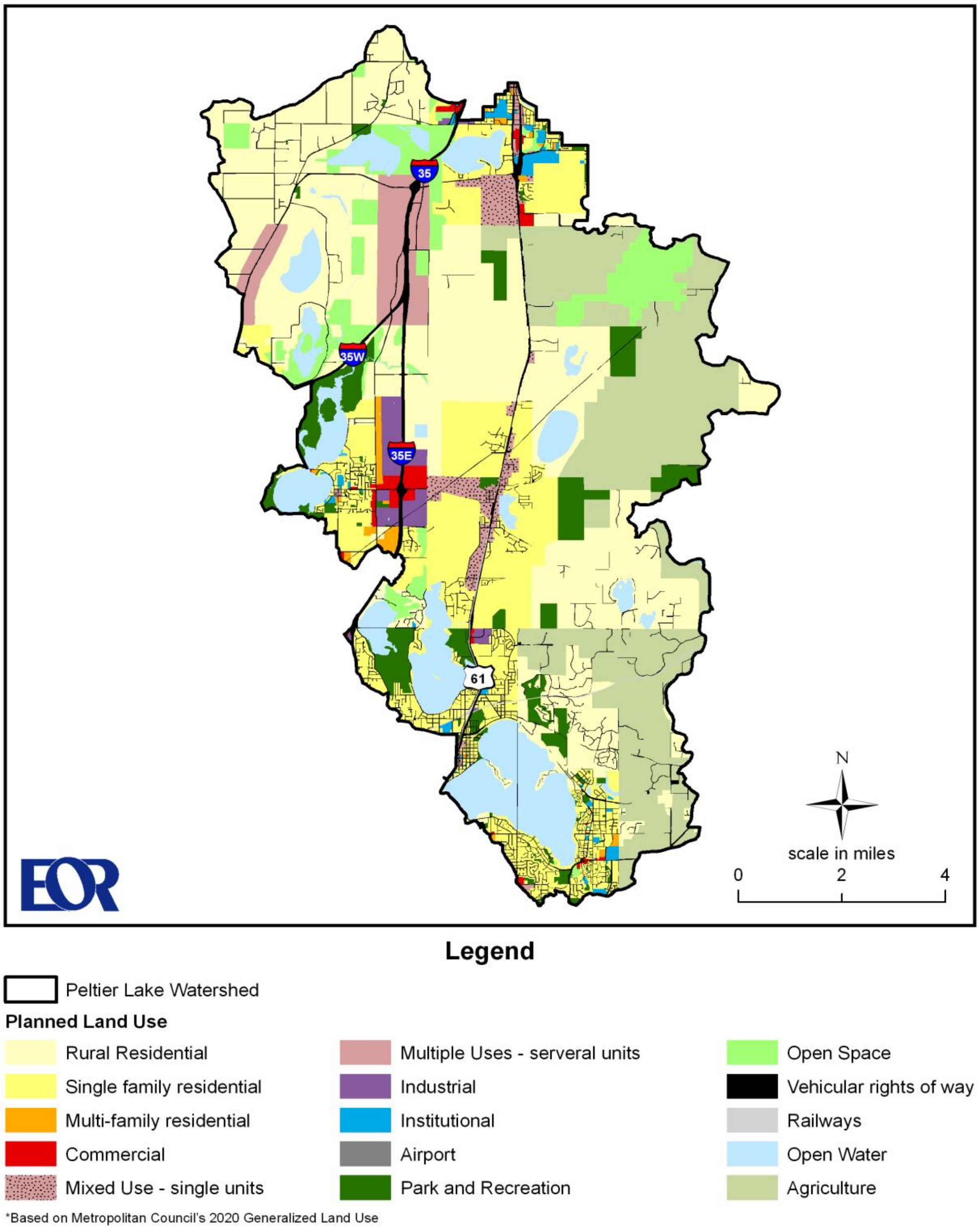

Figure 6. Planned Land Use in the Peltier and Centerville Lakes Watershed

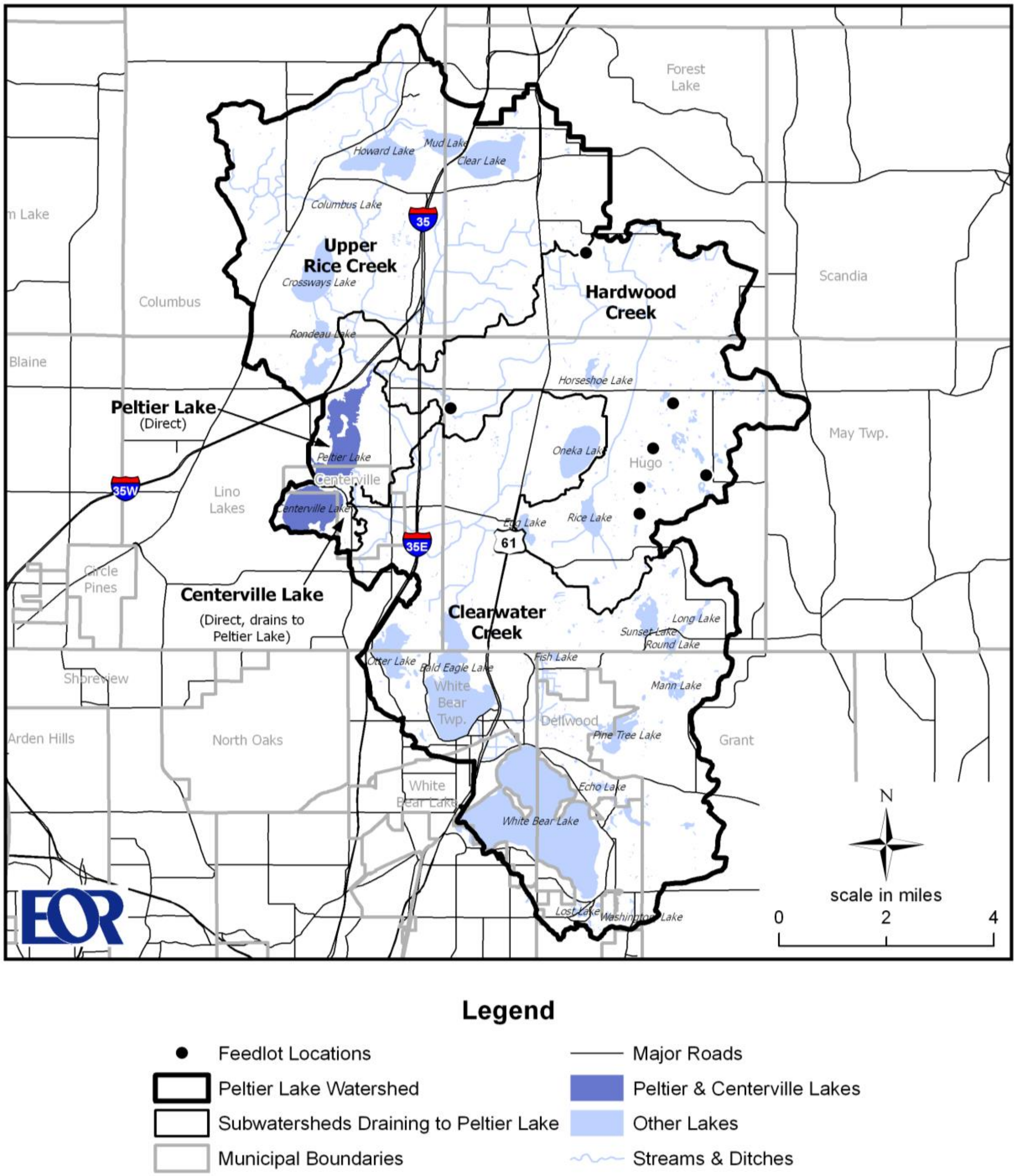

Figure 7. Feedlots in the Peltier and Centerville Lakes Watershed

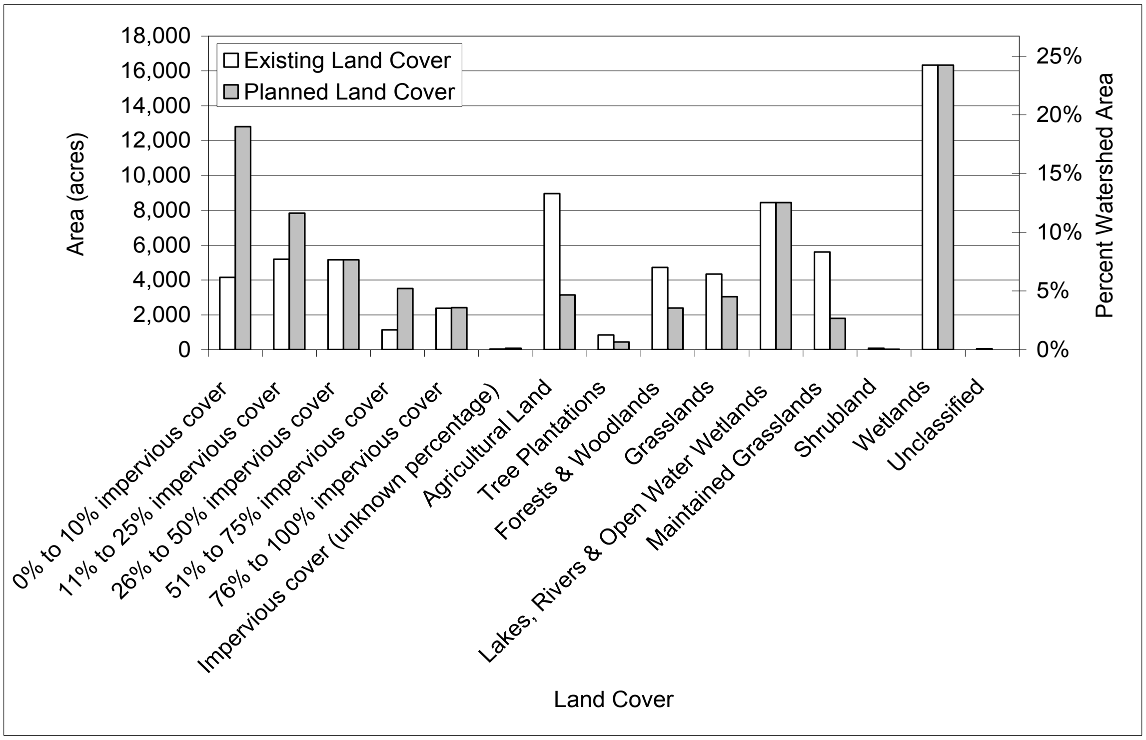

Figure 8. Peltier Lake Watershed Land Cover Summary

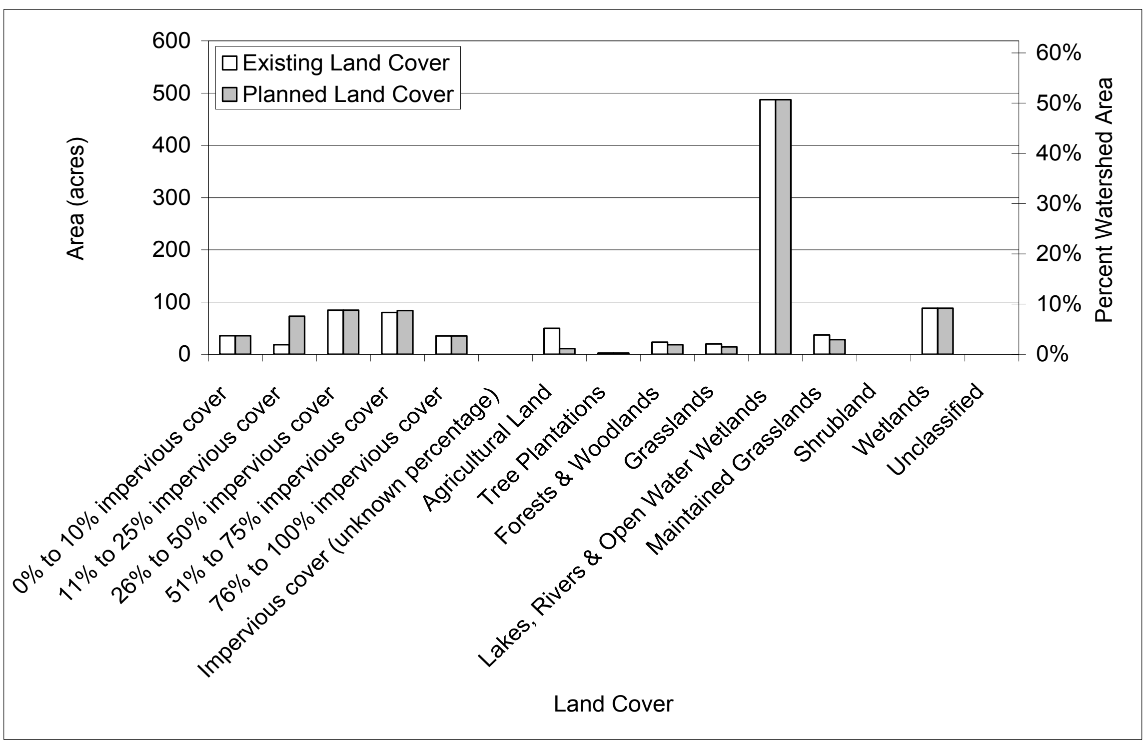

Figure 9. Centerville Lake Watershed Land Cover Summary

Population

Population is expected to increase in many of the cities and townships that intersect the Peltier Lake watershed (including the Centerville Lake watershed), with the greatest percent increases projected to occur in Lino Lakes, Forest Lake, and Hugo (Table 8).

Table 8. Current Population and Population Forecasts for Cities and Townships within the Peltier Lake Watershed

County	City or Township	Population				
		2000	2010	2020	2030	% Change 2000 to 2030
Anoka	Centerville	3,202	3,700	4,100	4,700	47%
Anoka	Columbus	3,957	4,000	4,240	4,680	18%
Anoka	Lino Lakes	16,791	23,700	27,500	31,300	86%
Ramsey	White Bear Twp.	11,293	13,100	13,500	13,500	20%
Ramsey	White Bear Lake	23,974	26,800	27,400	27,500	15%
Washington	Birchwood Village	968	950	930	930	-4%
Washington	Dellwood	1,033	1,060	990	970	-6%
Washington	Forest Lake	14,440	21,700	27,800	34,200	137%
Washington	Grant	4,026	4,400	4,450	4,500	12%
Washington	Hugo	6,363	19,100	29,000	40,000	529%
Washington	Mahtomedi	7,563	8,100	8,000	8,000	6%
Washington	May Twp.	2,928	3,200	3,600	4,000	37%
Washington	White Bear Lake	351	400	450	450	28%
Washington	Willernie	549	590	590	590	7%

Data from the Metropolitan Council's 2030 Regional Development Framework - Revised Forecasts, January 3, 2007.

Wildlife Resources

The Peltier Lake watershed contains many of the types of birds, amphibians, reptiles, and mammals typical of wetland and upland areas in this portion of the North Central Hardwood Forests ecoregion. A heron rookery exists on the island in the northern portion of Peltier Lake.

Lake Uses

Peltier Lake

Peltier lake was originally created in 1902 as a potable water source when the St. Paul Water Utility built a dam across Rice Creek to maintain water levels in Centerville Lake via its connection to Peltier Lake. Today, the lake is an important recreational resource for the area and the focal point for Anoka County’s Rice Creek Chain of Lakes Regional Park Reserve. The lake is still considered by the St. Paul Regional Water Services (SPRWS) as a contingency source of potable water. It is used recreationally for fishing and motorized and non-motorized boating, and there is an Anoka County public boat launch and fishing pier located along the south-west shore of the lake.

Starting in approximately 1998, the northern portion of the lake was intermittently used as a water-ski course. In 2002, the Cities of Centerville and Lino Lakes established a no-wake zone ordinance in that portion of the lake, with the City of Centerville's ordinance being permanent. In 2004, the City of Lino Lakes's ordinance also became permanent.

The lakeshore of Peltier Lake consists of Anoka County's Rice Creek Chain of Lakes Park Reserve along the west and north shore of the lake, a mix of single family residential and agricultural to the east, and single family residential homes along the southern portion of the shoreline.

Centerville Lake

Although formerly a source of both surface water and groundwater (via a system of shallow wells situated around the lake) to the SPRWS, use for drinking water supply has been highly curtailed because of the degraded condition of the lake and shallow groundwater feeding it. SPRWS still considers Centerville Lake as a back-up source of water for its system and retains all rights to its use even though it has sold some of its land holdings around the lake. Actual use of lake water would occur only under the most dire of circumstances, such as the severe drought situation in 1988 when the utility last used the water.

The lake is used recreationally for fishing, swimming, and motorized and non-motorized boating. There is an Anoka County swimming beach and public boat launch located along the west shore of the lake.

The lakeshore of Centerville Lake consists of Anoka County's Rice Creek Chain of Lakes Park Reserve along the south and southwest shore of the lake, and single family residential homes along the remainder of the shoreline.

Groundwater

A groundwater assessment was conducted to determine whether or not the lakes function as discharge lakes. Lake elevations relative to regional, nearby, and nearby upper bedrock groundwater elevations were examined, in addition to the surrounding surficial geology, to determine the lakes' dependence on groundwater (Appendix A). The groundwater investigation concluded that both Peltier Lake and Centerville Lake function as groundwater flow-through lakes, in that there are both groundwater discharge and groundwater recharge points. In systems with substantial groundwater input, nutrients from the groundwater input need to be taken into account in the nutrient balance of the lake. In addition, the groundwater and surface water interaction is an important component to consider when planning restoration activities.

Other Nonpoint Sources

Nonpoint source loading associated with watershed runoff (from areas not covered by National Pollutant Discharge Elimination System (NPDES) permits) primarily includes nutrients from agriculture and undeveloped areas. The agricultural sources include cropped farmland, feedlots, and pastures. Hardwood Creek is the largest subwatershed in the watershed and has the most agricultural land. There is one registered dairy operation immediately adjacent to this creek and several smaller farms with horses or livestock within 1,000 feet of the creek. In some cases, livestock have direct access to the stream. The primary effect of this direct access comes in the form of manure inputs to the stream, both directly and through non-buffered runoff. The manure inputs contribute to nutrient enrichment of the stream. In addition, there are areas where row crop agriculture is farmed up to the banks of the creek with little or no riparian buffer.

Septic systems that are either failing or illegally connected to tile lines are believed to not represent a problem in this watershed and are therefore not believed to be a contributing source. This conclusion is based on surveys and information collected by the watershed district and the counties. Any septic systems that are out of compliance are identified and addressed at the time of sale.

Atmospheric deposition is a relatively small source of phosphorus and is accounted for in the TMDL modeling (section 4E).

The primary internal sources of phosphorus are rough fish and curlyleaf pondweed. These sources are discussed more fully in sections 3B and 3C.

NPDES-Permitted Sources

There are nineteen National Pollutant Discharge Elimination System (NPDES) permits in the Peltier Lake watershed (Table 9) and four in the Centerville Lake Watershed (Table 10), not including the current construction stormwater permits.

Table 9. NPDES-Permitted Sources: Peltier Lake Watershed

Permit Type	Permit Name	Permit Number	Comments
MS4 Stormwater	Anoka County	MS400066	Mandatory MS4
MS4 Stormwater	Birchwood Village	MS400004	Mandatory MS4
MS4 Stormwater	Centerville	MS400078	Mandatory MS4
MS4 Stormwater	Dellwood	MS400084	Mandatory MS4
MS4 Stormwater	Forest Lake	MS400262	Designated MS4
MS4 Stormwater	Grant	MS400091	Mandatory MS4
MS4 Stormwater	Hugo	MS400094	Mandatory MS4
MS4 Stormwater	Lino Lakes	MS400100	Mandatory MS4
MS4 Stormwater	Mahtomedi	MS400031	Mandatory MS4
MS4 Stormwater	MNDOT Metro District	MS400170	Mandatory MS4
MS4 Stormwater	Ramsey County Public Works	MS400191	Mandatory MS4
MS4 Stormwater	Washington County	MS400160	Mandatory MS4
MS4 Stormwater	White Bear Lake	MS400060	Mandatory MS4
MS4 Stormwater	White Bear Township	MS400163	Mandatory MS4
MS4 Stormwater	Willernie	MS400061	Mandatory MS4
Construction stormwater	Various	Various	
Industrial stormwater	No current permitted sources	NA	
Individual	BP Pipelines North America, Inc.	MN0063754	Not expected source of phosphorus; no TP permit limit
Individual	Forest Lake Water Treatment Plant	MNG640118	1850 8th St. SE, Forest Lake; MPCA data estimates 0.9 pounds of phosphorus discharged per growing season
Individual	St. Croix Forge	MN0069051	5195 Scandia Trl N, Forest Lake; MPCA data estimates 1.0 pounds of phosphorus discharged per growing season
Individual	River City Asphalt, Inc.	MNG490149	Gravel pits; Not expected source of phosphorus; no TP permit limit

Table 10. NPDES-Permitted Sources: Centerville Lake Watershed

Permit Type	Permit Name	Permit Number	Comments
MS4 Stormwater	Anoka County	MS400066	Mandatory MS4
MS4 Stormwater	Centerville	MS400078	Mandatory MS4
MS4 Stormwater	Lino Lakes	MS400100	Mandatory MS4
Construction stormwater	Various	Various	
Industrial stormwater	No current permitted sources	NA	

Stormwater Runoff

Stormwater runoff is generated in the watershed during precipitation events. Certain types of stormwater runoff are covered under NPDES permits based on where the stormwater originates:

Municipal Separate Storm Sewer Systems

The Stormwater Program for Municipal Separate Storm Sewer Systems (MS4s) is designed to reduce the amount of sediment and pollution that enters surface and ground water from storm sewer systems to the maximum extent practicable. These stormwater discharges are regulated through the use of NPDES permits. Through this permit, the owner or operator is required to develop a stormwater pollution prevention program (SWPPP) that incorporates best management practices (BMPs) applicable to their MS4. The cities within the Peltier Lake watershed that are covered under MS4 permits are part of the EPA's Storm Water Phase II Rule, which extended coverage to certain small MS4s. All of the municipalities within the Peltier Lake watershed except for May Township and the City of Columbus are covered under the Phase II MS4 permit. Road authorities are also issued MS4 permits; the permitted road authorities in this watershed are Anoka County, Ramsey County, Washington County, and the Minnesota Department of Transportation (Mn/DOT).

Construction

Construction sites can contribute substantial amounts of sediment to stormwater runoff. The NPDES Stormwater Program requires that all construction activity disturbing areas equal to or greater than one acre of land must obtain a permit and create a SWPPP that outlines how runoff pollution from the construction site will be minimized during and after construction. The construction permit is valid for the duration of the construction activities. Current construction permits are not listed here because their duration is relatively short.

Industrial

The Industrial Permit applies to facilities with Standard Industrial Classification Codes in ten categories of industrial activity with significant materials and activities exposed to stormwater. Significant materials include any material handled, used, processed, or generated that when exposed to stormwater may leak, leach, or decompose and be carried offsite. The NPDES Stormwater Program requires that the industrial facility obtain a permit and create a SWPPP for the site outlining the structural and/or non-structural BMPs used to manage stormwater and the site's Spill Prevention Control and Countermeasure Plan. An annual report is generated documenting the implementation of the SWPPP.

There are no facilities with industrial stormwater permits within the boundaries of this project at this time.

Other NPDES-Permitted Point Sources

There are four non-stormwater NPDES-permitted point sources within the Peltier and Centerville Lakes watersheds (Table 9).

The permitted dischargers of concern in the Peltier Lake watershed are the City of Forest Lake's water treatment plant, which discharges water treatment backwash, and St. Croix Forge, which discharges non-contact cooling water. These facilities discharge upstream of Clear Lake, then to Mud and Howard Lakes before flowing into Rice Creek. The discharges are approximately eight miles upstream from the northern end of Peltier Lake.

1C. Pollutant of Concern

Role of Phosphorus in Lakes

TP is often the limiting factor controlling primary production in freshwater lakes in Minnesota. It is the nutrient of focus for this TMDL, and is sometimes referred to as the causal factor. As phosphorus concentrations increase, primary production also increases, as measured by higher chlorophyll-*a* concentrations. Chlorophyll-*a* concentrations are used as a proxy to measure the concentration of algae within the water column. Higher concentrations of chlorophyll lead to lower water transparency. Both chlorophyll-*a* and Secchi transparency are referred to as response factors, since they indicate the ecological response of a lake to excessive phosphorus input.

There is often a positive relationship between TP and chlorophyll-*a* in a lake, as is the case with both Peltier and Centerville Lakes (Figure 10). Similarly, a negative relationship is apparent between TP and Secchi depth (Figure 11).

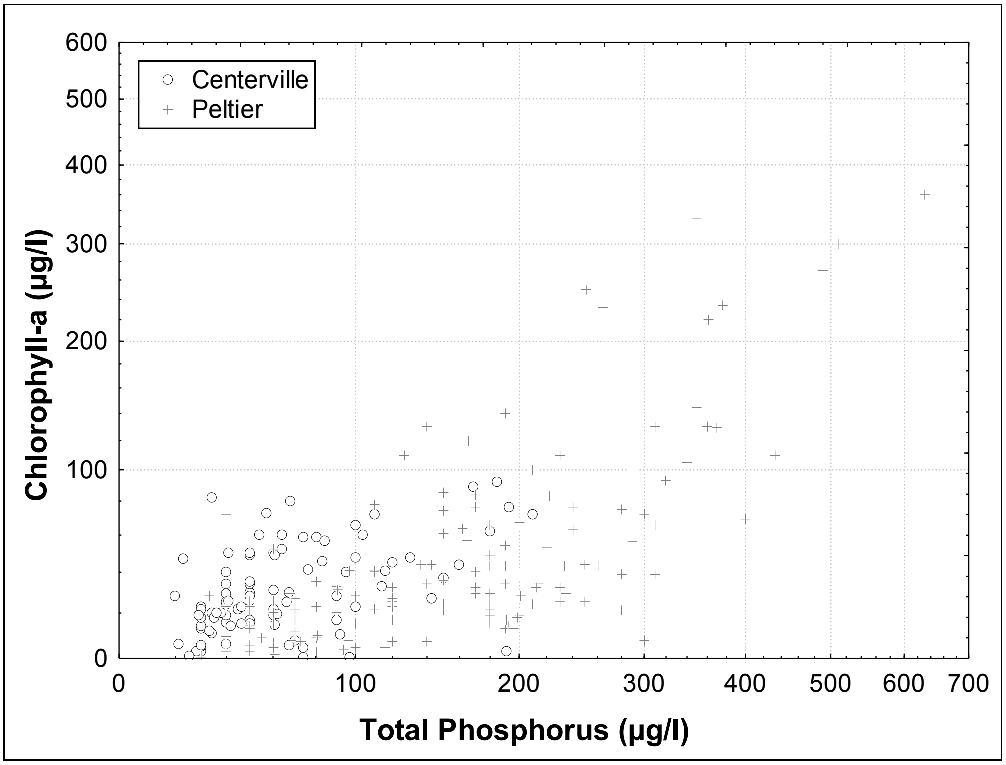

Figure 10. Relationship of Chlorophyll-*a* to TP in Peltier and Centerville Lakes, 1991-2006

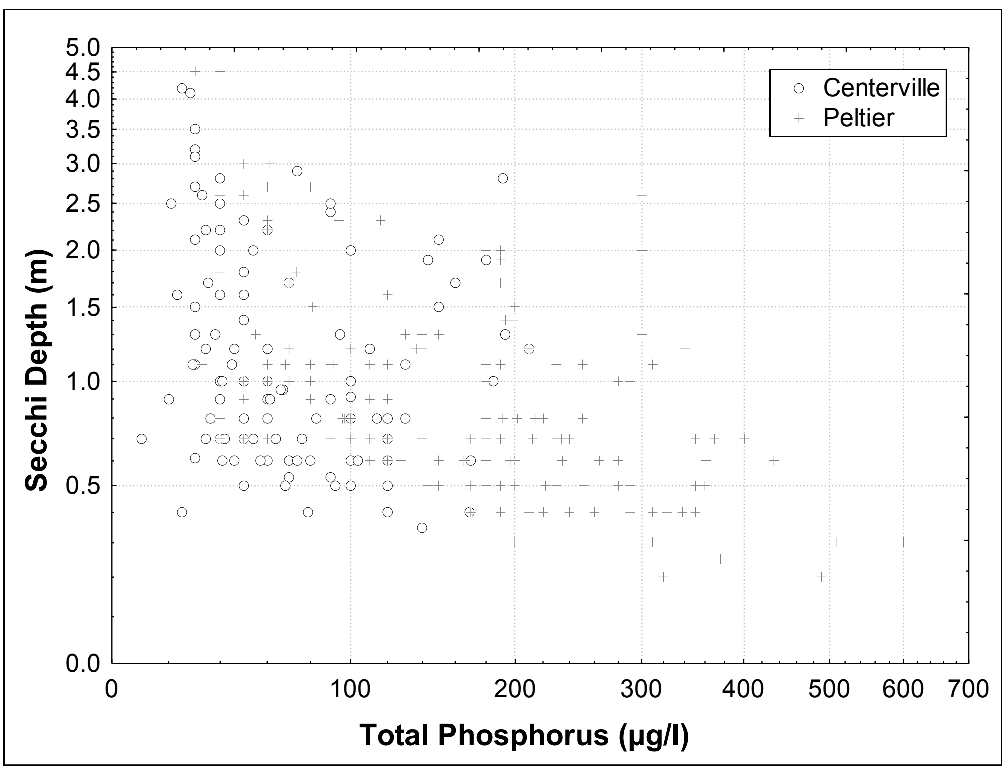

Figure 11. Relationship of Secchi Depth to TP in Peltier and Centerville Lakes, 1991-2006

Role of Phosphorus in Shallow Lakes

The relationship between phosphorus concentration and the response factors (chlorophyll and transparency) is often different in shallow lakes as compared to deeper lakes. In deeper lakes, primary productivity is often controlled by physical and chemical factors such as light availability, temperature, and nutrient concentrations. The biological components of the lakes (such as microbes, algae, macrophytes, zooplankton and other invertebrates, and fish) are distributed throughout the lake, along the shoreline, and on the bottom sediments. In shallow lakes, the biological components are more concentrated into less volume and exert a stronger influence on the ecological interactions within the lake. There is a more dense biological community at the bottom of shallow lakes than in deeper lakes because of the fact that oxygen is replenished in the bottom waters and light can often penetrate to the bottom. These biological components can control the relationship between phosphorus and the response factors.

The result of this impact of biological components on the ecological interactions is that shallow lakes normally exhibit one of two ecologically alternative stable states (Figure 12): the turbid, phytoplankton-dominated state, and the clear, macrophyte-dominated state. The clear state is preferred, since phytoplankton communities (composed mostly of algae) are held in check by diverse and healthy zooplankton and fish communities. Less nutrients are released from the sediments in this state. The roots of the macrophytes stabilize the bottom sediments, lessening the amount of sediment resuspended by the wind turbulence. Periodic winter fish kills are desirable, as they control the population of rough fish that also stir up bottom sediments and exacerbate internal loading. Rough fish forage in and resuspend bottom sediments and release nutrients into the water column through excretion.

Nutrient reduction in a shallow lake does not lead to a linear improvement in water quality (indicated by turbidity in Figure 12). As external nutrient loads are decreased in a lake in the turbid state, slight improvements in water quality may at first occur. At some point, a further decrease in nutrient loads will cause the lake to abruptly shift from the turbid state to the clear state. The general pattern in Figure 12 is often referred to as “hysteresis,” meaning that, when forces are applied to a system, it does not necessarily return completely to its original state, nor does it follow the same trajectory on the way back.

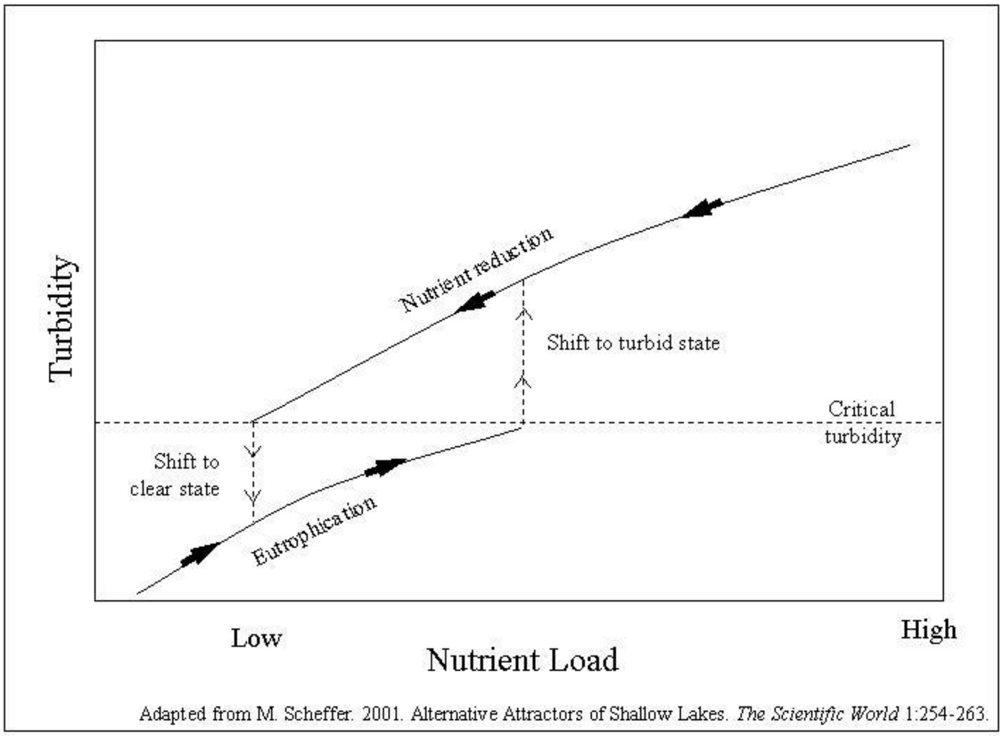

Figure 12. Alternative Stable States in Shallow Lakes

The biological response to phosphorus inputs will depend on the state of the lake. For example, if the lake is in the clear state, the macrophytes may be able to assimilate the phosphorus instead of algae performing that role. However, if enough stressors are present in the lake, increased phosphorus inputs may lead to a shift to the turbid state with an increase in algal density and decreased transparency. The two main categories of stressors that can shift the lake to the turbid state are:

- Disturbance to the macrophyte community, for example from wind, benthivorous (bottom-feeding) fish, boat motors, or light availability (influenced by algal density or water depth)
- A decrease in zooplankton grazer density, which allows unchecked growth of sestonic (suspended) algae. These changes in zooplankton density could be caused by an increase in predation, either directly by an increase in planktivorous fish that feed on zooplankton, or indirectly through a decrease in piscivorous fish that feed on the planktivorous fish.

This complexity in the relationships among the biological communities in shallow lakes leads to less certainty in predicting the in-lake water quality of a shallow lake based on the phosphorus load to the lake. The relationships between external phosphorus load and in-lake phosphorus concentration, chlorophyll concentration, and transparency are less predictable than in deeper lakes, and therefore lake response models are less accurate.

Another implication of the alternative stable states in shallow lakes is that different management approaches are used for shallow lake restoration than those used for restoration of deeper lakes.

Shallow lake restoration often focuses on restoring the macrophyte and zooplankton communities to the lake.

Peltier Lake exhibits the characteristics of a shallow lake in the turbid, phytoplankton-dominated state. Phytoplankton densities are high, and aquatic macrophytes are found only to a depth of about five feet. Preliminary lake profile data collected in 2008 indicate that the lake does thermally stratify, but only weakly. Strong winds can mix the entire water column; the lake can be classified as polymictic.

With only 61% of its surface area classified as littoral, Centerville Lake is not by definition a shallow lake. However, its maximum depth is only 19 feet and the lake exhibits some characteristics of a shallow lake in that the littoral regions likely do not remain stratified throughout the growing season. Preliminary lake profile data collected in 2008 support the theory that the lake is often weakly stratified, and is prone to whole-lake mixing on windy days. Centerville Lake can be classified as polymictic.

2. Applicable Water Quality Standards and Numeric Water Quality Targets

2A. Designated Uses

Peltier Lake is classified as a Class 2B, 3B, 4A, 4B, 5, and 6 water. Centerville Lake is classified as a Class 1C, 2Bd, and 3C water. Standards for Class 1 waters are for the protection of drinking water; water bodies are not currently being assessed by the MPCA for the beneficial use of domestic consumption and therefore standards for Class 1C waters are not presented here.

The most protective of the remaining classes is Class 2 waters, which are protected for aquatic life and recreation. MN Rules Chapter 7050.0140 Water Use Classification for Waters of the State reads:

> Subp. 3. Class 2 waters, aquatic life and recreation. Aquatic life and recreation includes all waters of the state which do or may support fish, other aquatic life, bathing, boating, or other recreational purposes, and where quality control is or may be necessary to protect aquatic or terrestrial life or their habitats, or the public health, safety, or welfare.

2B. Water Quality Standards

Water quality standards are established to protect the designated uses of the state's waters. Amendments to Minnesota's Rule 7050, approved by the EPA in May 2008, include eutrophication standards for lakes (Table 11). Eutrophication standards were developed for lakes in general, and for shallow lakes in particular. Standards are less stringent for shallow lakes, due to higher rates of internal loading in shallow lakes and different ecological characteristics. The standards apply to the growing season – June through September.

To be listed as impaired, the monitoring data must show that the standards for both TP (the causal factor) and either chlorophyll-*a* or Secchi depth (the response factors) were violated. If a lake is impaired with respect to only one of these criteria, it may be placed on a review list; a weight of evidence approach is then used to determine if these lakes will be listed as impaired. For more details regarding the listing process, see the *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for the Determination of Impairment* (MPCA 2007).

Centerville Lake was listed as an impaired water based on the general eutrophication standards, and Peltier Lake was evaluated as a shallow lake. According to the MPCA definition of shallow lakes, a lake is considered shallow if its maximum depth is less than 15 ft, or if the littoral zone (area where depth is less than 15 ft) covers at least 80% of the lake's surface area. The littoral area of Peltier Lake is 89% of the lake's total surface area (483 ac), and the lake is therefore considered shallow.

Table 11. MN Eutrophication Standards, North Central Hardwood Forests Ecoregion

Parameter	Eutrophication Standard, General	Eutrophication Standard, Shallow Lakes
TP (µg/l)	TP < 40	TP < 60
Chlorophyll-*a* (µg/l)	chl < 14	chl < 20
Secchi depth (m)	SD > 1.4	SD > 1.0

At the outset of this project an alternative water quality endpoint was proposed for Peltier Lake. This endpoint was a natural background condition and was based on paleolimnological diatom reconstructions done by the Science Museum of Minnesota for Peltier Lake (Appendix B). At this time, however, a formal natural background condition is not being proposed for Peltier Lake. Thus, only the current state eutrophication standards will apply. However, information and results relating to the previously sought natural background condition will remain in this TMDL document solely for reference and for possible reconsideration of an alternative endpoint in the future.

3. Impairment Assessment

3A. Background and Lake Descriptions

Peltier Lake is 483 acres in size, with a watershed area to lake area ratio of 140 (Table 12). It is a shallow lake, with a mean depth of 7 feet and a maximum depth of 16 feet (Figure 13). Approximately 89% of the surface area of the lake is littoral (less than 15 feet depth). The northern portion of the lake (around and north of the island) is 100% littoral.

Centerville Lake has approximately the same surface area as Peltier Lake (Table 12), but has a much smaller watershed, with a watershed to surface area ratio of approximately one. Its maximum depth (19 ft) is similar to that of Peltier (Figure 14), but it has a greater mean depth (12 ft) and a smaller proportion of its surface area is littoral (61%).

A complex flow system exists between Centerville and Peltier Lakes, with flow reversal not uncommon. Under low flow conditions, the small watershed draining to Centerville Lake feeds Peltier Lake. Following a storm, the volume of water flowing through Peltier Lake increases to the point that, as the water level of Peltier rises, its elevation is higher than that of Centerville Lake, and water flows from Peltier Lake to Centerville Lake. As water recedes from the system, the flow reverses again and water flows from Centerville Lake to Peltier Lake. This flow reversal is apparent in XP-SWMM modeling results. The flow from Peltier Lake to Centerville Lake during storm events is a source of TP to Centerville Lake.

Tributaries to Peltier Lake include Upper Rice Creek, Hardwood Creek, Clearwater Creek, and Anoka County Ditch 72 (ACD72). Entering Peltier from the northwest, Upper Rice Creek is the primary tributary, and has a contributing watershed of 18,700 acres. Land use is a broad mix of wetlands, agriculture, rural residential, and parts of the city of Forest Lake. Hardwood Creek enters Peltier from the northeast and contributes approximately 16,000 acres of predominantly wetland, agriculture, and rural residential lands. Clearwater Creek enters Peltier from the east. The entire Clearwater Creek watershed is approximately 28,500 acres. However, the watershed above Bald Eagle Lake will be addressed in the Bald Eagle Lake TMDL (in progress, 2010). The watershed area contributing to Clearwater Creek *below* Bald Eagle Lake is approximately 7,900 acres of rural residential, wetland, agriculture, commercial, and light industrial land use, and includes parts of the cities of Centerville and Hugo. Lastly, ACD72 is a closed-tile public drainage system serving agricultural and rural residential lands on the east side of Peltier Lake. The watershed served by the system is not completely known, but is estimated to be about 700 acres. With the exception of ACD72, water quality and flow monitoring data are available for each of the tributaries; details can be found in Section 4A. Large portions of the watershed above Peltier Lake were, at one time or another, used for agriculture. As such, many sections of both Hardwood and Clearwater Creeks were straightened; recent channel surveys have revealed unstable stream banks and beds. Although altercations have been made to water courses (i.e. ditching), and some residential and commercial development has occurred, streamflows are generally not flashy. All of the main tributary watersheds are topographically flat, and contain considerable wetland areas.

Centerville Lake does not have any stream or ditch tributaries, other than direct stormwater runoff received from the City of Centerville. Land use in the direct watershed is a mix of parks, residential, and commercial.

The recently completed Hardwood Creek TMDL has several implications for the Peltier and Centerville TMDL. In the Hardwood Creek TMDL, the stressor identification process indicated that *loss of habitat due to sedimentation* and *low dissolved oxygen* were the primary stressors. As such, the TMDL was written for total suspended solids (TSS) and biochemical oxygen demand (BOD). Although TP is often strongly correlated with TSS, TP reductions were not addressed in the Hardwood Creek TMDL. Reductions in TP to meet the assimilative capacity of Peltier Lake are expected to exceed reductions associated with TSS reductions in Hardwood Creek. Many of the actions outlined in the implementation strategy of the Hardwood Creek TMDL, such as stormwater management and streambank stabilization, are expected to benefit Peltier Lake by reducing TP loading. Ongoing monitoring associated with the Hardwood Creek TMDL will be used to determine if TP reduction goals of the Peltier and Centerville TMDL are being met.

Table 12. Lake Characteristics

Characteristic	Peltier	Centerville
Lake total surface area (ac)	483	495
Percent lake littoral surface area	89%	61%
Lake volume (ac-ft)	3,381	5,940
Mean depth (ft)	7	12
Maximum depth (ft)	16	19
Drainage area (mi^2)	106	0.7
Watershed area : lake area	140	0.9

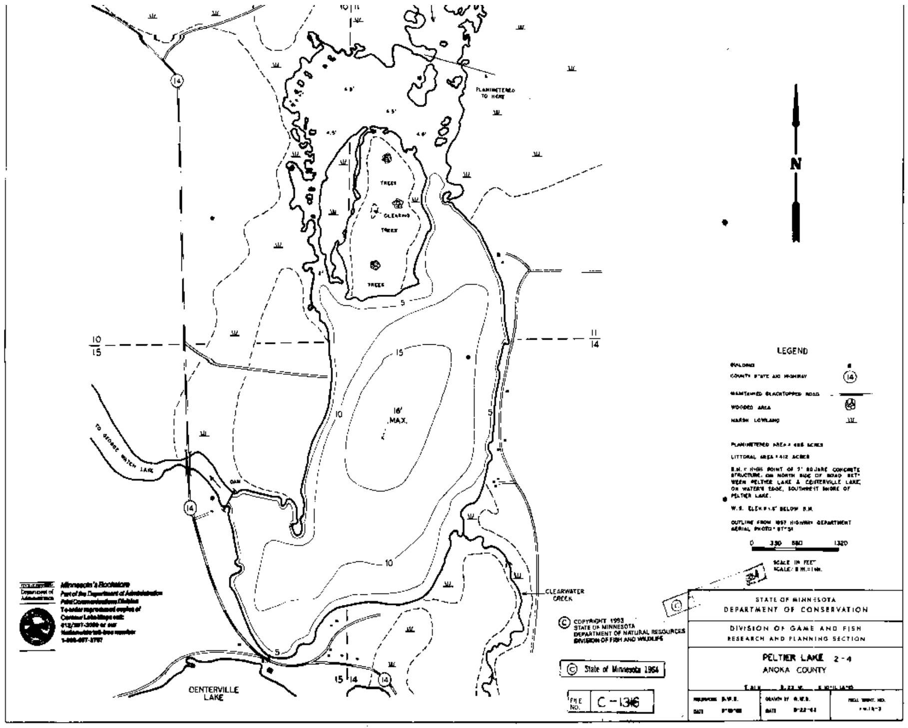

Figure 13. Peltier Lake Bathymetric Map

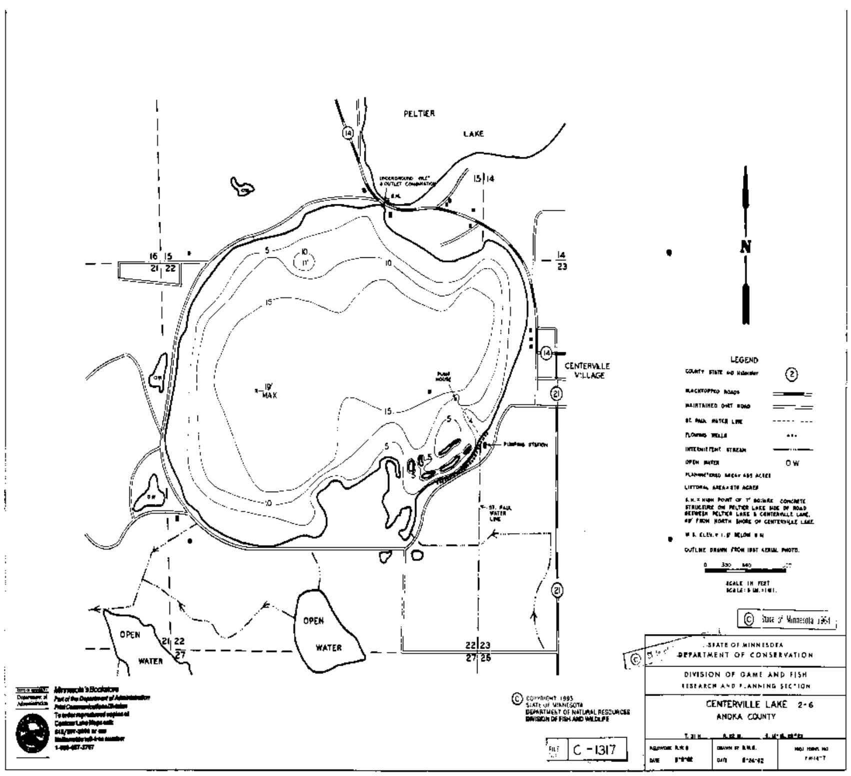

Figure 14. Centerville Lake Bathymetric Map

3B. Peltier Lake

In-lake monitoring data for Peltier Lake are available from 1990, 1991, 1994 through 2002, 2004, and 2006. The last ten years of data were used to calculate the water quality data means (Table 13); the lake was monitored for eight seasons within this ten-year period.

Peltier Lake ranges from eutrophic to hypereutrophic, with relatively higher TP and chlorophyll concentrations compared to transparency, as indicated by the TSI (Trophic State Index) values (Table 13). TP concentrations have varied over the years (Figure 15), with annual means ranging from approximately 100 to 300 µg/L. 2001 was the year with the poorest water quality. The same general pattern exists for chlorophyll-*a* (Figure 16) and Secchi depth (Figure 17).

Table 13. Surface Water Quality, Peltier Lake, 1997 - 2006

Parameter	Growing Season Mean (June – September)	Coefficient of Variation	Trophic State Index
TP (µg/L)	235	0.15	83
Chlor-*a* (µg/L)	84	0.31	74
Secchi depth (m)	0.83	0.16	63

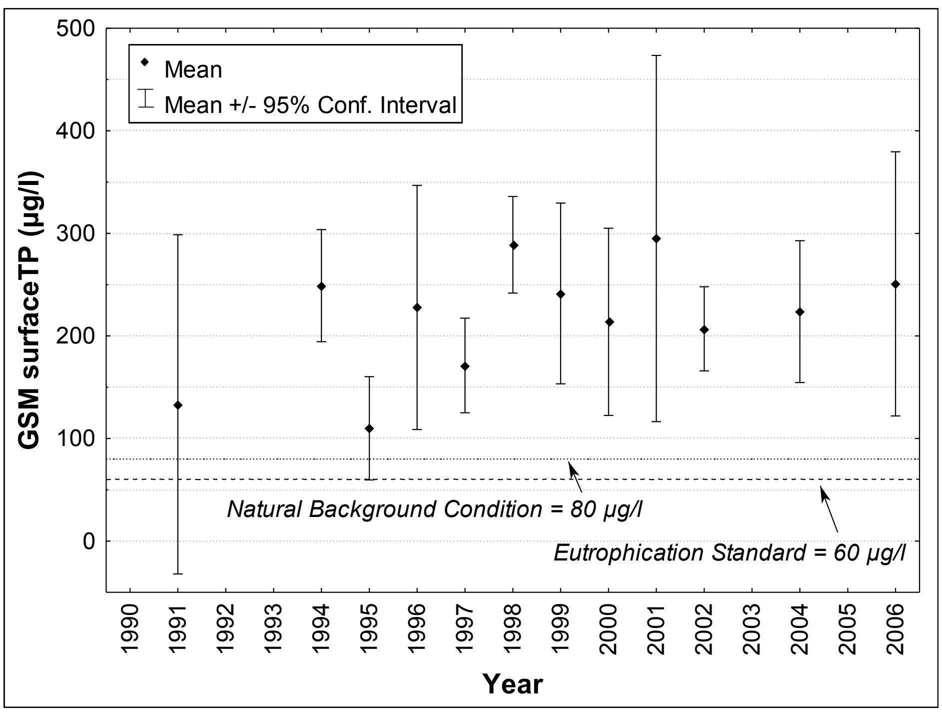

Figure 15. Total Phosphorus Monitoring Data, Peltier Lake

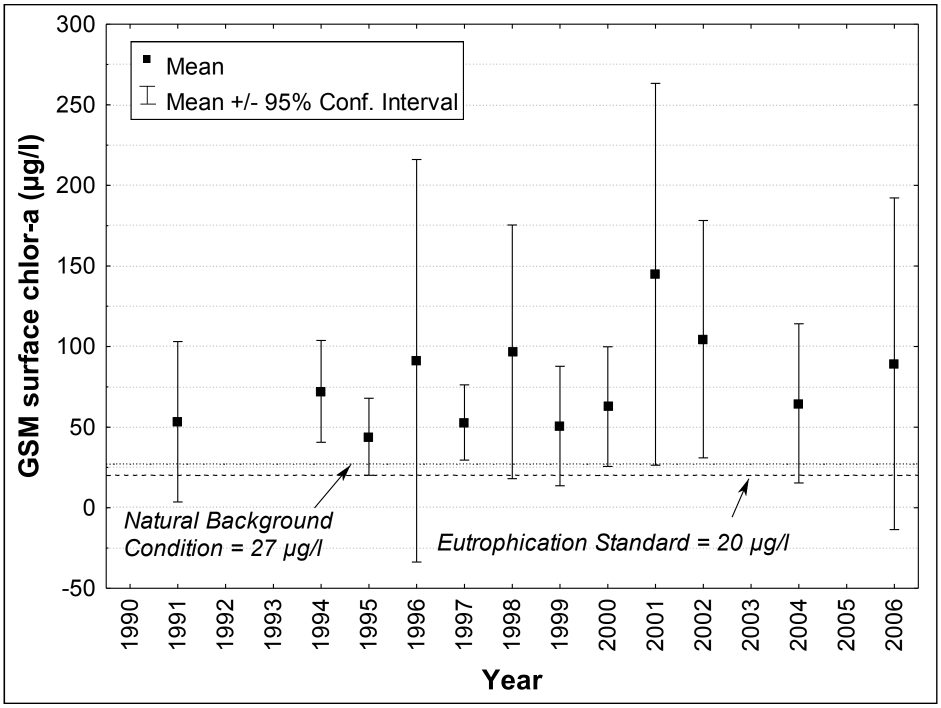

Figure 16. Mean Chlorophyll-*a* Monitoring Data, Peltier Lake

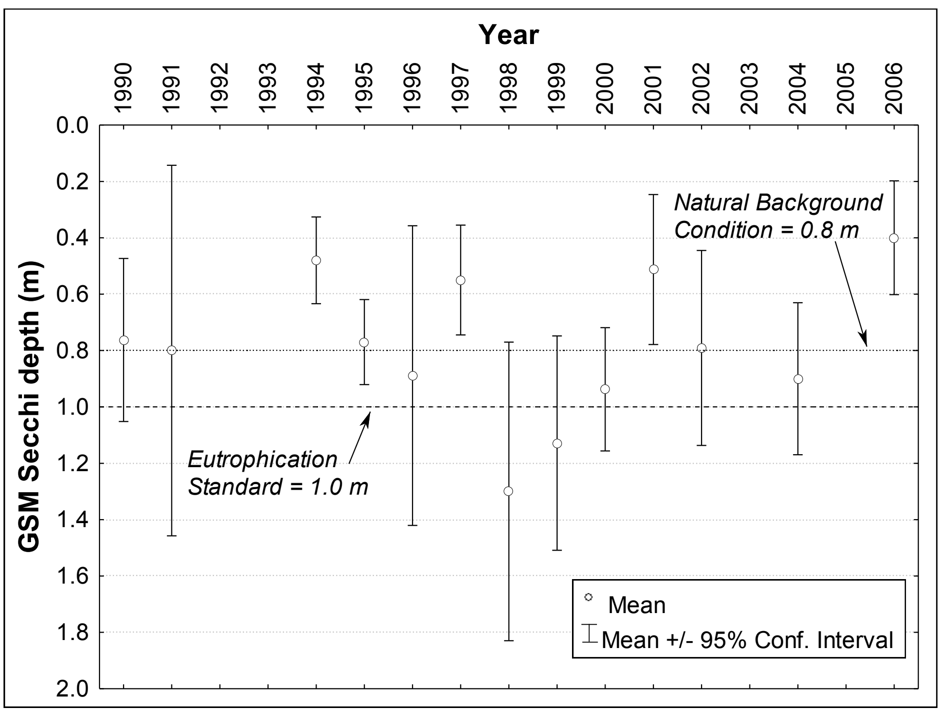

Figure 17. Secchi Depth Monitoring Data, Peltier Lake

Water quality in Peltier Lake generally worsens throughout the growing season (Figure 18 and Figure 19). In both 2001 and 2004, phosphorus and chlorophyll dramatically increased towards the end of July and beginning of August. Although somewhat late in the season for curlyleaf pondweed to normally die off, this could indicate the period of senescence of this non-native invasive plant.

Based on a 2007 DNR fish survey, black bullhead, black crappie, bluegill, bowfin, brown bullhead, common carp, golden shiner, green sunfish, largemouth bass, northern pike, pumpkinseed sunfish, walleye, white sucker, yellow bullhead, and yellow perch were found in Peltier Lake. Both channel catfish and walleye are regularly stocked in the lake, although neither appeared in the survey.

"Stunted" panfish, a phenomenon denoted by large populations of very small individuals, can exacerbate water clarity issues. The primary mechanism is through food web shifts, in which a large population of small panfish overgrazes large-bodied zooplankton, thus removing the biological "check" on algae populations. In Peltier Lake black crappie were sampled in higher than typical numbers compared to lakes with similar physical and chemical characteristics. Although the DNR report notes that many crappie were small in size, the population is not completely dominated by small individuals. Bluegill were sampled in average numbers, and in a wide range of sizes. Based on this survey, panfish stunting does not appear to be a major concern. A strong population of large northern pike may be effectively controlling the panfish population. Despite this, overgrazing on zooplankton is still possible if native vegetation is not present to provide sufficient refuge from planktivores.

Rough fish, especially carp, can contribute to internal phosphorus loading. There are two mechanisms: First, rough fish spawning and feeding activities re-suspend bottom sediments, making sediment phosphorus available for algal uptake. Second, rough fish uproot and kill native aquatic vegetation, thus making the sediment more susceptible to re-suspension. Based on data from previous fish surveys dating back to 1962, there were large populations of both carp and bullhead in the lake in the 1970s and 1980s, which then declined in the 1990s through the present. DNR has stocked channel catfish, hoping that predation on young-of-the-year rough fish would control their populations. Although rough fish populations are lower than previously sampled, they remain a concern, and a likely culprit for at least a portion of internal phosphorus loading.

Eurasian watermilfoil *(Myriophyllum spicatum)* is present in the lake. Curlyleaf pondweed *(Potamogeton crispus)* is also present and has been the focus of plant harvesting activities on the lake. Figure 20 shows the distribution of curlyleaf pondweed in 2005. In May of 2008, the MN DNR conducted a spring plant survey on Peltier Lake as part of their Sustaining Lakes in a Changing Environment (SLICE) program. Data collected in late May 2008 (written communication from Ray Valley, to RCWD, May 27, 2008) indicate the following for the point-intercept vegetation survey:

- Curlyleaf pondweed was detected at a 52% frequency, Eurasian milfoil at 18%, and coontail at 68%.
- Sprigs of curlyleaf pondweed were found at all depths sampled (up to 12 feet).

- The main vegetative blanket faded out at six feet in depth.

Figure 21, Figure 22, and Figure 23 show the results of the spring 2008 DNR SLICE vegetation survey. Note that the distribution of curlyleaf pondweed in Figure 21 is slightly different from that shown for 2005 in Figure 20. It is possible that coontail has out-competed the curlyleaf pondweed in the northern bay area, which could have implications for the vegetation management approach suggested in the implementation strategy.

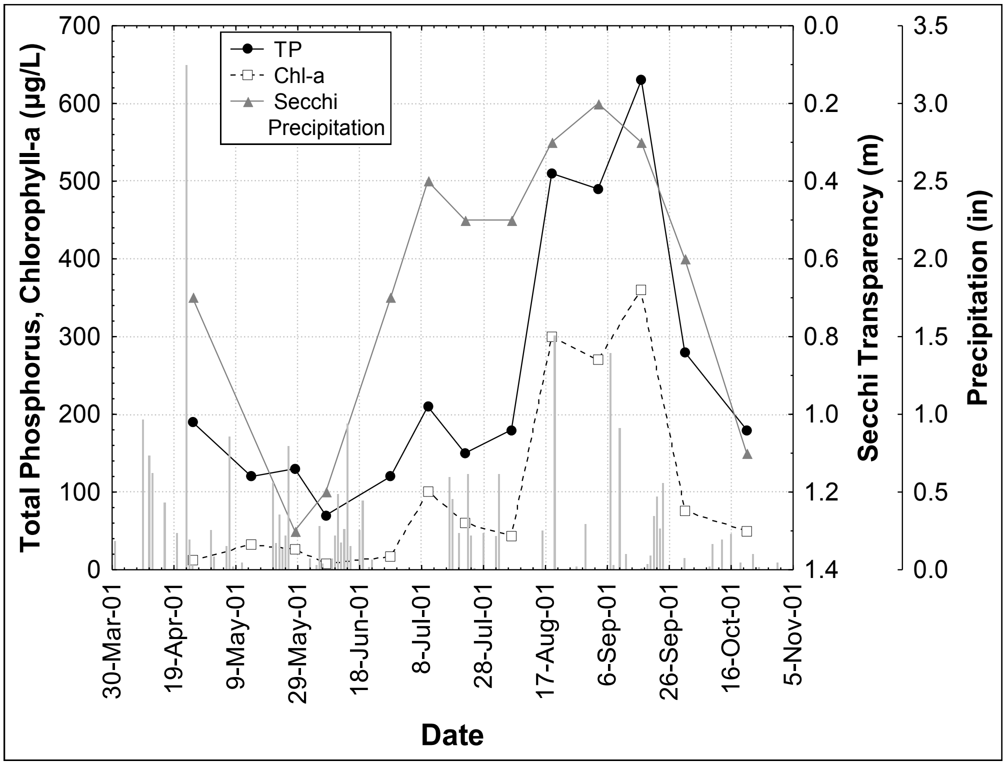

Figure 18. 2001 Seasonal Water Quality Patterns, Peltier Lake

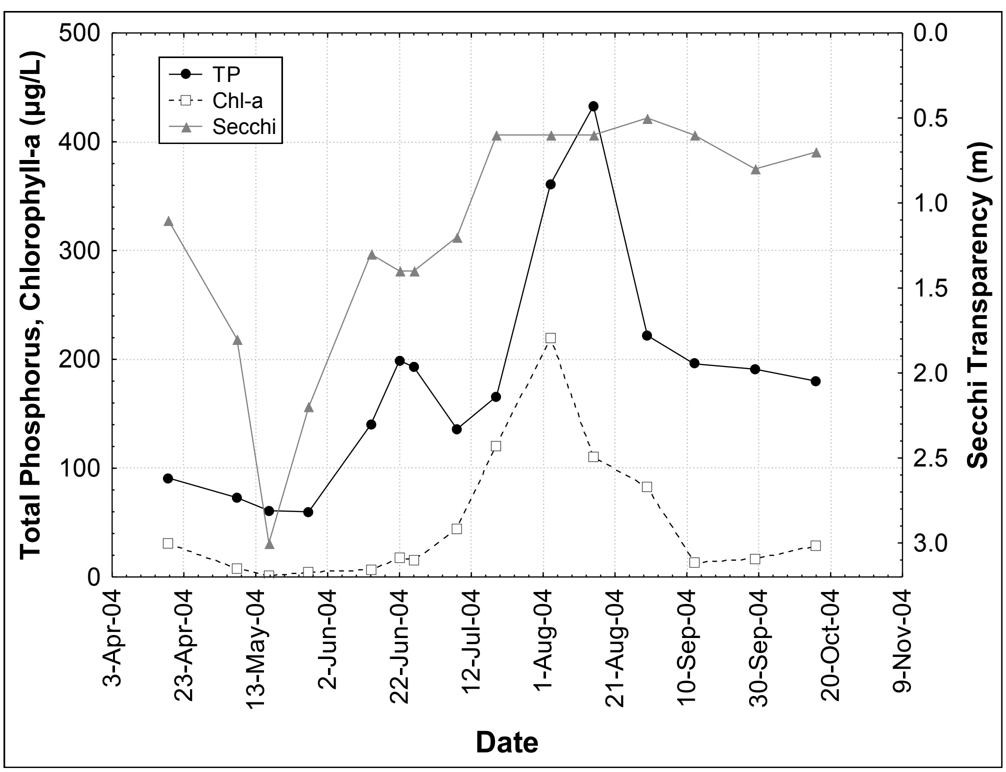

Figure 19. 2004 Seasonal Water Quality Patterns, Peltier Lake

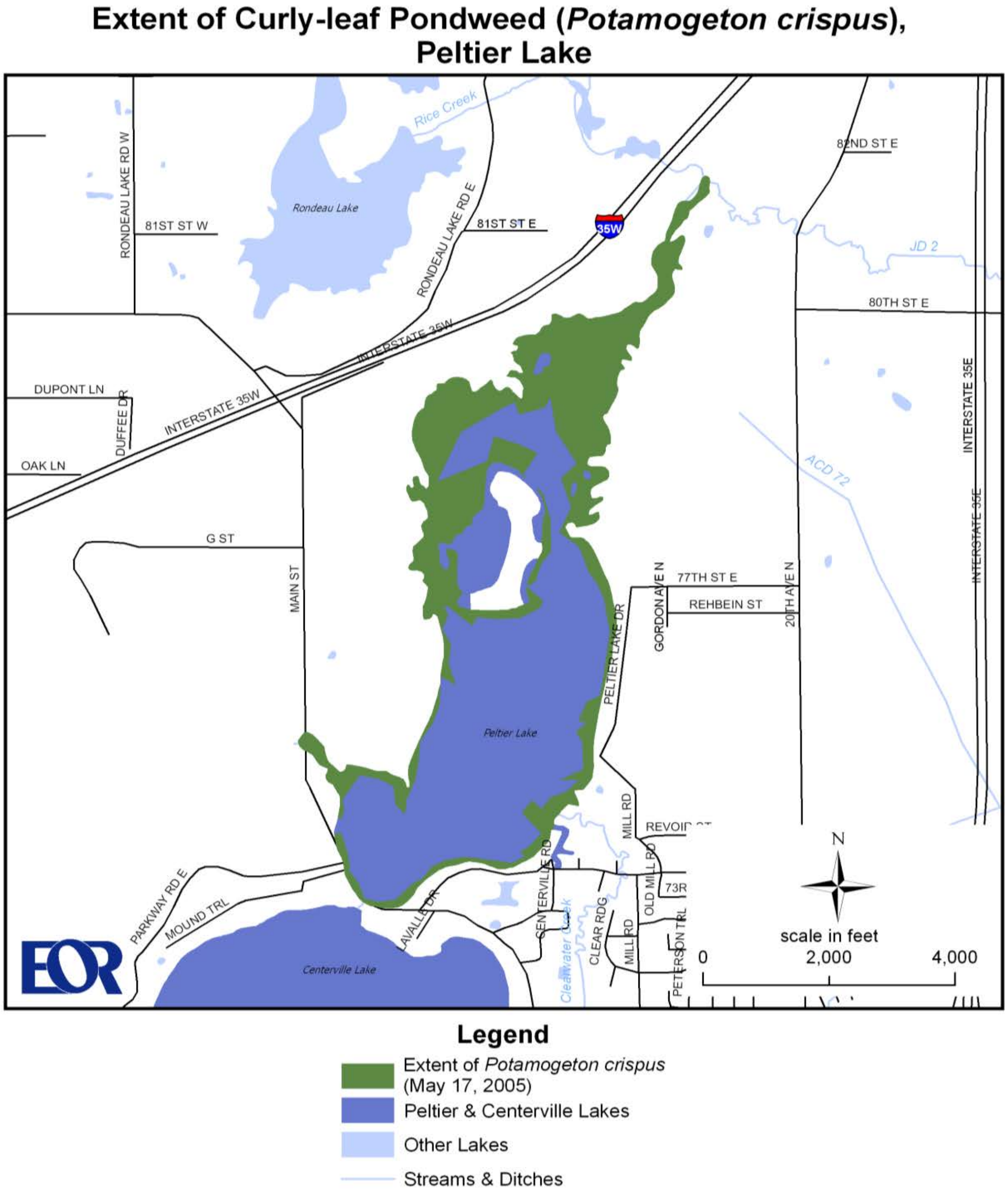

Figure 20. Extent of Curlyleaf Pondweed (*Potamogeton crispus*) in Peltier Lake, May 2005

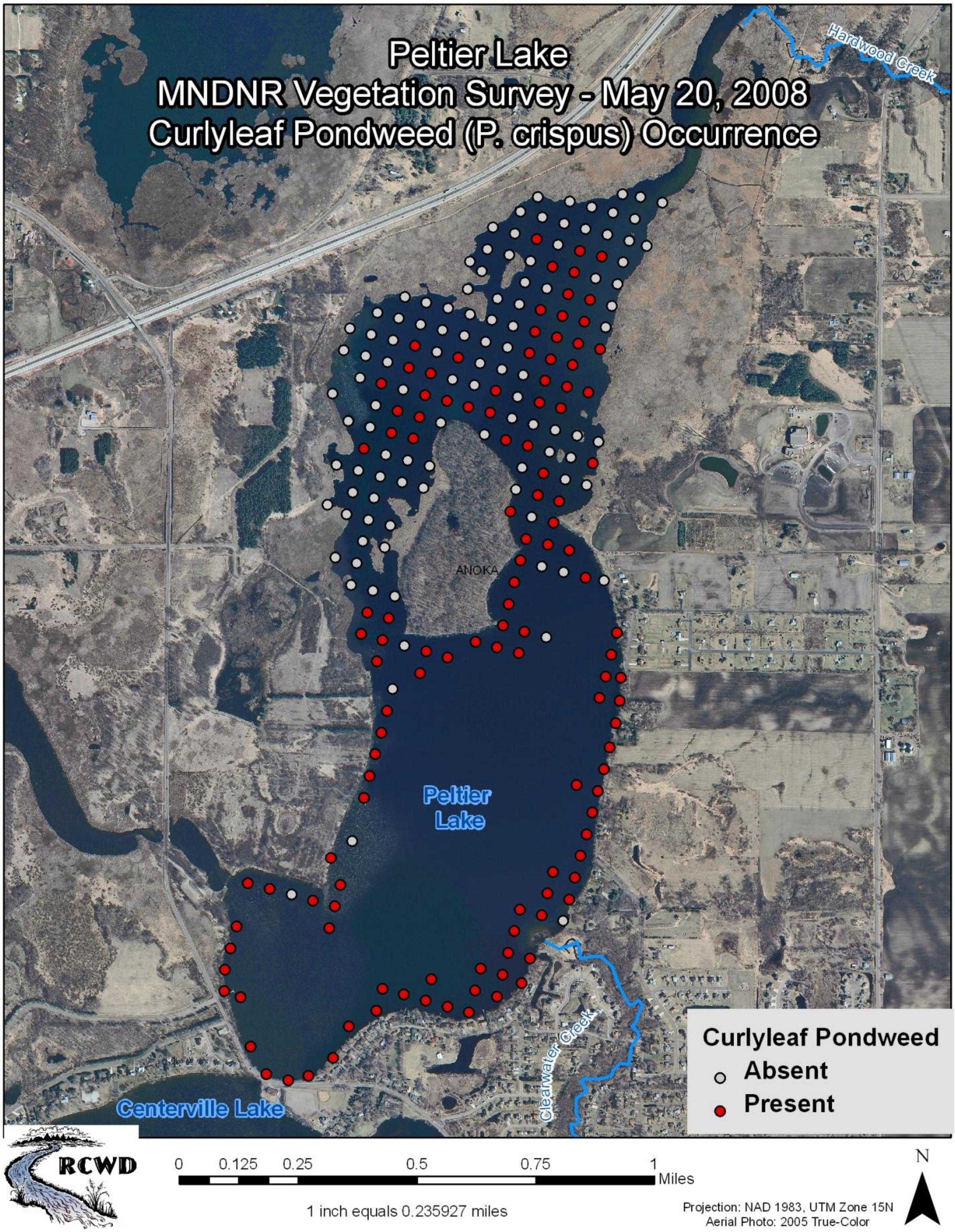

Figure 21. Extent of Curlyleaf Pondweed (*Potamogeton crispus*) in Peltier Lake, May 2008

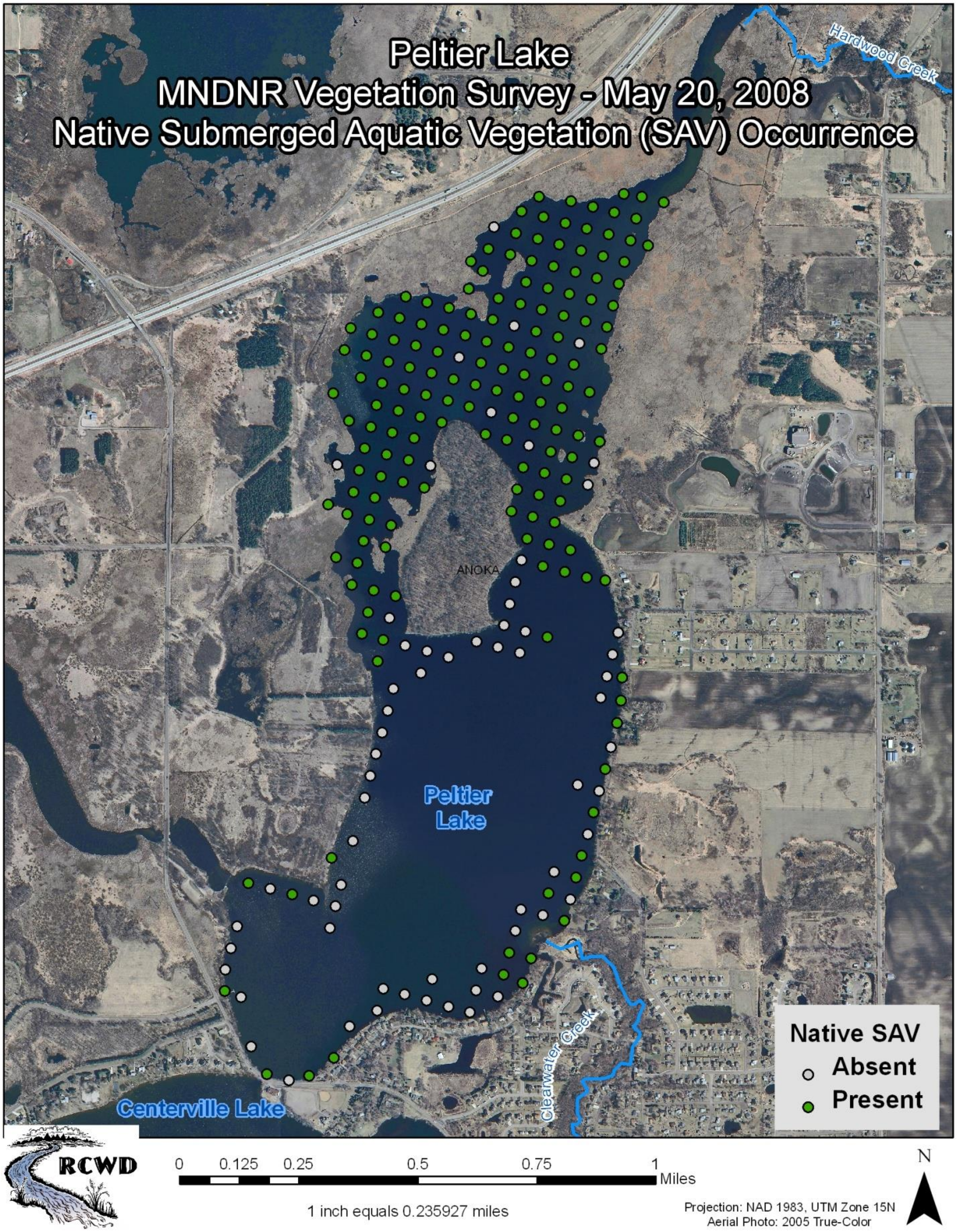

Figure 22. Extent of Native Submerged Vegetation in Peltier Lake, May 2008
Excludes unrooted plants (duckweed)

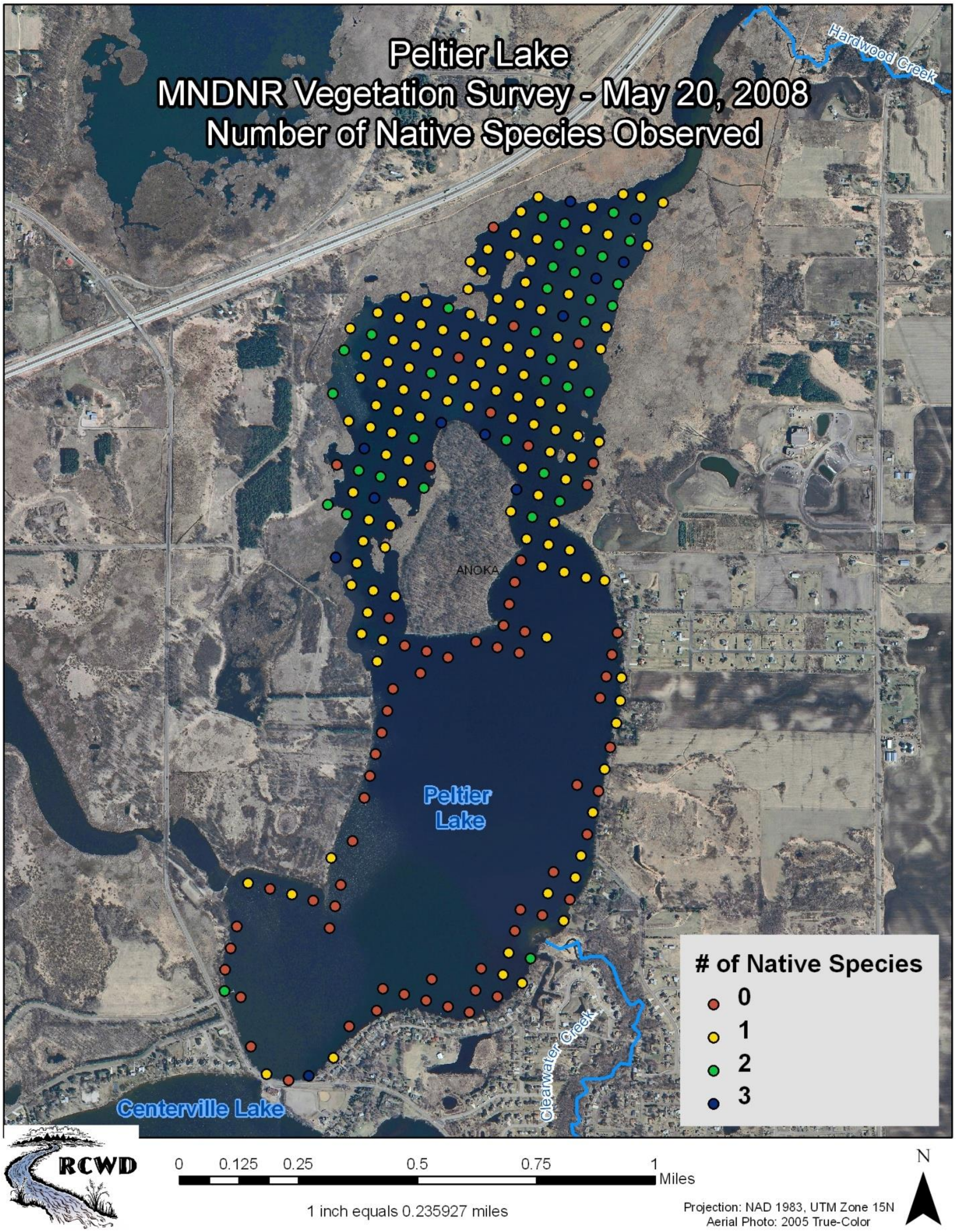

Figure 23. Native Species Count in Peltier Lake, May 2008
Excludes unrooted plants (duckweed)

3C. CENTERVILLE LAKE

In-lake monitoring data are available sporadically from 1980 to 1991, and for five seasons within 2000 through 2006. The last ten years of data were used to calculate the water quality data means (Table 14); the lake was monitored for five seasons within this ten-year period.

Centerville Lake is a eutrophic lake, with relatively higher chlorophyll concentrations compared to TP, as indicated by the TSI values (Table 14), and slightly better transparency. Monitoring data from the 1980s suggest that the water quality of the lake was worse then (Figure 24 through Figure 26). Water quality has fluctuated since 2000, but seems to be on a declining trend.

Table 14. Surface Water Quality, Centerville Lake, 2000 - 2006

Parameter	Growing Season Mean (June – September)	Coefficient of Variation	Trophic State Index
TP (µg/L)	59	0.14	63
Chlor-*a* (µg/L)	36	0.17	66
Secchi depth (m)	1.0	0.15	60

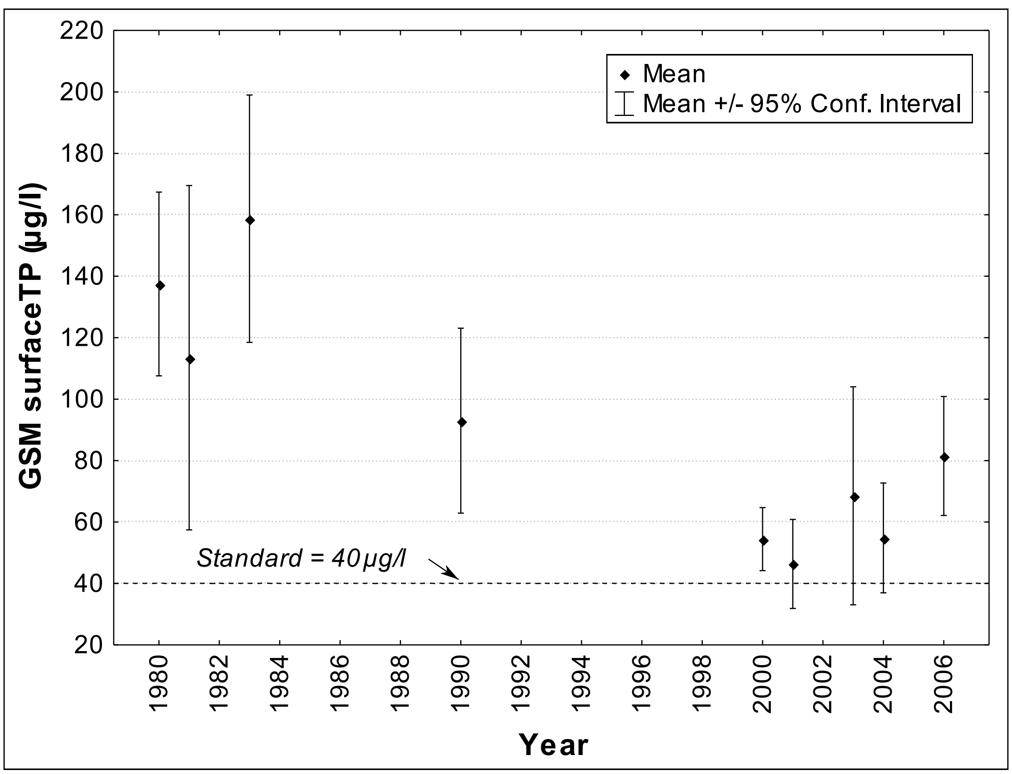

Figure 24. Total Phosphorus Monitoring Data, Centerville Lake

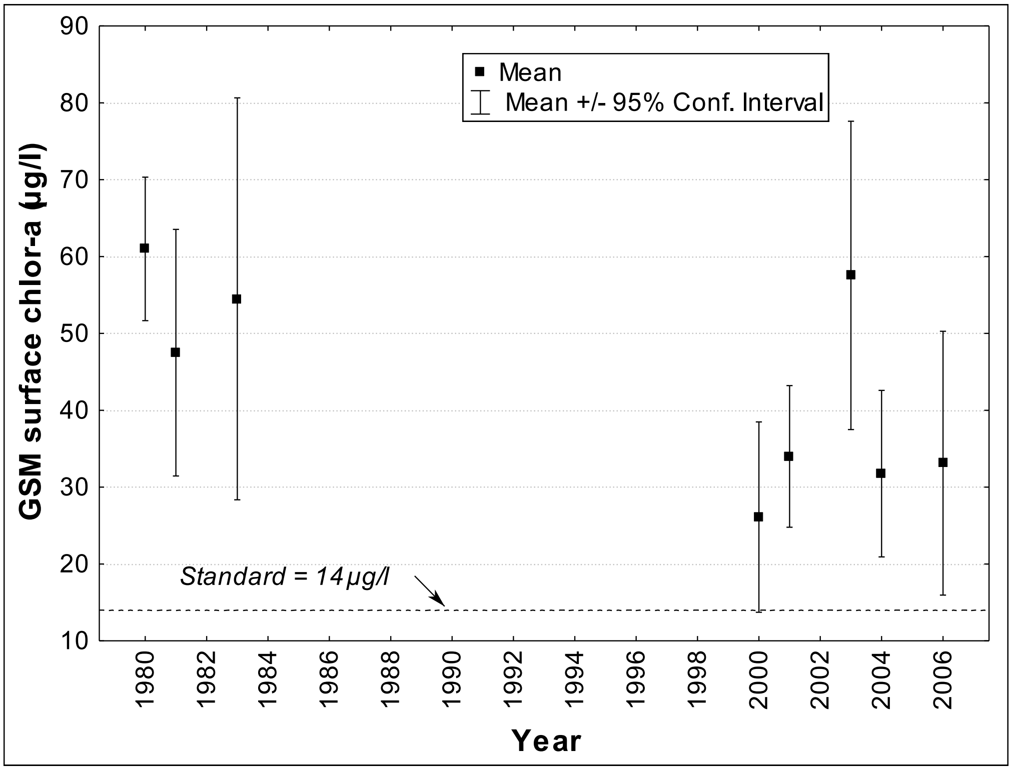

Figure 25. Chlorophyll-*a* Monitoring Data, Centerville Lake

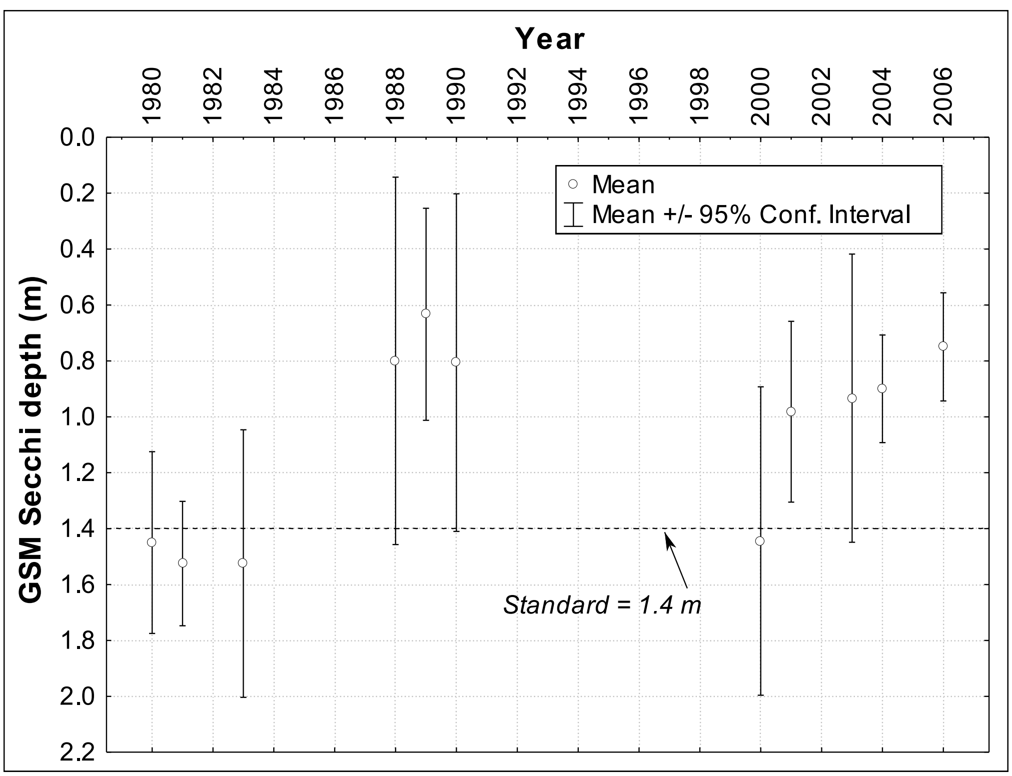

Figure 26. Secchi Depth Monitoring Data, Centerville Lake

TP in Centerville Lake fluctuates throughout the growing season, with an increase in September, which could indicate the time of fall turnover. Transparency worsens throughout the growing season (Figure 27 and Figure 28).

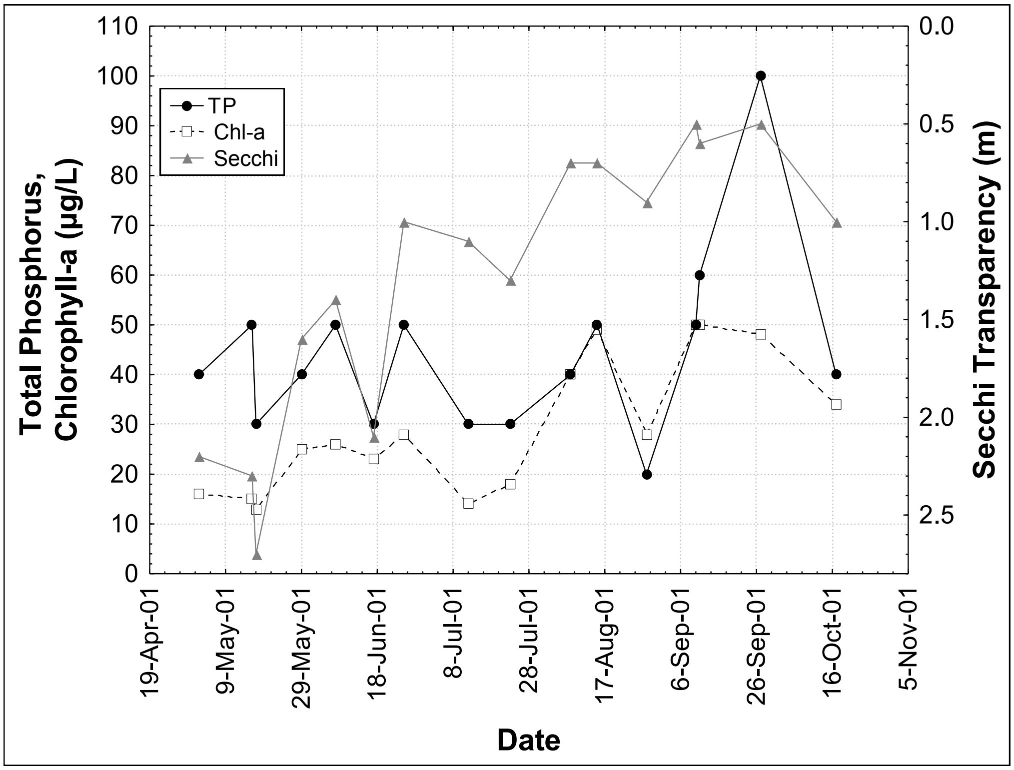

Figure 27. 2001 Seasonal Water Quality Patterns, Centerville Lake

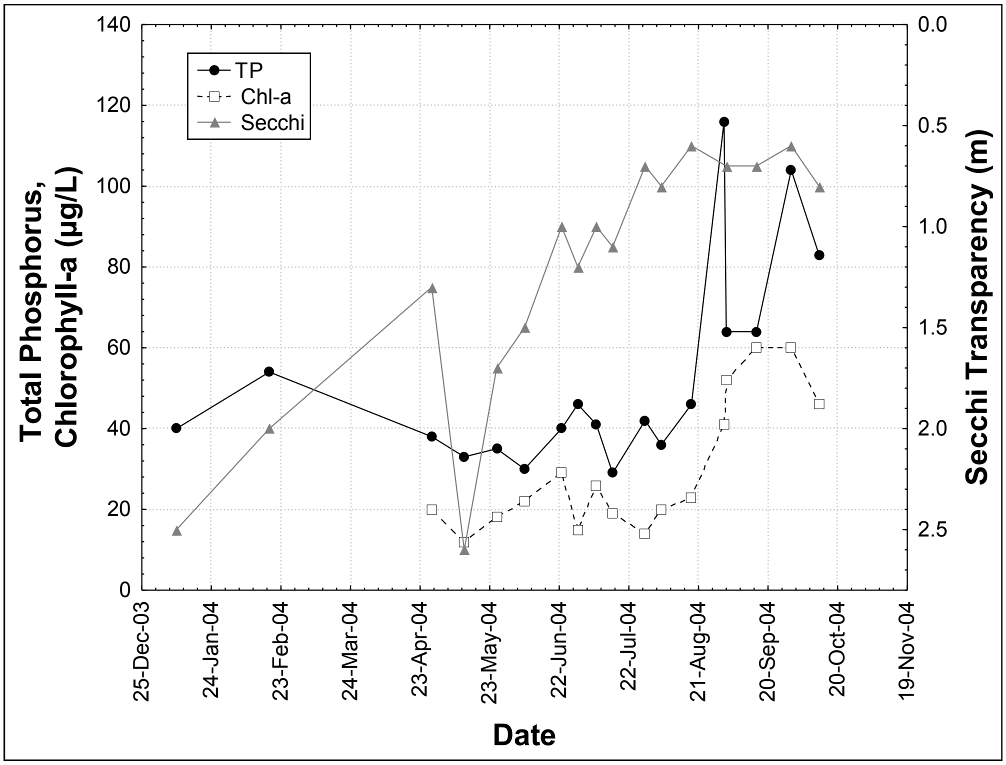

Figure 28. 2004 Seasonal Water Quality Patterns, Centerville Lake

Based on a 2007 DNR fish survey, black bullhead, black crappie, bluegill, bowfin, carp, channel catfish, golden shiner, hybrid sunfish, largemouth bass, northern pike, pumpkinseed, walleye, white sucker, yellow bullhead, and yellow perch were found in Centerville Lake. Walleye have been stocked regularly since 1999. Black crappie were sampled in much higher abundance compared to lakes with similar characteristics. However, the size distribution of both bluegill and black crappie was well balanced, making problems associated with stunted panfish unlikely. Northern pike were sampled in high abundance, and in large sizes, possibly providing a check on panfish stunting. Despite this, overgrazing on zooplankton is still possible if native vegetation is not present to provide sufficient refuge from planktivores.

Based on data from previous fish surveys dating back to 1962, there were large populations of both carp and bullhead in the lake in the 1970s and 1980s, which then declined in the 1990s through the present. This period of high carp and bullhead concentrations coincided with the poor water quality observed in the 1980s. Channel catfish, stocked in Peltier Lake to provide a predatory check on rough fish populations, have made their way into Centerville Lake. Although rough fish populations are lower than previously sampled, they remain a concern, and likely culprit for at least a portion of internal phosphorus loading.

Eurasian watermilfoil *(Myriophyllum spicatum)* and curlyleaf pondweed (*Potamogeton crispus*) are present in the lake.

4. Pollutant Loading

The categories of phosphorus loads to Peltier and Centerville Lakes are watershed runoff (which includes both permitted and nonpermitted stormwater sources), wastewater sources, internal loading, Peltier Lake backflow, groundwater discharge, and atmospheric deposition. Phosphorus loads from each of these sources were estimated and used as input into the lake response model (*Section 5: Loading Capacity*). This section describes the methods used to estimate the load from each phosphorus source category.

4A. Watershed Runoff

The watershed runoff loads for 2001 and 2004 were estimated from monitoring data and then used as input into the lake response model.

Methods

Monitoring data were available for both lakes and for Peltier Lake's three tributaries for the years 2000, 2001, and 2004. 2001 and 2004 were selected as modeling years since the precipitation for those two years was relatively average (Table 15). 2001 was used as the model calibration year, and 2004 was used as the model validation year (indicated by bold in Table 15).

Table 15. Precipitation in Vicinity of Peltier Lake Watershed (determined from MN Climatology Working Group data)

Year	Precipitation (in)	
	June - Sept	Annual
1999	16.4	29.8
2000	12.7	27.0
2001	**13.0**	**31.5**
2002	25.7	42.4
2003	10.9	27.3
2004	**12.3**	**31.3**
2005	18.9	34.1
2006	14.8	27.0
Average	*15.6*	*31.3*

The in-lake models (*Section 5: Loading Capacity*) were based on the growing season (June through September); therefore, this time period was also used for purposes of estimating the watershed volumes and loads.

The majority of the watershed runoff to Peltier Lake is from the combined inputs of Hardwood Creek, Clearwater Creek, and Upper Rice Creek (Figure 4). Runoff volumes from the tributaries were calculated from monitoring data (logged at 15-minute intervals). To estimate the runoff volume from the direct drainage areas (for both Peltier Lake and Centerville Lake), the depths of runoff from Upper Rice Creek and Hardwood Creek were averaged and applied to the direct drainage area. Clearwater Creek was not used since the low overall depth of runoff from that watershed is influenced by the fact that several of its subwatersheds are at times landlocked.

Daily TP loads from the tributaries were estimated based on stream flow and TP concentration (monitoring data) using the program Load Estimator (LOADEST). LOADEST was developed by the United States Geological Survey and estimates constituent loads in streams based on a time series of stream flow and constituent concentration. LOADEST develops a regression model that predicts constituent load based on flow. All available TP and flow data were used to develop the regression model (Table 16), and daily loads for the selected time periods were calculated based on that relationship. TP data were available for all three tributaries in 2001, and for all tributaries except for Upper Rice Creek in 2004. The Upper Rice Creek 2004 loading estimate was based on 2004 flow data and the regression model developed between flow and TP from the other years of data (2001, 2002, and 2006).

Table 16. Years of flow and TP Data Used to Create Regression Model in LOADEST

Tributary	Years of flow and TP data
Upper Rice Creek	2001, 2002, 2006
Clearwater Creek	1999-2005
Hardwood Creek	1999-2004, 2006

To estimate the average TP concentration from the Peltier Lake direct drainage area, the average of all three tributaries (219 µg/L) was used. The Centerville Lake direct drainage area average TP concentration was also estimated using Peltier Lake watershed runoff data: the total load to Peltier Lake divided by the total volume, or the flow-weighted average concentration (222 µg/L).

Results

TP concentrations in the watershed runoff ranged from162 µg/L to 276 µg/L (

Table 17 and Table 18). The depth of runoff during the growing season (June through September) across the watershed was approximately two inches; the depth of runoff in the Clearwater Creek watershed is lower due to the fact that a portion of the watershed is normally landlocked. The two highest watershed loads in 2001 (the model calibration year) are from Upper Rice Creek and Hardwood Creek. The load from Clearwater Creek is also substantial, and the direct drainage load to Peltier Lake and the outflow from Centerville Lake are minimal (

Table 17). Centerville Lake's watershed load all originates in its direct drainage area.

Table 17. Watershed Runoff to Peltier Lake, June through September

Subwatershed	Area (acres)	Runoff (ac-ft)		Average TP Concentration (µg/L)		TP Load (lbs)*	
		2001	2004	2001	2004	2001	2004
Upper Rice Creek	20,003	2,927	4,363	219	220	1,734	2,597
Hardwood Creek	16,164	2,656	2,547	268	276	1,926	1,903
Clearwater Creek	28,211	2,087	1,518	169	162	954	665
Centerville Lake outflow	961	155	490	48	50	20	67
Direct drainage	2,496	158	191	219	219	93	113
Total	*67,835*	*7,983*	*9,109*			*4,727*	*5,345*

*Loads are not annual loads, but rather loads over the course of the growing season (June through September). See Watershed Runoff (in Section 4A) and Loading Capacity (Section 5A) for more details.

Table 18. Watershed Runoff to Centerville Lake, June through September

Subwatershed	Area (acres)	Runoff (ac-ft)		Average TP Concentration (µg/L)		TP Load (lbs)	
		2001	2004	2001	2004	2001	2004
Direct drainage	466	61	74	222	222	37	44

4B. Wastewater Sources

The Forest Lake Water Treatment Plant and St. Croix Forge are the only wastewater discharge sources currently in the watershed. The facilities each discharge about 0.01 lbs of phosphorus daily (about 1 lb over the course of a growing season). This represents less than 1% of the total annual external load to the lake; this load was not directly input into the lake response model.

4C. Internal Loading and Peltier Lake Backflow

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

- Anoxic conditions in the overlying waters: Water at the sediment-water interface may remain anoxic for a portion of the growing season, and low oxygen concentrations result in phosphorus release from the sediments. If a lake's hypolimnion remains anoxic for a portion of the growing season, the phosphorus released due to anoxia will be mixed throughout the water column when the lake loses its stratification at the time of fall mixing. Alternatively, in shallow lakes, the periods of anoxia can last for short periods of time; wind mixing or recreational activity can then destabilize the temporary stratification, thus releasing the phosphorus into the water column.
- Physical disturbance by bottom-feeding fish such as carp and bullhead. This is exacerbated in shallow lakes since bottom-feeding fish inhabit a greater portion of the lake bottom than in deeper lakes.

- Physical disturbance due to wind mixing. This is more common in shallow lakes than in deeper lakes. In shallower depths, wind energy can vertically mix the lake at numerous instances throughout the growing season.
- Phosphorus release from decaying curlyleaf pondweed (*Potamogeton crispus*). This is more common in shallow lakes since shallow lakes are more likely to have nuisance levels of curlyleaf pondweed.

There are several ways that internal loading in lakes can be calculated, two of which were used here. The first is a mass balance approach using a lake response model. The total load to the lake is calculated based on the observed in-lake TP concentration and the lake response model. If the external loads to the lake are known, then the internal load can be calculated by difference. (The lake response model is discussed in *Section 5: Loading Capacity*.)

For Peltier Lake, the monitored load at the bottom of the three tributaries covers the majority of the watershed; it was therefore assumed that there were no substantial external loads that were not accounted for and that the mass balance approach is appropriate. Based on this method, the estimated internal load was 7875 lbs, or 15 mg/m^2-day (averaged over the growing season). This high rate is likely due to a combination of the following:

- Physical disturbance from wind mixing: In 2006, the surface TP concentration was not substantially different from the bottom TP concentration (Figure 29). The lake is mixed by wind intermittently throughout the growing season, which, if anoxic conditions develop at the sediment-water interface, causes phosphorus released from the sediments to completely mix with the surface waters.
- Physical disturbance from benthivorous fish: Although carp and bullhead populations may not be as high as they have been in the past, they are still present in the lake and likely contribute to some internal loading.
- Curlyleaf pondweed: Curlyleaf pondweed is an exotic macrophyte that emerges in early spring in lakes and usually dies off in June or July. During the die-off, the plants decompose and the phosphorus from the plant biomass is released into the water column, often leading to a spike in phosphorus concentration. Based on evidence from lakeshore homeowners that curlyleaf pondweed reaches nuisance levels in the lake, and on the monitoring data (Figure 29), it appears that curlyleaf pondweed die-off leads to a substantial increase in in-lake TP in July.

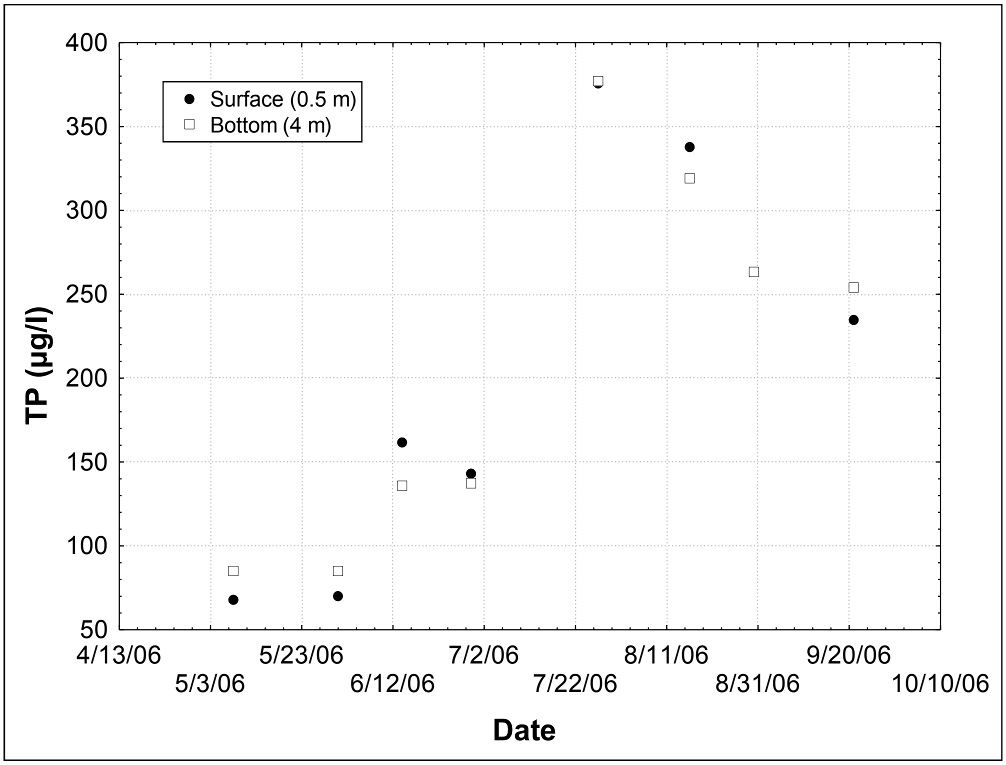

Figure 29. Peltier Lake Surface vs. Bottom Phosphorus Concentrations

For Centerville Lake, there were two unknown phosphorus sources – the internal load and the load that enters the lake through backflow from Peltier Lake during and after storm events. Internal loading rates are likely lower in Centerville Lake than in Peltier Lake due to the following:

- Centerville Lake is not as shallow as Peltier Lake and therefore wind mixing resulting in sediment re-suspension is less of a factor in leading to internal loading.
- Anoxia (less than 2 mg/L DO) does not frequently develop at the sediment-water interface in Centerville Lake (Figure 30), and surface and bottom phosphorus concentrations are similar to one another (Figure 31). High rates of hypolimnetic phosphorus release due to anoxia are likely not an issue.

Since internal loading in Centerville Lake is likely not extreme, it was assumed that the unknown load (the load needed to calibrate the TP model after the watershed loads were input) came from the Peltier Lake backflow, and internal loading rates were not further adjusted in the lake response model.

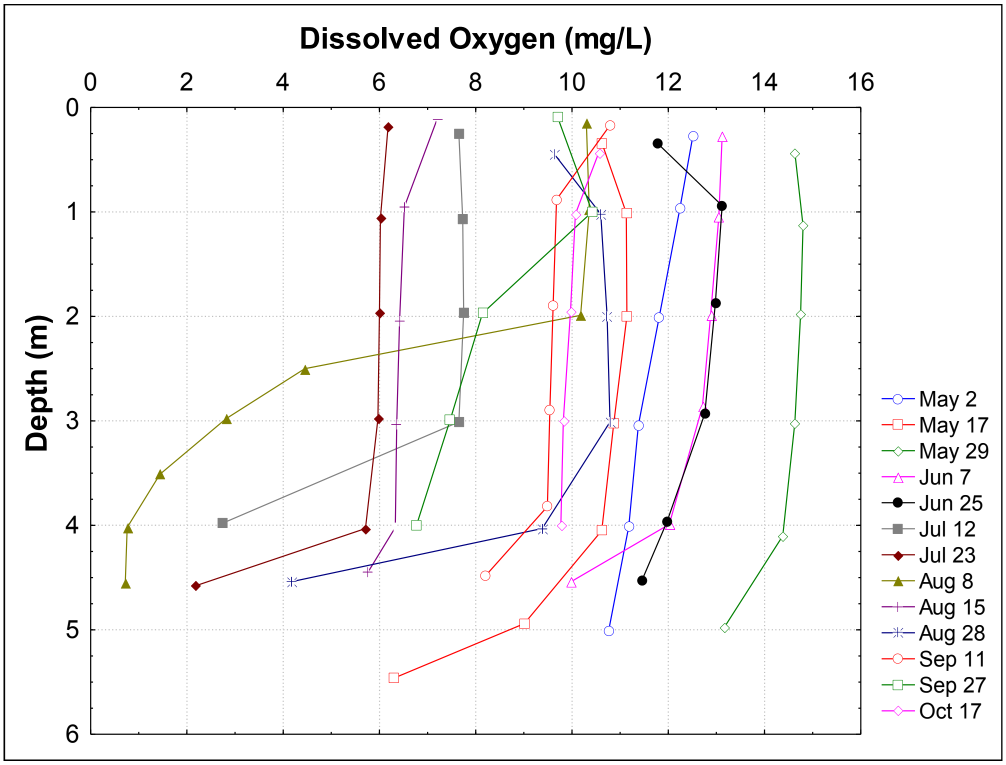

Figure 30. Centerville Lake DO Depth Profiles, 2001

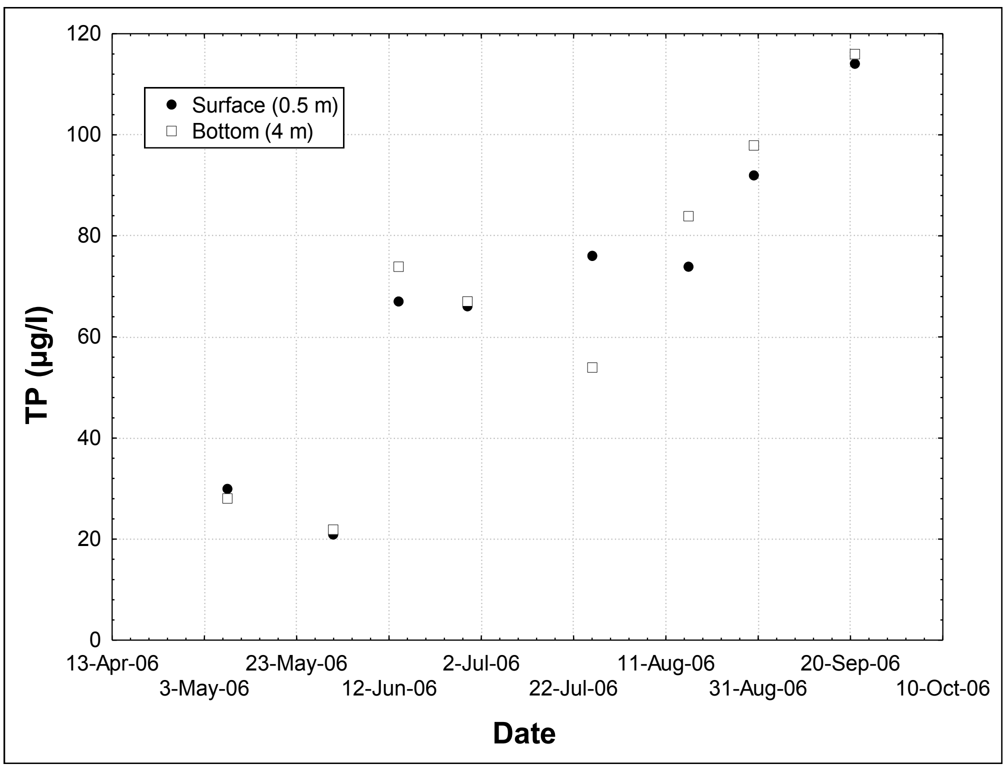

Figure 31. Centerville Lake Surface vs. Bottom Phosphorus Concentrations

Internal loads were also calculated based on sediment samples taken from the lake bottoms. Using equations developed by Nürnberg (2005) that relate internal loading rate to in-lake TP concentration, sediment TP concentration, and lake morphometry, the internal loading rate in Peltier was estimated to be 4.5 mg/m^2-day (averaged over the growing season, for purposes of comparison with rates used in the lake response model), and the internal loading rate in Centerville was estimated to be 1.9 mg/m^2-day.

The Peltier Lake internal loading estimate derived from the sediment samples (4.5 mg/m^2-day) was lower than the estimate derived from the mass balance approach (15 mg/m^2-day). Without actual *in-situ* measurements of internal loading rates, the internal loading estimate cannot be further refined. For the lake response model, it was assumed that the entire unknown load was from internal loading and the mass balance estimate was used.

The lower internal loading rate in Centerville Lake derived from the sediment samples (1.9 mg/m^2-day) is appropriate for a better-quality lake such as Centerville. Since the lake response model (Bathtub) assumes an average amount of internal loading (inherent in the model, see Section 5A for more information), there is no discrepancy with the estimate derived from the mass balance approach.

4D. Groundwater Discharge

The groundwater investigation (Appendix A) concluded that both Peltier Lake and Centerville Lake function as groundwater flow-through lakes, in that there are both groundwater discharge and groundwater recharge points. In systems with substantial groundwater input, nutrients from the groundwater input need to be taken into account in the nutrient balance of the lake. The volume of groundwater flux to the lakes was estimated using local groundwater head differences, estimated hydraulic conductivity of soils in the near shore zone of the lake, and groundwater-surface water interaction areas (see Appendix A for the complete groundwater study). This estimate was developed without specific groundwater elevations, gradients, and aquifer properties around the lakes. The estimate provides a wide range of potential groundwater input to the lakes; field study is required for more precise estimates.

The TP load from groundwater entering each lake was estimated. The load into Peltier Lake ranges from 0.0088 to 8.04 lbs/yr, and the load into Centerville Lake ranges from 0.0022 to 1.7 lbs/yr (Table 3 in Appendix A). Even at the upper end of the range, these estimates represent only 0.06% of the total load to Peltier Lake, and 1.1% of the total load to Centerville Lake. Due to the relative insignificance of the groundwater loads in the overall phosphorus budgets of the lakes, groundwater phosphorus inputs were not included in the in-lake models.

4E. Atmospheric Deposition

Atmospheric deposition (both wet and dry fall) over the growing season was estimated to be 43 lbs in Peltier lake and 44 lbs in Centerville Lake, calculated from the Bathtub default rate of 0.27 lbs/ac-yr (30 kg/km^2-yr). This rate falls within the range of rates reported by Heiskary and Wilson (1994), 0.2 to 0.4 lbs/ac-yr.

4F. LOAD SUMMARY

The main phosphorus sources to Peltier Lake are watershed runoff and internal loading, which represent 37% and 62% of the total load to the lake, respectively. The main phosphorus sources to Centerville Lake are watershed runoff, backflow from Peltier Lake, and atmospheric deposition which represent 25%, 46%, and 29% of the total load to the lake, respectively.

Table 19. Loading Summary

Source	Peltier Lake		Centerville Lake	
	Phosphorus Load (lbs/growing season)	Percent Total	Phosphorus Load (lbs/growing season)	Percent Total
Watershed runoff (2001 modeled)	4,727	37%	37	25%
Point sources	2	<1%	0	0%
Internal loading	7,875	62%	*	*
Backflow from Peltier	NA	NA	70	46%
Groundwater discharge (middle of range)	1	<1%	0.3	<1%
Atmospheric deposition	43	<1%	44	29%
Total	*12,648*		*151*	

*Not explicitly quantified, see 4C.

5. Loading Capacity

This section describes the derivation of the TMDL for Peltier and Centerville Lakes.

5A. Methods

To link phosphorus loads with in-lake water quality and to estimate the assimilative capacity of the lake, an in-lake water quality model was developed using Bathtub (Version 6.1). A publicly available model, Bathtub was developed by William W. Walker for the U.S. Army Corps of Engineers (Walker 1999). Bathtub has been used successfully in many lake studies in Minnesota and throughout the United States. Bathtub is a steady-state annual or seasonal model that predicts a lake's summer (June through September) mean surface water quality. Bathtub's time-scales are appropriate because watershed phosphorus loads are determined on an annual or seasonal basis, and the summer season is critical for lake use and ecological health. Bathtub has built-in statistical calculations that account for data variability and provide a means for estimating confidence in model predictions. The heart of Bathtub is a mass balance phosphorus model that accounts for water and phosphorus inputs from tributaries, watershed runoff, the atmosphere, sources internal to the lake, and (if appropriate) groundwater; and outputs through the lake outlet, groundwater (if appropriate), water loss via evaporation, and phosphorus sedimentation and retention in the lake sediments. Bathtub allows choice among several different mass balance phosphorus models. For deep lakes in Minnesota, the option of the Canfield-Bachmann lake formulation has proven to be appropriate in most cases and was used in this model. Bathtub's in-lake water quality predictions include two response variables, chlorophyll-*a* concentration and Secchi depth, in addition to total phosphorus concentration. Empirical relationships between in-lake total phosphorus, chlorophyll-*a*, and Secchi depth form the basis for predicting the two response variables.

Input data consisted of the 2001 and 2004 monitoring data summarized in Section 4A; the model was calibrated with 2001 data and validated with 2004 data.

Bathtub default rates were used for atmospheric deposition (both wet and dry fall). Precipitation data are from the MN Climatology Working Group, and evaporation was estimated from rates published in the MN Hydrology Guide (Table 20). The evaporation rate was lowered to account for high rates of precipitation and to address a negative water balance in the model. Change in storage was calculated based on weekly lake elevation data. Due to the short residence time in Peltier Lake, the averaging period was June through September, or four months. Due to this averaging period, loads to the lake are based on a growing season, as opposed to an entire year. Phosphorus model calibration was based on decay rates (default) as opposed to concentrations (Table 21). All model inputs are in Appendix C.

Table 20. Bathtub Input Parameters, 2001 Model

Parameter	Bathtub Input
Precipitation	13.0 in
Evaporation	13.4 in
Increase in storage	-0.067 m
Atmospheric deposition TP load rate	30 mg/m^2-yr
Averaging period	0.33 year

An average rate of internal loading is implicit in Bathtub since the model is based on empirical data. There are no direct estimates of internal loading in either Peltier Lake or Centerville Lake; the mass balance approach was used to estimate internal loading for the Peltier Lake model (described in *Section 4B: Internal Loading*). The loading rates used represent the internal load that is *in addition* to the average expected amount of internal load. Because of this approach, the internal load estimate, and the internal load portion of the nonpoint source loading goal, represents only the amount of internal load above the load implicitly assumed in the model.

Table 21. Bathtub Model Selections

Model	Selected Option
Phosphorus balance	8 – Canfield & Bachmann Lakes
Chlorophyll-*a*	2 – P, light, turbidity
Secchi depth	1 – vs. chl-*a* & turbidity
Phosphorus calibration	1 – decay rates
Calibration factor longitudinal dispersion	0.0025

After the model was calibrated to all parameters (TP, chlorophyll-*a*, and Secchi transparency), the endpoints (60 µg/L and 80 µg/L TP for Peltier, 40 µg/L TP for Centerville) were used as goals, and the TP loads to the lake were adjusted until the model predicted that the goal would be reached.

The model output includes predictions of chlorophyll-*a* concentration and Secchi depth at the TP goal, in addition to predicted algal bloom frequencies, which are based on chlorophyll-*a* concentration.

Appendix C contains the Bathtub model inputs and outputs.

5B. Model Calibration and Validation

The TP concentration in Peltier Lake was calibrated using the mass balance approach, by adjusting the internal loading rate. The TP concentration in Centerville Lake was calibrated by adjusting the calibration factor for longitudinal dispersion. This factor influences the movement of phosphorus from one modeled segment to another due to diffusion (nutrients moving from a segment of higher concentration to a segment of lower concentration). The lowered calibration factor accounts for the physical restriction by the culverts between Centerville and Peltier Lakes.

After the TP model was calibrated, the model 2 chlorophyll equation was selected, as it best predicted the observed concentration. Lastly, the Secchi depth model was selected (Table 21), based on the model that best predicted the observed Secchi depth. The model was calibrated to the chlorophyll median, as opposed to mean. The chlorophyll mean was approximately twice as high as the median, and calibration to the mean would have required adjusting chlorophyll calibration factors, which is not recommended for use in Bathtub. The model accurately predicted chlorophyll median without having to adjust the calibration factor (Table 22).

Bathtub uses T-statistics to check calibration, providing three measures of error: T1 – observed error, T2 – error typical of model development set, and T3 – both observed and model data set error. In most cases, if the absolute values of T2 and T3 are less than two, then the model is considered to accurately match the observed data. T1 is used when additional estimates of internal load are added, since the error from the model development set cannot be used. For the Centerville model, T2 and T3 were examined to check model calibration and validation; for Peltier Lake T1 was used. For model calibration, the absolute value of all T-statistics examined was less than two, providing confidence in the sufficiency of the model calibration.

Table 22. Bathtub Calibration Results

Water Quality Parameter	Peltier Lake		Centerville Lake	
	2001 Observed (June-Sept)	Bathtub Predicted	2001 Observed (June-Sept)	Bathtub Predicted
TP (µg/L) mean	295	286	46	48
Chl-*a* (µg/L) median	81	71	28	20
SD (m) mean	0.5	0.5	1.0	1.2

Monitoring data from 2004 were used for model validation (Table 23). The TP load was estimated from monitoring data, and the internal loading rate from the existing conditions (2001) model was used. Predictions for all parameters except the Secchi depth for Peltier Lake were not significantly different from the observed values (using Bathtub's T1 and T3 T-statistics).

Table 23. Bathtub Validation Results

Water Quality Parameter	Peltier		Centerville	
	2004 Observed (June-Sept)	Bathtub Predicted	2004 Observed (June-Sept)	Bathtub Predicted
TP (µg/L) mean	224	278	55	50
Chl-*a* (µg/L) median	31	43	25	18
SD (m) mean	0.9	0.4	0.9	0.9

5C. RESULTS

Existing Conditions

The combined watershed load to Peltier Lake represents approximately 38% of the total load to the lake, and internal load represents approximately 62% of the phosphorus load to the lake (Table 24, Figure 32). Of the phosphorus loads to Centerville Lake, the largest load is from the backflow from Peltier (47%), followed by atmospheric deposition and the watershed load, at 29% and 24%, respectively (Table 24, Figure 33).

Table 24. Volume and TP Load Source Contributions, June – September 2001

Lake	Subwatershed	Volume (ac-ft)	% Volume	TP Load (lbs)	% TP Load
Peltier	Upper Rice Creek	2,927	34%	1,734	14%
	Hardwood Creek	2,656	31%	1,926	15%
	Clearwater Creek	2,087	25%	954	8%
	Centerville Lake	155	2%	20	0.2%
	Direct drainage	158	2%	93	0.7%
	Atm deposition	531	6%	43	0.3%
	Internal load	0	0%	7,875	62%
	Total	*8,514*		*12,645*	
Centerville	Watershed	61	10%	37	24%
	Atm deposition	542	90%	44	29%
	Peltier backflow	NA*	NA*	70	47%
	Total	*603*		*151*	

*Peltier backflow was approximated in Bathtub by adjusting the diffusion coefficient, therefore volumes were not estimated.

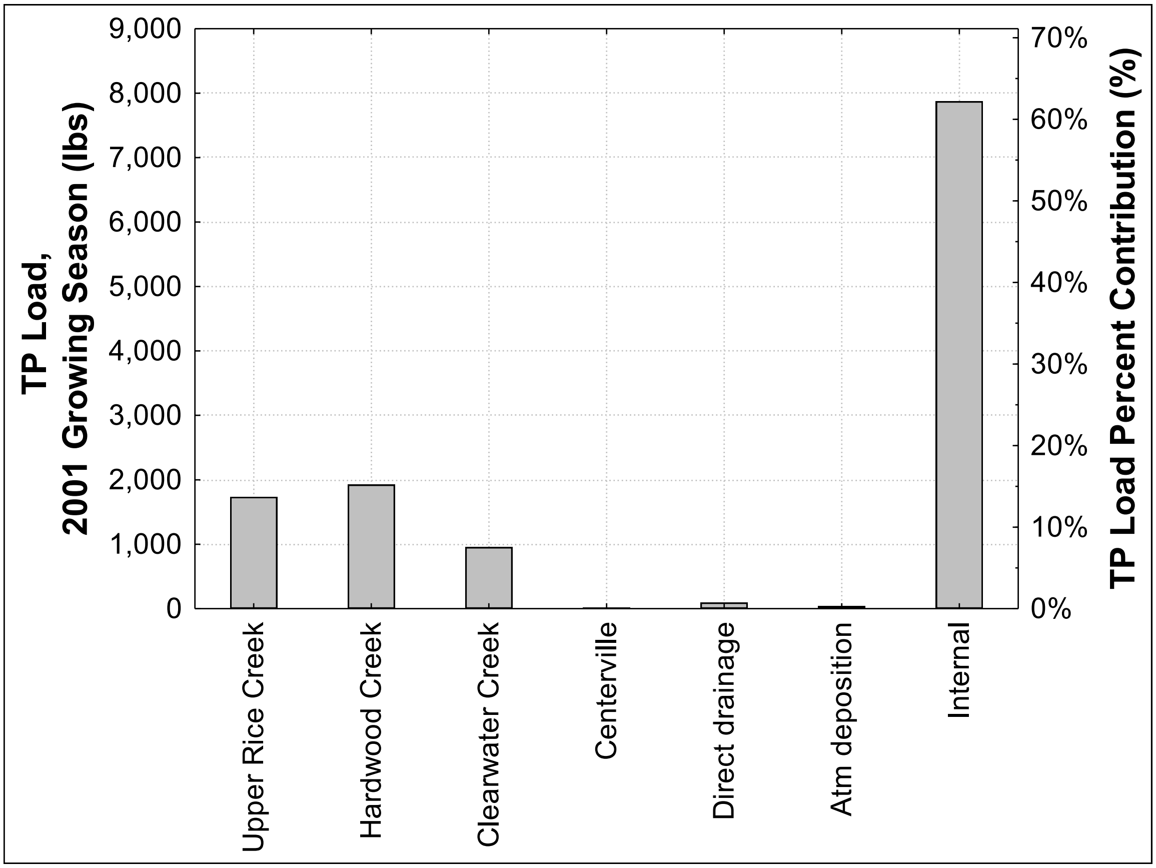

Figure 32. Phosphorus Loads to Peltier Lake, 2001 Growing Season

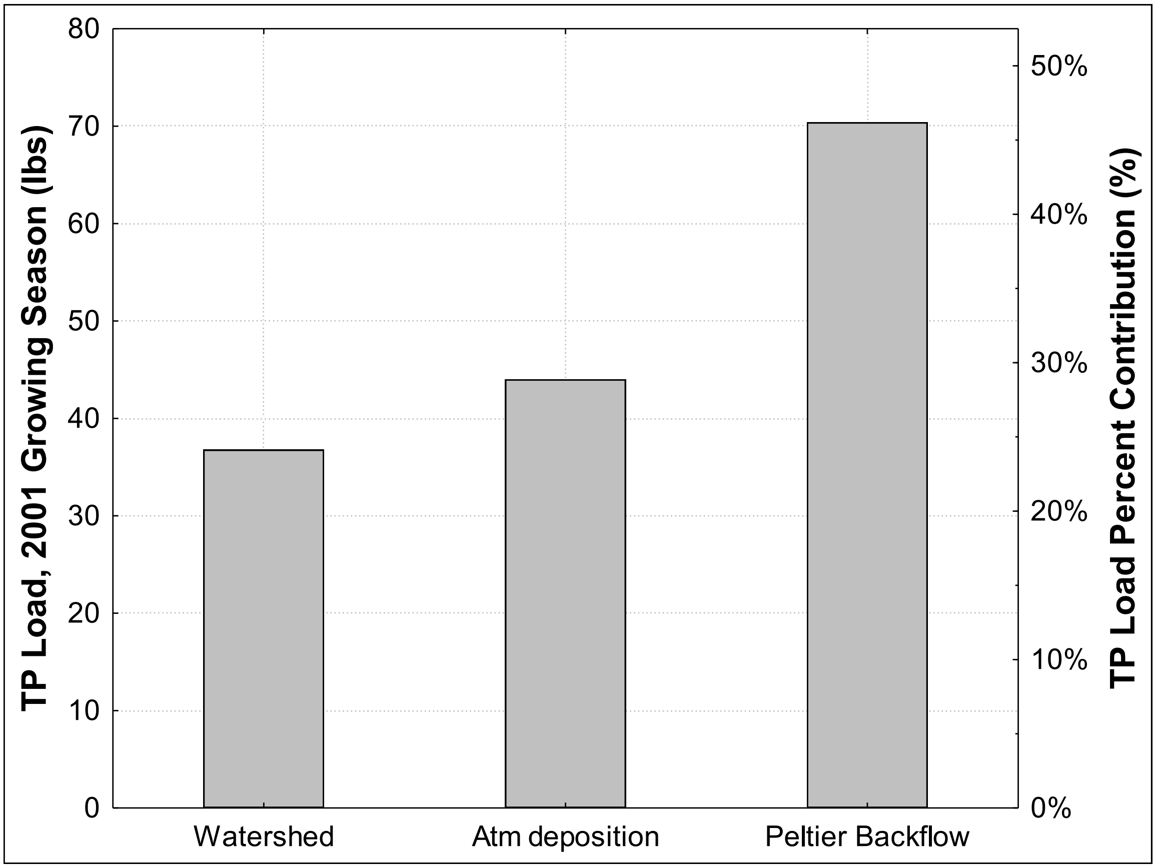

Figure 33. Phosphorus Loads to Centerville Lake, 2001 Growing Season

Assimilative Capacity

A loading scenario was developed for Centerville Lake to reach the eutrophication standard of 40 µg/L, and two separate loading scenarios were developed for Peltier Lake: one to reach the eutrophication standard of 60 µg/L TP and for reference only, one to reach the previously proposed natural background condition of 80 µg/L TP (Table 25). These total loads to the lakes represent the assimilative capacity, or TMDL, of each lake. This assimilative capacity will be split up between the load allocation and the wasteload allocation in Section 6:

$$TMDL = LA + WLA$$

Table 25. Existing Loads and Assimilative Capacities

Lake	Model Scenario	Total Load to Lake during Growing Season (lbs)	Total Daily Load to Lake (lbs)	% Reduction Relative to Existing
Peltier	Existing	12,646	104	--
	Assimilative Capacity at Natural Background Condition (80 µg/L)	2,597	21.3	79%
	Assimilative Capacity at Eutrophication Standard (60 µg/L)	1,855	15.2	85%
Centerville	Existing	151	1.2	--
	Assimilative Capacity at Eutrophication Standard (40 µg/L)*	95	0.8	37%

*This loading scenario accounts for Peltier Lake achieving the natural background condition of 80 µg/L. Centerville Lake improves due to the decreased loading from Peltier Lake backflow.

The assimilative capacity is based on the lake meeting the TP, chlorophyll-*a* and Secchi standards. For Peltier Lake, under the modeled scenarios for the eutrophication standard (60 µg/L TP) and the natural background condition (80 µg/L TP), the chlorophyll-*a* standard is not predicted to be met, but the Secchi standard is met (Table 26). It should be noted that the confidence in the results for these response variables is limited due to limits in the robustness of the empirical equations and datasets used in the BATHTUB program for these variables. MPCA staff believes it is more accurate to rely on the relationships between phosphorus, chlorophyll-*a* and Secchi depth that were derived in developing the lake nutrient standards for Minnesota lakes contained in Minn. Rule 7050 (Heiskary and Wilson, 2005). These relationships are based on a dataset encompassing a large cross-section of lakes within each of the state's ecoregions, including separate analysis of shallow- and deep-lake data (which BATHTUB datasets do not distinguish). Clear relationships were established in the Minnesota datasets between the causal factor total phosphorus and the response variables chlorophyll-*a* and Secchi disk. Based on these relationships it is expected that by meeting the phosphorus targets for Peltier Lake the chlorophyll-*a* and Secchi targets will likewise be met.

Since the Bathtub model included both Peltier Lake and Centerville Lake, two models were developed to examine the goal scenarios: one in which the state eutrophication standards are met for both lakes, and one in which the state eutrophication standards are met for Centerville Lake and the natural background condition is met for Peltier Lake. In both models, Centerville Lake meets water quality standards when Peltier Lake meets its water quality goal.

Table 26. Predicted In-Lake Water Quality under Observed Conditions and Achievement of Standards, Compared to Actual Standards

Lake	Condition	In-Lake Conditions		
		TP (µg/L)	Chlor-a (µg/L)	Secchi (m)
Peltier	Existing, observed	295	81	0.5
	80 µg/L TP Modeled Scenario	80	41	0.9
	60 µg/L TP Modeled Scenario	60	33	1.1
	State Eutrophication Standard, Shallow Lakes	<60	<20	>1.0
Centerville	Existing, observed	46	28	1.0
	40 µg/L TP Modeled Scenario*	29 / 30	13	1.6
	State Eutrophication Standard, General	<40	<14	>1.4

*Under the modeled goal scenarios, the improvements in water quality in Peltier Lake lead to improvements in water quality in Centerville Lake that go beyond the achievement of the standard for Centerville Lake. The TP values shown are for the impact of the Peltier state standard scenario and the Peltier NBC scenario on Centerville Lake, respectively. The modeled chlorophyll and Secchi are the same in both models.

To reach the Peltier Lake assimilative capacity, load reductions for each subwatershed range from 50% to 68% for the eutrophication standard (Table 27). The relative load reductions for each subwatershed are based on the current loading of each subwatershed; the loading goals are based on all subwatersheds having equal loading rates. Therefore, the percent load reduction for Hardwood Creek is higher than the percent load reduction for the other subwatersheds because Hardwood Creek currently has the highest loading rate.

Table 27. Peltier Lake Loading Goals by Source

Source	Existing Loading (lbs/growing season)	Natural Background Condition 80 µg/L		Eutrophication Standard 60 µg/L	
		Load Goal (lbs/growing season)	% Reduction	Load Goal (lbs/growing season)	% Reduction
Upper Rice Creek	1,734	950	45%	673	61%
Hardwood Creek	1,926	862	55%	611	68%
Clearwater Creek	954	678	29%	480	50%
Direct drainage	93	51	45%	36	61%
Atm deposition	43	43	0%	43	0%
Internal load	7,875	0	100%	0	100%
Centerville Lake	20	13	37%	12	40%
Total	*12,645*	*2,597*	*79%*	*1,855*	*85%*

For Centerville Lake, the load that originates as backflow from Peltier Lake needs to be reduced by 79% (Table 28). This will be achieved if Peltier Lake reaches the natural background condition of 80 µg/L TP, and further reductions in the watershed will not be needed.

Table 28. Centerville Lake Loading Goals by Source

Source	Existing Loading (lbs/growing season)	Load Goal (lbs/growing season)	% Reduction
Watershed	37	37	0%
Atm deposition	44	44	0%
Peltier backflow*	70	15*	79%
Total	*151*	*96*	*36%*

*Loading goal achieved through Peltier Lake reaching the 80 µg/L goal

Both external and internal load reductions will be needed for Peltier Lake. The lake response model suggests that internal loading needs to be eliminated completely, and that external loading needs to be reduced overall by 62% to reach the eutrophication standard. This, however, is based on a lake response model that is not able to predict the shift between the turbid, phytoplankton-dominated state and the clear, macrophyte-dominated state in shallow lakes. It should be noted that when internal loading is set to zero in the Bathtub model, the model inherently assumes a certain amount of internal loading (see Section 5A: Loading Capacity Methods), which is not quantifiable.

Critical Conditions

Critical conditions in Peltier Lake and Centerville Lake occur in the summer, often in August and September (see Figure 18, Figure 19, Figure 27, and Figure 28), when TP concentrations peak and clarity is at its worst. The water quality standards are based on growing season averages. The load reductions are designed so that the lakes will meet the water quality standards over the course of the growing season (June through September).

6. TMDL Allocations

The TMDL for each lake was apportioned between the wasteload allocation (WLA) and the load allocation (LA). The WLA includes loads that originate in areas covered by an NPDES permit. These include portions of MS4 communities that are nonagricultural and that are projected to be served by stormwater conveyances by 2020 (e.g., residential, commercial, industrial), road authorities (counties, Mn/DOT), and other point sources. The LA includes loads that originate in non-MS4 communities (City of Columbus and May Township), portions of MS4 communities that are either agricultural or otherwise not projected to be served by stormwater conveyances in 2020, internal loading, and atmospheric deposition. (Projected land use for 2020 is shown in Figure 6.)

The watershed load (including both MS4 and non-MS4 communities) was divided between the WLA and LA according to the amount of upland area in each category. The upland area was selected to represent the developable area in the watershed; it includes the total watershed area with the lake and wetland area subtracted out.

As a result of the above analysis, the acreage in the Peltier Lake watershed subject to the WLA and LA categories is 13,744 and 28,416 acres, respectively. The acreage in the Centerville Lake watershed subject to the WLA and LA categories is 276 and 114 acres, respectively.

The WLAs and LAs are presented in terms of phosphorus loading per day, in addition to phosphorus loading per growing season. The modeling and load estimates were based on growing season loads, and these loads were divided by the number of days in a growing season (June through September, or 122 days) to determine the daily loads.

Existing loads are provided and represent estimated loads for 2001. Thus, 2001 is considered the baseline year to be used for evaluating and crediting loading reductions for this TMDL.

6A. Margin of Safety

The margin of safety (MOS) is included in the TMDL equation to account for both the inability to precisely describe current water quality conditions and the unknowns in the relationship between the load allocations and the in-lake water quality. A MOS may be either explicitly calculated or implicitly included in the modeling assumptions and approach to calculating the TMDL.

An implicit MOS was incorporated into this TMDL by using conservative assumptions. These were used to account for an inherently imperfect understanding of the lake system and to ultimately ensure that the nutrient reduction strategy is protective of the water quality standard.

Conservative modeling assumptions included applying sedimentation rates from the Canfield-Bachmann model that likely under-predict the sedimentation rate for shallow lakes. Zooplankton grazing plays a large role in algal and subsequent phosphorus sedimentation in shallow lakes. However, the Canfield-Bachmann equation does not account for the higher sedimentation rates expected in healthy shallow lake systems.

Additionally, empirical relationships used to predict chlorophyll-*a* and Secchi transparency are more established for deep lakes and do not account for zooplankton grazing critical to maintaining a clear water state in shallow lakes. Consequently, the models likely under-predict the clarity response of the lake to reduced phosphorus concentrations.

An additional conservative assumption specific to Centerville Lake is that this lake would meet its standard with Peltier Lake backflow contributions only meeting 80 µg/L TP even though Peltier's TMDL is set for 60 µg/L TP.

6B. Wasteload Allocations

The stormwater sources (regulated MS4 entities except for Mn/DOT Metro District, construction stormwater, and industrial stormwater) were given categorical WLAs for both Peltier Lake (Table 29) and Centerville Lake (Table 31). The categorical WLA covers all stormwater sources indicated above; the load reductions identified by the WLAs will need to be met by this group as a whole. Mn/DOT Metro District received an individual WLA for Peltier Lake, per their request, and does not have any roads in the Centerville Lake watershed. It should be noted that Rice Creek Watershed District is considered a regulated MS4 due to its authority over some public ditches. However, for the drainage area covered by this TMDL it has not been determined if the public ditches here are "waters of the state" or treatment conveyances that treat stormwater. It is not possible to be both. For the purposes of moving forward with this TMDL the RCWD drainages systems will be considered part of the load allocation for this TMDL. Should it later be determined that the ditches are stormwater conveyances a correction will be made to the TMDL to move them to the categorical WLA. It should further be noted that the district has expressed that they are committed to the same level of work to pursue pollutant load reductions regardless of which category they are placed in.

The WLA for Mn/DOT Metro District WLA was simply based on their fraction of the total land area in the regulated stormwater WLA category. Mn/DOT's right-of-way land area in the Peltier Lake watershed is 105 acres, based on data provided by them, with 86 of those acres falling under NPDES coverage and, thus, being subject to the WLA.

If additional stormwater discharges come under permit coverage within the watershed, it may be necessary to transfer WLA from one MS4 to another. This may occur if the Census Bureau-defined Urban Area expands, if new county- or state-owned roads within the Urban Area are built, or if existing roads are expanded. In these cases, WLA will be transferred to these new entities based on the process used to set wasteload allocations in the TMDL. Affected permittees will be notified and will have an opportunity to comment on the reallocation.

The Forest Lake Water Treatment Plant WLA was calculated according to the following:

- The average discharge is 29,000 gallons per week; increasing that by 25 percent would be a maximum discharge of 36,250 gallons/week or 5180 gallons/day or 0.00518 MGD.
- There were three TP samples taken from the plant, one of which was a composite sample, which should be the most representative of what the actual P concentration is. That value, 0.1 mg/L, was increased to 0.3 mg/L to allow for variability.

- Loading per day is: 0.00518 MGD x 0.3 mg/L x 8.34 conversion factor = 0.013 lbs P/day. Over the growing season: 0.013 x 122 days = 1.6 lbs P.

The St. Croix Forge WLA was calculated according to the following:

- The maximum permitted flow rate is 0.00205 MGD.
- The long term average TP effluent concentration is 1.62 mg/L (May 2008 – March 2013); increased by 25 percent to account for uncertainty = 2.025 mg/L.
- Loading per day is: 0.00205 x 2.025 x 8.34 = 0.034 lbs P/day. Over the growing season: 0.034 x 122 days = 4.1 lbs P.

Table 29. TP Wasteload Allocations: Peltier Lake

Permit Type	Permit Name	Permit Number	Existing TP Load (lbs/day)	Natural Background Condition, 80 µg/L		Eutrophication Standard, 60 µg/L	
				WLA (lbs/day)	% Reduction	WLA (lbs/day)	% Reduction
MS4 stormwater	Anoka County	MS400066	12.50	6.75	46%	4.78	62%
MS4 stormwater	Birchwood Village	MS400004					
MS4 stormwater	Centerville	MS400078					
MS4 stormwater	Dellwood	MS400084					
MS4 stormwater	Forest Lake	MS400262					
MS4 stormwater	Grant	MS400091					
MS4 stormwater	Hugo	MS400094					
MS4 stormwater	Lino Lakes	MS400100					
MS4 stormwater	Mahtomedi	MS400031					
MS4 stormwater	Ramsey County Public Works	MS400191					
MS4 stormwater	Washington County	MS400160					
MS4 stormwater	White Bear Lake	MS400060					
MS4 stormwater	White Bear Township	MS400163					
MS4 stormwater	Willernie	MS400061					
Construction stormwater	Various	Various					
Industrial stormwater	No current permitted sources	NA					
MS4 stormwater	MNDOT Metro District	MS400170	0.08*	0.04	46%	0.03	62%
Industrial wastewater	Forest Lake Water Treatment Plant	MNG640118	0.01	0.01	0%	0.01	0%
Industrial wastewater	St. Croix Forge	MN0069051	0.01	0.03	0%	0.03	0%
Total			*12.60*	*6.84*	*46%*	*4.86*	*61%*

*Mn/DOT's existing TP load was not independently calculated; rather, this figure is an estimate based on back-calculating from the same reduction percentage the other MS4 entities will collectively be required to meet.

Table 30. Growing Season TP Wasteload Allocations: Peltier Lake

Permit Type	Permit Name	Permit Number	Existing Load (lbs/ growing season)	Natural Background Condition, 80 µg/L		Eutrophication Standard, 60 µg/L	
				WLA (lbs/growing season)	% Reduction	WLA (lbs/growing season)	% Reduction
MS4 stormwater	Anoka County	MS400066	1,526	824	46%	583	62%
MS4 stormwater	Birchwood Village	MS400004					
MS4 stormwater	Centerville	MS400078					
MS4 stormwater	Dellwood	MS400084					
MS4 stormwater	Forest Lake	MS400262					
MS4 stormwater	Grant	MS400091					
MS4 stormwater	Hugo	MS400094					
MS4 stormwater	Lino Lakes	MS400100					
MS4 stormwater	Mahtomedi	MS400031					
MS4 stormwater	Ramsey County Public Works	MS400191					
MS4 stormwater	Washington County	MS400160					
MS4 stormwater	White Bear Lake	MS400060					
MS4 stormwater	White Bear Township	MS400163					
MS4 stormwater	Willernie	MS400061					
Construction stormwater	Various	Various					
Industrial stormwater	No current permitted sources	NA					
MS4 stormwater	MNDOT Metro District	MS400170	9*	5	46%	4	62%
Industrial wastewater	Forest Lake Water Treatment Plant	MNG640118	1	1.6	0%	1.6	0%
Industrial wastewater	St. Croix Forge	MN0069051	1	4.1	0%	4.1	0%
Total			*1,537*	*835*	*46%*	*593*	*61%*

*Mn/DOT's existing TP load was not independently calculated; rather, this figure is an estimate based on back-calculating from the same reduction percentage the other MS4 entities will collectively be required to meet.

Table 31. TP Wasteload Allocations: Centerville Lake

Permit Type	Permit Name	Permit Number	Existing Load (lbs/day)	WLA (lbs/day)	% Reduction
MS4 stormwater	Anoka County	MS400066	0.21	0.21	0%
MS4 stormwater	Centerville	MS400078			
MS4 stormwater	Lino Lakes	MS400100			
Construction stormwater	Various	Various			
Industrial stormwater	No current permitted sources	NA			

Table 32. Growing Season TP Wasteload Allocations: Centerville Lake

Permit Type	Permit Name	Permit Number	Existing Load (lbs/growing season)	WLA (lbs/growing season)	% Reduction
MS4 stormwater	Anoka County	MS400066	26	26	0%
MS4 stormwater	Centerville	MS400078			
MS4 stormwater	Lino Lakes	MS400100			
Construction stormwater	Various	Various			
Industrial stormwater	No current permitted sources	NA			

6C. Load Allocation

The LA includes loads that originate in non-MS4 communities (City of Columbus and May Township), portions of MS4 communities that are either agricultural or otherwise not projected to be served by stormwater conveyances in 2020, internal loading, and atmospheric deposition. Although the load designated for each of these sources was estimated separately, they are jointly included as one overall LA.

Watershed Runoff From Land Area Not Covered Under NPDES Permits

The City of Columbus and May Township are not covered under NPDES MS4 permits. Their portion of the LA was differentiated from the watershed runoff that falls under the WLA based on the amount of developable area in each city/township. The developable area was approximated with the upland area, or the total area minus the lakes and wetlands. The portions of MS4 communities that are not technically covered under NPDES permits (i.e., areas that are either agricultural or otherwise not projected to be served by stormwater conveyances, such as open space, park and recreation, and rural residential) are also included in the LA. Again, the area taken up by lakes and wetlands are not used in the land area calculations.

Internal Loading

The portion of the LA that accounts for internal loading was based on the lake load response model (Bathtub model). In order for Peltier Lake to achieve either the natural background conditions goal or the state eutrophication standard, the internal load input to the model had to be reduced to zero. Although the load in the model is identified as zero, the model still implicitly assumes an average amount of internal loading, which was not quantified for this study. (See Loading Capacity Methods, Section 4A, for more details.)

Atmospheric Deposition

The portion of the LA that accounts for atmospheric deposition (both wet and dry) was based on the load estimate in the existing conditions model. It was assumed that atmospheric deposition will remain constant, and that load reductions in atmospheric deposition are not warranted.

Load Allocation Summary

For Peltier Lake, the total load allocation is 10.3 lbs/day for the eutrophication standard (Table 33). The LA is considered one total LA (as opposed to several individual LAs), but it is divided up here to illustrate the magnitude of the different sources. The LAs for Peltier Lake consist of loading from non-MS4 stormwater runoff, atmospheric deposition, internal loading, and loading from the Centerville Lake outflow. The loading to Centerville Lake (which influences the Centerville Lake outflow load to Peltier Lake) is taken into account in the WLAs and LAs for the Centerville Lake TMDL.

Table 33. TP Load Allocations: Peltier Lake

Source	Existing Load (lbs/day)	Natural Background Condition, 80 µg/L		Eutrophication Standard, 60 µg/L	
		LA* (lbs/day)	% Reduction	LA (lbs/day)	% Reduction
Non-MS4 stormwater	26	14	46%	9.9	62%
Atmospheric deposition	0.35	0.35	0%	0.35	0%
Internal	65	0	100%	0	100%
Centerville Lake outflow	0.16	0.098	40%	0.090	44%
Total	*91*	*14.5*	*95%*	*10.3*	*96%*

Table 34. Growing Season TP Load Allocations: Peltier Lake

Source	Existing Load (lbs/growing season)	Natural Background Condition, 80 µg/L		Eutrophication Standard, 60 µg/L	
		LA* (lbs/growing season)	% Reduction	LA (lbs/growing season)	% Reduction
Non-MS4 stormwater	3173	1708	46%	1208	62%
Atmospheric deposition	43	43	0%	43	0%
Internal	7,875	0	100%	0	100%
Centerville Lake outflow	20	12	40%	11	44%
Total	*11,111*	*1,763*	*84%*	*1,262*	*89%*

Centerville Lake's total LA is 0.57 lbs/day (Table 35), which includes non-MS4 stormwater runoff, the load from the Peltier Lake backflow, and atmospheric deposition.

Table 35. TP Load Allocations: Centerville Lake

Source	Existing Load (lbs/day)	LA (lbs/day)	% Reduction
Non-MS4 stormwater runoff	0.090	0.090	0%
Peltier Lake backflow	0.57	0.12	79%
Atmospheric deposition	0.36	0.36	0%
Total	*1.02*	*0.57*	*45%*

Table 36. Growing Season TP Load Allocations: Centerville Lake

Source	Existing Load (lbs/growing season)	LA (lbs/growing season)	% Reduction
Non-MS4 stormwater runoff	11	11	0%
Peltier Lake backflow	70	15	79%
Atmospheric deposition	44	44	0%
Total	*125*	*69*	*45%*

6D. Reserve Capacity

Because future land use is already factored into the WLA estimate no portion of the allowable loading is being explicitly set aside as reserve capacity.

6E. TMDL ALLOCATION SUMMARY

Table 37. TMDL Allocation Summary

Lake and Standard	TMDL (lbs/day)	WLA (lbs/day)	LA (lbs/day)
Peltier Lake: Natural background condition (80 µg/L)	21.3	6.8	14.5
Peltier Lake: Eutrophication standard (60 µg/L)	15.2	4.9	10.3
Centerville Lake: Eutrophication standard (40 µg/L)	0.8	0.2	0.6

7. Seasonal Variation

In-lake water quality models predict growing season or annual averages of water quality parameters based on growing season or annual loads, and the MPCA's nutrient standards are based on growing season averages. Symptoms of nutrient enrichment normally are the most severe during the summer months; the nutrient standards set by the MPCA were set with this seasonal variability in mind.

This is the case for both of these lakes; critical conditions in both Peltier Lake and Centerville Lake occur at the end of the summer (Figure 18, Figure 28, Figure 27, and Figure 28), when TP concentrations peak and clarity is at its worst.

Another way that seasonal variability is taken into account is that BMPs will be designed to handle peak runoff in spring when vegetation cover is minimal.

8. Monitoring Plan

The following monitoring plan lays out the different types of monitoring that will need to be completed in order to track the progress of implementation activities associated with Peltier Lake and Centerville Lake, and of associated changes in water quality due to the management practices.

The RCWD, through the Metropolitan Council's Citizen Assisted Monitoring Program (CAMP), has been monitoring Peltier Lake fairly consistently since 1994, and Centerville Lake fairly consistently since 2000. Details of the RCWD monitoring protocol can be found in the RCWD 2004 Water Quality Monitoring Report.

Monitoring will occur after implementation activities are initiated in order to evaluate the effectiveness of the BMPs, and will continue throughout the implementation period until water quality standards are attained. Monitoring will be conducted by the Rice Creek Watershed District and/or as part of the CAMP program.

The following parameters, which apply to both lakes unless otherwise noted, will be part of the monitoring plan:

- TP, soluble reactive phosphorus, nitrogen, chlorophyll-*a*, and transparency will be monitored biweekly during the growing season.
- At least one year of winter nitrate data should be obtained in Peltier Lake. Winter nitrate has been shown to be an indicator of plant species richness in shallow lakes and can provide information on nitrogen loading and the potential for aquatic macrophyte restoration (James et al. 2005). This information can help target future management practices aimed at reducing nitrogen loading to the lake.
- Depth profiles of temperature and dissolved oxygen will be taken biweekly during the growing season at the deepest portion of the lake and at a location in the littoral zone.
- Two macrophyte surveys should be undertaken annually: 1) in the spring, when curlyleaf pondweed is at its peak, and 2) mid-summer, after curlyleaf has died back and native plants and Eurasian watermilfoil are growing abundantly. Macrophyte data are especially important on Peltier Lake, where curlyleaf pondweed likely contributes to internal loading.
- Zooplankton monitoring should be undertaken for a full season every five years. Monitoring should start in early spring (March or April), when large zooplankton peak; zooplankton community dynamics during this period influence the water quality during the remainder of the growing season.
- A fish survey should be completed once every five years to obtain data on fish population abundance and size distribution, year class strength as well as to evaluate management activities. Surveys should be conducted following the *Manual for Instruction of Lake Survey*, Special Publication No. 147 from the Minnesota Department of Natural Resources (DNR)

9. Implementation Strategy

This Implementation Strategy sets the stage for action by providing the overall approach to the management practices needed to achieve the TMDL. The strategies that follow are defined in more detail in the Implementation Plan, which will be submitted under separate cover to the MPCA.

9A. Approach to Lake Restoration

Lake restoration activities can be grouped into two main categories: those practices aimed at reducing external nutrient loads, and those practices aimed at reducing internal loads. The focus of restoration activities will depend on the lake's nutrient balance and opportunities for restoration. In a lake that does not have an excessive internal loading problem, like Centerville Lake, the focus will be on reducing external loads. In a lake that does have high internal loading rates, such as Peltier Lake, key practices to address internal loading will be an essential component along with external load reduction efforts.

In shallow lakes, there can be a rapid switch from the clearwater state to the turbid state, and vice versa. As BMPs are being implemented, they may seem ineffective at first because the lake has the tendency to remain in the turbid state, but a rapid shift can occur when TP loads and turbidity reach the critical threshold.

Although controlling the internal load in Peltier Lake will be central to restoring the lake, controlling the external loads is essential in the restoration of a shallow lake. A restoration is less likely to be stable when external nutrient loads are still high (Moss et al. 1996).

This discussion separates the management strategies into practices addressing watershed load, internal load, and the hydrologic exchange between Peltier Lake and Centerville Lake.

9B. Watershed Load

Due to the relatively large size of the Peltier Lake watershed (over 67,500 acres) compared to the Centerville Lake watershed (466 acres), the implementation strategy is dominated by actions that must occur within the watershed draining to Peltier Lake. In the event that MS4 permit holders are not demonstrating progress on WLA reductions the MPCA may reallocate the categorical WLA and assign individual WLAs to MS4s. MS4s will be notified and will have an opportunity to comment on the reallocation.

Peltier Lake Watershed Implementation Strategy

Implement Existing Planning and Regulatory Efforts

The Peltier Lake watershed already has several plans in place to decrease the watershed phosphorus load, including:

- Hardwood Creek Biotic Impairment TMDL implementation strategy
- JD4 Resource Management Plan (RMP), with RCWD rules adoption
- Lino Lakes RMP

- RCWD Rules
- Related rules and plans
- Construction and Industrial Stormwater Permits

The following are summaries of each of the programs that will be used to reduce the watershed phosphorus load.

Hardwood Creek Biotic Impairment TMDL implementation plan

To reach the water quality goal for Hardwood Creek, the sub-watershed load will need to be lowered by 68%. The Implementation Plan of the Hardwood Creek Biotic Impairment TMDL focuses on the following implementation actions:

- Streambank restoration and bank stabilization at several locations along Hardwood Creek
- Forested riparian buffers
- Stormwater management, regulations through existing RCWD Rules and volume standards (see details below)

Action Strategy: Adopt Hardwood Creek TMDL and begin implementing measures in Implementation Strategy.

Actions currently underway: In 2009, the RCWD received a Federal 319 Grant to complete several major projects identified in the Hardwood Creek TMDL Implementation Plan. These projects include the re-meandering of a previously ditched section of Hardwood Creek, the construction of a sediment-catching floodplain bench, the stabilization of eroding creek banks, repair and stabilization of eroded areas related to drainage structures (drain tile), and improved management of livestock adjacent to the creek. Collectively, these projects are expected to reduce phosphorus loading in Hardwood Creek by approximately 50%.

JD4 Resource Management Plan

The JD4 RMP, referred to as "RMP 2," covers approximately one-third of the Upper Rice Creek watershed. RMP 2 is an implementation framework that RCWD has developed to manage both upland and natural features through identification of critical management components (such as land preservation and ditch maintenance) and priority BMPs. The RMP was accepted for public review by the RCWD, which has also released a draft implementation rule for agency and public review. Adoption of the RMP and rules occurred in June of 2008.

The RMP Rule will address issues such as runoff volume and rate control, preferred BMPs, and wetland alteration/preservation.

Action Strategy: Implement the RMP rules and BMP strategies.

Lino Lakes and Columbus Resource Management Plans

The Lino Lakes Resource Management Plan (RMP 3) and the Columbus Resource Management Plan are a watershed-based natural resource plans for input into the Lino Lakes and Columbus Comprehensive Plans. They are based upon both existing resource and full build-out conditions.

The plans came about through partnerships between the RCWD and the Cities of Lino Lakes and Columbus to coordinate resource protection efforts in rapidly growing areas.

Portions of Lino Lakes and Columbus contribute to the direct drainage areas, Upper Rice Creek, Hardwood Creek, and Clearwater Creek watersheds. The RMPs contain specific BMP and site locations for implementation of these practices. A watershed rule under development establishes a wetland preservation corridor to protect the high quality wetlands in the city, and also addresses volume control. The Lino Lakes RMP was adopted in June of 2009, and associated rules were adopted in 2009. The Columbus RMP was initiated in 2008; associated rules were adopted in 2010.

Action Strategy: Continue implementing Lino Lakes and Columbus RMPs, and administer associated rules.

Rice Creek Watershed District Rules

The regulatory program of the RCWD will be a key implementation feature to yield improvement in the quality of runoff entering the Rice Creek Chain of Lakes. The current rules in effect in RCWD were adopted on February 13, 2008. Specific rules expected to contribute to water quality improvement in Peltier Lake include stormwater management (Rule C), erosion control (Rule D), wetland alteration (Rule F) and drainage systems (Rule I). Collectively, these rules are expected to contribute to the eventual achievement of watershed runoff goals. They can be supplemented by select water quality and runoff improvement projects undertaken by public agencies, including the RCWD, and private land owners/developers.

Action Strategy: Effectively implement RCWD rules and revise as necessary to adapt to watershed needs.

Related Rules and Plans

There are also other rules and plans being implemented within the area draining to Peltier Lake.

The I-35E Corridor Areawide Urban Alternative Review (AUAR - 2005) covers a 4,500-acre portion of eastern Lino Lakes bordering I-35E. The document includes a mitigation plan that will help the city avoid, minimize, or mitigate environmental impacts from development of the AUAR area. This document will be used in conjunction with the city's Local Comprehensive Plan and the LL RMP, as well as RCWD rules, to implement effective stormwater controls for a large portion of Lino Lakes tributary to Peltier Lake. BMPs such as bio-swales, wet prairies, and wetlands will be used in conjunction with more structural BMPs to effectuate water quality improvement.

An Environmental Assessment Worksheet (EAW) for the City of Centerville Downtown Development was prepared in 2007 in anticipation of expected downtown improvements. The EAW contains general proposed runoff improvements that, although short on details, espouse improved runoff quality as a goal of re-development. The majority of the 37.4 acres being re-developed drain to Peltier Lake via Clearwater Creek, although a small portion also drains to Centerville Lake. Implementation of the framework laid-out in the EAW will occur under the auspices of the RCWD rules, MPCA's NPDES Construction Permit, and the city's NPDES MS4 program. The city has also received funding assistance via a 2008 BWSR grant program to help with the implementation costs of various BMPs. The city has also applied for RCWD Urban Stormwater Remediation Cost-Share funds to route downtown area runoff to a pond and park irrigation system, thus further diverting direct, untreated runoff from Centerville Lake.

All of the communities within the watershed draining to Peltier and Centerville Lakes, with the exception of Columbus and May Township, are NPDES MS4 communities. Each of these communities was required to prepare a Notice of Intent to receive their initial permit. The Notice of Intents go through a series of information pertaining to stormwater control programs within a community. Each community is also required to prepare a five-year SWPPP and report on the progress of BMP implementation annually. MPCA and the RCWD can work with these communities via their SWPPPs and MS4 regulatory programs to implement the watershed improvements needed for achieving the WLA for permitted MS4 areas and load allocation for nonpoint and non-MS4 sources.

Action Strategy: Continue to implement the water quality improvement elements of these three programs.

Construction and Industrial Stormwater Permits *(applies to Centerville Lake also)*

The wasteload allocation for stormwater discharges from sites where there is construction activities reflects the number of construction sites > 1 acre expected to be active in the watershed at any one time, and the Best Management Practices (BMPs) and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at construction sites are defined in the State's NPDES/SDS General Stormwater Permit for Construction Activity (MNR100001). If a construction site owner/operator obtains coverage under the NPDES/SDS General Stormwater Permit and properly selects, installs and maintains all BMPs required under the permit, including those related to impaired waters discharges and any applicable additional requirements found in Appendix A of the Construction General Permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. It should be noted that all local construction stormwater requirements must also be met.

The wasteload allocation for stormwater discharges from sites where there is industrial activity reflects the number of sites in the watershed for which NPDES industrial stormwater permit coverage is required, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at the industrial sites are defined in the State's NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000) or NPDES/SDS General Permit for Construction Sand & Gravel, Rock Quarrying and Hot Mix Asphalt Production facilities (MNG490000). If a facility owner/operator obtains coverage under the appropriate NPDES/SDS General Stormwater Permit and properly selects, installs and maintains all BMPs required under the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. It should be noted that all local stormwater management requirements must also be met.

Additional Elements for the Peltier Lake Implementation Strategy
Following are additional implementation tools that are not yet initiated, but could contribute to load reductions to Peltier Lake in the future.

New TMDL Studies
Clearwater Creek, which drains directly to Peltier Lake, is on the 2008 303(d) list of impaired water for impaired biota (aquatic macroinvertebrates and fish). The stressor identification process for these two impairments has been initiated by the RCWD, with plans to complete the TMDL at some point in the future.

Howard Lake, located in the headwaters of Upper Rice Creek and which also drains to Peltier Lake, was recently removed from the 303(d) list of impaired water bodies for nutrient/eutrophication biological indicators and, therefore, does not need a TMDL. In 2003, the DNR conducted a reclamation project on the lake to remove rough fish. This resulted in a pronounced improvement in lake water quality and a resulting reduction in the load of phosphorus from the headwaters of Rice Creek. RCWD will continue to monitor the lake.

A TMDL and implementation plan for Bald Eagle Lake was completed in 2012. Future improvements in Bald Eagle Lake water quality should reduce the phosphorus load that is transported and delivered to Peltier Lake through Clearwater Creek.

Action Strategy: Carry out implementation in the Bald Eagle Lake watershed. Continue monitoring water quality in Howard Lake, and initiate a TMDL study if warranted.

Other Resource Management Plans
RCWD plans to continue developing RMPs in the Upper Rice Creek watershed. This watershed contains many ditch systems and watersheds that will undergo development in the foreseeable future. Establishing RMPs helps to balance the needs of development with natural resource protection while meeting TMDL goals.

Action Strategy: RCWD explore the need for new RMPs and initiate them as identified.

Centerville Lake Watershed Implementation Strategy

Because the implementation practices occurring in the Peltier Lake watershed will have a significant effect on Centerville Lake via the backflow from Peltier Lake, the watershed component of the Centerville Lake Implementation Strategy primarily consists of implementing controls for Peltier, as noted in the previous section. Possible elimination of the backflow from Peltier Lake is discussed in Section 9D. Beyond these two major actions, runoff controls from the City of Centerville's MS4 program, from construction and industrial stormwater, from low density shoreline development in parts of Lino Lakes surrounding the lake, and from a large acreage of public park along the west and south sides of the lake also contribute to load reduction.

Action Strategy: Use existing runoff control programs, Peltier Lake load reductions, and possible elimination of backflow to manage the area draining directly to Centerville Lake.

9C. INTERNAL LOAD

Internal load was estimated to be approximately 62% of the TP load to Peltier Lake; internal load reduction in this lake will require aggressive management practices. The internal load in Centerville Lake was estimated to be substantially lower, and the load allocations do not call for a reduction in internal loading.

Existing Management Practices in Peltier Lake

Winter aeration

A winter aeration system on Peltier Lake has operated as needed since 1988. Located on the west side of the lake, the aerator, which is owned by the DNR and operated by Anoka County Parks, maintains oxygen concentrations high enough to prevent a fish winterkill. The DNR monitors oxygen concentrations during late winter months, and these data are used to determine whether the aerator is needed. If an eradication program for rough fish is ever seriously explored, turning this aerator off for the winter could be a part of the approach. In recent years, Anoka County Parks has not operated the aerator because oxygen levels have been sufficient to support fish over winter. The aerator was not operated in 2008 due to mechanical difficulties; it was repaired in 2009. During the winter of 2010/2011, another mechanical failure occurred. Due to the relatively severe winter (early ice and snow), a partial winterkill occurred.

Curlyleaf Pondweed Harvesting

Several lakeshore property owners have undertaken curlyleaf pondweed harvesting in certain areas of the lake. Some lack of enforcement for permitted weed removal has been noted for private cutting. Alternative approaches through lake drawdown or chemical eradication are discussed below.

In-Lake Implementation Strategy for Peltier Lake

Discussions on possible in-lake management approaches have included the DNR (Divisions of Fisheries, Ecological Services, and Water), MPCA, RCWD, members of the public, and the SPRWS. Although perspectives are markedly different, all agree that water quality improvements resulting from the TMDL program will assist each in achieving their specific lake management goals, whether that's water supply, fish production, or simply cleaner water. Any successful lake management program will need to rectify any program differences among the various management entities.

No single management practice or approach will resolve the problem of internal loading. Any success that will be achieved will have to be obtained through a multi-faceted approach using a mix of different techniques specified in the Implementation Plan. Caution will be needed to evaluate the repercussions that individual decisions have on other parts of the resource. For example, getting an immediate improvement in clarity would introduce the possibility of rapid macrophyte growth over much of the lake. Currently, the plants grow only to a depth of about five feet before they are shaded-out.

A package of management approaches needs to be crafted to address the many aspects of the problem. The package needs to be implemented in its entirety and monitored for effects – only then can the result be quantified and effectiveness documented. It is an iterative process that will take many years to accomplish within an adaptive management framework. All parties will need to work closely with MPCA on developing the strategy to implement this multi-faceted approach. A proposed Peltier Lake In-Lake Management Program (PLIMP) is contained in the Implementation Plan.

Appendix D contains a list of potential in-lake management techniques considered for the Peltier Lake Implementation Strategy. Following is the set of in-lake measures that were chosen to include in an overall approach. In most cases, a feasibility study must be performed to describe the details of the implementation step.

Drawdown/Macrophyte Control

This action is proposed to improve the lake's littoral vegetation through aeration of the sediments to allow the germination of certain native plant seeds, and consolidation of the sediments to improve the sediment's ability to support rooted macrophytes. Exposing sediment to the air also promotes oxygenation and consolidation of organic debris. The most significant target of the Peltier Lake drawdown would be the elimination of curlyleaf pondweed turions. Secondary impacts such as increased presence of Eurasian water milfoil need to be monitored.

Shoreline and Littoral Vegetation Management

A buffer of native shoreline vegetation should be established around the perimeter of the lake, possibly supplemented by cost-share and educational programs with shoreline property owners. Without a healthy littoral community of both emergent and submergent vegetation, zooplankton and other macroinvertebrates do not have sufficient habitat and refugia. Littoral vegetation management also can provide an energy break between waves on the water and an erosive shoreline. Follow-up plant management with attention to both shoreline and littoral vegetation should occur after a drawdown. This includes proper enforcement of weed harvesting permits so that cut weeds are removed from the lake.

Chemical/Physical Macrophyte Control

Selective use of chemicals or physical harvesting for control of nuisance macrophytes should be part of the overall strategy with the realization that it will likely be a long-term, annual process that will only succeed in controlling populations, but never eradicating them permanently. The overall macrophyte management plan should be to manage for a native macrophyte population as part of any chemical application or physical harvesting effort. Limits on chemical application within a Natural Environment Lake will need to be explored.

Fisheries Management

A fisheries management plan should be developed in cooperation with the Minnesota DNR to balance the fisheries goals of the lake with the water quality goals of the lake.

Currently a very good mix of both planktivores (zooplankton eaters) and piscivores (predatory fish-eaters) exists in the lake and further alteration of populations does not appear to be needed. Further exploration of a biomanipulation or trophic cascade approach would need to have better phytoplankton and zooplankton data.

The dam at the Peltier Lake outlet does not effectively serve as fish barrier for the upstream movement of fish. There is also nothing stopping the free movement of fish from the upper part of the watershed downward into the lake. This severely limits the success of any rough fish eradication program in the lake if upstream controls are not also implemented. These controls would by necessity have to include massive eradication and/or installation of many new fish barriers. The eradication, fish barrier approach has been effective for Howard Lake, but a much larger scale would be needed to protect Peltier Lake.

As part of the overall management strategy, a rough fish survey is proposed. This survey would then be part of the database used to select among many options for rough fish control, including chemical eradication and fish harvesting as options. The fisheries element should also include the installation of several fish barriers to prevent both the upstream and downstream migration of carp into Peltier Lake. Further biomanipulation should not occur until a better sense of in-lake biological conditions is available.

Dredging

Removal of select areas of sediment from Peltier, although not a top priority technique, could be done after a sediment survey to determine both nutrient content and depth of sediment. It could be part of the drawdown option to remove a certain amount of material while the water level is lowered. This would have the extra benefit of removing the turions contained within the removed sediment.

Aeration

Aeration is also an essential part of the overall strategy because of the role it plays in keeping predators alive over the winter. Although this aeration was instituted as a fisheries strategy, it does play a role in the overall ecologic health of the lake. Collecting additional dissolved oxygen profiles for the lake in all seasons would assist the decision-making process in regards to future aeration. Reverse aeration is also an option for eradication of fish by circulating anoxic bottom water under the ice during the winter.

Surface Use

The northern portion of Peltier Lake has been a settling area for the upper part of the watershed and contains several feet of loosely settled, easily disturbed sediment. Control of surface water activities in this area should be continued. This will be especially critical if a macrophyte rehabilitation program is able to re-introduce native vegetation in this sensitive area.

Monitoring

The multi-faceted approach to management of Peltier Lake necessitates an adaptive management monitoring program to define changes and the success of various management actions. Peltier Lake is one of the sentinel lakes under the DNR’s Sustaining Lakes in a Changing Environment (SLICE) program. Initial and continuing data collection will depend upon available DNR and cooperator funding, but DNR intends to collect the following data to supplement on-going RCWD and Met Council CAMP data collection:

- Spring trap-netting for pike
- Spring macrophyte survey (curlyleaf pondweed focus)
- August macrophyte survey (post-curlyleaf pondweed)
- Summer trap-netting

- Spring electro-fishing
- Monthly zooplankton counts
- Chlorophyll-*a* measurements

Water quality data are currently collected through the Met Council's CAMP program, but only for surface samples and with no biological data. RCWD will continue to assess the data collection program to assure that adequate data are available to describe lake quality and the adaptive changes necessary to refine implementation programs.

Alum

Agency reviewers of possible approaches recognized that alum is a short-term measure only, and would not likely be successful because of the shallow depth of Peltier Lake. Factors such as wind and boat turbulence, macrophyte incursion below the alum layer, and disturbance by the rough fish population would all be limiting factors for the success of alum. For these reasons, alum use is not recommended at this time.

Permitting

DNR permits will be required if some of the options are to be used. Specifically, there is a need for an aquatic plant management permit and a work in public waters permit if any dredging or drawdown were to occur.

Action Strategy: The following in-lake implementation strategy is proposed for controlling the in-lake release of phosphorus in Peltier Lake:

- Develop implementation priorities in coordination with the external load reduction strategy
- Implement a multi-faceted approach to in-lake nutrient control that includes the following elements:
    - Macrophyte control via drawdown, soil compaction, and promotion of re-vegetation with native plants and possible chemical spot control
    - Establishment of a shoreline and littoral vegetation management program
    - Fish management, starting with collection of phytoplankton data, a rough fish population survey and installation of rough fish barriers as identified after the survey
    - Consideration of spot sediment removal if shown by testing to be beneficial and cost-effective
    - Maintaining the winter aeration program to keep a healthy predator population
    - Consideration of biomanipulation after plankton data are better established and when needed to adjust the desired fish population
    - Increased collection of in-lake data to reflect the changes brought about by the Implementation Strategy

Centerville Lake

Existing Management Practices in Centerville Lake

Winter aeration

A winter aeration system on Centerville Lake has operated as needed since 1988. Located on the east side of the lake at the SPRWS pump station complex, the aerator was installed to maintain oxygen concentrations high enough during the winter months to prevent a fish winterkill. As with Peltier, this system could be turned off if a fish eradication program is ever attempted. DNR believes that this aeration system is at least partially responsible for the successful fishery currently in the lake.

Alum Treatment

An alum treatment program was conducted in Centerville Lake in 1998. Figure 24 shows that phosphorus levels in the lake were higher in the years before 1990 than they were in the years following 2000 (no data exist from 1991-1999), which lends some credence to the success of the alum addition. The absence of large numbers of nuisance rough fish has also helped the longevity of the 1998 treatment.

Inflow and Outflow from Peltier Lake

The single factor that perhaps has had more impact on the quality of Centerville Lake than any other is the hydraulic connection with Peltier Lake (Table 19). There is currently free-flow of water between the two lakes. In past years, the SPRWS relied on water flowing from Peltier Lake into Centerville Lake to supply an additional drinking water volume to the Centerville pump station. The last time the lake was actually used for supplementing St. Paul's supply was during the 1988 drought. Although SPRWS would consider Centerville Lake only in an emergency, the possibility of its use in the future for water supply cannot be eliminated.

In-Lake Implementation Strategy for Centerville Lake

The strategy for in-lake improvements to Centerville Lake does not require any internal loading reductions, but rather a continued maintenance approach to retain current conditions. Also included are precautionary recommendations for the protection of Centerville Lake during the implementation of the in-lake efforts proposed for Peltier Lake.

Mitigate Drawdown Effect from Peltier

If the drawdown of Peltier Lake is implemented as recommended, the culvert connection between the two lakes should be blocked so that water does not drain also from Centerville Lake during the drawdown. Emergency outflow provisions will need to be made to prevent high water from building on Centerville Lake when the outflow culvert is blocked. A water level rise on Centerville Lake in the winter of 2007-2008 with an inadvertent blockage of the culvert indicated that low water was not a problem in Centerville Lake during the cold weather season, but an analysis will be needed to assure that lake levels stay up if Peltier Lake is drawn down during the warm season.

Shoreline and Littoral Vegetation Management.
A buffer of native shoreline vegetation should be established around the perimeter of the lake, possibly supplemented by cost-share and educational programs with shoreline property owners. Without a healthy littoral community of both emergent and submergent vegetation, zooplankton and other macroinvertebrates do not have sufficient habitat and refugia. Littoral vegetation management also can provide an energy break between waves on the water and an erosive shoreline.

Fisheries Management.
The Minnesota DNR is satisfied with the current fish status in Centerville Lake and does not suggest any immediate changes. DNR believes that the aeration system has helped to establish a good predator fish population that has succeeded in keeping the rough fish population down. No further recommendations are made at this time other than possible continuation of the aeration system during the winter. Control of rough fish on Peltier will also eliminate the possible contribution of these fish through the connection culvert.

Action Strategy: The following approach is proposed for maintaining in-lake conditions in Centerville Lake:

- Develop implementation priorities in coordination with the Implementation Strategy developed for Peltier Lake;
- Establish a shoreline and littoral vegetation management program;
- Continue the winter aeration program for fish management; and
- Increase collection of in-lake data to reflect the changes brought about by the Implementation Strategy.

9D. Exchange between Peltier and Centerville Lakes

A hydraulic connection via a 48-inch culvert exists between Centerville and Peltier Lakes, with flow reversal common depending upon relative lake levels. Under low flow conditions, the small watershed draining to Centerville Lake feeds Peltier Lake. Under high flow conditions, flow from the Peltier Lake watershed fills Peltier Lake rapidly, and the flow is reversed, with Peltier Lake feeding Centerville Lake. This reversal of flow leads to a substantial phosphorus load from Peltier Lake flowing into Centerville Lake, estimated to be approximately 50% of the total load to Centerville Lake. This flow exchange between the two lakes could potentially be removed or adapted such that flow could not enter Centerville from Peltier, thus decreasing the total load to Centerville Lake.

Action Strategy: As part of the TMDL Implementation Plan, RCWD, in cooperation with SPRWS, should explore the means to prevent flow from Peltier Lake into Centerville Lake while assuring that flow into Centerville Lake could occur under emergency conditions, and develop procedures for operation of the connecting culvert.

9E. Estimated Cost of Implementation

Cost estimates (Table 38) for the implementation strategy are developed in the implementation plan. The total cost is approximately $29,000,000. Funding is expected to be drawn from a combination of various sources including district funds, MS4 funds, state and federal grants and private funds.

Table 38. Implementation Cost Estimate

Program Element	Cost	Comments
RCWD aggregator role in implementing TMDL program	Up to $50,000 per year for five years	Includes organization and leadership of the Implementation Work Group
Bald Eagle Lake TMDL Study	(Completed)	
Clearwater Creek TMDL Study	TBD	
Additional monitoring of Hardwood Creek	$5,000 per year	Add to RCWD monitoring program
Additional monitoring of JD4	$5,000 per year	Add to RCWD monitoring program
Monitoring Lino Lakes RMP results	$10,000 per year	Add to RCWD monitoring program
Upper Rice Creek monitoring	$10,000 per year	Add to RCWD monitoring program
MPCA estimate (March 2006) of restoration costs for Hardwood Creek	$4,850,000	March 17, 2006 MPCA document entitled “Estimated Restoration Costs for Implementation projects – 2006 to 2008”*
JD4 RMP Area • MPCA estimate (March 2006) of restoration costs for JD4 RMP Area within upper Rice Creek sub-watershed • Ditch repair recommended in JD-4 RMP	• $1,371,600 • $8,140,000	• Based on MPCA estimate of $300 per acre of sub-watershed* • JD-4 RMP adopted by RCWD in 2008
MPCA-based (2006) estimate of restoration costs for Upper Rice Creek sub-watershed (not including Hardwood Creek or JD-4 RMP area)	$4,629,900	Based on MPCA estimate of $300 per acre of sub-watershed*
MPCA-based (2006) estimate of restoration costs for Clearwater Creek sub-watershed	$8,463,300	Based on MPCA estimate of $300 per acre of sub-watershed*
MPCA-based (2006) estimate of restoration costs for direct drainage to Peltier Lake	$748,800	Based on MPCA estimate of $300 per acre of sub-watershed*
MPCA-based (2006) estimate of restoration costs for direct drainage to Centerville Lake	$139,800	Based on MPCA estimate of $300 per acre of sub-watershed*
Engineering/environmental study of Peltier lake drawdown	$50,000	Study to assess engineering approach and environmental impact

Program Element	Cost	Comments
Peltier shoreline survey and template preparation (note no implementation cost until defined by survey)	$15,000	Study to determine extent of improvements needed and preparation of repair templates
Fisheries management study of Peltier (note study only with no implementation until recommendations developed)	$35,000	Study preliminary to fish management to define extent of rough fish population and management options once that is known; fish barrier installation could total $100,000 if found to be needed after study, plus any costs associated with fish management
Collection of additional dissolved oxygen profile data on Peltier Lake	$5,000-10,000 per year	This would better define the oxygen conditions and need for aeration
Increased RCWD and DNR staffing for oversight and regulatory enforcement	$10,000 per year	Annual technical and regulatory oversight
RCWD assumption of lead monitoring role for Peltier Lake	$10,000 per year	Add to RCWD monitoring program
Centerville Lake shoreline survey and template preparation (note no implementation cost until defined by survey)	$5,000	Study to determine extent of improvements needed and preparation of repair templates; will use output from similar Peltier study
Supplemental bio-monitoring of Centerville Lake	$7,500 per year addition to RCWD monitoring program	Supplements routine lake monitoring
RCWD engineering feasibility study of altering Peltier/Centerville interconnection	$10,000 (study cost only)	Alter culvert for one-way flow with ability to allow two-way in emergency

* Issued as MPCA guidance "Methodology and Assumptions for TMDL Nonpoint Source Pollution Restoration Planning Estimates" - Spring, 2008

The following summaries are based on these cost estimates:

- Engineering and environmental studies to further define implementation details – $115,000
- Increased RCWD activity
    - Monitoring – $47,500 per year
    - Increased oversight and regulatory enforcement – $10,000 per year split with DNR
- Sub-watershed costs
    - MPCA-based "estimated restoration costs for implementation projects" for JD4, Hardwood Creek, Clearwater Creek, Upper Rice Creek and direct drainage to Peltier and Centerville Lakes – $20,383,400
    - Ditch repairs recommended in JD4 RMP plan – $8,140,000

10. Reasonable Assurances

Reasonable assurances must be provided to demonstrate the ability to reach and maintain water quality endpoints.

10A. Individual Programs

New RCWD and RMP Rules

On February 13, 2008 the RCWD adopted a new set of rules under which the district reviews projects within the watershed. RCWD has a long history of regulatory programs and has successfully implemented these new rules since adoption. These rules apply across the entire watershed, thus have the potential to reduce both point and nonpoint pollutant loading.

Specific rules expected to contribute to water quality improvement in Peltier Lake include stormwater management (Rule C), erosion control (Rule D), wetland alteration (Rule F), and drainage systems (Rule I). Rule C requires volume control and water quality treatment for the first 1.1 inches of stormwater runoff from properties or roads being developed or redeveloped. Rule D requires that bare soils associated with construction projects be stabilized to prevent erosion associated with stormwater runoff. The RCWD also protects wetlands through Rule F and the implementation of the Wetland Conservation Act. The RCWD maintains permit review and inspection programs to ensure compliance of these rules.

In addition to its standard set of rules, RCWD adopted special rules for two RMP areas within the Peltier and Centerville Lakes watershed. The JD4 RMP ("RMP-2") rules were adopted in 2008 and will be used to implement the details of the JD4 RMP. These more specific rules are meant to preserve high quality wetland habitat, and promote wetland restoration to benefit water quality.

Similarly, the Lino Lakes RMP and its supporting rule were adopted in 2009. This RMP was developed to work with the city's Comprehensive Plan.

RCWD Capital Improvement Plan

The RCWD's Capital Improvement Plan (CIP), defined in their 2010 Watershed Management Plan, identifies significant resources for the implementation of the Peltier and Centerville Lake TMDL. Between 2010 and 2015, the RCWD CIP calls for approximately $250,000 per year to fund projects identified in the Peltier and Centerville TMDL Implementation Plan. Activities funded through the RCWD CIP will target reductions in both stormwater (MS4 and non-MS4) phosphorus load, and internal (LA) phosphorus load.

TMDLs

Various other TMDLs within the Peltier and Centerville Lakes TMDL boundaries are either underway or will be done in the future. The larger projects among these are briefly described below.

The Hardwood Creek impaired biota (fish) and low dissolved oxygen TMDL is completed and will lead to improved water quality from the Hardwood Creek watershed. In 2009, the RCWD received a Federal 319 Grant to complete a major stream restoration project on Hardwood Creek. Significant reductions in sediment and phosphorus loading are expected from this project.

Within the Clearwater Creek sub-watershed the Clearwater Creek impaired biota (aquatic macroinvertebrates and fish) TMDL will be started at some point in the future.

A TMDL and implementation plan for Bald Eagle Lake was completed in 2012. Improvements in water quality in Bald Eagle Lake should decrease the phosphorus load being delivered to Peltier Lake through Clearwater Creek.

NPDES MS4 Program

The Peltier and Centerville Lakes watershed has MS4 permit programs in place for Forest Lake, Hugo, Grant, Dellwood, Mahtomedi, Willernie, Birchwood Village, White Bear Lake, White Bear Township, Centerville, and Lino Lakes. The City of Columbus and May Township are the only entities within the watershed that are not MS4 communities.

Under the MS4 program, each permitted community must develop a SWPPP that lays out the ways in which the community will actively and effectively manage its stormwater. SWPPPs are required to incorporate the results of any approved TMDLs within their area of jurisdiction, subject to review by the MPCA. The SWPPPs for the Cities of Centerville and Lino Lakes will also incorporate the results of the Downtown EAW and Northeast Development AUAR, respectively.

With oversight added by the RCWD and implementation of the various rules and programs noted above, reasonable assurance can be given that communities within the subject watershed will be properly managing their stormwater.

Drinking Water System

Centerville Lake is part of the St. Paul Regional Water Service (SPRWS) water supply system. Water from this lake can be pumped into an aqueduct that flows to the Vadnais chain of lakes supplying the St. Paul system. Although this is strictly an emergency component of the system because of its relatively poor quality, the SPRWS does consider it an important potential source of water and will monitor the efforts underway to keep it as clean as possible. The utility has some very strong authorities on what happens in both Peltier and Centerville Lakes and should be considered as a major stakeholder in any management program. This lends some additional assurance that efforts will be pursued to implement effective clean-up programs.

In-Lake Program

In addition to efforts to control external pollution from affecting Peltier and Centerville Lakes, there are efforts underway to look at various internal controls. The implementation strategy

(Section 9C) identifies many different, yet integrated efforts that are recommended for in-lake control of phosphorus.

The framework recommended in the accompanying TMDL Implementation Plan lays out a logical approach under the leadership of the RCWD through the newly created Implementation Work Group (see next section). Members of this group will include all of the regulatory and planning stakeholders needed to put together a prioritized approach for in-lake management. These entities will work together to define what needs to be done and implement an effective program to accomplish it.

10B. Summary

In summary, there are federal, state, watershed, local, and water utility authorities in place to provide a reasonable assurance that the implementation efforts within this TMDL study will go forward. The implementation plan accompanying this TMDL report recommends that the RCWD take on a leadership role and work with the many stakeholders involved in lake management to implement a series of improvement measures for the lakes. Establishment of an Implementation Work Group under the leadership of the RCWD is recommended as a way to integrate the various stakeholders in a united and defined effort. Although this work group is not yet formed, the long history of RCWD cooperation with agencies and communities suggests that it can be a viable implementation framework within which progress will be pursued.

11. Public Participation

Public participation for the Peltier and Centerville Lakes TMDL study consisted of several Technical Advisory Committee (TAC) and stakeholder input meetings. All of the meetings were held jointly with the Lower Rice Creek Chain of Lakes Study.

In addition, an opportunity for public comment on the draft TMDL report was provided via a public notice in the State Register from January 30 to February 29, 2012.

TAC Meetings

Technical Advisory Committee meetings were held on:

- Dec. 12, 2006 joint TAC with RMP/Comp. Plan
- March 1, 2007
- May 1, 2008

Attendee organizations at one of more of these meetings included the following:

- Anoka County Parks
- Blue Water Science
- City of Centerville
- City of Forest lake
- City of Hugo
- City of Lino Lakes
- Emmons & Olivier Resources, Inc.
- Metropolitan Council Environmental services
- Minnesota Board of Water and Soil Resources
- Minnesota Department of Natural Resources
- Minnesota Department of Transportation
- Minnesota Pollution Control Agency
- Rice Creek Watershed District
- Wenck Associates, Inc.

Stakeholder/Public Input Meetings

Stakeholder and public input meetings were held on November 19, 2007, and July 31, 2008. Attendees included residents from around the two lakes, city representatives, the RCWD, Emmons & Olivier Resources, Inc. (consultant), and Wenck Associates (consultant).

12. References

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13. Appendices

Appendix A: Groundwater assessment, Chain of Lakes

Appendix B: Historical water quality and biological change in Peltier Lake

Appendix C: Bathtub model inputs and outputs

Appendix D: Potential in-lake management techniques considered for the Peltier Lake implementation strategy

Appendix A: Groundwater Assessment, Chain of Lakes

Groundwater Assessment: Chain of Lakes

Surface water resources, such as lakes, are influenced by surface hydrology, local groundwater flow, regional groundwater flow, locally perched groundwater, precipitation, topography, geology, and soil type. Identifying a lake's dependence on groundwater is critical to managing the surface watershed and groundwatershed in order to protect these resources. This assessment includes the following lakes in the Rice Creek Chain of Lakes: Peltier Lake, Centerville Lake, George Watch Lake, Marshan Lake, Reshanau Lake, Rice Lake, and Baldwin Lake.

1.0 Groundwater Function of the Chain of Lakes

The groundwater function of a lake can be defined as the character of interaction between the lake and the surrounding groundwater. Lakes have varying degrees of groundwater interaction. Lakes can be classified as groundwater recharge (lake loses water), groundwater discharge (lake gains water), or flow-through (both recharge and discharge occur in different areas). Soil type, both underlying and on the margins of a lake, partially controls the magnitude of groundwater interaction.

The groundwater function of the Chain of Lakes was investigated and determined based on the following criteria:

1. Comparison of the lake elevation to regional surficial groundwater elevations
2. Comparison of the lake elevation to nearby surficial groundwater elevations
3. Comparison of the lake elevation to nearby upper bedrock groundwater elevations
4. Surficial geology in the Chain of Lakes area

1.1 Comparison of Lake Elevation To Regional Surficial Groundwater Elevation

Lake elevation compared to surrounding groundwater elevation is a strong indicator of the groundwater function. Lakes gain or lose water to the surrounding aquifers depending on the elevation of the lake water level relative to the groundwater level in the aquifers. If the lake elevation is higher than the water table, the lake is either perched or recharging the groundwater. If the lake elevation is lower than the water table elevation, the lake is a discharge point for regional groundwater. If the lake elevation is equal to or sloping with the regional water table, the lake has groundwater flow-through characteristics.

Figure 1 illustrates regional Quaternary aquifer contours. The Quaternary water table in the Chain of Lakes region has been mapped by the Minnesota Geological Survey (MGS) and Minnesota DNR (DNR). Sources of water table information include:

- Plate 6 of the Ramsey County Geologic Atlas (MGS, 1992),
- Plate 5 of the Washington County Geologic Atlas (MGS, 1990), and
- Plate 2 of Regional Hydrogeologic Assessment RHA-1 (MnDNR).

The local water table gradient slopes towards the Chain of Lakes from the west, north, and east (Figure 1). In the area of the Chain of Lakes, water levels in Quaternary water table wells and Quaternary buried artesian wells often have similar water elevations. The similar water elevation of these aquifers is likely due to variable and laterally discontinuous sand and clay layering that allows mixing of these two aquifers.

Comparison of the Chain of Lakes' normal surface water elevations (880-885 feet) to the regional Quaternary water table elevation illustrates that based on the available data, average lake elevations are at elevations that would be expected of regional groundwater elevations, therefore the Chain of Lakes can be classified as flow-through lakes.

1.2 Comparison of Lake Elevation To Nearby Quaternary Groundwater Elevation

Comparison of a lake's surface water elevation to nearby Quaternary aquifer elevations can help define the groundwater function of the lake. Figure 1 shows the regional water table contours and the locations of shallow wells within the area. The lakes' normal water elevations (800-885') were compared to nearby shallow groundwater elevations obtained from the County Well Index (CWI). Lake elevations within the Chain are at or below the nearby Quaternary groundwater elevations. The Chain appears to be a local and regional discharge area for surficial groundwater. These data support a groundwater flow-through or discharge function for the lakes within the Chain.

1.3 Comparison of Lake Elevation and Upper Bedrock Groundwater Elevation

There are limited bedrock wells that contain data within the CWI for the study area. Figure 2 shows the bedrock aquifer wells with groundwater elevation data associated with the St. Peter, Prairie du Chien, Jordan, and St. Lawrence-Franconia aquifers. The bedrock aquifer gradient is to the southwest, towards the regional discharge area at the Mississippi River. Measured water elevations for upper bedrock aquifers were investigated to determine bedrock groundwater elevations in relation to the lakes.

Comparison of lake elevation and bedrock aquifer elevations shows that groundwater elevations in the bedrock aquifers are roughly even with the elevation of the lakes. This suggests that groundwater flow is lateral or upward rather than downward which supports a flow through or discharge function for the lakes.

1.4 Surficial Geology in the Chain of Lakes Area

Surficial geology can be used as an indicator of the degree of surface water and groundwater interaction. Sandy soils allow for a higher connection of surface water and groundwater than clayey soils. Clayey soils restrict the movement of water. The Chain of Lakes is located along the eastern margin of the New Brighton Sand Facies Unit and parallel to the St. Croix Moraine. The Chain of Lakes occupies what is inferred to be two broad parallel troughs created by meltwater flowing under Superior Lobe ice (Meyer and Patterson, 1999). The Chain of Lakes is bounded to the east by quaternary till deposits of the Grantsburg sub lobe deposited by Des Moines Lobe glaciation. The western margin of the chain is predominately composed of loamy till under fine sands and large swaths of organic clay and peat. West of the loamy till is the laterally extensive New Brighton Sand facies unit of the Anoka Sand Plain (Figure 3).

Geologic cross-sections were developed using a GIS tool developed by the Minnesota Department of Health and data from the MGS CWI to look at the relationship between geology, the regional surficial water table, and lake bathymetry for the Chain of Lakes. Cross section geology was described using the primary lithology description identified in the County Well Index by the MGS, coupled with surficial geology interpretations in the Anoka Quadrangle map (M97) published by the MGS. Regional surficial water table elevations were estimated using water table contours from Plate 6 of the Ramsey County Geologic Atlas (MGS, 1992), Plate 5 of the Washington County Geologic Atlas (MGS, 1990), and Plate 2 of Regional Hydrogeologic Assessment RHA-1 (DNR). Lake bathymetric profiles were determined by estimating the bathymetric profile along the transect line of interest using bathymetric maps published by the DNR. Figure 3 depicts the orientation of the cross section lines relative to the Chain of Lakes. Figures 4 through 10 illustrate the transition and variation of surficial geologic units in the vicinity of the Chain of Lakes.

The geologic cross-sections illustrate that the Chain of Lakes is located along a transition in surficial geology from a laterally extensive sand unit located west of the lakes to a laterally extensive till unit located to the east. Illustrated in the cross sections is the connectivity of regional and local groundwater tables and the surface water elevation the Chain of Lakes. The connectivity is visible in the large areal extent of wetlands and groundwater dependent natural resources in the Chain of Lakes region (Figure 11). The degree of groundwater interaction in the lakes is variable with a higher degree of interaction for those lakes bordering the Anoka Sand Plain to the west, and lower interaction for those lakes that border the till deposits to the east.

1.5 Groundwater Function Conclusion

The groundwater function of the Chain of Lakes has been determined to be flow-through. Groundwater function was determined based on the similar elevation of the normal water elevation of the lakes and the elevation of both surficial and bedrock groundwater in the region, the propensity of geologic materials in the region to transmit water, and the large number of wetlands and groundwater dependent natural resources in the region.

The availability of baseflow discharge measurements is limited in the Chain of Lakes. Additional monitoring could provide a quantitative analysis of groundwater contribution to the Chain.

2.0 Total Phosphorus Loading to Chain of Lakes

The connectivity of lakes within the Chain of Lakes to the local and regional groundwater table based on analysis of groundwater and surface water elevations and surficial geologic materials warranted estimating the volume of groundwater entering the lakes annually. Without specific groundwater elevations, gradient(s), and aquifer properties around the lakes, an estimated groundwater flux to the lakes was quantified. The estimated flux was determined using local groundwater head differences, estimated and actual hydraulic conductivity of geologic materials in the near shore zone of the lakes, and groundwater-surface water interaction areas determined through the use of GIS.

2.1 Methodology and Inputs

Groundwater flux into the lakes was calculated using the Darcy flux equation:

$$Q = Ki A$$

Where, Q = Flux in cubic feet/second
K= Hydraulic conductivity in feet/second
i = Horizontal hydraulic gradient in feet/feet (unit less)
A = Area in square feet

Hydraulic Conductivity (K)

Values of hydraulic conductivity were assigned based on the geologic material located along the periphery of the lake. A range of hydraulic conductivity values was used, offering low and high hydraulic conductivity estimates for each of the parent materials. Hydraulic conductivity values (Table 1) used for the calculations were based on values for different soil types developed by Domenico and Schwartz (1998) and a specific value for New Ulm loamy till collected adjacent to Clearwater Creek and determined by a falling head permeability test.

Table 1. Hydraulic Conductivity Values

Material	Description	Low K Value [ft/sec]	High K Value [ft/sec]	Source
New Ulm Formation Loamy Till	Loam textured unsorted sediment.	3.12E-09	3.12E-09	Falling Head Permeability Test (2007)
New Ulm Formation Loamy Till under Lake Sand	New Ulm formation till beneath as much as 20 feet of fine grained sand	6.56E-07	6.56E-04	Domenico and Schwartz (1998); Fine grain sand values
Peat	Fine grained organic material	6.56E-07	6.56E-04	Domenico and Schwartz (1998); Fine grain sand values
New Brighton Sand Facies	Very fine to med grained sand	2.95E-06	1.64E-03	Domenico and Schwartz (1998); Medium grain sand values
New Ulm Formation Twin Cities Member	Loam to sandy loam textured unsorted sediment	3.12E-09	6.56E-06	Falling Head Permeability Test (2007) for low K value; Domenico and Schwartz (1998); till for high K value

Hydraulic Gradient (i)

The hydraulic gradient, the difference in hydraulic head between two points divided by the distance between the two points, was calculated from difference measurements made using GIS. Horizontal hydraulic gradients were determined for each of the lakes within the Chain of Lakes (Table 2). Centerville and Reshanau were assumed to be influenced only by the eastern groundwater gradient due to their location east of Rice Creek and because they are topographically higher in elevation than the creek. Peltier lake was also assumed to be only influenced by the eastern groundwater gradient. Marshan Lake was determined to be only influenced by the western groundwater gradient. Calculated hydraulic gradients are presented within the results table for each lake. Horizontal gradients were calculated using known ditch elevations within the Anoka Sand plain, existing Quaternary groundwater contour data and lake normal water elevations.

Table 2. Horizontal Groundwater Gradients

Lake	East Gradient [ft/ft]	West Gradient [ft/ft]
Peltier	0.002	--
Centerville	0.002	--
George Watch	0.002	0.002
Marshan	--	0.001
Reshanau	0.002	--
Rice	0.001	0.002
Baldwin	0.001	0.002

Surface Area (A)

The area of groundwater-surface water interaction was calculated by creating a lakebed interaction area at each of the lake’s wetted perimeters. The groundwater-surface water interaction area was calculated as the product of an interaction depth of 5 feet multiplied by the length of the interaction zone (Figure 12). This area was created with the assumption that the majority of surface water-groundwater interaction is taking place around the littoral edge of the lake. All interaction areas were assumed to have a homogeneous lithology that corresponds to the geologic material mapped around the periphery of the lake. Numerous studies have shown that the rate of exchange between surface water and groundwater decreases exponentially with distance from shore (McBride and Pfannkuch, 1975; Lee, 1976; Winter, 1978; Lee et al., 1980; Harvey et al., 2000). The exponent is a function of variables such as lakebed slope, upland slope, anisotropy, lake width, lake depth, and the thickness of the aquifer.

Phosphorus Concentration

Total phosphorus concentration of shallow groundwater to the east of the Chain of Lakes is assumed to be 0.044 mg/L. This value was determined using the average phosphorus concentration of three wells sampled during 2007 in the Centerville Lake area. The wells were set in the Quaternary Buried Artesian Aquifer and had total phosphorus concentrations ranging from 0.032 mg/L to 0.057 mg/L. The average value used is similar to the average total phosphorus concentration of five shallow wells located northeast of the project area along Hardwood Creek. Total phosphorus concentration in those wells ranged from 0.027 mg/L to 0.097 mg/L. The Hardwood Creek wells ranged from 14 to 18 feet deep and were set in peat, fine sand, or loamy till.

As part of the MPCA's Ambient Monitoring and Assessment Program, groundwater quality samples were collected within the Quaternary water table aquifer at one site between 1992 and 1996 within the City of Lino Lakes and west of the Chain of Lakes. The total phosphorus concentration was 0.3436 mg/L. This value was used for groundwater flow to the Chain of Lakes from the west.

Phosphorus concentration varies in groundwater and is partially a function of natural rates of mineral weathering, anthropogenic causes such as agriculture practices or faulty septic systems, and the natural decomposition of organic matter present in the shallow aquifer matrix. Oxidation of peat in the vicinity of the Chain of Lakes may elevate phosphorus levels above the assumed values.

3.0 Total Phosphorus Loading Results

Total phosphorus (TP) loadings were calculated based on the groundwater flux and concentration of TP in groundwater. Table 3 summarizes the calculated results for each lake within the Chain of Lakes.

Table 3. Total Phosphorus Loading Summary

	Groundwater Inflow		Phosphorus Load	
Lake	**Low [cfs]**	**High [cfs]**	**Low [kg/yr]**	**High [kg/yr]**
Peltier	9.32E-05	0.093	0.004	3.655
Centerville	2.02E-05	0.020	0.001	0.783
George Watch	3.22E-04	0.258	0.069	49.008
Reshanau	1.84E-04	0.114	0.007	4.493
Marshan	8.04E-05	0.047	0.025	14.272
Rice	3.04E-04	0.198	0.068	40.515
Baldwin	5.29E-05	0.053	0.011	11.209

4.0 Summary and Conclusions

Groundwater flux and total phosphorus loading attributed to groundwater has been estimated to investigate the magnitude of total phosphorus loading attributed to groundwater in the Chain of Lakes. The Chain of Lake's elevation relative to the local water table, the ability of local surficial geology to readily transmit water, and localized hydraulic gradients in the region classify the Chain of Lakes as groundwater flow through lakes. Loading analysis suggests that groundwater contributes between 0.2 and 124 kilograms of phosphorus annually to the Chain of Lakes.

To accurately define the rate of groundwater-surface water interaction within the Chain of Lakes would require an extensive study. Such a study would characterize site specific geologic materials, hydraulic gradients, aquifer properties, and phosphorus concentrations. Data collected in a site specific study could be used in the development of a groundwater model that would help define the extent of groundwater interaction and groundwater flux rates.

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Figures

Figure 1: Regional Water Table Contours in the Chain of Lakes Region

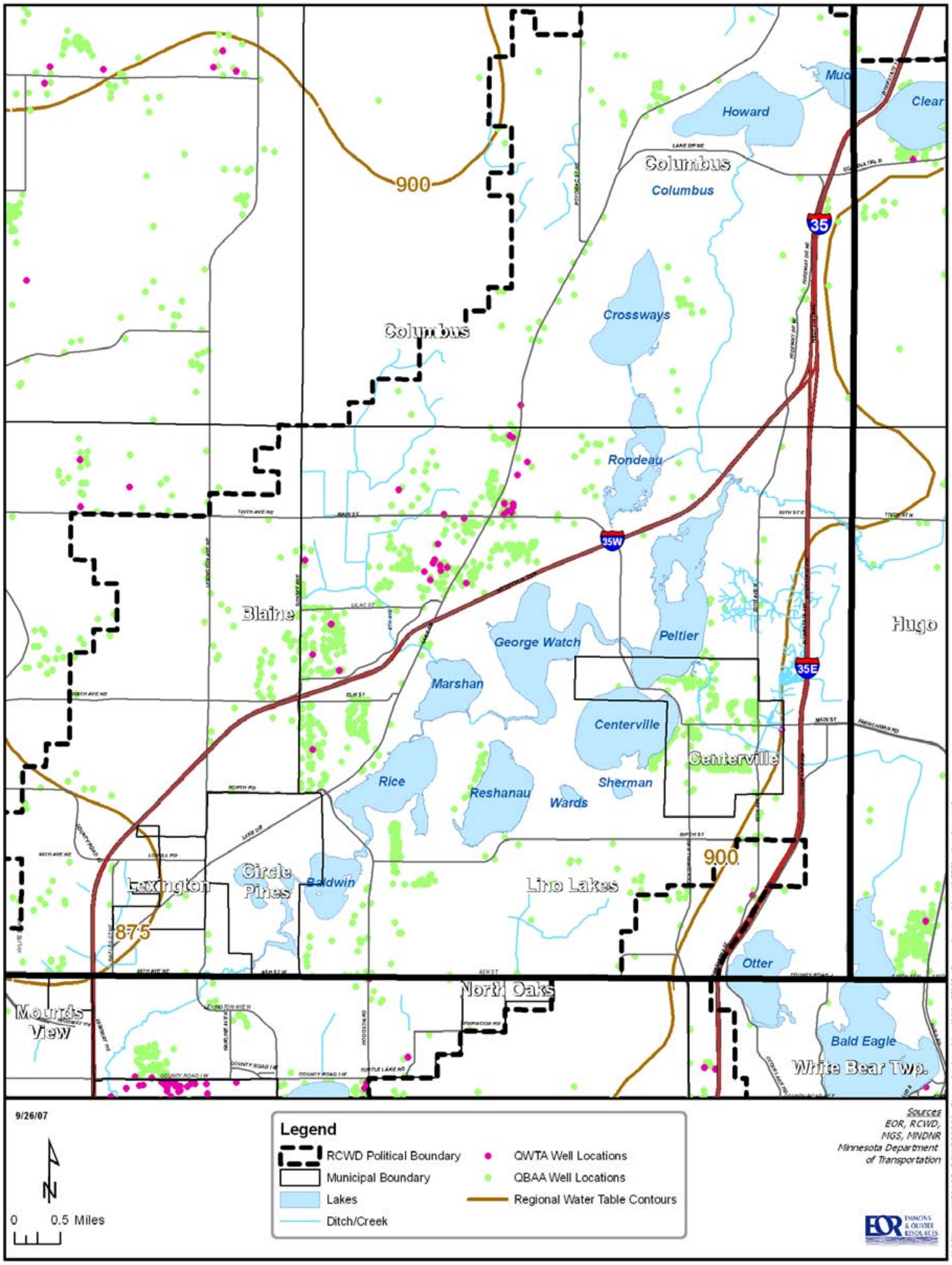


Figure 2: Bedrock Groundwater Elevations in the Chain of Lakes Region

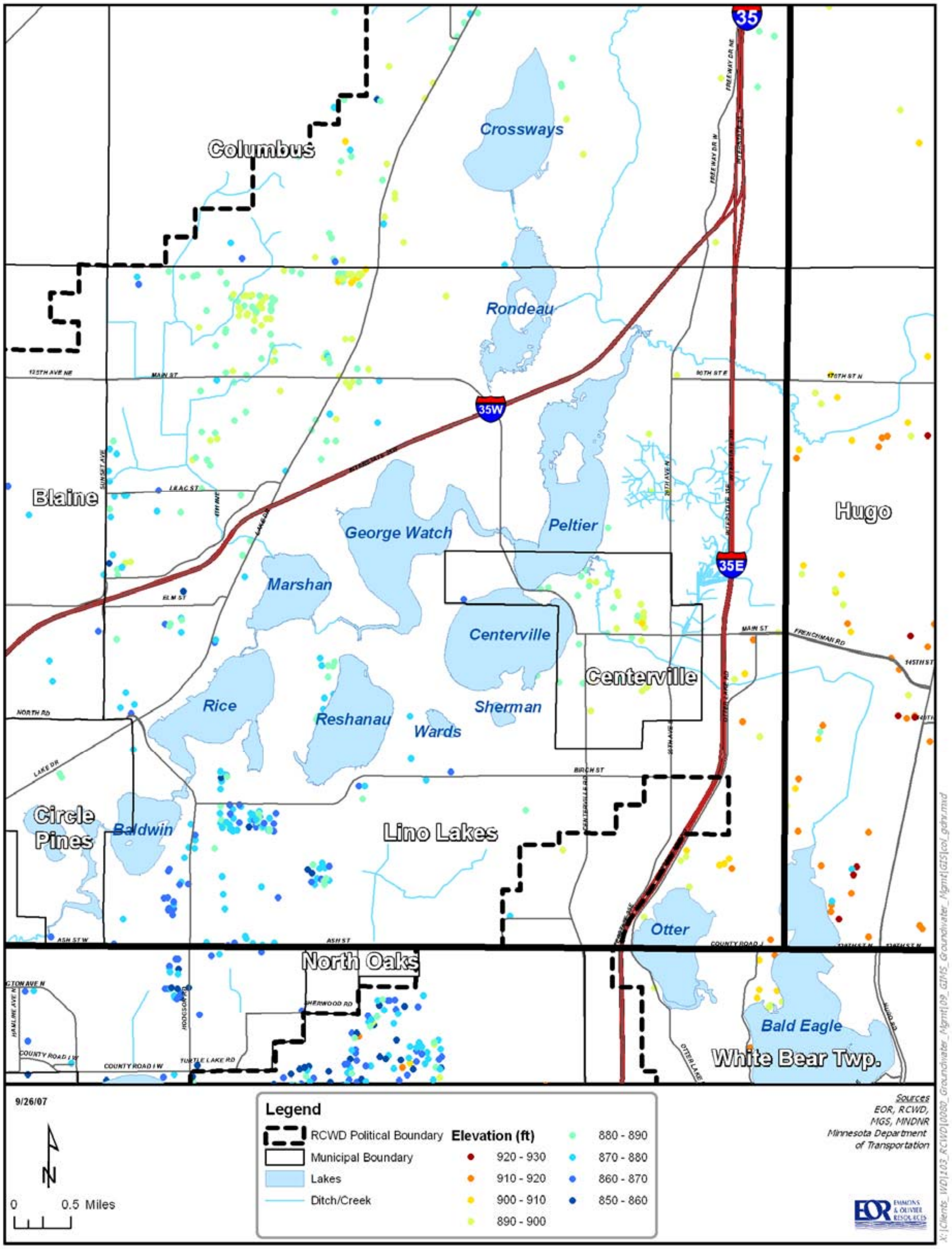


Figure 3: Surficial Geology of the Chain of Lakes Region and Transect Locations

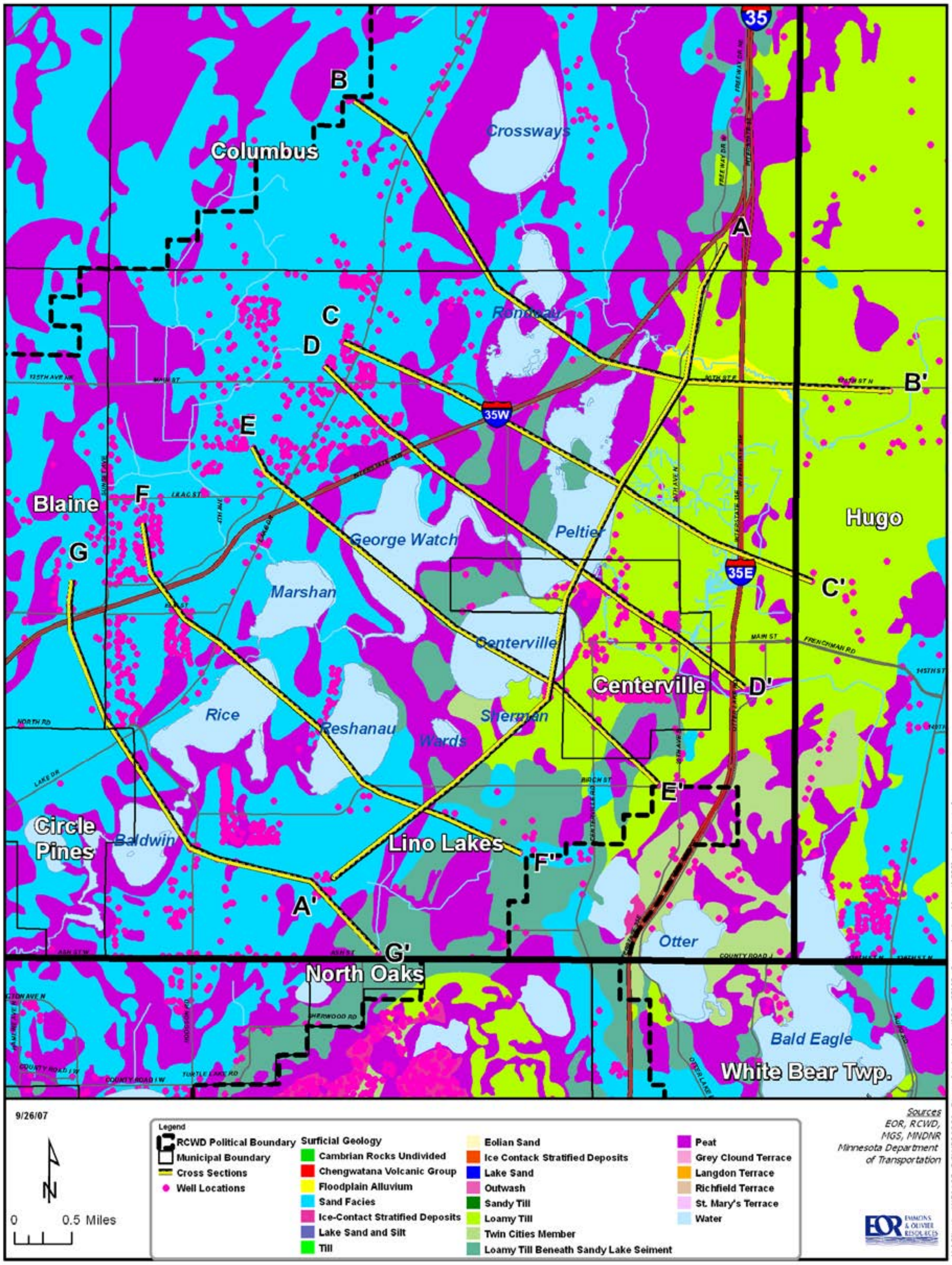


Figure 4: Chain of Lakes A-A' Cross Section

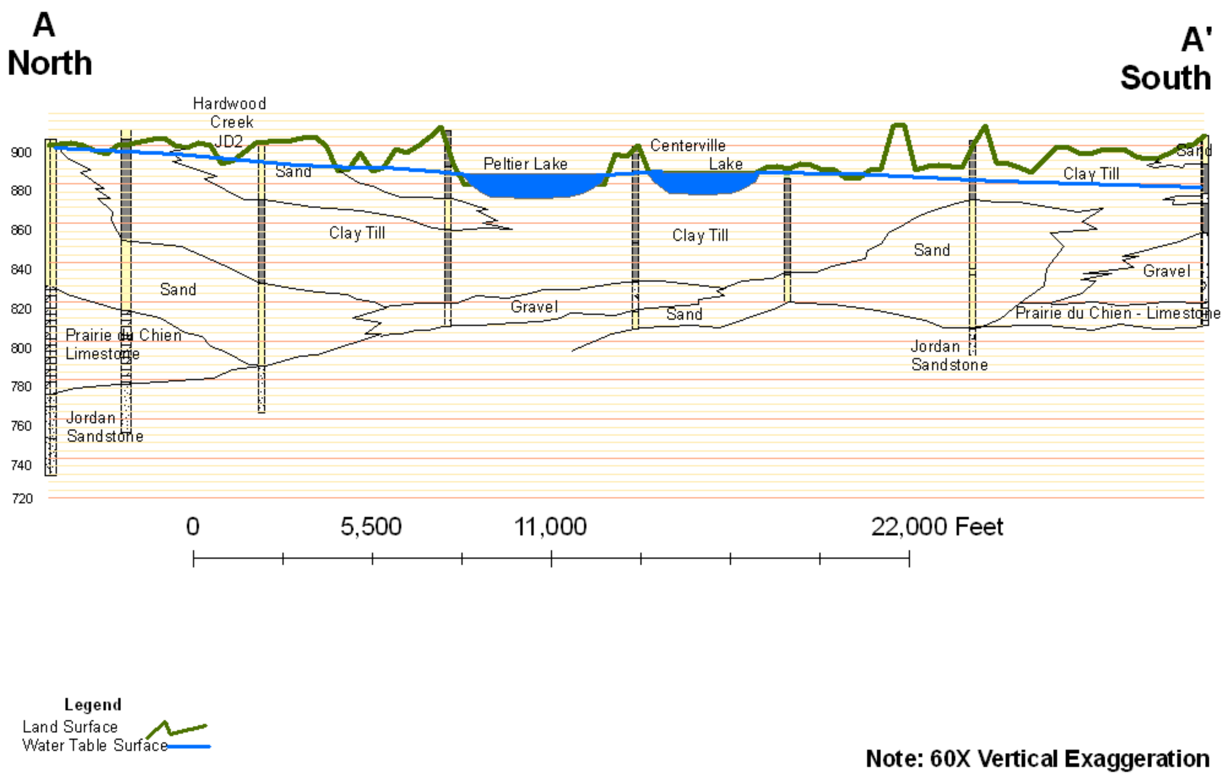


Figure 5: Chain of Lakes B-B' Cross Section

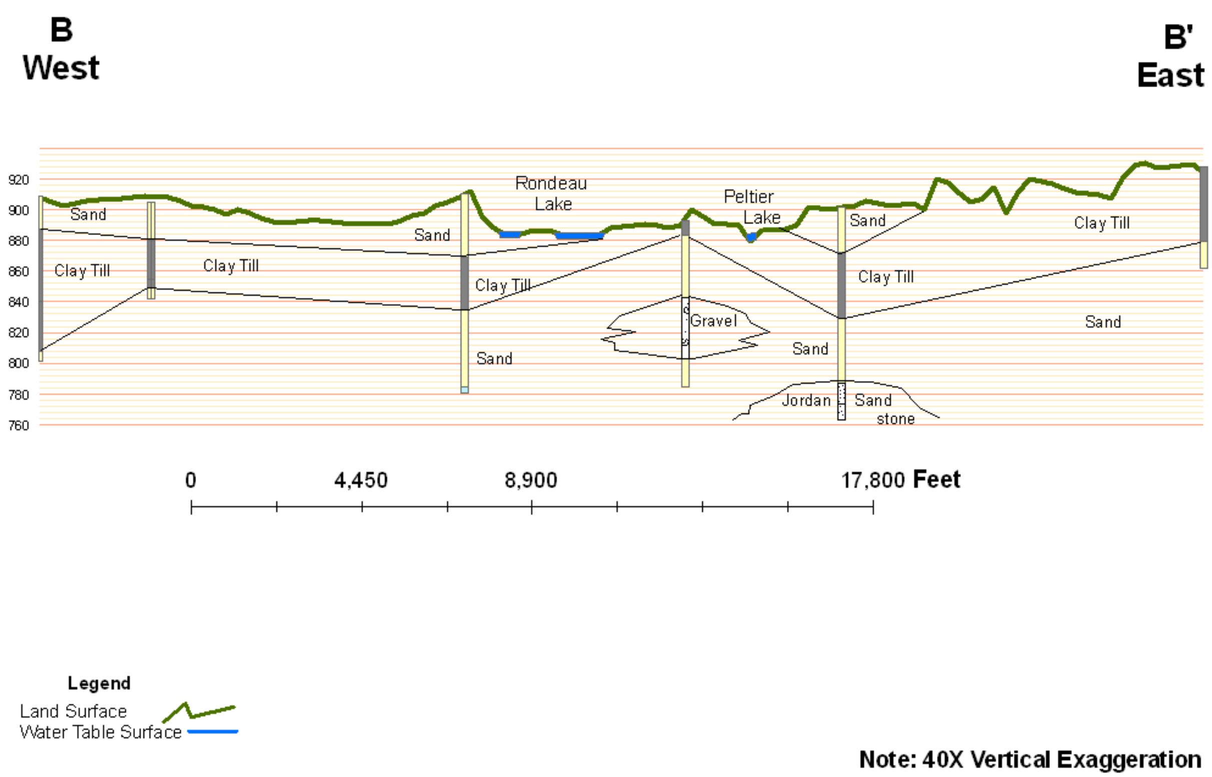


Figure 6: Chain of Lakes C-C' Cross Section

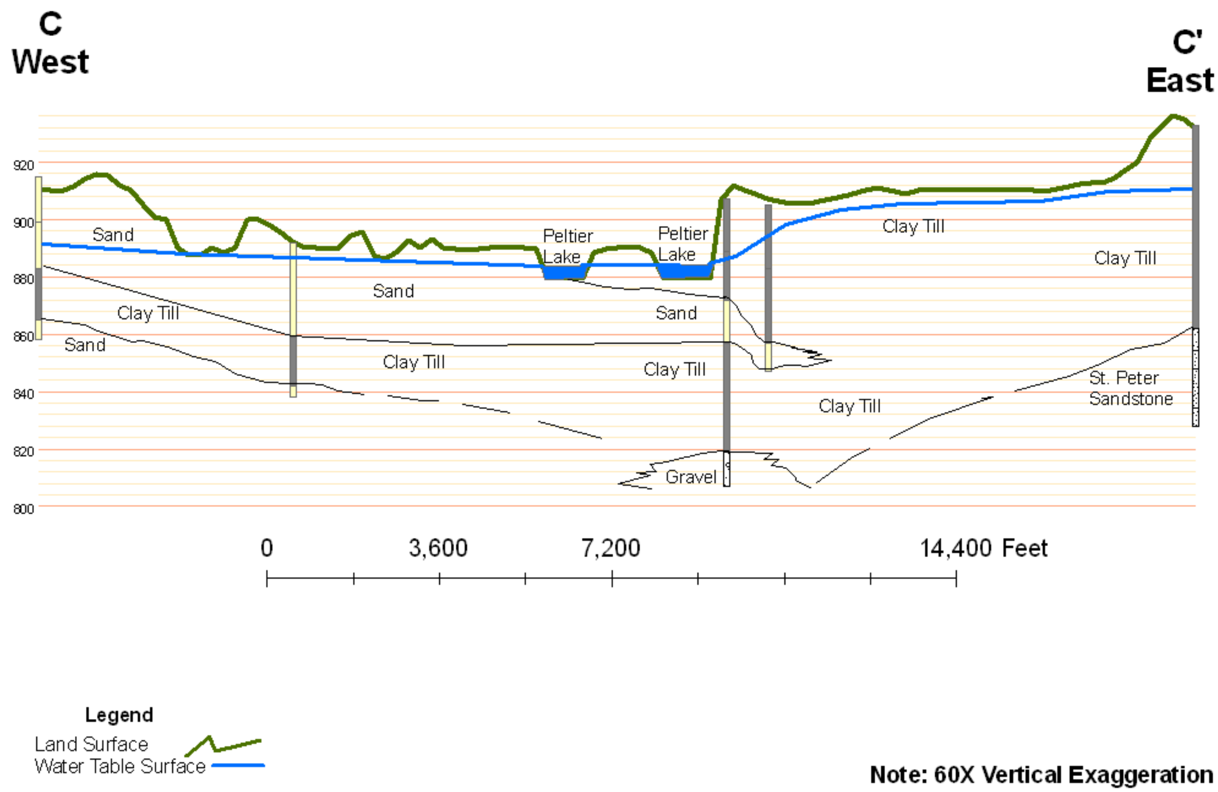


Figure 7: Chain of Lakes D-D' Cross Section

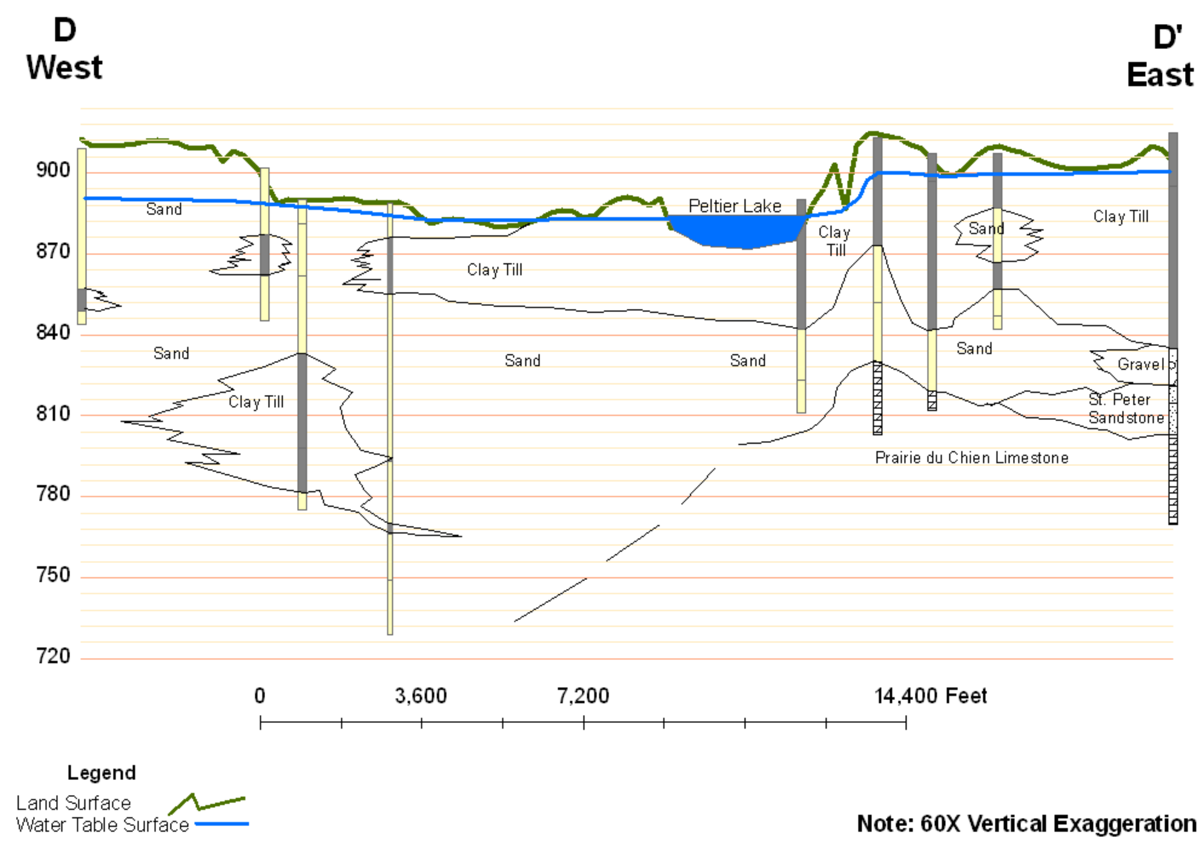


Figure 8: Chain of Lakes E-E' Cross Section

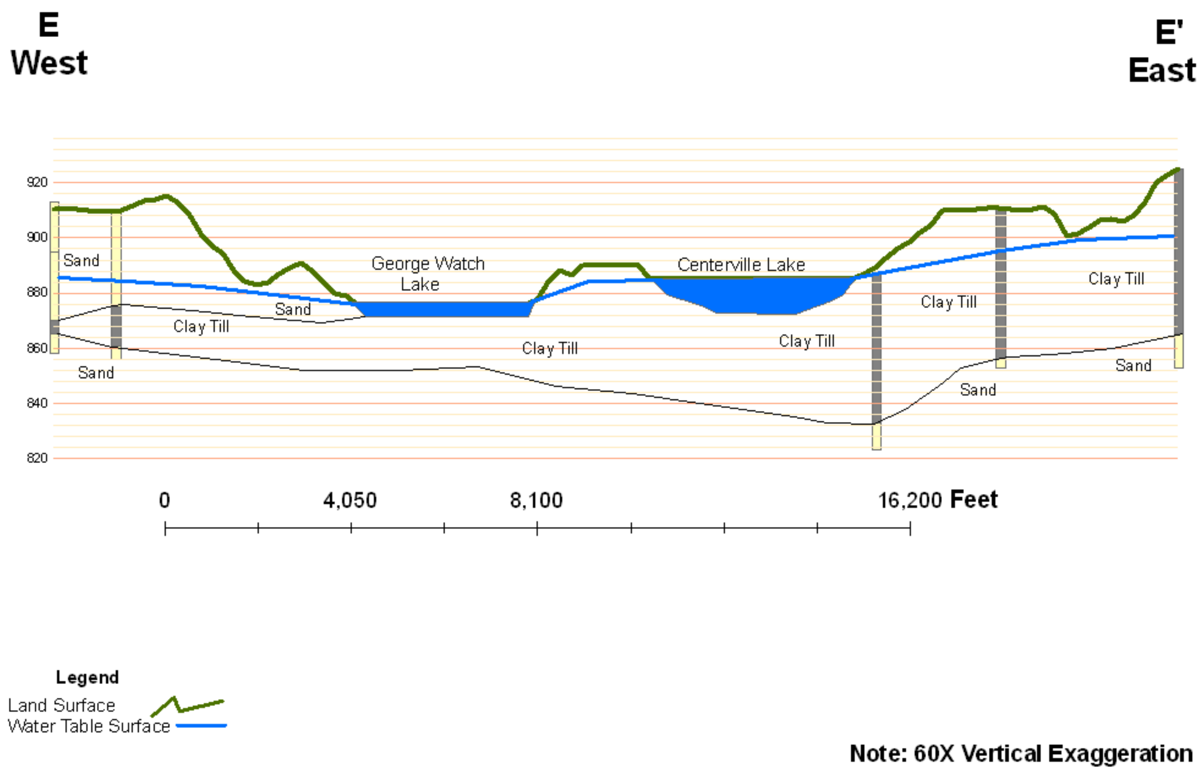


Figure 9: Chain of Lakes F-F' Cross Section

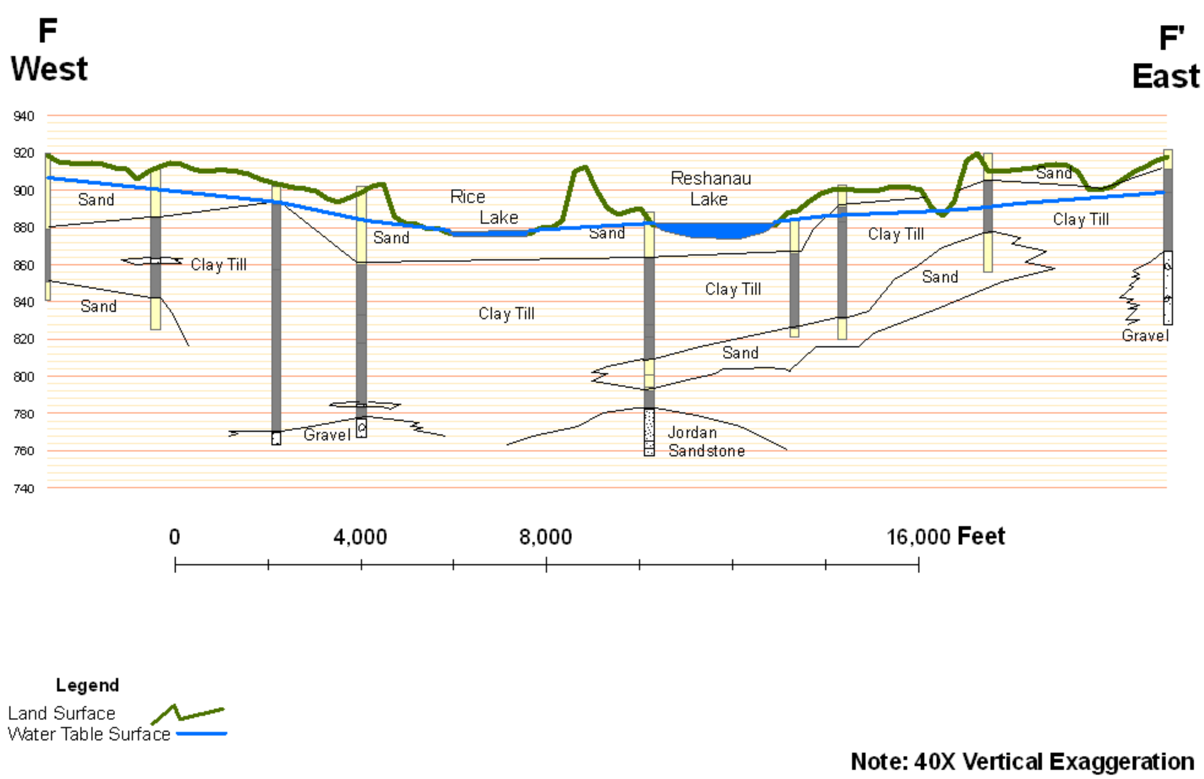


Figure 10: Chain of Lakes G-G' Cross Section

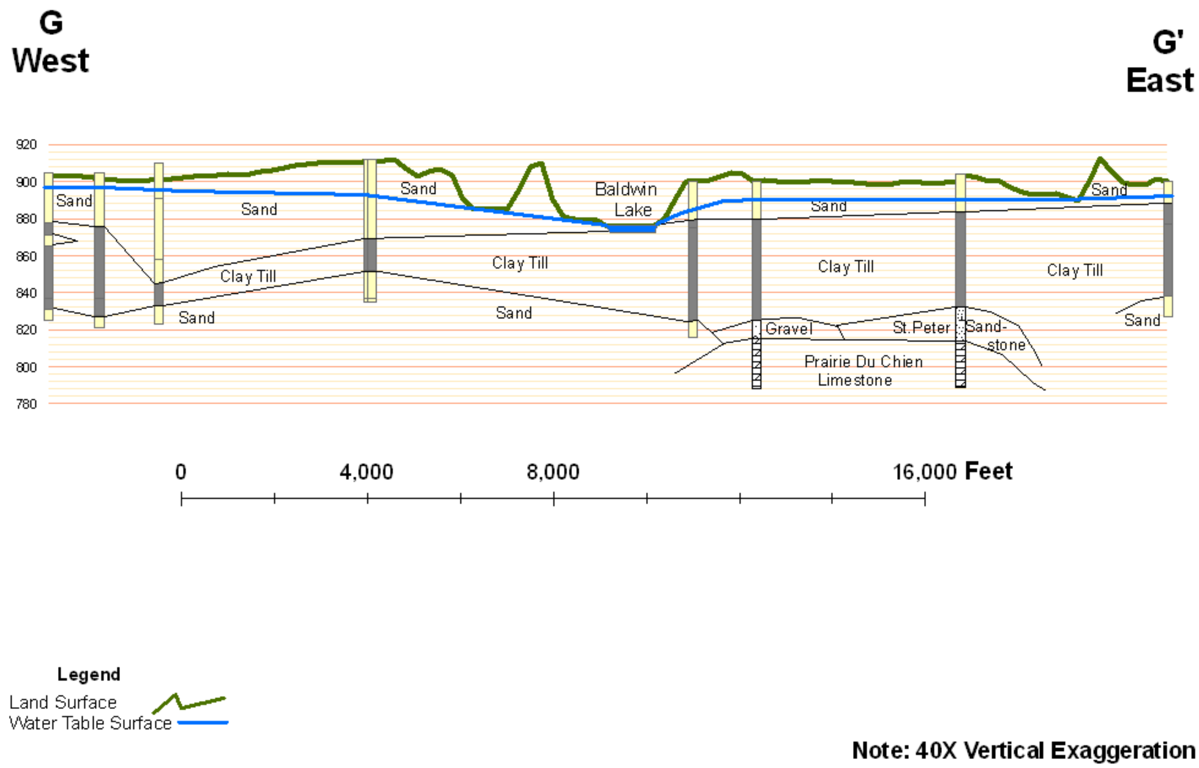


Figure 11: Groundwater Dependent Resources in the Chain of Lakes Region

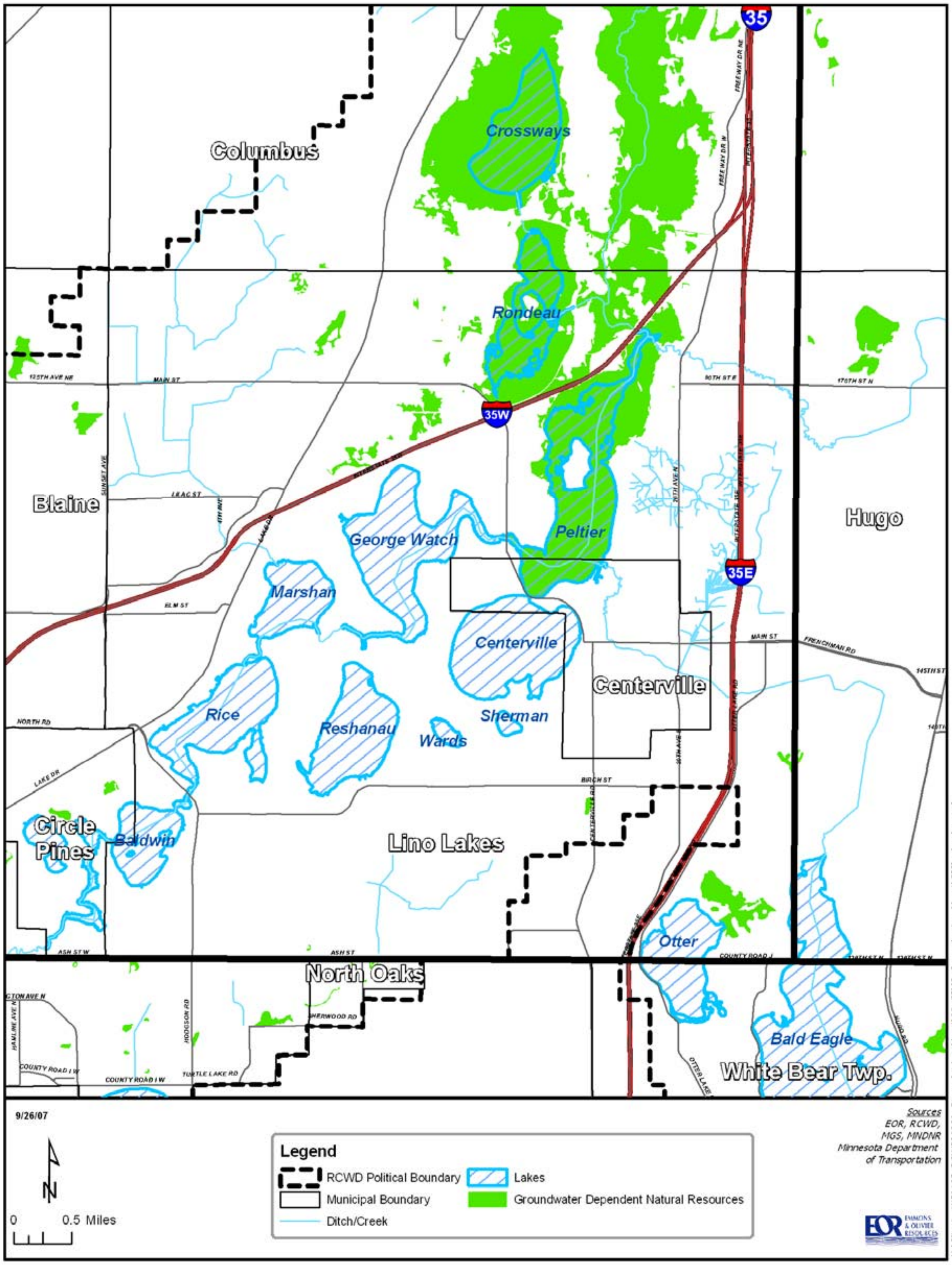
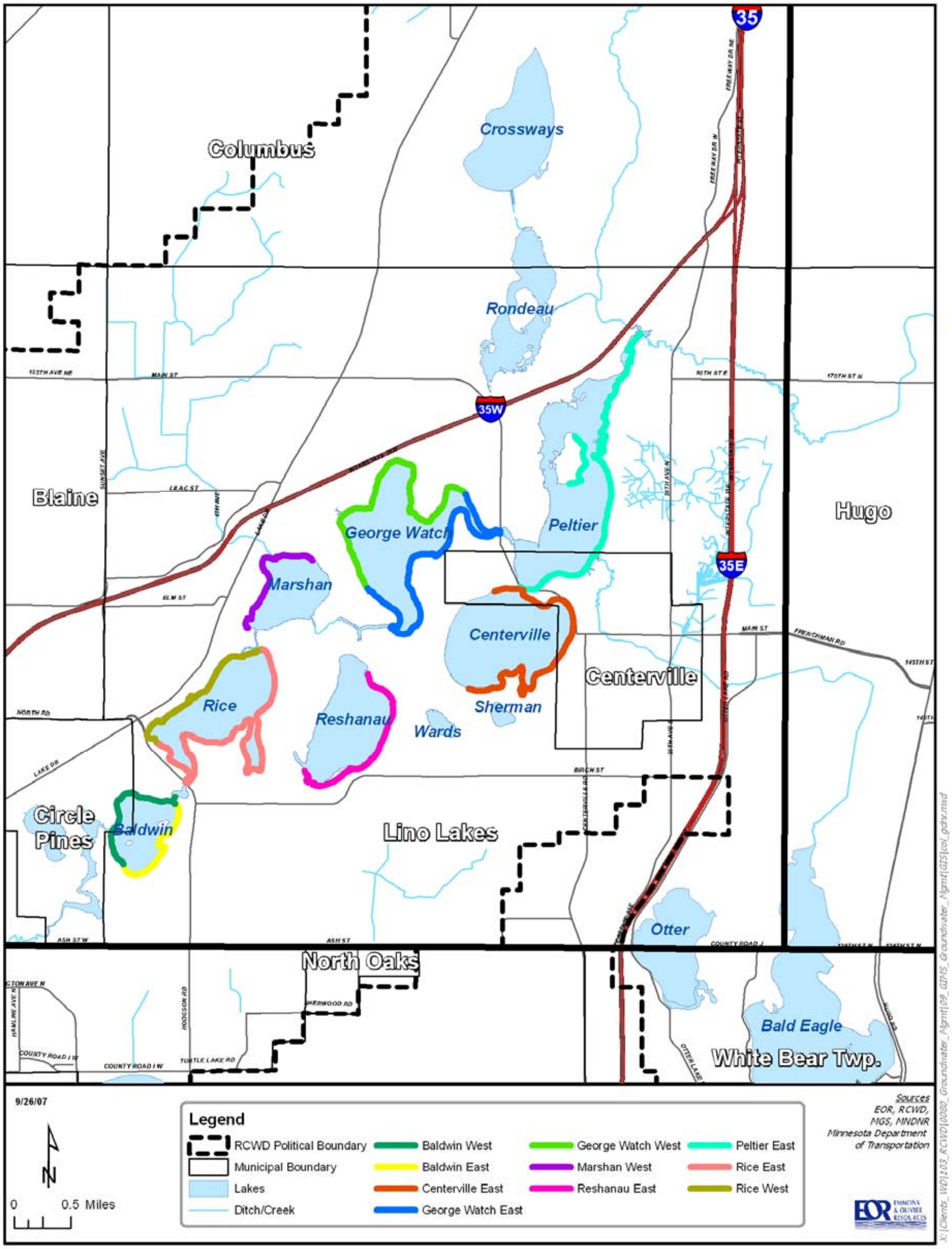


Figure 12: Groundwater-Surface Water Interaction Areas within the Chain of Lakes



Appendix B: Historical water quality and biological change in Peltier Lake

Historical Water Quality and Biological Change in Peltier Lake, Anoka Co., MN

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REPORT CONTENTS

EXECUTIVE SUMMARY

1. In this project, we use paleolimnological techniques to reconstruct the trophic and sedimentation history of Peltier Lake, Anoka County, Minnesota.

2. The ~2.6 m core sequence recovered from Peltier Lake captured sediments from ca 1840-present including pre-Euroamerican settlement, post-settlement and pre-damming, and post-damming.

3. Peltier Lake has a very fast sedimentation rate. This produces somewhat greater uncertainty in dating and sedimentation rates, especially in early 210-Pb dates, than we expect from other central MN lakes.

4. The major event recorded in the Peltier core is dated at 1885 AD and located 200 cm downcore. It is recorded as a major increase in magnetics and an increase in inorganic sedimentation. We believe this shift marks settlement and land clearance in the Peltier watershed, which would have been characterized by erosional events and a shift in sediment sources to the basin.

5. Damming is recorded as a slight decrease in magnetics and is located approximately 150 cm downcore.

6. The diatom communities can be separated into 3 zones in the core: 1. bottom-1915, 2. 1939-1985, 3. 1985-2006. The lake has been continuously dominated by three species: *Aulacoseira granulata*, *A. ambigua*, and *Stephanodiscus niagarae* with several small *Stephanodiscus* species. Zone 1 has high abundance of *Aulacoseira* species, a higher proportion of benthic/attached species, and many chrysophyte cysts. Zone 2 has lower abundance of *Aulacoseira* species and higher abundance of *Stephanodiscus niagarae*, *S. hantzschii*, and *S. parvus*. Zone 3 again has higher abundance of the *Aulacoseira* species, decreased abundance of several small *Stephanodiscus* spp., and increased abundance of several eutrophication indicators including *Fragilaria capucina* v. *mesolepta* and *S. hantzschii* f. *tenuis*.

7. The major biological change in the core occurs around WWII. There was a large community shift in the diatoms from Zone 1 to Zone 2. Several indices of eutrophication record this even including a sharp increase in the plankton to benthic diatom ratio and the diatom to chrysophyte cyst ratio (Table 1).

8. Phosphorus reconstructions (Fig. 6) show that Peltier Lake is currently hypereutrophic (>100 ppb TP). This increase in TP is coincident with the WWII-era biological change. Samples deposited previous to WWII, including presettlement, pre-damming, and immediate post damming samples, have diatom-inferred TP levels that are estimated from 60-80 ppb TP, i.e. Peltier Lake has long been a productive and eutrophic system, but was not historically hypereutrophic. Our two lowest samples (1840s) show spurious high TP reconstructions that are difficult to interpret. The diatom communities are clearly different than modern samples (higher benthics, higher c-cysts) but are made up of the same three species that dominate the rest of the

core. Given the shifts in magnetics and LOI during this time, it may be that Peltier Lake was a more hydrologically dynamic system (lake level changes) than we see in the dammed lake today.

9. Other work to be considered on the Peltier core would include confirmation of dating model using pollen and 137-Cs. We could analyze diatoms in a sample from the 1920s. Pigment analysis may help clarify the onset of blue-green algal blooms and algal productivity. Biogenic silica analysis would also help us understand changes in historical algal productivity.

INTRODUCTION

Within the glaciated regions of the Upper Midwest, lakes feature prominently in the landscape and are a valued resource for tourism, municipalities, home and cabin owners, recreational enthusiasts, and wildlife. Current and historical land and resource uses around the lakes in Anoka County, including shoreline development, sport fisheries, waste and stormwater discharge, water level management, and agriculture, have raised concerns about the state of the lakes and how to best manage them in a future certain to bring change. To effectively develop management plans, knowledge of the natural state of a lake and an understanding of the timing and magnitude of historical ecological changes become critical components. In this project, we use paleolimnological techniques to reconstruct the trophic and sedimentation history of Peltier Lake, Anoka County, Minnesota. Results will provide a management foundation for TMDL development by determining the natural or reference condition of these lakes and reconstructing a history of water quality and ecological changes that have occurred in the lake during the last 150 years.

With any lake management plan it is important to have a basic understanding of natural fluctuations within the system. Reliable long-term data sets, on the order of 30 - 50 years, are generally not available for most regions of the country. Through the use of paleolimnological techniques and quantitative environmental reconstruction, we can estimate past conditions, natural variability, timing of changes, and determine rates of change and recovery. This type of information allows managers and researchers to put present environmental stresses into perspective with the natural variability of the system. It can also be used to determine response to and recovery from short-term disturbances.

Peltier Lake is located in southwest Anoka County and is part of the Rice Creek drainage. The lake is approximately two miles long (N-S) and one mile wide (E-W). The lake is largely a single shallow basin with a max depth of 16 ft recorded forty years ago. A large wooded island separates the larger and deeper southern basin from the smaller and shallower northern basin. Two streams, Rice Creek and Hardwood Creek feed the northern basin, whereas Clearwater Creek enters along the SE shore of the southern basin. A single outlet, Rice Creek, drains Peltier Lake to George Watch Lake along its SW shoreline, although some southern drainage may enter Centerville Lake during high water. The outlet to George Watch Lake has been controlled by a dam since 1905, although details of the water management of Peltier Lake have not been located.

The primary aim of this project is to quantitatively reconstruct historical environmental change in Peltier Lake utilizing paleolimnological analysis of a dated sediment core (Anderson and Rippey 1994, Dixit and Smol 1994). The lake currently has marginal to poor water quality and is the subject of local and state concern. This project will provide data necessary to develop management plans that include an understanding of presettlement conditions, pre- and post-damming conditions, historical lake response to landuse and past management, and development of management targets through TMDL planning. Analytical tools used include radioisotopic dating of the core, geochemical analyses to determine local sediment accumulation rates, and analysis of subfossil algal (diatom) communities. Multivariate analyses, diatom-based transfer functions, and comparison of algal assemblages with an 89 Minnesota lake data set are used to relate changes in trophic conditions and algal communities to human impacts in the local watershed.

METHODS-SEDIMENT CORING

One piston core and one Livingston core were collected in October of 2006 (Table 1). The piston core was taken using a drive-rod piston corer equipped with a 7 cm diameter polycarbonate barrel (Wright 1991). A Livingston corer was used to collect a secondary core from sediment depths below that of the piston core. The piston core was transported to the shore and extruded vertically in 2-cm increments to a depth with cohesive sediment texture (50 cm). Core sections, material remaining in the core barrel, and the Livingston core (wrapped in aluminum foil), were returned to the laboratory and stored at 4°C.

METHODS-MAGNETIC SUSCEPTIBILITY LOGGING AND CORE IMAGING

Magnetic susceptibility provides a non-destructive measure of relative quantity and size of ferro-magnetic minerals. Increases in magnetic susceptibility signatures may be correlated with land use changes including land clearance, increased terrestrial-derived sediments, and paleosols. Decreases in magnetic susceptibility often accompany increased carbonate and organic fluxes to the sediments from increased productivity.

A Geotek Standard MSCL with an automated trackfeed was used for magnetic susceptibility logging. Susceptibility measures were taken at 1-cm intervals, which integrated a signal over a 5-10-cm length of core. Following susceptibility logging, cores were split lengthwise, physically described, and digital images taken of each core section using a Geoscan Corescan-V. Following scanning, cores were returned to storage at 4°C. Magnetic susceptibility logging and core imaging were performed at the Limnological Research Center's core lab facility at the University of Minnesota.

METHODS-LEAD-210 DATING

Sediments have been analyzed for lead-210 activity to determine age and sediment accumulation rates for the past 150-200 years. Lead-210 was measured at numerous depth intervals by lead-210 distillation and alpha spectrometry methods, and dates and sedimentation rates were determined according to the c.r.s. (constant rate of supply) model (Appleby and Oldfield 1978). Dating and sedimentation errors were determined by first-order propagation of counting uncertainty (Binford 1990).

METHODS-BIOGEOCHEMISTRY

Weighed subsamples were taken from regular intervals throughout the piston and Livingston cores for loss-on-ignition (LOI) analysis to determine dry density and weight percent organic, carbonate, and inorganic matter. Sediment subsamples were heated at 105ºC for 24 hr to determine dry density, then sequentially heated at 550°C and 1000°C to determine organic and carbonate content from post-ignition weight loss, respectively.

METHODS-DIATOM AND NUMERICAL ANALYSES

Fifteen core sections were prepared for diatom analysis (Table 2). Samples listed as pre-settlement have approximate dates based on extrapolation of the Pb-210 model below1886 by assuming a constant sediment accumulation rate prior to settlement.

Diatoms and chrysophyte cysts were prepared by placing approximately 0.25 cm^3 of homogenized sediment in a 50 cm^3 polycarbonate centrifuge tube, adding 2-5 drops of 10% v/v HCl solution to dissolve carbonates. Organic material was subsequently oxidized by adding 10 ml of 30% hydrogen peroxide and heating for 3 hours in a 85°C water bath. After cooling the samples were rinsed with distilled deionized water to remove oxidation biproducts. Aliquots of the remaining material, which contains the diatoms, were dried onto 22x22 mm #1 coverglasses, which were then permanently attached to microscope slides using Zrax mounting medium. Diatoms were identified along random transects to the lowest taxonomic level under 1250X magnification (full immersion optics of NA 1.4). A minimum of 400 valves was counted in each sample. Abundances are reported as percentage abundance relative to total diatom counts. Identification of diatoms used regional floras (e.g. Patrick and Reimer 1966, 1975, Edlund 1994, Camburn and Charles 2000) and primary literature to achieve consistent taxonomy.

Species present at greater than 1% relative abundance in two or more samples or at greater than 5% relative abundance in one sample were included in further analyses; the same selection criteria were used by Ramstack et al. (2003). Stratigraphies of subdominant diatoms were plotted again core date. Relationships among diatom communities within a sediment core were explored using Correspondence Analysis (CA), which available in the the software package R (Ihaka & Gentleman 1996).. Core depths/dates were plotted in ordinate space and their relationships and variability used to identify periods of change, sample groups, and ecological variability among core samples. A general rule for interpretting a CA is that samples that plot closer to one another have more similar assemblages.

Downcore diatom communties were also used to reconstruct historical epilimnetic phosphorus levels in Peltier Lake. A transfer function for reconstructing historical logTP was earlier developed based on the relationship between modern diatom communities and modern environmental variable in 89 Minnesota lakes (Edlund and Ramstack 2006) using weighted averaging (WA) regression with inverse deshrinking and bootstrap error estimation (C2 software; Juggins 2003). The strength of the transfer function was evaluated by calculating the squared correlation coefficient (r^2=0.83) and the root mean square error (RMSE=0.181) between the observed logTP with the model estimates of logTP for all samples. Bootstrapping is used in model validation to provide a more realistic error estimate (RMSEP, the root mean square error of prediction=0.208) because the same data are used to both generate and test the WA model (Fritz *et al.* 1999). Reconstructed estimates of logTP (diatom-inferred TP, or DI-TP) for each downcore sample were determined by taking the logTP optimum of each species, weighting it by its abundance in that sample, and determining the average of the combined weighted species optima. Reconstucted logTP values are plotted downcore and also backtransformed to TP in ppb. The error bars represent the root mean squared error of prediction (RMSEP, bootstrapped), i.e. the error of the model. In interpreting change in a reconstruction, we assign significance to changes that are greater than the RMSEP (Ramstack et al. 2003).

RESULTS & DISCUSSION-CORING, MAGNETIC SUSCEPTIBILITY AND CORE IMAGING

A 2.02 m long piston core and a 1.03 m long Livingston core were recovered from the south basin of Peltier Lake on October 30, 2006. Coring location and recovery details are provided in Table 1. Both the piston and Livingston cores were logged for magnetic susceptibility (Fig. 2), split, imaged, and described (Figs 1, 2). There was minimal color change or obvious stratigraphy in the core. The magnetic susceptibility analysis and imaging are performed on the intact portion of the core; therefore these data do not exist for the portions of the core that were field sectioned (top 50 cm of the piston core). There is a rise in magnetic susceptibility at the top of the Livingston core and in the corresponding bottom portion of the piston core, at approximately 190-200cm depth in the core (Fig. 2). An increase in magnetic susceptibility is often seen at the time of European settlement, when initial land clearance increased the amount of terrestrial-derived sediments to the lake.

RESULTS & DISCUSSION-BIOGEOCHEMISTRY

Sediments from Peltier Lake have historically been dominated by inorganics (Fig. 4). There is a distinct shift in the relative amounts of organic and inorganic material at about 190 cm in the core, which coincides with the rise in magnetic susceptibility. Based on the 210-Pb dating model, this change occurred at approximately 1890, which again suggests that this shift pre-dates damming of the system and more closely corresponds with initial settlement, land clearance, and the onset of agriculture.

RESULTS & DISCUSSION-DATING AND SEDIMENTATION

Peltier Lake showed a monotonic decrease in ^{210}Pb activity and reached supported levels below 160 cm core depth. Figure 3 show the unsupported lead-210 activity, the resulting lead-210 dating model, and the sediment accumulation rate for Peltier Lake. The lead-210 model dates the rise in magnetic susceptibility (approx. 190-200 cm) at about 1880-1890, which suggests that the rise in magnetics pre-dates damming of the system and is a result of initial land clearance in the area. Because of the very high sedimentation rates in Peltier Lake, levels of unsupported Pb-210 are diluted compared to lakes with more modest sedimentation rates, which leads to somewhat greater uncertainty in the dating models.

Sedimentation rates have not varied considerably in the recent history of Peltier Lake (Fig. 3). There is a period from 1900 through the 1940s that has slightly higher sedimentation rates in comparison to pre-damming and post-1940s levels. An initial peak in sedimentation (ca. 1910) may correspond to construction of the dam at Peltier's outlet. Increased water depth and inundation can both increase and shift depositional patterns in a reservoir.

RESULTS & DISCUSSION-DIATOM STRATIGRAPHY

The diatom communities can be separated into three zones in the core: 1. core bottom-1915, 2. 1939-1985, 3. 1985-2006 (Fig. 1). The diatom community has been continuously dominated by three species: *Aulacoseira granulata*, *A. ambigua*, and *Stephanodiscus niagarae* with several small *Stephanodiscus* species (Fig. 5). Zone 1 has high abundance of *Aulacoseira* species, a higher proportion of benthic/attached species, and many chrysophyte cysts. Zone 2 has lower abundance of *Aulacoseira* species and higher abundance of *Stephanodiscus niagarae, S. hantzschii*, and *S. parvus*. Zone 3 again has higher abundance of the *Aulacoseira* species, decreased abundance of several small *Stephanodiscus* spp., and increased abundance of several eutrophication indicators including *Fragilaria capucina* v. *mesolepta* and *S. hantzschii* f. *tenuis*. Overall, the species in the diatom community of Peltier Lake are indicative of eutrophy although some can also be found in mesotrophic systems (e.g. *Aulacoseira ambigua*, *Stephanodiscus niagarae*).

RESULTS & DISCUSSION-PHOSPHORUS RECONSTRUCTION

Downcore total phosphorus reconstructions (Fig. 6) show that Peltier Lake is currently hypereutrophic (>100 ppb TP). This increase in TP is coincident with the WWII-era biological change in Peltier Lake. Modern TP levels in Peltier Lake are often even higher than our reconstructed values (>150 ppb; Westrick pers. comm.). It is not possible to reconstruct TP values >200 ppb TP using our current calibration models and, at these extreme phosphorus levels, other abiotic gradients are controlling diatom abundances. Samples deposited previous to WWII, including presettlement, pre-damming, and immediate post damming samples, have diatom-inferred TP levels that are estimated from 60-80 ppb TP, i.e. Peltier Lake has long been a productive and eutrophic system, but was not historically hypereutrophic. Our two lowest samples (1840s) show spurious high TP reconstructions that are difficult to interpret. The diatom communities are clearly different than modern samples (higher benthics, higher c-cysts, Table 3), but are made up of the same three species that dominate the rest of the core. Given the shifts in magnetics and LOI during this time, it may be that Peltier Lake was a more hydrologically dynamic system (lake level changes) than we see in the dammed lake today. In interpreting change in a reconstruction, we assign significance to changes that are greater than the RMSEP (Ramstack et al. 2003). In the case of Peltier this condition is met when comparing the post settlement/immediate post damming nutrient levels with modern diatom-inferred levels in the lake.

CONCLUSION AND RECOMMENDATIONS

Based on diatom analysis, Peltier Lake has been a eutrophic system during pre-European settlement, post-Eurosettlement, pre-damming, and immediate post-damming with diatom-inferred TP levels of 60-80 ppb. A major ecological shift toward more eutrophic to hypertrophic conditions occurred in the 1940s as indicated by biological shifts and increased diatom-inferred TP levels (90-125 ppb TP). Other work to be considered on the Peltier core would include further confirmation of the dating model using pollen and/or 137-Cs. We could analyze diatoms in a sample from the 1920s to fill the gap where some of the major changes occurred. Pigment analysis may help clarify the onset of blue-green algal blooms and algal productivity. Biogenic silica analysis would also help us understand changes in historical algal productivity.

ACKNOWLEDGEMENTS

Todd Bentler (SCWRS) assisted with coring. Erin Mortenson and Dan Engstrom (SCWRS) performed loss-on-ignition and 210-Pb analysis. The University of Minnesota's Limnological Research Center and Anders Noren are acknowledged for coordinating magnetics logging and core scanning.

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TABLES

Table 1. Core type, date of collection, location, depth of sampling site, length of core recovered, and results of field sectioning.

Type of Core	Coring Date	Coring Location	Water Depth (m)	Core length (m)	Sediment depth (m)	Field sectioned (cm)
Piston	30X2006	45°10'37.1" N 93°03'31.3" W	4.73	2.02	0-2.02	50
Livingston	30X2006	45°10'37.1" N 93°03'31.3" W	4.73	1.03	1.82-2.85	--

Table 2. Samples prepped for diatom analysis.

Sample Depth (cm)	Lead-210 Date
2	2006
24	1996
38	1985
50	1976
60	1968
72	1957
84	1947
96	1939
120	1923
132	1915
144	1908
168	1896
184	1886
220	Pre-settlement (approx. 1862)
244	Pre-settlement (approx. 1847)
264	Pre-settlement (approx. 1834)

Table 3. Two indicators of eutrophication, planktonic to benthic diatom ratio (P:B) and the diatom to chrysophyte cyst ratio (diatom:cyst), suggest dramatic ecological changes occurred in Peltier Lake at about the time of WWII. These indicators suggest a response to changes in nutrient loading and a shift to more water column algal productivity.

Date	Depth (cm)	P:B	Diatom:cyst ratio
2006	0-2	10.3	35.7
1996	22-24	9.9	82.6
1985	36-38	10.2	46.0
1976	48-50	14.1	45.3
1968	58-60	12.4	59.3
1957	70-72	11.8	34.1
1947	82-84	17.7	31.7
1939	94-96	10.7	20.6
1915	130-132	4.0	13.8
1908	142-144	4.3	9.9
1896	166-168	5.4	4.1
1886	182-184	5.4	7.8
1862	218-220	2.5	2.3
1847	242-244	5.5	3.6
1840	250-252	10.3	9.3

FIGURES

Figure 1. Images of the piston and Livingston cores. The piston core image begins at 50cm because the top of the core was sectioned in the field.

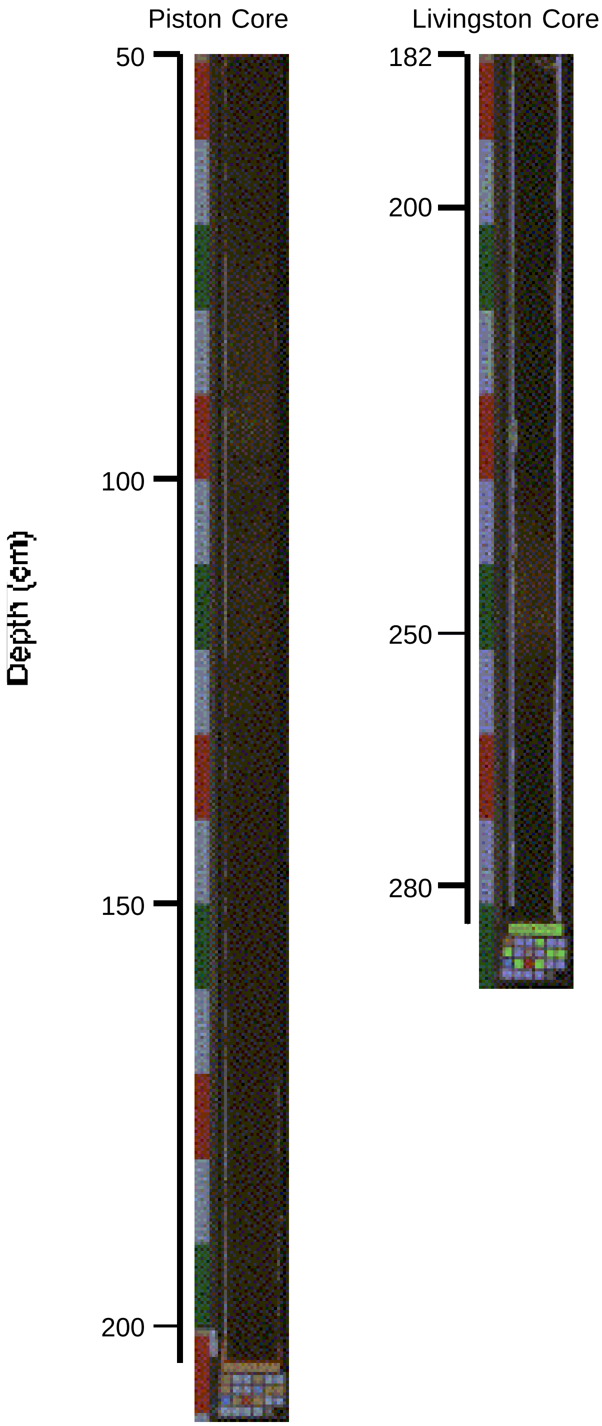


Figure 2. Magnetic susceptibility profiles from the piston and Livingston cores. Cores are overlapped during the coring process to insure a continuous sediment record is recovered.

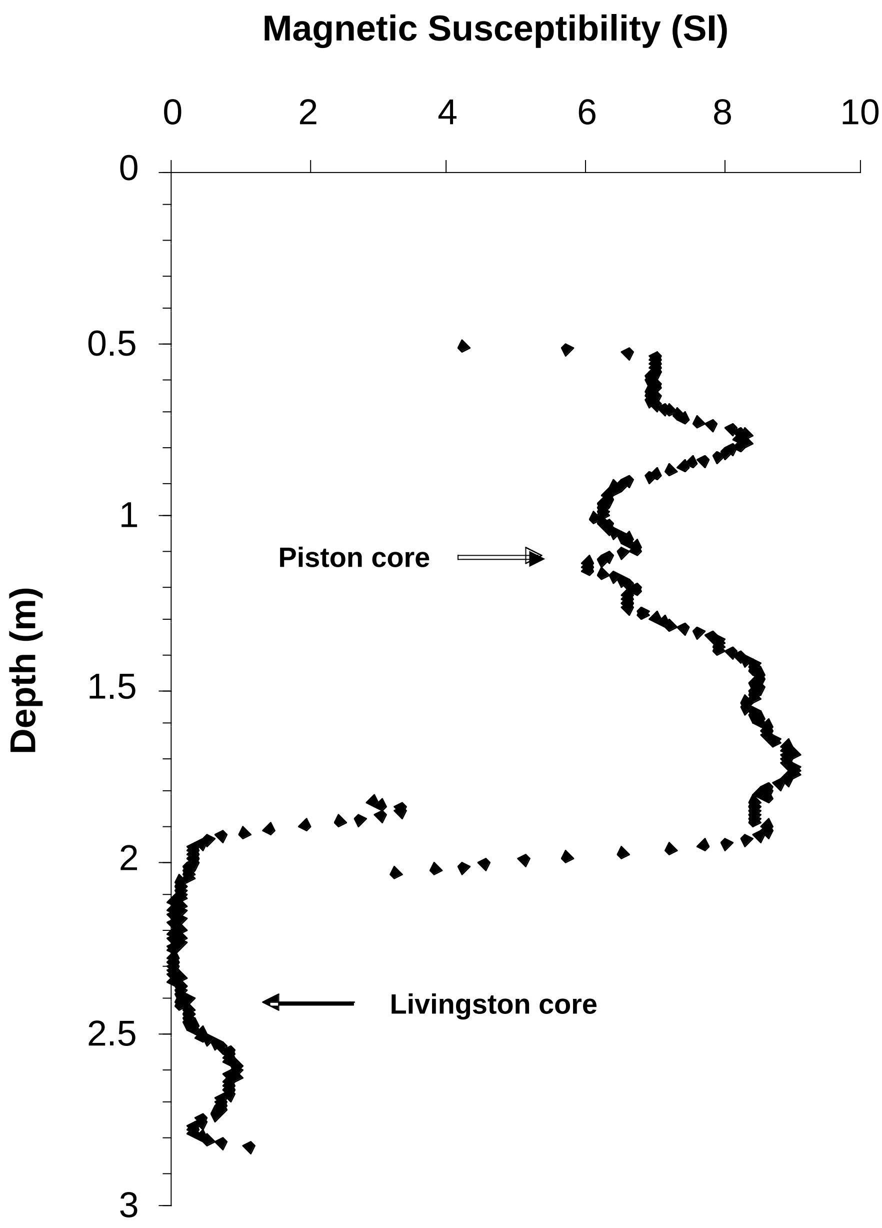


Figure 3. Unsupported lead-210 activity, resulting dating model, and sediment accumulation rate.

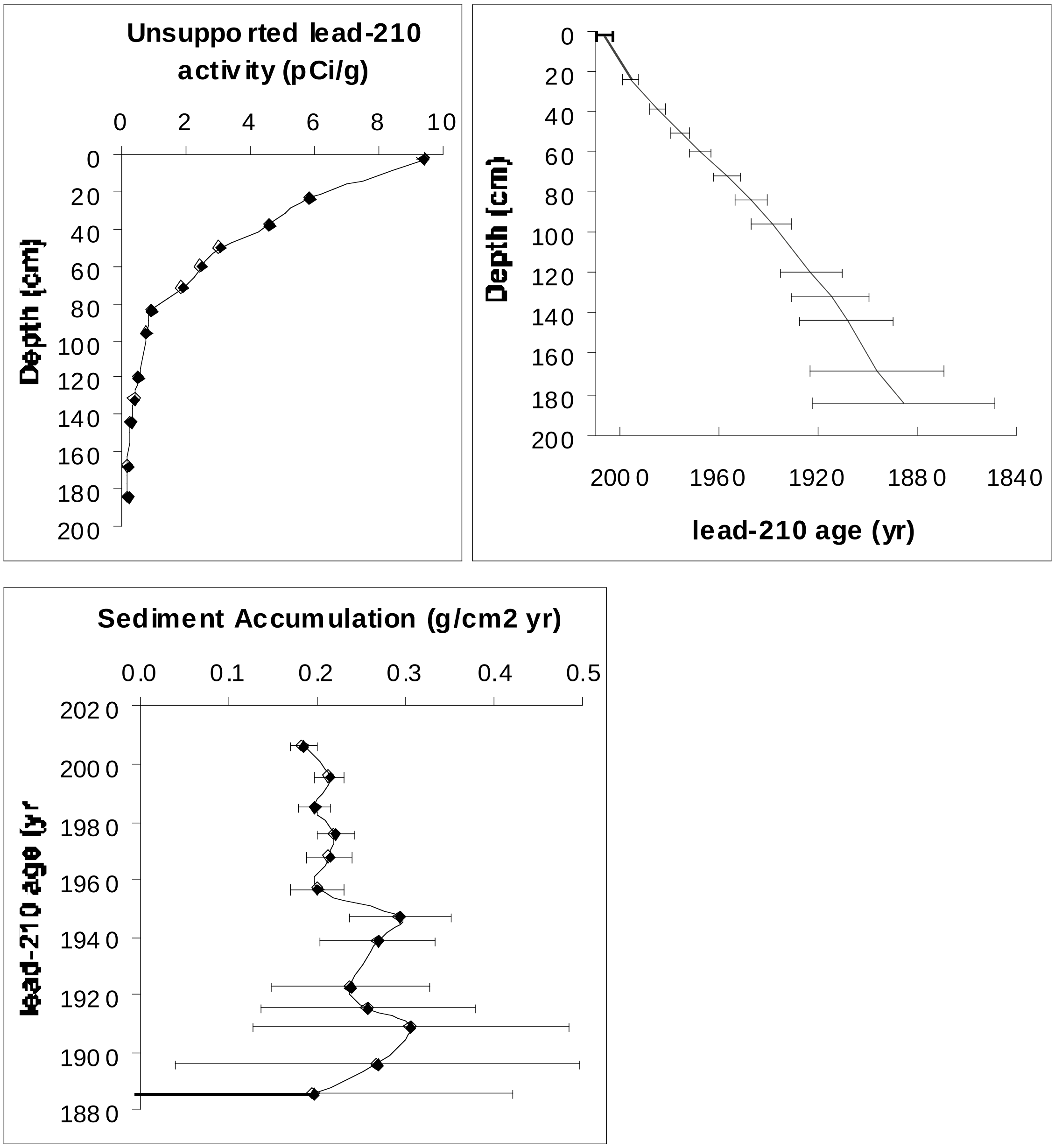
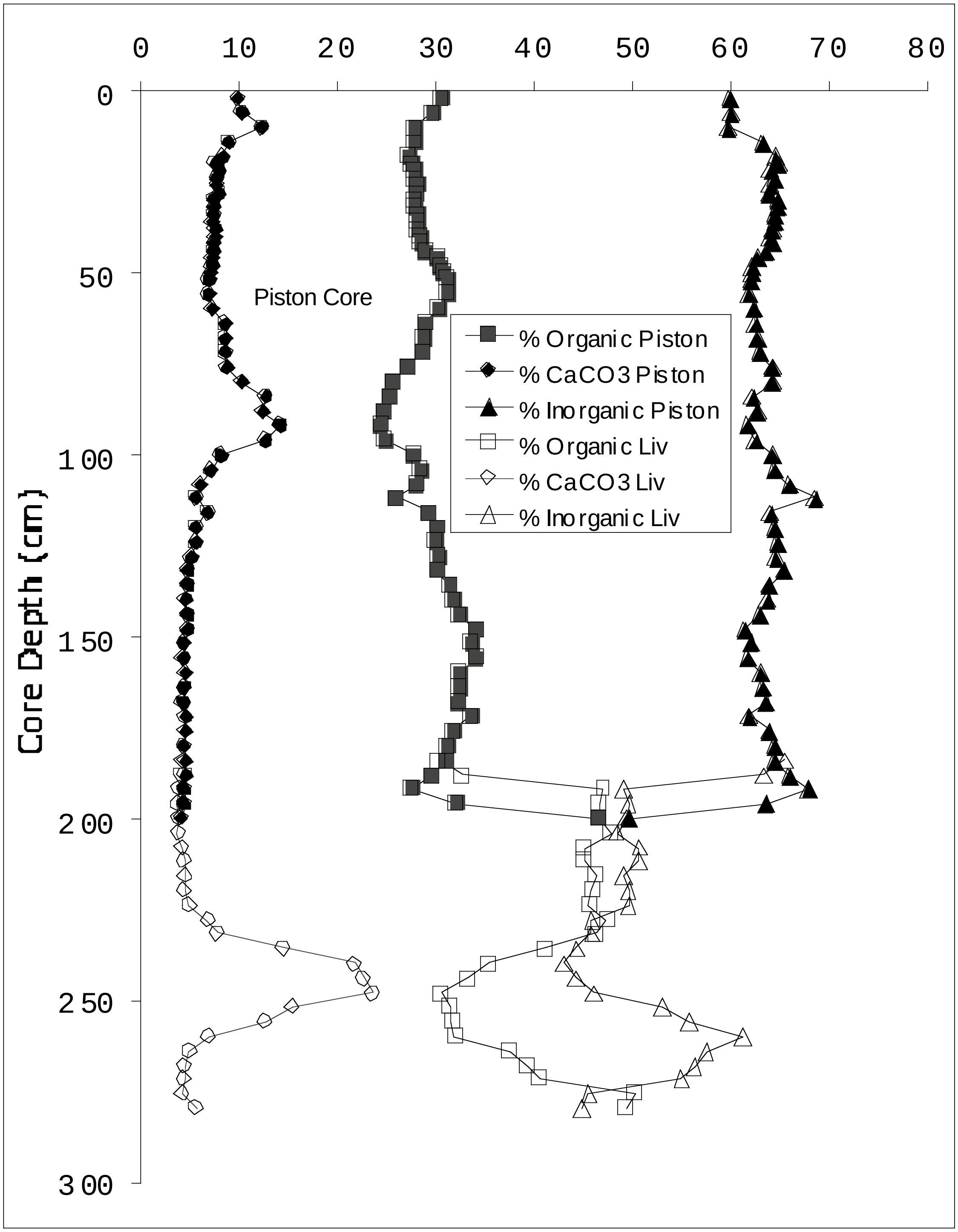


Figure 4. Percent concentration of organic, $CaCO_3$, and inorganic matter in the piston and Livingston cores.



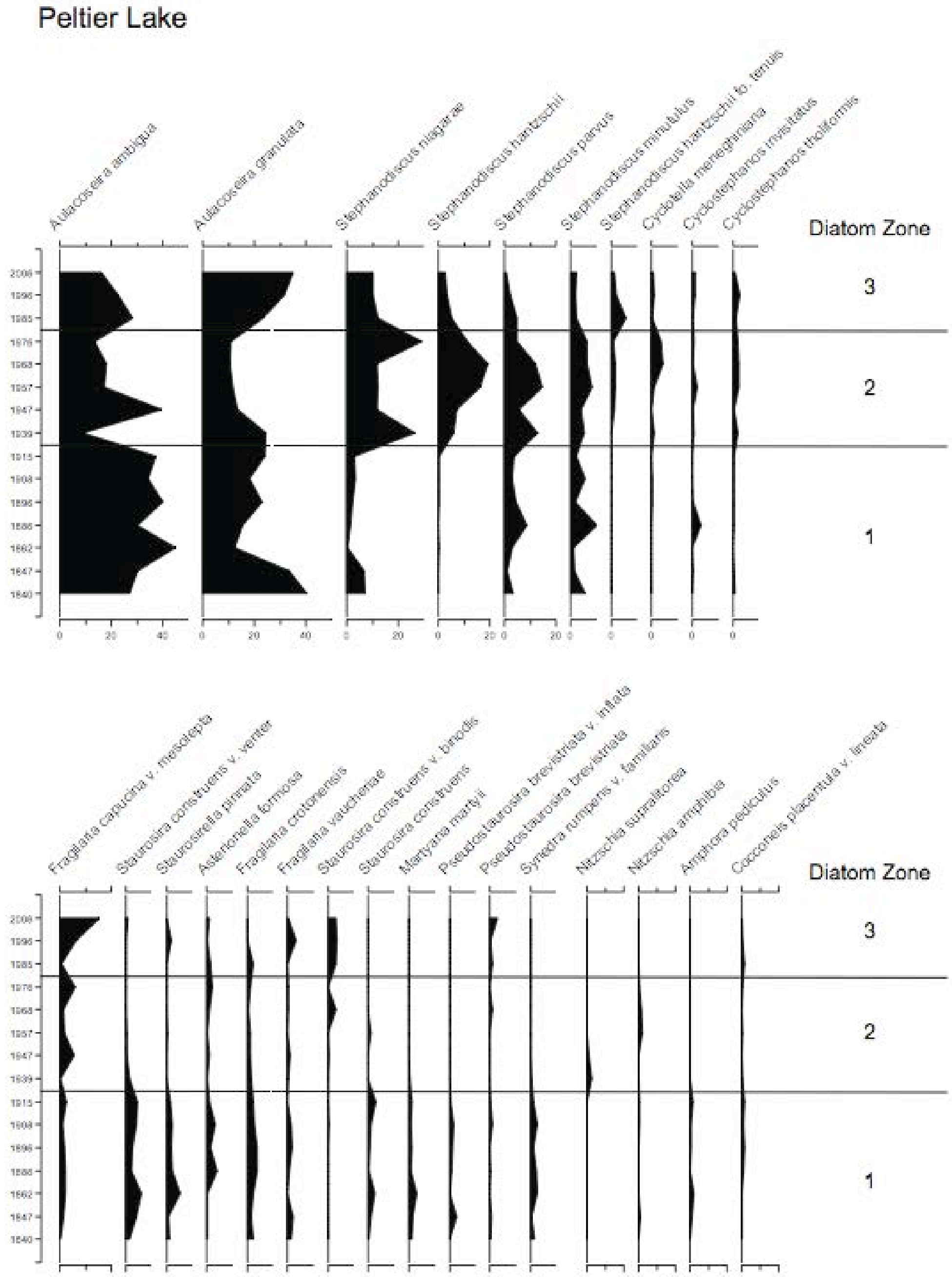


Fig. 5. Downcore stratigraphies for subdominant diatom taxa in Peltier Lake 1840-2006. Three stratigraphic zones identified using correspondence analysis are indicated with horizontal lines.

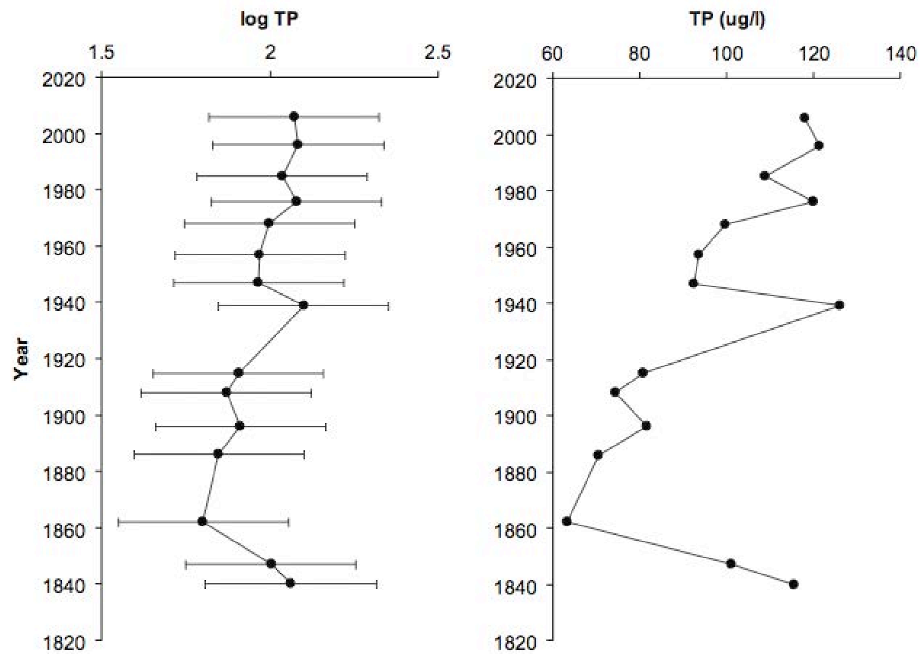


Fig. 6. Diatom-inferred total phosphorus reconstructions for Peltier Lake 1840-2006. Total phosphorus is reconstructed as log TP; error bars represent the bootstrapped root mean square error of prediction for the Minnesota lakes diatom calibration model. Peltier Lake is currently hypereutrophic (>100ppb TP). This increase in TP is coincident with the WWII-era biological change. Samples deposited previous to WWII, including presettlement, pre-damming, and immediate post damming samples, have diatom-inferred TP levels that are estimated from 60-80 ppb TP, i.e. Peltier Lake has long been a productive and eutrophic system, but was not historically hypereutrophic. Our two lowest samples (1840s) show spurious high TP reconstructions that are difficult to interpret (see text).

Appendix C. BATHTUB model inputs and outputs

2001 Calibration Input

Description:

June 1 - September 30, 2001
TP means
Chl medians (means were ~2x the medians, model calibrated much better to medians)

Global Variables	Mean	CV
Averaging Period (yrs)	0.33	0.0
Precipitation (m)	0.33	0.0
Evaporation (m)	0.34	0.0
Storage Increase (m)	-0.067	0.0

Atmos. Loads (kg/km^2-yr)	Mean	CV
Conserv. Substance	0	0.00
Total P	30	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	0	NONE
Error Analysis	1	MODEL & DATA
Availability Factors	1	USE FOR MODEL 1 ONLY
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	1	NOTEPAD

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Centerville Lake	2	2	2	3.7	1.5	3.6	0.12	0	0	0.3	0.53	0	0	0	0
2	Peltier	0	1	1.96	2.13	3.5	2.1	0.12	0	0	0.08	10.37	0	0	15	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean
1	0	0	46	0.14	0	0	28	0.08	1	0.15	0	0	0	0	0	0	0
2	0	0	295	0.26	0	0	81	0.35	0.51	0.22	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean
1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
2	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Upper Rice Creek	2	1	81	10.8	0	0	0	219	0.21	0	0	0	0	0	0
2	Hardwood Creek	2	1	65	9.8	0	0	0	268	0.09	0	0	0	0	0	0
3	Clearwater Creek	2	1	114	7.7	0	0	0	169	0.1	0	0	0	0	0	0
4	Peltier Direct	2	1	10	0.582	0	0	0	219	0	0	0	0	0	0	0
5	Centerville direct	1	1	1.89	0.226	0	0	0	222	0	0	0	0	0	0	0

Model Coefficients	Mean	CV
Dispersion Rate	0.002	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

2001 Calibration Output

Component:		TOTAL P	Segment:		1	Centerville Lake	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
5	1	Centerville direct	0.2	10.2%	50.2	24.3%	222
PRECIPITATION			2.0	89.8%	60.0	29.1%	30
TRIBUTARY INFLOW			0.2	10.2%	50.2	24.3%	222
NET DIFFUSIVE INFLOW			0.0	0.0%	96.1	46.6%	
***TOTAL INFLOW			2.2	100.0%	206.3	100.0%	93
ADVECTIVE OUTFLOW			0.6	25.7%	27.4	13.3%	48
***TOTAL OUTFLOW			0.6	25.7%	27.4	13.3%	48
***EVAPORATION			2.1	92.6%	0.0	0.0%	
***STORAGE INCREASE			-0.4	-18.2%	-19.5	-9.5%	48
***RETENTION			0.0	0.0%	198.3	96.1%	

Hyd. Residence Time = 44.7416 yrs
Overflow Rate = 0.1 m/yr
Mean Depth = 3.7 m

Component:		TOTAL P	Segment:		2	Peltier	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Upper Rice Creek	10.8	34.4%	2365.2	13.7%	219
2	1	Hardwood Creek	9.8	31.2%	2626.4	15.2%	268
3	1	Clearwater Creek	7.7	24.5%	1301.3	7.5%	169
4	1	Peltier Direct	0.6	1.9%	127.5	0.7%	219
PRECIPITATION			2.0	6.2%	58.8	0.3%	30
INTERNAL LOAD			0.0	0.0%	10738.4	62.3%	
TRIBUTARY INFLOW			28.9	91.9%	6420.4	37.2%	222
ADVECTIVE INFLOW			0.6	1.8%	27.4	0.2%	48
***TOTAL INFLOW			31.4	100.0%	17245.0	100.0%	549
ADVECTIVE OUTFLOW			29.8	94.8%	8510.1	49.3%	286
NET DIFFUSIVE OUTFLOW			0.0	0.0%	96.1	0.6%	
***TOTAL OUTFLOW			29.8	94.8%	8606.2	49.9%	289
***EVAPORATION			2.0	6.4%	0.0	0.0%	
***STORAGE INCREASE			-0.4	-1.3%	-113.7	-0.7%	286
***RETENTION			0.0	0.0%	8752.4	50.8%	

Hyd. Residence Time = 0.1420 yrs
Overflow Rate = 15.0 m/yr
Mean Depth = 2.1 m

2004 Validation Input

Description:

June - September
chl medians
TP and Secchi means

Global Variables	Mean	CV
Averaging Period (yrs)	0.33	0.0
Precipitation (m)	0.31	0.0
Evaporation (m)	0.34	0.0
Storage Increase (m)	-0.283	0.0

Atmos. Loads (kg/km^2-yr)	Mean	CV
Conserv. Substance	0	0.00
Total P	30	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	0	NONE
Error Analysis	1	MODEL & DATA
Availability Factors	1	USE FOR MODEL 1 ONLY
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	1	NOTEPAD

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P	
Seq	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Centerville Lake	2	2	2	3.7	1.5	3.6	0.12	0	0	0.63	0.25	0	0	0	0
2	Peltier	0	1	1.96	2.13	3.5	2.1	0.12	0	0	1.45	0.27	0	0	15	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppt
Seq	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean
1	0	0	55	0.15	0	0	25	0.15	0.9	0.1	0	0	0	0	0	0	0
2	0	0	224	0.14	0	0	31	0.34	0.9	0.13	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppt
Seq	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean
1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
2	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Upper Rice Creek	2	1	81	16.1	0	0	0	220	0.21	0	0	0	0	0	0
2	Hardwood Creek	2	1	65	9.4	0	0	0	276	0.1	0	0	0	0	0	0
3	Clearwater Creek	2	1	114	5.6	0	0	0	162	0.39	0	0	0	0	0	0
4	Peltier Direct	2	1	10	0.703	0	0	0	219	0	0	0	0	0	0	0
5	Centerville direct	1	1	1.89	0.273	0	0	0	222	0	0	0	0	0	0	0

Model Coefficients	Mean	CV
Dispersion Rate	0.002	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

2004 Validation Output

Component: **TOTAL P** **Segment:** **1** **Centerville Lake**

Trib	Type	Location	Flow hm^3/yr	Flow %Total	Load kg/yr	Load %Total	Conc mg/m^3
5	1	Centerville direct	0.3	12.7%	60.6	27.4%	222
PRECIPITATION			1.9	87.3%	60.0	27.1%	32
TRIBUTARY INFLOW			0.3	12.7%	60.6	27.4%	222
NET DIFFUSIVE INFLOW			0.0	0.0%	100.4	45.4%	
***TOTAL INFLOW			2.2	100.0%	221.0	100.0%	103
ADVECTIVE OUTFLOW			1.8	83.9%	90.8	41.1%	50
***TOTAL OUTFLOW			1.8	83.9%	90.8	41.1%	50
***EVAPORATION			2.1	95.8%	0.0	0.0%	
***STORAGE INCREASE			-1.7	-79.7%	-86.2	-39.0%	50
***RETENTION			0.0	0.0%	216.4	97.9%	

Hyd. Residence Time = 81.1565 yrs
Overflow Rate = 0.0 m/yr
Mean Depth = 3.7 m

Component: **TOTAL P** **Segment:** **2** **Peltier**

Trib	Type	Location	Flow hm^3/yr	Flow %Total	Load kg/yr	Load %Total	Conc mg/m^3
1	1	Upper Rice Creek	16.1	45.4%	3542.0	19.6%	220
2	1	Hardwood Creek	9.4	26.5%	2594.4	14.3%	276
3	1	Clearwater Creek	5.6	15.8%	907.2	5.0%	162
4	1	Peltier Direct	0.7	2.0%	154.0	0.9%	219
PRECIPITATION			1.8	5.2%	58.8	0.3%	32
INTERNAL LOAD			0.0	0.0%	10738.4	59.4%	
TRIBUTARY INFLOW			31.8	89.7%	7197.6	39.8%	226
ADVECTIVE INFLOW			1.8	5.1%	90.8	0.5%	50
***TOTAL INFLOW			35.5	100.0%	18085.5	100.0%	510
ADVECTIVE OUTFLOW			35.1	99.0%	9753.3	53.9%	278
NET DIFFUSIVE OUTFLOW			0.0	0.0%	100.4	0.6%	
***TOTAL OUTFLOW			35.1	99.0%	9853.7	54.5%	281
***EVAPORATION			2.0	5.7%	0.0	0.0%	
***STORAGE INCREASE			-1.7	-4.7%	-466.9	-2.6%	278
***RETENTION			0.0	0.0%	8698.7	48.1%	

Hyd. Residence Time = 0.1249 yrs
Overflow Rate = 17.1 m/yr
Mean Depth = 2.1 m

TMDL Scenario: State Eutropication Standards Input

Description:

June 1 - September 30, 2001
TP means
Chl medians (means were ~2x the medians, model calibrated much better to medians)

Eutrophication std of 60 ug/L

Global Variables	Mean	CV
Averaging Period (yrs)	0.33	0.0
Precipitation (m)	0.33	0.0
Evaporation (m)	0.34	0.0
Storage Increase (m)	-0.067	0.0

Atmos. Loads (kg/km^2-yr)	Mean	CV
Conserv. Substance	0	0.00
Total P	30	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	0	NONE
Error Analysis	1	MODEL & DATA
Availability Factors	1	USE FOR MODEL 1 ONLY
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	1	NOTEPAD

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Centerville Lake	2	2	2	3.7	1.5	3.6	0.12	0	0	0.3	0.53	0	0	0	0
2	Peltier	0	1	1.96	2.13	3.5	2.1	0.12	0	0	0.08	10.37	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppt
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean
1	0	0	46	0.14	0	0	28	0.08	1	0.15	0	0	0	0	0	0	0
2	0	0	295	0.26	0	0	81	0.35	0.51	0.22	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppt
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean
1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
2	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Upper Rice Creek	2	1	81	10.8	0	0	0	85	0.21	0	0	0	0	0	0
2	Hardwood Creek	2	1	65	9.8	0	0	0	85	0.09	0	0	0	0	0	0
3	Clearwater Creek	2	1	114	7.7	0	0	0	85	0.1	0	0	0	0	0	0
4	Peltier Direct	2	1	10	0.582	0	0	0	85	0	0	0	0	0	0	0
5	Centerville direct	1	1	1.89	0.226	0	0	0	222	0	0	0	0	0	0	0

Model Coefficients	Mean	CV
Dispersion Rate	0.002	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

TMDL Scenario: State Eutropication Standards Output

Component:		TOTAL P		Segment:	1	Centerville Lake	
			Flow	Flow	Load	Load	Conc
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
5	1	Centerville direct	0.2	10.2%	50.2	40.9%	222
PRECIPITATION			2.0	89.8%	60.0	48.9%	30
TRIBUTARY INFLOW			0.2	10.2%	50.2	40.9%	222
NET DIFFUSIVE INFLOW			0.0	0.0%	12.6	10.3%	
***TOTAL INFLOW			2.2	100.0%	122.8	100.0%	55
ADVECTIVE OUTFLOW			0.6	25.7%	16.3	13.3%	29
***TOTAL OUTFLOW			0.6	25.7%	16.3	13.3%	29
***EVAPORATION			2.1	92.6%	0.0	0.0%	
***STORAGE INCREASE			-0.4	-18.2%	-11.6	-9.5%	29
***RETENTION			0.0	0.0%	118.1	96.1%	

Hyd. Residence Time =	44.7416	yrs
Overflow Rate =	0.1	m/yr
Mean Depth =	3.7	m

Component:		TOTAL P		Segment:	2	Peltier	
			Flow	Flow	Load	Load	Conc
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
1	1	Upper Rice Creek	10.8	34.4%	918.0	36.3%	85
2	1	Hardwood Creek	9.8	31.2%	833.0	32.9%	85
3	1	Clearwater Creek	7.7	24.5%	654.5	25.9%	85
4	1	Peltier Direct	0.6	1.9%	49.5	2.0%	85
PRECIPITATION			2.0	6.2%	58.8	2.3%	30
TRIBUTARY INFLOW			28.9	91.9%	2455.0	97.0%	85
ADVECTIVE INFLOW			0.6	1.8%	16.3	0.6%	29
***TOTAL INFLOW			31.4	100.0%	2530.1	100.0%	81
ADVECTIVE OUTFLOW			29.8	94.8%	1780.8	70.4%	60
NET DIFFUSIVE OUTFLOW			0.0	0.0%	12.6	0.5%	
***TOTAL OUTFLOW			29.8	94.8%	1793.5	70.9%	60
***EVAPORATION			2.0	6.4%	0.0	0.0%	
***STORAGE INCREASE			-0.4	-1.3%	-23.8	-0.9%	60
***RETENTION			0.0	0.0%	760.4	30.1%	

Hyd. Residence Time =	0.1420	yrs
Overflow Rate =	15.0	m/yr
Mean Depth =	2.1	m

TMDL Scenario: Natural Background Condition (Peltier) and State Standards (Centerville) Input

Description:

June 1 - September 30, 2001
TP means
Chl medians (means were ~2x the medians, model calibrated much better to medians)

Natural background conditions std

Global Variables	Mean	CV
Averaging Period (yrs)	0.33	0.0
Precipitation (m)	0.33	0.0
Evaporation (m)	0.34	0.0
Storage Increase (m)	-0.067	0.0

Atmos. Loads (kg/km^2-yr)	Mean	CV
Conserv. Substance	0	0.00
Total P	30	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	0	NONE
Error Analysis	1	MODEL & DATA
Availability Factors	1	USE FOR MODEL 1 ONLY
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	1	NOTEPAD

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Centerville Lake	2	2	2	3.7	1.5	3.6	0.12	0	0	0.3	0.53	0	0	0	0
2	Peltier	0	1	1.96	2.13	3.5	2.1	0.12	0	0	0.08	10.37	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppt
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean
1	0	0	46	0.14	0	0	28	0.08	1	0.15	0	0	0	0	0	0	0
2	0	0	295	0.26	0	0	81	0.35	0.51	0.22	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppt
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean
1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
2	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Upper Rice Creek	2	1	81	10.8	0	0	0	120	0.21	0	0	0	0	0	0
2	Hardwood Creek	2	1	65	9.8	0	0	0	120	0.09	0	0	0	0	0	0
3	Clearwater Creek	2	1	114	7.7	0	0	0	120	0.1	0	0	0	0	0	0
4	Peltier Direct	2	1	10	0.582	0	0	0	120	0	0	0	0	0	0	0
5	Centerville direct	1	1	1.89	0.226	0	0	0	222	0	0	0	0	0	0	0

Model Coefficients	Mean	CV
Dispersion Rate	0.002	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

TMDL Scenario: Natural Background Condition (Peltier) and State Standards (Centerville) Output

Component: TOTAL P — **Segment: 1 Centerville Lake**

Trib	Type	Location	Flow hm^3/yr	Flow %Total	Load kg/yr	Load %Total	Conc mg/m^3
5	1	Centerville direct	0.2	10.2%	50.2	38.6%	222
PRECIPITATION			2.0	89.8%	60.0	46.1%	30
TRIBUTARY INFLOW			0.2	10.2%	50.2	38.6%	222
NET DIFFUSIVE INFLOW			0.0	0.0%	19.9	15.3%	
***TOTAL INFLOW			2.2	100.0%	130.1	100.0%	58
ADVECTIVE OUTFLOW			0.6	25.7%	17.3	13.3%	30
***TOTAL OUTFLOW			0.6	25.7%	17.3	13.3%	30
***EVAPORATION			2.1	92.6%	0.0	0.0%	
***STORAGE INCREASE			-0.4	-18.2%	-12.3	-9.5%	30
***RETENTION			0.0	0.0%	125.1	96.1%	

Hyd. Residence Time = 44.7416 yrs
Overflow Rate = 0.1 m/yr
Mean Depth = 3.7 m

Component: TOTAL P — **Segment: 2 Peltier**

Trib	Type	Location	Flow hm^3/yr	Flow %Total	Load kg/yr	Load %Total	Conc mg/m^3
1	1	Upper Rice Creek	10.8	34.4%	1296.0	36.6%	120
2	1	Hardwood Creek	9.8	31.2%	1176.0	33.2%	120
3	1	Clearwater Creek	7.7	24.5%	924.0	26.1%	120
4	1	Peltier Direct	0.6	1.9%	69.8	2.0%	120
PRECIPITATION			2.0	6.2%	58.8	1.7%	30
TRIBUTARY INFLOW			28.9	91.9%	3465.8	97.9%	120
ADVECTIVE INFLOW			0.6	1.8%	17.3	0.5%	30
***TOTAL INFLOW			31.4	100.0%	3542.0	100.0%	113
ADVECTIVE OUTFLOW			29.8	94.8%	2372.1	67.0%	80
NET DIFFUSIVE OUTFLOW			0.0	0.0%	19.9	0.6%	
***TOTAL OUTFLOW			29.8	94.8%	2392.0	67.5%	80
***EVAPORATION			2.0	6.4%	0.0	0.0%	
***STORAGE INCREASE			-0.4	-1.3%	-31.7	-0.9%	80
***RETENTION			0.0	0.0%	1181.6	33.4%	

Hyd. Residence Time = 0.1420 yrs
Overflow Rate = 15.0 m/yr
Mean Depth = 2.1 m

Appendix D. In-Lake Management Techniques

In-Lake Management Techniques

BMP	Pros	Cons	Comments
Alum			
• In-lake (water column stripping and sediment inactivation)	- Rapid short-term improvement in water column and sediment P - Proven longevity (usually over 10 years) - Can be used for water column and/or bottom sediment sealing - Al-bound P not biologically available even under anoxic conditions - Secondary metal binding in sediment possible - Application technology can assure optimum conditions - P binds tightly to Al salts over a wide range of ecological conditions, including low or zero dissolved oxygen	- Potential Al (+3) toxicity and ineffectiveness if not applied at proper dose and pH - External load must be reduced or alum layer will be covered with new source of sediment P - Deep floc layer could have effect on benthos and floc can effect fish gill membranes - Possible application difficulties in shallow lakes with dense macrophytes - Increased clarity could lead to more macrophyte growth - Not appropriate for high alkalinity lakes	Cost approximately \$400-\$1,200 per acre of surface application Welch and Cooke for 2002 dollars = \$560/ha (~\$230/a) Recommend never use without watershed load reduction
• Inflow (interception)	- Possible BMP when watershed treatments need time or are too costly - Can be combined with in-lake treatment as P reduction strategy	- Floc settling area needed - Cost for installation and annual operation can be high - Commits watershed manager to chemical system until other watershed BMPs implemented - Increased clarity could lead to more macrophyte growth	Could be costly for set-up and annual chemicals and maintenance

Ferric Chloride	- 52-84% inflowing P reduction at Tanners Lake - Both Fish Lake and Tanners Lake showed improvement after installation of inflow treatment system - Fe not as toxic as Al	- Must expose large portion of lake inflow to treatment - P can release from sediment under anoxic conditions so aeration must be continued indefinitely	
Ca-hydroxide	- Good for treatment of relatively hard water, shallow lakes	- Not proven effective for Long Lake Chain of Lakes implementation - Effectiveness only shown for short-term (~2 years)	
Drawdown	- Consolidates and oxygenates sediment - Can be effective in reducing the growth of rooted aquatic plants, enhancing the consolidation of lake bottom sediments, expanding the oxidation of organic bottom sediments in these shallow areas, and concentrating fish into deeper portions of the lake for further management	- Could result in loss of macrophytes, and erosion of fines and organic content - Disruptive to natural cycles - Can introduce more light and heat to deeper lakes (promote algal growth) - Might promote rapid establishment of resistant macrophyte species	Recommend to be completed in the winter and consists of drawing the water levels within the lake down four to six feet, and allowing the sediments in the shallower areas to freeze, consolidate, and decompose under significantly different conditions than those present in the lake when they are under water; water levels would be allowed to rebound to previous levels in the spring following this treatment

Biomanipulation ("trophic cascade")	- A method of physically manipulating the biology of the lake (fish species, plant species, etc.) in an effort to alter the food web and ultimately address water quality problems - Based on the prediction that increased piscivore abundance will result in decreased planktivore abundance, increased zooplankton abundance, and increased zooplankton grazing pressure leading to reductions in phytoplankton abundance and improved water clarity	- Influenced by many factors and can be risky, especially if rough fish present in large numbers - Results might take time to see - Increased clarity could lead to more macrophyte growth - Must be accompanied with external load reductions	Sound ecological approach but subject to many variables
Macrophyte Control (predominantly invasive plant reduction)	- Rooted macrophytes can reduce turbulent mixing and sediment re-suspension, and increase sedimentation rates - Macrophyte beds provide shelter for zooplankton, as well as fish and macroinvertebrates - Macrophyte beds increase spatial and temporal temperature heterogeneity of the aquatic habitat	- Macrophyte beds in shallow lakes can prevent mixing and aeration - Effective control of invasive macrophytes usually involves chemical use - Physical control can lead to spread of invasives (ex. curly-leaf pondweed turion release)	

Macrophyte Harvesting	- Provides immediate solution to macrophyte problem in non-chemical manner	- Needed frequently; not a systemic approach - Can lead to spreading of invasives	
Hypolimnetic Withdrawal	- Removes hypolimnetic water with high probable TP and low (or no) oxygen content - Can be low energy, unobtrusive approach to lake P reduction	- Can send TP problem downstream also with likely DO depression (possibly mitigated by aerated outlet) - Limited value in shallow, polymictic lakes - High levels of other pollutants like ammonia, Fe and Mn sent downstream - Has potential to lower water level and warm lake through removal of colder bottom water	
Barley Straw	- Low cost, low tech, “natural” approach	- Experimental - Must be well oxygenated water - Affect on West Nile Virus via straw ??	Limited results to show good level of performance over long-term
Sediment Removal (dredging)	- Effective way to remove P-laden, oxygen demanding sediment - Can be combined with drawdown project - Remove organic sediments and return bottom to natural conditions - Can be used for control of rooted macrophytes	- Much more costly than most other methods (30x alum) - Can be only short-term effectiveness	Cost ~ \$18,000/ha (~\$7,300/a) in 2005

	- Can be a routine function to remove sediment deltas at inflow points		
Rough Fish (carp and bullheads) Exclusion	- Can be major bioturbation factor reduced - Removal of these fish can decrease turbidity and resuspension of bottom sediments which can decrease phosphorus sediment release - Rough fish can be removed selectively by commercial fisherman or through chemical means (rotenone)	- Difficult to get full removal for LT; removal every other year can be a solution - Problem will return unless a long-term solution, such as a fish barrier, is installed	Exclusion of carp (ref. in Kelton and Chow-Fraser) can reduce turbidity and nutrients up to 45%
Artificial Hypolimnetic Aeration (pumping of oxygen)	- Can facilitate mixing and relieve effects of anoxia - Oxygenated environment reduces the amount of nutrients that are released into the water column from the bottom sediments of the lake	- Energy intensive - Can be only locally effective if not properly sized	
Shoreline Buffers/Protection	- Improves habitat	- Limited (albeit positive) water quality improvement potential	
Water Level Fluctuation	- Can be used to synthesize natural ecologic conditions	- Not applicable to all lake situations - Exposure of shallow sediment could trigger homeowner disagreement with approach - Requires controllable outlet and active management	

Algaecide and Herbicide	- Can be used to effectively kill algae and rooted aquatic plants in a lake - Can be targeted to small areas	- Treatment is required annually - Due to the use of chemicals, has some limited potential environmental side effects	
Rotenone	- Commonly used pesticide to eradicate unbalanced or nuisance fish populations - Opens the door to introduction of new fish in a more desirable combination	- Is not species-specific so all fish are killed - Can be costly	
Reverse aeration	- Under ice method wherein aerator turned on after thick ice cover developed to bring anoxic water from the bottom throughout the entire water column to starve fish of oxygen	- Not commonly used method - Fish trapped under the ice? - Is DO low enough to kill rough fish or will they selectively survive if DO is not low enough?	- Need to hear some first-hand experience from locations where it's been tried