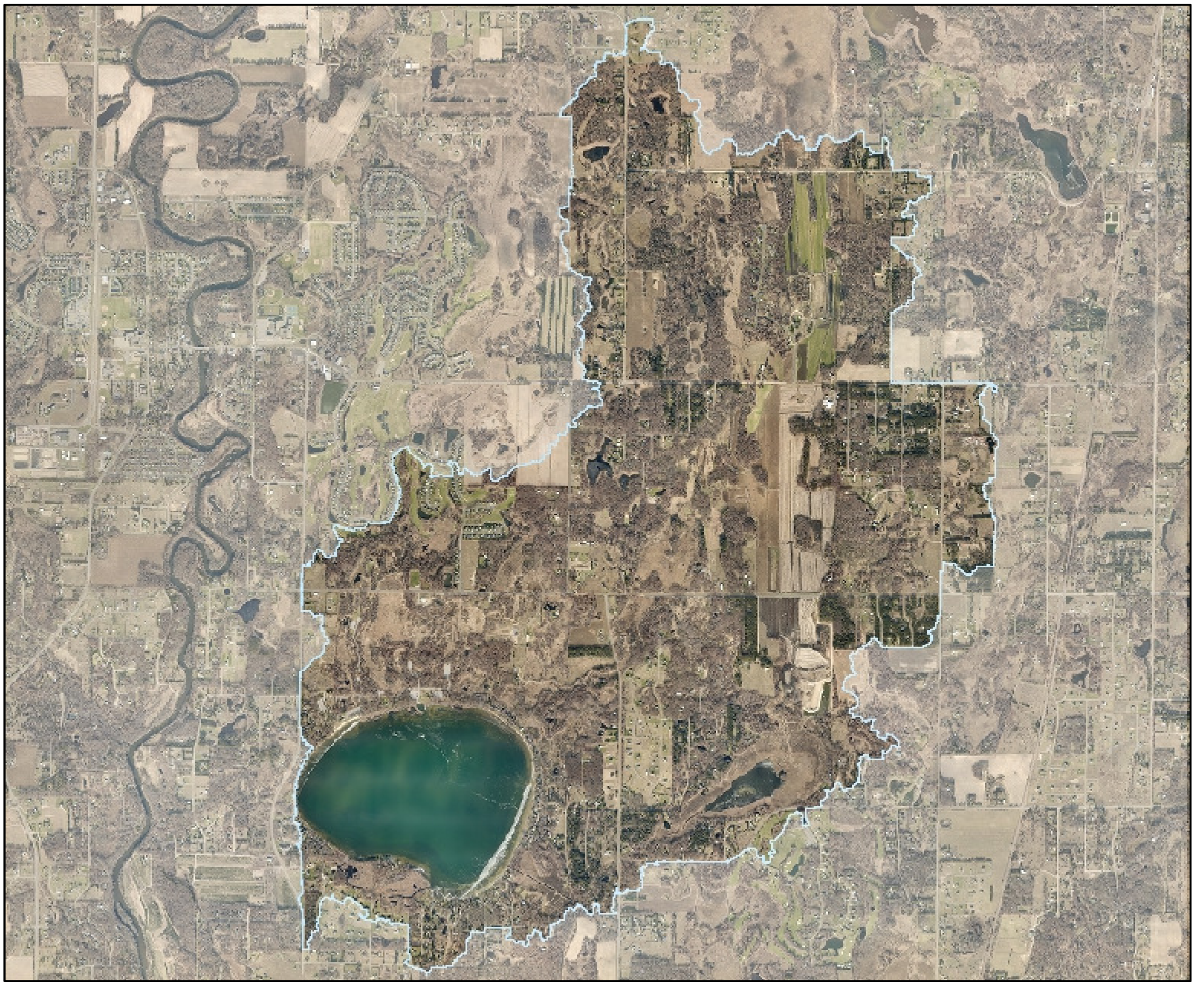


Lake George Water Quality Improvement Assessment

Phase 1: Lakeshed Analysis

Prepared by:

ANOKA CONSERVATION DISTRICT

for the

LAKE GEORGE IMPROVEMENT DISTRICT (LGID) AND

LAKE GEORGE CONSERVATION CLUB

CLEAN WATER LAND & LEGACY AMENDMENT

Partial funding provided by the Clean Water Fund (from the Clean Water, Land, and Legacy Amendment).

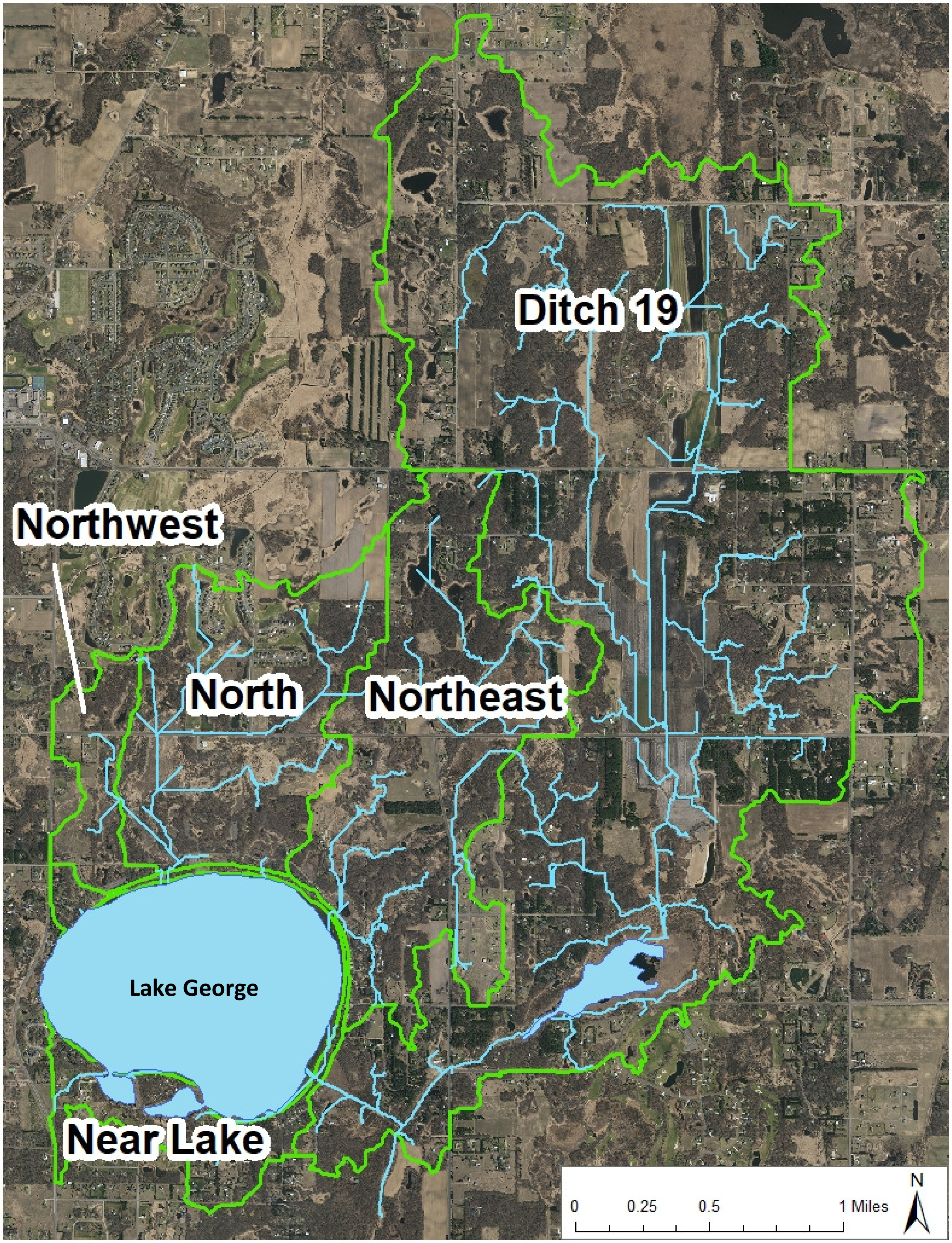
December 2018

Cover Photo: Lake George area 2017 aerial photograph

Contents

Figures and Tables

Lake George lakeshed map with subwatersheds referred to in this report



Executive Summary

This two-part study of the Lake George lakeshed is aimed at determining the causes of, and potential solutions to, declining water clarity in Lake George. In this report are the results of monitoring and modeling of the lakeshed that lend insight into causes of declining water clarity, and actions to address that problem. Actions are ranked by their cost effectiveness at reducing nutrient loading to the lake. It is anticipated that phase 2 of this study analyzing in-lake and near-lake factors will follow in the coming years. Watershed managers and cities should use this report to guide lake water quality improvement efforts.

The first part of this study included two years of water quality and hydrology monitoring of direct drainages to Lake George. Those data informed the development of two computer models of the lakeshed, a P8 urban catchment model for water quality analysis and a Storm Water Management Model (SWMM) for hydrology analysis. These models were used to determine the lake's nutrient and water budgets, and the effects of changes within the lakeshed. These efforts helped determine drivers of lake water quality decline. Findings of monitoring and modeling included:

- Lake water quality has shown a decline since 1998 (20-year trend). Lake transparency has declined and phosphorus concentrations have increased. Both are slow incremental changes that are statistically significant.
- The lake's five subwatersheds deliver varying amounts of phosphorus to the lake. In order of most to least they are: Ditch 19, northeast, north, near lake, and northwest subwatersheds. Substantial amounts of pollutants generated in the Ditch 19 subwatershed are removed by Grass Lake, which serves as a filter or settling basin. While near lake pollutant loading is amongst the lowest in total, it is the highest on a per-acre basis and deserves attention because pollutants generated there go directly into the lake, not into wetlands that may offer some filtering.
- A cause of water quality decline is more frequent wet years driving increased runoff to the lake. Among the sources of phosphorus are large wetland complexes, which drain to the lake more during months or years of high precipitation.
- Anticipated future land use changes could significantly increase nutrient loading to the lake.
- A shifting aquatic plant community in the lake may be destabilizing shallow lake sediments and increasing phosphorus concentrations in the lake by replacing once abundant native pondweeds with invasive species.

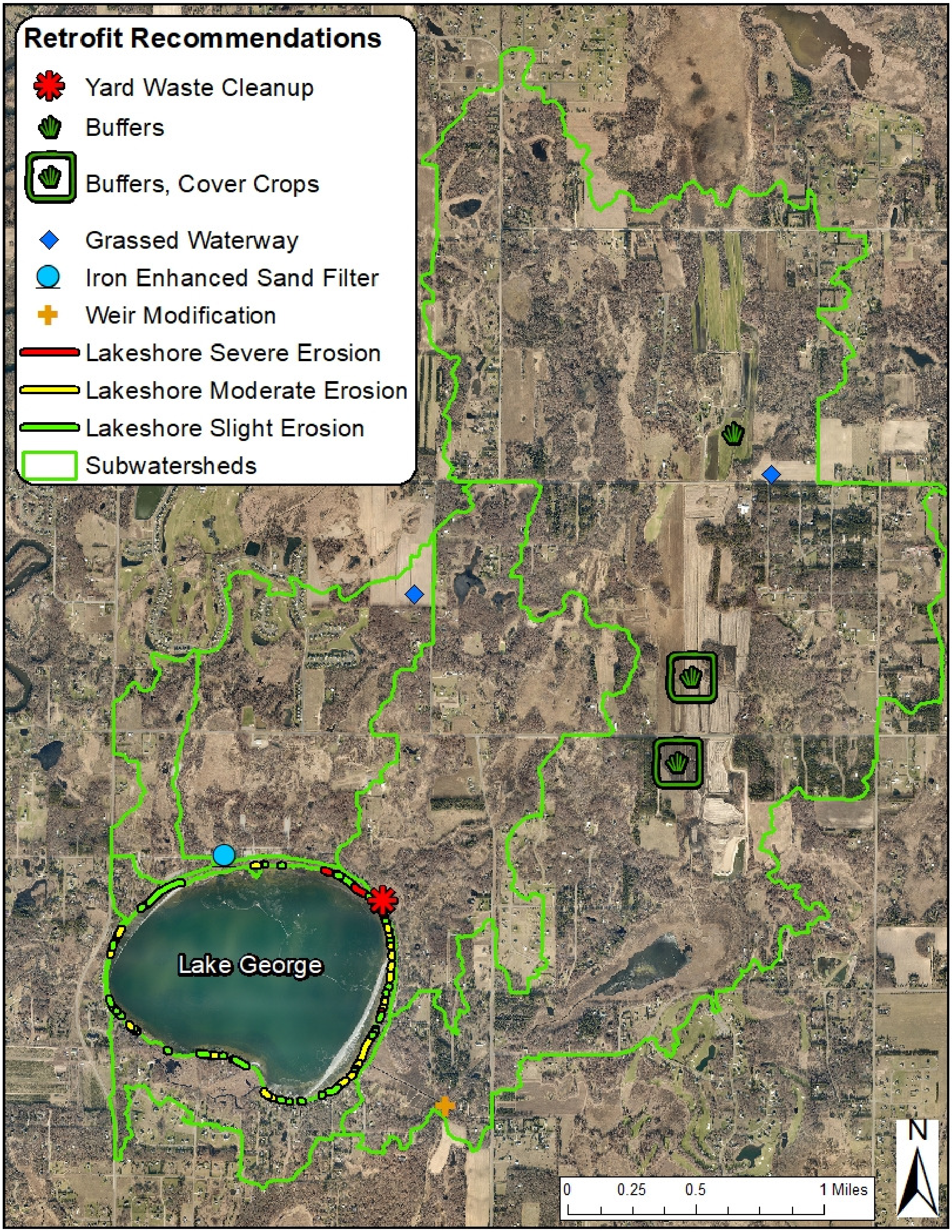
The second part of this study included identifying and ranking projects for the treatment of stormwater draining from the lakeshed to Lake George, and actions to be implemented on a broader scale to protect lake water quality. Potential projects identified during this analysis were modeled to estimate reductions in total phosphorus (TP), total suspended solids (TSS), and if possible, volume. Cost estimates were developed for each project, including up to 30 years of operations and maintenance. Projects were ranked by cost effectiveness with respect to their reduction of TP. A variety of projects were identified, including:

- Lakeshore stabilizations and/or buffer installations,
- Installation of riparian buffers, cover crops, and grassed waterways in agricultural areas,
- Reconstruction of the Ditch 19 weir,
- One iron enhanced sand filter, and
- Good housekeeping recommendations.

At Lake George, preventing future water quality declines is as important as correcting past water quality declines. For this reason, the table of prioritized actions on the following pages includes both projects to improve current water quality and actions to ensure land use change does not result in degradation. This study found that increased frequency of wet years is also a significant contributing factor to Lake George water quality declines, and given that annual precipitation is difficult to control, other offsetting actions are imperative.

This report provides conceptual sketches or photos of recommended water quality improvement projects. The intent is to provide an understanding of the approach. If a project is selected, site-specific designs must be prepared. Many of the proposed projects will require engineered plan sets if selected. This typically occurs after committed partnerships are formed to install the project. Committed partnerships must include willing landowners when installed on private property.

The map and table on the next pages summarize potential projects and actions, and groups them based on direct impact to Lake George. These projects are organized in order of cost effectiveness at reducing phosphorus delivery to the lake.


Retrofit Recommendations
Yard Waste Cleanup
Buffers
Buffers, Cover Crops
Grassed Waterway
Iron Enhanced Sand Filter
Weir Modification
Lakeshore Severe Erosion
Lakeshore Moderate Erosion
Lakeshore Slight Erosion
Subwatersheds
Lake George
0
0.25
0.5
1 Miles
N

Summary of preferred stormwater retrofit opportunities ranked by cost-effectiveness with respect to total phosphorus (TP) reduction. TSS and volume reductions are also shown. For more information on each project refer to the catchment profile pages in this report. Projects indirectly impacting the lake are those upstream of wetlands or Grass Lake which may already provide some treatment. This should be considered when comparing cost effectiveness of projects, as proximity to the lake is not considered in pollutantant reduction estimates.

Projects Directly Impacting Lake George

Project Rank	Retrofit Type (refer to catchment profile pages for additional detail)	Subwatershed	Projects Identified	TP Reduction (lb/yr)	TSS Reduction (lb/yr)	Volume Reduction (ac-ft/yr)	Probable Project Cost (2018 Dollars)	Estimated Annual Operations & Maintenance (2018 Dollars)	Estimated cost/ lb-TP/year (30-year)
1	Lakeshore Stabilization- Severe Erosion	Lake Adjacent	100 Linear-ft	3.64	4,512	n/a	$16,555	$150	$193
2	Iron Enhanced Sand Filter (IESF)	North Inlet	1 (3 sizes)	20-40	488-976	n/a	$394,072-S487,844	$1,676-$3,352	$741-$490
3	Lakeshore Stabilization- Moderate Erosion	Lake Adjacent	100 Linear-ft	0.52	612	n/a	$11,555	$150	$1,035
4	Ditch 19 Weir Modification	Ditch 19	1 (2 scenarios)	-1.6-4.5	4-344	3.8-5.8	$300,000	$0	-$6,061-$2,242
5	Shoreline Buffers	Near Lake	85	0.03	8	0.03	$3,652	$66	$6,568
6	Lakeshore Stabilization- Slight Erosion	Lake Adjacent	100 Linear-ft	0.08	62	n/a	$11,555	$150	$6,982

Projects Indirectly Impacting Lake George

7	Grassed Waterway	North Inlet	1 (2 sizes)	1.3-1.6	314-337	0.51-0.74	$6,372-$7,196	$50-$100	$197-$213
8	Cropland Riparian Buffers- 50'	Ditch 19	3 variations	17.62-53.03	140.26-422.12	n/a	$16,408-$35,883	$3,524-$10,606	$223-$231
9	Cropland Riparian Buffers- 16.5'	Ditch 19	4 variations	2.08-9.10	25.52-111.65	n/a	$8,916-$16,341	$800-$3,500	$444-$528
10	Grassed Waterway	Ditch 19	1 (2 sizes)	0.3-0.4	78-84	0.13-0.19	$5,750-$5,951	$13-25	$561-$612
11	Cropland Cover Crops	Ditch 19	3 variations	19.0-56.9	203-610 (tons)	n/a	$72,547-$203,042	$68,751-$199,246	$3,618-$3,750

Summary of recommended non-structural actions to protect Lake George water quality

Stormwater Action	Importance Ranking	Description of the Action
Yard waste disposal cleanup	High	Clean up yard waste disposal identified in the Northeast watershed in this report. Take educational or other actions needed to ensure further disposal does not occur in the future.
MIDS Stormwater Standards	High	Minimal Impact Design Standards (MIDS) for stormwater focus on containing and infiltrating as much stormwater as possible. These standards are especially important as precipitation levels increase, and open areas develop. Keeping stormwater, and the pollutants it contains, on the land and allowing it to infiltrate into the ground is a key strategy. The City of Oak Grove is the land use authority, and would be responsible for any such stormwater standards with the guidance of the Upper Rum River Watershed Management Organization. A special effort with these groups to consider customized stormwater standards for the Lake George watershed is recommended.
Phase 2: In-Lake Study	High	A study to determine the effects of in-lake factors on Lake George, and recommend future management action is advised. In-lake factors that can affect water quality include game fish, rough fish, in-lake sediment stability, wave action, lake usage, aquatic vegetation, and others. While Phase 1 of this study found many water quality correlations and contributing factors from the lakeshed, there may be other in-lake factors affecting water quality as well.
Maintain or Enhance Near-Lake Wetlands	High	Wetlands through with the North and Northeast inlets to the lake drain should be protected or enhanced. These wetlands reduce pollutants coming from the upper watershed before they reach the lake. Efforts to channelize the current dispersed flow through these wetlands is not advised.
Public Education	Moderate	Ongoing outreach and education to homeowners regarding actions they can take (or shouldn't take) in order to keep the lake health is recommended. Specifically, dumping of leaves, sediment, and other yard waste near the lake can have a large impact on lake water quality. Additionally, mowing to the waters' edge and eliminated native vegetation increases shoreline erosion rates and allows stormwater to run overland umimpeeded to the lake. Over fertilization and the use of phosphorus fertilizers near a lake contribute to algal proliferation and decreased water clarity. All of these issues can be addressed by educated homeowners. The message has to be spread in an effective, informative and actionable way.
Continue AIS Management with Native Vegetation in Mind	Moderate	Herbicide treatments to control aquatic invasive species (AIS) should continue to be done in a way mindful of lake health. Certain native species of aquatic vegetation can be negatively affected by herbicide treatments targeting invasive species. These native species are important to the lake for a host of reasons, including the water quality benefit they provide. Continue selecting herbicide treatment areas, chemicals and timing in a way that minimizes impacts on native plants.
Shoreland Septic Inventory and Replacement	Low	Locate and replace non-compliant septic systems in the shoreland zone. Due to a community septic system serving much of the Lake George area, septic system concerns are lessened. However, maintenance or correction of septic systems should be a priority for all others.

Abbreviations

Listed below are some abbreviations used frequently throughout the text:

ACD: Anoka Conservation District

AIS: Aquatic Invasive Species

BMP: Best Management Practice

BWSR: Board of Water and Soil Resources

CLP: Curly-leaf Pondweed

CoCoRaHS: Community Collaborative Rain, Hail, and Snow Network

DEM: Digital Elevation Model

LGID: Lake George Improvement District

LiDAR: Light Detection and Ranging

P8: Program for Predicting Polluting Particle Passage thru Pits, Puddles, and Ponds

TDP: Total Dissolved Phosphorus

TP: Total Phosphorus

TSS: Total Suspended Solids

SWAT: Soil and Water Assessment Tool

SWMM: Storm Water Management Model

URRWMO: Upper Rum River Watershed Management Organization

WAT Year: Water Year Precipitation, or the precipitation that falls from October 1- September 30

WinSLAMM: Source Loading and Management Model for Windows

WRAPS: Watershed Restoration and Protection Strategy

Background

Lake George is located in northwestern Anoka County, Minnesota. The lake and its lakeshed lie within the Rum River Watershed. The 535-acre lake has a lakeshed of 5,253 acres, spanning the cities of Oak Grove (75%) and St. Francis (25%). While the lake reaches a maximum depth of 32 feet, its littoral zone makes up 74% of the lake's surface area (Lund 2018), making it act like a shallow lake in many ways. It is a highly valued lake. Recent water quality declines prompted this study to better understand the causes of that decline and prioritize efforts to correct it.

Lake George has been a regional water quality and ecological gem, as well as a recreational hotspot for decades. The Lake George Regional Park on the north shore of the lake includes a large public beach and boat launch. It receives over 200,000 visits annually. Lake George is one of the clearest lakes in Anoka County. The limited development within the lakeshed and a diverse native plant community make Lake George resilient to the water quality and ecological decline seen in so many surrounding lakes that are also subject to intense recreational use and suburban development in their watersheds.

During the past twenty years, Lake George water quality has declined. The initial indicator of water quality change was a sustained, statistically significant trend of decreasing water clarity (measured by Secchi disk) starting near the end of the 20th Century. This trend in water clarity is paired with a trend in increasing total phosphorus during summer months. Based on Metropolitan Council's lake water quality report card method, Lake George has shifted from a consistent A letter grade lake to a consistent B grade. The Rum River WRAPS report (Minnesota Pollution Control Agency, RESPEC 2017) identifies Lake George as the only lake in the watershed with a declining water quality trend out of 19 lakes examined.

In 2016, the Anoka Conservation District (ACD) secured grant funding through the State Clean Water Fund to intensively monitor the contributing lakeshed of Lake George, identify pollutant loading and sources, and rank water quality improvement projects by cost-effectiveness. Match funding for the study was provided by the Lake George Improvement District (LGID) and Anoka Conservation District (ACD). This report is the result of that study.

Lake George is fortunate to have citizens and scientists working together to actively manage the lake. The LGID was formed in 2009 to try to address issues with lake water quality, aquatic invasive species, and to raise funding to sustain the health of the lake. The LGID has worked diligently to map and treat aquatic invasive species (AIS) within the lake, recruit volunteers for Secchi transparency and lake level monitoring, and to continue funding for annual professional water quality monitoring. The Lake George Conservation Club is an older citizen organization that also provides grassroots energy for lake management and is responsible for a number of lakeshore health projects. The Upper Rum River Watershed Management Organization is a joint powers organization of four communities which is charged with managing water resources in the vicinity, and has collaborated on lake monitoring and lakeshore restoration projects. Anoka County Parks operates the regional park and is the largest lakeshore landowner, and is mindful of lake health when considering park management. The Anoka Conservation District is a county-level agency that has collaborated with the above groups on a number of efforts including this study. All of these organizations will play a role in implementing the recommendations of this study to stop declining water quality and begin to improve it.

Lakeshed Conditions

Land Use

Land use affects water quality. The Lake George lakeshed is a mix of residential, agricultural and open space (Table 1). Similar to much of the north Twin Cities metro area, land use in the Lake George lakeshed is suburbanizing. This continued development in future years will be guided by the Oak Grove and St. Francis Comprehensive Plans. With about 75% of the lakeshed contained within Oak Grove, including all of the lower reaches of the lakeshed, development in this city will likely have the largest impact on the lake water quality.

According to the Oak Grove Comprehensive Plan (City of Oak Grove 2010 update), the window of time from 2008-2030, represented by Figure 1 (2016 land use) and Figure 2 (2030 projected land use), is the first of two stages of development in the city. During this period, low-density growth will be promoted with a maximum of four lots per ten acres, each having private wells and septic systems. The second stage of development will involve denser housing and regional utilities in the portions of the city within the Metropolitan Urban Service Area (MUSA), none of which lies within the Lake George lakeshed. Since none of the MUSA development will occur within the Lake George lakeshed, large rural lots and low-density housing are anticipated to persist beyond 2030.

In the St. Francis portion of the lakeshed, land use is projected to remain mostly agricultural with the western fringes reserved as natural areas (City of St. Francis 2009). This portion of the lakeshed is not projected to shift to rural residential, and may look similar in 2016 and 2030.

As a whole, the primary land use conversion projected in the lakeshed is a shift from large tracts of undeveloped land to rural residential usage. About half of the lakeshed is projected to make this shift by the year 2030. We do recognize that over time development pressures increase and other similar communities in the past have intensified development through revised plans.

Table 1 2016 to 2030 Projected Land Use Change in the Lake George Lakeshed

	2016 Acres	**2030** Acres	**Change in Acres**	**Change in Lakeshed**
Agricultural/Farmstead	648.93	846.57	+197.64	+4.17%
Commercial/Retail	2.66	8.05	+5.39	+0.11%
Extractive	16.05	0	-16.05	-0.34%
Golf Course	111.52	111.52	0.00	0.00%
Industrial/Utility	2.99	19.1	+16.11	+0.34%
Institutional	0.8	0	-0.80	-0.02%
Park/Recreational/Public/Reserve	455.23	686.78	+231.55	+4.89%
Seasonal/Vacation	9.99	0.00	-9.99	-0.21%
Rural Residential	870	2936.46	+2066.46	+43.61%
Low Density/Attached Residential	4.18	130.18	+126.00	+2.66%
High Density Residential	0	0.26	+0.26	+0.01%
Undeveloped	2614.99	0	-2614.99	-55.18%

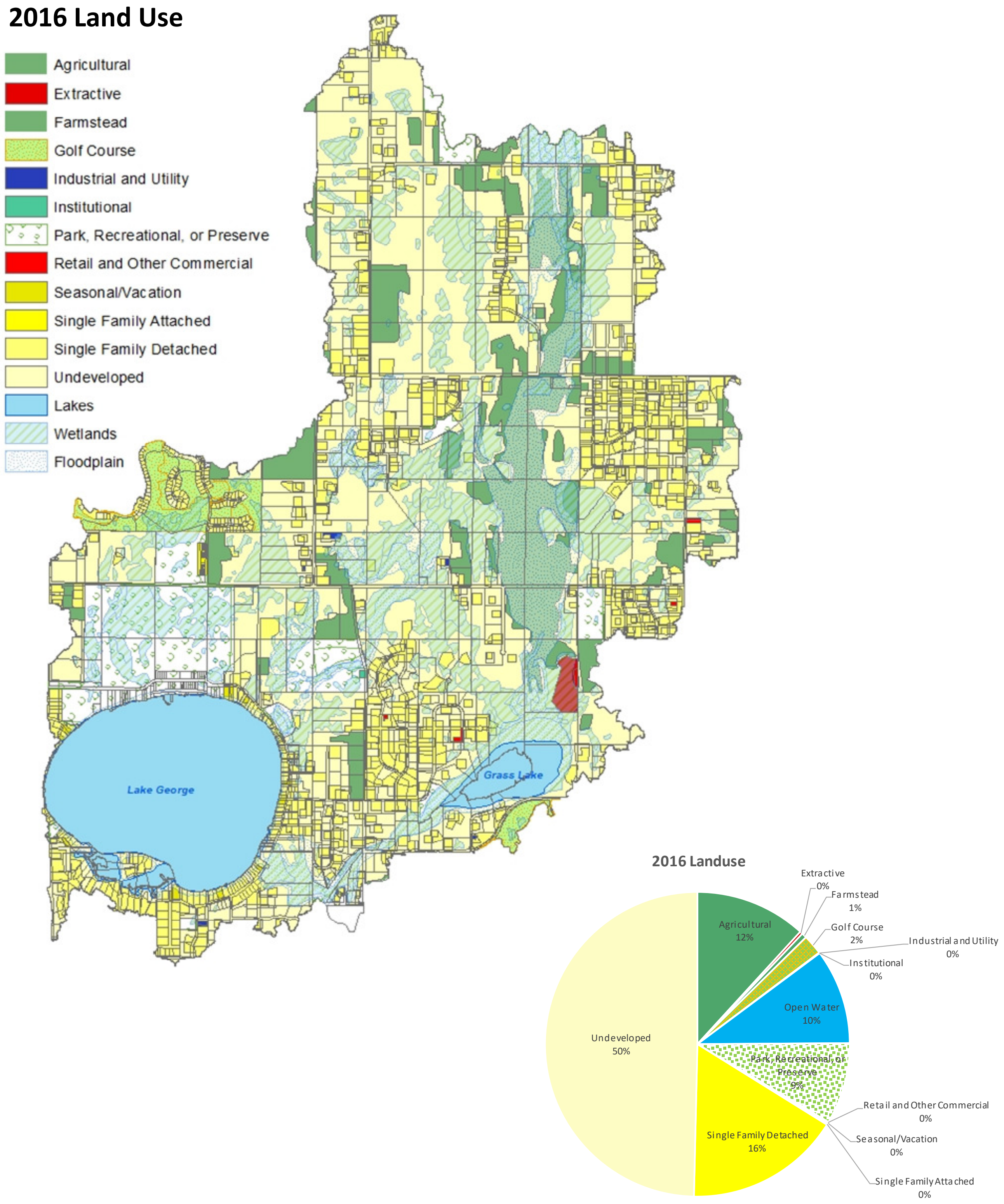


Figure 1 2016 Land Use, Lake George Lakeshed

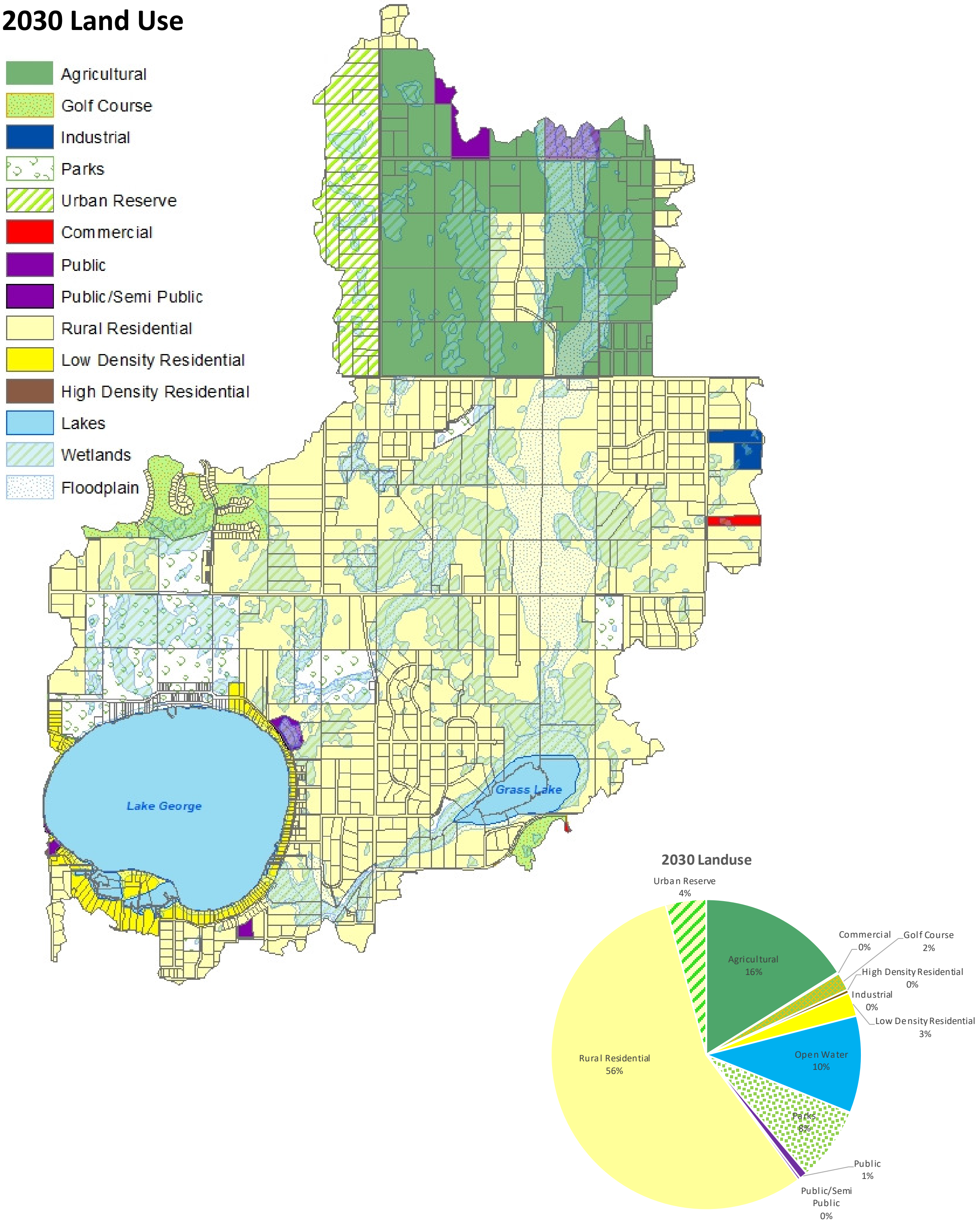


Figure 2 Projected 2030 Land Use, Lake George Lakeshed. Sources: Met Council, Oak Grove 2030 Comprehensive Plan

Best Management Practices (BMPs)

BMPs are projects or practices aimed at improving or protecting water quality. Understanding current practices helps inform possible causes of water quality problems and ways to address them. This study inventoried current BMPs and their effectiveness.

The primary type of stormwater best management practice currently installed in the Lake George lakeshed is wet detention basins in the more recently and densely developed areas of the lakeshed. The City of Oak Grove identified 109 ponds within the city as part of their storm pond inventory, 20 of which lie within the Lake George lakeshed (Figure 3 Existing Stormwater Ponds in the Lake George lakeshed, City of Oak Grove). The surface area of these 20 constructed basins totals 12.36 acres. Most of these existing stormwater ponds are located in the north subwatershed in the Zion Parkway development and lie hydrologically distant from Lake George.

On the lakeshore, residents have installed vegetated buffers. The number installed is unknown, but the objective of these projects is to filter runoff to the lake, stabilize eroding shoreline and provide near-shore habitat. While perhaps 10-20 of these projects have been installed, most homeowners maintain their shoreline as mowed grass, retaining wall or rip rap, and may clear aquatic vegetation.

Other BMPs are less conspicuous and scattered. For example, parking lots in the regional park are graded to drain away from the lake. Several tributaries to the lake drain through wetlands, which are not intentionally constructed but may provide water quality benefits.

Only small portions of the lakeshed are served by municipal stormwater conveyances. This is likely of benefit to the lake by keeping more water on the landscape where it can infiltrate.

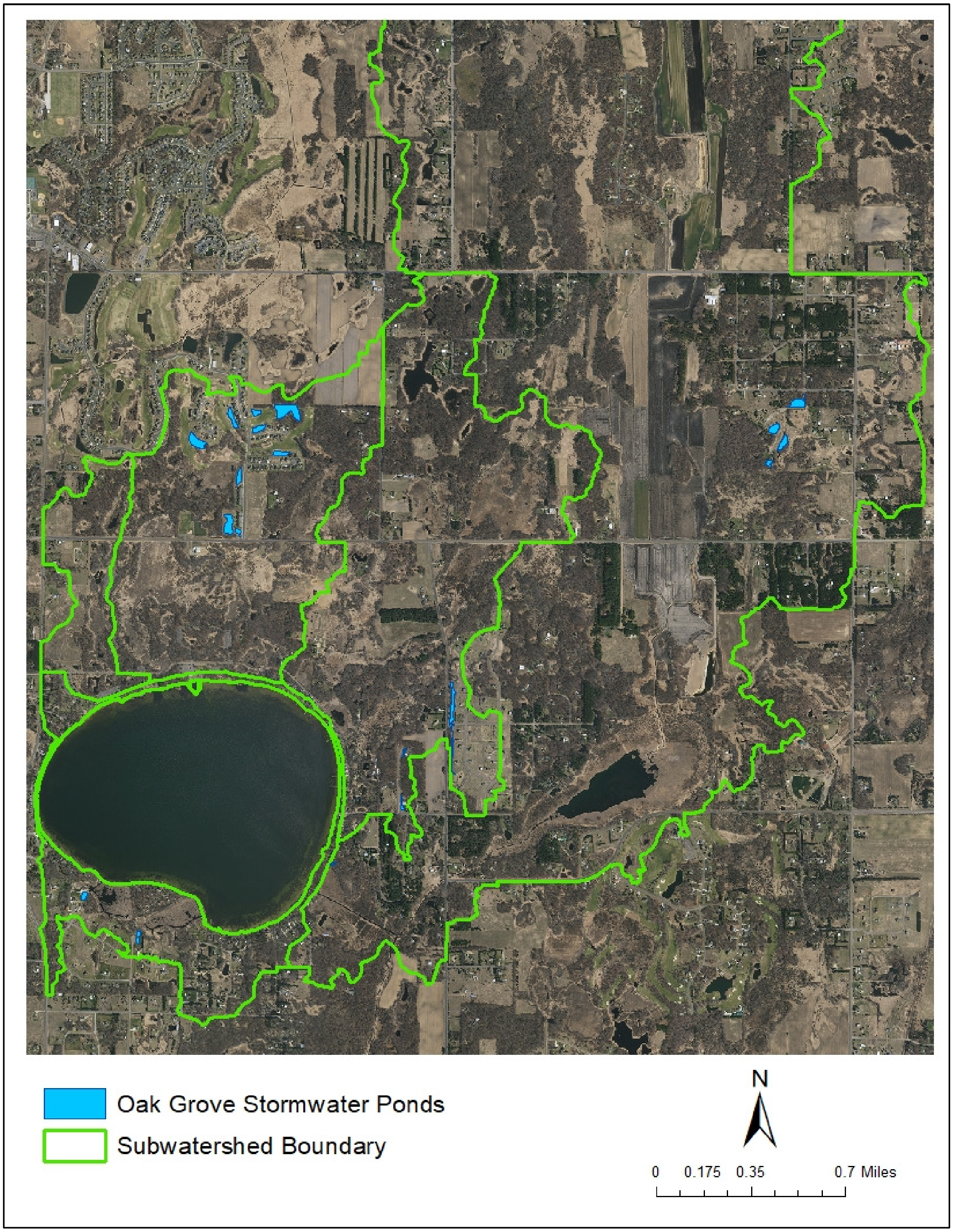


Figure 3 Existing Stormwater Ponds in the Lake George lakeshed, City of Oak Grove

Lakeshed Loading to Lake George

Lakeshed Water Quality Monitoring

ACD monitored the water quality of three major subwatersheds draining to Lake George: the Ditch 19, north inlet, and northeast inlet subwatersheds at their respective outfall locations, as well as throughout their subwatersheds, in 2016 and 2017. Analysis focused on nutrient and TSS loading to Lake George from its lakeshed. Figure 4 shows the water quality monitoring sites in the Lake George lakeshed. Figure 5 shows total and dissolved phosphorus concentrations at the monitored inlets and Ditch 19 at Nightingale Street. Figure 6 shows transparency of all monitored sites. This monitoring and modeling allow estimation of pollutant and water budgets for the lake.

Ditch 19 is the largest of the Lake George subwatersheds. It is also the only subwatershed that drains primarily agricultural landscapes, rather than large tracts of wetland. While water quality in the upper reaches of this system can be poor during storm events, Grass Lake in the lower portions of the subwatershed seems to be an effective natural BMP, removing much of the pollutant load from Ditch 19 before it reaches Lake George. Additionally, Ditch 19 serves as an outlet and elevation control for Lake George via a weir structure just west of Nightingale Street and southeast of the lake. Hydrology and model data indicate that Lake George outlets via Ditch 19 more often than it takes Ditch 19 water in, reducing the direct water quality effects Ditch 19 water may have on the lake. The pollutant concentrations in Ditch 19 were between those observed in other lake inlets, but because the volume of water is greater, and this stream discharges into the lake only during high water conditions (when water quality was poorer), the total pollutant load from Ditch 19 into the lake is greater than other tributaries.

The second largest subwatershed, the northeast inlet subwatershed, flows primarily through large wetland systems with small portions developed into low-density housing. The upstream monitoring site, 221st East of Nightingale, had the highest average dissolved phosphorus concentrations of all the monitored sites. Downstream at the northeast inlet to the lake, however, the lowest average dissolved phosphorus was observed compared to other lake inlets, suggesting that the wetland across South Lake George Drive from the inlet channel is an effective natural BMP for dissolved phosphorus. Even after 72% of dissolved phosphorus was removed from its subwatershed, the inlet channel still had high levels of particulate phosphorus. This suggests the loading of particulate debris either from, or into, the wetland near the lake inlet channel. This inlet had the poorest clarity on average of the monitored subwatersheds due to high levels of particulates and dark tannin staining (see Figure 6). Overall, the northeast inlet has the highest nutrients and suspended solids concentrations (for loads see next section) discharging to Lake George.

The north inlet enters Lake George through the County Regional Park. The northern half of this subwatershed is comprised of medium density housing with storm sewer lines and retention basins. After crossing south of 221st Avenue, the water from this subwatershed flows through a sprawling wetland complex that makes up much of the Lake George Regional Park. This inlet had clearer water on average than the NE inlet, but still exhibits tannin staining and high levels of dissolved phosphorus, especially during storm events.

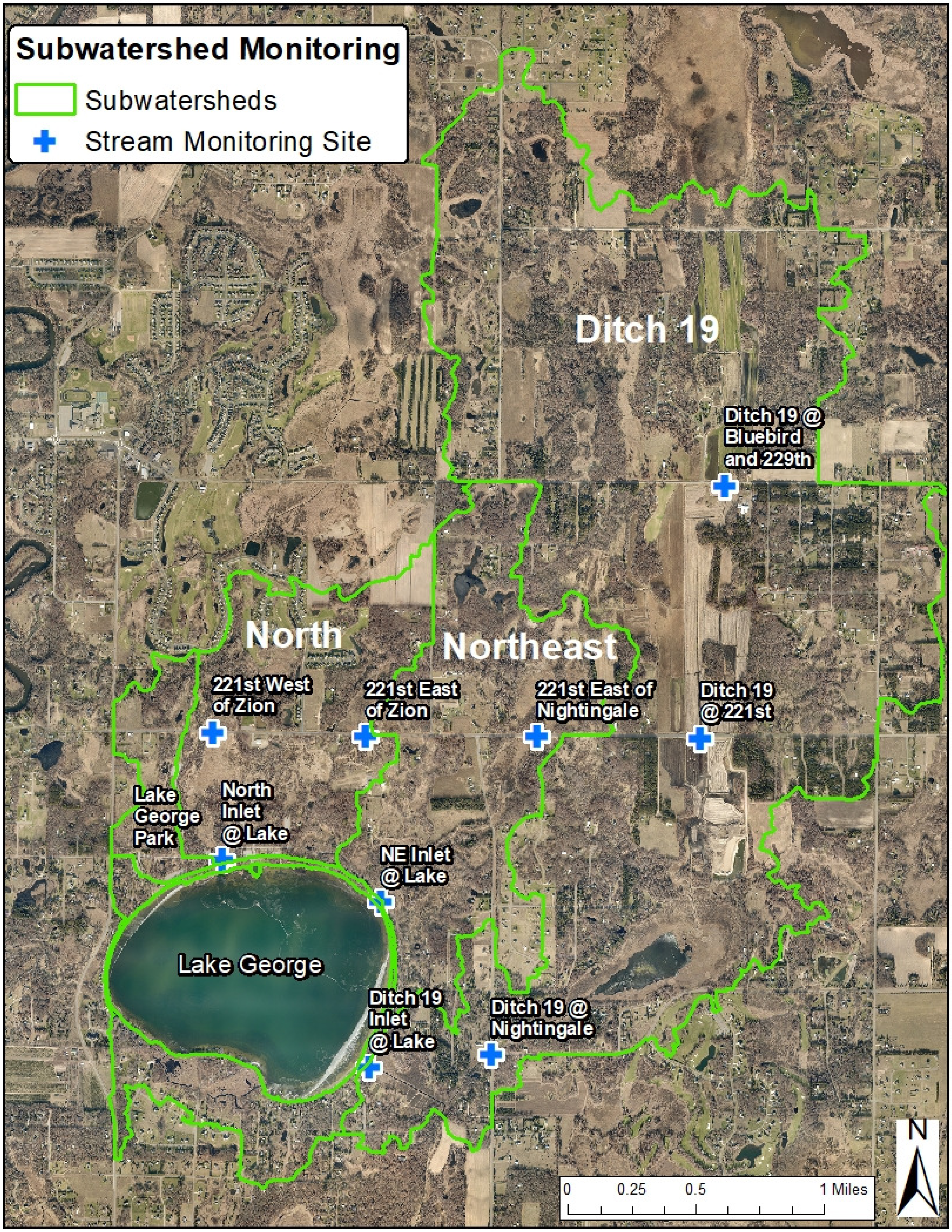


Figure 4 Anoka Conservation District Water Quality Monitoring Sites in the Lake George Lakeshed 2016-2017

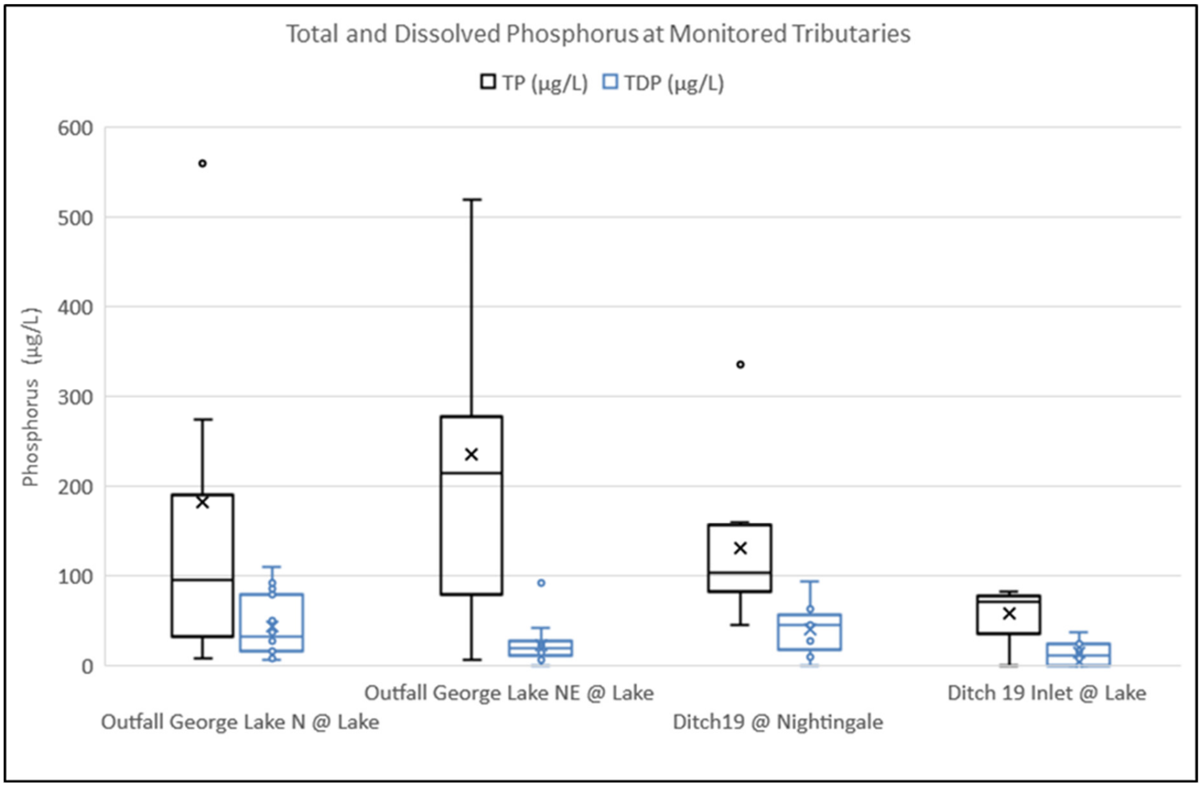


Figure 5 Total and Dissolved Phosphorus at Monitored Inlets and Nightingale St.

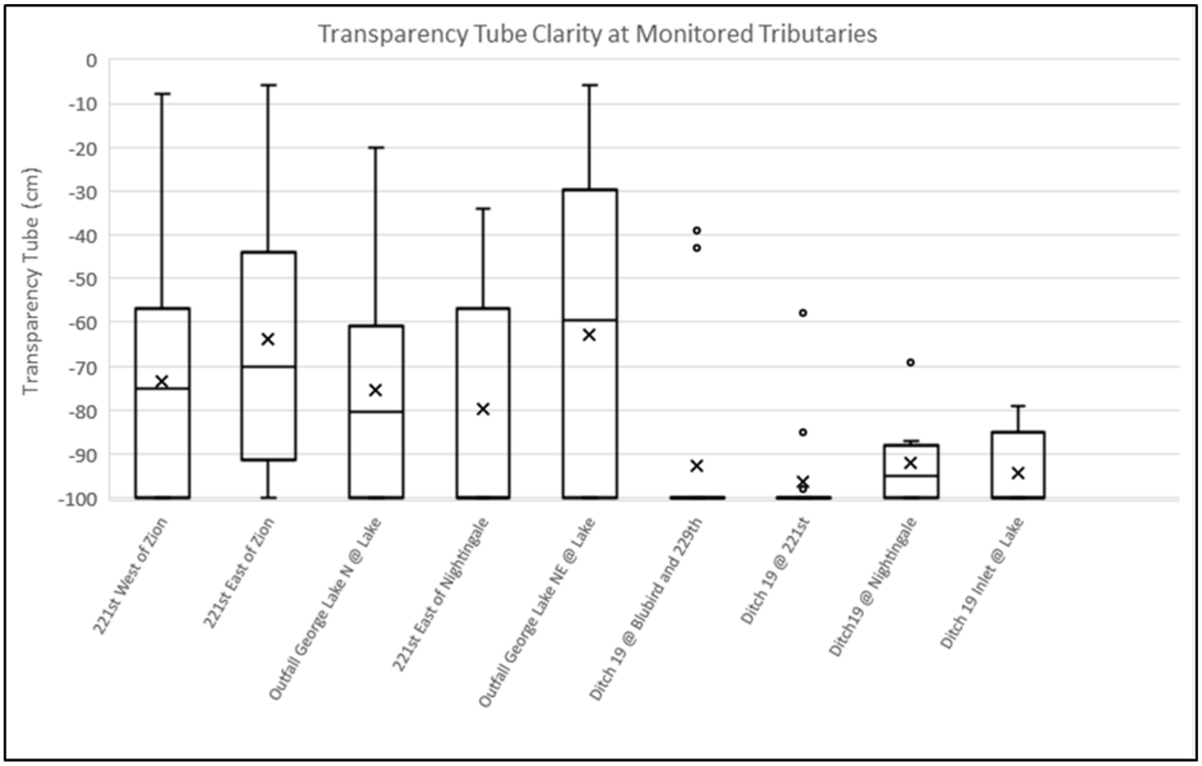


Figure 6 Transparency Tube Clarity at all Monitored Sites

Lakeshed Models

Two models of the Lake George Lakeshed, P8 and SWMM, were used to determine the hydrologic and nutrient loading from each subwatershed to the lake. Each model was calibrated to approximately match field-collected monitoring data using best available local precipitation records. For an in depth explanation of the development of these two models, see the Lakeshed Modeling Methods section on page 49.

Current (2016) land use practices, normal precipitation (5/1/2017-11/30/2017 precipitation record), and a lake/Ditch 19 outlet weir elevation of 901.59’ above MSL (NAVD88) serve as baseline modeling conditions for this report. The effects of high precipitation, land use change to projected 2030 conditions, and a weir restoration elevation shift of +0.49’ were also modeled to determine changes in lakeshed loading to the lake due to these factors.

Baseline modeling suggests that the largest portion of the total phosphorus and suspended solid load from the lakeshed comes from Ditch 19, about 36% of each. However, because of the larger relative size of the Ditch 19 subwatershed, it has the lowest loading per acre for both total phosphorus (TP) and total suspended solids (TSS) to the lake. Grass Lake is effectively treating Ditch 19 water before it approaches Lake George. Ditch 19 water south of Grass Lake generally has lower nutrients and better clarity than the other lake tributaries. We must also consider that Ditch 19 serves as an outlet for Lake George most of the time under baseflow conditions, meaning much of the water from this subwatershed never flows to Lake George itself.

According to the models, the north, northeast, and northwest subwatersheds all have similar concentrations and loading of TP per acre to Lake George. This makes sense given that all of these subwatersheds have similar proportions of land use and landscape types. The northeast subwatershed, however, contributes more TSS to the lake than the others according to the models. These results do not align with monitoring results. Generally, the northeast inlet had lower TSS concentrations than the north inlet during water quality monitoring. However, the northeast inlet did have higher particulate phosphorus concentrations, and lower clarity than the north inlet during water quality monitoring.

The near lake portions of the Lake George lakeshed were not monitored for water quality due to the lack of defined streams or outfall locations. This portion of the lakeshed is much more developed than the other subwatersheds, and has the largest modelled loading of TP and TSS per acre. While there are some stormwater retention basins in place in the developments to the southwest of Lake George, the models suggest that the opportunity exists for much more treatment of stormwater near the lake itself. Much of the near-lake areas of the lakeshed draining directly to Lake George lack any stormwater treatment. Lakeshore property best practices by homeowners immediately adjacent to the lake can have a positive impact on lake water quality.

Table 2, Table 3, Figure 7, and Figure 8 summarize modeled flow volume, total phosphorus, and TSS input from individual subwatersheds to Lake George under baseline conditions.

Table 2 Flow and TP Loading to Lake George by Subwatershed, Baseline Model Conditions

Subwatershed	Modeled Flow to Lake (Acre-ft)	Average TP Conc. (mg/L)	TP to Lake (pounds)	TP to Lake (pounds/acre)
North	90.32	0.19	46.67	0.0863
Northeast	93.02	0.24	60.71	0.0805
Near Lake	17.36	0.54	25.49	0.1161
Northwest	19.20	0.20	10.44	0.0829
Ditch 19*	115.40	Storm Avg. 0.25	78.54	0.0250

* Ditch 19 net flow and loading from sum of storms that caused flow into Lake George. Excludes conditions when Ditch 19 was not flowing into Lake George.

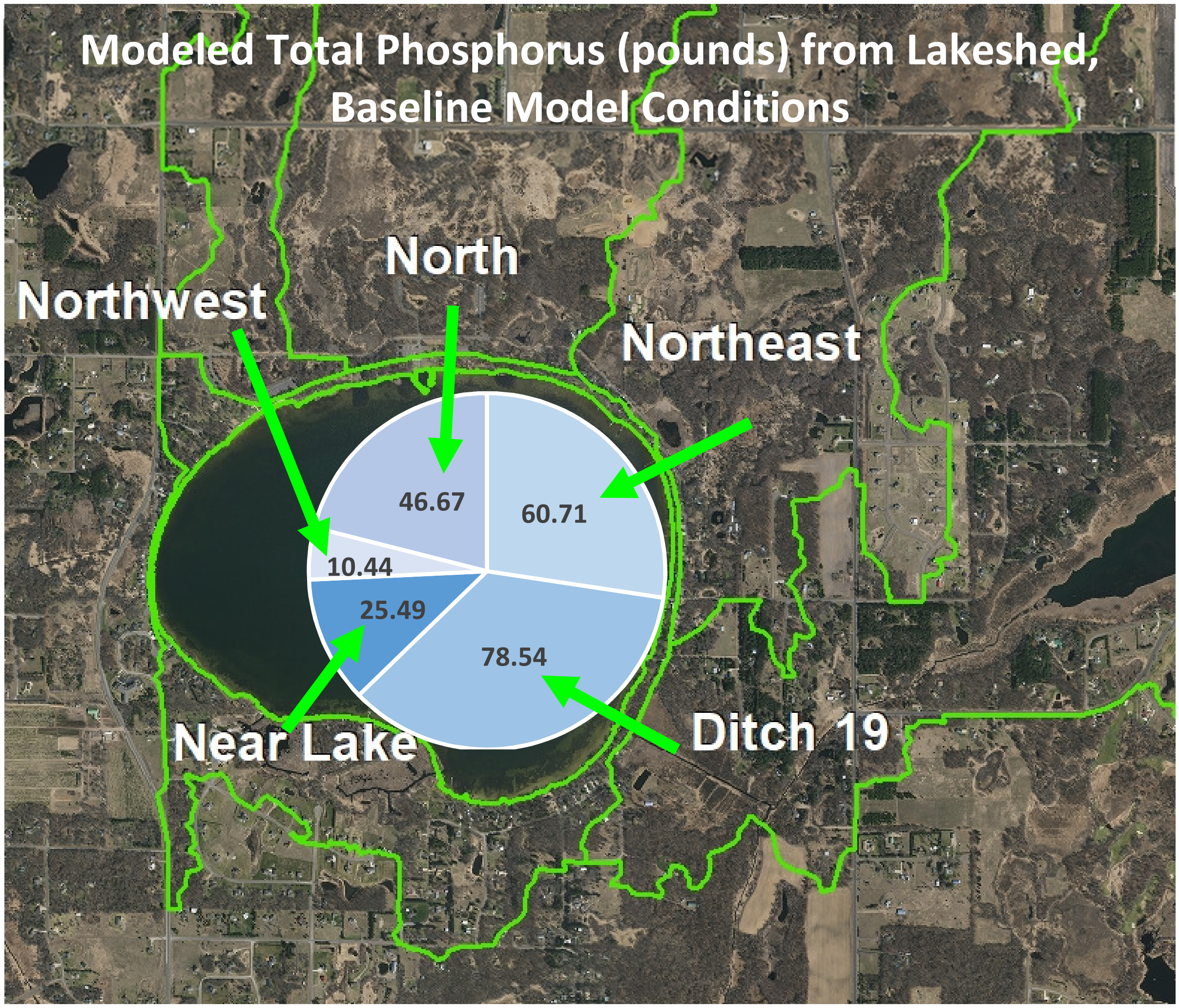


Figure 7 Total Phosphorus loading (pounds) by subwatersheds using baseline P8 and SWMM Models

Table 3 Flow and TSS Loading to Lake George by Subwatershed, Baseline Model Conditions

Subwatershed	Modeled Flow to Lake (Acre-ft)	Average TSS Conc. (mg/L)	TSS to Lake (pounds)	TSS to Lake (pounds/acre)
North	90.32	3.98	978	1.81
Northeast	93.02	10.57	2674	3.55
Near Lake	17.36	95.03	4485	20.43
Northwest	19.20	5.9	308	2.45
Ditch 19*	115.40	17.44	4805	1.53

* Ditch 19 net flow and loading from sum of storms that caused outlet flow into Lake George. Excludes conditions when Ditch 19 was not flowing into Lake George.

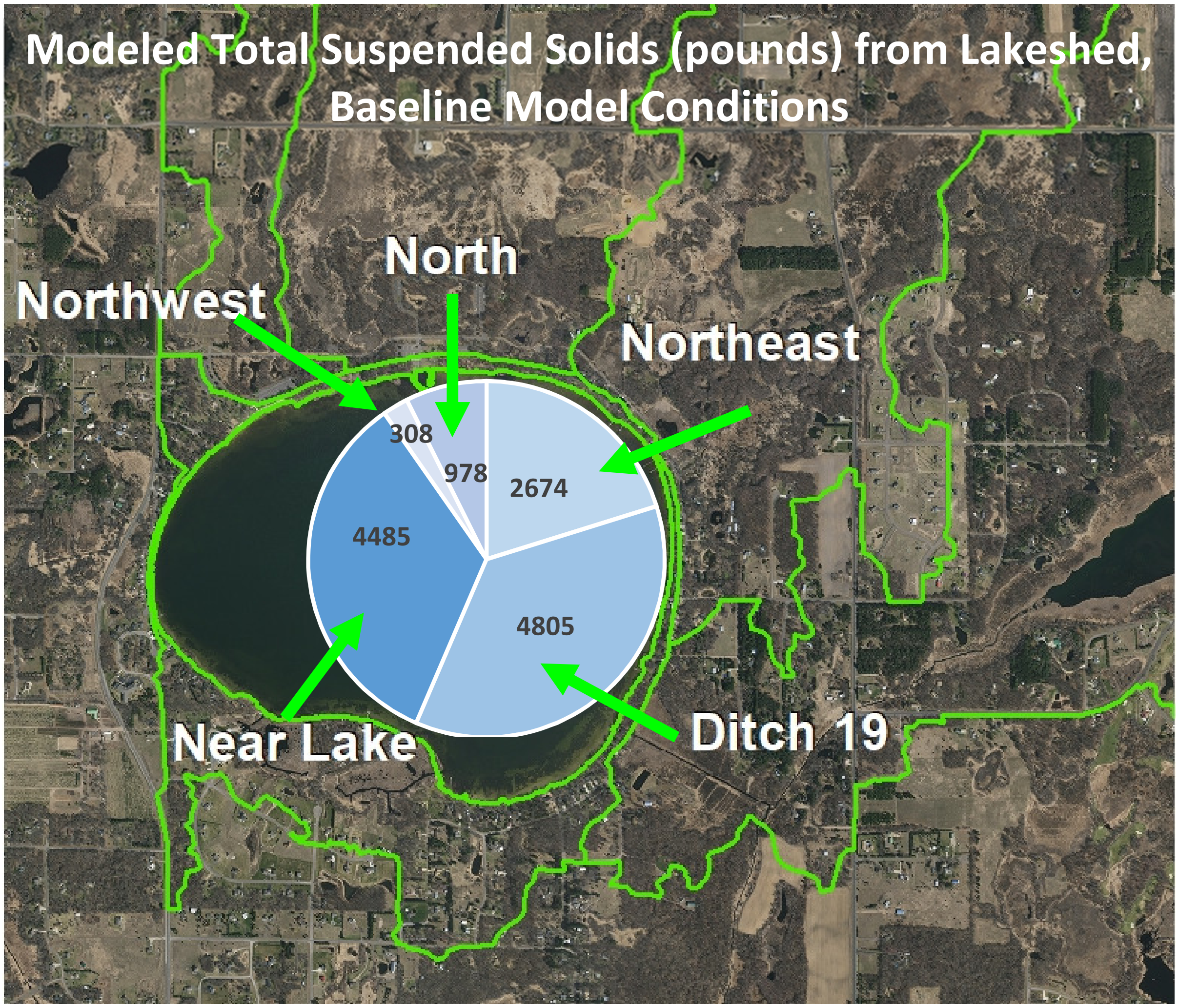


Figure 8 TSS loading (pounds) by subwatersheds using baseline P8 and SWMM Models

Analysis of Water Quality Change

Lake Water Quality Trends

Lake George has one of the most comprehensive water quality monitoring datasets in Anoka County, with nutrient and clarity data dating back to 1974. While Lake George is not currently listed by the State for any water quality impairments other than mercury in fish, an apparent trend of declining lake water quality has caused concern and a renewed focus on monitoring and intervention. Below is an analysis of the available data and an interpretation of the lake's water quality and changes over time.

Historically, Lake George has had very good water quality considering its proximity to the metro and high volume of recreational use, especially throughout the summer months. Much of the credit for a good record of water quality in Lake George is likely attributable to the low rate of development in the contributing lakeshed, and the fact that almost a third of the lake's circumference is undeveloped county parkland. However, concern about possible water quality declines began around 2010.

Annual average summertime (June-August) Secchi transparency in Lake George has declined on a statistically significant basis over the last 10 and 20-year time spans. Figure 9 shows the range and average of summer Secchi transparency in Lake George from 1998- 2018 (14 of these years were monitored). A transparency decline by a regression analysis is statistically significant. Interestingly, however, removing 2011-2017 from the long-term Secchi record eliminates that trend, with the period from 2011-2017 having an average transparency value of just 7.57 feet compared to the long-term average of 10.07 feet.

In a separate analysis by the State of Minnesota, Lake George was found to have strong evidence for decreasing water quality based on the seasonal Kendall-Mann statistical analysis using median summertime Secchi transparency (Minnesota Pollution Control Agency, RESPEC 2017). Lake George was the only lake in the Rum River watershed to have this trend out of 19 eligible lakes.

Average TP has increased on a statistically significant basis over the same 20-year time span, but with more variability over the last 10 years. Figure 11 shows the inverse trend over time in Secchi transparency and total phosphorus in Lake George throughout the monitoring record. Each parameter seems to reach somewhat of a turning point shortly after the turn of the century with no evident trend prior. A non-homogeneity analysis of the TP record in Lake George dating back to 1981 shows a significant jump in the data between the years 2002 and 2005. The average TP concentration from 1981-2002 was 20.4 µg/L, which increased to 26.0 µg/L from 2005-2017 (Figure 12).

Chlorophyll-a, the photosynthetic pigment found in algae and cyanobacteria, has also been measured in Lake George by ACD since 1999. This is about the same 20-year period that summertime clarity and phosphorus show declining water quality trends. Summertime mean chlorophyll-a, however, does not show the same increasing trends (Figure 13).

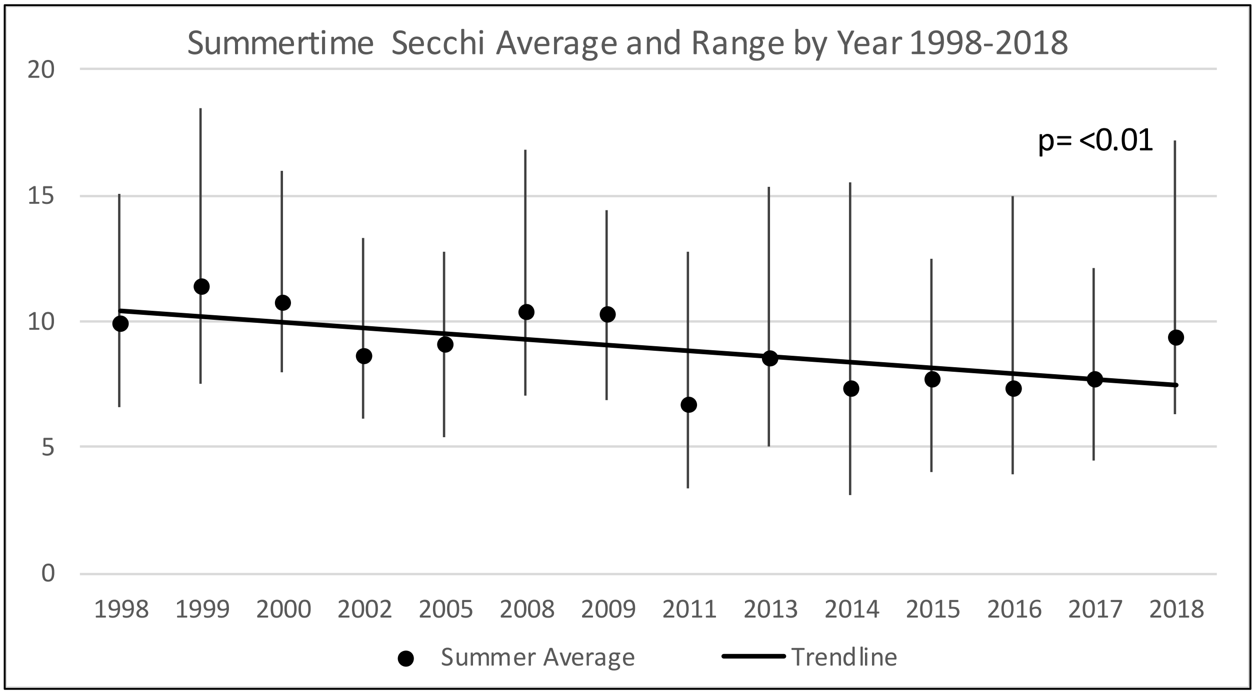


Figure 9 Summertime Secchi Average and Range, Lake George 1998-2018

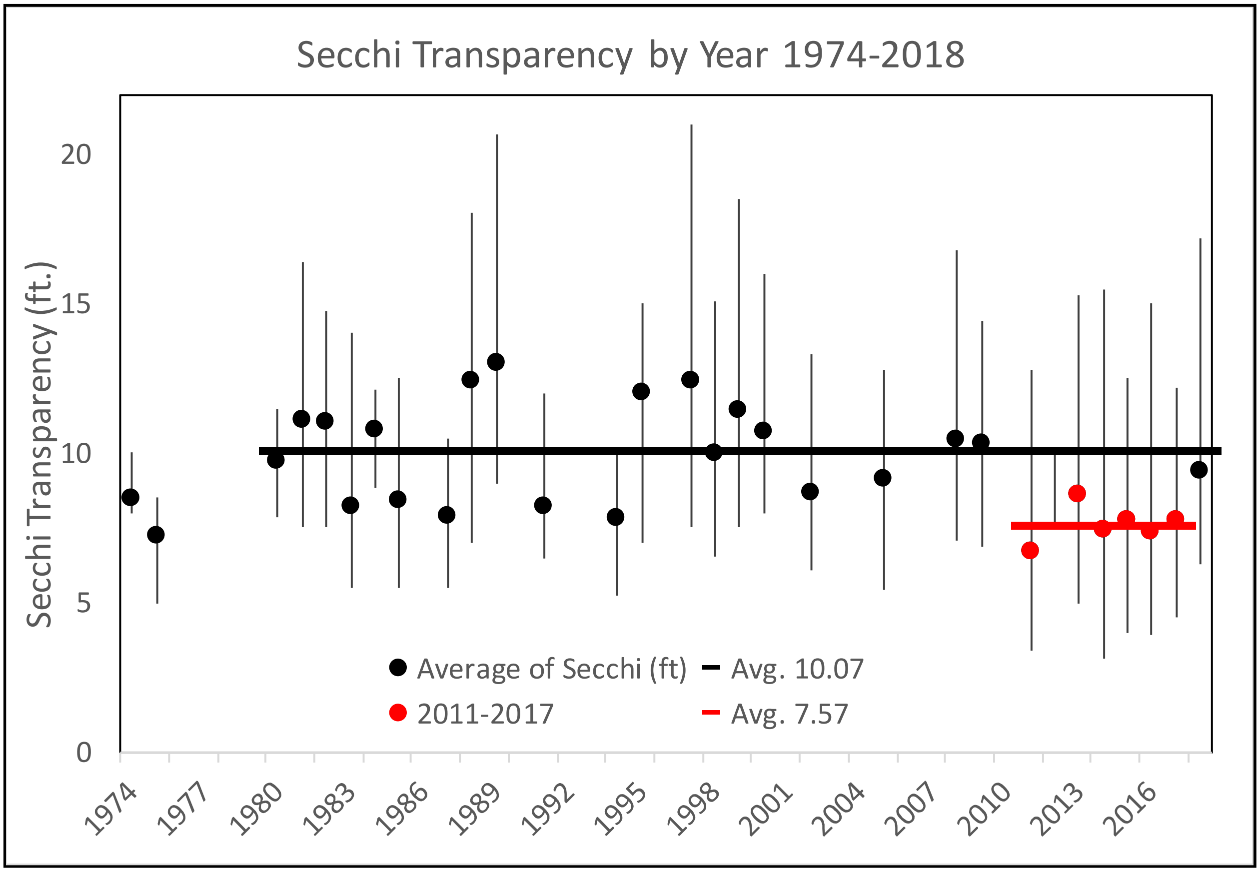


Figure 10 1974-2018 Lake George Secchi Transparency Trend Excluding 2011-2017

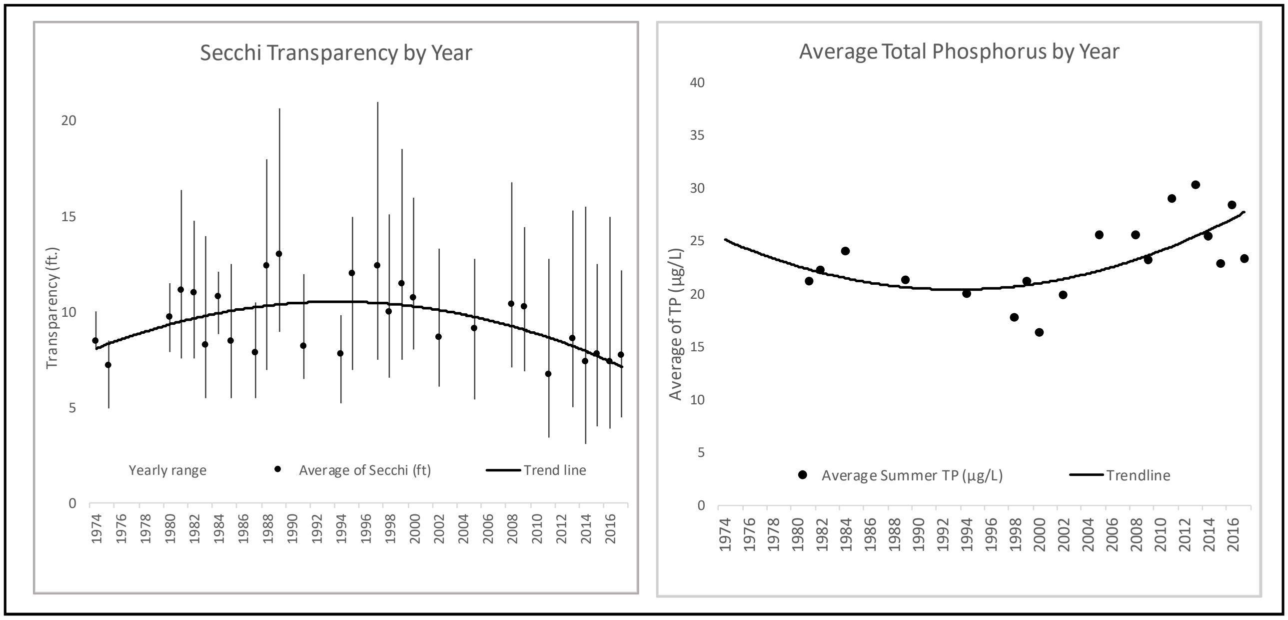


Figure 11 Inverse trends in Annual Secchi and Average Total Phosphorus, Lake George

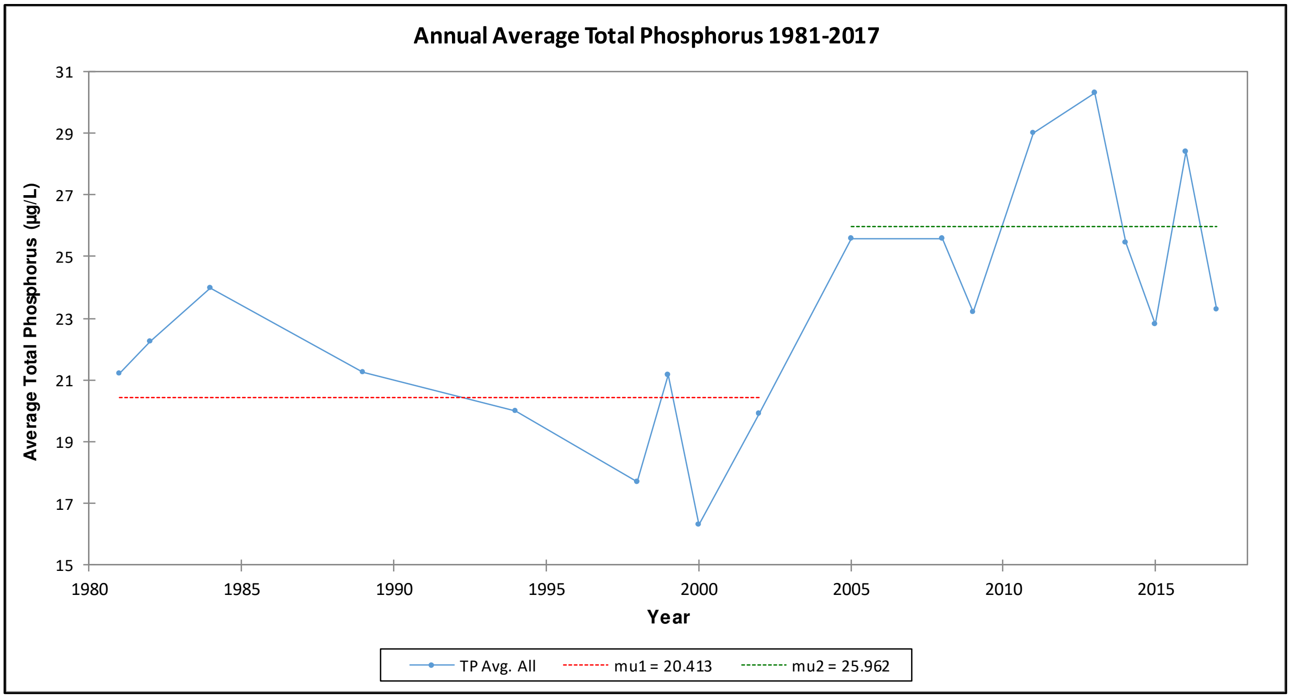


Figure 12 Non-homogeneity of Annual Average Total Phosphorus in Lake George

Causes of Decreased Lake Transparency Examined

When looking at causes of changes of lake water quality, we focused on causes of changes in lake transparency. Other parameters such as nutrients and chlorophyll-a are also common measures of "water quality." In this case, we chose to focus on transparency because it is the parameter with the strongest trend, and is reflective of changes in the other parameters. Possible causes of transparency change include algal growth, tannin staining, plant community shift and AIS treatments, lake recreation, climate change factors, land use changes and local factors such as deterioration of the lake's water level control weir in Ditch 19 (Table 4).

Table 4 Causes of Lake George Water Quality Change Examined

Cause Examined	**Apparent Level of Impact**
Increased Algal Growth	Low
Tannin Staining	Low
In-lake Plant Community Changes	Unclear, but does not appear to be high
Lake Herbicide Treatments	Low
Increased Recreational Boat Traffic	Low
More Frequent Wet Years	High
Warmer Water	Low
Land Use Change	Medium
Ditch 19 Weir Deterioration	Medium

Increased Algal Growth

Many lakes in this region of the country are experiencing transparency decline due to increased algal growth often caused by nutrient increases from agricultural, development, and other non-point pollution sources, or in-lake sediment resuspension. These nutrients act as fertilizer in the lake promoting excessive algal growth. The lake water turns greener over time as algae proliferates and clarity is reduced.

Chlorophyll-a, a measurement of algal growth, has been sampled in Lake George since 1999. If increased algae was the driver of decreasing clarity, we would expect to see an increase in chlorophyll-a over that same timeframe. ANOVA (Figure 13) and seasonal summer Mann-Kendall regression analyses show no change in chlorophyll-a since 1999. With no significant change in either chlorophyll-a or Carlson's Trophic State Index in Lake George, it does not appear that increased algal growth is anything more than possibly a minor driver of poorer clarity.

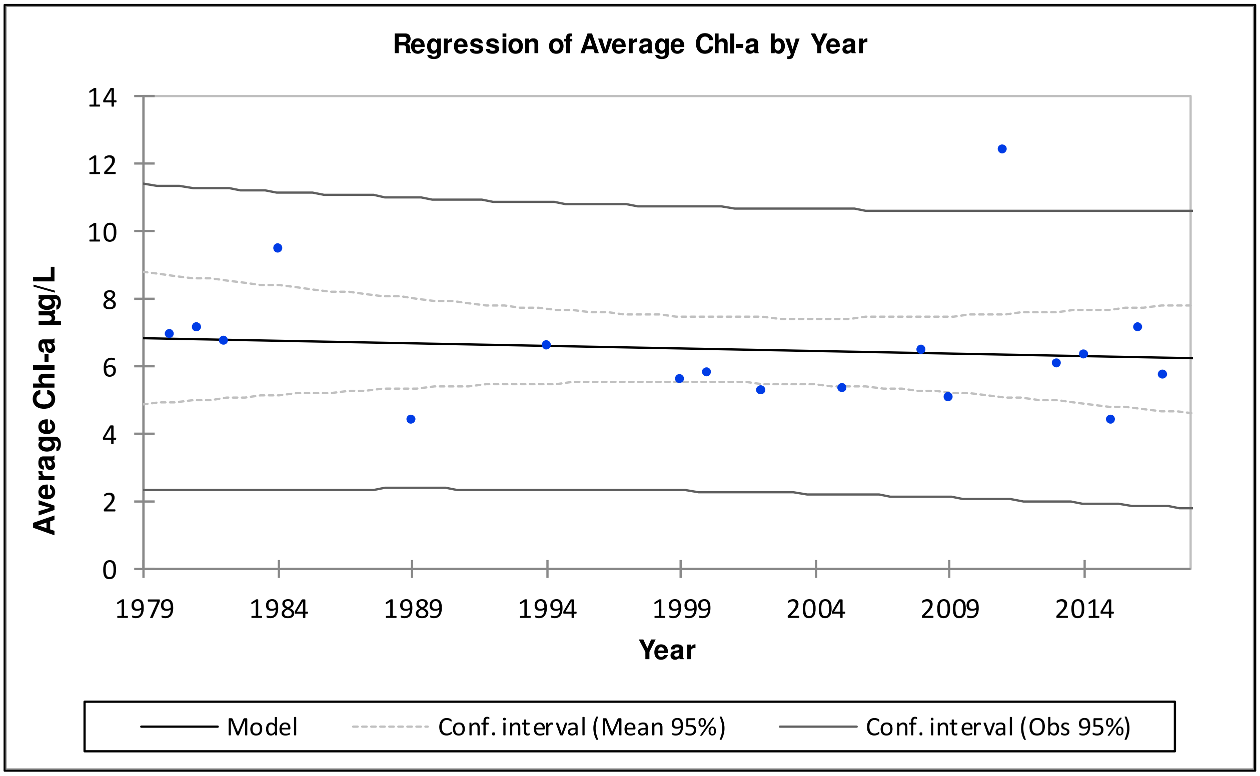


Figure 13 Linear Regression of Average Chlorophyll-a in Lake George 1999-2017

Tannin Staining

Tannins are acidic leachates from decomposing material that cause a brownish staining to water. Waters draining through wetlands may acquire this staining. Lake George water is not tannin stained to the naked eye. However, Lake George has a number of wetlands in its lakeshed (Figure 14) which might contribute tannins in amounts that casual observers would notice in the incoming streams but not in the lake. It is unclear whether these tannins have increased over time.

Tannins have not been measured directly, but because tannin staining is acidic, lower pH can be one indicator of higher tannin concentrations. The subwatersheds with the largest percentage of land cover as wetlands do have the lowest pH. There are not, however, monitoring records to show if the pH has changed over time.

It is reasonable to consider that any factors that might cause the lake's water budget to have proportionately more water from the north or northeast subwatersheds might result in more tannin staining reaching the lake. Specifically, deterioration of the Ditch 19 weir or increased stormwater discharge in the north or northeast subwatersheds might have this effect.

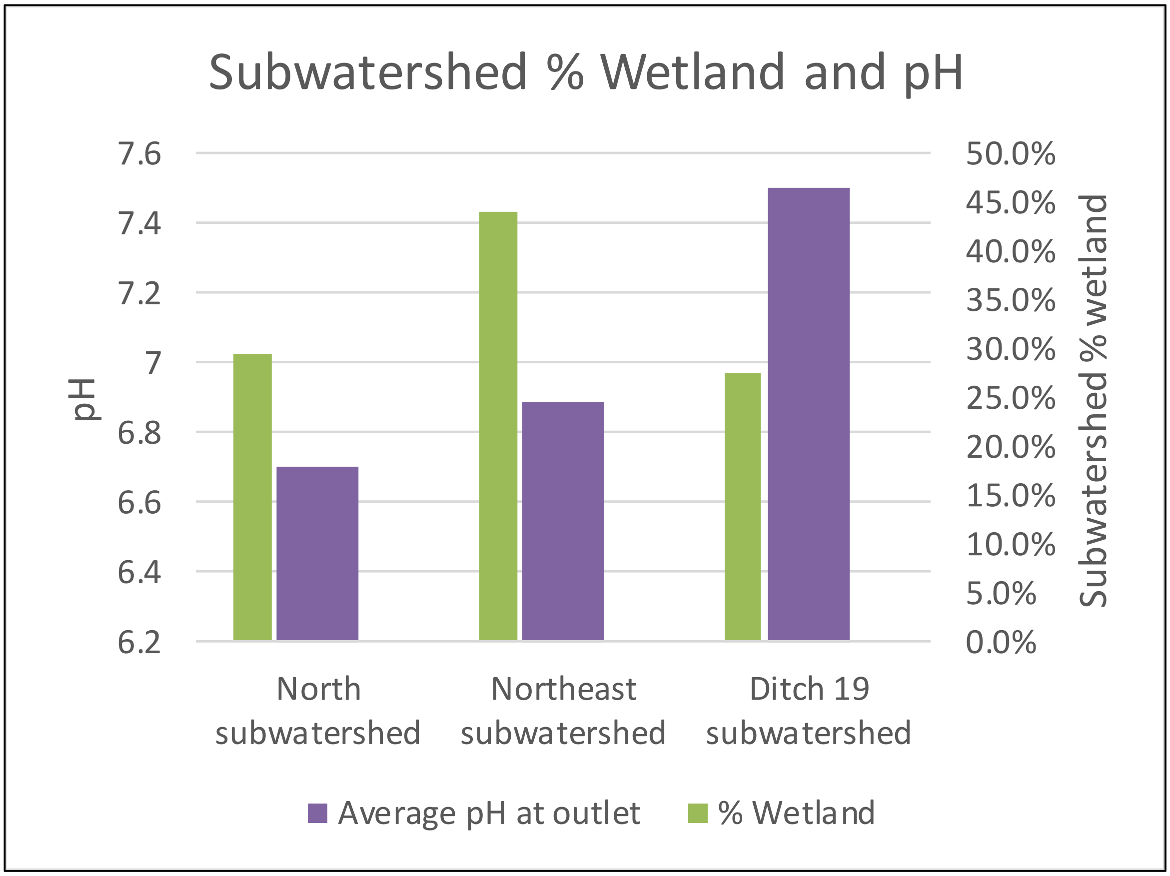


Figure 14 pH and wetlands in lake tributaries.

In-Lake Plant Community Changes

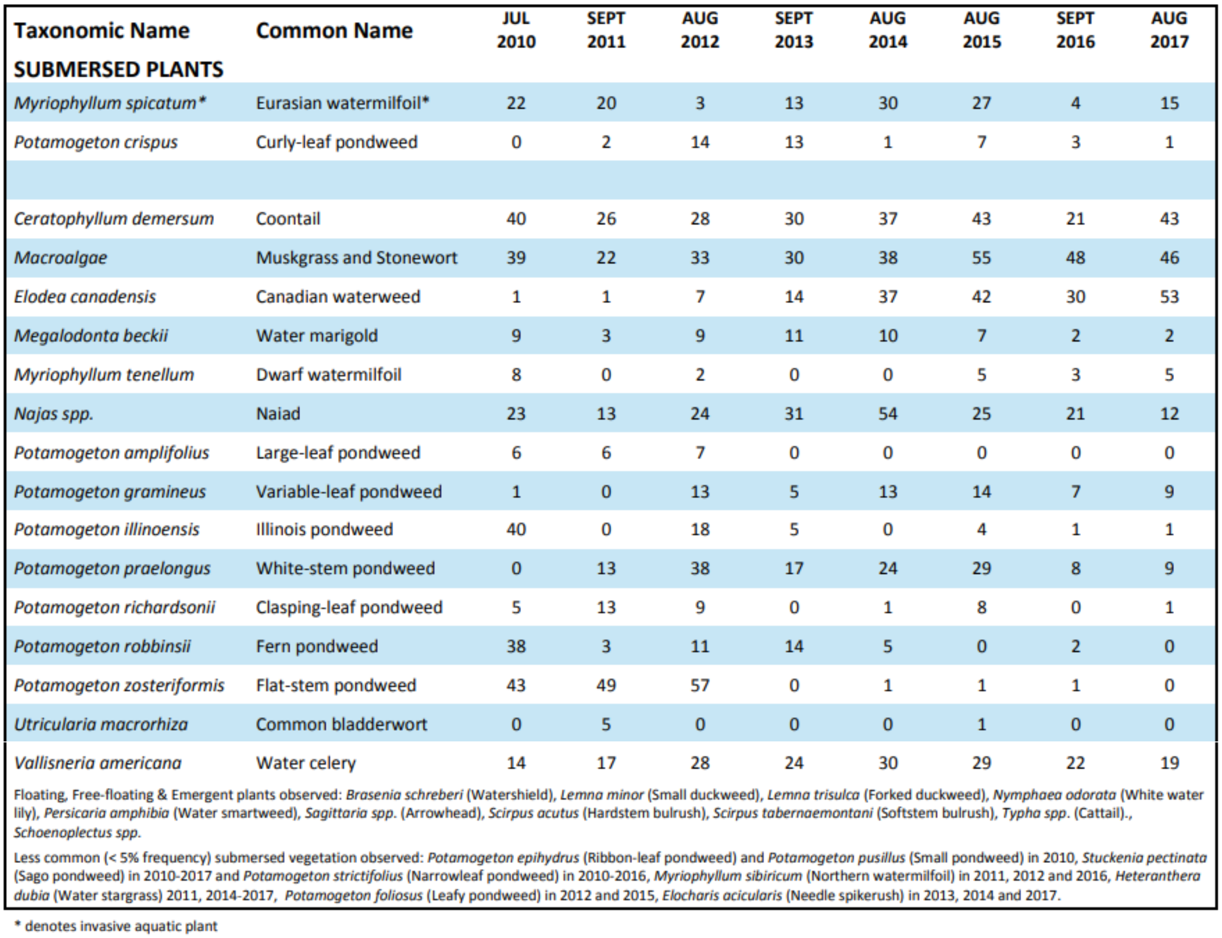
A robust native plant community is important for stabilizing sediment on the lake bottom in shallow areas where wave action occurs, and acting as a nutrient sink by consuming phosphorus and nitrogen during growth. Invasive aquatic vegetation can displace native plant species and take over the littoral zone of a lake. Species composition may affect water quality through timing of decomposition, shifts from bottom-blanketing species to other species, or other ecological interactions.

The invasive species, Eurasian watermilfoil, was first confirmed in Lake George in 1998. The invasive plant, curly-leaf pondweed also exists in Lake George, though it is unclear exactly when this plant became established. The water quality effects caused by the presence of these species in lakes is still a developing science. Results vary among studied lakes from a net water quality improvement to a net water quality decline after the introduction and treatment of these species.

The MN DNR has performed annual point intercept surveys of submersed vegetation in Lake George since 2010. While there does not appear to be a decline in the overall number of native plant observations since 2010, relative species frequencies have shifted, and changes in aquatic plant communities have been observed. Figure 15 from the MN DNR 2017 Lake George Aquatic Vegetation Report (Lund 2018) shows a decline in many native pondweed species, especially from 2012 to 2013. A couple of notable species include large leaf pondweed, which has not been documented since 2012, and Flat-stem pondweed, which dropped from 57 observations in 2012 to zero or one observation each year since. Conversely, Canadian waterweed has increased from once observation in 2010 and 2011 to over 50 observations in 2017.

The first treatment for curly-leaf pondweed using the herbicide Endothall occurred in 2013 across 43 acres of Lake George. This corresponds with the timing of native pondweed decline. Similar treatments were subsequently performed each year through 2017, though the acreage treated varied. Endothall treatments may be negatively affecting native pondweed species while helping other species proliferate. Endothall was not applied in 2018 due to its potential effects on native pondweed species.

While the actual water quality effects of shifting plant communities in Lake George is unclear, it is apparent that native plant community abundances have shifted, and two species of invasive plants are established throughout the lake’s littoral zone. It is possible that the shifting plant community composition in Lake George may be providing less net water quality benefit than the original native composition that existed in the past. Native pondweeds in particular root deep into the substrate and stabilize sediments against wave erosion. The loss of these species may be increasing the internal loading of sediment into the water column and decreasing clarity.



Taxonomic Name	Common Name	JUL 2010	SEPT 2011	AUG 2012	SEPT 2013	AUG 2014	AUG 2015	SEPT 2016	AUG 2017
SUBMERSED PLANTS									
*Myriophyllum spicatum**	Eurasian watermilfoil*	22	20	3	13	30	27	4	15
Potamogeton crispus	Curly-leaf pondweed	0	2	14	13	1	7	3	1
Ceratophyllum demersum	Coontail	40	26	28	30	37	43	21	43
Macroalgae	Muskgrass and Stonewort	39	22	33	30	38	55	48	46
Elodea canadensis	Canadian waterweed	1	1	7	14	37	42	30	53
Megalodonta beckii	Water marigold	9	3	9	11	10	7	2	2
Myriophyllum tenellum	Dwarf watermilfoil	8	0	2	0	0	5	3	5
Najas spp.	Naiad	23	13	24	31	54	25	21	12
Potamogeton amplifolius	Large-leaf pondweed	6	6	7	0	0	0	0	0
Potamogeton gramineus	Variable-leaf pondweed	1	0	13	5	13	14	7	9
Potamogeton illinoensis	Illinois pondweed	40	0	18	5	0	4	1	1
Potamogeton praelongus	White-stem pondweed	0	13	38	17	24	29	8	9
Potamogeton richardsonii	Clasping-leaf pondweed	5	13	9	0	1	8	0	1
Potamogeton robbinsii	Fern pondweed	38	3	11	14	5	0	2	0
Potamogeton zosteriformis	Flat-stem pondweed	43	49	57	0	1	1	1	0
Utricularia macrorhiza	Common bladderwort	0	5	0	0	0	1	0	0
Vallisneria americana	Water celery	14	17	28	24	30	29	22	19

Floating, Free-floating & Emergent plants observed: *Brasenia schreberi* (Watershield), *Lemna minor* (Small duckweed), *Lemna trisulca* (Forked duckweed), *Nymphaea odorata* (White water lily), *Persicaria amphibia* (Water smartweed), *Sagittaria spp.* (Arrowhead), *Scirpus acutus* (Hardstem bulrush), *Scirpus tabernaemontani* (Softstem bulrush), *Typha spp.* (Cattail)., *Schoenoplectus spp.*

Less common (< 5% frequency) submersed vegetation observed: *Potamogeton epihydrus* (Ribbon-leaf pondweed) and *Potamogeton pusillus* (Small pondweed) in 2010, *Stuckenia pectinata* (Sago pondweed) in 2010-2017 and *Potamogeton strictifolius* (Narrowleaf pondweed) in 2010-2016, *Myriophyllum sibiricum* (Northern watermilfoil) in 2011, 2012 and 2016, *Heteranthera dubia* (Water stargrass) 2011, 2014-2017, *Potamogeton foliosus* (Leafy pondweed) in 2012 and 2015, *Elocharis acicularis* (Needle spikerush) in 2013, 2014 and 2017.

* denotes invasive aquatic plant

Figure 15 Table of plant frequency of occurrence for submersed vegetation within the littoral zone of Lake George (Lund 2018)

Lake Herbicide Treatments

While the previous analysis looked at changes in the plant community over time, we also examined whether herbicide treatments have short-term negative effects on lake water quality. Some have hypothesized that invasive plant die-offs following these treatments may have water quality consequences including releasing nutrients during mass decomposition, though treatments are done before plants become large. This does not appear to be the case.

In 2014 and 2015 the Anoka Conservation District monitored water quality in Lake George shortly before and after Endothall treatments for Curly-leaf pondweed. No obvious change in any water quality parameter was detected due to these treatments. It is worth noting, however, that samples were collected at the deepest point of the lake at one meter of depth, consistent with all other lake samples collected by ACD. It is possible that these treatments do have localized impacts on water quality for a period of time after the treatment that is not detectable in the middle of the lake.

Increased Recreational Boat Traffic

Lake George is busy in the summer with boat traffic, as has been the case for decades. In some lakes, especially shallow lakes, disturbance of lake sediments by boat propellers can affect water quality, especially water clarity. We did not find strong evidence that days with high boat traffic drive poorer water quality.

We examined whether boat traffic might contribute to water quality degradation by comparing average Secchi readings by the day of the week in which they were observed. While records of boat traffic do not exist, we can assume the heaviest boat traffic occurs during the weekends from June-September. Therefore, we might expect Secchi clarity to be poorest on Mondays and Tuesdays during these months if boat prop disturbance is affecting water clarity.

Figure 16 compares average Secchi depth for days of the week over the long-term record (1974-2017) and more recently from 2011-2017 through the months of June to September. We included both time periods to help reduce sampling day bias. Monitoring data is not evenly distributed across days of the week, with most recent professional monitoring occurring in mid-week. Over the long-term record, Secchi clarity is poorest on Monday and Tuesday, while highest on Sunday readings. These findings would support the notion that weekend boat traffic may reduce clarity. However, during recent years, Secchi clarity is consistent across most weekdays except Wednesday when it is at its clearest. Wednesday is the highest frequency sampled day from 2011-2017, likely affecting that average. While we cannot completely rule out boat traffic having an effect on monitored water clarity, it does not appear to be a major driver of decreased clarity over the short term.

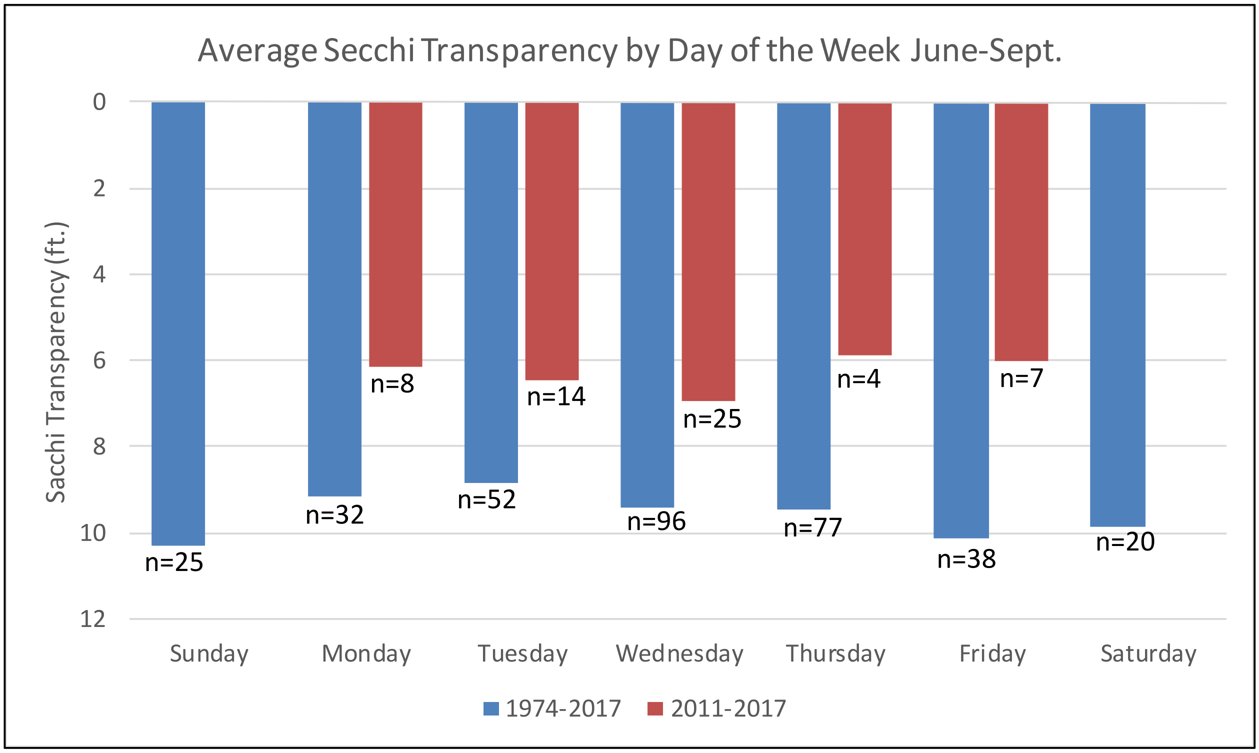


Figure 16 Average Secchi by Day of the Week June-Sept. in Lake George

More Frequent Wet Years

We examined whether variations in annual precipitation might be responsible for lake changes in transparency or nutrients. Lake tributaries were found to have the highest nutrients and lowest clarity during storms in general. Knowing that lakes often respond to average conditions over time, not individual storms, we compared lake conditions in wet and normal years. Wet years have poorer lake clarity. Moreover, wet years have become more frequent and poorer lake clarity has become more sustained. It appears that more frequent wet years can explain significant amounts of the water quality change seen in Lake George.

Water year precipitation is the total precipitation that falls from October 1 of the preceding year through September 30 of the reported year, rather than the total for a given calendar year. We use water year precipitation instead of calendar year precipitation totals because precipitation that falls as snow during the latter part of a calendar year is transported through the lakeshed as runoff the following year during spring melt instead of when it falls. The average water year precipitation over the past 100 years in the Lake George lakeshed is 29.5”, while the 90th percentile water year precipitation total is 37.7”. This 90th percentile water year precipitation total will represent a 10-year precipitation year for this report and our definition of a “wet year.”

These wet, 10-year precipitation years seem to cause an immediate decline in summertime Secchi clarity throughout the monitoring record. During, or immediately following, wet years, average Secchi clarity decreases by up to 2.74 feet compared to the long-term average (Table 5). Secchi clarity then rebounds during normal or dry precipitation years until the next wet year causes another decline. The frequency of 10-year precipitation years has increased recently, not allowing Secchi clarity to rebound. Four of the eight water years from 2010-2017 had over 37.7” of rain (Figure 17). Thus, at least for this period, an event that normally occurs 10% of the time occurred 50% of the time. During this same period, we see the longest sustained stretch of poor average annual Secchi on record.

If we remove the average annual Secchi clarity results from the particularly wet period of 2010-2017, there is no decline in Secchi clarity during 1981-2009 (Figure 18). Additionally, a homogeneity test shows a significant change ($p=0.025$) in the Secchi record starting in year 2010 (Figure 19), suggesting that the recent frequency of wet years have at least contributed to the long-term declining trend in Secchi clarity.

Specific recent years provide examples of the effect wet years have on Lake George transparency. Water years 2010 and 2011 each had greater than 37.7” precipitation. In 2011 the lake had its lowest average Secchi clarity and the highest average summertime total phosphorus on record. A superficial look at the graphed annual Secchi averages from 1974-2017 shows what appears to be the start of rebounding Secchi clarity in 2013 (not a wet year). This rebound is cut short, however, by the wet years of 2014 and 2016.

We also find that lake clarity is poorest during years when the lake level is high. From 1983 to 2017, there are 15 years with both lake level and Secchi transparency readings. In these years, there is a statistically significant correlation of high lake levels and poor Secchi transparency (Figure 20). It is likely that groundwater input to the lake is more constant than inflow from the lakeshed. During wetter years, lake levels are elevated due to increased runoff from the lakeshed.

Model results comparing loading during the thawed portion (5/1-11/30) of a normal precipitation year (2017) to a wet, 10-year precipitation year (2016) lend some insight into potential sources of increased runoff from the lakeshed. Total phosphorus increased by 24% (Figure 21), and total runoff increased by 19% (Figure 22) during the wet year. These increases are relevant only to the specific difference in precipitation during those two years, but what is more insightful is the comparison of pollutant loading change between individual subwatersheds.

High precipitation increased runoff and total phosphorus input to the lake from the northwest, north, and northeast subwatersheds by just a small amount according to the models. However, the Ditch 19 total phosphorus input increased by 56% with a runoff increase of 42%. The Near Lake subwatershed had an increase in runoff and total phosphorus load of 24% each. 96% of the total phosphorus load increase and 84% of the runoff increase from the lakeshed due to increasing precipitation came from these two subwatersheds. Figure 21 and Figure 22 show the total phosphorus load and runoff volume from the lakeshed by subwatershed for model years 2016 and 2017 using 2016 land use.

Water quality monitoring data from the lakeshed tributaries verifies model results that storm flows degrade water quality. During sampling at the three tributaries, average total dissolved phosphorus concentrations increased in each during storm flows, and more than doubled at the north inlet channel (Figure 22). Total suspended solids (TSS) concentrations also increased at the north inlet and Ditch 19 during storm flows (Figure 24). Similar to the model output, the NE inlet displayed only a small rise in total dissolved phosphorus (TDP), and a decline in total suspended solids (TSS), concentrations during storms. The open water wetland across South Lake George Drive from this inlet appears to be an effective BMP for mitigating storm flow pollutant loads at this inlet. However, storm flows do degrade water quality in the north inlet channel at the lake, meaning the models underestimate the loading increase from this subwatershed.

Table 5 Secchi Clarity Deviation from Mean During or Following 10-year Precipitation Years

Years with water year precipitation exceeding 90th percentile (>37.7" precipitation)	Same or following year Average Secchi (ft.)	Deviation in Secchi from Average (ft.)
Long Term Average (1974-2017)	9.43	N/A
1985	8.42	-1.01
1990	8.17	-1.26
1991	8.17	-1.26
1993	7.80	-1.63
2001	8.62	-0.81
2002	8.62	-0.81
2010	6.69	-2.74
2011	6.69	-2.74
2014	7.38	-2.05
2016	7.36	-2.07

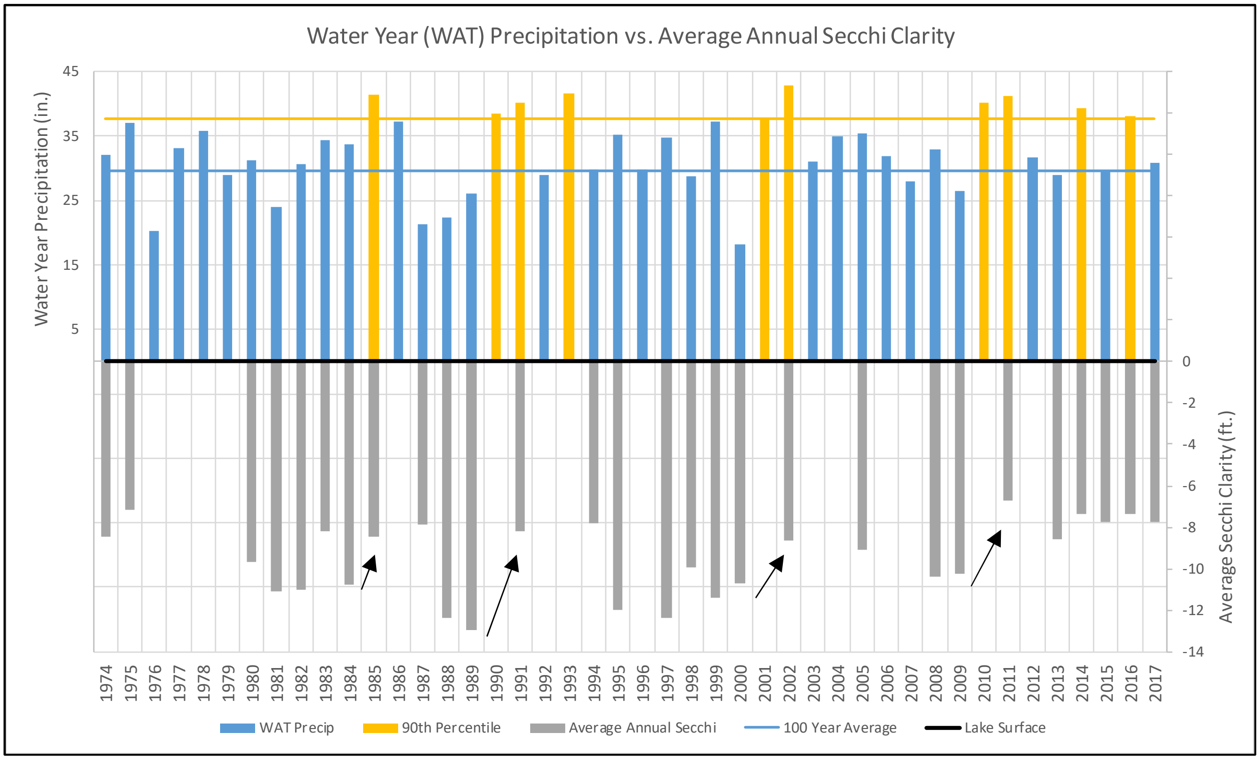


Figure 17 Area Water Year Precipitation and Average Secchi Clarity in Lake George Since 1974

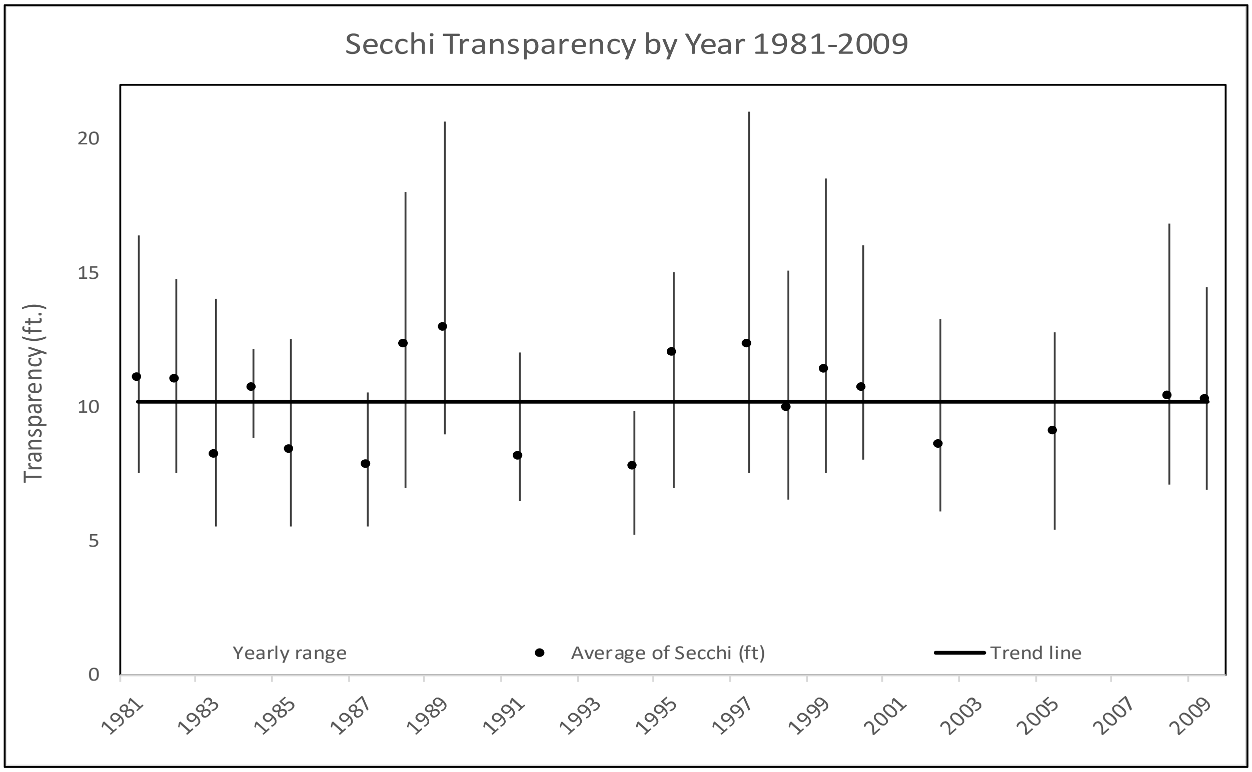


Figure 18 Secchi Transparency Average, Range, and Trend 1981-2009, Lake George

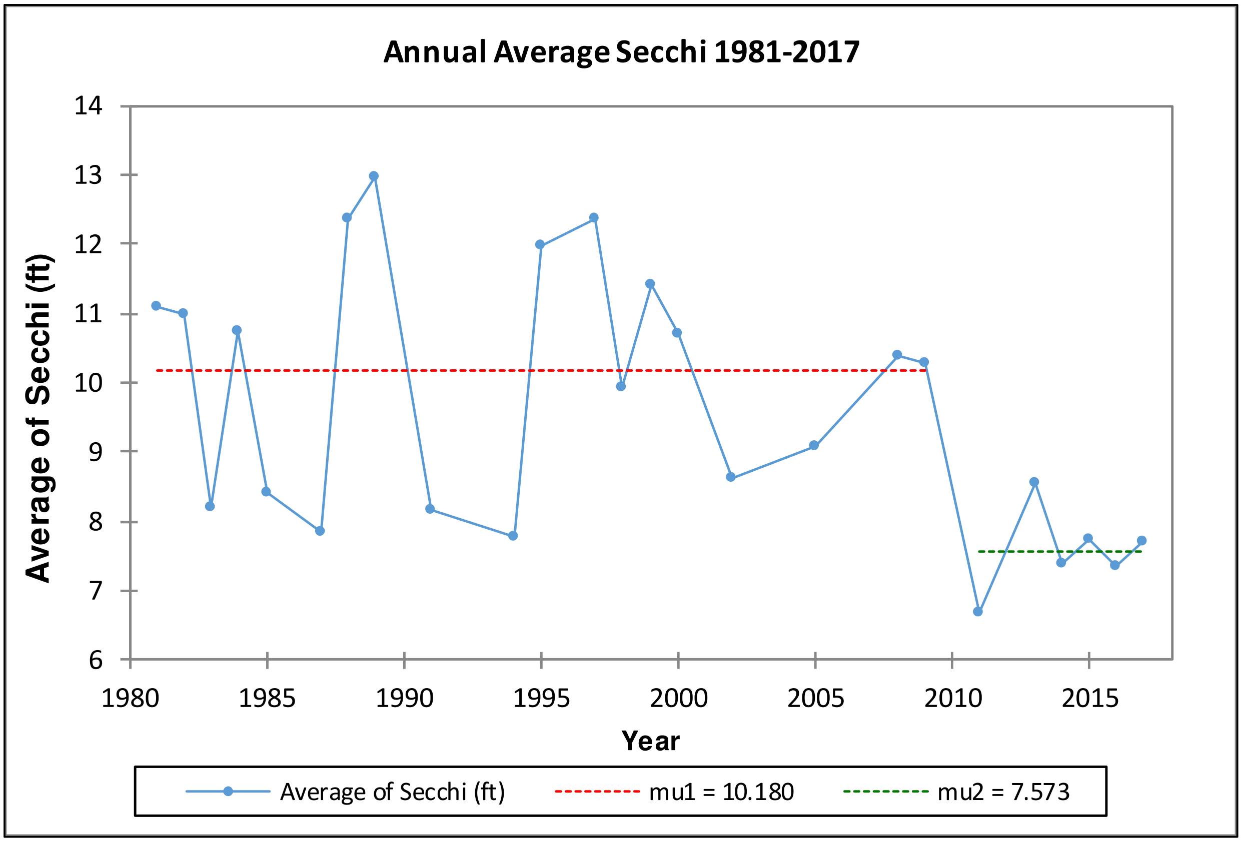


Figure 19 Average Annual Secchi Non-homogeneity, Lake George 1981-2017

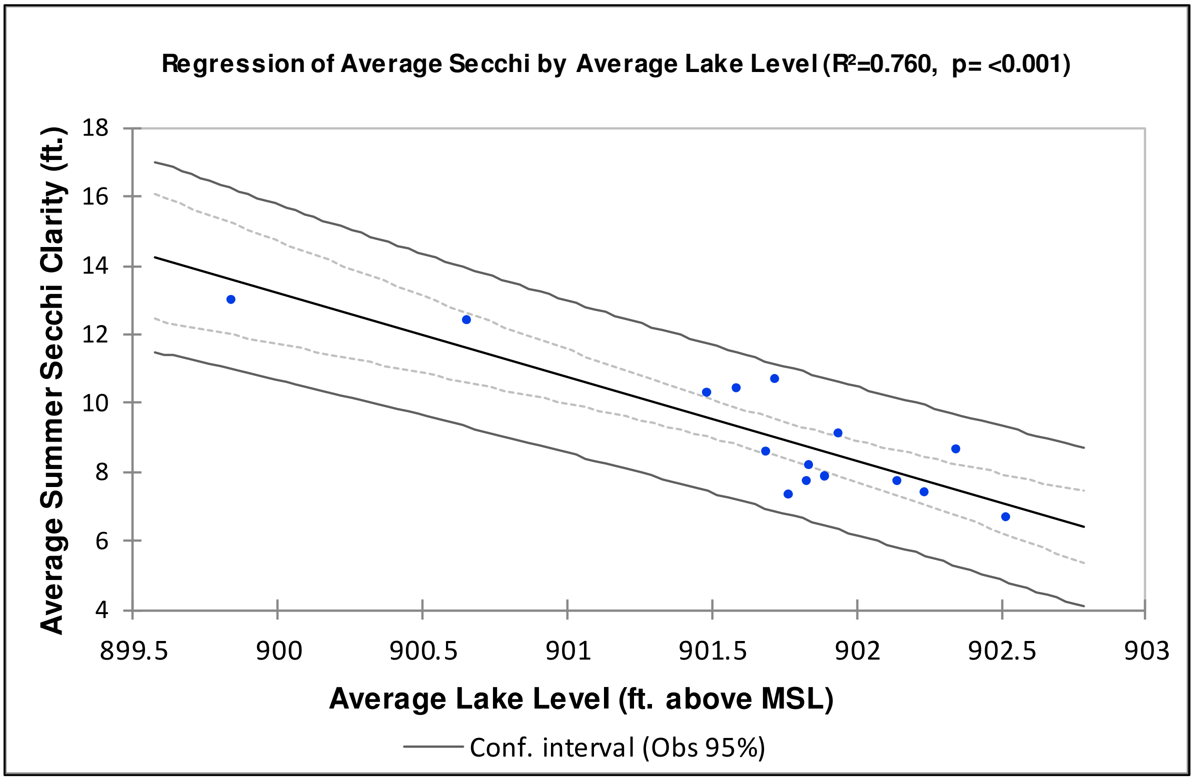


Figure 20 Regression of Average Summer Secchi vs. Average Lake Level, Lake George

Modeled Total Phosphorus Loading (pounds) from Lakeshed to Lake George Normal Precipitation Year (Model Year 2017, Top) vs Wet Year (Model Year 2016, Bottom)

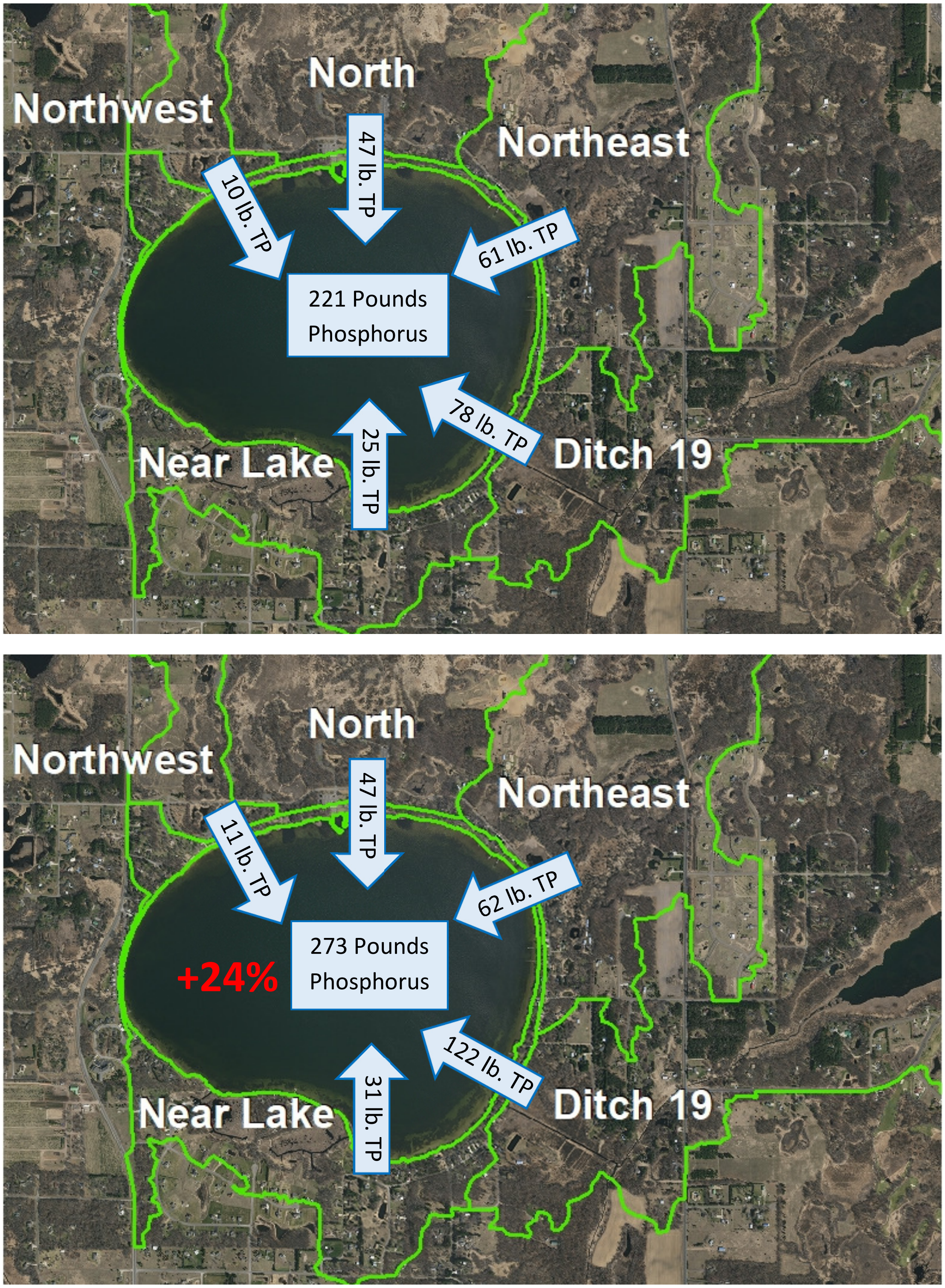


Figure 21 Modeled Total Phosphorus Loading from Lakeshed 2016 Land Use, Normal Precipitation Year (top) vs. Wet Year (bottom)

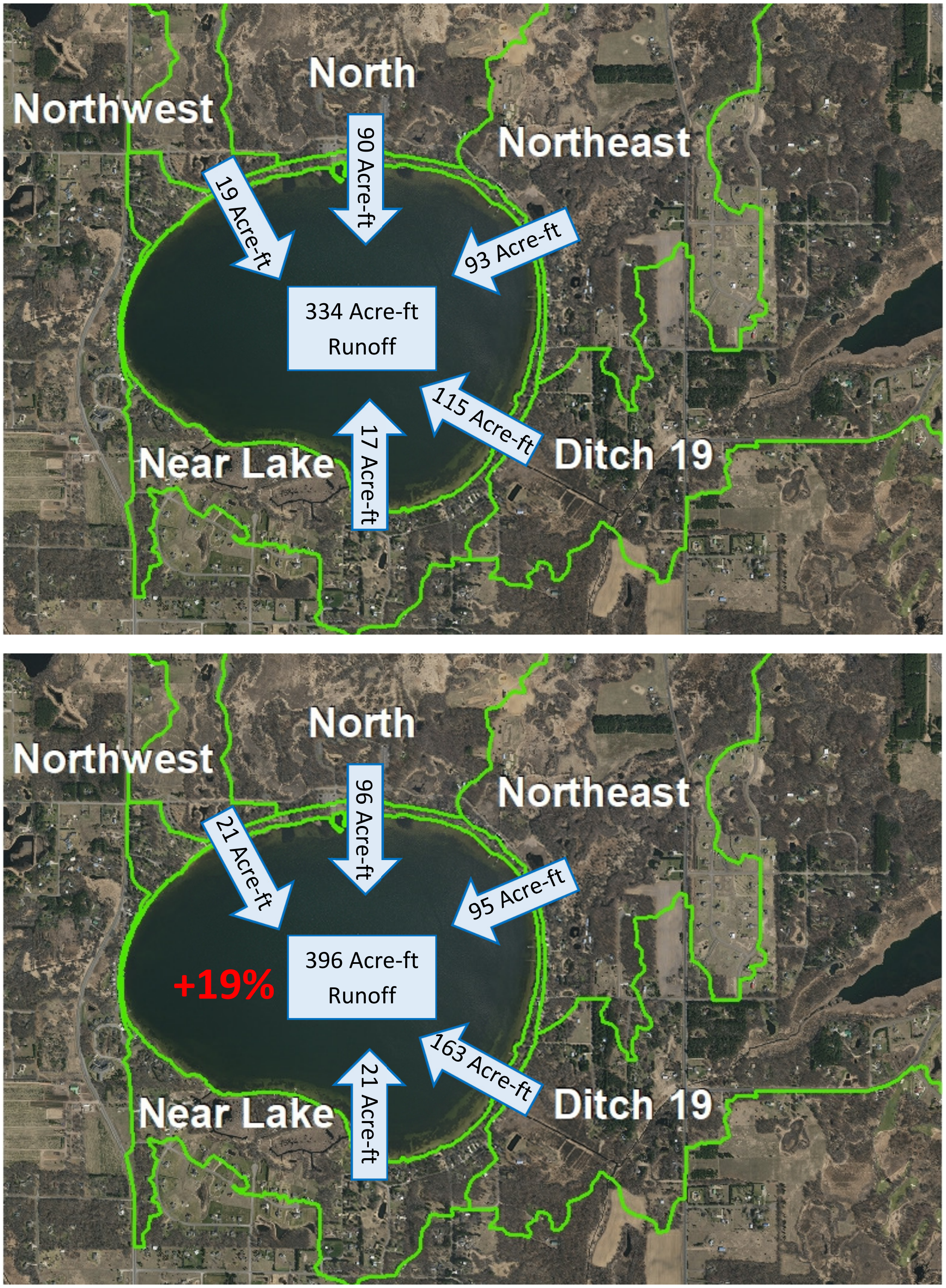

Modeled Runoff Volume (Acre-feet.) from Lakeshed to Lake George Normal Precipitation Year (Model Year 2017, Top) vs Wet Year (Model Year 2016, Bottom)

Figure 22 Modeled Runoff Volume from Lakeshed 2016 Land Use, Normal Precipitation Year (top) vs. Wet Year (bottom)

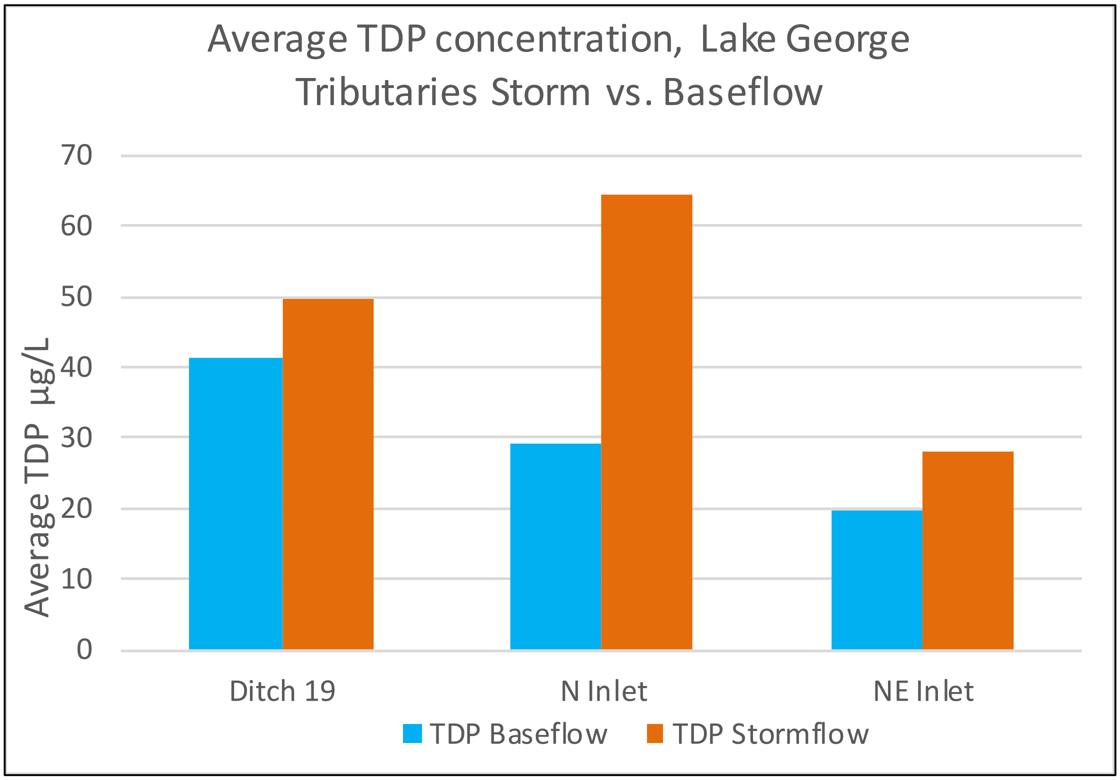


Figure 23 Lake George tributary TDP concentrations, baseflow vs. storm flow

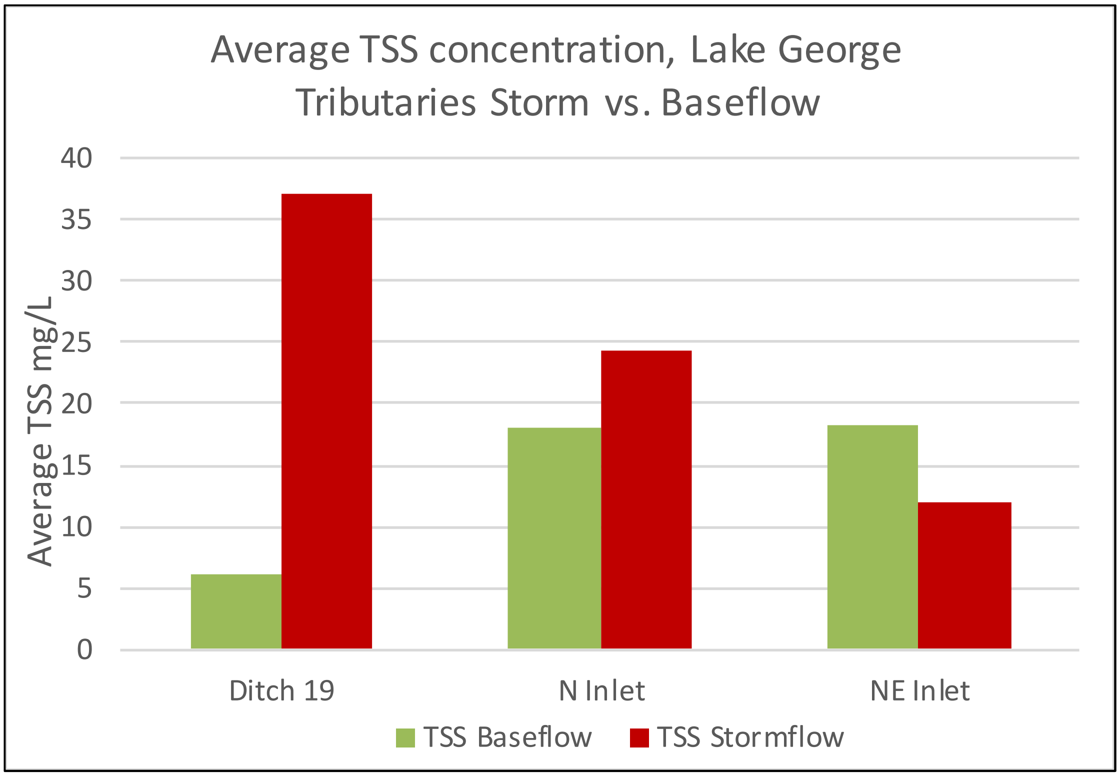


Figure 24 Lake George tributary TSS concentrations, baseflow vs. storm flow

Warmer Water

Lake warming over time can cause increased biological activity including enhancing plant and algae growth that may affect water quality. Lake George water clarity is best when the water is cooler (Figure 25). However, this is of little surprise given that seasonally lakes are usually clearest in spring and fall when biological activity is lower. The important question then is whether the lake has warmed over time. It does not appear that the lake has warmed across years since 1999 (Figure 26).

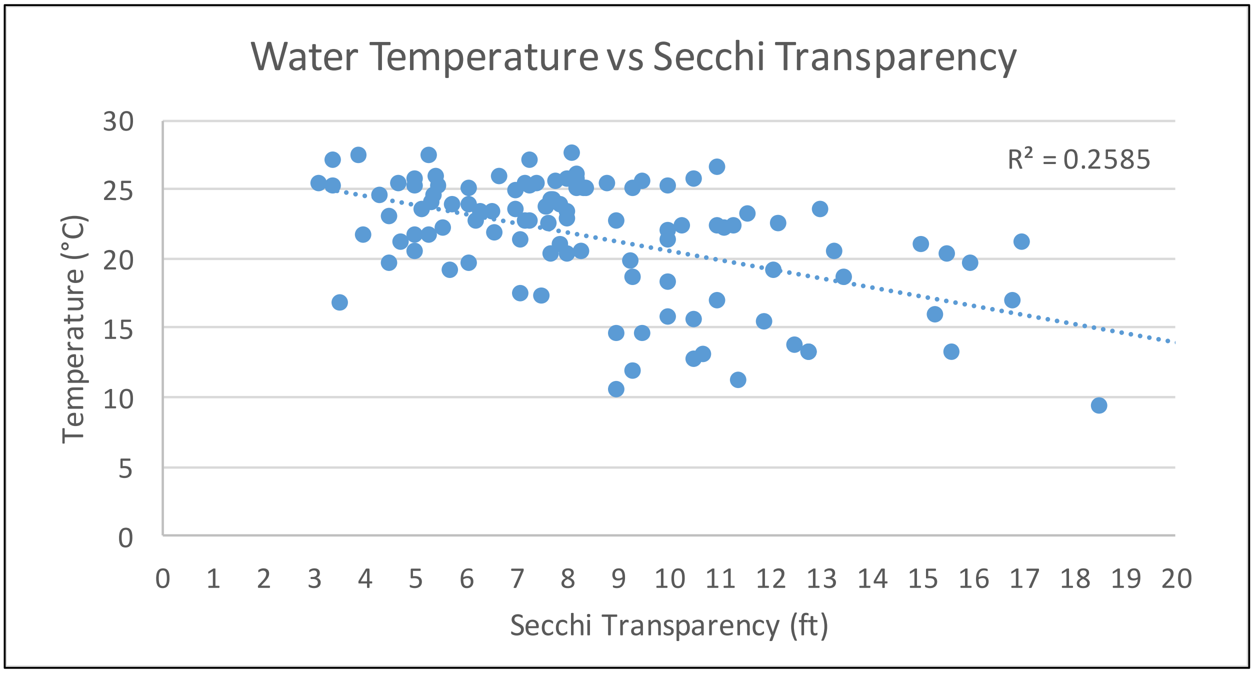


Figure 25 Lake George transparency and water temperature scatter plot

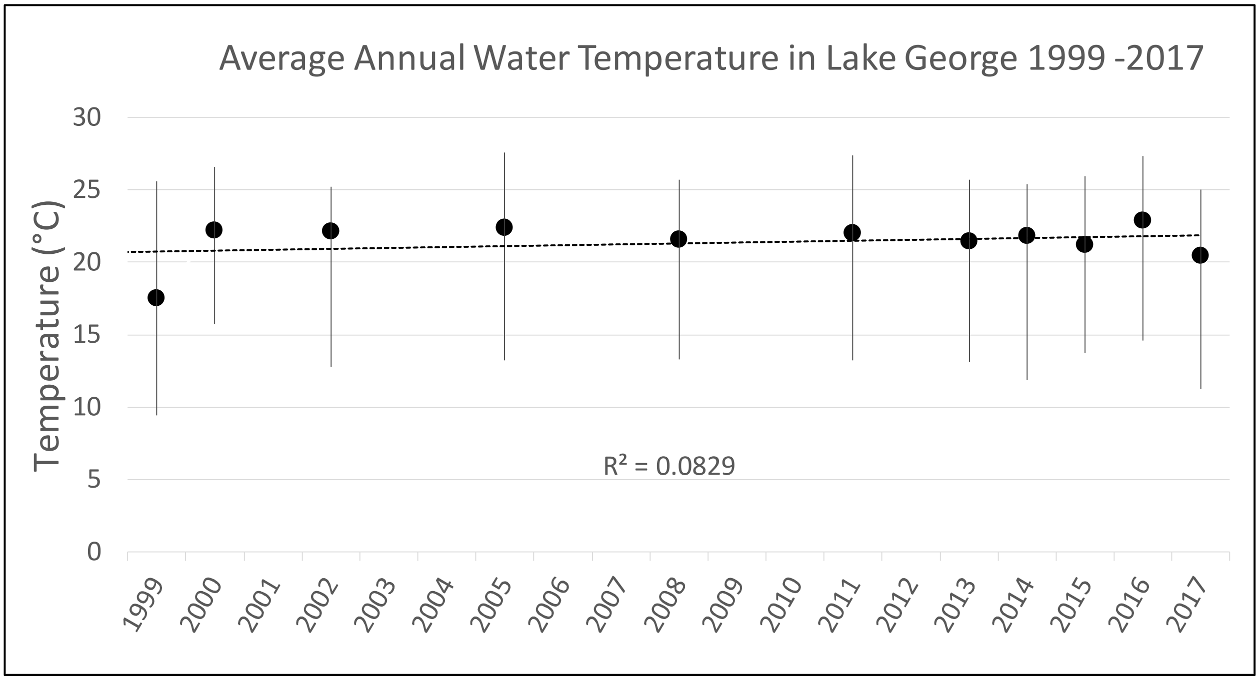


Figure 26 Lake George average water temperature across years

Land Use Change

Changes in the proportions and types of land uses that make up a lakeshed can have dramatic effects on lake water quality. We modeled current and projected land uses specific to the Lake George lakeshed to estimate whether land use changes will affect lake water quality. The anticipated land use changes will result in larger nutrient and sediment loading to the lake assuming no additional stormwater treatment.

Land use change can result in greater stormwater runoff and conveyance systems that deliver water to lakes and rivers. As more natural land gets converted to houses, streets, parking lots, and even fields, less precipitation is able to infiltrate as it falls, causing an increase in stormwater runoff. This runoff can cause issues with flooding in a developed landscape so stormwater conveyances, like ditches and storm sewers are often used to flush the water away even faster. As development continues, infiltration continues to decrease and stormwater conveyances continue to move more water to lakes and streams more rapidly. Nutrients and sediment are carried with stormwater runoff. While stormwater treatment ponds and other practices can remove some of these pollutants, they do not remove it all.

As mentioned earlier in this report, land use change in the Lake George lakeshed is shifting toward more rural residential. Loading of total phosphorus and total suspended solids was modeled with high precipitation and normal precipitation using both current land use and projected 2030 land use for each subwatershed of the Lake George lakeshed. The models assume no additional BMPs or stormwater treatment practices are installed and gives a worst case scenario that shows how not implementing practices to contain and treat stormwater as development continues could affect Lake George.

We also sought to compare pre-2016 land use to 2016 land use to estimate how much these conversions have contributed to changes in the lake. We were unable to do so due to lack of compatible resolution past land use data. As such, this analysis focuses on the possible impacts of future development, not the impacts of past changes.

In a normal precipitation year, total phosphorus transported to the lake increased by 65% when comparing 2016 land use to 2030-projected land use in the lakeshed, assuming no additional stormwater treatment (Figure 27). Runoff volume from the lakeshed increased by 56% under the same modeled conditions (Figure 28). These increases are even more significant than the effects of a wet year compared to a normal precipitation year with current land use.

Assuming it is at least possible, and potentially even likely, that high precipitation years and continued development will both continue to occur into the future makes the need for maximizing stormwater treatment even more pressing. When combining the effects of high precipitation and continued development by modeling current land use and normal precipitation vs. 2030-projected land use and a wet precipitation year, both total phosphorus and runoff volume to Lake George from the lakeshed double. Precipitation patterns into the future cannot be predicted, but a stormwater management strategy aimed to treat the worst-case scenario, rather than long-term averages may be in order. If recent years are any indication, the long-term average rainfall may only represent a dry year in the near future.

Modeled Total Phosphorus Loading (pounds) from Lakeshed to Lake George, Normal Precipitation, 2016 Land Use (Top) vs. Projected 2030 Land Use (Bottom)

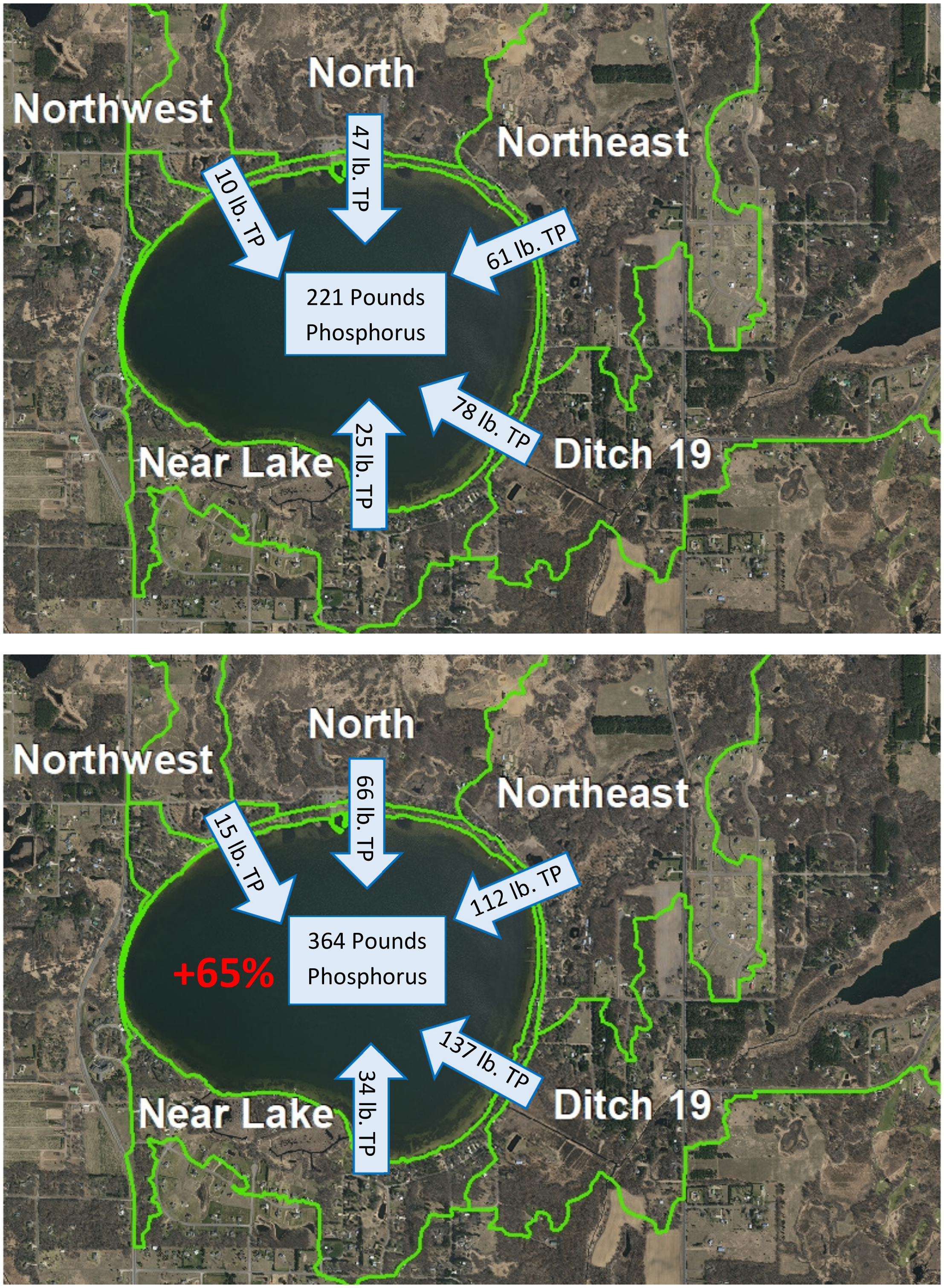


Figure 27 Modeled Total Phosphorus Loading from Lakeshed 2016 Land Use, Normal Precipitation 2016 Land Use (Top) vs. Projected 2030 Land Use (Bottom)

Modeled Runoff Volume (Acre-feet) from Lakeshed to Lake George, Normal Precipitation, 2016 Land Use (Top) vs. Projected 2030 Land Use (Bottom)

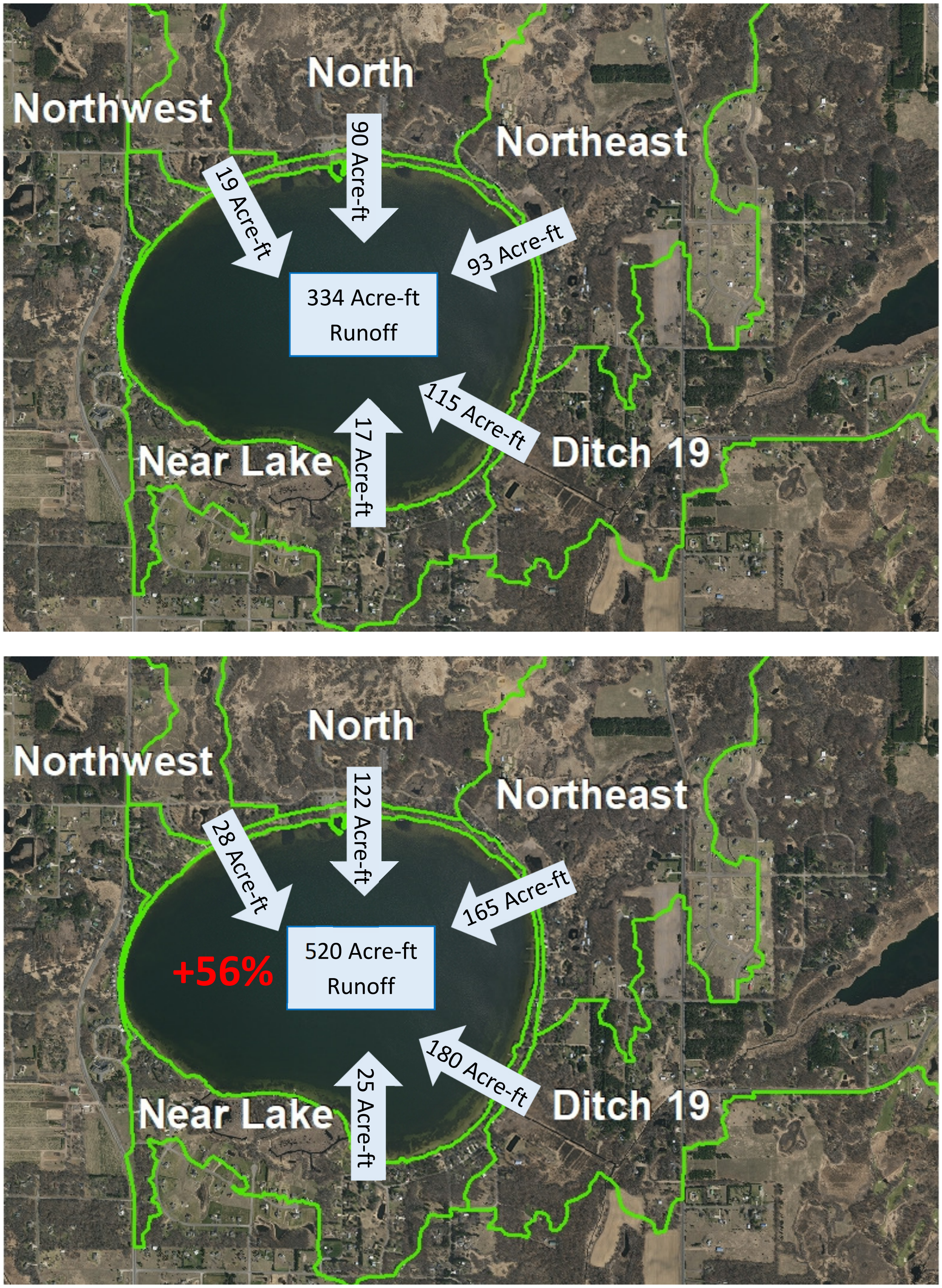


Figure 28 Modeled Runoff Volume from Lakeshed 2016 Land Use, Normal Precipitation, 2016 Land Use (Top) vs. Projected 2030 Land Use (Bottom)

Ditch 19 Weir Deterioration

The Ditch 19 weir southeast of Lake George serves as an inlet, outlet and level control structure for Lake George. Over the decades, the steel weir has deteriorated and is no longer functioning at its original elevation. This has consequences for lake levels and lake water quality. Weir deterioration is likely a contributing factor to clarity declines in Lake George, but is not the major driving cause.

Whether Ditch 19 flows into Lake George or the lake outflows to the ditch is dependent upon water levels. See Figure 29 depicting Ditch 19, the weir location, and the connector channel to Lake George. Ditch 19 flows from the northeast before approaching the weir structure. Water then either flows west towards Lake George or south over the weir towards the Rum River. Under baseflow conditions, water flows out of Lake George via the connector channel into Ditch 19 and south over the weir. Intense storm events in the watershed may raise Ditch 19 water levels over Lake George levels and reverse flow in the connector channel towards Lake George for a short period of time. The elevation of the weir structure ultimately serves at the water level control device for Lake George.

The current sheet piling weir structure, and preceding concrete control features have a long, but fragmented historical record dating back to at least 1895 (MN Department of Natural Resources, Staff Correspondence 2017). However, there is very little documentation of the progression of disrepair of the current weir. The weir was constructed with a spillway elevation of 902.08’ (NAVD88) in the 1950s. An ACD survey conducted 11/30/2017 suggests that the lowest point over the weir spillway controlling elevation in Ditch 19 is now 901.59’ (NAVD88), 0.49’ lower than design.

The current weir is rusting away. It is approximately 6 inches lower than constructed. This results in the lake outflowing to the ditch more often. The lake receives Ditch 19 water less often. This has implications for the lake’s water budget and water quality that are best explored with the hydrologic model that is based on actual observed Ditch 19 water levels and water quality. Modeling the design spillway elevation vs. the current effective spillway elevation results in only a negligable change in flow to Lake George through Ditch 19 with current land use practices in the lakeshed (+/- 2% flow). However, with projected 2030 land use modeled, the design weir at 0.49’ higher reduces storm event runoff to the lake from Ditch 19 by 6.2% during a wet year, and by 7.9% during a normal precipitation year. Total phosphorus loads to the lake were reduced by 5.6% and 8.0% respectively under the same conditions.

According to the SWMM model, the repaired weir should help combat some of the effects of development and potentially increased storm intensity by reducing storm flows to the lake from Ditch 19, particularly during high precipitation and increased runoff due to development scenerios. See Appendix 2 for model loading results at weir elevations 901.59’ and 902.08’ (NAVD88).

The weir is scheduled to be replaced in 2019 to the original design elevation. The effective change in spillway elevation will be about six inches higher than currently, which will likely have an impact on both average lake levels and loading to the lake from the lakeshed, especially from Ditch 19. The new weir structure will also facilitate fish passage to and from the lake from downstream, a function the current weir design prevents. This will likely have an impact on fish communities in Lake George by aiding the spawning of gamefish species.

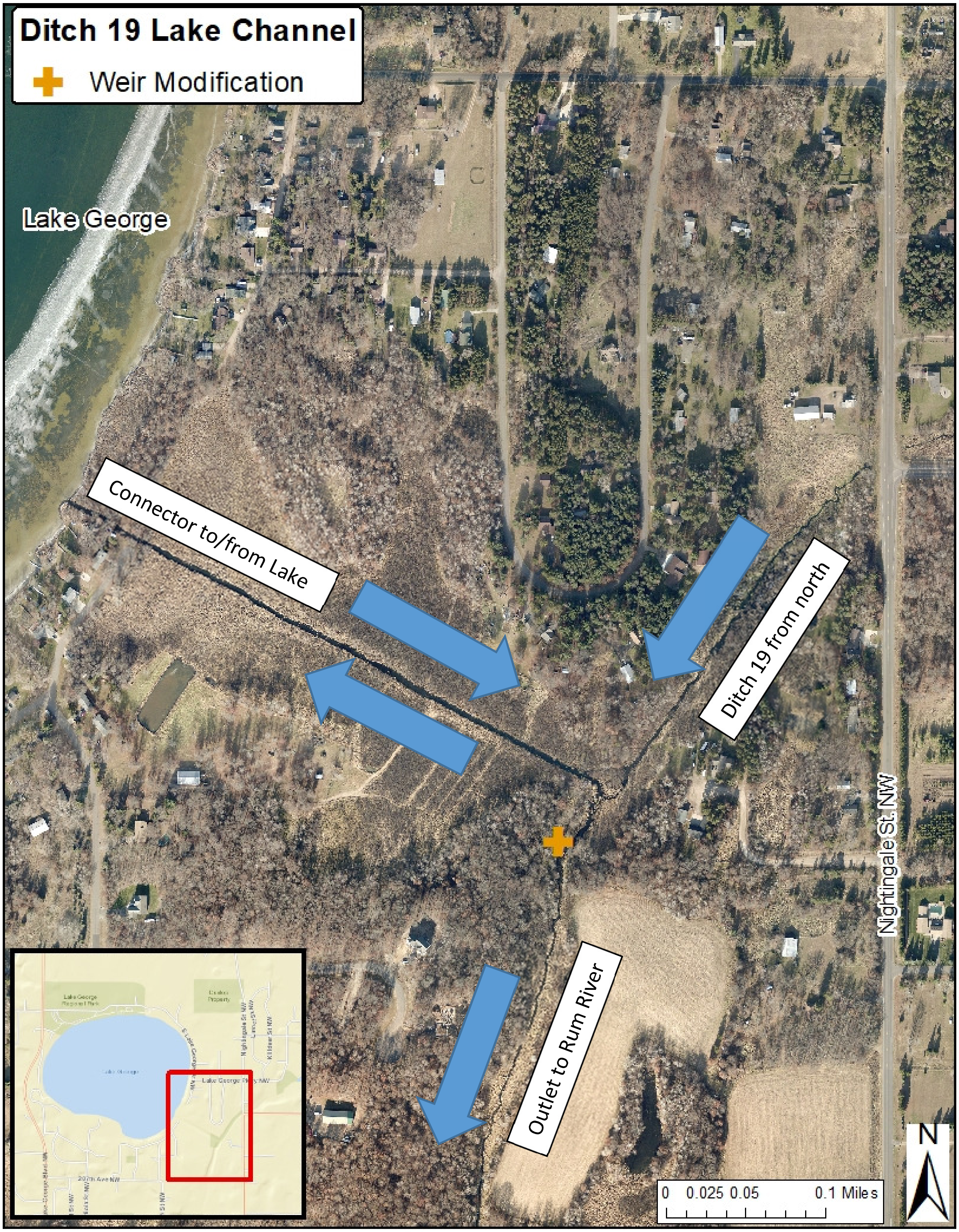


Figure 29 Ditch 19 weir and lake connector channels

Factors Not Examined

Lakes and lakesheds are very large systems that are sensitive to many environmental factors, both outside and inside the lake itself. The water quality of a lake represents the equilibrium reached by all of these factors interacting with each other. While we have examined many of the potential contributing factors to Lake George's decline in water quality from the lakeshed in this report, there remain a number of factors within and immediately surrounding the lake itself that may be contributing to water quality issues. Some of the factors that may be affecting the water quality of Lake George but not examined in this report include rough fish, game fisheries, in-lake nutrients from sediment and lake turnover, wave action, and a host of other potential factors contributing to a water quality decline.

Lakeshed Modeling Methods

The Anoka Conservation District contracted Wenck Associates engineering firm to build computer models of the Lake George lakeshed to assess the effects of land use change, weir repair, precipitation changes and project installation on the water quality of Lake George. Two models were produced; a SWMM model used for hydrologic modelling and a P8 model used for water quality modelling. Used in conjunction, these models give us a good idea of hydrologic and pollutant loading into Lake George from its lakeshed and individual subwatersheds.

The lakeshed and individual catchments were delineated using ArcSWAT software and a 1-meter digital elevation model (DEM) of the area. Catchments were then given impervious fractions and runoff curve numbers based on land use types and acreage. Existing basins were built into the models and given storage capacities based on LiDAR elevation data. For more information on model development, see Appendix 3- Wenck Associates Technical Memos

Hydrologic and nutrient loading from the lake were modeled using the P8 and SWMM models in conjunction. Models were run from 1/1/2013 to 11/30/2017, with results recorded from 5/1/2016-11/30/2017. Winter model flow and loading results can vary greatly, so the loading period assessed for years 2016 and 2017 was 5/1-11/30 of each year.

Hydrologic results in SWMM were recorded in continuous 15-minute intervals. To calculate total flow to the lake from each subwatershed during a normal precipitation year, flow was totaled from each subwatershed to the lake from 5/1/2017 to 11/30/2017. To calculate total flow to the lake from each subwatershed during a wet or high precipitation year, flow was totaled from each subwatershed to the lake from 5/1/2016 to 11/30/2016. For precipitation totals used in data analysis and model runs see Table 6 Precipitation Totals for Model Years and WAT Years 2016 & 2017

Water quality results as average concentrations of total phosphorus (TP) and total suspended solids (TSS) are reported by catchment from P8 run during the same time intervals, as either a time interval average or storm event average. For all subwatersheds other than Ditch 19, this time interval concentration average was applied to the total inflow to the lake to determine model year loading in pounds. For Ditch 19, which has a net flow out of Lake George but reverses to the lake during large storm events, storm event average concentrations were applied to the total storm event flow of each storm that reversed flow to the lake to calculate event based loads. All events that caused a reversed net flow for at least one full day had an event load calculated and were included in the annual load sum.

Table 6 Precipitation Totals for Model Years and WAT Years 2016 & 2017

Year, Modeled and Precipitation WAT	WAT Year Precipitation Total (in.) *MN Climatology Office*	Model Year Interval (5/1-11/30) Precipitation Total (in.) St. Francis Composite CoCoRaHS gauges
2016	38.02	29.92
2017	30.91	24.53

Management Strategies for Lake Water Quality

A variety of management strategies to improve lake water quality were identified and included in the recommendations on the following pages. Subwatershed pollutant loading and the estimated water quality benefits from each project were modeled or calculated using a variety of software tools. Table 7 lists the project types identified, a description of each, estimated project life, and the model or calculator used to estimate the treatment efficacy of each.

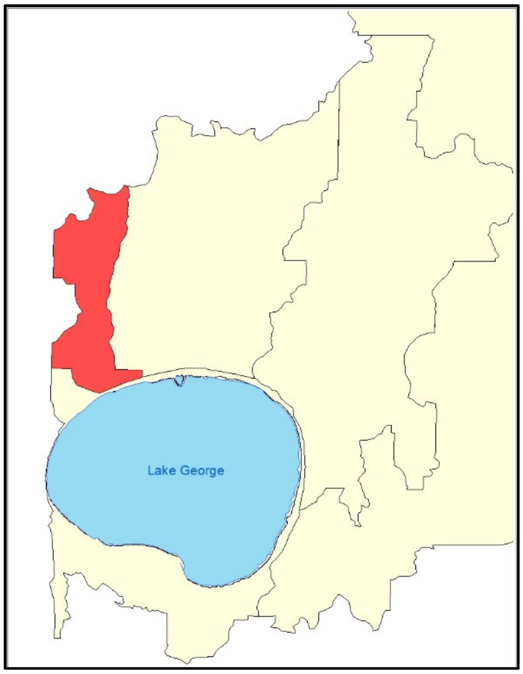
Table 7 Project Types Identified in the Lake George Lakeshed

Project Type	Description	Project Life (Years)	Modeling Method
Lakeshore Stabilizations	Stabilization of actively eroding lakeshore through structural and bioengineering techniques	10	WI NRCS Shore Erosion Calculator
Shoreline Buffer Strips	Native vegetation planted along the lakeshore to filter sediment and phosphorus from overland storm runoff before it enters the lake	10	WinSLAMM
Ag. Land Riparian Buffers	Perennial vegetation planted along drainage ways through agricultural fields to filter sediment and phosphorus	10	BWSR Buffer Decision Support Tool
Ag. Land Cover Crops	A non-harvested crop planted between regular crop rotations to improve soil and prevent erosion	1	BWSR Buffer Decision Support Tool
Grassed Waterway	Planting channelized depressions in ag fields with perennial vegetation to filter sediment and phosphorus, and avoid gully formation	10	WI NRCS Grassed Waterway Calculator
Iron Enhanced Sand Filter	Iron Enhanced Sand Filters are filters through which stormwater or a stream is filtered. The filter contains positively charged iron which bind with negatively charged dissolved phosphate and stores it indefinitely	30	Anoka Conservation District IESF Calculator
Yard Waste Cleanup	Remove yard waste and/or sediment disposed of in or next to waterbodies, and prevent future similar disposal	n/a	n/a
Weir Modification	Rehabilitate the Ditch 19 weir which serves as a hydrologic control for Lake George	50	SWMM P8

Catchment Profiles

Northwest Subwatershed

Subwatershed Summary	
Acres	126
Dominant Land Cover	Parkland/Undeveloped
Volume (acre-ft./yr)	19
TP (lb/yr)	10
TSS (lb/yr)	308



Subwatershed Description

The northwest subwatershed is characterized primarily by undeveloped or park land use, with about 10% of the subwatershed consisting of rural residential usage. There is no channelized outfall to Lake George from this subwatershed. Wetlands in the lower reaches of the subwatershed contain most runoff with overflow passing overland and across a county park parking lot to enter the lake.

Existing Stormwater Treatment

No dedicated stormwater conveyance or treatment infrastructure exists in this subwatershed. With natural wetlands providing storage for most runoff, the only real potential area to catch overflow would be to intercept that which flows overland across the parking lot adjacent to the lake. Most of the parking lot area however, slopes back toward the wetlands to its north and not the lake. Little, if any, runoff reaches the lake untreated from this subwatershed.

Project Recommendations

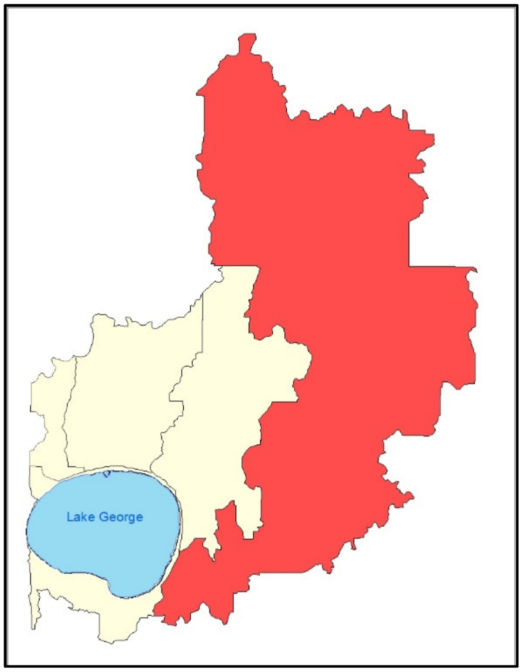
Due to the land use of this subwatershed being almost exclusively undeveloped open, wooded, or wetland space with no defined drainage to Lake George, we have no BMP or good housekeeping project recommendations in this area.

Water Quality

Due to the lack of a defined inlet, water quality was not monitored for this subwatershed. Modeled data, however, shows the lowest pollutant loads by mass and mass per acre for this subwatershed. With so little development in the watershed, and wetlands receiving storm water near the lake, there are no water quality concerns to address for this subwatershed.

Ditch 19 Subwatershed

Subwatershed Summary	
Acres	3,136
Dominant Land Cover	Undeveloped
Volume (acre-ft./yr)	115
TP (lb/yr)	78
TSS (lb/yr)	4,805



Subwatershed Description

The Ditch 19 subwatershed makes up about 65% of the total Lake George lakeshed. The primary land cover is a mix of ditched row crop and sod agriculture with vacant upland and wetland. Approximately 350 acres of this subwatershed are actively farmed. Row cropped areas have intensive ditching with no vegetated buffer strips resulting in ditch slumping and filling. Approximately 400 acres of three separate rural developments lie within the subwatershed. Each of these developments is comprised of lots 2 to 10 acres in size with single-family houses. There is also a 25-acre sand mining operation.

Existing Stormwater Treatment

Approximately 2,900 acres or 92% of the subwatershed flows through Grass Lake before crossing Nightingale Street and approaching Lake George. Monitoring efforts suggest that Grass Lake is quite effective at treating stormwater from most of the Ditch 19 subwatershed before it approaches Lake George. There are additionally four small detention basins in one of the developments that provide some level of containment and treatment of stormwater. There is concern that while Grass Lake provides effective treatment today, its capacity to do so in the future may be limited if upstream lands are not managed in a way that minimizes sediment and nutrient generation. In general, land that is disturbed for agriculture and mining in this subwatershed is done so in a manner that is highly susceptible to erosion.

Water Quality

The Ditch 19 subwatershed generally had good to fair water quality during baseflow conditions throughout the subwatershed, but during storm flows water quality and clarity degraded substantially in the upper reaches. Grass Lake is shown by both modeling and monitoring data to be an effective natural filter or settling basin to treating Ditch 19 water. Additionally, Ditch 19 only inlets into Lake George during high flows when ditch levels are higher than the lake, therefore most Ditch 19 water never enters Lake George. Due to these factors, projects installed in this subwatershed, especially upstream of Grass Lake, will not result in the full reported removal rates at the lake itself.

Project Recommendations

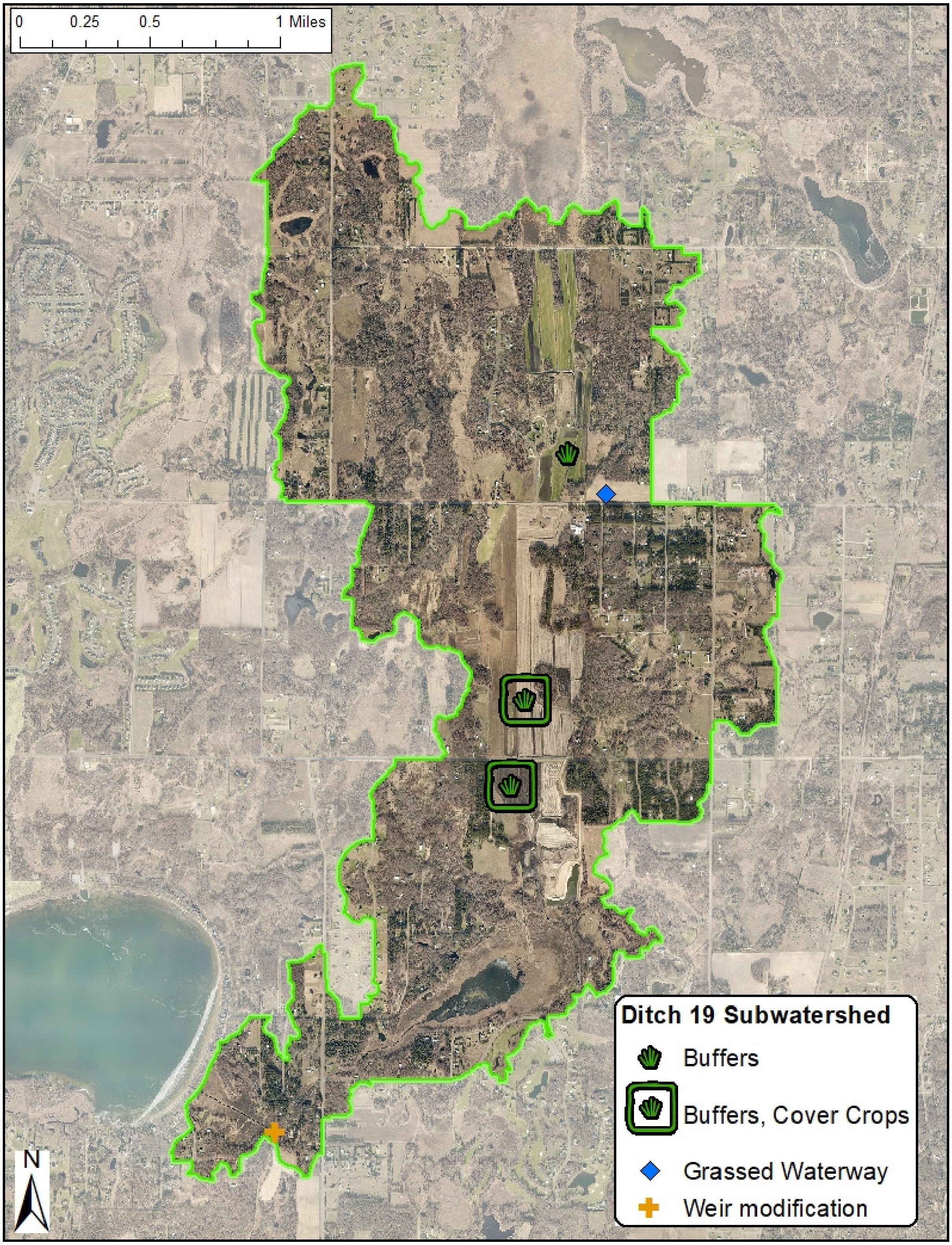


Figure 30 Ditch 19 Subwatershed BMP Retrofit Recommendations

Cropland Buffers

Location- Ditch 19 subwatershed, agricultural ditches

Property Ownership- Private

Description- Vegetative buffers planted along ditches remove sediment and nutrients from stormwater flowing overland as sheet flow or in field gullies before the water enters the ditch system. Cropland that is periodically tilled up and left bare, is especially susceptible to sediment and nutrient loss to sheet flow, and readily allows gullies to form where water channelizes due to the lack of any stabilizing vegetation.

In the Ditch 19 subwatershed, there are 17.5 miles of bufferable ditch (one mile of ditch with field on both sides has two bufferable miles). Of these 17.5 miles, 5.5 miles are now required to have 16.5-foot wide buffers of perennial vegetation in place by state law. Cost benefit analyses are provided for this scenario, as well as various scenarios of increased buffer implementation beyond the minimum required by law.

Growing and harvesting sod within the buffer area is considered compliant with MN law, but in this analysis buffers acres installed in sod fields are expected to be permanently in place and not harvested. Sod field buffers are only included in the 100% cost benefit scenarios because they are the least likely to be installed.

Conceptual image- How buffers protect water

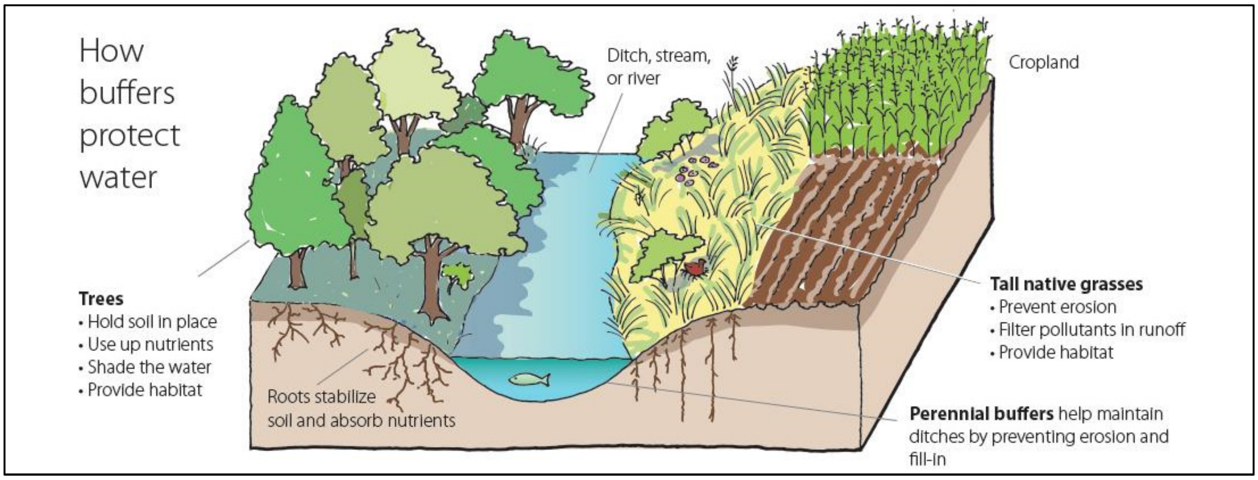


Figure 31 How buffers protect water (Governor Proposes Buffer Initiative to Protect, Improve Water Quality 2015)

Cropland Riparian Buffers- 16.5'

	Cost/Removal Analysis	New Treatment	% Reduction	New Treatment	% Reduction	New Treatment	% Reduction	New Treatment	% Reduction
Treatment	**16.5' Buffers Installed**	Required by Law Only		50% Row Crop Ditches		100% Row Crop Ditches		100% Row + Sod Ditches	
	Ditch Miles Buffered	4.00	22.9%	5.82	33.2%	11.63	66.5%	17.50	100.0%
	BMP Treatment Area	8.00	Acres	11.63	Acres	23.26	Acres	35.00	Acres
	TP (0.26 lb/acre/yr)	2.08	1.0%	3.02	1.5%	6.05	3.0%	9.10	4.6%
	TSS (3.19 ton/acre/yr)	25.52	1.9%	37.10	2.8%	74.20	5.7%	111.65	8.5%
	Volume (acre-feet/yr)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Cost	**Administration & Promotion Costs***	$3,212		$3,212		$3,212		$3,212	
	Design & Construction Costs**	5,704		6,702		9,901		13,129	
	Total Estimated Project Cost (2018)	**$8,916**		**$9,914**		**$13,113**		**$16,341**	
	Annual O&M***	$800		$1,163		$2,326		$3,500	
Efficiency	**30-yr Average Cost/lb-TP**	**$528**		**$494**		**$457**		**$444**	
	30-yr Average Cost/1,000lb-TSS	**$21**		**$20**		**$19**		**$18**	
	30-yr Average Cost/ac-ft Vol.	**n/a**		**n/a**		**n/a**		**n/a**	

*44 hours at $73/hour for promotion and administration

**$275/acre for site prep and installation plus 48 hours at $73/hour for design/contracting

***Mow once per year at $100/acre

Cropland Riparian Buffers- 50'

	Cost/Removal Analysis	New Treatment	% Reduction	New Treatment	% Reduction	New Treatment	% Reduction	New Treatment	% Reduction
Treatment	**16.5' Buffers Installed**	50% Row Crop Ditches		100% Row Crop Ditches		100% Row + Sod Ditches			
	Ditch Miles Buffered	5.82	33.2%	11.63	66.5%	17.50	100.0%		
	BMP Treatment Area	35.24	Acres	70.48	Acres	106.06	Acres		
	TP (0.50 lb/acre/yr)	17.62	8.8%	35.24	17.7%	53.03	26.6%		
	TSS (3.98 ton/acre/yr)	140.26	10.7%	280.53	21.4%	422.12	32.2%		
	Volume (acre-feet/yr)	n/a	n/a	n/a	n/a	n/a	n/a		
Cost	**Administration & Promotion Costs***	$3,212		$3,212		$3,212			
	Design & Construction Costs**	13,196		22,887		32,671			
	Total Estimated Project Cost (2018)	**$16,408**		**$26,099**		**$35,883**			
	Annual O&M***	$3,524		$7,048		$10,606			
Efficiency	**30-yr Average Cost/lb-TP**	**$231**		**$225**		**$223**			
	30-yr Average Cost/1,000lb-TSS	**$15**		**$14**		**$14**			
	30-yr Average Cost/ac-ft Vol.	**n/a**		**n/a**		**n/a**			

*44 hours at $73/hour for promotion and administration

**$275/acre for site prep and installation plus 48 hours at $73/hour for design/contracting

***Mow once per year at $100/acre

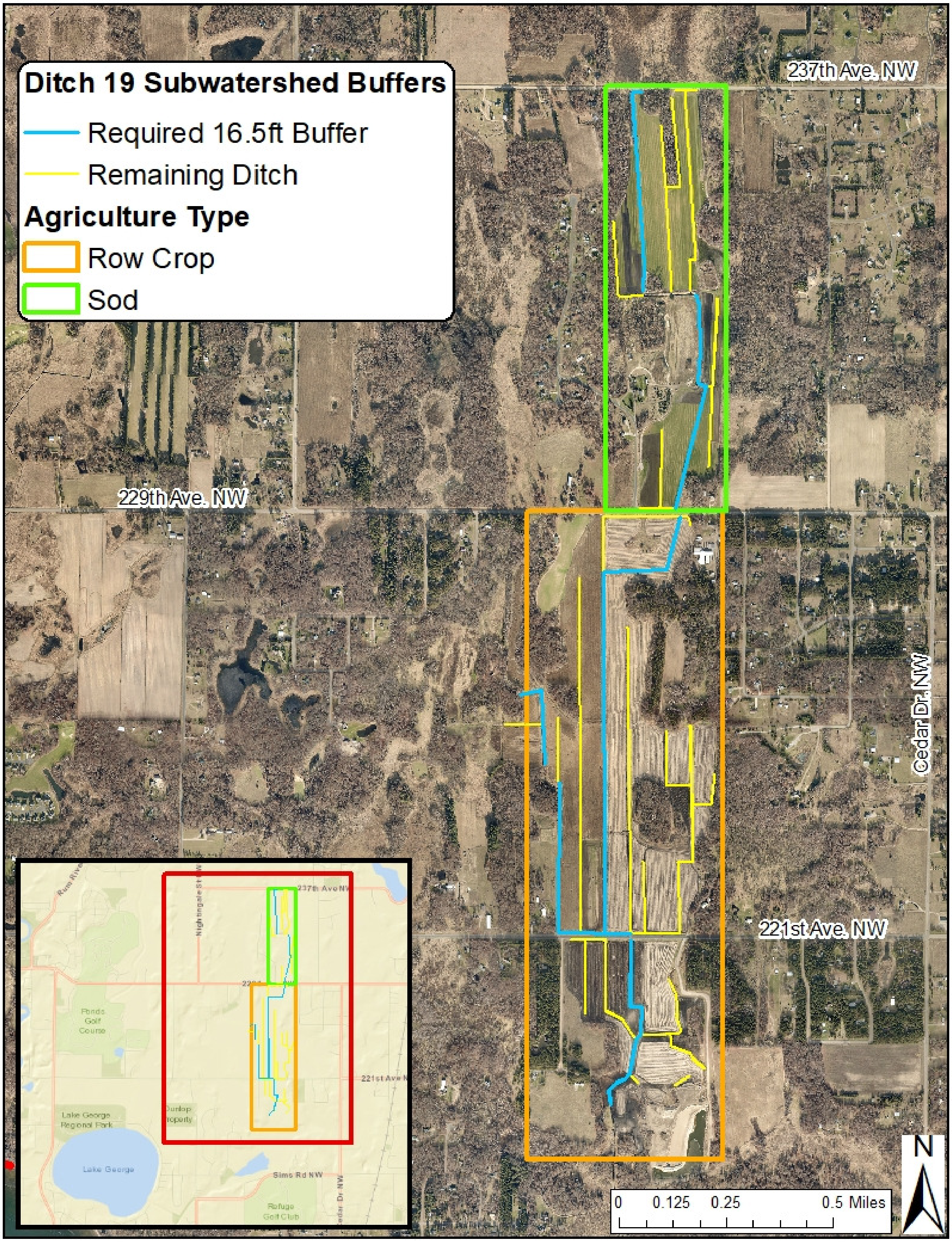


Figure 32 Ditch 19 subwatershed ditches in agricultural areas where buffers could be installed

Cropland Cover Crops

Location- Ditch 19 subwatershed, row cropped fields

Property Ownership- Private

Description- Cover crops are a non-harvested crop planted between regular crop rotations to improve soil health, prevent erosion, and even increase yields of cash crops in some circumstances (NRCS Minnesota 2013). They would not be installed in areas planted in sod. Cover crops help stabilize the soil in agricultural fields by quickly vegetating the field after tillage. This is especially true when cover crops are planted and germinate after fall tilling where the soil would otherwise remain bare until the following spring. Rather than remove sediment and nutrients already travelling in stormwater, cover crops help to hold those same soil particles and nutrients in place on the field itself.

Cover crops can be far more cost effective than the costs presented in this report. We assumed the practice would be implemented on small, dispersed fields that are common locally. If planted on large acreages with cheap seed by farmers already owning the planting equipment, the cost per unit area would be lower. A University of MN study (Lazarus and Keller 2018) found the cost of planting cover crops on 13 Minnesota farms cost an average of $43.93/acre and $36.80/acre in 2016 and 2017 respectively. Our scenario assumes equipment rental may be required and efficiency will be lower due to smaller plots of land being cover cropped. Incentive payments are available through the state or federal government for planting cover crops where they have not been planted in the past.

Cropland Cover Crops

	Cost/Removal Analysis	New Treatment	% Reduction	New Treatment	% Reduction	New Treatment	% Reduction	New Treatment	% Reduction
Treatment	**Cover Crops Installed**	25% Row Crop		50% Row Crop		100% Row Crop			
	Acres Cover Cropped	79.09	25.0%	158.18	50.0%	237.26	75.0%		
	TP (lbs) (0.24 lb/acre/yr)	19.0	9.5%	38.0	19.0%	56.9	28.6%		
	TSS (tons) (2.57 ton/acre/yr)	203	15.5%	407	31.0%	610	46.6%		
	Volume (acre-feet/yr)	n/a	n/a	n/a	n/a	n/a	n/a		
Cost	**Administration & Promotion Costs***	$3,796		$3,796		$3,796			
	Design & Construction Costs**	68,751		133,998		199,246			
	Total Estimated Project Cost (2018)	**$72,547**		**$137,794**		**$203,042**			
	Annual O&M***	$68,751		$133,998		$199,246			
Efficiency	**30-yr Average Cost/lb-TP**	**$3,750**		**$3,651**		**$3,618**			
	30-yr Average Cost/1,000lb-TSS	**$175**		**$170**		**$169**			
	30-yr Average Cost/ac-ft Vol.	**n/a**		**n/a**		**n/a**			

*52 hours at $73/hour for promotion and administration

**$150/acre for site prep, seed, and installation, 48 hours at $73/hour for design/contracting

***Annual replanting=design and construction cost

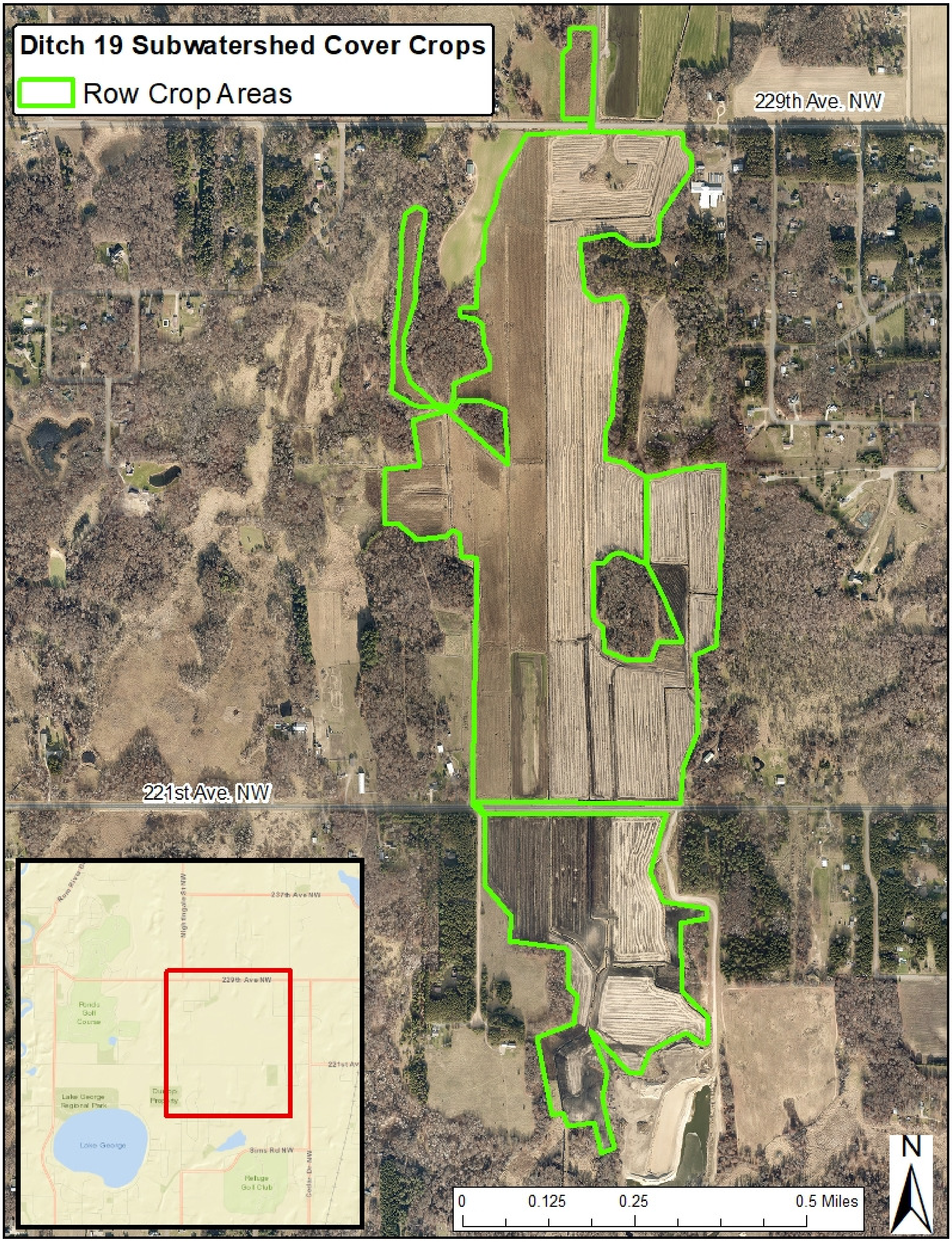


Figure 33 Fields in Ditch 19 subwatershed lacking cover crops

Grassed Waterway

Location- East side of Ditch 19 subwatershed, north of 229th Ave. NW

Property Ownership- Private

Description- Grassed waterways are wide channelized depressions that move water across farmed ground without causing soil erosion (Stone and McKague 2009). Perennial vegetation is maintained within the channel to slow down runoff from the rest of the field or drainage area. When runoff slows down passing through the channel, infiltration increases, and sediment and nutrients drop out of suspension and are left behind. This reduces flow volume, and sediment and nutrient delivery downstream. A grassed waterway was considered for a channelized depression on the east side of the Ditch 19 subwatershed in a small field to the north of 229th Avenue NW.

The drainage area of this sub catchment was too small at 4.7 acres to model a standard trapezoidal grassed waterway. However, we were able to get design dimensions for a parabolic shaped grassed waterway using the WI NRCS Grassed Waterway Calculator. The catchment for this grassed waterway has similar soils and slopes as the North inlet subwatershed grassed waterway catchment, and is about ¼ the acreage, therefore, we assumed ¼ of the length as well as runoff and treatment benefits in the cost-benefit analysis using calculator-suggested sizing for depth and width.

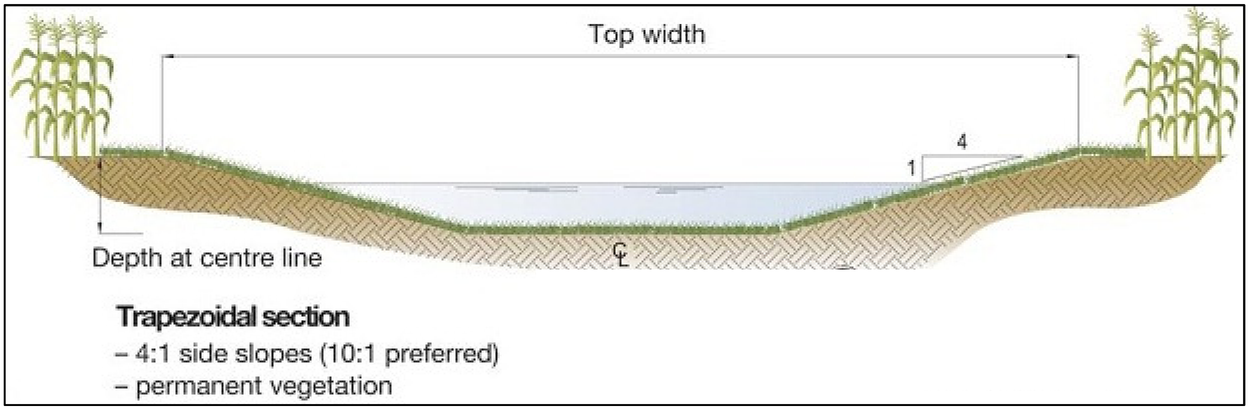


Figure 34 Grassed waterway cross section ((Stone and McKague 2009)

Figure 35 A grassed waterway installed by the Chisago SWCD, MN (Chisago SWCD n.d.)

Grassed Waterway

	Cost/Removal Analysis	New Treatment	% Reduction	New Treatment	% Reduction	New Treatment	% Reduction
Treatment	Grassed Waterway (linear ft.)	50		100			
	BMP Foot Print	500	Sq. ft.	1,000	Sq. ft.		
	TP (lbs)	0.3	0.4%	0.4	0.5%		
	TSS (lbs)	78	1.6%	84	1.8%		
	Volume (acre-feet/yr)	0.13	0.1%	0.19	0.2%		
Cost	Administration & Promotion Costs*	$3,796		$3,796			
	Design & Construction Costs**	1,954		2,155			
	Total Estimated Project Cost (2018)	**$5,750**		**$5,951**			
	Annual O&M***	$13		$25			
Efficiency	**30-yr Average Cost/lb-TP**	**$612**		**$561**			
	30-yr Average Cost/1,000lb-TSS	**$1.30**		**$1.33**			
	30-yr Average Cost/ac-ft Vol.	**$1,597**		**$1,204**			

*52 hours at $73/hour for promotion and administration

**\$4/ft^2 for grading, stabilizing + $150/acre seeding + 24 hours at $73/hour for design/contracting

***0.25$/ft. Rates from Chisago SWCD

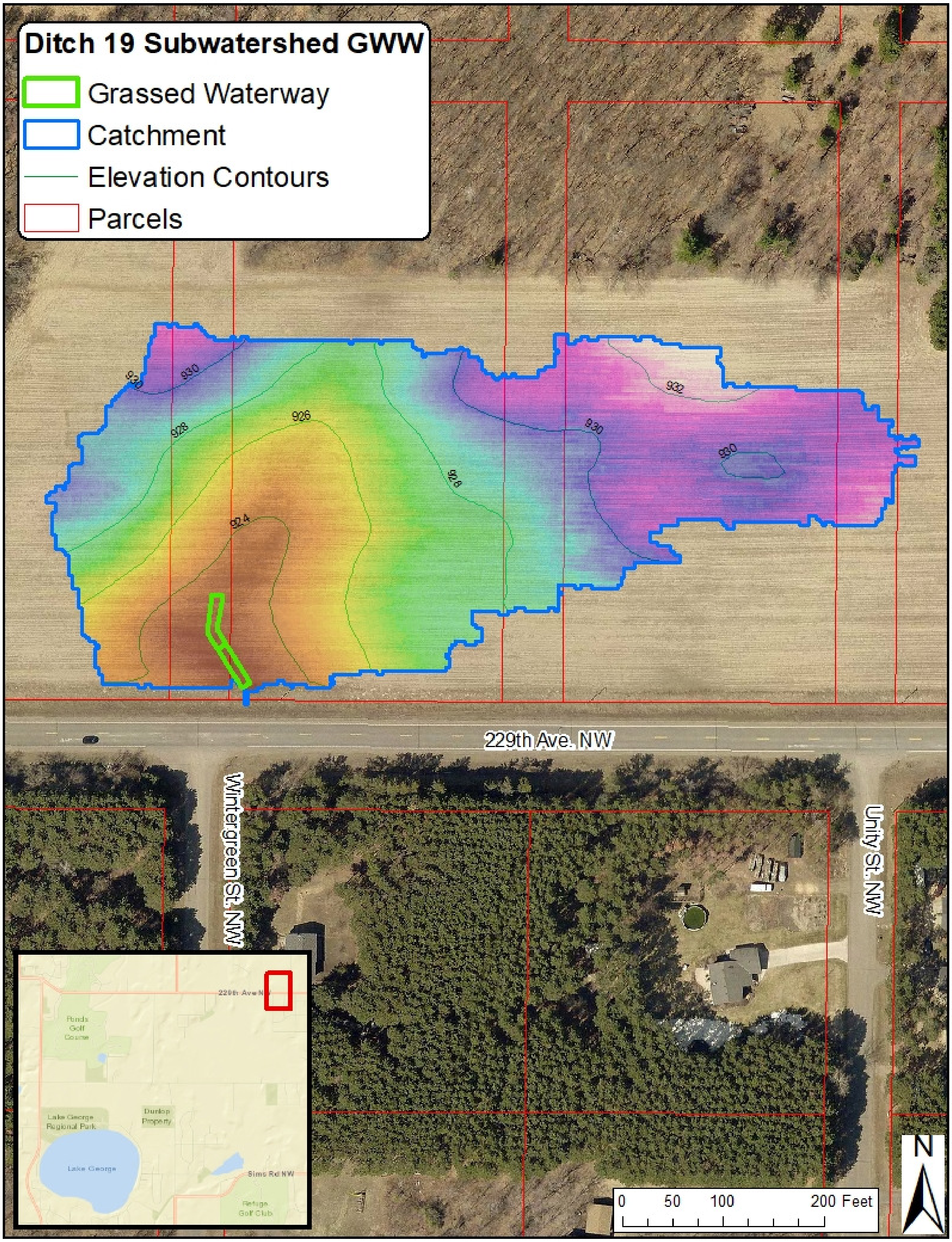


Figure 36 Ditch 19 subwatershed grassed waterway concept

Weir Modification

Location- Ditch 19 downstream of Lake George connector channel (

Figure 38)

Property Ownership- Public, City of Oak Grove

Description- The current sheet piling weir structure, and preceding concrete control features have a long, but fragmented historical record dating back to at least 1895 (MN Department of Natural Resources, Staff Correspondence 2017). However, there is very little documentation of the progression of disrepair of the current weir. The weir was constructed with a spillway elevation of 902.08' (NAVD88) in the 1950s. An ACD survey conducted 11/30/2017 suggests that the lowest point over the weir spillway controlling elevation in Ditch 19 is now 901.59' (NAVD88), 0.49' lower than design (Figure 37).

The Ditch 19 weir structure is scheduled to be replaced in 2019 to the original design elevation. The effective change in spillway elevation will be about six inches higher than current, which will likely have an impact on both average lake levels and loading to the lake from the lakeshed, especially from Ditch 19.

As of the writing of this report, the project is still in the early design phase so no conceptual images were available, and the cost benefit analysis of the project is based on a rough budget estimate. Cost estimate scenarios are provided for a normal precipitation year and wet year for this project. During a normal precipitation year, the models actually show a negligible net increase in loading loading of phosphorus into Lake George after the weir reconstruction. During a wet year, however, the weir provides reductions in total phosphorus, total suspended solids, and volumetric flow into Lake George through Ditch 19.These effects will be exacerbated even more as continued development in the subwatershed send more storm runoff downstream.

The effects of this weir reconstruction project go far beyond the pollutant removals analyzed for the other projects in this report, so cost benefit analysis does not paint a true picture of the project's effects. This weir reconstruction will likely have a noticeable impact on average lake level by restoring the original hydrology of the lake dating back to the early 1900's. The new weir structure will also facilitate fish passage to and from the lake from downstream, a function the current weir design prevents. This will likely have an impact on fish communities in Lake George by aiding the spawning of gamefish species.

Figure 37 Deteriorating weir structure, November 2017

Weir Modification

	Cost/Removal Analysis	New Treatment	% Reduction	New Treatment	% Reduction	New Treatment	% Reduction
Treatment	Number of BMPs	Normal Year		Wet Year			
	TP (lb/yr)*	-1.6	-2.1%	4.5	5.7%		
	TSS (lb/yr)*	4	0.1%	344	7.2%		
	Volume (acre-feet/yr)*	3.8	3.1%	5.8	3.6%		
Cost	Administration & Promotion Costs	$50,000		$50,000			
	Design & Construction Costs	250,000		250,000			
	Total Estimated Project Cost (2018)**	**$300,000**		**$300,000**			
	Annual O&M**	$0		$0			
Efficiency	**30-yr Average Cost/lb-TP**	**-$6,061**		**$2,242**			
	30-yr Average Cost/1,000lb-TSS	**$2,500,000**		**$29,070**			
	30-yr Average Cost/ac-ft Vol.	**$2,667**		**$1,727**			

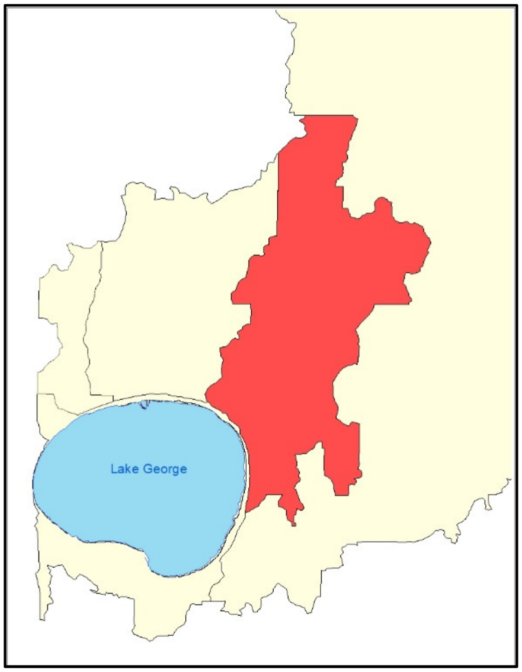
* Loading from storms reversing flow into the lake from Ditch 19 only

**Early project estimate

Figure 38 Map of the Ditch 19 weir structure location

Northeast Inlet Subwatershed

Subwatershed Summary	
Acres	754
Dominant Land Cover	Undeveloped
Volume (acre-ft./yr)	93
TP (lb/yr)	61
TSS (lb/yr)	2,674



Subwatershed Description

The northeast inlet subwatershed is primarily undeveloped, vacant land consisting of a mix of wetland and wooded upland. Approximately 60 acres of this subwatershed is made up of large lot agricultural farmsteads and related fields. Approximately 45 acres of the subwatershed consists of 2.0 to 2.5-acre rural residential lots to the east of Lake George.

Existing Stormwater Treatment

This subwatershed lacks storm sewers and stormwater detention basins. Stormwater is conveyed through the subwatershed via ditches, swales, and large wetland complexes that provide some infiltration and treatment. Runoff is lastly held in a four-acre open water wetland on the northeast side of Lake George before a being delivered under South Lake George Drive via a culvert to the 125-foot lake inlet channel.

Additional treatment opportunities in this subwatershed are limited in the current setting. Most of the area upstream of the lake is wetland. Monitoring indicated high amounts of phosphorus being transferred to Lake George via the inlet from the four-acre wetland across South Lake George Drive. While a filter for water at this location might be considered, because most of the phosphorus is not dissolved it would not need to be an iron-enhanced filter that targets dissolved phosphorus. Any such filter would likely need to be built in an area that is currently wetland, making it largely impractical.

Water Quality

The northeast inlet channel entering Lake George has high nutrient and sediment concentrations. This site had the highest concentrations of phosphorus of the three lake inlets. However, dissolved phosphorus at this inlet was low. Storm events did not have higher nutrients or sediment, suggesting that the open water wetland across South Lake George Drive is effective at dampening or capturing storm-related pollutants from the rest of the subwatershed. There does seem to be a high amount of particulate phosphorus and TSS during baseflow conditions at this inlet. This may be from the wetlands themselves. Yard waste, sediment and other debris placed along the channel and in the wetland may also contribute.

Project Recommendations

Figure 39 NE Inlet Subwatershed BMP Retrofit Recommendations

Yard Waste Cleanup

Location- Northeast inlet channel

Property Ownership- Public (DNR) and Private

Description- There are debris piles (leaves, sediment, and grass clippings) dumped into the wetland to the east of the roadside and along the north side of the inlet channel to the lake. The dumping of these types of debris immediately upstream of the outfall to the lake can contribute to lake pollutant loading. Cleanup and prevention of future waste disposal is warranted.

The map in Figure 40 shows the locations of the dumping site as well as ACD's water quality monitoring site at this inlet. The 2014 aerial photography in this map also show the depositional fan entering the lake from this inlet due to low water levels at the time the picture was taken, a clear indication that significant loading is happening at this site. This type of depositional fan is caused by larger grain sediment, like sand, that one would not expect to have washed out of a wetland in large volumes (Figure 41 is a photo of upstream wetlands). Debris piled along the north side of the inlet channel warrants removal (Figure 42).

A cost benefit analysis cannot be provided for this type of "good housekeeping" practice like for the installation of specific BMPs without further studying the types and amounts of debris contributed to this site annually. Additionally, costs associated with cleaning up the existing debris and changing habits would be up to the private landowner. However, advocating for this cleanup and behavioral change through mailings or signage could have important benefits for lake water quality at a relatively low cost.

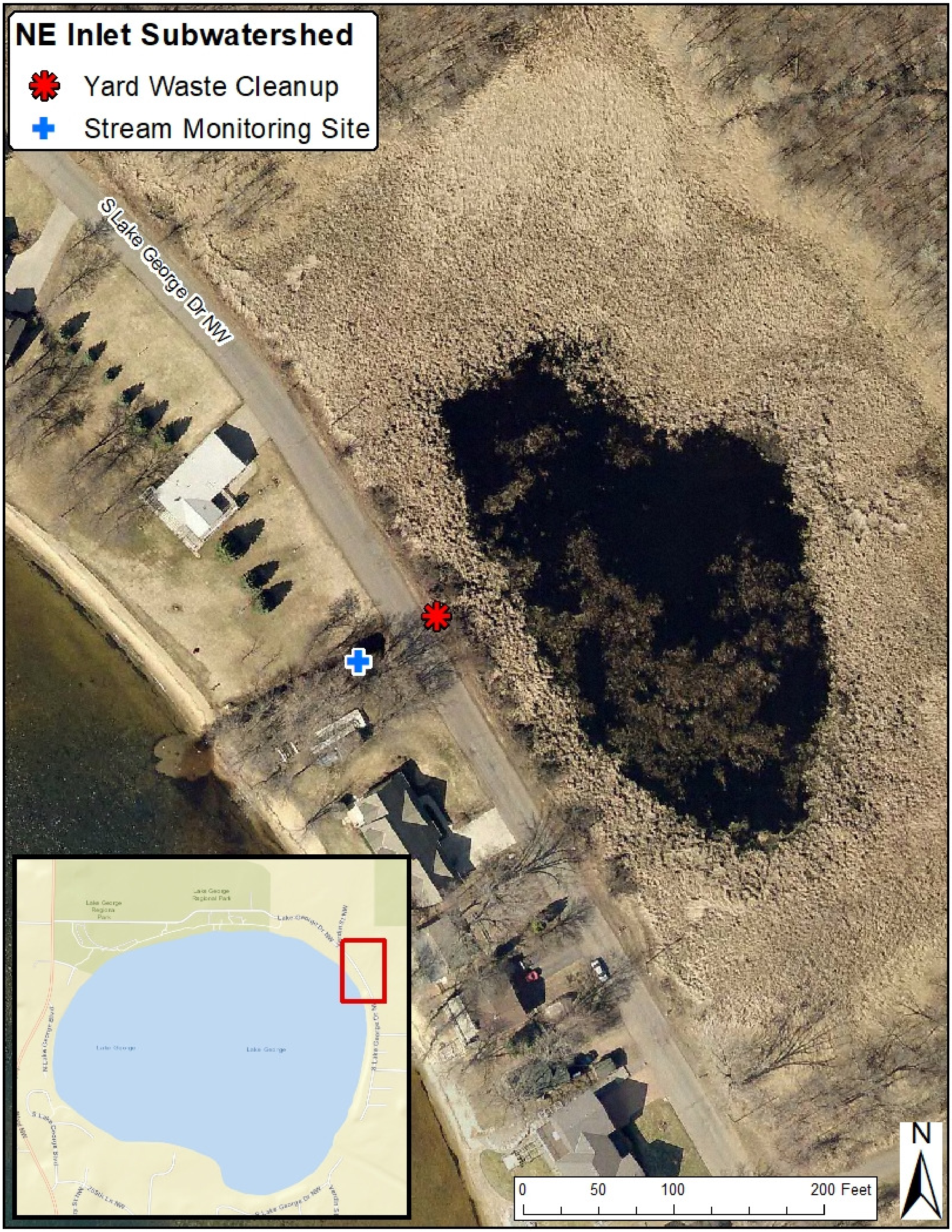


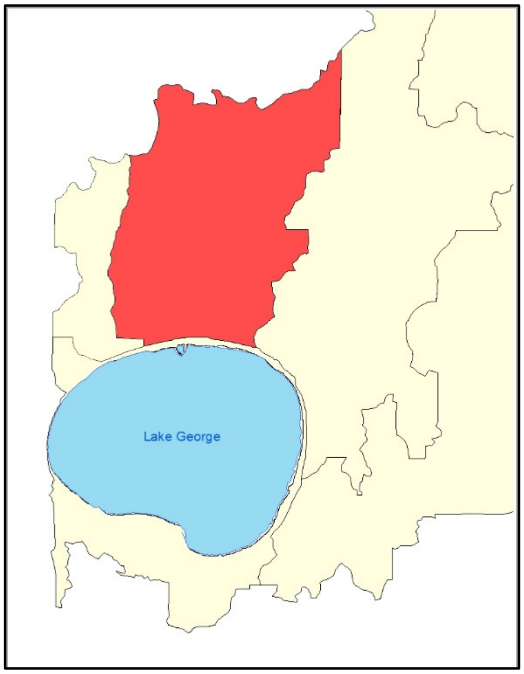
Figure 40 NE Inlet Dumping Site and ACD Water Quality Monitoring Site

Figure 41 Wetland near outlet of NE lake inlet.

Figure 42 Debris piled along north side of NE inlet channel, 2017

North Inlet Subwatershed

Subwatershed Summary	
Acres	541
Dominant Land Cover	Parkland/Undeveloped
Volume (acre-ft./yr)	90
TP (lb/yr)	47
TSS (lb/yr)	2,674



Subwatershed Description

The north inlet subwatershed is primarily divided into two parts by land use type. The northwestern most portion of the subwatershed (approximately 113 acres) is comprised of golf course with small, single family residential lots. The remainder of the subwatershed has undeveloped parkland and wetland with a few 10-acre residential lots in the northeastern portion. Stormwater from the developed portions of the subwatershed must flow through the large tracts of undeveloped lands and wetlands before approaching the lake, so treatment will be most effective in the lowest reaches of the subwatershed just before the water enters Lake George.

Existing Stormwater Treatment

Existing stormwater treatment practices within this subwatershed consist of approximately a dozen online wet detention basins in the developed northwestern portions with a golf course and small lot residential areas. These ponds should sufficiently treat stormwater from the currently developed area of the subwatershed. Stormwater runoff not contained by these basins flows through a 200+ acre undeveloped wetland complex before entering Lake George in the county park via a 250-foot inlet channel.

Water Quality

The North inlet to the lake has the highest monitored levels of dissolved phosphorus of the three inlets during storm events. TDP concentrations more than doubled on average during storm events at this inlet. The models also showed an increase in volume from this inlet during high precipitation years. Mitigation of TDP and TSS, especially during wet years and individual storm events will directly reduce loading of these pollutants to the lake.

Project Recommendations

Figure 43 North Inlet Subwatershed BMP Retrofit Recommendations

Iron Enhanced Sand Filter

Location- Lake George Regional Park, north lake inlet

Property Ownership- Public, Anoka County

Description- An iron enhanced sand filter (IESF) placed immediately before the outfall into Lake George at the north inlet would maximize the benefits of this type of practice. The IESF bed would treat up to 100% of the runoff from the subwatershed, and treated water would not pick up additional pollutants before entering the lake. There is enough area for installation between the inlet channel, walking trail, and boat landing parking lot to treat 100% of runoff from the subwatershed assuming normal runoff conditions. The proposed site is within the county park (Figure 45).

Iron enhanced sand filters are a type of filtration BMP that utilize reactive iron (Fe^+) mixed with a sand filtration media to remove dissolved constituents. The main target of and IESF is dissolved phosphorus in the form of phosphate, which binds with the iron and remains trapped in the sand filter bench. Another benefit of an IESF is the removal of color from water, a potentially important, though not quantified, benefit given the tannin stained nature of water at this inlet (Overview for Iron Enhanced Sand Filter 2015).

The concept image in Figure 45 shows the possible sizing, location, and power sources for an IESF bed with pump placed at the north inlet to Lake George. A 12" deep mixed media bed would be placed between Lake George Drive NW and the walking trail to the south. Water from the north inlet channel would be collected into a stilling area before being pumped over the iron-sand media for infiltration. Filtered water would then outlet to the lake inlet channel to the south of the stilling area. Based on a media bed footprint ranging from 7,300 ft^2 to 14,600 ft^2, 50%-100% of thawed season runoff from the north inlet subwatershed could be treated assuming normal precipitation and current land use.

Conceptual image – Iron Enhanced Sand Filter

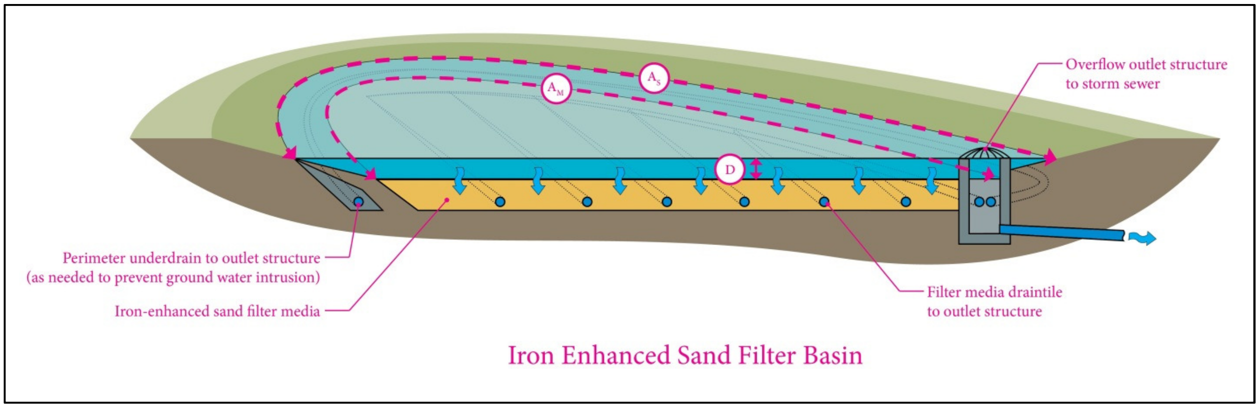


Figure 44 Cross-section of a conceptual iron enhanced sand filter (Types of Iron Enhanced Sand Filter 2016)

Iron Enhanced Sand Filter

	Cost/Removal Analysis	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**
Treatment	**%Treatment of Volume***	50%		75%		100%	
	Total Size of BMPs	7,300	Sqare ft.	10,950	Sqare ft.	14,600	Sqare ft.
	TP (lb/yr)	20.0	42.6%	30.0	63.8%	40.0	85.1%
	TSS (lb/yr)*	488	49.9%	732	74.8%	976	99.8%
	Volume (acre-feet/yr)	n/a	n/a	n/a	n/a	n/a	n/a
Cost	**Administration & Promotion Costs**	$22,000		$22,000		$22,000	
	Design & Construction Costs	372,072		413,458		465,844	
	Total Estimated Project Cost (2018)	**$394,072**		**$435,458**		**$487,844**	
	Annual O&M**	$1,676		$2,514		$3,352	
Efficiency	**30-yr Average Cost/lb-TP**	**$741**		**$568**		**$490**	
	30-yr Average Cost/1,000lb-TSS	**$30,352**		**$23,264**		**$20,095**	
	30-yr Average Cost/ac-ft Vol.	**n/a**		**n/a**		**n/a**	

* Assumes 90 acre-feet/yr

** Based on 100% Particulate P removal

***$10,000/acre

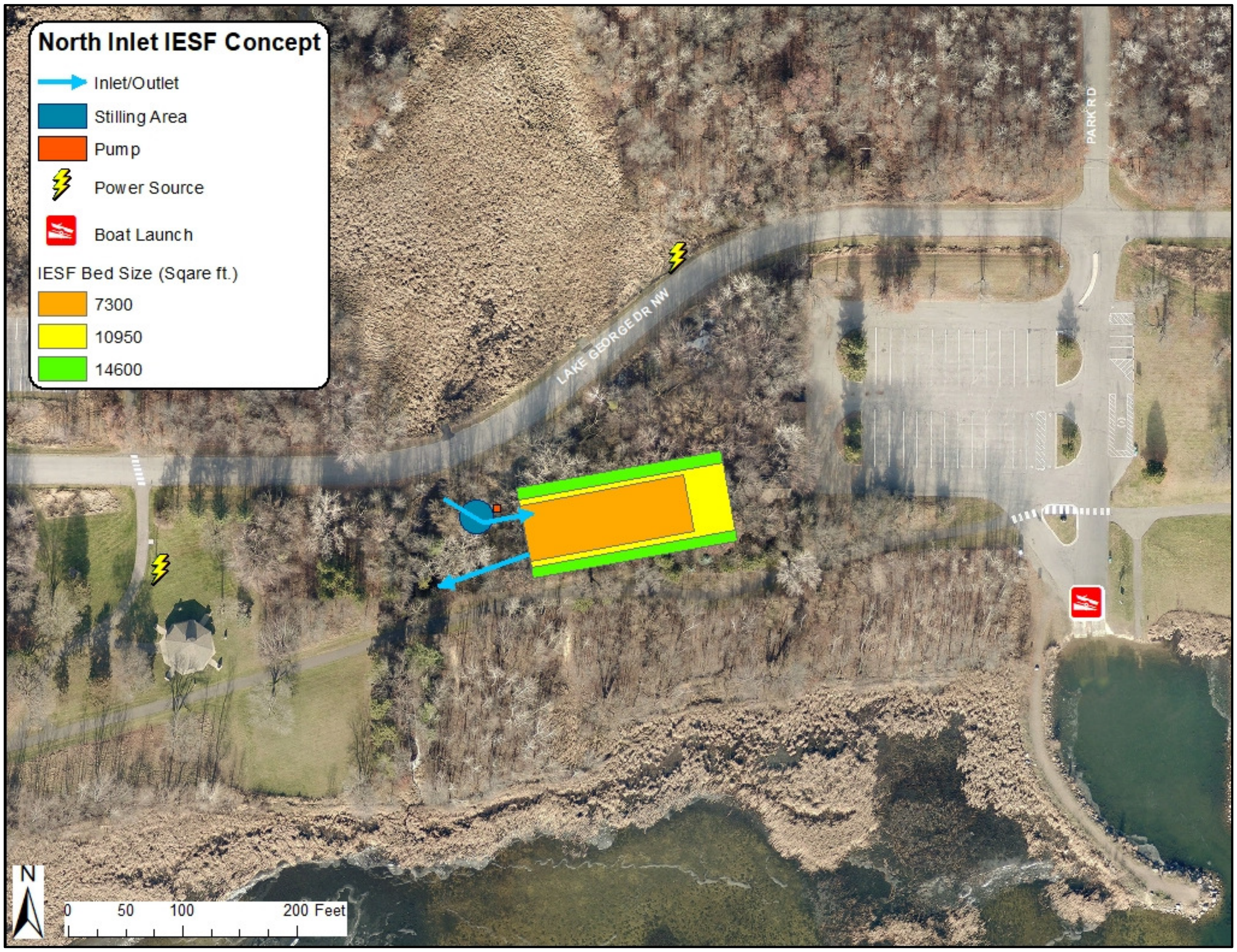


Figure 45 North Inlet IESF Concept

Grassed Waterway

Location- NE corner of north inlet subwatershed, catchment LG2-51S

Property Ownership- Private

Description- Grassed waterways are wide channelized depressions that move water across farmed ground without causing soil erosion (Stone and McKague 2009). Perennial vegetation is maintained within the channel to slow down runoff from the rest of the field or drainage area. When runoff slows down passing through the channel, infiltration increases, and sediment and nutrients drop out of suspension and are left behind. This reduces flow volume, and sediment and nutrient delivery downstream. Two grassed waterway lengths are presented for catchment LG2-51S. Both designs include a trapezoidal shaped channel with a 1ft. deep, 15-foot wide bottom, with 10:1 side slopes for a total top width of 35 feet. At 3.5% grade, this channel shape provides enough hydraulic passage for a 100-year, 24-hour storm event from the 17.3-acre drainage area. This channel configuration is presented in 200-foot and 400-foot lengths.

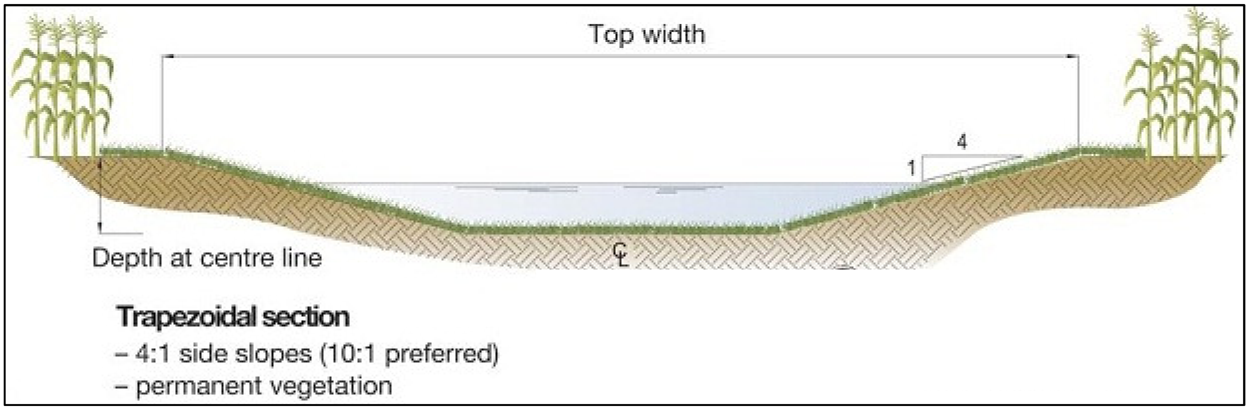


Figure 46 Grassed waterway cross section (Stone and McKague 2009)

Figure 47 A grassed waterway installed by the Chisago SWCD, MN (Chisago SWCD n.d.)

Grassed Waterway

	Cost/Removal Analysis	New Treatment	% Reduction	New Treatment	% Reduction	New Treatment	% Reduction
Treatment	**Grassed Waterway (linear ft.)**	200		400			
	BMP Foot Print	7,000	Sq. ft.	14,000	Sq. ft.		
	TP (lbs)	1.3	2.8%	1.6	3.4%		
	TSS (lbs)	314	32.1%	337	34.4%		
	Volume (acre-feet/yr)	0.51	0.6%	0.74	0.8%		
Cost	**Administration & Promotion Costs***	$3,796		$3,796			
	Design & Construction Costs**	2,576		3,400			
	Total Estimated Project Cost (2018)	**$6,372**		**$7,196**			
	Annual O&M***	$50		$100			
Efficiency	**30-yr Average Cost/lb-TP**	**$197**		**$213**			
	30-yr Average Cost/1,000lb-TSS	**$0.42**		**$0.50**			
	30-yr Average Cost/ac-ft Vol.	**$513**		**$458**			

*52 hours at $73/hour for promotion and administration

**$4/ft^2 for grading, stabilizing + $150/acre seeding + 24 hours at $73/hour for design/contracting

***0.25$/ft. Rates from Chisago SWCD

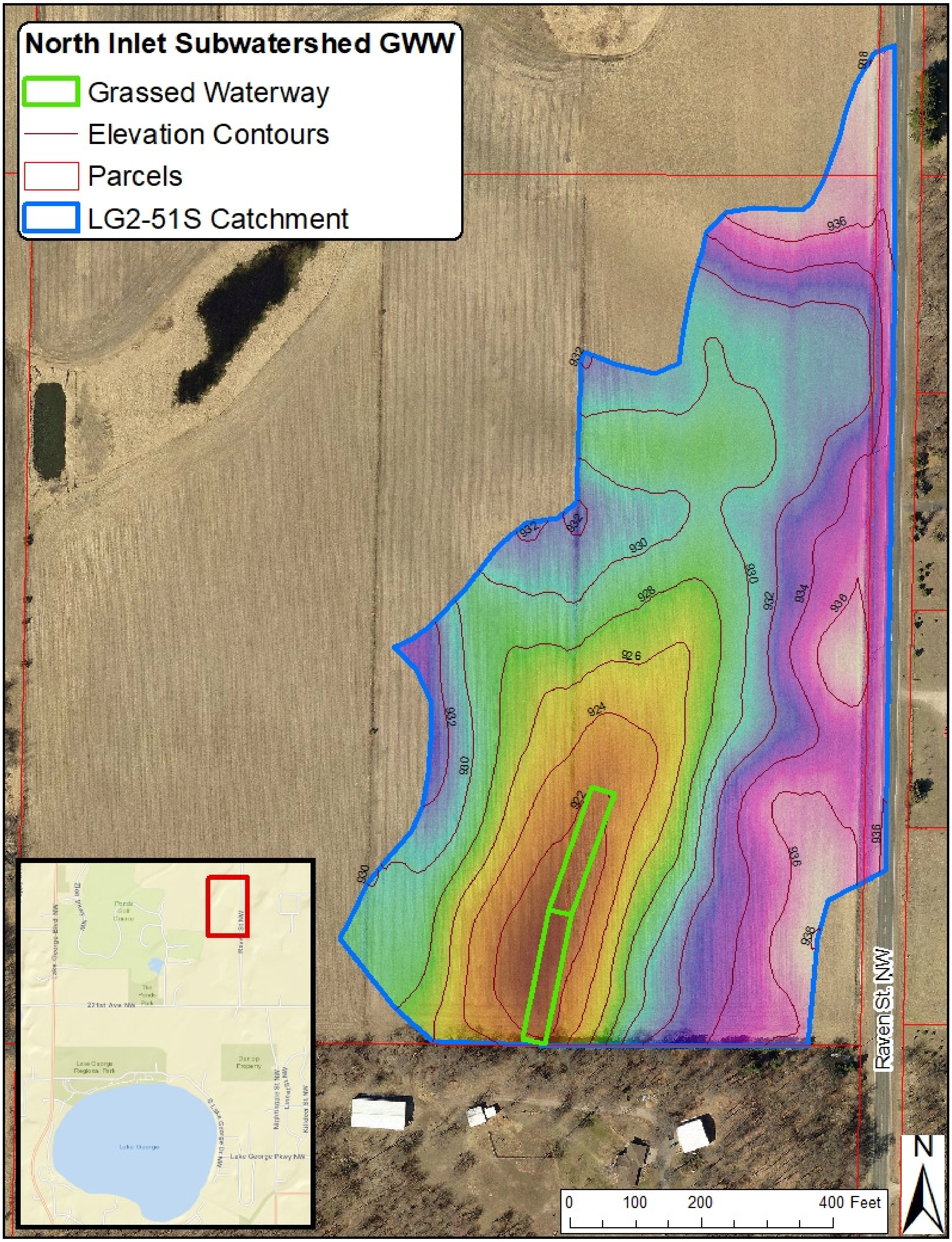
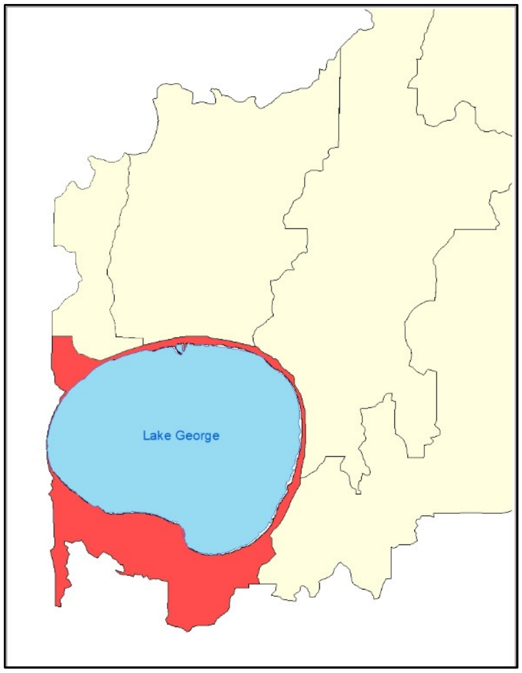


Figure 48 North inlet grassed waterway concept

Near Lake Subwatershed

Subwatershed Summary	
Acres	220
Dominant Land Cover	Single Family Residential
Volume (acre-ft./yr)	17
TP (lb/yr)	25
TSS (lb/yr)	4,485



Subwatershed Description

The near lake drainage to Lake George is the only subwatershed in which the dominant land cover is residential. Inland lots that lack lake frontage typically range from 1.0 to 2.5 acres. Lakeshore homes are mostly 0.25 to 0.5 acres. Approximately 30% of the lake's shoreline is undeveloped parkland.

Existing Stormwater Treatment

There are three wet detention ponds within the subwatershed on the south side of Lake George. These basins are isolated, and do not discharge into the lake except during flooded conditions. No stormwater infrastructure exists along the roadways in this subwatershed. Runoff runs overland or in roadside swales. Discharge into the lake is dispersed and mostly runs across properties on or near the lakeshore.

Water Quality

Due to the lack of a defined inlet, water quality was not monitored for this subwatershed. Modeled data, however, shows a high amount of TSS loading, likely attributable to proximity of impervious surfaces to the lake. Because flow to the lake is dispersed, practices on many individual properties are needed.

Project Recommendations

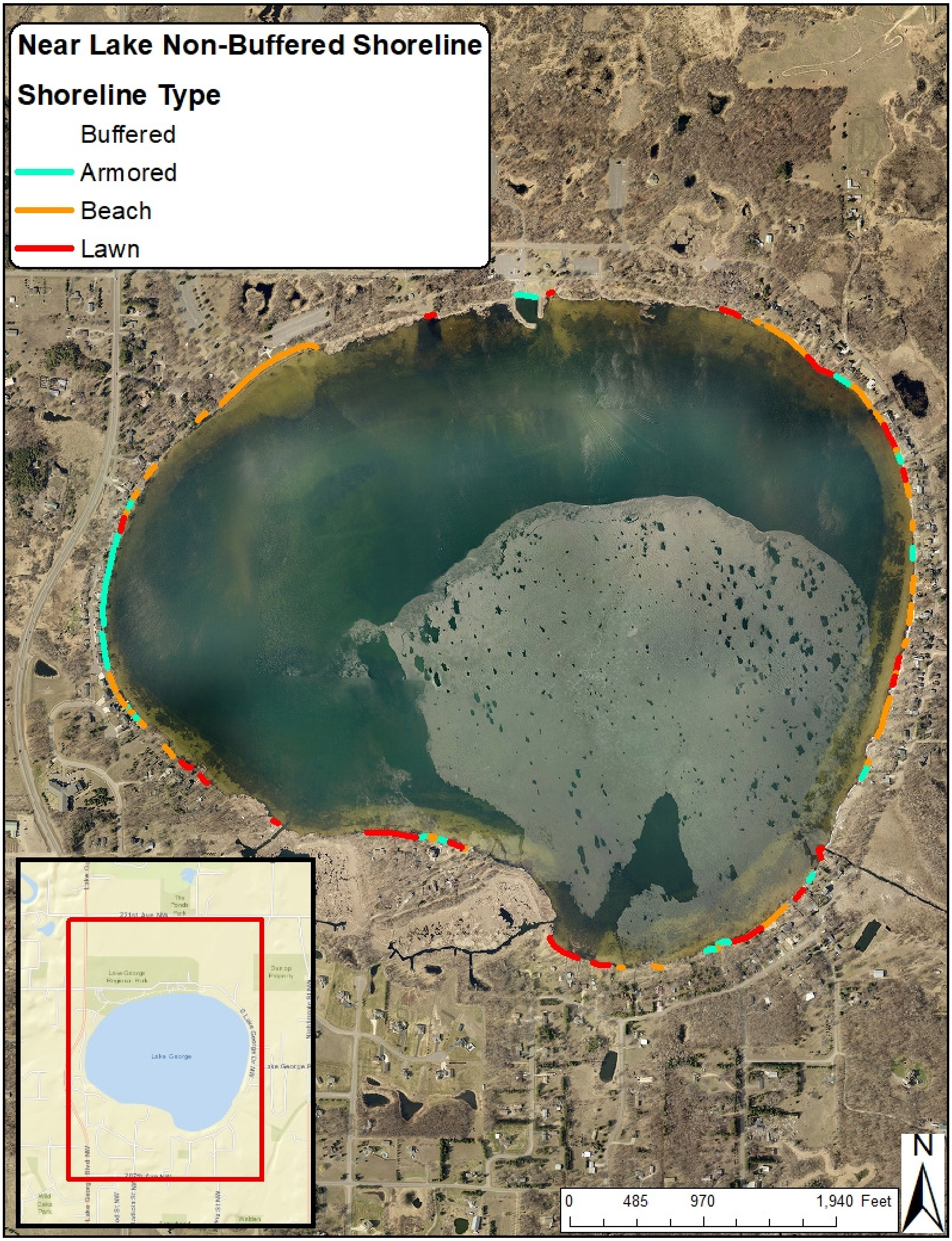


Figure 49 Lake George shoreline buffer inventory

Shoreline Buffers

Location- Lake George lakeshore areas not currently buffered

Property Ownership- Private, Public (Anoka County Parks)

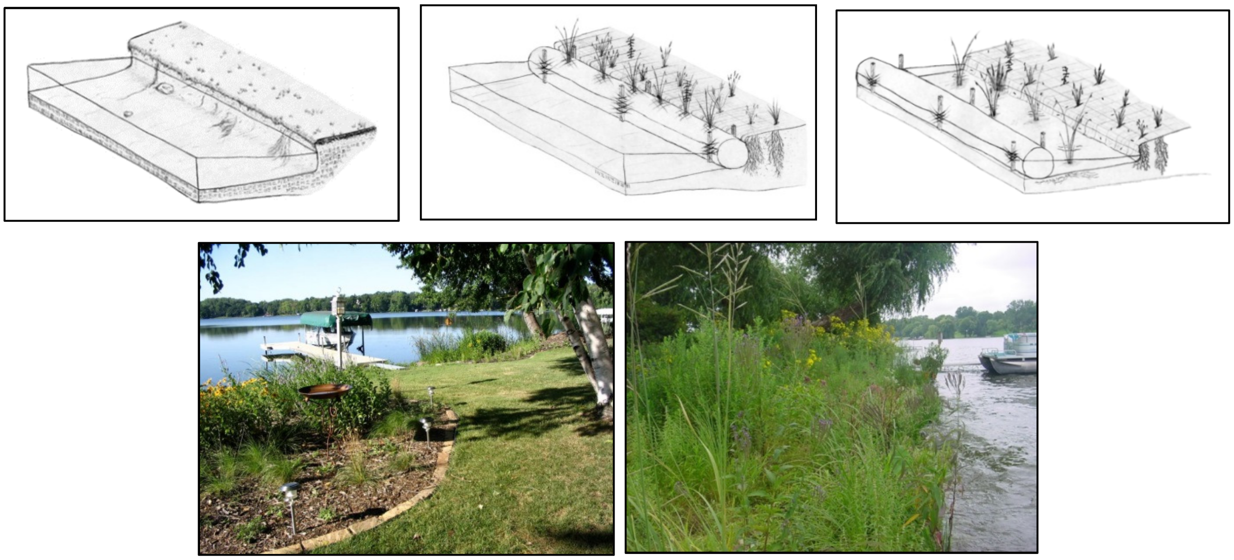
Description- Native vegetation buffer plantings along lakeshores provide soil stability and reduce erosion when installed as part of a stabilization project. They can also act as natural filter strips for overland stormwater runoff, removing more suspended solids and nutrients than lawn mowed to the water's edge. This section focuses on only the filtration benefits of buffer strips as a stormwater practice, which are somewhat consistent lake wide, rather than the shoreline stabilization effects, which will vary greatly depending on erosion severity and land use type.

The cost benefit scenarios below illustrate the pollutant reduction benefits of lakeshore buffers. In the next section on lakeshore stabilizations, buffer strips will be assumed to be installed as a part of the bigger shoreline stabilization effort, therefore the benefits of buffers for both shoreline stabilization and stormwater runoff filtration are included in the cost benefit analysis for those projects.

ACD identified approximately 8,500 feet of Lake George shoreline (about half of the lakes' total shoreline) that lacked vegetative shoreline buffers. It was assumed that a representative lot with 100 feet of lakefront would plant 70 feet into buffer to still provide boat and other recreational access. Additionally, buffers were assumed to be installed at 15 feet wide. Reducing or increasing the width of the buffer will have an effect on its filtration efficiencies and cost relative to pollutant removal.

As an alternative to buffers, lakeshore homeowners might consider leaving minor ice ridges in place. These ridges prevent runoff from yards and roofs into the lake. However, they do not provide secondary habitat benefits as a native plant buffer would.

Conceptual images – Native Plant Restorations



Shoreline Buffers

	Cost/Removal Analysis	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**
Treatment	**Shoreline Buffered (linear-ft)**	70		50%		100%	
	Total Size of BMPs	1,050	Square-ft	44,625	Square-ft	89,250	Square-ft
	TP (lb/yr)	0.03	0.1%	1.22	4.9%	2.43	9.7%
	TSS (lb/yr)	7.94	0.2%	337	7.5%	674	15.0%
	Volume (acre-feet/yr)	0.03	0.2%	1.13	6.6%	2.25	13.2%
Cost	**Administration & Promotion Costs***	$292		$12,410		$24,820	
	Design & Construction Costs**	3,360		142,800		285,600	
	Total Estimated Project Cost (2018)	**$3,652**		**$155,210**		**$310,420**	
	Annual O&M***	$66		$2,811		$5,622	
Efficiency	**30-yr Average Cost/lb-TP**	**$6,568**		**$6,568**		**$6,568**	
	30-yr Average Cost/1,000lb-TSS	**$23,677**		**$23,677**		**$23,677**	
	30-yr Average Cost/ac-ft Vol.	**$7,092**		**$7,092**		**$7,092**	

*4 hours at $73/hour for promotion and administration

**Assumes hired landscaping labor, $3.20/Square-ft

***Assumes replacing plants and mulch every 10 years

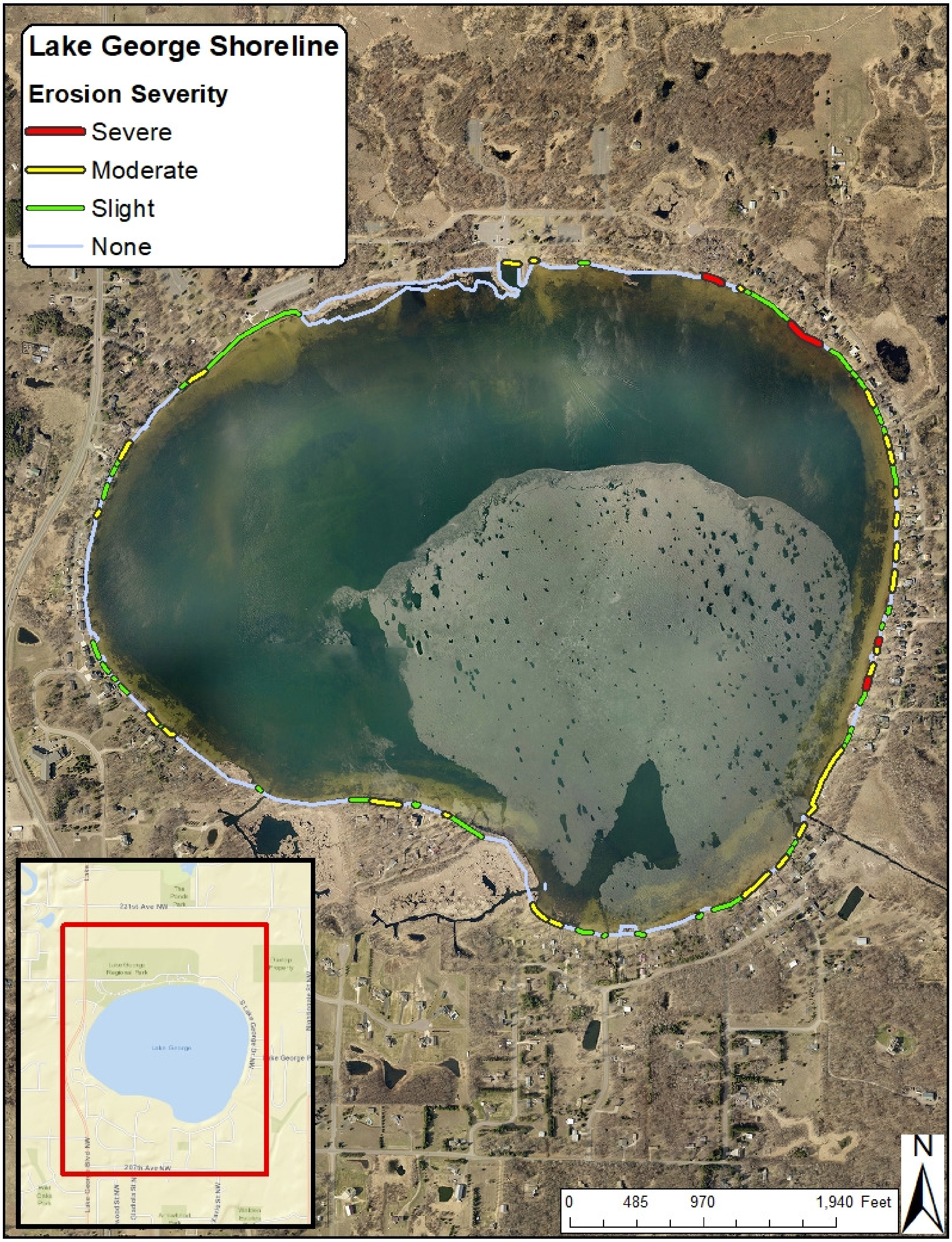


Figure 50 Lake George shoreline erosion severity inventory

Lakeshore Stabilizations

The Anoka Conservation District performed a shoreline erosion survey of Lake George in 2018, identifying areas of shoreline erosion and classifying them based on erosion severity. A total of 69 eroding shoreline segments were identified. These segments were identified by erosion severity, not parcel boundary.

Pollution reduction cost benefit numbers are also based on erosion severity (slight, moderate, severe) and a representative project length of 100 feet. The erosion severity scale and pollution removals for stabilized shorelines are based on the Wisconsin NRCS Shore Erosion Calculator. Shoreline stabilization projects also commonly include native vegetation buffer plantings that provide an additional benefit of stormwater runoff filtration. These assumed buffer installations are included in the cost and pollutant removal estimates for projects.

Projects with slight or moderate erosion have a lower materials and installation cost per linear foot. ($75/linear ft.) than severe projects ($125/linear ft.). A slight or moderately eroding shoreline may be corrected with natural fiber erosion control and establishment of native, deep-rooted vegetation. Severely eroding shorelines with exposed faces may require regrading and/or armoring or other structural support, thus the higher cost per linear foot. Shoreline stabilization projects also commonly include native vegetation buffer plantings that provide an additional benefit of stormwater runoff filtration and habitat. These assumed buffer installations are included in the cost and pollutant removal estimates for projects outlined below.

Conceptual images – Native Plant Restorations

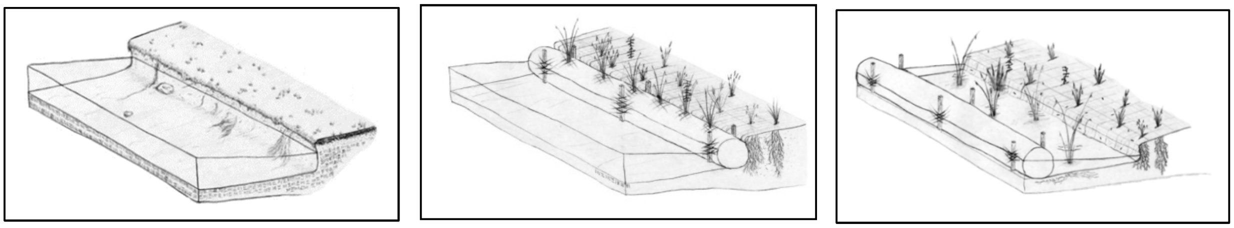


Table 8 Shoreline erosion assumptions used in calculating TSS and TP loading to Lake George

Shoreline Erosion Severity	Lateral Recession Rate (ft./yr)	Eroding Face (ft.)	Description
Slight	0.01	0.5	Some bare shore, but active erosion is minimal. Minor or no vegetative overhang. No exposed tree roots
Moderate	0.06	1.0	Shore is predominately bare, with some undercutting and vegetative overhang. Some exposed tree roots, but no slumps or slips.
Severe	0.30	1.5	Shore is bare, with vertical slope and/or severe vegetative overhang. Many exposed tree roots and some fallen trees and slumps or slips.

Table 9 Shoreline loading to Lake George based on erosion severity inventory

Erosion Severity	# Shoreline Segments	Total Length (ft.)	Average Length (ft.)	Loading to Lake (lb. TSS)		Loading to Lake (lb. TP)	
				Total	Per 100 ft.	Total	Per 100 ft.
Slight	40	4,358	109	2,179	50	1.74	0.04
Moderate	25	2,843	114	17,058	600	13.65	0.48
Severe	4	477	119	21,465	4,500	17.17	3.6

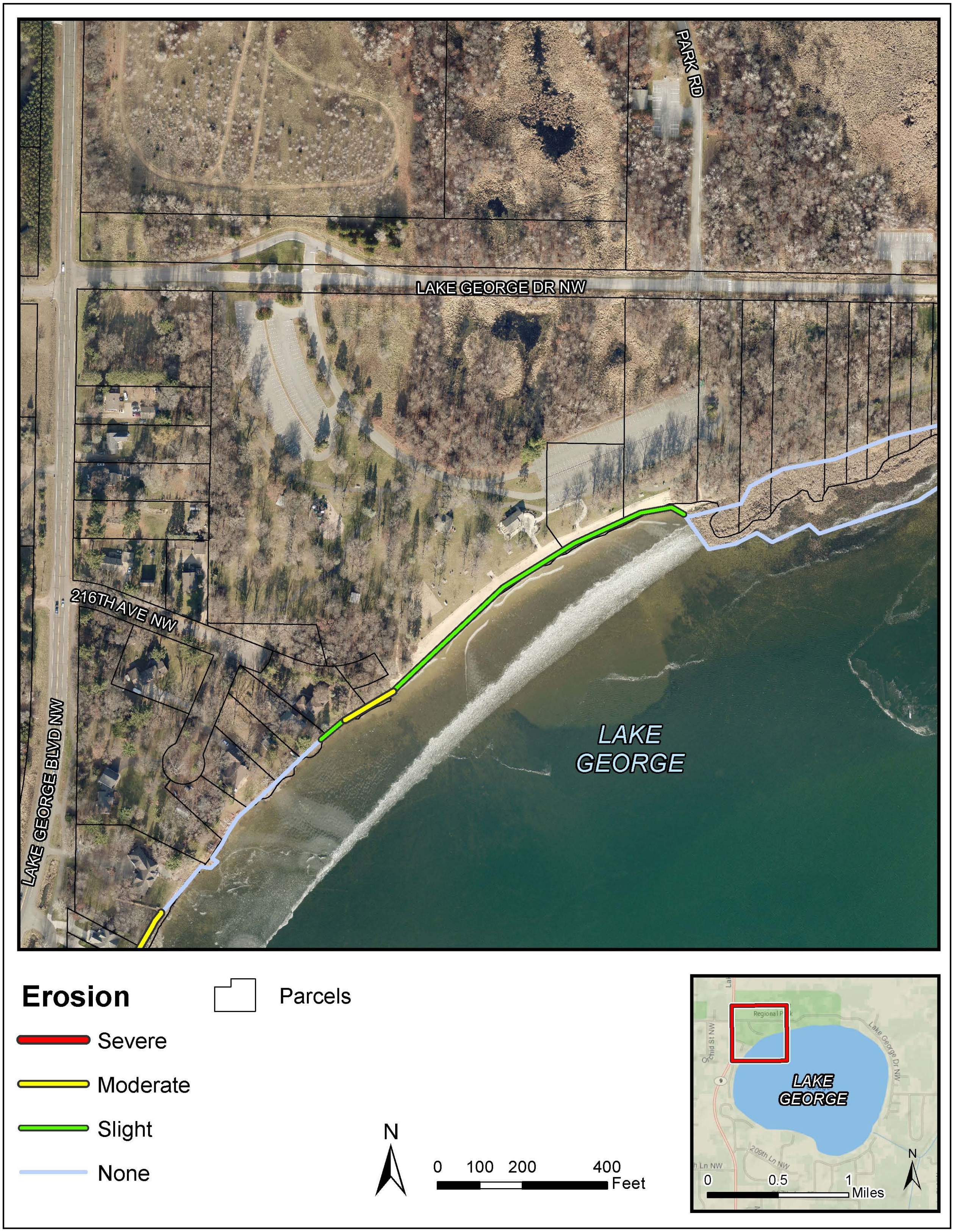
Lakeshore Stabilization

	Cost/Removal Analysis	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**	**New Treatment**	**% Reduction**
Treatment	**Shoreline Erosion Severity**	Slight		Moderate		Severe	
	Total Size of BMPs	100	linear-ft	100	linear-ft	100	linear-ft
	TP (lb/yr)	0.08	0.2%	0.52	1.6%	3.64	11.2%
	TSS (lb/yr)	62	0.2%	612	1.5%	4,512	11.1%
	Volume (acre-feet/yr)	0.03	0.2%	0.03	0.2%	0.03	0.2%
Cost	**Administration & Promotion Costs***	$4,055		$4,055		$4,055	
	Design & Construction Costs**	7,500		7,500		12,500	
	Total Estimated Project Cost (2018)	**$11,555**		**$11,555**		**$16,555**	
	Annual O&M***	$150		$150		$150	
Efficiency	**30-yr Average Cost/lb-TP**	**$6,982**		**$1,035**		**$193**	
	30-yr Average Cost/1,000lb-TSS	**$8,660**		**$875**		**$156**	
	30-yr Average Cost/ac-ft Vol.	**$20,201**		**$20,201**		**$26,492**	

*(35 hours at $73/hour for promotion and administration) + ($1,500 for design)

**$75/linear-ft (slight, moderate), $125/linear-ft (severe) for materials and labor

***$1.5/linear-ft/year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LAKE GEORGE DR NW
216TH AVE NW
LAKE GEORGE BLVD NW
LAKE GEORGE
Erosion
Severe
Moderate
Slight
None
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Lake George Dr NW
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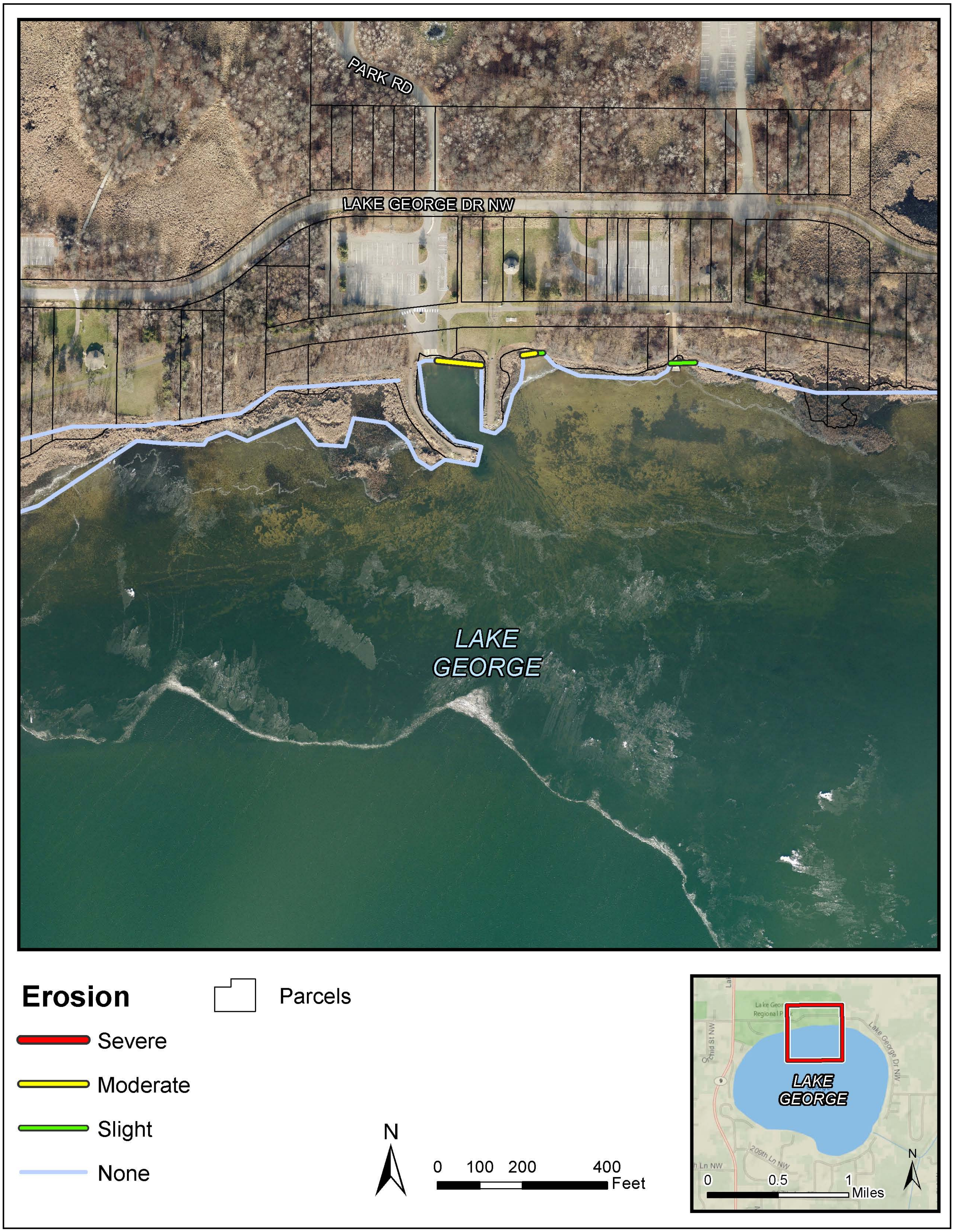
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LAKE GEORGE DR NW
LAKE GEORGE
Erosion
Severe
Moderate
Slight
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Parcels
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Feet
LAKE GEORGE
205th Ln NW
Lake George Dr NW
0
0.5
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Miles
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LAKE GEORGE DR NW
VERDIN ST NW
LAKE GEORGE
Erosion
Severe
Moderate
Slight
None
Parcels
N
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200
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Feet
Lake George Regional Park
LAKE GEORGE
205th Ln NW
0
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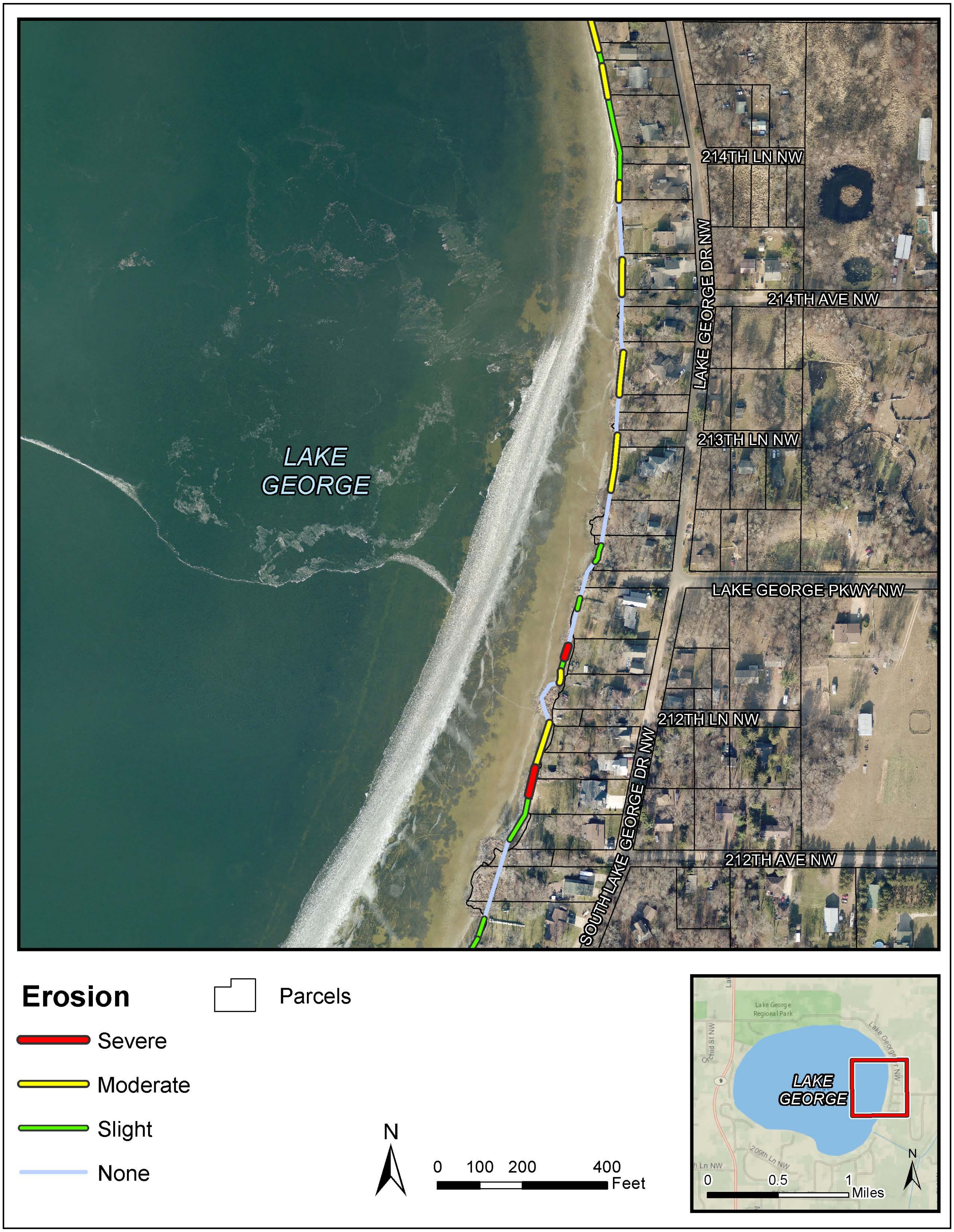
Miles
N


214TH LN NW
LAKE GEORGE DR NW
214TH AVE NW
213TH LN NW
LAKE GEORGE
LAKE GEORGE PKWY NW
212TH LN NW
SOUTH LAKE GEORGE DR NW
212TH AVE NW
Erosion
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Lake George Regional Park
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0 0.5 1 Miles
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LAKE GEORGE
SOUTH LAKE GEORGE DR NW
XAVIS ST NW
VERDIN ST NW
Erosion
Severe
Moderate
Slight
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Parcels
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Feet
Lake George Regional Park
Lake George Dr NW
Orchid St NW
LAKE GEORGE
205th Ln NW
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Miles
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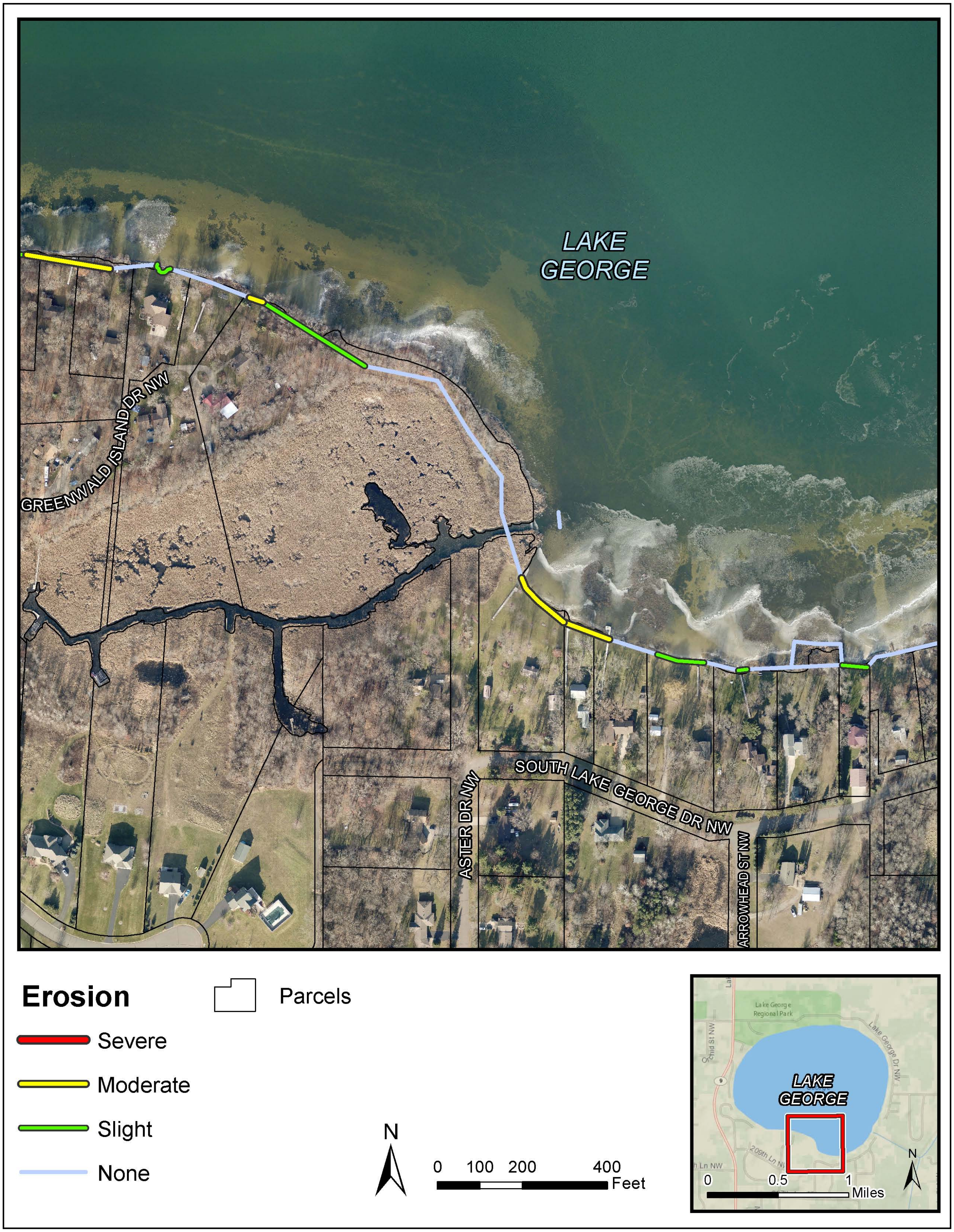
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SOUTH LAKE GEORGE DR NW
ASTER DR NW
ARROWHEAD ST NW
Erosion
Severe
Moderate
Slight
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0 100 200 400
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Lake George Regional Park
Lake George Dr NW
LAKE GEORGE
205th Ln NW
0 0.5 1
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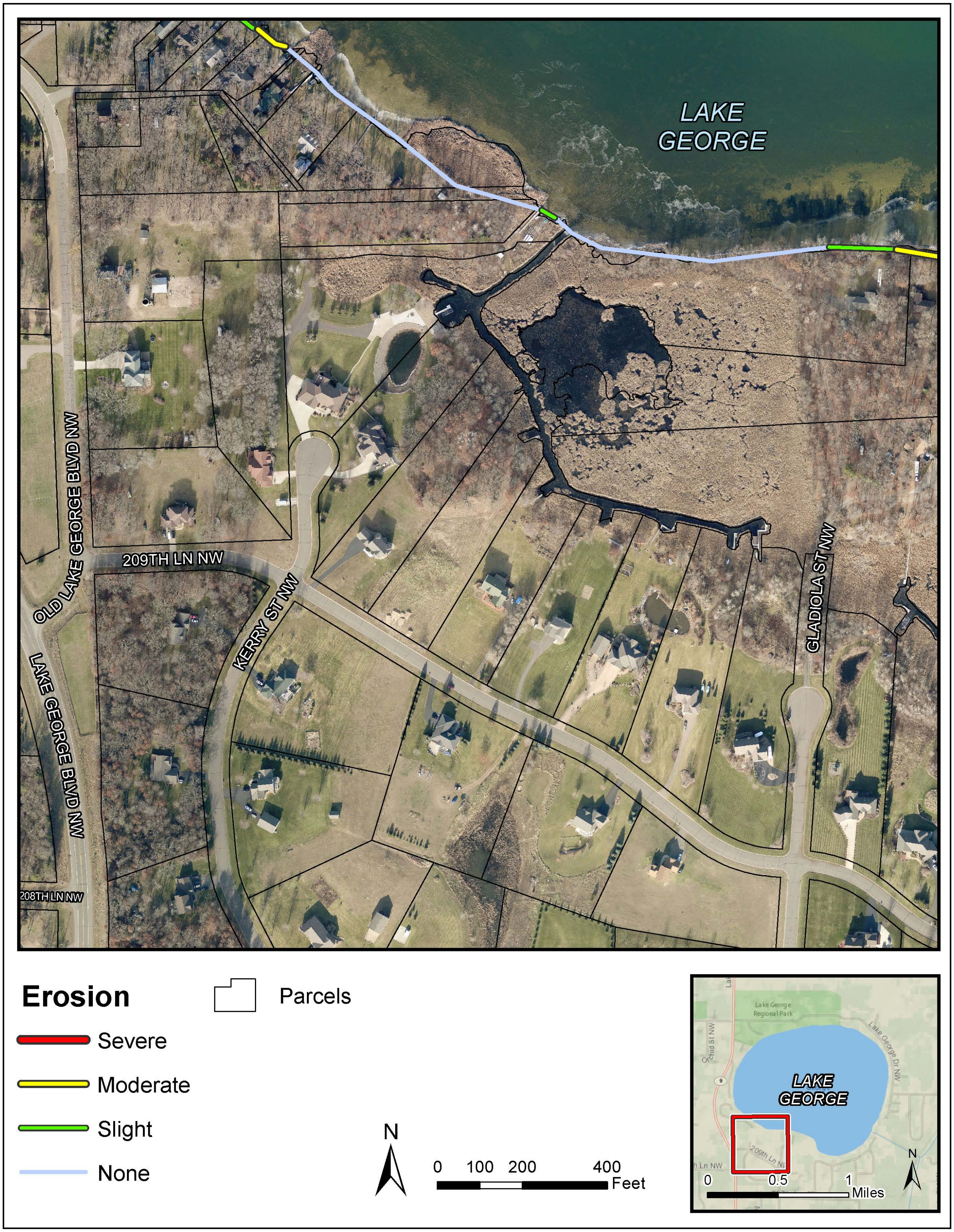
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OLD LAKE GEORGE BLVD NW
209TH LN NW
KERRY ST NW
GLADIOLA ST NW
LAKE GEORGE BLVD NW
208TH LN NW
Erosion
Severe
Moderate
Slight
None
Parcels
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Lake George Regional Park
Lake George Dr NW
Orchid St NW
LAKE GEORGE
209th Ln NW
0 0.5 1 Miles
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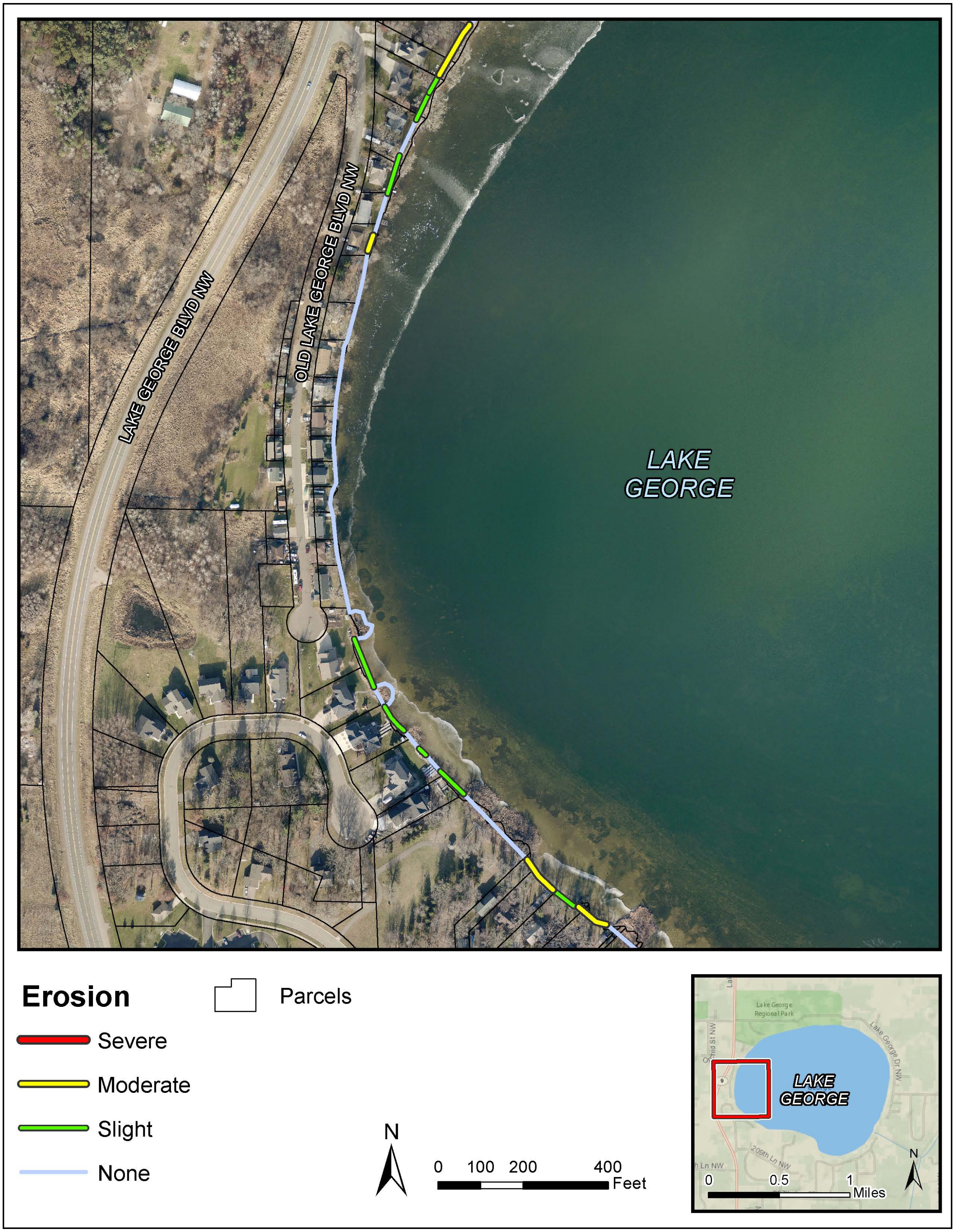
LAKE GEORGE BLVD NW
OLD LAKE GEORGE BLVD NW
LAKE GEORGE
Erosion
Severe
Moderate
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0 100 200 400
Feet
Lake George Regional Park
Lake George Dr NW
Orchid St NW
206th Ln NW
LAKE GEORGE
0 0.5 1
Miles
N

Project Ranking

The table on the following page summarizes potential projects in the Lake George lakeshed. Projects are ranked from most cost effective to least cost effective based on cost per pound of phosphorus removed. These ranked projects are split into three groups: 1) those with direct water quality benefits to Lake George, 2) those with indirect benefits to Lake George and 3) other non-structural changes and considerations to prevent future water quality deterioration.

Projects with indirect benefits reduce pollutants in the watershed, but those pollutants may not entirely reach the lake presently. Their pollutant reductions will not be fully realized at the lake. For example, a project upstream of Grass Lake indirectly benefits Lake George because Grass Lake already treats some of that water and because most Ditch 19 water bypasses the lake.

Aside from projects to improve water quality now, there are significant opportunities to protect against future water quality degradation. As development occurs, stormwater management and treatment is important. Keeping water on the land, rather than exporting it to ditches, streams and ultimately the lake should be a top priority. Additionally, good housekeeping or cultural practices can benefit lake water quality. These include proper fertilizer use, yard waste disposal, maintaining native aquatic vegetation and many others.

Summary of preferred stormwater retrofit opportunities ranked by cost-effectiveness with respect to total phosphorus (TP) reduction. TSS and volume reductions are also shown. For more information on each project refer to the catchment profile pages in this report. Projects indirectly impacting the lake are those upstream of wetlands or Grass Lake which may already provide some treatment. This should be considered when comparing cost effectiveness of projects, as proximity to the lake is not considered in pollutantant reduction estimates.

Projects Directly Impacting Lake George

Project Rank	Retrofit Type (refer to catchment profile pages for additional detail)	Subwatershed	Projects Identified	TP Reduction (lb/yr)	TSS Reduction (lb/yr)	Volume Reduction (ac-ft/yr)	Probable Project Cost (2018 Dollars)	Estimated Annual Operations & Maintenance (2018 Dollars)	Estimated cost/ lb-TP/year (30-year)
1	Lakeshore Stabilization- Severe Erosion	Lake Adjacent	100 Linear-ft	3.64	4,512	n/a	$16,555	$150	$193
2	Iron Enhanced Sand Filter (IESF)	North Inlet	1 (3 sizes)	20-40	488-976	n/a	$394,072-S487,844	$1,676-$3,352	$741-$490
3	Lakeshore Stabilization- Moderate Erosion	Lake Adjacent	100 Linear-ft	0.52	612	n/a	$11,555	$150	$1,035
4	Ditch 19 Weir Modification	Ditch 19	1 (2 scenarios)	-1.6-4.5	4-344	3.8-5.8	$300,000	$0	-$6,061-$2,242
5	Shoreline Buffers	Near Lake	85	0.03	8	0.03	$3,652	$66	$6,568
6	Lakeshore Stabilization- Slight Erosion	Lake Adjacent	100 Linear-ft	0.08	62	n/a	$11,555	$150	$6,982

Projects Indirectly Impacting Lake George

7	Grassed Waterway	North Inlet	1 (2 sizes)	1.3-1.6	314-337	0.51-0.74	$6,372-$7,196	$50-$100	$197-$213
8	Cropland Riparian Buffers- 50'	Ditch 19	3 variations	17.62-53.03	140.26-422.12	n/a	$16,408-$35,883	$3,524-$10,606	$223-$231
9	Cropland Riparian Buffers- 16.5'	Ditch 19	4 variations	2.08-9.10	25.52-111.65	n/a	$8,916-$16,341	$800-$3,500	$444-$528
10	Grassed Waterway	Ditch 19	1 (2 sizes)	0.3-0.4	78-84	0.13-0.19	$5,750-$5,951	$13-25	$561-$612
11	Cropland Cover Crops	Ditch 19	3 variations	19.0-56.9	203-610 (tons)	n/a	$72,547-$203,042	$68,751-$199,246	$3,618-$3,750

Figure 51 Identified retrofit projects ranked by cost effectiveness for removing TP

Summary of recommended non-structural actions to protect Lake George water quality

Stormwater Action	Importance Ranking	Description of the Action
Yard waste disposal cleanup	High	Clean up yard waste disposal identified in the Northeast watershed in this report. Take educational or other actions needed to ensure further disposal does not occur in the future.
MIDS Stormwater Standards	High	Minimal Impact Design Standards (MIDS) for stormwater focus on containing and infiltrating as much stormwater as possible. These standards are especially important as precipitation levels increase, and open areas develop. Keeping stormwater, and the pollutants it contains, on the land and allowing it to infiltrate into the ground is a key strategy. The City of Oak Grove is the land use authority, and would be responsible for any such stormwater standards with the guidance of the Upper Rum River Watershed Management Organization. A special effort with these groups to consider customized stormwater standards for the Lake George watershed is recommended.
Phase 2: In-Lake Study	High	A study to determine the effects of in-lake factors on Lake George, and recommend future management action is advised. In-lake factors that can affect water quality include game fish, rough fish, in-lake sediment stability, wave action, lake usage, aquatic vegetation, and others. While Phase 1 of this study found many water quality correlations and contributing factors from the lakeshed, there may be other in-lake factors affecting water quality as well.
Maintain or Enhance Near-Lake Wetlands	High	Wetlands through with the North and Northeast inlets to the lake drain should be protected or enhanced. These wetlands reduce pollutants coming from the upper watershed before they reach the lake. Efforts to channelize the current dispersed flow through these wetlands is not advised.
Public Education	Moderate	Ongoing outreach and education to homeowners regarding actions they can take (or shouldn't take) in order to keep the lake health is recommended. Specifically, dumping of leaves, sediment, and other yard waste near the lake can have a large impact on lake water quality. Additionally, mowing to the waters' edge and eliminated native vegetation increases shoreline erosion rates and allows stormwater to run overland umimpeeded to the lake. Over fertilization and the use of phosphorus fertilizers near a lake contribute to algal proliferation and decreased water clarity. All of these issues can be addressed by educated homeowners. The message has to be spread in an effective, informative and actionable way.
Continue AIS Management with Native Vegetation in Mind	Moderate	Herbicide treatments to control aquatic invasive species (AIS) should continue to be done in a way mindful of lake health. Certain native species of aquatic vegetation can be negatively affected by herbicide treatments targeting invasive species. These native species are important to the lake for a host of reasons, including the water quality benefit they provide. Continue selecting herbicide treatment areas, chemicals and timing in a way that minimizes impacts on native plants.
Shoreland Septic Inventory and Replacement	Low	Locate and replace non-compliant septic systems in the shoreland zone. Due to a community septic system serving much of the Lake George area, septic system concerns are lessened. However, maintenance or correction of septic systems should be a priority for all others.

Figure 52 Non-structural actions to protect water quality

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Appendix 1- Model Input Parameters

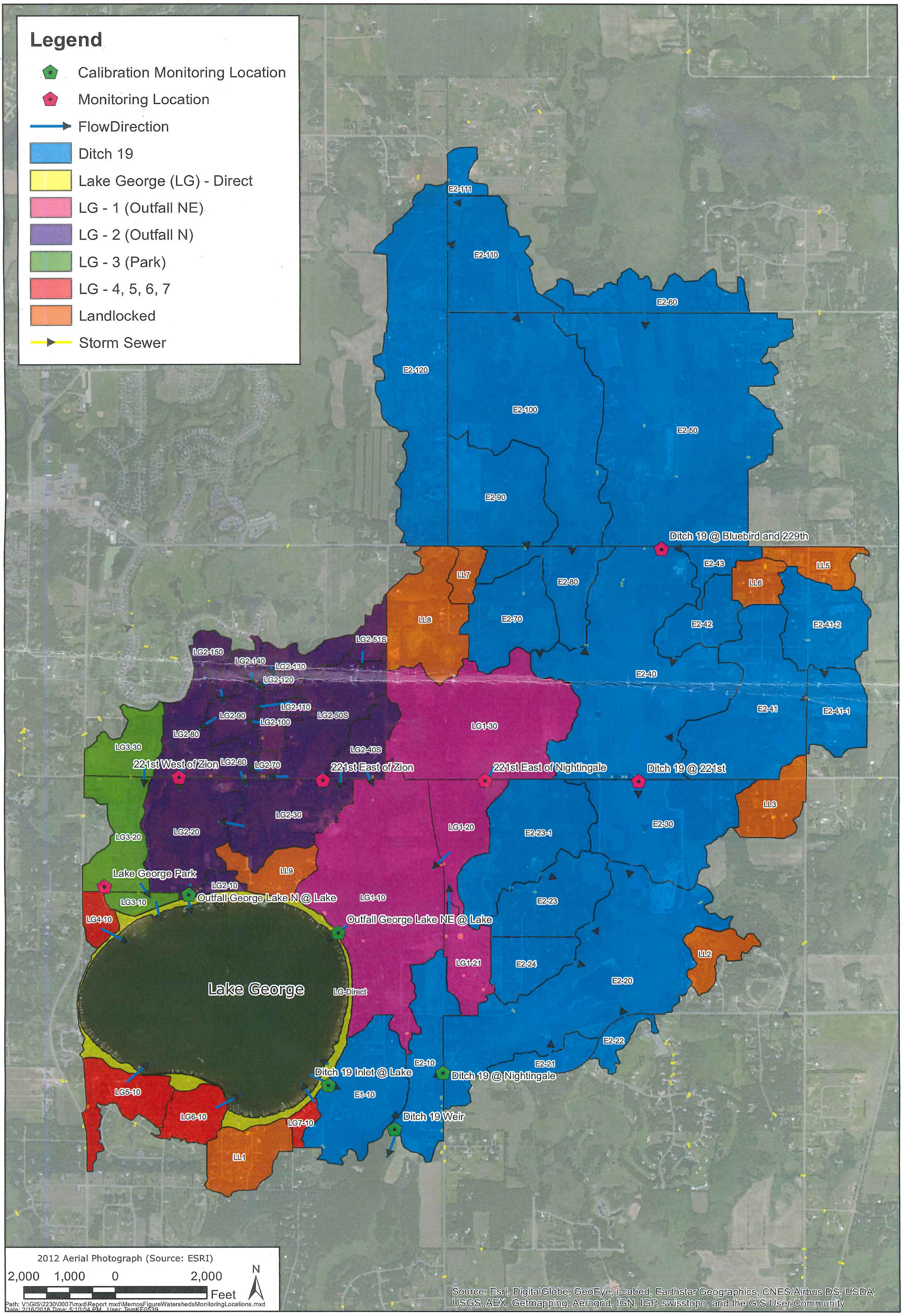
Appendix 1-A: Lake George Lakeshed Subwatersheds and Flow Direction Used in Models

Appendix 1-B: Subwatershed Impervious Fraction and Runoff Curve Numbers, 2016 Land Use

Appendix 1-C: Subwatershed Impervious Fraction and Runoff Curve Numbers, 2030 Land Use

Appendix 1-D: Modeled Precipitation Record

Appendix 1- A: Lake George Lakeshed Catchments, Subwatersheds, and Flow Direction Used in Models



2012 Aerial Photograph (Source: ESRI)

Path: V:\GIS\2230\0007\mxd\Report mxd\MemosFigureWatershedsMonitoringLocations.mxd
Date: 2/16/2018 Time: 5:10:04 PM User: TemKE0539

Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

ANOKA CONSERVATION DISTRICT	WENCK ASSOCIATES	FEB 2018
Lake George Watershed	Responsive partner. Exceptional outcomes.	Figure 1

Appendix 1- B: Modeled Catchment Impervious Fraction and Runoff Curve Numbers, 2016 Land Use

Basin ID	Imp. Fraction	CN
E1-10	0.08813349	47.5
E2-10	0.089811666	48.1
E2-100	0.062515519	56.0
E2-110	0.067201192	45.6
E2-111	0.144129166	39.2
E2-120	0.080441698	47.6
E2-20	0.063225857	55.5
E2-21	0.117381375	46.5
E2-22	0.100791773	52.7
E2-23	0.087976067	47.3
E2-24	0.140603808	43.1
E2-30	0.073755963	53.3
E2-40	0.056374259	61.1
E2-41	0.083827172	53.8
E2-41-1	0.082969205	49.1
E2-41-2	0.097114417	52.2
E2-42	0.129566306	43.4
E2-43	0.154223055	40.7
E2-50	0.071306003	55.0
E2-60	0.094011	50.7
E2-70	0.101395946	55.1
E2-80	0.084864945	55.5
E2-90	0.054610651	55.0
LG-Direct	0.147332491	53.1
LG1-10	0.086469092	50.7
LG1-20	0.069629935	55.1
LG1-21	0.164838412	40.9
E2-23-1	0.081886721	52.7
LG1-30	0.062312872	54.5
LG2-10	0.1	54.8
LG2-100	0.114225929	45.6
LG2-110	0.15399234	39.4
LG2-120	0.157685579	49.0
LG2-130	0.077796999	55.3
LG2-140	0.156390013	54.7
LG2-150	0.122182932	47.9
LG2-20	0.1	57.0
LG2-30	0.083569992	54.3
LG2-40S	0.070868489	47.5
LG2-50S	0.071632476	47.6
LG2-51S	0.05	49.0
LG2-60	0.10901151	46.1
LG2-70	0.092368047	46.1
LG2-80	0.07589622	58.8
LG2-90	0.113146263	53.8
LG3-10	0.1	50.6
LG3-20	0.092967748	53.0
LG3-30	0.06540298	52.8
LG4-10	0.162300773	39.6
LG5-10	0.115198501	47.0
LG6-10	0.121216327	49.3
LG7-10	0.155725932	41.5
LL1	0.147759277	41.2
LL2	0.061406356	46.4
LL3	0.150969992	42.5
LL5	0.147631916	45.4
LL6	0.191150283	39.0
LL7	0.068253368	61.3
LL8	0.083411683	48.7
LL9	0.096085852	49.3

Appendix 1- C: Modeled Catchment Impervious Fraction and Runoff Curve Numbers, 2030 Land Use

Basin ID	Imp. Fraction	CN
E1-10	0.216595818	55.8236
E2-10	0.175966396	55.2785
E2-100	0.114960649	62.84042
E2-110	0.129427863	52.30606
E2-111	0.170537982	48.4824
E2-120	0.081781839	50.09398
E2-20	0.144712337	60.11361
E2-21	0.188783282	55.59716
E2-22	0.271961892	58.62813
E2-23	0.2	56.05064
E2-24	0.199619968	52.42354
E2-30	0.180277338	56.35737
E2-40	0.2	64.09243
E2-41	0.2	60.8718
E2-41-1	0.309201871	57.0788
E2-41-2	0.324109658	55.83136
E2-42	0.2	52.36086
E2-43	0.2	50.07412
E2-50	0.218903555	62.00838
E2-60	0.264509478	59.78698
E2-70	0.171432597	61.27349
E2-80	0.169746215	60.72293
E2-90	0.098241898	61.40066
LG-Direct	0.23583908	53.92417
LG1-10	0.216165429	56.95869
LG1-20	0.187524919	61.46157
LG1-21	0.2	50.62584
E2-23-1	0.2	60.78053
LG1-30	0.2	61.63541
LG2-10	0.1	54.79294
LG2-100	0.150242202	46.49692
LG2-110	0.16624336	46.08056
LG2-120	0.15360715	53.39047
LG2-130	0.171974159	58.29243
LG2-140	0.162571728	58.92089
LG2-150	0.152702846	52.53423
LG2-20	0.142358976	61.00651
LG2-30	0.141331253	57.44437
LG2-40S	0.2	55.98901
LG2-50S	0.161992561	51.69703
LG2-51S	0.2	49
LG2-60	0.114171143	46.60142
LG2-70	0.177496034	46.7496
LG2-80	0.163052709	63.46157
LG2-90	0.114953824	56.55519
LG3-10	0.1	50.59015
LG3-20	0.165086378	58.39407
LG3-30	0.165479395	56.57337
LG4-10	0.16165652	42.93423
LG5-10	0.195879247	48.69335
LG6-10	0.199717873	53.30474
LG7-10	0.355703832	47.84286
LL1	0.191094758	44.82701
LL2	0.2	54.95465
LL3	0.2	51.83164
LL5	0.2	53.83761
LL6	0.2	49.00998
LL7	0.2	68.82949
LL8	0.180888648	57.06162
LL9	0.144607263	50.82605

Appendix 1- D: Modeled Precipitation Records

Gauge Name	Gauge Type	Record Start Date	Record End Date	Number of Observations
St. Francis 1.13 ESE	CoCoRaHS	2011-04-01	Current	1183
St. Francis 4.0 E	CoCoRaHS	2010-01-16	Current	2273

Appendix 2- Model Output Results

Appendix 2-A: Subwatershed Loading to Lake George, 2016 Land use, 5/1-11/30 2017 Precipitation, Weir 901.59 (Baseline)

Appendix 2-B: Subwatershed Loading to Lake George, 2016 Land use, 5/1-11/30 2016 Precipitation, Weir 901.59

Appendix 2-C: Subwatershed Loading to Lake George, 2030 Land use, 5/1-11/30 2017 Precipitation, Weir 901.59

Appendix 2-D: Subwatershed Loading to Lake George, 2030 Land use, 5/1-11/30 2016 Precipitation, Weir 901.59

Appendix 2-E: Subwatershed Loading to Lake George, 2016 Land use, 5/1-11/30 2017 Precipitation, Weir 902.08

Appendix 2-F: Subwatershed Loading to Lake George, 2016 Land use, 5/1-11/30 2016 Precipitation, Weir 902.08

Appendix 2-G: Subwatershed Loading to Lake George, 2030 Land use, 5/1-11/30 2017 Precipitation, Weir 902.08

Appendix 2-H: Subwatershed Loading to Lake George, 2030 Land use, 5/1-11/30 2016 Precipitation, Weir 902.08

Appendix 2- A Subwatershed Loading to Lake George, 2016 Land use, 5/1-11/30 2017 Precipitation, Weir 901.59 (Baseline)

Subwatershed	Flow to Lake (acre-ft)	TP (mg/L)	TP (lbs) to Lake	TSS (mg/L)	TSS (lbs) to Lake
North Inlet	90.32	0.19	46.67	3.98	977.51
Northeast Inlet	93.02	0.24	60.71	10.57	2673.79
Northwest	19.20	0.20	10.44	5.90	308.04
Near Lake	17.36	0.54	25.49	95.03	4485.52

Ditch 19 to Lake Storm Event Sum	115.40	0.26	78.54	17.44	4805.08
Ditch 19 Out of Lake	-488.52	0.03	-33.21	4.00	-5313.84

2017 Storm Date	Duration (hrs)	Rain (in)	TP (mg/L)	TP (lbs)	TSS (mg/L)	TSS (lbs)
May 16-18	71.00	2.06	0.30	12.90	25.08	1078.41
June 14	23.00	0.68	0.31	0.02	26.29	1.70
June 28-30	71.00	1.70	0.28	2.12	20.39	154.42
July 12-13	47.00	0.82	0.30	1.02	23.61	80.40
August 3-4	47.00	1.75	0.29	7.21	21.61	537.06
August 10-11	47.00	0.84	0.31	1.34	27.02	117.00
August 16-19	95.00	1.40	0.28	2.89	20.07	206.97
August 26-27	47.00	0.99	0.32	0.68	27.59	59.01
September 23-27	119.00	1.19	0.29	0.86	22.07	65.27
October 1-4	95.00	3.85	0.23	49.49	11.64	2504.83
2017 Total		15.28		78.54		4805.08

Appendix 2- B Subwatershed Loading to Lake George, 2016 Land use, 5/1-11/30 2016 Precipitation, Weir 901.59

Subwatershed	Flow to Lake (acre-ft)	TP (mg/L)	TP (lbs) to Lake	TSS (mg/L)	TSS (lbs) to Lake
North Inlet	96.01	0.18	47.00	3.92	1023.48
Northeast Inlet	95.48	0.24	62.31	10.71	2780.76
Northwest	21.19	0.19	10.95	6.22	358.44
Near Lake	21.30	0.54	31.28	94.03	5446.60

Ditch 19 to Lake Storm Event Sum	162.65	0.27	121.74	18.87	8915.95
Ditch 19 Out of Lake	-589.51	0.03	-40.08	4.00	-6412.36

2016 Storm Date	Duration (hrs)	Rain (in)	TP (mg/L)	TP (lbs)	TSS (mg/L)	TSS (lbs)
May 24	23.00	2.04	0.30	24.69	25.02	2063.93
July 10-12	71.00	2.75	0.26	48.62	16.73	3128.40
August 11	23.00	2.27	0.29	20.21	23.18	1615.57
September 5-8	95.00	3.10	0.26	18.41	17.88	1266.37
November 19	23.00	1.00	0.33	6.95	31.52	663.67
November 27-30	95.00	0.93	0.25	2.86	15.56	178.02
2016 Total		12.09		121.74		8915.95

Appendix 2- C Subwatershed Loading to Lake George, 2030 Land use, 5/1-11/30 2017 Precipitation, Weir 901.59

Subwatershed	Flow to Lake (acre-ft)	TP (mg/L)	TP (lbs) to Lake	TSS (mg/L)	TSS (lbs) to Lake
North Inlet	121.94	0.20	66.32	4.67	1548.54
Northeast Inlet	164.80	0.25	112.04	12.89	5776.68
Northwest	28.25	0.20	15.36	6.02	462.45
Near Lake	23.34	0.50	34.46	85.03	5859.84

Ditch 19 to Lake Storm Event Sum	180.46	0.27	137.01	17.27	9795.28
Ditch 19 Out of Lake	-630.54	0.03	-42.87	4.00	-6858.60

2017 Storm Date	Duration (hrs)	Rain (in)	TP (mg/L)	TP (lbs)	TSS (mg/L)	TSS (lbs)
May 16-18	71.00	2.06	0.30	25.10	25.05	2095.93
June 14	23.00	0.68	0.32	2.12	26.53	175.47
June 28-30	71.00	1.70	0.28	8.15	20.55	598.39
July 12-13	47.00	0.82	0.30	4.25	23.74	335.98
August 3-4	47.00	1.75	0.29	22.06	21.69	1649.74
August 10-11	47.00	0.84	0.32	3.71	27.09	314.43
August 16-19	95.00	1.40	0.28	10.05	20.13	722.28
August 26-27	47.00	0.99	0.32	1.91	27.64	165.22
September 23-27	119.00	1.19	0.29	3.55	22.10	270.48
October 1-4	95.00	3.85	0.26	53.76	16.00	3308.50
October 22	23.00	0.83	0.34	0.73	31.13	67.26
November 5	23.00	0.21	0.25	1.62	14.15	91.60
2017 Total		16.32		137.01		9795.28

Appendix 2- D Subwatershed Loading to Lake George, 2030 Land use, 5/1-11/30 2016 Precipitation, Weir 901.59

Subwatershed	Flow to Lake	TP (mg/L)	TP (lbs) to Lake	TSS (mg/L)	TSS (lbs) to Lake
North Inlet	136.29	0.19	70.42	3.90	1445.43
Northeast Inlet	203.68	0.23	127.39	10.33	5721.63
Northwest	32.97	0.20	17.93	6.03	540.59
Near Lake	34.37	0.51	47.66	87.69	8195.02

Ditch 19 to Lake Storm Event Sum	265.60	0.26	196.21	17.57	14480.47
Ditch 19 Out of Lake	-765.78	0.03	-52.06	4.00	-8329.66

2016 Storm Date	Duration (hrs)	Rain (in)	TP (mg/L)	TP (lbs)	TSS (mg/L)	TSS (lbs)
May 24	23.00	2.04	0.30	41.99	25.02	3501.81
June 11-15	119.00	1.19	0.31	0.15	26.11	12.62
June 20	23.00	0.59	0.33	0.05	30.01	4.40
July 10-12	71.00	2.75	0.25	61.56	14.79	3642.03
July 24	23.00	1.43	0.28	4.10	21.96	321.49
August 11	23.00	2.27	0.29	31.80	22.95	2516.94
August 19-22	95.00	2.01	0.24	0.09	12.39	4.50
September 5-8	95.00	3.10	0.25	23.29	15.95	1485.96
September 22-26	119.00	1.45	0.30	1.74	23.93	138.46
October 5	23.00	0.77	0.42	3.79	47.42	427.43
October 17-18	47.00	0.94	0.31	3.10	26.55	265.48
November 19	23.00	1.00	0.33	19.97	31.40	1899.70
November 27-30	95.00	0.93	0.24	4.59	13.57	259.65
2016 Total		20.47		196.21		14480.47

Appendix 2- E Subwatershed Loading to Lake George, 2016 Land use, 5/1-11/30 2017 Precipitation, Weir 902.08

Subwatershed	Flow to Lake (acre-ft)	TP (mg/L)	TP (lbs) to Lake	TSS (mg/L)	TSS (lbs) to Lake
North Inlet	90.32	0.18	44.21	3.92	962.78
Northeast Inlet	93.03	0.24	60.72	10.71	2709.49
Northwest	19.20	0.19	9.92	6.22	324.74
Near Lake	17.36	0.54	25.49	94.03	4438.32

Ditch 19 to Lake Storm Event Sum	119.15	0.27	80.19	18.87	4801.18
Ditch 19 Out of Lake	-476.20	0.03	-32.37	4.00	-5179.86

2017 Storm Date	Duration (hrs)	Rain (in)	TP (mg/L)	TP (lbs)	TSS (mg/L)	TSS (lbs)
May 16-18	71.00	2.06	0.30	12.19	25.08	1019.39
June 28-30	71.00	1.70	0.28	1.66	20.39	120.86
July 12-13	47.00	0.82	0.30	0.81	23.61	63.65
August 3-4	47.00	1.75	0.29	6.58	21.61	490.55
August 10-11	47.00	0.84	0.31	1.11	27.02	97.07
August 16-19	95.00	1.40	0.28	2.47	20.07	176.91
August 26-27	47.00	0.99	0.32	0.37	27.59	32.26
September 23-27	119.00	1.19	0.29	0.69	22.07	52.19
October 1-4	95.00	3.85	0.23	54.30	11.64	2748.30
2017 Total		14.60		80.19		4801.18

Appendix 2- F Subwatershed Loading to Lake George, 2016 Land use, 5/1-11/30 2016 Precipitation, Weir 902.08

Subwatershed	Flow to Lake (acre-ft)	TP (mg/L)	TP (lbs) to Lake	TSS (mg/L)	TSS (lbs) to Lake
North Inlet	92.01	0.18	47.00	3.92	1023.48
Northeast Inlet	95.40	0.24	62.26	10.71	2778.46
Northwest	21.19	0.19	10.95	6.22	358.44
Near Lake	21.30	0.54	31.28	94.03	5446.60

Ditch 19 to Lake Storm Event Sum	156.86	0.27	117.28	18.87	8571.67
Ditch 19 Out of Lake	-578.89	0.03	-39.36	4.00	-6296.81

2016 Storm Date	Duration (hrs)	Rain (in)	TP (mg/L)	TP (lbs)	TSS (mg/L)	TSS (lbs)
May 24	23.00	2.04	0.30	23.19	25.02	1938.91
July 10-12	71.00	2.75	0.26	47.23	16.73	3038.79
August 11	23.00	2.27	0.29	19.95	23.18	1594.92
September 5-8	95.00	3.10	0.26	17.85	17.88	1227.47
November 19	23.00	1.00	0.33	6.25	31.52	596.86
November 27-30	95.00	0.93	0.25	2.81	15.56	174.72
2016 Total		12.09		117.28		8571.67

Appendix 2- G Subwatershed Loading to Lake George, 2030 Land use, 5/1-11/30 2017 Precipitation, Weir 902.08

Subwatershed	Flow to Lake (acre-ft)	TP (mg/L)	TP (lbs) to Lake	TSS (mg/L)	TSS (lbs) to Lake
North Inlet	121.94	0.20	66.32	4.67	1548.55
Northeast Inlet	164.80	0.25	112.04	12.89	5776.65
Northwest	28.25	0.20	15.36	6.02	462.45
Near Lake	25.34	0.50	34.46	85.03	5859.84

Ditch 19 to Lake Storm Event Sum	175.12	0.27	131.18	17.27	9360.55
Ditch 19 Out of Lake	-619.73	0.03	-42.13	4.00	-6741.08

2017 Storm Date	Duration (hrs)	Rain (in)	TP (mg/L)	TP (lbs)	TSS (mg/L)	TSS (lbs)
May 16-18	71.00	2.06	0.30	24.57	25.05	2051.78
June 14	23.00	0.68	0.32	1.73	26.53	143.71
June 28-30	71.00	1.70	0.28	7.56	20.55	554.59
July 12-13	47.00	0.82	0.30	3.95	23.74	312.80
August 3-4	47.00	1.75	0.29	20.92	21.69	1565.01
August 10-11	47.00	0.84	0.32	3.61	27.09	305.32
August 16-19	95.00	1.40	0.28	9.53	20.13	684.94
August 26-27	47.00	0.99	0.32	1.63	27.64	140.93
September 23-27	119.00	1.19	0.29	3.22	22.10	245.61
October 1-4	95.00	3.85	0.26	54.28	16.00	3340.29
November 5		0.21	0.25	0.17	14.15	15.58
2017 Total		15.49		131.18		9360.55

Appendix 2- H Subwatershed Loading to Lake George, 2030 Land use, 5/1-11/30 2016 Precipitation, Weir 902.08

Subwatershed	Flow to Lake	TP (mg/L)	TP (lbs) to Lake	TSS (mg/L)	TSS (lbs) to Lake
North Inlet	136.29	0.19	70.42	3.90	1445.43
Northeast Inlet	203.68	0.23	127.39	10.33	5721.49
Northwest	32.97	0.20	17.93	6.03	540.59
Near Lake	34.37	0.51	47.66	87.69	8195.02

Ditch 19 to Lake Storm Event Sum	257.81	0.26	191.29	17.57	14053.38
Ditch 19 Out of Lake	-753.34	0.03	-51.22	4.00	-8194.40

2016 Storm Date	Duration (hrs)	Rain (in)	TP (mg/L)	TP (lbs)	TSS (mg/L)	TSS (lbs)
May 24	23.00	2.04	0.30	41.34	25.02	3448.07
July 10-12	71.00	2.75	0.25	61.24	14.79	3622.92
July 24	23.00	1.43	0.28	3.57	21.96	280.25
August 11	23.00	2.27	0.29	30.28	22.95	2396.18
September 5-8	95.00	3.10	0.25	24.04	15.95	1533.53
September 22-26	119.00	1.45	0.30	1.15	23.93	91.86
October 5	23.00	0.77	0.42	3.34	47.42	376.79
October 17-18	47.00	0.94	0.31	2.54	26.55	217.42
November 19	23.00	1.00	0.33	19.19	31.40	1826.01
November 27-30	95.00	0.93	0.24	4.60	13.57	260.35
2016 Total		16.68		191.29		14053.38

Appendix 3- Wenck Associates Model Technical Memos

Appendix 3-A: P8 Technical Memo

Appendix 3-B: EPA SWMM Technical Memo

Appendix 3-A P8 Technical Memo

Technical
Memo

To: Jamie Schurbon, Anoka Conservation District
Jared Wagner, Anoka Conservation District

From: Kirby Templin, Wenck
Jeff Strom, Wenck

Date: March 3, 2018

Subject: [DRAFT] Lake George P8 Model Information and Comments.

This technical memorandum summarizes input data, assumptions, and comments for the Lake George P8 Model.

1.0 Watershed Delineation

The Lake George watershed and individual catchments were delineated by the Anoka Conservation District (ACD) using a Soil and Water Assessment (SWAT) model that utilized LiDAR elevation DEM, a field collected culvert inventory and stormwater maps obtained from the City of Oak Grove for areas with storm sewer. Wenck further refined these drainages and subcatchments such that catchment discharges generally matched existing water monitoring locations. Final catchments used in the P8 model are shown in the attached Figure 1.

2.0 Data Sources

- Precipitation and temperature data was obtained from the National Weather Service (NWS) site in Andover, MN and from the Minneapolis-St. Paul (MSP) International Airport site. The Andover site is closer to the Lake George Watershed, so the precipitation and temperature data that was available from this site was used in the precipitation and Temperature files. The precipitation and temperature files include the years 1979-2017.
    - MSP 1/1/1979 to 5/2/2007.
    - Andover 5/3/2007 to 12/31/2017. There were some missing data gaps in the Andover data that were supplemented with data from the MSP site.
    - Precipitation and temperature data can be obtained from this website. http://www.dnr.state.mn.us/climate/historical/acis_stn_meta.html
- The 2016 Generalized Landuse was used to estimate curve number and percent impervious. The curve number and percent impervious assumptions are summarized in Table 1.
- Hydrologic soil data for the watershed was obtained from the NRCS Web Soil Survey.

3.0 Calibration Parameters (Changes from P8 defaults)

- Hydrologic Calibration (Table 2 and Figure 2)
    - For developed watersheds drained by stormsewer/curb and gutter to constructed stormwater ponds, 100 percent of the impervious fraction was considered directly connected. For all other watersheds, the impervious fraction was split 50/50 between indirectly connected and directly connected impervious. These inputs are found in the 'Watersheds' window for each watershed.

    - An aquifer was built into the p8 model as a device. The time of concentration for the aquifer was set at 1 year (8,760 hours) based on observed reaction time in monitored Lake George elevations compared to annual precipitation totals. This device is found in the 'Device' window.
    - The Evapo-Transpiration Calibration Factor was set to 2. This is found in the 'ET/Snowmelt' window.
- TSS Calibration (Table 3)
    - For constructed stormwater ponds, the device Particle Removal Scale Factor was set to 1. For non-constructed ponds (such as wetlands and ditches/drainageways) the Particle Removal Scale Factor was set to 0.02. This input is found in the 'Device' window for each device. The Particle Removal Scale Factor was adjusted to better fit the TSS model results to available monitoring data.
- TP Calibration (Table 3)
    - The Global Scale Factor for TP was set to 1.7. This is found in the 'Water Quality Components' window. The Global Scale Factor was adjusted to better fit the TP model results to available monitoring data.

4.0 Model Comments

- The model's 'start date' is one year before the 'keep date' to allow for model dynamics to equalize.
- Table 4 provides information about the devices used in the P8 model.

Table 1. Landuse Curve Number and Percent Impervious Assumptions.

Landuse	Impervious Fraction	Hydrologic Soil Group						
		A	A/D	B	B/D	C	C/D	D
AREA	**IMP FRACTION**	**A**	**A/D**	**B**	**B/D**	**C**	**C/D**	**D**
Agricultural	0.05	49.0	66.5	69.0	76.5	79.0	81.5	84.0
Airport	0.3	68.0	78.5	79.0	84.0	86.0	87.5	89.0
Commercial	0.67	49.0	66.5	69.0	76.5	79.0	81.5	84.0
Extractive	0.05	49.0	66.5	69.0	76.5	79.0	81.5	84.0
Farmstead	0.1	49.0	66.5	69.0	76.5	79.0	81.5	84.0
Golf Course	0.1	39.0	59.5	61.0	70.5	74.0	77.0	80.0
Industrial and Utility	0.5	68.0	78.5	79.0	84.0	86.0	87.5	89.0
Institutional	0.32	39.0	59.5	61.0	70.5	74.0	77.0	80.0
Major Highway	0.5	49.0	66.5	69.0	76.5	79.0	81.5	84.0
Mixed Use Commercial	0.67	49.0	66.5	69.0	76.5	79.0	81.5	84.0
Mixed Use Industrial	0.5	68.0	78.5	79.0	84.0	86.0	87.5	89.0
Mixed Use Residential	0.6	39.0	59.5	61.0	70.5	74.0	77.0	80.0
Multifamily	0.6	39.0	59.5	61.0	70.5	74.0	77.0	80.0
Office	0.32	39.0	59.5	61.0	70.5	74.0	77.0	80.0
Open Water	0	85.0	85.0	85.0	85.0	85.0	85.0	85.0
Park, Recreational, or Preserve	0.1	39.0	59.5	61.0	70.5	74.0	77.0	80.0
Parks & Recreation Areas	0.1	39.0	59.5	61.0	70.5	74.0	77.0	80.0
Public Semi-Public	0.67	49.0	66.5	69.0	76.5	79.0	81.5	84.0
Railway	0.2	68.0	78.5	79.0	84.0	86.0	87.5	89.0
Retail and Other Commercial	0.67	49.0	66.5	69.0	76.5	79.0	81.5	84.0
Seasonal/Vacation	0.2	39.0	59.5	61.0	70.5	74.0	77.0	80.0
Single Family Attached	0.3	39.0	59.5	61.0	70.5	74.0	77.0	80.0
Single Family Detached	0.2	39.0	59.5	61.0	70.5	74.0	77.0	80.0
Single Family Residential	0.3	39.0	59.5	61.0	70.5	74.0	77.0	80.0
Undeveloped	0.05	39.0	59.5	61.0	70.5	74.0	77.0	80.0

Table 2. Hydrology Calibration Summary.

	Estimated Volumes (AF)	
	Year 2016 (5/3/16 to 11/29/16)	Year 2017* (4/18/17 to 11/7/17)
Monitoring Data	773.68	429.96
P8 Model Results	761.89	936.06

* The monitored volume estimate may be lower than actual based on environmental factors that influenced flows during the monitoring period (beaver dams, etc).

Table 3. Average TP and TSS Concentration Calibration Summary for years 2016-2017.

	Ditch 19 at Nightingale		Lake George North Tributary		Lake George Northeast Tributary	
	TSS (ppm)	TP (ppb)	TSS (ppm)	TP (ppb)	TSS (ppm)	TP (ppb)
Monitoring Data	6.0	102	9.0	95	8.0	214
P8 Model Results	5.2	79	3.3	184	10.4	234

Figure 2. Flow at Ditch 19 Weir.

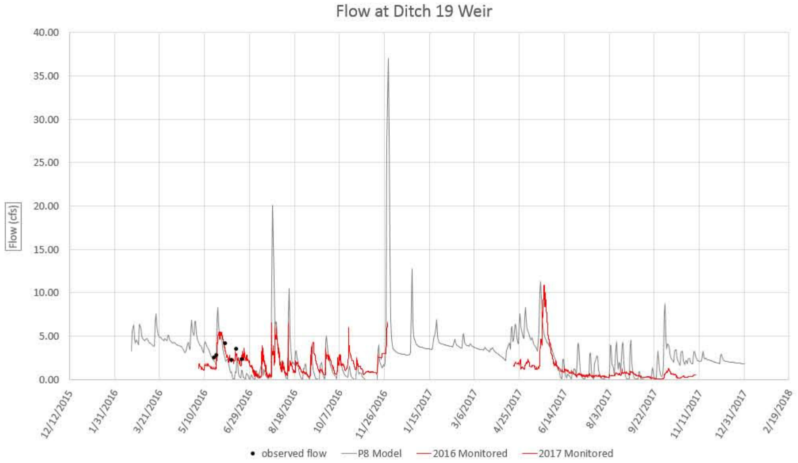


Table 4. Lake George P8 Model Device Inputs and Assumptions.

Basin ID	P8 Device	Model Assumptions
Aquifer	Aquifer	-
E1-10	Pond	LiDAR, Survey, Split Impervious Fraction 50/50 (Direct/Indirect)
E2-10	Pond	LiDAR, Survey, Split Impervious Fraction 50/50 (Direct/Indirect)
E2-100	Pond	LiDAR, Anoka County Water Resources GIS, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed Dead Pool Depth of 1 ft
E2-110	Pond	LiDAR, Assumed Outlet, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed Dead Pool Depth of 1 ft
E2-111	Pond	LiDAR, Assumed Outlet, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed Dead Pool Depth of 3 ft
E2-120	Pond	LiDAR, Assumed Outlet, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed Dead Pool Depth of 1 ft
E2-20	Pond	LiDAR, Anoka County Water Resources GIS, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed Dead Pool Depth of 3 ft
E2-21	Pond	LiDAR, Assumed Outlet, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed Dead Pool Depth of 1 ft
E2-22	Pond	LiDAR, Assumed Outlet, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed Dead Pool Depth of 1 ft
E2-23	Pipe	-
E2-23-1	Pond	LiDAR, Assumed Outlet, Split Impervious Fraction 50/50 (Direct/Indirect)
E2-24	Pipe	-
E2-30	Pond	LiDAR, Anoka County Water Resources GIS, Split Impervious Fraction 50/50 (Direct/Indirect)
E2-40	Pond	LiDAR, Anoka County Water Resources GIS, Split Impervious Fraction 50/50 (Direct/Indirect)
E2-41	Pipe	-
E2-41-1	Pond	LiDAR, Assumed Outlet, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed Dead Pool Depth of 1 ft
E2-41-2	Pond	LiDAR, Assumed Outlet, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed Dead Pool Depth of 1 ft
E2-42	Pipe	-
E2-43	Pipe	-
E2-50	Pond	LiDAR, Anoka County Water Resources GIS, Split Impervious Fraction 50/50 (Direct/Indirect)
E2-60	Pond	LiDAR, Anoka County Water Resources GIS, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed Dead Pool Depth of 1 ft
E2-70	Pond	LiDAR, Assumed Outlet, Split Impervious Fraction 50/50 (Direct/Indirect)
E2-80	Pond	LiDAR, Anoka County Water Resources GIS, Split Impervious Fraction 50/50 (Direct/Indirect)
E2-90	Pond	LiDAR, Assumed Outlet, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed Dead Pool Depth of 1 ft
Lake George	Pipe	-
LG1-10	Pond	LiDAR, Assumed Outlet, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed Dead Pool Depth of 1 ft
LG1-20	Pond	LiDAR, Assumed Outlet, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed Dead Pool Depth of 1 ft
LG1-21	Pipe	-
LG1-30	Pond	LiDAR, Assumed Outlet, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed Dead Pool Depth of 1 ft
LG2-10	Pond	LiDAR, Assumed Outlet, Split Impervious Fraction 50/50 (Direct/Indirect)
LG2-100	Pond	As-Built Grading, Assumed Outlets size, Impervious Fraction 100% Direct
LG2-110	Pond	As-Built Grading, Assumed Outlets size, Impervious Fraction 100% Direct
LG2-120	Pond	As-Built Grading, Assumed Outlets size, Impervious Fraction 100% Direct

Basin ID	P8 Device	Model Assumptions
LG2-130	Pond	As-Built Grading, Assumed Outlets size, Impervious Fraction 100% Direct
LG2-140	Pond	As-Built Grading, Assumed Outlets size, Impervious Fraction 100% Direct
LG2-150	Pond	As-Built Grading, Assumed Outlets size, Impervious Fraction 100% Direct
LG2-20	Pond	LiDAR, Assumed Outlet, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed Dead Pool Depth of 1 ft
LG2-30	Pond	LiDAR, Assumed Outlet, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed Dead Pool Depth of 1 ft
LG2-40S	Pond	LiDAR, Assumed Outlet, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed Dead Pool Depth of 1 ft
LG2-50S	Pond	LiDAR, Assumed Outlet, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed Dead Pool Depth of 1 ft
LG2-51S	Pipe	-
LG2-60	Pond	LiDAR, Assumed Outlet, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed Dead Pool Depth of 1 ft
LG2-70	Pond	As-Built Grading, Assumed Outlets size, Impervious Fraction 100% Direct
LG2-80	Pond	LiDAR, Assumed Outlet, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed Dead Pool Depth of 1 ft
LG2-90	Pond	LiDAR, Assumed Outlet, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed Dead Pool Depth of 1 ft
LG3-10	Pond	LiDAR, Assumed Outlet, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed Dead Pool Depth of 1 ft
LG3-20	Pond	LiDAR, Assumed Outlet, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed Dead Pool Depth of 1 ft
LG3-30	Pond	LiDAR, Assumed Outlet, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed Dead Pool Depth of 1 ft
LG4-10	Pipe	-
LG5-10	Pipe	-
LG6-10	Pipe	-
LG7-10	Pipe	-
LG-Direct	Pipe	-
LL1	Pond	LiDAR, Landlocked, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed 1.6 in/hr Infiltration Rate, Assumed Dead Pool Depth of 1 ft
LL2	Pond	LiDAR, Landlocked, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed 1.6 in/hr Infiltration Rate, Assumed Dead Pool Depth of 1 ft
LL3	Pond	LiDAR, Landlocked, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed 1.6 in/hr Infiltration Rate, Assumed Dead Pool Depth of 1 ft
LL5	Pond	LiDAR, Landlocked, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed 1.6 in/hr Infiltration Rate, Assumed Dead Pool Depth of 1 ft
LL6	Pond	LiDAR, Landlocked, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed 1.6 in/hr Infiltration Rate, Assumed Dead Pool Depth of 1 ft
LL7	Pond	LiDAR, Landlocked, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed 1.6 in/hr Infiltration Rate, Assumed Dead Pool Depth of 1 ft
LL8	Pond	LiDAR, Landlocked, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed 1.6 in/hr Infiltration Rate, Assumed Dead Pool Depth of 1 ft
LL9	Pond	LiDAR, Landlocked, Split Impervious Fraction 50/50 (Direct/Indirect), Assumed 1.6 in/hr Infiltration Rate, Assumed Dead Pool Depth of 1 ft
Splitter-Aquifer	Splitter	-

Basin ID	P8 Device	Model Assumptions
Splitter-Aquifer-Lake George	Splitter	-
Splitter-LG-40S	Splitter	-
Splitter-LG-50S	Splitter	-
Weir Collection Point	Pipe	-

Technical Memo

WENCK
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To: Jamie Schurbon, Anoka Conservation District
Jared Wagner, Anoka Conservation District

From: Bryce Cruey, Wenck
Jeff Strom, Wenck

Date: May 2, 2018

Subject: Lake George EPASWMM Model Information and Comments.

This technical memorandum summarizes input data, assumptions, and comments for the Lake George EPASWMM Model.

1.0 Watershed Delineation

The Lake George watershed and individual catchments were delineated by the Anoka Conservation District (ACD) using a Soil and Water Assessment (SWAT) model that utilized LiDAR elevation DEM, a field collected culvert inventory and stormwater maps obtained from the City of Oak Grove for areas with storm sewer. Wenck further refined these drainages and subcatchments such that catchment discharges generally matched existing water monitoring locations.

2.0 Data Sources

- Options
    - Dates - For continuous simulation, select the dates for the period of time you want to simulate. For event simulation, select a summer date, and end the model a couple days later so that the peak runoff is captured at the location of interest.
- Climatology
    - Temperature - The temperature data is included in what is called a climate file (a SWMM format). The data is the same data as used in the P8 model. Please refer to the P8 model memo for additional details. The location of the climate file will need to re-pathed as shown in Figure 1.
    - Evaporation - Evaporation data is entered as Monthly averages. The averages were obtained from http://www.dnr.state.mn.us/climate/wxsta/pan-evaporation.html
    - Wind Speed - Wind Speed data is entered as Monthly averages. The averages were obtained from https://weatherspark.com/m/10405/12/Average-Weather-in-December-in-Minneapolis-Minnesota-United-States#Sections-Wind
- Hydrology
    - Event Rain Gages - Event based precipitation rain gages are Atlas14 precipitation depths with the 24-hour MSE3 distribution. Included are 2, 10, and 100-year 24-hour event gauges.
    - Continuous Rain Gages - The continuous simulation precipitation rain gage included in the model can reference one of three time series datasets included in the model. The three datasets included are:
        - Andover 1N/MSP gauge – which is a composite rainfall record from the Andover 1N gage and MSP monitoring stations. This is the same

        precipitation data used in the P8 model. Please refer to the P8 model memo for additional details.
        - St Francis Calibration Gauge – This gauge is a composite gauge of the two CoCoRaHS gauges located near St. Francis. These two gauges are the closest to the watershed with data records shown in Table 1. This data record is used for calibration of the model.
        - Anoka count Composite Gauge – this gauge is a composite record of the two St. Francis gauges, and the other 9 gauges shown in Table 1. The purpose of this file is to extend the data record back further and fill in data gaps.
    - Subcatchments - The watershed characteristics CN and impervious percent are based on the same 2016 Generalized Landuse as used for P8. Similarly, the same hydrologic soil data characteristics that were used for P8 were used for EPASWMM. Please refer to the P8 model memo for additional details.
    - Subcatchments - The watershed width and slope was calculated based on LiDAR information and basin geometry.
- Hydraulics
    - Nodes – Storage Units – The storage for basins are based on the same information as used for the P8 model. Information sources are listed in the Description for each storage unit in the EPASWMM model. Please refer to the P8 model memo for additional details.
    - Links – Conduits - The conduits/outlets are based on the same information as used for the P8 model. Information sources are listed in the Description for each conduit in the EPASWMM model. Please refer to the P8 model memo for additional details.
    - Links – Outlets - The Ditch 19 weir stage discharge rating curve was entered in tabular form. The rating curve was created from gage measurements at the weir (see monitoring data memo for more details). This is listed in the Description for the outlet in the model.
    - Transects – These are cross sections used as outlets
- Curves
    - Rating Curves – This is the rating curve used for the Ditch 19 weir. See monitoring data memo for more details
    - Storage Curves – These are the storage curves used in the storage nodes.
- Timeseries
    - Event based time series are named 1-, 2-, 10-, and 100-year.
    - The continuous simulation time series is named ContinuousSimulation.

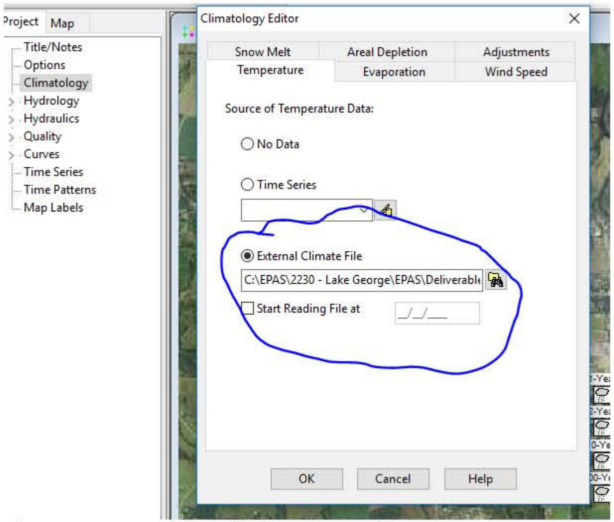
3.0 Calibration

- Hydrologic Calibration (Figure 2)
    - For developed watersheds drained by stormsewer/curb and gutter to constructed stormwater ponds, 100 percent of the impervious fraction was considered directly connected. For all other watersheds, the impervious fraction was split 50/50 between indirectly connected and directly connected impervious. These inputs are found under "Subarea Routing" and "Percent Routed" within the "Hydrology-subcatchments" window for each watershed.
    - Evaporation – Evaporation was included as monthly averages within the "Climatology Editor" under the Evaporation tab. Adjustments were made to evaporation to better fit monitoring data. These adjustments are found in the "Climatology Editor-Adjustments" tab.

- Lake Evaporation – Evaporation was also turned on for storage nodes BE2-20, BLakeGeorge, BLL1, BLL2, BLL3, BLL5, BLL6, BLL7, BLL8, BLL9. This evaporation for the storage nodes can be turned on in the "Hydraulics-Nodes-Storage Units" Window.

Table 1. Rain Gauges used to develop precipitation records in SWMM

Gauge Name	Gauge Type	Record Start Date	Record End Date	Number of Observations
Andover 1N	NWSLI	2007-05-03	Current	3903
Andover 2.1 NNW	CoCoRaHS	2011-04-01	Current	1344
Anoka 1.3 SSE	CoCoRaHS	2015-05-01	Current	901
Dayton 0.4 NE	CoCoRaHS	2011-03-22	Current	1105
East Bethel 1.1 NNW	CoCoRaHS	2011-04-01	Current	1377
East Bethel 3.1 NE	CoCoRaHS	2010-03-21	Current	1401
Elk River	NWSLI	1940-05-10	Current	2661
Ramsey 1.9 E	CoCoRaHS	2013-04-01	Current	772
Saint Francis 1.3 ESE	CoCoRaHS	2011-04-01	Current	1183
Saint Francis 4.0 E	CoCoRaHS	2010-01-16	Current	2273
Zimmerman 0.6 S	CoCoRaHS	2014-04-01	Current	1152



Climatology Editor

Source of Temperature Data:

○ No Data

○ Time Series

● External Climate File

C:\EPAS\2230 - Lake George\EPAS\Deliverable

☐ Start Reading File at _/_/__

Figure 1. Re-pathing of the climate file

Figure 2. Lake George water surface elevation modeled versus monitored.