In accordance with the EPA's Nine Key Elements

BIG GREEN LAKE WATERSHED MANAGEMENT PLAN

For 2021-2026

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<u>DRAFT 5</u>

Resubmitted September 2021

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Originally submitted to WDNR in January 2018

——— ACKNOWLEDGEMENTS ———

The primary author of this Lake Management Plan is Stephanie Prellwitz on behalf of the Green Lake Association and Big Green Lake Management Planning Team. Thanks to the following individuals for their writing contributions: Dave Bolha (WDNR), Sharon Dolan (Green Lake Association), Paul Gunderson (Green Lake County), Derek Kavanaugh (Green Lake County), Charlie Marks and Lisa Reas (Green Lake Sanitary District), Bill Miner (Green Lake Association), and Mark Sesing (Lake Management Consultant and retired Wisconsin Department of Natural Resources, WDNR, Water Resource Management Specialist). Andrew Craig (WDNR) provided guidance about the Nine Key Elements process and criteria.

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This lake management plan is dedicated to Charlie Marks,
administrator of the Green Lake Sanitary District and champion of Green Lake,
who passed away unexpectedly in January 2019.

Charlie dedicated two decades of his career to, in his words,
"doing what is right for the lake."

And so will we.

TABLE OF CONTENTS

Appendices

FORWARD

The Wisconsin Department of Natural Resources (WDNR) approved the Lake Management Plan for Big Green Lake (LMP) in January 2013. Mark Sesing prepared the 2013 LMP in close consultation and in partnership with the Lake Management Planning Team (LMPT) that includes, listed alphabetically:

Citizens of Wisconsin
City of Green Lake
City of Ripon
Fond du Lac County Land and Water Conservation Department
Green Lake Association
Green Lake Conservancy
Green Lake County Land Conservation Department
Green Lake Sanitary District
Natural Resources Conservation Service
U.S. Geological Survey
Wisconsin Department of Natural Resources

The original LMP was developed following the six steps in the Watershed Planning and Implementation Process, as outlined in the United States Environmental Protection Agency's (EPA) 2008 *Handbook for Development Watershed Plans to Restore and Protect Our Waters* [1].

Since the development and implementation of the LMP, much additional watershed data has been collected, more is understood about the Big Green Lake ecosystem and the impacts of pollutants on the system, and several specific actions have been taken.

Though there are several challenges facing the water quality and ecosystem of Big Green Lake, the primary pollutant of concern is phosphorus. This revised LMP serves as an update to the original LMP based on additional information obtained over the past five years, including relevant information from the 2018 *Draft Total Maximum Daily Loads for Total Phosphorus and Total Suspended Solids* for the Upper Fox and Wolf Basins [2].

The updated LMP specifically focuses on the primary pollutant of concern, phosphorus, while incorporating the EPA's Nine Key Elements of Watershed Plans, as detailed in the EPA's watershed handbook [1].

EXECUTIVE SUMMARY

The Big Green Lake watershed is 107 square miles and spans Big Green Lake (58%), Fond du Lac (41%) and Winnebago Counties (1%). Eight named tributaries are within the Big Green Lake watershed. The watershed drains into Big Green Lake through two major wetlands and three direct draining, named streams. The eastern estuary, the Silver Creek Estuary (SCE), is fed by two named streams. The southwest estuary, the County Highway K Marsh (CKM), is fed by three named streams. Additionally, three small lakes, fed by runoff and/or unnamed streams, are located within the watershed.

Land use in the watershed is primarily agricultural (65%) with 3% developed area. The City of Ripon's Wastewater Treatment Facility is the only point source in the watershed regulated by the National Pollutant Discharge Elimination System (NPDES). The watershed receives an average loading of 16,652 pounds of phosphorus per year (2013-2016 study period)

Over the long-term, Big Green Lake's water quality has degraded, as established by historic monitoring, sediment cores and other data. While Green Lake was once an oligotrophic lake, its water quality has declined, and it is now mesotrophic.

In 2014, the Wisconsin Department of Natural Resources (WDNR), with the support of the Lake Management Planning Team (LMPT), listed Big Green Lake as a 303(d) impaired water body because it fails to meet water quality criteria for dissolved oxygen in the thermocline during certain times of the year. As of this report's publication, the current assumption is that the metalimnetic oxygen minima is tied to phosphorus loading, as specified in the impairment listing, but the exact mechanism(s) are not fully understood and are undergoing further study.

Furthermore, based on USGS monitoring from 2012-2016, the lake has an average-summer near-surface phosphorus concentration of 17.0 µg/L (90% confidence intervals range from 14.8 to 18.1 µg/L). Since 2018, the lake "may exceed" the phosphorus criteria outlined in the Wisconsin Administrative Code of 15 µg/L and may be eligible to be listed as impaired for phosphorus based on 303(d) guidelines, in close coordination with the WDNR.

In addition, a recently approved report on the Upper Fox Wolf Basin Total Maximum Daily Load in February 2020 for Total Phosphorus [2] *provides further information on the potential and actual impacts of phosphorus in the watershed.*

The Big Green Lake Management Plan (LMP) was approved in 2013 and is due to be updated to incorporate more current data. The LMPT (LMPT) elected to update the LMP and simultaneously make the updated watershed plan ("the Plan") consistent with the Environmental Protection Agency's (EPA) Nine Key Elements.

Therefore, the intent of this Plan is to:

1. *Meet the EPA's guidelines for Nine Key Elements for watershed-based plans,*

2. *Incorporate only factors associated with phosphorus loading that drives Big Green Lake's impairment,*
3. *Extend to the geographic limits of the Big Green Lake watershed, and*
4. *Satisfy a five-year update of the LMP in accordance with the guidelines set by the Wisconsin Department of Natural Resources (WDNR).*

The ultimate goal of the LMPT is to return Green Lake to an oligotrophic lake, equivalent to a phosphorus concentration of 12 µg/L. Ongoing studies are currently determining the phosphorus reductions required to meet this water quality goal, originally specified in the 2013 LMPT.

A parallel plan, the Upper Fox-Wolf River TMDL report, divides the Green Lake watershed into six sub-basins (i.e., sub-basins 17, 18, 19, 20, 79, 83 and 87)—see Figure 1 and Table 1 below. The TMDL assigns each sub-basin with a different phosphorus reduction target, to meet either local water quality or downstream water quality. The phosphorus reduction target for each sub-basin ranges from 0%-80%. Sub-basin 87, Silver Creek, is the largest sub-basin and has a 76% total phosphorus reduction target. Sub-basin 20, the second largest sub-basin within the Green Lake watershed, encompasses Green Lake and has a 0% reduction phosphorus reduction target.

This Plan, developed by the LMPT, recommends an annual phosphorus loading reduction of 20% across the watershed, or an approximate annual reduction of 3,350 pounds of phosphorus to be achieved over the period 2020-2025. This would reduce annual phosphorus loading from 16,652 to 13,300 pounds. This reduction makes progress towards the Upper Fox Wolf River TMDL water quality goals and requires additional reduction measures after various studies (e.g., Diagnostic and Feasibility Study) and additional water quality monitoring are completed in the next five years.

The remaining phosphorus load reduction to meet the Upper Fox-Wolf River TMDL reduction targets will be achieved by implementing additional practices within sub-basins 17, 18, 19, 79, 83 and 87 over a-20 year time period. However, it is important to understand that Green Lake's water retention time is approximately 20 years—and this means achieving meaningful, measurable changes may take decades to materialize. All phosphorus reductions will be accomplished by various agencies and various practices, including wetland and stream restoration, agricultural best management practices (BMPs), urban BMPs, and shoreline practices.

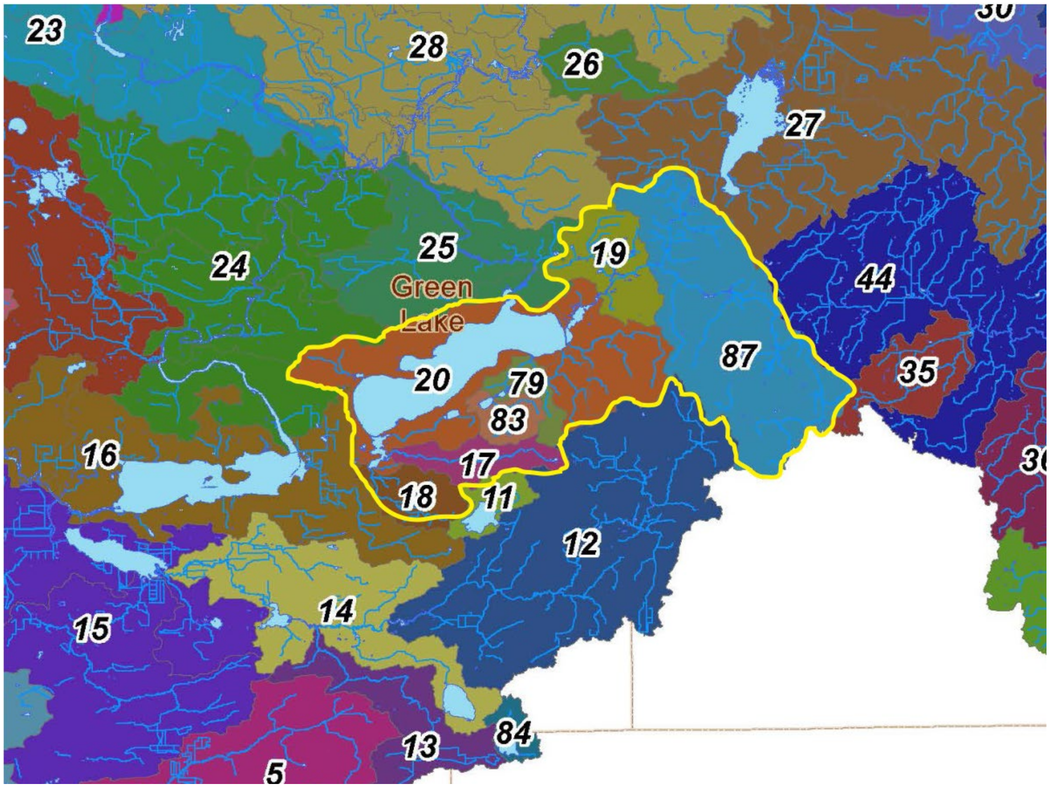

Figure 1. The Green Lake watershed (yellow boundary) contains seven subbasins as defined by the Upper Fox-Wolf TMDL [2]. Map modified from TMDL subbasin map [3].

Table 1.Seven subbasins are identified within the Upper Fox-Wolf TMDL [2].

TMDL ID	Subbasin Name	TMDL Local Reduction	TMDL Downstream Reduction	Downstream Waterbody	TMDL Total Reduction
17	Roy Creek	68%	0%	-	68%
18	Wuerches Creek	59%	0%	-	59%
19	Silver Creek – Below S Koro Rd	45%	0%	-	45%
20	Green Lake	0%	0%	-	0%
79	Hill Creek	80%	0%	-	80%
83	Big Twin Lake	0%	34%	Little Twin Lake	34%
87	Silver Creek – Above S Koro Rd	76%	0%	-	76%

1. INTRODUCTION

A. Purpose of Document

In January 2013, the Wisconsin Department of Natural Resources (WDNR) approved a *Lake Management Plan for Big Green Lake* [4]. Lake Management Plans (LMPs) remain current for a five-year period and much of the phosphorus-related information in the January 2013 LMP is outdated.

In addition to updating the LMP (“the Plan”), the Lake Management Planning Team (LMPT) elected to simultaneously have the Plan meet more rigorous standards, outlined by the United States Environmental Protection Agency (EPA). The EPA developed a *Development Watershed Plans to Restore and Protect Our Waters* [1] to guide the watershed planning and implementation process, which incorporates six steps. Included within these six steps are the EPA’s Nine Key Elements of watershed planning.

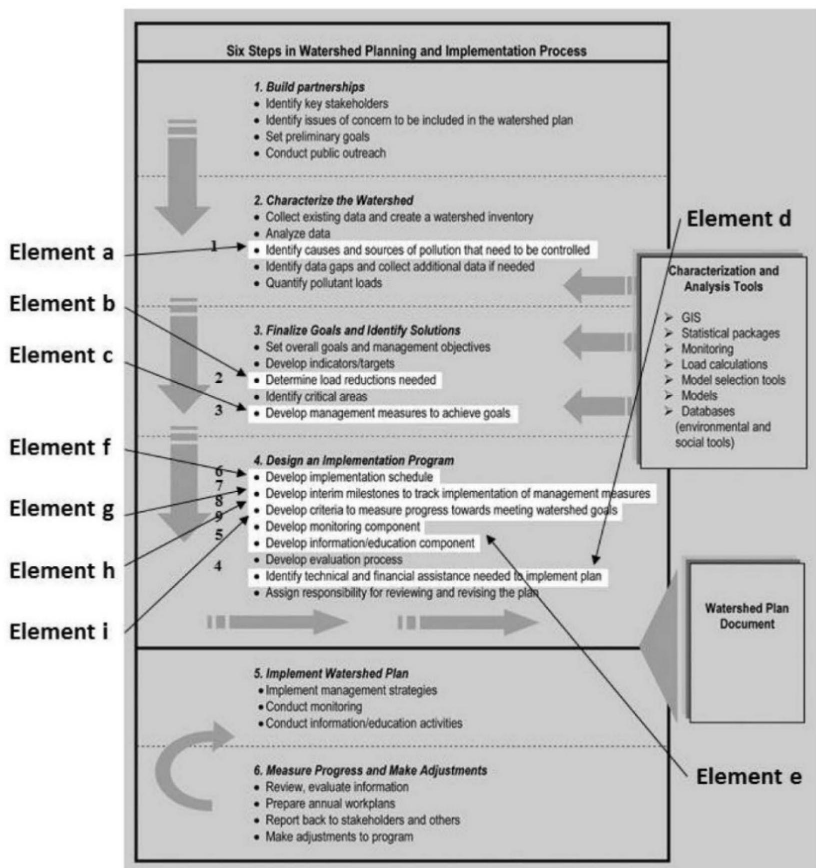

Figure 2. EPA's guidelines for watershed plans, illustrating the six steps and the Nine Key Elements [92].

B. Incorporation of the EPA's Nine Key Elements

This version of the Plan is organized around the six steps from the EPA's Handbook [1] and includes the following eight chapters:

- **Chapter 1**: Introduction
- **Chapter 2**: Partnerships
- **Chapter 3**: Hydrologic Characterization of Big Green Lake and Its watershed
- **Chapter 4**: Biological Characterization of Big Green Lake: Plant and Animal Species
- **Chapter 5**: Qualitative Characterization of Big Green Lake and Its Watershed
- **Chapter 6**: Phosphorus Loading Causes and Sources
- **Chapter 7**: Phosphorus Load Reduction Goals and
- **Chapter 8**: Implementation of Watershed Plan
- **Chapter 9**: Commitment to Measure Progress and Evaluate Plan

According to the WDNR, "watershed plans consistent with the EPA's Nine Key Elements provide a framework for improving water quality in a holistic manner within a geographic watershed" [5]. Watershed-based plans that meet the Nine Key Elements must incorporate:

- The ***causes and sources*** that will need to be controlled to achieve the load reductions estimated in the watershed-based plan (Chapter 6),
- An ***estimate of the load reductions*** expected for the management measured (Chapter 7),
- A ***description of the non-point source management measures*** that will need to be implemented to achieve the load reductions, and the critical areas where those measured need to be implemented (Chapter 7),
- An ***estimate of the technical and financial assistance needed***, including costs and the authorities that will be relied upon to implement the plan (Chapter 8),
- An ***information and education component*** to enhance public understanding and participation in the project (Chapter 8),
- A ***schedule for implementation*** of the non-point source management measures (Chapter 8),
- A ***description of interim, measurable milestones*** for determining whether non-point source management measures or other control actions are being implemented (Chapter 8),
- A ***set of criteria*** that can be used to determine whether load reductions are being achieved over time and substantial progress is being made toward attaining water quality standards (Chapter 8), and
- A ***monitoring*** component to evaluate the effectiveness of implementation efforts over time (Chapters 8 and 9).

C. Intended Audiences of Watershed Plan

The Plan is a phosphorus-based watershed plan that informs multiple audiences:

1. **The LMPT**, who will use the Plan as a work plan to synthesize, monitor, track, and assess phosphorus-reducing efforts around a unified strategy,
2. **The EPA**, who will review the LMP to verify that it is consistent with its Nine Key Elements,
3. **The WDNR**, who will review the Plan to verify it is consistent with its 5-year LMP review,
4. **The public**, who may be interested in learning more about efforts to protect and preserve the area's natural resources,
5. **Future grantors**, who may reference the document as one way to understand actions taken and to establish credibility of the LMPT, and
6. **The Green Lake Association (GLA) and other LMPT members**, who will use the plan as the basis for additional fundraising to support water quality goals.

2. PARTNERSHIPS

A. Brief History of the LMPT

The origin of the Big Green Lake partnerships began over half a century ago through a series of local action, statewide mandates and federal governmental programs.

1951: Proactive homeowners created the Green Lake Association (GLA) in 1951 after noting concerns in declining water quality. While the first lake organization in Wisconsin was organized about 1898 [5], the GLA continues to be one of Wisconsin's most active lake associations.

1964: The GLA orchestrated the creation of the Green Lake Sanitary District (GLSD) guided by a growing concern for failing and aging septic systems along the lake. The GLSD was formed to protect Big Green Lake and its resources with respect to sanitation, land, air, and water quality.

1978: The WDNR launched the Priority Watershed and Lakes Program to address nonpoint source pollution. This voluntary program identified farm fields, livestock areas, streambanks, shorelines, and urban areas that were sources of pollutant runoff. The program ended in 2009, and regulatory control transitioned to Chapters NR 151 and NR 216 in the Wisconsin Administrative Code [6].

1980: The Big Green Lake watershed was one of four watersheds selected in Wisconsin for participation in the Wisconsin Non-point Source Pollution Abatement Program, in large part because of its value as a high-quality water recreational resource. The primary role of the Big Green Lake Priority Watershed Plan [7] was to provide cost-sharing and technical assistance for the control of nonpoint source pollution using best management practices (BMPs) to reduce sediment and nutrient loading into Big Green Lake. Other evaluations and monitoring for the Big Green Lake Priority Watershed Plan followed between 1980 and 1997 [8] [9] [10] [11].

1982: Chapter 92 of the Wisconsin Soil Conservation District was revised, which "abolish[ed] conservation districts and create[ed] Land Conservation Committees" as a unit of county government [12]. This project helped spawn the Green Lake County Land Conservation Department.

2011: The LMPT was formed, with initial tasks of appraising data, convening a public advisory group, conducting a comprehensive assessment of the resource and its challenges. It also undertook the task of writing the LMP.

2013: The WDNR approved the LMP for Big Green Lake. The 2013 LMP was a springboard for increased best management practice (BMP) activity in the watershed.

Although other key groups, people and organizations formed and joined along the way, three key partnership groups—the Green Lake Association, Green Lake Sanitary District and Green Lake County Conservation Department—began several decades ago and continue to thrive today. Since 2012, other essential partners have joined the LMPT.

B. Summary of LMP Partners

i. City of Green Lake

The City of Green Lake, Green Lake County, began as the Village of Dartford in 1847. To date, it provides services for its 960 residents and includes 3.8 miles of shoreline along Big Green Lake, including 2.6 miles on Big Green Lake proper and 1.2 miles within the Green Lake Mill Pond (downstream of the South Lawson Drive bridge). The City's Public Works Department operates its NPDES-regulated wastewater treatment facility (WWTF), which *discharges outside* of the Big Green Lake watershed to the Puchyan River.

In 2016, the City of Green Lake was awarded a $19,000 WDNR Urban Stormwater Planning grant for a *Big Green Lake Storm Water Impact Study and Management Plan* [13]. The voluntary assessment, totaling $41,495, was completed with local support from the City, GLSD, and GLA. The plan's scope includes updating various ordinances, conducting a feasibility analysis of alternative funding mechanisms, and developing a storm water management plan for the developed urban area.

(920) 294-6312 www.cityofgreenlake.com

ii. City of Ripon

The City of Ripon, Fond du Lac County, was founded in 1849 and currently has 7,800 residents. In 1895, the City of Ripon became the first Wisconsin community to treat its wastewater. In 2003, the Ripon WWTF underwent a $7.5 million renovation to upgrade and expand its operation [14]. Today, the NPDES-regulated WWTF treats 1.3 million gallons of wastewater per day and discharges its treated effluent to Silver Creek, located within the Green Lake watershed. In 2015, the WDNR recognized the City of Ripon's WWTF as the Registered Laboratory of the Year for its outstanding commitment to producing high quality data.

The City of Ripon WWTF is the only point source in the watershed that also discharges to the watershed. There are other factories within the City of Ripon who discharge their effluent to the Ripon WWTF, so these are incorporated in the Ripon WWTF permit.

(920) 748-4916 www.cityofripon.com

iii. Fond du Lac County Land and Water Conservation Department

The Fond du Lac County Land and Water Conservation Department (LWCD) supports agricultural and natural resource management for the eastern reaches of the Big Green Lake watershed. The Fond du Lac County LWCD provides conservation planning assistance and technical service in soil and water conservation to landowners, land users, and decision makers of Fond du Lac County.

(920) 906-4672 www.fdlco.wi.gov

iv. Green Lake Association

The Green Lake Association (GLA) is a 501(c)3 non-profit, membership-funded, registered lake association created in 1951. It works to promote the conservation of Big Green Lake and its watershed with a singular focus on its water quality. The GLA has three full-time staff, two part-time staff, and summer interns, making it one of the few lake associations in Wisconsin that has paid staff. The organization coordinates water quality research, conservation projects, and outreach. Its annual operating budget of $600,000 comes from private donations and grants, including a 2016 $200,000 grant awarded by the WDNR for a substantial diagnostic and feasibility study for dissolved oxygen and phosphorus concerns.

In 2006, the GLA was awarded the Lake Association of the Year at the Wisconsin Lakes Partnership Convention. In 2016, the GLA received a Watershed Hero Impact Award at the Fox-Wolf Watershed Alliance's Inaugural Watershed Celebration. In 2019, it was co-awarded (with the Green Lake Conservancy and Green Lake Sanitary District) the Founders' Day Award by Ripon College for efforts in sustainability and conservation efforts.

(920) 294-6480 www.greenlakeassociation.org

v. Green Lake Conservancy

The Green Lake Conservancy (GLC) was formed in 1995 and is one of 50 dedicated Wisconsin 501©3 non-profit land trusts. The all-volunteer organization offers lake and watershed protection for environmentally sensitive areas through acquisitions, gifts, and conservation easements. To date, the GLC has helped acquire or purchase over 15 Conservancy properties.

In 2015, the Gathering Waters Conservancy, an umbrella organization assisting land trusts statewide, recognized the GLC as Land Trust of the Year. The GLC also partnered closely with the GLSD to purchase the Tichora Conservancy, previously named Camp Grow, with financial support from over 600 donors and a $1.7 million WDNR Knowles-Nelson Stewardship Grant.

(920) 294-3592 www.greenlakeconservancy.org

vi. Green Lake County Land Conservation Department

The Green Lake County Land Conservation Department (GLC-LCD) is a conservation-management unit for the western reaches of the Big Green Lake watershed. The GLC- LCD provides conservation planning technical assistance in soil and water conservation. The department offers numerous programs designed to protect and enhance the natural resources of Green Lake County.

Between 2012 and 2018, the GLC-LCD installed 116 BMPs totaling $1.7 million in the Big Green Lake watershed alone, thanks to landowner cooperation and pooling of funding from the Natural Resources Conservation Program's National Water Quality Initiative, WDNR, GLSD and GLA.

(920) 294-4051 www.co-green-lake.wi-us

vii. Green Lake Sanitary District

The Green Lake Sanitary District (GLSD) is a tax-funded entity was formed in 1964 to protect Big Green Lake and its resources regarding sanitation, land, air, and water quality. To date, it is comprised of over 2,200 tax parcels circling the lake's entire perimeter, excluding the City of Green Lake. In addition to coordinating solid waste collection spanning several townships, the GLSD oversees the treatment of wastewater from over 1,400 homes, served by sewer (1,000 homes) and private on-site wastewater treatment systems (400 homes), including septic and holding tank systems.

In 1996, Chapter 60 of the Wisconsin Administrative Code was amended to give sanitary districts additional powers to undertake lake management activities when at least 60% of a lake's shoreline is within the district [15]. As such, the GLSD facilitates nonpoint pollution abatement, aquatic plant harvesting, lake and watershed monitoring, land acquisition, and a fish rearing facility.

Between 1993 and 2016, the GLSD has received a total of over $2.3 million from 33 grants focused on the protection of the Big Green Lake watershed.

(920) 294-4488 www.glakesd.com

viii. Natural Resources Conservation Service

The United States Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS) is a federal agency born out of the Soil Conservation Service in 1935 [12]. The agency provides technical assistance to farmers and landowners.

The NRCS for Green Lake County has been particularly active in the Big Green Lake watershed. For example, the NRCS' National Water Quality Initiative (NWQI) funding has been a significant source of funding for BMPs in the Big Green Lake watershed in Green Lake County. NRCS directs NWQI funds toward conservation practices in focused watersheds in a concentrated area so that agriculture no longer contributes to the impairment of water bodies within these priority watersheds. This area of the watershed received NWQI funding for seven consecutive years.

Between 2012-2018, the NRCS has contributed over $1.2 million in BMPs in this portion of the watershed through this funding program. More information about this BMP program is available in Appendix A.

(920) 294-6140 www.nrcs.usda.gov

ix. United States Geological Survey

The United States Geological Survey (USGS) is a scientific agency within the federal government. In the Big Green Lake watershed, the USGS is largely responsible for collecting and analyzing stream samplers and in-lake sampling. The USGS is currently working in collaboration with the Michigan Technological University and the GLA on a diagnostic and feasibility study to better understand Green Lake's metalimnetic oxygen minima and phosphorus loading.

(608 821-3867 www.usgs.gov

x. Wisconsin Department of Natural Resources

The Wisconsin Department of Natural Resources (WDNR) is an agency of the state of Wisconsin charged with a mandate from the EPA to protect the waters of Wisconsin by issuing waste discharge permits to point sources and establishing statewide performance standards for nonpoint sources of pollution. While the agency contributes expertise and resources towards lake management strategies, the WDNR's lakes, rivers, and fisheries biologists are particularly involved in the Big Green Lake watershed.

(920) 787-3048 www.dnr.wi.gov

C. Summary of Other Key Partners

In addition to the core organizations mentioned in the previous section, the Big Green LMPT collaborates with other expert partners as needed, as shown in Figure 3.

i. Nelson Institute for Environmental Studies, UW-Madison

The Nelson Institute for Environmental Studies (Nelson Institute) is an interdisciplinary, freestanding unit at in the University of Wisconsin-Madison. The Nelson Institute supports interdisciplinary research in environmental studies.

Major projects by the Nelson Institute, led by Anita Thompson, include:

- **Big Green Lake Watershed Information System (2015-2016)** [16]**:** Institute students, Sarah Fuller and Annie Lord, and faculty worked with Big Green Lake stakeholders to compile information for a data hub, available at nelson.wisc.edu/greenlake. The goal of this information system is to support watershed management through the coordination of research efforts and the creation of a central database.
- **Silver Creek Estuary / County Highway K Marsh Estuary Study (2016-2017)** [17]: Sarah Fuller collected data within two vastly different estuaries—the Silver Creek Estuary (SCE) and the County Highway K Marsh (CKM)—on Big Green Lake to better understand the varying nutrient dynamics. More information about this study is in Section 5.D.i.
- **Legacy Phosphorus Study (2017-2021)** [18]**:** Rachel Johnson will attempt to quantify how much legacy phosphorus is stored in the CKM sub-watershed using a mass-balance approach to quantify legacy phosphorus stored in fields, streams, and the CKM.

ii. Ripon College

In part because of its proximity to Big Green Lake, Ripon College has had a long history of performing and supporting research, interns, and student projects throughout the Big Green Lake watershed.

Recent topics (2013-2017) include:

- Assessment of the trophic state of Big Green Lake [19],
- Aquatic vegetation changes over the past century [20],
- An exploration of Big Green Lake's metalimnetic oxygen minima [21] discussed in Chapter 5,
- Levels of dissolved oxygen materials flowing into the lake [22] [23],
- A field survey of Silver Creek [24], including its legacy phosphorus [25], and
- A math model to understand carp behavior and commercial fishing dynamics in Big Green Lake [26].

iii. UW-Extension

The University of Wisconsin-Extension has helped facilitate various education programs and assessments in the Big Green Lake watershed. Most notably, Aaron Thompson, formerly of UW-Stevens Point with an Extension appointment, conducted a social science survey of the watershed's farmer, discussed in Section 7.D.iii.

iv. Delta Institute

The GLA, on behalf of the LMPT, commissioned a Phosphorus Prioritization Tool [27] by the Delta Institute of Chicago, discussed more in Section 5.A.ii. The prioritization tool identifies 12 nutrient loading priority areas in the Big Green Lake watershed helping focus phosphorus reduction strategies.

i. Michigan Technological University

Michigan Technological University is currently working in collaboration with the USGS and the GLA on a diagnostic and feasibility study to better understand Green Lake's metalimnetic oxygen minima. Most notably, Cory McDonald has worked closely with the LMPT to provide limnological modeling expertise. Master's student, Mahta Maziri Saeed, completed a thesis on Green Lake's metalimentic oxygen minima [28].

D. Partnership Summary

The LMPT has recognized that dealing with a complex watershed like the Big Green Lake Watershed requires engaging multiple stakeholders and seeking guidance and expertise from diverse organizations. Figure 3 below illustrates the breadth and depth of these interactions.

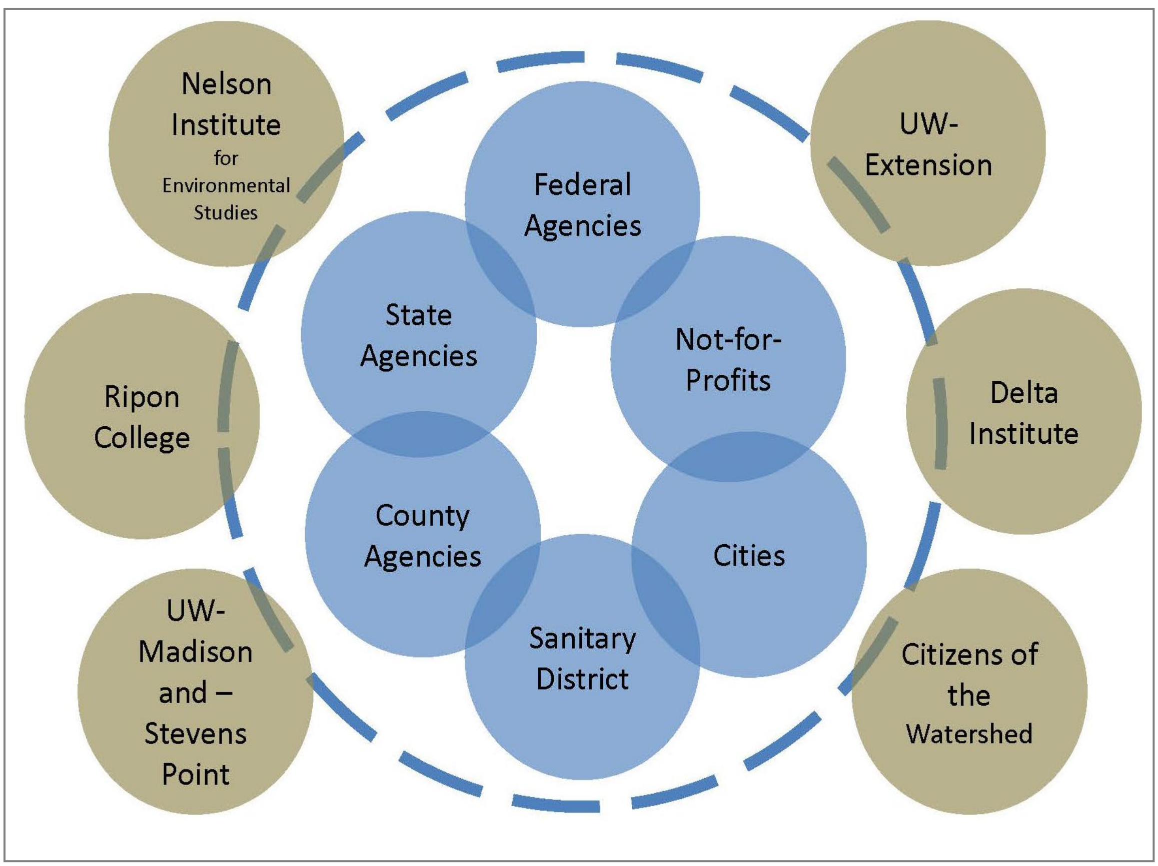

Figure 3. The Big Green LMPT includes various entities, spanning federal, state and county agencies, the Green Lake Sanitary District, municipalities and not-for-profits (shown inside the dotted line). Additional entities (shown in beige) serve as additional expert resources and are engaged as needed.

3. HYDROLOGIC CHARACTERIZATION OF BIG GREEN LAKE AND ITS WATERSHED

A. Formation of Big Green Lake

Big Green Lake formed approximately 17,000 years ago during the Cary sub-stage of the Wisconsin glaciation. During this period, a sheet of ice approximately 2.5 miles thick covered a deep valley and ancient river. As the massive continental glacier melted, it advanced and retreated, scouring the landscape in the process. An accumulation of glacial moraine—stones, boulders, and debris from the moving glacier—blocked the outlet of this deep valley on the west end of the lake basin. This dammed a glacial river and caused it to flood the scoured valley and overflow into the present-day Puchyan-Fox drainage system. Big Green Lake is a natural impoundment [29].

From this newly formed impoundment was born Big Green Lake: The deepest natural inland lake in the state of Wisconsin, which remarkably is also a glacial lake formed during the last Ice Age.

Big Green Lake Characteristics

Average Depth: 104 feet [30]

Greatest Depth: 236 feet [30]

Surface Area: 7,660 acres [28]

Volume: 762,000 acre-feet (248 billion gallons) [3]

Maximum Length: 7.3 miles [3]

Maximum Width: 2.0 miles [3]

Shoreline: 27.3 miles [3]

B. Lake Characteristics

Big Green Lake (Waterbody Identification Code, WBIC, 146100) is located within Green Lake County, Wisconsin. The lake has a surface area of 7,660 acres [30] (also cited as 7,346 acres and 7,920 acres in various sources) with over 27 miles of shoreline.

The outlet of Big Green Lake is the Puchyan River, which drains into the Fox River six miles northwest of the City of Green Lake. A dam constructed on the outlet maintains the water level approximately five feet higher than the natural lake basin.

The littoral bottom materials consist primarily of sand and gravel. Bedrock, silt, and muck are also present to a more limited extent. Rocks, boulders, and sparse aquatic vegetation provide fish cover [31].

i.Bathymetry

Big Green Lake's maximum depth is 236 feet [32] on the west side of the lake (see Figure 4). It contains a vast volume of water: 762,000 acre-feet, equivalent to 248 billion gallons [4].

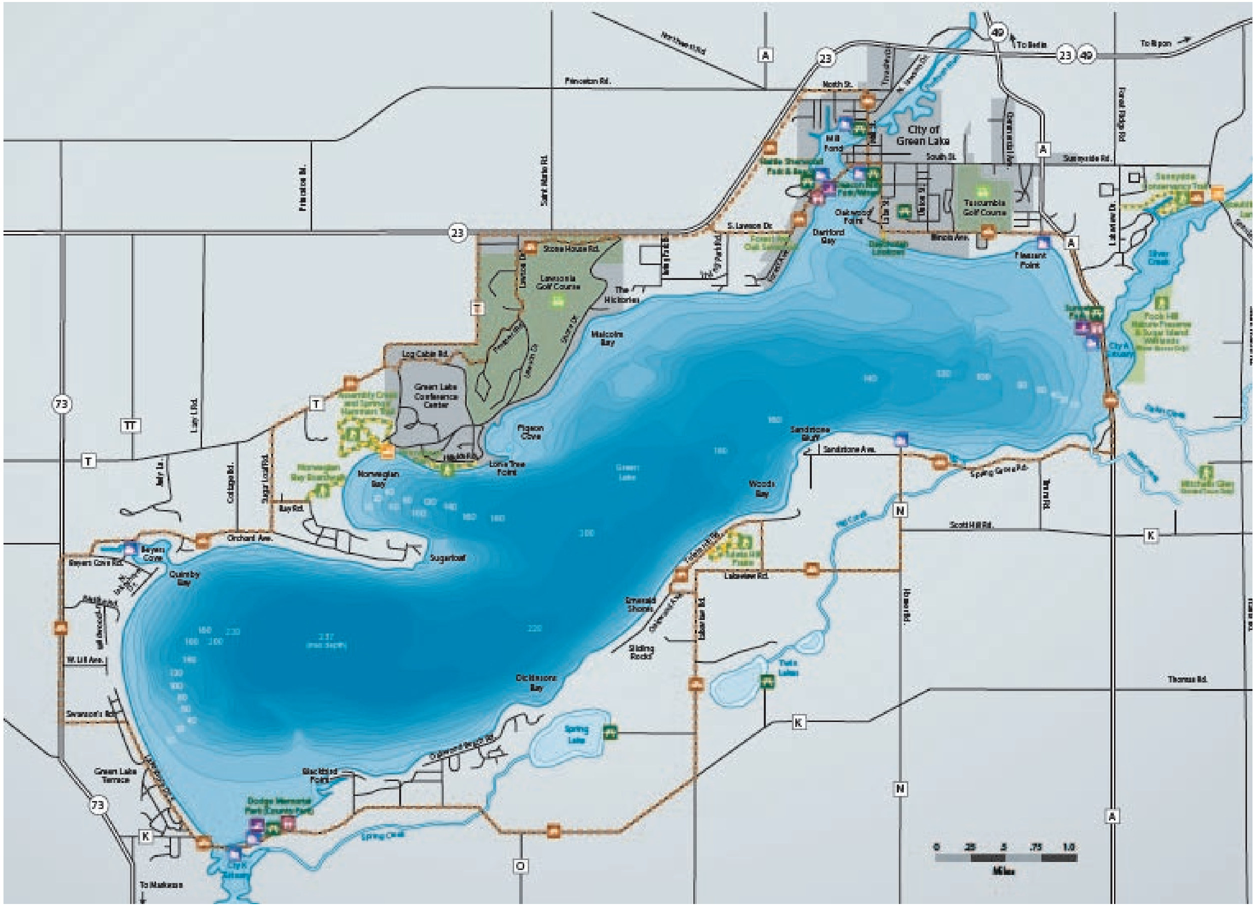

Figure 4. Big Green Lake is a glacial lake with an average depth of 104 feet and a maximum depth of 236 feet, located on the western portion of Big Green Lake.

Big Green Lake's littoral zone (the area of the lake that is close to shore) occurs approximately in areas shallower than 20 feet, outlined in turquoise in Figure 5.

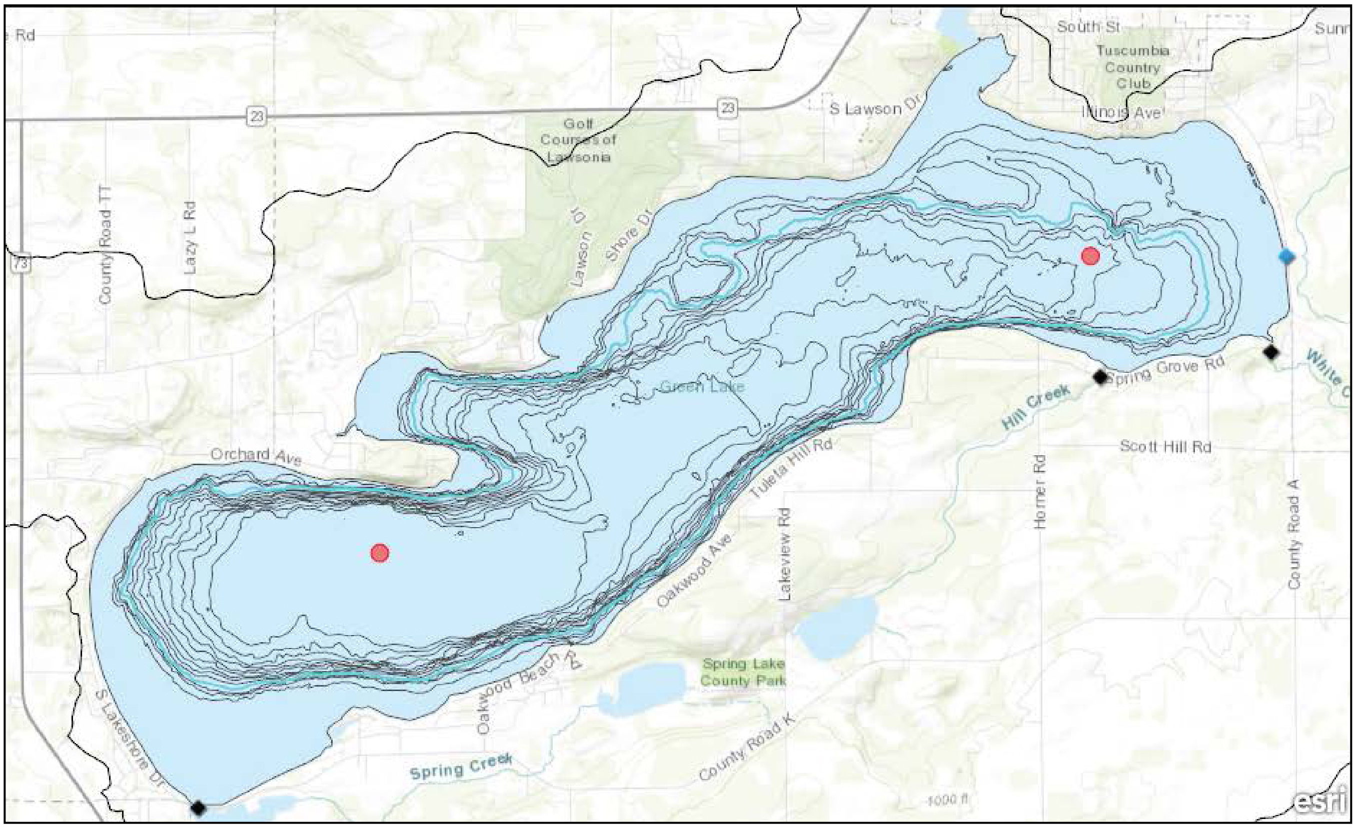

Figure 5. Big Green Lake's littoral zone occurs approximately in areas shallower than 20 feet, outlined in turquoise on a bathymetric map from the USGS [33]. Lake sampling sites are shown as a red dot, historic stream sampling as blue triangles and current stream sampling as black triangle (not all sampling sites are shown in this bathymetric map view).

ii. Retention Time

The outlet of Big Green Lake is the Puchyan River, which flows to the Fox River, through Lake Winnebago, back to the Fox River and eventually drains to Lake Michigan in Green Bay, Wisconsin. The Big Green Lake watershed is part of the Upper Fox watershed, Lake Michigan, and Great Lakes watersheds (Figure 6).

Given its inflow and generally slow release of water, the retention time of Big Green Lake is approximately 20 years, though this is a general parameter that depends on annual runoff (see Table 2). This retention time is substantially much longer than other of Wisconsin's inland lakes. While Lake Winnebago has a large surface area, for example, it is closely associated with a river system with large inflows and outflows, resulting in a retention time of only 7 months (see Table 2).

Big Green Lake's retention time of 21 years is comparable to Lake Huron (see Table 2), one of the five Great Lakes. This long retention time prevents the lake's water quality from fluctuating quickly from individual rain events, as seen from frequent blue-green algae blooms in Lake Winnebago and Lake Mendota in the summer of 2018, for example. Yet, Big Green Lake's relatively long retention time also makes it more difficult to improve water quality when concerns arise.

The LMPT is motivated to protect and ultimately improve Big Green Lake's water quality to oligotrophic conditions. If lake degradation continues, the lake could reach an ecological tipping point, after which point substantial water quality improvements would be difficult, if not impossible, to achieve.

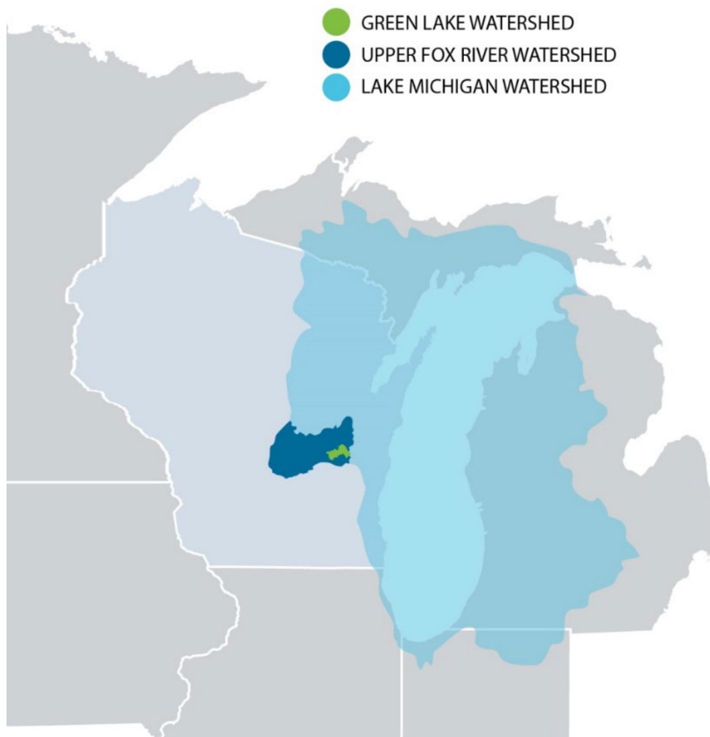

Figure 6. Green Lake is within the Upper Fox-Wolf and Lake Michigan watersheds. Its outlet, the Puchyan River, drains to the Fox River, to Lake Winnebago, and ultimately to Lake Michigan near Green Bay. Map provided by the GLA.

Table 2. Morphometric characteristics for Lake Winnebago, Big Green Lake, Lake Mendota and Lake Geneva. Big Green Lake holds the second largest volume of water of any lake in the state and is the deepest natural inland lake.

Lake	Lake Volume	Surface Area	Max Depth	Retention Time
Lake Huron	850 mi^3	14,720,000 ac	750 ft	21 years
Lake Winnebago	1.61 mi^3	131,939 ac	21 ft	0.6 years
Big Green Lake	**0.23 mi^3**	**7,920 ac**	**236 ft**	**21 years**
Lake Mendota	0.12 mi^3	9,781 ac	83 ft	5 years
Lake Geneva	0.10 mi^3	5,401 ac	135 ft	14 years

iii. Water Sources

The lake's retention time correlates its inflow of water. Big Green Lake's water sources are estimated to include rainfall (51%) and runoff (41%), with only a small portion coming from groundwater or springs (8%) (see Figure 7). Additional studies are needed to better understand Green Lake's water sources, particularly groundwater contributions.

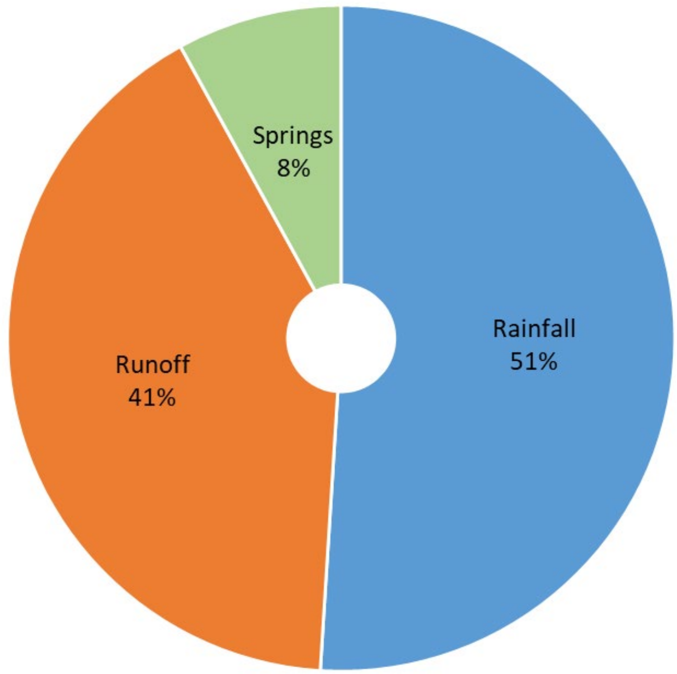

Figure 7. Big Green Lake receives water sources from rainfall, runoff, and springs.

In addition to direct runoff, the lake has eight named tributaries (Silver Creek, Dakin Creek, White Creek, Hill Creek, Spring Creek, Roy Creek, Wuerches Creek, and Assembly Creek) that flow to the lake.

The Silver Creek Estuary (SCE; confluence of Silver and Dakin Creeks) and the County Highway K Marsh (CKM; the confluence of Roy, Wuerches, and Spring Creeks) are the two largest tributaries to the lake, accounting for 48% and 15% of its watershed area, respectively.

Section 3.C summarizes the characteristics of these sub-watersheds.

C. Watershed Characteristics

The characteristics of the Big Green Lake watershed directly affect the water quality of the lake. The Big Green Lake watershed encompasses 107 square miles (or 68,676 acres) [32] of land and water (See Figure 8) with a 5.0:1 watershed-to-lake ratio. The geographic extents of the watershed lie within three counties: Green Lake County (58%), Fond du Lac County (41%), and Winnebago County (1%).

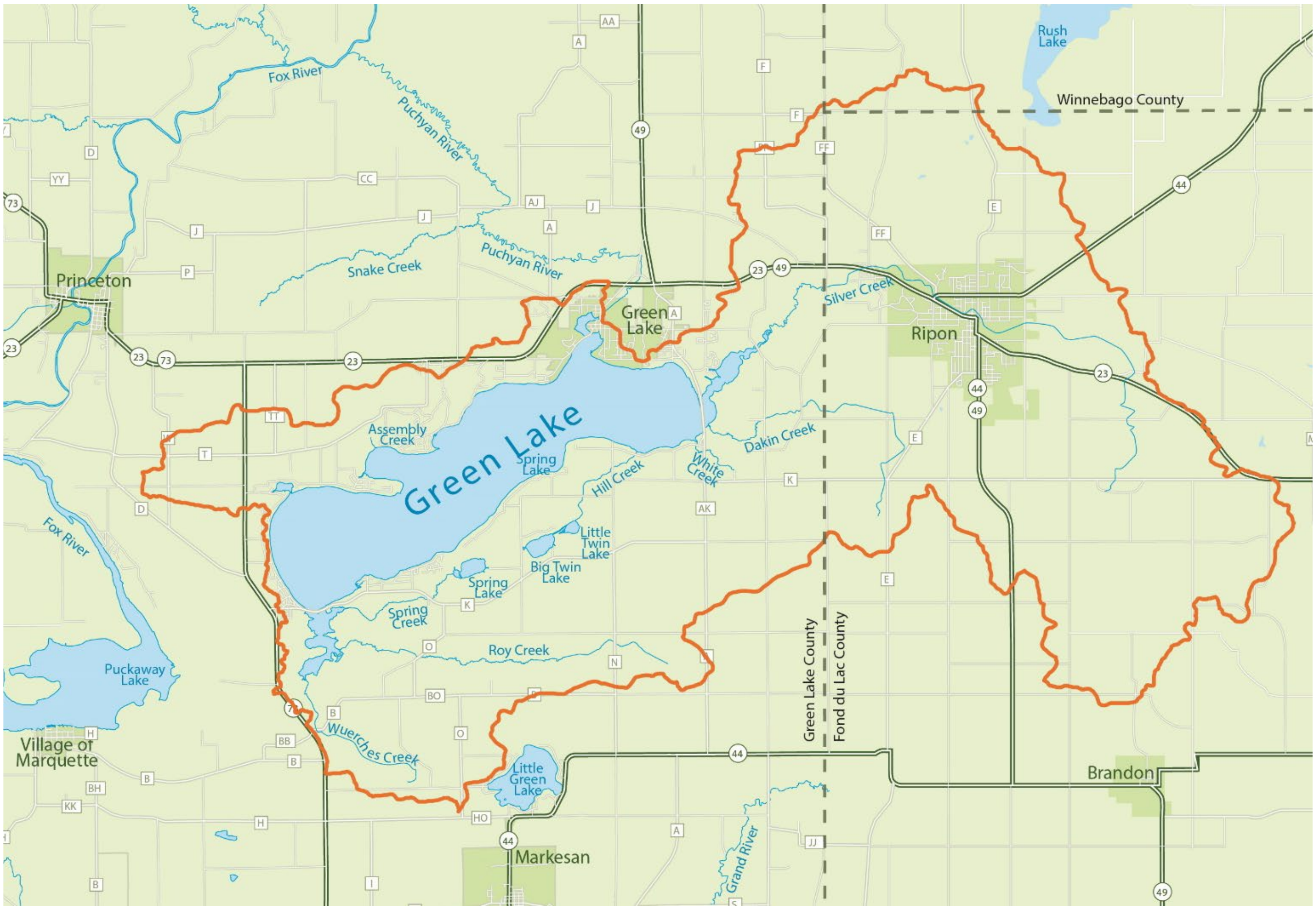

Figure 8. Big Green Lake watershed has eight tributaries (Assembly Creek, Dakin Creek, Hill Creek, Roy Creek, Silver Creek, Spring Creek, White Creek, and Wuerches Creek). The City of Green Lake and City of Ripon are located within the watershed.

A conceptual site model best represents the watershed and its hydrologic characteristics, as shown in Figure 9. The Green Lake watershed is comprised of wetlands, lakes, rivers, and cities. Precipitation, groundwater, and direct runoff also affect its hydrology.

Eight named rivers are in the Green Lake watershed, but not all directly drain to the lake. Several first flow through two major wetlands that drain into the lake. Silver and Dakin Creek flow to the Silver Creek Estuary (SCE) on the east side of Green Lake. Spring Creek (and Spring Lake), Roy Creek, and Wuerches Creek flow into the CKM on the southwest side of Green Lake. White Creek, Hill Creek (and the Twin Lakes), and Assembly Creek drain directly into the lake.

The cities of Ripon (population: 7,733) and Green Lake (population: 934) are both located within the watershed. The City of Green Lake does not entirely drain to Big Green: 545 acres (or 47.4%) of the 1,149-acre municipal limits are a tributary to the lake, including 199 acres that drain within the lake's Mill Pond located near the lake outlet [34]. The remaining 604 acres (52.6%) drain downstream to the Puchyan River [34]. The City of Green lake's wastewater effluent also drains outside of the Green Lake watershed, to the Puchyan River.

The City of Ripon is entirely located within the Silver Creek sub-watershed, including effluent from its wastewater treatment facility.

The lake discharges to a single outlet—the Puchyan River in downtown Green Lake, at the Green Lake dam—before flowing to the Fox River, Lake Winnebago, and Lake Michigan.

Big Green Lake's retention time (21 years) and its relatively small watershed (107 square miles) puts it in a unique position to test cost effective, science-based solutions for improving water quality for the Great Lakes. Over the long-term, the LMPT is interested in pursuing research and grant funding that creates a model for cleaner lakes in the region. Given the scope of accomplishing this in the Great Lakes, the Big Green Lake watershed is an efficient way to vet watershed management strategies.

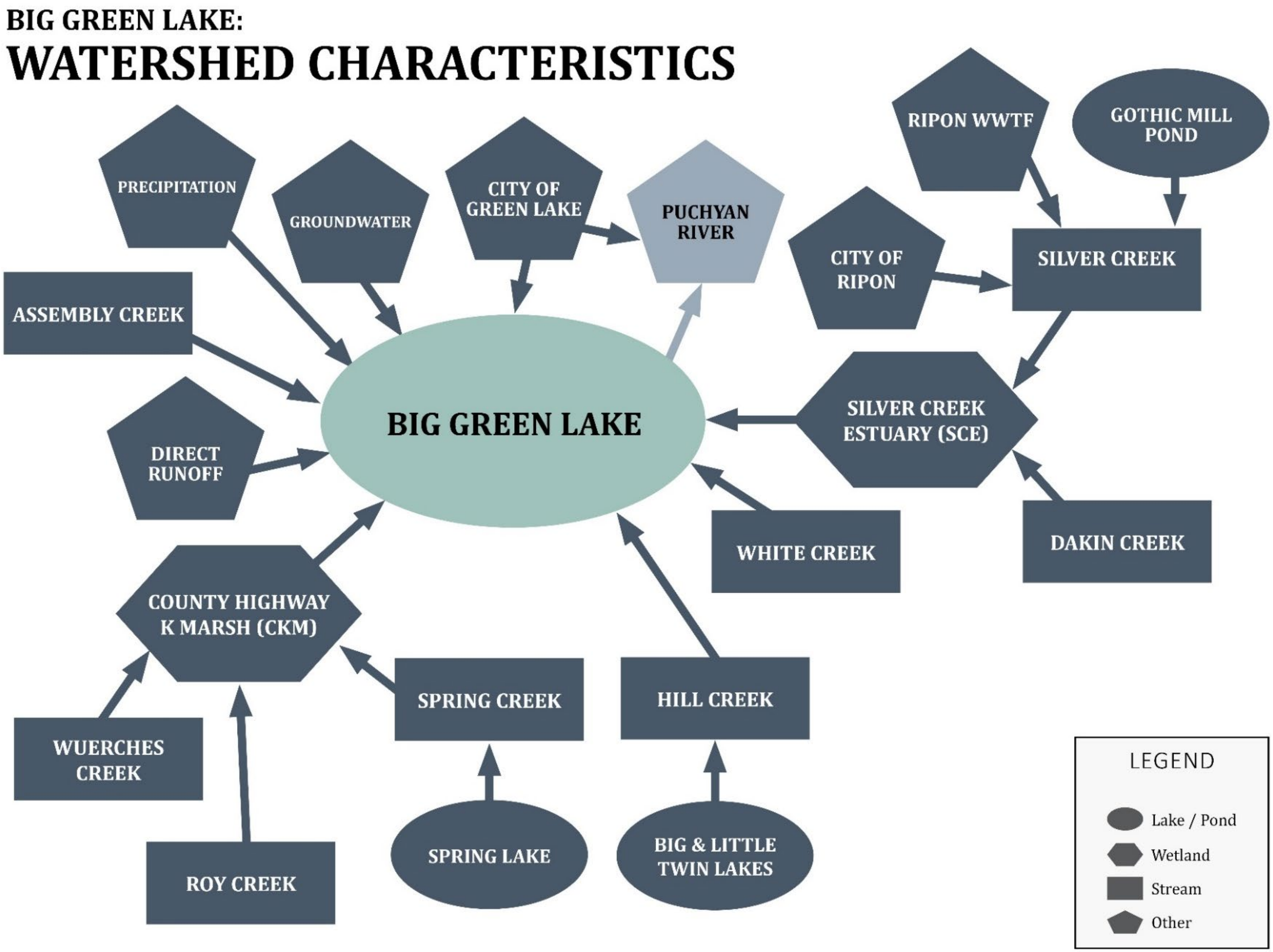

Figure 9. A conceptual site model of the Big Green Lake watershed is a visual representation of its sources and pathways.

The Big Green Lake watershed (10-digit Hydrologic Unit Code, HUC, 0403020109) is composed of two 12-digit HUCS: HUCS 04032010901 containing Dakin Creek and Silver Creek sub-watersheds, and HUC 040302010902 containing the remaining sub-watersheds to the west, as mapped in Figure 10.

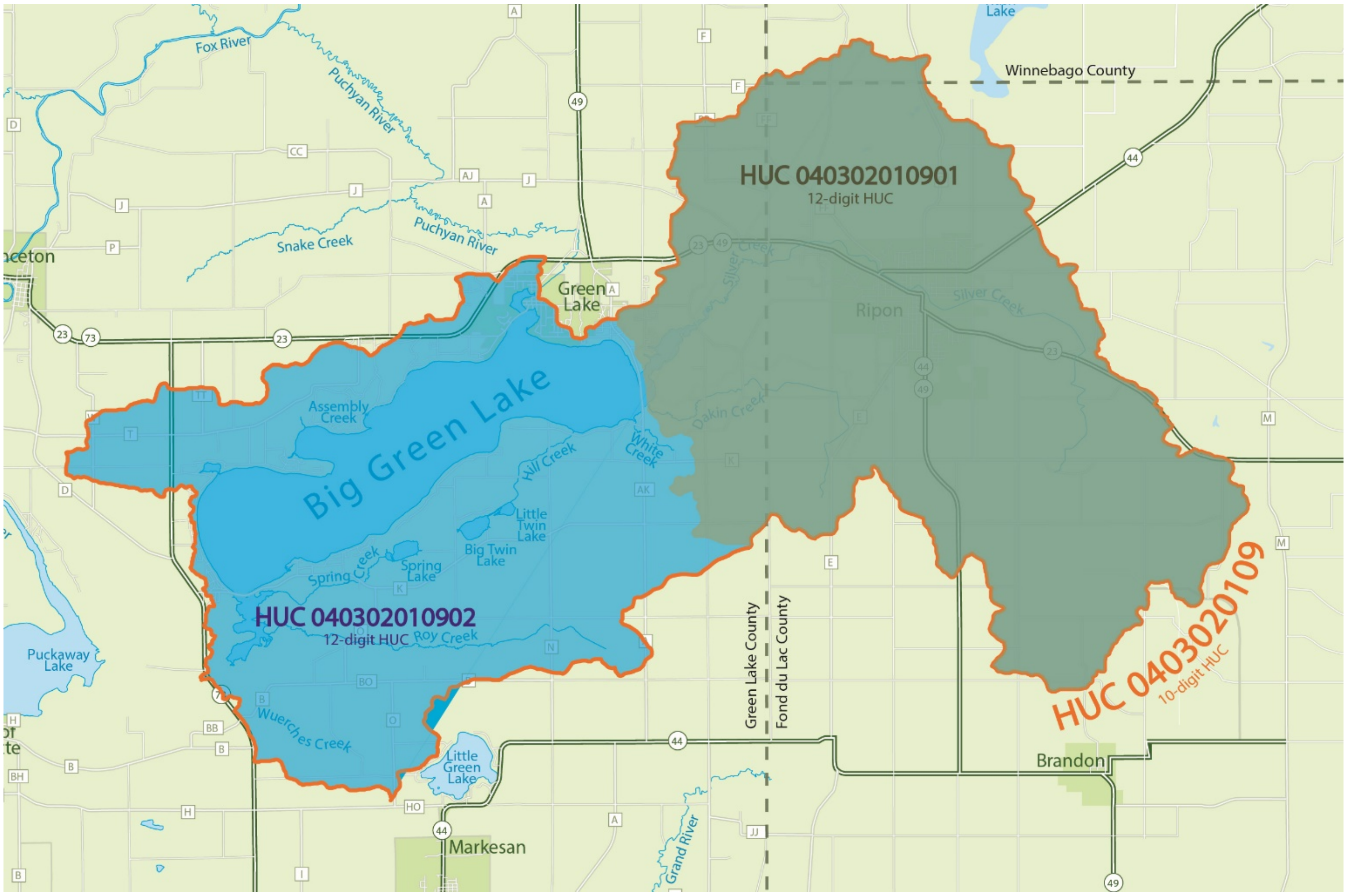

Figure 10. The Big Green Lake watershed (HUCS 0403020109) is comprised of two 12-digit HUCS: HUC 040302010901 to the west (Dakin and Silver Creek sub-watersheds) and HUC 040302010902 to the west (comprised of White, Hill, Spring, Roy, Wuerches, and Assembly Creek sub-watersheds).

A conceptual site model of the Big Green Lake watershed and its sub-watersheds (Figure 11) shows the flow path and water quality of the various named streams, lakes, and wetlands.

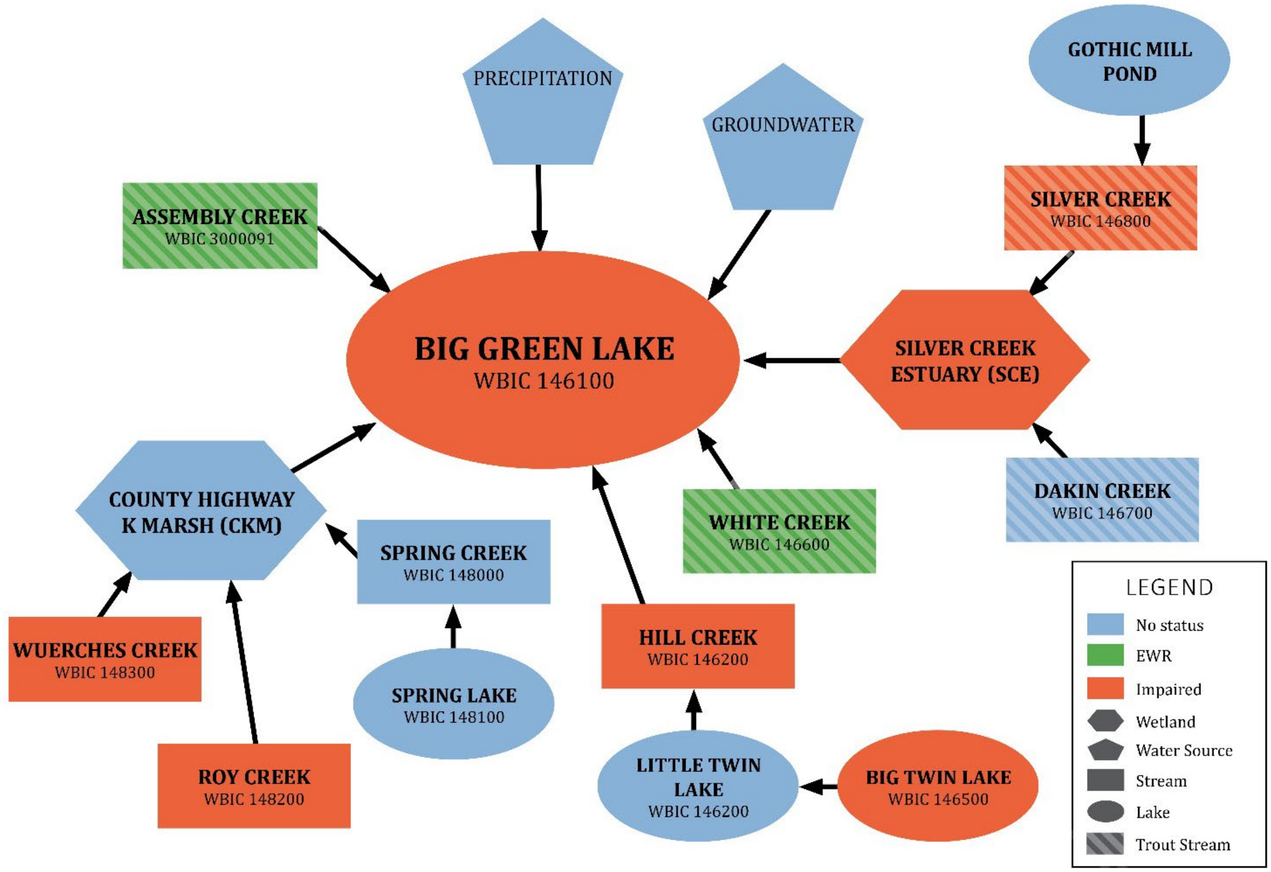

Figure 11. A conceptual site model of the Big Green Lake watershed illustrates the flow path and WDNR's water quality classification for its eight named tributaries, two major wetlands and three smaller lakes. These waterbodies are designated as no status (blue), an Exceptional Water resource (EWR, green), impaired (red) and a trout stream (hatched).

i. Watershed Characteristics: Land Use

According to the WDNR's watershed assessments [32], 65% of the Big Green Lake 107 square mile watershed is agricultural land use (see Figure 12 and Figure 13). The remainder of the watershed is comprised of open land and water (15.5%), forests (8.8%), wetlands (5.8%) and suburban (3.2%) land cover. The remainder of its land use constitutes slightly over one and a half percent of the total land cover; these include urban (0.9%), grassland (0.8%) and barren (.07%).

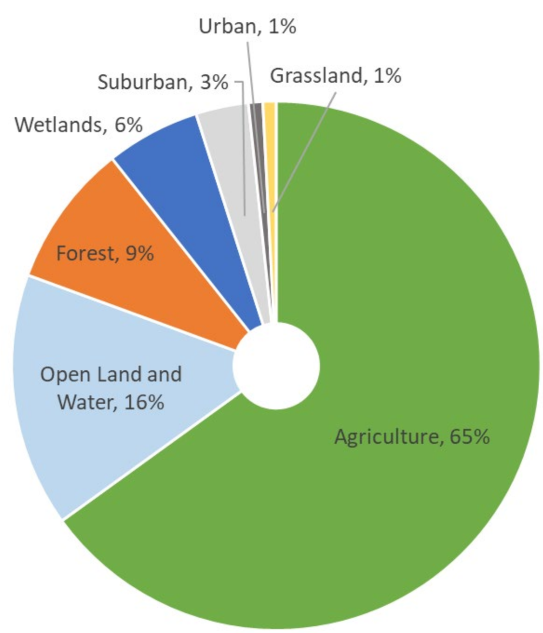

Figure 12. The Big Green Lake watershed is primarily agricultural (65%) and open land/water (16%). The remaining land uses – forest, wetlands, suburban, urban and grassland – make up less than 20% of the rest of the watershed.

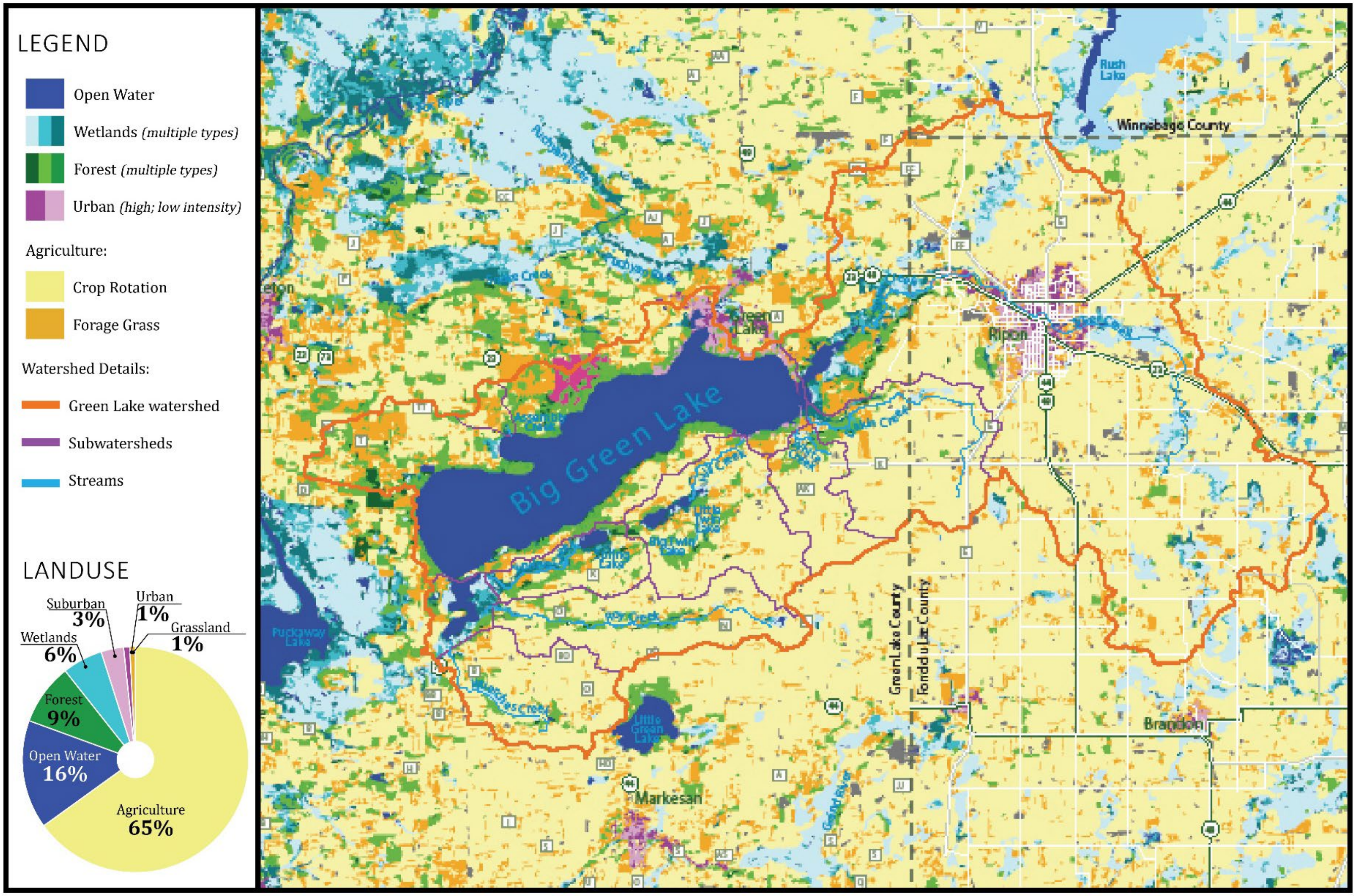

Figure 13. A land use map shows that agricultural land use, including crop rotation, and forage grass, dominates the Big Green Lake watershed.

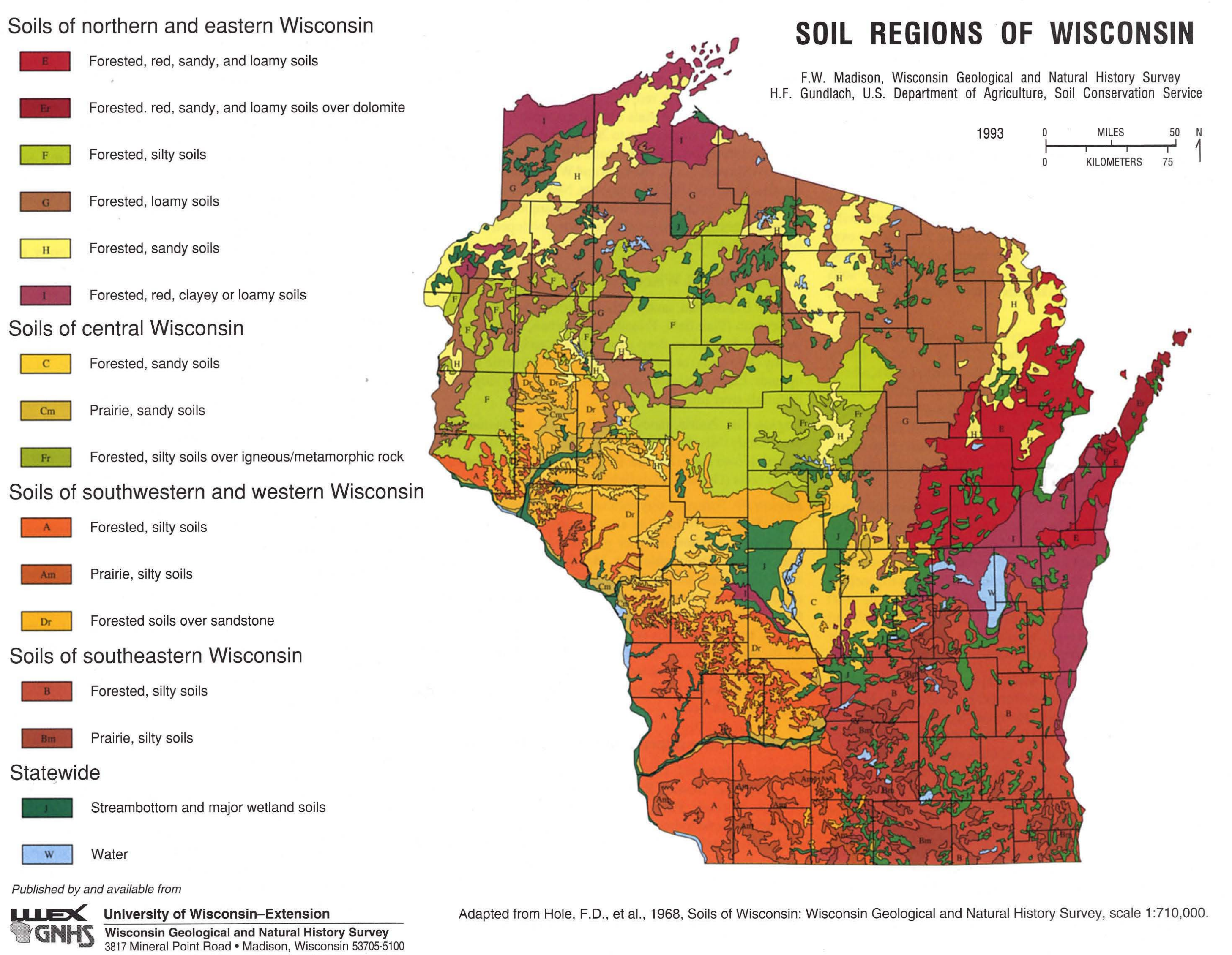

Figure 14. The Big Green Lake watershed is primarily composed of forested silty soils and prairie silty soils, with some stream bottom and major wetland soils, as shown in this soil region map of Wisconsin [35].

ii. Watershed Characteristics: Sub-Watersheds

The Big Green Lake watershed is comprised of eight named streams. The following section summarizes each of these eight named sub-watersheds, listed alphabetically.

a) Assembly Creek Sub-Watershed

The Assembly Creek sub-watershed is 1 square mile, located entirely within Green Lake County. Assembly Creek directly discharges into Big Green Lake. The Assembly Creek tributary is discussed in Section 3.C.ii.a).

The Upper Fox-Wolf River TMDL report identifies Assembly Creek as sub-watershed 20 [2].

Figure 15. A map of the Big Green Lake watershed (outlined in dark orange) shows the extent of the Assembly Creek sub-watershed (filled in light orange) and the other sub-watersheds (outlined in purple).

b) Dakin Creek Sub-Watershed

The Dakin Creek sub-watershed is 7 square miles, divided equally between Green Lake County (3.5 square miles) and Fond du Lac County (3.5 square miles). Dakin Creek (and Silver Creek) flows into the SCE before discharging into Big Green Lake. The Dakin Creek tributary is discussed in Section 3.C.v.b).

The Upper Fox-Wolf River TMDL report identifies Dakin Creek as sub-watershed 20 [2].

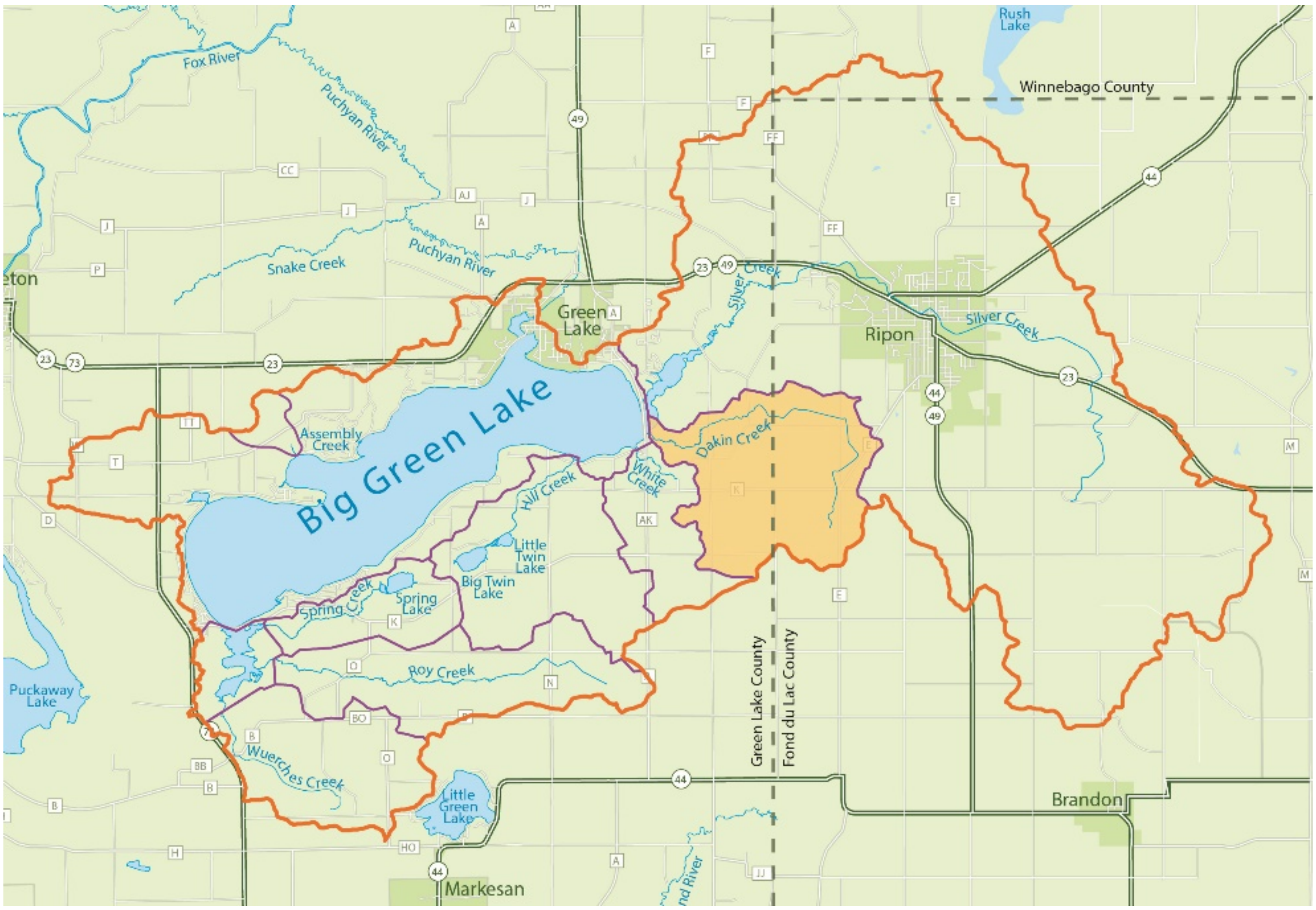

Figure 16. A map of the Big Green Lake watershed (outlined in dark orange) shows the extent of the Dakin Creek sub-watershed (filled in light orange) and the other sub-watersheds (outlined in purple).

c) Hill Creek Sub-Watershed

The Hill Creek sub-watershed is 7 square miles, locally entirely within Green Lake County. Big Twin Lake and Little Twin Lake are located within the Hill Creek sub-watershed (as discussed in Section 3.C.iv.a). The Hill Creek tributary is discussed in Section 3.C.v.c).

The Upper Fox-Wolf River TMDL report identifies Hill Creek as sub-watersheds 79 and 83 [2].

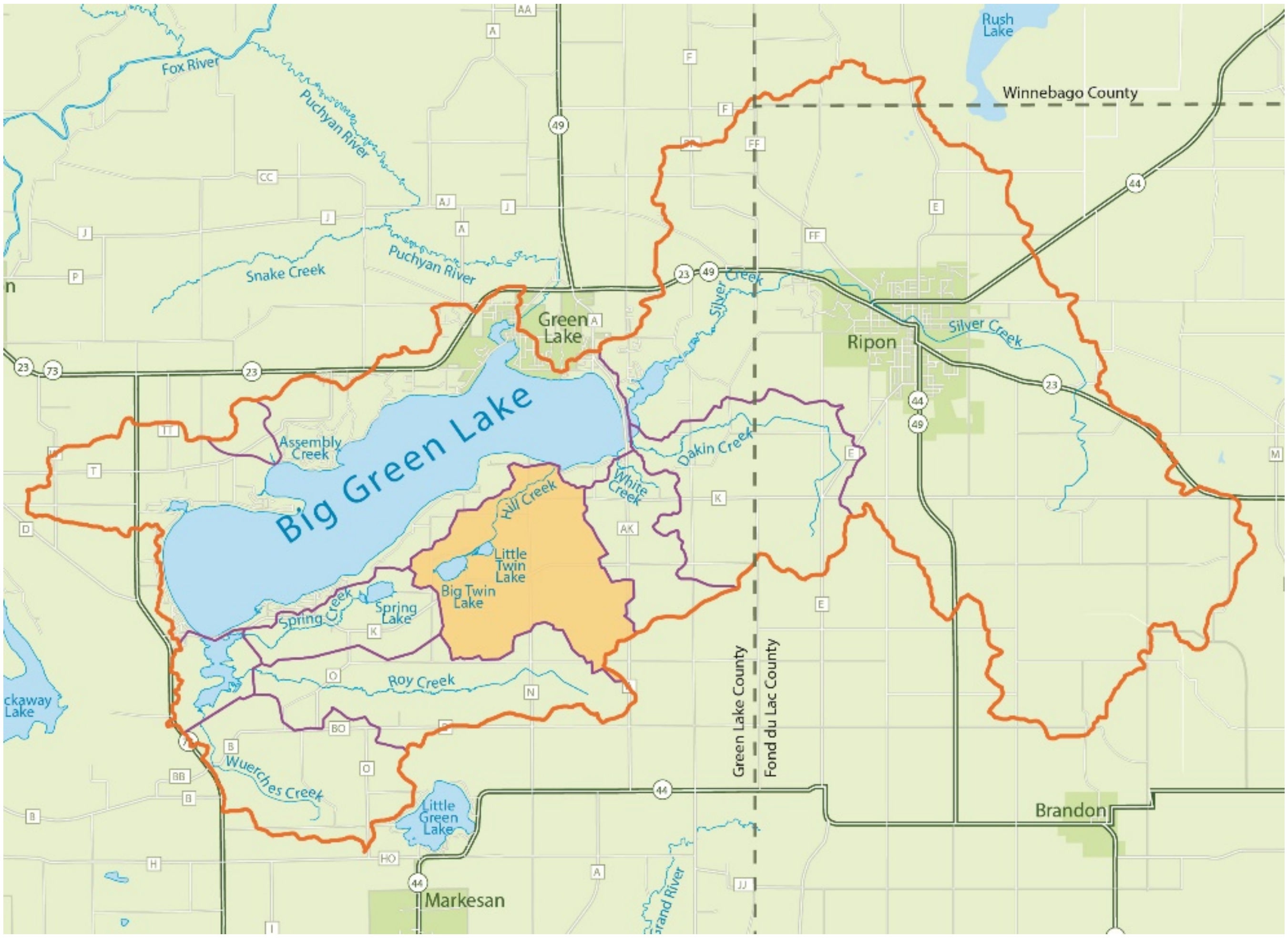

Figure 17. A map of the Big Green Lake watershed (outlined in dark orange) shows the extent of the Hill Creek sub-watershed (filled in light orange) and the other sub-watersheds (outlined in purple).

d) Roy Creek Sub-Watershed

The Roy Creek sub-watershed is 6 square miles, located entirely within Green Lake County. Roy Creek discharges into the CKM (along with the Spring and Wuerches sub-watersheds) before discharging into Big Green Lake at the County Highway K bridge at the southwest inlet. The Roy Creek tributary is discussed in Section 3.C.v.d).

The Upper Fox-Wolf River TMDL report identifies Roy Creek as sub-watershed 17 [2].

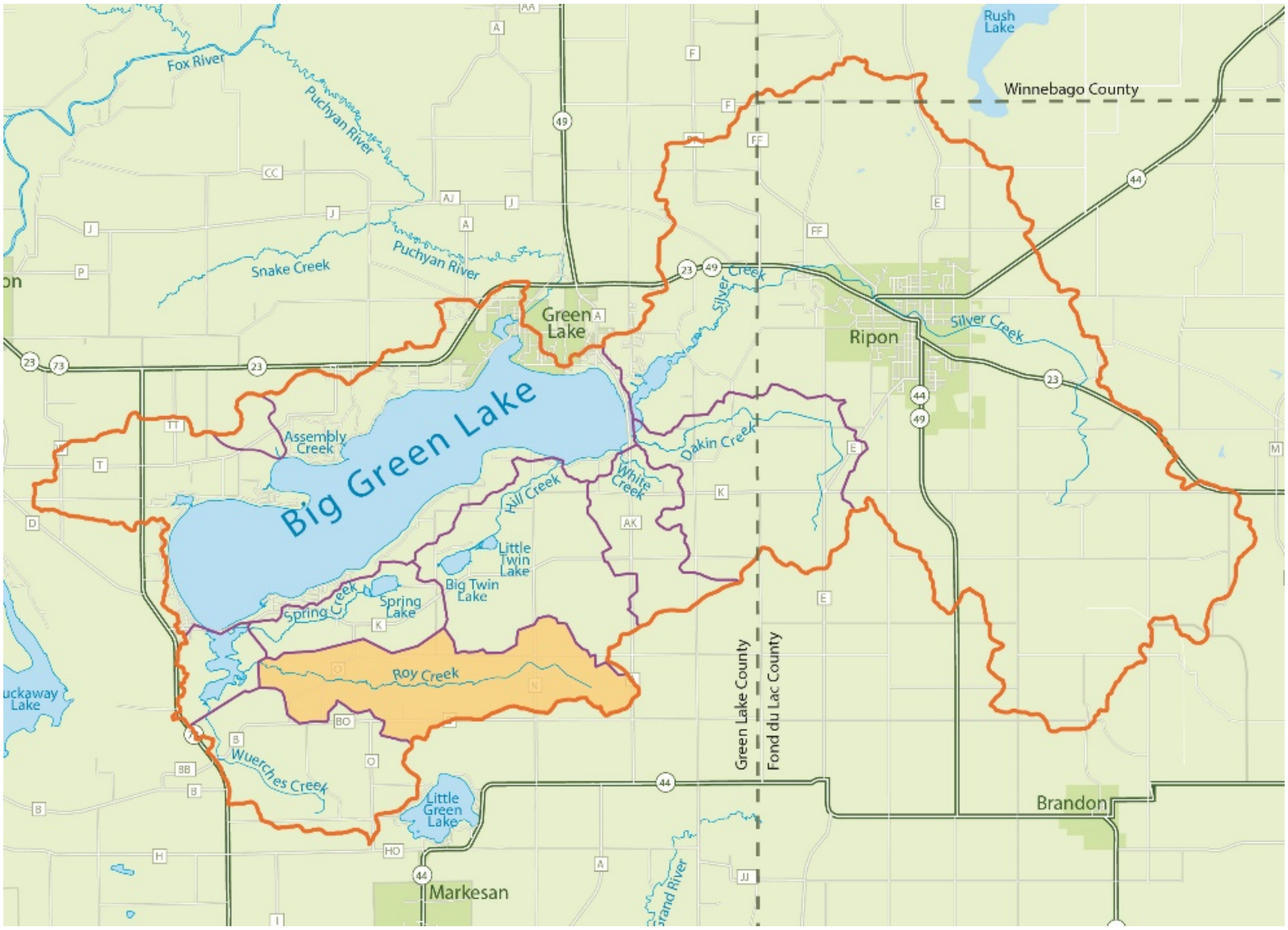

Figure 18. A map of the Big Green Lake watershed (outlined in dark orange) shows the extent of the Roy Creek sub-watershed (filled in light orange) and the other sub-watersheds (outlined in purple).

e) Silver Creek Sub-Watershed

The Silver Creek sub-watershed is the largest of all eight sub-watersheds. It drains 48 square miles and accounts for 45% of Big Green Lake watershed's area. The Silver Creek watershed includes the City of Ripon. The Silver Creek tributary is discussed in Section 3.C.v.e).

The Silver Creek sub-watershed is divided into three counties: Green Lake County (7 square miles or 15% of the sub-watershed's area), Fond du Lac County (40 square miles or 83%), and Winnebago County (1 square mile or 2%).

Downstream of Spaulding Hill Road, Silver Creek and Dakin Creek flow into the SCE (See Section 3.C.vi.a) before flowing into the east side of Big Green Lake at County Highway A in Green Lake County.

The Upper Fox-Wolf River TMDL report identifies Silver Creek as sub-watersheds 19 and 87 [2].

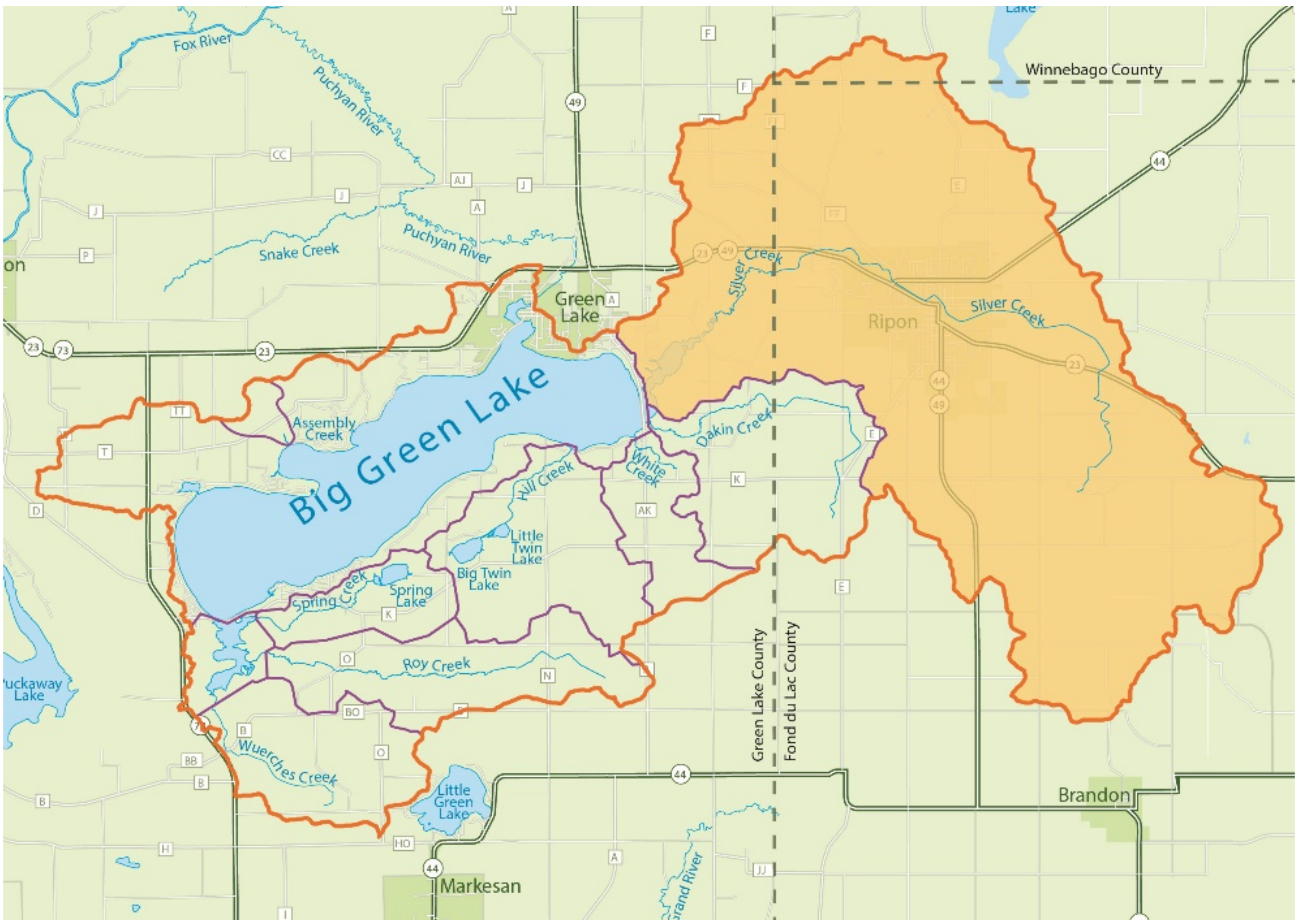

Figure 19. A map of the Big Green Lake watershed (outlined in dark orange) shows the extent of the Silver Creek sub-watershed (filled in light orange) and the other sub-watersheds (outlined in purple).

f) Spring Creek Sub-Watershed

The Spring Creek sub-watershed is 3 square miles, located entirely within Green Lake County. Spring Lake is located within the Spring Creek sub-watershed. Spring Creek outlets into the CKM (with the Roy and Wuerches sub-watersheds) before discharging into Big Green Lake at the County Highway K bridge at Green Lake's Southwest Inlet. The Spring Creek tributary is discussed in 3.C.ii.f).

The Upper Fox-Wolf River TMDL report identifies Spring Creek within sub-watershed 20 [2].

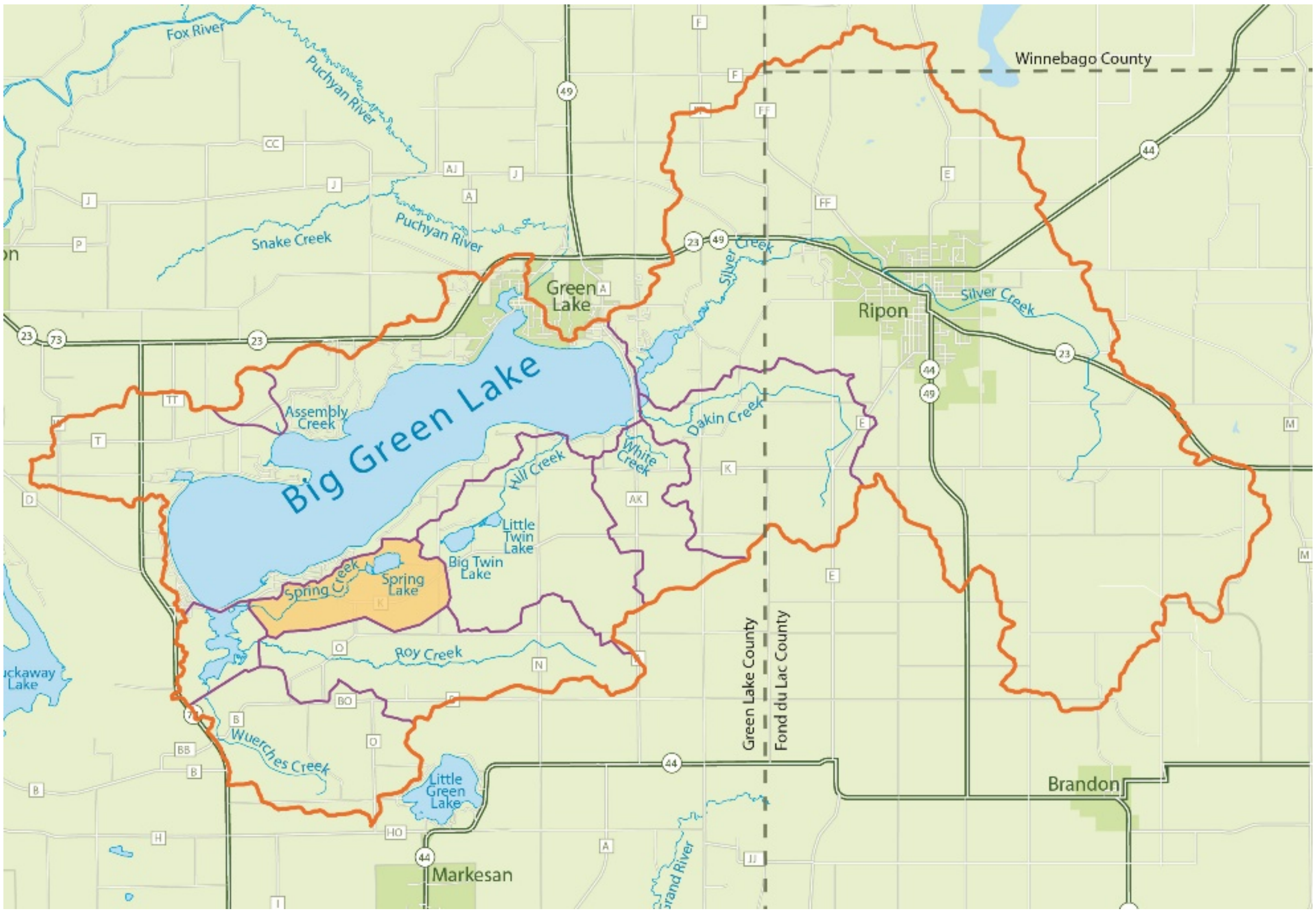

Figure 20. A map of the Big Green Lake watershed (outlined in dark orange) shows the extent of the Spring Creek sub-watershed (filled in light orange) and the other sub-watersheds (outlined in purple).

g) White Creek Sub-Watershed

The White Creek sub-watershed is 3 square miles, located entirely within Green Lake County. White Creek directly discharges into Big Green Lake just west of the SCE and County Highway A. The White Creek tributary is discussed in Section3.C.ii.g).

According to the 2013 LMP, White Creek was known to have Wisconsin's highest sediment loadings prior to 1998 when measured on a per-acre basis. In this period, the unit area load of suspended solids was 338 tons per square mile, compared to median loads for the ecoregion of 130 tons per square mile [4]. White Creek sub-watershed's relatively small size helped to constrain impacts to the lake. In response to the findings of the USGS, the LMPT deployed best management practices in the watershed to abate the high sediment loads. Presently, the WDNR classifies the condition of White Creek as "good" [36].

The Upper Fox-Wolf River TMDL report identifies White Creek within sub-watershed 20 [2].

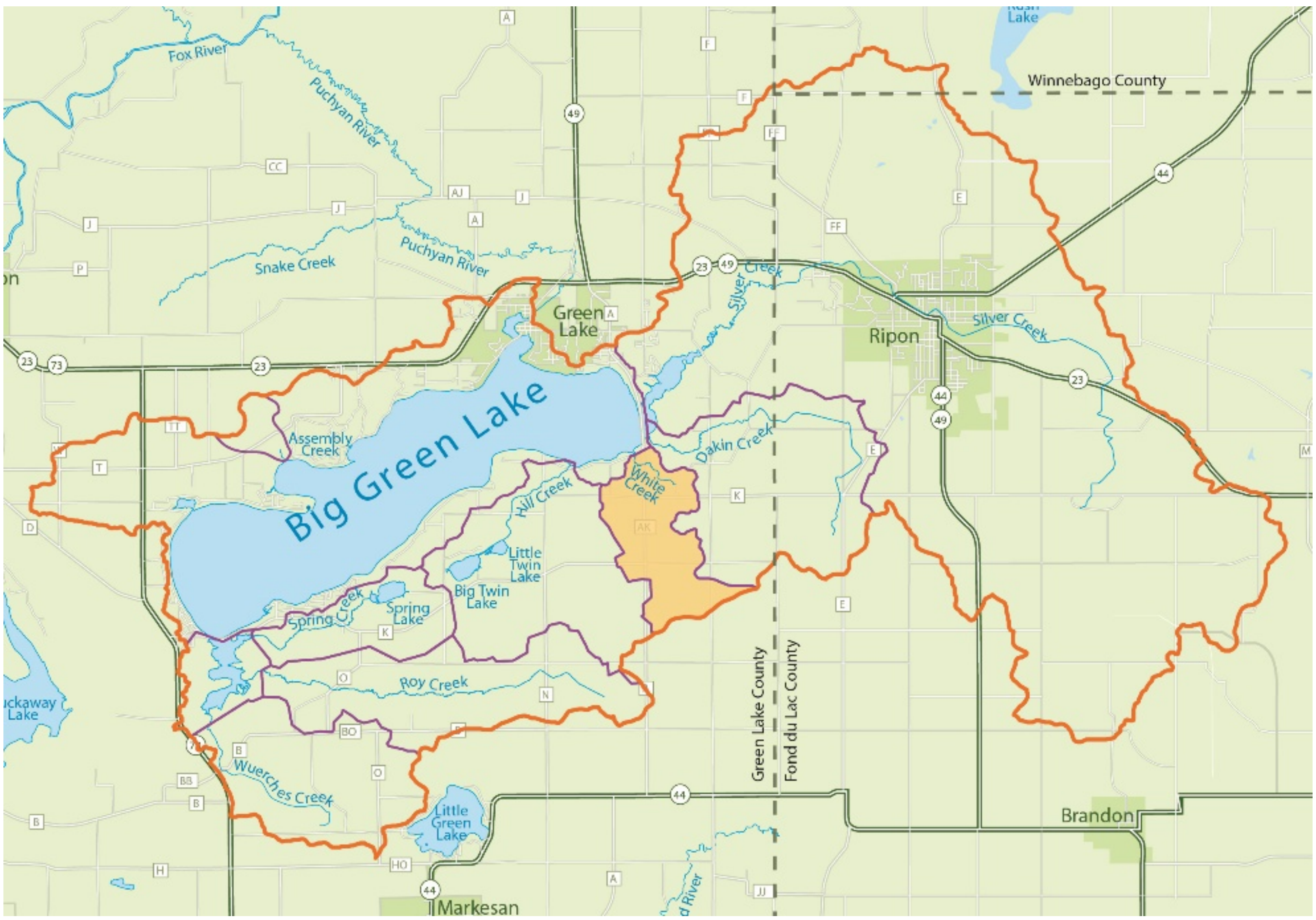

Figure 21. A map of the Big Green Lake watershed (outlined in dark orange) shows the extent of the White Creek sub-watershed (filled in light orange) and the other sub-watersheds (outlined in purple).

h) Wuerches Creek Sub-Watershed

The Wuerches Creek sub-watershed is 5 square miles, located entirely within Green Lake County. Wuerches Creek outlets into the CKM (with Roy and Spring sub-watersheds) before discharging into Big Green Lake at the County Highway K bridge. The Wuerches Creek tributary is discussed in Section 3.C.v.h).

The Upper Fox-Wolf River TMDL report identifies Werches Creek as sub-watershed 18 [2].

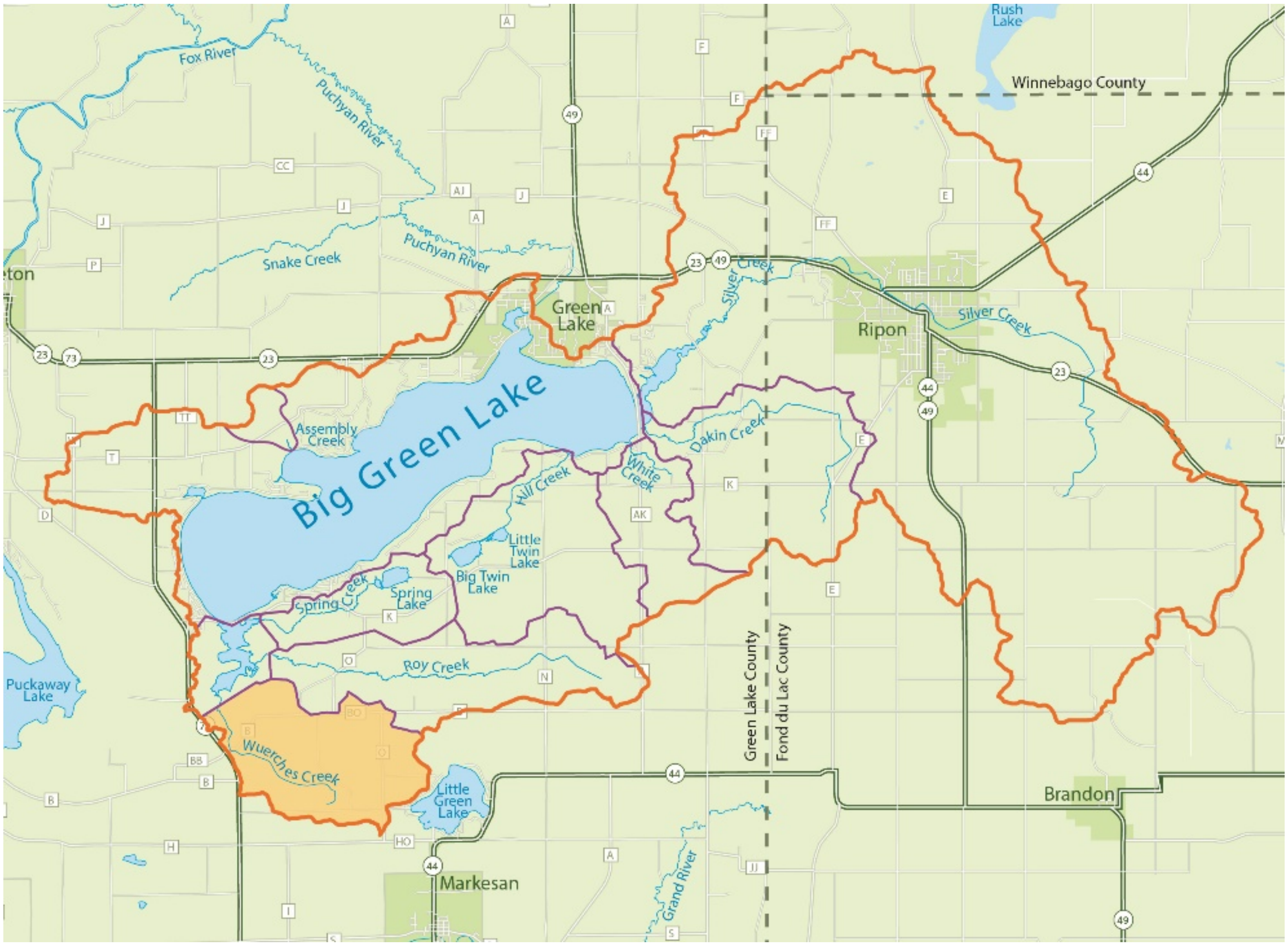

Figure 22. A map of the Big Green Lake watershed (outlined in dark orange) shows the extent of the Wuerches Creek sub-watershed (filled in light orange) and the other sub-watersheds (outlined in purple).

iii. Watershed Characteristics: Ecological Landscape

The following paragraphs were taken from the WDNR's watershed information on Big Green Lake [32]:

"The Big Green Lake Watershed is covered by two ecological landscapes: The Southeast Glacial Plains and the Central Sand Hills.

"The Southeast Glacial Plains Ecological Landscape makes up the bulk of the non-coastal land area in southeast Wisconsin. This Ecological Landscape is made up of glacial till plains and moraines. Most of this Ecological Landscape is composed of glacial materials deposited during the Wisconsin Ice Age, but the southwest portion consists of older, pre-Wisconsin till with a more dissected topography. Soils are lime-rich tills overlain in most areas by a silt-loam loess cap. Agricultural and residential interests throughout the landscape have significantly altered the historical vegetation. Most of the rare natural communities that remain are associated with large moraines or in areas where the Niagara Escarpment occurs close to the surface. Historically, vegetation in the Southeast Glacial Plains consisted of a mix of prairie, oak forests and savanna, and maple-basswood forests. Wet-mesic prairies, southern sedge meadows, emergent marshes, and calcareous fens were found in lower portions of the Landscape. End moraines and drumlins supported savannas and forests. Agricultural and urban land use practices have drastically changed the land cover of the Southeast Glacial Plains since Euro-American settlement. The current vegetation is primarily agricultural cropland. Remaining forests occupy only about 10% of the land area and consist of maple-basswood, lowland hardwoods, and oak. No large mesic forests exist today except on the Kettle Interlobate Moraine which has topography too rugged for agriculture. Some existing forest patches that were formerly savannas have succeeded to hardwood forest due to fire suppression.

"The Central Sand Hills Ecological Landscape is located in central Wisconsin at the eastern edge of what was once Glacial Lake Wisconsin. The landforms in this Ecological Landscape are a series of glacial moraines that were later partially covered by glacial outwash. The area is characterized by a mixture of farmland, woodlots, wetlands, small kettle lakes, and cold water streams, all on sandy soils. The mosaic of glacial moraine and pitted outwash throughout this Ecological Landscape has given rise to extensive wetlands in the outwash areas, and the headwaters of cold water streams that originate in glacial moraines. The growing season is long enough for agriculture, but the sandy soils limit agricultural productivity somewhat. Historic upland vegetation consisted of oak-forest, oak savanna, and tallgrass prairie. Fens were common in this Ecological Landscape and occurred along with wet-mesic prairie, wet prairie, and rare coastal plain marshes. Current vegetation is composed of more than one-third agricultural crops, and almost 20% grasslands with smaller amounts of open wetland, open water, shrubs, barren, and urban areas. The major forested type is oak-hickory, with smaller amounts of white-red-jack pine, maple-basswood, lowland hardwoods, aspen-birch, and spruce-fir."

iv. Watershed Characteristics: Lakes

In addition to Big Green Lake, the Big Green Lake watershed has 655 acres of smaller lakes. Big Twin Lake and Little Twin Lake (a two-lake complex called Twin Lakes) and Spring Lake are all located on the south side of Big Green Lake.

a) Big and Little Twin Lakes

Twin Lakes (WBIC 146500) is a 74-acre, eutrophic, two-lake system located one mile south of Big Green Lake (see Figure 23) within the Hill Creek subwatershed. Big Twin Lake drains to Little Twin Lake through an intermittent ditch, which flows to Big Green Lake via Hill Creek. Big Twin Lake is as an impaired water body for total phosphorus indicated by excessive algal growth.

The maximum depth is 46 feet (found on Big Twin Lake) with an average depth of 17 feet [37]. The lake complex has a bottom containing 15% sand, 15% gravel, 10% rock, and 60% muck [37]. The Little Twin Lake bottom is 20% sand and 80% muck [38]. The fishery supports panfish, largemouth bass, northern pike and walleye. The WDNR documents that Twin Lake has Chinese mystery snail, curly-leaf pondweed, Eurasian water-milfoil and hybrid cattails as aquatic invasive species.

Prior to 1963, the lake was over-populated by carp causing turbid water and poor fishing [31].

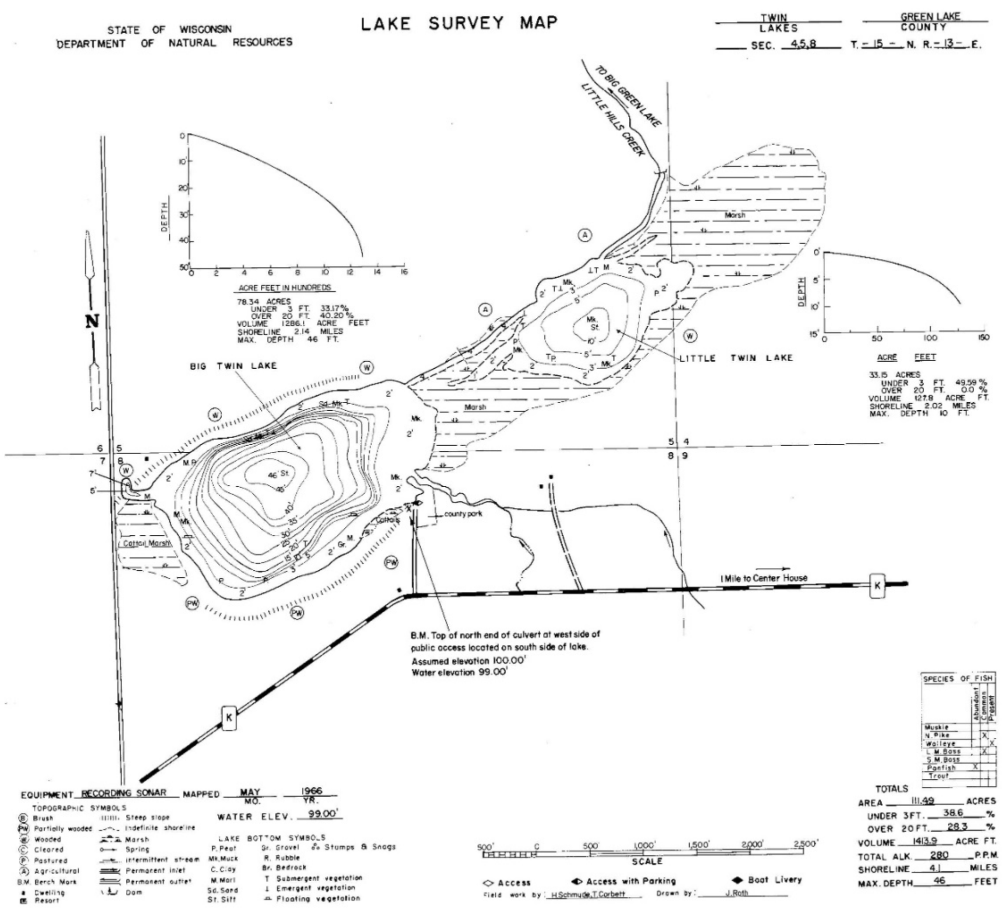

Figure 23. Big and Little Twin Lakes, as shown is this historical lake map from the WDNR, are eutrophic lakes located on the south side of Big Green Lake within the Big Green Lake watershed. [39]

b) Spring Lake

Spring Lake (WBIC 148100) is a 62-acre, mesotrophic lake [40] (see Figure 24) within the Spring Creek subwatershed. Spring Lake outlets to Spring Creek, which enters the east side of CKM before flowing to Big Green Lake. Spring Lake has a mean depth of 14 feet with a lake bottom comprised of 50% sand and 50% muck.

The fishery supports panfish, largemouth bass, northern pike and walleye. Verified aquatic invasive species found in the lake include curly-leaf pondweed and Eurasian water-milfoil. Non-verified aquatic invasive species include narrow-leaf cattail and zebra mussels.

From the WDNR's 2017 Water Quality Monitoring Plan [31]: "Spring Lake is a hard water, marl lake separated from Big Green Lake by a narrow ridge. The lake is spring fed and the outlet, Spring Creek, provides a continual flow into Big Green Lake."

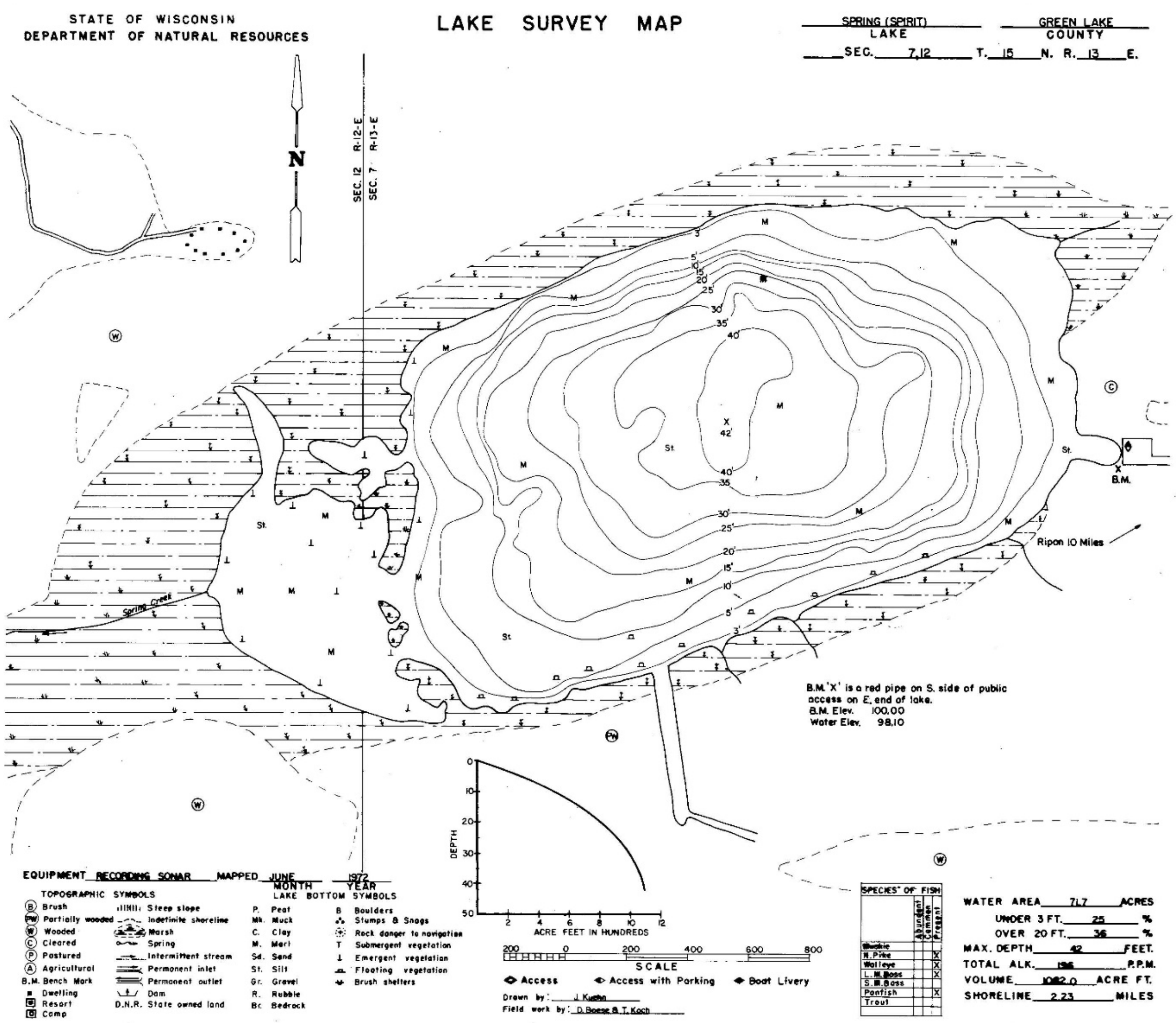

Figure 24. A historic bathymetric map of Spring Lake from the WDNR shows the outlet of Spring Creek, which flows to the east side of the CKM before entering Big Green Lake [41].

v. Watershed Characteristics: Rivers

There are 141 miles of streams and rivers in the Big Green Lake watershed [42], though a more thorough understanding of the entire stream network in the watershed is needed. There are eight named tributaries to Big Green Lake: Assembly Creek, Dakin Creek, Hill Creek, Roy Creek, Silver Creek, Spring Creek, White Creek, and Wuerches Creek. Assembly Creek, Hill Creek, and White Creek discharge directly into Big Green Lake. Roy, Wuerches, and Spring Creeks discharge to the County K Marsh (CKM) before flowing into Big Green Lake at County Highway K, Big Green Lake. Spring Creek and Dakin Creek discharge into the Silver Creek Estuary (SCE) before flowing into Big Green Lake at County Highway A, Green Lake County.

A total of 1.3 miles of streams in the watershed are identified as Exception Resource Waters (ERW). ERWs are surface waters that provide outstanding recreation opportunities, support valuable fisheries and wildlife habitat, have good water quality, and are not significantly impact by human activities. Fewer than 0.5% (1,544 lakes) of Wisconsin's 15,000 lakes and impoundments are designated as ERWs [43].

There are eight named streams within the Green Lake watershed, which appear as seven subbasins in the Upper Fox Wolf TMDL (see Figure 25).

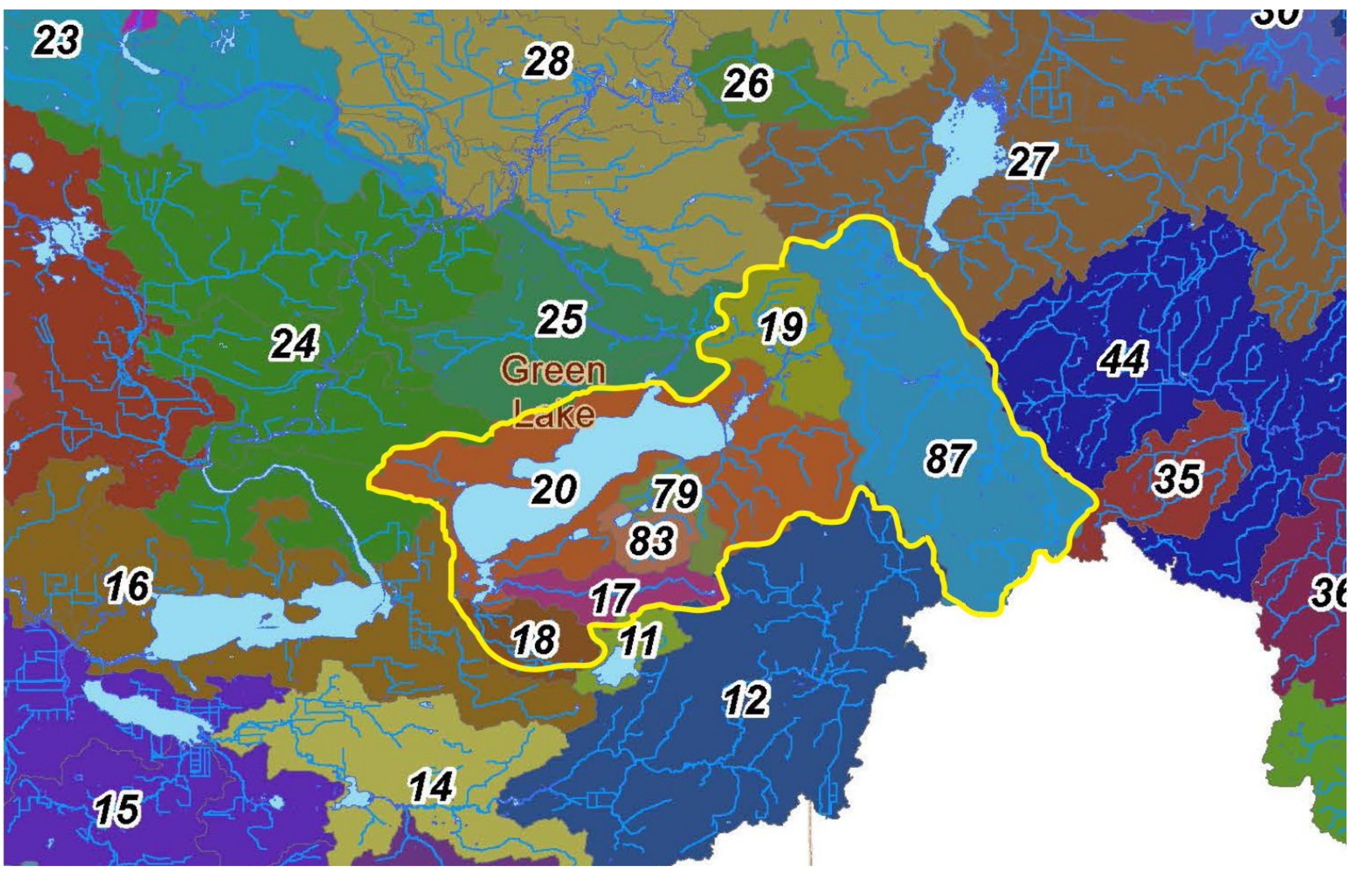

Figure 25. Green Lake has seven subbasins identified within the Upper Fox Wolf TMDL [2]. Map modified from TMDL subbasin map [3] to include Green Lake watershed boundary (in yellow).

Six miles in the Big Green Lake watershed are classified as trout waters by the WDNR, as shown in Table 3. However, the WDNR had not documented brook trout during fish surveys in Dakin Creek since the 1950s. This is attributed to degraded habitat, though the stream is not listed as impaired. In 2020, 970 brook trout were stocked in Dakin Creek following habitat improvements and a perched culvert replacement on Skunk Hollow Road.

Table 3. Six miles of streams in the Big Green Lake watershed are identified as trout waters.

Waterbody Name	WBIC	Start Mile	End Mile	Trout Class	Trout ID
Assembly Creek	3000091	0	0.19	Class I	3378
White Creek	146600	0	1.11	Class I	17
Dakin Creek	146700	0	2.78	Class II	1528
Silver Creek	146800	12.41	14.36	Class II	1529

In addition to the lake itself, there are ten tributaries (some named and some unnamed) within the Big Green Lake watershed that are impaired (see Figure 26 and Table 4). Fifty percent of the watershed's rivers and streams provided poor habitat for fish and aquatic life, 28% provides good habitat, and 22% is unknown [32].

Table 4 and Figure 26 (below) describe the 303(d) impaired waters within the Green Lake watershed. Nearly all impairments are from total phosphorus or sediment / total suspended solids pollutants.

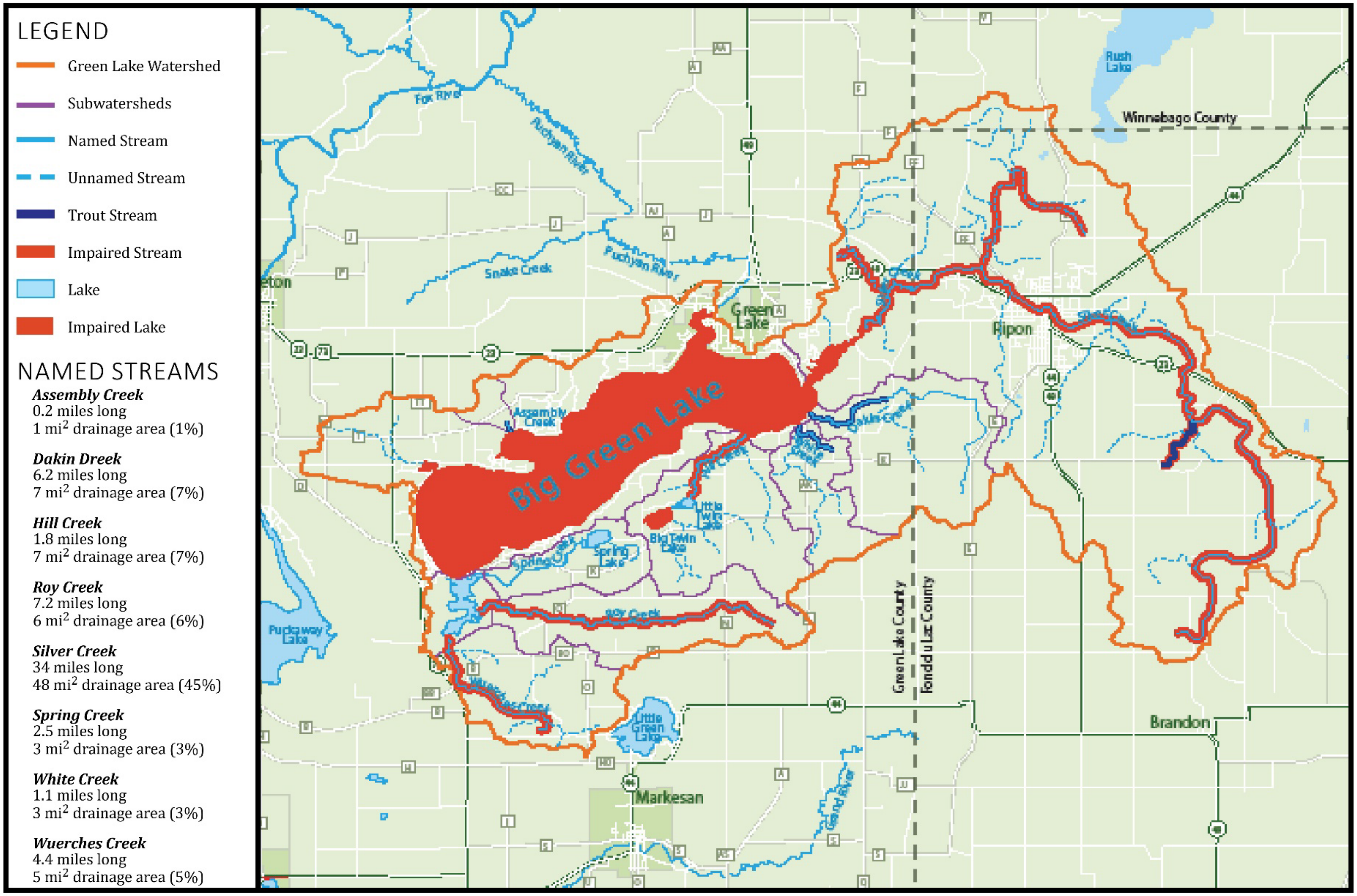

Figure 26. A total of 10 streams and lakes are impaired (shown in red) in the Big Green Lake watershed (watershed boundary in orange). Details about each impairment is outlined in Table 4.

Table 4. Excluding the lake itself and direct runoff, there are ten water bodies within the Big Green watershed that are 303(d) listed for various pollutants.

Waterbody Name	Water Type	Date Listed	Pollutant	Impairment Indicator
Big Green Lake	Lake	4/1/2014 4/1/2002	Total Phosphorus PCBs	Low Dissolved Oxygen Contaminated Fish Tissue
Roy Creek	River	4/1/2014 4/1/2002	Total Phosphorus Sediment / Total Suspended Solids	Degraded Biological Community Degraded Habitat
Wuerches Creek	River	4/1/2008 4/1/1998	Total Phosphorus Sediment / Total Suspended Solids	Low Dissolved Oxygen, Elevated Water Temperature Degraded Habitat
Big Twin Lake	Lake	4/1/2014	Total Phosphorus	Excessive Algal Growth
Hill Creek	River	4/1/2016 4/1/2002	Total Phosphorus Sediment / Total Suspended Solids	Degraded Biological Community Degraded Habitat
Silver Creek Mouth	Lake	4/1/2012	E.coli	Recreational Restrictions – Pathogens
Silver Creek	River	4/1/2018 4/1/1998	Total Phosphorus Sediment / Total Suspended Solids	Impairment Unknown Elevated Water Temperature, Degraded Habitat
Unnamed Trib to Silver Creek	River	4/1/2017	Total Phosphorus	Degraded Biological Community
North Trib to Silver Creek	River	4/1/2016	Total Phosphorus	Impairment Unknown
Unnamed Trib to Silver Creek	River	4/1/2016	Total Phosphorus	Impairment Unknown

a) Assembly Creek

Assembly Creek (WBIC 000091), sometimes documented as "Assemble Creek" in various documents, is a 0.2 mile stream that directly discharges to Big Green Lake. The WDNR classifies this entire tributary as an ERW under NR 102 and a Class I Trout Water under the Fisheries Program.

Appendix H [44] of the Upper Fox-Wolf River TMDL report estimates Assembly Creek, located in sub-basin 20, needs a 0% total phosphorus reduction to meet local water quality standards.

b) Dakin Creek

Dakin Creek (WBIC 16700) is a 6.2-mile stream that discharges into the SCE before flowing into the eastern inlet of Big Green Lake. There are 0.02 miles of unnamed tributaries to Dakin Creek [45]. The WDNR classifies this as a Class II Trout stream (start mile 0.0 to end mile 2.8) under the Fisheries Program. The WDNR does not classify this river as impaired. Appendix H [44] of the Upper Fox-Wolf River TMDL report estimates Dakin Creek, sub-basin 20, needs a 0% total phosphorus reduction to meet local water quality standards.

c) Hill Creek

Hill Creek (WBIC 146200) is 1.8-mile stream (plus 2.4 miles in unnamed tributaries) that is listed as an impaired water body with degraded biological community and degraded habitat from total phosphorus and total suspended solids [45]. Hill Creek is the outlet of Twin Lakes and directly drains to Big Green Lake on its southern shore.

Hill Creek, from Little Twin Lake to Big Green Lake, was assessed by the WDNR during the 2016 listing cycle. Total phosphorus sample data exceed 2016 WisCALM listing criteria for the Fish and Aquatic Life use and biological impairment was observed, meaning at least one macroinvertebrate or fish Index of Biotic Integrity scored in the poor condition category.

Between 2017-2020, the USGS had a sampling station (USGS 040734615) on Hill Creek near the mouth of Big Green Lake.

Appendix H [44] of the Upper Fox-Wolf River TMDL report estimates Hill Creek consists of two sub-basins: 79 and 83. Sub-basin 79 requires an 80% total phosphorus reduction to meet local water quality standards. Sub-basin 83 needs a 34% total phosphorus reduction to meet downstream water quality standards in Big Twin Lake and 0% reduction to meet local water quality standards.

d) Roy Creek

Roy Creek (WBIC 148200) is 7.2 miles in length and outlets into the CKM before flowing into Big Green Lake under the County Highway K bridge. The WDNR classified Roy Creek as an impaired water body in 2002 and total phosphorus in 2014.

The 2016 WDNR assessments showed continued impairment by phosphorus. Total phosphorus sample data exceed 2016 WisCALM listing criteria for the Fish and Aquatic Life use. However, available biological data do not indicate impairment (no macroinvertebrate or fish Index of Biotic Integrity scored in the "poor" condition category). Based on the most updated information, no change in existing impaired waters listing is needed.

A discontinued USGS monitoring station (USGS 04073458) was historically located at the County Highway O bridge on Roy Creek. The station was active from 2012 through 2017.

Appendix H [44] of the Upper Fox-Wolf River TMDL report shows Roy Creek, sub-basin 17, needs a 68% total phosphorus reduction to meet local water quality standards.

e) Silver Creek

Silver Creek is the largest tributary to Big Green Lake, totaling over 34 miles (or 28%) of all stream miles in the watershed, including 13.4 miles in the named tributary and 21.0 miles of unnamed tributaries [45].

Silver Creek (146800) has been on the impaired waters list for sediment/total suspended solids since 1998 with elevated water temperature as impairment.

A dammed portion of Silver Creek forms the City of Ripon's Gothic Mill Pond (15.5 acres). This dam eliminates fish migration and results in several related problems like clam distribution, trout migration, and excessive warming [31]. The shallow, silt-bottomed impoundment consists primarily of common suckers and carp, along with a variety of panfish species, bullheads, and northern pike.

Silver Creek is classified as Class II trout waters (from start mile 12.4 to end mile 14.4), though its water quality condition is poor.

The City of Ripon's Wastewater Treatment Facility discharges its effluent to Silver Creek. More on this pollutant source is discussed in Section 6.C.

A USGS monitoring station (USGS 04073466) is located at Spaulding Road from 2011 to present. A monitoring station was historically located downstream of the SCE at County Highway A in Green Lake County (USGS 04073468), but this monitoring station was discontinued due to electrical interference problems. The GLSD maintains grab samples at this location to assess treatment efficiency from the SCE.

Appendix H [44] of the Upper Fox-Wolf River TMDL report shows Silver Creek is comprised of two sub-basins: 19 and 87. Sub-basin 19 needs a 45% total phosphorus reduction to meet local water quality standards. Sub-basin 87 needs a 76% reduction to meet local water quality standards.

f) Spring Creek

Spring Creek (WBIC 148000) is a 2.5 mile stream that is the outlet of Spring Lake. Spring Creek enters the east side of the CKM before flowing to Big Green Lake. Spring Creek is not currently considered impaired.

Appendix H [44] of the Upper Fox-Wolf River TMDL report shows Spring Creek, sub-basin 20, needs a 0% total phosphorus reduction to meet local water quality standards.

g) White Creek

White Creek (WBIC 46600) is a 1.1 mile creek with 3.1 miles of unnamed tributaries [45]. The entire tributary's length is identified by the WDNR as an ERW under NR102 and a Class I Trout Water under the Fisheries Program.

White Creek was assessed by the WDNR during the 2018 listing cycle. New biological (macroinvertebrate Index of Biotic Integrity scores) sample data were clearly below the 2018 WisCALM listing thresholds for the Fish and Aquatic Life use. This water was meeting this designated use and was not considered impaired.

A USGS monitoring station was located at Spring Grove Road and White Creek from 1981 through 1988, 1996 to 2012, and 2017 to 2020.

Appendix H of the Upper Fox-Wolf River TMDL report shows White Creek, sub-basin 20, needs a 0% total phosphorus reduction to meet local water quality standards.

h) Wuerches Creek

Wuerches Creek (WBIC 148300) is a 4.4-mile stream (plus 1.9 miles of unnamed tributaries) on the impaired waters list in 1998 for sediment/total suspended solids and in 2008 for total phosphorus. It is impaired because of its low dissolved oxygen, elevated water temperature and degraded habitat. Wuerches Creek flows into the CKM before entering Big Green Lake.

Appendix H [44] of the Upper Fox-Wolf River TMDL report shows Wuerches Creek, sub-basin 18, needs a 59% total phosphorus reduction to meet local water quality standards.

vi. Watershed Characteristics: Wetlands

The Big Green Lake watershed has 5,102 acres of wetlands [46], including two major wetland complexes: The SCE on the eastern inlet and the CKM at the southwestern inlet. The SCE and CKM receive most of the lake's water input and large amounts of phosphorus and sediments [47] [48] [49]. In total, the SCE and CKM sub-watersheds represent 59% of the Big Green Lake watershed area, per the latest phosphorus budget calculations.

While these estuaries are comparable in wetland area (see Table 5 and Figure 27), they vary in terms of sub-watershed area, retention time and – most noticeably – water quality, as discussed in the following section.

Table 5. A comparison of the wetland and sub-watershed size and retention time [50] of the SCE and CKM.

Wetland	Wetland Area (acres)	Sub-Watershed Area (mi^2)	Retention Time (days)
Silver Creek Estuary	215	48	9.4 days
County Highway K Marsh	269	15	40.3 days

Figure 27. The CKM (west) and the SCE (east) are two major wetland systems that receive the majority of flow, nutrients and sediment into Big Green Lake. The CKM is an algae-dominated system with high carp populations, while the SCE system has abundant macrophytes and clear water.

In addition to the major wetland complexes, smaller wetlands are located throughout the Big Green Lake watershed. The phosphorus retention of these smaller wetlands in generally high to very high, with only a few isolated sections shown as potentially restorable (Figure 28 and Figure 29).

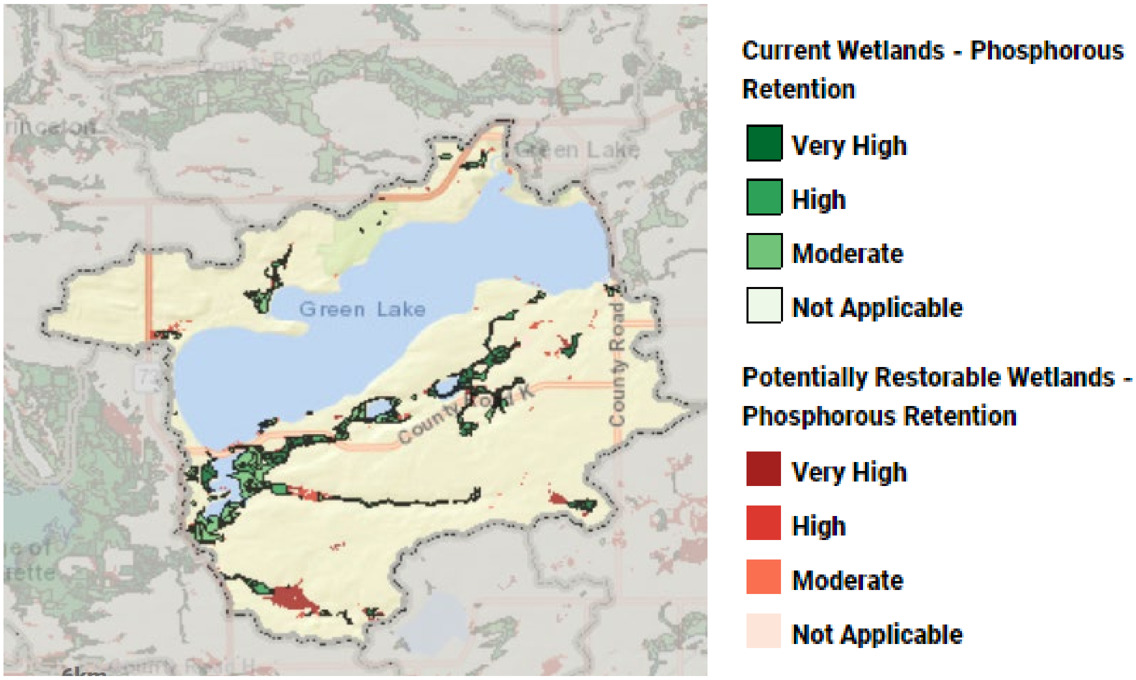

Figure 28. Wetlands and potentially restorable wetlands for the western sub-watersheds (excluding Dakin Creek and Silver Creek in the eastern watershed, shown in Figure 29) in Big Green Lake, including estimates of phosphorus retention for current and existing wetlands.

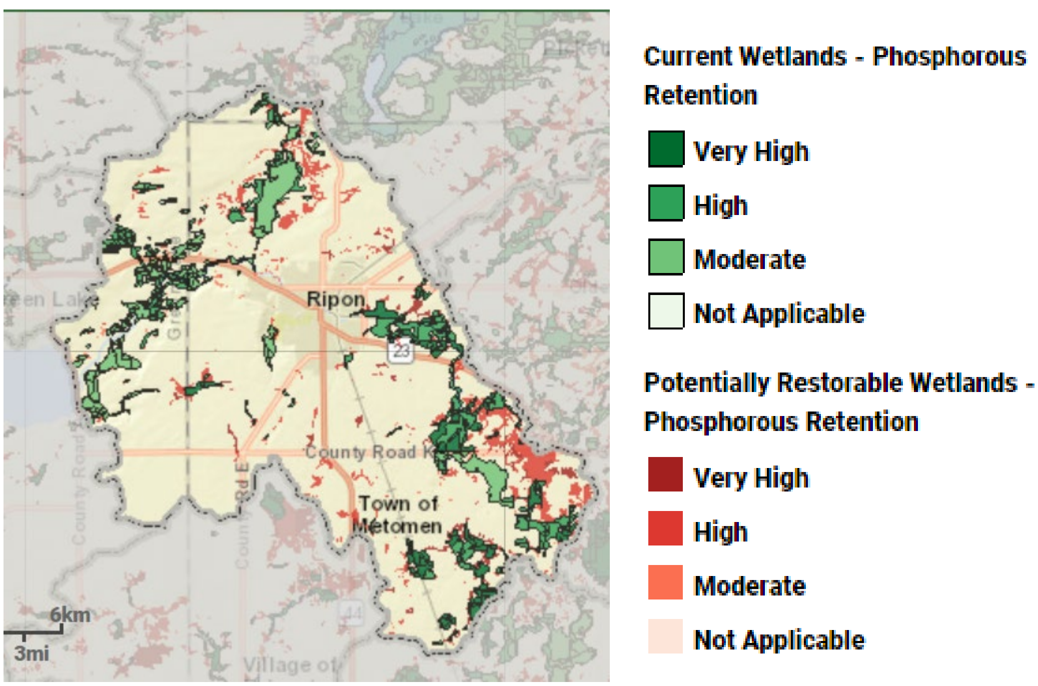

Figure 29. Wetlands and potentially restorable wetlands for the Dakin Creek and Silver Creek sub-watersheds in Big Green Lake, including estimates of phosphorus retention for current and existing wetlands.

a) Silver Creek Estuary

Photograph 1. An aerial view of the SCE shows relatively clear water (background) in comparison with Big Green Lake (foreground).

Photograph 2. An innovative carp bubble barrier installed by the GLSD on the SCE in 2006, and the previous physical structure installed in 2002, are largely credited for the restoration from an algae-dominated to a macrophyte-dominated system.

The SCE is a 215-acre estuary on the northeast side of Big Green Lake and is the confluence of Silver and Dakin Creeks; it enters the lake proper at the County Highway K bridge. The retention time of the SCE is 9.4 days and the SCE is generally less than 4 feet deep [50] [51]. The SCE sub-watershed is 48 square miles, representing 44% of the Big Green Lake watershed.

The SCE is currently inhabited with macrophytes and has relatively clear water [49], as shown in Photograph 1, though native duckweed grows to nuisance levels and at times hinders navigability.Before a concerted effort around 2002 to exclude carp from the SCE, the SCE was a turbid, algae-dominated system with no macrophytes, similar to conditions currently found in the CKM [17].

In the early 2000s, the GLSD designed and installed an innovative bubble barrier at the outlet of the SCE, on the County Highway A bridge (see Photograph 2). Prior to this effort, significant carp activity during the spring-summer spawning season prohibited beneficial aquatic plants from growing. Native aquatic plant communities were able to re-establish after the addition of the carp barrier that prevented the invasive species from moving from the lake to the vulnerable estuary. Around this same time, in 2003, the Ripon WWTF made substantial upgrades to its system.

According to Fuller [17]: “the SCE equilibrium has shifted to macrophyte dominance and supports prolific submergent, floating-leaf, and free-floating communities.”

A general summary of the successful restoration strategy on SCE follows [52]:

- 1987: USGS gage at County A bridge at the SCE outlet
- 1998: A survey shows turbid conditions and no macrophytes

- 2002: The GLSD and WDNR install a physical bubble barrier
- 2003: The Ripon WWTF makes plant upgrades
- 2004: The GLSD makes its first aquatic weed harvest
- 2006: The GLSD replaces the physical bubble barrier with a bubble barrier design. A survey shows macrophytes dominate the SCE.
- 2008: The bubble barrier is replaced after a major storm.
- 2012: The USGS gage is moved to the SCE inlet at Spaulding Hill Road
- 216-2017: The Nelson Institute for Environmental Studies measures nutrients within the SCE and CKM as part of an estuary comparison study.

The water quality conditions of the SCE are discussed in Section 6.C.

b) County Highway K Marsh

The CKM is a 269-acre marsh on the southwest side of Big Green Lake and is the confluence of Spring, Roy, and Wuerches Creeks; the CKM enters Green Lake proper at the County Highway K bridge. The retention time of the CKM is 40.3 days [50] and the system has an average depth of about 2 feet [53]. The CKM sub-watershed is 15 square miles, representing 14% of the Big Green Lake watershed.

The CKM is an algae-dominated system with turbid water and high carp density (See Photograph 3 through Photograph 6), though recent carp removal efforts have noticeably decreased the carp population [49] and additional restoration activities are underway. A plume of sediment from the CKM flowing into Big Green Lake under the County Highway K bridge is often visible.

While a physical carp barrier has been installed at the County Highway K bridge with a bubble barrier component added in 2016, carp densities remain high enough in this system that they are currently credited by the LMPT to be the primary cause of its degradation.

Beginning in 2013, the LMPT began a more concerted effort to restore the CKM (see Table 6**Error! Reference source not found.**). This primarily has included repairs and retrofits to a physical carp barrier (see Photograph 5), carp exclosures for macrophyte establishment from propagule plantings (see Photograph 6), and carp removal within the CKM (see Figure 30).

In the spring of 2020, the GLSD installed 2,300 feet of turbidity curtain in the CKM to create two isolated bays to reduce both wind and carp disturbance (see Figure 31). A third bay was created using 1,200 feet safety fence to isolate just carp disturbance. The CKM was then inoculated with a combination of sago pondweed, wild celery, wild rice, and arrowhead (see Figure 32).

In 2020, the WDNR Fisheries Department voiced support for replacing the carp barrier to ensure carp migration into the CKM is reduced to a minimum to support the restoration of the CKM.

Photograph 3. The color difference between the CKM (foreground) and Big Green Lake (background) demonstrates the significance turbidity of the degraded wetland system.

Photograph 4. The CKM (left) is a turbid-algae-dominated system that generates a visible sediment plume to Big Green Lake (right). The color difference demonstrates the significant turbidity of the degraded wetland system.

Photograph 5. Improvements to a carp barrier has been successful at preventing the migration of carp from Big Green Lake (right of barrier) to the SKM (left of barrier).

Photograph 6. Macrophyte establishment has not substantially expanded outside of the carp exclosures in the CKM, as shown with the sago pondweed (left side of exclosure) and waterlily (right side) in this exclosure.

Table 6. A summary of restoration activities in the CKM from 2013 through 2018 shows extensive efforts, though measurable restoration progress has been limited.

Year	Restoration Activity in CKM
2013	• **Spring 2013**. The WDNR installed three 8' x 8' carp exclosures with sides constructed of various materials (geotextile fabric, snow fence and no sides as control) and planting regimes (no plants for seedbank assessment, half planted, fully planted). Planted propagules only grew in areas where carp disruption was prevented. **2013 carp removal totals in CKM: 0 pounds**
2014	• **Spring 2014**. GLSD made repairs from damage due to overwintering carp exclosures. The GLSD added additional structures to total eight carp exclosures in the CKM. • **May 2014**. WDNR determined the current physical carp barrier allowed for lake-to-wetland migration of sexually mature carp. • **September 2014**. WDNR dove the carp barrier and discovered a large gap (8" high x 8' long)

Year	Restoration Activity in CKM
	directly under the dropdown gate. • **October 2014**. GLSD made repairs to physical carp barrier to prevent movement of sexually mature carp. Barrier was retrofit with 1-7/16" vertical bar spacing and added chain-link fencing underneath dropdown gate. **2014 carp removal totals in CKM: 85,000 pounds** *Via commercial fisherman*
2015	• **Spring 2015.** A commercial fisherman removed carp within CKM. • **June, July, and October 2015**. WDNR used a shocker boat to remove carp, with both DC and AC current, and fin clipped 258 carp. *Conclusion: Shocking was not effective with silt and water clarity in CKM. Carp dove into silt to avoid shocker boat*. • **July2015**. GLSD installed and maintained one WDNR fyke net to remove carp for 10 days. 138 carp (966 pounds) were removed. • **October 2015**. WDNR implanted 14 radio tags into 14 adult carp to study seasonal movements. *Conclusion: After monitoring until June 2017, WDNR determined that 12 of 14 carp (86%) moved out of lake during the winter. One two carp were routinely detected in CKM. These carp were successfully kept out of the CKM when tracked from 2015-2017.* • **November 2015**. WDNR/GLSD dove carp barrier for annual inspection. Found various minor gaps that GLSD repaired. • **December 2015**. Carp barrier was closed to prevent lakeside carp from entering CKM. **2015 carp removal totals in CKM: 3,120 pounds** *Via WDNR shocker boat + fyke nets*
2016	• **April 2016**. The GLSD added a bubble barrier component to the middle, drop-down section of the physical carp barrier. • **May– August 2016**. The GLSD installed and maintained a fyke net in the CKM. • **May 2016**. A commercial fisherman removed a total of 43,600 pounds of carp within CKM. • **May 27, 2016**. Spawning carp stacked up at such high densities that a large group beached the drop-down gate of the carp barrier (referred to as the "jailbreak" by the LMPT). Carp numbers in the fyke nets substantially increased afterwards. • **June 1, 2016**. The LMPT planted 12,500 native propagules inside and outside of carp exclosures (half sago pondweed, half wild celery). • **June 27, 2016**. The WDNR removed 85 carp via shocker boat. • **September 2016**. Carp barrier was opened to allow carp to return to lake. **2016 carp removal totals in CKM: 18,795 pounds** *Via WDNR shocker boat + fyke nets + commercial fisherman*
2017	• **February– June 2017**. GLSD closed and locked carp barrier. • **May 2017**. A commercial fisherman removed a total of 39,500 pounds of carp within CKM. The WDNR used a shocker boat to remove 110 mature carp. • **May 17, 2017**. The LMPT planted 20,000 propagules, approximately half sago pondweed and half wild celery. • **May – July 2017**. GLSD and GLA operated three fyke nets in CKM. Removed 720 mature carp and 240 immature carp, totaling 4,125 pounds. **2017 carp removal totals in CKM: 44,395 pounds**

Year	Restoration Activity in CKM
	Via WDNR shocker boat + fyke nets + commercial fisherman
2018	• **February—June 2018.** GLSD closed and locked carp barrier. • **May 2018**. The LMPT planted 20,000 propagules inside and outside of carp exclosures, all sago pondweed. • **May – July 2018**. GLSD and GLA operated four fyke nets in CKM. Removed a total of 1,988 pounds (148 mature carp and 136 immature carp). • **Summer 2018**. GLA measures the extents of eastern cattail perimeter to document cattail loss. The GLSD and USGS add cameras to gage station at bridge for real-time evaluation of carp activity at bridge and seasonal documentation of vegetation changes. **2018 carp removal totals in CKM: 79,988 pounds** *Via fyke nets + commercial fisherman*
2019	• **May 2019.** Commercial fishermen pulled carp from marsh and lake. Noted that the carp were noticeably smaller than what was taken from the lake. Commercial fishermen reported that the carp removal strategy is working well given the shift in the size and numbers of carp he's seeing there. **2019 carp removal totals in CKM: 2,500 pounds** *Via commercial fisherman*
2020	• **May 2019**. GLSD uses various material to create three isolated bays in the CKM. Two bays on the northeast and northwest shore of the CKM created from 2,300 feet of floating turbidity curtain. One bay on the southwest shore created from safety fence.

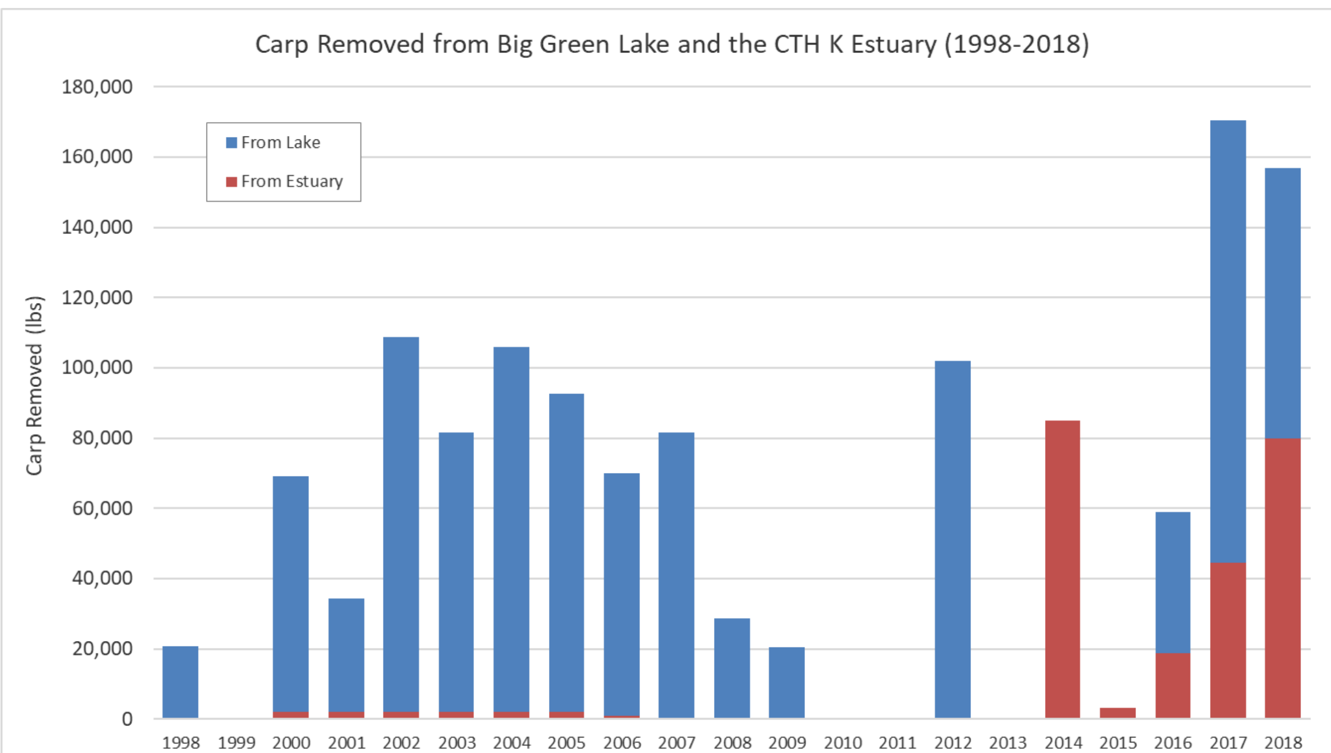

Figure 30. The LMPT removed carp within the CKM in an attempt to accelerate its restoration.

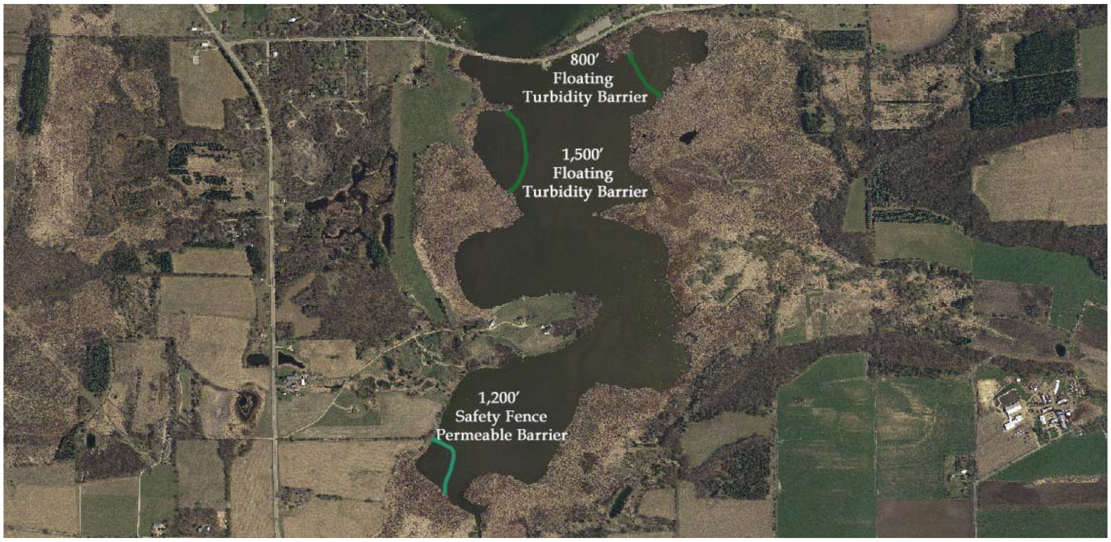

Figure 31. In May 2020, the GLSD used turbidity curtain and safety fence (as documented) to create three bays to isolate carp and/or wind disturbance to better understand the response of future potential restoration activities.

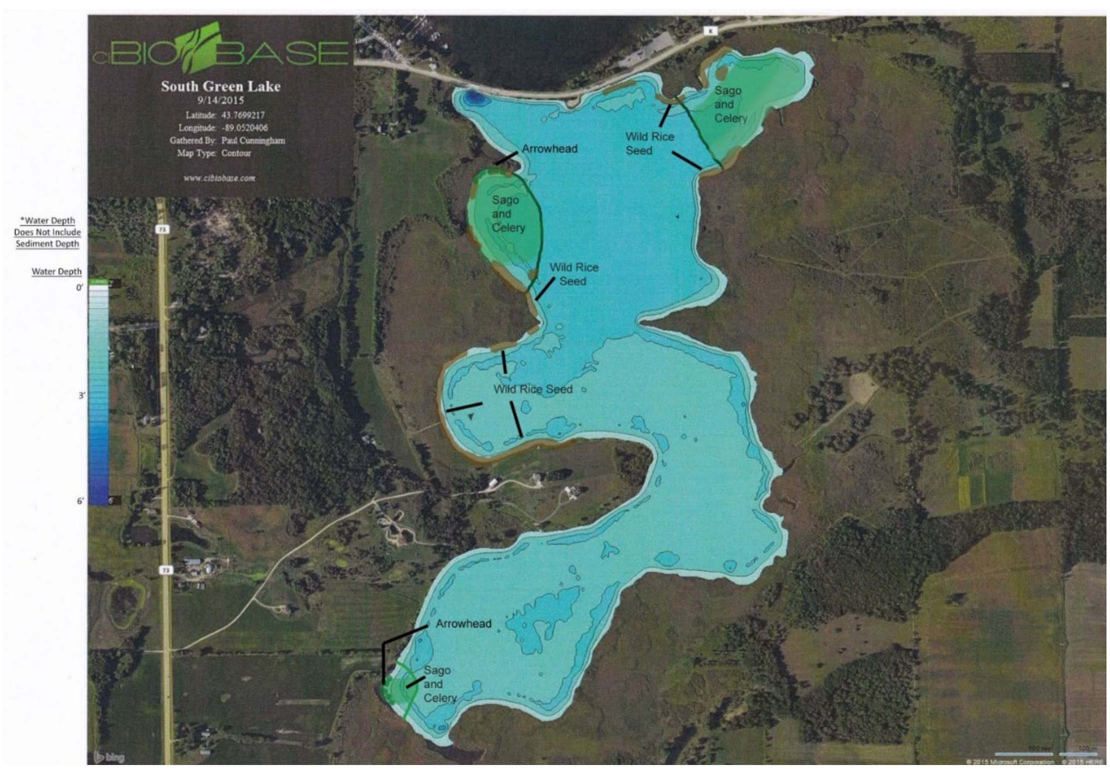

Figure 32. The three bays and other areas throughout the CKM were inoculated with various native macrophtye species.

Even given the restoration efforts outlined in Table 6, measurable restoration success in the CKM has been limited. The LMPT has documented the establishment of macrophytes within the carp exclosures, but expansion outside of the exclosures has been limited to waterlilies (known to be more tolerant to turbid conditions). Potential factors contributing to the degradation of the CKM include:

1. Carp activity, which re-suspends nutrients and prevents the establishment of macrophytes,
2. Nutrient inputs from degraded contributing watersheds and/or streams from the Roy, Wuerches and/or Spring Creek sub-watersheds,
3. Internal loading from within the CKM,
4. Disruptive forces of wind/wave energy, and/or
5. Permanent flooding from artificially elevated water levels from the Big Green Lake dam.

To date, there has been no study to determine the contributing factors and potential solutions for the restoration of this key inlet wetland system. The LMPT intends to pursue resources to undertake a comprehensive diagnostic and feasibility study. The impact of internal loading from the CKM's sediments is also unknown. Therefore, future efforts and funding to test pilot projects and other potential technological solutions to capture, treat, and/or remove phosphorus from the CKM and its sediments is critical.

In the meantime, while the feasibility of more intensive in-lake strategies within the CKM are studied, stream restoration along with best management practice implementation within the CKM sub-watershed should be a priority for the LMPT.

The water quality conditions of the CKM are discussed in Section 6.C.

D. Climatic Characteristics

According to Stephanie Herring, a climate scientist with the National Oceanic and Atmospheric Administration (NOAA), the climate has always been changing, "but for various reasons, the current change that we're experiencing now is particularly alarming, and that is because in the history of human civilization, the climate has never changed this rapidly" [54].

When Big Green Lake was formed approximately 10,000 years ago, this was around the time that human civilization began and global temperatures were very consistent [54]. Temperatures begin to rise towards the end of the 17th century, and then start to rise quickly around the Industrial Revolution [54]. According to Herring, in just 100 years, global temperatures transition from "some of the coldest temperatures that human civilization has experiences to some of the hottest" [54] because of changes in greenhouse gas emissions. Modern technology can fingerprint these greenhouse emissions and has confirmed the increase is "because of human activity" [54].

This changing climate has included changes in Wisconsin. Between 1950 to 2005, Wisconsin became wetter with a 10% increase in annual precipitation (3.1 inches) [55]. The increased precipitation occurred primarily in summer and autumn, according to the Wisconsin Initiative on Climate Change Impacts, "Wisconsin's climate is changing" [55]. This extensive report predicts "rising air temperatures [during winter and spring], shifting precipitation patterns and increases in heavy rain events."

Intense precipitation events may see a 25% increase in frequency combined with drought in the summer.

In the future, seasonal temperature increases and shifting precipitation patterns will put additional pressure on Big Green Lake and Wisconsin's other water resources. These climate changes may affect the quality of Wisconsin's water resources, including:

- More frequent algae blooms,
- Increased surface water temperatures,
- Shorter periods of ice cover,
- Lower dissolved oxygen levels,
- Decreased ice thickness,
- Increased number of freeze-thaw events,
- Increased number of high-water events causing flooding, and
- Increased sediment and nutrient loading.

While Big Green Lake may have seen some of these changes already, a changing climate will continue to put pressure on the lake's water quality. In particular, increased nutrient and sediment loading runoff events reinforce the need to prevent or control runoff from upland areas to improve degraded streams by reducing rapid flooding and nutrient retention. This may mean that additional conservation practices to those described in this Plan will need to be installed just to keep the pace with climate change.

Therefore, some best management practices described in this plan may be inadequate to meet this Plan's pollutant reduction goals. Research into the potential impact of climate change may be useful in designing future best management practices and other lake/watershed management measures.

i. Local Precipitation

According to the 2020 Upper Fox-Wolf TMDL report [2], the Big Green Lake watershed straddles two ecological landscapes: The Central Sands and the Southeast Glacial Plains.

> *"The Central Sand Hills has a mean growing season of 144 days, mean annual temperature of 44.8°F, mean annual precipitation of 33 inches, and mean annual snowfall of 44 inches. Although the climate is suitable for agricultural row crops, small grains, and pastures, the sandy soils somewhat limit agricultural potential."*
>
> *The Southeast Glacial Plains' "climate is typical of southern Wisconsin; mean growing season is 155 days, mean annual temperature is 45.9°F, mean annual precipitation is 33.6 inches, and mean annual snowfall is 39.4 inches. The climate is suitable for agricultural row crops, small grains, and pastures, which are prevalent in this ecological landscape."*

Historic precipitation from a gauge (Station 47-7209) in Ripon, Wisconsin indicates that the region may be experiencing more frequent, more intense runoff events (See Figure 33). These larger rain events can carry more soil erosive force, particularly during vulnerable spring conditions, and can contribute to increased legacy phosphorus loading from the watershed. The impact of the seasonality and intensity of these storms on downstream water quality is under-studied and requires further study.

Figure 33 is based on a rain gauge outside of the watershed. Baumgart noted in his 2015 SWAT model report a "lack of an appropriately placed rain gauge network" and suggested future modeling work would benefit from "a reliable station or set of stations within, or more near the drainage area upstream of the monitoring gauges." [48]

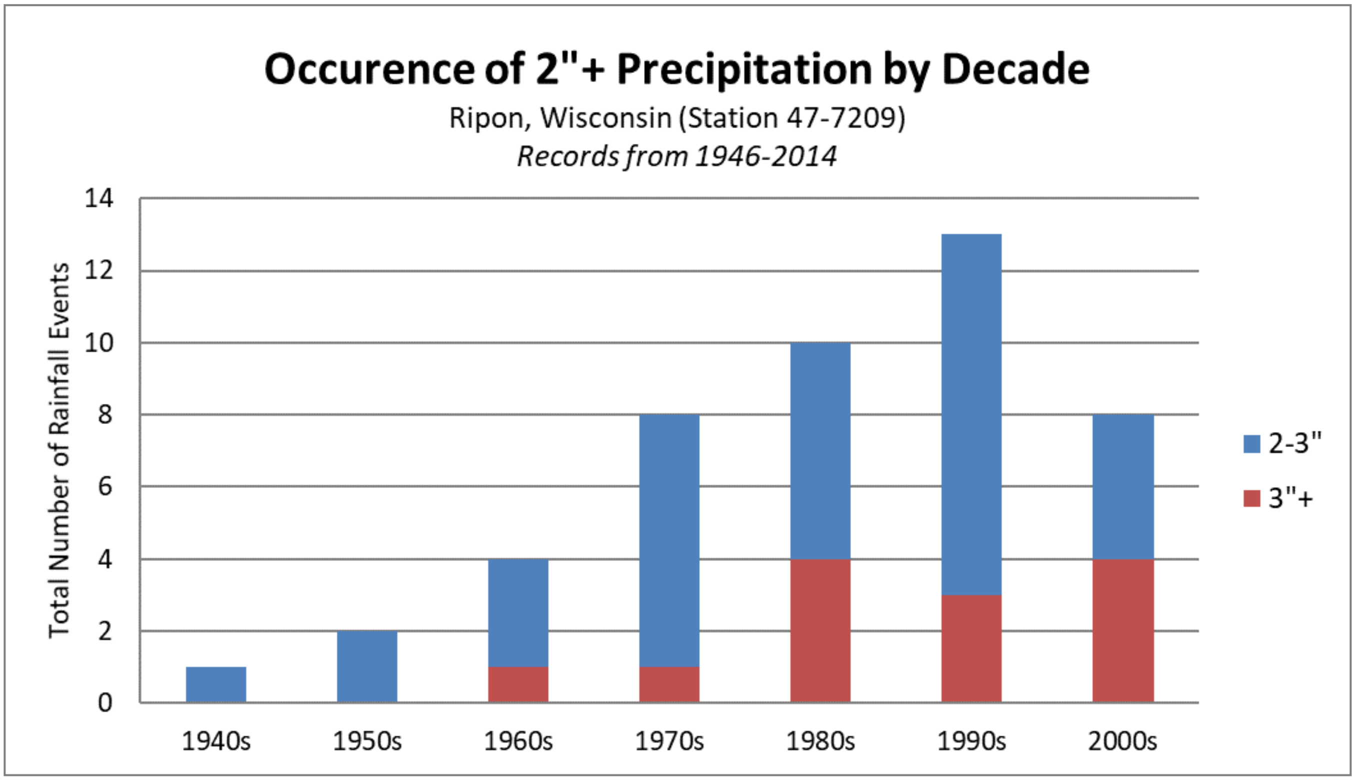

Figure 33. An analysis of precipitation at Ripon, Wisconsin indicates that the Big Green Lake watershed may be experiencing larger rain events more frequently, which can increase phosphorus loading and lead to increased lake eutrophication.

ii. Freeze-Thaw Dates

Big Green Lake's freeze and thaw dates have been monitored annually from 1939-present. These freeze and thaw dates are presently documented by J. Norton and the GLSD.

It is critical to establish consistent definitions of lake freezing and thawing, particularly for long-term datasets. In Green Lake:

- Ice-on: Complete ice cover from Sandstone to Robin Hood; not a completely frozen lake.
- Ice-off: Ability to take a boat from the east end of Green Lake to the west end. Ice chunks are okay.

J. Norton has used these consistent definitions since monitoring began; the GLSD changed from the original ice-on definition above to using the guideline of a completely frozen lake around 2000.

Based on the J. Norton data, the number of days that Big Green Lake remains frozen has decreased since 1939, changing from an average of 98 days in 1939 to 67 days in 2018 (See Figure 34 and Figure 35), or 31 fewer days of ice cover annually.

In addition to fewer days frozen each year, freeze/thaw records indicate that Big Green Lake may be freezing later each year, averaging December 23 for all data (1939-2018) and January 19 in the last five years (2014-2019).

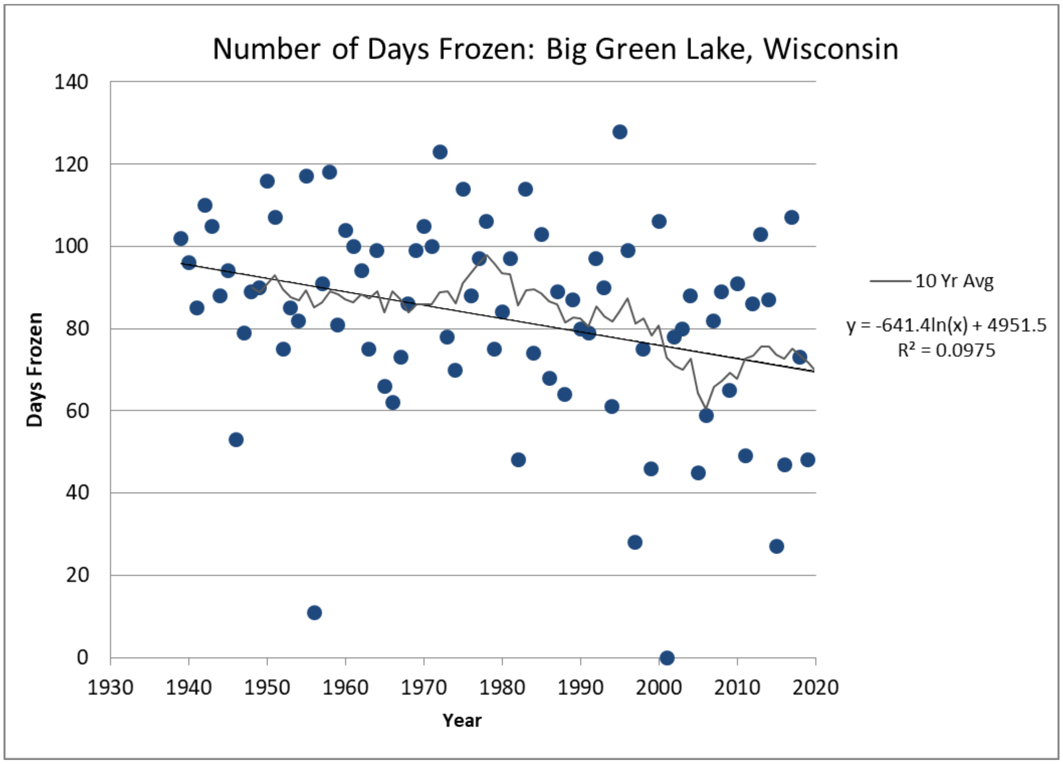

Figure 34. Freeze/thaw data collected annually since 1939 indicates that Big Green Lake is frozen fewer days each year.

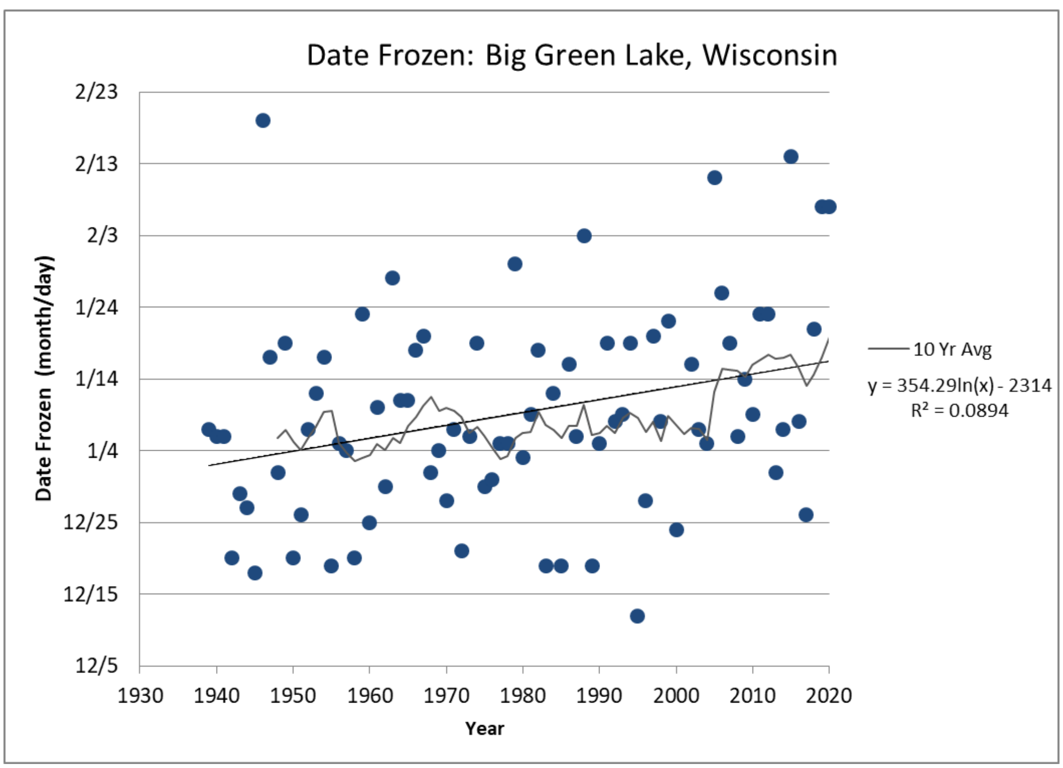

Figure 35. Freeze/thaw data collected annually since 1939 indicates that Green Lake is freezing later each year.

E. Impact of Big Green Lake Dam

i. History of Big Green Lake Dam

Anson and Richard Dart build a dam in 1845 at the outlet of Big Green Lake on the Puchyan River to power the village of Dartford's sawmill, located in present-day downtown Big Green Lake. Victor and Jessie Lawson later rebuilt the dam in 1900. The dam artificially maintains the water level about five feet higher than the lake's natural level.

The WDNR has the power and responsibility under Sec. 31.02 of the Wisconsin Statutes to regulate and control the level and flow of water in all navigable waters, including the Big Green Lake dam. The WDNR has issued an order requiring the City of Green Lake to operate the dam so that:

- The lake level shall not exceed elevation 796.49 between spring break-up and September 30, and
- Starting September 30, the level shall be lowered slowly to 795.74 by October 31 and maintained at that level until spring break-up.

Sec. 31.34 of the Wisconsin Statutes requires that the City of Green Lake shall, at all times, maintain 25% of the natural flow to the Puchyan River. The minimum flow is 7.2 cubic feet per second to maintain public access in downstream areas, though the minimum flow was not reached in 2017 and it has been several years since the City of Green Lake has had to measure and control the dam discharge to 7.2 cubic feet per second.

Photograph 7. The dam in downtown Green Lake artificially raises Big Green Lake's water level by 5 feet. Wisconsin Statues regulate the timing and elevation of its operation.

ii. Ecological Impacts of the Big Green Lake Dam

While the dam assists with recreation and lake access, ecologists recognize dams to be detrimental to a lake's natural functions. In particular, the Big Green Lake dam hinders the ecology function of two major wetland complexes—the SCE on the east side of the lake and the CKM at the southwest corner (sometimes referred to as the "Southwest Inlet") of the lake.

These wetlands had a fluctuating hydroperiod prior to the dam's installation. The dam artificially raises the water elevation by approximately five feet within the shallow wetlands so that the systems are now permanently flooded (see Figure 36). As a result, the dam likely diminishes the ability of these ecosystems to function as nutrient-absorbing wetlands that support improved water quality downstream in Big Green Lake. While wetland treatment is not consistent or predictable, artificially and permanently flooded wetlands have been shown to have less stable soils, less plant diversity, lower critical shear stress of its substrate, more organic matter, and contribute to more nutrient loading to downstream water resources when compared to wetlands with fluctuating hydroperiods (times with wet conditions and times with dry conditions) [56].

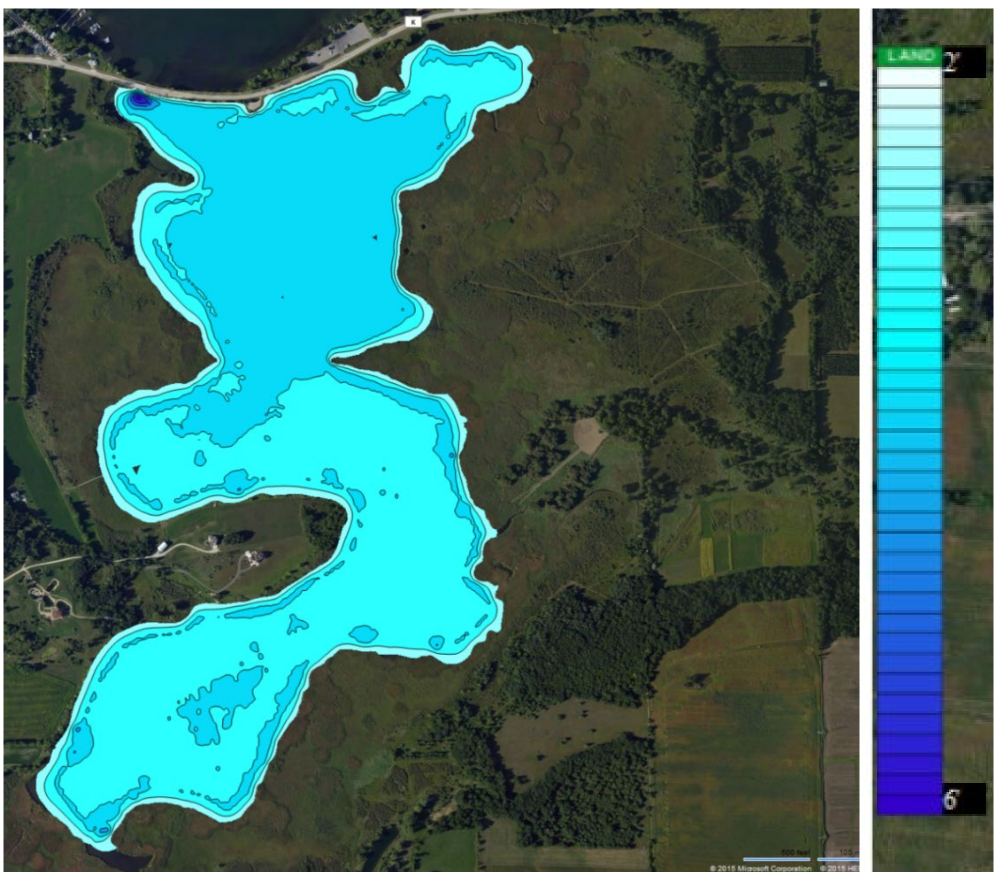

Figure 36. A bathymetric map of the CKM reveals water depths that range from approximately 2 to 4 feet, with an isolated section of 6 feet near the County Highway K bridge. This map suggests that, prior to the installation of the Big Green Lake dam that artificially raises the lake level by 5 feet, this wetland system would only be temporarily wet during rain events.

The wetland's artificially wet hydroperiod limits its viability as a healthy system that supports downstream water quality for Big Green Lake. Map by Paul Cunningham of the WDNR.

One indicator of the chronic implications of elevated water levels from the Big Green Lake dam is the retreat of cattails in the CKM. Historic photographs indicate that, prior to 1845, the CKM contained a meandering river with a cattail-dominated floodplain. A 2018 aerial photograph assessment conducted by the GLA suggests that, between 1992 and 2017 alone, cattail recession throughout the CKM to its perimeter averaged 43 feet. In some isolated areas, cattail recession during this period was over 125 feet.

While cattail growth abates shoreline erosion, substantial loss of cattail acreage may suggest that other aquatic plants more tolerant of wet conditions are now more suitable for these altered habitat conditions. It is unknown whether this aquatic plant transition could generate more phosphorus loading to the lake; more study of the phosphorus dynamics—from the entire CKM system, including the plants and its sediments—is needed.

4. BIOLOGICAL CHARACTERIZATION OF BIG GREEN LAKE: PLANT AND ANIMAL SPECIES

A. Fishery

Taken from the Green Lake County Land and Water Resource Management Plan [57], "Big Green [was] an oligotrophic lake [currently] managed for both cold- and warm-water fish. Cold-water species include brown and rainbow trout, splake, cisco, and lake trout. Most common warm water species are northern pike, walleye, perch, largemouth and smallmouth bass, bluegill, black crappie, rock bass, white bass, channel catfish, and black bullhead. Pumpkinseed, carp, and white sucker are also present. The lake is well known for the excellent summer and winter fishing it offers."

Cold- and warm-water species are often described in terms of whether they are pelagic/open water versus littoral. The littoral zone is defined as the near shore area where sunlight penetrates all the way to the sediment and allows aquatic plants to grow. This depth in Big Green Lake is approximately 20 feet deep. Big Green Lake's surface area greater than 20 feet depth is 4,675 acres (see Figure 5), representing a littoral zone of 61% and a pelagic zone of 39%.

In terms of its native fish, the WDNR has conducted a Cisco gill net survey from 2016-2017, which concluded that Big Green Lake has a healthy Cisco fishery with some of the highest densities in Wisconsin [58].

The WDNR also maintains several stocked fished species in Big Green Lake. Records beginning in 1972 indicated the following stocked fish species and average annual stocking totals on Big Green Lake from 1972-2017:

- Brown trout (1972-2014): 13,710
- Lake trout (1972-2017): 21,730
- Muskellunge (1988-2017): 1,795
- Northern pike (1989-2010): 16,710
- Northern pike x muskellunge (1988-2002): 2,015
- Rainbow trout (1972-2017): 16,562
- Splake (1986): 10,000
- Walleye (1999-2017): 4,038,610

B. Invasive Species

Big Green Lake is a fishing destination, making it more prone to increased boat traffic. Improperly cleaned boat and boating gear on a higher-traffic lake increases the probability that Big Green Lake will be infected with new invasive species and/or infect other lakes with its existing invasive species.

Aquatic invasive species (AIS) have the potential to disrupt native species and water conditions in Wisconsin lakes. A single species has the potential to change water clarity, change spawning success, increase nuisance conditions, stimulate algae blooms, decrease aesthetics, and hurt economics connected to Big Green Lake and tourism. For example, zebra mussels were discovered on Big Green Lake in the early 2000s and have already concentrated nutrient and weed growth on shore, spurred the exacerbation of filamentous algae and increased water clarity.

The LMPT is gravely aware that there are invasive species that Big Green Lake does not yet have. Lake Mendota, for example, is driving distance from Big Green Lake and has spiny water fleas at the highest documented concentrations in the world. Decontamination decreases the probability of new invasive species infecting the lake, which disrupt food web dynamics and permanently alter its natural ecology.

Given these risks, the LMPT is currently pursuing the installation of boat washing stations at public boat launches to wash boats with pressurized water before entering Big Green Lake. A 2010 study [59] determined that high-pressure washing of macrophytes had a 83% ± 4% removal rate and high-pressure washing of small-bodied organisms had a 91% ± 2% removal rate. Low-pressure washing of macrophytes and small-bodies organisms only had a 62% ± 3% and 74% ± 6% removal rate, respectively. Currently, hand-removal of invasive species is the only method of prevention, though this is not monitored consistently.

In addition, Green Lake would benefit from enhanced signage at public boat launches and a strong presence of annual Clean Boats Clean Waters inspectors at all of its boat launches to reduce the chance of a new invasive species being introduced into Big Green Lake and permanently altering its natural ecology.

The following is a summary of the invasive plant, fish, invertebrate and wetland plant species currently found in Big Green Lake and its watershed.

Photograph 8. Invasive zebra mussels collect on a pair of sunglasses pulled from the bottom of Big Green Lake. Photo provided by Phil Burkart.

i. Invasive Aquatic Plants

The following invasive plants have been verified on Big Green Lake and/or lakes in its watershed as of 2018:

- **Curly-Leaf Pondweed** (*Potamogeton crispus*): Discovered in Big Green Lake in 1971. This AIS has been verified and vouchered.
- **Eurasian Water-Milfoil** (*Myriophyllum spiactum*): Discovered on Big Green Lake on June 30, 1969. This species has been verified and vouchered.
- **Hybrid Water-Milfoil** (Eurasian x Northern): Discovered on October 7, 2010. This species has been verified but not vouchered.

The following invasive plants have <u>not</u> been verified on Big Green Lake and/or lakes in its watershed as of 2018: Brittle Waternymph (*Najas minor*), Java Water Dropwort (*Oenanthe javanica*), Starry Stonewort (*Nitellopsis obtusa*), Water Hyacinth (*Eichhornia crassipes/azurea*), Water Lettuce (*Pistia stratiotes*) and Yellow Floating Heart (*Nymphoides peltata*).

ii. Invasive Fish

The following invasive fish have been verified on Big Green Lake and/or lakes in its watershed:

- **Common Carp**: Big Green Lake has a long-documented history of carp, which were intentionally stocked in Big Green Lake and other Wisconsin Lakes in the late 1800s. From a 2011 *Lake Tides* newsletter [60]: "The U.S. Commission of Fish and Fisheries began an intensive carp cultivation effort in 1877… By 1894, as many as 35,000 rough fish were being stocked in Wisconsin waters each year." See Section 5.B.x for data on a commercial fishing operation by the LMPT to protect the CKM.

The following invasive fish have <u>not</u> been verified on Big Green Lake and/or lakes in its watershed as of 2018: Alewife (*Alosa pseudoharengus*), Rainbow Smelt (*Osmerus mordax*) and Round Goby (*Neogobius melanostomus*).

iii. Invasive Invertebrates

The following invasive invertebrates have been verified on Big Green Lake and/or surface waters in its watershed:

- **Chinese Mystery Snail** (*Cipangopaludina chinensis*): Not verified on Big Green Lake, but verified (but not vouchered) on the Twin Lakes in June 2011.
- **Rusty Crayfish** (*Orconectes rusticus*): Discovered on Silver Creek within the Big Green Lake watershed in 2005. This species is verified but not vouchered.
- **Freshwater Jellyfish** (*Craspedacusta sowerbyi*): Found on Big Green Lake, discovery date unknown.
- **Zebra Mussel** *(Dreissena polymorpha*): The WDNR and GLSD found on Big Green Lake in 2000 (reported as 2005 in some sources). This species has been verified but not vouchered.

The following invasive invertebrates have <u>not</u> been verified on Big Green Lake and/or surface waters in its watershed as of 2018: Asiatic Clam (*Corbicula fluminea*), Banded Mystery Snail (*Viviparus georgianus*), Faucet Snail (*Bithynia tentaculata*), Japanese Mystery Snail *(Cipangopaludina japonica*), New Zealand

Mudsnail (*Potamopyrgus antipodarum*), Red Swamp Crayfish (*Procambarus clarkii*) and Spiny Waterflea (*Bythotrephes cederstroemi*).

iv. Invasive Wetland Plants

The following invasive wetland plants have been verified on Big Green Lake and/or surface waters in its watershed:

- **Purple Loosestrife**: Found on the CKM within Big Green Lake in 2005. This species has been verified and vouchered. The LMPT operates a successful purple loosestrife beetle program to control this invasive species.
- **Reed Canary Grass**: Found throughout the watershed's wetlands.

C. Aquatic Plants

Long-term nutrient loading and its resultant eutrophication of the lake may have stimulated changes to the lake's aquatic plant community. Increased nutrient concentrations stimulate algae growth, which in term reduces light penetration in the littoral zone, as indicated by aquatic plant survey data gathered by Rickett et al. since 1921 [61]. Maximum depths of plant colonization have decreased, indicating water clarity losses over the last century, as demonstrated by M.J Bumby, C. Marks, and the WDNR [62].

Zebra mussels have also had negative consequences for the lake's water quality. Scientific studies have shown a connection between the introduction of zebra mussel and the exacerbation of filamentous algae growth [63], and Big Green Lake is no exception. Regularly occurring filamentous algae growth has been documented on Big Green Lake since the 2000s after zebra mussels were verified on the lake.

Furthermore, zebra mussels have increased invasive weed growth on the perimeter of the lake. Zebra mussel excrement creates a nutrient-concentrated ring in the lake's shallow waters, which serves as nutrients for plant growth.

The GLSD currently holds the aquatic plant management permit on Green Lake. An aquatic plant management plan will be provided to the WDNR separate from this Plan.

i. Native Duckweed

In addition to invasive species growth, a growing contingency of Green Lake shoreline owners—within the SCE, on Green Lake's east end, and throughout Green Lake—have expressed concern over the growing prevalence of duckweed in the SCE and lake. There are areas of the SCE and times of year when the water's surface is 100% covered in duckweed (see Photograph 9 through Photograph 12). Duckweed is produced and concentrated in the SCE and is pushed into the lake proper after wind or rain events. While the duckweed is generally dissipated in the lake after some time, it does concentrate heavily on Green Lake's eastern shore.

At times, the duckweed is concentrated thick enough to impede navigation; there are reports of sailing classes on Green Lake's east shore having to be canceled because of impossible navigation through the duckweed. While duckweed extents are not measured, there is consensus that it has worsened in recent years, with the initial increase since the early 2000s.

Duckweed originates in the SCE and any potential management is dependent on the following factors:

- Duckweed is a native plant, so the WDNR limits to how it can or cannot be managed. Any management needs to occur in collaboration with the WDNR.
- The GLSD has a permit to mechanically remove aquatic plants from Green Lake. All manual and mechanical removal of aquatic plants in Wisconsin is regulated by Chapter NR 109 [64]. NR 109 specifies that:
    - Aquatic plant management is for navigational purposes only, not aesthetics.
    - NR 109.01(1): "The department may designate any aquatic plant as an invasive aquatic plant for a water body or a group of water bodies if it has the ability to cause significant adverse change to desirable aquatic habitat, to significantly displace desirable aquatic vegetation, or to reduce the yield of products produced by aquaculture."
    - NR 109.06(2)(a): "Removal of native plants is limited to a single area with a maximum width of no more than 30 feet measured along the shoreline provided that any piers, boatlifts, swimrafts and other recreational and water use devices are located within that 30-foot wide zone and may not be in a new area or additional to an area where plants are controlled by another method."
- The GLSD's current permit with the WDNR specifies:
    - In the SCE, where duckweed is concentrated, the GLSD is permitted to cut one navigational path down the center with "spokes" to individual piers.
    - The GLSD is not permitted to remove aquatic plants *en masse* from the lake or its wetlands. This includes not permitting the mass removal of duckweed by skimming the surface.
- The GLSD's current weed harvester is not effective as it could be at removing duckweed. The GLSD can potentially modify the harvester to be more effective at picking up duckweed, but any removal under the current permit would be limited to harvest areas outlined above.
- Duckweed is a native plant, so it cannot be chemically treated. Only invasive plants can be chemically treated, and only after getting a WDNR permit, per NR 107 [65].

Presently, the GLSD has not been given permission from the WDNR to remove duckweed from the SCE and/or Green Lake outside of its usual navigation paths specified in its aquatic plant permit. Per the WDNR, duckweed cannot be harvested en masse or chemically treated.

Communication from the WDNR (T. Johnson, Sept 4, 2020) clarified the WDNR's position:

- "The Department would not be willing to change the designation of duckweed to invasive as we feel that it does not meet the minimum requirements in code. Please keep in mind that it is a native plant that is very prolific and does well in shallow water systems (lakes and marshes) throughout the watershed."
- "We might allow management within existing harvesting lanes or in a manner that does not impact water quality and/or native aquatic plants. As we discussed, I don't see herbicides being a viable management option."
- "At this point, we would like to see a well thought out proposal that has sufficient detail for the Department to make informed permitting decisions. Depending on what you propose to do, it may be necessary to involve other programs to evaluate whether or not a permit would be needed or issued."

Photograph 9. Duckweed is a native floating plant that grows at nuisance levels in some areas of Big Green Lake, such as the SCE, shown here. While Big Green Lake is not its ideal habitat, more intense, more frequent rain events are making this more common.

Photograph 10. There are locations and times throughout the year where the SCE has 100% coverage of duckweed.

Photograph 11.During large rain events, large groupings of duckweed get pushed into the lake proper from the SCE.

Photograph 12. Duckweed accumulates on Green Lake's eastern shore. Shown here, a rake the water on Green Lake's east end demonstrates the thick accumulation on the lake.

Beginning in 2020, a Duckweed Mitigation Task Force has met frequently to develop a duckweed mitigation strategy that meets the parameters outlined above. After extensive cross-industry research, the Task Force recommends a multi-prong approach to mitigate duckweed:

1. Install wingwalls off the County Highway A bridge to capture daily duckweed flows and to create duckweed removal zones,

2. Install an automated duckweed removal system within the existing harvesting lane under the County Highway A bridge, and
3. Utilize paddle aerators and other devices within the SCE and other duckweed concentration zones to create surface turbulence to prevent the accumulation of duckweed.

These recommendations will require proof-of-concept validation and will be part of a future formal presentation to the WDNR to ensure the strategy in in compliance with current permits and codes.

5. QUALITATIVE CHARACTERIZATION OF BIG GREEN LAKE AND ITS WATERSHED

Big Green Lake has an extensive history of water quality monitoring, including research conducted by Marsh (1891-1897), Birge and Juday (1911-1914, See [66]), Hutchinson (1975), Stauffer (1985), the WDNR's long-term trend monitoring (1986-2001), Water Action Volunteers and citizen scientists (1981-present) and the USGS (1981-present).

A listing of Big Green Lake-related publications is on the Nelson Institute for Environmental Studies' "Big Green Lake Watershed Information System" website [16].

Several factors may have led to the degradation of Big Green Lake's water quality. While lakes naturally age, anthropogenic impacts accelerate this lake aging process from centuries to decades. The developed watershed and its developed shoreline have undoubtedly left a lasting mark on the lake, including agricultural land use in the watershed (see Figure 12).

In addition, precipitation patterns have changed, with an increase in the frequency of large rain events (see 3.D.i). These modifications to the watershed have resulted in increased phosphorus loading to the lake, which may have caused increased hypoxic conditions in both the metalimnion and hypolimnion of the lake.

These extensive datasets offer quantitative validation that, over the long-term, Big Green Lake's water quality is degrading. Specifically, Big Green Lake and nine other water bodies are listed as impaired by the WDNR, as summarized in Table 7.

Photograph 13. Dr. Edward Asahel Birge reading an anemometer at the weather station on Big Green Lake, Wisconsin, in 1912. Birge was recognized as one of the pioneers of the study of limnology.

Table 7. Including the lake itself, there are ten water bodies within the Big Green watershed that are 303(d) listed for various pollutants.

Waterbody Name	Water Type	Date Listed	Pollutant	Impairment Indicator
Big Green Lake	Lake	4/1/2014 4/1/2002	Total Phosphorus PCBs	Low Dissolved Oxygen Contaminated Fish Tissue
Roy Creek	River	4/1/2014 4/1/2002	Total Phosphorus Sediment / Total Suspended Solids	Degraded Biological Community Degraded Habitat
Wuerches Creek	River	4/1/2008 4/1/1998	Total Phosphorus Sediment / Total Suspended Solids	Low Dissolved Oxygen, Elevated Water Temperature Degraded Habitat
Big Twin Lake	Lake	4/1/2014	Total Phosphorus	Excessive Algal Growth
Hill Creek	River	4/1/2016 4/1/2002	Total Phosphorus Sediment / Total Suspended Solids	Degraded Biological Community Degraded Habitat
Silver Creek Mouth	Lake	4/1/2012	E.coli	Recreational Restrictions – Pathogens
Silver Creek	River	4/1/2018 4/1/1998	Total Phosphorus Sediment / Total Suspended Solids	Impairment Unknown Elevated Water Temperature, Degraded Habitat
Unnamed Trib to Silver Creek	River	4/1/2017	Total Phosphorus	Degraded Biological Community
North Trib to Silver Creek	River	4/1/2016	Total Phosphorus	Impairment Unknown
Unnamed Trib to Silver Creek	River	4/1/2016	Total Phosphorus	Impairment Unknown

To fully illustrate the current quality of the Big Green Lake watershed and the challenges it faces now and into the future, the next two sections present detailed discussions of the pollutant loading originating from the land in the watershed and the measured impacts on surface water within the watershed.

A. Qualitative Characterization of the Land

The various land uses within the Big Green Lake watershed have contributed to adverse impacts on stream, wetland, and lake water quality. Over 65% of the land use in the watershed is agricultural and much of the Big Green Lake shoreline has been developed for several decades. Legacy phosphorus in the soil and sediments—coupled with more frequent, heavy precipitation and physically impaired streams—contribute to pollutant loading to Big Green Lake.

The information regarding various studies and modelling efforts presented in this section supports the 9 Key Elements discussions: “Causes and Sources” in Chapter F and “Non-point Source Management Measures” in Chapter 7.

i. Pollutant Loading: Big Green Lake SWAT Models, 2000 and 2015

Big Green Lake watershed managers used the Soil and Water Assessment Tool (SWAT) in 2000 and 2015 to estimate phosphorus and total suspended solids (TSS) loading from the watershed. Paul Baumgart from UW-Green Bay developed both SWAT models. SWAT is a hydrology model with the following components: weather, surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond and reservoir storage, crop growth and irrigation, groundwater flow, reach routing, nutrient loading, pesticide loading and water transfer. [67]

The 2000 SWAT model estimated average annual loads of phosphorus and TSS to Big Green Lake and its watershed from 1987-1998, totaling 33,820 pounds of phosphorus loading annually (see Table 8). The report compared the predicted annual loads to observed amounts, using the model to estimate potential reductions in phosphorus and TSS under alternative management scenarios. The 2000 SWAT model used inputs of land cover, land use, tillage practices, nutrient management, climate, and stream characteristics from 1987-1998. The Wuerches Creek sub-watershed had high yields for TSS and phosphorus (See Figure 37 and Figure 38).

The 2015 SWAT model used inputs of land cover, land use, tillage practices, nutrient management, soil materials, and stream flows from 1998-2012, totaling 23,960 pounds of phosphorus loading annually. Average annual discharge and loads from the Ripon Municipal Wastewater Treatment Facility were included in the model calibration and validation simulations. Wuerches Creek and White Creek sub-watersheds had the highest simulated TSS yield (See Figure 39). Like the 2000 results, the Wuerches Creek sub-watershed had the highest modeled phosphorus yield (See Figure 40 and Figure 41).

Both versions included many of the same parameters, including dividing the Big Green Lake watershed into 25 polygons of relatively equal size. In both models, White Creek was erroneously routed through the SCE. While there are some nuances between both versions, the similarities allow for general comparisons of the 2000 [68] and 2015 [48] SWAT model results.

A finer analysis of the 25 polygons draining to the lake shows a general improvement of phosphorus and TSS loading between 2000 and 2015. While the exact process between 2000 and 2015 could not be replicated, the SWAT models show substantial phosphorus and TSS reductions that are consistent with expectations based on best management practice installation over 15 years.

Results from Baumgart's 2000 and 2015 SWAT model show similarities, indicating highest sediment loading from the Wuerches and White Creek sub-watersheds, each ranging from 301 to 650 tons annually. Assembly, Spring, and portions of Silver Creek have the lowest annual sediment loading. The Wuerches Creek sub-watershed also indicates the highest phosphorus loading for the 2000 and 2015 SWAT models, generating 3,000-4,500 pounds of phosphorus annually.

Table 8. Two SWAT models conducted in 2000 and 2015 estimated annual phosphorus and sediment loading.

	2000 SWAT Model	2015 SWAT Model
Phosphorus Loading	33,820 pounds	23,960 pounds
TSS Loading	3,707 tons	2,946 tons

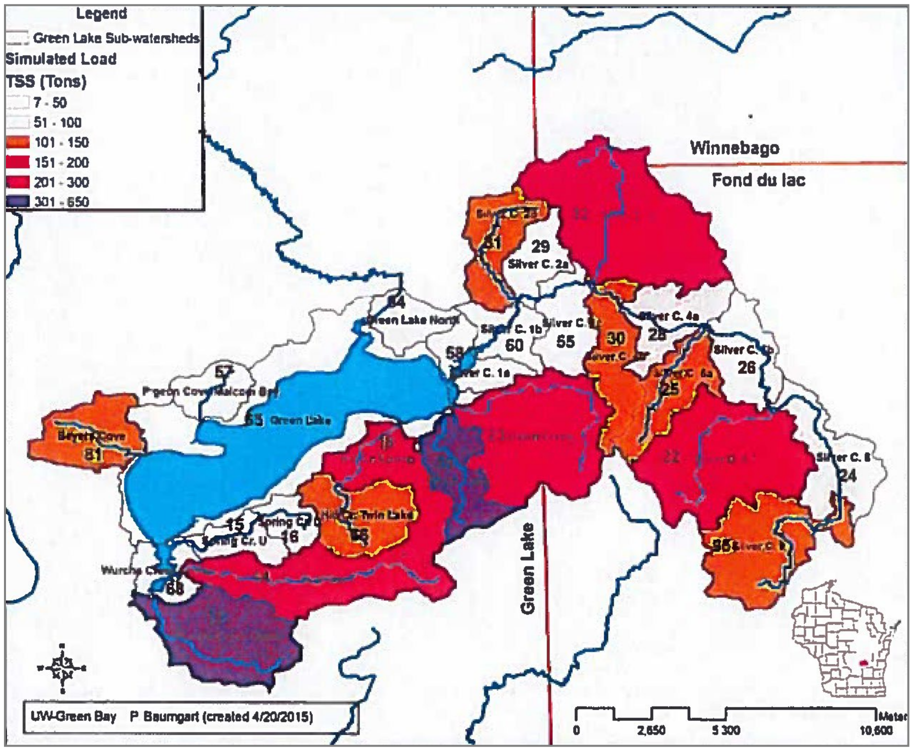

Figure 37. Total suspended sediment loading (tons) for the Big Green Lake watershed based on the 2000 SWAT model [68].

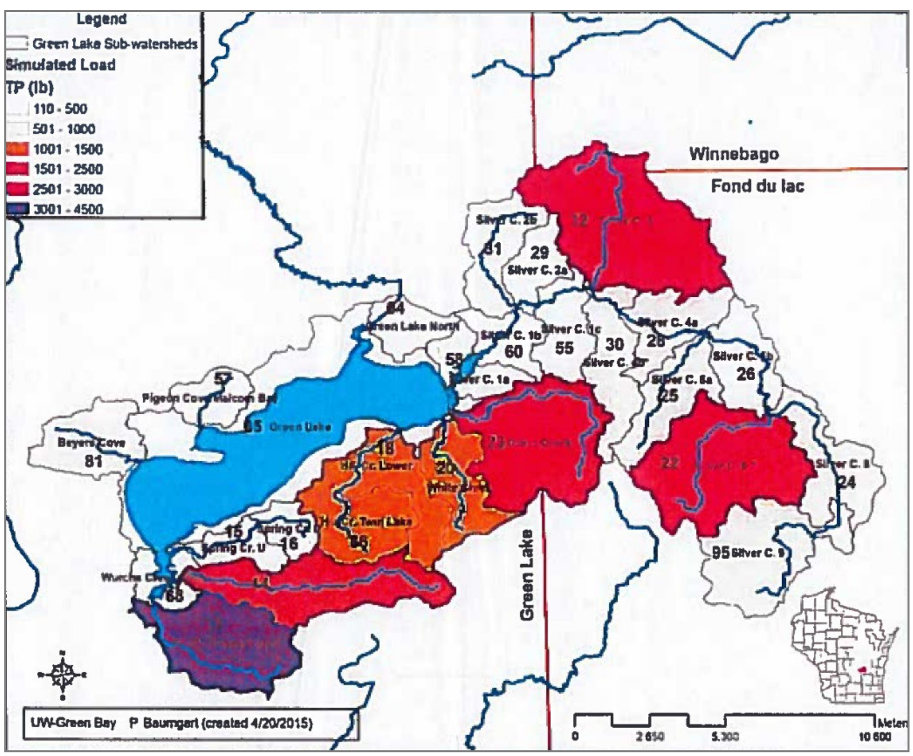

Figure 38. Total phosphorus loading (pounds) for the Big Green Lake watershed based on the 2000 SWAT model [68].

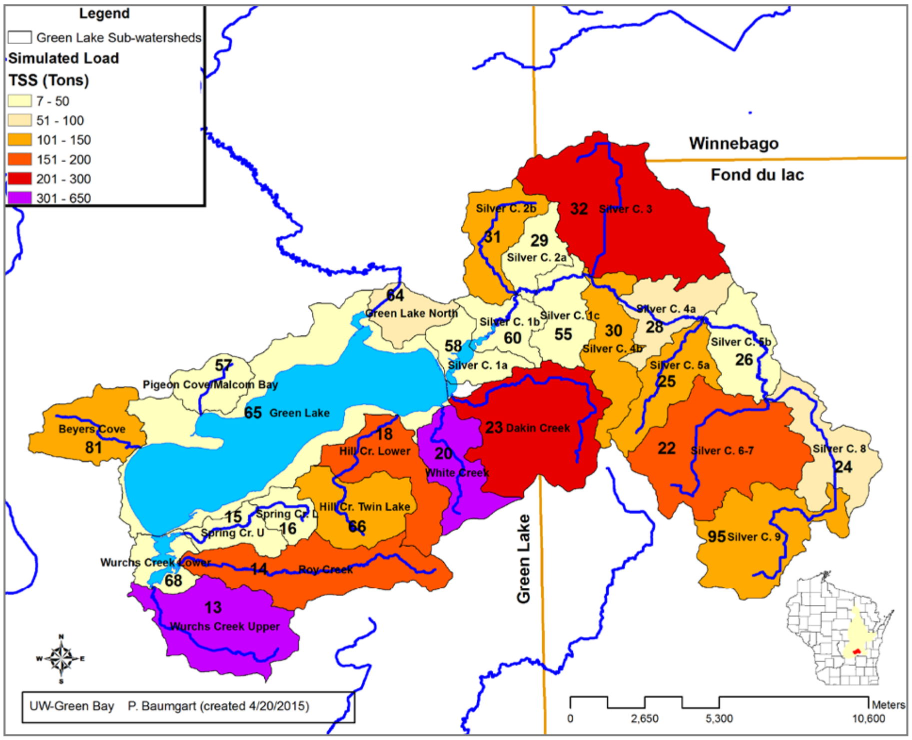

Figure 39. Total suspended sediment loading (tons) for the Big Green Lake watershed based on the 2015 SWAT model [48].

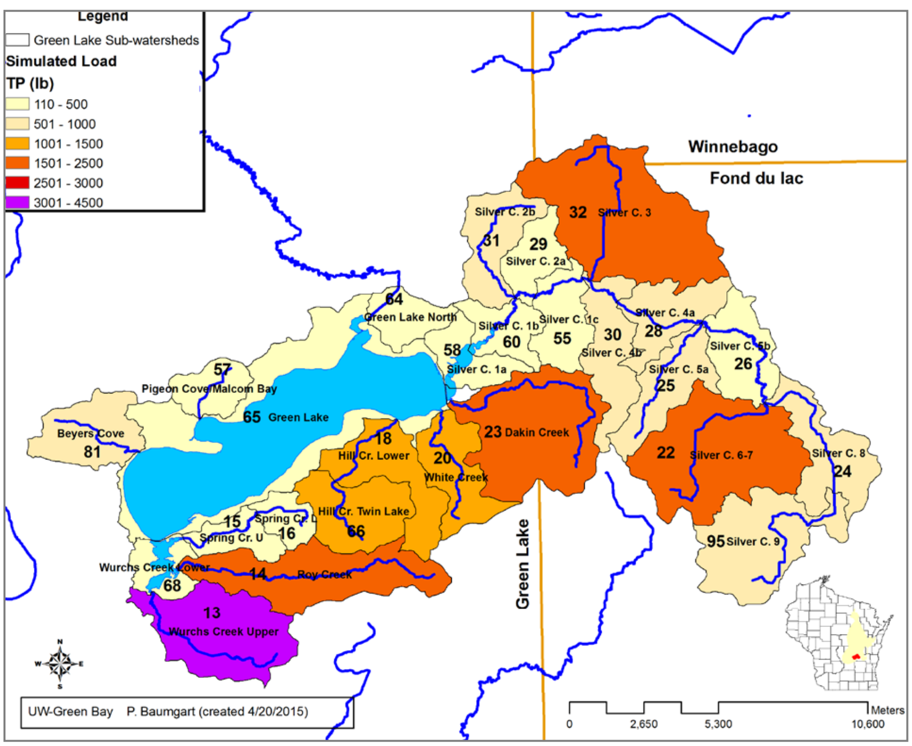

Figure 40. Total phosphorus loading (pounds) for the Big Green Lake watershed based on the 2015 SWAT model [48].

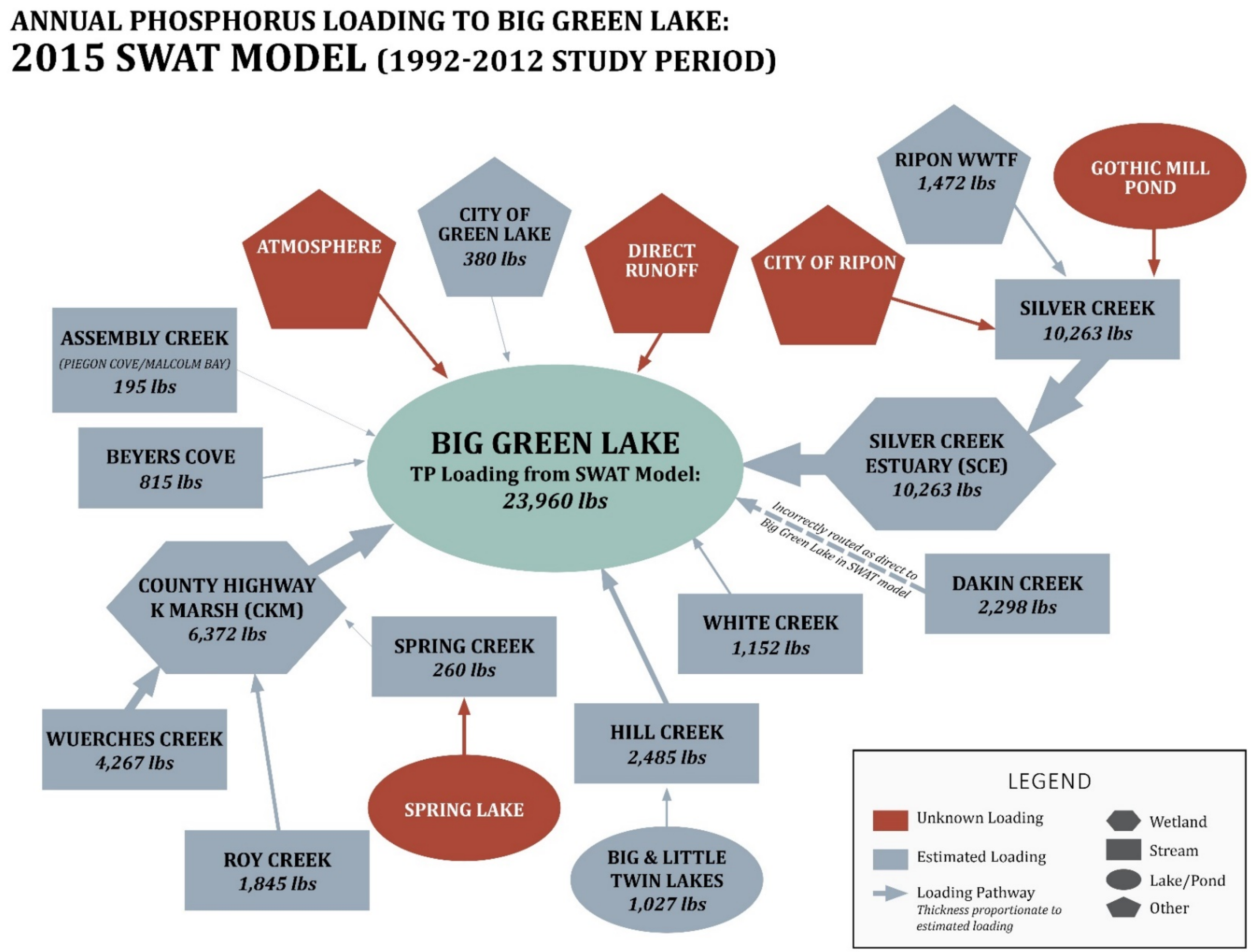

Figure 41. Though more rigorous estimates now exist, a conceptual site model provides a visual representation of the sources and pathways of annual phosphorus loading estimated from the 2015 SWAT model [48].

In 2017, Dale Robertson of the USGS revised the 2015 SWAT model [48] estimates with stream sampler data from the 2013-2016 study period, when available—only relying on Baumgart's SWAT model estimates throughout the Big Green Lake watershed for ungauged portions of the watershed.

Table 9 summarizes phosphorus pollutant loading for these three estimates (2000 SWAT model, 2015 SWAT model and 2015 SWAT model with USGS revisions). Phosphorus pollutant loading was estimated at 23,960 pounds from the 2015 SWAT model [48] and 16,652 pounds when modified with the USGS stream data.

The LMPT considers the 2015 SWAT Model Revised (16,652 pounds of annual total phosphorus loading between 2013-2016) to be the most reliable estimate of total phosphorus loading for the Big Green Lake watershed.

Table 9. Comparison of phosphorus (pounds) and total suspended solids (TSS) loading for the 2000 and 2015 Soil and Water Assessment Tool (SWAT) for the Big Green Lake watershed. The 2015 SWAT Model Revised (totaling 16,652 pounds of phosphorus/year) is the LMPT's preferred existing methodology to estimate phosphorus loading.

	2000 SWAT Model	2015 SWAT Model	2015 SWAT Model Revised
Average Phosphorus Loading	33,820 pounds	23,960 pounds	**16,652 pounds** Agreed Base P loading (2013-2016)
Average TSS Loading	3,707 tons	2,946 tons	*Not calculated*

ii. Delta Institute Phosphorus Prioritization Plan (2016)

Big Green Lake has not achieved its water quality goals in terms of low dissolved oxygen and high phosphorus concentrations. Among other strategies, continued phosphorus-reducing practices are required.

In 2016, the Green Lake Association on behalf of the LMPT worked with the Delta Institute to develop a method to prioritize phosphorus-reducing practices in the watershed. Prior to this effort, the LMPT lacked a systematic way to identify and rank nutrient loading priority areas in the watershed. Prioritizing the location of conservation projects is a cost-effective way to expedite water quality improvements downstream.

The Delta Institute conducted a nutrient loading analysis of the Big Green Lake watershed using a series of watershed models that incorporate information about topography, soil types, rainfall, and land cover. The Delta Institute developed an Erosion Vulnerability Assessment for Agricultural Lands (EVAAL) for the Big Green Lake watershed to identify areas that have moderate- to high-erosion indexes created by sheet, rill, and gully erosion (Figure 42). These results were compared to Baumgart's 2015 Soil and Water Assessment Tool watershed model [48] and other phosphorus loading data.

Existing agricultural BMPs (and those currently planned until 2017) were mapped based on information provided by the Green Lake County Land Conservation Department. Similar cost-share programs did not yet exist for Fond du Lac County, though documentation of BMPs is now in development given progress in this part of the watershed.

Results of the EVAAL model were used to identify 12 nutrient loading priority areas (NLPAs) in the Big Green Lake watershed—six in Green Lake County and six in Fond du Lac County—based on high-density clusters of high nutrient loading and low-density clusters of existing BMPs (See Figure 43). These 12 NLPAs total 6,862 tillable acres in the watershed with an estimated 15,096 pounds of phosphorus loss annually (or 2.2 pounds/acre).

These NLPAs were identified using EVAAL model results, aerial photographs, and other relevant digital data. The LMPT may field-verify these NLPAs and adjust the prioritization based on those finding in combination with EVAAL model results. The NLPAs and EVAAL analysis identify critical areas in the Green Lake watershed for cost effective adoption of BMPs and are consistent with EPA's element 3 requirements.

The resultant Phosphorus Prioritization Plan [27] has been an effective decision-making tool to implement practices to reduce sediment and phosphorus loading. It also provides guidance for addressing several Key Elements discussed in Chapters 6, 7, and 8 including:

- Causes and Sources (Chapter 6)
- Load Reductions Expected (Chapter 7)
- Non-point Source Management Measures (Chapter 7)
- Technical and Financial Assistance Needed (Chapter 8)
- Criteria to Determine if Load Reductions are Being Achieved (Chapter 8)

In particular, the Phosphorus Prioritization Plan:

- Identifies **agricultural nutrient loading priority areas** throughout the Big Green Lake watershed,
- Determines the **location and type of best management practices** (BMPs) to achieve proposed (but not data-based) phosphorus reduction goals of 25% by 2025 and 35% by 2035 through field-level implementation scenarios,
- Calculates the **funding gap** to install BMPs through the NRCS' Environmental Quality Incentives Program ("EQIP") at 25%, 50% and 75%,
- Compiles a list of potential **grant opportunities** that may cover the remaining funding gap, and
- Provides the necessary information to enhance agricultural outreach that **increases the adoption of conservation practices in the watershed.**

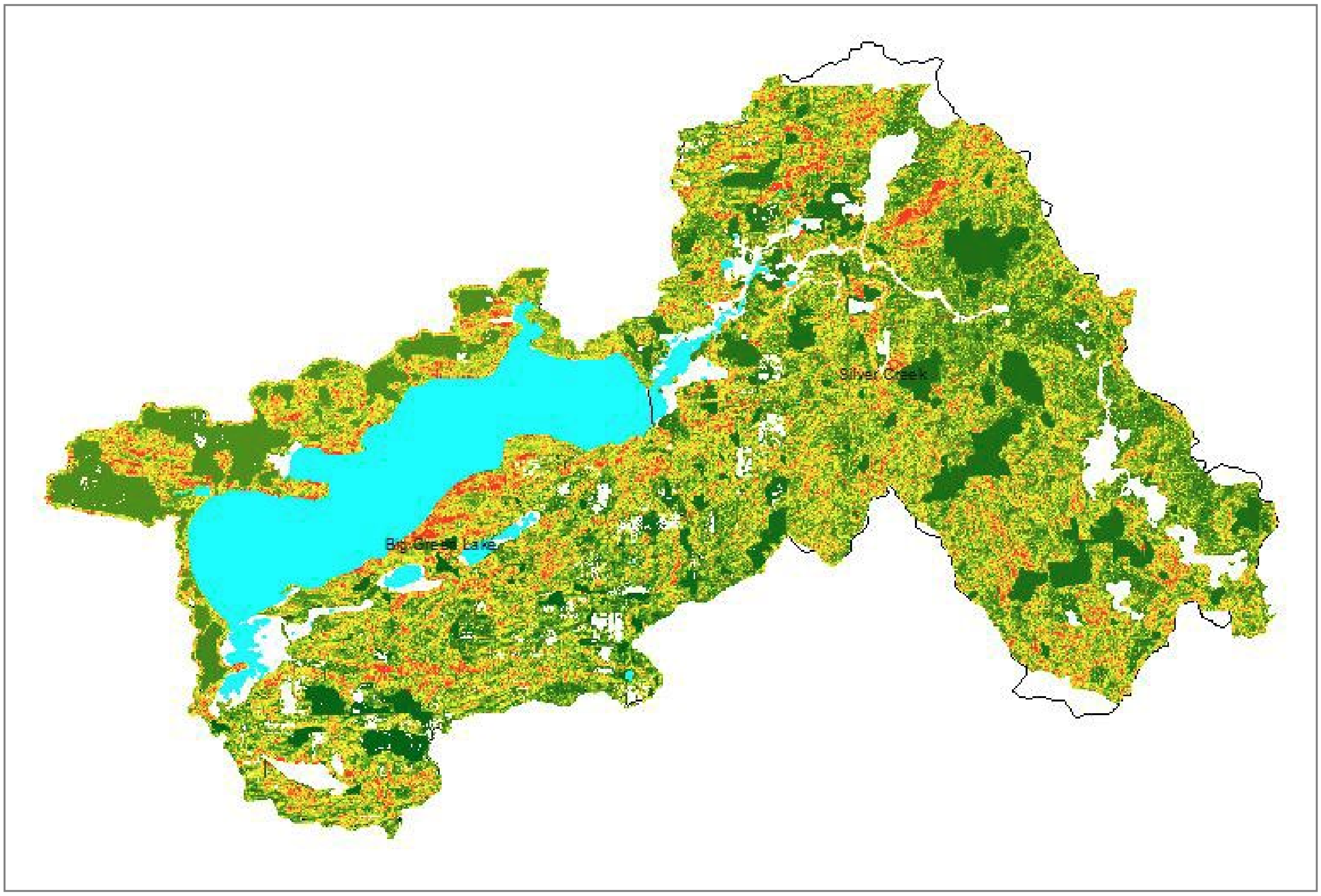

Figure 42. Results of an EVAAL model of the Big Green Lake watershed, used to identify areas that have moderate- to high-erosion indexes created by sheet, rill and gully erosion. Areas in red indicate high erosion indexes and green indicate low erosion indexes.

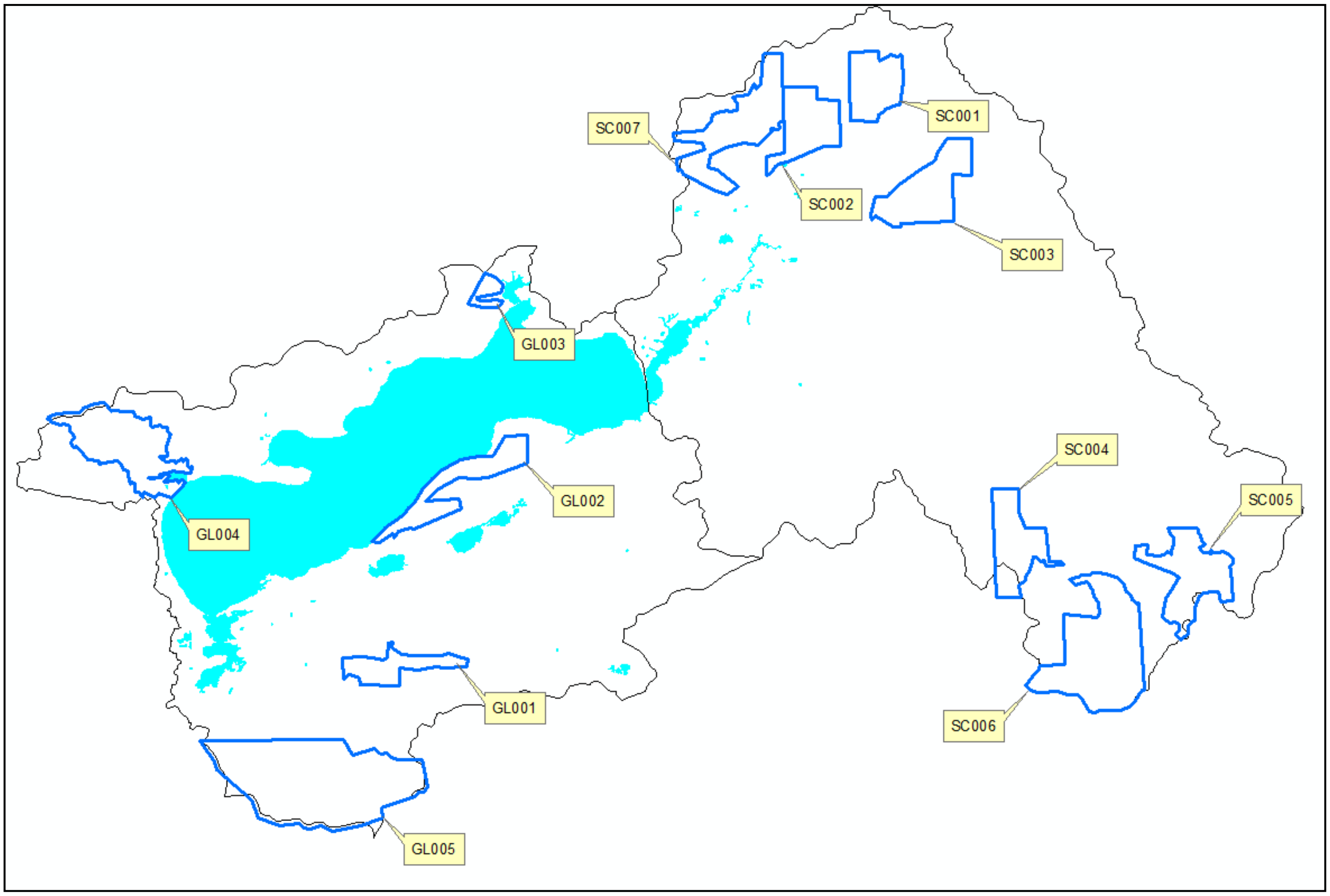

Figure 43. Twelve nutrient loading priority areas were selected based on high-density clusters of high nutrient loading and low-density clusters of existing BMPs.

Within each NLPA, the Delta Institute conducted field-level implementation scenarios to identify hypothetical areas suitable for a suite of soft and hard best practices such as mulch tillage, no-till, cover crops, filter strips, and grassed waterways.

The quantity and size of these BMPs were determined so that all field-level implementation scenarios from the 12 NLPAs totaled milestone annual phosphorus reduction goals of 25% (or 5,990 pounds) and 35% (or 8,386 pounds). These reduction goals were based on previous total phosphorus loading of 23,960 pounds/year, which has since been refined to 16,652 pounds/year.

The annual reduction goals are for annual edge-of-field phosphorus reductions and do not account for delivery to Big Green Lake. Finally, these reduction goals are not tied to water quality standard-based goals and will need to be modified when required reduction goals are better understood.

The Phosphorus Prioritization Plan estimated a potential funding gap range to reduce phosphorus by 6,990 pounds and 8,310 pounds (equivalent to a 25% and 35% reduction in phosphorus loading; base loading for this study assumed to be 23,960 pounds per year). The funding range was based on provided EQIP funding at the 25%, 50%, and 75% level, as detailed in Table 10, for the implementation period of 2016-2025 (for a 25% reduction from 23,960 pounds) and 2016-2035 (for a 35% reduction from 23,960 pounds).

Table 10. The Phosphorus Prioritization Plan estimates a $112,700-$488,300 funding gap to reduce phosphorus by 5,990 pounds and a $332,850-$1,442,300 to reduce phosphorus by 8,386 pounds).

Hypothetical scenarios to achieve two levels of phosphorus reductions	**Percent of BMP cost covered by EQIP funding** **25% covered**	**50% covered**	**75% covered**
HYPOTHETICAL SCENARIO 1: **PHOSPHORUS REDUCTION of 6,990 POUNDS BY 2025**			
Soft-practice cost: $ 360,360 *Hard-practice cost: $ 162,192* *Total cost: $522,552*	**Total cost + 15% contingency: $ 600,935**		
Estimated EQIP funding received by 2025	$ 112,700	$ 225,350	$ 338,000
Estimated funding gap through 2025	$ 488,300	$ 375,600	$ 262,900
Funding Gap: $ 112,700 – $488,300			
HYPOTHETICAL SCENARIO 2: **PHOSPHORUS REDUCTION OF 8,310 POUNDS BY 2035**			
Soft-practice cost: $ 1,301,430 *Hard-practice cost: $ 242,172* *Total cost: $1,543,602*	**Total cost + 15% contingency: $ 1,775,142**		
Estimated EQIP funding received by 2035	$ 332,850	$ 665,700	$ 998,500
Estimated funding gap through 2035	$ 1,442,300	$ 1,109,500	$ 776,600
Funding Gap: $ 332,850 – $1,442,300			

These costs were based on assumptions about the types and quantities of soft and hard practices selected, which are outlined in Table 11 and Table 12.

*Table 11. A 2016 Delta Institute Report estimated the total cost of soft- and hard-practice implementation costs to reduce phosphorus by **5,970 pounds (25% of 23,960 lbs/year**) between 2016 and 2025 [27].*

Load Reduction of 5,970 lbs/yr—From Delta Institute				
Practice	**Annual P reduced (lbs)**	**Acres/yr implemented (ac/yr)**	**Annual Cost to Maintain**	**Total Cost**
SOFT PRACTICES				
Mulch Till	850	500	$ 11,800	$ 61,600
No Till	820	500	$ 14,750	$ 77,000
Cover Crops	1,660	1,000	$ 42,480	$ 221,760
Soft Practice Total	**3,330**	**2,000**	**$ 69,030**	**$ 360,360**
Practice	**Annual P reduced (lbs)**	**Linear ft/yr implemented (ft/yr)**	**Annual Cost to Maintain**	**Total Cost**
HARD PRACTICES				
Filter Strips	600	20,000	$ 2,926	$ 27,032
Grass Waterways	2,040	20,000	$ 14,632	$ 135,160
Hard Practice Total	**2,640**	**40,000**	**$ 17,558**	**$ 162,192**
TOTAL	**5,970**	**N/A**	**$ 86,588**	**$ 522,552**
TOTAL with 15% contingency			**$ 99,576**	**$ 600,935**
$/lb-P Reduced (Total)				**$ 101**

Table 12. A 2016 Delta Institute estimated the total cost of soft- and hard-practice implementation costs to reduce phosphorus by 8,310 pounds (35% of 23,960 lbs/year) between 2016 and 2035 [27]. This table corrects an addition typo in the original Delta Institute report for a sub-total annual cost of hard practices.

Load Reduction of 8,310 lbs/yr—From Delta Institute				
Practice	**Annual P reduced (lbs)**	**Acres/yr implemented (ac/yr)**	**Annual Cost to Maintain**	**Total Cost**
SOFT PRACTICES				
Mulch Till	850	500	$ 13,800	$ 190,600
No Till	1,640	1,000	$ 34,500	$ 329,000
Cover Crops	2,158	1,300	$ 64,584	$ 781,830
Soft Practice Total	**4,648**	**2,800**	**$ 112,884**	**$ 1,301,430**
Practice	**Annual P reduced (lbs)**	**Linear ft/yr implemented (ft/yr)**	**Annual Cost to Maintain**	**Total Cost**
HARD PRACTICES				
Filter Strips	600	20,000	$ 2,926	$ 27,032
Grass Waterways	3,060	30,000	$ 8,556	$ 215,140
Hard Practice Total	**3,660**	**50,000**	**$ 11,482**	**$ 242,172**
TOTAL	**8,308**	**N/A**	**$ 124,366**	**$ 1,543,602**
TOTAL with 15% contingency			**$ 143,021**	**$ 1,775,142**
$/lb-P Reduced (Total)				**$ 214**

iii.Comparison of SWAT Model and Phosphorus Prioritization Plan

While phosphorus prioritization tools are helpful to target specific areas with BMPS in the Big Green Lake watershed, these methods do not always align with various recommendations.

The 2015 SWAT Model [48] considers sub-watersheds within the Green Lake watershed but categorizes entire watersheds as a single simulated phosphorus load.

The 2016 Delta Institute Phosphorus Prioritization Plan [27] used EVAAL as the basis for grouping areas of higher phosphorus runoff potential. EVAAL allows for a field-scale, finer resolution of simulated phosphorus loading than the SWAT model, but Delta Institute's priority areas were identified by hand, without statistical models. Additionally, priority areas by the Delta Institute are not limited to agricultural land uses.

When these two priority tools are compared in Table 13, there is some alignment of priority areas—particularly for Roy, Wuerches, and some sub-watershed of Silver Creek.

Table 13. A comparison of two phosphorus prioritization tools—the 2015 SWAT model [48] from Figure 40 and the 2016 Delta Institute Phosphorus Prioritization Plan [27] from Figure 43—for sub-watersheds in the Big Green Lake watershed. SWAT Model total phosphorus loads are categorized as low, medium, and high loading. For clarity, the Upper Fox-Wolf TMDL subbasin IDs [34] are also included. Subwatersheds with the best agreement between the 2015 SWAT Model and 2016 Delta Institute Phosphorus Prioritization Plan are shown with an asterisks.

		2015 SWAT Model:		2016 Delta Institute Phosphorus Prioritization Plan:	
Waterbody Name	Upper Fox-Wolf TMDL ID	SWAT ID	Simulated Load TP (lb) (low, medium, high)	Delta Institute ID	
Roy Creek	17	14	Medium	GL001	*
Direct Flow	20	65	Low	GL002	
Direct Flow	20	65	Low	GL003	
Beyers Cove	20	81	Low	GL004	
Wuerches Creek	18	13	High	GL005	*
Silver Creek	87	32	Medium	SC001	*
Silver Creek	19	29, 31, 32	Low to Medium	SC002	
Silver Creek	87	32	Medium	SC003	*
Silver Creek	87	22	Medium	SC004	*
Silver Creek	87	24, 95	Low	SC005	
Silver Creek	87	95	Low	SC006	
Silver Creek	19	31, 32	Low	SC007	

iv. Crop Transect Surveys (2012-Present)

Since 2000, the Green Lake County Land Conservation Department has annually performed a transect survey of the cropland in the county. The transect survey consists of a set of GPS points setup throughout Green Lake County. At each point, the crop fields are checked for a variety of parameters including crops grown, residue at planting, tillage type, slopes, soils, and other runoff factors. These same points are checked each year to document changes in farming practices.

With the collection information at each site, soil loss calculations are generated and compared from one year to the next. Trends and patterns can be seen throughout the years. From 2012 to 2016, Green Lake County has estimated an overall countywide soil loss reduction from 1.47 tons/acre/year to 1.22 tons/acre/year. Within the Big Green Lake watershed for the same period, that reduction has improved from 1.50 tons/acre/year to 1.21 tons/acre/year. The U.S. Department of Agriculture defines "tolerable soil loss" as 5 tons/acre/year, a rate that equals a net zero of soil formation and soil erosion, the very notion of tolerable rates of soil erosion has been questioned by conservationists for decades.

The Fond du Lac County Land and Water Conservation Department has conducted crop transect surveys in the past, as recently for the 2015 SWAT model, but Fond du Lac County does not have the intention of completing additional surveys in the immediate future.

v. Barnyard and Storage Unit Inventory, Green Lake County (2017)

In the late 1980s, the Big Green Lake LCD completed an inventory of barnyards in the Big Green Lake watershed (excluding Fond du Lac County) to assess each lot's potential for phosphorus runoff. At that time, 43 barnyards were identified, with 30 listed as potential resource concerns. All resource concerns for these concerned lots were corrected to minimize the phosphorus entering the lake.

Thirty years later, in 2017, the barnyards within the Big Green Lake watershed were re-inventoried. There are now 14 total barnyard lots, three identified as potential resource concerns (see Table 14 and Figure 44). With funds available through NWQI and local partners, the Land Conservation Department will work with these few individuals to correct any issues that are causing runoff.

Fond du Lac County LWCD has not completed any barnyard inventories for the Fond du Lac County portion of the Green Lake watershed, though they have likely completed a walkover for assessment of NR 151 compliance. As of March 2021, Fond du Lac County LWCD reports no known issues from barnyards in the watershed.

Table 14. Green Lake County LCD completed a barnyard inventory in 2017. The results of that survey are reported by TMDL sub-basin.

TMDL Sub-Basin	Name	Total Barnyards	Resource Concern Barnyards
17	Roy Creek	5	1
18	Wuerches Creek	0	0
19	Silver Creek – Below S Koro Rd	0 (In Green Lake County portion)	0 (In Green Lake County portion)
20	Green Lake Direct Drainage Dakin Creek White Creek	 3 2 1	 1 0 0
79	Hill Creek	3	1
87	Silver Creek – Above S Koro Rd	N/A; Not part of Green Lake County inventory	N/A; Not part of Green Lake County inventory
	Total:	**14**	**3**

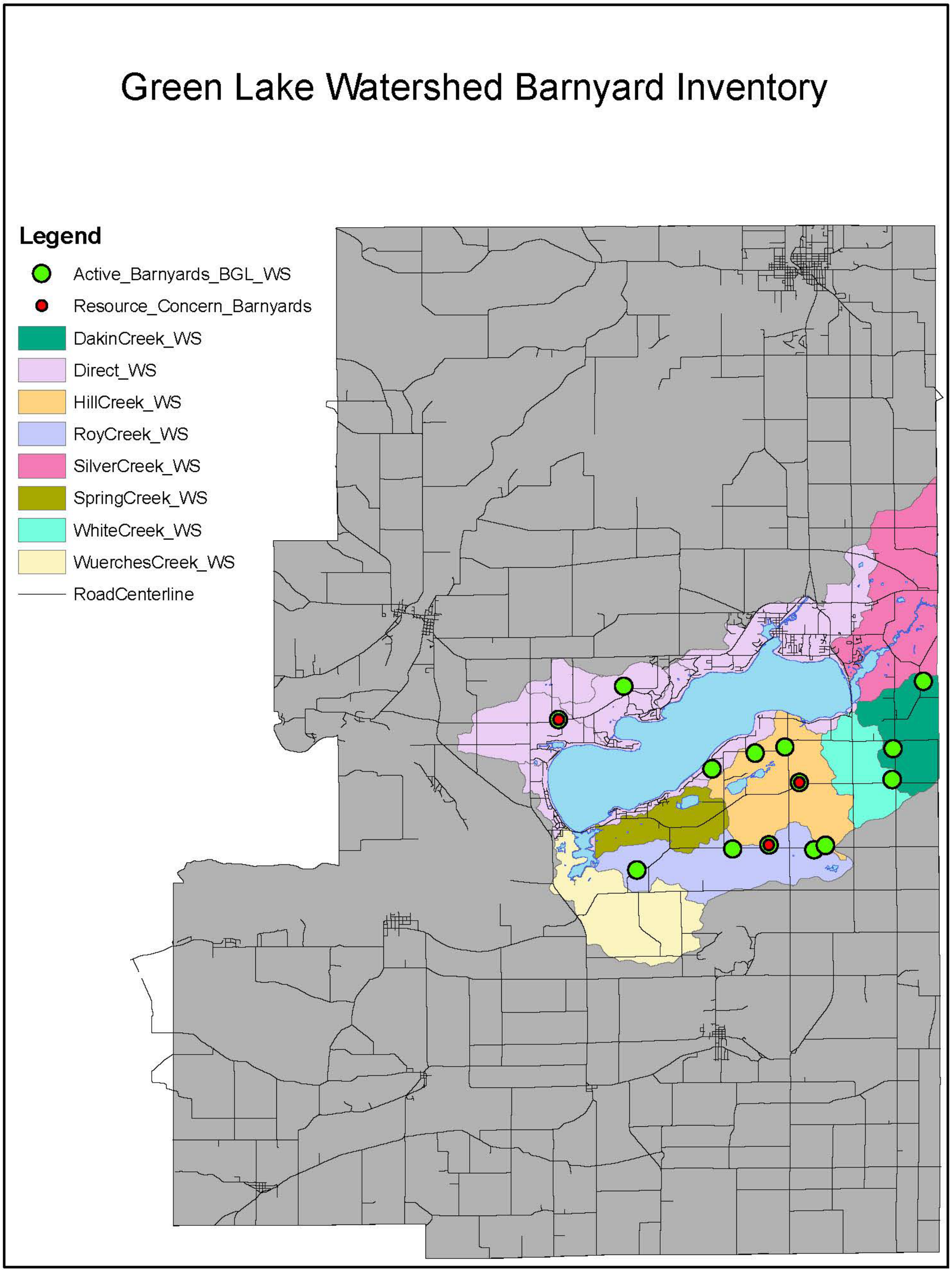

Figure 44. A map of the 2017 Green Lake County LCD barnyard inventory in the Green Lake watershed.

vi. Land and Water Resource Plans for Fond du Lac and Big Green Lake Counties (2018)

Green Lake County's Land and Water Resource Management Plan (LWRMP) is a locally driven document that promotes wise use of the County's natural resources resulting in a healthy economic environment, while still protecting the County's natural resources for long-term stability.

Green Lake County's first LWRMP was written in 1999, with subsequent updates in 2005 and 2011. Plan updates were previously required on a 5-year schedule, whereas now DATCP has adopted a 10-year schedule. In 2018, Green Lake County updated its plan to meet these new requirements. This LWRMP incorporates the latest updates to the Lake Management Plan for Big Green Lake.

The driving force behind the Fond du Lac County Land and Water Resource Management Plan is to maintain funding levels needed to implement the conservation practices and programs to make a positive impact on resources in the County. Fond du Lac County's Land and Water Resource Management Plan is currently being updated for 2018-2028.

vii. City of Green Lake Stormwater Management Plan (2018)

The City of Green Lake was awarded a WDNR Urban Nonpoint Source and Storm Water Management Grant to assess the City's phosphorus and sediment contributions to the lake. The City of Green Lake is not an MS4 (10,000 or more residents) and has no regulatory requirement to reduce phosphorus. However, this voluntary measure represents the City's commitment to improving Big Green Lake's water quality.

The "Stormwater Quality Assessment and Improvement Plan: City of Green Lake" is currently in its final stages of approval with the WDNR [34]. Preliminary information from the study was used to provide the following data concerning pollutant loading to Big Green Lake.

The study examined the urban impact of the City of Green Lake (1,149 acres in size) on nearby water bodies: 945 acres that drain to Big Green Lake (including 199 acres to the Mill Pond, near the outlet of Big Green Lake) and 870 acres that drain outside of the Big Green Lake watershed to the Puchyan River. The entire watershed boundary beyond the municipal limits was considered in all calculations.

Assuming an annual total phosphorus loading from the Big Green Lake watershed of 16,652 pounds, the City of Green Lake contributes on average 415 pounds of phosphorus per year (275 pounds to Big Green Lake proper and 140 pounds to the Mill Pond), or 2.5% total annual phosphorus loading to Big Green Lake (See Table 15).

Table 15. Estimates of total annual phosphorus loading from the City of Green Lake.

Watershed	Sub-Watershed	Sub-Watershed Area (ac)	Sediment Loading (tons-TSS/yr)	Phosphorus Loading (lbs-P/yr)
Big Green Lake	Big Green Lake	346	30.3	275
	Mill Pond	199	14.7	140
Puchyan River *(outside of Big Green Lake watershed)*	N/A	604	56.7	435
Total		**1,419 ac**	**101.8 tons-TSS/yr**	**850 lbs-P/yr**

B. Qualitative Characterization of the Lake

Long-term nutrient loading from the land has caused Big Green Lake to be more productive in terms of algae and aquatic plant growth. A history of extensive lake monitoring has allowed Green Lake's degradation to be quantified.

The lake's trophic state index (TSI) calculated from both phosphorus and chlorophyll-a concentrations indicates that the lake is now mesotrophic (See Figure 45). Big Green Lake's TSI calculated from Secchi depth shows that the lake at times oligotrophic (TSI less than 40.0)—though this is likely be caused by the introduction of zebra mussels in 2005, which improves water clarity apart from nutrient loading.

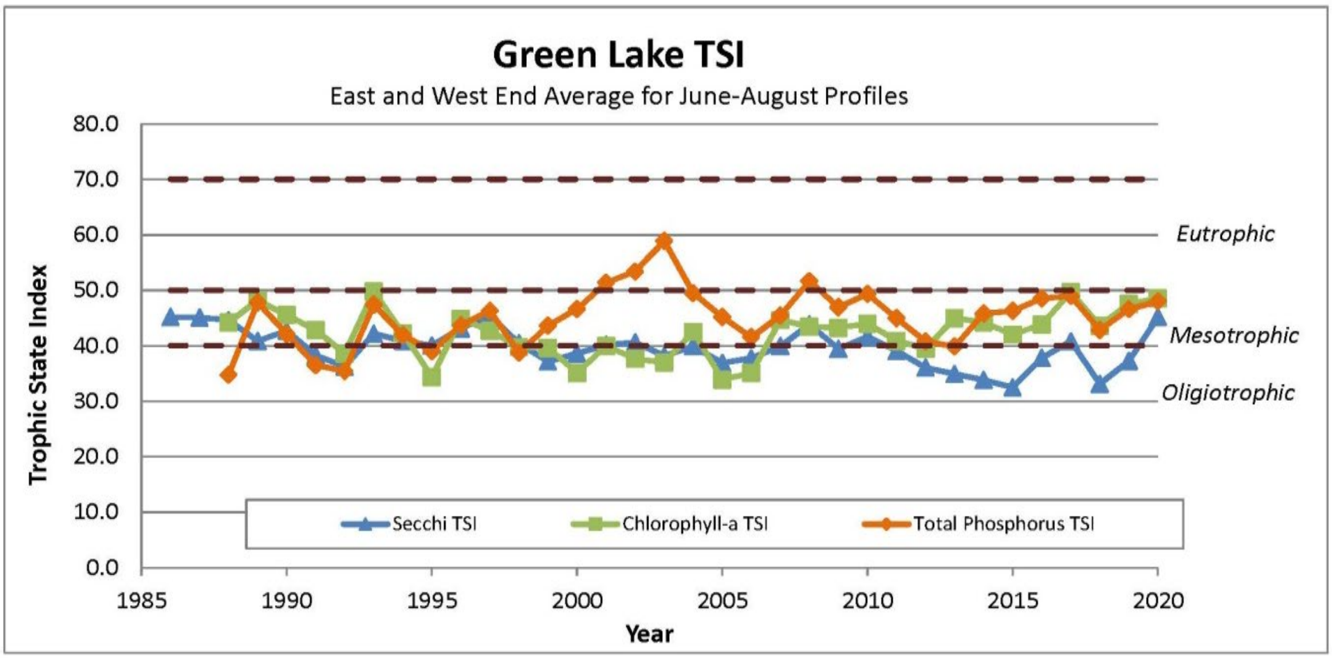

Figure 45. Recent chlorophyll-a and total phosphorus data indicates that Big Green Lake is mesotrophic lake based on corresponding Trophic State Index calculations (TSI = 40-50). The effects of zebra mussels in improving water clarity results in the lake being classified at times as oligotrophic based on Secchi depth calculations.

The following sections summarize the data available for phosphorus loading on the lake.

i. Water Clarity (1986 to Present)

Various agencies, volunteers and associations have monitored Secchi depth since 1986. This water clarity data shows the east basin typically has poorer clarity than the west basin of the lake (See Figure 46). This difference may be due to several factors. The east end of Big Green Lake is shallower compared to the west. Furthermore, the east end receives major tributary flow from Silver Creek, a 48 square-mile drainage area, representing 45% of the Big Green Lake watershed area. However, the flow patterns within Green Lake are not well understood, and the LMPT recommends the completion of a flow model to identify if there is any short-circuiting from Silver Creek.

Water clarity in Big Green Lake has improved since the 1980s, and particularly since about 2010. This improvement in clarity (now measuring 5m to 6m on average) is suspected due to zebra mussel colonization.

This AIS-related condition at first glance appears to be positive, but it has its downside. Because the mussels compartmentalize soluble phosphorus at the benthic level, filamentous algae growth is often stimulated. The algae (most of which is a *Cladophora sp*.) can inhibit several facets of lake ecosystems including fish spawning, native invertebrate populations, and recreational use. The zebra mussels are just one variable factor facing management.

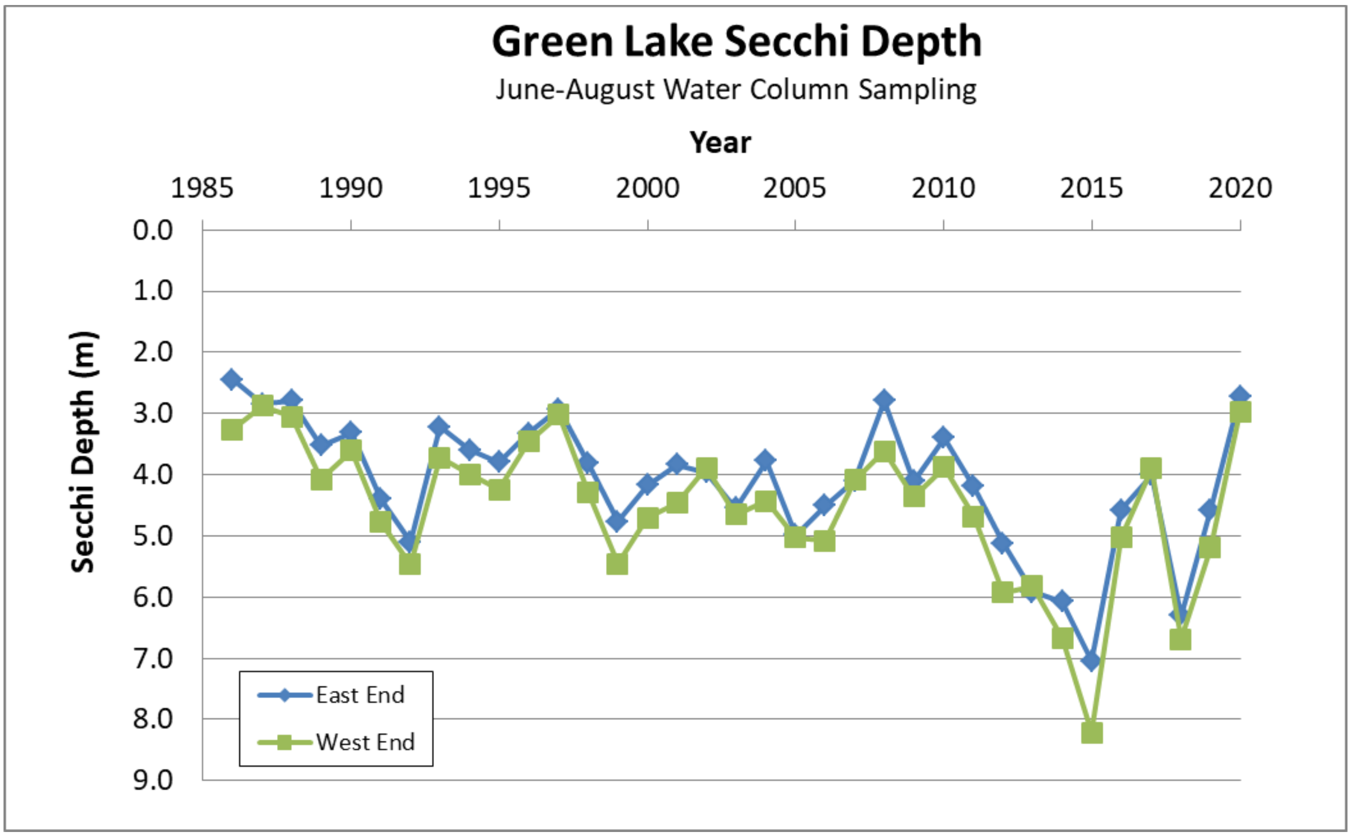

Figure 46. Big Green Lake has seen a general improvement in Secchi depth since measured in 1987. This in large part is caused by zebra mussel activity, an aquatic invasive species first discovered in Big Green in 2005. Note the reverse y-axis on this chart to allow the lake surface to be at the top of the axis.

ii. GLSD Beach Sampling (1989-Present)

The Green Lake Sanitary District has collected bacteria (most recently *Escherchia coli, E.coli*) samples from six beaches and two tributaries since 1989: Pilgrim Center Camp, Dodge County Memorial Park, Hattie Sherwood, Camp Grow, Sunset Party and the Big Green Lake Conference Center. The GLSD collects a single grab sample, at each of the six sites, once a week from Memorial Day through Labor Day. Samples are collected 1 foot below the surface in 3 to 6 feet of water and tributary samples are from the surface.

The Environmental Protection Agency and Wisconsin Administrative Code HS 171 require that beaches have an advisory sign informing the public of increase health risk when a water sample exceeds 235 colony-forming units of *E.coli* per 100 milliliters of water (235 CFU/100 mL).

There have been several recent beach advisories or closings from high *E. coli* samples since 1990:

- In 2002 at the Green Lake Conference Center,
- In 2018, in the Green Lake Conference Center, which dissipated below 235 CFU/100 mL in a week,
- Twice in 2019 at Dodge Memorial County Park; levels were between 235 and 999 CFU/100 mL, triggering a beach advisory instead of a beach closure, and
- In 2020 at Sunset Park, where E. coli levels spiked at 2,400 CFU/100 mL and then a prompt resample was 276 CFU/100 mL, just over the 235 CFU/100 mL beach advisory threshold.

In addition to this sampling, the LMPT recommends the regularly monitoring of blue-green algae within its beaches and other lake access points.

iii. WiLMS Lake Model (1999)

Stemming from a 1998 DNR Lake Protection Grant, Big Green Lake's 1999 Wisconsin Lake Modeling Suite (WiLMS) [47] examined the impact of watershed pollutants. Monitoring data was used to calibrate a model and to develop a lake phosphorus loading response curve.

The report concluded that, based on spring total phosphorus concentrations, the lake was eutrophic. Some criticisms of this conclusion exist, however, because spring data were used in a summer-average model.

This study concluded that Silver Creek contributed 44% of the lake's annual total phosphorus loading, which constituted 50% of the tributary loading. The CKM was the second largest source of phosphorus, contributing 13% of the total and 15% of the tributary input.

The WiLMS model recommended establishing an in-lake total phosphorus goal and developing sufficient best management practices to meet that goal.

WiLMS is being updated as part of a Diagnostic and Feasibility study, which will be completed in 2021 (see Section 5.B.vi).

iv. USGS Lake Monitoring (2004-Present)

Within the most recent decades, several organizations have collected water quality data, including the USGS, WDNR, citizen monitoring, GLSD, and UW-Madison. Of these, the USGS has the most robust and complete water quality program directed at in-lake and tributary monitoring.

Since 2004, the GLSD has contracted with the USGS to conduct extensive in-lake monitoring. Prior to 2004, the WDNR (1981-2004), researchers, and citizen scientists recorded lake measurements on Big Green Lake.

The USGS conducts in-lake sampling at two sites within Big Green Lake: The Deep Hole / West End and the East End, shown as red dots in Figure 47.

In-lake USGS sampling occurs once a month from April through September on both the Deep Hole (Table 2) and East End (Table 17) sites. Additional bi-weekly sampling also occurs in July and August. The USGS compiles data after the end of every water year. Data are available from the USGS' online NWIS database [33] and the WDNR's SWIMS database [69]. This monitoring program and data helps provide a baseline of the current water quality in Big Green Lake that can be used to assess progress towards achieving the LMPT's water quality improvement goals detailed in Chapters 8 and 9.

Once a month, from April through September, at both the Deep Hole and East End sites, the USGS collects a series of measurements from 1.6 feet below the water surface and approximately every meter thereafter: Temperature, specific conductance, pH, dissolved oxygen, and chlorophyll-a. In addition to measurements throughout the water column, the USGS collects water samples at various depths. The sampling regime is detailed in Table 16. The Wisconsin State Laboratory of Hygiene conducts all sample analyses.

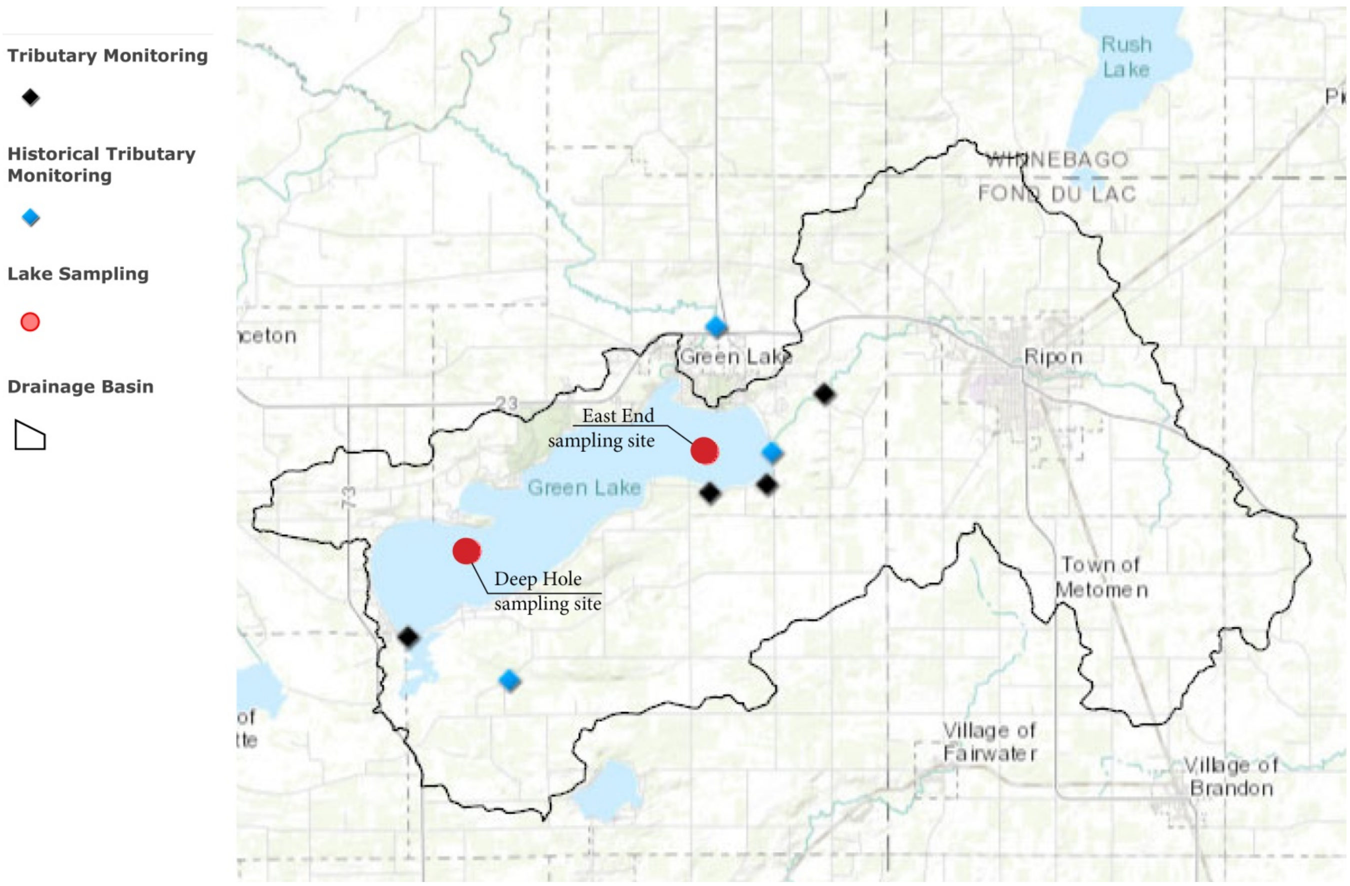

Figure 47. The USGS conducts in-lake sampling at two sites on the lake, shown as red dots: Deep Hole (west end) and East End.

Table 16. The USGS measures water quality monthly and bi-monthly at the West End / Deep Hole site. "Spring chemistry" includes turbidity, color, hardness, dissolved calcium (Ca), dissolved magnesium (Mg), dissolved sodium (Na), dissolved potassium (K), acid neutralizing capacity (ANC), total chlorine (Cl), dissolved sulfate (SO_4), dissolved silica (Si), dissolved iron (Fe), dissolved manganese (Mn), and total dissolved solids (TDS). "All nutrients" includes total and dissolved phosphorus (P), nitrite plus nitrate (NO_2+NO_3), Total Kjeldahl nitrogen (TKN) and ammonium (NH_4). In 2017 only, total and dissolved organic carbon were added to "all nutrients".

Depth	April		May	June	July (x2)	August (x2)	September
0.5 m below surface	Spring chemistry, chlorophyll-a		All nutrients, chlorophyll-a	All nutrients, chlorophyll-a	All nutrients, chlorophyll-a	All nutrients, chlorophyll-a	All nutrients, chlorophyll-a
Just below thermocline	–		–	–	–	–	TP
5.0 m above bottom	–		–	–	–	–	TP
2.0 m above bottom	–		–	–	–	–	TP
1.0 m above bottom	TP		TP	TP	TP	TP	TP

Table 17. The USGS collects various water quality samples monthly and bi-monthly at the East End site.

Depth	April	May	June	July (x2)	August (x2)	September
0.5 m below surface	TP, chlorophyll-a	TP, chlorophyll-a	TP, chlorophyll-a	TP, chlorophyll-a	TP, chlorophyll-a	TP, chlorophyll-a
1.0 m above bottom	TP	TP	TP	TP	TP	TP

v. Big Green Lake Shoreline Survey (2016)

In 2015, the GLC-LCD initiated a countywide shoreland inventory on 10 public access lakes, including Big Green Lake. LCD staff worked with the WDNR to develop a standardized approach and base metric.

The inventory was of the 35-foot primary buffer, extending inward from the water's edge. Categories contained in the survey included natural/disturbed primary buffer, tree canopy, shrub cover, herbaceous cover, impervious area, lawn, farmland, structures in the riparian area, hydrologic modifications, bank zone modifications, and littoral zone features.

On Big Green Lake in particular, the crew surveyed nearly 25 linear miles of shore and 1,115 individual parcels. The GIS-based data will be used in the future to produce interpretive maps and aid future management decisions. GIS linked database was created, so interpretive maps could be produced to aid future management/planning decisions.

At the conclusion of the data compilation, an informational mailer was sent out to all lakeshore properties owners on the identified lakes outlining the project. This mailer directed landowners to the full report and encouraged them to preserve or restore shoreland areas.

A summary of the final report from 2017 [70] found:

> *"Green Lake has a large percentage of impacted shoreland properties, both riparian and littoral impacts. The lakeshore was developed early and is experiencing a redevelopment period. Narrow lots with hardened shorelines are common. The large size and vast depth of the lake leads to increased wave energy, which can influence shoreline stability, especially when combined with development pressures of removing shoreland vegetation and replacing it with monotypic lawn grasses. The lake would likely benefit from the restoration of a large portion of the shoreland properties."*

A summary of the major findings is in Table 18:

Table 18. A 2016 shoreline survey on Big Green Lake assessed several shoreline conditions.

Shoreline Description	Total
Natural Shoreline Conditions (by Parcel)	
>50%	22% (255)
>75%	20% (226)
100%	7% (88)
Bank Modifications	
Riprap	62% (694)
Seawall	7% (84)
Erosion	0.8% (10)
Littoral Modifications	
Pier/Dock	80% (893)
Boat Lift	69% (767)
Swim Raft	12% (129)
Mooring Buoys	5% (55)
Homes <35 feet	1.5% (17)
Buildings <35 feet	14% (159)
Commercial <35 feet	0.9% (10)
Stairs <35 feet	36% (401)
Other Modifications	12% (135)
Aquatic Plants	
Emergent	10% (113)
Floating Leaf	12% (134)
Natural Shoreline (% of Shoreline)	30%

The results will be incorporated into comprehensive lake management plans throughout the County to help preserve undeveloped shoreline and preserve/restore any disturbed or eroding shoreline areas. Any projects that invest in shoreline restoration and/or preservation of natural shorelines would benefit Big Green Lake.

vi. Big Green Lake Diagnostic and Feasibility Study (2016-2019)

Big Green Lake has a long-term trend of water quality decline based on the following indicators:

1. A metalimentic oxygen minima ("MOM") near the thermocline that has intensified since documented in the 1900s and prompted Big Green Lake to be 303(d) listed by the WDNR in 2014,
2. Hypolimentic hypoxia, shown by decreasing dissolved oxygen concentrations in lake profiles, and
3. Total phosphorus concentrations consistently high enough that Big Green Lake is eligible to be 303(d) listed as impaired since it does not meet its water quality criteria of 15 µg/L.

While indicators (2) and (3) are most likely linked to phosphorus loading, the exact mechanisms causing Big Green Lake's MOM, including the role of phosphorus, is presently unknown.

Furthermore, the feasibility of improving water quality as measured by indicators (1)-(3), of de-listing the lake for its metalimnetic oxygen minima, and of implementing DNR-approved management strategies required to meet these water quality goals is unknown.

Figure 48. One of two monitoring buoys located on Big Green Lake will collect dissolved oxygen and temperature data in 2017 and 2018. The data will be combined with an extensive sampling campaign and be incorporated into various lake models

In 2016, the WDNR awarded the Green Lake Association a Lake Protection Grant for a Diagnostic and Feasibility Study to better understand these issues. The field and modeling portion of the study was concluded in 2020 and a final report will be issued to the WDNR in June 2021. The Diagnostic and Feasibility Study will:

1. Provide an understanding of the factors leading to hypoxic conditions that develop in the metalimnion and hypolimnion,
2. Identify processes leading to elevated phosphorus concentrations, specifically linkages between total phosphorus and these phenomena,
3. Quantify total phosphorus and/or pollutant reductions needed to achieve water quality goals for dissolved oxygen and phosphorus,
4. Determine the influence of anthropogenic/natural/climatic processes,
5. Identify the feasibility of management for anthropogenic processes needed to improve water quality and potentially de-list Big Green Lake,
6. Support the update of the Lake Management Plan with findings, and
7. Help guide significant phosphorus loading reduction efforts in the watershed.

To accomplish these goals, the Diagnostic and Feasibility Study implemented a comprehensive sampling/monitoring campaign in combination with various lake models. As it relates to the Nine Key Elements, the study will quantify specific phosphorus reductions to meet water quality goals, for both dissolved oxygen and phosphorus.

Once WDNR-approved study results are available, the Plan's reduction goals, required BMPs, and critical priority areas will be re-evaluated by the LMPT with applicable adjustments to the Plan's implementation and evaluation milestones.

vii. Phosphorus Concentration (Based on 2012-2016 Monitoring)

Based on USGS monitoring from 2012-2016, the lake has an average-summer (June-August) near-surface phosphorus concentration of 17.0 µg/L (90% confidence intervals range from 14.8 µg/L to 18.1 µg/L; see Figure 49 and Figure 50).

Wisconsin Administrative Code NR 102.06 (4)(b) establishes phosphorus criteria for total phosphorus in surface waters. For a two-story fishery lake such as Big Green Lake, total phosphorus concentrations at the lake's surface should not exceed 15 µg/L.

Therefore, the LMPT team recommends that the WDNR re-evaluate Green Lake for an additional impairment listing for high phosphorus levels based on its exceedance of 15 µg/L based on its water quality criteria.

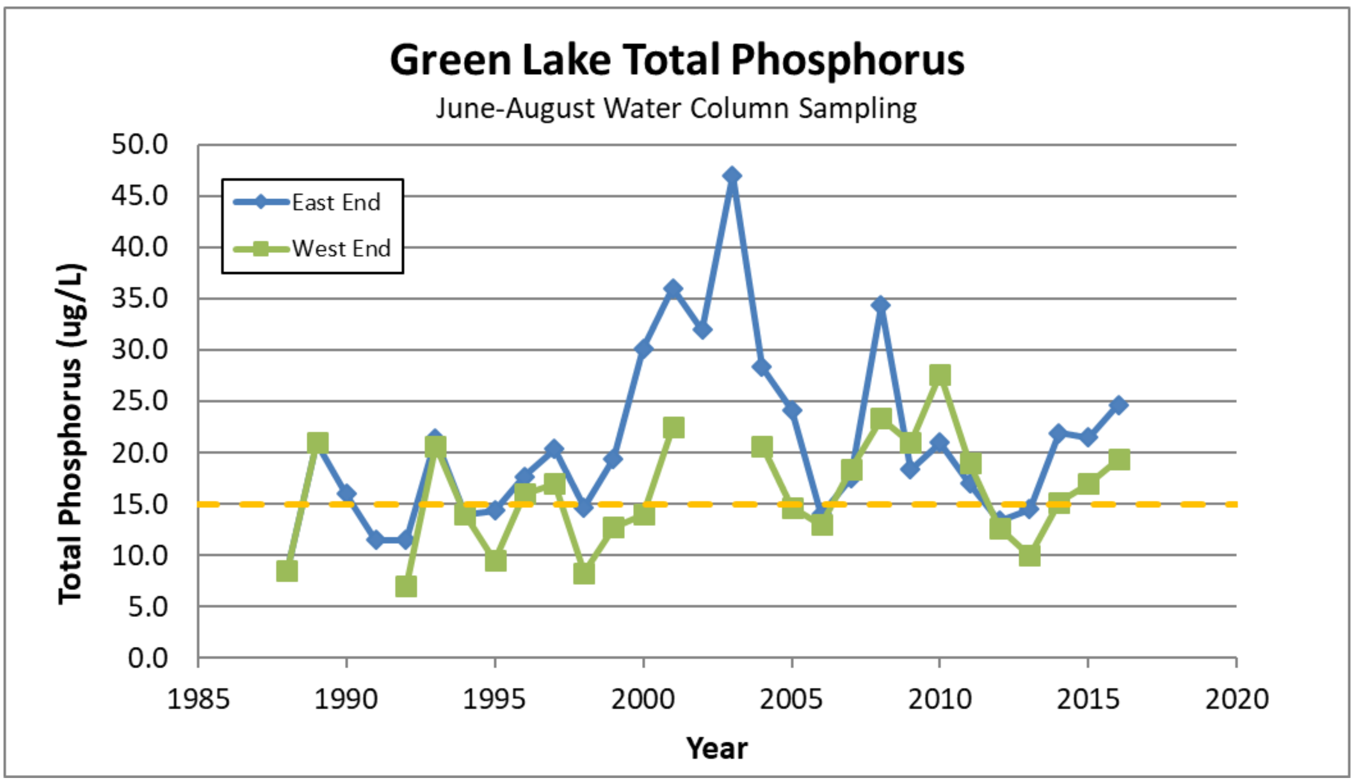

Figure 49. Big Green Lake's total phosphorus (mg/L) concentration has been measured by the WDNR (1988-2001) and the USGS (2004-present). Wisconsin Administrative Code 102 establishes that Big Green Lake's phosphorus concentrations at the lake's surface should not exceed 15 µg/L (shown as dashed yellow line).

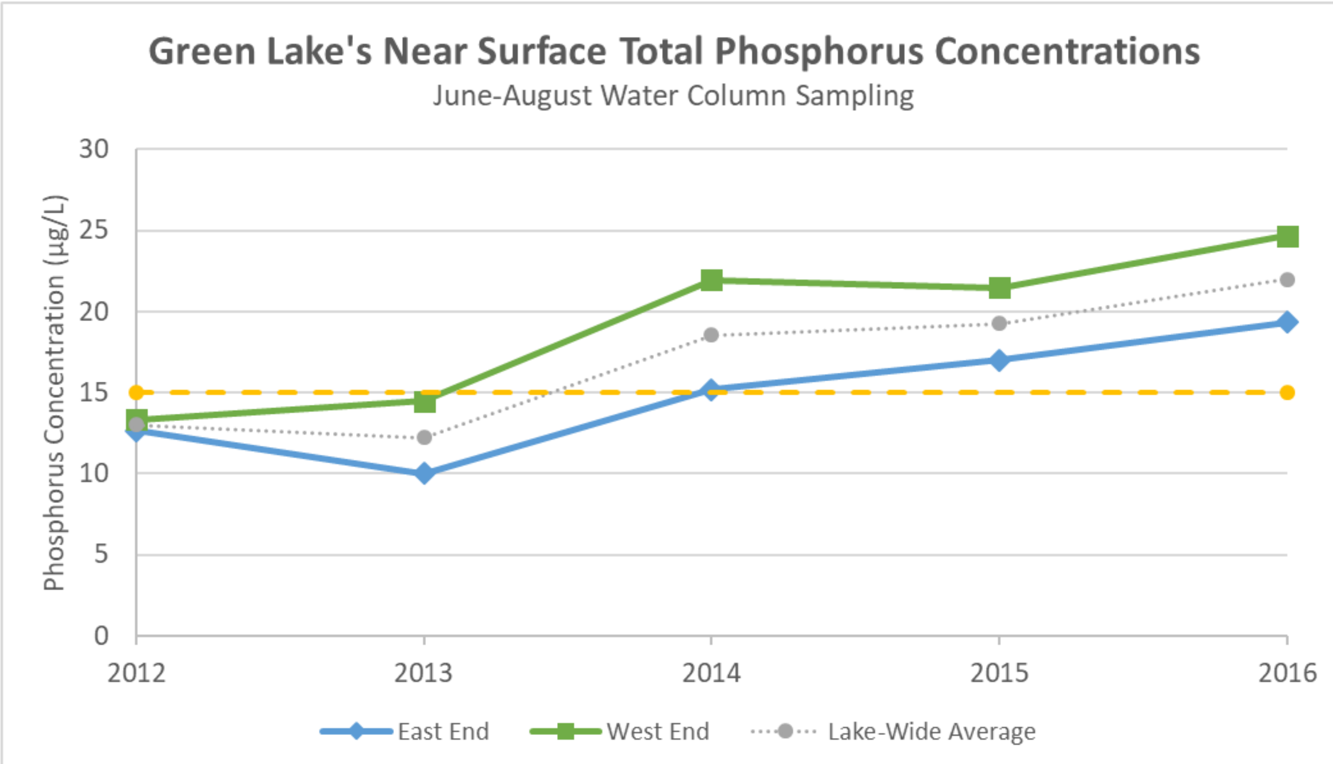

Figure 50. Average-summer near-surface lake-wide phosphorus concentration for Big Green Lake, with confidence limits as defined by the WDNR. Big Green Lake has a phosphorus concentration of 17.0 µg/L using methods established as part of Wisconsin's phosphorus criteria. Wisconsin Administrative Code 102 establishes that Big Green Lake's phosphorus concentrations at the lake's surface should not exceed 15 µg/L (shown as dashed yellow line). The lake "may exceed" these standards since 90% confidence internals range from 14.8 to 19.1 µg/L based on 2012-2016 monitoring.

viii. Chlorophyll-a Concentration

Changes in chlorophyll-a concentrations generally follow changes in phosphorus concentrations. Despite the correlation, chlorophyll-a concentrations are lower than expected relative to phosphorus levels based on trophic state relations. This phenomenon is not fully understood, but believed to be driven by zooplankton and zebra mussel dynamics.

WisCALM 2018 specifies that deep two-story fishery lakes such as Big Green Lake should have chlorophyll-a concentrations that do not exceed 20.0 µg/L during 95% of the time. Annual averages based on data from June-August from 1987 through 2015 were well below this value. However, chlorophyll-a concentrations exceeding this value have been measured on the east end of the lake. Big Green Lake's chlorophyll-a levels appear relatively stable (See Figure 51).

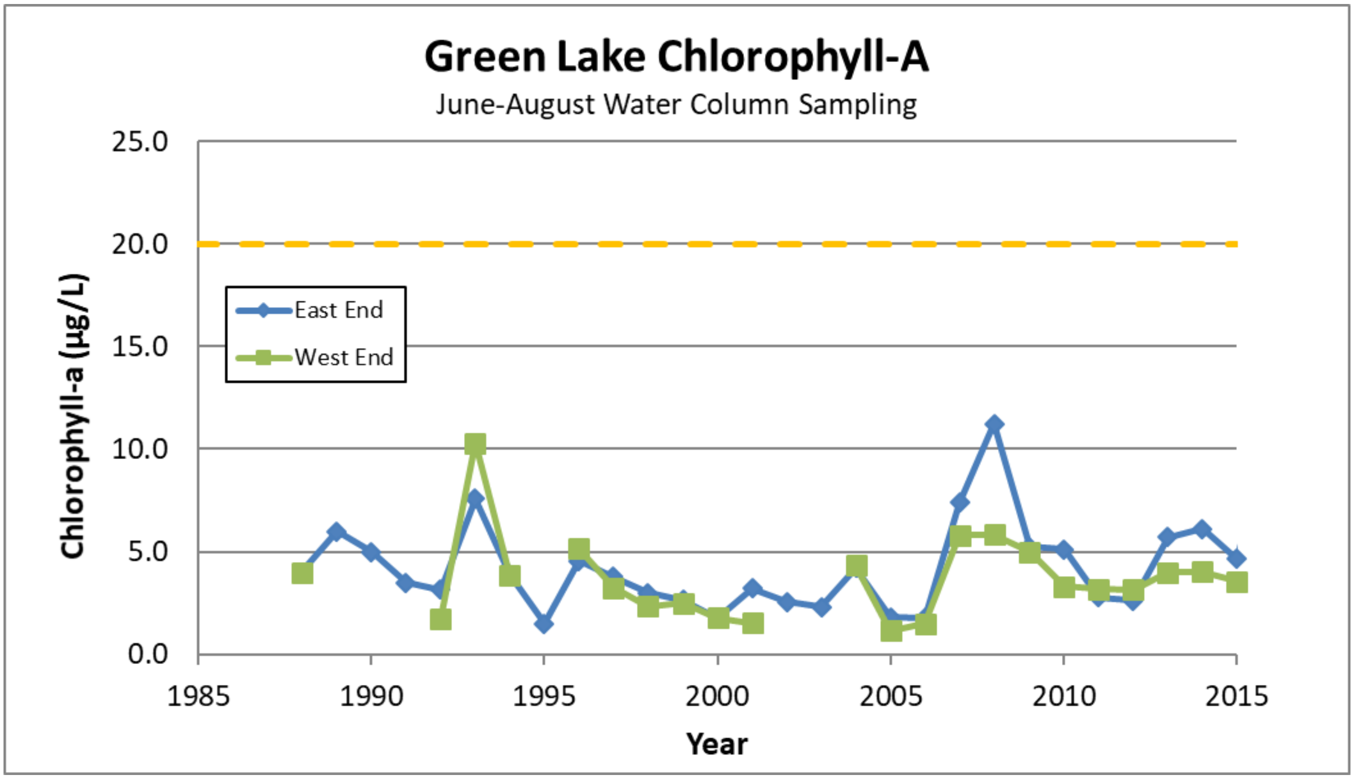

Figure 51. Big Green Lake's chlorophyll-a levels meet water quality standards that specify a maximum chlorophyll-a concentration of 20 µg/L (shown as yellow line).

ix. Dissolved Oxygen Concentration

Big Green Lake has two lake depth ranges with long-term decreases in dissolved oxygen concentrations: the thermocline (located at a depth of about 30 to 65 feet, or 10 to 20 meters) and the hypolimnion.

Metalimnetic and hypolimnetic oxygen minima have been documented in Big Green Lake by Birge and Juday as early as the early 1900s [66], though these were much less pronounced than those observed more recently (See Figure 52). Stauffer observed the dissolved oxygen minima in 1978 [71], and they appeared to be worse than in the early 1900s. Recent data collected by the USGS show that the dissolved oxygen minima have continued to get worse (See Figure 53) and there is notable inter-annual variability in the extent of hypoxia (See Figure 54 and Figure 55).

Oxygen depletion commonly occurs in the deep waters of stratified or ice-covered lakes, when oxygen-consuming processes deplete a finite pool of oxygen that is isolated from atmospheric exchange or photosynthetic (oxygen-producing) processes. Typically, the most intense oxygen demand occurs at the sediment interface, so that a zone of hypoxic or anoxic water is present at the bottom of the hypolimnion or throughout the hypolimnion.

a) Metalimnetic Oxygen Minima

In some systems, a metalimnetic oxygen minimum (MOM) forms near the thermocline, such as found in Big Green Lake. While extreme MOM is relatively uncommon in natural lakes, extreme MOMs are frequently observed in reservoirs [72]. MOMs have also been documented in many large alpine European lakes [73].

Low oxygen conditions can be detrimental to fisheries (with fish kills occurring in extreme cases). MOMs specifically have been documented to negatively impact both fish [74] and crustacean populations [75].

Although hypolimnetic oxygen minima are typically believed to primarily be caused by oxygen consumption by the bottom sediments, the formation of the MOM is generally attributed to in situ oxygen consuming processes [76] [77] [78] [79] [73], specifically the respiration of zooplankton and heterotrophic bacterial activity. As water column oxygen dynamics are largely controlled by the relative magnitudes of photosynthesis and respiration, Shapiro [77] suggested that the MOM phenomenon should occur any time the thermocline is located below the compensation point (the depth where respiration and photosynthesis are balanced). Furthermore, it may often be overlooked due to insufficient vertical sampling frequency [77] or because it coincides with hypolimnetic oxygen depletion.

In the metalimnion, dissolved oxygen concentrations consistently drop below 5 mg/L while the lake is stratified during late summer. Wisconsin Administrative Code NR 102.04 (4)(a) specifies that concentrations greater that 5 mg/L in surface waters are required for optimal conditions for fish and aquatic life. This MOM varies from year-to-year, but consistently appears during stratified conditions and has generally worsened over time. This deficit is of concern because aquatic organisms, especially fish, require sufficient dissolved oxygen to stay alive.

While there is annual variability in the magnitude and depth of the MOM, presently it is consistently developing year-after-year during stratified conditions (from approximately July through September, see Figure 55). The layer of low dissolved oxygen measuring <5mg/L is located from about 30 feet (10 meters) from the water's surface and extends to a depth of 49 to 66 feet (15 to 20 meters).

As a result of this long-term degradation, the WDNR listed Big Green Lake as an "impaired waterbody" in 2014 for low levels of dissolved oxygen near the thermocline. The current pollutant is listed as phosphorus, though the mechanisms causing the MOM are not fully understood. Therefore, the LMPT is in the process of working with the USGS and other experts to determine which data/information and hydrodynamic tools would be best suited for examining how to improve water quality.

Consequently, lakes designated as "impaired" in Wisconsin typically have greater funding opportunities from government agencies to help understand and alleviate the identified problem. Furthermore, having the State identify Big Green Lake as impaired better enables all parties to identify specific strategies and solutions for returning our water body to acceptable water quality.

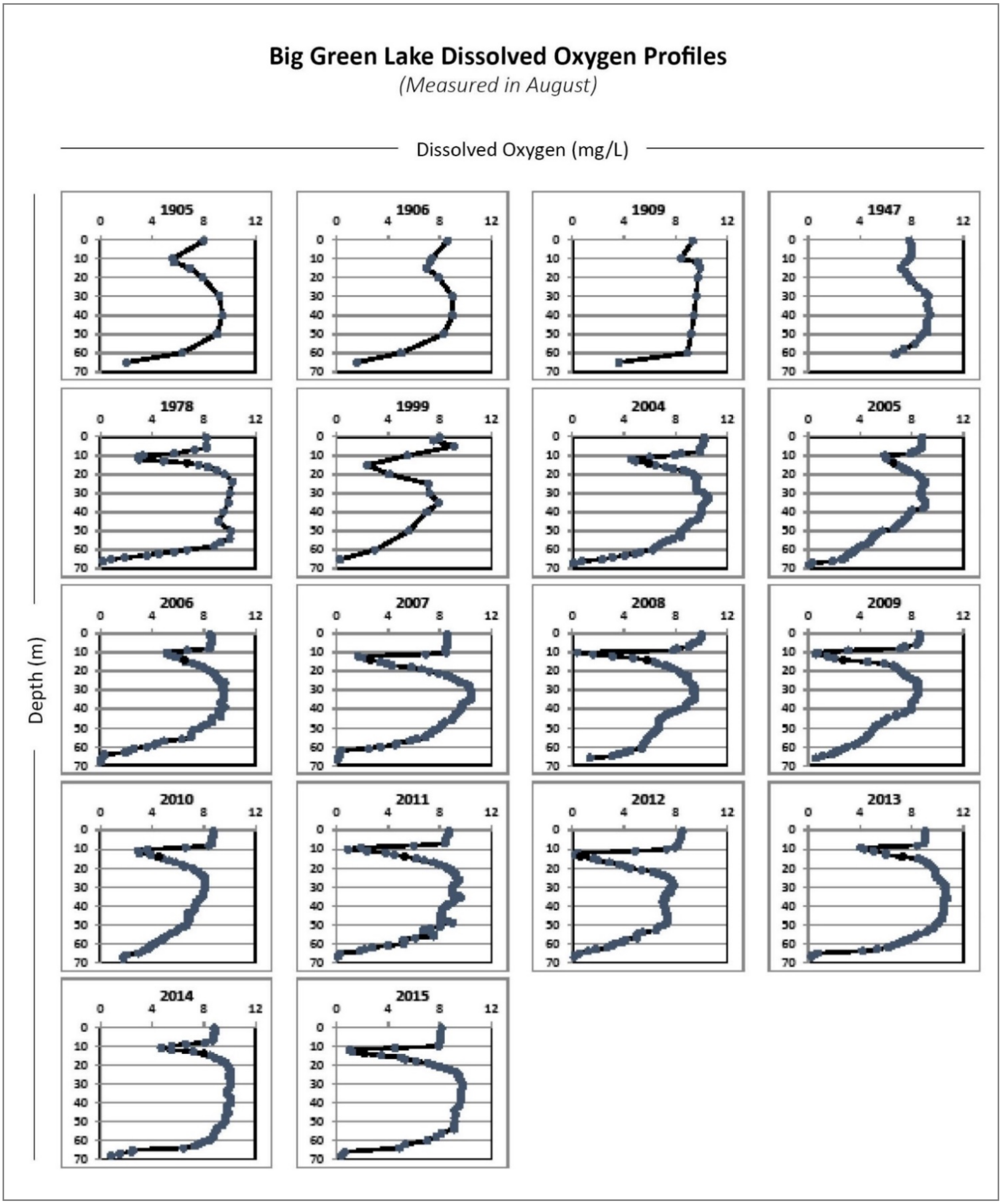

Figure 52. Big Green Lake has a well-documented MOM, dating back to 1905 by Birge and Juday. More recent data show the MOM has been increasing in intensity.

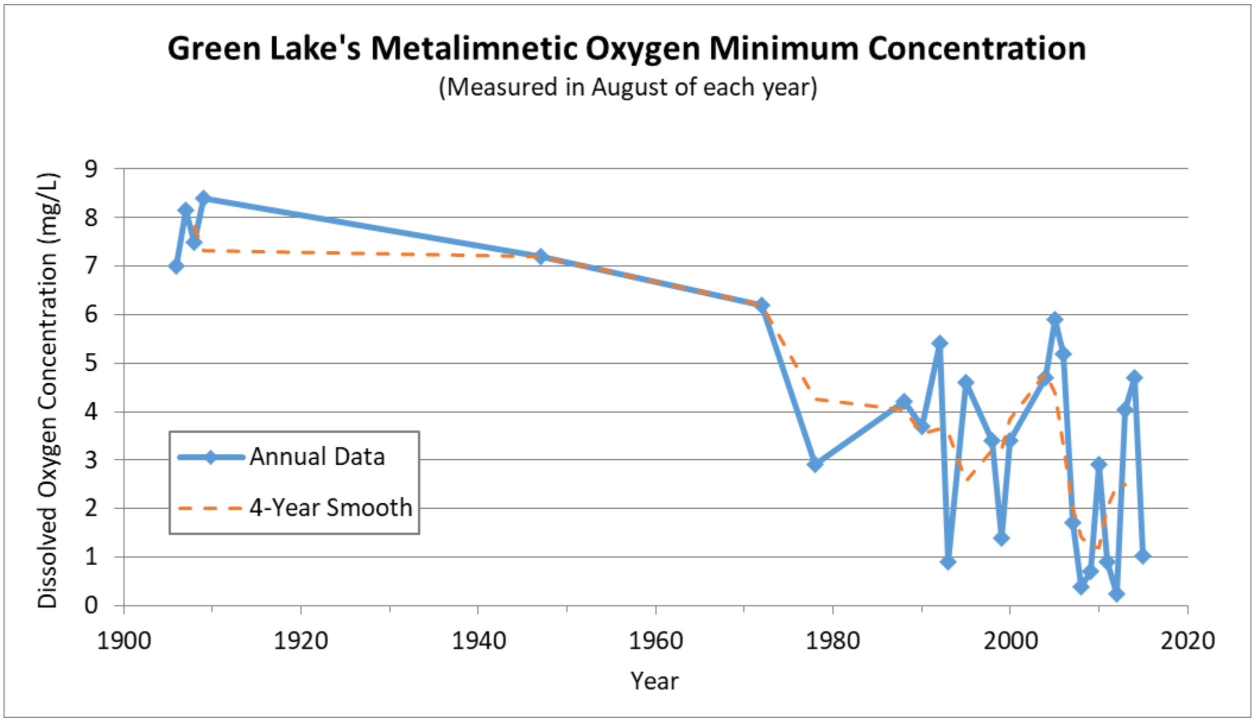

Figure 53. Data collected from the early 1900s to 2017 indicate that Big Green Lake's metalimnetic oxygen minima is getting more s sever over time. Since the 1970s, measured dissolved oxygen values are often below the optimal level of 5 mg/L.

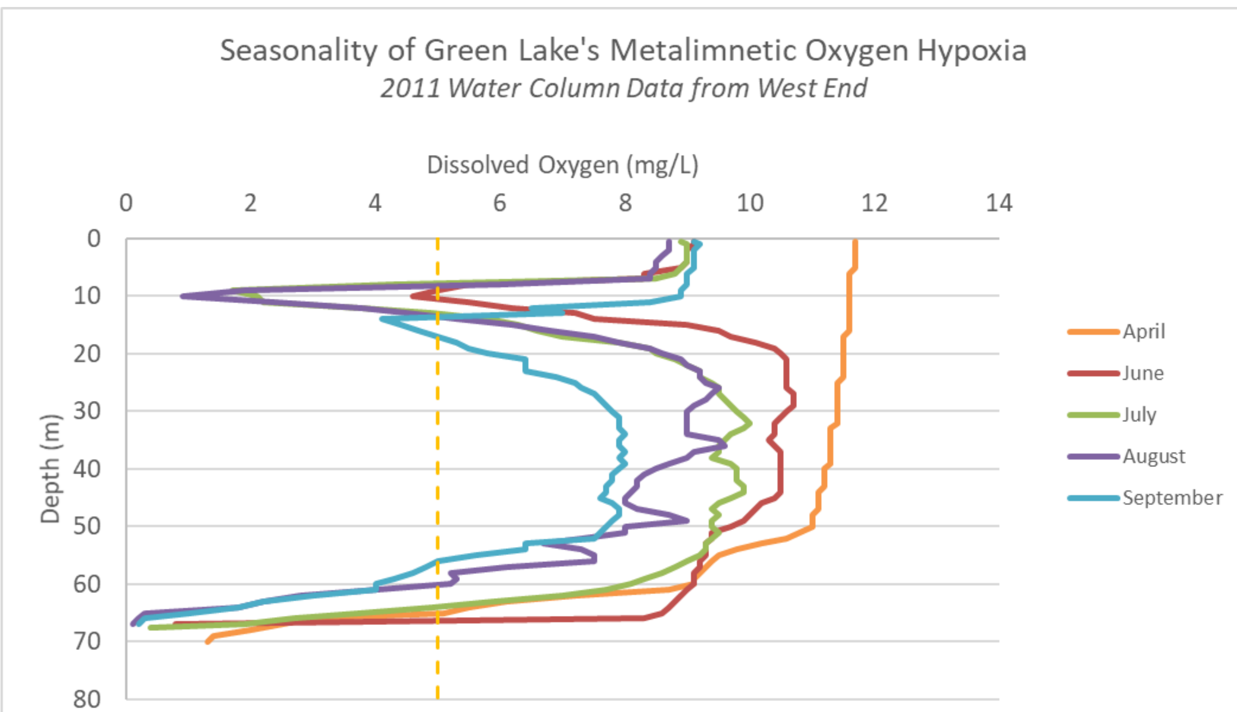

Figure 54. 2011 dissolved oxygen profile data from the West End sampling point demonstrates the seasonality of Big Green Lake's metalimnetic oxygen minima. The water quality criteria of 5 mg/L of dissolved oxygen is shown as a yellow dashed line.

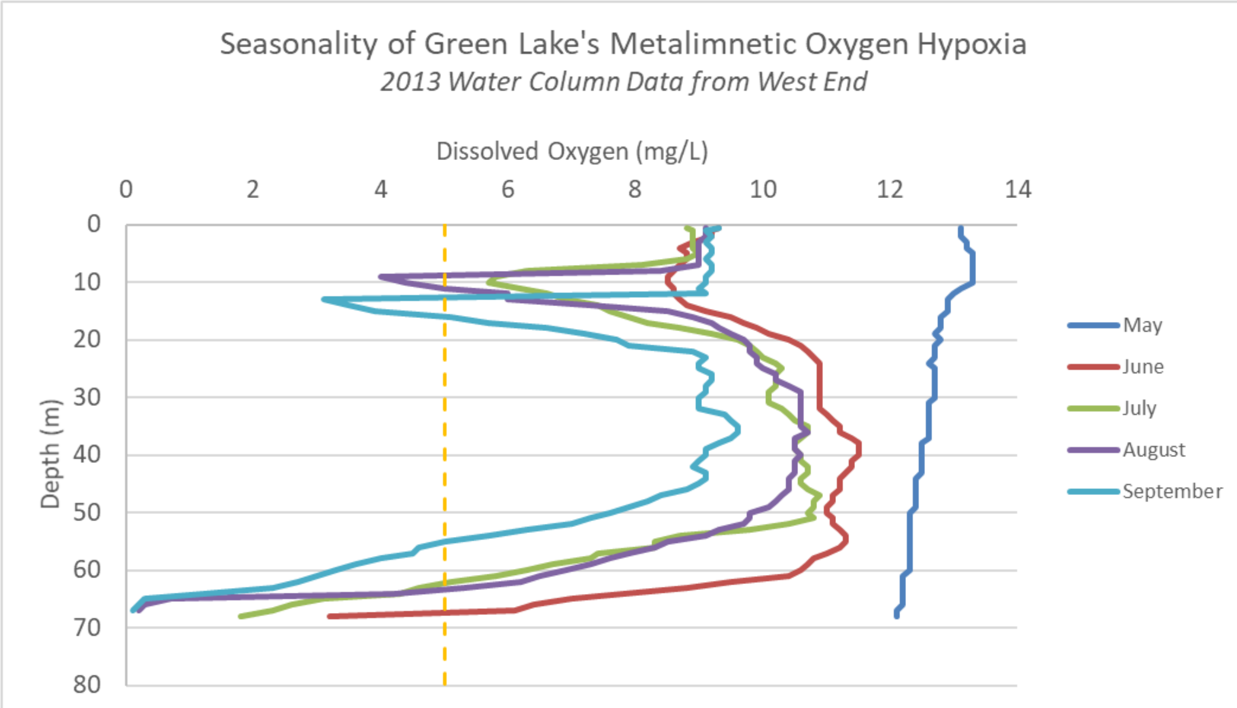

Figure 55. 2013 dissolved oxygen profile data from the West End sampling point demonstrates the seasonality of Big Green Lake's metalimnetic oxygen minima. The water quality parameter of 5 mg/L of dissolved oxygen is shown as a yellow dashed line.

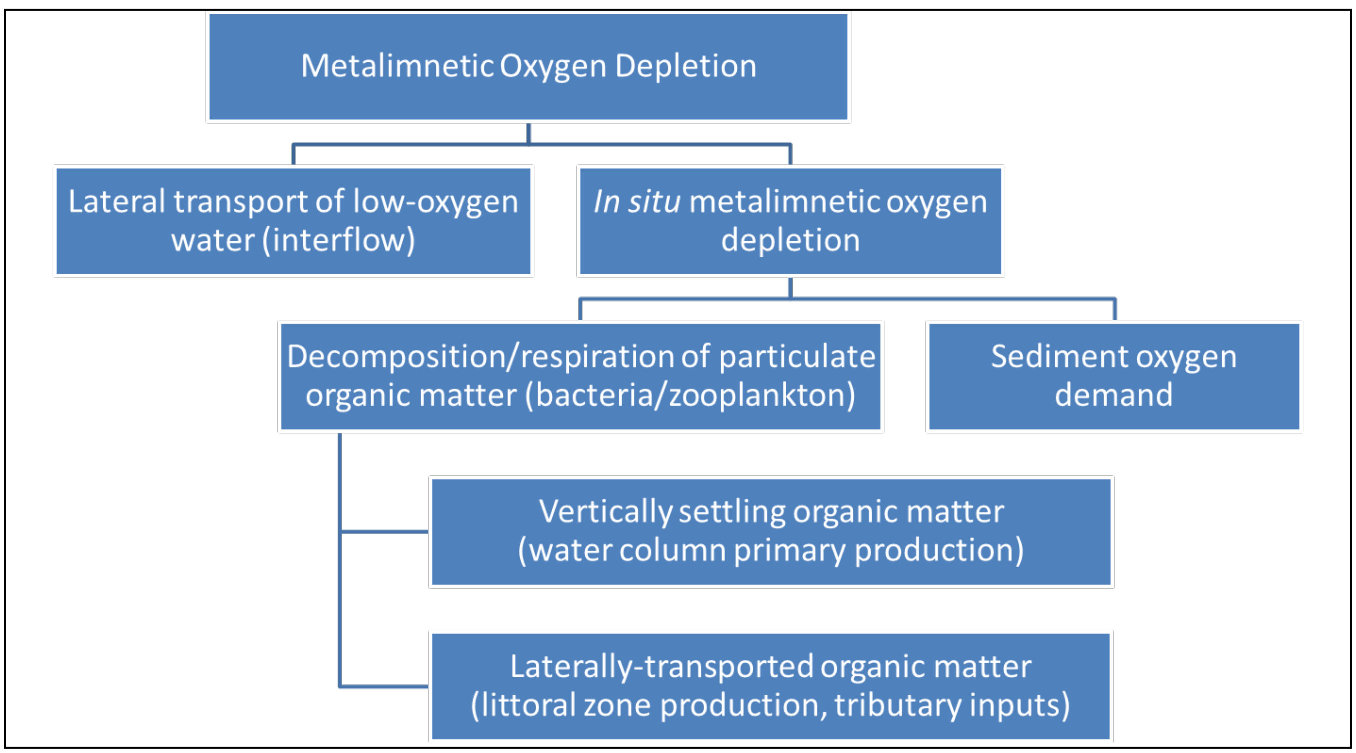

Figure 56. Potential drivers of metalimentic hypoxia in Big Green Lake.

A 2014 report by Watras [80] presented evidence that the MOM in Big Green Lake may indeed be induced by in-situ processes, most notably indicated by complimentary O_2 and CO_2 profiles in the metalimnion. No chlorophyll peak was observed in the metalimnion, though Stauffer [34] did observe one occasionally, and chlorophyll peaks are frequently observed in the lower regions of the epilimnion in recent data collected by the USGS.

Climate change may also play a role in the development of a MOM in Big Green Lake. For example, rainfall records from 1946-present from a nearby precipitation gauge (Station 47-7209) document an increase in 3" or larger rainfall events beginning in the 1980s. Freeze-thaw records maintained from 1939-present suggest that Big Green Lake is experiencing approximately a month less of annual ice cover.

x. Dissolved Oxygen Impairment (2014)

The WDNR applies specific water quality criteria to all Wisconsin lakes—Big Green Lake included—to determine if the water body in question should be classified as "impaired." These criteria measure the relative health of water resources in the state and guide management actions.

The water quality criteria for Big Green Lake are provided below:

Phosphorus	Dissolved Oxygen	Chlorophyll-a
<15 µg/L	>5 mg/L * ** Measured below 5 mg/L at mid-depth and in the deepest areas of the lake*	<20 µg/L during 95% of the time

The above parameters have been monitored for several years on Green Lake through a partnership with the WDNR, USGS, and GLSD. As summarized in the sections above, the results of monitoring over the past five years allows the WDNR to determine if Big Green Lake meets the criteria applied to the lake:

Phosphorus	Dissolved Oxygen	Chlorophyll-a
17.0 µg/L	<5 mg/L	4 µg/L

When the criteria are exceeded, the lake can be designated as impaired as it pertains to the criteria for that specific parameter. Extensive monitoring on Green Lake demonstrates that there is divergence with dissolved oxygen and phosphorus for Big Green Lake. Chlorophyll-a complies with the recommended criteria.

Therefore, because of the MOM (low dissolved oxygen at the thermocline), the WDNR listed Big Green Lake was listed as an "impaired" water body in 2014 [81]. The hypoxia is believed to be caused by excess nutrients – primarily phosphorus – but this phenomenon is not well-understood. As discussed earlier, the Diagnostic and Feasibility study is expected to determine which data, information and hydrodynamic tools would best be suited to help clarify the reasons behind the MOM.

This deficit is of concern because aquatic organisms, especially fish, require sufficient dissolved to stay alive. Although the low dissolved remains within a band of 5 meters or so during late summer, there is concern with respect to its cause and potential for expansion.

Consequently, lakes designated as "impaired" in Wisconsin typically have greater funding opportunities from government agencies to help understand and alleviate the identified problem. Furthermore, having the State identify Big Green Lake as impaired further enables all parties to identify specific strategies and solutions for returning our water body to acceptable water quality.

Big Green Lake is not presently listed as "impaired" for phosphorus. Although the 17.0 µg/L concentration is above the 15 µg/L impairment criteria, confidence limits caused by the variability in phosphorus concentrations fall slightly below the 15 µg/L. Therefore, presently, Big Green Lake does not meet the impairment criteria as it pertains to phosphorus.

Despite the "non-impairment" determination for phosphorus loading, the primary concern for Big Green Lake continues to be excessive phosphorus loading and it is possible the WDNR could be listed as impaired for phosphorus in the future. Phosphorus causes unwanted and excessive plant and algal growth and is believed to play a role in the current impairment of low dissolved oxygen near the thermocline.

C. Qualitative Characterization of Rivers

Excluding Big Green Lake itself, there are several tributaries within the Big Green Lake watershed that are 303(d)-listed as impaired waterbodies for various pollutants, as shown in Figure 26 and Table 4 in Section 3.C.

Tracking of water quality throughout Green Lake's watershed is possible because of extensive water quality monitoring. Since 1981, the GLSD has contracted with the USGS to conduct stream monitoring. In addition, the WDNR also continues to collect period grab samples from Big Green Lake's tributaries through Water Action Volunteers and WDNR staff.

i. USGS Stream Monitoring

The USGS has historically measured continuous discharge and estimated sediment and phosphorus loading at six tributary and outlet sites around the lake (see

). The USGS and GLSD, in consultation with the LMPT, have added, relocated, and/or discontinued sites as needed and as resources allow (Table 4).

The USGS presently monitors two tributary sites for nutrients within the Big Green Lake watershed (See

): Silver Creek at Spaulding Hill Road and the Southwest Inlet at County Highway K. These two inlets represent nearly 60% of the Green Lake watershed's area (48 square miles and 15 square miles, respectively) and 65% of its phosphorus loading [82].

The GLSD also coordinates with the USGS the collection grab samples at the Big Green Lake Inlet at County Highway A to estimate full loading from Silver Creek (between Spaulding Hill Road and County Highway A) and to evaluate wetland performance of the County Highway A Estuary.

There is currently no active monitoring station at the outlet of the lake, at the Puchyan River. This data would significantly help in both monitoring and modeling activities; monitoring could be enhanced by reactivating a station at the Puchyan River outlet of the lake. This would also allow lake managers to determine the lake's phosphorus and water budget. As funds allow, the LMPT supports the re-activation of the Puchyan River sampling station.

Table 19. With the GLSD's fiscal sponsorship, the USGS currently monitors two sites on Green Lake. As of 2021, the USGS monitors nutrients for Green Lake's two primary stream sites within the Big Green Lake watershed, representing approximately 70% of Green Lake's tributary inputs.

Site Name	USGS Gage #	Years of Gage Operation	Years of Load Computation	Active Gage	Discontinued Gage
Silver Creek at Spaulding Hill Rd	04073466	2012-2021	2012-2020	X	
Southwest Inlet at Highway K	040734605	2012-2021	2012-2020	X	
Silver Creek at Highway A	04073468	1987-2011	1988-2020		X
White Creek at Spring Grove Rd	04073462	2011 2018-2020	2011 2018-2020		X
Hill Creek near the mouth	040734615	2018-2020	2018-2020		X
Puchyan River at Green Lake (outlet)	04073470	1997-2012	1997-2017 2021 (computed by R. Johnson) [83]		X

The GLSD has committed to maintaining two USGS gages—Silver Creek Estuary at Spaulding Hill Rd and the Southwest Inlet at County Highway K—for the next five years to provide an ongoing baseline for the water quality sampling program. Additional monitoring will be added as funding supports.

ii. WDNR Stream Monitoring

Between 2014 and 2015, D. Bolha conducted two targeted watershed assessments—for Big Green Lake TWA [42] and for tributaries on the south side of Green Lake [84]—to gather baseline water quality assessment data in the Big Green Lake watershed with biological, inorganic chemistry, and habitat surveys that provide valuable information for future comparison. A total of 20 sites were monitored as part of this assessment (See Figure 57).

Considerable stream restoration and watershed BMP work has been completed since the targeted watershed assessment was complete. More BMPs are also planned for the future by multiple agencies, including Green Lake County Land Conservation Department (GLC-LCD), Natural Resource Conservation Service (NRCS), Green Lake Sanitary District (GLSD), and the Green Lake Association within the watershed.

While the USGS active stream sampling program measures inputs for two main sites (Table 4), there is limited water quality data upstream in the headwaters of Big Green Lake's tributaries. This WDNR watershed assessment helps provide a finer resolution on upstream water quality and will be used as criteria to evaluation plan implementation (Element 8)—though additional funding upstream of the inlet sites would help better prioritize nutrient hotspots and BMP priority locations.

A secondary goal of this project was to determine Wisconsin Administrative Code ch. NR 102 (NR 102) phosphorus water quality criteria exceedances and degraded biological community and habitat impairments for US-EPA Clean Water Act Section 303(d) listing purposes for the creeks in the Big Green Lake watershed.

The 2014-2015 monitoring of the streams in the Big Green Lake watershed indicate that the water quality has been significantly impacted by environmental degradation. The phosphorus concentrations in most of the streams were near or above Wisconsin's TP criteria.

Figure 57 below shows map of monitoring stations and results from the DNR's Targeted Watersehd Approach (TWA) monitoring. As plan implementation occurs, the LMPT GLC-LCD, GLSD, and NRCS will continue to consult with WDNR water quality biologists during the next ten years. These consultations may result in future watershed assessments being completed by WDNR within selected TMDL sub-basins, particularly within sub-basins where substantial implementation and maintenance of phosphorus reduction BMPs has been confirmed over multiple years.

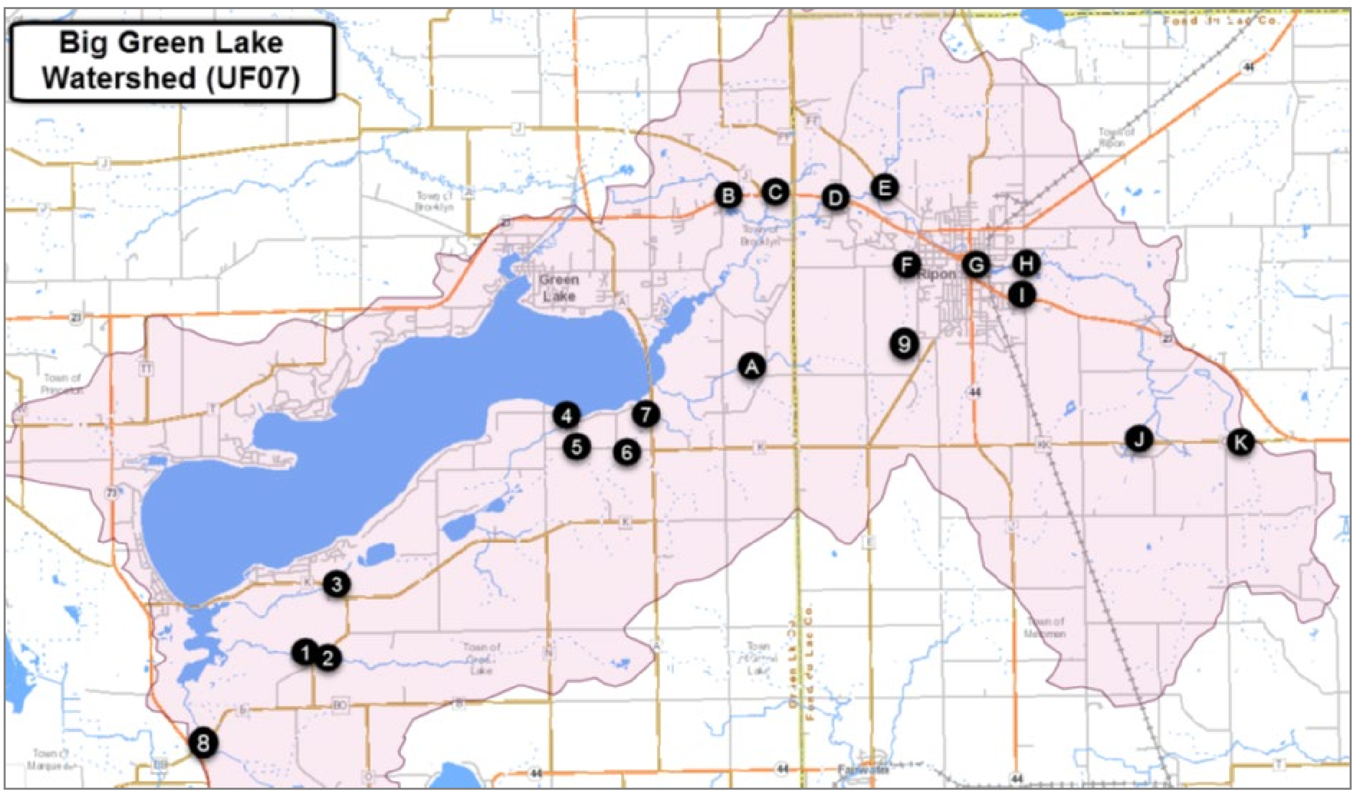

Figure 57. The WDNR collected water quality samples from 20 stream sites as part of a 2014-2015 baseline water quality assessment. Sampling parameters and total phosphorus concentration results for all stations are shown below-.

Table 5: Monitoring stations and parameters measured at each location in the Southern Big Green Lake Watershed in 2014.

SWIMS Station ID	Site Name	WBIC	Parameters Measured	Map ID
10041576	Roy Creek Downstream of County Hwy O	148200	Aquatic Macroinvertebrate, Wadable Fish Survey, Quantitative habitat survey	1
10021317	Roy Creek 200 Feet Above County Hwy O	148200	Aquatic Macroinvertebrate, Wadable Fish Survey, Quantitative habitat survey	2
243026	Spring Creek Upstream of County Hwy K	148000	TP, Aquatic Macroinvertebrate, Wadable Fish Survey, Quantitative habitat survey	3
10033838	Hill Creek Upstream of Spring Grove Road	146200	TP, Aquatic Macroinvertebrate	4
10041578	Unnamed Tributary to Hill Creek Upstream from Scott Hill Road	5027219	TP, Aquatic Macroinvertebrate, Wadable Fish Survey, Quantitative habitat survey	5
10042146	Unnamed Tributary to White Creek Upstream from Scott Hill Rd	5027243	TP, Aquatic Macroinvertebrate	6
243059	White Creek Upstream Spring Grove Road	146600	Aquatic Macroinvertebrate, Wadable Fish Survey, Quantitative habitat survey	7
10012583	Wuerches Creek Upstream County Road B	148300	Aquatic Macroinvertebrate, Wadable Fish Survey, Quantitative habitat Survey	8

Table 6: Monitoring stations and parameters measured at each location in the Silver Creek Watershed in 2014.

SWIMS Station ID	Site Name	WBIC	Parameter Measured	Map ID
10037918	Dakin Creek E of FDL County Line	146700	TP, TSS, Wadable Fish Survey, Qualitative Habitat Survey, Continuous Temperature	A
10041508	Unnamed Trib to Silver Creek at Hwy 23	146900	TP, TSS, Wadable Fish Survey, Qualitative Habitat Survey, Continuous Temperature	B
10041507	Unnamed Trib to Silver Creek at Murray Rd	147000	TP, TSS, Wadable Fish Survey, Qualitative Habitat Survey, Continuous Temperature	C
203080	Silver Creek at Koro Rd	146800	TP, TSS, Wadable Fish Survey, Qualitative Habitat Survey, Continuous Temperature	D

10016330	Unnamed Trib to Silver Creek at Trail (County FF)	147400	TP, TSS, Wadable Fish Survey, Qualitative Habitat Survey, Continuous Temperature	E
10040834	Unnamed Trib to Silver Creek US Arcade Rd	5026964	TP, TSS	F
10015911	Silver Creek DS Scott Street Dam	146800	TP, TSS, Wadable Fish Survey, Qualitative Habitat Survey, Continuous Temperature	G
10021299	Silver Creek at Douglas St (Hwy 44)	146800	TP, TSS, Continuous Temperature	H
10041506	Unnamed Trib to Silver Creek at Hwy 23	5027015	TP, TSS, Wadable Fish Survey, Qualitative Habitat Survey	I
10041510	Silver Creek at County KK	146800	TP, TSS, Wadable Fish Survey, Qualitative Habitat Survey, Continuous Temperature	J
10041509	Unnamed Trib to Silver Creek at County KK	147700	TP, TSS, Wadable Fish Survey, Qualitative Habitat Survey, Continuous Temperature	K

Table 10: Total Phosphorus Lower 90% Confidence Limits and Water Quality Criteria Exceedance Status of 4 Creeks in the Southern Big Green Lake Watershed in 2014.

	Hill Creek Site 4	Spring Creek Site 3	Unnamed Trib to White Creek - Site 6	Unnamed Trib to Hill Creek - Site 5
LCL (90%) mg/L	0.0894	0.0172	0.0465	0.0433
Exceedance Level	Exceeds	Meets	Meets	Meets

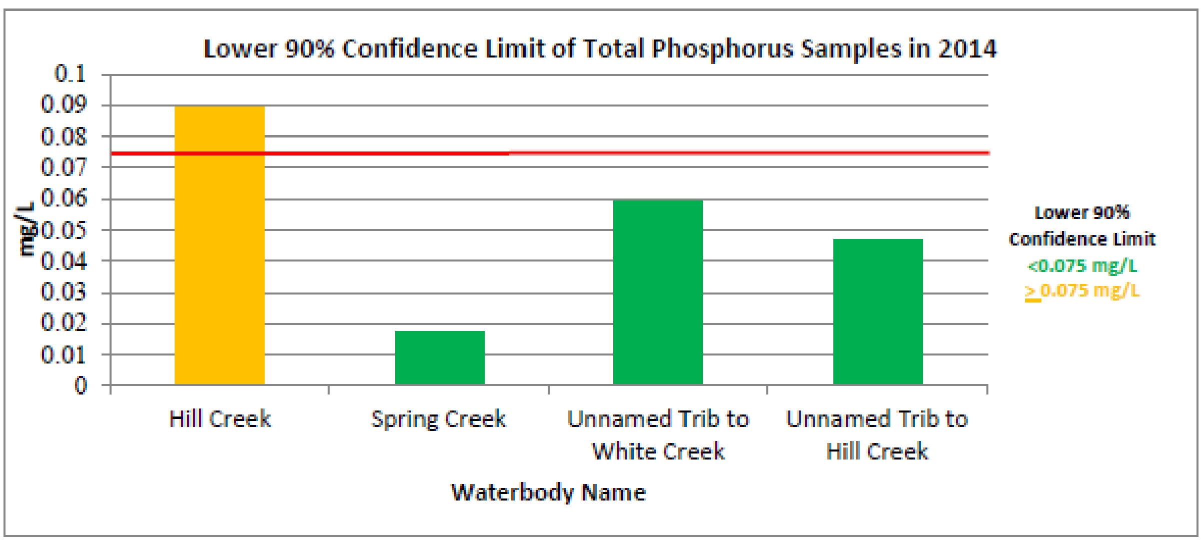

Figure 8: Total Phosphorus Lower 90% Confidence Limit in Creeks Sampled in 2014 (with 0.075 mg/L WQC red line) in the Southern Big Green Lake Watershed in 2014.

Table 11: Total Phosphorus Lower 90% Confidence Limit and Water Quality Criteria Exceedance Level of Samples Collected in the Silver Creek Mainstem from Upstream to Downstream in 2014.

	Silver Creek at Hwy KK Site J	Silver Creek Above Gothic Millpond at Hwy 44 Site H	Silver Creek Below Gothic Mill Pond Site G	Silver Creek at Koro Rd Site D
LCL (90%) mg/L	0.0225	0.0925	0.0605	0.077
Exceedance Level	Meets	Exceeds	Meets	Exceeds

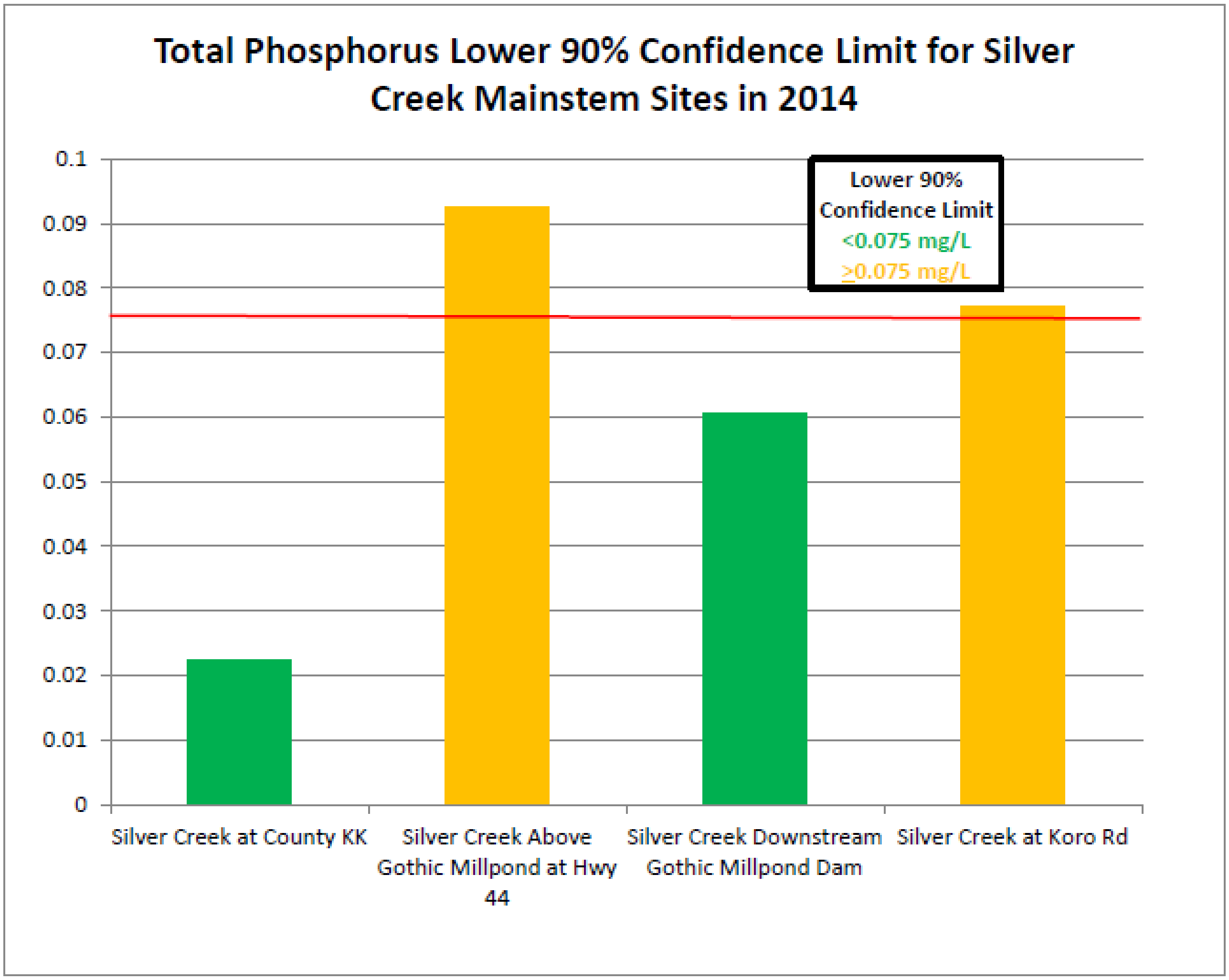

Figure 9: Total Phosphorus Lower 90% Confidence Limit and Water Quality Criteria Exceedance Level of Samples Collected in the Silver Creek Mainstem from Upstream to Downstream in 2014 (with 0.075 mg/L WQC red line).

Table 12: Total Phosphorus Lower 90% Confidence Limit and Water Quality Criteria Exceedance Level of Samples Collected in the Tributaries of the Silver Creek Watershed in 2014.

	Unnamed Site B	Unnamed Site C	Unnamed Site E	Unnamed Site F	Unnamed Site I	Unnamed Site K	Dakin Creek Site A
LCL (90%) mg/L	0.0859	0.0576	0.1426	0.0836	0.0245	0.1011	0.0401
Exceedance Level	Exceeds	Meets	Exceeds	Exceeds	Meets	Exceeds	Meets

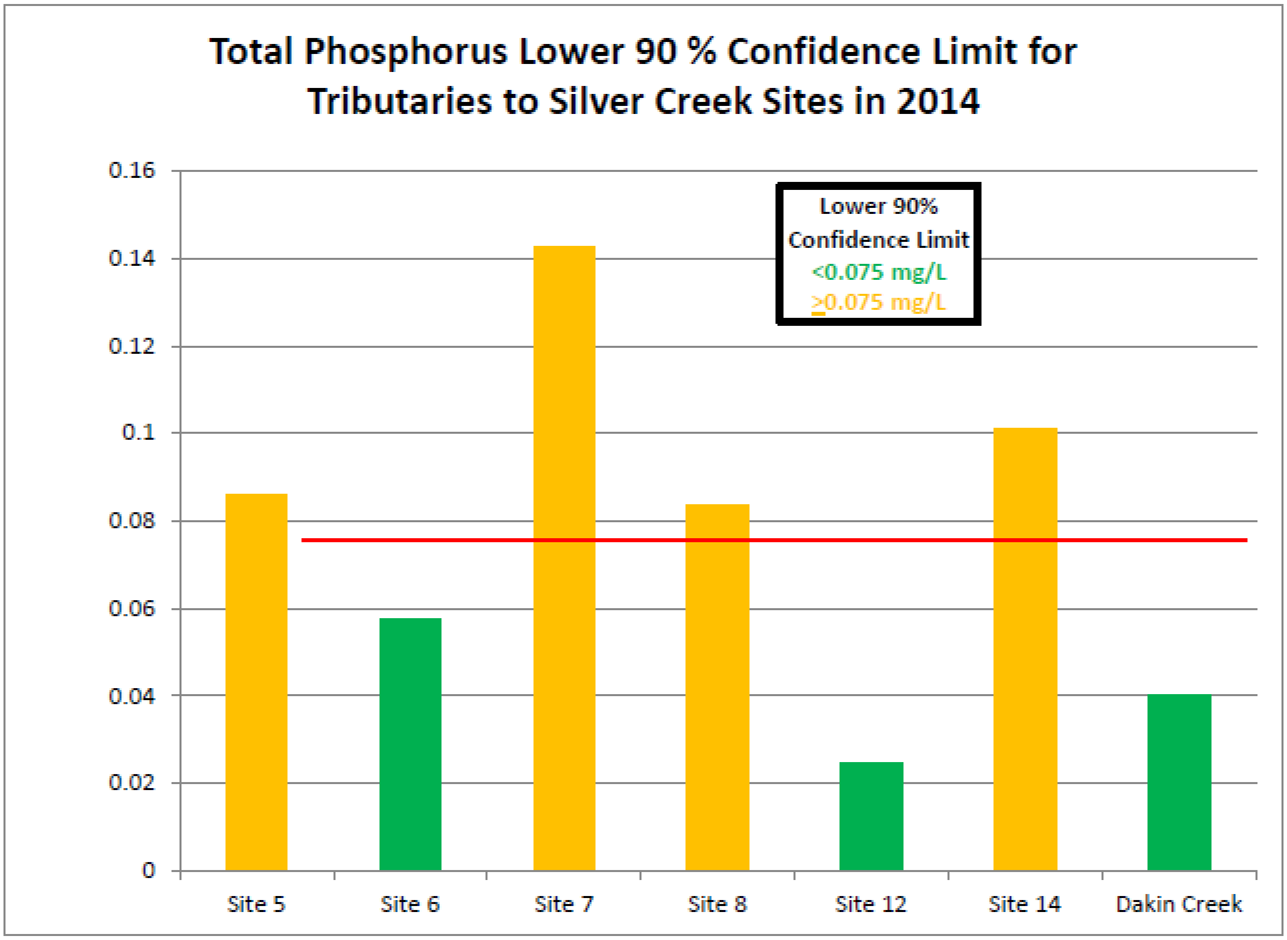

Figure 10: Total Phosphorus Lower 90% Confidence Limit and Water Quality Criteria Exceedance Level of Samples Collected in the Tributaries of the Silver Creek Watershed in 2014 (with 0.075 mg/L WQC red line).

iii. Stream Assessment (2014 and 2015)

In 2014, the Green Lake County Land Conservation Department (GLC-LCD) conducted an on-the-ground survey of 27 miles of five tributaries to Big Green Lake. These tributaries included streams that were classified as impaired or outstanding water resources by the Wisconsin DNR (Roy, Wuerches, Hill, White, and

Dakin). In 2015, the Green Lake Association and Ripon College conducted a stream assessment for Silver Creek.

The purposes of the tributaries survey and the stream assessment were to document stream condition, stream habitat, bank erosion and quality/width of stream buffers. Data that were collected included channel condition, buffer zone, bank stability, bank height, water appearance, nutrient enrichment, and in-stream fish cover. Inventories were conducted within the buffer zone including, buffer width, ground cover, shrub cover and tree cover.

Staff navigated to preset survey points located every 150 feet along stream corridors and tributaries. See Figure 32) At each survey point, the stream segment (150 feet) was analyzed using a method based on the Federal USFS Stream Visual Assessment Protocol (SVAP). The data were entered into a database linked to a GIS map, which allowed the development of interpretive maps and the prioritization of stream restoration projects.

A complete copy of the 270-page final report for the tributary survey within Green Lake County is available by contacting the GLC-LCD at lcd@co.green-lake.wi.us. Data for Silver Creek and Dakin Creek in Fond du Lac County is available by contacting the FDL-LWCD at melanie.boone@fdlco.wi.gov.

Survey results were mapped for Green Lake County, only, for all five streams surveyed in that county: Dakin, Hill, Roy, White, and Wuerches Creeks. An excerpt showing bank height, one indication of stream erosion measured in this study, is shown for every mapped sub-watershed in Green Lake County (see Figure 59 through Figure 62). Fond du Lac County LWCD did not create similar maps for Silver Creek; Assembly and Spring Creeks were not surveyed as part of this study.

Since the stream survey completion, the watershed has experienced a large number of significant rainfall events causing significant new stream erosion (tell story about Roy Creek here?). In addition, intermittent streams feeding the named streams were not surveyed and may be significant sources of sediment and P loading. The LMP recommends that updated surveys, including intermittent streams, be conducted on a subwatershed basis in temporal conjunction with planned restoration activities.

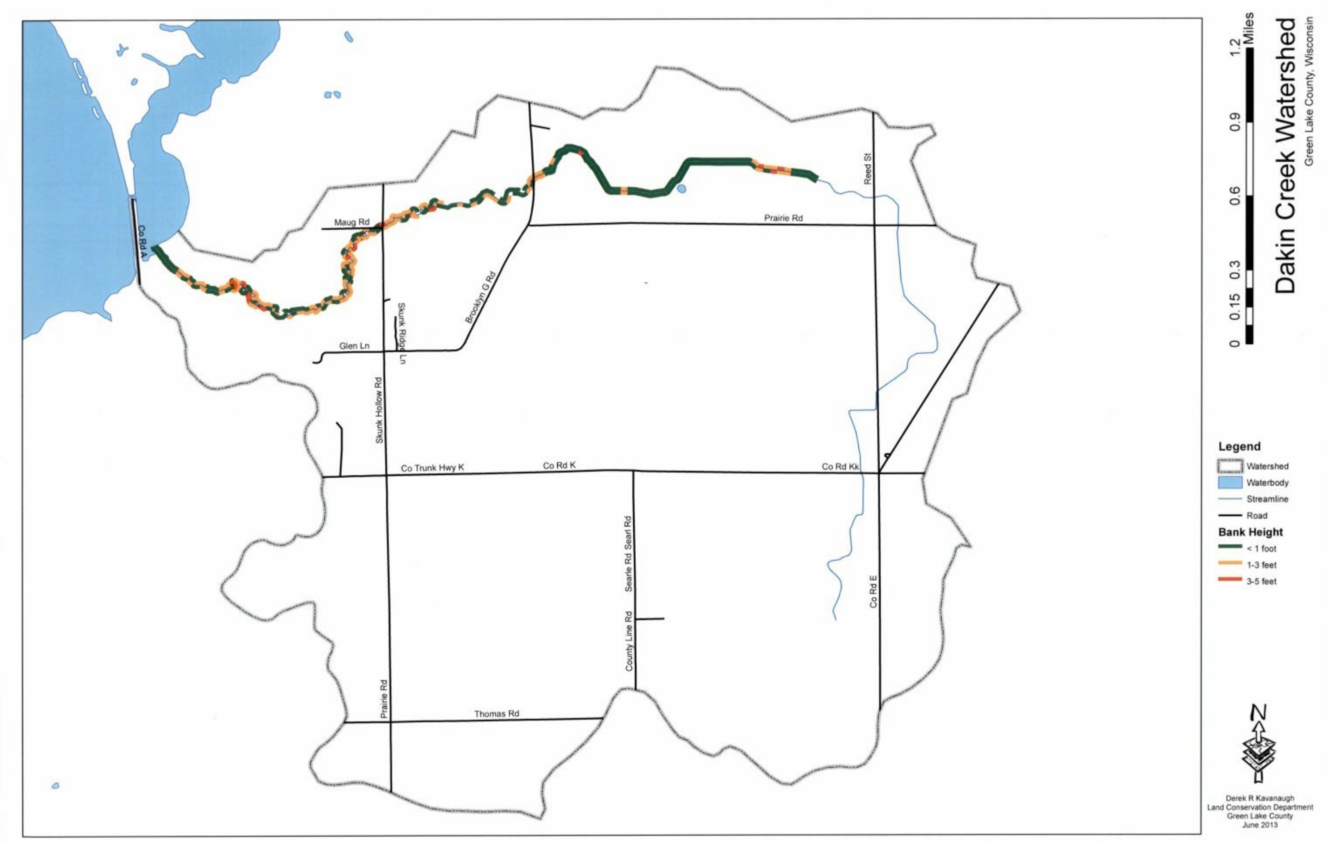

Figure 58. An example of GIS-based bank height data generated for the Dakin Creek watershed as part of the Big Green Lake Buffer Assessment Project. Bank heights of <1 foot are shown in green, 1-3 feet in yellow, and 3-5 feet in red.

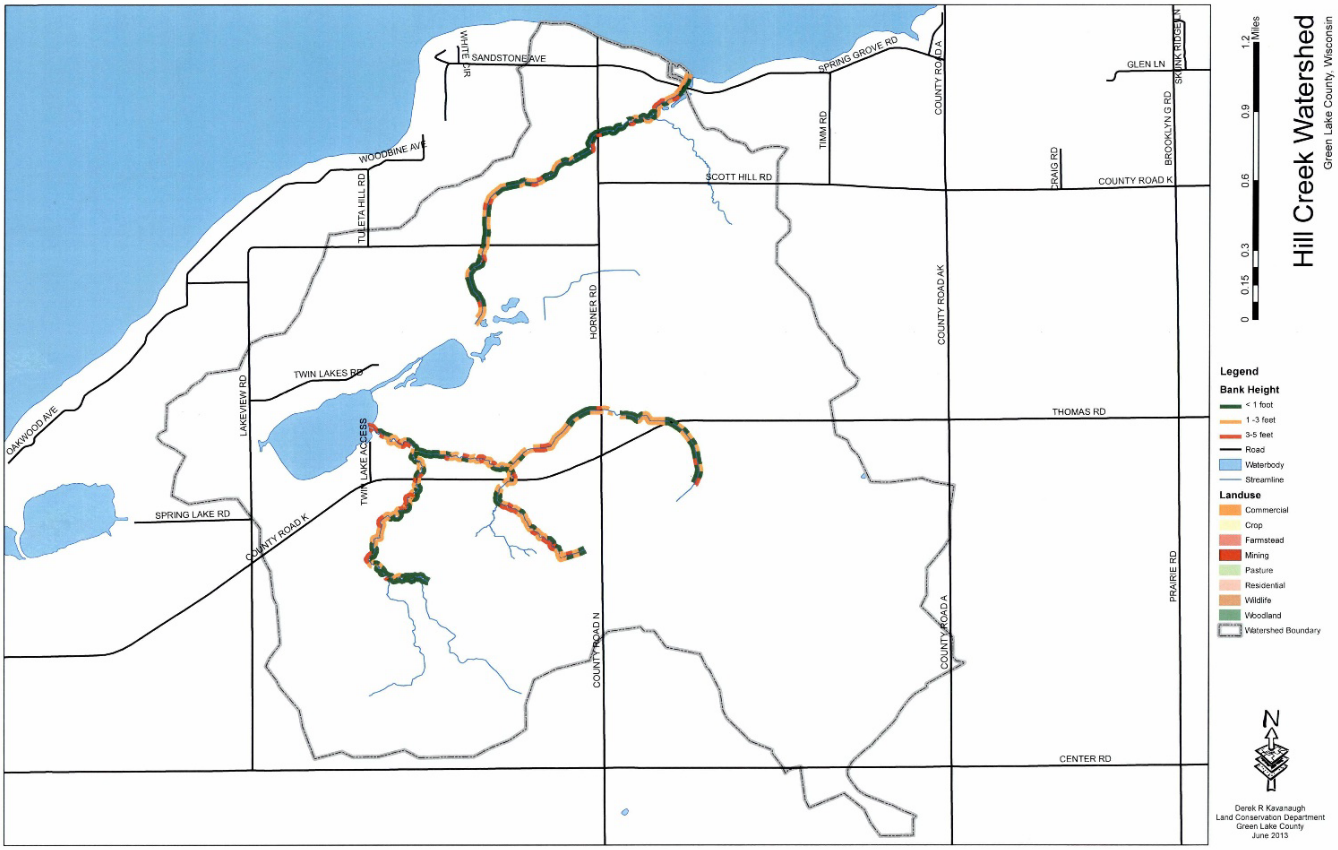

Figure 59. An example of GIS-based bank height data generated for the Hill Creek watershed as part of the Big Green Lake Buffer Assessment Project. Bank heights of <1 foot are shown in green, 1-3 feet in yellow, and 3-5 feet in red.

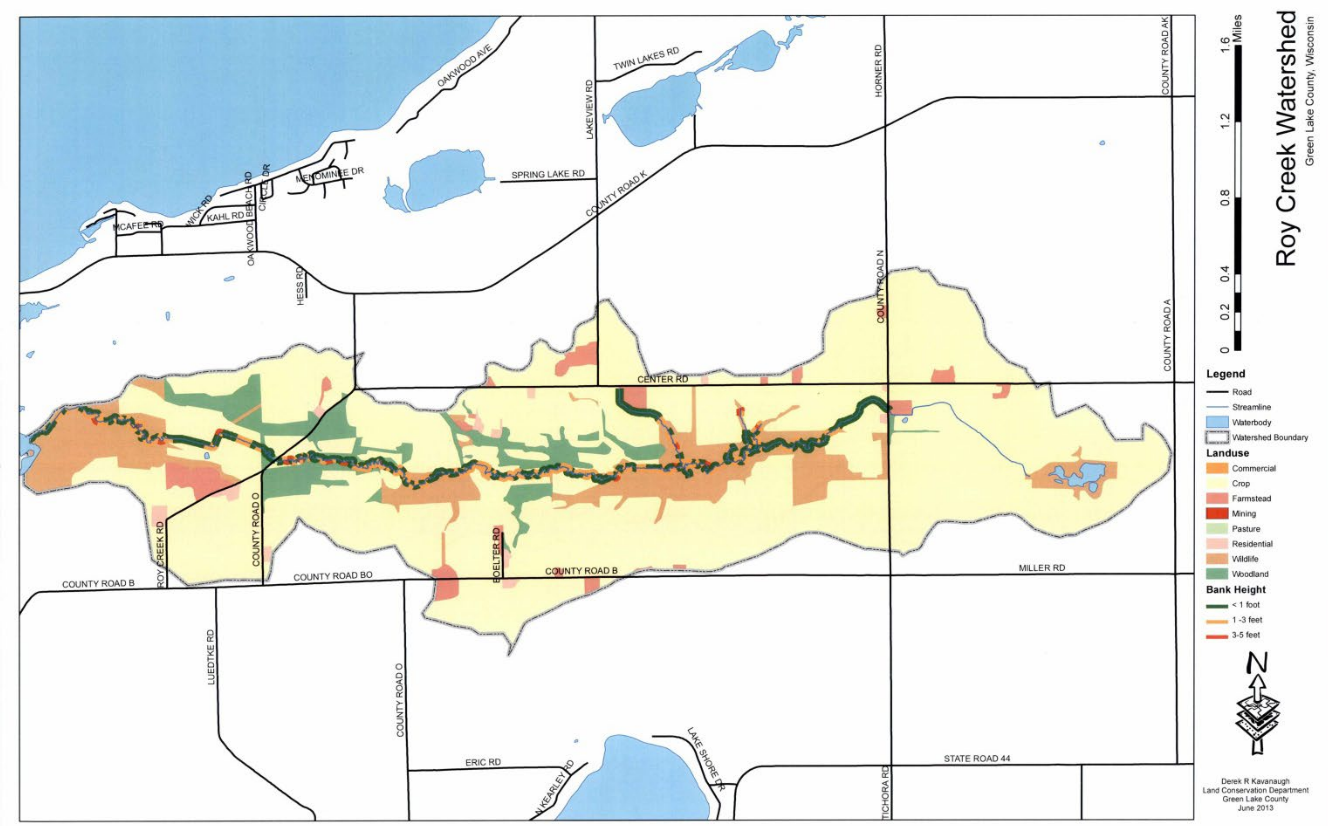

Figure 60. An example of GIS-based bank height data generated for the Roy Creek watershed as part of the Big Green Lake Buffer Assessment Project. Bank heights of <1 foot are shown in green, 1-3 feet in yellow, and 3-5 feet in red.

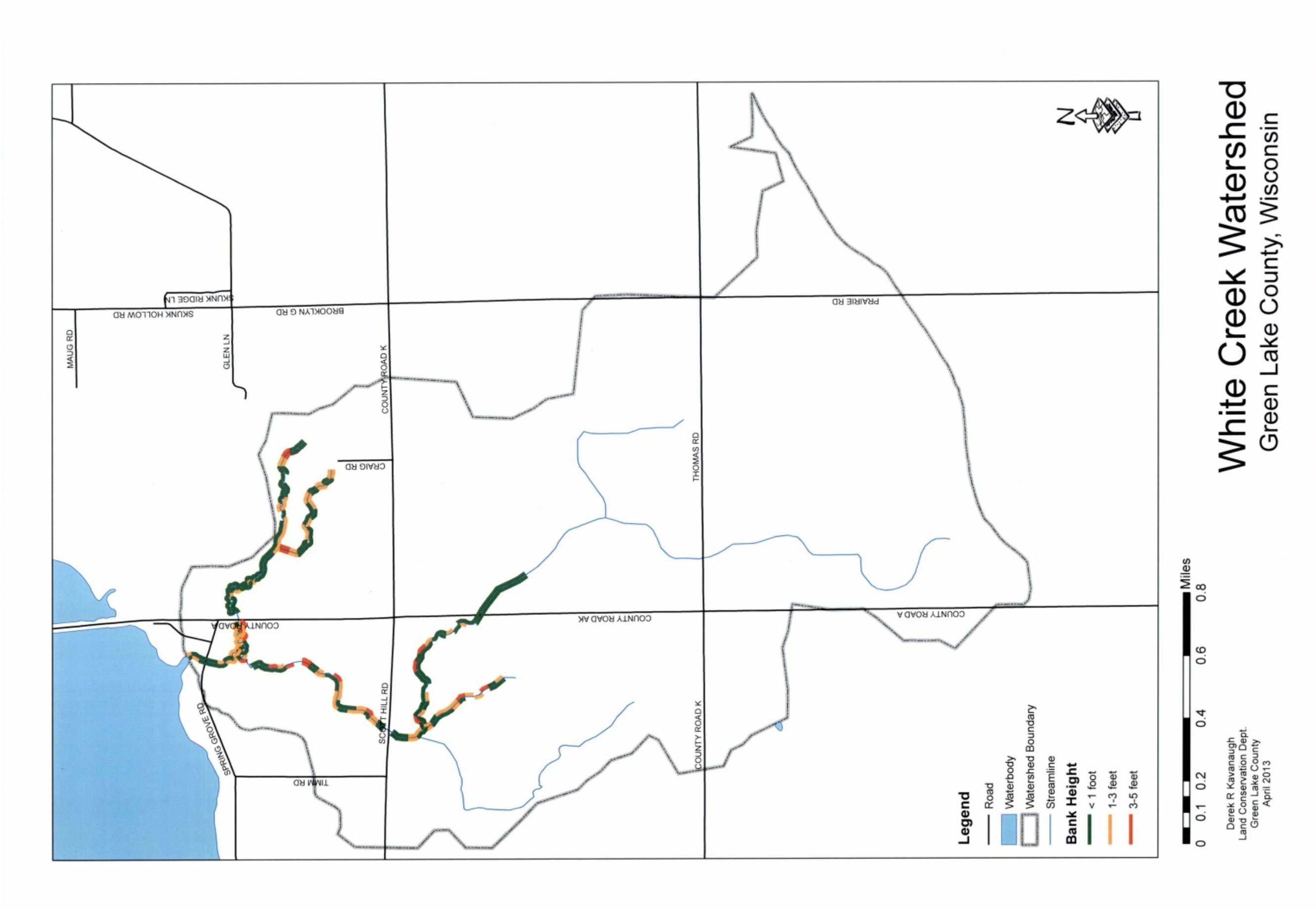

Figure 61. An example of GIS-based bank height data generated for the White Creek watershed as part of the Big Green Lake Buffer Assessment Project. Bank heights of <1 foot are shown in green, 1-3 feet in yellow, and 3-5 feet in red.

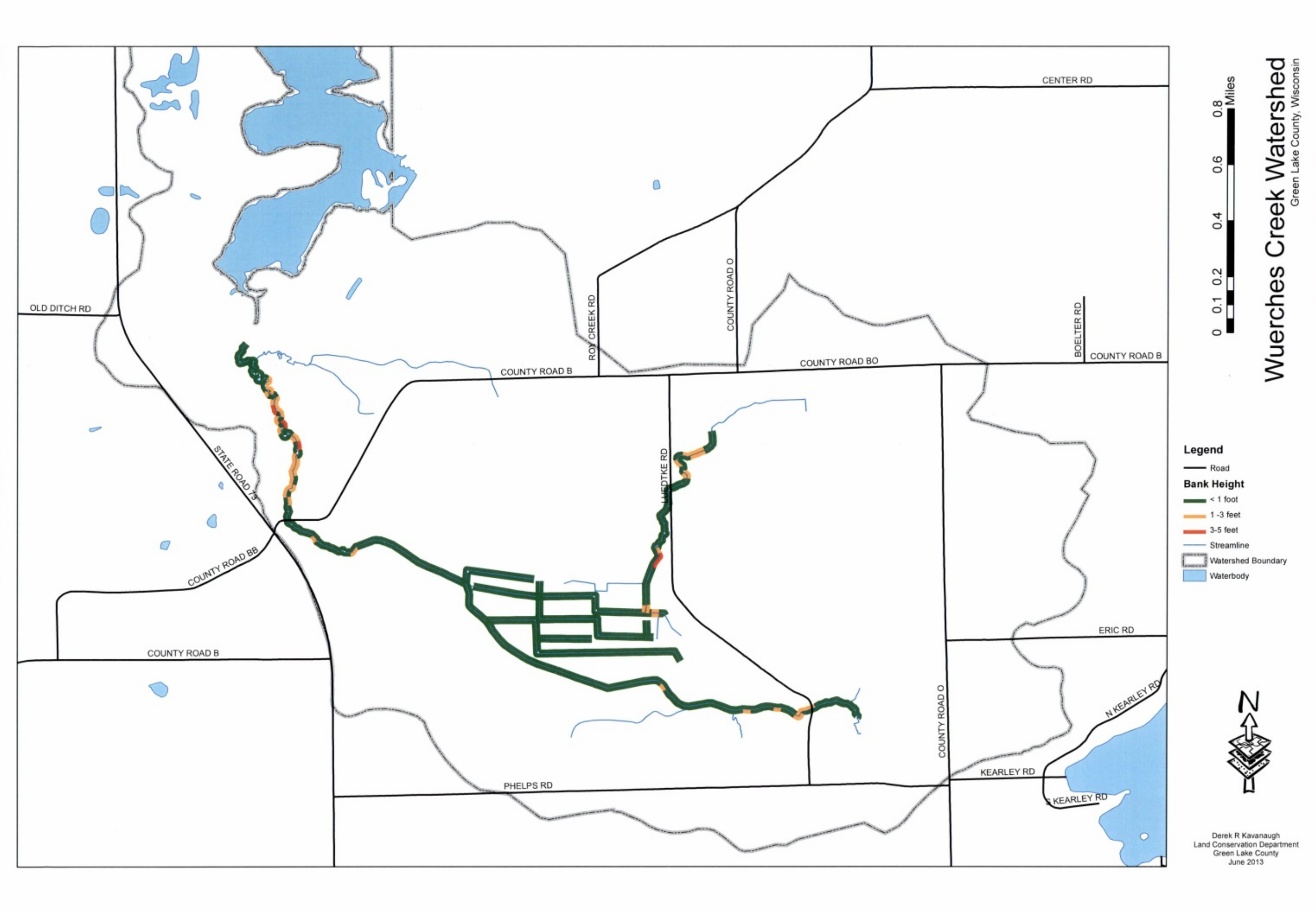

Figure 62. An example of GIS-based bank height data generated for the Wuerches Creek watershed as part of the Big Green Lake Buffer Assessment Project. Bank heights of <1 foot are shown in green, 1-3 feet in yellow, and 3-5 feet in red.

Overall, the Green Lake County inventory found all five streams to have very poor SVAP scores, with some streams falling within the 100% poor category (see Figure 33). Most of the streams had a minimum 35-foot buffer (79%-90%) with one exception, Wuerches Creek (53%). Although there were buffers present on most streambanks, the quality of the buffers varied. The typical buffer lacked understory growth and was dominated by invasive species and annual forbs. Streambanks lacked substantial root systems to stabilize and protect soil from erosion.

Most of the streambank miles were stable or moderately stabile (80%-97%), though portions of each stream had areas of severely eroding bank. Some of these areas had 7-foot-high vertical eroding banks. In some areas, much of this damage is suspected to have occurred during a severe (100 yr event+) rainfall event in June 2008, which caused increases in stream entrenchment within stream corridors that already had significant sediment accumulation from decades of upland erosion.

The streams are transitioning thru a natural re-stabilization process of bank collapse and erosion, which takes years to decades to naturally stabilize. Other areas experience erosion because of a lack of root structure in the bank due to mature forest canopies shading preferable forb/grass species, and invasion of shallow rooted invasive species.

Also, the following summary of streambank conditions in the watershed is from DNR's 2017 Targeted Watershed Assessment for Green Lake Report:

> Green Lake County LCD conducted an inventory of Roy, Wuerches, Hill, and White Creeks, and their associated Unnamed Tributaries to assess the condition of their riparian buffers, stream bank erosion, and instream habitat. The Green Lake County Soil Conservation Technician (D. Kavanaugh) completed a summary report of the 2014 buffer assessment, "Green Lake Buffer Assessment Project" (*Buffer Assessment Report, Kavanaugh, 2014*). In the report Roy, Wuerches, Hill, and White Creek subwatersheds averaged 11.25% of their stream length had unstable banks with active erosion (Buffer Assessment Report 2014) (Appendix C, Table 27, Figure 25).

[BIG GREEN LAKE TWA WQM PLAN 2017] August 1, 2017

> According to data collected at the USGS Gage Station 04073458, Roy Creek discharged a total of 240 tons of suspended sediment and 740 lbs. of TP in 2013 (USGS 2013). The majority of this sediment and nutrient discharge occurred in early spring during snowmelt and rain events. Rain events and snowmelt carry sediment and TP into the creek in addition to increasing water velocity and discharge volume. The increased velocity and discharge during this period increases the potential for bank erosion on the unstable banks in the subwatersheds.

Table 27: Percentage of Unstable and Actively Eroding Streambanks in Creeks in the Southern Big Green Lake Watershed (Green Lake County LCD 2014).

Creek Name	Roy Creek	Wuerches Creek	Hill Creek	White Creek	Average
Percent Unstable Banks	11%	3%	15%	16%	11.25%

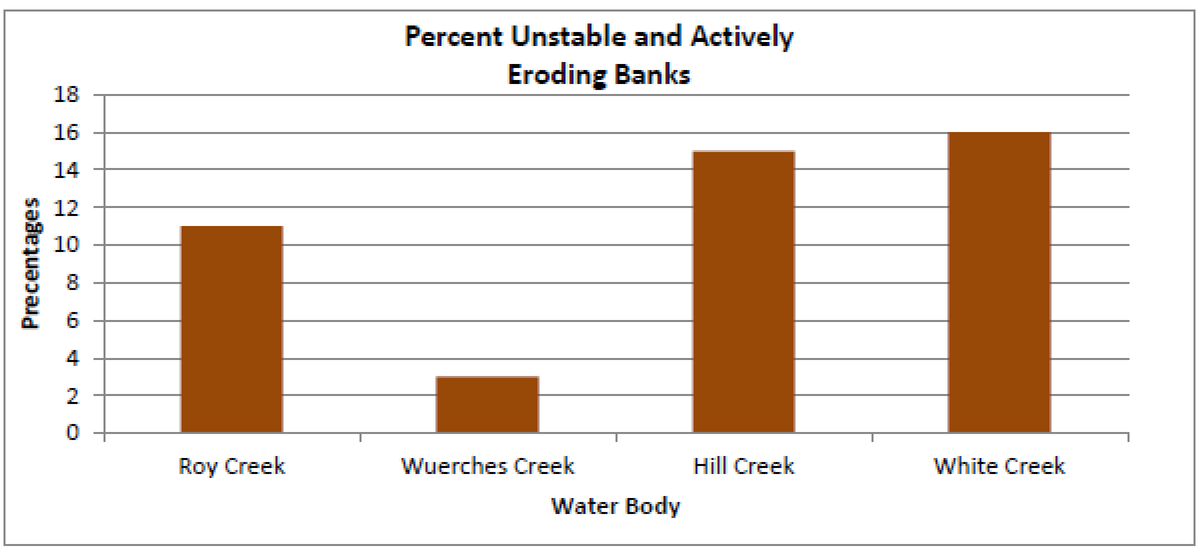

Figure 25: Percentage of Unstable and Actively Eroding Stream banks in Creeks in the Southern Big Green Lake Watershed (Green Lake County LCD 2014).

Given the extent and severity of streambank erosion in the watershed, the Green Lake Land Conservation Department has been working with landowners to speed the stabilization process by removing excess deposits of topsoil within the stream corridor and recreating riparian floodplains to reduce water velocity and soil erosion. Tree canopies are thinned, and soil stabilizing seed mixtures are planted in the process.

With the aid of the GIS-based data and interpretive maps, Land Conservation Department staff has had success when contacting landowners who have property severely eroding streambanks. In some instances, these landowners have entered into conservation agreements to stabilize and restore the banks. Over three miles of streams banks have been stabilized following the 2014 inventory, with work continuing as staff and funding become available. Funding has been provided from several sources including landowners, Green Lake County, Natural Resource Conservation Service, Green Lake Sanitary District, and Green Lake Association.

D. Qualitative Characterization of Wetlands

Green Lake's two primary wetland systems – County Highway K Marsh (CKM) and Silver Creek Estuary (SCE) – both have USGS monitoring at the outlets. As discussed previously, these two wetland systems have substantially different capacities to assimilate nutrients. The proposed future diagnostic and feasibility study is needed to better understand the causes of degradation and potential solutions for the restoration of the CKM.

i. Nelson Institute Estuary Study (2016-2018)

In 2019, Sarah Fuller of UW-Madison's Biological Systems Engineering Department completed a multi-year study on "Temporal and Spatial Variation of Nutrients and Sediment in the Marshes of Green Lake." [17] Fuller confirmed that the CKM is highly degraded and acts as a source for nutrients to Big Green Lake; the SCE generally acts as a sink for nutrients [17].

In all seasons, TP concentrations at the outlet of the SCE decreased following carp reduction and upgrades to the only point source, the Ripon WWTF. Samples collected from within the CKM has higher TP concentrations than its inlets. Over 11 sampling events, CKM did not retain TP (while the SCE did retain TP over the same period), as shown in Figure 63.

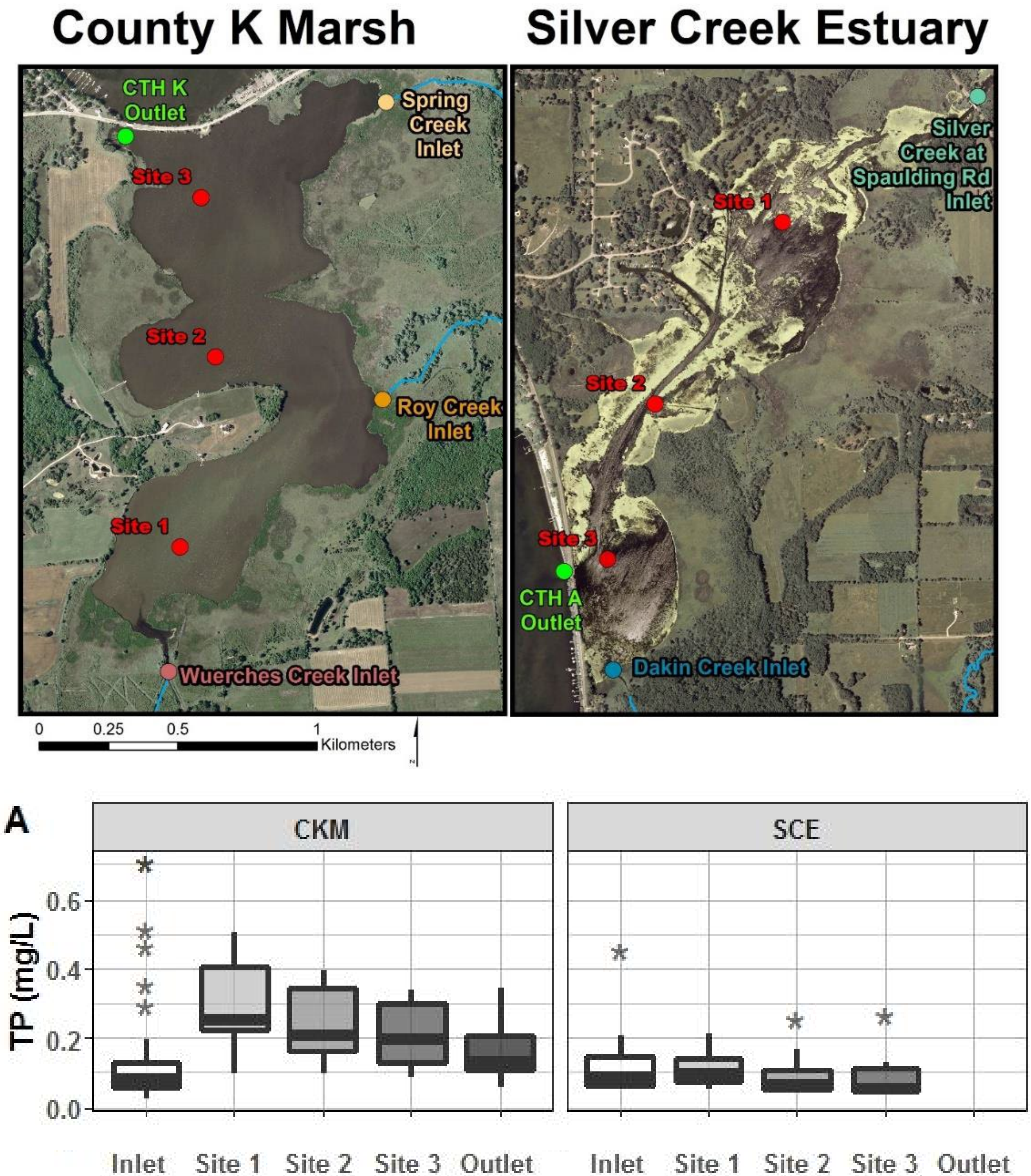

Figure 63. Sarah Fuller found profoundly different phosphorus dynamics in the CKM versus the SCE [17]. The CKM is a consistent source of phosphorus to Green Lake, while the SCE retains phosphorus.

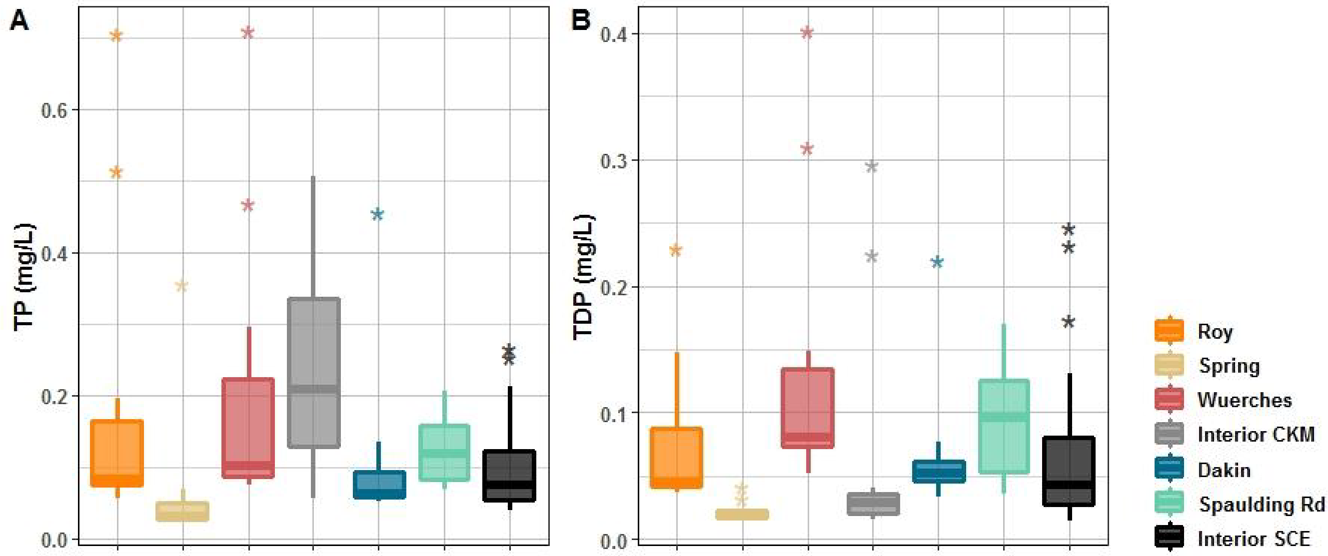

Figure 64. Phosphorus samples collected from the three streams draining to the CKM (Roy, Spring, and Wuerches Creeks) and the interior of the CKM demonstrate that TP is higher within the CKM than its contributing streams. Phosphorus samples collected from the two streams draining to the SCE (Dakin and Silver Creek at Spaulding Road) demonstrate that phosphorus within the SCE is generally similar or lower than its contributing streams.

Fuller's study further demonstrates the significant restoration potential within the CKM.

E. Qualitative Characterization of Sediments

i. Nelson Institute Legacy Phosphorus Study (2018-2019)

From a research preview [18] presented to the Green Lake Association's Board of Directors:

> *"Phosphorus is an essential nutrient for plant growth and is regularly applied to fields and lawns in the form of fertilizer and manure. When the amount of phosphorus applied is more than the amount removed (by plants or runoff), however, phosphorus begins to build up in excess.*
>
> *"Soils, streams, wetlands, estuary sediments and biomass can all be stores of phosphorus that accumulate over the years as the results of different management practices. Rather than flushing out of a watershed, this accumulated phosphorus is moved, recycle and redeposited, and continues to act as a source of phosphorus to downstream water bodies for years or decades. This phosphorus – known as legacy phosphorus – is challenging to manage. Since legacy phosphorus stays in watersheds for extended times, it can effectively mask the positive effects of best management practices.*
>
> *"Recent research in the Yahara watershed and other areas in the US has attempted to quantify how much legacy phosphorus is stored in a given watershed in a given year through a mass-balance, or a phosphorus approach. Like a checkbook, the amount added minus the amount removed is equal to the amount left, or in this case, the amount stored."*

The Nelson Institute for Environmental Studies is currently conducting a legacy phosphorus study in the County Highway K watershed, including Roy, Wuerches, and Spring Creeks and the CKM Marsh itself. The 2018-2019 study will attempt to quantify legacy phosphorus stored in fields, streams, and the marsh.

The research preview [18] will "aim to answer larger questions, such as: Have changed in management practices been effective in reducing the buildup of legacy phosphorus in the watershed? What is the time estimate for drawing down stored phosphorus, under different land management scenarios? How does storage of legacy phosphorus in the Silver Creek [sub-]watershed (Silver and Dakin Creeks, and the SCE) compare to that for the CKM watershed?"

ii. Sediment Cores (1999 and 2016)

Sediment cores extracted by Garrison via the WDNR and Onterra Consulting (in 1999 and 2016, respectively) and historic lake monitoring suggests that, prior to European settlement, Big Green Lake was an oligotrophic lake. Relic diatoms in the sediment cores indicate that the lake's water quality during the 1800s was very good [85]. Sediment and phosphorus accumulation remained low until about the 1920s-1930S, when they began to increase slightly throughout the lake [85].

Lake sediment core analyses indicate increases in phosphorus and sediment accumulation, as shown in both the 1999 and 2016 sediment core data. In the deeper western basin, the Iron:Manganese ratio in sediments has declined since 1950, indicating a decrease of oxygen in the bottom waters of the lake [85]. Elevated phosphorus loading in the post-World War II period may have increased productivity in the lake causing accelerated oxygen depletion in the hypolimnion. Dissolved oxygen concentrations are now lower in deeper areas of the hypolimnion compared to pre-1950.

Soil erosion in the watershed also increased significantly beginning around 1920-1930. This was likely the result of increased mechanization of agriculture. In addition, following World War II, the use of commercial fertilizers increased, thereby increasing delivery of phosphorus to the lake.

According to sediment diatom analyses, the highest lake phosphorus concentrations in the last 150 years occurred within the last 20 years based on the 1999 sediment core data. Diatoms were not analyzed as part of the 2016 sediment cores, so the subsequent decades following 1999 were not analyzed.

The 2016 cores suggest that the sedimentation rate of Big Green Lake decreased from its peak of 0.08 $g/cm^2/yr$ in the 1970s to 0.06-0.07 $g/cm^2/yr$.

Agricultural management – including tillage practices and fertilizer application using post-World War II technology – urban development, and increased frequency and intensity of runoff events are likely factors in the recent increases in sediment input into the lake. Evidence of these impacts on the lake's eutrophication is seen within lake sediment profiles [85].

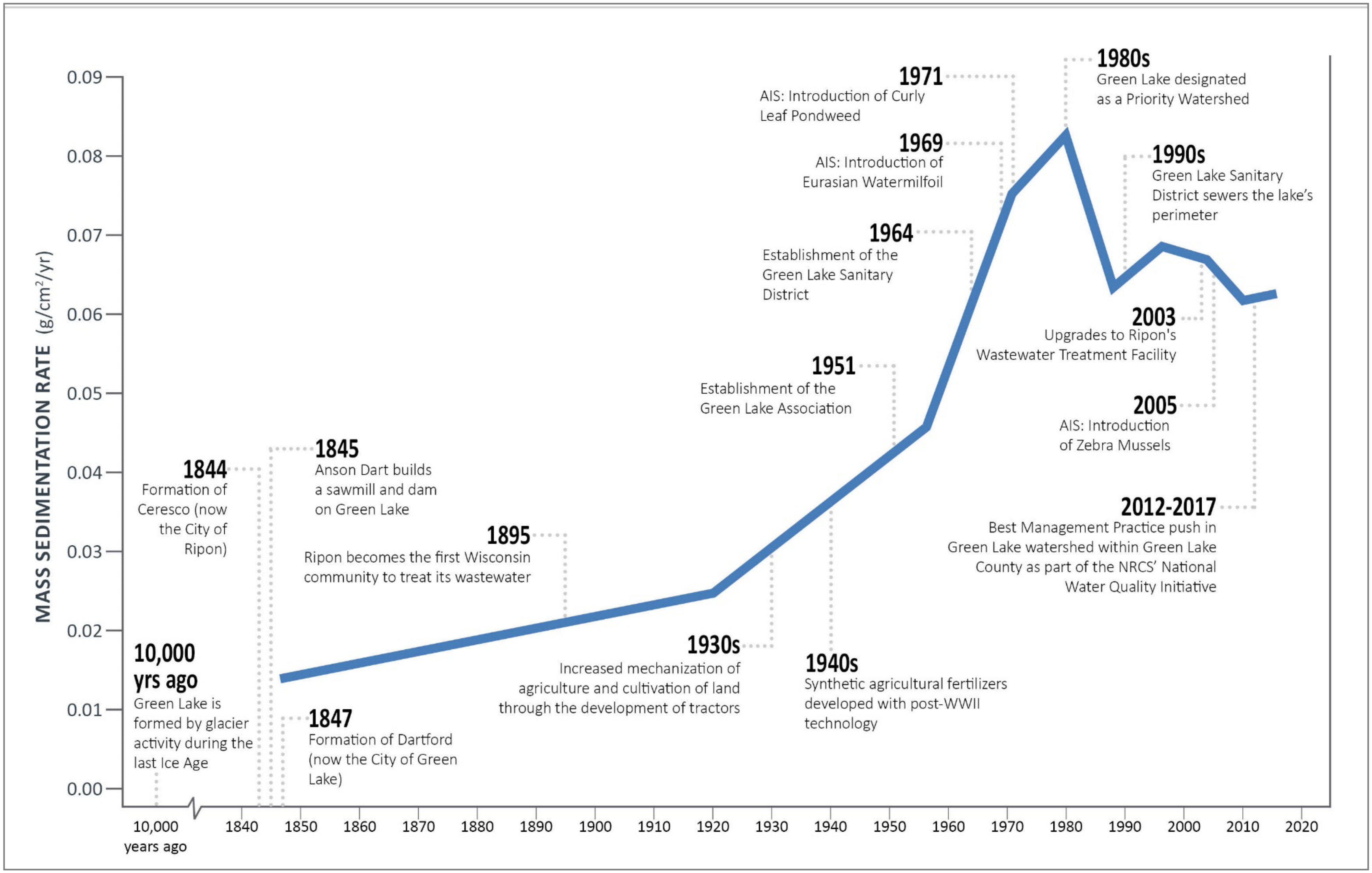

Figure 65. Sedimentation rates determined from Paul Garrison's (Onterra Consulting) 2016 core (east end; core GR-2) suggests Big Green Lake has seen an increase in sedimentation rates (g/cm²/yr) since the 1920s. Sedimentation rates have generally decreased since the early 1980s.

F. Qualitative Characterization of Point Sources

The Ripon Wastewater Treatment Facility (WWTF) is the only point source located in the Big Green Lake watershed that also discharges its effluent within the watershed—in this case, to Silver Creek within the City of Ripon municipal limits.

Interestingly, in 1895, Ripon became the first Wisconsin community to treat its wastewater. The current facility was constructed in 1975 and underwent an expansion and upgrade in 2002 to 2003. Upgrades included "two new, one-million-gallon oxidation ditches; two new covered 400,000 gallon clarifiers; new preliminary treatment building; new ultraviolet disinfection process; and renovation of the control building" [86], totaling a cost of $7.5 million.

The Ripon WWTF treats an average flow of 1.8 million gallons per day and a maximum of 6.8 million gallons per day, "utilizing the conventional oxidation ditch design of the activated sludge process of wastewater treatment" [86].

Under its current permit, the Ripon WWTF's discharge limit is 1.0 mg-P/L-effluent. Using all biological treatment, the WWTF's average effluent concentration has met these limits (see Figure 66).

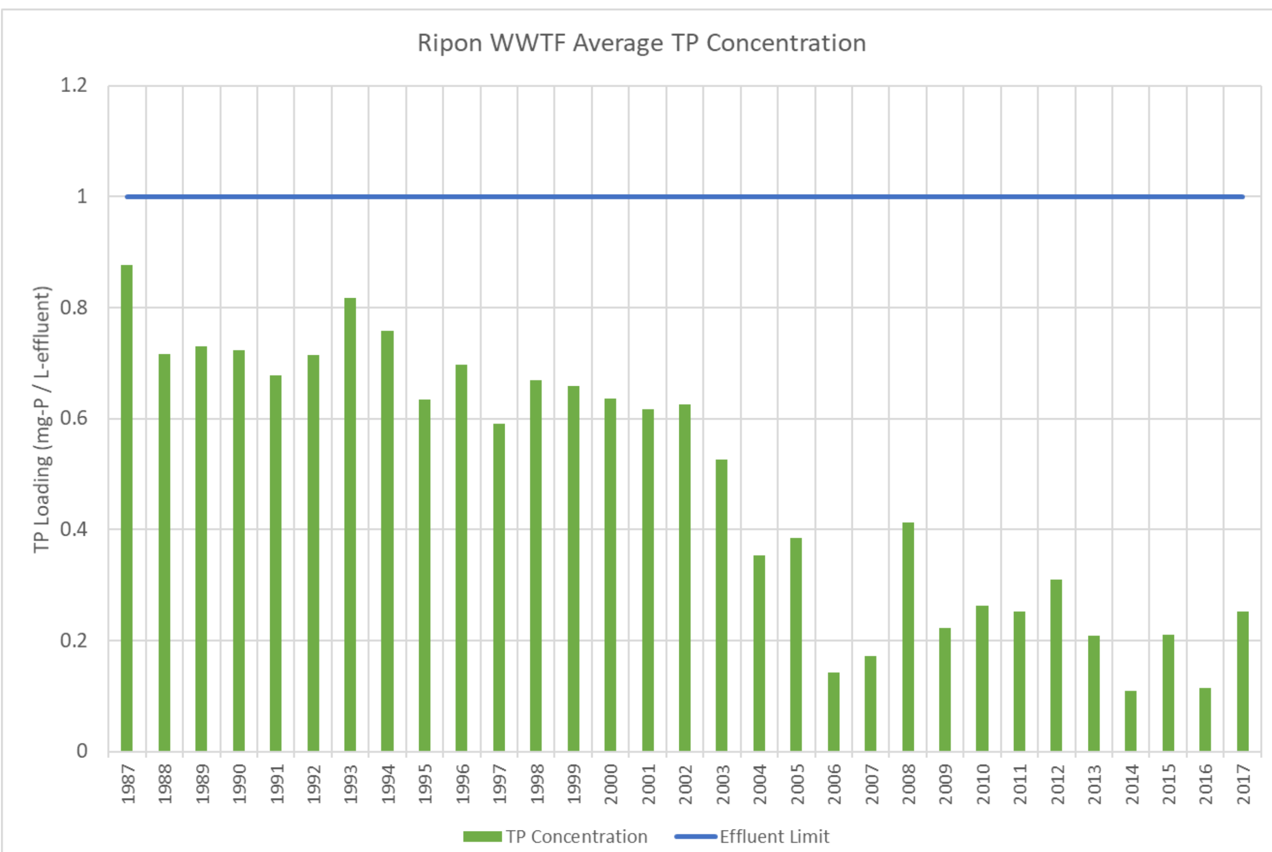

Figure 66. The City of Ripon Wastewater Treatment Facility is the only point source in the watershed that discharges its effluent in the watershed. Its annual averages are below its effluent limit of 1.0 mg-P/L-effluent, as indicated by the blue line.

6. PHOSPHORUS LOADING CAUSES AND SOURCES

A. Baseline Phosphorus Loading (2013-2016)

This Plan uses baseline phosphorus loading to Big Green Lake of **16,652 pounds per year** based on 2013-2016 average loadings (see Table 20). This phosphorus loading estimate is based on:

- **USGS stream monitoring (measured loading)**. Wherever possible, monitored phosphorus loading data at a USGS gage represents the most reliable quantification of phosphorus loading. This estimate was based on measured values from USGS gauges representing 91% of the watershed (SCE, White Creek, Hill Creek, Roy Creek, and the CKM).

- **SWAT model (estimated loading)**. In areas where measured phosphorus loading was not available, phosphorus loading was estimated from the 2015 SWAT model completed by the University of Wisconsin-Green Bay [48].

- **Atmospheric deposition (estimated loading)**. Small amounts of phosphorus naturally occur from rainfall-induced atmospheric deposition. Atmospheric deposition is an estimate using nearby precipitation gauges and an assumed rainfall phosphorus concentration of 0.036 mg/L, per the recommendations of the USGS.

Table 20. A summary of the sources, pathways, receiving body and corresponding phosphorus loading to Big Green Lake, including measured, estimated and unknown sources.

SOURCES	PATHWAYS	WATER QUALITY INDICATORS	RECEIVING BODY	PHOSPHORUS LOADING TO RECEIVING BODY	PHOSPHORUS LOADING TO BIG GREEN LAKE	
AGRICULTURAL RUNOFF 44,512 acres 65% of watershed	Runoff		Creeks + Creek Sediment	***12,320 lbs*** [D]	Unknown	
CITY OF GREEN LAKE RUNOFF 1,149 acres (945 acres to lake)	Runoff		Big Green Lake	***850 lbs*** [A]	***380 lbs*** [E] - ***415 lbs*** [A]	2%
CITY OF RIPON RUNOFF 3,213 acres (all to Silver Creek)	Runoff		Silver Creek	Unknown		
RIPON WWTF EFFLUENT 1.8 MGD average	Discharge pipe		Silver Creek	**699 lbs** [C]		
CREEKS + CREEK SEDIMENT 141 miles of named tributaries	Silver Creek	Class II Trout Stream; Impaired	Silver Creek Estuary	**7,620 lbs** [D]		
	Dakin Creek	Class II Trout Stream	Silver Creek Estuary	***2,298 lbs*** [E]		
	Roy Creek	Impaired	County Highway K Marsh	**667 lbs** [D]		
	Wuerches Creek	Impaired	County Highway K Marsh	***4,267 lbs*** [E]		
	Spring Creek		County Highway K Marsh	***260 lbs*** [E]		
	White Creek	Class I Trout Stream	Big Green Lake	***1,152 lbs*** [E]	***1,152 lbs*** [E]	7%
	Hill Creek	Impaired	Big Green Lake	***2,485 lbs*** [E]	***2,485 lbs*** [E]	15%
	Assembly Creek	Class I Trout Stream	Big Green Lake	***195 lbs*** [E]	***195 lbs*** [E]	1%
SILVER CREEK ESTUARY 215 acres		Impaired	Big Green Lake		**6,778 lbs** [D]	41%

DATA SOURCES
A City of Green Lake Stormwater Management Plan
B USGS Measurements
C City of Ripon WWTF Effluent Measurements
D USGS Stream Sampler Data
E 2015 SWAT Model
D 2018 Draft Fox-Wolf TMDL

Measured Loading
Estimated Loading
Unknown Loading

Table 20 continued.

SOURCES	PATHWAYS	WATER QUALITY INDICATORS	RECEIVING BODY	PHOSPHORUS LOADING TO RECEIVING BODY	PHOSPHORUS LOADING TO BIG GREEN LAKE	
COUNTY HIGHWAY K MARSH 269 acres	Discharge		Big Green Lake		**2,853 lbs** [D]	17%
BIG GREEN LAKE LEGACY SEDIMENT	Direct Uptake		Big Green Lake		Unknown	
SHORELINE RUNOFF 27.3 miles of shoreline	Runoff		Big Green Lake		***815 lbs*** [E] ***Beyers Cove only***	5%
ATMOSPHERIC DEPOSITION	Direct		Big Green Lake		***1,995 lbs*** [B]	12%
				TOTAL:	**16,652 LBS - P/YR**	

DATA SOURCES

A City of Green Lake Stormwater Management Plan
B USGS Measurements
C City of Ripon WWTF Effluent Measurements
D USGS Stream Sampler Data
E 2015 SWAT Model
D 2018 Draft Fox-Wolf TMDL

Measured Loading
Estimated Loading
Unknown Loading

B. Causes

Glacial activity formed Big Green Lake approximately 17,000 years ago during the last Ice Age. From that moment forward, this oligotrophic lake began to experience a natural aging process. While all lakes naturally age, anthropogenic impacts accelerate this degradation process from centuries to decades. Several sources of data show us that Big Green Lake, now a mesotrophic lake, is no exception.

Sediment cores collected and assessed from the bottom of Big Green Lake by Garrison (previously discussed in Section 5.E.ii: Sediment Cores) document sedimentation rates after the 1840s—right after the founding of Ceresco (now the City of Ripon) and Dartford (now the City of Green Lake)—to today. These sediment cores show two periods of notable sedimentation increased after the 1920s and the 1960s. These sedimentation rates peaked in the 1980s and have begun a general decline since then (as shown in Figure 65).

Human activity is responsible for these increased sedimentation rates and accompanying lake degradation. Nearshore and urban development; poorly managed septic systems and wastewater systems; excessive chemical fertilizer; inadequate nutrient management, including improper manure application; and more intensive tillage are some examples of negative human impacts on Big Green Lake's water quality.

In this same period, climate change has resulted in more intense, more frequent rain events that more easily transfer nutrients downstream to Big Green Lake. As discussed in Section 3.D:

> *"While Big Green Lake may have seen some of these changes already, a changing climate will continue to put pressure on the lake's water quality. In particular, increased nutrient and sediment loading runoff events reinforce the need to improve degraded streams, enabling them to mitigate rapid flooding and assimilate nutrients; and may mean that more and more conservation practices need to be installed just to keep the pace. In the future, many best management practice designs could prove to be inadequate to function as designed."*

The lake has responded to these land management and climatic pressures with elevated phosphorus levels above its water quality standard and a metalimnetic oxygen minima. Results of the Diagnostic and Feasibility Study (discussed in Section 5.B.vi) will shed much-needed light on phosphorus reduction levels and potential management strategies to achieve water quality goals.

As this study wraps up, the LMPT will continue to install phosphorus-reducing conservation practices to offset the negative impacts from human activity and climate change.

C. Sources

Phosphorus loading to Big Green Lake comes from a variety of anthropogenic and natural sources – including, but not limited to, agricultural runoff, urban runoff, septic systems, legacy phosphorus in sediments and streams, atmospheric deposition, wetlands, forests, and actively eroding streambanks. These sources are traditionally classified as point or nonpoint sources and will be discussed individually in the following sections.

- **Point sources**. The EPA defines point source pollution as "any single identifiable source of pollution from which pollutants are discharged, such as a pipe, ditch, ship or factory smokestack" [87]. While the Clean Water Act allows for regulation of these facilities, the Big Green Lake watershed only has one point source that directly discharges to a waterway—the Ripon Wastewater Treatment Facility. Other industries in the watershed (a former cookie factory, canning factories, a washing machine factory) route their wastewater to the treatment facility before discharging any effluent into Silver Creek. Two additional point sources within the watershed—namely, the Green Lake Sanitary District and the City of Green Lake Wastewater Treatment Facility—discharge outside of the watershed.

- **Nonpoint sources**. As mentioned in the 2020 Upper Fox-Wolf River TMDL report [2], nonpoint source pollution is "typically driven by watershed runoff, or the movement of water over the land surface and through the ground into waterbodies," including agricultural and urban runoff. The Clean Water Act does not directly regulate nonpoint source pollution, though it does provide recommendations and mechanisms to address these problems. Nonpoint source pollution is "well-recognized to be one of the last major hurdles to achieving state and national water quality goals" [88].

As discussed in Section 5.F.A, baseline annual phosphorus loading to Big Green Lake is calculated as 16,652 pounds per year (based on 2013-2016). A conceptual site model provides a visual representation of the sources and pathways of annual phosphorus loading to Big Green Lake (Figure 67).

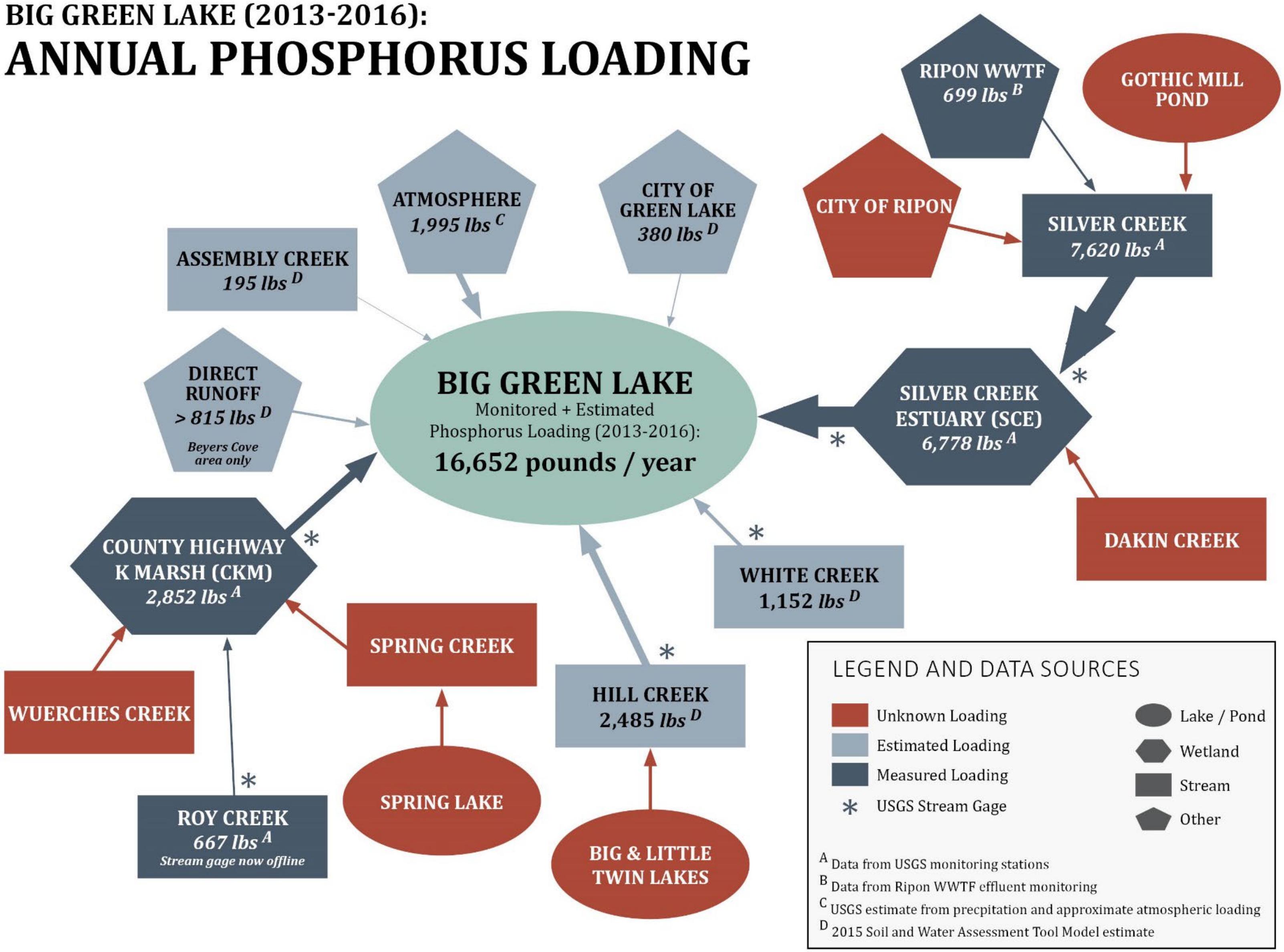

Figure 67. A conceptual site model of the sources and pathways of phosphorus loading to Big Green Lake, calculated as 16,652 pounds of phosphorus annually.

This conceptual site model demonstrates several important points:

- Not all phosphorus loading is feasible for phosphorus reductions. Atmospheric deposition accounts for 1,995 pounds (12%) of annual phosphorus loading, for example, though there are no reductions proposed in Chapter 7.
- The SCE and CKM represent significant phosphorus loading (41% and 17%, respectively), yet both also encompass more complex systems—the SCE in particular. Other sub-watershed inputs—like White Creek and Hill Creek—also contribute phosphorus loading, which comes from less complex systems.
- Though the LMPT uses stream samplers to measure 91% of phosphorus loading *near* Big Green Lake's major inlets, there is a data gap *upstream* of these samplers. As a result, the LMPT must rely on computer models to estimate much of this nutrient loading, as well as other tools to prioritize nonpoint-source-driven phosphorus loading. These prioritization tools will be discussed in more detail in Chapter 7.

It is also beneficial to take nutrient loading a step further—not only estimating by its major inputs, but also estimating by its representative land use. Given general uncertainties of runoff-induced phosphorus loading upstream of the USGS stream samplers, the best current estimate of land-use-based phosphorus loading comes from the 2020 Upper Fox-Wolf TMDL [2]. The TMDL did not assess Big Green Lake watershed separately for this estimate, but rather included it as part of a regional watershed called the "Fox River above Lake Butte des Morts" (see Figure 68).

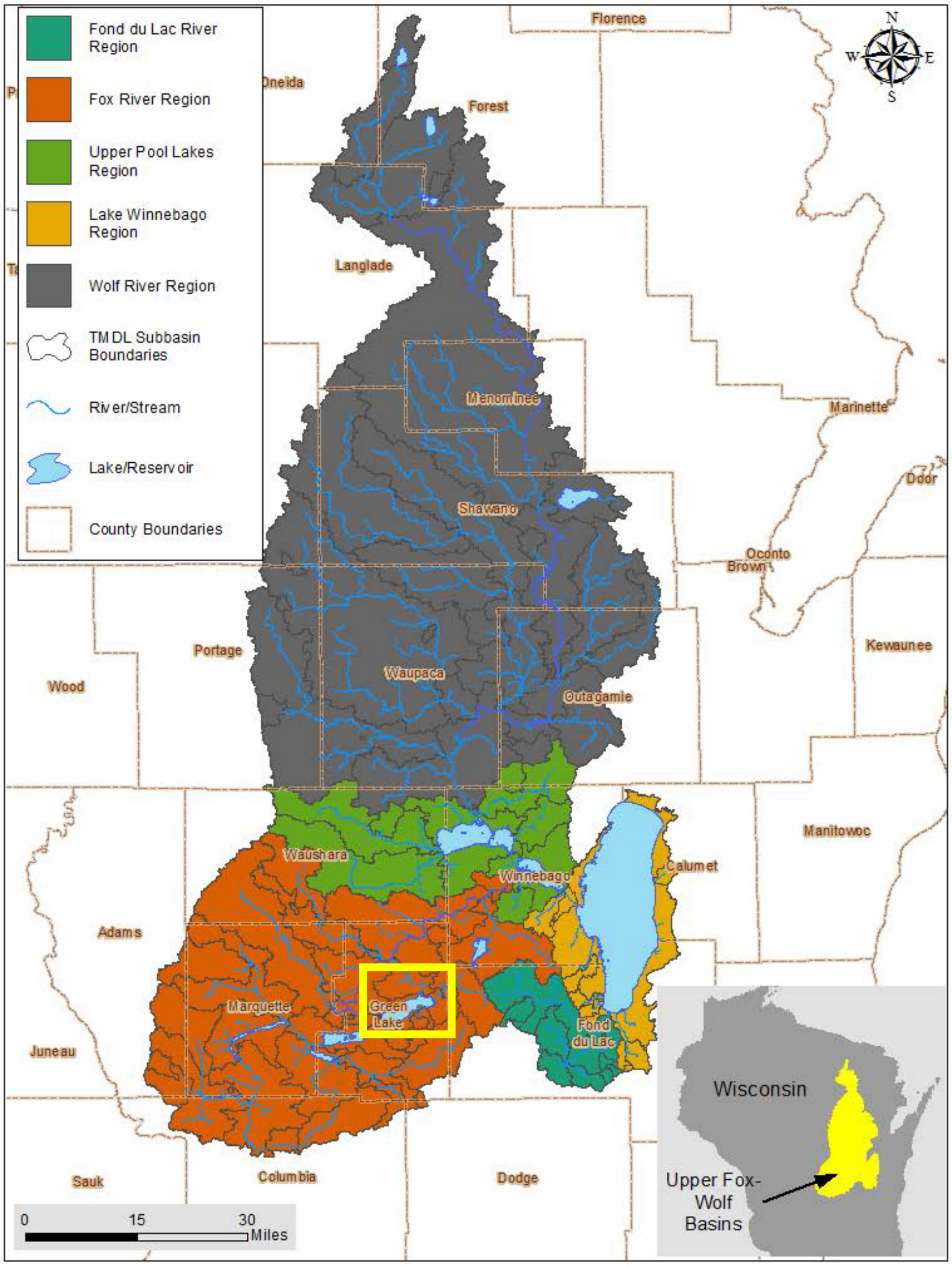

Figure 68. The Big Green Lake watershed is included in the regional watershed, the Fox River Region, in the 2020 Upper Fox-Wolf TMDL. Emphasis added around Big Green Lake. Excerpt of Figure 12 in the 2020 TMDL report [2].

The draft TMDL estimates 195,573 pounds of baseline total phosphorus loading for the Fox River Region, which includes the Big Green Lake watershed. Using the land-use-based loading in the larger Fox Region is as an indicator of land-use-based loading in the Big Green Lake watershed (see Table 21).

Table 21. Baseline total phosphorus loading for the Fox River Region, including the Big Green Lake watershed, as outlined in the 2020 Upper Fox-Wolf TMDL Report.

General Source Category	Source	FOX RIVER REGION Baseline Phosphorus Loading (lbs/yr)	FOX RIVER REGION Baseline Phosphorus Loading (%)
Background (11%)			
	Forest and Wetland	20,699	11%
	Groundwater	0	0%
	Atmospheric	0	0%
Nonpoint Agriculture (74%)			
	Cropland	95,217	49%
	Pasture	48,405	25%
Non-Regulated Urban (4%)			
	Non-Regulated Urban	7,747	4%
	Nearshore Septic	911	<1%
Point Source (11%)			
	Regulated MS4 Urban	188	<1%
	General Permits	866	<1%
	Individual Permits	21,540	11%
Total		**195,573**	**100%**

A comparison of baseline phosphorus loading percentages in the Fox River Region (Table 21) to land use percentages in the Big Green Lake watershed (see Table 22 and Figure 69) seems to indicate that:

- **Background land use** (wetlands, forests, open land and water) contributes disproportionately less phosphorus than its land use area (11% loading versus 30% area),
- **Agricultural land use** (cropland, pasture) contributes *disproportionally more phosphorus* than its land use area (74% loading versus 66% area), and
- **Urban land use** contributes a proportionate amount of phosphorus loading compared to land use (4% loading and 4% area).

In all cases, the LMPT should make long-term investments in additional measurements in the Big Green Lake watershed to confirm these general conclusions.

Table 22. Land use area in the Big Green Lake watershed compared to baseline phosphorus loading in the Fox River Region, which includes the Big Green Lake watershed.

General Source Category	Land Use in Big Green Lake Watershed AREA (%)	Baseline Phosphorus Loading in Fox River Region PHOSPHORUS LOADING (%)
Background *Wetland, Forest, Open Land and Water*	30%	11%
Agriculture *Cropland and Pasture*	66%	74%
Urban *Urban and Suburban*	4%	4%
Point Source	Unknown	11%
Total	**100%**	**100%**

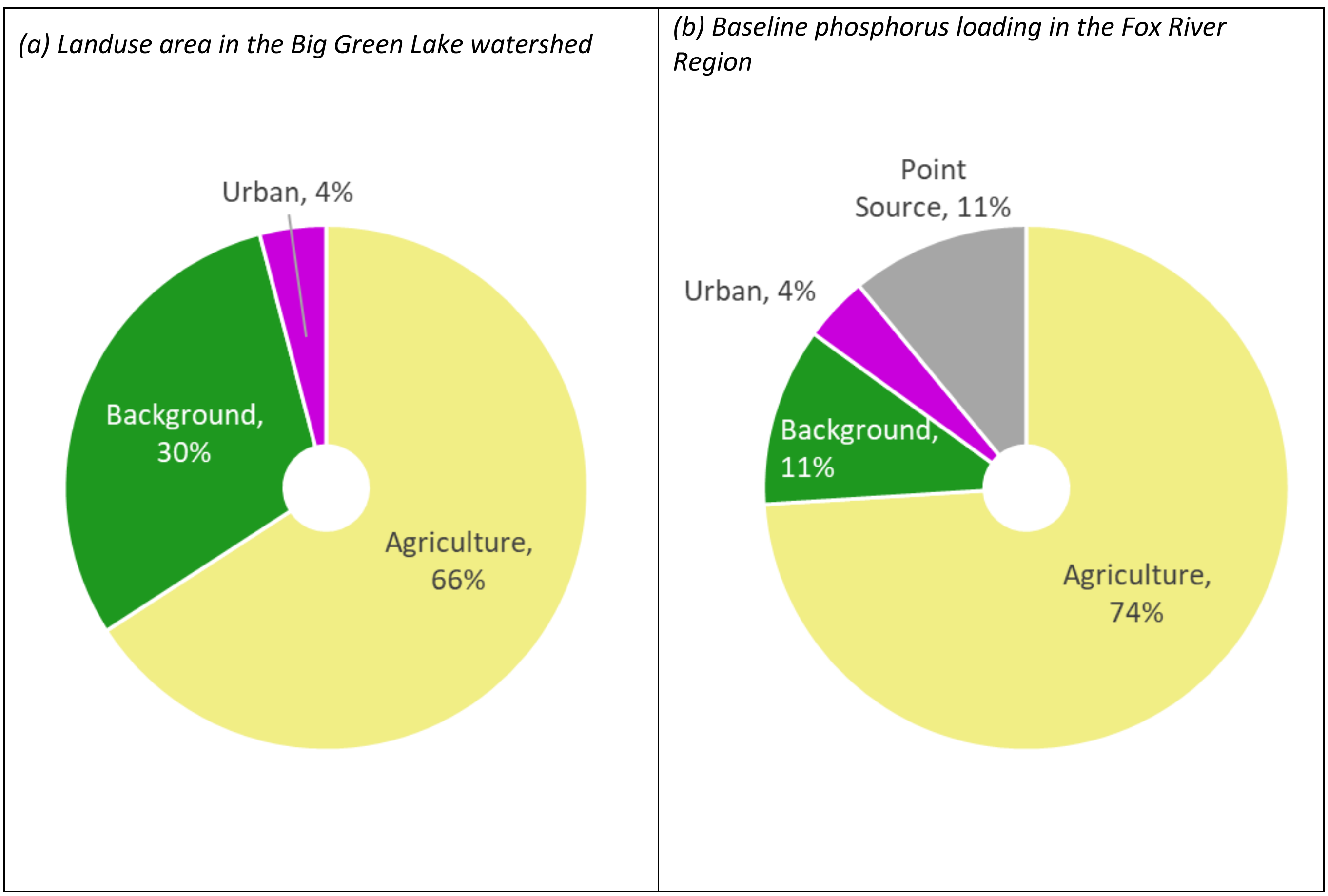

Figure 69. Land use area in the Big Green Lake watershed (a) compared to baseline phosphorus loading in the Fox River Region (B), which includes the Big Green Lake watershed.

Since Big Green Lake's watershed-specific models and rigorous monitoring data estimate total baseline phosphorus loading of 16,652 pounds per year in the Big Green Lake watershed, land-use-specific loading can be extrapolated from the Fox River Region estimates, as shown in Table 23.

Table 23. Phosphorus loading estimates from the Fox River Region of the 2020 Upper Fox-Wolf River TMDL provide an indicator of phosphorus loading by land use in the Big Green Lake watershed, using known loading of 16,652 pounds per year.

General Source Category	FOX RIVER REGION Baseline Phosphorus Loading by Land Use (%) [46]	BIG GREEN LAKE WATERSHED Baseline Phosphorus Loading by Land Use (lbs)
Background	11%	1,832 lbs
Nonpoint Agriculture	74%	12,322 lbs
Non-Regulated Urban	4%	666 lbs
Point Source	11%	1,832 lbs
Total	**100%**	**16,652 lbs**

More information about each of the primary land-use-specific phosphorus sources is detailed in the following sections.

i. Background Loading: County Highway K Marsh

USGS stream gages determined that the CKM contributes 17% (2,853 pounds) of Big Green Lake's annual phosphorus loading. The CKM is a degraded, algae-dominated system that is a haven to carp, particularly during spawning. The exact causes of CKM's degradation are unknown, though the LMPT believes it is a combination of:

1. **Upstream land management** in the Roy and Wuerches sub-watersheds (supported by the Phosphorus Prioritization Plan's Nutrient Loading Priority Area and SWAT model results),
2. **Stream erosion** in Roy and Wuerches Creeks (supported by the streambank assessment),
3. **Carp activity** in the CKM that disrupts aquatic plant establishment and re-suspends sediment,
4. **High turbidity** that disrupts aquatic plant establishment, and/or
5. **Wind/wave energy** that disrupts aquatic plant establishment and re-suspends sediment.

The restoration of the CKM is a top priority for the LMPT, which has invested in several management efforts previously discussed in Table 6. Despite these restoration attempts, measurable improvements have been limited to the expansion of aquatic vegetation in carp exclosures and at the northern edge of the wetland's periphery.

With support of the LMPT, the GLA formed an advisory team to complete a diagnostic and feasibility proposal as ongoing restoration activities continue. The recommendation of that advisory team, approved by the WDNR in March 2019, is to install a pilot project consisting of isolated bays of turbidity curtain. The protected bays will be inoculated with native propagules. The LMPT will utilize the principles of adaptive management to move the location of the turbidity curtain, expand the current isolated bays if/when wetland restoration is a success, and adjust the strategy as needed to support the restoration of the CKM.

Additionally, the CKM system would benefit from an intensive focus and study of upstream phosphorus contributions, BMP implementation, shoreline restoration of streams and intermittent streams, along with the feasibility of using technological intervention to intercept and/or treat soluble phosphorus as an interim solution pending completion of BMP implementation. The exact technological intervention tool and its location (whether out the outlet of the CKM, within the CKM, and/or upstream in the watershed) is not yet determined. A feasibility study assessing this type of strategy would be worthwhile.

The LMPT supports the use of new and existing technology to capture and treat phosphorus—both in the CKM system and other stream, wetland, retention pond, and lake systems throughout the watershed to test pilot projects.

ii. Background Loading: Legacy Phosphorus

"For decades, phosphorus has accumulated in Wisconsin soils," begins a news report on a recent UW-Madison study in the Yahara watershed to understand legacy phosphorus. "Though farmers have taken steps to reduce the quantity of the agricultural nutrient applied to and running off their fields, a 'legacy' of abundant soil phosphorus has a large, direct and long-lasting impact on water quality" [89].

This overabundance of phosphorus can be found in both Wisconsin's soils and its stream sediments. The report [89] continues:

> *"Scientists have long believed that excess soil phosphorus is a culprit behind the murky waters and smelly algal blooms in some of Wisconsin's lakes and rivers. Conventional efforts, like no-till farming and cover crops, have tried to address nutrient runoff by slowing its movement from soils to waterways.*
>
> *"However, simply preventing runoff and erosion does not address the core problem of abundant soil phosphorus, and this overabundance could override conservation efforts. Solutions should be focused on stopping phosphorus from going onto the landscape or mining the excess amount that is already built up."*

Legacy phosphorus—also known as historical phosphorus—can be found within streams, wetlands, and/or Green Lake's bottom sediments. Legacy phosphorus, which is re-solubilized and mobilized through various phosphorus cycling processes, complicates achieving expected phosphorus reductions. In recent years, scientists and watershed managers are finding that water quality is not responding as well as expected to implemented conservation practices [90]; this slower and smaller response is likely caused by legacy phosphorus.

Legacy phosphorus is the accumulated phosphorus that can serve as a long- term source of phosphorus to surface waters . In soil, legacy phosphorus builds up much more rapidly than the phosphorus withdrawals from crop uptake. In stream channels, legacy phosphorus can result from sediment deposition of particulate phosphorus, sorption of dissolved phosphorus onto riverbed sediments or suspended sediments, or by incorporation into the water column [90].

Therefore, water quality in the tributary streams or within Green Lake itself may not respond to implementation of conservation practices in the watershed as quickly as expected due to remobilization of legacy phosphorus .

Since removal of phosphorus within the soil on farmland is likely not feasible, it is most appropriate to contain that phosphorus in place through various practices/projects including: BMPs, stream bank restoration, acquisition of particularly vulnerable farmland, retention ponds/stormwater basins, constructed wetlands, etc. In addition, the role of technological solutions in the capture of soluble P should be explored.

These are activities currently planned and underway. However, Green Lake's declining water quality indicates that these actions should be accelerated. When implemented at the appropriate scale, containment of legacy phosphorus in the watershed should significantly reduce the ongoing excess phosphorus loading from these land-based watershed sources, ultimately enhancing the watershed's capacity to naturally protect the lake against future severe rainfall events. This containment and protection will allow the lake to start recovering.

Additionally, it is beneficial to accelerate the lake's ability to attenuate, or "self-clean," phosphorus by addressing the internal loading from already in-place legacy phosphorus — whether in sediments in the estuaries, certain bays or areas within the lake, or in the water column itself.

Some studies underway (being conducted by R. Johnson and A. Thompson of UW-Madison, C. McDonald of Michigan Technological University, and D. Robertson of the USGS) will help the LMPT understand the legacy phosphorus in the lake and may lead to restoration or technological options.

Regardless, more aggressive research is needed to understand the role of legacy phosphorus —within Big Green Lake and throughout the watershed—and how it can be addressed through the lake and watershed system. Treatment options to address Green Lake's legacy phosphorus will benefit from research and innovative thinking.

Ultimately, the exact extents of legacy phosphorus in the Big Green Lake- watershed is unknown, though a 2018-2019 study by Johnson (see Section 5.E.i) targeted on the CKM will attempt quantify its role in the degradation of Big Green Lake.

iii. Background Loading: Eroded Streambanks

A 2014/2015 stream assessment (previously discussed in Section 5.C.iii) quantified areas of actively eroding streambank within all named streams in the Big Green Lake watershed. The LMPT estimates that over 11 miles of streambank are actively eroding, resulting in vertical banks that negatively impact the ability of a stream to mitigate flooding and assimilate nutrients. These areas serve as direct conduits for nutrient loading to the lake, magnified by the direct exposure to legacy sediments.

The LMPT has already restored 20,700 feet of streambank and shoreline protection between 2012-2018, including 2,400 feet on Roy Creek and 5,470 feet on a tributary to Hill Creek most recently. The LMPT continues to make stream restoration a main strategy in reducing phosphorus loading to Big Green Lake given this direct source of nutrients.

However, since the stream assessment was completed significant rainfall events have resulted in creation of additional highly eroded areas. The LMP recommends that the stream surveys be updated and that stream restoration plans be created.

One stream restoration effort on Dakin Creek planned for 2019-2020 will attempt to reestablish native brook trout—an indicator of clean water—on this trout stream, whose presence has not been documented by the WDNR since the 1950s.

iv. Non-Point Agricultural Loading

The 2020 Upper Fox-Wolf River TMDL estimates 74% total phosphorus loading comes from agricultural land use (cropland 49%, pasture 25%) in the Fox River Region, which includes the Big Green Lake watershed [2].

This equates to 12,322 pounds of estimated annual phosphorus loading from non-point agricultural runoff in the Big Green Lake watershed.

Agricultural runoff can come from a combination of chemical fertilizer runoff, manure runoff and eroding sediment—all of which contain phosphorus in various forms. Agricultural lands typically have less vegetative cover than natural areas, particularly outside of the growing season, and are therefore prone to erosion—and phosphorus loading—during storm events.

WPDES permits regulate concentrated animal feeding operations (CAFOs). CAFOs are operations with 1,000 animal units, defined as "an animal equivalent of 1,000 pounds live weight and equates to 1,000 head of beef cattle, 700 dairy cows, 2500 swine weighing more than 55 pounds, 125 thousand broiler chickens, or 82 thousand laying hens or pullets" [91].

There are four CAFOs in Green Lake County and 15 CAFOs in Fond du Lac County, though no CAFOs fall within the geographic extents of the Big Green Lake watershed. However, some CAFOs are permitted to spread manure within the watershed. Generally, the LMPT does not consider manure to be a primary cause of agricultural nutrient loading in the Big Green Lake watershed with what is known at this time.

Given the characteristics of the Big Green Lake watershed, the LMPT has prioritized strategies that focus instead on refining nutrient management, increasing infiltration, and reducing erosion. Crop surveys completed by the land conservation departments as part of Baumgart's 2015 SWAT model indicate that over 40% of Big Green Lake's agricultural watershed acreage uses conventional tillage (Table 24). Conventional tillage results in full-width ground disturbance and minimal crop residue on the surface, leaving the surface bare and without protection.

Approximately 30% of assessed areas participate in mulch tillage (full-width tillage that disturbs the entire the soil surface prior to and/or during planting, but crop residue is left on the surface) and 20-30% participate in no-till (the ground is left undisturbed from harvest to planting, except for minimally invasive disc openers or other similar tools during planting).

Table 24. Assessment of tillage management in the Big Green Lake watershed.

County	Conventional Tillage	Mulch Tillage	No-Till
Fond du lac County (Silver Creek 2014)	43.1%	29.4%	27.5%
Green Lake County (2012)	40.1%	39.6%	20.3%

While data indicates that agriculture is the primary source of phosphorus loading to Big Green Lake, the LMPT has made substantial progress in reducing its impact. Between 2012 and 2018, over 120 practices totaling $1.8 million have been installed or are planned for installation in Green Lake County alone. The GLSD acquired a WDNR grant in 2016 and already has at least 20 projects in various stages of construction or planning.

The LMPT has a strong foundation to build on in large part because of its supportive local farmers. Because "agriculture is often a locally and regionally significant source of water pollution that is frequently exempt from Clean Water Act (CWA) regulations," [88] success in the Big Green Lake watershed will likely come from this strong history of voluntary participation instead of regulation.

v. Non-Regulated Urban Loading: Cities of Green Lake and Ripon

Developed areas can be sources of phosphorus and sediment. Municipalities serving populations greater than 10,000, or a population density of 1,000 or more per square mile, are required to have a municipal separate storm sewer system (MS4). MS4s are regulated nonpoint sources that require WPDES storm water permits. The Big Green Lake watershed has two cities, Green Lake and Ripon, whose populations do not meet these criteria and are therefore not required to meet these stricter pollutant discharge requirements.

A voluntary stormwater management plant completed by the City of Green Lake estimates its annual phosphorus loading to the Big Green Lake watershed to be 415 pounds of phosphorus per year (275 pounds to Big Green Lake proper and 140 pounds to the Mill Pond), or 2.5% total annual phosphorus loading to Big Green Lake. The LMPT does not consider this to be a primary source of phosphorus loading to the lake.

There are no estimates of phosphorus loading from the City of Ripon. The LMPT aims to work with the City of Ripon in the mid-term to complete a stormwater management plan similar to the one completed by the City of Green Lake, though any participation would be voluntary. Additional high-resolution sampling on Silver Creek would also help to quantify phosphorus reductions from the City of Ripon.

vi. Point Source Loading: Ripon WWTF

The Ripon WWTF (Permit # 21032) is the only treatment plant located within the watershed that also discharges its effluent within the watershed—in this case, to Silver Creek. Between 2013-2016, the WWTF discharged 699 pounds of phosphorus per year (see Figure 70). The WWTF has a WPDES permit with a discharge limit of 1.0 mg-P/L-effluent.

On average, the WWTF is meeting its permit limits (see Figure 66) and the LMPT does not consider this to be a major source of phosphorus loading. Substantial reductions are not required based on its current permit, nor would phosphorus reductions be cost effective when compared to other options.

Interestingly, in 1895, Ripon became the first Wisconsin community to treat its wastewater. The current facility was constructed in 1975 and underwent an expansion and upgrade in 2002 to 2003. Upgrades included "two new, one-million-gallon oxidation ditches; two new covered 400,000 gallon clarifiers; new preliminary treatment building; new ultraviolet disinfection process; and renovation of the control building," totaling a cost of $7.5 million [86].

The Ripon WWTF treats an average flow of 1.8 million gallons per day and a maximum of 6.8 million gallons per day, "utilizing the conventional oxidation ditch design of the activated sludge process of wastewater treatment" [86].

Under its current permit, the Ripon WWTF's discharge limit is 1.0 mg-P/L-effluent. Using all biological treatment, the WWTF's average effluent concentration has met these limits (see Figure 55).

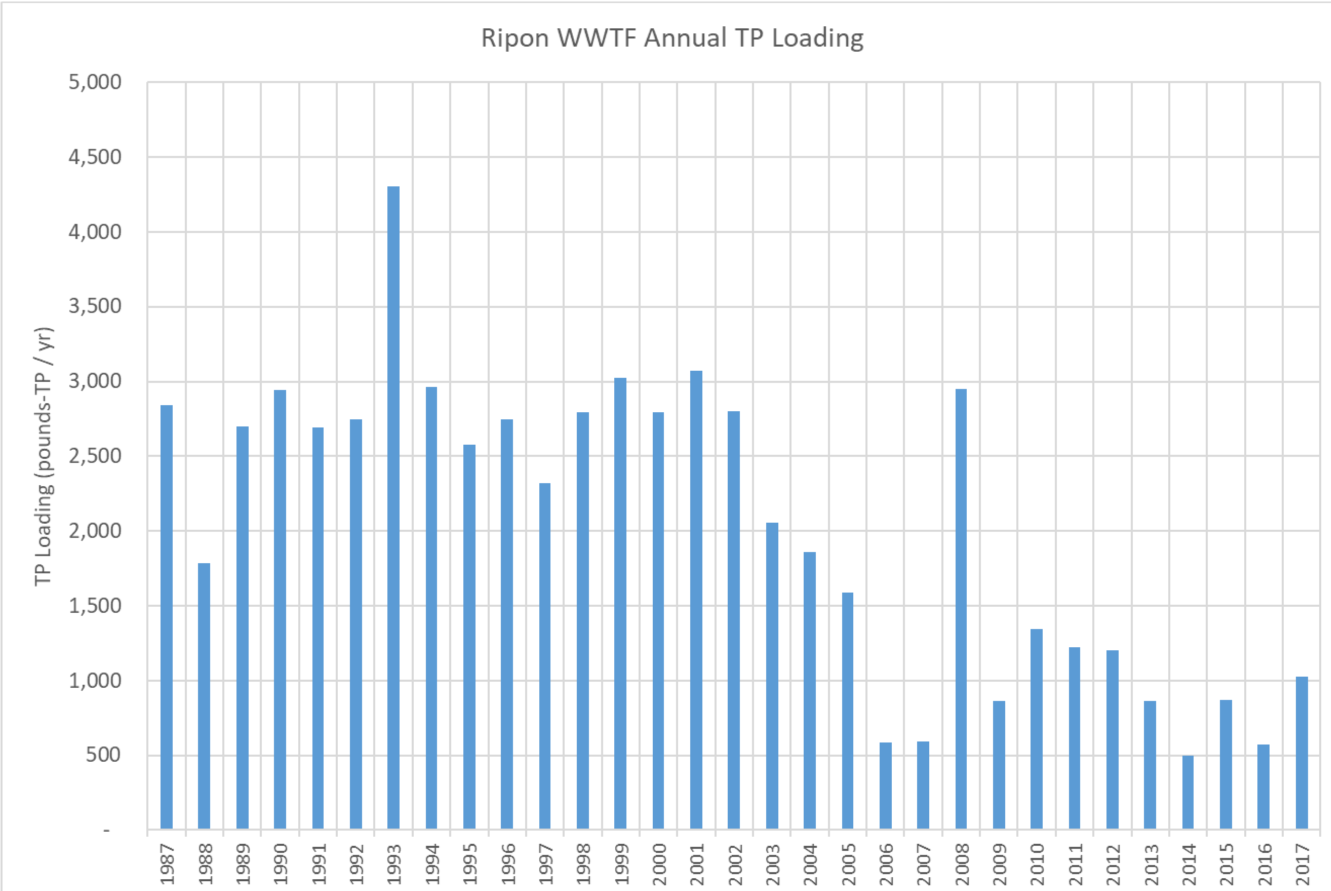

Figure 70. The Ripon WWTF discharged, on average between 2013 and 2016, 699 pounds of phosphorus annually.

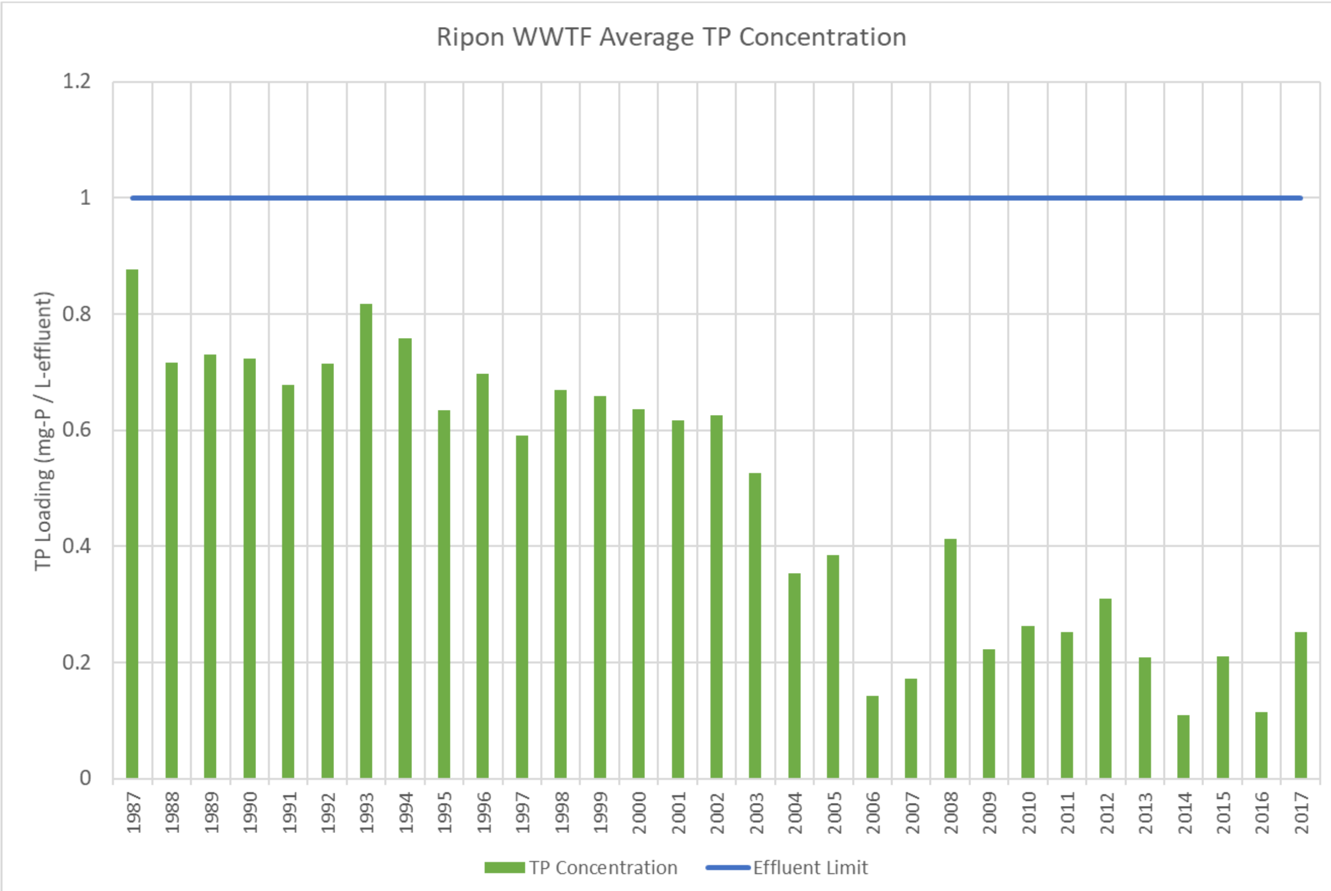

Figure 55. The City of Ripon Wastewater Treatment Facility is the only point source in the watershed that discharges its effluent in the watershed. Its annual averages are below its effluent limit of 1.0 mg-P/L-effluent, as indicated by the blue line.

i. Uncontrollable Source: Atmospheric Deposition

Small amounts of phosphorus naturally occur from rainfall-induced atmospheric deposition. In the Big Green Lake watershed, atmospheric deposition is estimated to be 1,995 pounds per year, based on precipitation from nearby gauges and an assumed rainfall phosphorus concentration of 0.036 mg/L, as provided by D. Robertson of the USGS.

ii. Uncontrollable Source: Waterfowl as a Phosphorus Source

Waterfowl present on Green Lake are an uncontrollable source of phosphorus loading to Green Lake. A 1980 study conducted by Ripon College estimated that the annual contribution of Canada Geese to Green Lake was 5% of the annual phosphorus load, or 1,280 pounds of its then-estimated 26,290 pounds of total loading [36].

Longer periods of open water allow for waterfowl to be present on the water more days each year, potentially adding to the total phosphorus load of the lake. It would be worthwhile to better understand the potential loading source and implications of geese based on more recent data and more open-water days.

Increases in uncontrollable phosphorus sources to Green Lake will mean greater required reductions for its controllable sources, outlined in the previous sections.

iii. Uncontrollable Source: Groundwater

Researchers at the University of Wisconsin-Eau Claire found that “the regional bedrock geology may also be a source of phosphorus to the hydrologic system.” [92] The ongoing study found that “despite historic assumptions that phosphorus is immobile in groundwater systems, the study provides evidence that phosphorus is highly mobile in the subsurface.” [92]

The amount of potential phosphorus pollution from groundwater flowing to Big Green Lake is an unknown uncontrollable source that needs further study to assess and quantify.

7. PHOSPHORUS LOAD REDUCTION GOALS AND EXPECTATIONS

Big Green Lake has a phosphorus concentration above optimal standards (17.0 µg/L instead of the target of 15.0 µg/L) and the lake is currently impaired for low levels of dissolved oxygen near its thermocline (target of 5.0 mg/L), potentially caused by excessive phosphorus loading. As of 2018, Big Green Lake is not listed as impaired for its high phosphorus concentrations, but water quality trends indicate that may be a possibility in the near-term.

These symptoms indicate that, over the long-term, Big Green Lake's water quality is not what it once was. Long-term monitoring, sediment cores, and other data also indicate that the lake's water quality is degrading.

The goal of the LMPT is to protect, improve, and ultimately restore Green Lake's water quality—back to an oligotrophic lake—to meet the needs of future generations. Specifically, the LMPT has water quality goals of:

- By 2025, achieve a **20% phosphorus reduction** of controllable phosphorus sources across the watershed, to 13,300 pounds per year.
- By 2040, in approximately 20 years, achieve an **in-lake phosphorus concentration below 15 µg/L**, which is the water quality criteria for Big Green Lake, by. require **reducing phosphorus loading by 44% in the watershed to meet** the estimated loading capacity of Big Green Lake, as determined in the Upper Fox-Wolf TMDL [93]. More research will help to better understanding the phosphorus loading reductions required to reach this in-lake phosphorus concentration
- By 2070, in approximately 50 years, **return Green Lake to an oligotrophic lake by achieving an in-lake phosphorus concentration of 12 µg/L**. This is the same long-term water quality goal outlined in the 2013 LMP [4].

Furthermore, the LMPT recommends working closely with the WDNR to develop criteria for de-listing Green Lake for low dissolved oxygen in its metalimnion. Currently, the LMPT is not aware of any criteria to de-list lakes for a metalimnetic oxygen minima. Green Lake's water quality criteria is currently 5 mg/L of dissolved oxygen. Once these criteria are developed, the LMPT has a long-term goal of **improving the lake's metalimnetic oxygen minima to the point that it is no longer listed as impaired for low dissolved oxygen.**

Reducing phosphorus loading is a substantial undertaking and the lake's retention time of approximately 20 years means meaningful, measurable changes will take decades to materialize. Therefore, the LMPT is committed to building on its legacy of ambitious conversation practices and incorporating new, innovative technology to achieve the goal of a cleaner, healthier lake.

The 2020 Upper Fox-Wolf TMDL [2] lists the following benefits from reducing phosphorus loading:

- Reduced density, frequency, and duration of nuisance algal blooms resulting in lowered health risks to humans and animals – especially pets
- Increased dissolved oxygen concentrations that will support a more diverse and robust community of fish and other aquatic life
- Increased water clarity/transparency due to the stabilizing effect of increased submerged aquatic vegetation
- Improved biotic integrity index scores for fish and macroinvertebrate communities
- Improved qualitative and quantitative aquatic habitat ratings
- Reduced water temperatures
- Improved pH levels
- Increased numbers and safety of swimmers, boaters, wind-surfers, and other water craft users

There are many phosphorus sources to Big Green Lake, yet not all are feasible to address or even measure. Further, while the LMPT has a robust stream sampling plan that directly measures phosphorus loading for 90% of its inlets, there are significant data gaps upstream of those sampling stations. This understanding of loading throughout the watershed becomes critical when implementing strategies aimed at reducing runoff-based nutrient loading.

While additional upstream monitoring would benefit the LMPT's phosphorus reduction strategy, there are several other tools in place, discussed later in Section 7.D.ii, to target phosphorus reductions in priority areas.

A. Studies Affecting Future Phosphorus Loading Goals

i. Fox-Wolf TMDL

The Upper Fox River and Wolf River watersheds are two separate basins that converge within a series of pool lakes in Winnebago County before finally flowing collectively into Lake Winnebago and eventually Lake Michigan at Green Bay. Big Green Lake is located within the Upper Fox River watershed.

The 2020 Total Maximum Daily Load (TMDL) for the Upper Fox-Wolf Watersheds for total phosphorus and total suspended solids identifies the sources of the pollutants and the reductions necessary to address water quality impairments on a sub-watershed scale.

Sub-watersheds within the Green Lake watershed detailed in the Upper Fox-Wolf TMDL are: sub-basins 17, 18, 19, 20, 79, 83, and 87. These are outlined in Figure 71 and Table 25.

The TMDL's method of de-listing each sub-watershed is more geographically specific than the intention of this Plan. This Plan's goal is to de-list Green Lake (only) and not necessarily each individual sub-watershed in its system.

Therefore, achieving the watershed-wide reduction may not meet the TMDL reduction within each sub-basin in Big Green Lake watershed.

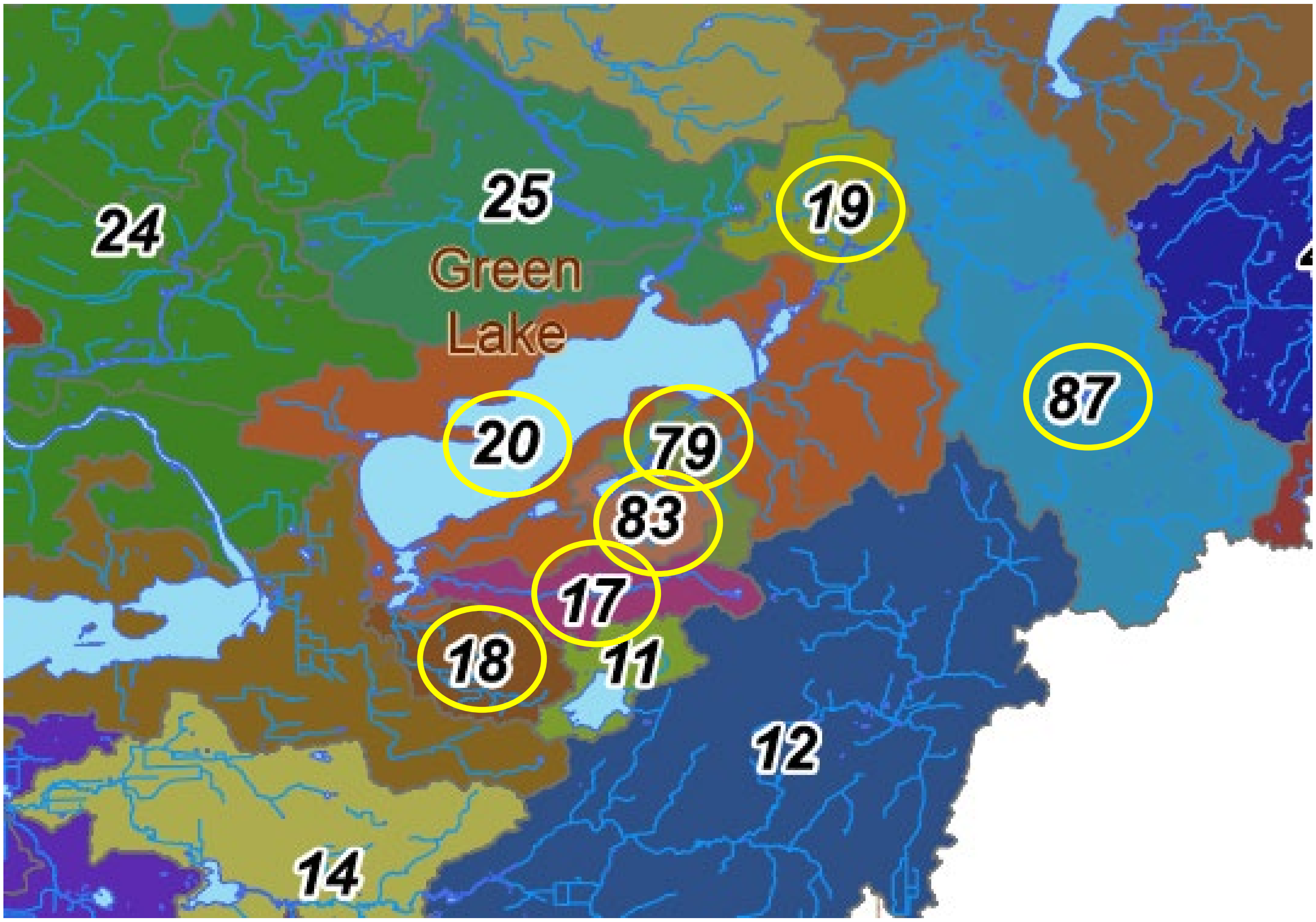

Figure 71. Upper Fox-Wolf TMDL Report reach map within Green Lake watershed reaches—Reaches 17, 18, 19, 20, 79, 83, and 87—denoted in yellow circles.

Table 25. Waterbodies and impairment listings on the WDNR 2018 303(d) list within the Green Lake watershed as addressed in the Upper Fox Wolf TMDL [2]. Note: TP criterion vary by waterbody classification.

Waterbody Name	WATERS ID	WBIC	Start Mile	End Mile	TMDL Subbasin	Impairment Indicator(s)	Pollutant(s)	TP Criterion (µg/L)
Green Lake (Big Green)	11023	146100	N/A	N/A	20	Low DO	TP	15
Big Twin Lake	11025	146500	N/A	N/A	83	Excess Algal Growth	TP	30
Hill Creek	11024	146200	0	2	79	Degraded Habitat	TSS	75
North Tributary to Silver Creek	936838	147400	0	4	87	Impairment Unknown	TP	75
Roy Creek	11030	148200	0	7	17	Degraded Habitat Impairment Unknown	TSS TP	75
Silver Creek	11028	146800	1	12	19, 87	Elevated Water Temperature, Degraded Habitat Impairment Unknown	TSS TP	75
Silver Creek	359092	146800	12	14	87	Elevated Water Temperature, Degraded Habitat	TSS	75
Unnamed Trib to Silver Creek	5476567	147700	0	8	87	Impairment Unknown	TP	75
Unnamed Trib to Silver Creek	5476590	146900	0	3	19	Degraded Biological Community	TP	75
Wuerches Creek	359163	148300	0	4	18	Degraded Habitat Low DO, Elevated Water Temp	TSS TP	75

The TMDL examines phosphorus loads and allocation of loads on a sub-basin scale, as shown in Table 26 and Table 27.

Table 26. From Appendix G of the TMDL [2], baseline total phosphorus loading by source category for each TMDL subbasin in the Big Green Lake watershed. Total TP loads were generated by the SWAT model (calibrated with recent WQ monitoring data).

TMDL	Subbasin	Background TP	Agricultural TP	Non-Regulated Urban TP	General Permits TP	Regulated MS4 Urban TP	Individual Permits	Total TP
17	Roy Creek	13	938	4	0.4	0	0	**955**
18	Wuerches Creek	10	1,730	11	1	0	0	**1,752**
19	Silver Creek – Below S Koro Rd	35	1,040	20	2	0	0	**1,097**
20	Green Lake	133	1,652	203	20	0	0	**2,008**
79	Hill Creek	3	534	3	0.3	0	0	**540**
83	Big Twin Lake	9	445	11	1	0	0	**466**
87	Silver Creek – Above S Koro Rd	41	3,521	111	11	0	5,484	**9,168**
							All TMDL Reaches:	**15,986**

Table 27. From Appendix H of the Upper Fox-Wolf TMDL [2]: Allocations of total phosphorus load by source for each TMDL subbasin in the Green Lake watershed. All loads shown as pounds of phosphorus per year and were generated by the SWAT model. There are no regulated MS4s in the Green Lake watershed, so this column from Appendix H was eliminated.

TMDL ID	Subbasin Name	Total Load (LA+WLA+RC)	Load Allocation (LA)	Background	Ag Nonpoint	Non-Regulated Urban	Wasteload Allocation (WLA)	General Permit	Individual Permits	Reserve Capacity
17	Roy Creek	327	311	13	297	1	0	0	-	16
18	Wuerches Creek	768	729	10	714	5	1	1	-	38
19	Silver Creek – Below S Koro Rd	646	614	35	568	11	2	2	-	30
20	Green Lake	2,106	1,988	133	1,652	203	20	20	-	98
79	Hill Creek	115	109	3	105	1	3	3	-	6
83	Big Twin Lake	327	310	9	294	7	1	1	-	16
87	Silver Creek – Above S Koro Rd	2,329	903	41	836	26	1,312	11	1,301	114
	All TMDL Reaches:	**11,582**	**5,208**	**4,710**	**4,720**	**1,593**	**1,378**	**38**	**1,619**	**318**

The TMDL examines each individual impaired reach and determines load reductions required to achieve water quality criteria, as outlined in Table 28:

Table 28. From Appendix H of the Upper Fox-Wolf TMDL [2]: Annual total phosphorus reductions required to meet water quality targets and additional reductions to meet targets in downstream waterbodies. Reductions were generated from the SWAT model.

TMDL ID	Subbasin Name	Local Reduction		Downstream Reduction		Downstream Waterbody	Total Reduction	
		lbs/yr	%	lbs/yr	%		lbs/yr	%
17	Roy Creek	628	68%	-	0%	-	628.0	68%
18	Wuerches Creek	984	59%	-	0%	-	984.0	59%
19	Silver Creek – Below S Koro Rd	450	45%	-	0%	-	450.0	45%
20	Green Lake	-	0%	-	0%	-	-	0%
79	Hill Creek	426	80%	-	0%	-	426.0	80%
83	Big Twin Lake	-	0%	138	34%	Little Twin Lake	138	34%
87	Silver Creek – Above S Koro Rd	6,838	76%	-	0%	-	6,838	76%
	Total TMDL Reaches:	**9,326**					**9,464**	

The TMDL specifies agricultural edge of field target TP reductions in TMDL reaches within the Big Green Lake watershed, as outlined in Table 29. These edge of field values will be used when discussing and implementing new or additional cropland practices across the watershed to meet this plan's phosphorus reduction goals.

Table 29. From Appendix J of the TMDL, Agricultural total phosphorus (TP) yield targets for TMDL subbasins. Targets are comparable to outputs from SnapPlus and correspond to attainment of TMDL agricultural load allocations. The targets are calculated from baseline yields for each TMDL subbasin and percent reduction for the TMDL subbasin.

TMDL ID	Subbasin Name	Baseline TP (lbs/ac/yr)	% TP Reduction (lbs/ac/yr)	Target TP (tons/ac/yr)
17	Roy Creek	4.12	68%	1.31
18	Wuerches Creek	4.24	59%	1.75
19	Silver Creek – Below S Koro Rd	2.97	45%	1.62
20	Green Lake	3.66	0%	3.66
79	Hill Creek	4.30	80%	0.84
83	Big Twin Lake	4.30	34%	2.83
87	Silver Creek – Above S Koro Rd	3.95	76%	0.94

For HUC-12s in the Green Lake watershed, the TMDL specifies TP reductions, as outlined in Table 30.

Table 30 From Appendix J of the Upper Fox-Wolf TMDL: Agricultural total phosphorus (TP) yield targets for HUC12s. Targets are comparable to outputs from SnapPlus and correspond to attainment of TMDL agricultural load allocations. The targets are calculated from baseline yields for each HUC12 and percent reductions each TMDL subbasin that intersects the HUC12.

HUC12	TMDL Subbasin	Baseline TP (lbs/ac/yr)	% TP Reduction (lbs/ac/yr)	Target TP (tons/ac/yr)
040302010901	19, 20, 87	3.86	58%	1.61
040302010902	17, 18, 20, 79, 83	3.85	27%	2.79

Section 5.1.4 of the TMDL [2] also specifies that Green Lake (TMDL subbasin 20) has **a loading capacity of 9,319 pounds of phosphorus per year**, which is the maximum pollutant load the lake can handle to achieve Green Lake's water quality standard of 15 µg/L.

Using the 2013-2016 measured annual phosphorus loading of 16,652 pounds of phosphorus per year, achieving the loading capacity of 9,319 pounds of phosphorus per year would require a 44% phosphorus reduction within the watershed[1].

This Plan will be updated with more specific reductions focused on achieving in-lake water quality goals after the completion of a Diagnostic and Feasibility study, which is discussed in the following section.

[1] *16,652 (baseline) – 9,319 (Green Lake loading capacity) = 7,333 lbs P reduction required to meet TMDL. 7,333/16,652 = 44% reduction*

ii. Diagnostic and Feasibility Study

In 2019, a Diagnostic and Feasibility Study correlating water quality goals with phosphorus and/or other pollutant reductions is set to be complete. This Diagnostic and Feasibility study will be much more rigorous than the large-scale TMDL and will use actual loading when water quality data is available.

Therefore, if the TMDL establishes phosphorus load reductions prior to completion of the Diagnostic and Feasibility study, the Lake Management Planning team will use the Diagnostic and Feasibility study to submit a formal amendment to replace appropriate sections within TMDL with Diagnostic and Feasibility-based phosphorus reduction goals.

B. Interim Phosphorus Load Reduction Goals

A 2017 calculation estimates that, on average, the Big Green Lake watershed contributes 16,652 pounds of phosphorus per year to the lake.

Data indicates that Big Green Lake has elevated levels of phosphorus loading, which may also contribute to the lake's impairment of low dissolved oxygen levels near the thermocline. Phosphorus reductions throughout the watershed are therefore needed to achieve optimal water quality within the lake.

To date, and as a consideration of this Plan, no studies correlate the lake's natural ability to assimilate phosphorus to phosphorous loading from the watershed. Correlating water quality goals with required phosphorus reductions is one aim of the Diagnostic and Feasibility study, with an estimated completion date of 2019.

In the interim, by 2026, the Lake Management Planning Team will strive to implement best management practices to achieve an annual phosphorus load reduction of 20%, or 3,350 pounds of phosphorus per year. This will reduce total annual phosphorus loading from 16,652 pounds per year to 13,300 pounds per year.

This value is not based on water quality goals and will be modified once the Diagnostic and Feasibility Study is completed. This amount of reduction falls short of the Upper Fox-Wolf River TMDL phosphorus reduction target which vary by sub-basin and have a range of 0-80%—but this Plan is intended as a lake focus and not a sub-watershed focus.

Given that some of Big Green Lake's phosphorus loading comes from background loading—an estimated 1,995 pounds of phosphorus per year comes from atmospheric deposition, for example, and no reasonable phosphorus reductions should be expected from this source—achieving a 20% reduction in annual phosphorus loading will fall disproportionately on other sources of loading. Most likely, these reductions will fall disproportionately on non-point agricultural runoff, which accounts for 65% of the Big Green Lake watershed's area and an estimated 74% of its estimated annual phosphorus loading.

Implementation of the Nine Key Elements Plan assumes an **annual phosphorus load reduction of 20%** (or a reduction by **3,350 pounds** per year) by 2026.

This will reduce total annual phosphorus loading from 16,652 to **13,300 pounds per year**.

It is also reasonable to consider how target reductions of 13,300 pounds of phosphorus per year compares to the lake's natural capacity to assimilate phosphorus. The Diagnostic and Feasibility study will provide the most comprehensive estimate to-date of Big Green Lake's target loading capacity. Currently, however, the 2020 Upper Fox-Wolf River TMDL provides the best assessment of Big Green Lake's target loading capacity, estimated as 9,319 pounds (Table 16 in [2]).

The LMPT recognizes that this is the proposed target reductions of 13,300 pounds per year is greater than the TMDL's loading capacity estimate of 9,319 pounds. However, the LMPT has rigorous stream sampling data and lake concentration data, which suggests that the lake is nearly at its water quality criteria in terms of its phosphorus concentration—measured as 17.0 µg/L instead of the target of 15.0 µg/L.

Therefore, the LMPT believes a 20% reduction in phosphorus loading to 13,300 pounds per year is a reasonable interim target that supports our water quality goals. Meeting the Upper-Fox Wolf TMDL phosphorus reduction targets will require achieving additional phosphorus load reductions over a 10- to 20-year time period.

The criteria for meeting the TMDL reductions is described in greater detail below in section C.

C. Estimating Phosphorus Loading Reductions from BMPs

Best management practices (BMPs) are structures or practices that aim to intercept soil loss and the resultant phosphorus loading from nonpoint sources to downstream water bodies. Sediment erosion occurs in three types: sheet, rill, and gully erosion. BMPs can be "hard" practices—permanent, constructed facilities that need to be maintained such as sediment basins, terraces, retention ponds, streambank/shoreline protect or grassed waterways—or they can be "soft" practices—such as areas planted in buffer strips or cover crops to limit phosphorus loading, primarily from cropland.

Regardless of the BMP in place, not all edge-of-field sediment and phosphorus nutrients calculated by models can be transported to streams or other waterbodies. Some phosphorus remains in the field and can accumulate—either in field, at the field edge, or in areas between the field boundary and a downstream water body. The accumulated phosphorus is known as legacy phosphorus. Therefore, soil and phosphorus loss at the edge-of-field is almost always greater than soil and phosphorus delivery to a nearby waterbody.

This Plan tracks phosphorus reductions based on estimated phosphorus captured by a BMP (see Figure 72). The method of tracking sediment and phosphorus reduction varies by the BMP installed, as outlined below.

For all BMPs, it is necessary to estimate phosphorus capture/delivery from sediment capture/delivery. In the Big Green Lake watershed, actual data from the White Creek USGS station (2006-2012) confirmed that 1 ton of soil contains 1.5 pounds of phosphorus. This conversation factor is used for all BMPs reduction estimates in this Plan.

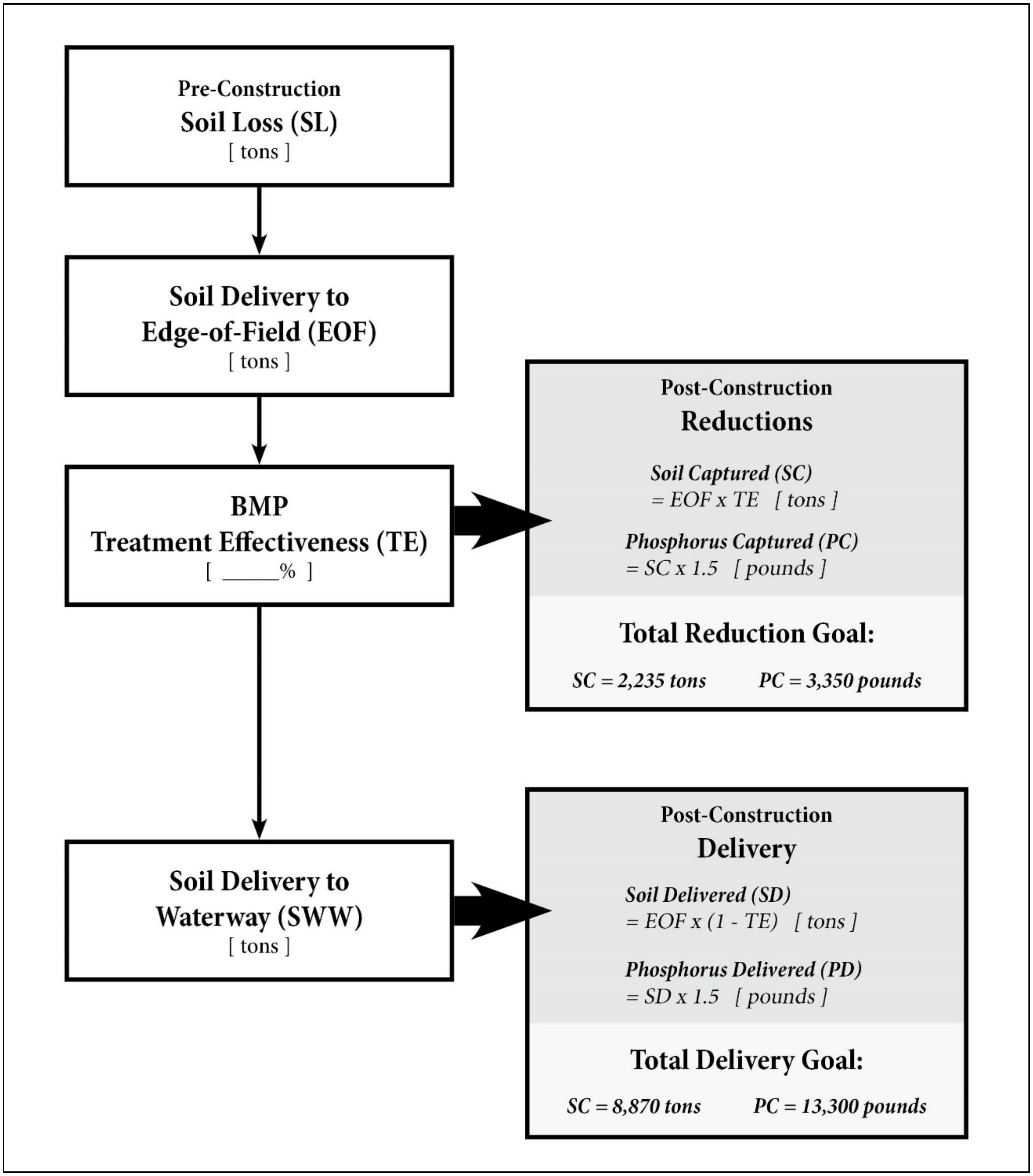

Figure 72. Phosphorus reductions from BMPs are tracked by phosphorus captured (PC), as shown in this schematic. The 3,350 lbs of captured phosphorus in Figure 59 represents an 20% reduction from baseline load of 16,652 lbs TP/yr. The reduction is estimated from multiple BMPs implemented on 4,240 cropland acres, which is appx 10% of the total cropland acres in the watershed. This reduction makes progress towards, but will not meet the Upper Fox-Wolf River TMDL phosphorus reduction targets in the watershed. The reduction targets vary by sub-basin and range from 0-80%.

Soil Delivery to Edge-of-Field (EOF). For each BMP, edge-of-field soil erosion is calculated using the Revised Universal Soil Loss Equation (RUSLE 2).

BMP Treatment Effectiveness (TE). Each BMP has a unique treatment effectiveness that varies by practice, as outlined in Table 31. BMPs with an engineered outlet, such as a grade stabilization structure or retention pond, have a TE provided by the corresponding design software used. These outlet structures often discharge directly to a waterway. To determine the TE of other practices, various trials using common buffer widths and slopes found within the Big Green Lake watershed were used in RUSLE 2. It was found that approximately 10% of sediment loss from the edge-of-field was delivered, a value that is also supported by the WDNR's recommendations.

Soil Captured (SC) and Phosphorus Captured (PC). The treatment effectiveness of each BMP results in some soil and phosphorus being captured.

Soil Delivery to Waterway (SWW). After edge-of-field delivery and BMP treatment, any soil or phosphorus that is not captured is assumed to be delivered to the downstream waterway. In the Big Green Lake watershed, it is estimated that 16,652 pounds of phosphorus is delivered annually. Therefore, the PC by each BMP is a direct reduction of this annual loading.

Soil Delivered (SD) and Phosphorus Delivered (SD). Soil delivery to a waterway is also used to estimate phosphorus delivery.

For annual phosphorus reduction calculations, a distinction is made between a "hard" structural practice and a "soft" practice. Once installed, structural practices (i.e., grade stabilization structures, streambank protection, waterways) perform a sediment/phosphorus reduction function annually, if properly maintained. Therefore, once installed, structural practices are included in future annual estimates of phosphorus reductions.

Soft practices (i.e., cover crops, no-till) need to be implemented annually to achieve a phosphorus/sediment reduction. Reductions are only considered in years the practice is installed.

Table 31. Treatment effectiveness (TE) and soil delivery to the waterway (SWW) varies by BMP.

Best Management Practice	Treatment Effectiveness (TE)	Soil Delivery to Waterway (SWW)
HARD PRACTICES – Phosphorus reductions tabulated annually after installation, pending structure maintenance.		
Barnyard runoff systems	90%	10%
Diversion	90%	10%
Grade stabilization structure	See BMP Model Output	See BMP Model Output
Grade Stabilization Structure with tile	See BMP Model Output	See BMP Model Output
Grassed waterway	90%	10%
Grassed waterway with underground outlet	90%	10%
Heavy use protection	100%	0%
Lined waterway	90%	10%
Roof runoff structure	90%	10%
Sediment basin	See BMP Model Output	See BMP Model Output
Stream crossing	90%	10%
Streambank and shoreline protection	100%	0%
Terrace	90%	10%
Underground outlet	90%	10%
Waste facility closure	90%	10%
Waste storage facility	90%	10%
Waste treatment system	90%	10%
Water and sediment control basin	See BMP Model Output	See BMP Model Output
SOFT PRACTICES – Phosphorus reductions tabulated only in years installed.		
Buffers	85%	15%
Contour farming	90%	10%
Cover crops	90%	10%
Critical area stabilization	90%	10%
No-till	90%	10%

Example calculations for BMP phosphorus reductions can be found in Appendix D.

D. Phosphorus Reduction Strategies

The phosphorus reduction strategies for the Big Green Lake watershed incorporate results of several comprehensive studies already completed and additional studies underway. The strategies include efforts to reduce phosphorus discharges at the source through BMPs and enhance the assimilative capacities of the streams, wetlands, and shorelines within the watershed that serve as the pathways of pollutant migration to Big Green Lake.

For consistency, these phosphorus reduction strategies are group into four categories: background, non-point agriculture, non-regulated urban, and point sources.

For each BMP, the cost per unit is based on implemented BMP data from 2012-2018 provided by the Green Lake County Land Conservation Department. Similarly, the 2026 implementation target for each BMP is based on data within the Big Green Lake watershed from 2012-2018, when available. The LMPT already has substantial momentum on BMP installation and is confident the annual BMP targets are achievable by 2026.

Phosphorus reductions from hard structures that have a cumulative reduction capacity—specifically, BMPs that reduce phosphorus annually after construction, as discussed in the previous section—are tallied cumulatively from 2021-2026. For example, the same retention pond installed in 2021 is included in annual phosphorus reductions in 2026. Phosphorus reductions from soft BMPs that need to be implemented annually are not considered cumulative in these calculations are detailed in Table 33 and Table 34 in the following section.

The proposed phosphorus reduction strategies, shown in Table 33 and Table 34 of this Plan are planned to be implemented on, or treat runoff from, 4,240 cropland acres, which represents approximately 10% of the 44,600 total agricultural acres in the watershed. The reduction strategies implemented at this scale are estimated to generate 5,730 pounds of phosphorus reductions per year by 2026 and equates to a 1.05 lbs/P/acre/yr average reduction. This includes a factor of safety of 170% above target reductions of 3,350 pounds of phosphorus per year.

These reductions come from background sources (6% of phosphorus reductions) and from non-regulated agricultural sources (94% of phosphorus reductions).

i. Summary of Total Phosphorus Reduction Milestones

This Plan is intended to achieve an annual phosphorus load reduction to Green Lake of 20% (or a reduction by 3,350 pounds per year) by 2026. This will reduce total annual phosphorus loading from 16,652 to 13,300 pounds per year.

As described earlier in this Plan, Green Lake's baseline (2013-2016) phosphorus load has been measured at 16,652 pounds-P/yr. To meet the Upper Fox-Wolf River TMDL load capacity for Green Lake (TMDL subbasin 20)—which has a loading capacity of 9,319 pounds of phosphorus per year—a 44% phosphorus reduction would be necessary. Using the 1.05 lbs/P/acre/yr average BMP reduction, meeting a 44% reduction will require implementing BMPs outlined in Table 33 and Table 34 on 16% of cropland acres (i.e., 7,000 acres) in the watershed. Achieving the 16% BMP threshold in the watershed will require a 10-year period to complete.

For reference, and not within the scope of this Plan, to meet all Upper Fox-Wolf River TMDL sub-basin phosphorus reduction targets (which range from 0-80%) will require implementing BMPs outlined in Table 33 and Table 34 on 28% of cropland acres (12,687 acres) in the watershed. Using the 1.05 lbs/P/acre average reduction, the 28% BMP threshold is estimated to generate 13,321 lbs/P/yr reduction and represents an 80% total reduction in phosphorus loading from baseline loading conditions (16,652 lbs/P/yr). Achieving the 28% BMP threshold in the watershed will require a 10-20 period to complete.

The proposed phosphorus reduction strategy in this Plan reflects expected outcomes from a variety of BMPs to be incorporated throughout the entire Green Lake watershed over a five-year period on 10% of total cropland acres. **The primary objective of the Plan is to improve conditions in Green Lake** and only to meet the Upper Fox-Wolf River TMDL phosphorus reductions targets, over time. Achieving additional phosphorus load reductions to meet TMDL reduction goals will require implementing the same or similar BMPs on approximately 16% and 28% of cropland acres, which will require a 10-20 year time period to achieve.

However, since the long-term goal of the LMPT is to achieve these more substantial targets mentioned within the TMDL, so this Plan also includes an estimate of the resources required for a 44% and 80% reduction, as shown in Table 32.

Table 32. Phosphorus reduction milestones for this Plan (20%), as denoted by an asterisk, and other reductions mentioned within the Upper Fox-Wolf TMDL (44% and 80%).

Phosphorus Reduction Milestone	Timeline	Cropland Acres with BMPs	Percent of Total Cropland Acres in Watershed[2]	Reduction (lbs/P/year)	Priority TMDL Sub-basin for BMPs[3] Focus BMPs in critical areas located in each sub-basin
20%*	5 years	4,240	10%	4,480	79, 87, 17, 18, 19, 83, 20
44%	10-years	7,000	16%	7,350	79, 87, 17, 18, 19, 83, 20
80%	10-20 years	12,687	28%	13,321	79, 87, 17, 18, 19, 83, 20

Table 33 and Table 34 document goals for specific practices required to achieve a total 20% phosphorus reduction of 4,480 pounds/year by 2026. These goals draw a distinction between background loading, soft BMPs, and hard BMPs based on the following assumptions:

- *Background loading practices (*carp removal, lake weed removal) and *soft BMPs* are required to be completed on an annual basis for phosphorus reduction goals. Therefore, their costs are incurred on an annual basis, in addition to any potential capital expenditures.
- The benefits of *hard BMPs* are cumulative over the five-year period (e.g., phosphorus reductions from a retention pond installed in year 1 is still reducing similar phosphorus rates in year 5). Therefore, costs for hard BMPs are incurred over the life of the five-year study period.

Namely, the practices introduced in Table 33 and Table 34 to achieve the reduction goals of this Plan include:

- **Background Loading**
    - **Aquatic plant harvesting**. The GLSD annually removes aquatic plants from Green Lake, which is a form of phosphorus removal. Previous nutrient analyses from plant tissue samples are used to equate aquatic plant removals with phosphorus reductions.
    - **Carp removal**. The GLSD and GLA cost-share the removal of invasive carp from Green Lake proper and the CKM annually. Carp are particularly destructive in the CKM. Removing carp from the CKM is a form of phosphorus removal, as phosphorus is found within their body tissue and from the resuspension of sediment in these shallow waterbodies. Phosphorus equivalents to carp removal is based on previous studies.

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[2] Green Lake Watershed has 44,600 total cropland acres.

[3] Order of sub-basins in table reflects largest to smallest P % reduction amount. Critical areas within each sub-basin, as identified by EVAAL and NLPAs from the Delta Institute Phosphorus Prioritization Plan (2016), will be first priority for BMP adoption.

- **Duckweed mitigation and harvesting**. The GLA and GLSD are currently working on a duckweed mitigation and harvesting proposal for the WDNR. These strategies—still in their proof-of-concept phase and not yet approved by the WDNR—were previously discussed in Section 4.C.i. However, if approved, duckweed removal would also represent a form of phosphorus removal and is captured here for thoroughness. Nutrient content of duckweed tissue samples is still being analyzed, so no phosphorus removal is attributed to it yet.

- **Non-Point Agriculture, Soft Practices**
  - **Cover crops**. Cover crops have been shown to increase soil stability and reduce phosphorus loading to downstream water resources. This strategy is supported by a GLSD Soil Health Program, in close collaboration with the Green Lake and Fond du Lac County Land Conservation Departments.
  - **Cover crop interseeder program**. The GLA is currently working on a cover crop interseeder program to provide free use of a drill for the purpose of planting cover crops earlier in the season.
  - **Buffers**. Green Lake County Land Conservation Department has an ongoing buffer program with acres in the Green Lake watershed. Additionally, the GLA is considering raising funds for expanding this buffer program.
  - **Grassland**. Replacing conventional agriculture with permanent cover, such as grasslands, is a phosphorus-reduction strategy.
- **Non-Point Agriculture, Hard Practices**
  - **Manure management**. Providing infrastructure to contain manure supports more thoughtful manure management and reduces phosphorus to downstream water resources.
  - **Resident management**. Leaving residue on the fields prevents exposed and tilled fields from flowing downstream to water resources.
  - **Sediment basins**. The Green Lake watershed frequently uses sediment basis to capture and slow runoff to downstream water resources as a phosphorus-reduction strategy. These practices are designed particularly for runoff attenuation and sedimentary phosphorus removal.
  - **Sediment basin CAPTure retrofit structures**. The GLA is pursuing grant funds for tested and effective soluble P capture technology, CAPTure, to reduce soluble P from agricultural runoff, particularly in the CKM. These are small footprint, passive filtration devices—which use highly-sorptive, long lasting capture media, with hydraulically controlled discharge—would be retrofit to existing retention ponds in the watershed. CAPTure structures are a patent-pending filter device designed by GLA project partner, Kieser & Associates under a separate Great Lakes Protection Fund (GLPF) grant. Such technology applications are necessary, as current agricultural runoff detention structures are ineffective at removal of soluble phosphorus.
  - **Stream restoration**. Historic rain events have caused sizeable damage to Green Lake's intermittent and perennial streams. Stream restoration is a strategy to address sites of active erosion and reduce direct conduits of phosphorus runoff.
  - **Terraces**. Using terraces to breakup continuously sloping fields reduces phosphorus runoff from agricultural acres.
  - **Waterways, grassed and lined**. Waterways installed at the low point of agricultural fields slows runoff and reduces phosphorus loading.

Table 33 details phosphorus reduction goals and efficiencies for each practice detailed above. Table 34 details the cost of implementing these practices on an annual basis and over the period of this Plan from 2021-2026.

Table 33. By 2026, the following combination of phosphorus reduction strategies implemented over 4,240 acres will achieve phosphorus reduction targets of 5,730 pounds per year. The goal is a 20% reduction to reduce phosphorus loading from 16,652 pounds per year to 13,300 pounds of phosphorus per year, so this includes a factor of safety of nearly 170%. Achieving the additional phosphorus reduction goals (44% and 80% reduction) will require replicating or adopting similar practices within the watershed over a 10- to 20-year period.

Activity	Annual Goal		Treatment Efficiency (lbs-P / Unit)		2026 P-Target (lbs-P / yr)		Cost Efficiency ($ / lb-P)
BACKGROUND LOADING					**350**	**lbs**	
Aquatic plant harvesting	570	tons	0.6	lbs-P/tons-plants	320	lbs	$1,020
Carp removal	5,000	lbs carp	0.01	lbs-P/lbs-carp	30	lbs	$1,340
Duckweed mitigation & harvesting	TBD		TBD		TBD		TBD
NON-POINT AGRICULTURE: SOFT PRACTICES					**690**	**lbs**	
Cover crops	200	ac	0.4	lbs-P/ac	90	lbs	$560
Cover crop interseeder program	100	ac	0.4	lbs-P/ac	50	lbs	$1,690
Buffers	5,280	ft	0.1	lbs-P/ft	530	lbs	$20
Grassland (perennial cover, CRP and/or critical area seeding)	2	ac	1.1	lbs-P/ac	20	lbs	$220
NON-POINT AGRICULTURE: HARD PRACTICES					**4,690**	**lbs**	
Manure management (waste storage facility)	120	ac	0.3	lbs-P/ac	170	lbs	$940
Residue management (including no tillage)	20	ac	1.2	lbs-P/ac	120	lbs	$20
Sediment basin / grade stabilization structure	660	ac	0.7	lbs-P/ac	2,360	lbs	$150
Sediment basin CAPTure retrofit structures	80	acres	0.5	lbs-P/ac	200	lbs	$900
Stream restoration	5,280	ft	0.04	lbs-P/ft	1,180	lbs	$350
Terrace	40	ac	1.0	lbs-P/ac	210	lbs	$440
Waterways (grassed and lined)	2,780	ft	0.03	lbs-P/ft	450	lbs	$220
				Total:	**5,730**	**lbs/yr**	
				Target:	**3,350**	**lbs/yr**	170% safety factor

Table 34. The total cost to achieve a 20% reduction (to reduce phosphorus loading from 16,652 pounds per year to 13,300 pounds of phosphorus per year, with a nearly 140% factor of safety) is nearly $475,000 annually with capital investments of nearly $350,000, totaling approximately $2.3 million over 5 years.

Activity	Annual Goal		Annual Cost/Unit		# Units for 5 Yrs		Annual Cost ($)	Capital Cost ($)	Total Cost for 5 Yrs ($)
BACKGROUND LOADING (Costs incurred annually)						**Subtotal:**	**$113,000**	**$250,000**	**$815,000**
Aquatic plant harvesting	570	tons	$65,000	/yr	2,850	tons	$65,000	$-	$325,000
Carp removal	5,000	lbs carp	$8,000	/yr	25,000	lbs carp	$8,000	$-	$40,000
Duckweed mitigation & harvesting			$40,000	/yr	N/A		$40,000	$250,000	$450,000
NON-POINT AGRICULTURE: SOFT PRACTICES (Costs incurred annually)						**Subtotal:**	**$109,100**	**$32,000**	**$141,100**
Cover crops	200	ac	$50	/ac	1,000	ac	$50,000	$-	$50,000
Cover crop interseeder program	100	ac	$105	/ac	500	ac	$52,500	$32,000	$84,500
Buffers	5,280	ft	$0.25	/ft	26,400	ft	$6,600	$-	$6,600
Grassland (perennial cover, CRP and/or critical area seeding)	2	ac	$430	/ac	10	ac	$860	$-	$4,300
NON-POINT AGRICULTURE: HARD PRACTICES (Costs incurred at implementation)						**Subtotal:**	**$252,460**	**$60,000**	**$1,322,200**
Manure management (waste storage facility)	120	ac	$265	/ac	600	ac	$31,760	$-	$158,790
Residue management (including no tillage)	20	ac	$14	/ac	100	ac	$290	$-	$1,420
Sediment basin / grade stabilization structure	660	ac	$100	/ac	3,300	ac	$66,210	$-	$331,050
Sediment basin CAPTure retrofit structures	80	acres	$1,800	/ac	400	ac	$36,000	$60,000	$240,000
Stream restoration	5,280	ft	$15	/ft	26,400	ft	$80,980	$-	$404,890
Terrace	40	ac	$453	/ac	200	ac	$18,140	$-	$90,680
Waterways (grassed and lined)	2,780	ft	$7	/ft	13,900	ft	$19,080	$-	$95,370
NON-REGULATED URBAN – *None proposed currently*						**Subtotal:**	**$0**	**$0**	**$0**
POINT SOURCES – *None proposed currently*						**Subtotal:**	**$0**	**$0**	**$0**
						Total:	**$475,420**	**$342,000**	**$2,282,600**

These phosphorus reductions are based on treatment efficiencies, calculated from following considerations:

- **Background Loading**
  - ***Aquatic plant harvesting***. The GLSD keeps annual records of aquatic plant removal from its AQWEED program. Each truckload is about one ton of wet weight in aquatic plants. These aquatic plants were previously sampled for phosphorus concentration and determined to contain about 0.55 pounds of phosphorus per ton of wet weight aquatic plants.
  - ***Carp removal***. To evaluate phosphorus reductions from carp harvesting, two primary phosphorus generation sources are considered, researched by Sesing [94]: phosphorus reduction via carp biomass harvesting, and phosphorus reduction due to carp behavior/feeding considerations. These considerations result in a conversion ratio of 1.85% of carp weight harvested as phosphorus.
    - *Phosphorus reduction via carp biomass harvesting (trapping, netting).* When carp are harvested, they are essentially "mined" from the system. The phosphorus component in carp biomass is estimated at 0.5% to 1.0% (Robertson, D. et al). As a moderate estimate, calculations assume 0.75%.
    - *Phosphorus reduction due to carp behavior/feeding considerations*. When carp are harvested or eliminated, a reduction is phosphorus is also realized through the elimination of their behavioral mechanisms responsible for generation/regeneration of phosphorus. In effect, the bottom plowing, aquatic plan destruction and food solubilization. A single carp will disturb sediment through resuspension, disrupt aquatic plants and regenerate phosphorus by solubilizing nutrients, including phosphorus. Referenced literature suggests nutrient generation of 0.011 pounds of phosphorus per pound of carp per year.
- **Non-Point Agriculture**
  - For all BMPs, sediment capture is calculated based on the individual BMP and its treatment efficiency, as outlined in Section 7.C. Once sediment capture is determined, treatment efficiency is based on the relationship that 1 ton of sediment contains 1.5 pounds of phosphorus. All phosphorus reductions are based on indirect measurements from modeled results of previously designed BMPs in the Big Green Lake watershed.
- **Non-Regulated Urban**
  - Given the relative phosphorus contribution and impact of urban BMPs, no BMPs are formally considered in annual phosphorus reduction targets. However, the LMPT will continue to work with these entities to implement effective practices for downstream water quality. In this case, the recent Green Lake stormwater management plan, detailed in the following section, provides guidance for efficient areas and priority areas.
- **Point Sources**
  - Given that the only point-source in the watershed, the Ripon WWTF, is currently meeting its effluent criteria, no official target reductions are considered in this plan—

though urban education programs, including proper management of leaves and grass pickup, will be part of the education program.

ii. Priority Areas for Phosphorus Loading Reduction

The LMPT has invested in several prioritization tools, discussed in Chapter 5, that provide priority areas for BMPs. Whenever possible, the location of BMPs should be determined based on these priority areas to maximize phosphorus reductions to Big Green Lake.

a) Best Management Practices in Agricultural Priority Areas

The Delta Institute's Phosphorus Prioritization Plan provides 12 nutrient loading priority areas in the Big Green Lake watershed (discussed in Section 5.A.ii). These are areas most likely to erode based on soil types, land use, slope and other parameters based on the EVAAL model. The LMPT will target BMPs in these areas whenever possible to maximize efficiencies.

Additionally, the 2015 SWAT model identifies areas with higher phosphorus loading. The LMPT will target BMPs in these priority areas whenever possible to achieve this Plan's phosphorus reduction goals.

b) Stream Bank Restoration in Stream Priority Areas

The LMPT conducted a detailed streambank inventory of all named streams in the watershed, as discussed in Section 5.C.iii. This data was used to create a ranking of actively eroding streambank. However, since the survey was conducted additional highly eroded sections of streambank have been observed. To ensure the resources as applied to the most highly eroded areas the LMPT recommends that stream restoration plans be created on a subwatershed basis in close temporal relation to planned activities.

Whenever possible, areas that are ranked highest for erosion will be targeted first for streambank restoration practices.

c) Buffer Priority Areas

The Green Lake Land Conservation Department is launching a Green Lake Buffer Program in 2019. In determining where to cost-share these buffers, the department will use their Green Lake County Buffer Ranking Calculator to award buffer priority areas with more points in its ranking process.

Whether through this new Green Lake County program and additional programs, buffer strips, prairie strips, easements, and other management practices to take selected areas of land out of intensive agricultural production to establish perennial vegetation are important measures to protect Green Lake. Buffers will not only reduce the existing agriculture acres pollutant loads, but also can treat/reduce upgradient cropland runoff from reaching surface waters.

d) BMPs in the County Highway K Marsh Sub-Watershed

The restoration of the CKM is a priority for the LMPT. To reduce phosphorus loading from this major inlet, the LMPT will target BMPs in the CKM sub-watershed, which includes Roy, Wuerches, and Spring Creeks and their sub-watersheds.

Additionally, new technology, retrofitted practices, and/or strategic removal of legacy phosphorus sediment in the subwatershed and the CKM will help to expedite the decreased loading of phosphorus from this subwatershed. Pilot projects and feasibility studies may be required to implement new approaches to this critical area.

iii. Other Areas of Phosphorus Loading Reduction

a) City of Green Lake and Ripon

While there are no non-regulated urban phosphorus reductions include in provided target reductions, the LMPT will work with the City of Ripon and City of Green Lake to reduce phosphorus loading to Big Green Lake to the maximum extent practicable.

The City of Green Lake's stormwater study [34] provides some guidance on priority areas, particularly from street sweeping, leaf management, swales (27 existing), and structural BMPs (24 existing). A cost and performance analysis for 12 BMPs (including 5 new and 7 retrofit structures) were considered. Seven of these structures Implementing all new/retrofitted BMPs would result in a reduction of 14.6 tons per year of sediment and 84.4 pounds per year of phosphorus at a cost of $713,000. The projects vary both in terms of effectiveness and in terms of cost-per-pound of pollutant removed.

Recommendations of the report include:

- Securing maintenance agreements for privately owned BMPs,
- Implementing a program to require inspection and routine maintenance of structural stormwater management practices,
- Revising the post-construction stormwater management ordinance,
- Implementing a systematic program for measuring infiltration rates within structural BMPs throughout the City,
- Conducting BMP topographic surveys,
- Retrofitting existing water quality BMPs at a construction cost of $121,000 and savings of 28.8 pounds phosphorus per year,
- Construct new BMPs at a construction cost of $592,000 and savings of 55.6 pounds-phosphorus/year, and
- Modify the City's street sweeping program.

Implementing all recommended new and retrofit structural BMPs could be sufficient to trap 30.7% of annual sediment loading and 22.4% of phosphorus loading from the City of Green Lake annually.

In addition to best practices listed above within the City of Ripon, the Gothic Mill Pond may offer an opportunity to retrofit or add technology to capture phosphorus within the Silver Creek sub-watershed, the largest sub-basin in the green lake watershed.

iv. Critical Stakeholders of Phosphorus Loading Reduction

In 2016, the DNR awarded the Green Lake Association a Lake Planning grant to implement a social science survey of landowners within the Big Green Lake watershed. This effort was conducted by

Aaron Thompson from UW-Stevens Point in collaboration with the UW-Extension Center for Land Use and Education.

The purpose of the survey was to “improve agricultural operations performance with NR151 by focusing on understanding the needs and priorities” of the Big Green Lake watershed community [95]. Over 459 surveys were sent with 184 valid responses, representing a 40.1% response rate.

Using data collected from an attempted census of agricultural landowners, a stakeholder profile was developed to provide a better understanding of landowners’ current behaviors (i.e., adoption of conservation practices), attitudinal factors motivating support or opposition to watershed management, and informs discussion of governance alternatives (i.e. support for farmer-led initiatives) for decision-making about conservation efforts on agricultural lands.

This report begins by examining who responded to the survey and comparing this with information about agricultural landowners and producers in the region to evaluate the potential for bias in the survey results. Once this basic level of demographic analysis was completed, the process used attitude information measured by the survey questionnaire to differentiate amongst producers based on their goals and priorities. These groups were then analyzed to determine their preference for different application variables, such as experience and interest in conservation practices, perceived barriers to participation, and trusted partners working within the watershed.

Finally, the report summarized what is known about landowners in seven geographic unique areas within the watershed to support the development of landscape strategies that are responsive to the needs of those who live and work the land in these areas.

The Lake Management Planning Team is in the process of reviewing these results and determining next steps to enhance landowner involvement in watershed management.

v. Non-Quantifiable Phosphorus Reduction Strategies

There are a series of other practices within the Big Green Lake watershed that have phosphorus reduction potential that are not quantified in the phosphorus tracking plan.

a) Fish Sticks

In the winter of 2016, the LMPT placed woody structures along the shore of four Conservancy properties. These Fish Stick structures protect shoreline areas showing the heaviest signs of erosion at Sunnyside, Pool’s Hill, Norwegian Bay, and Hammers Trail. In total, 180 to 240 trees were placed at the four sites, funded by a WDNR Healthy Lakes grant awarded to the GLSD with financial support from the GLA. In addition to erosion control, these projects provide valuable ecosystem and aquatic habitat benefits.

These projects have been successful to-date, with Hammers Trail being the property with the most need. At this site alone, 15 fish stick structures were placed along 300-feet of shoreline. In the fall of 2016, by local organizations and volunteers planted 2,300 deep-rooting native wetland sedges, rushes, grasses, and native plants to enhance erosion protection. Additionally, 20 students from Big Green Lake High School planted 50 red osier dogwood shrubs in April 2017.

b) Revitalization of Shoreline Vegetation Program

The Green Lake Association and Green Lake Sanitary Districted started the Revitalization of Shoreline Vegetation Program (RSVP) in 1998. Since then, over 100 properties have been restored as protective lake and tributary buffers throughout the watershed and shoreline.

Highlights of the program include:

- 100+ project sites restored and growing (3-5 new projects per year)
- 10,000+ feet of water frontage restored on Big Green Lake and its tributaries
- 150,000+ square feet of restored project sites
- 10+ local landscapers, nurseries, lawn care and tree services with extensive training and certified to correctly restore water frontage

RSVP provides ongoing training to keep local contractors certified and up-to-date on the latest shoreline restoration methods and practices. RSVP projects have been completed on both private and public properties.

These types of streambank and shoreline restoration projects have the added benefit of provided critical fish spawning habitat. Priority of shoreline restoration projects should be given to areas with active and/or high rates of active erosion.

c) Conservancy Properties

The Green Lake Sanitary District and Big Green Lake Conservation acquire and/or accept properties throughout the Big Green Lake watershed. These properties are collectively known as Conservancy Properties. In addition, the Green Lake Conservancy works with lake owners to establish conservation easements that allow landowners to protect their land in perpetuity.

To date, 15 Conservancy Properties exist. The Green Lake Sanitary District and Green Lake Conservancy are currently organizing a substantial fundraising effort to acquire a 40-acre property known as Camp Grow, valued at approximately $4 million.

The Conservancy Properties are restored and/or maintained as natural areas consisting of wetlands, prairies, and other important ecosystems. Several sites include ambitious invasive species removal efforts and “Fish Sticks” woody structure installations. While the exact impact of these areas are not measured, it is clear they are collectively making a benefit to Big Green Lake.

d) Regenerative Agriculture

The LMPT is supportive of efforts to convert areas of more conventional agricultural land in the Big Green Lake watershed to regenerative agriculture, which focuses on using soil health principles to maintain living cover and increase cropland residue levels to prevent soil erosion. This may require strategic property acquisition, training programs, field days, grazing workshops, demonstration farms, and other mechanisms to reduce the agricultural footprint on Green Lake’s downstream water quality.

Programs for first-generation farmers could also be critical, as Aaron Thompon’s 2016 social science survey revealed that the average age of a farmer in the Big Green Lake watershed in 64 years old. These programs could help attract first-generation farmers, provide training, arrange mentorships, and/or share equipment, as needed.

8. IMPLEMENTATION OF WATERSHED PLAN

A. Implementation Schedule

This Plan has a twenty-year implementation schedule. The LMPT meets quarterly to discuss lake management progress. After Plan approval, a portion of these meetings will be used to ensure its timely implementation. The following steps will be followed annually for the first five years of Plan implementation to ensure: 1) proposed practices (specified in Table 33 and Table 34) are being implemented, and 2) this Plan's 20% phosphorus reduction milestone is met.

After the 20% reduction milestone is met, the same or similar meeting frequency and the types/amounts of practices in Table 33 and Table 34 will be replicated on additional cropland acres to meet the TMDL's 44% and 80% TMDL based phosphorus reduction milestones over a twenty-year period.

- First quarter:
    - Assess implementation progress from the previous year and modify the Plan as needed.
    - Review stream sampler and lake phosphorus water quality data from the previous year in a "State of the Lake" presentation by the USGS.
    - Review target phosphorus reductions for the current year, as detailed in Table 33 and Table 34. Consider overarching strategies and focus areas and appoint an oversight organization for each effort.
    - Submit and collect construction bids.
- Second quarter:
    - Determine project construction schedule. Start construction.
- Third quarter:
    - Continue project construction.
    - Identify resource protection concerns that should be addressed in the following calendar year.
    - Conduct an initial assessment of potential funding gaps and identify additional preliminary sources of funding.
    - Submit completed BMPs to the Green Lake Association for implementation tracking.
    - Schedule a grant scoping meeting with the WDNR.
- Fourth quarter:
    - Submit WDNR Lake Protection and/or River Protection Grants, if applying (due November 1).

- Present final BMP implementation to the LMPT.
- Complete EQIP applications by the sign-up deadline for the upcoming calendar year.
- Determine potential funding gaps and identify grants or other funding sources. Identify an oversight organization for each targeted grant.

B. Milestones to Track Implementation of Management Measures

Because of GLSD funding, the LMPT has a robust river- and lake-monitoring program to verify how BMP implementation progress correlates to water quality improvements. These monitoring efforts will continue over the next ten years to ensure the Plan is being implemented appropriately.

Specifically, monitoring will:

- Utilize USGS stream samplers to directly measure phosphorus loading its tributaries. Coordinate with the USGS to estimate the remaining phosphorus loading from ungaged inputs.
- Utilize the USGS lake sampling program to measure phosphorus concentrations in the lake. Compare annual phosphorus concentrations to Big Green Lake's target concentration of 15 µg/L.

In addition to collecting data on the watershed's stream phosphorus loading and its lake phosphorus concentration, the LMPT will track progress on implemented BMPs. These target reductions from various activities were discussed and outlined previously in Table 33 and Table 34 and includes parameters such as: feet of streams restored, acres of agricultural runoff treated with a specific BMP, tons of carp removed, and/or pounds of aquatic plants removed.

Additionally, total phosphorus reduction milestones will be based on the schedule found in Table 35.

Table 35. Total phosphorus reduction milestones for this Plan (20% reduction) and TMDL reductions (44% and 80%).

Phosphorus Reduction Milestone	Timeline	Cropland Acres with BMPs	Percent of Total Cropland Acres in Watershed[4]	Reduction (lbs/P/year)	Priority TMDL Sub-basin for BMPs[5] Focus BMPs on critical areas in each sub-basin
20%	5 years	4,240	10%	4,480	79, 87, 17, 18, 19, 83, 20
44%	10-years	7,000	16%	7,350	79, 87, 17, 18, 19, 83, 20
80%	10-20 years	12,687	28%	13,321	79, 87, 17, 18, 19, 83, 20

[4] Green Lake Watershed has 44,600 total cropland acres.
[5] Order of sub-basins in Table 35 reflects largest to smallest P % reduction amount. Critical areas within each subwatershed, as identified by EVAAL and NLPA's from the Delta Institute Phosphorus Prioritization Plan (2016), will be first priority for BMP adoption.

C. Measurement of Progress Toward Watershed Goals

The GLA will annually obtain from the Land Conservation Departments records of phosphorus reduction tracking in the third and fourth quarter. The LMPT will internally approve these annual numbers before publication in any external communications.

The phosphorus tracking plan has several activity classifications: background; non-point agriculture; non-regulated urban, and point sources. The LMPT will develop consistent tracking and standard operation procedures for phosphorus calculations to all partners.

The primary point of contact for these tracking activities are outlined in Table 36.

If less than 70% of the BMP implementation milestones are being met for the five year and 10- to 20-year milestone periods, the Plan will need to be evaluated and revised to either change the P reduction milestone(s) or to implement projects or actions to achieve the milestone(s) that are not being met.

Table 36. Sources of data for the Phosphorus Reduction Tracking Plan.

Activity	Agency Responsible for Data	Source of Data
Background Loading		
Aquatic plant harvesting	Green Lake Sanitary District	Annual documentation
Carp removal	Green Lake Sanitary District	Annual documentation
Wetland restoration of CKM	USGS	USGS monitoring station
Non-Point Agriculture		
BMPs in Fond du Lac County	Green Lake Sanitary District	Annual documentation
BMPs in Green Lake County	Green Lake County Land Conservation Department	Annual documentation
Non-Regulated Urban		
City of Green Lake	City of Green Lake	Annual documentation
City of Ripon	City of Ripon	Annual documentation
Point Sources		
Ripon WWTF	City of Ripon	Effluent monitoring

i. Minimum Progress Criteria for Revisiting Plan Milestones

This Plan contains several milestones that will be carefully tracked and monitored over time to determine if sufficient progress is being made to meet plan goals/pollutant reductions. The following criteria will be used to determine if Plan milestones and reduction goals should be revised due to minimal progress achieved:

- Less than 25% of planned cropland practices or estimated load reductions are met by year 5.
- Less than 25% of funding is available/awarded to implement plan by year 5.
- Less than 25% of funding for conservation staff is awarded/available by year 5.

- Conservation staff shortages occur and technical assistance resources are limited for two years between years 1-5.

D. Water Quality Monitoring Components and Milestones

With the addition and relocation of monitored tributaries beginning in late 2017, approximately 90% of the watershed is being monitored for phosphorus loading, among other water quality and quantity parameters.

The GLSD has committed for the next ten years to continuing to fund water quality monitoring at a minimum of the two major inlets to Green Lake: Silver Creek and County Highway K. Water quality monitoring will be expanded as funds allow.

WDNR water quality biologists will be consulted with annually by the LMPT, GLC-LCD, and others to confirm which sub-basins have substantial BMPs and to determine if more specific follow up water quality monitoring is warranted.

Calculations of future phosphorus loading from the remaining ungauged areas will be extrapolated from relationships found using Baumgart's 2015 SWAT model [48].

Below are some water quality milestones for this Plan (which reflect EPA's element 7, 8, and 9 criteria). These milestones will be used in tandem with other criteria to evaluate Plan implementation over the Plan's 20-year schedule.

Table 37. Water quality milestones for this Plan (which reflect EPA's element 7, 8, and 9 criteria) on a sub-watershed scale. These milestones will be used in tandem with other criteria to evaluate Plan implementation over the Plan's 20-year schedule.

				Milestone			
TMDL ID	**Subbasin Name**	**Station**[6]	**Baseline TP Concentration** (µg/L)	**5 yr TP** (µg/L)	**10 yr TP** (µg/L)	**15 yr TP** (µg/L)	**20 yr TP** (µg/L)
17	Roy Creek	1,2	TBD	TBD	TBD	TBD	TBD
18	Wuerches Creek	8	TBD	TBD	TBD	TBD	TBD
19	Silver Creek – Below S Koro Rd	B	86	80	75	75	75
20	Green Lake	4, 6, A	40, 47, 40	40	40	40	40
79	Hill Creek	4	89	85	75	75	75
83	Big Twin Lake	TBD	TBD	TBD	TBD	TBD	TBD
87	Silver Creek – Above S Koro Rd	D, H	77, 92	75, 85	75	75	75

[6] Station ID from 2014-15 DNR Targeted Watershed Assessment – see Chapter 5 for map of stations.

Table 38. Green Lake water quality milestones for this Plan (which reflect EPA's element 7, 8, and 9 criteria. These milestones will be used in tandem with other criteria to evaluate Plan implementation over the Plan's 20-year schedule.

Location	Parameter	Baseline	5-yr Milestone	10-yr Milestone	15-yr Milestone	20-yr Milestone
Green Lake	Total Phosphorus (µg/L)	17	17	16	15	15
Green Lake	Chlorophyll-*a*[7] West End (µg/L)	4	4	4	4	4
Green Lake	Chlorophyll-*a* East End (µg/L)	4.8	4.8	4.8	4.8	4.8
Green Lake	Dissolved Oxygen[8] (mg/L)	2.9[9]	3	3.5	4	5

This Plan recognizes that estimated pollutant load reductions and expected improvement in water quality or aquatic habitat—in tributary streams or Green Lake itself—may not occur immediately following implementation of practices due to several factors (described below) that will need to be taken into consideration when evaluating water quality data. These factors can affect or mask progress that Plan implementation has made elsewhere.

Consultation with the WDNR and water quality biologists will be critical when evaluating water quality or aquatic habitat monitoring results. Milestones for pollutant load reductions are shown in Table 33 and Table 34 in the previous section.

If the target values/goals for water quality improvement for the milestone period are not being achieved, the water quality targets or timetable for pollutant reduction will need to be evaluated and adjusted as necessary.

The following criteria will be evaluated by the LMPT and County Land Conservation Department staff when water quality and aquatic habitat monitoring is completed (by USGS and WDNR, respectively) after implementation of practices:

- Changes in land use or crop rotations within the same watershed where practices are implemented. (Is there an increase in cattle numbers, corn silage acres, and/or urban areas that may be negatively impacting stream quality and water quality effort?)
- Location in watershed where land use changes or crop rotations occur. (Where are these changes occurring in relation to implemented practices?)
- Watershed size, location where practices are implemented, and location of monitoring sites.

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[7] WisCALM 2020 specifies that deep two-story fishery lakes such as Big Green Lake should have chlorophyll-a concentrations that do not exceed 10.0 µg/L during 95% of the time during July-August.

[8] Wisconsin Administrative Code NR 102.04 (4)(a) specifies that concentrations greater than 5 mg/L are required for optimal conditions for fish and aquatic life. Per WDNR, Green Lake's dissolved oxygen concentrations in the metalimnion should only decrease below 5 mg/L fewer than 25% of years.

[9] Based on August profile data in the metalimnion from 2013-2016.

- Climate, precipitation, and soil conditions that occurred before and during monitoring periods . (Climate and weather patterns can significantly affect growing season, soil conditions, and water quality)
- Frequency and timing of monitoring.
- Percent of watershed area (acres) or facilities (number) meeting NR 151 performance standards and prohibitions.
- Percent of watershed area (acres) or facilities (number) that maintain implemented practices over time.
- Extent of gully erosion on crop fields within watershed over time. (How many are maintained in perennial vegetation vs. plowed under each year?)
- Extent of streambank erosion and stability within sub-basins of the watershed; how much sediment may be contributing phosphorus and TSS to the stream.
- How legacy sediments already within the stream, watershed, lake, and wetlands may be contributing phosphorus and sediment loads to Green Lake and its tributaries.
- Presence and extent of drain tiles in watershed area in relation to monitoring locations. (Do these drainage systems contribute significant phosphorus and sediment loads to receiving streams?)
- Does monitored stream meet index of biological integrity (IBI) and habitat criteria, but does not meet TMDL water quality criteria?
- Are TMDL reduction targets reasonable? Load reductions predicted by models could be overly optimistic.
- Green Lake water residence time—estimated to be 20 years.

E. Management Milestones

Implementation of this Plan will require considerable growth in required human capital in areas of project management, communication, research, tracking BMP implementation (i.e., location, type, extent/acres, and associated P reduction), and reporting.

The LMPT will actively seek grants, alternative funding, and advocate for appropriate budgets for personnel to support this robust initiative. These additional dollars may be used to hire extra staff and/or consultants to manage various components outlined in the Plan.

Examples of five-year management milestones to support this 20-year Plan include, but are not limited to:

- Consultants and/or project managers within the LMPT to track, prioritize, strategize, and report on Plan efforts.
- Consultants and/or researchers to investigate various water quality issues to inform the strategy.
- Additional staff for BMP implementation and relationship development within the NRCS, Fond du Lac County Land and Water Conservation Department, and Green Lake County Land Conservation Department.
- Additional staff for the GLA to enhance research initiatives, tracking, communication efforts.

- Additional staff in the GLSD to increase BMP design and/or maintenance.
- Ensuring water quality monitoring within selected sub-basins in the watershed continues—to evaluate in stream P concentrations over time.

F. Information and Education Actions

By design, watershed plans require active participation of the citizens within the watershed. Often, a lack of understanding or watershed management goals can result in a lack of this critical landowner participation.

The LMPT coordinates a series of information and education components to enhance understanding and to garner feedback on water quality improvement strategies. It is expected the information and education activities described below will be maintained or expanded upon over the next five years.

i. Ag Outreach Coordinator

Fifty-eight percent of the Big Green Lake watershed is located within Green Lake County. Due to the size and value of the lake to Green Lake County, both the lake and watershed are given a large share of the Green Lake County Land Conservation Department's time and resources.

Forty-one percent of the Big Green Lake watershed is located within Fond du Lac County. This portion of the watershed represents only 8% of Fond du Lac County's entire area. Fond du Lac County is larger and has other major watersheds (i.e., Lake Winnebago, Rock River) that require the Fond du Lac County Land and Water Conservation ("L&WC") Department's time.

Consequently, the LMPT recommends the development of an Ag Outreach Coordinator position within the Green Lake Sanitary District to bridge the gap between available staff time and conservation practice requirements in the entire watershed, but especially within the Fond du Lac portion of the watershed.

The Ag Outreach Coordinator should be an experienced land and water professional whose main responsibilities are building relationships and identifying potential best management practices (BMPs) within the Fond du Lac County portion of the Big Green Lake watershed. The most recent Ag Outreach Coordinator was a former Green Lake County NRCS District Conservationist. This knowledgebase has expedited the success of this effort.

In general, the Ag Outreach Coordinator serves to identify potential BMP locations and gain landowner cooperation. Fond du Lac County L&WC staff design and install the BMP.

Between 2015-2017, the Ag Outreach Coordinator has successfully signed up over 50 BMPs within the Fond du Lac County portion of the Big Green Lake watershed to divert phosphorus loading from the watershed. Six projects totaling 360 pounds of phosphorus per year were installed in 2017, and additional installation projects will take place in 2018 and beyond.

To build on the success of this program, the Green Lake Sanitary District previously increased the Ag Outreach Coordinator's hours from 5 hours per month to 100 hours per month. The Coordinator will build on the Delta Institute's Phosphorus Prioritization Plan [27] to focus outreach within 12 nutrient loading priority areas, among other priority areas previously identified.

However, given the need to increase the rate of BMP adoption throughout the watershed, this Plan has a milestone to hire an additional ag outreach coordinator position—either within the Land Conservation Department(s), as a separate consultant over the next five years to meet this Plan's BMP/Phosphorus reduction milestones, and/or within the GLSD.

ii. Meetings with Property Owners

Members of the Lake Management Planning team regularly meet with property owners as it relates to efforts within the Lake Management Plan. These interactions include, but are not limited to, meetings with shoreline owners, non-farming landowners, producers, municipal staff, and citizens within the watershed.

iii. Conservation Field Day

In 2017, the GLA hosted the first-annual Green Lake Area Conservation Field Day. The purpose of Field Day was to:

1) Increase farmers' understanding of soil health improvement practices and funding opportunities, and
2) Increase shoreline owners' understanding of practices farmers are implementing in the watershed to improve water quality.

Over 60 participants attended the Field Day led by local, county, state, and federal experts. A series of demonstrations, a soil pit, rainfall simulator and a bus tour of best management practices were incorporated into the event.

iv. Demonstration Farms

One demonstration farm, locally sponsored by the GLA and part of the Upper Fox-Wolf Farm Demonstration Network, currently exists in the Green Lake watershed (Silver Creek sub-basin), at Pollack-Vu Dairy. The increase of demonstration farms throughout the Big Green Lake watershed would provide an important opportunity for producers to see and hear first-hand accounts from neighbors about new best management practices that are working.

v. Non-Farming/Absentee Landlord Training

Non-farming and/or absentee landowners rent a portion of farmed acres in the Big Green Lake watershed. Aaron Thompson's 2016 social science survey revealed that, often, these non-farmer landowners do not know enough about farming practices to even begin advocating for them with their renters [95].

Specifically, this study [95] determined that the average age of a farmer in the watershed is 64 years old; Non-Operating Landowners (NOLs) were the oldest population at 67.6 years. Landlords own a sizable portion of the watershed's agricultural acres (45%) and 70% are looking to fully-retire, yet only one in four NOLs have a clear understanding of what they will do with their land in the future.

Among all stakeholder groups identified in this survey, NOLs placed the highest value in water quality benefits of conservation practices but reported the least experience. Forty-five percent of NOLs have a positive view of stewardship and were very willing to work with outside organizations.

In addition, outside research indicates that adoption of most federally funded farm conservation programs can be lower for NOLs and their lessees (Masuda, 2021). Additional barriers are found among female NOLs, typically due to lack of an agricultural background and familiarity with state and federal programs (Petrzelka, 2020).

Therefore, training events that educate and empower landowners on conservation clauses, soil health, tillage practices, and other management strategies offers an important opportunity to increase the adoption of BMPs in the Green Lake watershed.

Additionally, succession planning – whether with non-farming landowners or farming landowners – offers an educational tool to help preserve the small family farm in the Big Green Lake watershed.

vi. Presentations to Outside Groups

Members of the Lake Management Planning team regularly present information to outside groups. In 2017 alone, various Lake Management Planning partners presented to over 18 outside groups. As a result, each year, hundreds of additional citizens become more familiar with watershed management efforts.

vii. Interns and Local Student Projects

Each year, members of the LMPT regularly partner with local organizations and students for internships and student projects. Partner organizations for these internships and projects include but are not limited to: Big Green Lake High School, Lumen Charter School, Ripon College, Nelson Institute for Environmental Studies, and the University of Wisconsin-Oshkosh.

viii. Legislative Outreach

The LMPT reaches out to legislators within the watershed on an as-needed basis. In addition, legislators are invited to the Green Lake Association's Annual Meeting.

G. Enforcement Components

Table 33 and Table 34 of the Plan presents recommended actions over the next five years that will achieve the Plan's 20% pollutant reduction goal and make progress towards achieving the water quality targets and TMDL based watershed goals for both tributary streams and Green Lake itself. Once the five-year, 20% reduction milestone is met, Table 33/Table 34 practices will be expanded/replicated to additional acres in the watershed (16% and 28% of cropland acres) to meet the TMDL's 44% and 80% reduction goals over a twenty-year period (Table 39).

Table 39. Total phosphorus reduction milestones for this Plan (20% reduction) and TMDL reductions (44% and 80%).

Phosphorus Reduction Milestone	Timeline	Cropland Acres with BMPs	Percent of Total Cropland Acres in Watershed[10]	Reduction (lbs/P/year)	Priority TMDL Sub-basin for BMPs[11] Focus BMPs on critical areas in each sub-basin
20%	5 years	4,240	10%	4,480	79, 87, 17, 18, 19, 83, 20
44%	10-years	7,000	16%	7,350	79, 87, 17, 18, 19, 83, 20
80%	10-20 years	12,687	28%	13,321	79, 87, 17, 18, 19, 83, 20

Existing runoff management standards have been established by the State of Wisconsin. Chapter NR 151 provides runoff management standards and prohibitions for agriculture. This Plan recommends implementation of and—if necessary, as a last resort—enforcement of the agricultural and urban state runoff standards (following the procedures described under NR 151.090 and NR 151.095).

NR 151.005 (Performance standard for Total Maximum Daily Loads) states that a crop producer or livestock producer subject to this chapter shall reduce discharges of pollutants from a livestock facility or cropland to surface waters, if necessary, to meet a load allocation in a US EPA and state approved TMDL.

Local ordinances and regulations will also be used to implement conservation practices and compliance. Green Lake County Land Conservation Department, Fond du Lac County Land and Water Conservation Department, and the NRCS will work with landowners to implement conservation practices. Landowners will be educated on programs and funding available to them as well as current state and local agricultural regulations.

The LMPT believes that any enforcement components should be implemented only as a last resort. In general, any success to our strategy exists because the LMPT partners with agencies and landowners in a relationship established on trust.

In rare or exceptions circumstances, members of the LMPT, in consultation with WDNR staff, may pursue a Notice of Discharge. The notice of discharge program is an enforcement process through Chapter NR 243 in the Wisconsin Administrative Code. Depending on the severity of the discharge, the

[10] Green Lake Watershed has 44,600 total cropland acres.
[11] Order of sub-basins in Table 35 reflects largest to smallest P % reduction amount. Critical areas within each subwatershed, as identified by EVAAL and NLPA's from the Delta Institute Phosphorus Prioritization Plan (2016), will be first priority for BMP adoption.

owner or operator may be required to apply for a Wisconsin Pollutant Discharge Elimination System (WPDES) permit to properly address the discharge issues.

In certain cases, operations may be eligible for cost-share funding to address discharge issues identified in a DNR-issued Notice of Discharge. These operations should work directly with the local governmental unit to determine eligibility or apply for funding.

Once the discharge is addressed, the WDNR issues a satisfaction letter to close out the Notice of Discharge. This letter identifies that the operation is now in compliance with the application requirements and completes the enforcement process. If an owner or operation that has been issued a Notice of Discharge does not address the discharge issues identified, the WDNR may pursue additional enforcement to ensure corrective actions are taken.

Plan implementation efforts for agricultural cropland/operations in the watershed will reflect the following priority:

- Priority 1 – Achieve compliance with NR 151 performance standards on priority agricultural acres/operations in the watershed;
- Priority 2 – Achieve compliance with NR 151 performance standards on remaining non-priority agricultural acres/operations in the watershed;
- Priority 3 – After a majority of agricultural cropland or operations in the watershed are determined in compliance with the existing NR 151 standards, then adoption of additional practices on agricultural acres/operations already in compliance with NR 151 will be completed to further reduce pollutant loads from agricultural sources in watershed.

H. Operation & Maintenance of Practices via Cost-Sharing

Under NR 151, the requirement for County LCD or WDNR to make an offer of cost-sharing when requiring agricultural operations to meet one or more agricultural performance standards and prohibitions may apply.

Cost-sharing of the practices described in this Plan (such as vegetated filter strips, grassed waterways, water and sediment control basins, treatment wetlands, wetland restoration, barnyard runoff control, manure storage, and streambank stabilization including crossings and fencing), may also require a landowner to agree to a 10-year maintenance period. In some instances, the GLSD may also agree to fulfil this role.

For annual cropland practices that require re-installation of management each year—such as conservation tillage, cover crops, and nutrient management— landowners are required under NR 151 to maintain the practice for each period that cost sharing is available. Therefore, annual assistance may be required to maintain these cropland practices during the implementation of this Plan. However, NR 151 also states once a farm operation or landowner is documented in compliance with a NR 151 performance standard, the farm operation or landowner must remain in compliance with the standard without cost sharing.

Both County Land Conservation Department and WDNR staff are responsible for documenting NR 151 compliance to landowners/farms. It is important to clarify that some practices, such as nutrient management plans, are also a performance standard, while other practices, such as cover crops and reduced tillage, help to meet a performance standard (i.e., soil erosion and phosphorus index).

Over time, agricultural operations in the watershed may select different practices than cost shared, to maintain compliance with a NR 151 performance standard.

> *Example: Farm X receives three years of cost share for implementing no-till tillage and cover crops on some steep slope fields to meet P-Index and Soil Erosion 168 performance standards and receive a compliance determination for meeting the two standards from the County LCD. After the three-year cost share period expires, farm X stops using no-till tillage and cover crops, but remains in compliance with the NR 151 standards by farming on the contour and changing crop rotation to include a year of winter wheat.*

Upon completion of the operation and maintenance period for selected management practices, point sources within or outside of the watershed may be able to work with farm operations and landowners in the Green Lake watershed to continue implementation of the BMPs under a pollutant trading agreement (non-EPA 319 monies).

I. Costs and Technical and Financial Assistance Resources to Implement Plan

i. Summary of Costs

In addition to the cost of BMPs themselves, it will take a series of additional supporting resources to implement this Plan, as outlined in Table 40.

Table 40. Summary of total costs to implement this Plan (20% P reduction) and the TMDL (80% P reduction).

Cost Category	Unit Cost	# Units/Year	Annual Cost	5-Year Cost (20% P Load Reduction)	20-Year Cost (80% P Load Reduction)[12]
BMP Implementation	Varies by BMP – See Table 33 & Table 34	Varies by BMP – See See Table 33 & Table 34	Varies by BMP – See Table 33 & Table 34	$2,282,600	$9,100,000
Technical Assistance					
Conservationists, Agronomists, and/or Outreach Coordinators[13]	$75,000/yr	3 positions	$225,000	$1,125,000	$4,500,000
Data Tracking Professionals[14]	$75,000/yr	1 position	$75,000	$375,000	$1,500,000
Administration Assistance[15]	$60,000/yr	2 positions	$120,000	$600,000	$2,400,000

[12] Assumed to be four times the five-year cost (to expand water quality program from 20% to 80% phosphorus reduction).
[13] Two additional professional outreach coordinators (conservationists, agronomists, and/or outreach coordinators) for every 15,000 acres of agricultural acres. Staff may exist within Land Conservation Departments, the GLSD, the GLA, and or other LMPT partners. There are 44,600 acres of ag land in the watershed.
[14] One additional data tracking professional per watershed.
[15] One additional administrative assistant per county.

Cost Category	Unit Cost	# Units/Year	Annual Cost	5-Year Cost (20% P Load Reduction)	20-Year Cost (80% P Load Reduction)[12]
Surface Water Quality Monitoring[16]	$20,000/station	7 locations	$140,000	$700,000	$2,800,000
Education & Information	Varies	Varies	$20,000	$100,000	$400,000
Legacy Phosphorus & Additional Research	Varies	Varies	Varies	$500,000	$1,000,000
			Approximate Total Costs	**$4,325,330**	**$15,375,990** **Future Value[17]: $32,000,000**

[16] Ideally 7 monitoring locations: Silver Creek Estuary, White Creek, Hill Creek, Roy, Wuerches, County Highway K, and Puchyan River.
[17] Calculated based on x4 the five-year cost. Future given present value based on 5% interest rate, 15 periods, and compounding 1 time per year.

ii. Summary of Resources

Cost estimates for the practices to implement this plan are described in Table 34. The following resources are available to meet these practice costs and may also cover a portion of staff costs to implement the plan:

a) EPA 319 Watershed Grants

In Wisconsin, EPA 319 funds are split into several different grant opportunities managed by the DNR:

(1) Targeted Runoff Management Program

The Targeted Runoff Management (TRM) Grant Program offers competitive grans for local governments for controlling nonpoint source pollution. Grants reimburse costs for agriculture or urban runoff management practices in targeted, critical geographic areas with surface water or groundwater concerns.

Deadline: April 15; accepted projects start January 1
Website: http://dnr.wi.gov/Aid/TargetedRunoff.html

(2) Surface Water Grants

The DNR's Surface Water Grant program includes: Lake Management Planning; Lake Protection & Classification; River Protection; River Planning; and Aquatic Invasive Species Control.

Deadline: Pre-Proposal: September 2; Full Proposal: November 1
Website: http://dnr.wi.gov/Aid/SurfaceWater.html

b) Urban Nonpoint Source & Storm Water Grant Management

The DNR's Urban Nonpoint Source & Storm Water (UNPS&SW) Management Grant Program offers competitive grants to local governments. Grants reimburse costs of planning or construction projects controlling urban nonpoint source and stormwater runoff pollution. Eligible areas are urban lands with population density of at least 1,000 people per square mile or non-permitted commercial or municipally-owned use. Projects may be in areas that are expected to become urban within 20 years.

Deadline: April 15; accepted projects start January 1
Website: http://dnr.wi.gov/Aid/UrbanNonpoint.html

c) USDA-NRCS Farm Bill Programs

The USDA-NRCS has a series of Farm Bill Programs, including:

- Environmental Quality Incentives Program (EQIP)
- National Water Quality Initiative
- Wildlife Habitat Incentives Program
- Wetland Reserve Program
- Conservation Reserve Program
- Conservation Reserve Enhanced Program
- Conservation Security Program

- National Water Quality Initiative

All programs have different rules and regulations.

Deadline: Varies
Website: http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/farmbill/

d) URDA-NRCS Conservation Innovation Grants

NRCS provides funding opportunities for agriculturalists and others through various programs. Conservation Innovation Grants (CIG) is a voluntary program intended to stimulate the development and adoption of innovative conservation approaches and technologies, while leveraging Federal investment in environmental enhancement and protection, in conjuction with agricultural production. Under CIG, Environmental Quality Incentives Program funds are used to award competitive grants to non-Federal governmental or nongovernmental organizations, Tribes or individuals.

Website: http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/cig/

e) Regional Conservation Partnership Program

The Regional Conservation Partnership Program (RCPP) promotes coordination between NRCS and its partners to deliver conservation assistance to producers and landowners. NRCS provides assistance to producers through partnership agreements and through program contracts or easement agreements. RCPP combines the authorities of four former conservation programs – the Agricultural Water Enhancement Program, the Chesapeake Bay Watershed Program, the Cooperative Conservation Partnership Initiative and the Great Lakes Basin Program. Assistance is delivered in accordance with the rules of EQIP, CSP, ACEPT and HFRP, and in certain areas, the Watershed Operations and Flood Prevent Program.

Website: http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/farmbill/rcpp/

f) Great Lakes Restoration Initiative

The Great Lakes Restoration Initiative (GLRI) accelerates efforts to protect and restore the largest system of fresh surface water in the world: The Great Lakes. The four main initiatives are: cleaning up Great Lakes areas of concern; preventing and controlling invasive species; reducing nutrient runoff that contributes to harmful or nuisance algae blooms; and restoring habitat to protect native species. GLRI was recently expanded to the Big Green Lake watershed and may be a source of significant direct and indirect funds to implement the Plan.

Website: http://greatlakesrestoration.us/

g) Fund for Lake Michigan

The mission of the Fund for Lake Michigan is to support efforts, particularly those in south eastern Wisconsin, that enhance the health of Lake Michigan and its shoreline and tributary systems for the benefit of the people, plants and animals that depend upon the system for water, recreation and commerce.

Website: http://www.fundforlakemichigan.org/

h) Private Donations

The GLA has turned into a successful fundraising arm of the LMPT. In five years, the GLA has raised nearly $700,000 for donor-restricted "pillar projects" aimed at three categories:

- Project Green Acres, which funds agricultural BMPs, demonstration farms, agricultural equipment, and future farmer scholarships,
- Project Clean Streams, which funds stream and wetland restoration, and
- Project Invader Defense, which funds various aquatic invasive species mitigation and prevention measures.

The GLA's Board of Directors recently approved a multi-million-dollar capital campaign, which will be used as a local cash match to leverage the above-listed grants.

i) General Property Tax (Mill Levy)

The laws governing the formation and operation of sanitary districts can be found in Chapter 60 of the Wisconsin State Statutes. The GLSD is a municipal, taxing entity that uses a portion of its generated tax revenue to fund lake protection activities.

Additionally, Wis. Stat. § 60.782 generally authorizes a sanitary district that has jurisdiction of at least 60% of a lake's shoreline to exercise the powers of a lake district if no lake district had been established on the lake.

- Per Wis. Stat. § 60.77(6)(b), *sanitary district taxes* are capped at a rate of 1 mill ($1.00 per $1,000 of equalized valuation of all taxable property in the district), except for taxes levied for required maintenance and operation or for the payment of principal and interest on debt.
- Per Wis. Stat. § 33.30(4)(a), *lake district* taxes are capped at the rate of 2.5 mills or $2.50 per $1,000 of equalized valuation. This cap applies only to the costs of operation, it does not apply to taxes levied to pay principal and interest on debt.

Therefore, in addition to its current (lower) taxing rate, the GLSD may choose to exercise its authority as a lake district to increase taxes to fund a portion of the Plan.

9. COMMITMENT TO MEASURE PROGRESS AND EVALUATE PLAN

Considerable effort has been put forward by numerous entities—local, state, federal, and non-government organizations making up the LMPT—to perform the extensive planning necessary to address the complex water quality issues facing the Big Green Lake watershed. A comprehensive LMP for Big Green Lake was first developed and approved in 2013. Numerous implementation efforts including installing BMPs throughout the watershed, restoring degraded shorelines, performing comprehensive studies, monitoring lake and tributary streams, and educating stakeholders have been initiated to address the concerns outlined in that original LMP.

Much more is planned, and much more is needed. This document, the Big Green Lake Watershed Plan (Plan), is a continuation of those efforts based on more recent information and an enhanced understanding of the factors affecting the lake's water quality.

This chapter of the Plan reinforces the continuing commitment of the LMPT to routinely measure progress, identify necessary actions, and evaluate the effectiveness of this twenty-year Plan. It includes sections addressing the LMPT's Plan review and evaluation process to:

- Cerify Plan milestones are or are not being met,
- Responsible parties for performing reviews and revisions,
- The process for sharing results,
- The use of annual work plans,
- Procedures for reporting to stakeholders, and
- Adjusting the plan as needed.

A. Review and Evaluation Process

Various activities within the Plan will be performed according to schedules established for those specific activities, such as routine monitoring; stream restoration; installation/maintenance of BMPs; estimating P reductions from BMPs; water quality monitoring; and completion/evaluation of comprehensive studies.

As each activity is performed, the individual or organization responsible for that activity will report the results to all members of the LMPT for review and consideration if the information warrants making any immediate adjustments to the Plan. These reviews will assess the following areas:

- Processes being employed to implement the program. *Are they effective?*
- Progress in meeting an activity's overall objective. *Has it been completed? Is it on schedule?*

- Specific results of implementation activities
- Feedback from stakeholders, where applicable

Where reviews indicate an implementation milestone is not being met, the organization responsible for the review will evaluate potential factors impacting performance including such factors as weather, resource or technical assistance considerations, social acceptance, or simply over estimating the expected outcome of the activity. If necessary, a meeting of the LMPT will be convened to discuss the interim findings from the activity assessment and any next steps warranted.

Progress and success of this Pan will be tracked by the following components:

1. Information and education activities and participation,
2. Pollution reduction evaluation based on BMPs installed,
3. Water quality monitoring, and
4. Administrative review.

The GLSD, LMPT, Green Lake County Land Conservation Department, Fond du Lac County Land & Water Conservation Department will be responsible for tracking progress of the Plan. GLSD and the Land Conservation Departments also need to work with NRCS and WDNR staff to track progress and implement projects in the watershed

Progress reports will be completed annually over the first five years of this Plan's schedule and shared with WDNR staff and other watershed stakeholders.

A **final report** will be prepared at the end of the five-year project and may include the following information, when pertinent, compiled by all LMPT members. During the remaining fifteen years of this Plan's 20-year schedule, the same or similar criteria (below) will be used to evaluate Plan implementation.

1. **Information and education summaries**:
    a. Number of landowners and/or operators in the watershed plan area.
    b. Number of eligible landowners and/or operators in the watershed plan area.
    c. Number of landowners and/or operators contacted.
    d. Number of cost-share agreements signed.
    e. Number and type of information and education activities held; who led the activity; how many attended; any measurable results, if possible.
    f. Number of informational fliers/brochures distributed.
    g. Number of one-on-one contacts made with landowners in the area.
    h. Number of media/press release submitted by LMPT partners.
    i. Comments or suggestions for future activities.

2. **Installed BMPs in the watershed will be mapped by Green Lake County LCD and Fond du Lac County Land & Water Conservation Departments using GIS-based software**.
    a. Pollution reductions from completed projects will be evaluated (using RUSLE 2, SnapPlus, or other sediment reduction models) for upland cropland practices.
    b. The BARNY or equivalent model (e.g., APLE-lots) will be used for estimating barnyard practice reductions.

c. Installation dates, design specifications, operation and maintenance periods, practice inspections, estimated load reductions, and cost share sources/amounts will also be tracked in a GIS database.
d. Report parameters for pollutant reduction evaluation for BMPs installed, including:
    i. Planned and completed BMPs.
    ii. Pollutant load reductions and percent of goal planned and achieved.
    iii. Cost-share funding source of planned and installed BMPs.
    iv. Number of operations check to make sure management plans (nutrient management, grazing management) are being followed by landowners.
    v. Number of checks to make sure practices are being operated and maintained properly.
    vi. Changes in land use or land management in watershed that may impact BMP effectiveness.
    vii. Variations in weather that may have influenced implementation of BMPs or effectiveness of installed BMPs.

3. **Water quality monitoring reporting parameters**, including:
    a. Total phosphorus for all streams monitored by the USGS.
    b. Macroinvertebrate index of biotic integrity, if and where measured by the WDNR and/or Water Action Volunteers.
    c. Lake water quality monitoring report, including total phosphorus, chlorophyll-*a*, secchi depth, dissolved oxygen, and all other parameters monitored by the USGS.

4. **Administrative review tracking and reporting**, including:
    a. Status of grants relating to project.
    b. Status of project administration, including data management and BMP monitoring.
    c. Status of nutrient management planning, and easement acquisition and development.
    d. Number of cost-share agreements.
    e. Total amount paid for BMP installation and the amount contributed by partner and/or landowner.
    f. Total amount of landowner reimbursements made.
    g. Information and education expenditures.
    h. Staff salary and fringe benefits expenditures.
    i. Total expenditures for the counties.

In addition to assessing progress with implementation activities, the Plan will also review and evaluate data that indicates progress towards reaching this Plan's 20% reduction goals and the TMDL's 44% and 80% pollutant reduction goals.

Specifically, the LMPT will evaluate cropland or other areas with BMPs that might reduce expected progress and assess whether:

- Management activities (BMPs) have been implemented or maintained correctly over time

- Weather-related events that may prevent BMP establishment or reduce/eliminate BMP performance and expected pollutant reduction efficiency
- Pollutant reduction targets are reasonable in terms of scale (acres of cropland required) timeframes and landowner interest/participation.
- Other BMP management/maintenance and performance factors, as described within the following EPA memorandum are "*Adjusting for Depreciation of Land Treatment When Planning Watershed Projects*"—https://www.epa.gov/sites/production/files/2015-10/documents/tech_memo_1_oct15.pdf, are present within the watershed and may be impacting estimated P reduction from adopted BMPs

B. Responsibility for Reviewing and Revising Plan

All members of the LMPT share responsibility for reviewing the Plan for its effectiveness. If it is determined by the LMPT that a revision to the Plan is necessary, those revisions will be contracted by a consultant, who will be managed by the GLA, to ensure document consistency and version control. The revised Plan will remain a draft document until approved by the relevant approving authority.

C. Sharing of Results

As mentioned above, there are several concurrent activities under the control of various LMPT members. As those activities are performed and outcomes identified, results will be reported to all LMPT members.

If the LMPT concludes that there are results or specific information that should be reported to the entire stakeholder community, the appropriate procedures and methodologies detailed in Section E. below will be implemented.

D. Annual Work Plans

In the first quarter of each year, individual entities will commit to completing various projects of the Plan. To formalize this commitment, entities will submit a brief work plan outlining basic details such as:

- A general timeline
- Potential funding sources and funding gaps
- Grants to consider and grant deadlines
- Related field activities and field schedule.

E. Reporting to Stakeholders

i. Mailed Publications

The GLSD distributes an annual newsletter to district residents (approximately 1,500 households) and the GLA distributes two publications per year to its members and stakeholders (approximately 760 households per mailing).

There may be an opportunity to either expand these mailings or to develop stakeholder-targeted mailings (i.e. an watershed-based newsletter to farmers).

ii. Email Listserves

The Green Lake Association regularly distributes "e-blasts" to over 1,000 individuals within and beyond the Big Green Lake watershed.

iii. Websites and Social Media

City of Green Lake
http://cityofgreenlake.com/

Fond du Lac County Land and Water Conservation Department
http://www.fdlco.wi.gov/departments/departments-f-m/land-and-water-conservation

Green Lake Association
www.greenlakeassociation.org
https://www.facebook.com/GreenLakeAssociation/

Green Lake Conservancy
http://www.greenlakeconservancy.org/

Green Lake County Land Conservation Department
http://www.co.green-lake.wi.us/departments.html?Department=13

https://www.facebook.com/GreenLakeCountyLCD/

Green Lake Sanitary District
www.glakesd.com

Nelson Institute for Environmental Studies: Big Green Lake
http://nelson.wisc.edu/greenlake/

U.S. Geological Survey: Big Green Lake
http://www.arcgis.com/home/webmap/viewer.html?webmap=5595f0ed3a4443c59c8e3f5f9e2068c1&extent=-89.1296%2C43.7117%2C-88.6373%2C43.9235

Wisconsin DNR: Big Green Lake
http://dnr.wi.gov/water/watershedDetail.aspx?code=UF07&Name=Big%20Green%20Lake

iv. Press Releases

Press releases are regularly sent to the *Big Green Lake Reporter*, *Ripon Commonwealth Press*, *Big Green Laker*, and other local/regional newspaper publications, particularly by the GLA. At least 15 press releases were distributed in 2017.

v. Annual Meetings

The GLA hosts an annual meeting held the third Saturday of June. Approximately 50-70 members and community members attend this event to receive updates on current initiatives and lake projects.

vi. State of the Lake Presentation and Annual Report

The USGS provides an annual State of the Lake presentation in the spring of each year. Generally, one presentation is given directly to the LMPT and other is given to the Green Lake Sanitary District's commissioners and open to the public.

There may be an opportunity to produce an annual State of the Lake publication on behalf of the LMPT.

F. Making Adjustments to Plan

The Plan's effectiveness will be evaluated in an ongoing manner as discussed in Section A above. In addition, the Plan will be revisited annually by the LMPT to determine if adjustments to the Plan are warranted, as illustrated in Figure 73 below.

The LMPT will employ a standard iterative process that incorporates the basic steps following development of implementation, assessment, and adjustment. Adjustments to the Plan will be considered "Draft" until approved by the relevant agency.

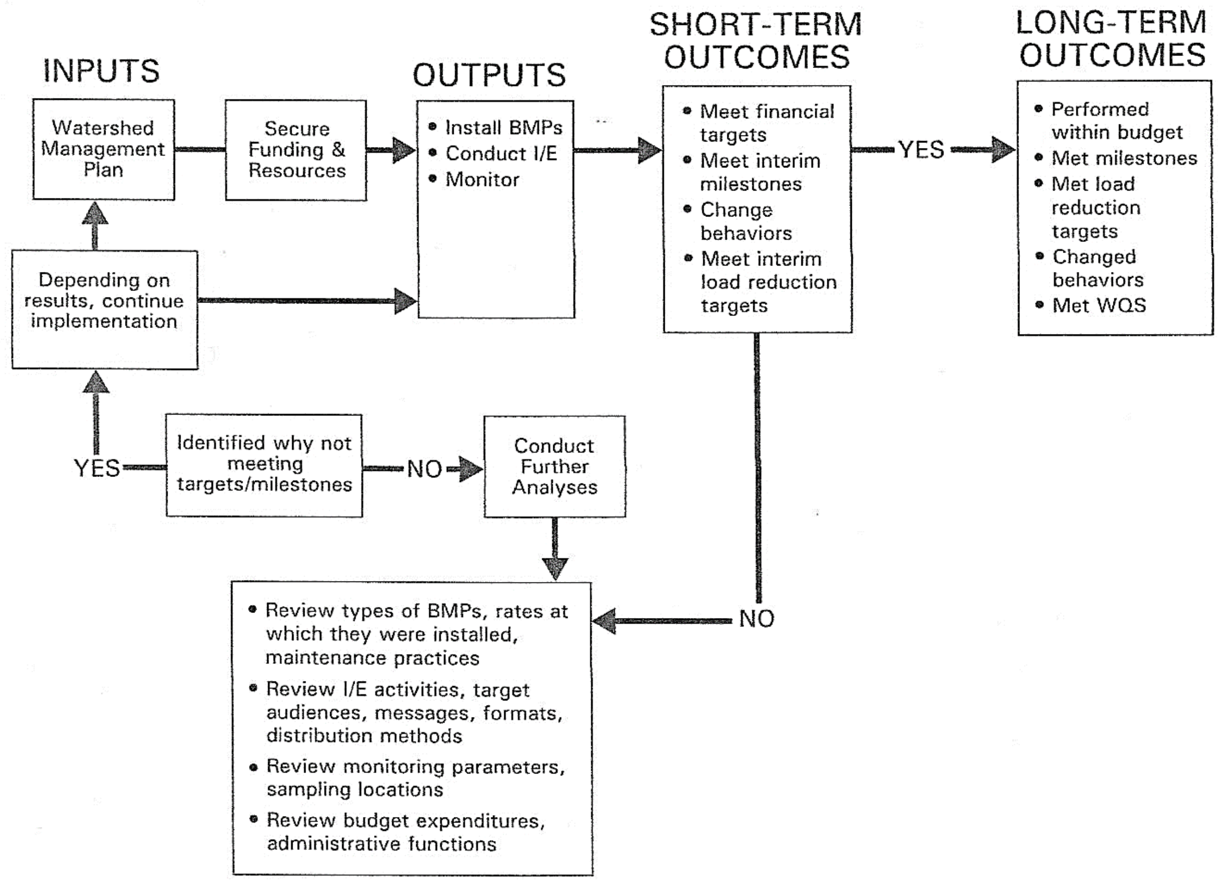

Figure 73. The LMPT will evaluate the Plan using an iterative process using the guidelines outlined in the Handbook for Developing Watershed Plans [1].

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