COMMUNITY ASSISTANCE
PLANNING REPORT NO. 58
(3RD EDITION)

A LAKE MANAGEMENT PLAN FOR PEWAUKEE LAKE

WAUKESHA COUNTY, WISCONSIN

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

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WAUKESHA COUNTY, WISCONSIN

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A LAKE MANAGEMENT PLAN FOR PEWAUKEE LAKE

EXECUTIVE SUMMARY

A Management Plan for Pewaukee Lake and its Watershed

The Lake Management Plan for Pewaukee Lake (the Plan) is the third comprehensive management plan for this Lake and was developed to provide a set of targeted, specific recommendations to improve Pewaukee Lake, its tributaries, and ecological conditions throughout the watershed. This Plan supplements and builds upon previous plans and recommendations, such as the 1984 and 2003 lake management plans (see sewrpc.org); the 2017 aquatic plant management plan; and studies by the Wisconsin Department of Natural Resources (WDNR), the United States Geological Survey (USGS), and Wisconsin Lutheran College (WLC). Many recommended management measures from the previous editions of this Plan, such as educational programming, acquiring wetland parcels, promoting native aquatic species, and enhanced water quality monitoring, have been incorporated into past and ongoing Lake management practices.

Characteristics of Pewaukee Lake and its Watershed

Pewaukee Lake has long been renowned for its natural beauty and clear, clean water, as is historically evident by its robust ice harvesting business in the late 1800s. Currently, the Lake, one of the largest in southeastern Wisconsin, enjoys comparatively good water clarity, a healthy aquatic plant community, and is among the most popular musky fisheries in southeastern Wisconsin. Located in the metropolitan Milwaukee area, its visitors and residents engage in a wide variety of recreational pursuits including sailing, fishing, swimming, water-skiing, and other activities.

The Lake is fed by surface-water runoff draining from a 24.8 square mile watershed. The watershed is located entirely within Waukesha County but is divided between several cities, villages, and towns. Agricultural and residential land uses occupy the largest amount of land area within the watershed. Overall lake ecosystem health is commonly a direct reflection of watershed land use and management.

Four named tributaries (Audley, Coco, Meadowbrook, and Zion Creeks) and two unnamed tributaries contribute water to the Lake. Groundwater is also a significant source of water to the Lake, with springs being particularly common in the northwestern portion of the Lake and Coco Creek. As a consequence of abundant cold, mineral-rich groundwater discharge, Coco Creek is a coldwater stream hosting a population of trout, and the Lake has hard (mineral rich) water.

Pewaukee Lake is home to many recreational pursuits, including sailing, swimming, water-skiing, and fishing.

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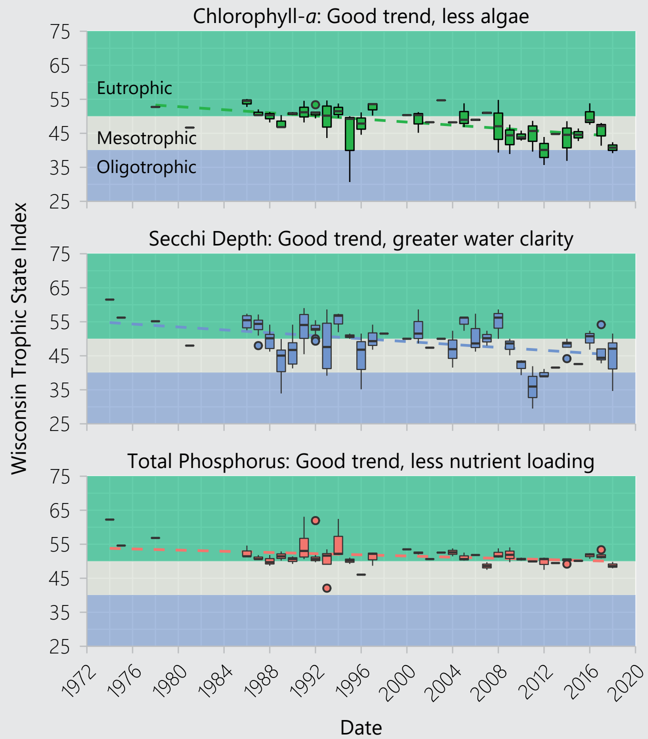
Justification for Plan

In spite of human-induced stressors, the Lake enjoys generally good water quality and conditions supporting a wide variety of use. Nevertheless, water resource features are commonly quite vulnerable to disturbance, a situation that can diminish the value of these high-value natural resource assets. In recognition of this concern, members of the Lake community are interested in evaluating topics that can be used to evaluate changes in the Lake's community value and ecological health. Many of these topics were evaluated as part of this plan. Examples of some topics of particular and widespread interest include the following:

- Water Quality Trends
- Aquatic Plant Management
- Water Level Regulation and Outlet Dam Operation
- Shoreline Stability, Riparian Buffers, and Floodplain Protection
- Restoring Natural Hydrology in a Changed Landscape

Water Quality Trends

In general, overall Lake water quality has improved since consistent monitoring began in the mid-1970s. Through this period, Lake water has become clearer, while total phosphorus and chlorophyll-*a* concentrations (indicators of algal abundance), have declined. Additionally, the extent of summertime anoxic (no oxygen) water near the lake bottom in the west basin has substantially decreased, providing more suitable habitat for aquatic organisms in the summer and helping alleviate conditions that promote phosphorus release from lake-bottom sediment. Although data is much more limited, water quality in most of the Lake's tributary streams' also appears to be stable or improving. These water quality improvements are a testament to the positive impact of active management conducted on the Lake and in the watershed.



Source: Wisconsin Department of Natural Resources and SEWRPC

Greater water clarity as well as reduced algal abundance and total phosphorus suggest improving water quality.

45 years of consistent water quality monitoring provides invaluable insight to the Lake's health. Continued monitoring is essential for tracking progress and identifying threats.

While great progress has been made toward improving water quality, conditions change and new threats often become evident. For example, chloride, a component of common rock salt, is injurious to freshwater organisms at relatively low concentrations. Chloride concentrations have been consistently increasing in Pewaukee Lake for decades. The 146 mg/l chloride concentration measured in 2018 is almost 30 times greater than the 5 mg/l observed in the early 1900s. This concentration is fast approaching regulatory limits and may already be high enough to diminish the success of certain sensitive desirable native species. In a more directly tangible vein, Lake water may begin to taste salty by the year 2070 unless action is taken to reduce chloride loads. Such water quality insights are only possible thanks to the 45 years of consistent monitoring, much of which conducted by volunteers.

Aquatic Plant Management

Aquatic plant harvesting has removed up to 52,348 pounds of phosphorus from Pewaukee Lake since 1988.

Pewaukee Lake's aquatic plants have been a management priority for decades. Excessive nuisance aquatic plants, especially exotic invasive species, can compromise the ability of the Lake to provide quality recreational opportunities and impede navigation. Well-planned and dedicated aquatic plant management completed in the recent past has protected native aquatic plant species, controlled nuisance species, and removed substantial amounts of phosphorus from the Lake. Muskgrass (*Chara* spp.), one of the most dominant native species, stabilizes lake bottom sediment, removes phosphorus from the water column, and should be protected wherever and whenever practical. Aquatic plant management efforts embrace this goal. Recent surveys reveal that muskgrass has become more widespread while the invasive Eurasian watermilfoil (*Myriophyllum spicatum*) is less widespread than it has been in the past. Since 1988, aquatic plant harvesting by the Lake Pewaukee Sanitary District (LPSD) and the Village of Pewaukee has removed up to 52,348 pounds of total phosphorus from the Lake, an amount equal to between 10 to 34 percent of the nonpoint source phosphorus loading to the Lake during this period. The Plan recommends actions to further refine aquatic plant management efficiency and effectiveness; the Village of Pewaukee and LPSD aquatic plant management coordination can be a substantial contributor to this goal.

Promoting Native Aquatic Plants:

The Lake's aquatic plant diversity is greater than measured anytime in the previous 25 years.

Water Level Regulation and Outlet Dam Operation

The Lake outlet dam was modified in 2010.

Pewaukee Lake's water level has been artificially elevated by a dam for nearly 180 years. The dam considerably increased water depth, changing the former marshy eastern basin into a shallow lake and submerging marshy areas around the Lake's shoreline. The former weir-type dams had very limited capacity to vary water discharge rates. The dam was rebuilt in 2010, incorporating a bottom draw gate that now allows the dam operator a high degree of control over dam discharge rates and Lake water levels. This modification enhances capacity to diminish the duration of slow-no-wake periods, retain excessive runoff, augment downstream dry weather flow, and influence a number of other factors of interest to the community and/or that affect waterbody ecology. It is important to note that the dam is not designated as a flood control structure.

Balancing Lake elevation with outlet discharge rates can be a matter of controversy and concern, especially to those who have property and/or infrastructure near the Lake or the Pewaukee River downstream of the Lake. To help the dam operator select a discharge rate that considers multiple factors requires input from and compromise amongst many stakeholders. The current Plan provides data and suggests approaches to help balance the needs and desires of Lake users/riparians, downstream property owners, the ecological health of the Lake and River, and dam design/operation realities. For example, the plan stresses the importance of maintaining operable gates and gate discharge capacity during all seasons and suggests measures that promote reliable all season, all condition gate operability.

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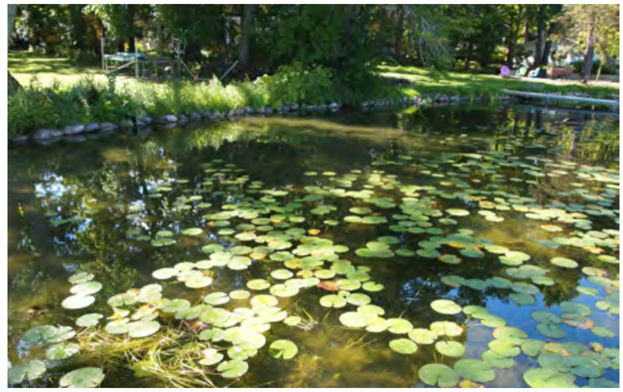
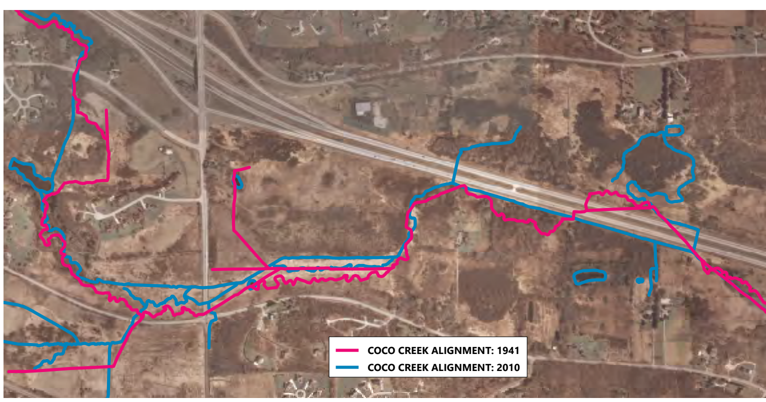


Pewaukee Lake's shoreline has many opportunities (left image) to expand vegetated buffers (right image). Buffers help reduce phosphorus and sediment loading as well as protect the shoreline from erosion. Native aquatic vegetation can reduce erosive wave force and enhance fish and wildlife habitat.

Shoreline Stability, Riparian Buffers, and Floodplain Protection

Protecting and enhancing wetland parcels as well as implementing best management practices (BMPs) within the watershed has helped contribute to reduced waterbody pollutant loads and improved water quality. Expanded/improved vegetative shoreline protection and riparian buffers can further improve water quality, protect shorelines from wave erosion, and enhance fish and wildlife habitat throughout the watershed. Management attention should prioritize actions that reconnect floodplains which, in turn, enhances floodwater detention, helps mitigate downstream flooding, and generally decreases wet-weather runoff nutrient and sediment loads. A comprehensive inventory of priority areas and parcels for riparian and shoreline buffers as well as storm drainage systems is provided in the Plan.



Southeastern Wisconsin streams were heavily channelized. For example, long reaches of Coco Creek were ditched between 1941 (pink line) and 2010 (blue line). Channelization contributes to loss of fish and wildlife habitat, reduced ability to store and filter floodwaters, and increased capacity to carry eroded sediment to the Lake.

Restoring Natural Hydrology in a Changed Landscape

Prior to European settlement, lands draining to Pewaukee Lake were covered with oak savanna, oak forest, and wetlands. Agricultural and residential land uses now dominate the watershed. Urban development is expected to comprise 57 percent of the watershed by 2050. Land conversion has changed the way precipitation falling upon the watershed behaves. In general, less water soaks into the ground, less is detained on the surface, more water exits stream basins as surface-water runoff, and runoff leaves the landscape more quickly. These factors amplify both the minimum and maximum streamflow. Some of the factors changing the watershed's hydrology include deforestation, stream channelization, dam construction, wetland draining/filling, and an ever increasing proportion of the land surface covered by impervious surfaces (e.g., buildings, roads, parking lots).

Examples of Key Management Strategies to Protect and Enhance Pewaukee Lake and its Watershed

- **Enhance stakeholder coordination and cooperation to foster even greater improvements in operational efficiency, funding availability, water quality, recreational potential, and ecological health**
- **Adopt dam operation guidance that benefits waterbody users, waterbody ecology, and property owners located both upstream and downstream of the outlet dam. Resolve dam operational problems (e.g., ensure reliable all-season, all-condition operation)**
- **Actively promote and financially support buffers, rain gardens, and other best management practices (BMPs) along shorelines and riparian areas as well as modern agricultural practices (e.g., cover crops) in upland areas**
- **Preserve groundwater infiltration areas to regulate runoff, maintain water supply, and protect critical habitat in Lake tributaries**

Overall, hydrologic changes reduce the landscape's ability to capture, filter, detain, and retain precipitation, particularly of excessive rainfall events. Consequently, the landscape is prone to more frequent and severe floods and less capable of maintaining adequate water supplies that support water quality/ecology, potable water demands, and recreational needs. The recommendations in this Plan suggests actions that can help communities protect drinking water supply, water quality, ecological integrity, and recreational use.

Funding and Partnerships

Developing, expanding, maintaining and enhancing partnerships are essential elements to efficiently achieving lake and watershed management goals. The Pewaukee Lake area is home to a wide variety of organizations that are interested and oftentimes involved in the betterment of the Lake and its watershed. In addition to several governmental agencies with missions that include promoting and protecting the Lake, examples of organizations that focus on the Lake and its watershed include the Pewaukee Women's Club, the Pewaukee River Partnership, the Pewaukee Chapter of Walleyes for Tomorrow, the Pewaukee Kiwanis Club, the Pewaukee School District, the Boy Scouts of America, and the Badger's Fisherman League. An example of interagency cooperation includes cooperation between the LPSD, local land trusts, and private landowners to preserve land through conservation easements, land purchases, and land donations. Restoration, education, and outreach efforts will continue to be instrumental in promoting a culture of waterbody protection.

Established partnerships and actionable plans enhance funding opportunities to implement Plan elements. For example, interested municipalities and certain other organizations can sponsor Healthy Lakes Program grants, allowing shoreline owners to apply for funding to implement recommended BMPs such as fish sticks, rain gardens, native vegetation buffers, diversions, and rock infiltration areas. Implementing only the Healthy Lake BMPs on at least 75 percent of the shoreline properties would tangibly reduce Lake pollutant loading all while improving fish and wildlife habitat. A variety of federal and state funding sources promote conservation practices and protect water quality, including programs by the Natural Resource Conservation Service (NRCS) and the Wisconsin Department of Agriculture, Trade and Consumer Protection.

The Lake Pewaukee Sanitary District and the Pewaukee Chapter of Walleyes for Tomorrow have lead several habitat restoration and education efforts. Examples include invasive species removal from streambanks (left) and installing fish sticks in the Lake (right).

Conclusion: Focused Management Improves Conditions for All

Pewaukee Lake and its watershed have significant economic, aesthetic, quality-of-life, and ecological value. Dedicated management continues to improve water quality and enhance the aquatic plant community within the Lake. All opportunities are enhanced through active partnering with others interested in the Lake, its watershed, and the community that has grown up in the midst of these valuable natural resource assets. Widespread Plan endorsement and/or Plan adoption can be used to demonstrate the broader community's united resolve to achieve tangible goals, a situation that commonly results in greater execution efficiency and which can help foster receipt of grant funding.

The measures presented in this Plan primarily focus on those that can be implemented through collaboration between local organizations and individuals, such as the LPSD; Lake residents; the Pewaukee chapter of Walleyes for Tomorrow; Waukesha County; the WDNR; the Cities of Delafield, Pewaukee, and Waukesha; the Towns of Delafield, Lisbon, and Merton; and the Villages of Hartland, Pewaukee, and Sussex. The plan must be adaptable to addresses challenges that will arise during implementation. Watershed implementation is primarily a volunteer effort, but this effort needs support from targeted technical and financial assistance. All communities within the watershed must commit and collaborate to reach compliance with existing regulations, which in turn help improve the Lake's condition.

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INTRODUCTION 1

Credit: SEWRPC Staff

Pewaukee Lake lies within U.S. Public Land Survey Sections 7, 8, 17, and 18 of Township 7 North, Range 19 East and Sections 12, 13, 14, 15, 22, 23, and 24 of Township 7 North, Range 18 East in north-central Waukesha County, Wisconsin. The eastern end of the Lake is located partially in the Village of Pewaukee and partially in the City of Pewaukee. The Lake's western basin lies entirely in the Town of Delafield. Pewaukee Lake, together with its associated watershed and wetlands, is an important high-quality natural resource and is a substantial asset to the local and regional community. For this reason, preserving and enhancing the Lake's health is an issue of considerable interest to resource managers, Lake residents, Lake users, and others who benefit from the Lake's recreational, ecological, and aesthetic value.

1.1 HISTORICAL CONTEXT

Pewaukee Lake offers a remarkable variety of water based recreational opportunities and has been the focus of the surrounding lake-oriented communities for well over a century. Over the years, the Lake has experienced various management challenges including excessive aquatic plant growth, recreational use conflicts, water quality related use limitations, and public concerns over perceived aesthetic degradation. The Lake is located in the Milwaukee metropolitan area, a situation contributing to high demand for more urban development (particularly residential development) in the Lake's watershed. Past, ongoing, and probable future development stresses the natural environment and places increasing demands on the Lake to provide for a wide variety of oftentimes intensive water-based recreational opportunities.

Residents of the Pewaukee Lake community have historically made decisions to protect and improve the Lake's water quality and ecology. This included forming the Lake Pewaukee Sanitary District (LPSD), and using the LPSD as a mechanism to collect, coordinate, and disseminate information on the Lake and its watershed. Pewaukee Lake residents have become increasingly concerned about present and future impacts of pressures on the Lake and its ecosystem. These concerns relate to observations and perceptions such as decreased water clarity, increased aquatic plant growth, Lake water deterioration from nonpoint source pollution, and user-related aesthetic degradation and use conflicts. A brief timeline of the history of Pewaukee Lake is included in Table 1.1.

Table 1.1
Timeline of Pewaukee Lake Management Events

Date	Event	Source[a]
1838	First dam constructed to provide power for a mill; Pewaukee Lake created	CAPR 58-2 SEWRPC report
1848	Construction begins on plank road	LP Historical Charlie Shong (former LPSD Manager)
	Village of Pewaukee incorporated	CAPR 58-2 SEWRPC report
1855	Railroad completed in Pewaukee Lake area; led to increase in population of area	LP Historical Charlie Shong (former LPSD Manager)
1873	First large passenger boat; Lady of the Lake sidewheeler	LP Historical Charlie Shong (former LPSD Manager)
1878	First commercial icehouse built on north shore of Pewaukee Lake (Best Brewery, Milwaukee)	LP Historical Charlie Shong (former LPSD Manager)
1886	Carp delivered to Pewaukee Lake for stocking purposes	WI Commissioner of Fisheries Biennial Report
1888	Christopher Starke uses steam dredge to create Peninsula (1st dredging on lake)	LPSD files
	Aquatic plants cut to allow operation of mail boat	LPSD files
1890	Most of west end shoreland developed for residential (agriculture still dominant in watershed)	LP Historical Charlie Shong (former LPSD Manager)
	Meadowbrook stream ditched to aid building electric railway	LP Historical Charlie Shong (former LPSD Manager)
1894	Waukesha Beach amusement park opens/Milwaukee Electrical provides rail service (until 1948)	LP Historical Charlie Shong (former LPSD Manager)
1898	Steam-powered weed cutter used by ice companies	LP Historical Charlie Shong (former LPSD Manager)
1899	White bass and walleye planted in Pewaukee Lake	WI Commissioner of Fisheries Biennial Report
1900	Beginning of significant urban development in Pewaukee Lake watershed	CAPR 58-2 SEWRPC report
	Wisconsin Geological and Natural History Survey studies Lake's genesis and morphology	CAPR 58-2 SEWRPC report
1901	Rainbow trout planted in Pewaukee Lake	WI Commissioner of Fisheries Biennial Report
1906	Armour ice house burns; end of large scale commercial ice industry	LP Historical Charlie Shong (former LPSD Manager)
1920	WDNR 1992 core samples indicate increase in sedimentation from 1920s	LP Historical Charlie Shong (former LPSD Manager)
	Almost all of shoreline developed by this date; decline in water quality	LP Historical Charlie Shong (former LPSD Manager)
1937	A single haul removes 10,000 pounds of gar from Pewaukee Lake	CAPR 58-2 SEWRPC report
1937-1949	WDNR annual fish stocking	CAPR 58-2 SEWRPC report
1930	Public sanitary service provided to Lake area	CAPR 58-2 SEWRPC report
1938	Lake residents begin to organize in response to water quality and algae issues	LP Historical Charlie Shong (former LPSD Manager)
1944	Formation of Lake Pewaukee Sanitary District	CAPR 58-2 SEWRPC report
	LPSD begins cutting of aquatic plants on Lake	MR 56 SEWRPC report
	Wisconsin Conservation Department starts intermittently collecting water quality data	CAPR 58-2 SEWRPC report
1945	Chemical herbicide (sodium arsenite) treatments begin	LPSD files
	Septic systems inspections begin	LP Historical Charlie Shong (former LPSD Manager)
1946	State requires Pewaukee to remove cut weeds from Lake	LPSD files
1947	LPSD begins harvesting aquatic plants	LPSD files
1950-2000	Spreadsheet data DNR fish stocking records	SEWRPC file FISH
1950-1967	Aquatic plant chemical controls used	WDNR FX-2 report
1951-1952	WDNR annual fish stocking	CAPR 58-2 SEWRPC report
1962	LPSD begins use of 2,4-D to control aquatic plants	LPSD files
1963	LPSD discontinues use of sodium arsenite	LPSD files
	Water Quality analysis by WDNR	WDNR FX-2 report
1965	Boat survey	WDNR FX-2 report

Table continued on next page.

Table 1.1 (Continued)

Date	Event	Source[a]
1966	Eurasian Watermilfoil (EWM) first observed in the Lake	LPSD files
	US Soil Conservation Service conducts soil survey of PL area	SEWRPC PR 8 report
	Water Quality analysis by WDNR	WDNR FX-2 report
1967	Lake Hydrography and Morphology compiled	WDNR FX-2 report
	Aquatic species abundance list	SEWRPC file AQ PL
	Recommendations by WDNR	WDNR FX-2 report
1967-1981	WDNR annual musky stocking	MR 56 SEWRPC report
1975	Curly-leaf pondweed first identified in the Lake	Online WDNR
1976	Sanitary sewers begin to be installed around lake perimeter homes	LPSD files
	Plant survey	CAPR 58-2 SEWRPC report
1976-1977	Phytoplankton survey	CAPR 58-2 SEWRPC report
1978	Wisconsin Legislature mandates Wisconsin Wetlands Inventory	CAPR 58-2 SEWRPC report
1983	Village decides not to modify dam	SEWRPC file NEWS
1984	SEWRPC publishes CAPR 58 1st Ed. WQMP (first lake/watershed plan)	SEWRPC file box
1985-2004	Native aquatic plant populations increase; milfoil density decreases	LPSD files
1985	Chemical herbicide treatments discontinued	LPSD files
1986	WDNR Starts Long Term Trend Water Quality Monitoring Program	CAPR 58-2 SEWRPC report
	Citizen Volunteer Enrolled in Self-Help Monitoring Program	CAPR 58-2 SEWRPC report
1988	LPSD Starts Keeping Plant Harvesting Data	CAPR 58-2 SEWRPC report
1990	LPSD begins buying wetlands in watershed	SEWRPC file Rec/Cons
1991	WDNR survey finds musky, largemouth bass, northern pike, panfsh common	FM-800-91 WDNR publication
	LPSD receives $10K grant from WDNR for WQ study (inflow study)	SEWRPC file NEWS
1992	LPSD plant survey finds EWM widespread and abundant/dominant	MR 56 SEWRPC report
	LPSD develops Aquatic Plant Management Plan for the Lake	SEWRPC file Reports
	Core samples taken of lake sediment (WDNR)	LPSD files / WDNR files
1994	WDNR prepares nonpoint source pollution control report for Upper Fox River basin	WDNR PUBL-WR-366-94
	WDNR 1994 Sensitive Area Assessment	SEWRPC file Reports
1995	SEWRPC boat survey	CAPR 58-2 SEWRPC report
	SEWRPC conducts lake use surveys	MR 56 SEWRPC report
1999	City of Pewaukee incorporated	CAPR 58-2 SEWRPC report
2000	Summer fish kill due to bacteria (WDNR)- newspaper report	SEWRPC file FISH
2002	City of Pewaukee attempts to do their own aquatic plant control	LP Historical Charlie Shong (former LPSD Manager)
2003	Blue-green algae issues	SEWRPC file NEWS
	Phosphorus ban proposed	SEWRPC file NEWS
2004	Zebra mussels first identified in the Lake	Online WDNR
	WDNR decision to allow 2,4-D use on the Lake	LPSD files
2010	Chinese mystery snail first identified in the Lake	Online WDNR
2011	E. coli analyses from UW-Milwaukee School of Freshwater Sciences	LPSD file
2014	2014 LPSD Harvesting Report	LPSD file
	E. coli analyses from UW-Milwaukee School of Freshwater Sciences	LPSD file
2016	Wisconsin Lutheran College aquatic plant survey	CAPR-58
2019	Starry stonewort first identified in the Lake	Online WDNR

[a] *The category of each source is designated with the following colors:*

- History
- Fish
- Aquatic Plants
- Land Use
- Geology
- Water Quality
- Pollution Control
- Recreation
- Invasives
- Soil
- Lake Physical
- Recommendations
- Reports
- Conservation

Source: Lake Pewaukee Sanitary District, Wisconsin Department of Natural Resources, and SEWRPC

The public's interest in sustainable land use, quality of life, and water quality has led to numerous reports that either focus on Pewaukee Lake and its watershed, or contain information of interest to Lake management. The following list provides a few examples of the kinds of documents that provide information useful to managing Pewaukee Lake.

Federal Reports

- 1836 – Federal land survey
- 1892 and 1909 – U. S. Geological Survey (USGS) 15-minute topographic maps covering the Lake and its watershed
- 1966 – U.S. Soil Conservation Service soil survey that included the Pewaukee Lake area
- 1975 – U.S. Environmental Protection Agency (USEPA) produced a National Eutrophication Study that included Pewaukee Lake
- 2012 – USGS report describing a groundwater/surface water flow model for the upper Fox River basin, including Pewaukee Lake and its tributaries
- 2014 – Federal Emergency Management Agency (FEMA) updates flood insurance rate maps for portions of the watershed. These maps illustrate the extent of flooding under a range of flood severity.

State Reports

- 1886 – Wisconsin Commissioners of Fisheries biennial report on fish culture and fish stocking, including stocking in Pewaukee Lake
- 1963 – Wisconsin Conservation Department Surface Water Resources of Waukesha County
- 1967 – John Batha, UW-Madison, limnological study of Pewaukee Lake
- 1970 – Wisconsin Department of Natural Resources (WDNR) Lake Use Report No. FX-2 on Pewaukee Lake
- 1975 – Wisconsin Geological and Natural History Survey (WGNHS) Ground-Water Resources of Waukesha County, Wisconsin
- 1994 – WDNR Sensitive Areas Assessment Report for Pewaukee Lake
- 2001 – WGNHS Pleistocene Geology of Waukesha County, Wisconsin
- 2004 – WGNHS Preliminary Bedrock Geologic Map of Waukesha County, Wisconsin
- 2013 – WDNR comprehensive fishery survey report of the Lake
- 2019 – WDNR preliminary report about 2018 fishery survey of the Lake

Local Reports

- SEWRPC
    - 1969 – Planning Report No. 12, *A Comprehensive Plan for the Fox River Watershed*
    - 1977 – Planning Report No. 27, *A Park and Open Space Plan for Southeastern Wisconsin*
    - 1979 – Planning Report No. 30, *A Regional Water Quality Management Plan*

    - 1980 – Community Assistance Planning Report (CAPR) No. 42, *A Park and Open Space Plan for the Town and Village of Pewaukee*
    - 1984 – CAPR No. 58, *A Water Quality Management Plan for Pewaukee Lake*
    - 1989 – CAPR No. 137, *A Park and Open Space Plan for Waukesha County*
    - 1992 – Planning Report No. 40, *A Regional Land Use Plan*
    - 1996 – Memorandum Report No. 56, *A Lakefront Recreational Use and Waterway Protection Plan*
    - 2003 – CAPR No. 58 (2nd edition), *A Water Quality Management Plan for Pewaukee Lake*
- Wisconsin Lutheran College
    - 2000 – Biological Evaluation report
    - 2005 – *Pewaukee Lake Phosphorus Monitoring 2003-2004*
    - 2006 – Minnow and Small Fish Assemblages of Pewaukee Lake
    - Reports on aquatic plant surveys conducted by Wisconsin Lutheran College for years 2002, 2004, 2006, 2007, 2008, 2009, 2010, 2011, 2013, 2014, and 2016
- Other Local Organizations
    - 1971 – Aqua Tech report on Pewaukee Lake water quality, aquatic plants, and related topics
    - 1992 – LPSD developed *An Aquatic Plant Management Plan for Pewaukee Lake*
    - 1992 – Pewaukee Lake Citizens Advisory Committee report on aquatic plant management
    - 1997 – LPSD report on purchases made as part of their Wetland Conservancy Fund
    - 1998 – Milwaukee Zoological Society report on area bird species
    - 2007 – Eco-Resource Consulting report for LPSD on aquatic plants of Pewaukee Lake

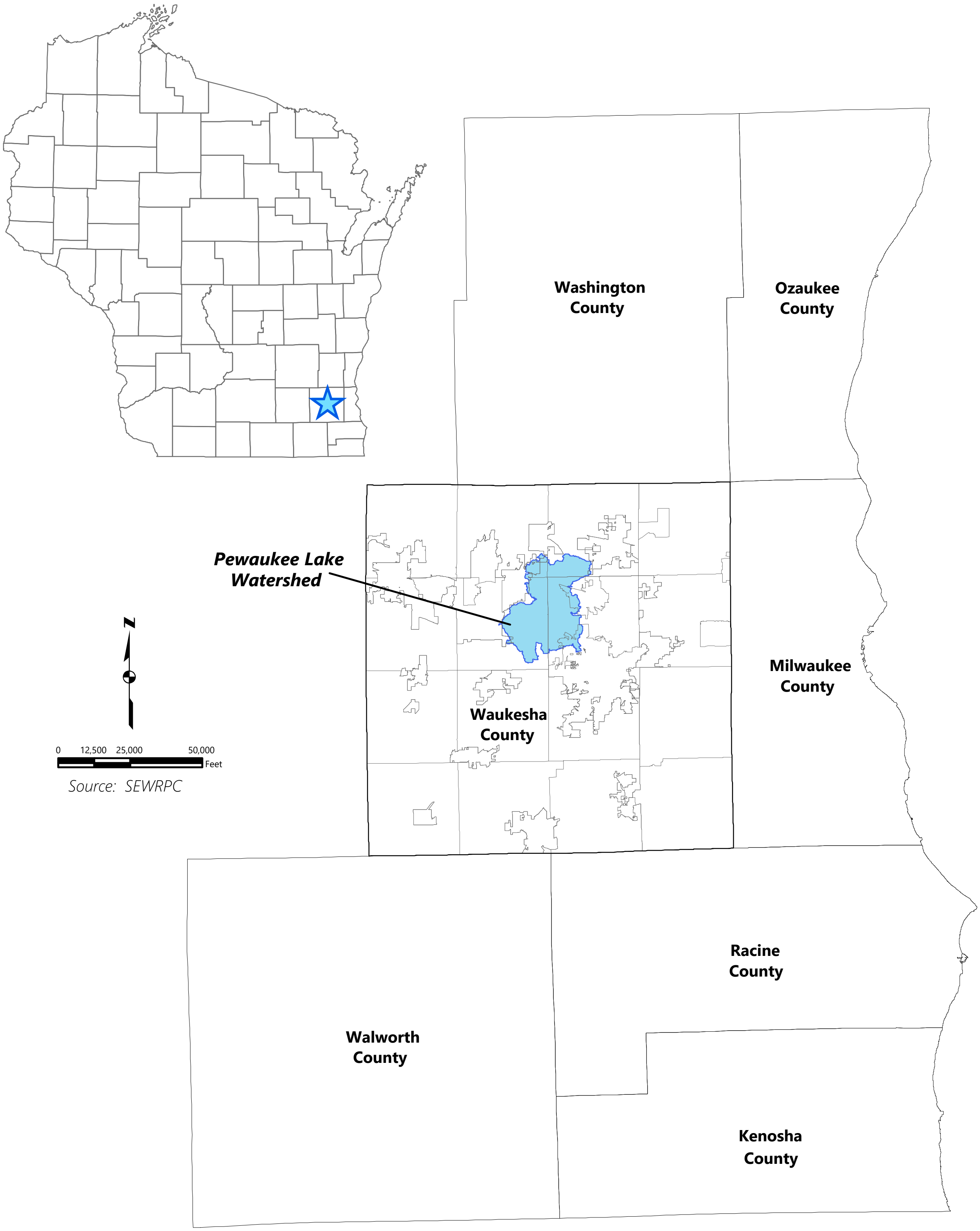
1.2 PLAN PURPOSE, ORGANIZATION, AND FOCUS

Located in the north-central portion of Waukesha County (see Map 1.1), Pewaukee Lake provides a unique warmwater system that remains healthy despite a long history of intensive use as well as intensive and extensive past, ongoing, and projected future urbanization within its watershed. The Lake's continued vitality is a testament to the benefits of proactive and well-planned Lake management.

Pewaukee Lake is a premier water resource asset in the Milwaukee Metropolitan area. Development of the plan program described in this report was funded in part by a WDNR grant awarded to the LPSD through the *Wisconsin Administrative Code* Chapter NR 190, "Lake Management Planning Grants" program. Examples of major grant program deliverables include the following items.

- Compile watershed and water quality information. Examine trends and implications. The morphometry of the Lake and the hydrology of the Lake and its watershed must also be closely examined and related to observed or potential future conditions.
- Estimate nutrient, sediment, and pollutant loads to the Lake. This requires detailed study of land uses within the area where surface water runoff drains to the Lake.

Map 1.1
Location of the Pewaukee Lake Watershed Study Area



Source: SEWRPC

- Identify sensitive areas and critical species areas.
- Evaluate Lake tributaries, with particular attention paid to streambank erosion.
- Examine the aquatic plant community, and identify appropriate management actions that further the goals of Lake users and Lake health.
- Assist the LPSD with a survey of Lake resident concerns. This will help identify topics of most interest and/or that are poorly understood by Lake residents.
- Develop recommendations that help the LPSD monitor the Lake's overall condition, help protect water quality, foster public participation and understanding, preserve or enhance recreational use, and safeguard the ecology of the Lake.
- Prepare a comprehensive written report and present the findings at a public meeting. The inventory and aquatic plant management plan elements presented in this report conform to requirements and standards set forth in relevant *Wisconsin Administrative Codes*.[1]

This protection plan is the third in a series of lake management plans developed for Pewaukee Lake by the Southeastern Wisconsin Regional Planning Commission (SEWRPC). The first plan was published in 1984 with an amended version published in 2003.[2,3] This plan represents the continuing commitment of government agencies, non-governmental organizations, municipalities, and citizens to diligent lake planning and natural resource protection.

This plan is divided into three chapters. Chapter One briefly outlines the plan's purpose, summarizes basic Lake characteristics and assets, and describes general goals and objectives. Chapter Two presents and interprets information needed to understand Lake conditions and the factors that could imperil Lake health. Finally, Chapter Three discusses approaches to protect and enhance the Lake and its watershed. Chapter Three recommendations aim to enhance and preserve Pewaukee Lake's native plant community, ecology, and water quality, while allowing Lake users and watershed residents opportunities for safe and enjoyable recreation within the Lake and the Lake's watershed.

The health of a lake or stream is usually a direct reflection of land use and management within the lake's watershed (the land surrounding a lake that slopes toward the lake or a tributary stream, and that contributes runoff to the lake).[4] In the face of human-induced change, active intervention is often necessary to stabilize, maintain, or enhance resource conditions. This protection plan focuses on what can be done to *protect* critical resources from human-induced deterioration and *prevent* future water pollution or resource degradation. This plan complements other existing programs and ongoing management actions in the Pewaukee Lake watershed and represents the continuing commitments of government agencies, municipalities, and citizens to diligent land use planning and natural resource protection. This plan recommends appropriate and feasible watershed management measures to help enhance and preserve the water quality, aesthetics, and ecological integrity of Pewaukee Lake and its tributaries and provide the public with opportunities for safe and enjoyable recreation within Pewaukee Lake and its watershed. This document's primary purpose is to review and analyze available data and provide an updated management framework with specific recommendations. Such information enables organizations to take appropriate measures to protect the health and use value of Pewaukee Lake.

[1] *This plan has been prepared pursuant to the standards and requirements set forth in the following chapters of the* Wisconsin Administrative Code*: Chapter NR 1, "Public Access Policy for Waterways;" Chapter NR 40, "Invasive Species Identification, Classification and Control;" Chapter NR 103, "Water Quality Standards for Wetlands;" Chapter NR 107, "Aquatic Plant Management;" and Chapter NR 109, "Aquatic Plants Introduction, Manual Removal and Mechanical Control Regulations."*

[2] *SEWRPC Community Assistance Planning Report No. 58,* A Water Quality Management Plan for Pewaukee Lake, Waukesha County, Wisconsin*, March 1984.*

[3] *SEWRPC Community Assistance Planning Report No. 58, 2nd Edition,* A Lake Management Plan for Pewaukee Lake, Waukesha County, Wisconsin*, May 2003.*

[4] *In Pewaukee Lake's case, runoff from roughly 25 square miles drains to the Lake. The watershed is densely populated and is intensively used for various residential and commercial purposes.*

This protection plan provides practical guidance for maintaining or enhancing water quality within the Pewaukee Lake watershed and for managing lands that drain directly and indirectly to the Lake and its tributary streams. The plan is developed to assist units of government, nongovernmental organizations, businesses, and citizens in developing strategies benefiting the natural assets of Pewaukee Lake and protecting sensitive and other high-value habitats within its watershed. By applying the strategies outlined in this plan, the natural environment will be enriched and preserved. In addition, carefully planned urban development can preserve ecological benefits that directly benefit human habitation. For example, planning can create and maintain desirable aesthetics, groundwater recharge areas, and wildlife corridors, all of which benefit Pewaukee Lake's ecology, watershed residents and businesses, and visitors.

1.3 GENERAL CHARACTERISTICS OF PEWAUKEE LAKE AND ITS WATERSHED

Although Pewaukee Lake is classified by the WDNR as a drainage lake, the Lake has a relatively small watershed given its large open-water surface area. Several small tributaries enter the Lake, all of which are classified as headwater streams. The Lake's outlet is located at the extreme eastern end of the Lake and is dammed, raising the Lake's water elevation and substantially increasing the extent of open water. The Lake's outlet flows into the Pewaukee River. The Pewaukee River joins the Fox River just north of the City of Waukesha. The Fox River flows in a southerly direction through Waukesha, Racine, and Kenosha Counties; crosses the Wisconsin-Illinois state line; and then flows through the northern Illinois Chain-of-Lakes, discharging to the Illinois River near Ottawa, Illinois. From there, the Illinois River flows to the southwest, entering the Mississippi River north of the City of Saint Louis, Missouri. Water from Pewaukee Lake and its watershed ultimately discharges to the Gulf of Mexico.

Even though Pewaukee Lake has a large areal extent and is one of Waukesha County's largest lakes by volume, much of the Lake is relatively shallow. The Lake and its watershed cover nearly 25 square miles. Chapter Two provides more detail regarding the morphometry, morphology, and hydrology of Pewaukee Lake and its tributary streams and relates these characteristics to water quality, aquatic plants, fisheries, recreation, and overall Lake management.

Pewaukee Lake and its watershed provide numerous, widely varying, recreational assets. Prominent public access points and recreational features include Lakefront Park in the Village of Pewaukee at the Lake's extreme east end and the Pewaukee Boat Launch (owned by the Waukesha County Department of Parks and Land Use) at the extreme west end of the Lake. Large swaths of wetland have been protected in the watershed and can be accessed by the public. For example, the LPSD owns several tracts just north of the Lake and in the Coco Creek subwatershed. Other parcels are also open for public use (e.g., shoreline bait shops and boat liveries). Finally, a large numbers of homes surround the Lake, residences that typically focus on the Lake and its recreational opportunities and the aesthetic appeal it provides.

The Lake successfully supports a spectrum of recreational interests as evidenced by boat counts and observations completed by SEWRPC staff during summer 2016 (see Chapter 2 for more details). Lake users engage in full-body contact uses (such as swimming and water skiing) as well as pleasure cruising, high-speed boating, fishing, and other activities. Additionally, as is further described in Chapter 2, the Lake's watershed contains critical species habitat areas and a variety of wetlands, uplands, and woodlands. The watershed likely supports a large number of resident animal species, including several species of reptiles and amphibians; small and large mammals, insects, and invertebrates; and a number of transient bird species that may be found in the area during seasonal migrations.[5]

[5] *These estimates are based on bird, amphibian, and reptile databases for the Region.*

1.4 LAKE PROTECTION GOALS

General lake protection goals that aim to maintain and enhance the Lake's assets were developed as a part of this planning process. The goals listed below were developed in consultation with the WDNR, LPSD, the City of Pewaukee, the Village of Pewaukee, the Town of Delafield, and the public. The goals also directly address goals established in the Waukesha County Comprehensive Development Plan and the Waukesha County Land and Water Resources Management Plan.[6,7]

- Examine the Lake's aquatic plant community
    - Document the status of the Lake's aquatic plant community, with particular emphasis on the occurrence and distribution of nonnative species. Use this information to better understand the changes and dynamics of the Lake's aquatic plant community.
    - Evaluate the impact of aquatic plants on Lake use and habitat value.
    - Identify measures and methods useful to reduce the extent and abundance of nonnative aquatic plant species.
    - Reduce the risk of nonnative aquatic species spreading to other waterbodies.
    - Provide the bulk of the information needed to successfully apply for an aquatic plant management permit.
- Update descriptions of watershed conditions. This includes identifying and quantifying potential point and nonpoint sources of pollution, nutrient and sediment inputs, and nutrient and contaminant balances. Also, provide conceptual examples of projects that could be undertaken to mitigate the impact of identified sediment and pollution sources.
- Identify the extent of existing and potential future water quality problems likely to be experienced in the Lake. This includes examining the Lake's water quality using physicochemical monitoring data collected as part of ongoing water quality monitoring programs. In addition, estimate future water quality changes and provide advice regarding appropriate future monitoring activity.
- Assess the degree and intensity of recreational water use in and around Pewaukee Lake.
- Formulate appropriate management objectives, action plans, public information and education strategies, ordinances, and other possible responses to the identified threats and problems.
- Provide advice and concepts describing management, enhancement, and restoration measures that address identified issues of concern and could improve current and future Lake health and ecological resilience/resistance. This likely will include active measures as well as outreach and education.

Conscientiously implementing the actions recommended herein should provide an important step toward achieving the LPSD's desired Lake use/protection objectives over time.

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[6] *Waukesha County Department of Parks and Land Use,* A Comprehensive Development Plan for Waukesha County, Waukesha, Wisconsin*, February 24, 2009, www.waukeshacounty.gov/defaultwc.aspx?id=39496.*

[7] *Waukesha County Department of Parks and Land Use,* Waukesha County Land and Water Resource Management Plan*, 2012.*

RESOURCE INVENTORY 2

Credit: SEWRPC Staff

2.1 INTRODUCTION

Even though Pewaukee Lake (the Lake) is a treasured community and ecological resource, human activity in and around the Lake and within its watershed inadvertently contributes to management challenges and could lead to future problems and concerns. To better define and understand these issues, and to help maintain water body characteristics supporting quality recreational use and the Lake's great latent ecological value, the Lake Pewaukee Sanitary District (LPSD) and the Southeastern Wisconsin Regional Planning Commission (Commission) executed an agreement to identify community concerns, evaluate Lake and watershed resource conditions, conduct informational meetings, and develop a management plan addressing these concerns.

As a part of the planning process, issues of most concern were identified through various means, including an initial informational workshop with members of the Lake community, meetings of the LPSD, investigation by Commission staff, and polling of Lake user sentiments and concerns.[8,9] Table 2.1 lists priority issues identified by this process.

These issues are the basis for the topics addressed in this management plan. This chapter provides information and interpretations that will 1) help answer questions posed by the LPSD and concerned community members, and 2) help with development of concepts to safeguard long-term Lake health and human-based values.

Table 2.1
Issues and Concerns

Issues and Concerns	
1	Water Quantity
2	Water Quality
3	Pollutant and Sediment Sources and Loads
4	Aquatic Plants
5	Floating Algae and Cyanobacteria
6	Shoreline Condition and Habitat Value
7	Recreational Use and Facilities
8	Fish and Wildlife
9	Plan Implementation

Source: SEWRPC

[8] *Pewaukee Lake Improvement Association,* Perceptions and Priorities for Pewaukee Lake – 2005 Survey Results*, undated questionnaire distributed April 2005.*

[9] *SEWRPC,* Pewaukee Lake Watershed Questionnaire*, distributed August 2014.*

2.2 LAKE AND WATERSHED PHYSIOGRAPHY

The condition and overall health of a waterbody is directly related to the natural and human-induced characteristics and natural features within the area draining to the waterbody. This assemblage of unique natural features and processes can be collectively referred to as physiography. This section describes the Lake and watershed physiography including the shape and arrangement of landscape features, the composition and arrangement of soil and rock, tributary streams and Lake basin shapes, how water moves through the area, and how humans influence the landscape.

The landscape characteristics and land use practices around a lake control a lake's water quality and overall character. Therefore, it is important to characterize the area draining to a lake—its watershed—to understand natural resource elements, human manipulation, potential pollution sources and risks to the lake's water quality. Several items need to be examined in order to complete this characterization, including:

1. **The location and extent of a lake's watershed**—Before characterizing watershed features, its extent must be quantified. The delineation process involves carefully examining land surface elevation data to delineate the area from which water draining from the land surface eventually reaches a waterbody. This analysis provides the basis for determining whether potential pollutant sources threaten a waterbody. For example, if a pollution source is near a waterbody but outside the watershed, contaminated surface runoff from that source would not reach the waterbody, and, therefore, may not be an issue of concern in terms of water quality.

2. **Natural resource factors**—The arrangement and composition of soil and rock, climatic variables, vegetation, and other factors dictate much of a lake's overall character. Therefore, it is important to understand the topography, geology, hydrology, and climate prevailing in the lake's watershed.

3. **Existing land use types and distribution**—The extent and location of various land uses within the watershed can help predict the type and amount of pollution reaching a waterbody. Land use conditions can be represented with models to estimate total pollutant loads entering a waterbody, evaluate the relative contribution of certain land uses or areas, and predict consequences of land use change. Once loads are estimated, management efforts can be efficiently focused on those areas generating the greatest loads. For example, if agriculture is predicted to be the primary source of phosphorus to a water body, initial pollution reduction efforts may be focused on this land use.

4. **Historical land use types and distribution**—Being aware of past land use changes can provide context for understanding what caused past waterbody health issues, particularly when considered with contemporaneous water quality monitoring data or well-documented historical issues. For example, if a long-term lake property owner remembers or recorded the years of heavy aquatic plant growth, large algal blooms, or low or high water levels, those conditions can be correlated with historical land use changes to examine if something changed to cause an issue (such as an increase in impermeable surfaces or installation of stormwater infrastructure). This information can help offer insight into how a waterbody may react to similar future changes and situations.

5. **Future planned land use types and distribution**—In addition to past and current land use in a watershed, planned land use changes can help estimate future conditions. This information helps target areas that may need active or pre-emptive management in the future, as well as estimate the potential type and magnitude of future pollution issues.

6. **The nature and locations of pollutant sources (if applicable)**—Many human activities contribute pollutants to waterbodies. Many potential pollutant sources are stringently regulated. However, some may continue to be significant pollution sources. An example is private onsite wastewater treatment systems (POWTS), commonly known as septic systems. POWTS can be a significant source of phosphorus when not properly maintained and are usually a substantial source of chloride. Consequently, it is important to investigate whether POWTS exist within a watershed.

Watershed Extent and Topography

Pewaukee Lake covers 2,446 acres and receives runoff from a 13,432 acre watershed draining north-central Waukesha County.[10] Most of the watershed's runoff is delivered to the Lake through four named tributaries (Audley, Coco, Meadowbrook, and Zion Creeks).

The ground-surface elevation in the Pewaukee Lake watershed varies by roughly 280 feet, with elevations of approximately 852 feet above National Geodetic Vertical Datum, 1929 adjustment (NGVD 29) found along the Lake's shoreline to elevations of almost 1130 feet above NGVD 29 at the crest of prominent hills and ridges in the northern and southwestern portions of the watershed (see Map 2.1). Nevertheless, almost two-thirds of the watershed is less than 100 feet higher than the Lake water surface.

Areas of significant topographic relief are prone to long and/or steep slopes. Steeply sloping areas are less likely to store or infiltrate water and are more likely to experience significant erosion, especially when actively cropped, developed, or urbanized. Eroded sediments are transported to lakes, streams, and wetlands where they settle and have the potential to cover desirable granular substrates. Furthermore, sediments often contain significant amounts of nutrients, and can contain a variety of pollutants. Slopes in the Pewaukee Lake watershed range from less than 1 percent to greater than 20 percent. As shown on Map 2.2, most areas within the Pewaukee Lake watershed are relatively level, with 39 percent of the watershed underlain by land surfaces sloping at 2.5 percent or less, and 72 percent sloping at 6 percent or less. Nevertheless, steeply sloping land is found throughout the watershed, including areas close to the Lake. Steeply sloping land is found along the Lake's northwestern shoreline and in areas set well back from the Lake's shoreline draining to Audley, Coco, and Zion Creeks.

The topography of land surfaces, as well as the composition and layering of underlying soil, can significantly affect the type and amount of pollutants and sediment washed into the lakes, streams, and wetlands by rainfall and snowmelt. Generally, less permeable soils and steeper slopes translate to more erosive potential and a greater ability to carry pollutants and sediment to receiving waters. This situation can be exacerbated if slopes are unvegetated, paved, or relatively impermeable. Runoff volume reportedly increases rapidly as slopes increase from zero to about 3 percent. Further increases in slope only slightly increase runoff volume.[11] However, the same study found that soil erosion increased only gradually up to a slope of 4 percent. Soil erosion significantly increased when slopes were greater than 4 percent.

Weather and Climate

Weather and climate describe the same parameters: atmospheric temperature, precipitation, humidity, wind speed, cloud cover, and other conditions. However, weather and climate are not synonymous. The term "weather" generally refers to conditions over short periods of time (e.g., minutes, hours, days, weeks). In contrast, the term "climate" describes long term weather averages, and typically considers time periods of decades or longer. Long periods of weather data allow climate estimates to be made, and allow changes to climate to be noted. Weather conditions have been recorded in Waukesha County for well over 100 years. The average monthly temperatures, precipitation, snowfall, and snow depth recorded at the Waukesha Water Works between 1893 and 2016 are provided in Table 2.2.

Climate is dynamic and has changed many times over the Earth's history. Wisconsin climate data is based on weather observations that extend back at most only about 180 years. "Long-term" precipitation and temperature trends are often based on records spanning a few decades (generally from about the 1970s or 1980s to the present). The available data indicate that Wisconsin's climate is changing.[12] Many aspects of the landscape's water resource asset base respond to climate and can serve as indicators of climate change at various temporal and spatial scales. Historical data analysis demonstrates that water resources are intimately linked to local and regional climate conditions. Long-term records of lake water levels, lake-

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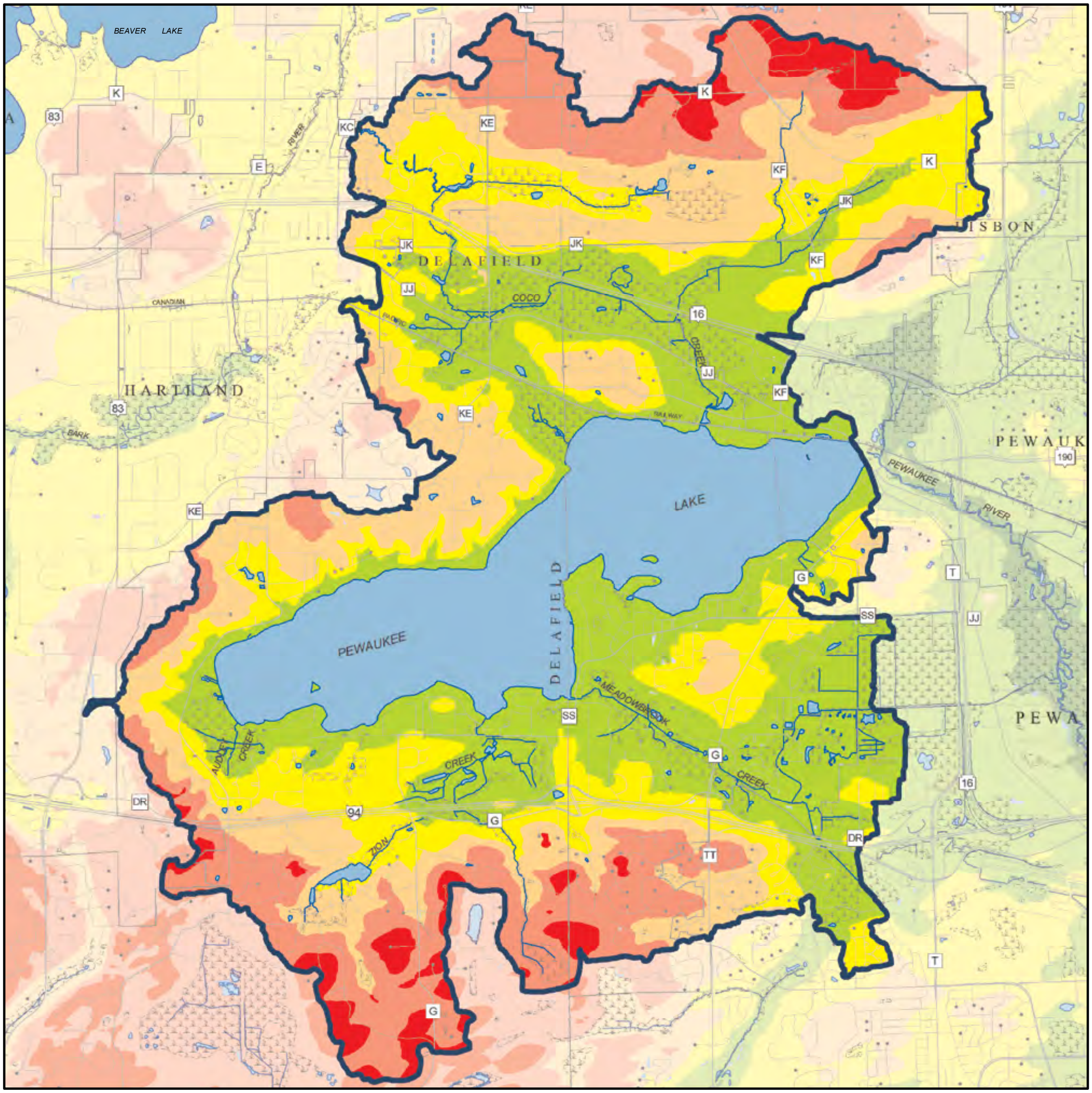
[10] *The Pewaukee Lake watershed boundary was delineated using two-foot interval ground elevation contours developed from a 2003 digital terrain model.*

[11] *F.L. Duley and O.E. Hays, "The Effects of Degree of Slope on Run-off and Soil Erosion,"* Journal of Agricultural Research, *45(6): 349-360, 1982.*

[12] *C.J. Kucharik, S.P. Serbin, S. Vavrus, E.J. Hopkins, and M.M. Motew, "Patterns of Climate Change Across Wisconsin from 1950 to 2006,"* Physical Geography, *31(1): 1-28, 2010.*

Map 2.1
Pewaukee Lake Watershed Physiography



ELEVATION (IN FEET)

- 800-850
- 850-900
- 900-950
- 950-1000
- 1000-1050
- 1050-1125

- SURFACE WATER
- WETLAND
- STREAM
- WATERSHED BOUNDARY

Note: Elevation in feet above National Geodetic Vertical Datum, 1929 Adjustment.

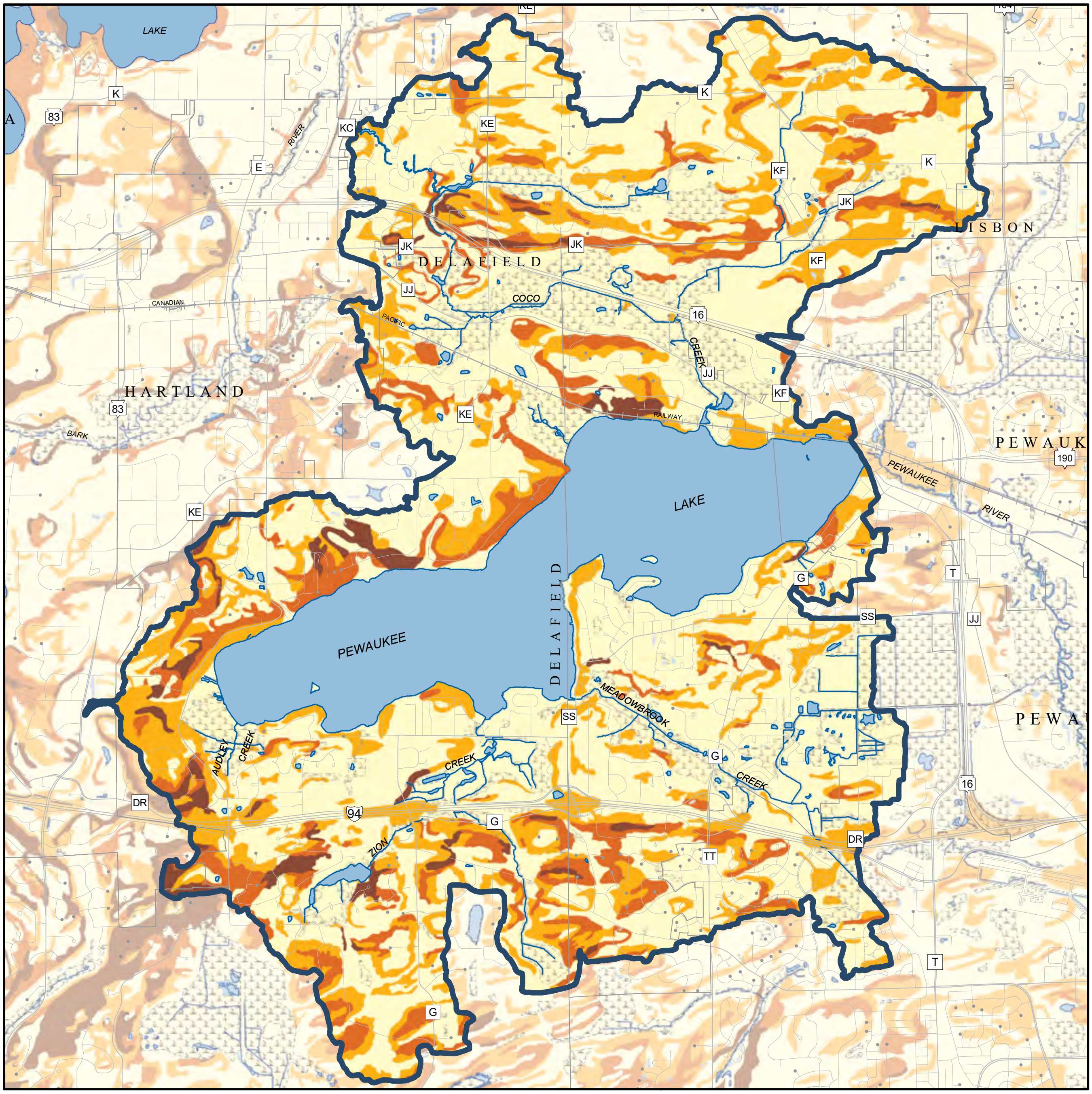
Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each legend category.

N

0 1,250 2,500 5,000 Feet

Source: SEWRPC

Map 2.2
Land Surface Slope Within the Pewaukee Lake Watershed



SOILS HAVING SLOPES RANGING FROM 0 TO 6 PERCENT

SOILS HAVING SLOPES RANGING FROM GREATER THAN 6 TO 12 PERCENT

SOILS HAVING SLOPES RANGING FROM GREATER THAN 12 TO 20 PERCENT

SOILS HAVING SLOPES OF GREATER THAN 20 PERCENT

SURFACE WATER

WETLAND

STREAM

WATERSHED BOUNDARY

Note: Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each legend category.

N

0 1,250 2,500 5,000 Feet

Source: Natural Resources Conservation Service and SEWRPC

Table 2.2
Period of Record Monthly Climate Summary: 1893-2016

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max. Temperature (°F)	27.20	30.60	41.70	56.00	68.10	77.90	83.00	80.70	72.90	60.9	44.90	31.60	56.30
Average Min. Temperature (°F)	11.30	14.40	24.50	35.80	45.80	55.50	60.80	59.30	51.60	40.90	29.00	17.10	37.20
Average Total Precipitation (in.)	1.50	1.27	2.17	3.03	3.50	3.75	3.44	3.560	3.42	2.43	2.18	1.66	31.91
Average Total Snowfall (in.)	11.00	7.80	8.10	2.00	0.20	0.00	0.00	0.00	0.00	0.30	2.70	8.50	40.60
Average Snow Depth (in.)	5.00	4.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	1.00

Source: Western Regional Climate Center

ice duration, groundwater levels, and stream baseflow are correlated with long-term trends in atmospheric temperature and precipitation.[13]

The Wisconsin Initiative on Climate Change Impacts (WICCI) concludes that projected future climate change will affect Wisconsin's water resource quantity and quality.[14] However, WICCI also found clear evidence from analysis of past and probable future climate trends that different geographic regions of Wisconsin will respond differently to climate change (see Figure 2.1). These differences reflect local variation in land use, soil type, groundwater characteristics, and runoff and seepage response to precipitation. This illustrates the importance of including existing and future conditions as part of the watershed protection plan strategy.

Climate change seems to be altering water availability (volume and timing), distribution and intensity of rainfall over time, and whether precipitation falls as rain or snow, each of which affects water's movement through the water cycle. As shown in Figure 2.2, water entering the landscape arrives as precipitation (rain and snowfall) that either falls directly on waterbodies; runs off the land surface and enters streams, river, wetlands, and lakes; or percolates through the soil, recharging groundwater that flows underground and re-emerges as springs, seeps, or human well discharge, all which can feed lakes, wetlands, and streams.

Even absent climate change, when portions of the hydrologic cycle change, the surface-water and groundwater system may be affected. For example, intense groundwater pumping and consumptive use can reduce or completely deplete flow in local streams (see the "Groundwater Resources" subsection below). Climate change may expose the vulnerabilities of water supplies within a given natural system or human community, and this vulnerability is commonly proportional to how much humans have altered the water cycle. Water supply vulnerability is often most evident during protracted dry weather while flooding and infrastructure failure are most evident during extremely wet weather.

The WICCI Water Resources Working Group (WRWG) incorporated WICCI's 1980-2055 temperature, precipitation (including occurrence of events), and changes in snowfall projection to evaluate potential hydrologic process and resource impacts.[15] This team of experts identified and prioritized the most serious potential water resource problems related to anticipated climate change, and proposed strategic adaptation

[13] *Wisconsin Initiative on Climate Change Impacts (WICCI), Wisconsin's Changing Climate: Impacts and Adaptation, Nelson Institute for Environmental Studies, University of Wisconsin-Madison, and Wisconsin Department of Natural Resources, February 2011.*

[14] *Wisconsin Initiative on Climate Change Impacts, February 2011,* op. cit.

[15] *The Water Resources Working Group (WRWG) included 25 members representing the Federal government, State government, the University of Wisconsin System, the Great Lakes Indian Fish and Wildlife Commission, and the Wisconsin Wetlands Association. Members were considered experts in the fields of aquatic biology, hydrology, hydrogeology, limnology, engineering, and wetland ecology in Wisconsin. Over the course of a year, the group convened to discuss current climate-related water resources research, potential climate change impacts, possible adaptation strategies, and future research and monitoring needs across the entire State of Wisconsin. For more details on climate change, impacts, adaptation, and resources visit www.wicci.wisc.edu/water-resources-working-group.php.*

strategies to address those impacts across the State of Wisconsin (see below). The WRWG offers the following guidance to help local communities develop adaptation strategies:[16]

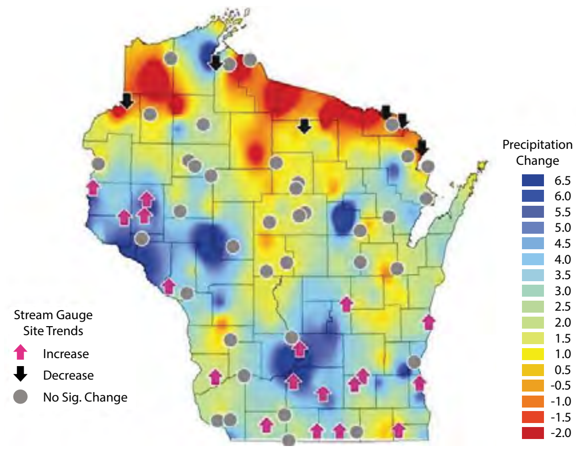
Minimize threats to public health and safety by anticipating and managing for extreme events-floods and droughts. *We cannot know when and where the next flooding event will occur or be able to forecast drought conditions beyond a few months, but we do know that these extreme events may become more frequent in Wisconsin in the face of climate change. More effective planning and preparing for extreme events is an adaptation priority.*

Increase resiliency of aquatic ecosystems to buffer the impacts of future climate changes by restoring or simulating natural processes, ensuring adequate habitat availability, and limiting human impacts on resources. *A more extreme and variable climate (both in temperature and precipitation) may mean a shift in how we manage aquatic ecosystems. We need to try to adapt to the changes rather than try to resist them. Examples include managing water levels to mimic pre-development conditions at dams and other water level structures, limiting groundwater and surface water withdrawals, restoring or reconnecting floodplains and wetlands, and maintaining or providing migration corridors for fish and other aquatic organisms.*

Stabilize future variations in water quantity and availability by managing water as an integrated resource, keeping water "local" and supporting sustainable and efficient water use. *Many of our water management decisions are made under separate rules, statutory authorities, administrative frameworks, and even different government entities. This can lead to conflicting and inconsistent outcomes. In the face of climate change, the more we can do to integrate these decisions at the appropriate geographic scale, the better adapted and ready for change we will be. In addition, treating our water as a finite resource and knowing that supply will not always match demand will allow for more sustainable water use in the future.*

Maintain, improve, or restore water quality under a changing climate regime by promoting actions to reduce nutrient and sediment loading. *Water quality initiatives will need to be redoubled under a changing climate in order to minimize worse-case scenarios such as fish kills, harmful blue-green algae blooms, or mobilization of sediments and nutrients and to prevent exacerbation of existing problems.*

Figure 2.1
River Baseflow and Precipitation Change in Wisconsin: 1960-2006



From 1950-2006, Wisconsin as a whole became wetter, with an increase in annual precipitation of 3.1 inches. This increase has primarily occurred in southern and western Wisconsin, while northern Wisconsin experienced some drying. Concomitantly, stream baseflow increased in wetter areas.

Source: Water Resources Working Group of the Wisconsin Initiative on Climate Change Impacts and SEWRPC

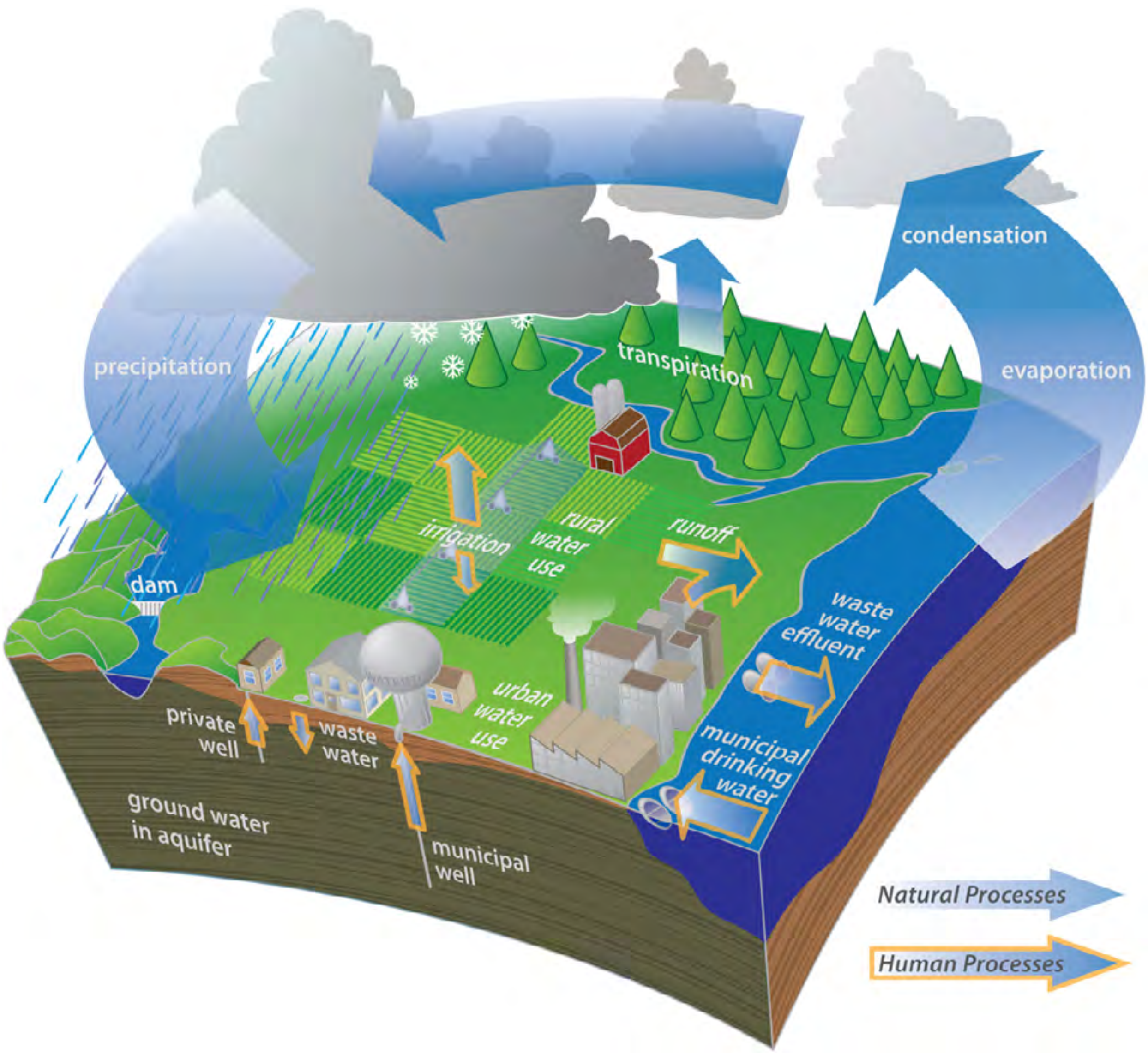
Studies in the Pewaukee River basin have evaluated local climatic change.[17] Overall, available data suggest that the local climate is becoming increasingly warm and wet. Most additional precipitation is falling in the fall and winter, and wetter than normal spring weather is often a harbinger of greater than normal annual precipitation. Records of ice thaw have been collected at Pewaukee Lake since 1936.[18] In that time, the average ice thaw date on the Lake has shifted from April 3rd to March 26th, consistent with trends from

[16] *Wisconsin Initiative on Climate Change Impacts, February 2011,* op. cit.

[17] *For a more detailed description of perceived climate change in the local area, and descriptions of the possible effect of climate change on flora, fauna, water resources, and other factors, see SEWRPC Community Assistance Report No. 313,* Pewaukee River Watershed Protection Plan*, December 2013.*

[18] *Ice records at Pewaukee Lake provided by Bill Browns and Dick Nowacki.*

Figure 2.2
Human Influence on Hydrologic Cycle



This schematic shows how human processes associated with land use development affect how water moves through the hydrologic cycle. Water returns to the atmosphere through evaporation (process by which water is changed from liquid to vapor), sublimation (direct evaporation by snow and ice), and transpiration (process by which plants give off water vapor through their leaves).

Source: Water Resources Working Group of the Wisconsin Initiative on Climate Change Impacts and SEWRPC

Geneva Lake in Walworth County as well as Lake Mendota and Lake Monona in Dane County.[19] Changes in patterns of precipitation and ice cover can impact dam operation (see Section 2.4, "Lake Level Manipulation and Management") as well as the growth of aquatic plants (see Section 2.7, "Aquatic Plants"). Such insight should be integrated into water resource management planning and water infrastructure design.

Geology and Soils

Essentially all of Waukesha County was covered by glacial ice until approximately 15,000 years ago. Eastern Waukesha County was overridden by glaciers flowing southwest out of the Lake Michigan Basin, depositing sediment now known as the Oak Creek Formation and the New Berlin Member of the Holy Hill Formation. Glaciers overriding western Waukesha County followed Green Bay, Lake Winnebago, and other lowlands,

[19] *Information on changes in lake ice is provided at www.epa.gov/climate-indicators/climate-change-indicators-lake-ice.*

and entered Waukesha County from the northwest depositing sediments known as the Horicon Member of the Holy Hill Formation. The two lobes of glacial ice met and formed the prominent ridges of the Kettle Interlobate Moraine (commonly referred to as the "Kettle Moraine").

Glaciers transported vast quantities of unsorted sediment (diamicton) to the area and deposited these sediments under and at the distal end of glacial ice. When glacial diamicton is deposited directly by glacial ice, it is referred to as till. Till deposited under glacial ice is termed ground moraine, while that deposited near the wasting end of a glacier forms a terminal moraine. Melting glaciers released enormous volumes of water, and this water flowed away from the glacier transporting and sorting sediment. Sorted glacial sediment is commonly referred to as glaciofluvial sediment (outwash) when deposited by flowing water or glaciolacustrine sediment (glacial lake deposits) when deposited in still water. The chaotic and rapidly changing environment near melting glacial ice commonly creates complexly interlayered assemblages of till and water-lain sediment. Ice blocks can separate from the main body of ice and can be buried in sediment. When the buried ice block melts, an irregular land surface marked by conspicuous steep-walled depressions ("kettles") results.

Unlike the other large lakes of northwestern Waukesha County formed in the Kettle Interlobate Moraine (an area rich in permeable glaciofluvial sediment), Pewaukee Lake is found in fine-grained ground moraine of the Holy Hill Formation. This means that the Pewaukee Lake watershed generally has gentler slopes, less relief, and generally finer grained, less permeable sediment than many of the other large lakes of Waukesha County. The conspicuous hills found to the north and south of the Lake are drumlins, features deposited under relatively thick glacial ice, and often incorporating layers of impermeable clayey sediment. This also contrasts to the hills surround the other large lakes, which are commonly composed of permeable sand and gravel. Pewaukee Lake is believed to be a result of erosion created by glacial meltwater, while many of the other lakes have basins formed by melting of large blocks of buried glacial ice.

Despite its position on a northeast-southwest trending buried bedrock ridge composed of erosion resistant Silurian-age Niagara Dolomite, bedrock is buried by glacial sediment throughout almost all of the Pewaukee Lake watershed. A few bedrock outcroppings are known, including areas about a half mile south of the Lake and east of Elmhurst Road, just west of Zion Creek, and several areas at and near the northeastern corner of the watershed (see Map 2.3). Most of the Lake, much of lower Coco Creek Watershed, and the upland area immediately north of the central portion of the Lake occupy a comparatively low area on the buried bedrock ridge. In these low areas, the dolomitic bedrock has been eroded away exposing the older underlying soft and easily eroded Ordovician-age Maquoketa Shale or even older Ordovician-age dolomite. Meadowbrook Creek generally parallels the path of a northwest-southeast bedrock fault that is mapped to being in the middle of the Lake.[20]

Soils are the uppermost layers of terrestrial sediment and are the result of weathering and biological activity. The type of soil underlying the area depends on several factors including landscape position and slope, parent material, hydrology, and the types of plants and animals present. Soils of the Hocheim-Theresa Association dominate the Pewaukee Lake watershed, covering over 95 percent of its area (see Map 2.4). Hocheim-Theresa Association soils are generally well drained, have a subsoil consisting of clay loam and silty clay loam, with parent materials being glacial till and loess (wind-deposited silt). Limited portions of the watershed just south of the Lake's west basin and at the extreme northeast corner of the watershed are occupied by soils of the Pella association. These soils are formed in glacial till, are poorly to well drained, and may have a relatively thin silty clay and clay loam soil with bedrock found at shallow depth. Only a few feet of unconsolidated sediment are present in some areas and bedrock outcroppings can occur. A very small area of Rodman-Casco association soils is found at the very edge of the watershed west and southwest of the Lake. Soils of the Rodman-Casco association are typically well drained, with subsoils often dominated by sand and gravel although clay and silt layers are found. The Rodman-Casco association soils are typical of the Kettle Moraine and are commonly found in areas of irregular topography and great topographic relief.[21]

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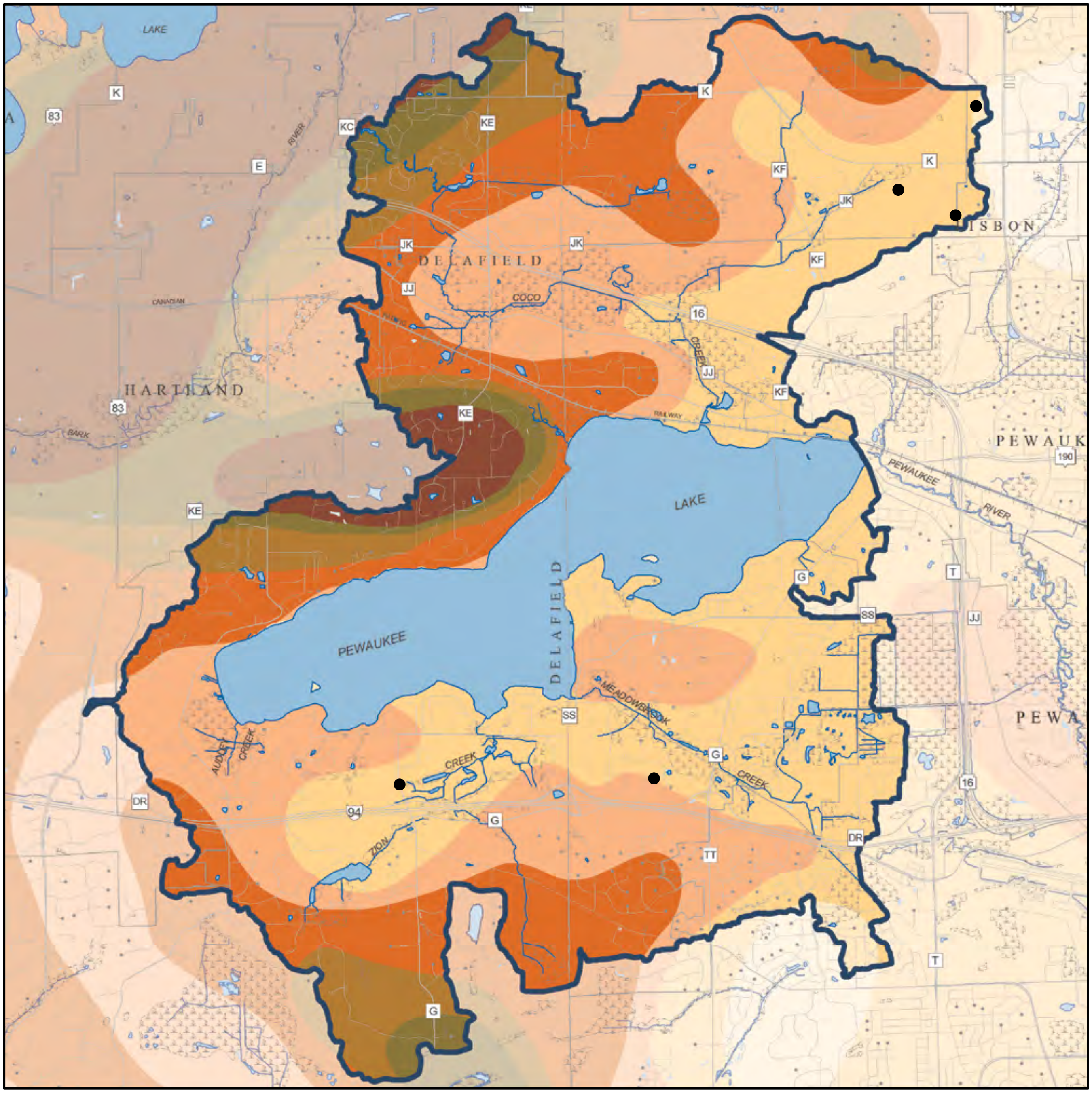
[20] *K.M. Massie-Ferch and R.M. Peters,* Preliminary Bedrock Geology of Waukesha County, Wisconsin, *Wisconsin Geological and Natural History Survey Open-File Report 2004-15B, 2004.*

[21] *J.A. Steingraeber and C.A. Reynolds,* Soil Survey of Waukesha County, Wisconsin*, United States Department of Agriculture, 1971.*

Map 2.3
Unconsolidated Sediment Thickness Within the Pewaukee Lake Watershed



DEPTH TO BEDROCK (IN FEET)

- 0-25
- 25-50
- 50-100
- 100-150
- 150-200
- 200-250
- 250-400
- BEDROCK OUTCROPPING
- SURFACE WATER
- WETLAND
- STREAM
- WATERSHED BOUNDARY

Note: The information shown on this map is general in nature, and may not reflect localized variations.

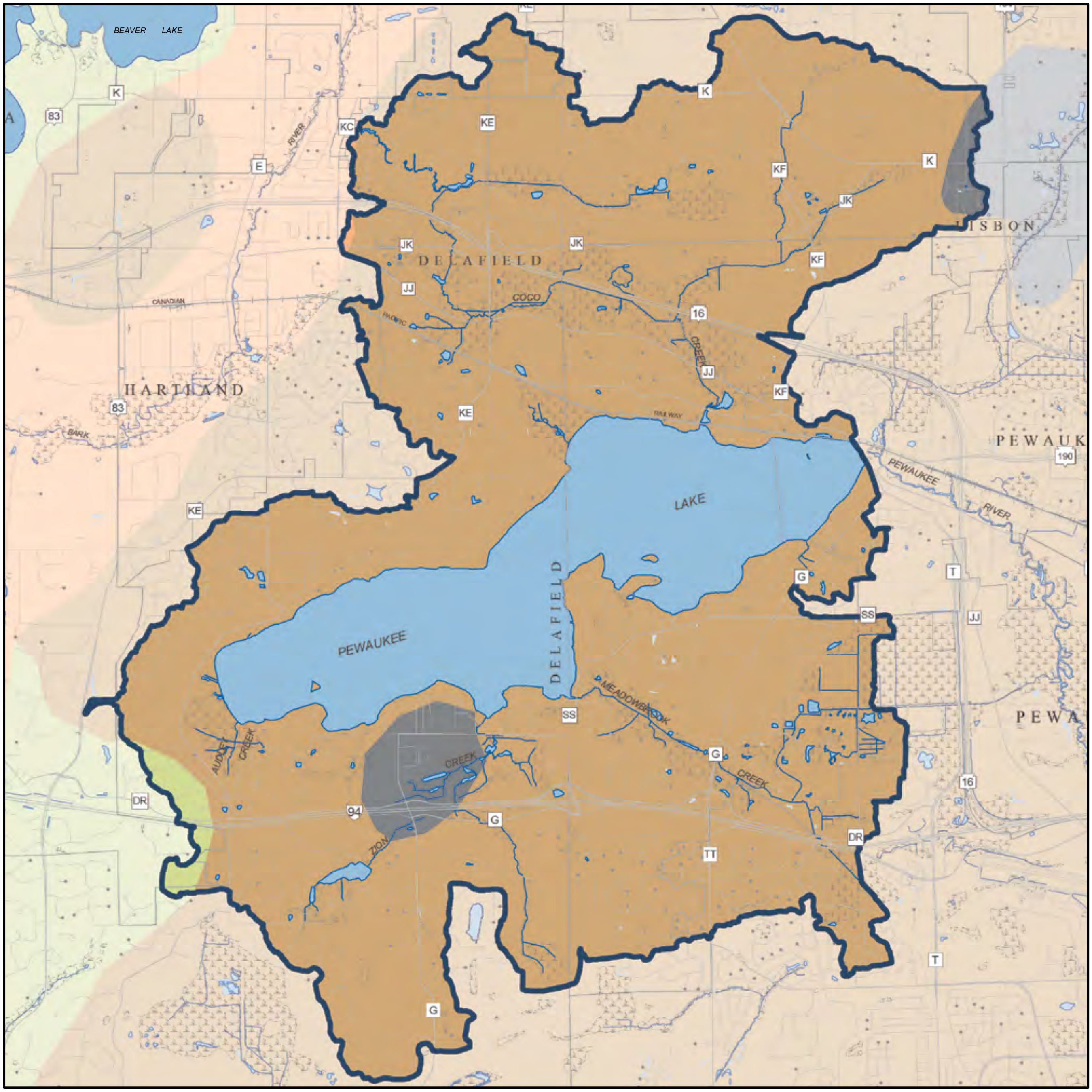
Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each legend category.

N

0 1,250 2,500 5,000 Feet

Source: Wisconsin Geological Natural History Survey and SEWRPC

Map 2.4
Pewaukee Lake Watershed Soil Associations



FOX-CASCO
HOCHHEIM-THERESA
PELLA-MODERATELY SHALLOW VARIANT/KNOWLES
RODMAN-CASCO
SURFACE WATER
WETLAND
STREAM
WATERSHED BOUNDARY

0 1,250 2,500 5,000 Feet

Note: Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each legend category.

Source: Natural Resources Conservation Service and SEWRPC

Hydric soils are formed when soils are saturated for extended periods of time. Hydric soils indicate groundwater near the land surface, ponding, or extended flooding and are commonly associated with wetlands areas. One-quarter of the Pewaukee Lake watershed is underlain by soils exhibiting some hydric characteristics. Most of these areas are located in wetlands paralleling major tributaries and in embayments along Pewaukee Lake's shoreline (see Map 2.5). Many hydric soil areas were likely drained for human use or were inundated shortly after the dam was built and Lake level increased about 180 years ago. Hydric soil areas often are sites of physical and biological processes that protect and sustain a lake's water quality and ecology and therefore warrant protection.

Vegetation

Before European settlement, oak savanna was the dominant vegetation assemblage in the Pewaukee Lake watershed (see Map 2.6). Oak savanna is a prairie environment with scattered oak trees. In general, oak savannas have at least one tree per acre but have less than half the land area covered by tree canopy. White, bur, and black oaks were particularly common in oak savannas. Modest-sized tracts of oak forest were found along the Lake's southern and eastern shorelines and in the uplands to the north of the Lake. Wetlands fringed many of the Lake's tributary streams and low elevation shorelines. After European settlement, native vegetation throughout the watershed was largely removed and supplanted by vegetation associated with agricultural or urban land uses, although some pockets of native vegetation remain.

Water Resources

Pewaukee Lake and its contributing watershed form a major headwater of the Pewaukee River, a fourth order river that joins the Fox River just upstream of Waukesha, Wisconsin.[22] The Pewaukee River's headwaters receive water from surface-water and groundwater sources. Four named streams, several small unnamed streams and ditches, broad wetland areas, ponds, and reservoirs occupy lands draining to Pewaukee Lake. This section provides information regarding the hydrology, morphometry, general characteristics, and management issues related to lakes, streams, floodplains, wetlands, and groundwater in the Pewaukee Lake watershed.

Pewaukee Lake

In its modern configuration, Pewaukee Lake is the largest lake in Waukesha County. The Lake's west basin is a natural lake, however, the eastern basin was created when the Pewaukee River was dammed. Without the dam, open water areas would be roughly half of the current size, and would be almost exclusively confined to the West Basin. Please see Section 2.4, "Lake Level Manipulation and Management," for more information regarding human water level manipulation.

<u>Origins</u>

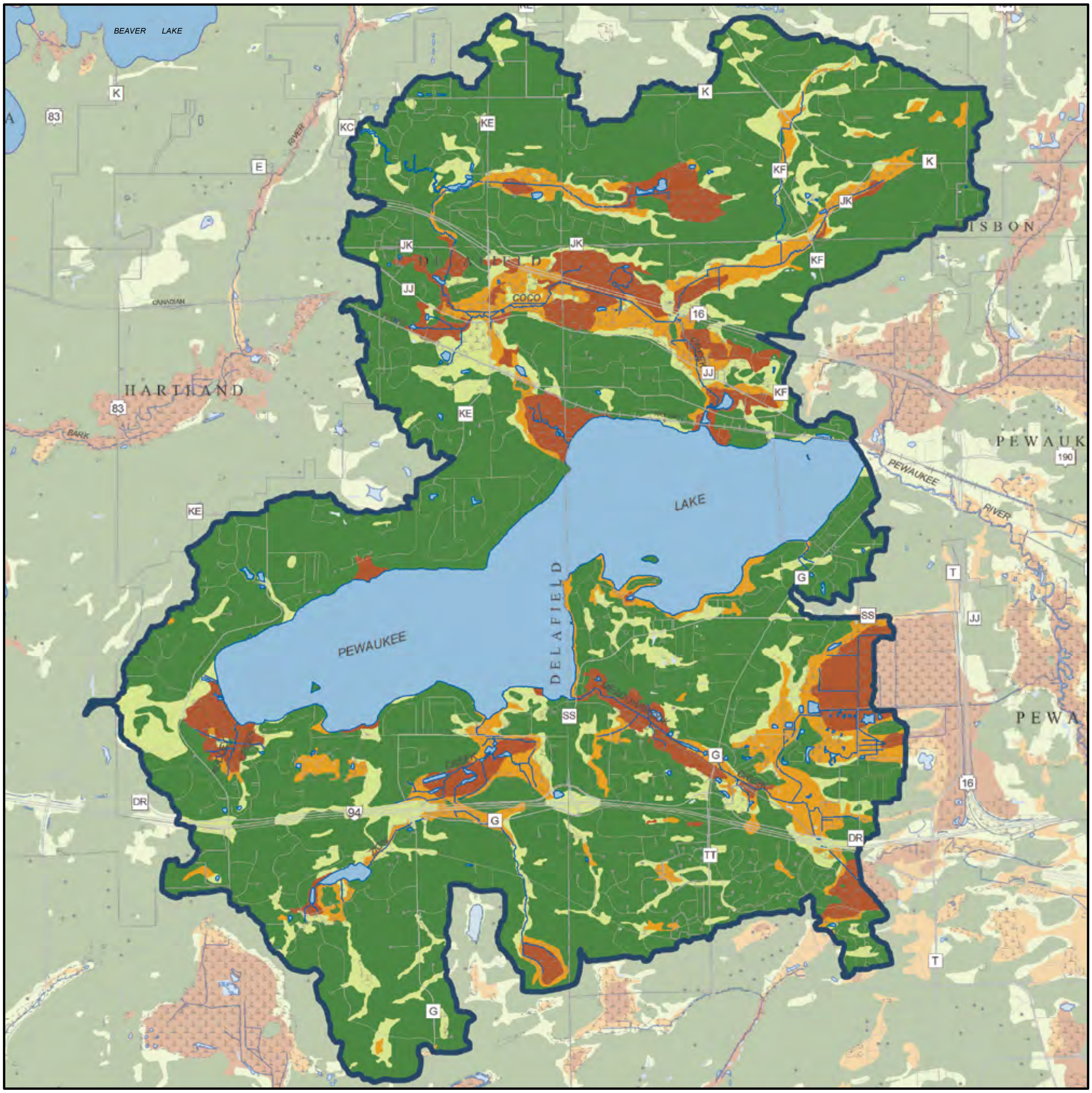
The prominent valley in which Pewaukee Lake lies was formed by erosion caused by glacial meltwater flowing west under and away from glaciers moving out of the lowland that is now Lake Michigan. Pewaukee Lake's genesis is believed to be similar to several of Southeastern Wisconsin's largest lakes (e.g., Geneva Lake, Lake Como, and Delavan Lake). An early version of Pewaukee Lake formed when glaciers were still present in the local area and water drained out of the present Lake's northwest corner. This early lake had a water surface elevation well over 100 feet higher than the Lake's present water surface elevation. As glacial ice retreated further to the east, water began to drain out of the Lake's eastern basin in the headwater area of Coco Creek, and later out of the south via Pebble Creek.[23] After glacial ice completely left the area, lower discharge points became available and Pewaukee Lake began to drain to the east via the Pewaukee River as it does today. After leaving the Lake, water draining from the Lake now flows about 4.4 miles down the Pewaukee River where it joins the Fox River.

---

[22] *Stream order refers to a stream classification concept developed by Arthur Strahler and Robert Horton during the 1940s and 1950s. Headwater perennial tributaries are assigned a stream order of 1 and are labelled first order streams. When two first order streams converge, a second order stream is formed, when two second order streams converge, a third order stream is formed, and so on. When a lesser order stream converges with a higher order stream, the larger stream's order remains unchanged.*

[23] *L. Clayton,* Pleistocene Geology of Waukesha County, Wisconsin*, Wisconsin Geological and Natural History Survey, Bulletin 99, 2001.*

Map 2.5
Hydric Soils Within the Pewaukee Lake Watershed



HYDRIC

PREDOMINANTLY HYDRIC

PREDOMINANTLY NON-HYDRIC

NON-HYDRIC

SURFACE WATER

WETLAND

STREAM

WATERSHED BOUNDARY

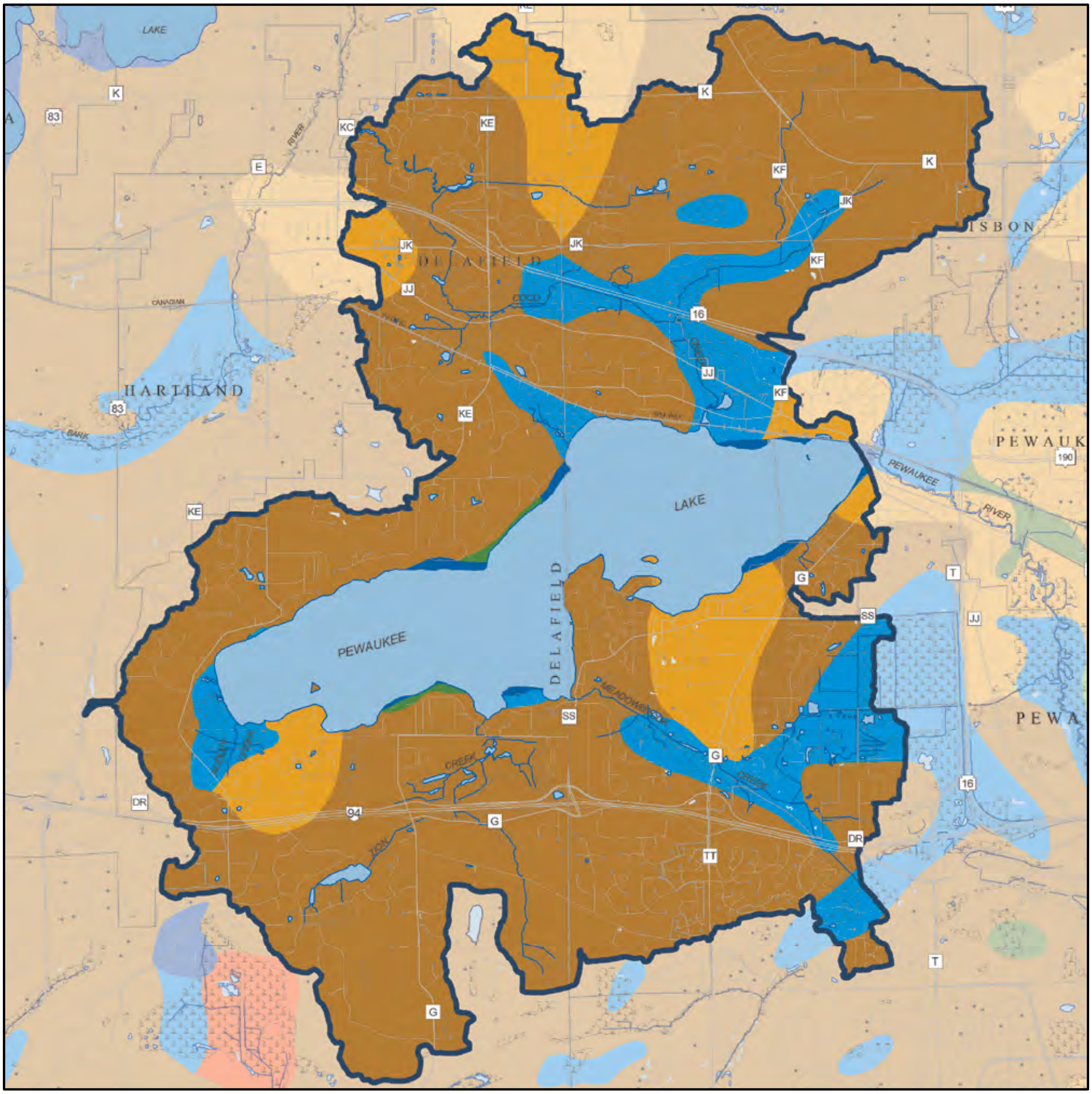
Note: Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each legend category.

N

0 1,250 2,500 5,000 Feet

Source: Natural Resources Conservation Service and SEWRPC

Map 2.6
Presettlement Vegetation Within the Pewaukee Lake Watershed: 1836



OAK SAVANNA
OAK FOREST
MAPLE-BASSWOOD FOREST
LOWLAND HARDWOOD FOREST
CONIFER SWAMP
WETLANDS
LAKE, RIVER, STREAM
SURFACE WATER
WETLAND
STREAM
WATERSHED BOUNDARY

Note: Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each legend category.

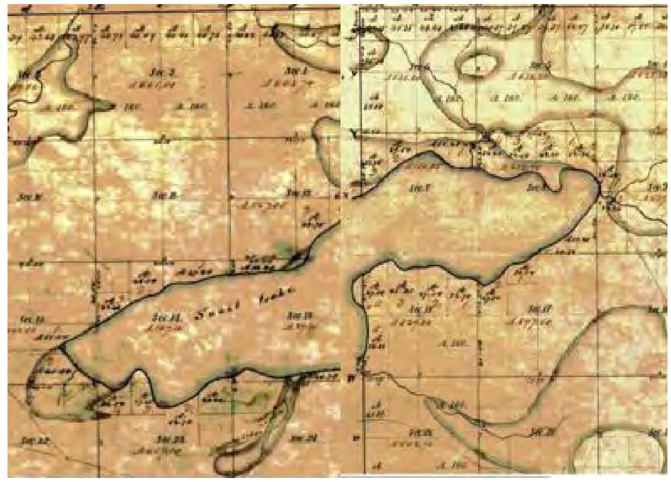
N

0 1,250 2,500 5,000 Feet

Source: SEWRPC

The first US Public Land Survey was completed in the Pewaukee area during 1836 (see Figure 2.3). This survey identifies the western half of the Lake as "Snail Lake," while the eastern portion of the Lake was identified as marshland with water depths ranging between 0.5 and 1.0 foot. In 1842, the territorial government granted Asa Clark permission to construct a dam on the "Little Fox River" just downstream of the marshland portion of the Lake to power a mill.[24] The dam raised the Lake's natural water elevation approximately six feet. As a result, the large marshland just east of Snail Lake and lands along the perimeter of the Snail Lake were inundated, doubling the Lake's open water surface area, and forming what is today known as Pewaukee Lake. Water power was used for a variety of purposes, including milling feed and producing electricity for lighting.[25] Although the dam no longer produces power, Lake water elevations are still controlled by the dam at the east end of the Lake.

Figure 2.3
1836 Public Land Survey Sketch Map



Source: University of Wisconsin Digital Collections and SEWRPC

Morphometry and Hydrology

As it exists today, Pewaukee Lake covers 2,446 acres (see Table 2.3). The Lake contains approximately 34,000 acre-feet of water at normal Lake elevation and is oriented with its long axis running roughly east-west. The Lake measures roughly 4.5 miles long and 1.4 miles wide at its widest point and has about 12.8 miles of shoreline. About 16 percent of the Lake area is less than five feet deep, 62 percent has a water depth between five and 20 feet, and about 22 percent of the Lake is greater than 20 feet deep. Silt and muck are the predominant lake bottom materials. Coarser grained sediments (sand, gravel, boulders) are found primarily along shorelines.

The Wisconsin Department of Natural Resources (WDNR) classifies Pewaukee Lake as a drainage (flow-through) lake, which means that the Lake has both a defined inflow and outflow. Pewaukee Lake has two distinct basins: the deep natural lake to the west (45 foot maximum water depth), and the shallow former marsh that was inundated by the outlet dam over 175 years ago (10 foot maximum water depth). Refer to Map 2.7 for details regarding Lake bathymetry. Although the Lake's two basins are nearly equal in areal extent (i.e., the west basin covers about 1290 acres, while the east basin covers about 1156 acres), almost four-fifths of the Lake's total water volume is found in the Lake's western basin. Both the east and west Lake basin have several tributary streams. The Lake has a single outlet at the eastern extreme of the Lake's shallow eastern basin. Three islands are present in the Lake: one in the western basin and two in the eastern basin.

The volume of water entering and leaving the lake varies depending upon changes in precipitation, evaporation, and dam operation. According to a U.S. Geological Survey (USGS) study,[26] precipitation falling directly upon the Lake accounts for approximately 57 percent of the Lake's water supply. Streams and direct surface water runoff contributes about 27 percent of the Lake's water supply, while groundwater discharging to the Lake contributes the remaining 16 percent. The amount of water that the USGS predicts is contributed by surface-water runoff closely mirrors the average estimated discharge of the individual streams entering the Lake. Many of these streams are fed by groundwater, which increases the actual importance of groundwater to the Lake's overall water budget. Groundwater is critical to sustain dry weather water levels and critical habitat types, and its importance should not be underestimated. No wastewater, industrial process, cooling, or

[24] *L.S. Smith,* The Water Powers of Wisconsin*, Wisconsin Geological and Natural History Survey, Bulletin No. XX, Economics Series No. 18, 1908.*

[25] *Ibid.*

[26] *D.T. Feinstein, M.N. Fienen, J.L. Kennedy, C.A. Buchwald, and M.M. Greenwood,* Development and Application of a Groundwater/Surface-Water Flow Model Using MODFLOW-NWT for the Upper Fox River Basin, Southeastern Wisconsin*, U.S. Geological Survey Scientific Investigations Report 2012-5108, 2012.*

other artificial point sources are known to contribute water to the Lake or its tributary streams. Over half (52 percent) of the water leaving Pewaukee Lake is evaporated into the atmosphere. Less than 1 percent of the water leaving the Lake leaves the Lake via groundwater. The Pewaukee River receives the bulk of the remaining water leaving the Lake, with approximately 47 percent of the Lake's water exiting via the outlet dam.

According to the U.S. Geological Survey study, Pewaukee Lake's outflow over the outlet dam averages about 7.5 cubic feet per second, less than the value predicted by WDNR's PRESTO-Lite tool (10.1 cubic feet per second) and reported by the Village of Pewaukee.[27] Water volumes leaving the Lake via the Pewaukee River were also estimated using data from the USGS stream gaging station on the Fox River in Waukesha. The gaging station data was used to determine the average water yield for areas upstream of Waukesha, and the water yield that can be expected 90 percent of the time. While these values are not specific to the Pewaukee Lake watershed, they are representative of typical conditions in the local area. This exercise determined that annual water yield averages 12.2 inches, ranging as low as 4.1 inches during very dry years and as high as 21.0 inches per year during very wet years. This translates to an average annual watershed outflow of 20.6 cubic feet per second, a value substantially higher than the values estimated by the USGS or WDNR. During very dry years, average watershed outflow can fall to 3.9 cubic feet per second, and during wet years, average annual flow can increase to 35.7 cubic feet per second. During very dry years, the volume of water evaporated from the Lake's surface can exceed that contributed by precipitation falling upon the Lake's surface.

Table 2.3
Hydrology and Morphometry of Pewaukee Lake

Parameter	Pewaukee Lake
Size and Shape	
Open Water Surface Area	2,446 acres
Watershed Area[a]	13,432 acres
Shoreline Length	14.0 miles
General Lake Orientation	E-W
General Shape	Irregular elongated oval, two distinct lobes
Maximum Length	4.5 mile
Maximum Width	1.4 mile
Shoreline Development Factor[b]	2.02
Depth	
Maximum Depth	45 feet
Mean Depth	14 feet
Lake area with <5 feet water depth	393 acres
Lake area with water depths between 5 and 20 feet	1,528 acres
Lake area with > 20 feet water depth	525 acres
Hydrology	
Lake Volume	34,000 acre-feet
Lake Type	Drainage
Residence Time[c]	
Average weather	2.3 years
Prolonged dry weather	12 years
Prolonged wet weather	1.3 years

[a] *This watershed area is based on the most current elevation refinements made possible through Commission digital terrain modeling analysis. The watershed area includes all areas that slope toward the lake, but does not include the Lake itself.*

[b] *Shoreline development factor (SDF) is the ratio of the Lake's measured shoreline length to the circumference of a circle of the same area. Values close to one indicate a nearly circular lake. SDF can be used as an indicator of biological activity (i.e. the higher the value, the more likely the lake will be to have a productive biological community). Lakes with high SDF's have more shoreline per acre of surface area, and are prone to heavy human pressure.*

[c] *Residence time is the number of years required for natural water sources under typical weather conditions to fill the lake one time. Natural water sources include runoff from surrounding areas, precipitation falling directly upon a lake, water entering from tributary streams, and water contributed to a lake by groundwater. The calculation uses unit area runoff values representative of the Fox River upstream of Waukesha Wisconsin. Wet and dry values are based upon transient flows, and are not meant to represent long-term sustained conditions.*

Source: Wisconsin Department of Natural Resources and SEWRPC

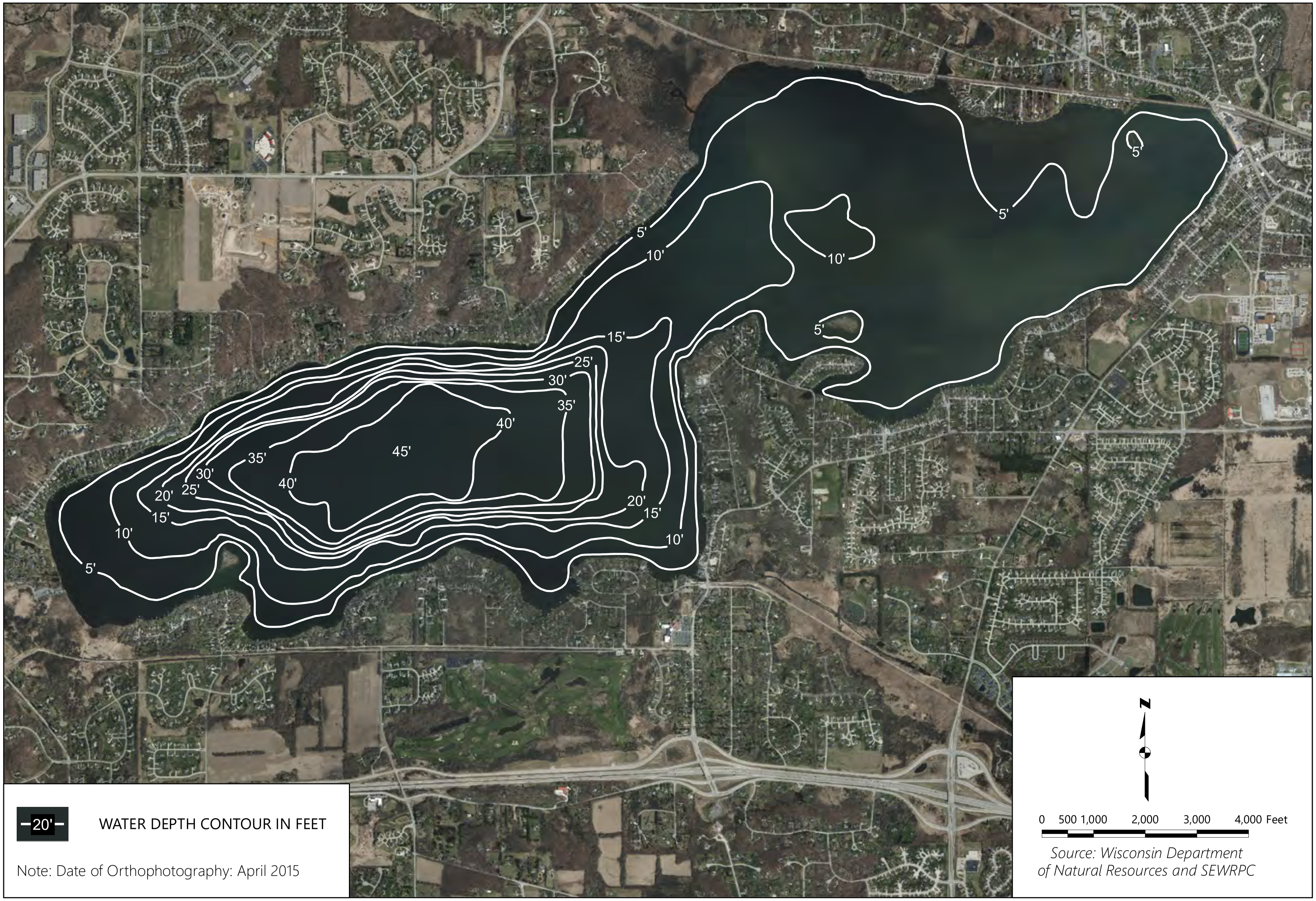
Several morphologic and hydrologic parameters are used to judge the potential impact of human influence on a lake. These parameters are described below.

Watershed/Lake Area Ratio contrasts the size of a lake to its contributing watershed. Lakes with higher ratios are typically considered more vulnerable to human influence and prone to water quality problems. However, the way the watershed is used can greatly influence the amount of pollutants carried to the Lake. As a rule of thumb, lakes with a watershed/lake ratio greater than 10:1 often experience some water quality issues. Pewaukee Lake's watershed/lake area ratio is approximately 5.5:1, while the typical Wisconsin inland lake has a watershed/lake area ratio of 7:1.[28] This finding suggests that the Lake is slightly less vulnerable to human influence and land use than a typical Wisconsin lake.

[27] *D.J. Naze,* Operation and Maintenance Plan, *Pewaukee Lam Dam*, *Village of Pewaukee, Wisconsin, 2018*.

[28] *R.A. Lillie and J.W. Mason,* Limnological Characteristics of Wisconsin Lakes*, Wisconsin Department of Natural Resources Bulletin No. 138, 1983*.

Map 2.7
Pewaukee Lake Water Depth Contours



Retention Time refers to the average length of time needed to replace the lake's entire water volume.[29] In general, lakes with larger watershed/lake area ratios have shorter retention times. Retention time can help determine how quickly transient pollutant loads can be flushed from a lake. For example, if retention times are short, pollutants are flushed out of a lake fairly quickly. In such cases, management efforts can likely focus on pollutant and nutrient loads contributed to the lake from the watershed. In contrast, lakes with long retention times tend to accumulate nutrients and pollutants. These can eventually become concentrated in bottom sediments as opposed to flushed downstream. In this case, in addition to preventing external pollution from entering a lake, it also may be necessary to employ in-lake water quality management efforts to address pollutants not readily flushed from the lake.

With a lake-wide retention time averaging 2.3 years, Pewaukee Lake's flushing rate is slightly slower than Wisconsin statewide averages.[30] As such, apparent water quality may improve slowly if nutrients inputs to the Lake decrease. The deeper western portion of the Lake likely has a greater retention time than the overall average, reinforcing this situation in the deep western basin. Whatever the case, when it comes to maintaining or improving water quality, the importance of management actions that limit nutrient inflow from the watershed into the Lake cannot be over emphasized.

Shoreline Development Factor compares the length of a lake's shoreline to the perimeter of a perfect circle of identical area. Higher values result when lakes exhibit irregular shapes including such features as bays and peninsulas. Lakes with high shoreline development factors are commonly more biologically productive and have larger proportions of shallow nearshore areas (or *littoral zone*). Extensive littoral zones are conducive to aquatic plant growth which can grow to nuisance levels and which may impede navigation. The littoral zone generally represents the most productive habitat for plant and animal life in a lake. All other things being equal, a lake with a large shoreline development factor would be expected to have more plant and animal life than a lake having a low development factor. Given their longer shoreline lengths per acre of surface water, lakes with high shoreline development factors also commonly have greater numbers of residential lots per surface area of lake and therefore can be subjected to heavy human use pressure.

Pewaukee Lake has a shoreline development factor of 2.02, meaning that the Lake has about twice as much shoreline when compared to a perfectly circular lake. Nearby Nagawicka Lake has a similar form and a similar shoreline development factor. However, Okauchee Lake has a very irregular shape with many bays and points, and consequently has a shoreline development factor of over 3.0. The Lake's shoreline is nearly entirely developed by residential lots. Thus, the Lake is subject to significant human use pressure with a high number of lots per acre of Lake surface area.

Lake-basin bathymetry and bottom sediment composition can also influence a lake's biological productivity. To illustrate, lakes with large, nearly flat, shallows covered with soft bottom sediments are generally more biologically productive than uniformly deep lakes with rocky bottoms. As shown on Map 2.7, water depths throughout Pewaukee Lake's eastern basin are quite shallow. The eastern basin's bottom is quite flat and is composed primarily of soft sediment (silt and muck). Given these factors, Pewaukee Lake (especially the eastern half) would be expected to have moderately high biological productivity, relatively nutrient-rich water, and the ability to support abundant aquatic plant growth and a productive warmwater fishery.

Small Lakes, Wetlands, Streams, and Floodplains

Although Pewaukee Lake is the dominant surface-water feature of Waukesha County, it is not the only aquatic environment in the Pewaukee Lake watershed. A few small lakes exist in the watershed, including

[29] *The terms "flushing rate" and "hydraulic residence time" are also commonly used to describe the amount of time runoff takes to replace one lake volume. Flushing rate is the mathematic reciprocal of retention time, while hydraulic residence time is the same value as retention time. Therefore, while residence and retention time are expressed in years and have units of time, flushing rate is typically expressed as the number of times lake water is completely replaced by runoff in one year, and is therefore a rate (units/time).*

[30] *Retention times vary with prevailing weather conditions. During periods of heavy precipitation, a lake may have a lower retention time. Conversely, during drought, retention times can be longer. In Pewaukee Lake's case, the retention time may be as low at 1.3 years during prolonged wet weather and 12 years during prolonged dry weather. These values are instantaneous rate estimates at a discrete point in time. Weather conditions change, and with changing weather conditions, retention times frequently increase or decrease.*

a 3.8 acre semi-natural lake located a short distance upstream of the mouth of Coco Creek that likely formed after dam construction. Artificial lakes and ponds have been created throughout the watershed for aesthetic purposes, recreational use, stormwater management, and erosion control. These include a 14.4 acre, 16-foot deep reservoir near the headwater area of Zion Creek sometimes referred to as Salow Lake, ponds excavated within a wetland area along the lower reaches of Zion Creek, and scores of other ponds constructed throughout the watershed. The still water environments available in lakes and ponds are supplemented by marshy and low-lying areas, the largest found adjacent to the Lake's tributaries (see Map 2.8). Approximately 1,360 acres of defined wetlands are found in the Pewaukee Lake watershed.[31] Collectively, these smaller water bodies and wetlands can store appreciable volumes of floodwater, and can therefore help reduce runoff intensity.

Viewed from above, the network of water channels forming a river system typically displays a branch-like pattern as shown in Figure 2.4. A stream that flows into a larger stream or river is considered a tributary to the larger waterbody. The entire area drained by a single river system is termed a drainage basin or watershed. Streams normally increase in size in the downstream direction. In the stream order classification system, lower order streams correspond to the smaller headwater tributaries. The first visible traces of streams are labelled first-order streams. Second-order streams are formed where two first order streams converge, third order streams are formed where two second order streams converge, and so on. As water travels from headwater streams toward the mouth of larger rivers, streams gradually increase width and depth as well as the amount of water they discharge.

The Pewaukee Lake system is somewhat unusual in that six mapped tributaries converge within Pewaukee Lake. The named tributaries are the third-order Coco and Meadowbrook Creeks, second-order Zion Creek, and first-order Audley Creek. Two additional first-order streams are unnamed. One unnamed stream enters the west basin near West Lakeside Drive and another enters the east basin just south of the railroad. The physical characteristics and predicted biological community of these streams is summarized in Table 2.4. These streams contribute a significant amount of the water reaching Pewaukee Lake (see Figure 2.5), with the amount of water contributed by each mapped stream summarized in Table 2.5.

The Pewaukee River itself is a significant tributary of the upper Fox River of Southeastern Wisconsin. In fact, where the Pewaukee and Fox Rivers join, both are fourth order streams, and the Pewaukee River drains nearly a third of the combined fifth order river's watershed and contributes about a third of the combined flow. Pewaukee Lake and its headwaters comprise about two-thirds of the Pewaukee River's total watershed, and contributes up to three-quarters of its overall flow. [32]

Although dry for much of the time, floodplains are very important to water body function and health. During intense runoff periods (e.g., heavy or sustained rainfall or snowmelt), water elevations rise. Floodplains help convey, detain, and treat runoff and can help promote groundwater recharge. Mapped floodplains in the Pewaukee Lake watershed are located on Map 2.9. Approximately 797 acres of floodplain are found in the Lake's watershed.[33]

Groundwater Resources

General Principles and Importance

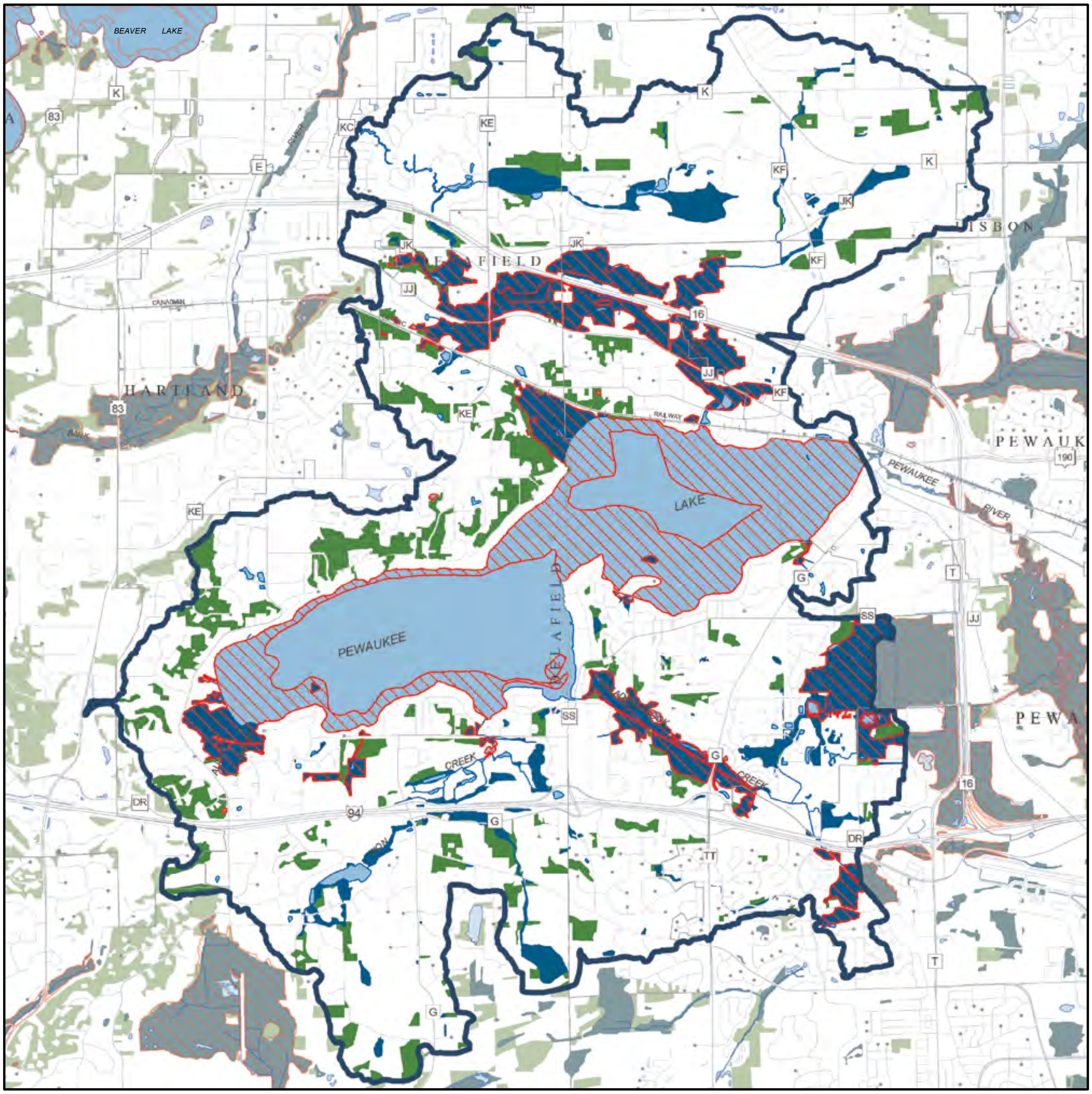
Groundwater includes water that has percolated into the earth and has reached areas of saturation below the Earth's surface. The free-water elevation of the shallowest saturated subsurface water-bearing media is commonly referred to as the "water table". Groundwater is not visible to casual observation except where it discharges to surface water (e.g., springs and seeps). Water in unsaturated soil above the water table can either return to the atmosphere via evapotranspiration or may move to aquifers if soil moisture increases through additional percolation from the surface.

[31] *Wetlands are discussed in greater detail in the land use section of this report (see "Natural Resource Elements" in Section 2.3, "Human Use and Occupation").*

[32] *Derived from Presto-Lite Watershed Delineation Reports available through WDNR's Watershed Restoration Viewer website: dnr.wi.gov/topic/SurfaceWater/restorationviewer.*

[33] *Floodplains are discussed in greater detail in the land use section of this report (see "Natural Resource Elements" in Section 2.3, "Human Use and Occupation").*

Map 2.8
Wetlands, Woodlands and ADID Wetlands Within the Pewaukee Lake Watershed



WETLANDS (2015)

WOODLANDS (2015)

ADID WETLANDS (2005)

SURFACE WATER

STREAM

WATERSHED BOUNDARY

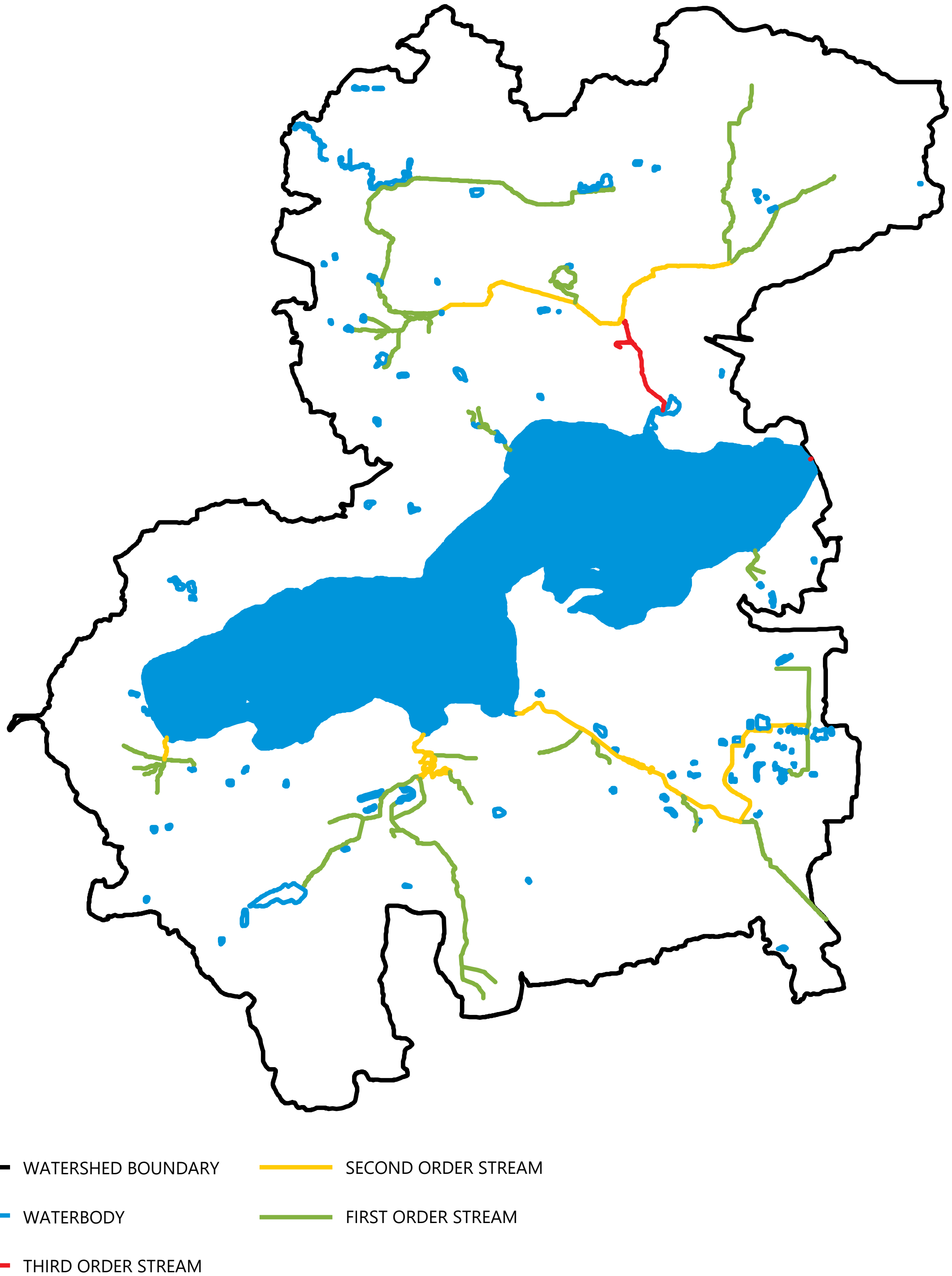
Note: Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each legend category.

N

0 1,250 2,500 5,000 Feet

Source: SEWRPC

Figure 2.4
Pewaukee Lake Tributary Network



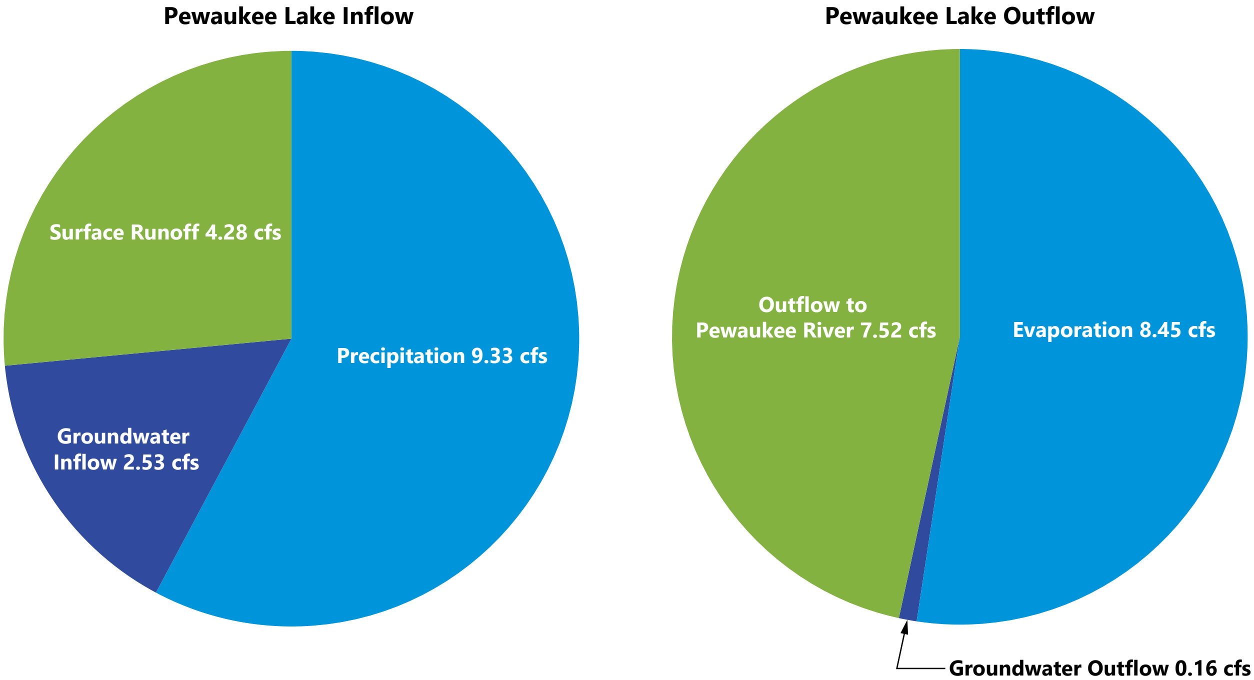
Source: SEWRPC

Table 2.4
Pewaukee Lake Tributary Characteristics and Predicted Habitat Types

Mapped Stream Name	Stream Order at Mouth	Watershed Area (square miles)	Predicted Stream Habitat Type and Channel Length (feet/percent of total stream length)				
			Coldwater	Cold Headwater	Cool-Cold Headwater	Warm Headwater	Macroinvertebrates
Audley Creek	First	0.56	1,166/100	--	--	--	--
Coco Creek	Third	8.31	3,032/16	2,277/12	9,963/54	--	3,294/18
Meadowbrook Creek	Second	5.75	--	8,222/53	--	2,400/16	4,785/31
Zion Creek	First	3.49	197/3	--	6,491/85	--	953/12
Unnamed – West Lakeside Drive	First	0.27	994/100	--	--	--	--
Unnamed – Railroad	First	0.40	--	--	236/47	--	271/53

Source: SEWRPC

Figure 2.5
Pewaukee Lake Water Budget



Note: Values devired from groundwater simulation model.

Source: U.S. Geological Survey and SEWRPC

In Southeastern Wisconsin, local precipitation is the source of most groundwater and essentially all groundwater is stored and moves in the natural pore spaces and fractures found in unconsolidated sediment and bedrock.[34] Sediment and rock units with significant porosity or fracturing are able to supply useable amounts of water over prolonged periods, and are referred to as "aquifers." Three aquifers underlie the Pewaukee Lake watershed, as summarized below in order of increasing depth from the land surface.

- **Sand and gravel aquifer**. This aquifer is primarily found in porous, coarse-grained sand and gravel deposited by glacial action. Much of the water feeding this aquifer infiltrates the land surface in the local area. Its thickness and properties vary widely, but it is an important water supply under many portions of Waukesha County. It is commonly highly vulnerable to contamination and over exploitation. Water quality and quantity can be significantly influenced by local land use change. The sand and gravel aquifer is commonly in good hydraulic communication with the underlying Niagara dolomite aquifer.

- **Niagara dolomite aquifer**. Water in this aquifer is stored and moves primarily in fractures. Much of the water found in this aquifer is derived from local stormwater infiltration. Although its water-bearing characteristics and thickness vary widely, it is a very important water supply aquifer. When located under a relatively thick layer of unconsolidated sediment, it is somewhat less vulnerable to contamination and overexploitation.

- **Sandstone aquifer.** The sandstone aquifer is commonly deeply buried and is found at depths well below the sand and gravel and Niagara dolomite aquifers. Water is stored and moves through fractures and the rock's innate porosity. This aquifer is very thick, but the water bearing characteristics vary widely with depth. A layer of low permeability Maquoketa shale which overlies the sandstone aquifer extends over the entire Pewaukee Lake watershed, thus, water recharging

[34] *A common local myth suggests that water flows in underground rivers from the far north (e.g., Lake Superior). Although a few small caves are found in Southeastern Wisconsin, they are not significant contributors to overall groundwater flow and do not extend appreciable distances.*

Table 2.5
Pewaukee Lake Tributary Flow Ranges

	Probability of Exceeding Flow (cubic feet per second)		
Mapped Stream Name	95 Percent (extremely dry weather)	50 Percent (average weather)	5 Percent (extremely wet weather)
Audley Creek	0.09	0.16	0.50
Coco Creek	0.88	2.13	12.90
Meadowbrook Creek	0.42	1.36	12.50
Zion Creek	0.58	1.16	4.18
Unnamed – West Lakeside Drive	0.03	0.06	0.25
Unnamed – Railroad	0.04	0.08	0.46
Total	2.04	4.95	30.79

Source: Wisconsin Department of Natural Resources and SEWRPC

the sandstone aquifer infiltrates through the shallow sand and gravel and dolomite aquifer to the west of the Pewaukee Lake watershed. Therefore, the sandstone aquifer is less vulnerable to local pollution sources in the watershed. The sandstone aquifer is an important public and industrial water supply, but because of the cost of establishing deep wells, is not commonly used for residential water supplies in the immediate area.

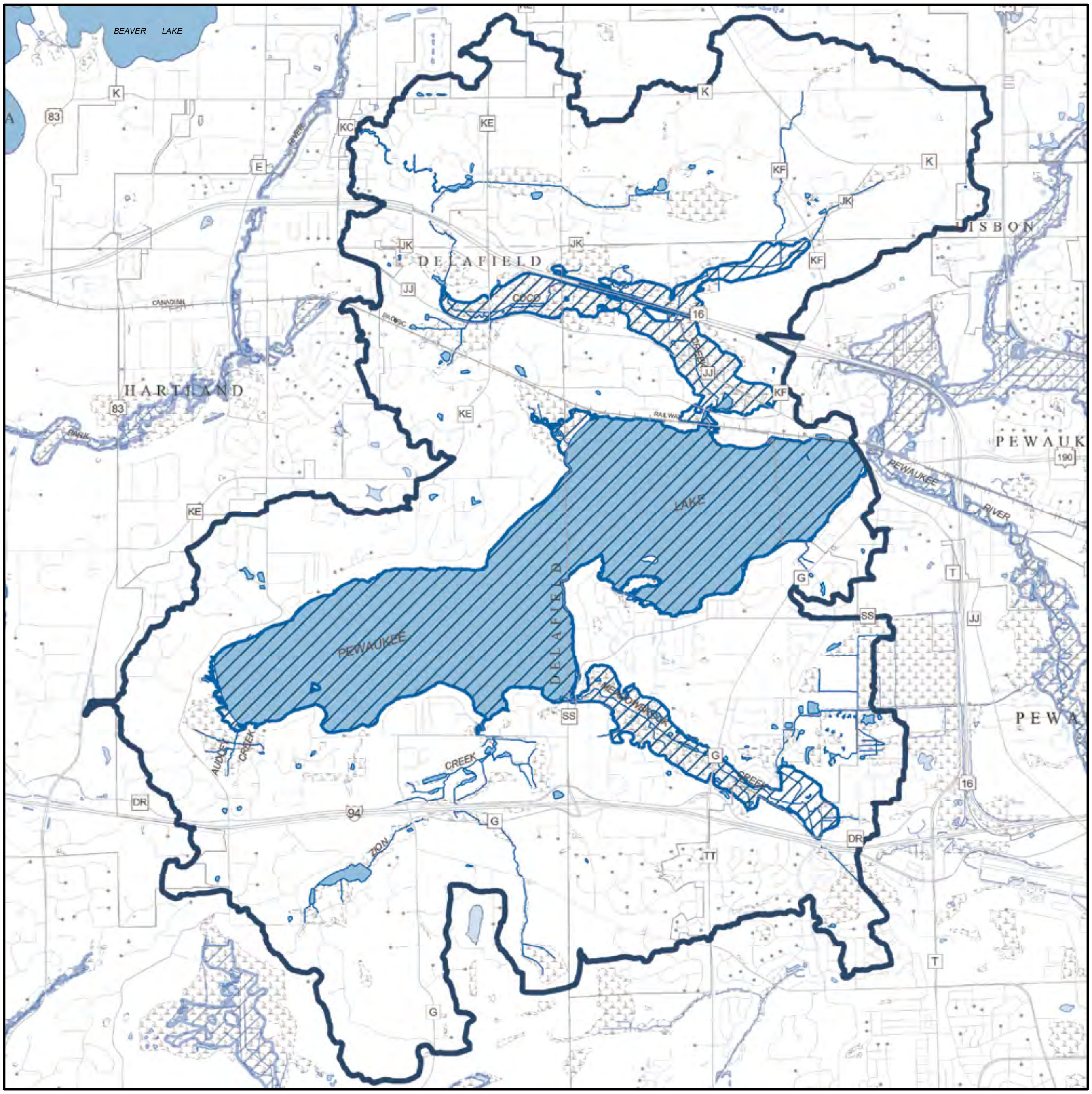
The amount, recharge, movement, and discharge of groundwater are controlled by several factors including precipitation, topography, soil permeability and structure, land use, and the lithology and water-bearing properties of rock units.

All residential, municipal, and industrial water supplies in the Pewaukee Lake watershed depend upon groundwater, making it a natural resource critical to human habitation. In general, groundwater supplies in the Region are adequate to support a growing population, agricultural demands, commerce, and viable and diverse industrial uses. However, overexploitation and attendant water shortages could occur in areas of concentrated development, nonconductive geology, and/or intensive water demand. In addition to supplying human needs, groundwater is important to the health, vitality, and overall ecology of natural systems. Groundwater sustains water levels and flow in lakes, wetlands, and perennial streams during dry weather. Groundwater systems also modulate flood flows by detaining water during wet weather. Groundwater that reaches surface waterbodies is commonly referred to as "baseflow". Baseflow can either directly enter large waterbodies, or it can enter small streams, ponds, and seeps tributary to larger waterbodies. Growing population and industry while maintaining vitality of valuable natural resource elements necessitates wisely developing and managing groundwater resources.

Baseflow sustains dry-weather Lake elevation and the flow of the perennial tributary streams. Groundwater typically contains little to no sediment or phosphorus, has a more stable temperature regimen, and commonly contains a lower overall pollutant load when compared to surface water runoff—all of which are favorable to aquatic life and the ecology of waterbodies. Groundwater-derived baseflow sustains water elevations and/or flow in many lakes, wetlands, and streams during drier weather periods. Reliable water elevations and flow regimens enables groundwater-fed waterbodies to maintain a diverse assemblage of plants and animals. Groundwater is critical to these waterbodies' ability to provide unique ecological functions. An outstanding example is the presence of trout in Coco Creek—groundwater discharging to the stream provides the cold water needed for trout to survive. Consequently, it is important to maintain baseflow from the aquifers that supply the Lake and the streams and wetlands that drain to the Lake.

Groundwater supplies are generally replenished by precipitation soaking into the ground and entering aquifers. Water that infiltrates the land surface and enters aquifers is often referred to as "groundwater recharge." Precipitation is the source of essentially all groundwater recharge, but recharge does not necessarily occur uniformly throughout the landscape, at the point where precipitation initially strikes the Earth, or uniformly throughout the year. Relatively flat undeveloped areas underlain by thick layers of granular permeable mineral soil are generally able to contribute more water to groundwater recharge, and are identified as having high or very high groundwater recharge potential. On the other hand, hilly areas underlain with low permeability (e.g., clay) soils and drained by storm sewers would likely be classified as

Map 2.9
Mapped Floodplains Within the Pewaukee Lake Watershed: 2014



ONE-PERCENT-ANNUAL-PROBABILITY (100-YEAR RECURRENCE INTERVAL) FLOODPLAIN (FEMA FIS, NOVEMBER 2014)

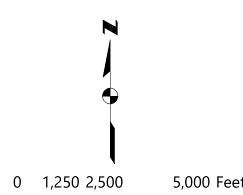
SURFACE WATER

WETLAND

STREAM

WATERSHED BOUNDARY

Note: Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each legend category.



Source: Federal Emergency Management Agency and SEWRPC having low recharge potential. However, it must be remembered that water running off from areas less conducive to groundwater recharge can still flow to areas more conducive to groundwater recharge and infiltrate there, becoming a component of groundwater flow. Most groundwater recharge occurs during periods of low natural water demand (i.e., when plants are dormant) and/or abundant precipitation or runoff. Little groundwater recharge occurs from small summer rains, even on the best sites, because plants and higher evaporation rates associated with higher temperatures consume the incident precipitation, returning it to the atmosphere. Evaluating groundwater recharge potential helps identify areas most important to sustainable groundwater supplies. The Commission evaluated groundwater recharge potential for all of Southeastern Wisconsin.[35] Such data can help planners decide which areas should not be covered with impervious surfaces and/or where infiltration basins would be most effective.

In most instances, the elevation of the water table is a subdued reflection of surface topography. The Commission has estimated water table elevation throughout the Region.[36] Topographically higher areas are commonly recharge areas, while lakes, wetlands, and streams are commonly groundwater discharge areas. Groundwater recharge/discharge systems occur on many spatial scales: long regional recharge/discharge relationships and short localized flow paths, both of which can be important contributors to a water body's overall water budget. While localized groundwater flow systems are commonly confined within a lake's surface watershed, regional groundwater flow paths may trace directions and distances out of phase with surface water feeding a lake. Therefore, some groundwater feeding a lake may originate in areas distant from the lake and/or outside the lake's surface watershed boundary. The relationship between short- and long-distance flow paths is illustrated in Figure 2.6.

Smaller-scale local groundwater flow paths commonly approximate surface water flow paths. However, to estimate the direction of more regionally extensive flow systems, groundwater elevation contours derived from measurements collected in water supply or monitoring wells need to be consulted. Since water normally moves perpendicular to elevation contours, groundwater flow directions can be predicted. When performing such analyses, it is necessary to consider the locations and elevations of streams, ponds, and lakes. This relationship can be used to predict if a surface water body is fed by groundwater, recharges groundwater, or has little interaction with groundwater. By combining these data, maps can be prepared identifying those land areas that likely contribute recharge and are, therefore, sources of baseflow to a surface water feature and those areas that convey groundwater directly to a lake.

As illustrated in Figure 2.6, groundwater and surface water systems are connected. Water sources include:

- **Precipitation** falling directly upon a water body. While this can be a significant water source to expansive features such as lakes and wetlands, it typically is not a significant contributor to a stream or river's total water budget

- **Surface runoff** (or overland flow) that travels over the land surface to a waterbody. Surface runoff is the primary source of wet-weather flow to most watersheds.

- **Hyporheic flow** (stream flow occurring in stream bed materials paralleling the general direction of stream flow). This is only important in streams and rivers. Hyporheic flow commonly persists even when visible stream flow ceases. Hyporheic flow initiates and sustains a large number of important geochemical and biological processes that support stream health.

- **Groundwater** is the primary source of water to most waterbodies during dry weather. In some instances, waterbodies lose water to the groundwater flow system.

Surface runoff and interflow are important during storm events, and their contributions typically are combined into a single term called the direct runoff component of streamflow. Groundwater, on the other hand, is most important for sustaining waterbodies during periods between storms and during dry times of the year and is often a substantial component of the total annual flow through a waterbody.

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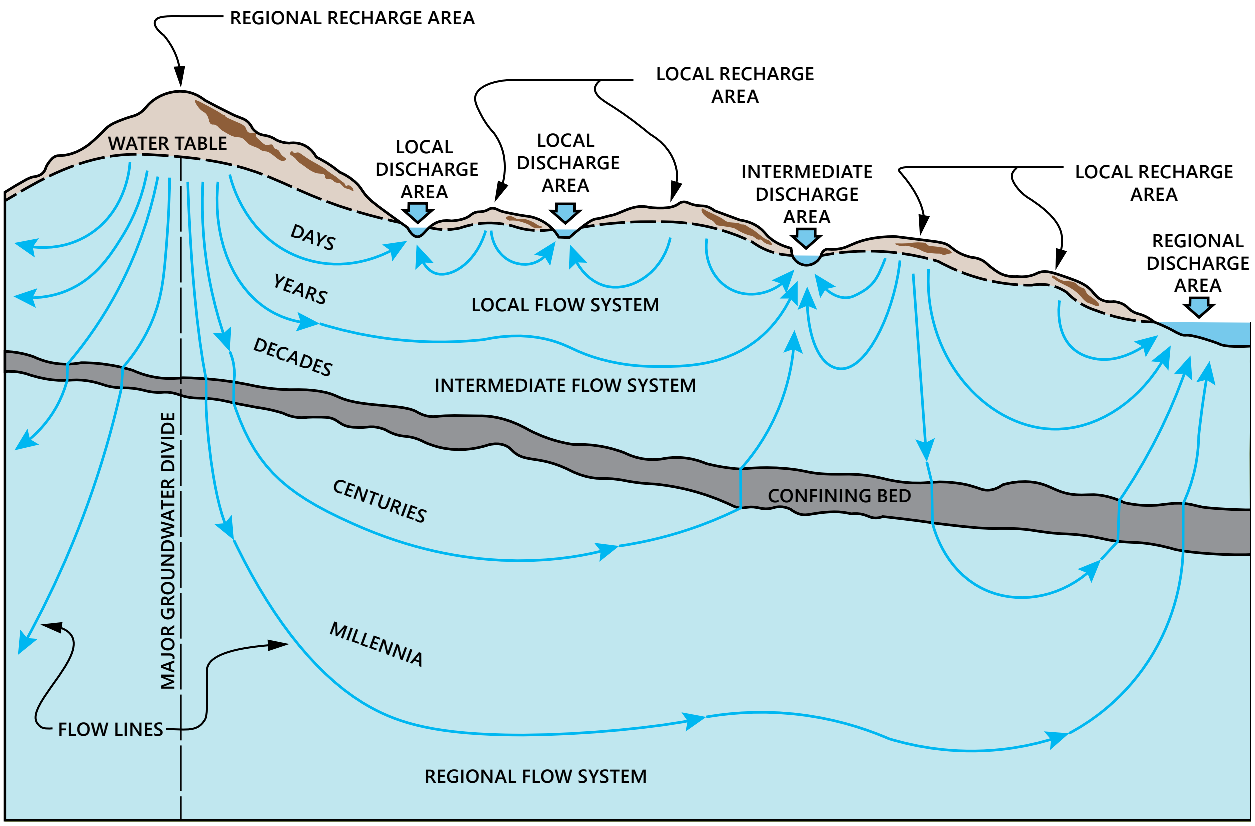
[35] *SEWRPC Technical Report No. 47,* Groundwater Recharge in Southeastern Wisconsin Estimated by a GIS-Based Water-Balance Method, *July 2008.*

[36] *SEWRPC Technical Report No. 37,* Groundwater Resources of Southeastern Wisconsin*, June 2002.*

Figure 2.6
Cross Section Depicting Local Versus Regional Goundwater Flow Paths



Source: Modified from A. Zaporozec in SEWRPC Technical Report No. 37, Groundwater Resources of Southeastern Wisconsin, *2002*

As shown in Figure 2.7, a waterbody gains water when groundwater elevations are higher than the adjacent waterbody (see Figure 2.7, "Gaining Stream"). Conversely, a perennial waterbody loses water wherever water table elevation is lower than the waterbody's elevation. In such instances, water seeps into the underlying groundwater system (see Figure 2.7, "Losing Stream"). In some instances (e.g., ephemeral streams) the water table may not be in contact with the surface water feature. Stream reaches that receive groundwater discharge are called gaining reaches and those that lose water to the underlying aquifer are called losing reaches. The rate at which water flows between a stream and its adjoining aquifer depends on the hydraulic gradient between the two waterbodies and also on the hydraulic conductivity of geologic materials that may be located at the groundwater/surface-water interface. For example, a clayey streambed will reduce the rate of flow between a stream and aquifer compared to a sandy or gravelly streambed. In the absence of surface-water contributions, streamflow volume increases along gaining reaches and decreases along losing reaches. Streams can have both gaining and losing reaches and the extent of these reaches may change based upon prevailing conditions. Since precipitation rates, evapotranspiration, water table elevations, and human-induced hydrologic stressors vary with time, a particular stream reach can switch from a gaining to a losing condition or from a losing to a gaining condition from one period of time to the next.

Groundwater is a dynamic, vital, yet often poorly understood resource. Water discharging to water bodies is replaced with water received from infiltrating precipitation, much of it in the local area. By combining data regarding groundwater recharge potential, groundwater flow direction, and the elevation of water bodies, a broad understanding of the interconnected nature of surface water and groundwater resources can be surmised. Maps can be prepared identifying land areas that more likely contribute to recharge and are, therefore, sources of baseflow to a waterbody. Such maps also can help illustrate the routes groundwater takes in the subsurface and whether a waterbody gains or loses water to the groundwater flow system. Such information helps resource managers plan where work should be focused. For example, this information can help resource managers identify parcels where action should be taken to maintain or enhance the landscape's ability to provide groundwater recharge or where features purposely designed to detain and infiltrate stormwater should be located.

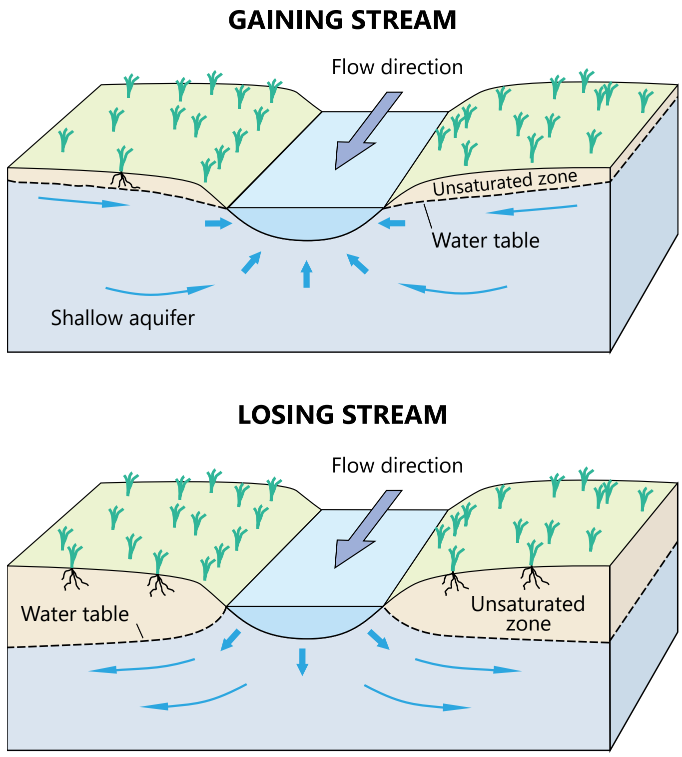
Human Influence

Humans deplete groundwater in two primary ways: 1) actively pumping water from aquifers, which reduces, or in extreme cases eliminates, natural groundwater discharge through springs and seeps, and 2) reducing groundwater recharge through land use changes that increase impervious cover and/or hasten runoff.

Development's Effects on Groundwater

Land use can profoundly alter the ability for an area to absorb water and contribute to groundwater recharge. Urban development decreases groundwater recharge potential. Most areas developed greater than 30 years ago route stormwater runoff directly to surface waters, discouraging groundwater recharge. Despite requirements of Chapter NR 151, "Runoff Management," of the *Wisconsin Administrative Code* calling to detain/infiltrate runoff from new developments, where practicable, such developments still have the cumulative effect of reducing groundwater recharge compared to pre-development conditions. In addition to reducing groundwater recharge, urban development places additional demand on groundwater supplies as water is extracted for various uses. Removing water from natural groundwater flowpaths reduces groundwater elevations and the volume of natural groundwater discharge to surface waterbodies.

Figure 2.7
Surface-Water/Groundwater Interaction



Source: Modified from T.C. Winter, J.W. Harvey, O.L. Franke, and W.M. Alley, Ground Water and Surface Water: A Single Resource, *U.S. Geological Survey Circular 1139, p. 9, 1998, and SEWRPC*

Depletion through artificial groundwater abstraction most commonly occurs when high-capacity wells, numerous smaller wells, or dewatering systems are operated without considering the effect pumping may have on naturally occurring groundwater discharge areas. Wells developed in the shallow aquifers often provide sufficient yield, but can negatively impact nearby surface water resources, and are generally more vulnerable to contamination than deeper bedrock wells. Communities tapping the shallow aquifer also face choices between using individual low-capacity household wells or developing a municipal water system with homeowners connecting to high-capacity municipal wells. In some cases, these communities have an overall negative groundwater balance because wastewater treatment plant effluent is pumped to discharge points outside of the watershed. In cases where development of high capacity wells in the shallow aquifer could negatively affect surface water resources, the Commission's regional water supply plan recommends conducting studies to evaluate the potential negative effects.[37] The plan also calls for installing systems to enhance infiltration in areas where such studies indicate a potential significant reduction in baseflow to surface waters.

Groundwater recharge can be reduced in many ways. Examples include hastening stormwater runoff, eliminating native vegetative cover and reducing soil's ability to absorb water (e.g., compaction, disrupted structure), ditching, tiling and otherwise draining wet areas, disconnecting floodplains from streams, and increasing the amount of impervious land cover all contribute to reduced stormwater infiltration, increased runoff, and reduced groundwater recharge. Similarly, if sanitary sewers are installed in areas now served by private onsite wastewater treatment systems, much of the water that currently re-enters the shallow aquifer is often conveyed to downstream discharge points outside of the watershed, a condition that could reduce

[37] *SEWRPC Planning Report No. 52,* A Regional Water Supply Plan for Southeastern Wisconsin*, December 2010.*

the volume of groundwater entering a lake or stream. Development and land management activities need to consider groundwater recharge, and actions to protect and enhance recharge should be a priority. Some communities have passed groundwater ordinances to protect precious resource elements and help assure groundwater supplies are sustainable in the long term.[38]

Waterbody Depletion

Although groundwater generally provides a safe and reliable source of potable water, groundwater extraction can seriously and adversely affect desirable, life-cycle critical, aquatic habitat. One of the most visible effects is reduced dry-weather flow and water levels in hydraulically connected lakes and streams—a process called depletion. Depletion stems from reduced discharge to springs and seeps feeding these waterbodies and has the potential to impact lakes, ponds, streams, rivers, and wetlands. The complex interconnection and interaction between surface and groundwater makes managing depletion challenging, particularly because significant delays may occur from the time when extraction begins to the time when the effects of that extraction are discerned in affected waterbodies. Other complicating factors may confound analysis and influence the timing, rate, and location of depletion. Nonetheless, managers should keep in mind several important factors when studying the relationship between surface-water features and groundwater pumping, including the following:

- Individual wells may not produce noticeable change. However, well clusters and/or unfavorable aquifer properties can combine to significantly decrease groundwater discharge to surface-water features.

- Basin-wide groundwater development typically occurs over a period of several decades. Therefore, resulting cumulative depletion effects may not manifest themselves for decades.

- Depletion may persist for extended periods of time after groundwater withdrawal ends. Aquifers take time to recover from long-term extraction stress. In some aquifers, maximum depletion may occur long after pumping stops, and full recovery of the groundwater system may take decades to centuries.

- Depletion can affect water quality in surface-water features and/or the aquifer. For example, in many streams, groundwater discharge sustains year-round habitat for fish and other aquatic organisms, by moderating seasonal temperature fluctuations, cooling stream temperatures in summer and warming stream temperatures in winter. Reduced groundwater discharge can degrade these moderating influences.

- Major factors affecting depletion timing and intensity are distance from a well to the stream and aquifer properties.

- Decreased discharge may be more isolated to certain waterbodies or waterbody segments or may be pervasive throughout the watershed.

Sustainable groundwater utilization does not solely depend on the rates at which groundwater systems are naturally replenished (recharged). Instead, sustainable pumping rates must consider myriad factors including aquifer properties, groundwater elevations, surface-water features, biologically acceptable minimum stream flows, and the wishes of the general public and regulatory agencies. These considerations underscore the need to employ an interdisciplinary approach that simultaneously considers both surface-water features and groundwater supplies.

An example of unsustainable groundwater use is extraction from the deep sandstone aquifer. Water levels in the deep sandstone aquifer were once above the ground surface, meaning that water rose to above the ground without pumping. The quality and abundance of this resource made it a prime target for large volume wells. On account of heavy withdrawals throughout the region, this aquifer's water levels have

[38] *The Village of Richfield in Washington County passed a groundwater protection ordinance over 10 years ago and uses the ordinance as a tool to regulate development that is consistent with long-term sustainability. More information about Richfield's groundwater ordinance can be found at the following website: www.richfieldwi.gov/index.aspx?NID=300.*

declined hundreds of feet since the 1800s, as shown in Figure 2.8, "Figure A." In much of the Region, including the Pewaukee Lake watershed, water movement from the shallow sand and gravel and dolomite aquifer into the deep sandstone aquifer is limited by the low permeability Maquoketa shale aquitard, a rock layer which forms a relatively impermeable barrier between the two aquifers and direct surface recharge. As a result, the rates of local groundwater recharge to the deep aquifer are much less than the rates that water is being extracted by pumping. The drawdowns of the deep aquifer are indicative of a water budget deficit and are the combined result of pumping primarily in Southeastern Wisconsin and Northeastern Illinois. In contrast, drawdowns in the shallow aquifer throughout the Region are much smaller (see Figure 2.8, "Figure B") despite the fact that nearly twice the amount of water is being extracted from it compared to the deep aquifer. The reason for the lower drawdowns is that the shallow aquifer is unconfined in most places. It receives direct recharge from precipitation and is also linked directly to surface waterbodies.

Management Tools – Plans and Models

The Commission developed a water supply system plan for the Southeastern Wisconsin Region.[39] This plan considers existing water demands, future development, sustainability, and protection of natural resource features. This plan is the third component of the Commission's regional water supply planning program. The other two elements were a groundwater resource inventory and a regional groundwater model.[40,41] The regional aquifer simulation model allows water levels in the deep and shallow aquifers under historical, current, and planned conditions to be predicted and allows the effects of different groundwater management alternatives on surface water resources to be simulated. Additionally, the model provides a framework within which more-detailed "inset" models may be developed to investigate site-specific groundwater-related questions, including the possible effects of high capacity wells on surface water resources. In summary, the model provides the capability of addressing the following questions:

- What is the sustainable capacity of an aquifer to supply human needs?
- How much have humans altered the groundwater system?
- What effect does human groundwater system alteration have on surface waters?

It is important to note that while the resolution of the regional groundwater models was considered sufficient and valid to compare differences in alternative plans, it may not be sufficiently fine to predict site-specific impacts, or may not be able to resolve differences in impacts between surface water or groundwater features that are in close proximity to one another.[42] Simulating conditions over a relatively small area such as the Pewaukee Lake watershed would require a refined model that includes more detailed site-specific hydrogeological data and smaller model cell size. As noted previously, in cases where development of high capacity wells in the shallow aquifer could negatively affect surface water resources, the Commission regional water supply plan recommends conducting detailed site-specific studies to evaluate potential negative effects and installing enhanced rainfall infiltration systems in areas where such studies indicate a potential significant reduction in baseflow to surface waters.

One of the most accessible and effective tools developed as part of the water supply planning effort is the groundwater recharge potential map derived from a soil-water balance recharge model developed for the Southeastern Wisconsin Region. Understanding groundwater recharge potential and its distribution on the landscape are key to making informed land use decisions that jointly consider human and environmental groundwater needs. Unlike the regional model discussed above, groundwater recharge potential maps are plotted at a significantly smaller grid size (about 100 feet on a side) and can therefore be directly employed for local level groundwater planning purposes. Therefore, these groundwater recharge potential

[39] *Ibid.*

[40] *SEWRPC No. 37, June 2002,* op. cit.

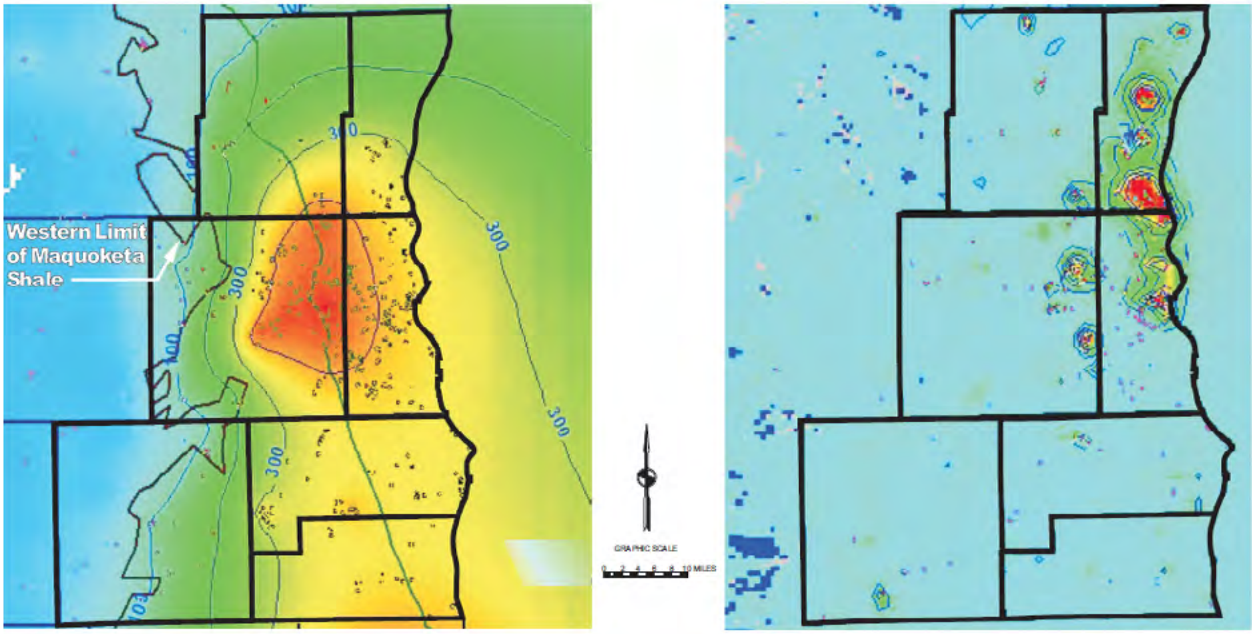
[41] *SEWRPC Technical Report No. 41,* A Regional Aquifer Simulation Model for Southeastern Wisconsin*, June 2005.*

[42] *Since the average grid cell size of the groundwater simulation model is over one-quarter square mile (about 2,500 feet on a side), the results from this regional modeling effort are not sufficiently detailed to estimate the impact of groundwater withdrawal on a site-specific basis. In other words, this regional model cannot specifically be used for local level groundwater supply planning purposes for the Pewaukee Lake watershed, because this area is too small.*

Figure 2.8
Simulated Groundwater Drawdowns for the Region

Figure A: Deep Aquifer – the red zones shows areas where pumping has depressed natural groundwater pressure head by more than 400 feet. In many areas, the deep aquifer naturally had pressure sufficient to produce artesian conditions.

Figure B: Shallow Aquifer – the red zones are areas where pumping has depressed the water table by more than 50 feet.



Source: U.S. Geological Survey, Wisconsin Geological and Natural History Survey, and SEWRPC Technical Report No. 46, Groundwater Budget Indices and Their Use in Assessing Water Supply Plans for Southeastern Wisconsin, *February 2010*

maps are generally applicable to the Pewaukee Lake watershed for identifying and protecting recharge areas that contribute most to baseflow of the lakes, streams, springs, and wetlands in the watershed, which is important to the goals of sustainable groundwater use and a healthy natural environment.

In summary, sustainable groundwater supplies provide reliable, high-quality water that supports both short-term and long-term needs and desires. Reliable water supplies support existing and new development, avoid undue influence on existing wells and natural groundwater discharge areas, and avoid reduced groundwater discharge or adulterated quality that could affect treasured and sensitive natural resource features.

Groundwater Conditions in the Pewaukee Lake Watershed

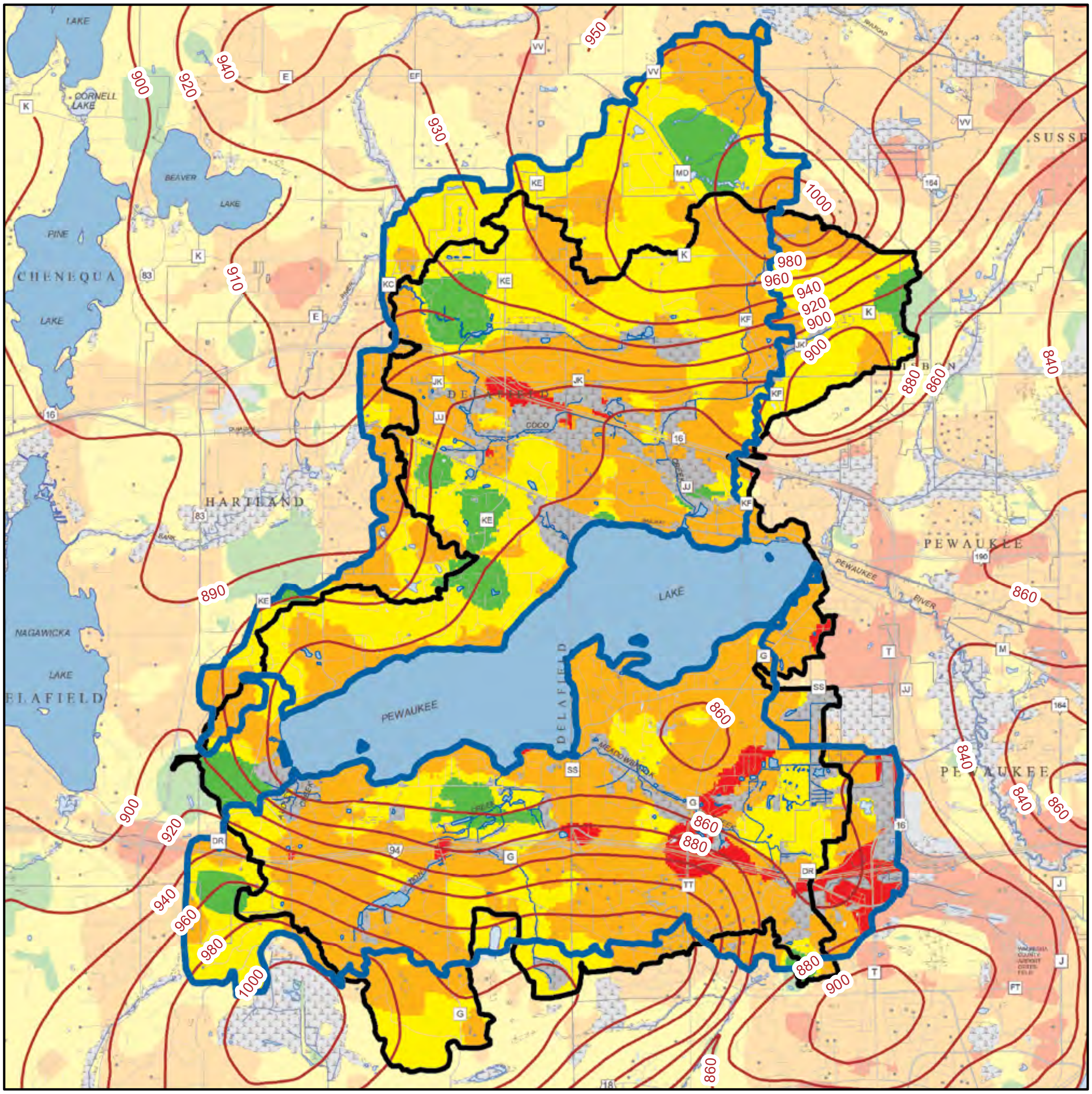
To help determine *where* management efforts could best protect groundwater recharge to aquifers feeding Pewaukee Lake, Commission staff analyzed groundwater elevation contours and groundwater recharge potential in the areas surrounding the Lake.[43] This inventory was not confined to the surface watershed (as was the case for the other inventories completed in this report) because the groundwater flow paths may extend outside of the surface-water watershed. The results of these inventories are described below.

Shallow groundwater elevation contours for the Pewaukee Lake area are shown in Map 2.10. Depth to groundwater varies considerably across the landscape. In and near waterbodies and wetlands, groundwater is found near the land surface, whereas it can be 150 feet or more below the land's surface in upland areas.[44] Pewaukee Lake lies in a prominent embayment in local water table contours, meaning that the Lake is a significant groundwater discharge area. Groundwater monitoring wells installed as part of an earlier study

[43] *SEWRPC Planning Report No. 52, December 2010,* op. cit.

[44] *The depth to groundwater for a particular area can be estimated by subtracting groundwater elevation values from surface topography values.*

Map 2.10
Groundwater Elevation Contours and Recharge Potential Within the Pewaukee Lake Groundwatershed



VERY HIGH

HIGH

MODERATE

LOW

UNDEFINED

WATER TABLE ELEVATION CONTOUR

SURFACE WATER

WETLAND

STREAM

SURFACE WATER WATERSHED BOUNDARY

MODEL-DEFINED GROUNDWATERSHED BOUNDARY

Note: Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each legend category.

N

0 1,500 3,000 6,000 Feet

Source: Wisconsin Geological and Natural History Survey and SEWRPC confirmed that groundwater discharged to the Lake in all areas except near the eastern end of the lake.[45] Based upon groundwater contour lines, springs and seeps are likely especially prevalent along the north, west, and southwest portions of the Lake.

The groundwatershed depicted on Map 2.10 is based upon the USGS MODFLOW model. The Commission recently completed research regarding the groundwater flow direction in the Bark River watershed upstream of Nagawicka Lake.[46] Groundwater contours examined as part of this study strongly suggest that the Pewaukee Lake groundwatershed extends slightly farther west in the Hartland area than suggested by the USGS groundwater model. Of most interest to the Pewaukee Lake study is the strong implication that the Bark River loses surface water to the groundwater flow system under parts of the Village of Hartland. Some of this Bark River sourced water appears to contribute to springs and seeps emerging along Pewaukee Lake's northwest shoreline and the headwaters of Coco Creek, both of which are noted as strong groundwater discharge areas. This suggests that stormwater infiltration practices implemented by the Village of Hartland in the southeast portion of their community could increase the volume of groundwater discharging to Pewaukee Lake and Coco Creek. Another example of the potentially larger groundwatershed is the narrow area directly to the west of Pewaukee Lake that has not been included in the groundwatershed by the USGS MODFLOW model. Instead, the model suggests that Pewaukee Lake water seeps into the Lake bottom and is contributed to the Nagawicka Lake watershed in this area. Given the groundwater elevation contours in the area, this scenario is unlikely.

A water balance study completed during the late 1970s concluded that groundwater contributes roughly 2000 acre-feet of water directly to the Lake each year. Furthermore, about 600 acre-feet of Lake water infiltrate into the Lake bottom near the Lake's outlet each year.[47] The USGS completed a groundwater flow model of the entire area.[48] The model suggests that groundwater contributes 1800 acre-feet of water to Pewaukee Lake each year, a value that agrees well with the 1970s water balance study.

The Lake's tributary streams also receive a large percentage of their flow from groundwater, and therefore indirectly contribute large volumes of groundwater to the Lake. Water balance studies suggest that tributary streams indirectly contribute almost 6,000 acre-feet of water to the lake each year. Based upon hydrographs and flow statistics compiled at the nearby USGS gage on the Bark River, roughly half (i.e., 3,000 acre-feet per year) of the water entering the Lake through tributary streams is likely groundwater. Therefore, on an overall basis, groundwater likely provides roughly 5,000 acre-feet of water to the Lake during a typical year.

Evaluating groundwater recharge potential helps identify areas most important to sustainable groundwater supplies. The Commission evaluated groundwater recharge potential for all of Southeastern Wisconsin.[49] The distribution of various groundwater recharge potential categories for the entire Pewaukee Lake watershed is illustrated in Map 2.10. Such data can help planners decide which areas should not be covered with impervious surfaces and/or where infiltration basins would be most effective. The Upper Fox River Basin model is calibrated to observed watershed conditions, and incorporates recharge rates ranging from 2.6 to 3.9 inches per year for the Pewaukee River watershed, which is consistent with previous studies for this part of Waukesha County.[50,51] These long-term average recharge rates are estimates, not associated with data collected any given year, and thus can greatly vary between seasons and years.

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[45] *SEWRPC Community Assistance Planning Report No. 58, 2nd Edition,* A Lake Management Plan for Pewaukee Lake, Waukesha County, Wisconsin*, May 2003.*

[46] *SEWRPC Community Assistance Planning Report No. 262, 2nd Edition,* A Lake Management Plan for Nagawicka Lake, Waukesha County*,* Wisconsin*, in press.*

[47] *Ibid.*

[48] *Feinstein et al., 2012,* op. cit.

[49] *SEWRPC Technical Report No. 47,* op. cit.

[50] *SEWRPC Technical Report No. 48,* Shallow Groundwater Quantity Sustainability Analysis Demonstration For The Southeastern Wisconsin Region*, November 2009.*

[51] *It is important to note that Pewaukee Lake was assigned a recharge rate of zero, because it is considered a groundwater discharge area and is therefore not a source for groundwater recharge.*

Notwithstanding controversy regarding the extent of the groundwatershed, the groundwater recharge area to the north of the Lake is not only the largest area, it is the also the area underlain by the highest percentage of high and very high recharge potential soils and is the area with the most undeveloped land. This area is critical to sustaining the recharge supplying groundwater to Coco Creek. Coco Creek's existing and regionally uncommon trout population is highly dependent on abundant groundwater discharge to the Creek. In addition to supporting groundwater dependent and unique natural resource elements, groundwater recharge areas supply potable water to all wells in the watershed. Without sufficient recharge, groundwater elevations fall, a situation that can compromise the utility of existing pumps and wells. This is especially important to the relatively shallow wells commonly used for household water supply.

Preserving and enhancing recharge potential within the groundwatershed, especially in the areas identified as having high and very high recharge potential, is essential to protecting the groundwater feeding the Lake and its tributaries. High and very high recharge potential sites should remain substantially open and may provide ideal sites to position stormwater infrastructure designed to infiltrate detained stormwater.[52] Infiltrating stormwater helps reduce peak flows and increases cool, high quality baseflow to waterbodies during dry periods, conditions that generally improve waterbody health.

Numerous wells are found throughout the watershed, with clusters centering on highly developed areas such as within the Cities of Pewaukee and Hartland and the Village of Pewaukee. All wells, as well as other human-induced groundwater abstraction such as quarry dewatering, diverts groundwater from natural discharge points, can reduce the flow of springs, seeps, and streams. Therefore, human demands placed on groundwater supplies should be considered as part of lake management planning.

To comprehend the potential impact of wells on groundwater supplies, consider that the Village of Hartland pumped an average of nearly 1,000,000 gallons per day during 2018 (roughly equal to 1.5 cubic feet per second). At that time, the Village pumped water from five wells, four located within or near the Pewaukee Lake groundwatershed and all drawing from sand and gravel layers less than 100 feet below the ground surface, the same aquifer that supplies water to Pewaukee Lake and its tributaries. Most water provided by the Village of Hartland ultimately is discharged to sanitary sewers that export water from the Pewaukee Lake watershed. The volume of exported water (roughly 1. 5 cubic feet per second) is significant when compared to the average water discharged from the Pewaukee Lake outlet (7.5 to 20.6 cubic feet per second), and is especially significant during periods of drought when average outlet flows can decline to less than four cubic feet per second. The Village of Hartland is not the sole operator of high capacity wells in the Pewaukee Lake groundwatershed. High capacity wells also extract groundwater for public and private water supplies. Furthermore, based upon the reported proportions of groundwater withdrawal in Waukesha County, it is likely that private domestic wells located within the Pewaukee River watershed can account for at least 25 percent of the total local groundwater supply from the shallow aquifers.[53] Modeling assumed that the majority of domestic pumping is returned to the shallow aquifer via mound and/or septic system infiltration, which is not likely to be the case in much of the Pewaukee Lake watershed. Therefore, depletion modeling may underestimate total demand.

Quarry dewatering can also influence water table elevations over large areas. For example the quarry operations near Sussex create pronounced cones of depression, and likely redirect a portion of the flow that would otherwise discharge to Coco Creek. As such, the quarry operations may affect groundwater discharge to the northeastern branch of Coco Creek.

Most of the Pewaukee Lake watershed is either served or is planned to be served by public sewers (see Map 2.11). All wastewater discharged to public sanitary sewers is exported from the watershed. Since the water discharged to sanitary sewers originates as groundwater drawn from within the watershed, human water use in areas served by public wastewater collection systems represents a significant net artificial demand placed upon the groundwater flow system feeding waterbodies in the Pewaukee Lake watershed. This decreases the volume of groundwater discharges to the watershed's waterbodies.

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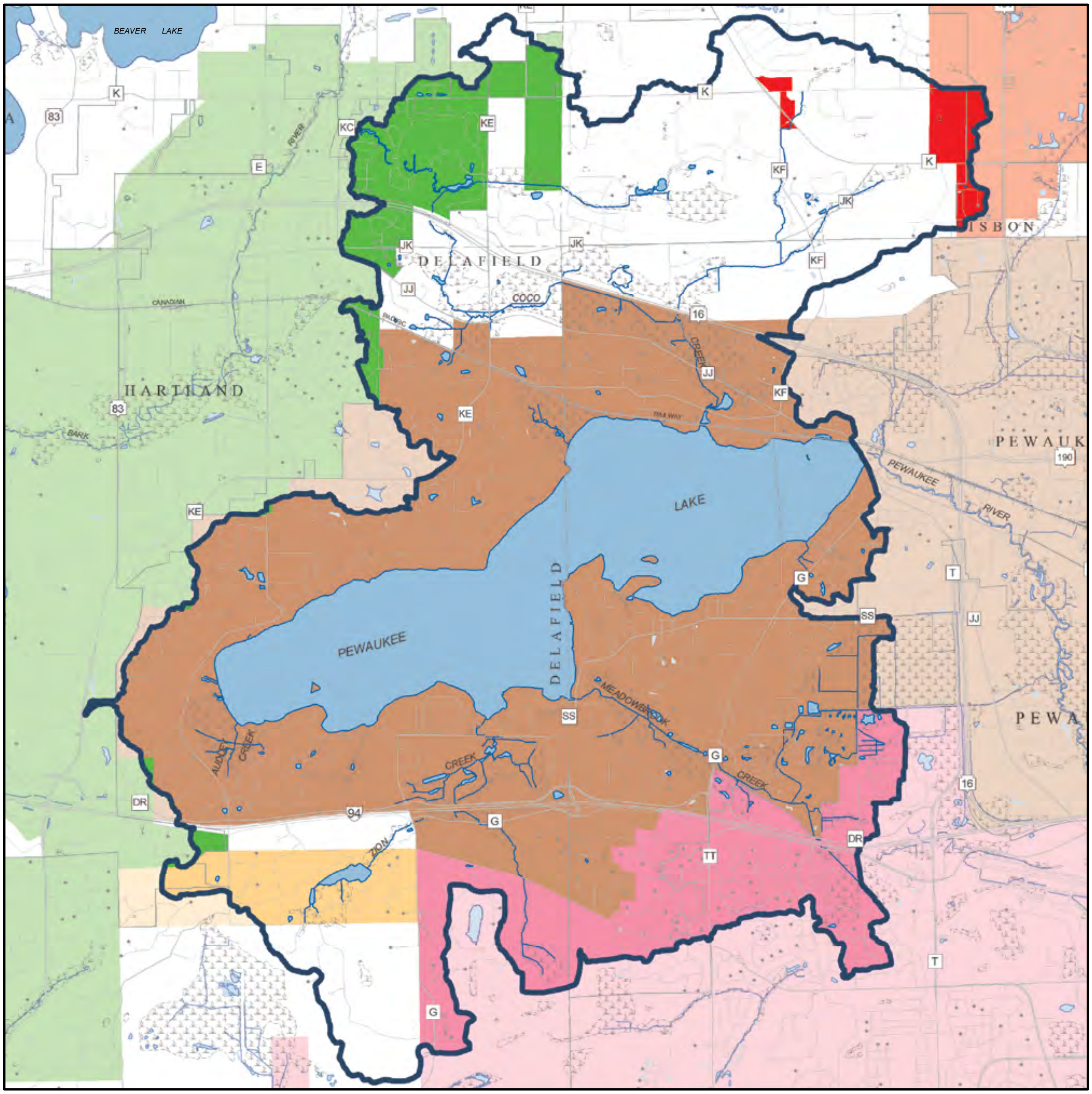
[52] *Care needs to be taken to infiltrate water that does not degrade the quality of groundwater resources. More information regarding stormwater infiltration is available from many sources, including the following website: learningstore.uwex.edu/assets/pdfs/g3691-3.pdf.*

[53] *Feinstein et al., 2012,* op. cit.

Map 2.11
Adopted Sanitary Sewer Service Areas Within the Pewaukee Lake Watershed: 2019



CITY OF WAUKESHA
CITY OF WAUKESHA OR FOX RIVER WATER POLLUTION CONTROL COMMISSION
FOX RIVER WATER POLLUTION CONTROL COMMISSION
DELAFIELD-HARTLAND WATER POLLUTION CONTROL COMMISSION
VILLAGE OF SUSSEX

SURFACE WATER
WETLAND
STREAM
WATERSHED BOUNDARY

Note: Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each legend category.

N

0 1,250 2,500 5,000 Feet

Source: SEWRPC

Since the Lake's water surface elevation is reportedly remaining within a desirable ranges during dry weather, groundwater pumping and impervious surfaces apparently have not yet unduly reduced baseflow to the Lake. Nevertheless, since groundwater flow systems react only slowly to change, decreases in baseflow may only be noticeable with time, and vigilance is warranted. Consequently, to maintain groundwater baseflow to the Lake and its tributary waterbodies, it is necessary to identify both high priority groundwater recharge areas for protection and watershed-wide practices that enhance recharge in all areas.

Groundwater is the water supply for all of the residences, agriculture, and industry within the Pewaukee Lake watershed. Additionally, it is a critical source of cool, clean water to the Lake and its tributaries; maintaining surface water elevations and stream baseflow during dry periods. However, human activities can imperil groundwater resources, particularly by depleting groundwater through increased demand and constructing impervious surfaces on high groundwater recharge areas. The loss of high recharge areas with increased urban development in the area will continue to place greater stress on groundwater supply within the watershed. Discussion of these problems and associated management recommendations are provided in Section 3.2, "Hydrology/Water Quantity."

2.3 HUMAN USE AND OCCUPATION

The health of a lake or stream is usually a direct reflection of the use and management of the lands surrounding the lake (i.e., the lake's watershed). This section should be used to better understand conditions within the watershed in order to identify potential sources of pollution and determine target areas for watershed management efforts. It can also provide context for understanding water quality data within the Lake.

Watershed land use and population density are important considerations for water quality management. Environmental stressors, such as soil erosion and water pollution, are often the result of human activities within a Lake's watershed. These environmental stressors become especially significant in areas that are in close proximity to lakes, wetlands, and streams where user conflicts can occur.

Cultural History

Humans first occupied Southeastern Wisconsin a few thousand years after glaciers retreated from the area. Several American Indian cultures rose and declined over the millennia. While some Indian cultures were subsistence hunter-gatherer cultures and modified the natural landscape to a very limited degree, others practiced agriculture and modified the native vegetation using fire to promote agricultural and favorable game conditions. Native Americans frequented the lakes of Waukesha County for thousands of years before European settlement. The meaning of the name "Pewaukee" is uncertain, with sources suggesting a meaning of "swampy" in the Ojibwa language,[54] a potential allusion to the extensive wetland that once occupied the Lake's east basin. However, other sources suggest that "Pewaukee" means "lake of shells" in Potawatomi or "place of flint" in Menominee.[55]

Although a few European adventurers, missionaries, trappers and traders had frequented the area since the 1600s, the 1800s witnessed the first great influx of European settlers to the Pewaukee Lake area. These settlers brought sweeping changes to the natural environment. The first Europeans settled in the vicinity of Pewaukee Lake during the 1830s.

As native forests and prairies were converted for agricultural use, and as more people settled in the area, public infrastructure was developed. A plank road along the north shore of Pewaukee Lake was proposed in 1844 and constructed in 1848 (see Figure 2.9) at a cost of $2000 per mile. It was at this time (1848) that Wisconsin became a State and the Village of Pewaukee was incorporated. As the area around Pewaukee Lake was settled and word of the Lake's natural beauty and commercial potential became more widely known, development pressure increased. A railroad was completed in 1855 (Figure 2.10) which resulted in an influx of settlers and visitors. By 1873, the first large passenger boat on the Lake, the sidewheeler "Lady of the Lake" (Figure 2.11), was brought to the Lake by Colonel N.P. Iglehardt and began steaming the waters of the Lake under the direction of Captain Henry Davy.

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[54] *V.J. Vogel,* Indian Names on Wisconsin's Map*, The University of Wisconsin Press, 1991.*

[55] *E. Callary,* Place Names of Wisconsin*, The University of Wisconsin Press, 2016.*

Increased commercial activity included establishment of robust ice harvesting businesses.[56] In 1878, the first icehouse (owned by Best Brewery of Milwaukee) was constructed on the north shore of Pewaukee Lake. Ice harvesters cut ice from the Lake and shipped it by rail to Milwaukee for use by the brewing and meat packing industries. The rail station used for loading Pewaukee ice onto trains was jokingly dubbed "Alaska." The Lake was known for its high quality "contact grade" ice. Contact grade refers to high clarity and purity such that it could be in direct contact with food or beverages, and is a testament to the water quality of the Lake during this period of time. As evidence of the enormity of the ice business on Pewaukee Lake at that time, the Wisconsin Lakes Ice and Coal Company put 500 ice cutters and handlers to work on Pewaukee Lake to harvest the winter ice with expectations of storing at least 250,000 tons of ice for Milwaukee consumption. By the early 1920s, the large scale commercial ice industry came to an end as mechanical refrigeration became widespread.

In 1888, Christopher Starke conducted the first dredging activities in Pewaukee Lake, using a steam dredge to create a peninsula of land (Starke's Peninsula – see Figure 2.12) for a housing development on the Lake's south shore. By 1890, most shoreline areas along the Lake's western end had been developed for residential use, although agriculture remained the dominant land use in the Lake's watershed. Also in 1890, portions of Meadowbrook Creek were straightened to accommodate construction of an electric rail line. In 1894, the Waukesha Beach amusement park opened on the southern shore of the Lake and Milwaukee Electric began operating electric rail service to and from Milwaukee, a service that continued until 1948 (Figure 2.13). Significant urban development in the Pewaukee Lake watershed began around 1900 and continued with a burst of development from 1920 through 1940. The Waukesha Beach amusement park closed in 1949.

Around this time, Lake users and residents recognized that water quality was deteriorating, which inspired formation of Lake resident organizations, such as the Pewaukee Lake Advancement Association. In 1943, an organizational meeting was held to consider creation of the LPSD to more formally address

[56] *L.E. Lawrence, "The Wisconsin Ice Trade,"* Wisconsin Magazine of History*, 48(4), Summer 1965.*

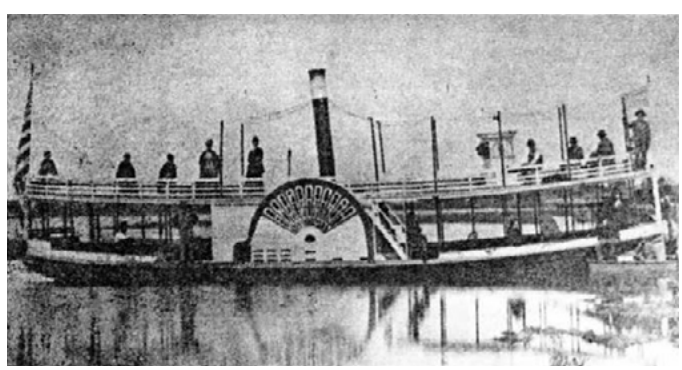
Figure 2.9
Artist Conception of Building the Plank Road

Source: Lake Pewaukee Sanitary District and SEWRPC

Figure 2.10
The Railroad Comes to Pewaukee Lake: 1855

Source: Lake Pewaukee Sanitary District and SEWRPC

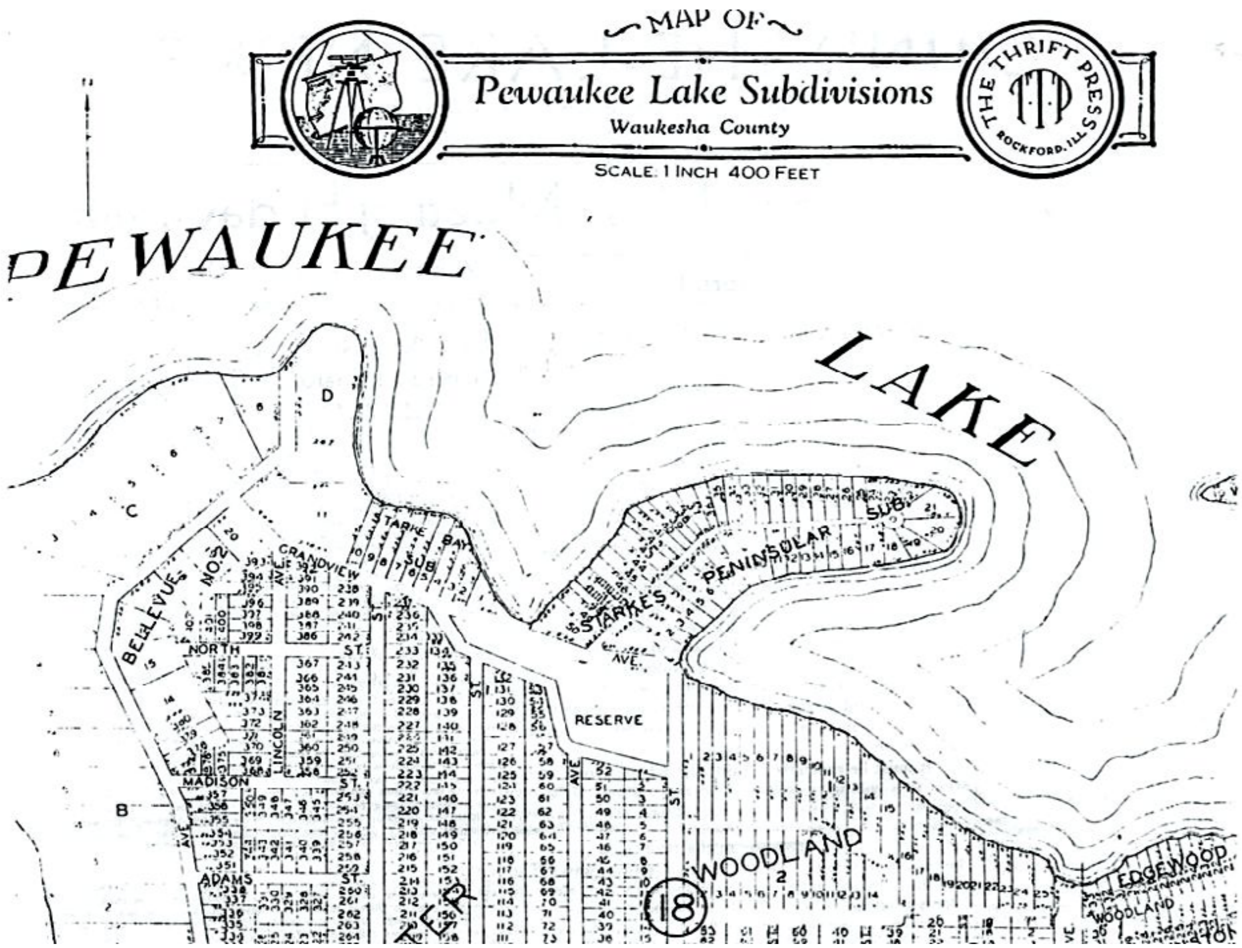
Figure 2.11
"Lady of the Lake" Sidewheeler: Circa 1873



The Lady of the Lake, a side-wheeler, was the first large passenger boat on Pewaukee Lake. Brought here in 1873 by Col. N.P. Iglegardt, it was operated by Capt. Henry Davy

Source: Lake Pewaukee Sanitary District and SEWRPC

Figure 2.12
Creation of the Artificial Peninsula "Starke's Peninsular Subdivision": Circa 1888



Source: Lake Pewaukee Sanitary District and SEWRPC

water quality and sanitation issues confronting Pewaukee Lake. In 1944, the LPSD was officially formed and a sanitary systems inspector was hired. The LPSD had three main objectives:

- Inspect sanitary disposal systems (suspected to be a major source of pollution of the Lake)
- Collect garbage
- Control nuisance aquatic plants

As a result of the LPSD formation, regular garbage collection at individual home sites began and septic system inspections were initiated during 1945.

Pewaukee Lake's bathymetry was first mapped in 1955. The resultant water-depth contour map was revised in 1966 (see Figure 2.14). In 1963, the WDNR completed a land use survey of the Lake's watershed and followed up in 1967 with a housing survey. Also in 1967, hydrology and bathymetry data were compiled and became part of the first WDNR Lake Use Report on Pewaukee Lake[57]. By 1976, public sanitary sewers began to be installed around the Lake as below average rainfall that year prompted a temporary closing of the dam gates at the east end of the Lake. In 1978, the Wisconsin legislature mandated an inventory of Wisconsin wetlands; the inventory was completed in 1982 for the counties of Southeastern Wisconsin and included the Pewaukee Lake watershed.

[57] *Wisconsin Department of Natural Resources Lake Use Report No. FX-2,* Pewaukee Lake, Waukesha County, Fox River Watershed, *1970*.

Historical Land Use

Prior to European settlement in the mid-1800s, the landscape within the Pewaukee Lake watershed consisted largely of oak savanna (oak opening): a transitional habitat between forest and grassland containing prairie grasses and forbs beneath widely spaced trees, primarily Bur oaks. Other natural habitats in the watershed included oak forest, open wetlands, and lowland hardwoods. The extent of these natural habitat types in the Pewaukee River watershed, derived from the original land survey records, is shown on Map 2.6.

Following European settlement, large portions of the landscape were converted to agricultural use. Natural vegetation was cleared to make way for crops. Efforts were made to open up wetlands to cultivation through ditching and draining of wet soils. Steeply sloped, non-arable lands were often grazed by livestock. This land conversion had significant consequences for water quality, water quantity, and wildlife habitat. For example, water quality has been compromised through increases in erosion leading to siltation of surface waters. In addition, natural waterways have been dredged and straightened to facilitate rapid runoff, bypassing natural functions of adjacent wetlands such as the absorption of flood waters. By 1940, agriculture was the most dominant land use and comprised over 70 percent of the total watershed area, based on the historical urban growth data and aerial photographs.

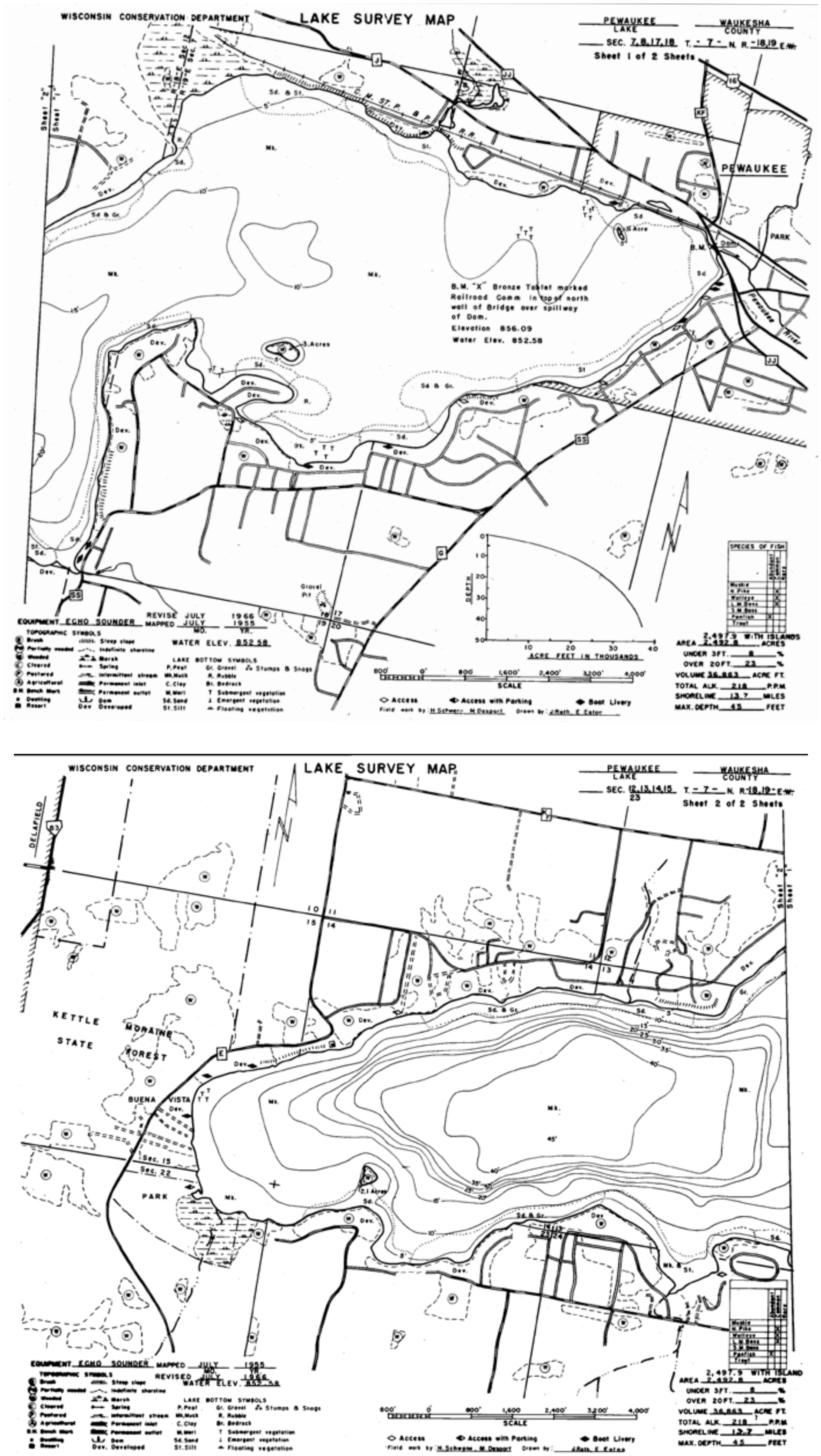
Agriculture remains a dominant land use, but has decreased in area by nearly 7,400 acres since the 1940s. This formerly agricultural land has been converted into residential and transportation land uses. The construction of Interstate Highway 94 and of State Highway 16 by 1950 subsequently contributed to the development of residential land use in the watershed. This second major phase of land conversion has led to other water quality and quantity-related issues, such as altering infiltration rates through an increase in impervious surfaces (paving, concrete walkways and roads, roof tops, etc.). However, some areas used for agriculture in the 1940s have reverted back to woodland and wetland, particularly along riverine corridors. This expansion of woods and wetlands have reduced the fragmentation of current environmental corridors, highlighting the capacity to shift the landscape from a "disturbed" to a more "natural" condition.

Figure 2.13
Pewaukee Lake Amusement Park and Electric Railway

Source: Lake Pewaukee Sanitary District and SEWRPC

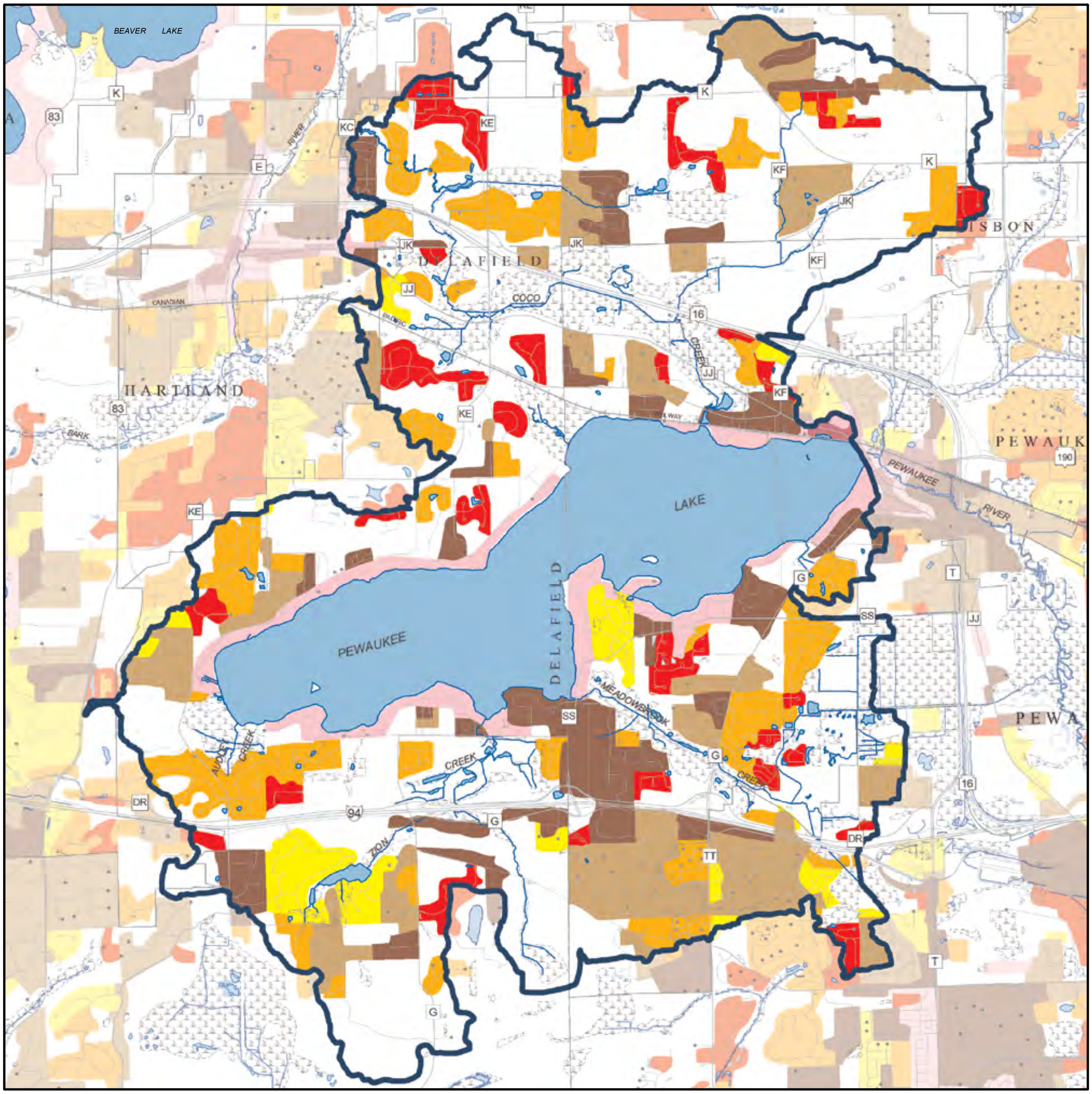
Historical records of urban growth and development can help inform the history of land use within a watershed. Urban growth within the Pewaukee Lake watershed is summarized on Map 2.12 and Table 2.6. As indicated on the map, much of the pre-1900 growth in the watershed centered on the Village of Pewaukee downtown

Figure 2.14
Pewaukee Lake Bathymetric Map: 1955 and Revised 1966



Source: Wisconsin Department of Natural Resources and SEWRPC

Map 2.12
Historical Urban Growth Within the Pewaukee Lake Watershed: 1850-2010



BEFORE 1900
1901-1950
1951-1970
1971-1980
1981-1990
1991-2000
2001-2010
SURFACE WATER
WETLAND
STREAM
WATERSHED BOUNDARY

Note: Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each legend category.

N

0 1,250 2,500 5,000 Feet

Source: SEWRPC

area.[58] As shown in Table 2.7 and in Figure 2.15, there were three 10-year time periods during which significant amounts of land were converted into urban use: 1950 to 1960, 1970 to 1980, and 1990 to 2000. From the 1950s to 1980, a post-war housing boom occurred throughout the entire watershed, probably spurred on by the construction of Interstate Highway 94 and State Highway 16. A lull in urban development occurred from 1980 to 1990, where urban growth dropped from about 1,500 acres in the preceding decade to less than third of that, or about 484 acres. After that slow period, urban growth increased from 1990 to 2000 to the highest recorded, or nearly 1,531 acres, which is consistent with the population and housing trends discussed below. Despite these fluctuations, urban growth in the watershed has shown two distinct patterns. First, the earliest growth that began around the perimeter of Pewaukee Lake continues to emanate from the Lake and expand outward. Second, growth is expanding around the perimeter of the watershed boundary from the outlying cities, towns, and villages.

Table 2.7 and Figure 2.16 show the growth of the population and the number of households in the Pewaukee Lake watershed between 1960 and 2010. Those periods of greatest urban growth shown in Figure 2.15 are reflected in similar increases in population and households: population increased 42 percent from 1970 to 1980 with a 54 percent increase in the number of households, while population increased 33 percent from 1990 to 2000 with a 45 percent increase in households.

Table 2.6
Historical Urban Growth Within the Pewaukee Lake Watershed

Year	Land Converted to Urban Use During Time Period (acres)
Before 1850	0.6
1851-1880	9.6
1881-1920	179.7
1921-1950	424.0
1951-1963	644.9
1964-1970	551.7
1971-1975	812.6
1976-1980	703.6
1981-1985	157.1
1986-1990	326.5
1991-1995	704.9
1996-2000	826.0
2001-2010	1,824.0
2011-2015	124.2
Total	7,289.4

Year	Total Urban Land Use: Acres	Total Urban Land Use: Percent of Contributing Watershed Area[a]
1850	0.6	0.0
1880	10	0.1
1920	190	1.4
1950	614	4.6
1963	1,259	9.4
1970	1,811	13.5
1975	2,623	19.5
1980	3,327	24.8
1985	3,484	25.9
1990	3,810	28.4
1995	4,515	33.6
2000	5,341	39.8
2010	7,156	53.3
2015	7,289	54.3

[a] *This watershed area does not include the 2,446 acres of Pewaukee Lake.*

Source: SEWRPC

Current and Planned Land Use

The Commission periodically quantifies the ways humans use land in Southeastern Wisconsin and projects how land use will change over the near term. Existing land uses in the Pewaukee Lake watershed were last evaluated in 2015. As shown in Table 2.8 and Map 2.13, as of 2015, a little less than half (45 percent) of the area tributary to Pewaukee Lake is used for various urban purposes. Residential use is the single largest land use in any category—rural or urban—occupying 4,569 acres (29.3 percent) of the land draining to the Lake. Almost 2,000 acres of the rural land use areas identified during 2015 are forecast to be converted to urban uses (mainly residential, along with increases in commercial, industrial, and transportation) based on local government comprehensive plans (see Map 2.14). Changing land use is likely to affect Pewaukee Lake in a number of ways, an example of which includes the mass of various pollutant types entering the Lake. For example, primary pollutants from rural/agricultural are sediment and nutrients (from fertilization) while pollutants from urban/residential uses are more likely to include metals (e.g., copper and zinc).

Political Jurisdictions

The Pewaukee Lake watershed lies entirely within Waukesha County (see Map 1.1). Pewaukee Lake open water area is shared by three communities: the City of Pewaukee, the Town of Delafield, and the Village of Pewaukee (see Table 2.9). Just over half of the total shoreline length is in the Town of Delafield, while

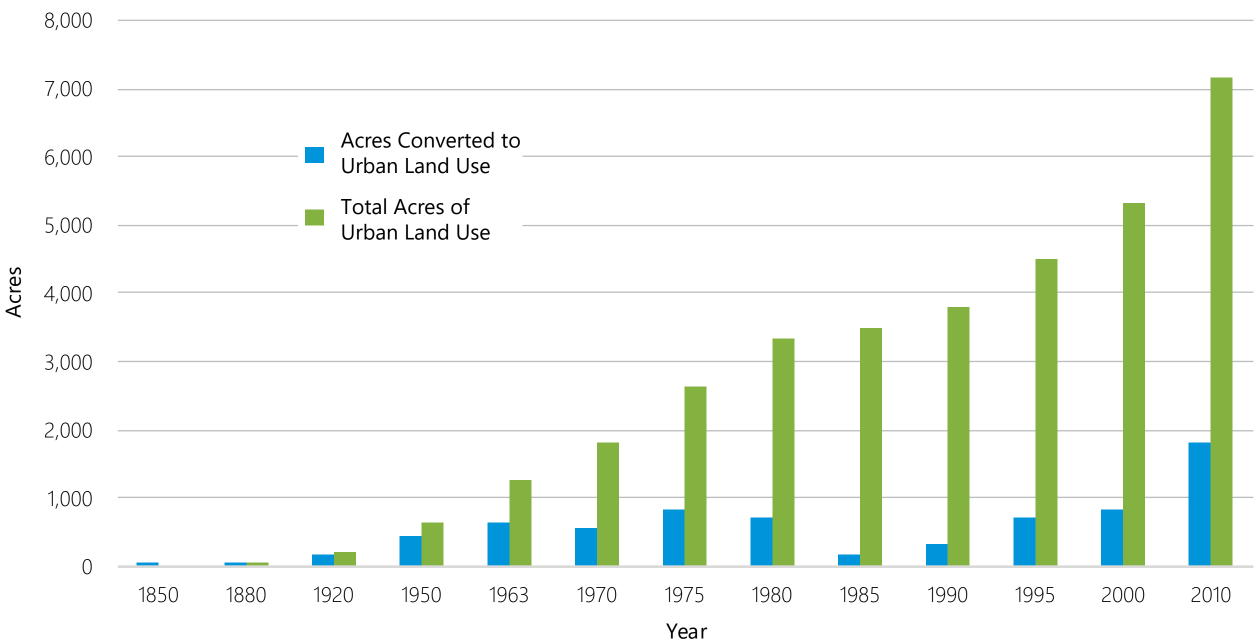
[58] *Information and resources on the history of Pewaukee is provided on the Pewaukee Areas Historical Society website at www.pewaukeehistory.org.*

Table 2.7
Populations and Households Within the Pewaukee Lake Watershed: 1960-2010

Year	Population			Households		
		Change from Previous Reference Period			Change from Previous Reference Period	
	Total	Number	Percent	Total	Number	Percent
1960	7,258	--	--	1,884	--	--
1970	8,109	851	11.8	2,321	437	23.2
1980	11,514	3,409	41.9	3,579	1,258	54.2
1990	12,795	1,281	11.1	4,356	777	21.8
2000	17,016	4,221	32.9	6,307	1,951	44.7
2010	19,775	2,759	16.2	7,648	1,341	21.3

Source: U.S. Bureau of Census and SEWRPC

Figure 2.15
Land Devoted to Urban Land Use Within the Pewaukee Lake Watershed: 1850-2015



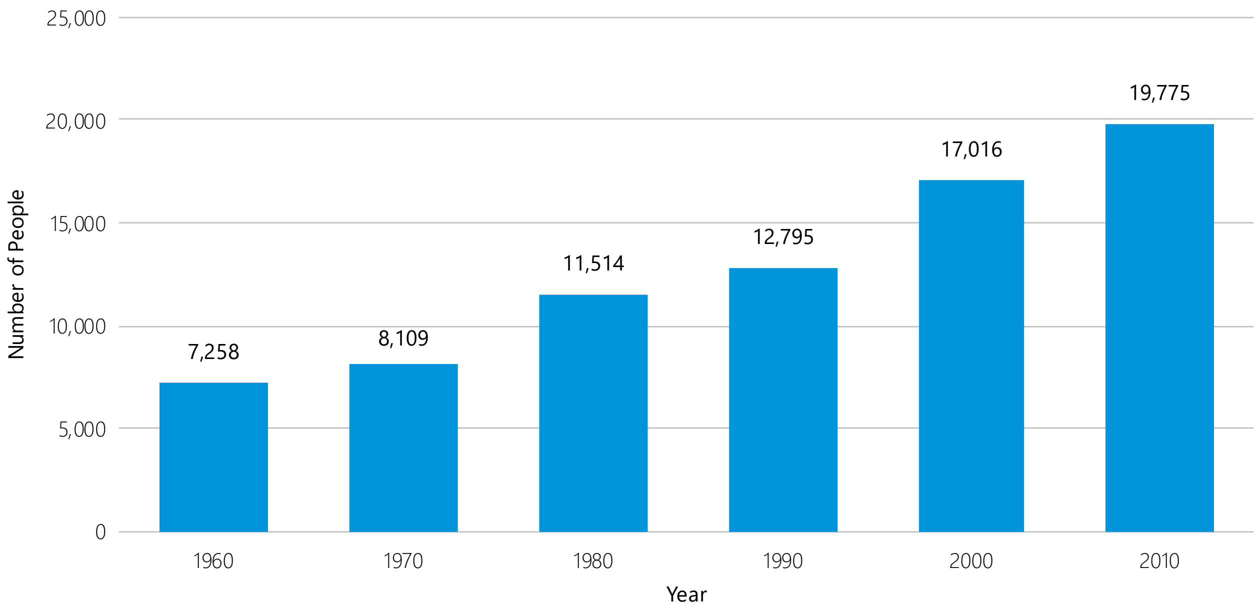
Source: SEWRPC

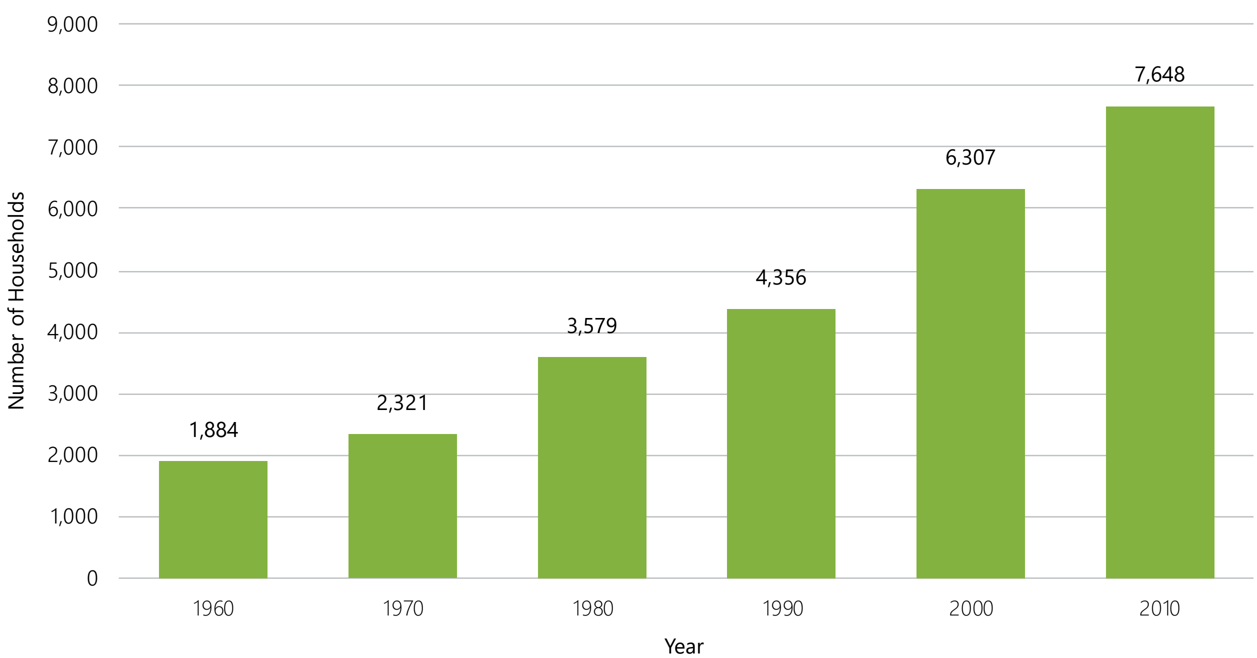
38 percent of the Lake's shoreline is in the City of Pewaukee and 12 percent in the Village of Pewaukee (see Table 2.10). The Lake is the ultimate discharge point for portions of the Cities of Delafield, Pewaukee, and Waukesha; the Towns of Delafield, Lisbon, and Merton; and the Villages of Hartland, Pewaukee, and Sussex (see Map 2.15 and Table 2.11). The Lake and its watershed are within easy driving to downtown Milwaukee. As the largest lake in Waukesha County, Pewaukee Lake is one the Milwaukee Metropolitan Area's premier water-based recreation lakes. These factors increase development and overall lake-use demand, which contributes to heavy pressure on the watershed's natural resource assets.

Sewer Service Area

Adopted sanitary sewer service areas are shown on Map 2.11. These sewer service areas have been delineated through a local sewer service area planning process. As part of this process, communities, assisted by the Commission, define a public sewer service area boundary that is consistent with local land use plans and development objectives. Sewer service area plans include detailed maps of environmentally significant areas within the sewer service area. Following plan adoption by the designated management agency for the wastewater treatment plant, the Commission considers local sewer service area plans for adoption. Once adopted by the Commission, the plans become a formal amendment to the regional water quality management plan and the Commission forwards the plans to the WDNR for approval.

Figure 2.16
Population and Households Within the Pewaukee Lake Watershed





Note: Watershed areas approximated by whole U.S. Public Land Survey quarter sections.

Source: U.S. Bureau of Census and SEWRPC

There are no wastewater treatment plants within the Pewaukee Lake watershed. Instead, sewage is pumped to a station in the Village of Pewaukee and then transported to the Fox River Pollution Control Center in the City of Brookfield for treatment and discharge to the Fox River. Sewer service areas have been adopted for most of the watershed except for parts of the Towns of Delafield, Lisbon and Merton and a portion of the City of Pewaukee.

Natural Resource Elements

Natural resources elements are features that remain integral parts of the Southeastern Wisconsin landscape that provision many human needs and desires and are vital to continued environmental health. Since environmental provisioning of human needs and desires and ecology are built on a network of abiotic and

Table 2.8
Land Use Within the Pewaukee Lake Watershed: 2015-Planned

Land Use Categories[a,b]	2015 Acres	2015 Percent of Total Tributary Drainage Area	Planned[c] Acres	Planned[c] Percent of Total Tributary Drainage Area	Change: 2015-Planned Acres	Change: 2015-Planned Percent (2015 base)
Urban						
Residential	4,733	29.8	5,657	35.6	+924	+19.5
Commercial	46	0.3	264	1.7	+218	+473.9
Industrial	21	0.1	138	0.9	+117	+557.1
Governmental and Institutional	110	0.7	270	1.7	+160	+147.7
Transportation, Communication, and Utilities	1,744	11.0	1,641	10.3	-103	-5.9
Recreational	636	4.0	747	4.7	+111	+17.4
Urban Subtotal	7,290	45.9	8,717	54.9	+1,427	+19.6
Rural						
Agricultural and Open Lands	3,559	22.4	2,132	13.4	-1,427	-40.1
Wetlands	1,358	8.6	1,358	8.6	0	0.0
Woodlands	1,125	7.1	1,125	7.1	0	0.0
Water	2,547	16.0	2,547	16.0	0	0.0
Rural Subtotal	8,589	54.1	7,162	45.1	-1,427	-16.6
Total	15,878	100.0	15,878	100.0	0	0.0

[a] *As approximated by whole U.S. Public Land Survey one-quarter sections.*

[b] *Off-street parking of more than 10 spaces are included with the associated land use.*

[c] *Planned land use is based on comprehensive plans adopted by local governments located within the Pewaukee Lake watershed.*

Source: SEWRPC

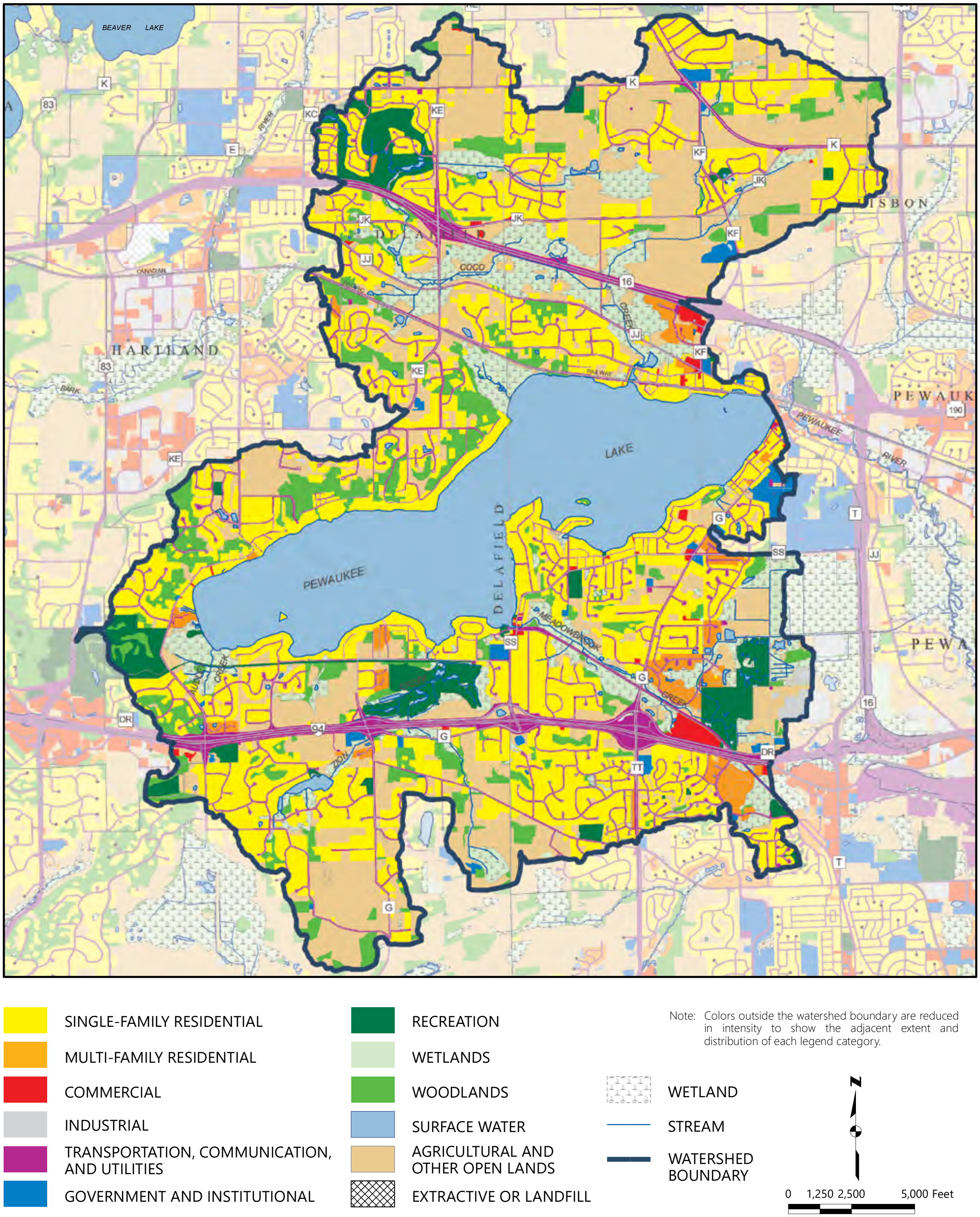
biotic relationships, deterioration or removal of one important relationship may cause damage throughout the entire network. For example, draining a wetland can eliminate the area's ability to supply important fish reproduction, nursery, and refuge functions, may compromise upland wildlife habitat value, can interrupt important groundwater recharge/discharge relationships, and can inhibit natural runoff filtration and floodwater storage. This loss in ecosystem function may further affect groundwater supply for domestic, municipal, and industrial use or its contribution to low flows in streams and rivers. Preserving natural resource elements not only improves local environmental quality but can also sustain and possibly enhance aquatic, avian, and terrestrial wildlife populations across the Region.

Floodplains

Section 87.30 of the *Wisconsin Statutes* requires that counties, cities, and villages adopt floodplain zoning to preserve floodwater conveyance and storage capacity and prevent new flood-damage-prone development in flood hazard areas. The minimum standards that such ordinances must meet are set forth in Chapter NR 116, "Wisconsin's Floodplain Management Program," of the *Wisconsin Administrative Code*. The required regulations govern filling and development within a regulatory floodplain, which is defined as the area that has a 1 percent annual probability of being inundated. The one-percent-annual-probability (100-year recurrence interval) floodplains within the Pewaukee Lake watershed are shown on Map 2.9. As required under Chapter NR 116, local floodland zoning regulations must prohibit nearly all development within the floodway, which is that portion of the floodplain with actively flowing water conveying the one-percent-annual-probability peak flood flow. Local regulations must also restrict filling and development within the flood fringe, which is that portion of the floodplain located beyond the floodway that is inundated during the one-percent-annual-probability flood, detaining floodwater for later release. Filling within the flood fringe reduces floodwater storage capacity and may increase downstream flood flows and flood depths/elevations. Approximately 797 acres of floodplain are present within the Pewaukee Lake watershed.

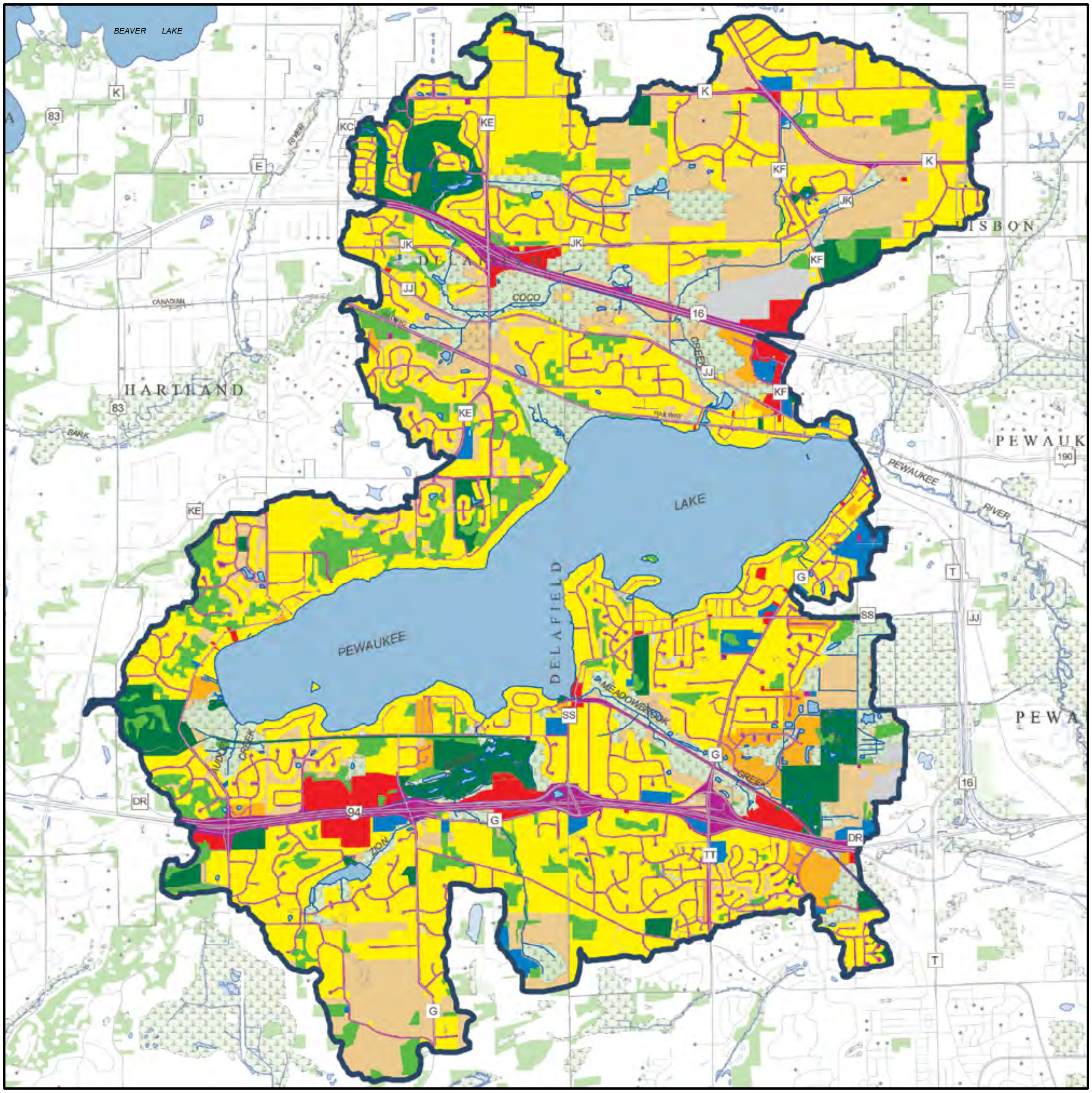
Ordinances related to floodplain zoning recognize existing uses and structures and regulate them in accordance with sound floodplain management practices. These ordinances are intended to: 1) regulate and diminish proliferation of nonconforming structures and uses in floodplain areas; 2) regulate reconstruction, remodeling, conversion and repair of such nonconforming structures—with the overall intent of lessening

Map 2.13
Generalized Land Use Within the Pewaukee Lake Watershed: 2015



Source: SEWRPC

Map 2.14
Pewaukee Lake Watershed Planned Land Use



SINGLE-FAMILY RESIDENTIAL

MULTI-FAMILY RESIDENTIAL

COMMERCIAL

INDUSTRIAL

TRANSPORTATION, COMMUNICATION, AND UTILITIES

GOVERNMENT AND INSTITUTIONAL

RECREATION

WETLANDS

WOODLANDS

SURFACE WATER

AGRICULTURAL AND OTHER OPEN LANDS

EXTRACTIVE OR LANDFILL

Note: Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each legend category.

Planned land use is based on comprehensive plans adopted by local governments located within the Pewaukee Lake watershed.

WETLAND

STREAM

WATERSHED BOUNDARY

0 1,250 2,500 5,000 Feet

Source: SEWRPC

Table 2.9
Pewaukee Lake Open-Water Jurisdiction

Depth Category (feet)	Town of Delafield (acres/percent)	City of Pewaukee (acres/percent)	Village of Pewaukee (acres/percent)
0-5	147/37	193/49	57/14
5-10	220/22	633/64	134/14
10-15	252/90	29/10	--
15-20	157/100	--	--
20-25	79/100	--	--
25-30	57/100	--	--
30-35	90/100	--	--
35-40	150/100	--	--
40-45	149/100	--	--
Total	1,301/55	855/36	191/8

Note: The total percentage does not equal 100 percent due to rounding.

Source: SEWRPC

Table 2.10
Pewaukee Shoreline Length by Municipality

Municipality	Shoreline Length (feet)	Percent of Total Shoreline
Town of Delafield	35,081	50
City of Pewaukee	26,264	38
Village of Pewaukee	8,349	12
Total	69,694	100

Note: Shoreline lengths do not include islands on Pewaukee Lake.

Source: SEWRPC

public responsibilities generated by continued and expanded development of land and structures inherently incompatible with natural floodplains; and 3) lessen potential danger to life, safety, health, and welfare of persons whose lands are subject to the hazards of floods.

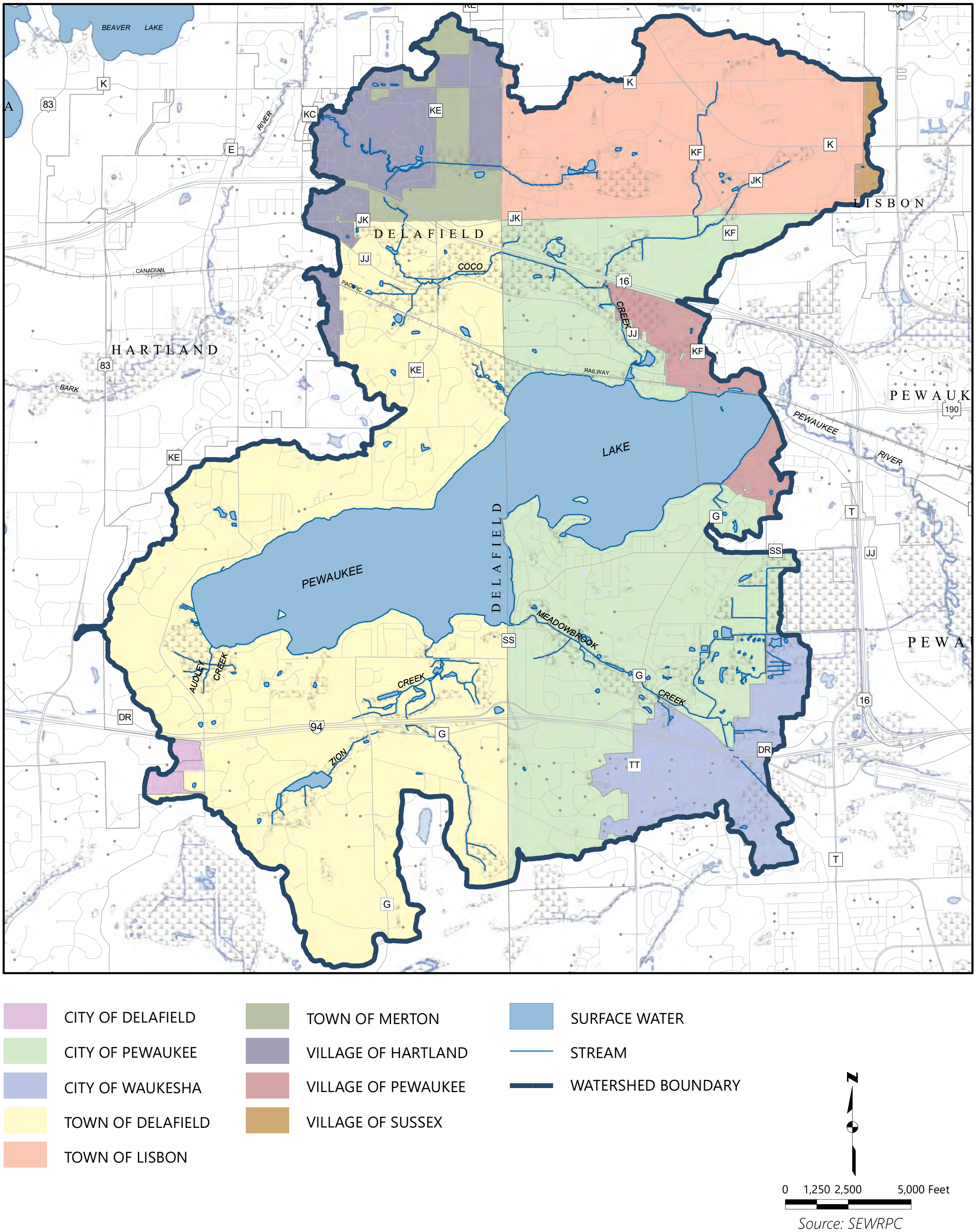
Wetlands

Historically, wetlands were largely viewed as wastelands, presenting obstacles to agricultural production and development. Private interests as well as governmental institutions supported the transformation of wetlands through large-scale draining and filling. Dramatic removal of wetland habitat occurred until scientific research revealed their value as incredibly productive and biologically diverse ecosystems.[59] Wetlands are most known for their variety of plant life, with communities composed of a mixture of submergent pondweeds, floating-leaf plants, emergent cattails, bulrush, and woody tamaracks, as just a few examples. Wildlife species that have been found to rely on, or are associated with, wetlands for at least part of their lives include: crustaceans, mollusks, and other aquatic insect larvae and adults; fishes, including forage fish and important gamefish species like trout, northern pike, and largemouth bass; amphibians; reptiles; mammals including deer; resident bird species like turkey as well as migrants like sandhill or whooping cranes. Thus, wetlands help maintain biologically diverse communities of ecological and economic value.

In addition to maintaining biodiversity, wetlands also store floodwaters, filter pollutants, improve water quality, protect groundwater aquifers, serve as sinks, sources, or transformers of materials, and provide recreation sites for boating and fishing. Recognition of the value and importance of wetlands has led to the creation of rules and regulations to protect wetlands globally, nationally (i.e., the Federal Clean Water Act of 1972), statewide, and locally. Most recently, the US Army Corp of Engineers and USEPA, in coordination with the U.S. Fish and Wildlife Service, WDNR, and the Commission have updated the delineation of wetlands in areas of special natural resource interest for the entire regional area to protect these areas and their

[59] *J.A. Cherry, "Ecology of Wetland Ecosystems: Water, Substrate, and Life,"* Nature Education Knowledge, *3(10): 16, 2012, www.nature.com/scitable/knowledge/library/ecology-of-wetland-ecosystems-water-substrate-and-17059765.*

Map 2.15
Pewaukee Lake Watershed Civil Divisions: 2019



Source: SEWRPC

associated critical species habitats (Advanced Delineation and Identification – ADID – lands; see Map 2.8).[60] These efforts are designed to protect or conserve wetlands and the ecosystem services they provide.

The term "ecosystem services" refers to any of the benefits that ecosystems—both natural and semi-natural—provide to humans.[61] In other words, ecosystem functions are classified by their abilities to provide goods and services that satisfy human needs,[62] either directly or indirectly. Examples of ecosystem services provided by wetland ecosystems are illustrated in Figure 2.17. The economic value of the ecosystem services provided by wetlands exceeds those provided by lakes, streams, forests, and grasslands and is second only to the value provided by coastal estuaries.[63] Society gains a great deal from wetland conservation. Therefore, it is essential to incorporate wetland conservation and restoration targets as part of this plan to guide management and policy decisions regarding the use and preservation of such ecosystems.

Table 2.11
Civil Divisions Within Pewaukee Lake's Watershed

Municipality	Acres of Watershed[a]	Percent of Watershed
Cities		
Delafield	59	0.4
Pewaukee	4,566	28.8
Waukesha	800	5.0
Towns		
Delafield	6,687	42.1
Lisbon	2,020	12.7
Merton	486	3.1
Villages		
Hartland	656	4.1
Pewaukee	545	3.4
Sussex	60	0.4

[a] *This watershed acreage includes 2,446 acre Pewaukee Lake.*

Source: SEWRPC

Wetlands are transitional areas, often possessing characteristics of both aquatic and terrestrial ecosystems while at the same time possessing features unique unto themselves. For regulatory purposes, the State of Wisconsin defines wetlands as areas where water is at, near, or above the land surface long enough to be capable of supporting aquatic or hydrophytic vegetation and which has soils indicative of wet conditions Three specific characteristics of wetlands are evaluated when a wetland determination is made including:

- Hydrology that results in wet or flooded soils
- Soils that are dominated by anaerobic (without oxygen) processes
- Rooted vascular plants that are adapted to life in flooded, anaerobic environments

These characteristics pose severe limitations for urban development, as wetlands have high water tables as well as high soil compressibility, instability, shrink-swell potential, and low bearing capacity. Thus, development in wetlands may result in flooding, wet basements, unstable foundations, failing pavements, and failing sanitary sewer and water lines. There are significant and costly onsite preparation and maintenance costs associated with the development of wetland soils, particularly in connection with roads, foundations, and public utilities.

[60] *Pursuant to Section NR 103.04(4) of the Wisconsin Administrative Code, wetlands in areas of special natural resources interest include those wetlands both within the boundary of designated areas of special natural resource interest and those wetlands that are in proximity to or have a direct hydrologic connection to such designated areas, which include Advanced Delineation and Identification study (ADID) areas. See SEWRPC Planning Report No 42,* Amendment to the Natural Areas and Critical Species Habitat Protection and Management Plan for the Southeastern Wisconsin Region*, December 2010. www.sewrpc.org/SEWRPCFiles/Publications/pr/pr-042-natural-areas-crit-species-habitat-amendment.pdf.*

[61] *Millennium Ecosystem Assessment,* Ecosystem Services and Human Well-Being: Wetlands and Water*, Synthesis. Report to the Ramsar Convention. Washington, DC: World Resources Institute. 2005.* millenniumassessment.org/en/Global.html.

[62] *R.D.S. de Groot, M.A. Wilson, and R.A.M. Bauman, "A Typology for the Classification, Description and Valuation of Ecosystem Functions, Goods and Services,"* Ecological Economics*, 41: 393-408, 2000, www.sciencedirect.com/science/article/pii/S0921800902000897.*

[63] *R.W. Costanza, R. d'Arge, R. de Groot, et al., "The Value of the World's Ecosystem Services and Natural Capital,"* Nature*, 387(6630): 253–260, 1997.*

Figure 2.17
Natural and Created Wetland Ecosystem Services

Service	Examples of Goods and Services Derived	Estimated value (1994 US $/ac^{-1} yr^{-1})[a]
REGULATION SERVICES		
Water quality		
Erosion control and sediment retention	Sediment filtration and storage capabilities that prevent downstream migration of sediment and improve downstream water quality.	NA
Waste treatment	Reduction of excess nutrient, organic, and metal loadings reduced through microbial degradation and/or sorption to improve water quality. Reduction of runoff temperature via shading and water's heat capacity.	1,690
Nutrient cycling	Reduction of nitrogen and phosphorus concentrations through denitrification and biological uptake.	NA
Hydrologic regulation	Moderation of the rate, volume, and frequency of surface runoff to provide flood and storm surge protection.	1,860
Climate regulation		
Greenhouse gas regulation	Maintenance of air quality and CO_2/CH_4 balance (through C sequestration); regulation of gases also influences climate effects.	54
Microclimate regulation	Maintenance of a favorable climate (such as temperature, precipitation) for human habitation, health, and cultivation.	NA
Soil formation	Building of land surface through the accumulation of organic material in wetlands.	NA
HABITAT SERVICES		
Refugia	Maintenance of biological and genetic diversity through provision of suitable habitat for resident or migratory plant and animal species. Includes the maintenance of populations of commercially harvested species and biological pest control services. This diversity forms the basis of many other ecosystem services.	123
PRODUCTION SERVICES		
Food production	Production of fish, game, fruits for small-scale hunting/gathering or aquaculture.	104
Raw materials	Production of trees, peat, and other biomass appropriate for lumber, fuel, or fodder.	43
INFORMATION SERVICES		
Recreation	Provision of opportunities for hunting, bird-watching, hiking, or other recreational uses.	232
Cultural	Provision of opportunities for noncommercial uses, including the use of wetlands for school excursions/education and for scientific research. Aesthetic, artistic, and spiritual values are also included.	357

[1]Adapted from Costanza et al., 1997, and de Groot, 2006)

[2]Value estimates for each service taken from Costanza et al. (1997). A listing of NA for individual services indicates that a formal valuation of this service had not yet been conducted.

Ecosystem services are products of the structure (for example, plant and animal community composition) and processes (such as nutrient cycling and decomposition) that characterize an ecosystem such as a wetland. These services also include food and raw material provision, air and water purification, biodiversity maintenance, and aesthetic and other cultural benefits to humans. These services can be attributed economic, social, and ecological values. Ideally, the inherent value of these services will guide management and policy decisions regarding the use and preservation of ecosystems.

Source: T.L. Moore and W.F. Hunt III, Urban Waterways: Stormwater Wetlands and Ecosystem Services, *North Carolina Cooperative Extension, 2011; Adapted from R.S. de Groot, M.A. Wilson, and R.M. Boumans, "A Typology for the Classification, Description, and Valuation of Ecosystem Functions, Goods, and Services,"* Ecological Economics, *41: 393-408, 2002*

Within the Pewaukee Lake watershed, wetlands total approximately 1,360 acres, or about 8.6 percent of the total watershed area, as illustrated on Map 2.16. The wetlands vary by community type, including aquatic beds, emergent/wet meadows, scrub/shrub, and forested, and in their floristic quality, from fair to excellent.[64]

[64] *For a greater description of the wetland community types and their floristic quality, see SEWRPC Community Assistance Planning Report No. 313,* op. cit.

As part of an effort to protect Pewaukee Lake's water quality, wildlife habitat, and areas of groundwater recharge, the LPSD, under direction of the citizen advisory committee, created the Wetland Conservancy Fund and began purchasing wetland areas in the Pewaukee Lake watershed. With the original goal of purchasing 350 acres of the most critical wetlands, the LPSD has purchased several wetland parcels, including: 46-acres in the Taylors Bay area, 75 acres along Coco Creek, 38 acres along Meadowbrook Creek, and 75 acres of previously converted farmland located on the upper reaches of Coco Creek (the Department of Transportation completed a wetland restoration project on 34 acres of this parcel). In addition, the LPSD has purchased additional parcels ranging in size from 32 to 56 acres, the majority of which is wetland habitat.

Uplands

Upland/woodland habitat is comprised of non-wetland natural areas. These areas are usually higher in elevation and farther from open water than wetlands, and thus are generally not as moist. However, there are many exceptions in this broad generalization of uplands, as can be seen within the Pewaukee Lake watershed. Upland habitat can sometimes be very difficult to distinguish from wetland, because these features form broad and complex mosaics or combinations across the landscape. It is precisely this combination and the linkages between these unique community types that provides the critical habitats to sustain healthy and diverse aquatic and terrestrial wildlife.

The upland habitat in the Pewaukee Lake watershed, shown in Map 2.16, is dominated by deciduous woodlands, with substantial areas of brush and grassland.[65] As most of this land was agricultural in the 1940s, these deciduous woodlands are an indication of the regrowth of forested lands within the watershed. The grassland areas may be under active management as pasture land or enrolled in a soil conservation program. There are also small portions of conifer and mixed (combinations of some or all of the others) upland communities.

Like wetlands ecosystems as described above, upland habitats also provide a variety of ecosystem services. Although the economic value of their ecosystem services is not as large as wetland ecosystems, these areas do provide important services worth protecting.[66] Uplands provide production of food, livestock, and crops, groundwater recharge and water quality, flood risk prevention, air quality protection, soil conservation, wildlife management potential through provision of critical breeding, nesting, resting, and feeding grounds, as well as refuge from predators for many species of upland game and nongame species, recreation, tourism, and education opportunities.

Another important contrast between upland and wetland is that the upland soils generally pose fewer limitations for urban development. In general, uplands have a lower water table, lower compressibility and greater soil stability, greater bearing capacity, and lower shrink-swell potential than wetland soils. These conditions usually result in less flooding, dry basements, more stable foundations, more stable pavements, and less failure of sanitary sewer and water lines. Therefore, there are significantly lower costs associated with onsite preparation and maintenance with the development of upland soils, particularly in connection with roads, foundations, and public utilities, making these areas highly desirable for urban development. Therefore, it is important to incorporate upland conservation and restoration targets as part of this plan to guide management and policy decisions regarding the use and preservation of such ecosystems.

Natural Resource Planning Features

The Commission has studied the distribution of natural resource elements in Southeastern Wisconsin for decades. As part of this study, it has labelled, ranked, and mapped important natural resource elements.

<u>Primary Environmental Corridors</u>

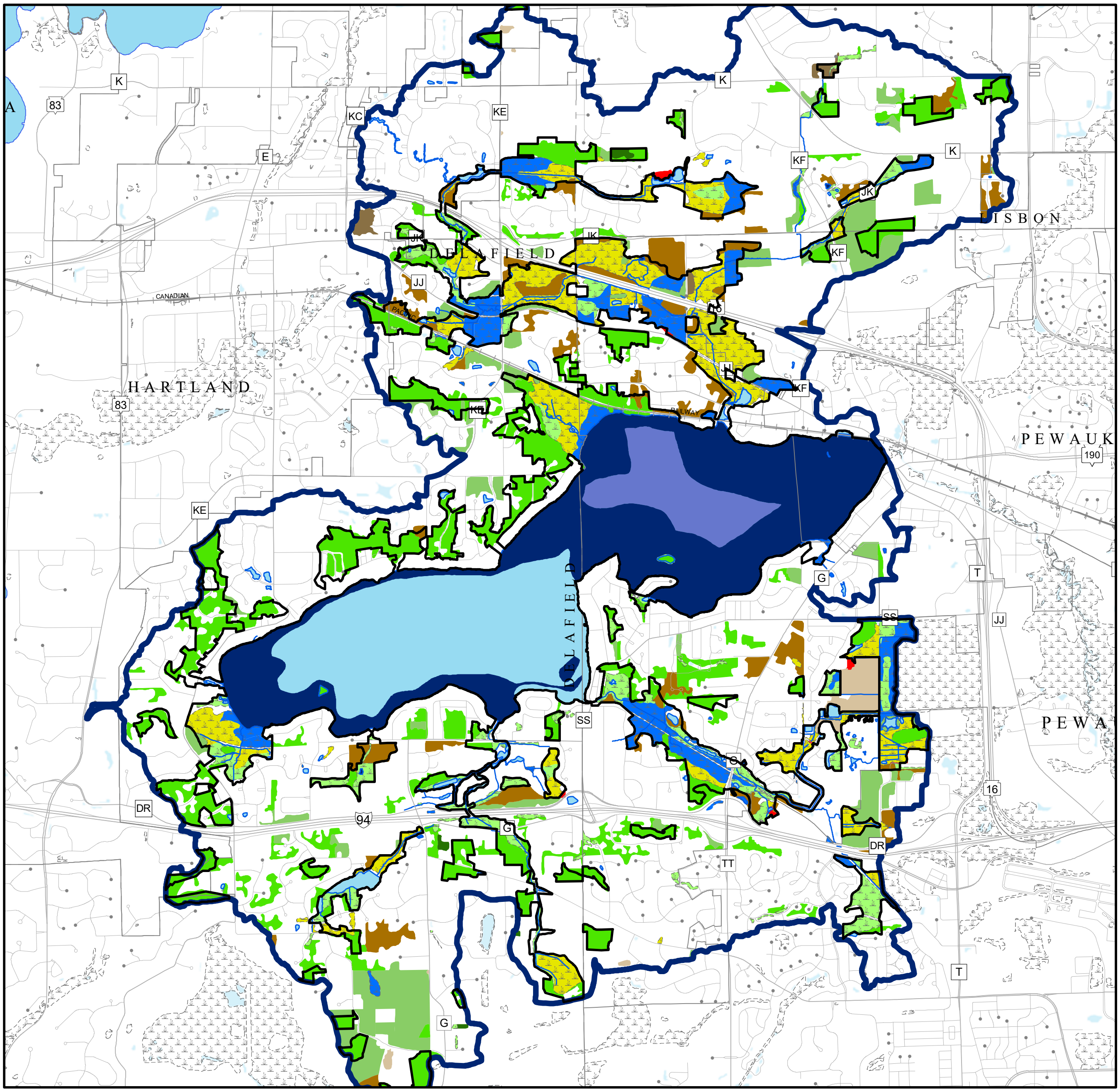
Primary environmental corridors (PEC) include a wide variety of important resource and resource-related elements. By definition, they are at least 400 acres in size, two miles in length, and 200 feet in width.[67] PEC encompassed about 4,254 acres, or about 32 percent of the Pewaukee Lake watershed, in 2015 (see Map 2.17). These PECs represent a composite of the best remaining elements of the natural resource

[65] *SEWRPC Planning Report No. 42,* op. cit.

[66] *R.W. Costanza et al., 1997,* op. cit.

[67] *SEWRPC Planning Report No. 42,* op. cit.

Map 2.16
Upland and Wetland Cover Types Within the Pewaukee Lake Watershed: 2010



UPLAND COVER TYPES

- BRUSH
- CONIFER
- DECIDUOUS
- GRASSLAND

WETLAND COVER TYPES

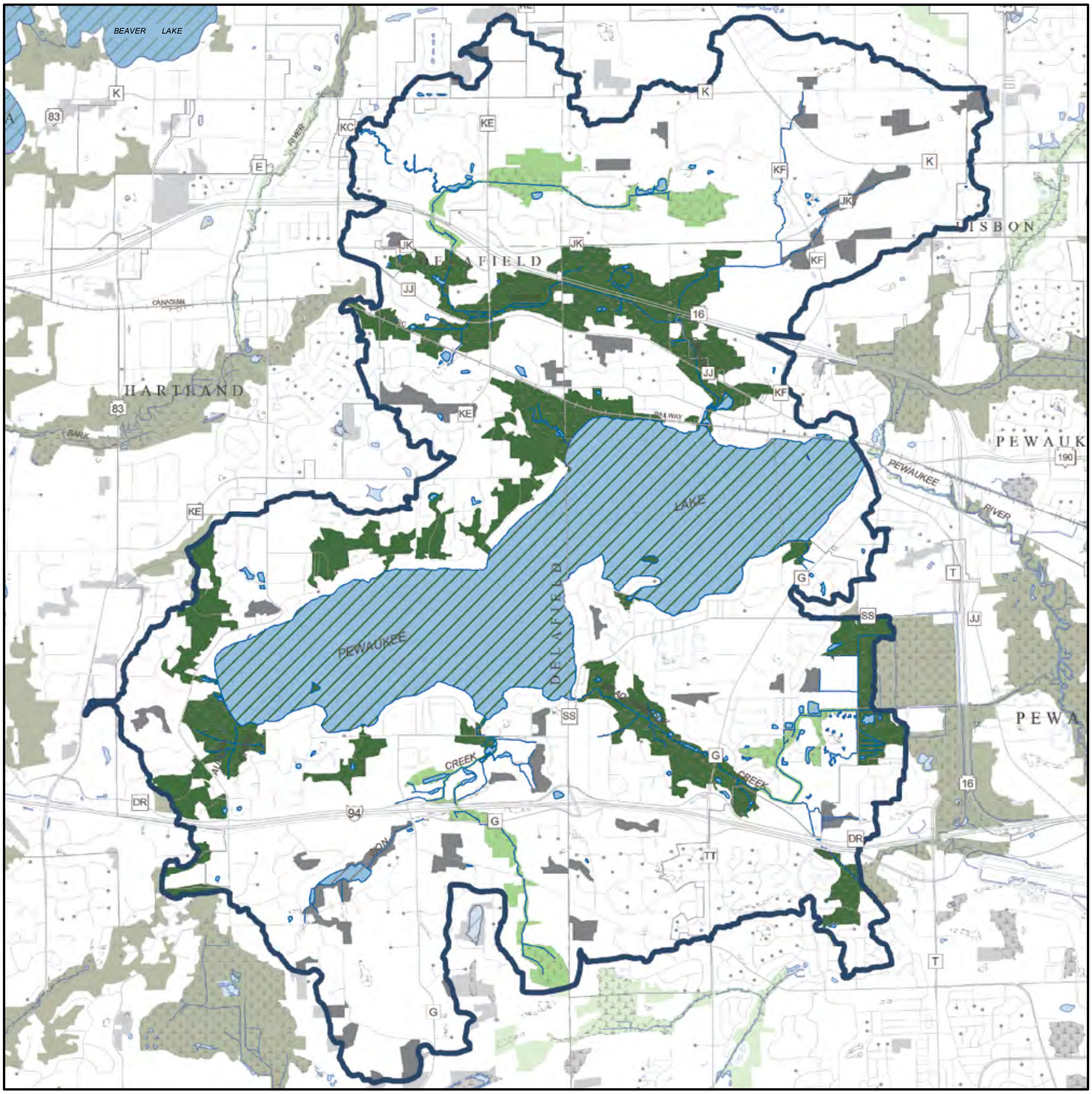
- AQUATIC BED
- DEEP WATER LAKE
- EMERGENT/WET MEADOW
- FILLED/DRAINED WETLAND
- FORESTED
- SCRUB/SHRUB
- SURFACE WATER
- STREAM
- WATERSHED BOUNDARY
- PRIMARY ENVIRONMENTAL CORRIDOR

N

0 1,250 2,500 5,000 Feet

Source: SEWRPC

Map 2.17
Environmental Corridors and Isolated Natural Resources Areas Within the Pewaukee River Watershed: 2015



PRIMARY ENVRIRONMENTAL CORRIDOR

SECONDARY ENVIRONMENTAL CORRIDOR

ISOLATED NATURAL RESOURCE AREA

SURFACE WATER

WATERBODIES IN ENVIRONMENTAL CORRIDOR

WETLAND

STREAM

WATERSHED BOUNDARY

Note: Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each legend category.

N

0 1,250 2,500 5,000 Feet

Source: SEWRPC

base, and contain almost all of the best remaining woodlands, wetlands, and wildlife habitat areas in the watershed. Although typically displayed as open water, lakes, rivers, streams, and associated shorelands are PECs for aquatic life. Thus, Pewaukee Lake and its associated shorelands are part of the highest quality natural resources within the Pewaukee Lake watershed, highlighting the importance of managing nearshore areas to protect their quality and integrity.

Secondary Environmental Corridors

Secondary environmental corridors (SEC) generally connect with the primary environmental corridors and are at least 100 acres in size and one-mile long. In 2015, secondary environmental corridors encompassed about 408 acres, or just over 3 percent of the watershed (see Map 2.17). Secondary environmental corridors are remnant resources that have been reduced in size compared to the larger PEC as described above, due to land development for intensive urban or agriculture purposes. However, secondary environmental corridors preserve ecosystem function by facilitating surface water drainage, maintaining pockets of natural resource features, as well as providing corridors for the movement of wildlife and dispersal of vegetation seeds.

Isolated Natural Resource Areas

Smaller concentrations of natural resource features that have been separated physically from the environmental corridors by intensive urban or agricultural land uses have also been identified. These natural resource areas, which are at least five acres in size, are referred to as isolated natural resource areas. Widely 4 percent, of the total study area in 2015, as shown in Map 2.17.

Natural Areas and Critical Species Habitat Sites

Natural areas, as defined by the Wisconsin Natural Areas Preservation Council, are tracts of land or water so little modified by human activity, or sufficiently recovered from the effects of such activity, that they contain intact native plant and animal communities believed to be representative of the pre-European settlement landscape (see Map 2.18). Natural areas are generally comprised of wetland or upland vegetation communities and/or complex combinations of both these fundamental ecosystem units. In fact, some of the highest quality natural areas within Southeastern Wisconsin are wetland complexes that have maintained adequate or undisturbed linkages (i.e., landscape connectivity) between the upland-wetland habitats, which is consistent with research findings in other areas of the Midwest.[68]

Natural areas have been identified for the seven-county Southeastern Wisconsin Region in SEWRPC Planning Report No. 42, "*A Regional Natural Areas and Critical Species Habitat Protection and Management Plan for Southeastern Wisconsin*," published in September 1997 and amended in 2008. This plan was developed to assist Federal, State, and local units and agencies of government, and nongovernmental organizations, in making environmentally sound land use decisions including acquisition of priority properties, management of public lands, and location of development in appropriate localities that will protect and preserve the natural resource base of the Region. Waukesha County uses this document to guide land use decisions. The identified natural areas were classified into the following three categories:

1. Natural area of statewide or greater significance (NA-1)

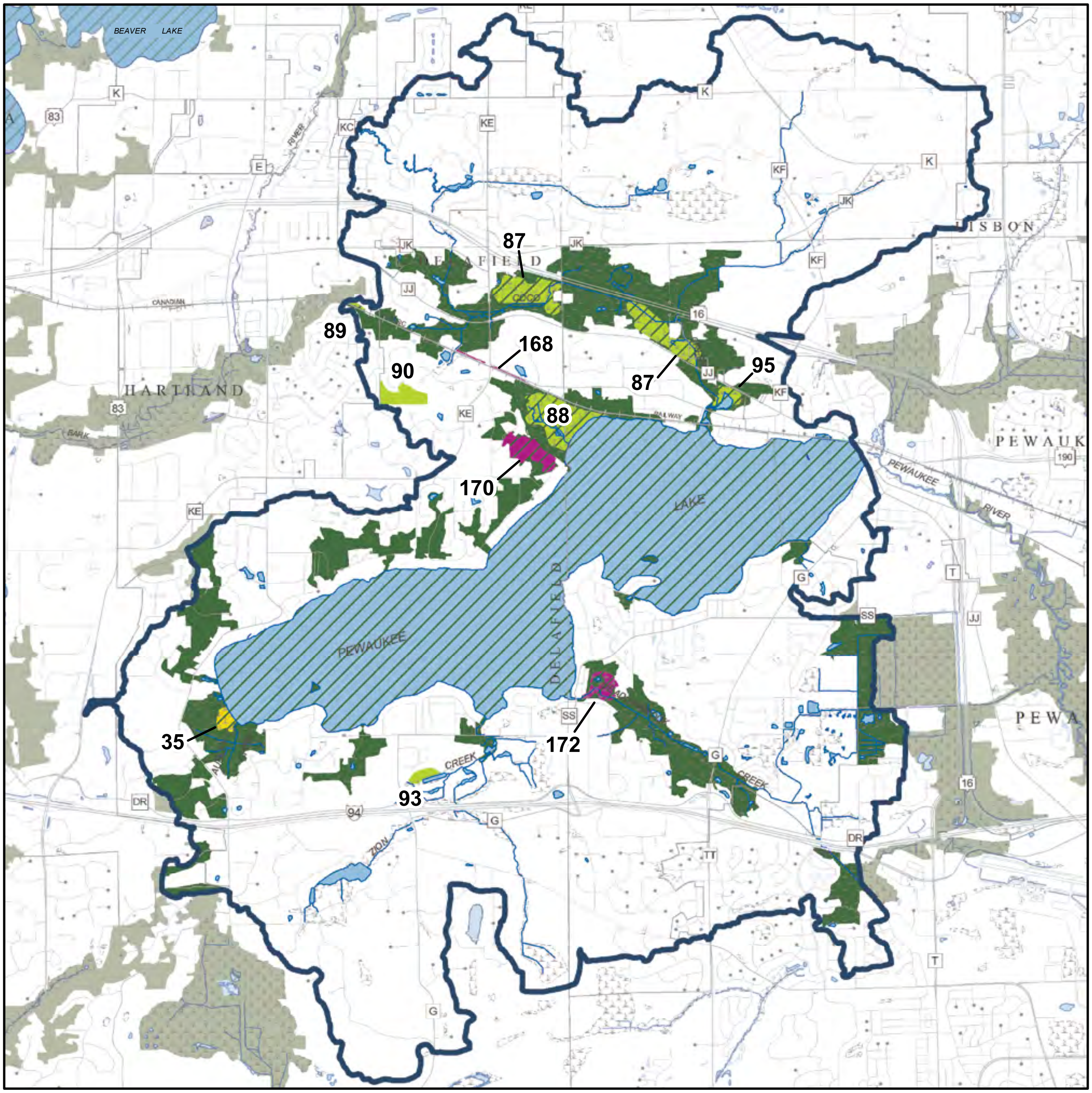
2. Natural area of countywide or regional significance (NA-2)

3. Natural area of local significance (NA-3).

Classification of an area into one of these three categories was based upon consideration of several factors, including the diversity of plant and animal species and community types present; the structure and integrity of the native plant or animal community; the extent of disturbance by human activity, such as logging, grazing, water level changes, and pollution; the frequency of occurrence within the Region of the plant and animal communities present; the occurrence of unique natural features within the area; the size of the area; and the educational value. The Pewaukee Lake watershed contains one natural area of countywide or regional significance (NA-2) and six natural areas of local significance (NA-3).

[68] *O. Attum, Y.M. Lee, J.H. Roe, and B.A. Kingsbury, "Wetland Complexes and Upland-Wetland Linkages: Landscape Effects on the Distribution of Rare and Common Wetland Reptiles,"* Journal of Zoology*, 275: 245-251, 2008.*

Map 2.18
Natural Areas and Critical Species Habitat Sites Within the Pewaukee Lake Watershed: 2010



NATURAL AREA OF COUNTYWIDE SIGNIFICANCE (NA-2)
NATURAL AREA OF LOCAL SIGNIFICANCE (NA-3)
CRITICAL SPECIES HABITAT SITE (CSH)
PRIMARY ENVIRONMENTAL CORRIDOR (2015)
SURFACE WATER
35 IDENTIFICATION NUMBER (SEE TABLE 2.13)

WETLAND
STREAM
WATERSHED BOUNDARY

Note: Any NA-2, NA-3, CSH or any water bodies that are included in primary environmental corridors are shown with a hatched pattern.

Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each legend category.

0 1,250 2,500 5,000 Feet

Source: SEWRPC

Within or immediately adjacent to bodies of water, the WDNR, pursuant to authority granted under Chapter 30 of the *Wisconsin State Statutes* and Chapter NR 170 of the *Wisconsin Administrative Code,* can designate environmentally sensitive areas on lakes that have special biological, geological, ecological, or archaeological significance, "offering critical or unique fish and wildlife habitat, including seasonal or life-stage requirements, or offering water quality or erosion control benefits of the body of water". Wisconsin law mandates special protections for these "sensitive areas", or "Critical Habitat Designation" areas, which are home to approximately 80 percent of the plants and animals on the state's endangered and threatened species list. A significant part of the critical habitat designation lies in the fact that it assists waterfront owners by identifying these areas so that they can design their waterfront projects to protect habitat and ensure the long-term health of the lake where they live. If a project is proposed in a designated Critical Habitat area, the permit process allows WDNR to ensure that proposed projects will not harm these sensitive resources. Those critical habitat areas in the Pewaukee Lake watershed are shown in Map 2.18 and described in Table 2.12. Of particular interest are the "Pewaukee Lake Access Fen" at the extreme western end of the Lake, and the "Pewaukee Lake Wetland" located on the northern shore of the Lake due to their close connection with the Lake itself. Not to be confused with Critical Habitat areas, the WDNR also designates Sensitive Areas on the Lake in which aquatic plant management is limited (see Section 3.5, "Aquatic Plants" more detail on Sensitive Areas).

Critical species are those plants, animals, or other organisms, considered by the Federal or State governments to be rare, threatened, or endangered, or of special concern. Twenty such species known to occur in the watershed are listed in Table 2.13 and include mussels, fish, reptiles, amphibians, birds, and plant species. Photos of each of these critical species and links to life history information are included in Figure 2.18.

2.4 LAKE LEVEL MANIPULATION AND MANAGEMENT CONCERNS

The Lake's outlet elevation was artificially raised about 180 years ago when a dam was built at the point where the Pewaukee River exits the Lake. Today's dam is not the same dam constructed in 1842. Several structures have been erected over the years, most of which relied primarily on a fixed weir elevation to pass water downstream. In such a structure, the amount of water passed by the dam increases as lake elevation increases. The relationship between lake elevation and flow over the recently replaced dam is shown in Figure 2.19. The current dam, built in 2010 and owned and operated by the Village of Pewaukee, uses subsurface gates to release water from the Lake. The outflow rate for the current dam depends upon both gate position and lake level elevation. The outlet dam raises the Lake's water elevation roughly eight feet.

The WDNR classified the lake outlet dam as a "high hazard" structure during 2005. Based on the high hazard rating, *Wisconsin Administrative Code* NR 333 required that the Pewaukee Dam's total spillway capacities be capable of passing the 1,000-year flood event without overtopping the engineered spillway, a finding requiring extensive changes to the dam. The Village of Pewaukee, the owner and operator of the dam, reconstructed the dam with bottomdraw gates and larger downstream concrete box culverts during 2010. The new dam became fully functional in 2011 (see Figure 2.20).

The 2011 dam's gates provide the capability to manipulate Pewaukee Lake's outflow and water elevation[69] and are designed to pass more water from the Lake. This allows the dam operator to draw down the water levels at will and at a much faster rate. However, these gates have changed the way water leaves the lake. Instead of passively passing over the top of the dam, the new structure draws water from under the water surface. Accommodating large increases in outlet flow to pass heavy precipitation and runoff now requires the dam operator to actively and physically alter dam gate positions. Similarly, to maintain Lake levels during extended periods of dry weather, the gates must be closed to a greater degree than wet weather.

The Wisconsin Department of Natural Resources (WDNR) ruled that the Lake's water elevation should be maintained between 852.20 and 852.80 feet (NGVD 1929). These water levels were based upon water levels made between 1920 and 1974. In general, higher water levels are meant to help to support summer recreation while lower levels help provide capacity to store early spring runoff and limit shoreland ice damage. The WDNR water level order stipulates that water levels should be gradually lowered to winter

[69] *A bottomdraw gate opens from the bottom up. The opening through which water leaves the lake is below the water surface and may not be visible.*

Table 2.12
Natural Areas and Critical Species Habitat Sites Within the Pewaukee Lake Watershed

Site Type	Number on Map 2.18	Name	Ownership	Size (acres)	Description
NA-2	35	Pewaukee Lake Access Fen	Waukesha County	10	Good quality calcareous fen on west side of Pewaukee Lake. Contains regionally uncommon plant species, including a good population of the State-designated threatened beaked spike-rush (*Eleocharis rostellata*). Site has improved with program of periodic burning.
NA-3	87	Capitol Drive Sedge Meadow and Wet Prairie	Lake Pewaukee Sanitary District, City of Pewaukee, and private	90	Moderate-quality sedge meadow, wet-mesic prairie, and shallow marsh. Disturbed by highway construction.
	88	Pewaukee Lake Wetland	Private	65	Moderate-quality wetland complex at northwest corner of Pewaukee Lake, consisting of shallow marsh, sedge meadow, and shrub-carr.
	89	Hartland Railroad Prairie	Private	4	Remnant mesic prairie, mostly on hill on north side of railway right-of-way. Characteristic species include big bluestem, rough blazing star, and prairie dock. Threatened by adjacent residential development.
	90	Prairie Wind Farm Woods	Private	22	Moderate-quality dry-mesic woods within residential development.
	93	Golf Cliff Ridge and Woods	Private	8	Small woodland containing limestone outcrops.
	95	Pewaukee Sedge Meadow	Private	13	Small, but good-quality sedge meadow, disturbed by ditching, highway construction, and residential development.
CSH	168	Jungbluth Road Railroad Prairie	Waukesha County and private	2	Small, narrow remnant of wet-mesic prairie between railway and highway.
	170	Taylor Road Woods	Private	30	Disturbed upland woods supports late coral-root orchid (*Corallorhiza odontorhiza*), a State-designated special concern species.
	172	Meadowbrook Prairie	Lake Pewaukee Sanitary District	16	Good population of small white lady's-slipper orchid (*Cypripedium candidum*), a State-designated threatened species, in managed wet-mesic prairie.

Note: The map numbers correspond to those presented in Amendment to SEWRPC Planning Report No. 42, *Amendment to the Natural Areas and Critical Species Habitat Protection and Management Plan for Southeastern Wisconsin*, December 2010.

Source: SEWRPC

levels between October 1st and 15th, gradually increased to summer levels between May 1st and May 15th, and held static during other periods to the extent practical.[70] Manipulating the gate changes the amount of water leaving the Lake, and can therefore influence water levels and help keep them within stipulated ranges.

Since lake elevation and outflow volume are both artificially controlled, and since water levels influence a wide variety of human desires and natural resource needs, water level management is an issue of significant interest. A few of the issues that relate to Lake water level management are briefly examined in this section.

Conditions Impeding Water Level Management

Pewaukee Lake's water levels have been artificially controlled for over 160 years to better serve a variety of human needs and desires. Water levels have been manipulated using flash boards and gates. All water level control structures require maintenance to operate reliably and are prone to operational challenges. As such,

[70] *Andrew Damon, Acting Administrator, Division of Enforcement, Wisconsin Department of Natural Resources, Order Associated with* Application of the Lake Pewaukee Sanitary District to Formally Establish the Existing Maximum Level and to Set a Minimum Level for Pewaukee Lake, Towns of Pewaukee and Delafield, Waukesha *County, 3-WR-1576, June 18, 1974.*

Table 2.13
Endangered and Threatened Species and Species of Special Concern Within the Pewaukee Lake Watershed: 2017

Common Name	Scientific Name	Status Under the U.S. Endangered Species Act	Wisconsin Status
Mussels			
Ellipse	*Venustaconcha ellipsiformis*	Not listed	Threatened
Fish			
Lake Chubsucker	*Erimyzon sucetta*	Not listed	Special concern
Pugnose Shiner	*Notropis anogenus*	Not listed	Threatened
Reptiles and Amphibians			
American Bullfrog	*Lithobates catesbeiana*	Not listed	Special concern
Blanchard's Cricket Frog	*Acris blanchardi*	Not listed	Endangered
Blanding's Turtle	*Emydoidea blandingii*	Not listed	Special concern
Butler's Garter Snake	*Thamnophis butleri*	Not listed	Special concern
Birds			
Black-Crowned Night-Heron	*Nycticorax nycticorax*	Not listed	Special concern/migrant[a]
Cerulean Warbler	*Dendroica cerulea*	Not listed	Threatened
Mammals			
Northern Long-Eared Bat	*Myotis septentrionalis*	Federally threatened	Endangered
Plants			
Autumn Coralroot	*Corallorhiza odontorhiza*	Not listed	Special concern
Beaked Spikerush	*Eleocharis rostellata*	Not listed	Threatened
Butternut	*Juglans cinerea*	Not listed	Special concern
Common Hoptree	*Ptelea trifoliata*	Not listed	Special concern
Hairy Beardtongue	*Penstemon hirsutus*	Not listed	Special concern
Hooker's Orchid	*Platanthera hookeri*	Not listed	Special concern
Kentucky Coffeetree	*Gymnocladus dioicus*	Not listed	Special concern
Prairie White-Fringed Orchid	*Platanthera leucophaea*	Federally threatened	Endangered
Small White Lady's Slipper	*Cypripedium candidum*	Not listed	Threatened

[a] *Migrant (i.e., fully protected by Federal and State laws under the Migratory Bird Act).*

Source: Wisconsin Department of Natural Resources, Wisconsin State Herbarium, United States Fish and Wildlife Service and SEWRPC

the Pewaukee Lake outlet experiences a variety of issues that require attention to allow water levels to be successfully manipulated. Examples of some of the more common and important concerns are discussed in this section.

Debris (e.g., leaves, uprooted and free floating aquatic plants, logs, floating ice) tends to be drawn to and accumulate just upstream of the Lake's outlet structure. Accumulating debris can reduce gate capacity and impede gate adjustment. To help clear debris, the gate has been opened more fully to allow debris to flush through the outlet works. However, during winter, ice can form in the outlet area and/or on gate components, locking the gate into a set position. In such circumstances, outflow from the lake cannot be adjusted until ice melts.[71] In anticipation of winter gate inoperability, the dam operator makes an intuitive assessment of how to position the gate to best achieve the desired winter season lake level.[72] However, this situation can lead to undesirable and uncontrollable fluctuation of the Lake's water elevation, particularly during heavy mid-winter rainfall or snowmelt events. Actions to promote safe and predictable dam operation are described in Chapter 3.

[71] *Personal communication, Daniel Naze, P. E., Village of Pewaukee Director of Public Works/Village Engineer, January 16, 2018.*

[72] *D.J. Naze, 2018,* op. cit.

Figure 2.18
Endangered, Threatened, and Special Concern Species Photos Within the Pewaukee Lake Watershed

MUSSELS

Ellipse

FISH

Lake Chubsucker

FISH (CONTINUED)

Pugnose Shiner

REPTILES AND AMPHIBIANS

American Bullfrog

REPTILES AND AMPHIBIANS (CONTINUED)

Blanchard's Cricket Frog

Blanding's Turtle

Figure 2.18 (continued)

REPTILES AND AMPHIBIANS (CONTINUED)

Butler's Garter Snake

BIRDS

Black-Crowned Night Heron (juvenile)

BIRDS (CONTINUED)

Black-Crowned Night Heron (adult)

Cerulean Warbler

MAMMALS

Northern Long-Eared Bat

PLANTS

Autumn Coralroot

Figure 2.18 (continued)

PLANTS (CONTINUED)

Beaked Spikerush

Butternut Tree

Common Hoptree

Hairy Beardtongue

Hooker's Orchid

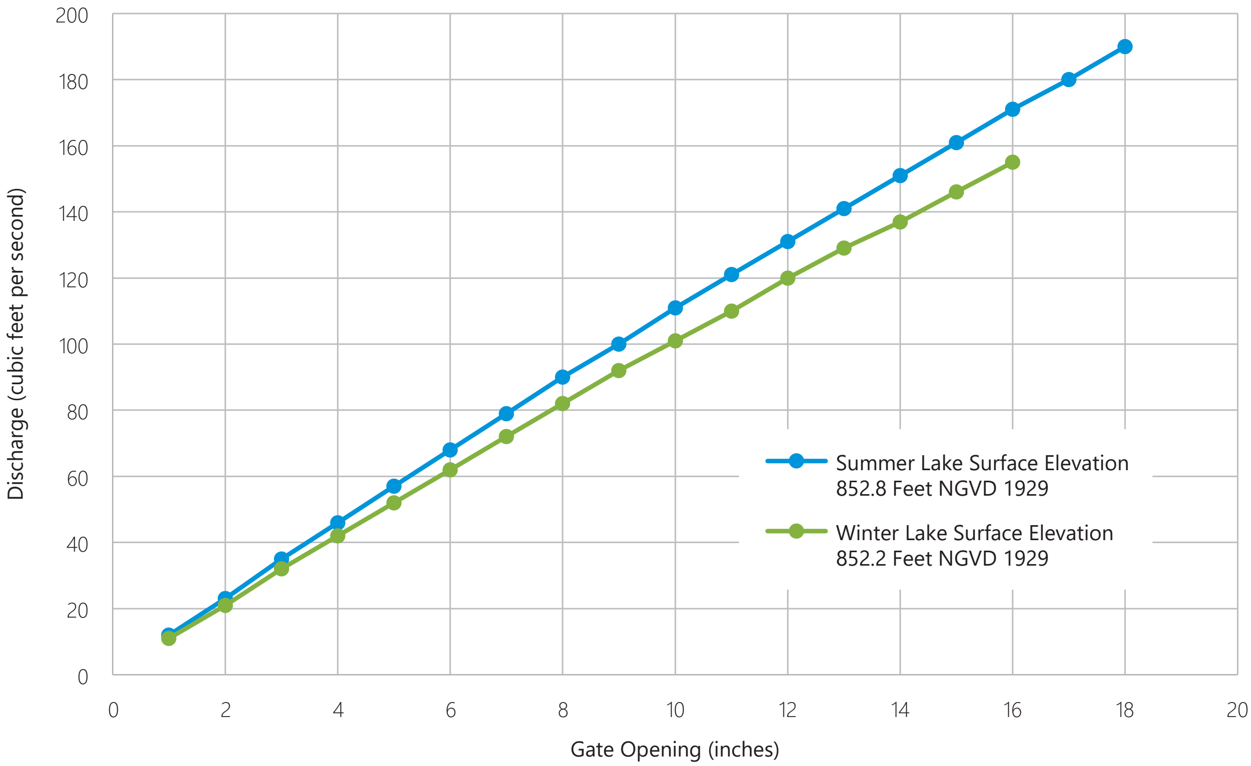
Kentucky Coffeetree

Prairie White-Fringed Orchid

Small White Lady's Slipper

Source: SEWRPC

Figure 2.19
Existing Pewaukee Lake Dam Discharge Capacity Nomogram



Source: David White, Engineer, Village of Pewaukee, and SEWRPC

Artificial Water Level/Flow Regimens

Pewaukee Lake and its dam influence and interrupt the physical, chemical, and biological continuity of the Pewaukee River watershed in many ways.[73] For example, the Lake modulates extreme tributary flows during all seasons. Furthermore, most sediment and nutrients carried by Lake tributaries remain in the Lake and are not passed downstream to the Pewaukee River, while the naturally cool water of the streams warms during summer as it passes through the Lake. Finally, the types of plants and animals living in still water are often quite different than those living in actively flowing water.

Similar to lakes, dams interrupt the normal upstream to downstream continuum of characteristics within a natural stream system.[74] An example of changes caused by Pewaukee Lake's outlet dam is its impact on the movement of fish and other aquatic organisms between the Lake, the Pewaukee River, and points further downstream. Fish from as far away as the Gulf of Mexico once migrated to Southeastern Wisconsin and certain migratory fish likely frequented Pewaukee Lake. The lake outlet dam and all other dams downstream of the Lake impede the ability of fish and other aquatic organisms to freely migrate. Fish may be able to move downstream but many cannot return to the Lake. Moreover, the installation of the bottom-draw gate on the dam has increased the potential for fish to be transported downstream to the Pewaukee River. Walleye abundance has anecdotally increased just below the dam since installing bottom-draw gate.

The artificial water level increase caused by the outlet dam not only inundated former wetland and upland habitat, but also influenced streams upstream of the dam. The lower portions of all stream tributaries to Pewaukee Lake were profoundly changed when the Lake was dammed and water levels rose. These formerly freely flowing stream segments were converted to quiescent water areas by the new reservoir,

[73] *J.V. Ward, and J.A. Stanford, The Serial Discontinuity Concept of Lotic Ecosystems, In* Dynamics of Lotic Ecosystems *(T.D. Fontaine and S.M. Bartell, editors), Ann Arbor Science Publishers, Ann Arbor, MI, pp. 29-42, 1983.*

[74] *R.L. Vannote, G.W. Minshall, K.W. Cummings, J.R. Sedell, and C.E. Cushing, "The River Continuum Concept,"* Canadian Journal of Fisheries and Aquatic Sciences, *37: 130-137, 1980.*

and the former channels likely filled with materials eroded from uplands converted to land uses that yielded much more sediment than long-standing natural conditions. Because of this, the lower portions of all streams feeding Pewaukee Lake do not contain naturally occurring cobbles or boulders and instead are underlain by thick deposits of silt, sand, and gravel.

Under natural conditions, a lake's water elevation normally rises in spring and declines during warm, dry summers. Certain plants and animal communities adapted to this rhythm and came to depend upon it. Humans tend to manage lake water levels out of phase with this natural rhythm, with water levels held highest during warm, dry summer weather (often artificially decreasing naturally low flows in outlet streams) and low during winter and early spring to lessen ice damage and detain floodwater. A growing body of scientific evidence suggests that water management practices based upon an arbitrary minimum flow or static lake elevation do not necessarily foster water body function and healthy ecosystems. However, most dam operation permits require essentially static water levels. Therefore, to protect freshwater biodiversity and maintain healthy waterbodies, it is desirable to attempt to mimic natural flow and water elevation variability to the extent practical. In streams, this includes mimicking flow volume, timing, duration, and rate of change. This can benefit rivers in many ways. For example, high flow events can flush accumulated sediment and flotsam, helping to maintain the stream channel's natural morphology, bed composition, and with its ability to pass flood water and provide suitable substrate for native organisms. Moreover, high flows can maintain the river's deep pools that provide sorely needed refuge areas during periods of low water. High flow events in early spring also are essential to migration and spawning of certain species of native fish (e.g., northern pike, suckers, and many prey species). Therefore, it is likely more beneficial to release large volumes of water for short periods of time in early spring as opposed to releasing small uniform quantities of water over long time frames. On a similar note, purposely managing lake water levels (to the extent possible within the operating order) may help promote the health of desirable plants and animals (e.g., bulrush).

Figure 2.20
Pewaukee Lake Dam Outlet Infrastructure Configuration

Pre-Construction

During-Construction: October 18, 2010

Post-Construction: August 15, 2011

Source: Charlie Shong and SEWRPC

Balancing Lake Water Elevations with Pewaukee River Flows

As opposed to a natural system or simple weir where lake water levels and outlet flows are essentially uncontrolled and vary only with lake elevation, Pewaukee Lake's gated dam allows the dam operator to exercise considerable discretion to modify outlet flow and thereby achieve various management objectives. Unfortunately, many of the management objectives may conflict with one another. For example, if water is held in the Lake to decrease flow in the Pewaukee River downstream of the dam, higher, longer term, or more serious flooding may occur around the Lake's shoreline. Therefore, maintaining desirable water elevations in the Lake and flow in the River requires balancing competing tradeoffs.

The water level order allows the dam operator to exercise prudence to achieve target lake elevations. The existing dam is designed to safely pass the enormous quantities of water associated with extreme precipitation events and may have to do so to maintain dam integrity. Passing large flows through the dam increases the stage of the Pewaukee River downstream of the Lake, a River stretch where the channel slope is relatively flat and flow is constrained by several bridges, artificially confined stream reaches, debris, and other obstructions. These conditions make the Pewaukee River downstream prone to substantial water level variation when large volumes of water are released from the Lake. In turn, this situation can flood downstream property, causing inconvenience and potential harm to those with properties abutting or influenced by the River. Although it is theoretically possible to temporarily modulate flows in the River with the Lake outlet dam to protect properties along the River, the Lake outlet dam was not designed to store floodwater to alleviate flooding, and holding back water during extreme events or on a regular basis could compromise the dam's long-term integrity. Additionally, the Federal Emergency Management Agency (FEMA) does not currently consider the dam a flood control structure. Therefore, while attempts are made to be sensitive to downstream flooding, the dam operator also must consider the ramifications of increasing or maintaining high water levels in the Lake.

Excessive and/or extreme Lake water elevation fluctuation is a great concern to the LPSD, resource managers, and residents of the Lake. Excessively low water elevations impedes Lake access and navigation and therefore may compromise recreational use, aquatic plant harvesting, and the ability of migrating fish to reach life-cycle critical habitat (e.g., spawning, nursery, feeding, and refuge areas). For example, northern pike spawning habitat is located in tributary streams and higher lake levels often promotes better fish passage into these tributaries. In contrast, excessively high lake water surface elevations can foster shoreline erosion, may promote decline of riparian and emergent vegetation, may help make shorelines more vulnerable to wave and ice damage, can flood buildings and infrastructure, and can allow clean water to enter sanitary sewers, which can force a sanitary sewer bypass event. To limit shoreline erosion, during periods of high water (defined as a water level of 853.4 feet above NVGD or greater), a local ordinance forbids operating boats at speeds faster than slownowake speed. When Lake elevations reach approximately 854.0 feet above NVGD, water is prone to enter low-lying buildings and sanitary sewer manholes, a condition that can damage property and overwhelm the sanitary sewer system's capacity. Even higher water levels begin to encroach on Wisconsin Avenue at the east end of the Lake. Water elevation thresholds are compared to recent Lake water elevations in Figure 2.21.

A substantial portion of the Pewaukee River's flow originates at the Lake outlet dam. During dry weather, the Lake acts as a reservoir, sustaining critical dry-weather flow. However, according to lake stage records, water levels in the Lake commonly fell below the former weir-type dam's control elevation, meaning that surface-water flow from the Lake to the River ceased during drought periods (see Figure 2.21). The current dam can draw water from several feet deeper than the old dam and can therefore contribute flow to the River during more intense drought. To protect aquatic organisms, the WDNR desires that some minimum level of flow (e.g., one cubic foot per second) be released from the Lake to the River, even if this means decreasing the Lake's water elevation below 852.2 feet above NVGD, the minimum water surface elevation goal.[75] Although there is no mandatory provision to maintain a minimum baseflow discharge at the Lake outlet to sustain the Pewaukee River's ecosystem, the Village generally opens the gate at least one full turn of the control mechanism to maintain a flow of about 0.5 cubic feet per second in the River immediately downstream of the dam.[76,77] This flow is similar to that measured by the Water Action Volunteers program downstream of the dam during drought periods. The River just downstream of the dam does receive additional dry weather flow through incidental leakage at the dam site, indirectly from the Lake via groundwater discharge, and from the North Branch of the Pewaukee River.

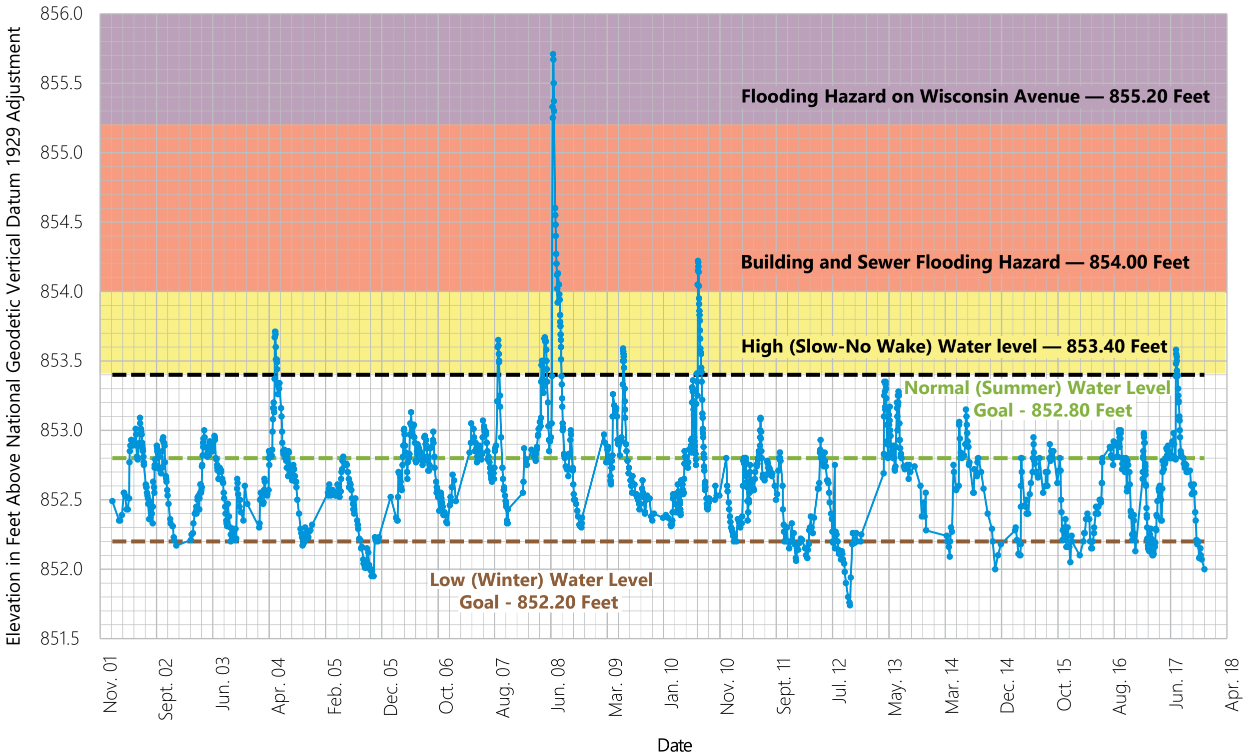
While the River's low flow can be maintained with few management problems, operating the dam's gates in a substantially open position can potentially flood low-lying downstream areas. The length and intensity of the flooding are related to outlet dam gate position and lake elevation. For a given volume of water, higher release rates will cause deeper flooding, but the flooding will persist for a shorter period of time, and

[75] *Personal communication with Michelle Hase, P. E., Water Regulations and Zoning Engineer, Wisconsin Department of Natural Resources.*

[76] *Personal Communication, David White, Engineer, Village of Pewaukee, August 2013.*

[77] *D.J. Naze, 2018,* op. cit.

Figure 2.21
Lake Water Surface Elevations and Their Influence on Lake Use and Infrastructures



Note: Floor of dam outlet elevation is 849.00 feet.

Source: Pewaukee Lake Sanitary District, Village of Pewaukee, and SEWRPC

may help maintain a clear stream channel and desirable habitat features. Conversely, slower release rates will limit the maximum depth of flooding, but the flooding will continue for longer periods of time, and the stream's ability to maintain desirable channel form and habitat conditions may be impaired. The depth and duration of flooding must be managed to minimize riparian damage and inconvenience, normalize Lake elevation over reasonably short periods of time, and promote desirable stream channel form and ecological health. Achieving this balance will require studying the conveyance capacity of the downstream channel and establishing reference point elevations to judge the effect of different gate positions.

The channel downstream of the dam is artificially constricted at several locations, a situation creating flood-prone areas. Examples include several undersized road/stream crossings that backwater floodwater and human-manipulated channels (e.g., filled floodplains, encroaching retaining walls) that compromise the River's conveyance and floodwater detention capacity. Although a comprehensive examination and description of these features is well beyond the scope of the this study, identifying features that accentuate flooding is a first step to improving the ability of the dam to pass flow volumes better in sync with the downstream river channel's capacity. A brief examination of FEMA flood profile for the Pewaukee River downstream of the dam reveals that floodwater backwaters at Wisconsin Avenue and at a point just upstream of State Highway 16. In addition to backwatering, flood elevations may be increased by human floodplain encroachment. As a starting point, it is highly advisable to investigate this reach, rectify conveyance capacity concerns, and thereby reduce flooding associated with normal dam operation.

Dam operation also has important implications for aquatic habitat. Lakes and streams typically reach their lowest levels in late summer. Frogs, turtles, and other herptiles burrow into bottom sediments in early fall to hibernate over the winter. Early lake draw down can mimic late season low water, assuring that herptiles hibernate in areas that remain submerged during winter water level drawdown. Natural lakes occasionally experience long periods of lower than normal water levels during extended periods of dry weather, a condition vital to regeneration of several desirable emergent aquatic plant species. Holding water elevations static year after year can favor undesirable changes in the aquatic plant community. In summary, a dynamic water management policy, to the extent practicable with the operating order of the dam, protects river channel form and function, ecological health, biodiversity and helps maintain the benefits that both Pewaukee Lake and the Pewaukee River provide.

Fitting the dam with a bottom-draw gate in 2010 has helped reduce the frequency of high surface water elevations on the Lake. Lake surface water elevations were monitored from 2001 to 2017 in cooperation with the Village of Pewaukee and the LPSD (see Figure 2.21). However, significant gaps in this data set occur during winter (e.g., winter of 2012) when data was not recorded as ice locked the gate into a set position. Casual correlation of 2003 – 2017 Lake surface elevation with larger rainfall events suggests that Lake elevations can rise approximately six inches for every 3.5 inches of rainfall within 24 hours (see Figure 2.22). This underscores the need to actively change gate position to match actual or forecast weather conditions, especially in winter when gates could be frozen and runoff can be heavy on frozen ground. Examples of suggestions to improve dam operation are included in Chapter 3.

Fitting the dam with a bottom-draw gate influenced the dam's tendency to entrain Lake-bottom sediment. Formerly, active flow was at the water surface, away from sediment. Now, the highest velocity water with the greatest capacity to move sediment is located near the Lake bottom, a situation which has increased the capacity to remove imported beach sand and other sediment from the east end of the Lake and ultimately redeposit this material downstream. This transport may be related to the recent reports of channel aggradation (i.e., filling) downstream of the dam. Several attempts to recreate a more functional stream channel have been made by the Village of Pewaukee, the Pewaukee River Partnership, and LPSD staff. Continued operation of the dam can affect the stability and composition of habitats downstream and is an issue of concern. More details regarding enhancement and protection are included in Chapter 3.

A staff gage affixed to the dam is used to monitor Lake water surface elevation. While functional, closely tracking water levels can be time-consuming, particularly during periods of rapidly changing water level. In addition, residents cannot conveniently review lake surface elevation and elevation trends. Hence, many calls of concern are made to the Village of Pewaukee and LPSD regarding water level questions, particularly during heavy rainfall, a situation taxing staff time by diverting effort to answering questions and away from protecting threatened infrastructure and/or responding to emergencies. Suggestions that may enhance water level monitoring and reporting are presented in Chapter 3.

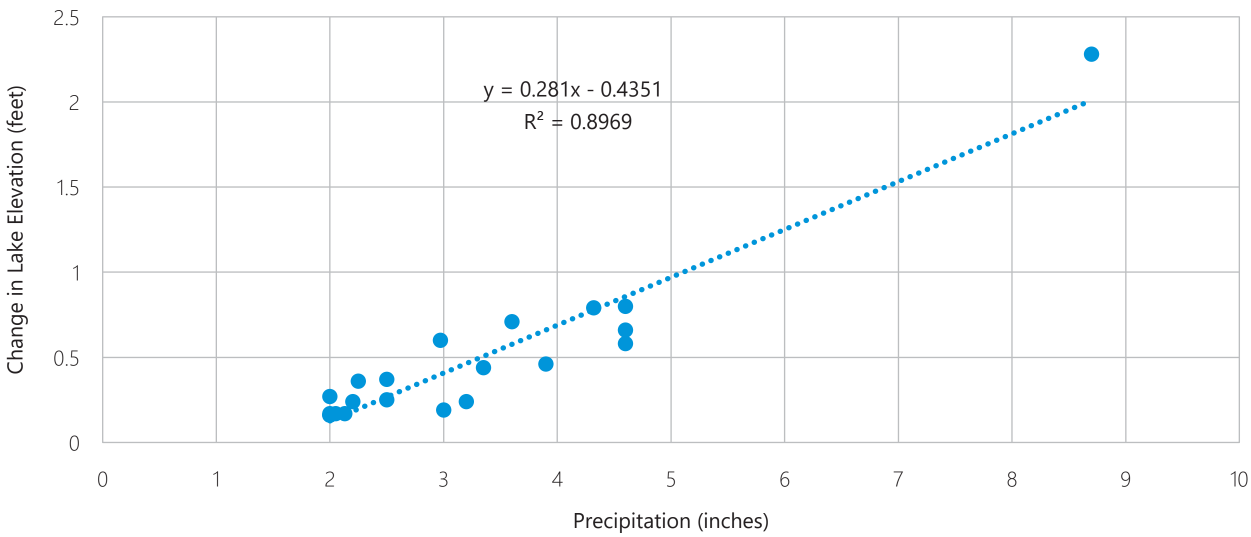
2.5 WATER QUALITY

Actual and perceived water quality are generally high priority concerns to lake and stream resource managers, residents, and Lake users. Concern is often expressed that pollutants entering the Lake from various sources have or could degrade water quality over time. The water quality information presented in this section can help interested parties better understand the current and historical conditions, trends, and dynamics of Pewaukee Lake and its major tributaries. By interpreting and applying this information, management strategies can target issues that have the highest likelihood of protecting the long-term health of these water bodies.

When discussing water quality, it is important to consider what "water quality" means, since individuals have varying perceptions, experiences, and levels of understanding. To the casual observer, water quality is commonly described using visual cues. For example, algae, cloudy water, and heavy growth of aquatic plants leads some to conclude a lake is "unclean." To judge if such a conclusion is merited and/or to quantify water quality, lake managers and residents must carefully examine specific chemical, physical, and biological parameters that influence or indicate water quality. Common metrics used to assess water quality include: water clarity, water temperature, and the concentrations of chloride, phosphorus, chlorophyll-*a*, and dissolved oxygen (DO) (see Table 2.14 for more information regarding the meaning and significance of these parameters).

Water quality metrics commonly respond in reaction to water quality changes. For example, nutrients from eroded topsoil and common fertilizers can cause a lake's phosphorus concentrations to increase. Increased phosphorus concentrations fuel algal growth. Increased algal abundance causes lake water to become cloudier, diminishing water clarity. Finally, chlorophyll-*a* concentrations (a measure of algae content) increase. In addition to water clarity, phosphorus, chlorophyll-*a*, and DO values, a number of other

Figure 2.22
Changes in Water Surface Elevation of Pewaukee Lake Caused by Precipitation Events Greater Than or Equal to Two Inches Within 24 Hours: 2003-2017



Note: These data are based upon daily readings of precipitation and lake level changes, except for three storm events that were a composite of total precipitation for the following dates; 6/7-6/8/2010, 6/22-6/24/2010, and 7/12-7/14/2017. The evaluation used the following gages for precipitation: Village of Pewaukee (5/11/2003-5/15/2018) and Pewaukee 3.8 WSW, USIWIWK0022, 3/3/2010-5/18/2018.

Source: Village of Pewaukee, NOAA, and SEWRPC

parameters can also help determine the "general health" of a lake. For example, the abundance of the bacteria *Escherichia coli*, commonly known as *E. coli*, is often measured as an indicator if lake water is safe for swimming while chloride concentrations are an indicator of overall human-induced pollution entering a lake.[78] Key water-quality indices must be regularly measured over long periods of time to develop a water quality maintenance and improvement program. This allows lake managers to establish baselines and identify trends.

Pewaukee Lake

To help quantify Pewaukee Lake's water quality, the Commission compiled available water quality data and analyzed these data in the context of relevant limnological factors. For example, by examining oxygen/temperature profiles, phosphorus concentrations, chlorophyll-*a* concentrations, and Secchi depth measurements, Pewaukee Lake is known to thermally stratify during summer, is prone to internal loading of phosphorus, and is meso-eutrophic.[79] These and other characteristics are examined and discussed in more detail in the following sections.

Lake Characteristics Influencing Water Quality

Water quality fluctuates over short- and long-term time periods. Therefore, thorough evaluation of lake water quality must rely on periodically monitoring various chemical and physical properties (ideally at the same depths and locations) over protracted time periods. Monitoring data are used to evaluate the level and nature of pollution within a lake, the risks associated with that pollution, the lake's ability to support various fish and recreational uses, and overall lake health. When examining water quality, it is

[78] *Chloride is used as an indicator of human-induced pollution because natural chloride concentrations are low in Southeastern Wisconsin. Chloride is a "conservative pollutant" meaning that it remains in the environment once released and is not attenuated by natural processes other than dilution. High chloride concentrations may result from road salt transported in runoff, fertilizer application, private onsite wastewater treatment systems that discharge to the groundwater that provides baseflow for streams and lakes, and a multitude of other sources.*

[79] *The trophic status of Pewaukee Lake was determined using the Wisconsin Trophic State Index value formula with Secchi disk measurements, total phosphorus levels, and chlorophyll-*a *levels.*

Table 2.14
Lake Water Quality Parameter Descriptions, Typical Values, and Regulatory Limits/Guidelines

Parameter	Description	Southeastern Wisconsin Values[a]		Regulatory Limit or Guideline	Pewaukee Lake Values	
		Median	Range		Median	Range
Chloride (mg/L)	Low concentrations (e.g., < 5 mg/L) naturally occur in lakes due to natural weathering of bedrock and soils. Human activities increase concentrations (e.g., road salts, wastewater, water softener regeneration) and can affect certain plants and animals. Chloride remains in solution once in the environment and **can serve as an excellent indicator of other pollutants.**	41	18-260	Acute toxicity[b,c] 757 Chronic toxicity[b,c] 395	60[d]	28-146
Chlorophyll-*a* (µg/L)	The major photosynthetic "green" pigment in algae. The amount of chlorophyll-*a* present in the water is an indicator of the biomass, or amount of algae, in the water. **Chlorophyll-*a* levels above 10 µg/L generally result in a green-colored water** that may be severe enough to impair recreational activities such as swimming or waterskiing and are commonly associated with eutrophic lake conditions.	9.9	1.8-706.1	2.6[e]	8.3[f]	0.94-36.1[f]
Dissolved Oxygen (mg/L)	Dissolved oxygen levels are one of the most critical factors affecting the living organisms of a lake ecosystem. Generally, dissolved oxygen levels are higher at the surface of a lake, where there is an interchange between the water and atmosphere, stirring by wind action, and production of oxygen by plant photosynthesis. Dissolved oxygen levels are usually lowest near the bottom of a lake where decomposer organisms and chemical oxidation processes deplete oxygen during the decay process. **A concentration of 5.0 mg/L is considered the minimum level below which many oxygen-consuming organisms, such as fish, become stressed**. Many species of fish are unlikely to survive when dissolved oxygen concentrations drop below 2.0 mg/L.	--	--	≥5.0[e]	7.8[g]	0.0-17.6
Growing Season Epilimnetic Total Phosphorus (µg/L)	Phosphorus enters a lake from natural and human-derived sources and is a fundamental building block for plant growth. Excessive phosphorus can lead to nuisance levels of plant growth, unsightly algal blooms, decreased water clarity, and oxygen depletion, all of which can stress or kill fish and other aquatic life**. A concentration of less than 30 µg/L is the concentration considered necessary in a drainage lake such as Pewaukee Lake** to limit algal and aquatic plant growth to levels consistent with recreational water use objectives. Phosphorus concentration exceeding 30 µg/L are considered to be indicative of eutrophic lake conditions.	30	8-720	30[e]	18.6[f]	10-160[f]

Table continued on next page.

Table 2.14 (Continued)

Parameter	Description	Southeastern Wisconsin Values[a]		Regulatory Limit or Guideline	Pewaukee Lake Values	
		Median	Range		Median	Range
Water Clarity (feet)	Measured with a Secchi disk (a ballasted black-and-white, eight-inch-diameter plate), which is lowered into the water until a depth is reached at which the disk is no longer visible. It can be affected by physical factors, such as suspended particles or water color, and by various biologic factors, including seasonal variations in planktonic algal populations living in a lake. **Measurements less than five feet are considered indicative of poor water clarity and eutrophic lake conditions**.	4.6	3-12	10.9[h]	5.9	0-17.4[f]
Water Temperature (°F)	Temperature increases above seasonal ranges are dangerous to fish and other aquatic life. Higher temperatures depress dissolved oxygen concentrations and often correlate with increases of other pollutants.	--	--	Ambient[e] 35-77 Sub-lethal[e] 49-80 Acute[e] 77-87	--[g]	32-83.5

[a] *Wisconsin Department of Natural Resources Technical Bulletin No. 138,* Limnological Characteristics of Wisconsin Lakes, *Richard A. Lillie and John W. Mason,* 1983.

[b] Wisconsin Administration Code *Chapter NR 105, Surface Water Quality Criteria and Secondary Values for Toxic Substances. July, 2010.*

[c] *Pollutants that will kill or adversely affect aquatic organisms after a short-term exposure are termed acutely toxic. Chronic toxicity relates to concentrations of pollutants that will kill or adversely affect aquatic organisms over long time periods (time periods that are a substantial portion of the natural life expectancy of an organism).*

[d] *1973-2018; Chloride concentrations have been consistently increasing across the region, and current chloride concentrations are likely higher.*

[e] Wisconsin Administrative Code *Chapter NR 102, Water Quality Standards for Wisconsin Surface Waters, November 2010.*

[f] *Values collected, during growing season (June 1 through August 31) 1972-2013 for Chlor-a, 1972-2016 for total phosphorus; for water clarity, values based on combined east and west basins annual average 1972-2016.*

[g] *Oxygen concentrations and temperatures vary with depth and season. Median values provide little insight to understand lake conditions.*

[h] *U.S. Environmental Protection Agency*, Ambient Water Quality Criteria Recommendations: Information Supporting the Development of State and Tribal Nutrient Criteria: Lakes and Reservoirs in Nutrient Ecoregion VII, *EPA 822-B-00-009, December 2000.*

Source: Wisconsin Department of Natural Resources, Wisconsin

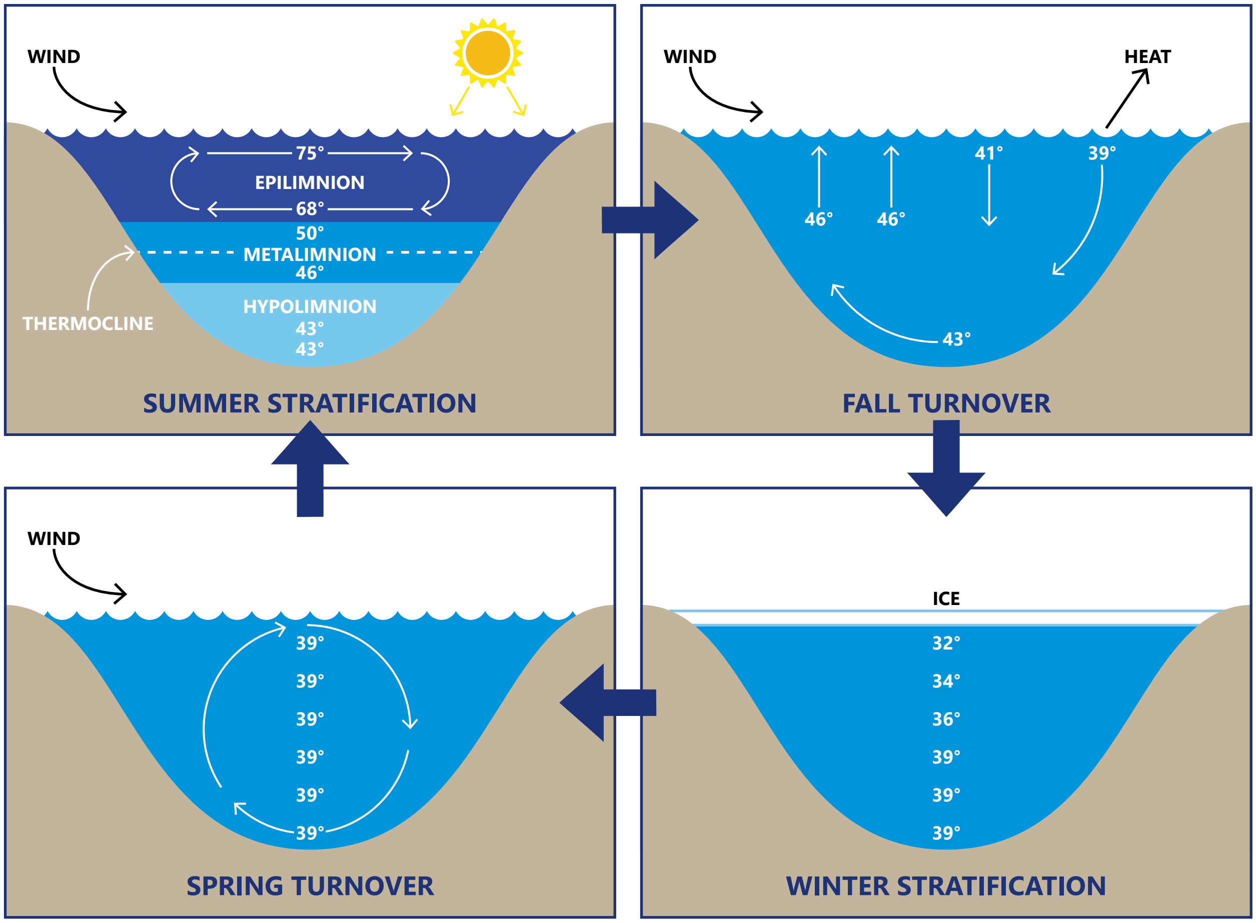
important to understand certain lake characteristics that provide context and meaning to the data. These lake characteristics include:

1. **A lake's residence time**—Residence time helps determine how quickly pollution problems can be resolved.

2. **Whether the lake stratifies and, if it does, when the lake mixes**—Stratification refers to a condition when the temperature difference (and associated density difference) between a lake's surface waters (the *epilimnion*) and the deep waters (the *hypolimnion*) is great enough to form thermal layers that can impede mixing of gases and dissolved substances between the two layers (see Figure 2.23).

3. **Whether internal loading is occurring**—*Internal loading* refers to release of phosphorus stored in a lake's bottom sediment under certain water quality conditions associated with stratification. Additional phosphorus loading can lead to increased plant and algal growth. If this is occurring, a water quality management plan may focus on in-lake phosphorus management efforts in addition to preventing polluted runoff from entering the lake.

Figure 2.23
Typical Seasonal Thermal Stratification Within Deeper Lakes



Source: Modified from B. Shaw, C. Mechenich, and L. Klessig, Understanding Lake Data, *University of Wisconsin-Extension, p. 3, 2004 and SEWRPC*

4. **The lake's current and past trophic status**—Lakes are commonly classified according to their degree of nutrient enrichment, or trophic status. The ability of lakes to support a variety of recreational activities and healthy fish and other aquatic life communities is often correlated with the lake's degree of nutrient enrichment. Three terms are generally used to describe the trophic status of a lake: oligotrophic (nutrient poor), mesotrophic (moderately fertile), and eutrophic (nutrient rich) (see Figure 2.24). Each of these states can happen naturally. Lakes tend to naturally shift to a more nutrient-rich state, a progression sometimes referred to as "aging" (see Figure 2.25). However, if a lake rapidly shifts to a more eutrophic state, human-induced pollution may be responsible for this change. An indicator of severe human pollution is when a lake displays "hyper-eutrophic" nutrient levels, a condition indicating highly enriched water (see Figure 2.26). Hyper-eutrophic conditions do not commonly occur under natural conditions, and are nearly always related to human pollutant sources.

5. **Lake tributary area/type**—Lakes with large tributary streams commonly receive larger sediment and nutrient loads than lakes that are fed primarily by precipitation or groundwater. The type of land use in the watershed greatly effects the pollutant loads carried by tributary streams. Lakes that are fed primarily by tributary streams are labeled drainage lakes.

Historical Data

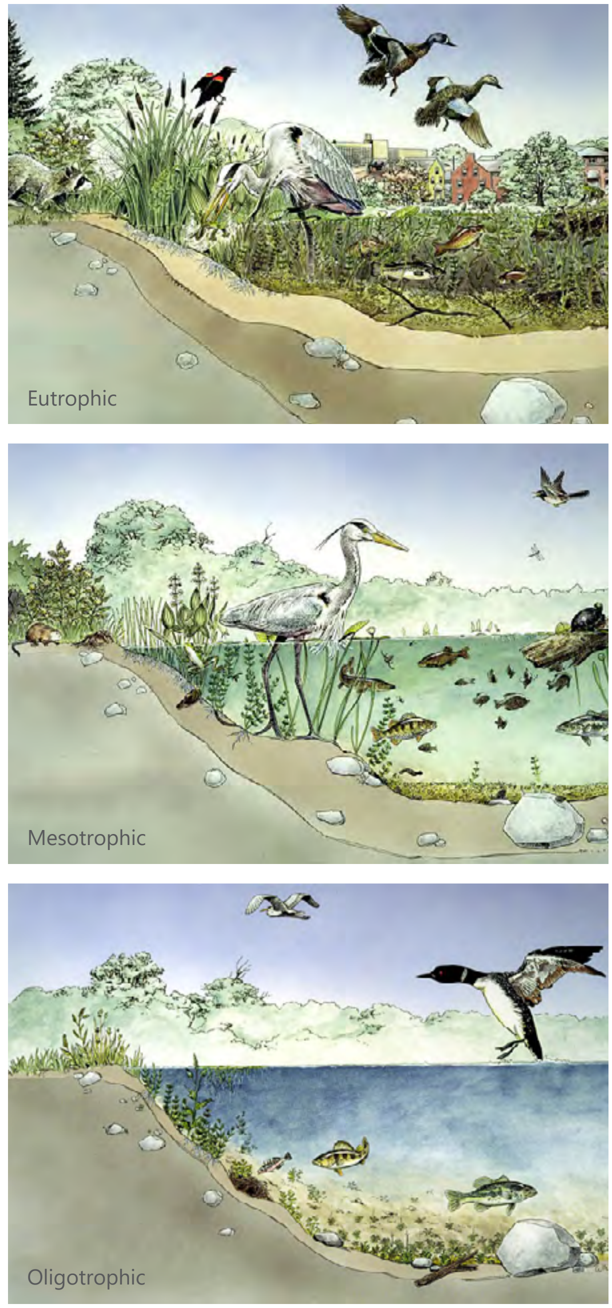
Pewaukee Lake has one of the longest running and most complete water quality records in Southeastern Wisconsin, dating from the turn of the previous century to the present day (i.e., over one hundred years). The earliest known water quality data for Pewaukee Lake dates back to the early 1900s, when Edward

Birge and Chancey Juday, widely-recognized pioneering lake researchers from the University of Wisconsin, collected basic information on the Lake.[80] The Wisconsin Conservation Department, now the Wisconsin Department of Natural Resources (WDNR), collected water chemistry data for Pewaukee Lake in 1944, 1946, and 1950, and between 1963 and 1966. Additional data were included in the 1963 WDNR Report, *Surface Water Resources of Waukesha County*,[81] and other data are included in miscellaneous WDNR file data and reports. The WDNR periodically monitored Pewaukee Lake's water quality between 1972 and 1981, and, under the auspices of their Long-Term Trend Monitoring Program, from 1986 to the present day.[82] During 1983, the WDNR published a compendium of water quality data for lakes in Wisconsin that allows the Lake's water quality to be contrasted to similar or nearby lakes.[83] Sediment core samples were collected by the WDNR from the lake bottom during 1994 that revealed increased sedimentation rates dating back to the 1920s.

State agencies are not the only organizations collecting water quality information at Pewaukee Lake. From 1986 through 1992, Pewaukee Lake residents participated in the WDNR Self-Help Lake Monitoring Program in which volunteers regularly collected and recorded basic water quality data and submitted their records to the WDNR for storage and compilation. The LPSD began monitoring water clarity with a Secchi disk in 1992. This monitoring effort has expanded over the years, and now includes biweekly temperature and oxygen profiles in both the east and west basins.

As illustrated in Map 2.19, water quality samples have been collected in Pewaukee Lake (east and west basins) and its three main tributaries: Coco Creek, Meadowbrook Creek, and Zion Creek. The primary sampling site for the Lake has historically been the "deep hole" in the west basin of the Lake. Water quality data from the shallow east basin of Pewaukee Lake are also included in this report to the extent such sampling has occurred.

Figure 2.24
Comparison of Lake Trophic Status



Source: UW-Extension Lakes Program and SEWRPC

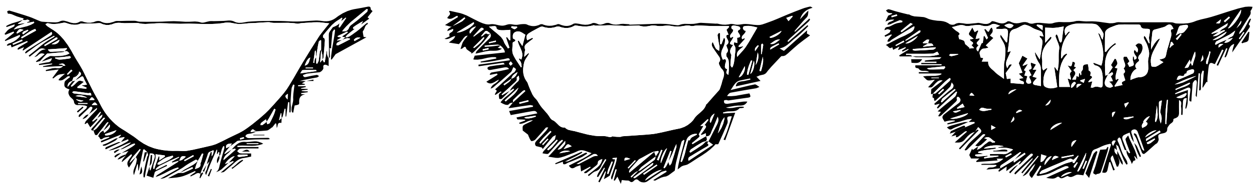
[80] *E.A. Birge and C. Juday,* The Inland Lakes of Wisconsin: The Dissolved Gases and their Biological Significance*, Wisconsin Geological and Natural History Survey Bulletin No. XXII, 1911.*

[81] *R.J. Poff and C.W. Threinen,* Surface Water Resources of Waukesha County*, Wisconsin Conservation Department, p. 69, 1963.*

[82] *Wisconsin Department of Natural Resources,* Pewaukee Lake, Waukesha County: Long-Term Trend Lake, 1986, *1986; Wisconsin Department of Natural Resources,* Pewaukee Lake, Waukesha County: Long-Term Trend Lake, 1987, *1987; E. R. Schumacher, Wisconsin Department of Natural Resources Fish Management Report No. 131,* Creel Survey on Pewaukee and Nagawicka Lakes, Waukesha County, Summer 1982, *February 1987; and Wisconsin Department of Natural Resources,* Pewaukee Lake Sensitive Area Study, *June 1994.*

[83] *Lillie and Mason, 1983, op. cit.*

Figure 2.25
Lake Aging's Effect on Trophic Status



OLIGOTROPHIC

- Clear water, low productivity
- Very desirable fishery of large game fish

MESOTROPHIC

- Increased production
- Accumulated organic matter
- Occasional algal bloom
- Good fishery

EUTROPHIC

- Very productive
- May experience oxygen depletion
- Rough fish common

Source: Modified from B. Shaw, C. Mechenich, and L. Klessig, Understanding Lake Data, *University of Wisconsin-Extension, p. 5, 2004 and SEWRPC*

At present, at least ten local government entities/non-profit organizations work to improve the water quality of the Lake. These include the following organizations and programs:

- Lake Pewaukee Sanitary District – aquatic plant harvesting, water quality monitoring, storm-water management, sensitive land preservation, sanitary services
- Town of Delafield – harvesting and wetlands programs
- City of Pewaukee – aquatic plant harvesting, wetland programs, and potentially stream restoration
- Village of Pewaukee – aquatic plant harvesting site share/pile pickup share, outlet dam operation
- Pewaukee River Partnership – stream monitoring, native plant sales
- Pewaukee Women's Club – prairie restoration and plantings
- Pewaukee Kiwanis – volunteers, student restoration work
- Pewaukee Waterski Club – donations to wetland/water resource funds/grants
- Pewaukee Chapter of Walleyes for Tomorrow – habitat and fisheries improvement efforts
- Waukesha County – MSA Education and Information Program

Temperature, Oxygen, and Stratification

During summer, many Wisconsin lakes (especially those with water depths greater than 20 feet) experience a layering of their waters known as "stratification" (see Figure 2.23, "summer stratification"). As summer progresses and surface waters warm, a difference in water temperature and density form a barrier between the shallow and deep waters. This barrier is comprised of a temperature gradient known as the *thermocline* (sometimes called the "metalimnion"), characterized by approximately 0.5°F of change per foot of water depth. The thermocline separates the warmer, less dense, upper layer of water (called the *epilimnion*) from the cooler, more dense, lower layer (called the *hypolimnion*). The thermocline is generally found somewhere between 10 and 30 feet below the surface, with the depth varying by lake, month, and year. As air temperatures go through seasonal warming and cooling cycles, lake waters experience resultant warming and cooling, leading to alternating periods of seasonal stratifications. Although stratification is more typical in summer, it does occur (usually weakly) in winter as well. In between these seasonal stratifications, the lake undergoes de-stratification or "mixing," which typically occurs in spring (called the "spring overturn") and fall (or "fall overturn"). The degree to which a lake "stratifies" has a major impact on both the chemical and biological activity in a lake, as well as the lake's water quality.

Temperature and DO profiles from data spanning nearly five decades were assembled for Pewaukee Lake; seasonal profiles based on this data are presented in Figure 2.28 for the east basin and Figure 2.29 for the west basin (see explanation of boxplot symbols in Figure 2.27).[84] Pewaukee Lake is a dimictic lake, meaning it completely mixes twice a year and is subject to thermal stratification during summer and winter, particularly in the west basin. The west basin profiles suggest that by August, the Lake is stratified with the thermocline established at depths of 23 to 32 feet in most years. During the spring and fall turnover, the lake has a generally uniform temperature throughout all depths. Winter stratification, although not readily apparent in Figure 2.29, may occur to a minor extent; however, winter profiles would have to be collected for confirmation. Conversely, the absence of stratification in the east basin of the Lake is confirmed through a similar comparison as shown in Figure 2.28. The lack of a defined thermocline in the east basin during summer is not surprising given this basin's shallow depth.

Figure 2.26
Potential Appearance of a Hyper-Eutrophic Lake

Source: University of Wisconsin-Stout and SEWRPC

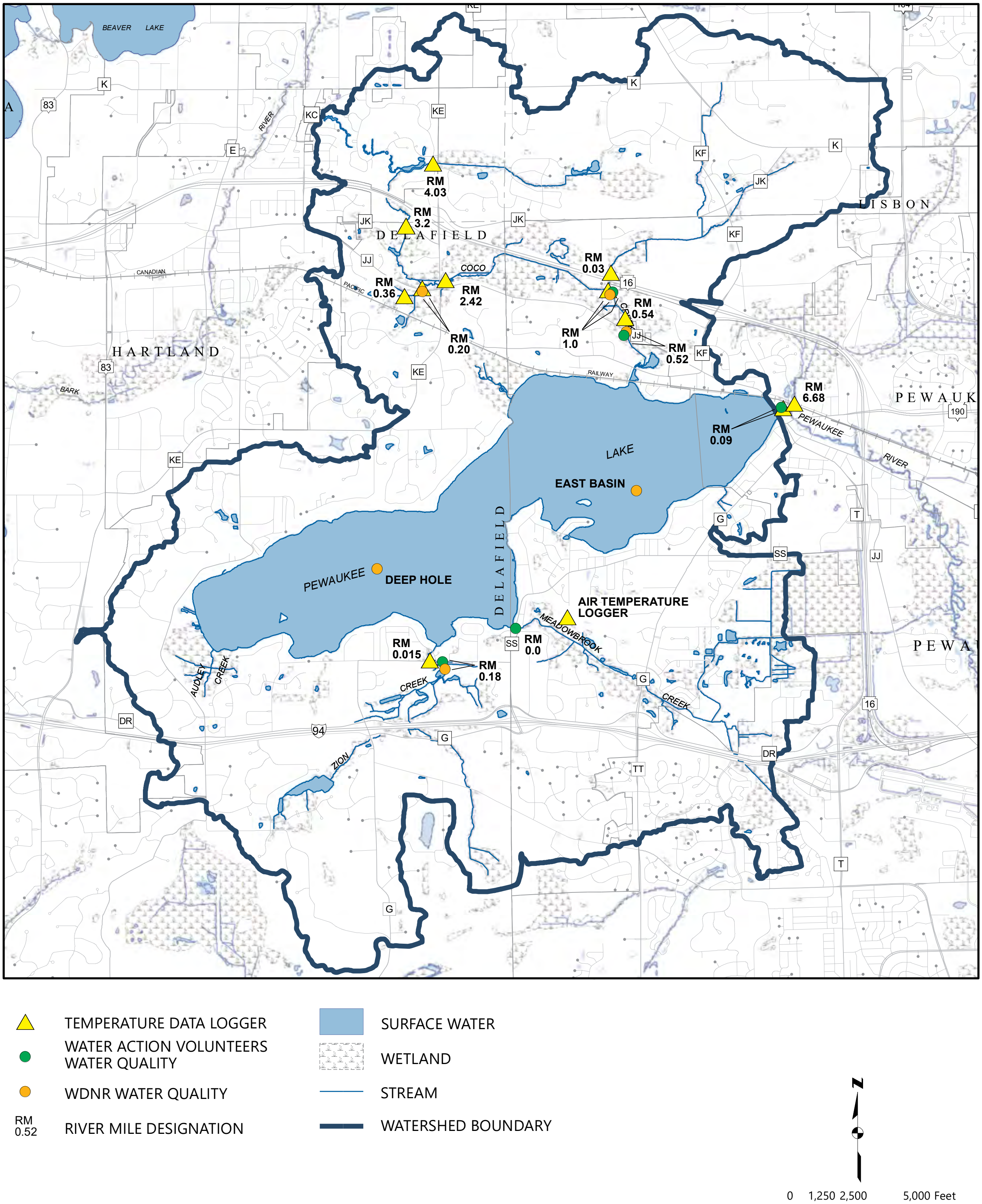
Dissolved oxygen (DO) levels are one of the most critical factors affecting the living organisms of a lake ecosystem. DO is generally higher at the surface of a lake where there is an interchange between the water and atmosphere, stirring by wind action (which aids in the process of diffusion of atmospheric oxygen into the surface waters at the air-water interface), and production of oxygen by plant photosynthesis. However, if a lake thermally stratifies during summer, the thermocline prevents oxygen-rich surface (epilimnion) waters from freely mixing with water in deeper portions (hypolimnion) of the lake. Meanwhile, metabolic processes that consume oxygen continue to occur in the hypolimnion throughout the summer. If oxygen demands in the hypolimnion during this time are high (such as in a nutrient-rich lake) or if the volume of isolated hypolimnetic water is small (limiting oxygen storage potential), oxygen levels in the deep portions of lakes generally begin to decline as summer wears on. A minimum DO concentration of 5 mg/l is considered necessary for survival of most species of fish. In many Southeastern Wisconsin lakes, as summer progresses, oxygen concentration in water below the thermocline may be reduced to less than 1.0 mg/l—a condition known as *anoxia*. Fortunately for fish and other oxygen-dependent organisms in the lake, oxygenated surface waters are able to mix throughout all depths of the lake when the thermocline breaks down during the fall and spring overturns.

Comparing DO profiles to the seasonal temperature profiles reveals the close relationship between DO and temperature, as governed by thermal stratification. In the west basin, the deepest portions of Pewaukee Lake commonly have less oxygen than surface water in all seasons, particularly during summer and winter stratification. Deep water anoxia is a common occurrence in stratified lakes and has been observed in approximately half of all Wisconsin lakes that are deep enough to thermally stratify.[85] By June, summer stratification develops and results in depleted oxygen levels below 23 feet depth (the level of the thermocline) with anoxic conditions at the 40-foot depth and below. Anoxia conditions are closest to the surface in July and August, with depths as shallow as 25 feet and below. During these periods, approximately 15 percent of the Lake's total water volume cannot support fish and most other desirable aquatic life (Figure 2.30) and anoxic waters cover about 450 acres of the Lake's bottom (Figures 2.31 and 2.32). More recently, anoxia has been occurring at shallower depths; however, the number of anoxic days has been decreasing (see Table 2.15). Anoxic conditions change annually based on fluctuations in temperature, precipitation, and supply of nutrients, as shown in (Figure 2.33). The east basin of Pewaukee Lake, which weakly stratifies, has been observed to develop anoxia in late summer and early fall.

[84] *Note that in Figure 2.29, there have been no new data collected during the winter season since the last report in 2003.*

[85] Lillie and Mason, 1983, *op. cit*.

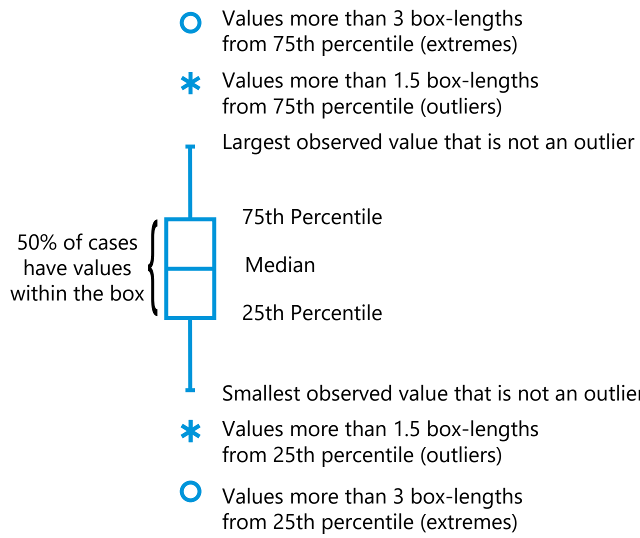
Map 2.19
Water Quality Monitoring Sites Within the Pewaukee Lake Watershed



Source: Water Action Volunteers, Wisconsin Department of Natural Resources, and SEWRPC

Fall turnover, between September and October in most years, naturally restores the supply of oxygen to the bottom water as the Lake becomes fully mixed. When mixed, oxygen concentrations vary little with depth and the Lake is capable of supporting aquatic life present at essentially all depths above 40 feet. However, winter stratification can also cause hypolimnetic anoxia to establish. Winter anoxia is more common during the years of heavy snowfall, when snow covers the ice, reducing the degree of light penetration and reducing algal photosynthesis that takes place under the ice. Winter DO concentrations in the west basin hypolimnion have historically fallen below the 5 mg/l level, indicating near anoxic conditions. However, a relatively large volume of the Lake retained adequate DO concentrations to sustain fish populations throughout the winter. At the end of the winter, DO concentrations in the bottom waters of the Lake have been restored during the period of spring turnover as the Lake is usually fully mixed by March or April.

Figure 2.27
Explanation of Symbols in Boxplot Figures



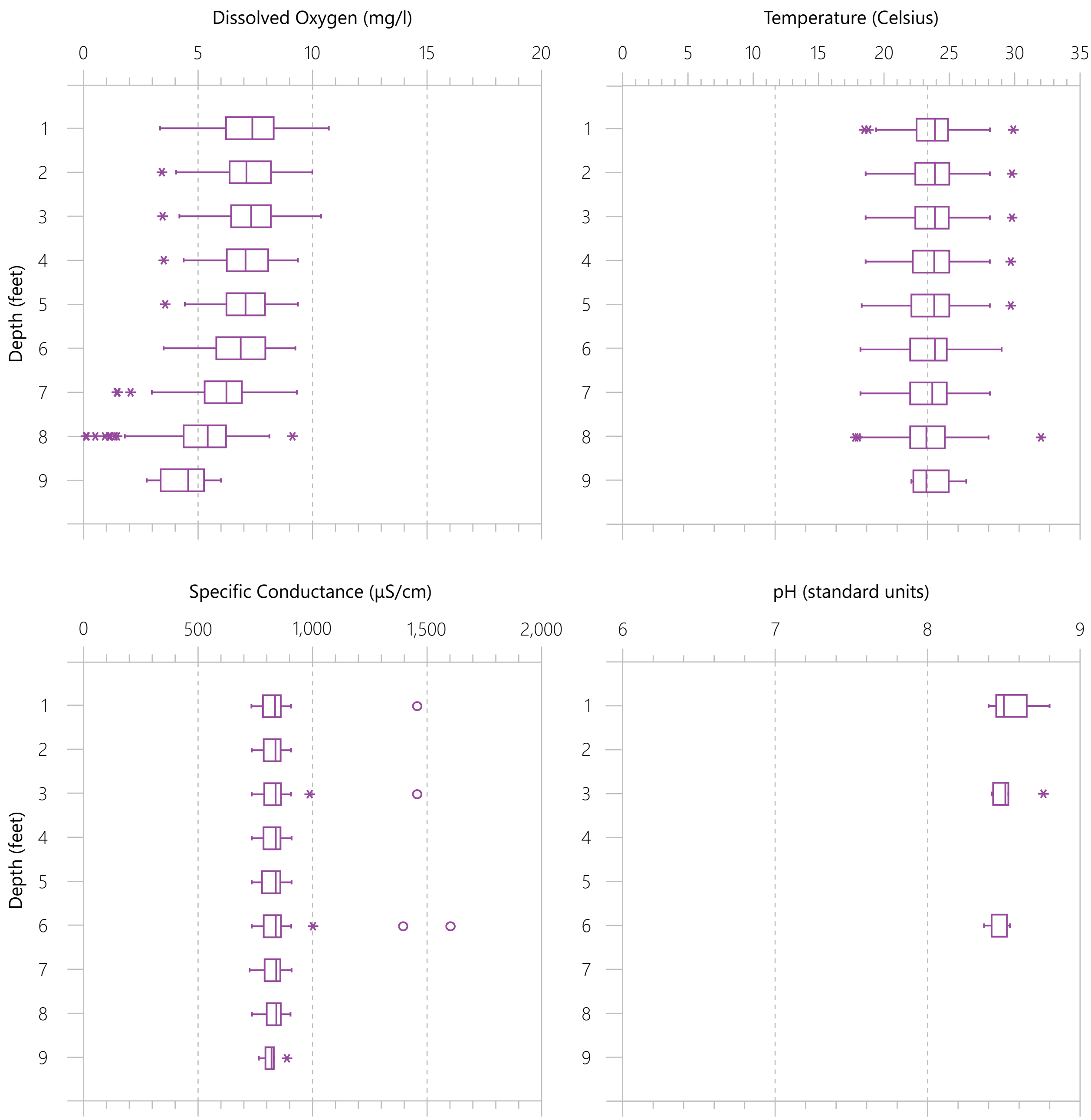
Source: SEWRPC

Temperature and oxygen profiles have noticeably changed over the period of available record. Figure 2.29 profiles show the distribution of temperature and oxygen concentrations for two time periods: data collected between 1972 and 2010, and data collected between 2011 and 2017. Reviewing these profiles, it becomes evident that the Lake's shallower areas are now much warmer in late spring before the Lake stratifies, but that this difference diminishes by late summer. The available data demonstrate that Pewaukee Lake has developed anoxia in its hypolimnion since at least 1972. In the west basin, the frequency of anoxic conditions has decreased over the period of record, with the 62 percent fewer anoxic days recorded in 2010 to 2015 than in 1972 to 2010. The east basin, however, developed anoxia at a depth of only 8 feet in early fall of 2012 and late summer of 2013. The DO data for this basin is extremely limited with more data required to determine how often this occurs.

Hypolimnetic anoxia can affect the concentrations of nutrients, such as phosphorus, in a lake's waters. Phosphorus is typically not particularly soluble in water, and often adheres to particles that settle to the lake-bottom. When bottom waters become void of oxygen, the activities of decomposer bacteria in the bottom sediments, together with certain geochemical reactions that occur only in the complete absence of oxygen, can allow phosphorus in plant remains and lake-bottom sediment to dissolve into the water column. This allows phosphorus that is otherwise trapped in deep lake-bottom sediment to be released into lake water. This release of phosphorus is referred to as "internal loading". The released phosphorus can then mix into the water column during the next turnover period, fueling plant and algae growth. Since the west basin of Pewaukee Lake does stratify, internal loading of phosphorus is a potential concern. For information on current internal loading conditions, refer to the internal loading discussion in Section 2.6, "Pollutant Loads."

Hypolimnetic anoxia can also affect fish populations. Depleted oxygen levels in the hypolimnion cause fish to move upward, nearer to the surface of the lakes, where higher DO concentrations exist. This migration, when combined with temperature, can select against some fish species that prefer the cooler water temperatures that generally prevail in the lower portions of the lakes. When there is insufficient oxygen at these depths, these fish are susceptible to summer kills, or, alternatively, are driven into the warmer water portions of the lake where their condition and competitive success may be severely impaired. In the 2002 survey of Pewaukee Lake, DO concentrations in the surface waters ranged from about 17.6 mg/l during winter to about 5.0 mg/l in the summer; hypolimnetic DO concentrations dropped to zero by mid- to late-June. Even at a depth of approximately 30 feet, oxygen concentrations were at or below the recommended minimum 5 mg/l level necessary to support many fish species.

Figure 2.28
Summer (June-August) Dissolved Oxygen, Temperature, Specific Conductance, and pH Profiles: Pewaukee Lake East Basin 2012-2017

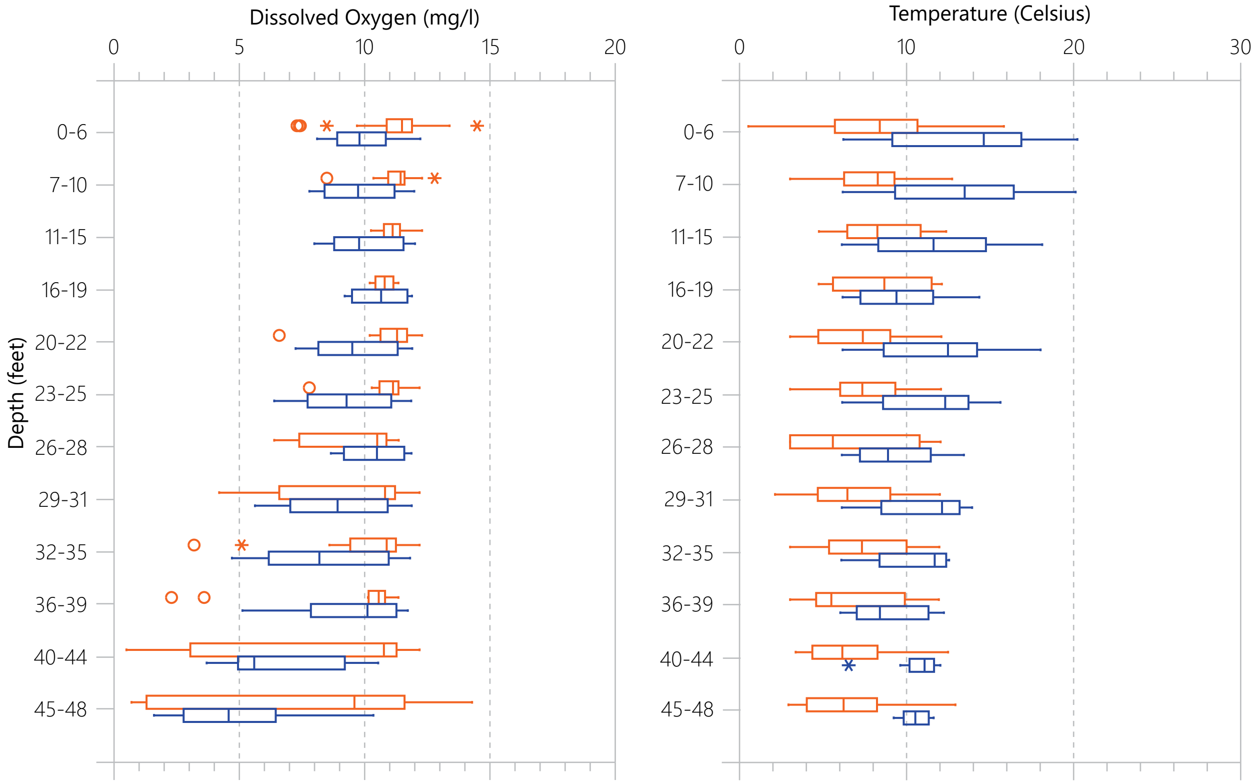


Source: Pewaukee Lake Sanitary District, Wisconsin Department of Natural Resources, and SEWRPC

Up to this point, the discussion of oxygen in lakes has focused on the DO concentration, as measured in mg/l. However, there is another important measure involving oxygen in water: oxygen *saturation*, expressed as a percent. Oxygen saturation refers to the concentration of oxygen measured in water compared to a concentration in equilibrium with the atmosphere at a given temperature; simply put, it is a *ratio* of the amount of oxygen actually dissolved in water to the total amount of oxygen that is possible to be held in that water at a given temperature and pressure. For example, if a sample of water at a given temperature is holding 5 mg/l of oxygen, but is capable of holding 10 mg/l of oxygen at that temperature, the water is said to be at 50 percent saturation—it is holding only half of what it is capable of holding at that temperature and pressure.

Figure 2.29
Pewaukee Lake Seasonal Dissolved Oxygen and Temperature Profiles: Pre-2010 and Post-2010

Spring (March-May)



Summer (June-August)

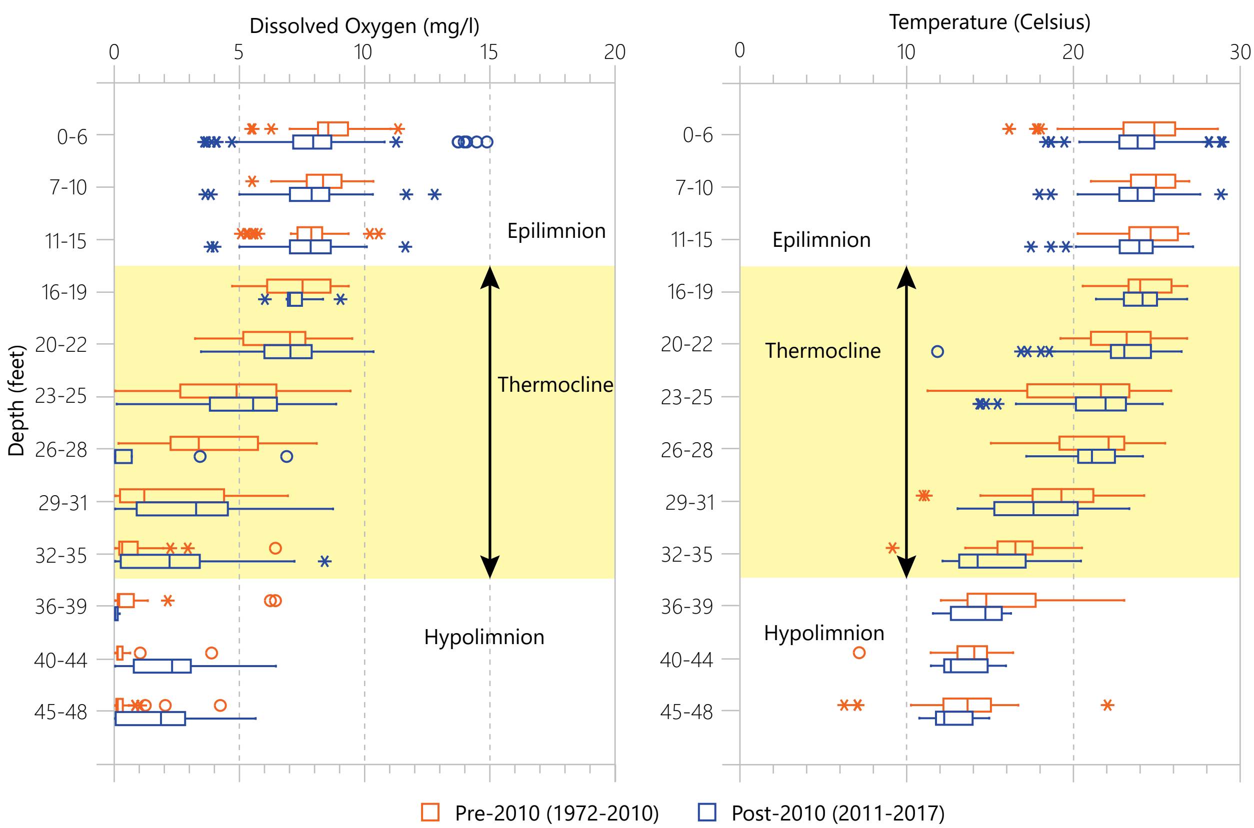
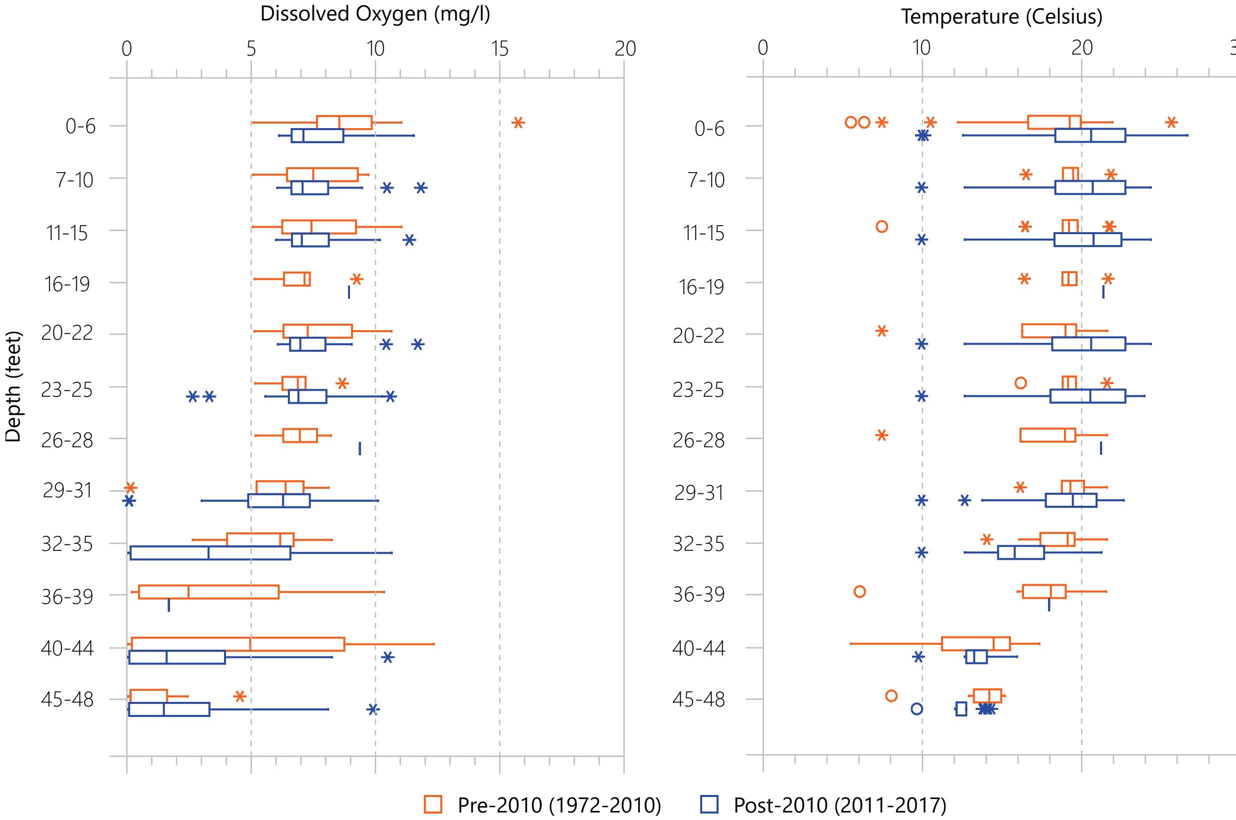


Figure 2.29 (continued)

Fall (September-November)



Note: The maximum concentration of dissolved oxygen in 0 degree celsius water is 14.6 mg/L. Values higher than this range suggest oxygen supersaturation or inaccurate instrument readings.

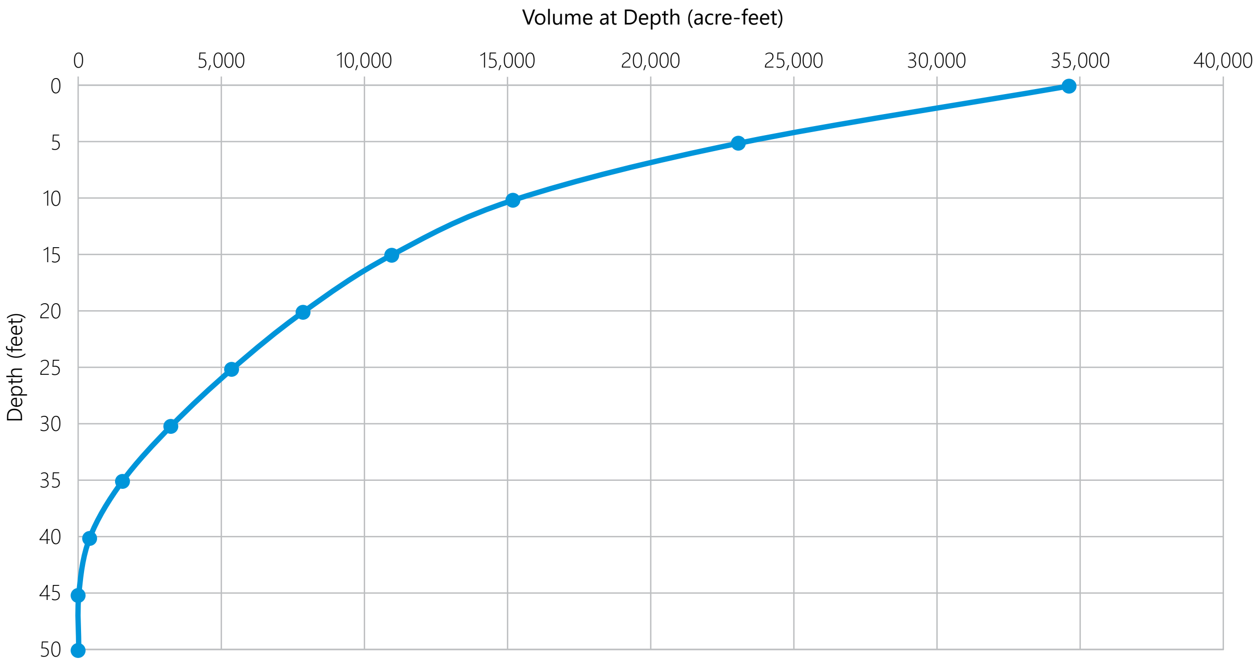
Source: Pewaukee Lake Sanitary District, Wisconsin Department of Natural Resources, and SEWRPC

Warm water holds less oxygen than cold water; consequently, warm water becomes oxygen-saturated at lower concentrations of DO than cold water. For example, at 90 percent saturation, water at 70°F will hold about 8 mg/l of DO while water at 50°F will hold over 10 mg/l of DO at the same saturation level of 90 percent.[86] During summer months, the warm waters at the surface of a lake may become saturated at relatively low DO concentrations. Thus, completely oxygen saturated warm waters can still have too little DO for fish, particularly cold-water species like trout. Additionally, oxygen saturation has its own consequences for aquatic life. Values between 90 and 110 percent saturation are generally considered desirable for aquatic life; however, supersaturation levels above 115 percent can be detrimental. Fish exposed to oxygen saturations greater than 115 percent can develop bubbles in their tissues (a condition similar to "the bends" experienced by deep-water divers).[87] Thus, under conditions of abnormally high surface temperatures in a lake, fish can become "squeezed" into an increasingly narrow range of depths between supersaturated surface waters above and an anoxic hypolimnion below. In addition, oxygen saturation can also fluctuate diurnally. Many waterbodies that experience oxygen supersaturation during the day can also experience low oxygen saturation levels at night, as oxygen-consuming activities such as respiration and decomposition occur at night without oxygen-producing photosynthesis. Such conditions are stressful to aquatic organisms and can also lead to fish kills in summer.

[86] *USGS DOTABLES at water.usgs.gov/software/DOTABLES.*

[87] *Supersaturation refers to a condition when the amount of dissolved substance exceeds the substance's maximum solubility in the solvent under normal circumstances. Such conditions are typically unstable. Dissolved gas comes out of water as bubbles.*

Figure 2.30
Water Depth Versus Lake Volume: Pewaukee Lake



Note: This graph relates the volume of water found at or above a certain lake depth. For example, roughly 15,000 acre-feet of the Lake volume is found in areas equal to or less than the upper 10 feet of the Lake's water column.

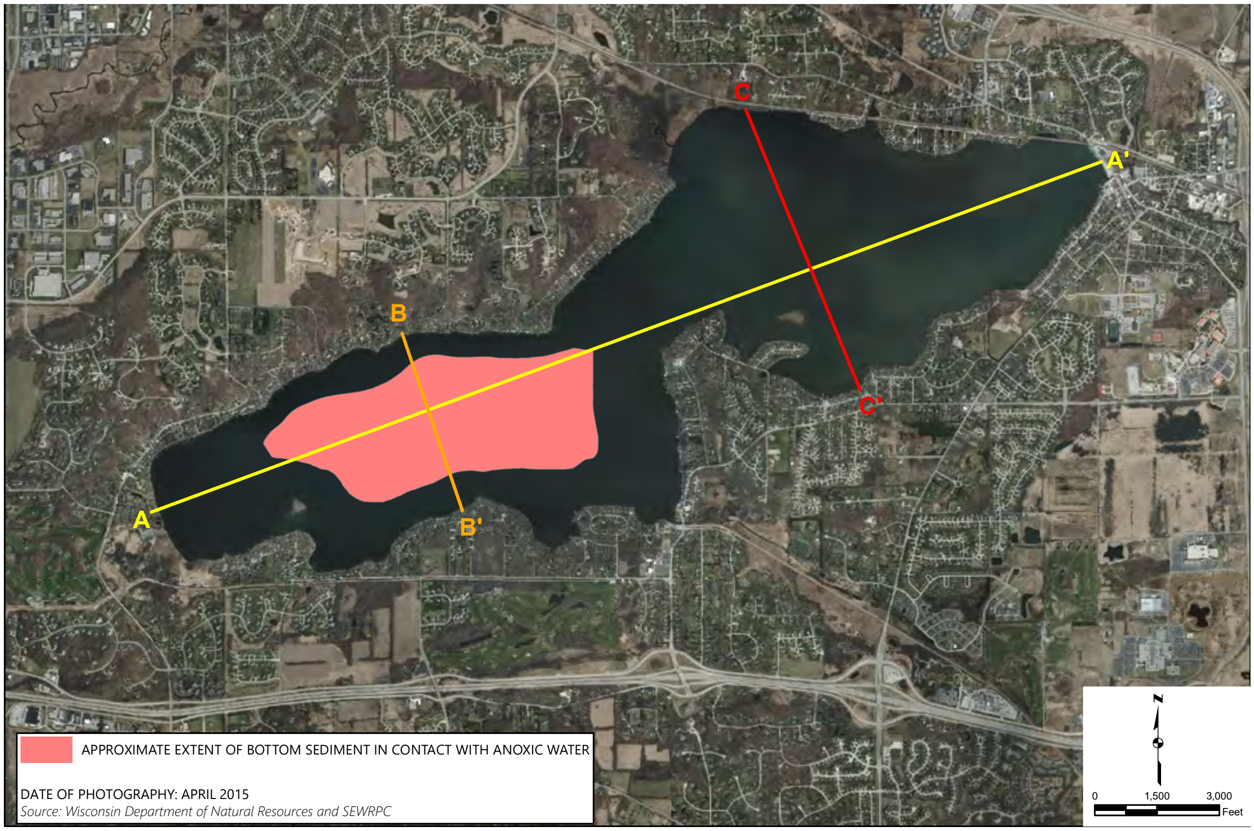
Source: Wisconsin Department of Natural Resources and SEWRPC

Daytime oxygen saturation profiles for the west basin of Pewaukee Lake during the spring and summer of 2014, 2015, and 2016 are presented in Figure 2.34. From these profiles, it would appear that percent saturation of oxygen in the Lake is generally at levels supportive of fish (90-110 percent), especially in the shallower depths of the Lake above the thermocline, with no periods of supersaturation in spring or summer. No such profiles have been collected at nighttime, but the lack of supersaturation indicates low likelihood of nighttime oxygen levels becoming critically low for fish. However, as also shown in these profiles, the oxygen saturation percentages decrease dramatically in the deeper depths below the thermocline from late spring to summer, which, when considered with the measured levels of DO below the 5 mg/l threshold (as presented in Figure 2.29), supports the interpretation that these low oxygen levels in the deeper waters of the Lake are limiting to fish and other oxygen-dependent aquatic life. Although chronic summer fish kills have not been reported for Pewaukee Lake, oxygen concentration profiles should be regularly and consistently measured, including profiles collected at night during the summer. Such proactive measures can detect early onset of oxygen supersaturation in daytime surface waters, or saturation levels peaking within or near the thermocline; both are conditions that could be suggestive of nutrient enrichment sourced in the hypolimnion and, as such, precursors to potential nighttime oxygen deficits.

Specific Conductance

Specific conductance is a measure of the ability of a liquid, such as lake water, to conduct electricity, standardized at a specific temperature (25°C). This ability is greatly dependent on the concentration of dissolved solids in the water: as the amount of dissolved solids increases, the specific conductance increases. During periods of thermal stratification, specific conductance can dramatically increase at the lake bottom due to an accumulation of dissolved materials trapped in the hypolimnion. Such a condition can lead to a significant concentration gradient, with higher conductance measurements in the deeper waters and lower conductance measurements in the surface waters. Such concentration gradients are a consequence of the "internal loading" phenomenon described previously.

Figure 2.31
Typical Extent of Pewaukee Lake's Bottom Sediment Covered with Anoxic Water During Late Summer



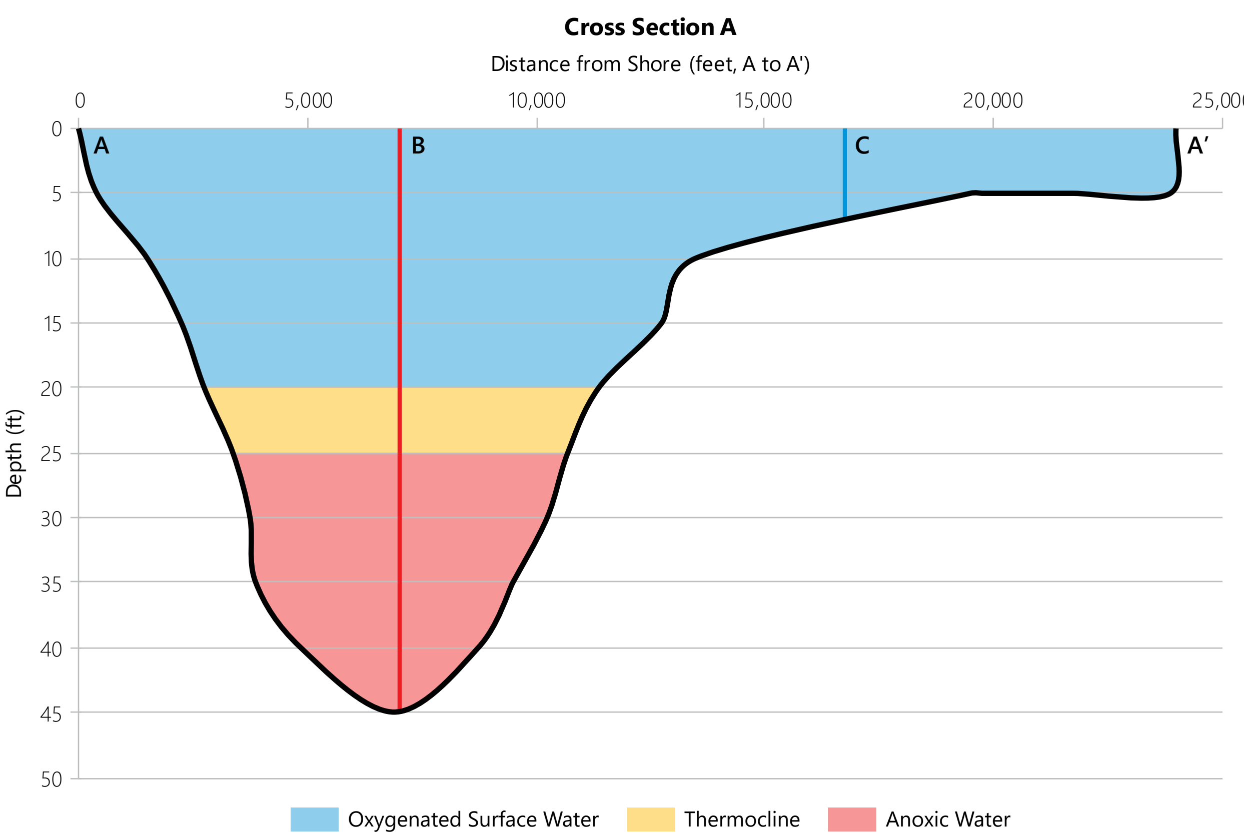
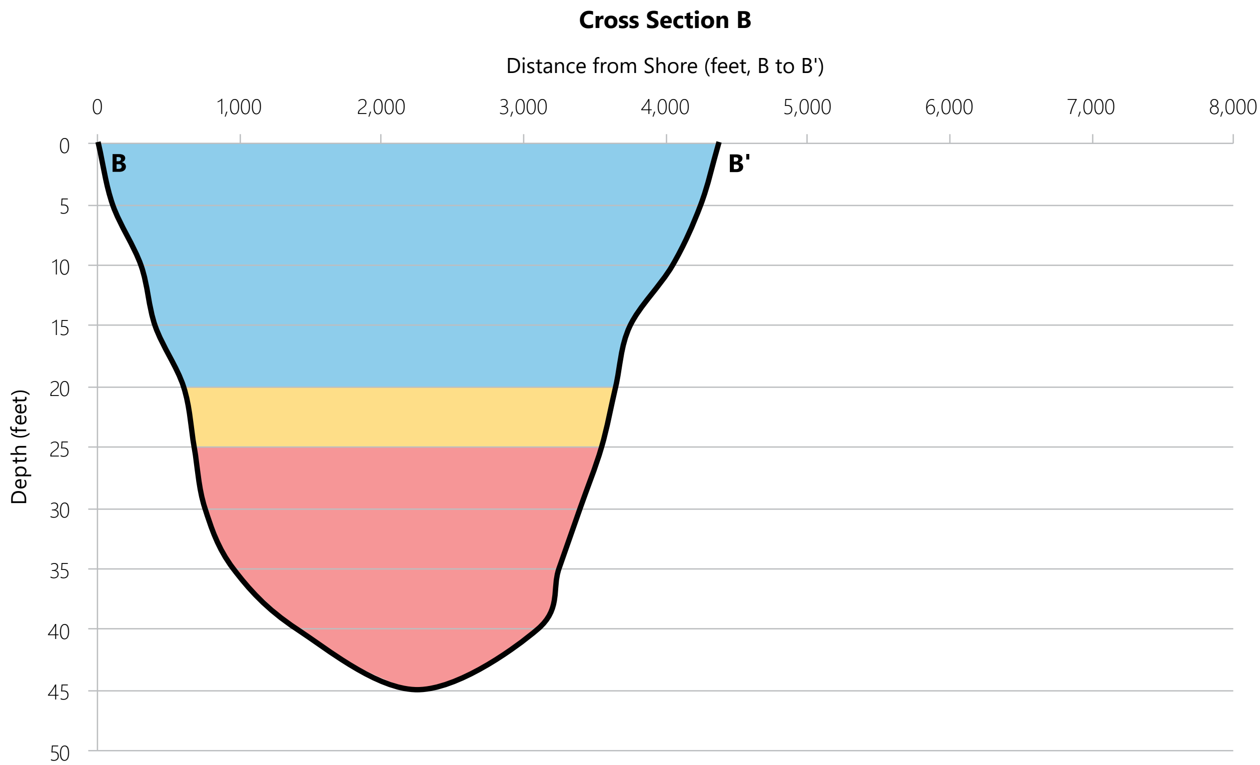
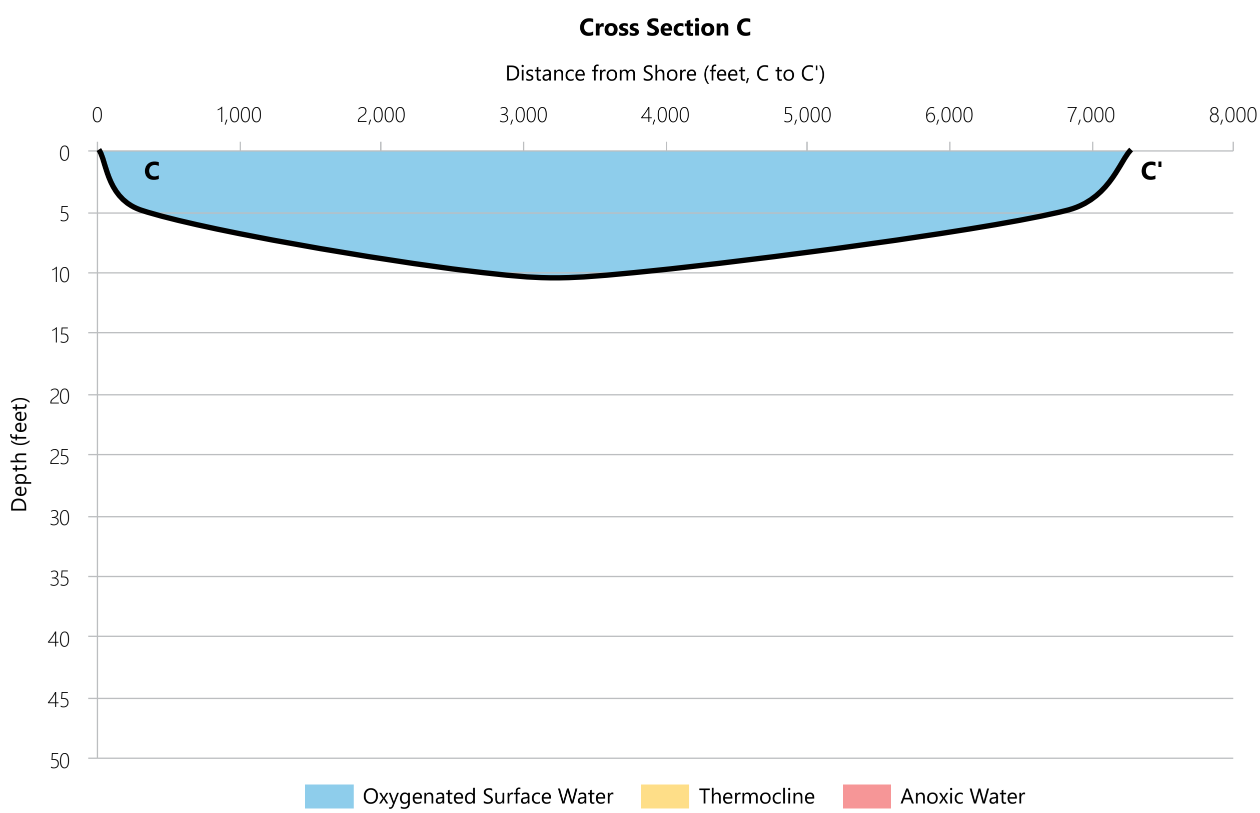


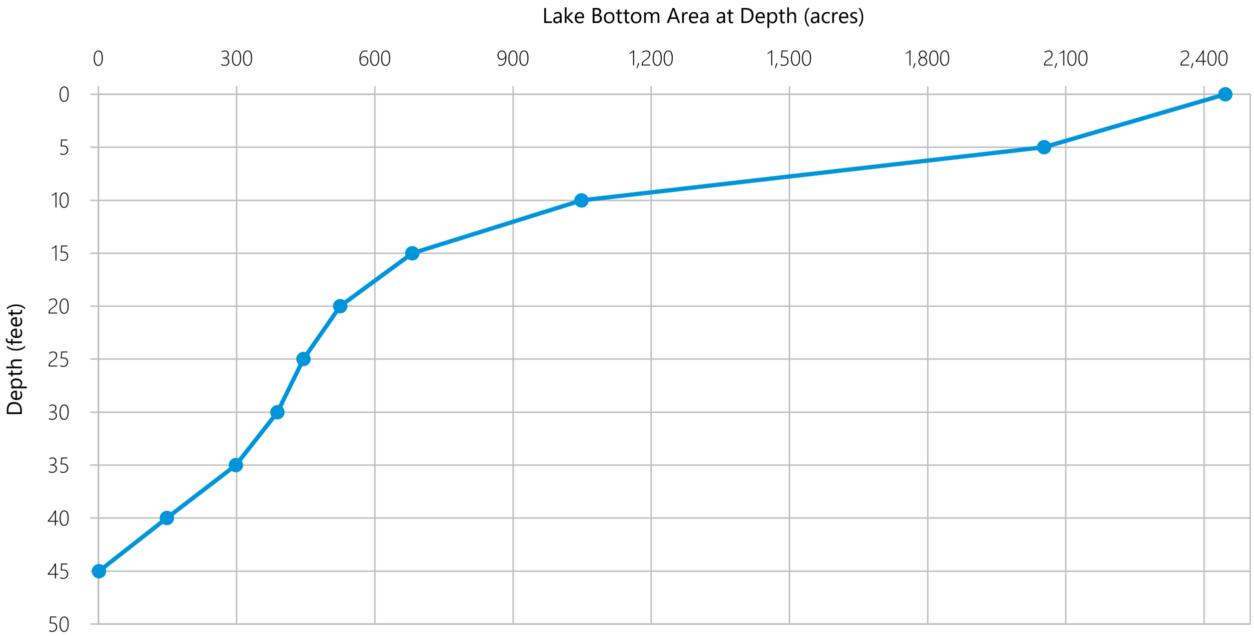
Figure 2.31 (continued)





Source: Wisconsin Department of Natural Resources and SEWRPC

Figure 2.32
Water Depth Versus Lake Area: Pewaukee Lake



Note: This graph relates the area of the Lake measuring at a prescribed depth. For example, roughly 400 acres of Pewaukee Lake's open water area is underlain by water at least 30 feet deep.

Source: Wisconsin Department of Natural Resources and SEWRPC

During the previous planning study,[88] significant surface to bottom conductivity gradients were observed, especially during the summer period. Although the relative levels of conductance were within the normal range for lakes in Southeastern Wisconsin[89], such gradients were interpreted at the time to be an indication that Pewaukee Lake did experience some degree of internal loading. Figure 2.35 presents seasonal specific conductance profiles for the west basin of Pewaukee Lake measured since the last study. The presented conductance gradients between shallow and deep water indicate that internal loading is likely still occurring.

pH and Acidity

The acidity of water is measured using the pH scale. The pH scale is a logarithmic measure of hydrogen ion (H+) concentration on a scale of 0 to 14 Standard Units (stu, or SU), with 7.0 indicating neutrality. Water with pH values lower than 7.0 stu has higher hydrogen ions concentrations and is more acidic, while water with pH values higher than 7.0 stu has lower hydrogen ion concentrations and is less acidic. Since the scale is logarithmic, each 1.0 pH change reflects a tenfold change in hydrogen ion concentration, e.g., a pH of 4 is *ten* times more acidic than a pH of 5 and a *hundred* times more acidic that a pH of 6. In Wisconsin lakes, pH can range anywhere from 4.5 in some acid-bog lakes to 8.4 in hard-water, marl lakes.[90]

Many chemical and biological processes are affected by pH, as are the solubility and availability of many substances. Different organisms are capable of tolerating different ranges of pH, with most preferring ranges between about 6.5 and 8.0 stu. Although moderately acidic (slightly below a pH of 7) does not usually harm fish, as pH drops to 6.5 or lower, some species can be adversely affected, especially during spawning. For example, at a pH of 6.5, walleye spawning can be inhibited; at a pH of 5.8, lake trout spawning is inhibited; and at a pH of 5.5, smallmouth bass disappear.[91] As pH continues lower, walleye, northern pike and other

[88] *SEWRPC Community Assistance Planning Report No. 58,* A Water Quality Management Plan for Pewaukee Lake, Waukesha county, Wisconsin, *March 1984.*

[89] *Lillie and Mason, 1983, op. cit.*

[90] *Wisconsin Department of Natural Resources, Byron Shaw, Christine Mechenich, and Lowell Klessig,* Understanding Lake Data*: www.uwsp.edu/cnr-ap/UWEXLakes/Documents/ecology/shoreland/background/understanding%20lake%20data.pdf.*

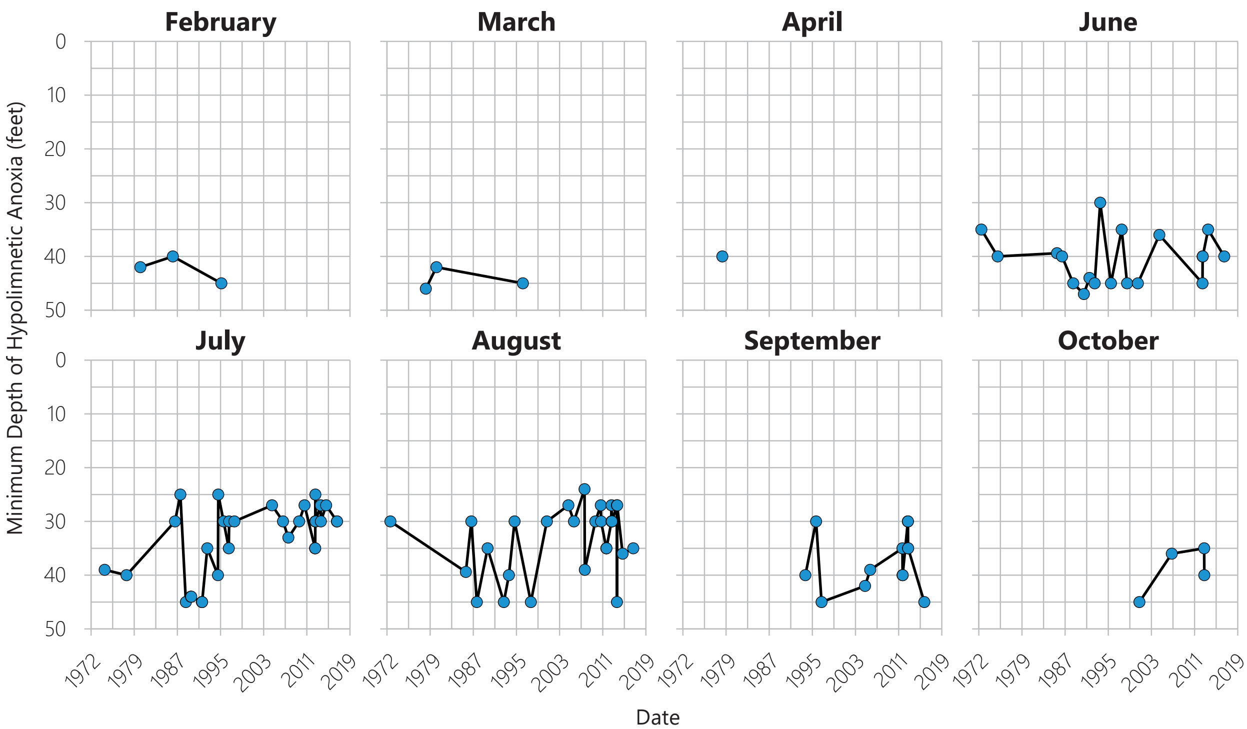
[91] *Ibid.*

Table 2.15
Pewaukee Lake Anoxia Frequency and Depth: Pre-2010 Versus Post-2010

	Pre-2010 (1972-2010)			Post-2010 (2011-2017)			Change: Pre-2010 vs Post-2010	
Month	Total No. Sample Dates	No. Anoxia Days (percent of total sample dates)	Mean Hypolimnetic Anoxia Depth (feet)	Total No. Sample Dates	No. Anoxia Days (percent of total sample dates)	Mean Hypolimnetic Anoxia Depth (feet)	Mean Depth (feet)	Occurrence of Anoxia (percent)
June	15	14 (93)	41	18	5 (28)	40	-1	-70
July	23	20 (87)	35	27	11 (41)	30	-5	-53
August	17	15 (88)	35	27	13 (48)	32	-3	-63
September	10	5 (50)	39	15	8 (53)	36	-3	7

Source: Wisconsin Department of Natural Resources and SEWRPC

Figure 2.33
Minimum Depth to Hypolimnetic Anoxia: Pewaukee Lake 1972-2017



Note: Anoxia is defined as a dissolved oxygen concentration of 1.0 mg/l or lower.

Source: Wisconsin Department of Natural Resources and SEWRPC

popular sport fishes gradually disappear and a pH of 3.0 is toxic to all fish.[92] In addition, many metals are more soluble in water with low pH than they are in water with high pH. Thus, toxicity of many substances for fish and other aquatic organisms can be affected by pH. Under low pH conditions, toxic metals, such as aluminum, zinc and mercury, can be released from lake sediment if present. At a pH of 5.0, aluminum is at its most poisonous, precipitating onto the gills of the fish in the form of aluminum hydroxide.[93]

Lakes have natural and man-made sources of acidity. Peat-bog lakes are naturally acidic due to the natural release of organic acids during decomposition; many such lakes are without fish.[94] Because of diffusion of carbon dioxide into water and associated chemical reactions, rainfall (in areas that are not impacted by air pollution) has a pH of about 5.6 stu; the pH of rainfall in areas where air quality is affected by oxides of nitrogen or sulfur tends to be lower. The mineral content of the soil and bedrock underlying a waterbody also has a strong influence on the waterbody's pH. Since carbonate bedrock, such as dolomite, underlies much of the Pewaukee Lake watershed, the pH in the Lake tends to be in the alkaline range between about 7.0 and 9.0 stu. Pollutants contained in discharges from point sources and in stormwater runoff can also affect a waterbody's pH. Further, photosynthesis by aquatic plants, phytoplankton, and algae can cause pH variations both on a daily and seasonal basis.

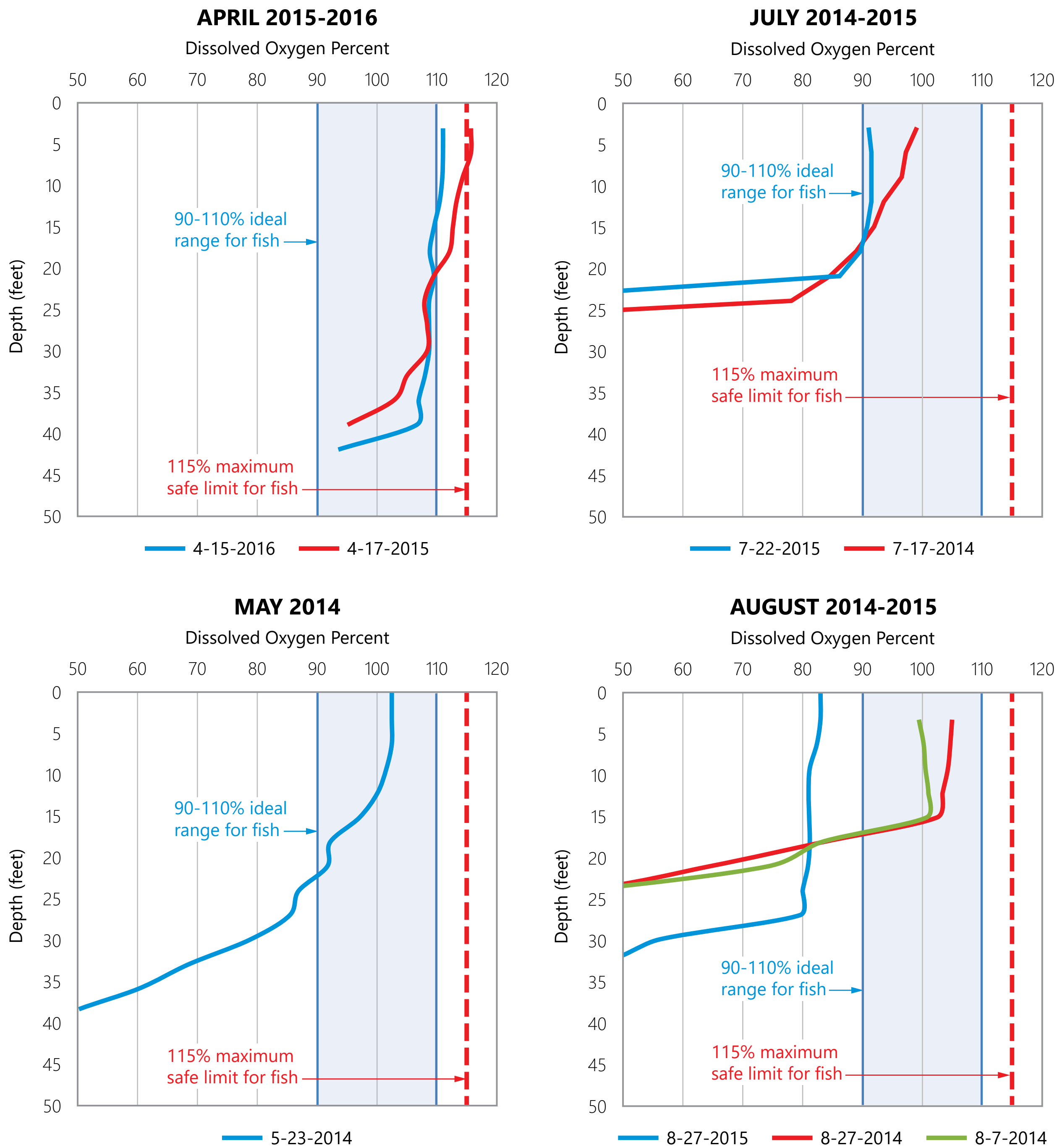
The pH of Pewaukee Lake ranges from 7.2 to 8.8, as determined from previous studies. Figure 2.35 shows seasonal profiles of pH measurements for Pewaukee Lake from 1972 to 2010 and 2010 to 2017. Lake pH has been quite stable; between 7.5 and 8.5 over the past 50 years (which is well within the range for warmwater fish and aquatic life – see Table 2.14). Like most lakes in Southeastern Wisconsin (mean pH

[92] *Ibid.*

[93] *www.air-quality.org.uk/13.php.*

[94] *T. Hellström, "Acidification in Lakes," In L. Bengtsson, R.W. Herschy, R.W. Fairbridge (eds.)* Encyclopedia of Lakes and Reservoirs*, 2012.*

Figure 2.34
Oxygen Saturation Profiles: Pewaukee Lake West Basin 2014-2017



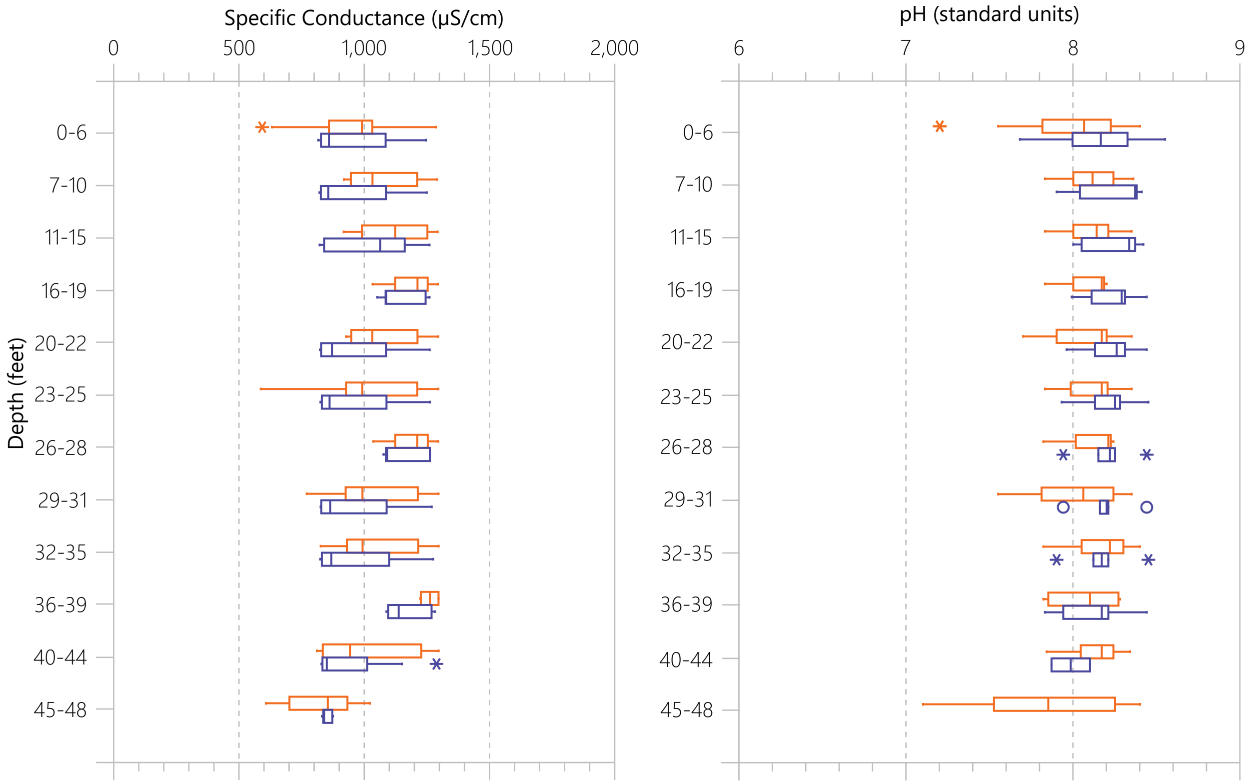
Source: Wisconsin Department of Natural Resources and SEWRPC

of 8.1), Pewaukee Lake is an alkaline waterbody.[95] However, concentrations within Pewaukee Lake did tend to be higher than 8.5 stu during the summer months. The summer pH profiles for the west basin clearly show the pH gradient created by the thermocline, an effect similar to that reflected in the summer profiles for conductivity, oxygen, and percent oxygen saturation. In summer, photosynthesis increases both lake DO concentrations and pH as algae and plants remove carbon dioxide from the water, raising pH, while oxygen is released as a byproduct of the photosynthetic reactions. Thus, summer and fall pH of Pewaukee Lake tends to be slightly higher than spring and winter pH.

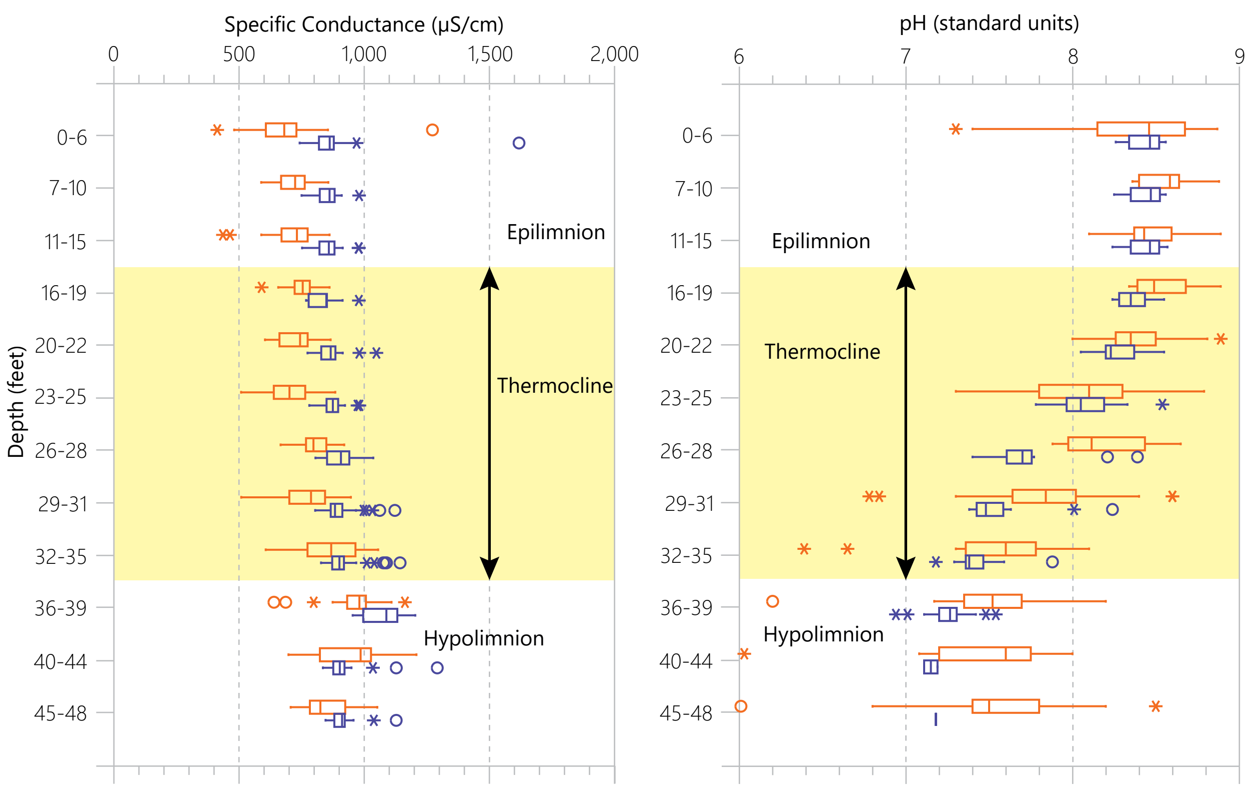
[95] *Lillie and Mason, 1983, op. cit.*

Figure 2.35
Seasonal Specific Conductivity and pH Profiles: Pewaukee Lake Pre-2010 and Post-2010

Spring (March-May)



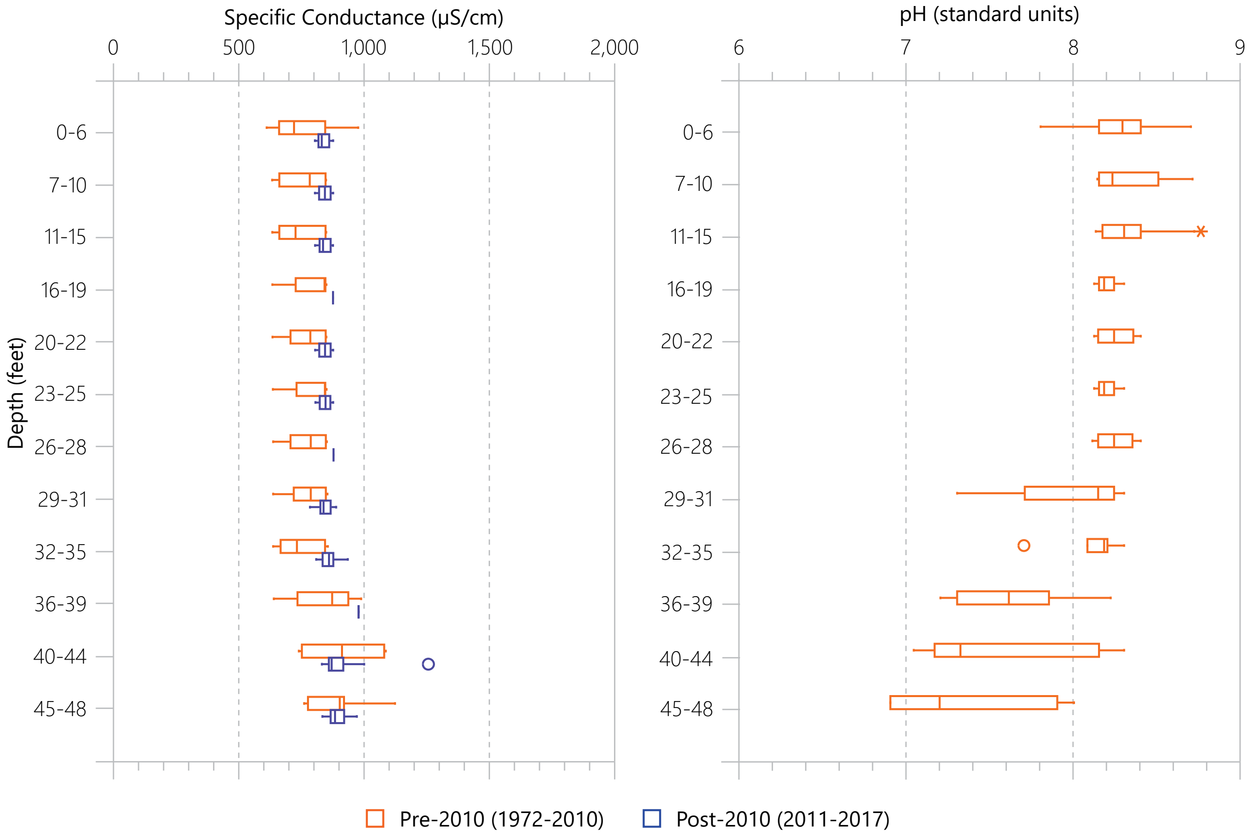
Summer (June-August)



Pre-2010 (1972-2010) Post-2010 (2011-2017)

Figure 2.35 (continued)

Fall (September-November)



Source: Pewaukee Lake Sanitary District, Wisconsin Department of Natural Resources, and SEWRPC

Alkalinity and Hardness

Alkalinity is a measure of the capacity of a lake to absorb and neutralize acids, known as "buffering". The alkalinity of a lake depends on the levels of bicarbonate, carbonate, and hydroxide ions present in the water. Lakes in Southeastern Wisconsin typically have a high alkalinity because of the types of soils and underlying bedrock in the Region's watersheds. In contrast, water *hardness* is a measure of the multivalent metallic ion concentrations, such as those of calcium and magnesium, present in a lake. Hardness is usually reported as an equivalent concentration of calcium carbonate ($CaCO_3$), measured in mg/l. If a lake receives groundwater through rock layers containing calcite and dolomite (both are limestone materials), the lake's alkalinity and hardness will be high. Soft-water lakes have calcium carbonate levels less than 60 mg/l; hard-water lakes contain levels over 120 mg/l.

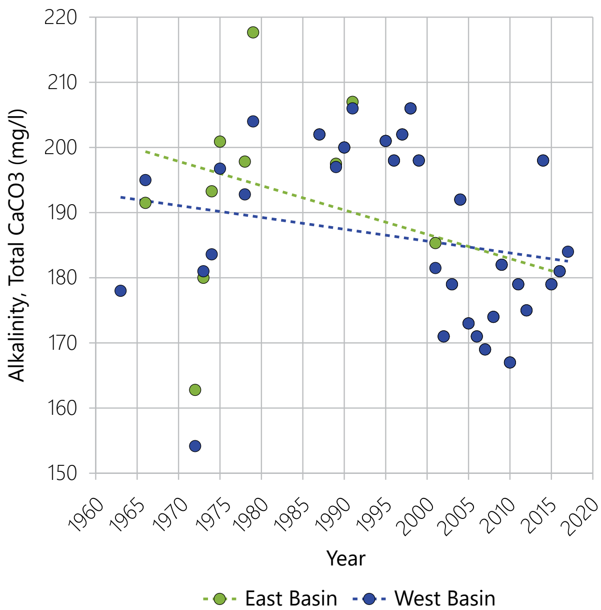
Pewaukee Lake may be classified as a hard-water alkaline lake, with average alkalinities of 201 and 198 mg/l and an average hardness of 249 mg/l in previous studies.[96,97] These alkalinities are within the normal range of lakes in Southeastern Wisconsin.[98] Total alkalinity and hardness in both basins are generally stable, with slight declines in more recent sampling (see Figures 2.36 and 2.37, respectively). Since Pewaukee Lake has a high alkalinity or buffering capacity, and because the pH does not fall below 7, the Lake is not considered susceptible to the harmful effects of acid rain.

[96] *SEWRPC Community Assistance Planning Report No. 58, 2nd Edition,* op. cit.

[97] *SEWRPC Community Assistance Planning Report No. 58, 2nd Edition,* op. cit.

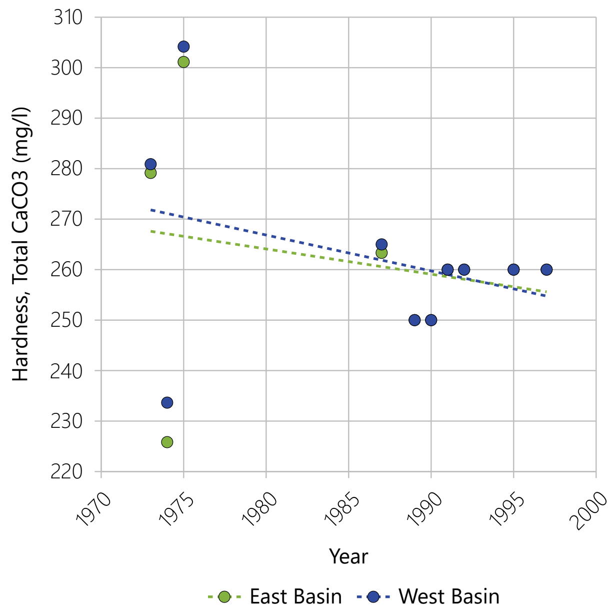
[98] *Ibid.*

Figure 2.36
Pewaukee Lake Mean Annual Alkalinity: 1963-2017



Source: Wisconsin Department of Natural Resources and SEWRPC

Figure 2.37
Pewaukee Lake Mean Annual Hardness: 1973-1997



Source: Wisconsin Department of Natural Resources and SEWRPC

Nutrients and Trophic Status

Nutrients are elements and compounds needed for plant and algal growth. They are often found in a variety of chemical forms, both inorganic and organic, which may vary in their availability to plants and algae. Typically, growth and biomass of plants and algae in a waterbody are limited by the availability of the nutrient present in the lowest amount relative to the organisms' needs. This nutrient is referred to as the *limiting nutrient*, where additions of this nutrient will increase organism growth and biomass. Phosphorus is usually, though not always, the limiting nutrient in freshwater systems. Under some circumstances nitrogen can act as the limiting nutrient.

Lake biological productivity is referred to in terms of "trophic status." Low productivity lakes with few nutrients, algae, and plants are in an *oligotrophic* status; lakes with moderate nutrients and productivity are in a *mesotrophic* status; and lakes with excessive nutrients and productivity are in a *eutrophic* status. Wisconsin trophic state index (WTSI) equations are used to convert summer water clarity, chlorophyll-*a* concentrations, and phosphorus concentrations to a common unit used to assess lake trophic status and allow comparison of status states between lakes.[99] WTSI values based upon chlorophyll-*a* are considered the most reliable estimators of lake trophic status, as this is the most direct measurement of algal abundance.

Figure 2.38 shows the trophic status of the west basin of Pewaukee Lake, as determined by summer surface measurements of these three parameters. Pewaukee Lake appears to be generally a mesotrophic lake with an average WTSI over the past five years of 44 in the west basin and 52 in the east basin. For a deep lowland drainage lake, these WTSI values are considered "excellent" lake condition for the deep west basin and "good" lake condition for the shallow east basin.[100] Both basins have seen an improvement in water conditions since the earliest measurements in the 1970s, as evidenced by the decline in WTSI values across all three parameters. WTSI values fluctuate slightly in both basins, likely caused by annual differences in temperature and rainfall as well as changes in land use over time.

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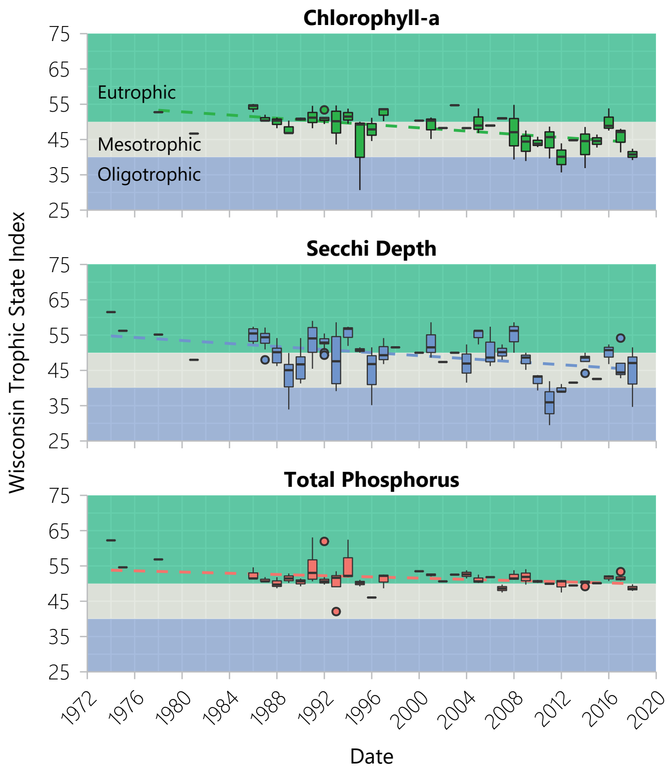
[99] *R.A. Lillie, S. Graham, and P. Rasmussen,* Trophic State Index Equations and Regional Predictive Equations for Wisconsin Lakes, Research Management Findings, Number 35*, Bureau of Research – Wisconsin Department of Natural Resources, May 1993.*

[100] *Wisconsin Department of Natural Resources,* Wisconsin 2020 Consolidated Assessment and Listing Methodology (WisCALM) Clean Water Act Section 303(d) and 305(b) Integrated Reporting*, April 2019.*

Chloride

Humans use chloride bearing materials for a multitude of purposes, such as road salt, water softening, industrial processes, agricultural nutrients and pesticides, pharmaceuticals, petroleum products, and a host of other substances in common use by modern society. As such, chloride concentrations are normally associated with human-derived pollutant concentrations and are, therefore, a good indicator of the overall level of human activity/potential impact and possibly the overall health of a water body. The most important anthropogenic source of chlorides to Pewaukee Lake is believed to be the salts used on roads for winter snow and ice control.[101]

Figure 2.38
West Basin of Pewaukee Lake Summer (June 1st to September 15th) Trophic State Index Trends: 1972-2017



Source: Wisconsin Department of Natural Resources and SEWRPC

Under natural conditions, surface water in Southeastern Wisconsin contains very low concentrations of chloride. Studies completed in Waukesha County lakes during the early 1900s reported concentrations of three to four mg/l of chloride; in fact, lakes in Southeastern Wisconsin had the lowest levels of chlorides statewide.[102] Most Wisconsin lakes saw little increase in chloride concentrations until the 1960s, but a rapid increase thereafter. Chloride was first measured in Pewaukee Lake during July 1963 at a concentration of 11.9 mg/l.

During the initial planning study in 1984,[103] chloride concentrations ranged from 32 to 54 milligrams per liter (mg/l), with an average of 38 mg/l. Samples collected in April 1999 contained 81.1 mg/l chloride, a value close to 700 percent higher than 1963. In August 2018, lake surface waters contained 146 mg/l chloride, which are concentrations much higher than those observed in many other Southeastern Wisconsin lakes.[104] Thus, the rate of chloride accumulation in Pewaukee Lake appears to have increased (see Figure 2.39). While the recent concentrations reported within Pewaukee Lake are below the WDNR standards of 395 mg/l for chronic toxicity and 757 mg/l for acute toxicity (see Table 2.14) established to protect fish and aquatic life, the increasing accumulation of chloride represents a decline in water quality that will be challenging to reverse.

Water Clarity

One of the three major determinants of trophic status is water clarity. Water clarity, or transparency, provides an indication of overall water quality—the greater the clarity, the better the water quality. Clarity may decrease because of turbidity caused by:

- high concentrations of small, aquatic organisms, such as algae and zooplankton

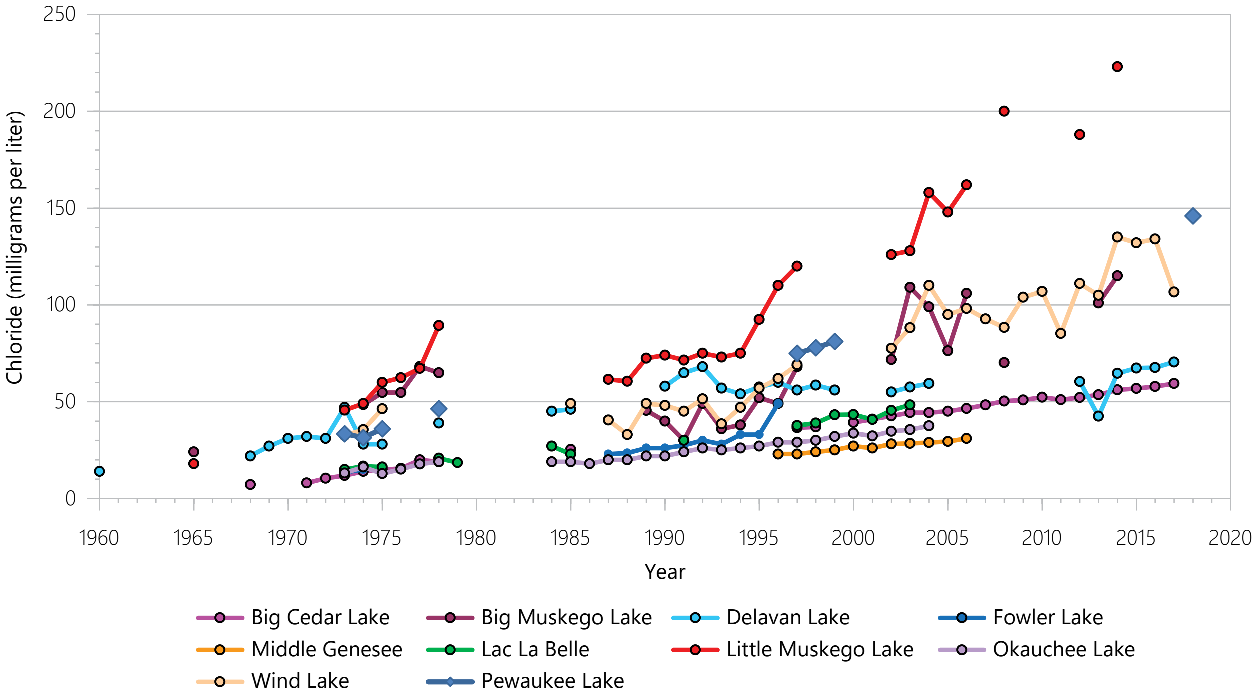
[101] *The major sources of chlorides to lakes in the Southeastern Wisconsin Region include both road salt applications during winter months and salts discharged from water softeners. This latter is of lesser importance to Pewaukee Lake, as such waters are conveyed to the public sewage treatment facility and the effluent therefrom is discharged to the Fox River downstream of the Lake.*

[102] Lillie and Mason, 1983, *op. cit.*

[103] *SEWRPC Community Assistance Planning Report No. 58, 2nd Edition,* op. cit.

[104] *Lillie and Mason, 1983, op. cit.*

Figure 2.39
Chloride Concentration Trends in Southeastern Wisconsin Lakes



Source: Wisconsin Department of Natural Resources and SEWRPC

- suspended sediment and/or inorganic particles
- color caused by high concentrations of dissolved organic substances (e.g., tannins that stain water of bog lakes in northern Wisconsin)

In most Southeastern Wisconsin lakes, water clarity is influenced by the abundance of algae and suspended sediment. Water clarity generally varies throughout the year as algal populations increase and decrease in response to changes in lake temperature, sunlight, and nutrient availability. Clarity is measured using a Secchi disk, a black-and-white, eight-inch-diameter disk. This disk is lowered into the water until it is no longer visible, at which point the depth is recorded, and then it is raised until visible again, when depth is recorded again (see Figure 2.40). The average of these depths is called the "secchi depth." Using these measurements, we can determine that the east basin of Pewaukee Lake has generally improved in water clarity since 1973 (see Figure 2.41), with the secchi depth more frequently hitting the lake bottom (8.5 ft.) in recent years. In the west basin, clarity had been steady until about 2008, with increased clarity since then. Large rainfall events and corresponding fluxes in surface water elevations can also influence water clarity. Sediment-induced declines in water clarity can occur due to heavy runoff from major rainstorms. Utilizing surface water elevations from the Lake outlet dam monitoring, we can see the changes in water clarity when surface water elevations peak following heavy rainfall (see Figure 2.42).

Zebra mussels (*Dreissena polymorpha*) can improve water clarity by removing particulate matter through filter-feeding. The WDNR verified the presence of zebra mussels in the Lake in the early 2000s. Zebra mussels may be influencing water clarity in the Lake, but that hypothesis has not been directly tested. Continued monitoring of water clarity will be an important part of any future water quality assessments.

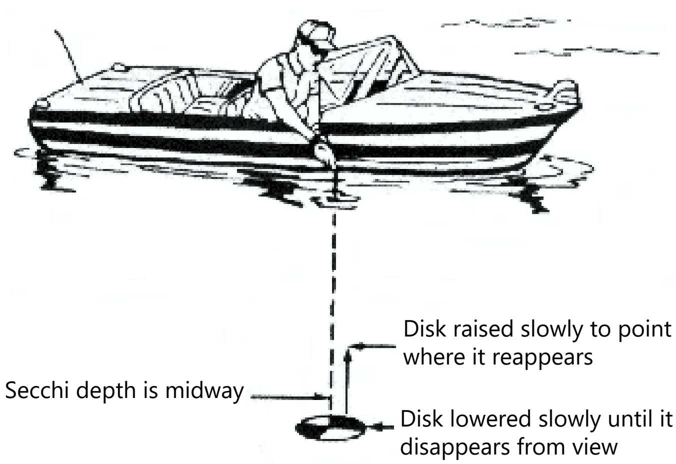
Chlorophyll-a and Algae

Chlorophyll-*a*, a photosynthetic pigment whose abundance is used to indicate algal biomass, is the most reliable metric of a lake's trophic status. Algae is an important and healthy part of lake ecosystems. Algae is a foundational component of lake food chains and produces oxygen in the same way as rooted plants. Many kinds of algae exist, from single-cell, colonial, and filamentous algae to cyanobacteria (see Figure 2.43).

Most algae strains are beneficial to lakes when present in moderate levels. However, the presence of toxic strains (see Figure 2.44), as well as excessive growth patterns, should be considered issues of concern. As with aquatic plants, algae grows faster in the presence of abundant phosphorus (particularly in stagnant areas). Consequently, when toxic or high volumes of algae begin to grow in a lake, it often is a sign of phosphorus enrichment or pollution.

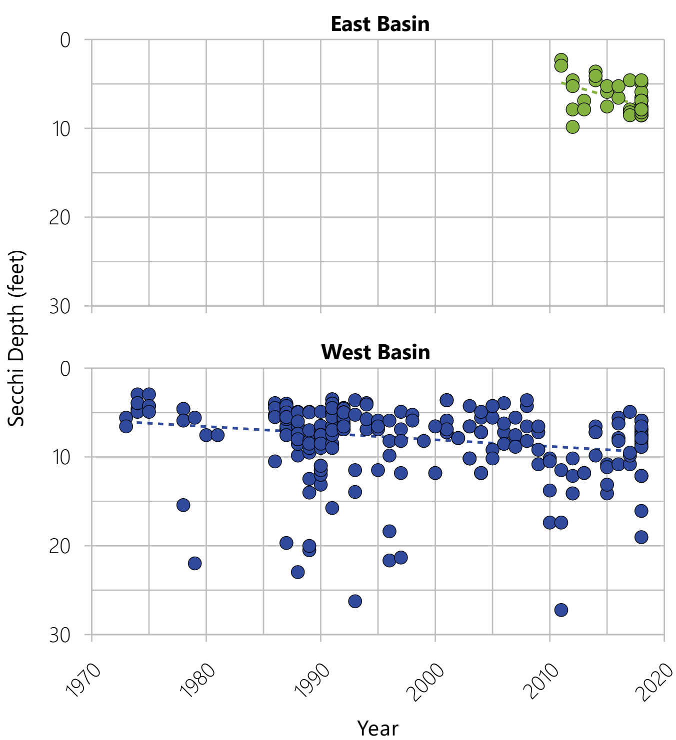
Algae populations are quantified by abundance and composition and can be examined to determine if the algae present are toxin-forming. Suspended algal abundance is estimated by measuring the chlorophyll-*a* concentration in the water column, with high concentrations associated with green-colored water. Mean summer chlorophyll-*a* measurements for both the west and east basins of Pewaukee Lake are always below the 27 µg/l threshold above which aquatic life impairment can occur and algae blooms are more prevalent (see Figure 2.45). Concentrations did occasionally approach the 20 ug/l limit for moderate algal levels, where Wisconsin lake users perceive some impairment to lake enjoyment by algae.[105] In June of 2008 and 2017, algal blooms led to closings at Pewaukee Beach.[106] If blooms become excessive and/or common, or if toxic algae are identified, regular monitoring should be considered. However, the overall trend indicates decreasing chlorophyll-*a* concentrations, indicative of reduced algal abundance. This trend is consistent with efforts by the LPSD to reduce pollutant loading by purchasing and protecting wetland parcels as well as implementing shoreline and stream buffers within the watershed (see Section 2.6, "Pollutant Loads" for more information).

Figure 2.40
Measuring Water Clarity with a Secchi Disk



Source: lakes.chebucto.org and SEWRPC

Figure 2.41
Pewaukee Lake Secchi Depth: 1973-2018



Source: Wisconsin Department of Natural Resources and SEWRPC

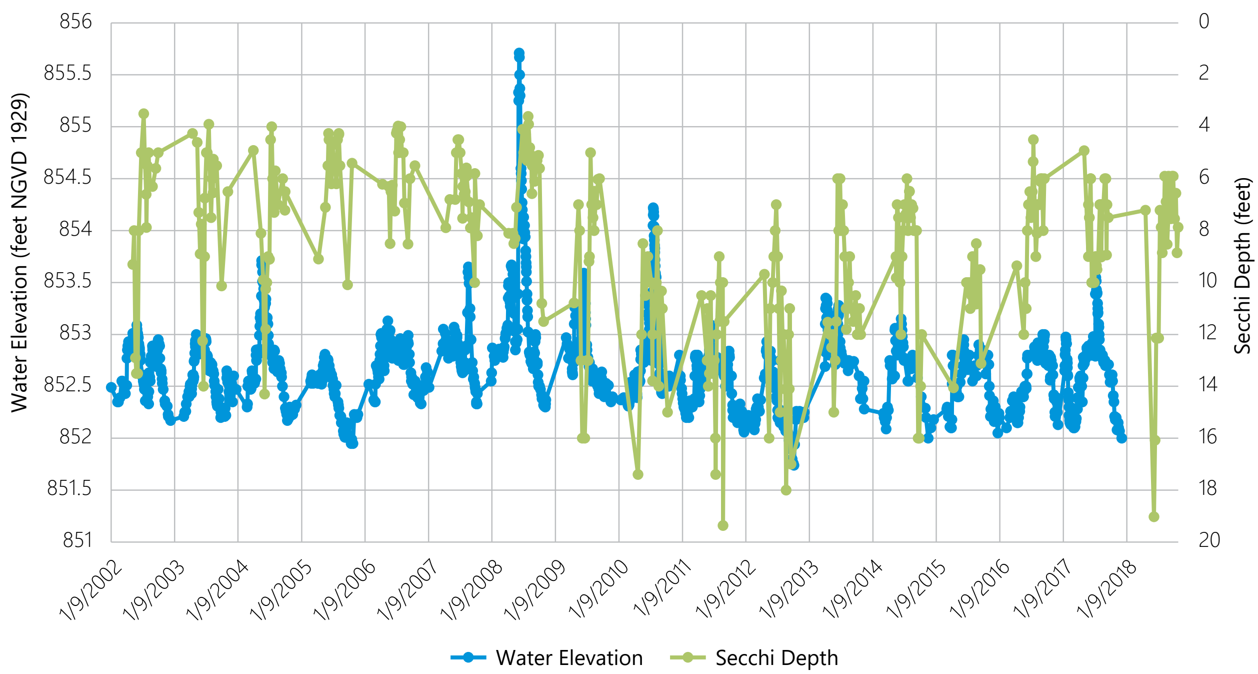
Phosphorus

The third major determinant of a lake's trophic status is the concentration of total phosphorus in the lake's water. Phosphorus is a key nutrient for aquatic plants and algae, with the availability of phosphorus often limiting their growth and abundance. Sources of phosphorus can vary across a watershed, with agricultural fertilizers and animal manure as the predominant phosphorus sources in rural areas while stormwater discharge and onsite wastewater treatment systems contribute phosphorus in urban areas.

[105] *Wisconsin Department of Natural Resources,* Wisconsin 2020 Consolidated Assessment and Listing Methodology (WisCALM) Clean Water Act Section 303(d) and 305(b) Integrated Reporting, *April 2019.*

[106] *"Pewaukee Beach closed due to blue-green algae" WBay News. 25 Jun 2017. www.wbay.com/content/news/Pewaukee-Beach-closed-due-to-blue-green-algae--430683173.html.*

Figure 2.42
Relationship Between Lake Surface Water Elevation and Secchi Depth: Pewaukee Lake 2002-2018



Source: Lake Pewaukee Sanitary District and SEWRPC

Two forms of phosphorus are commonly sampled in surface waters: total phosphorus and dissolved phosphorus. Total phosphorus consists of all of the phosphorus contained in material dissolved or suspended in water. Dissolved phosphorus consists of the phosphorus contained in material dissolved in water. In both these types, the phosphorus may be present in a variety of chemical forms. However, as the degree of eutrophication in freshwater systems correlates more strongly with total phosphorus concentration than with dissolved phosphorus concentration, the State's water quality criteria are expressed in terms of total phosphorus. Thus, water quality sampling tends to focus on assessing total phosphorus concentrations rather than dissolved phosphorus concentrations.

Total phosphorus in both basins of Pewaukee Lake has been decreasing since 1988, as shown in Figure 2.46. This trend indicates that either phosphorus loading to the Lake has declined or phosphorus removal from the water column, such as through aquatic plant harvesting, has increased; both of these topics are explored further in Section 2.6, "Pollutant Loads." Surface water samples collected during the growing season (June through August) generally have the lowest total phosphorus concentrations, with an average of 0.024 mg/l (see Figure 2.47). This phosphorus concentration is below the aquatic life impairment threshold of 0.030 mg/l for deep lowland drainage lakes[107] mandated by administrative code[108] (see Table 2.14). Samples collected in the west basin deeper than 30 feet have greater total phosphorus concentrations (mean of 0.16 mg/l) than surface water samples (mean of 0.02 mg/l) (see Figure 2.48), a pattern that may be indicative of internal phosphorus loading (see Section 2.6, "Pollutant Loads").

Nitrogen

Surface waters contain a variety of nitrogen compounds that are nutrients for plants and algae. Typically, only a small number of forms of nitrogen are examined and reported in water quality sampling. Total nitrogen includes all of the nitrogen in dissolved or particulate form in the water, excluding all gaseous forms of nitrogen. Total nitrogen is a composite of several different compounds that vary in their availability to algae and aquatic plants and in their toxicity to aquatic organisms. Many nitrogen-containing organic

[107] *Wisconsin Department of Natural Resources,* Wisconsin 2020 Consolidated Assessment and Listing Methodology (WisCALM) Clean Water Act Section 303(d) and 305(b) Integrated Reporting, *April 2019.*

[108] *Wisconsin Administrative Code Chapter NR 102,* op. cit.

compounds, such as amino acids, nucleic acids, and proteins that commonly occur in natural and polluted waters are included in total nitrogen. Common inorganic constituents of total nitrogen include ammonia, nitrate, and nitrite. These are the forms that most commonly support algal and plant growth. While nitrate (NO_3^-) can be toxic to humans at high concentrations (WDNR drinking water limit is 10 mg/l), nitrate concentrations in the Lake have been declining and now rarely exceed detection limits (0.19 mg/l). Thus, nitrate toxicity is not a concern in Pewaukee Lake.

A variety of point and nonpoint sources contribute nitrogen compounds to surface waters. In urban settings, nitrogen compounds from lawn fertilizers and other sources may be discharged through storm sewer systems and direct runoff into streams. Cross-connections between sanitary and storm sewer systems, illicit connections to storm sewer systems, and decaying sanitary and storm sewer infrastructure may contribute sanitary wastewater to waterbodies through discharges from storm sewer systems. In rural settings, nitrogen compounds from chemical fertilizers and animal manure may be contributed through discharges from drain tiles or direct runoff into waterbodies. Poorly maintained or failing onsite wastewater treatment systems can also contribute nitrogen compounds. In addition, some species of lake cyanobacteria "fix" nitrogen by converting otherwise inert gaseous nitrogen into ammonia or another compound usable by algae and plants.

Occasionally, nitrogen acts as the limiting nutrient for algal and plant growth in freshwater systems, typically when phosphorus concentrations are very high. In general, when the ratio of total nitrogen (N) to total phosphorus (P) concentrations is 15:1 or greater, the availability of phosphorus limits algal growth. Conversely, when this proportion is less than 10:1, nitrogen concentrations limit plant growth. Ratios between 15:1 and 10:1 are considered transitional.[109] During spring turnover on the Lake between 1987 and 2001, N/P ratios typically averaged in the high forties, and ranged from as low as 20:1 to as high as 100:1 (see Figure 2.49); such ratios clearly indicate that phosphorus is the main limiting factor for plant and algae growth. Spring nitrogen concentrations in the Lake fluctuated between 0.6 and 0.9 mg/l from 1987 to 2001, when the most recent spring measurement was taken (see Figure 2.50). Summer nitrogen concentrations have declined over time, from a high of 1.2 mg/l in 1992 to 0.5 mg/l in 2017. As the limiting nutrient in Pewaukee Lake, phosphorus should be the major focus of nutrient loading and algae bloom management decisions.

Figure 2.43
Common Types of Non-Toxic Algae

Hydrodictyon

Spirogyra

Chlamydomonas

Source: (1) Lewis Lab (2) University of New Mexico (3) Taranaki Regional Council & Landcare Research

[109] *Lillie and Mason, 1983, op. cit.*

Bacteria

The concentration of certain bacteria in water is measured in order to assess the quality of the water for drinking water supply and recreational uses. A variety of disease-causing organisms can be transmitted through water contaminated with fecal material. These organisms include bacteria, such as those causing cholera and typhoid fever; viruses, such as those causing poliomyelitis and infectious hepatitis; and protozoa, such as Giardia and Cryptosporidium. It is not practical to test surface waters for all of these diseasecausing organisms as rapid and inexpensive tests do not currently exist for many of these organisms. Instead, the sanitary quality of surface water is assessed by examining samples for the presence and concentrations of organisms indicating fecal contamination. Two groups of bacteria are commonly examined in surface waters of the Greater Milwaukee watersheds: fecal coliform bacteria and *Escherichia coli* (*E. coli*). All warm-blooded animals have these bacteria in their feces, so the presence of high concentrations of fecal coliform bacteria or *E. coli* in water indicates a high probability of fecal contamination. While most strains of these two bacterial groups have a low probability of causing illness they do act as indicators of the possible presence of other pathogenic agents in water, particularly when present in high concentrations.

Figure 2.44
Appearance of Toxic Algae Blooms

Microcystis

Cylindrospermopsis

Source: (1) National Oceanic and Atmospheric Administration
(2) St. John's River Water Management District

Fecal coliform bacteria are currently used to indicate the suitability of inland waters in Wisconsin for recreational uses.[110] The State requires that counts of fecal coliform bacteria in waters of the State not exceed 200 colony-forming-units (a measure of living cells) per 100 milliliters (cfu per 100 ml) as a geometric mean based on not less than five samples per month, nor exceed 400 cfu per 100 ml in more than 10 percent of all samples during any month. Pewaukee Lake has not exceeded fecal coliform limits.

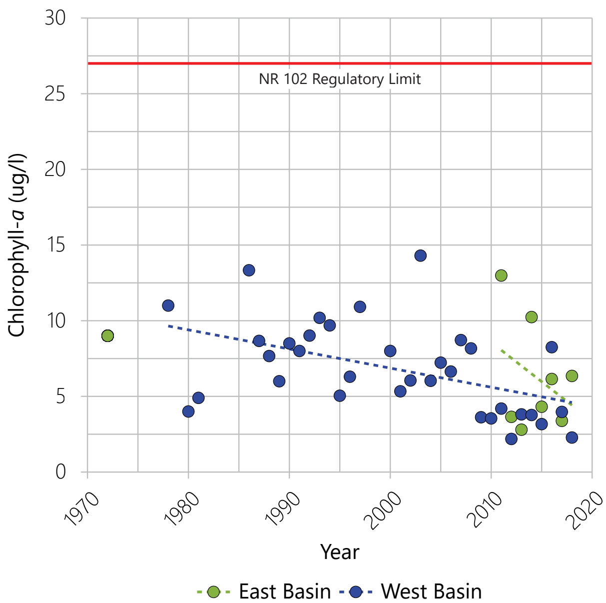
E. coli is a species of fecal coliform bacteria. The USEPA recommends using either *E. coli* or enterococci as indicators of fecal pollution in recreational waters for freshwater systems. Agencies participating in the monitoring of beaches in the Wisconsin Beach Monitoring program use *E. coli* as the indicator of sanitary quality of the associated waters. Water quality advisories are issued for beaches whenever the concentration of *E. coli* in a sample exceeds 235 cfu per 100 ml or whenever the geometric mean of at least five samples taken over a 30-day period exceeds 126 cfu per 100 ml. Beaches are closed whenever the concentration of *E. coli* exceeds 1,000 cfu per 100 ml. The City of Pewaukee Parks and Recreation Department monitors levels of *E. coli* at Pewaukee Beach. They post a green sign when *E. coli* counts are less than 235 cfu per 100 mL, a yellow sign when *E. coli* counts are between 235 and 999 cfu per 100 mL of water of water, and a red "closed" sign when *E. coli* counts exceed 1,000 cfu per 100 mL of water. These levels are in accordance to the EPA's good water quality guideline. The water is retested daily until the counts reach a safe level and the beach can be reopened.

Tributary Streams

Lakes and streams have strikingly different environments. This presents special challenges when dealing with water quality issues. This subsection will present data collected from the three main tributaries of

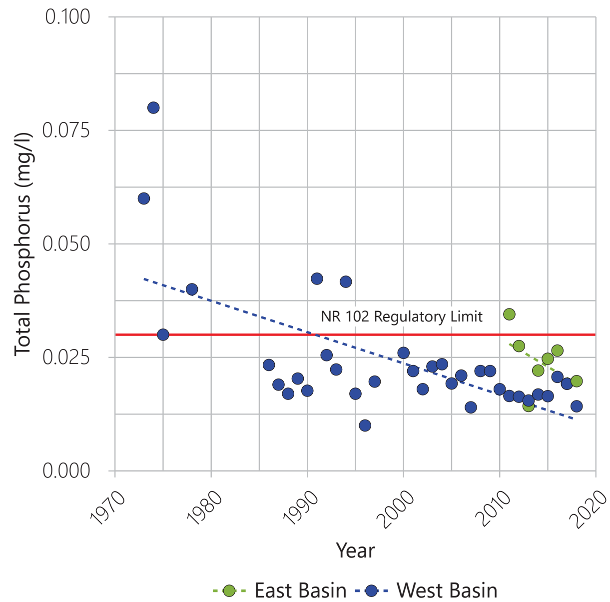
[110] *Wisconsin Department of Natural Resources,* Wisconsin 2020 Consolidated Assessment and Listing Methodology (WisCALM) Clean Water Act Section 303(d) and 305(b) Integrated Reporting, *April 2019.*

Figure 2.45
Mean Summer Chlorophyll-*a*: Pewaukee Lake 1973-2018



Source: Wisconsin Department of Natural Resources and SEWRPC

Figure 2.46
Mean Summer (June 1st to September 15th) Total Phosphorus: Pewaukee Lake 1973-2018



Source: Wisconsin Department of Natural Resources and SEWRPC

Pewaukee Lake: Coco Creek, Meadowbrook Creek, and Zion Creek. An analysis of these data will provide context to the water quality characteristics of Pewaukee Lake since a lake's tributaries play an important role in the overall health of the lake into which they flow. An understanding of these data should aid in developing management strategies for both the Lake and its tributaries.

Temperature and Oxygen

The interplay between temperature and oxygen in streams is different than that which occurs in lakes in several ways. For example, without stratification, streams avoid many of the complexities (hypolimnetic anoxia, internal loading, etc.) imposed on lakes that stratify. In addition, the continual movement of water in streams makes for a constant mixing of waters at the surface and below.

As in lakes, however, temperature is one of the most significant physical characteristics of a stream. In fact, along with flow, temperature is one of the key determinants of the biotic communities into which streams are commonly classified. Table 2.16 shows the water quality criteria for temperature for those streams that have a seven-day, 10-percent probability low flow (7Q10)[111] of less than 200 cubic feet per second (cfs). The 7Q10 of all of the streams in the Pewaukee Lake watershed is less than 200 cfs. Streams in temperate climates tend to range between freezing and around 80°F; the main Pewaukee tributaries fall into this range as shown in Figure 2.51. However, it should be noted that the temperatures in this figure are based on "grab samples"[112] that, while they can provide some useful data, are not able to reflect the comprehensive temperature dynamics that a more continual monitoring, such as from an electronic logging device, can achieve.

Commission staff deployed continuous monitoring devices at these locations to measure water temperatures and at one additional site to monitor air temperatures from 2010 through 2011.[113] Reaches within Zion Creek contained the warmest sites while Coco Creek and CTH JJ Tributary had the coldest sites. Due to the inability to recover the continuously recording temperature data logger at Meadowbrook Creek, it was not possible to compare the daily maximum temperatures of this system to other sites in the watershed.

[111] *Seven-day consecutive low flow with an annual probability of occurrence of 10 percent.*

[112] *A "grab sample" refers to a sampling taken once a day or even as infrequently as once a month, but not a continuous 24-hour measuring.*

[113] *SEWRPC Community Assistance Planning Report No. 313*, op. cit.

However, the samples collected by the Water Action Volunteers on Meadowbrook Creek indicate that the summer average temperatures from 2006 through 2012 was 72.3°F and the maximum temperature recorded at that site was 83.3°F. These temperatures suggest that Meadowbrook Creek is likely receiving groundwater input that is lowering water temperatures; a hypothesis supported by the Creek's classification as a cool headwater fishery. More detailed temperature information would need to be collected to verify this.

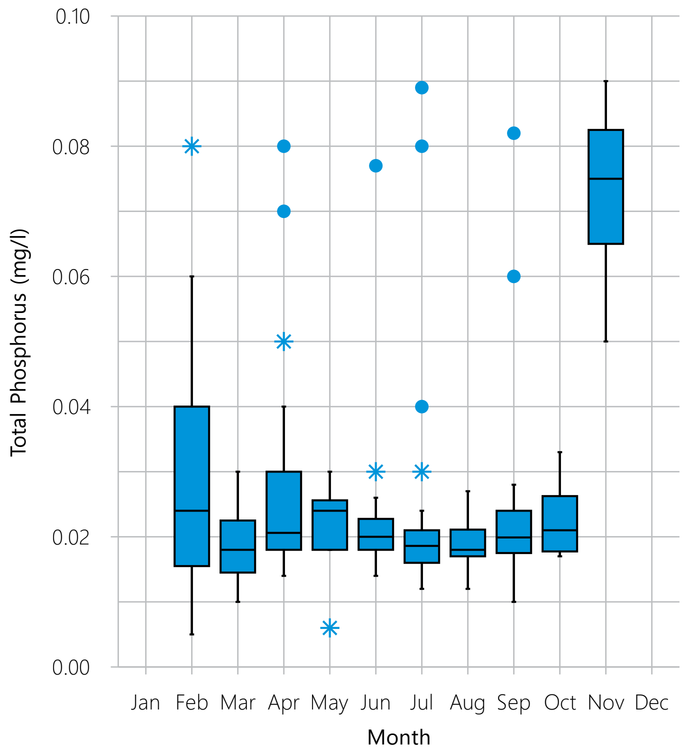
Coco Creek is the only designated coldwater fishery within the Pewaukee Lake watershed. Based upon the acute water quality criteria for temperature, coldwater streams should not exceed a daily maximum of 72.0°F in June or 73.0°F in July or August. The stations at RM 0.54 and RM 2.42 on the mainstem of Coco Creek and the Unnamed Tributary-2 at RM 0.36 meet these criteria 100 percent of the time. The remaining tributary sites to Coco Creek at RM 1.04 generally meet the coldwater criteria for the summer months more than 95 percent of the time. In addition, the mainstem site on Coco Creek at RM 1.00 met the coldwater criteria for the summer months between 75 percent to more than 95 percent of the time over a four year period from 2008 through 2011. In contrast, the two most upstream sites on the mainstem of Coco Creek at RM 3.20 and RM 4.03 only meet the summer month coldwater criteria about 50 percent of the time.

Brook trout and brown trout were recently found to not occur within streams where summer maximum daily water temperatures exceeded 81.7°F,[114] consistent with the fisheries findings summarized in Section 2.9, "Fisheries." Based on this limit, every site sampled on the main stem and tributary of Coco Creek can be considered capable of supporting trout (i.e., water temperatures are within thermal tolerance ranges for trout), except for the most upstream site at RM 4.03 (see Figure 2.51).

The acute water quality criteria for temperature in warmwater streams should not exceed a daily maximum of 84.0°F in June or August or 84.9°F in July. The Pewaukee Lake Outlet and Zion Creek are meeting the criteria about 75

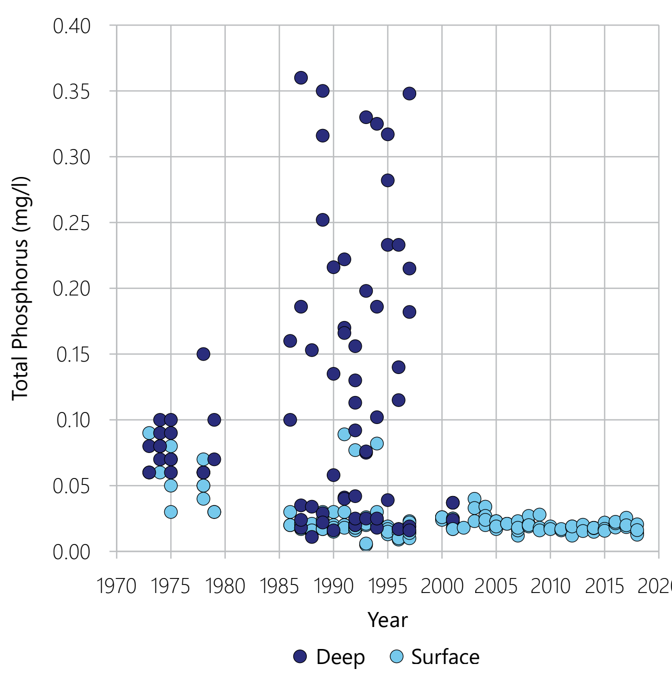
[114] *K.E. Wehrly, L. Wang, and M. Mitro, "Field-Based Estimates of Thermal Tolerance Limits for Trout: Incorporating Exposure Time and Temperature Fluctuation,"* Transactions of the American Fisheries Society, *139: 365-374, 2007.*

Figure 2.47
Monthly Near Surface Total Phosphorus Concentrations: Pewaukee Lake West Basin 1973-2018



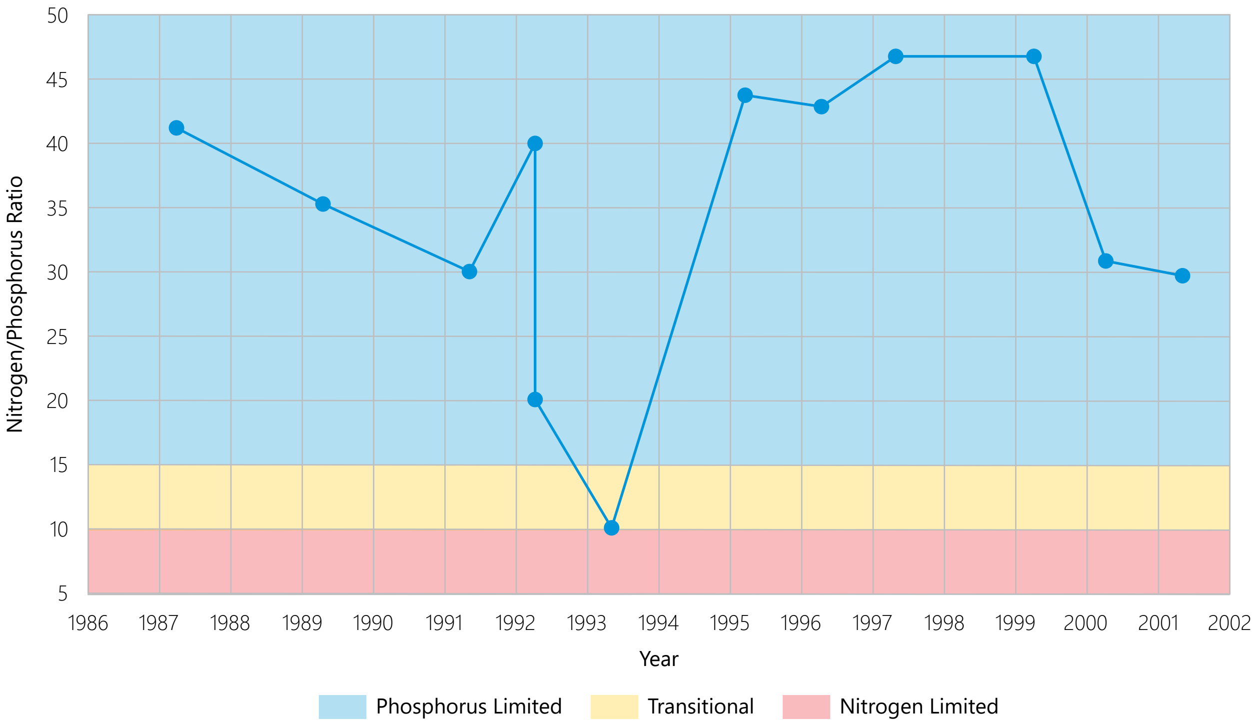
Source: Wisconsin Department of Natural Resources and SEWRPC

Figure 2.48
Total Phosphorus Concentrations of Water Collected from Various Depths: Pewaukee Lake West Basin 1972-2017



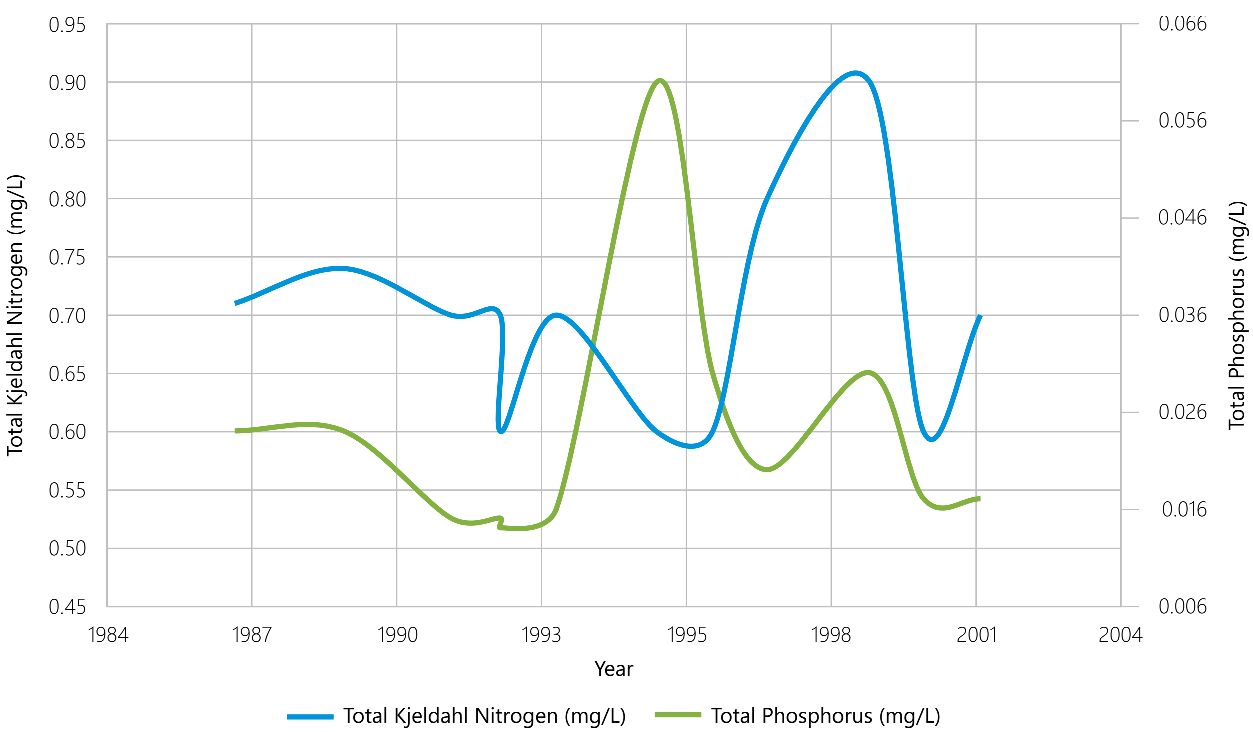
Source: Wisconsin Department of Natural Resources and SEWRPC

Figure 2.49
Spring (Fully Mixed) Nitrogen to Phosphorus Ratio Trend: Pewaukee Lake 1987-2001



Source: Wisconsin Department of Natural Resources and SEWRPC

Figure 2.50
Spring (Fully Mixed) Nitrogen and Phosphorus Trends: Pewaukee Lake 1987-2001



Source: Wisconsin Department of Natural Resources and SEWRPC

Table 2.16
Ambient, Sublethal, and Acute Water Quality Temperature Criteria (°F) for Designated Use Streams[a]

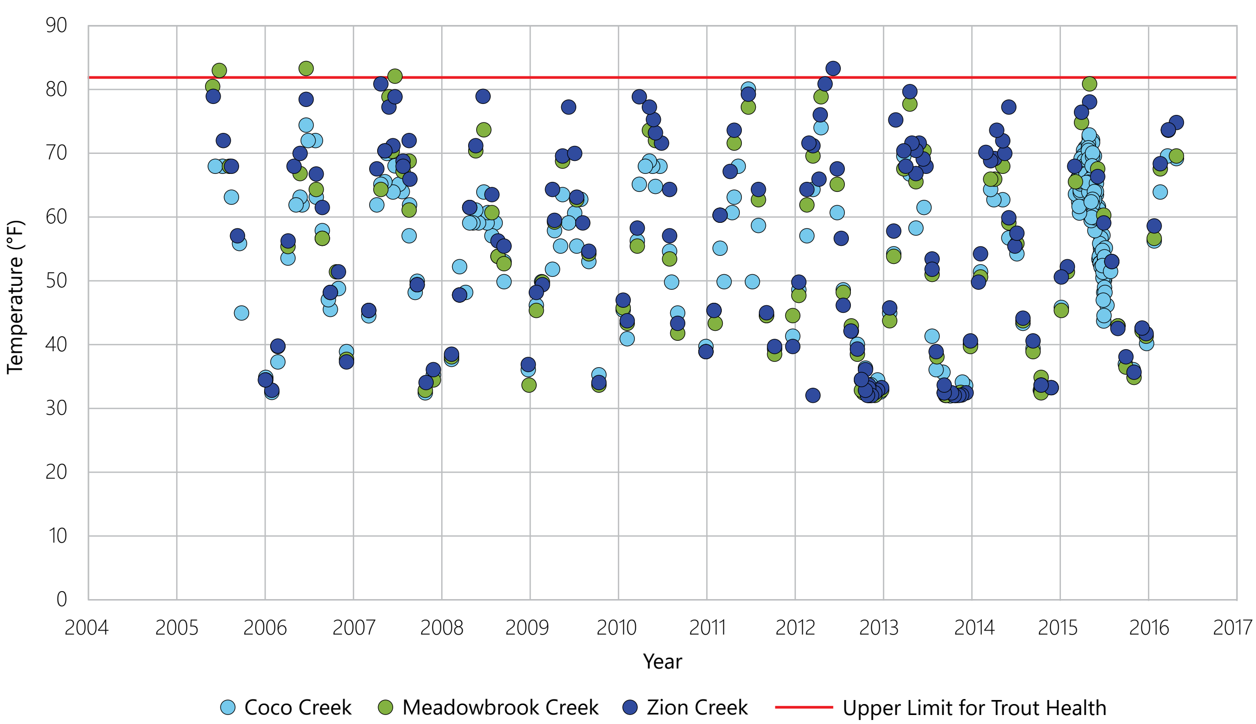
	Designated Use Category and Associated Temperature Criterion (°F)[b]								
	Cold Water Communities			Warmwater Sportfish or Forage Fish Communities			Limited Forage Fish Communities		
Month	Ambient	Sublethal	Acute	Ambient	Sublethal	Acute	Ambient	Sublethal	Acute
January	35.1	46.9	68.0	33.1	48.9	75.9	37.0	54.0	73.0
February	36.0	46.9	68.0	34.0	50.0	75.9	39.0	54.0	79.0
March	39.0	51.1	69.1	37.9	52.0	77.0	43.0	57.0	80.1
April	46.9	57.0	70.0	48.0	55.0	79.0	50.0	63.0	81.0
May	55.9	63.0	72.0	57.9	64.9	82.0	59.0	70.0	84.0
June	62.1	66.9	72.0	66.0	75.9	84.0	64.0	77.0	84.9
July	64.0	66.9	73.0	69.1	81.0	84.9	69.1	81.0	86.0
August	63.0	64.9	73.0	66.9	81.0	84.0	68.0	79.0	86.0
September	57.0	60.1	72.0	60.1	73.0	82.0	63.0	73.0	84.9
October	48.9	53.1	70.0	50.0	61.0	80.1	55.0	63.0	82.9
November	41.0	48.0	69.1	39.9	48.9	77.0	46.0	54.0	80.1
December	37.0	46.9	69.1	35.1	48.9	75.9	39.9	54.0	79.0

[a] *As set forth in Section NR 102.25 of the* Wisconsin Administrative Code, *small streams are waters with unidirectional 7Q10 flows less than 200 cubic feet per second. The 7Q10 flow is the seven-day consecutive low flow with a 10 percent annual probability of occurrence (10-year recurrence interval).*

[b] *The ambient, sublethal, and acute water quality temperature criterion specified for any calendar month shall be applied simultaneously to establish the protection needed for each identified fish and other aquatic life use. The sublethal criteria are to be applied as the mean daily maximum temperature over a calendar week. The acute criteria are to be applied as the daily maximum temperatures. The ambient temperature is used to calculate the corresponding acute and sublethal criteria and for determining effluent limitations in discharge permits under the Wisconsin Pollutant Discharge Elimination System.*

Source: Wisconsin Department of Natural Resources and SEWRPC

Figure 2.51
Pewaukee Lake Tributary Summer Temperatures Trends: 2005-2016



Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, Water Action Volunteers, and SEWRPC percent of the time. Most surprising, not only is the CTH JJ Tributary meeting the warmwater criteria 100 percent of the time, this site never exceeded 78.8°F, which means it is technically capable of supporting a coldwater trout fishery, as described above.

Whereas water temperature influences the types of species that can live in rivers (each aquatic species has a preferred range), temperature also governs the amount of oxygen that can be held in water (warmer water holds less oxygen than cool water[115]). The minimum DO standards for coldwater (trout) and warmwater streams, as set forth in Chapter NR 102 of the *Wisconsin Administrative Code*, are 6.0 and 5.0 mg/l, respectively. Minimum DO standards for coldwater streams are to maintain concentrations of 7.0 mg/l or greater during the trout spawning season. If the water in a stream, or other waterbody, becomes too warm, DO levels may be suboptimal (i.e., less than 5.0 mg/l) for many species of fishes and other aquatic organisms. However, streams can also become supersaturated with oxygen, generally above 15 mg/l, which can also be injurious to fish. Because the warmest water temperatures occur in the summer, this is the most important time of the year for determining physiological limitations for aquatic organisms based on DO concentrations.

Dissolved oxygen concentrations are generally within the range consider healthy for fish population, but Meadowbrook Creek and Zion Creek do attain concentrations outside of this range (see Figure 2.52). Meadowbrook Creek occasionally falls below 2.0 mg/l and almost never achieves 5.0 mg/l in summer, indicating that this system may be limiting to fish and other aquatic organisms. This Creek contains a high amount of organic matter, the decomposition of which can lower dissolved oxygen concentrations. Zion Creek had several measurements below the 5.0 mg/l level, as well as several measurements above the 15 mg/l level that roughly translates into 150 percent oxygen saturation (140 percent saturation can cause fish kills). Only Coco Creek had all oxygen measurements above the 5.0 mg/l level and below the 15 mg/l level, indicating the best conditions for supporting fish populations.

Specific Conductance

Meadowbrook Creek consistently had the highest specific conductance of the tributaries between 2006 and 2016 (see Figure 2.53). Specific conductivity is highest in the winter in all three tributaries, which is indicative of salt application before and during snow storms. Beginning in the fall of 2013, the average specific conductance appears to have shifted upward in all three tributaries, but it is unclear whether this is due to a change in sampling methodology or the actual condition of these streams.

Chloride

Chloride concentrations in Coco, Meadowbrook, and Zion Creeks are presented in Figure 2.54. Although there are relatively little data available on chloride in these three tributaries, it would appear that all three tributaries have elevated chloride concentrations. The samples collected from Meadowbrook Creek exceed the NR 102 Chronic toxicity threshold of 395 mg/l; however, Meadowbrook Creek has only been sampled in winter, when chloride attains its seasonal peak with contributions from road salt applications. Summer sampling of all three tributaries would better reflect whether chloride remains elevated throughout the year.

pH

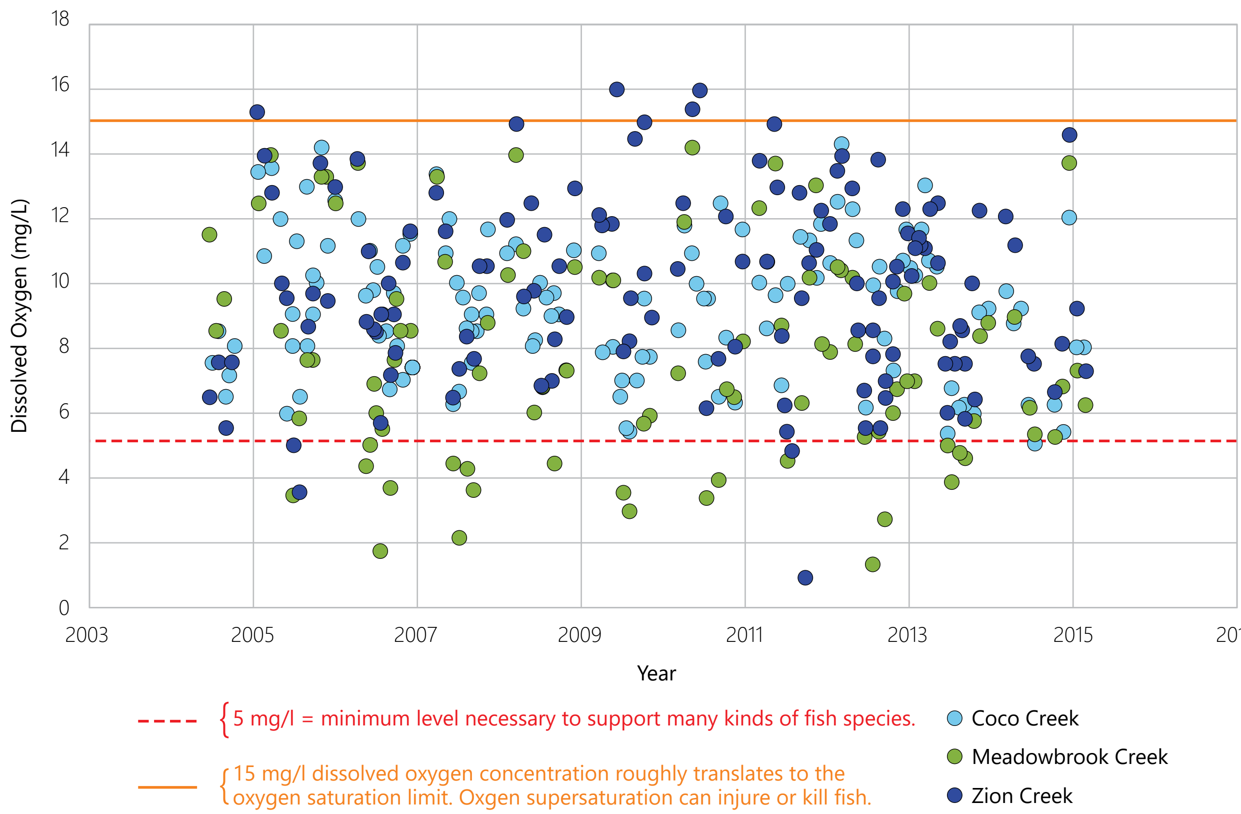
Coco, Meadowbrook, and Zion Creeks have pH levels that are consistent with each other and with the general range found in Pewaukee Lake (between 7.5 and 8.5 stu), as well as in Southeastern Wisconsin (8.1 stu) (see Figure 2.55). These pH levels indicate that these waters are neutral to slightly alkaline. Stream pH can vary with water sources, as precipitation is generally acidic to neutral while groundwater is neutral to alkaline.

Phosphorus

Tributaries can be a major source of phosphorus to lowland drainage lakes. Phosphorus data for the three tributaries of Pewaukee Lake is extremely limited (see Figure 2.56). There have been seven samples taken in Coco Creek, one of which was taken in 1990 and the remainder of which were taken in 2013. Zion Creek has been sampled nine times between 2012 and 2016 and no samples have been collected on Meadowbrook Creek. However, as flow rates (see Figure 2.57) were not measured during phosphorus sample collections, the total amount of phosphorus each tributary is contributing cannot be calculated. Thus, only phosphorus

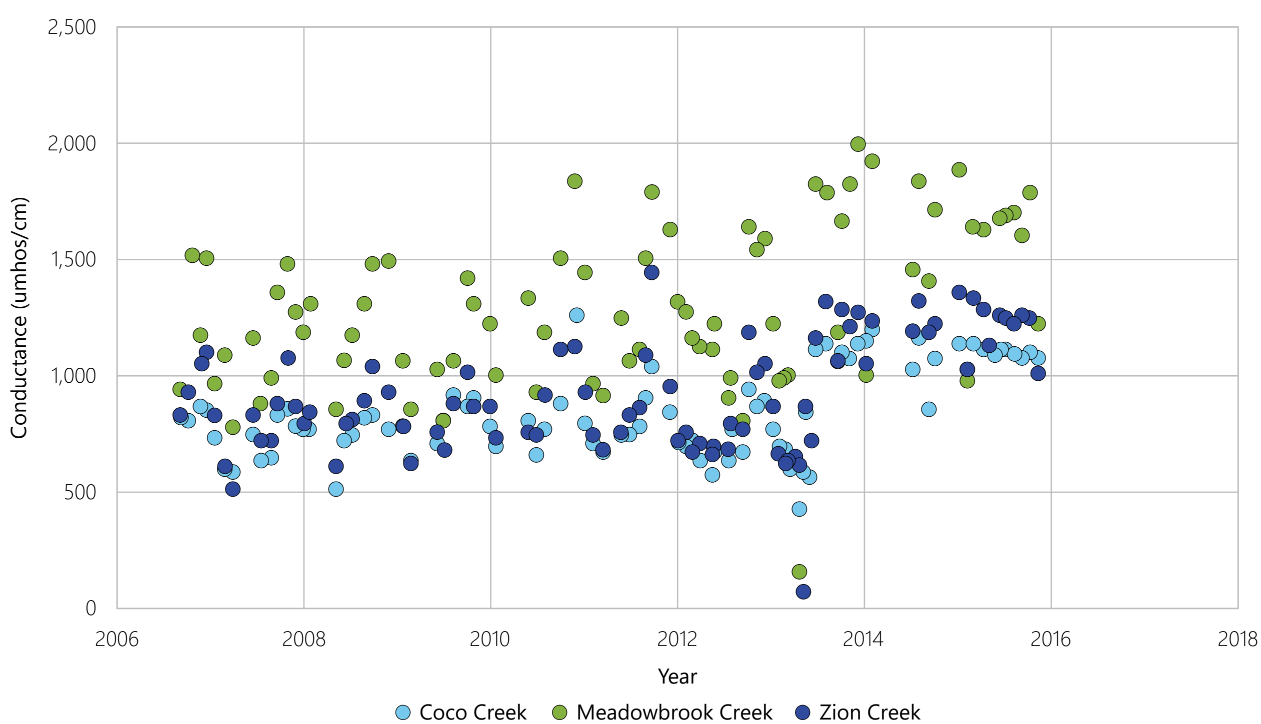
[115] *A key cause of increased stream temperatures is impervious surfaces (roadways, parking lots, buildings), which restrict infiltration of water, as discussed in Section 2.2, "Lake and Watershed Physiography."*

Figure 2.52
Pewaukee Lake Tributary Dissolved Oxygen Trends: 2005-2016



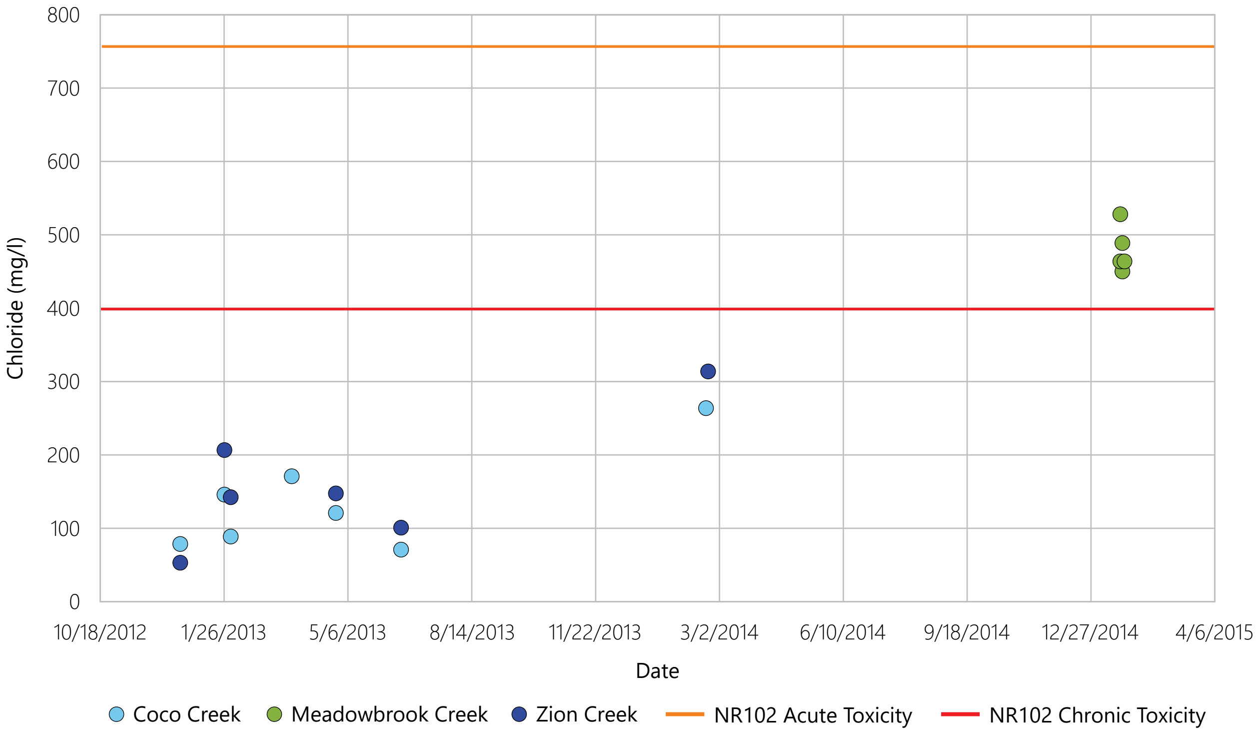
Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, Water Action Volunteers, and SEWRPC

Figure 2.53
Pewaukee Lake Tributary Specific Conductivity Trends: 2006-2016



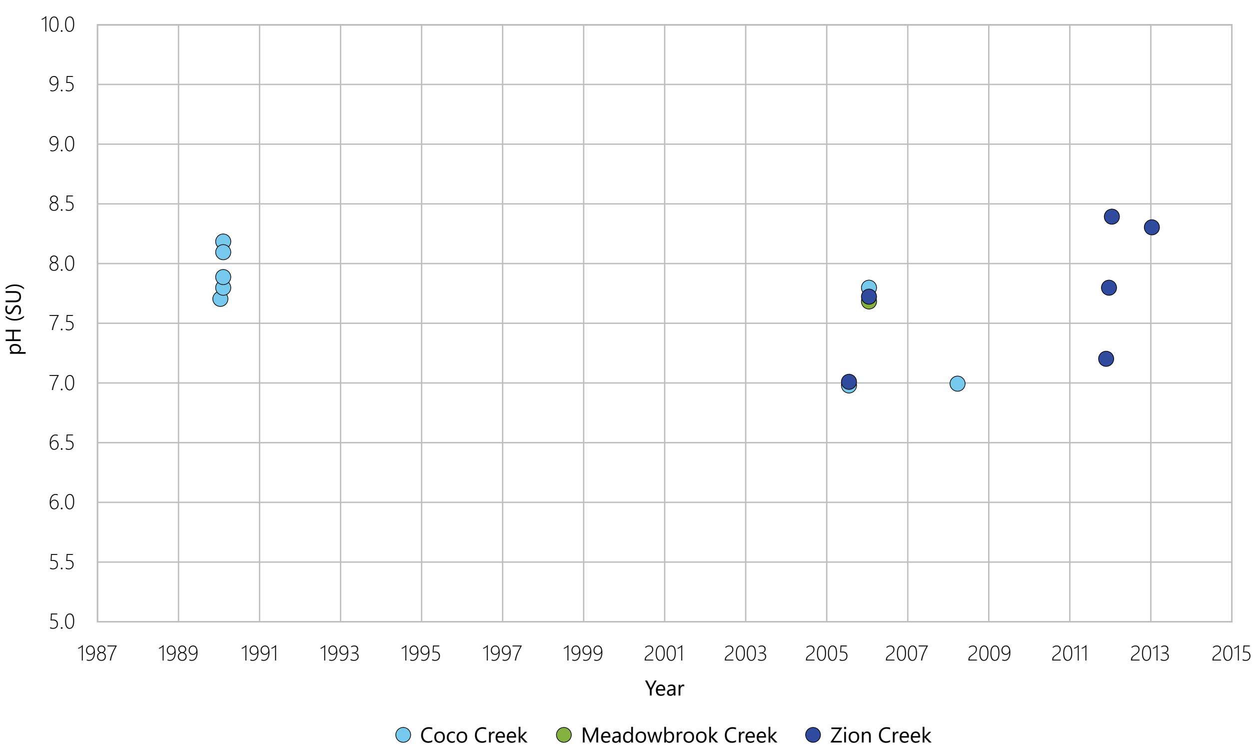
Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, and SEWRPC

Figure 2.54
Pewaukee Lake Tributary Chloride Concentration Trends: 2012-2014



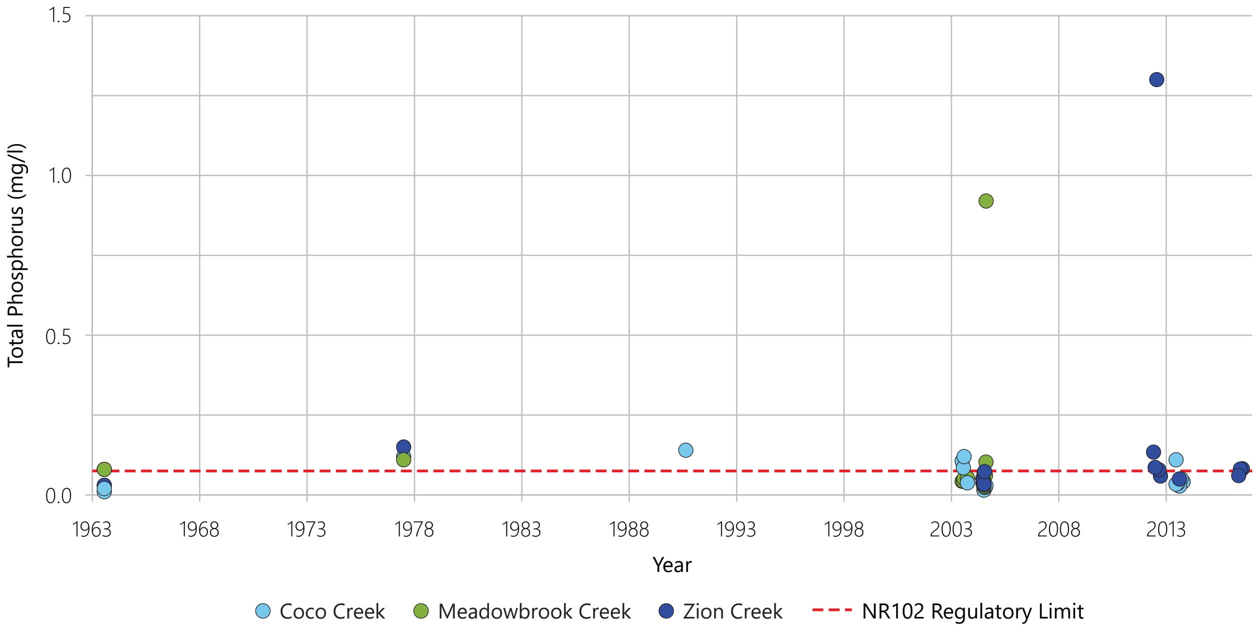
Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, and SEWRPC

Figure 2.55
Pewaukee Lake Tributary pH Trends: 1989-2013



Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, Water Action Volunteers, and SEWRPC

Figure 2.56
Pewaukee Lake Tributary Total Phosphorus Concentration Trends: 1990-2016



Source: Wisconsin Department of Natural Resources, Wisconsin Lutheran College, and SEWRPC

concentrations can be used to evaluate water quality. One sample taken in Zion Creek in 2012 was ten to twenty times higher than the other values,[116] causing the overall mean value to be tenfold higher than that of Coco Creek. However, the number of samples was very limited. Five samples taken in Coco Creek during 2013 averaged 0.034 mg/l (0.06 mg/l if the single sample from 1990 is included). Nine samples taken in Zion Creek during 2012 through 2016 averaged 0.210 mg/l, although the measurement taken in May of 2012 appears to be significantly outside the range of all other measurements (without that single high measurement, the average for Zion Creek would be 0.081 mg/l—just slightly above the 0.075 regulatory criteria designated for warmwater fish and aquatic life shown in Table 2.17). To better understand phosphorus contributions by the tributaries, phosphorus sampling should be concurrently measured with streamflow, allowing total phosphorus loads to be calculated.

Potential Biological Use

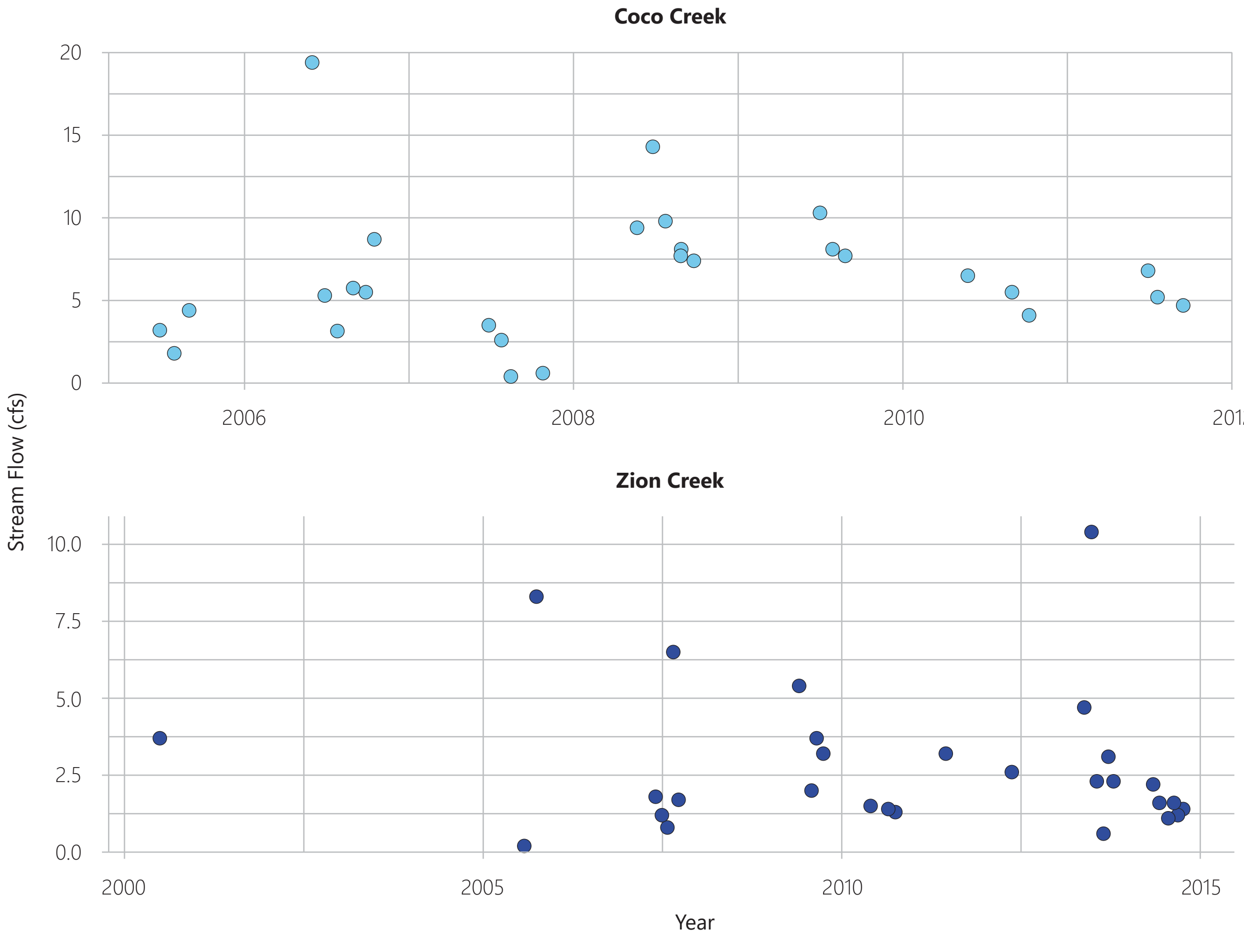
None of the streams or tributaries within the Pewaukee Lake watershed fully meets their potential biological uses or the fishable and swimmable water use goals set for the waters of the United States in the Federal Clean Water Act.[117] Coco Creek has been identified to be partially meeting its potential biological use designation, but Meadowbrook Creek and Zion Creek were reported as not meeting their potential biological uses. The cause or source of impairments identified by WDNR staff as part of their 2002 state of the basin report for this watershed include ditching or channelization, hydrologic modification, cropland erosion, barnyard or excessive lot runoff, construction site erosion, urban stormwater runoff, unspecified nonpoint source pollution, and storm sewers. These have caused numerous impacts to Pewaukee Lake and its tributaries in terms of degraded habitat (lack of cover, sedimentation, scouring, etc.), nutrient enrichment, temperature fluctuations or extremes, reductions in DO, sedimentation, stream flow fluctuations caused by land use development, bacteriological contamination, turbidity, and pesticide/herbicide toxicity (see Section 2.8, "Stream Habitat" for more information).[118]

[116] *The highest maximum recorded total phosphorus concentration ever observed within the Pewaukee Lake watershed was 1.3 mg/l on July 23, 2012, in Zion Creek. This observation indicates that Zion Creek remains impaired from excessive nutrient loading.*

[117] *Wisconsin Department of Natural Resources, Publication No. PUBL-FH-806-2002,* Wisconsin Trout Streams*, April 2002.*

[118] *Ibid.*

Figure 2.57
Pewaukee Lake Tributary Stream Flow Measurements: 1998-2017



Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, and SEWRPC

Despite these impairments, all of Coco Creek, beginning at CTH JJ (just upstream of Pewaukee Lake), has been designated by the WDNR as having the potential to support a Class I and Class II brown trout fishery.[119] A Class I trout stream is characterized as a high-quality trout water that has sufficient natural reproduction to sustain the native or naturalized populations. Consequently, streams of this category do not require stocking of hatchery raised trout. A Class II trout stream may have some natural trout reproduction, but not enough to utilize available food and space. Consequently, stocking is generally required to sustain a desirable sport fishery. In this regard, it should be noted that brown trout have been collected by the WDNR staff from Coco Creek as recently as July 2017 (see Section 2.9, "Fisheries").

Water Quality Summary

Overall, in many ways Pewaukee Lake represents a typical hard-water, alkaline lake that is considered to have relatively good water quality, especially since the implementation of public sewage treatment measures during the 1970s. The Lake is dimictic and stratifies during the summer at a depth of about 25 feet, below which depth waters become anoxic during late summer with internal loading of phosphorus being indicated, although not at levels deemed problematic since neither chronic summer algae blooms nor fish kills have been recorded; waters in the west basin above the thermocline remain well-oxygenated above the 5.0 mg/l threshold year round. Notwithstanding, Pewaukee Lake does show signs of stress from human influence and the potential for algal blooms, especially in the shallow east basin. Winterkill is not a problem in Pewaukee Lake as cross-sectional analysis shows that a substantial volume of the Lake provides adequate oxygenated water volume for the support of fish throughout the winter.

[119] *Ibid.*

Table 2.17
Water Quality Criteria for Streams Within the Pewaukee Lake Watershed

Water Quality Parameter	Designated Use Category[a]						Source
	Coldwater Community	Warmwater Fish and Aquatic Life	Limited Forage Fish Community (variance category)	Special Variance Category A[b]	Special Variance Category B[c]	Limited Aquatic Life (variance category)	
Temperature (°F)	--[d]	--[d]	--[d]	--[d]	--[d]	86.0	NR 102 Subchapter II
Dissolved Oxygen (mg/l)	6.0 minimum 7.0 minimum during spawning	5.0 minimum	3.0 minimum	2.0 minimum	2.0 minimum	1.0 minimum	NR 102.04(4) NR 104.04(3) NR 104.06(2)
pH Range (S.U.)	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	NR 102.04(4)[e] NR 104.04(3)
Fecal Coliform Bacteria (MFFCC)							NR 102.04(5)
Geometric Mean	200	200	200	1,000	1,000	200	NR 102.04(6)
Maximum	400	400	400	2,000	--	400	NR 102.06(2)
Total Phosphorus (mg/l)							NR 102.06(3)
Designated Streams[f]	0.100	0.100	0.100	0.100	0.100	0.100	NR 102.06(4)
Other Streams	0.075	0.075	0.075	0.075	0.075	--	NR 102.06(5) NR 102.06(6)
Chloride (mg/l)							
Acute Toxicity[g]	757	757	757	757	757	757	NR 105.05(2)
Chronic Toxicity[h]	395	395	395	395	395	395	NR 105.06(5)

[a] *NR 102.04(1) All surface waters shall meet the following conditions at all times and under all flow conditions: substances that will cause objectionable deposits on the shore or in the bed of a body of water, floating or submerged debris, oil, scum or other material, and materials producing color, odor, taste or unsightliness shall not be present in such amounts as to interfere with public rights in waters of the State. Substance in concentrations or combinations which are toxic or harmful to humans shall not be present in amounts found to be of public health significance, nor shall substances be present in amounts which are acutely harmful to animal, plant, or aquatic life.*

[b] *As set forth in Chapter NR 104.06(2)(a) of the* Wisconsin Administrative Code.

[c] *As set forth in Chapter NR 104.06(2)(b) of the* Wisconsin Administrative Code.

[d] *See Table 2.16.*

[e] *The pH shall be within the stated range with no change greater than 0.5 unit outside the estimated natural seasonal maximum and minimum.*

[f] *Designated in Chapter NR 102.06(3)(a) of the* Wisconsin Administrative Code. *There are no designated streams in the Pewaukee Lake watershed.*

[g] *The acute toxicity criterion is the maximum daily concentration of a substance that ensures adequate protection of sensitive species of aquatic life from the acute toxicity of that substance and will adequately protect the designated fish and aquatic life use of the surface water if not exceeded more than once every three years.*

[h] *The chronic toxicity criterion is the maximum four-day concentration of a substance that ensures adequate protection of sensitive species of aquatic life from the chronic toxicity of that substance and will adequately protect the designated fish and aquatic life use of the surface water if not exceeded more than once every three years.*

Source: Wisconsin Department of Natural Resources and SEWRPC

Key water quality parameters indicate the Lake is mesotrophic with regard to its level of nutrient enrichment. Like the majority of lakes in the Region, phosphorus is the key limiting nutrient regarding aquatic plant growth in Pewaukee Lake. Summer water clarity, and levels of chlorophyll-*a* and total phosphorus, have all shown improvement in recent years in both the west and east basins of the Lake, indicating that watershed management efforts have been effecting positive change in lake conditions. However, increasing chloride concentrations have been observed in Pewaukee Lake and should be a priority for future monitoring efforts.

The principal tributaries of Pewaukee Lake (Coco Creek, Meadowbrook Creek, and Zion Creek) are all important to the overall water quality of the Lake. As noted above, Coco Creek and its tributaries are the only streams in the Lake's watershed that are achieving coldwater standards. Coco Creek consistently provides a healthy oxygen-rich environment for aquatic life, while Meadowbrook Creek experiences occasional oxygen levels below the 5.0 mg/l threshold; Zion Creek experiences oxygen levels that drop below the 5.0 mg/l level and above the toxic supersaturation level of 15 mg/l. All three main tributaries have shown increases in chloride and specific conductivity over the past several years, with Meadowbrook experiencing the highest levels. As these tributaries are likely contributing to the increasing chloride concentrations in Pewaukee Lake, greater monitoring of chloride in these streams should be considered as well. Continued monitoring of the tributaries that includes rate of flow would greatly aid in the measuring of phosphorus entering the Lake, informing models of phosphorus loading. Further discussion of lake and tributary monitoring and management recommendations are provided in Section 3.3, "Water Quality", Section 3.4, "Pollutant and Sediment Sources and Loads," and Section 3.6, "Cyanobacteria and Floating Algae."

2.6 POLLUTANT LOADS

At the present time, most pollutants delivered to the Lake and its tributary streams are carried by runoff and wind. Very little pollution is deliberately discharged by humans to the Lake and its tributaries through wastewater discharge points. In-Lake processes are another significant contributor to overall phosphorus loads in many lakes and human activity can intensify their contribution.

The Commission estimated probable pollutant loads and in-lake phosphorous concentrations using the Unit Area Loading (UAL) model and the Wisconsin Lake Modeling Suite (WiLMS) model. The data generated by these models can help identify pollutants that may impinge upon the health of the Lake as well as the land uses and land areas responsible for elevated loads. To supplement model results, the Commission reviewed previous stream studies and completed an on-the-ground inventory during 2015 of sites with pronounced erosion along Coco, Meadowbrook, and Zion Creeks.

Historical Nutrient Budgets

Using measured concentrations from the Lake and its tributaries, a study conducted for the first Pewaukee Lake management plan determined that 14 percent of the nitrogen and 13 percent of the phosphorus entering the Lake came from direct drainage; 35 and 34 percent, respectively, from the inlets; 14 and 7 percent, respectively, from precipitation; and 37 and 46 percent, respectively, from dry fallout on the lake surface. Of the total mass of nutrients and sediment entering Pewaukee Lake, 72 percent of the nitrogen, 26 percent of the phosphorus, and 61 percent of the sediment was estimated to have remained in the Lake.[120]

Watershed-Sourced Loads

The most prevalent pollutants to lakes include sediment and nutrients, both of which have natural sources and sources that are attributable to human activity. Sediment and nutrients contribute to lake aging. Sediment and nutrient loads can greatly increase when humans disturb land cover and runoff patterns through activities such as tilling and construction, both of which typically loosen soil, increase runoff and in turn allow soil to more easily erode and eventually enter streams and lakes. In contrast, heavy metals, detergents, oils, and fertilizers were not common in the watershed under natural conditions and are essentially completely attributable to human activity.

Different human land use types contribute different types of pollution to water bodies. For example, phosphorus sources in rural areas may be correlated with agricultural fertilizers and animal waste delivered to waterbodies through overland runoff. In contrast, in urban areas, phosphorus from lawn fertilizers,

[120] *SEWRPC Community Assistance Planning Report No. 58,* op. cit.

clippings and leaves from ornamental plantings, and cleaning agents are often quickly conveyed to water bodies with little opportunity for attenuation. In 2010, the State of Wisconsin placed restrictions on the sale of some phosphorus-containing cleaning agents.[121] The State has also adopted a turf management standard limiting the application of lawn fertilizers containing phosphorus within the State,[122] potentially acting to reduce the amount of phosphorus discharged from urban settings. In both rural and urban areas, poorly maintained or failing onsite wastewater treatment systems have been found to contribute phosphorus to surface-water features.

Urban leaf litter can also be a substantial source of phosphorus pollution, particularly in urban sections of the watershed. A study conducted in the Lake Wingra watershed in Dane County indicates that 55 percent of the total annual residential phosphorus loading occurs during autumn, largely attributable to curbside and street-area leaf litter.[123] Leaves crushed by vehicular traffic leach greater amounts of phosphorus, particularly during wet weather. Runoff then washes the leached phosphorus into the stormwater drainage system and eventually into surface waters.

Effectively managing leaves on residential streets during the fall can significantly reduce the phosphorus loading from urban areas within the Lake watershed. The City of Pewaukee presently provides a City Recycling Center that accepts leaves and yard waste; the Village of Pewaukee and City of Waukesha offer curbside pickup of leaves on several dates each fall; residents of other municipalities whose property lies within the Pewaukee Lake watershed (see Map 2.15) should check with their local municipalities for proper disposing of leaves. Keeping leaves from collecting on residential streets through prompt leaf collection, and especially the timing of that collection from the streets, is a critical part of reducing external phosphorus loading from residential areas.

Tributary Nutrient Loading

A 2003-2004 study of phosphorus loading into Pewaukee Lake conducted by Wisconsin Lutheran College found that Coco Creek contributed the most phosphorus of any major tributary, with 48.4 percent of total tributary phosphorus loading.[124] Zion Creek contributed the second most at 34.0 percent, while Meadowbrook Creek contributed the least at 17.6 percent. Current predicted phosphorus loadings for the four main tributaries to Pewaukee Lake (Audley Creek, Coco Creek, Meadowbrook Creek, and Zion Creek), were estimated using the Pollutant Load Ratio Estimation Tool (PRESTO)[125] developed by the Wisconsin Department of Natural Resources, and are presented in Table 2.18. These findings do not completely agree with the Wisconsin Lutheran College study, as Coco Creek is still the main tributary contributor of phosphorus to Pewaukee Lake, at 2,337 pounds annually, but Meadowbrook Creek is the second largest contributor, at 1,547 pounds annually. Zion Creek falls to third, at 614 pounds annually, while Audley Creek only contributes 94 pounds annually. It is important to keep in mind that these values are estimates (80 percent confidence level) based on land uses within the sub-watershed of each tributary and assuming a typical year of average rainfall.

<u>Streambank Erosion</u>

Accelerated streambank erosion can contribute to total phosphorus and suspended sediment loading that is not accounted for in model estimates as well as impede navigation, and destroy aquatic habitat, spawning, and feeding areas. In general, urbanization increases runoff quantity during and immediately after precipitation or snowmelt. Higher runoff rates increase water velocity and overall stream power, resulting in

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[121] *Section 100.28 of the* Wisconsin Statutes *bans the sale of cleaning agents for non-household dishwashing machines and medical and surgical equipment that contain more than 8.7 percent phosphorus by weight. This statute also bans the sale of other cleaning agents containing more than 0.5 percent phosphorus by weight. Cleaning agents for industrial processes and cleansing dairy equipment are specifically exempted from these restrictions.*

[122] *On April 14, 2009, 2009 Wisconsin Act 9 created Section 94.643 of the* Wisconsin Statutes *relating to restrictions on the use and sale of fertilizer containing phosphorus in urban areas throughout the State of Wisconsin.*

[123] *Roger Bannerman of the USGS has described the findings of the Lake Wingra study in his presentation entitled* "Urban Phosphorus Loads: Identifying Sources and Evaluating Controls."

[124] *Wisconsin Lutheran College, Chemistry Department Technical Bulletin 001,* Pewaukee Lake Phosphorus Monitoring 2003-2004*, March 2005.*

[125] *dnrmaps.wi.gov/H5/?viewer=WI_TMDL.*

greater streambank erosion and bottom scour. These effects can be mitigated by sound land use planning combined with installing proper stormwater management practices.

Table 2.18
Predicted Values for Average Annual Phosphorus Load to Pewaukee Lake Tributaries from Nonpoint Sources

Waterbody	Average Predicted Phosphorus Load (lb/yr)	80 Percent Confidence Interval (lb/yr)
Audley Creek	94	45 – 197
Coco Creek	2,337	993 – 5,500
Meadowbrook Creek	1,547	649 – 3,684
Zion Creek	614	279 – 1,348

Source: Wisconsin Department of Natural Resources and SEWRPC

Where active streambank erosion was observed, Commission staff recorded information on bank height, length of eroding bank, and depth of undercutting and took photos. Most of the streambanks within the areas surveyed seemed stable and in generally good condition. In addition, the streambanks were generally not excessively high and seemed well-connected to the adjacent floodplain. For example, average maximum streambank height was 2.3 feet, but a few locations did exceed five feet in height (see Appendix A, Table A.1 on page 289). Hence, only about 0.5 mile (2,805 feet) of stream, or about 5.5 percent of the total 9 miles assessed, was observed to be potentially actively eroding as shown on Map A.5 and A.6 on pages 311 and 312 in Appendix A. These sites occur throughout the entire length of the tributaries, but the majority of the sites are located at the headwaters of Coco Creek. Within this sub-basin, the creek is less meandered (likely due to channelization in the past), is less buffered by natural vegetation due to encroachment of urban development, and contains a more restrictive floodplain. In contrast, the other reaches of the tributaries contain fewer actively eroding sites and are located within areas that contain much more extensive riparian buffers (see Map 2.20 and Insets 1 and 2) and are much more highly meandered. Intervention in the case of the headwaters of Coco Creek could include remeandering the stream to its historic condition, two-stage channel design construction, or slope stabilization with bioengineering and/or selective hard armoring with riprap stone, where appropriate (see Chapter 3 for more details).

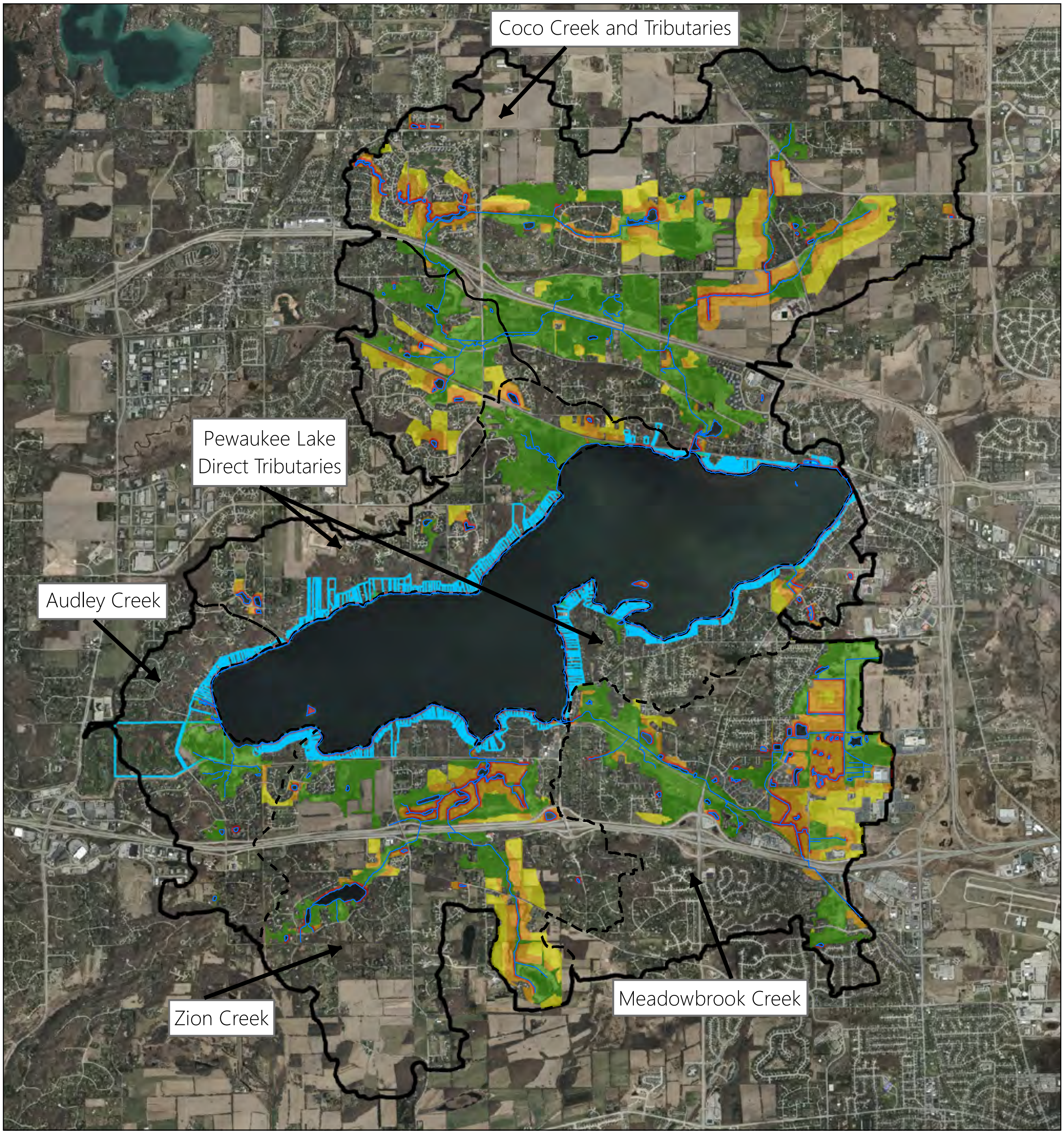
The reaches of surveyed tributaries have a slope of about 0.0066 feet/feet (35 feet per mile) or lower, which is consistent with a low gradient stream condition and the field observations of limited streambank erosion. Since lateral recession rates were unknown and could not be determined, it was not possible to calculate a pollutant load rate or the overall severity among these potentially actively eroding locations. However, there were a few sites that seemed more active than others sites and may be cause for concern as shown in Maps A.5 and A.6 in Appendix A, since this sediment is potentially contributing to the degradation of instream fisheries habitat and to pollutant loads into Pewaukee Lake. Therefore, this is an important issue of concern and recommendations related to streambank stability are included in Chapter 3.

Simulated Nonpoint Source Loads

The Commission simulated nonpoint source pollutant loads for suspended solids (sediment), phosphorus, and urban-derived metals to Pewaukee Lake using two land use based models. One simulation used the Wisconsin Lake Model Spreadsheet (WiLMS version 3.3.18) while the other used the Commission's unit area load-based (UAL) model developed for the Southeastern Wisconsin Region. These two models assume that a given land use type emits a set rate of pollutants on an annual basis.

Land use data for various time periods were entered into both models to predict pollutant loads to Pewaukee Lake. The loads predicted by the UAL model are summarized in Table 2.19. These calculations assume that urban land use is the only significant source of heavy metals. Heavy metals monitoring has not occurred within the Lake. However, urban areas should be targeted for mitigation measures if heavy metals become an issue within the Lake in the future. The UAL model estimates that 771 tons of suspended sediment and 3,941 pounds of total phosphorus are delivered to Pewaukee Lake each year from surface runoff under year 2015 land use conditions. Agricultural land uses are the major sediment and phosphorus contributors, at 62 percent of the sediment and 47 percent of the phosphorus reaching Pewaukee Lake. Low density residences and their associated roadways were the next largest contributors of phosphorus and sediment. Under planned conditions, current agricultural lands will be converted to urban land use. Consequently, the overall mass of sediment and phosphorus anticipated to be delivered to the Lake will decrease by 44 tons and 98 pounds, respectively. With proactive and aggressive pursuit of runoff water quality measures, sediment and phosphorus loading to the Lake can be even further reduced. Practices to reduce urban loading are addressed in more detail in Chapter 3.

Map 2.20
Potential Pewaukee Lake Watershed Shoreline and Riparian Buffers



EXISTING RIPARIAN BUFFER

75 FEET MINIMUM RECOMMENDED BUFFER WIDTH

400 FEET MINIMUM CORE HABITAT WIDTH FOR WILDLIFE PROTECTION

1000 FEET OPTIMAL CORE HABITAT WIDTH FOR WILDLIFE PROTECTION

PRIORITY TAX PARCELS FOR BUFFER PROTECTION

PEWAUKEE WATERSHED BOUNDARY

SUB-BASIN BOUNDARY

STREAM OR SURFACE WATER OUTLINE

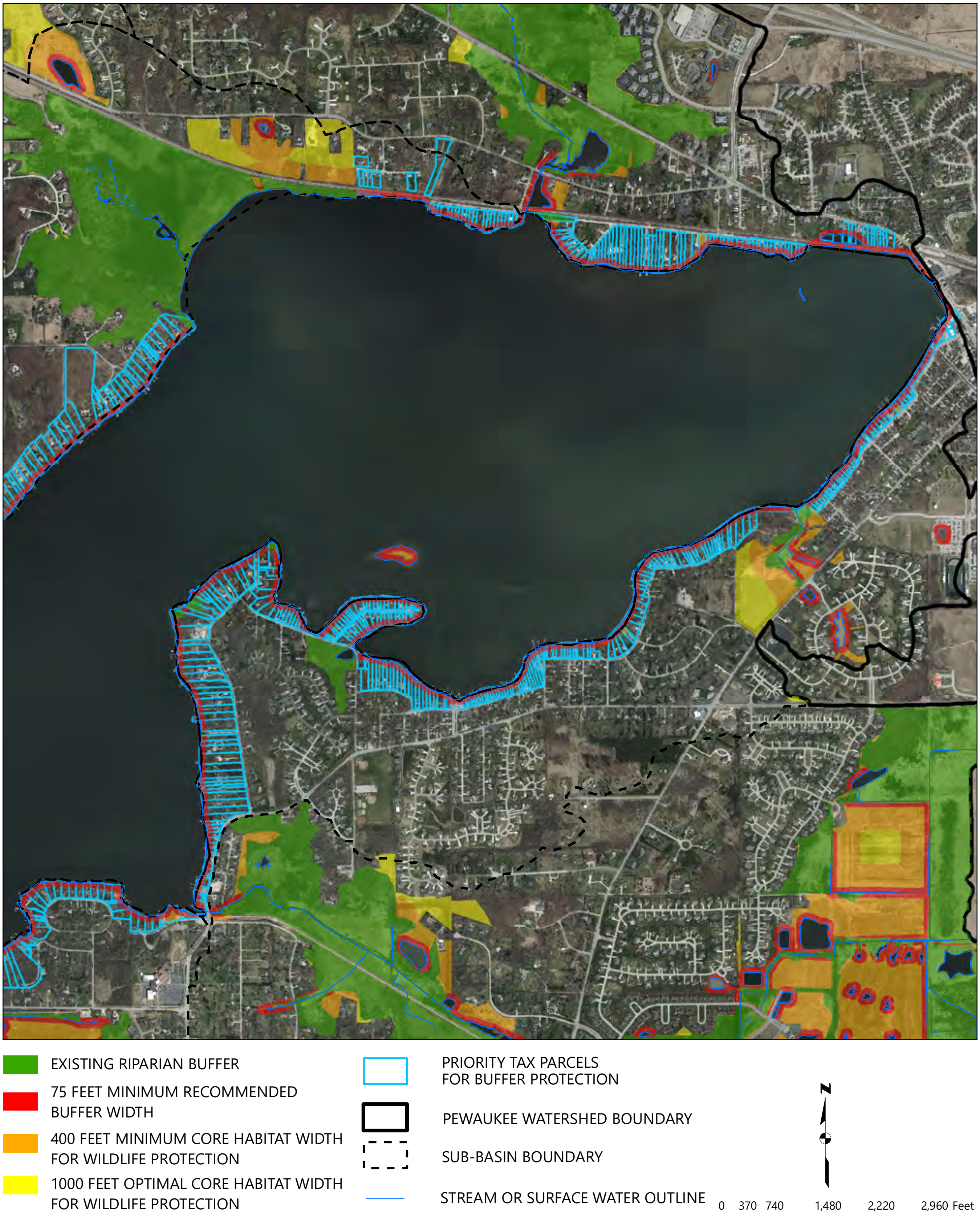
N

0 1,0502,100 4,200 6,300 8,400 Feet

Note: Date of Orthophotography: April 2015

Source: SEWRPC

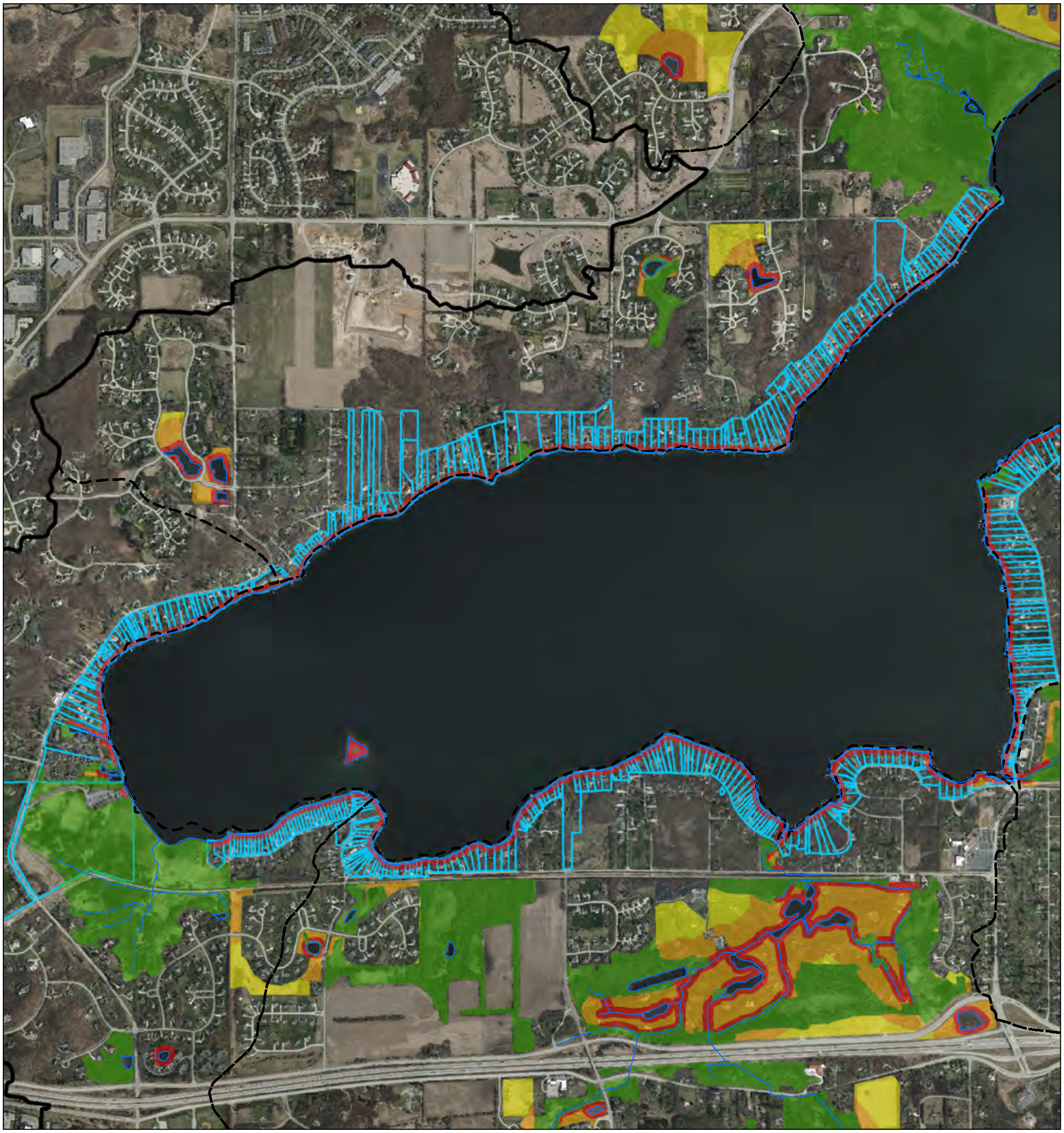
Map 2.20 – Inset 1
Potential Pewaukee Lake East Basin Shoreline and Riparian Buffers



Note: Date of Orthophotography: April 2015

Source: SEWRPC

Map 2.20 – Inset 2
Potential Pewaukee Lake West Basin Shoreline and Riparian Buffers



EXISTING RIPARIAN BUFFER

75 FEET MINIMUM RECOMMENDED BUFFER WIDTH

400 FEET MINIMUM CORE HABITAT WIDTH FOR WILDLIFE PROTECTION

1000 FEET OPTIMAL CORE HABITAT WIDTH FOR WILDLIFE PROTECTION

PRIORITY TAX PARCELS FOR BUFFER PROTECTION

PEWAUKEE WATERSHED BOUNDARY

SUB-BASIN BOUNDARY

STREAM OR SURFACE WATER OUTLINE

0 410 820 1,640 2,460 3,280 Feet

Note: Date of Orthophotography: April 2015

Source: SEWRPC

Table 2.19
Estimated Annual Land Use Pollutant Loads Within the Pewaukee Lake Watershed

Land Use Category	Pollutant Loads: 2015 Land Use			
	Sediment (tons)	Phosphorus (pounds)	Copper (pounds)	Zinc (pounds)
Urban				
Residential	97.5	1,159.7	42.6	329.5
Commercial	33.2	101.5	18.6	126.1
Industrial	14.3	44.4	8.3	56.5
Governmental	33.2	175.6	9.1	104.1
Transportation	85.0	178.4	389.3	1,323.2
Recreational	8.0	178.9	--	--
Urban Subtotal	271.1	1,838.6	447.9	1,939.3
Rural				
Agricultural	486.4	1,990.2	--	--
Wetlands	2.5	54.3	--	--
Woodlands	2.1	45.0	--	--
Water	9.8	13.5	--	--
Rural Subtotal	500.8	2,089.6	--	--
Total	771.9	3,928.2	447.9	1,939.3

Land Use Category	Pollutant Loads: Planned Land Use			
	Sediment (tons/year)	Phosphorus (pounds/year)	Copper (pounds/year)	Zinc (pounds/year)
Urban				
Residential	112.1	1,361.5	47.0	367.6
Commercial	103.5	316.9	58.1	393.4
Industrial	51.9	161.4	30.3	205.5
Governmental	68.9	364.3	18.9	215.9
Transportation	90.2	180.5	393.7	1,410.8
Recreational	9.0	201.7	--	--
Urban Subtotal	435.6	2,586.2	548.0	2,593.2
Rural				
Agricultural	277.5	1145.1	--	--
Wetlands	2.5	54.3	--	--
Woodlands	2.1	45.0	--	--
Water	9.7	13.5	--	--
Rural Subtotal	291.2	1,257.9	--	--
Total	727.4	3,844.1	548.0	2,593.2

Source: SEWRPC

Similar to the approach employed by the UAL model, the WiLMS model uses land use, hydrologic, and watershed area information to estimate the total flux of phosphorus to a lake during a typical year.[126] The WiLMS model produces a range of probable phosphorus load values (low, most likely, and high). In Southeastern Wisconsin, The Commission has found that WiLMS low range estimates best match the UAL model predictions, and therefore typically uses these estimates to predict in-lake phosphorus concentrations. Moreover, the USGS has found that models tend to over-predict phosphorus values for hard-water lakes (such as Pewaukee Lake). Given the significance of carbonate-induced phosphorus sequestration in hard-water lakes, this seems reasonable. For this reason, the WiLMS low range estimate is believed to best portray local conditions. The model uses the calculated load estimates to predict water quality in the receiving lake using regression equations that have been designed to fit a variety of lake types (e.g., deep

[126] *These models do not account for groundwater influx and exit from the lake. Models can be adjusted to include this variable if sufficient interest is expressed by lake users and managers as part of a future study. Groundwater is a very important component of the water budget of Pewaukee Lake. Including groundwater in future models may not necessarily improve the accuracy of the models, but will account for and potentially eliminate a currently untested variable from the simulation process.*

lakes, reservoirs, and general lake models). Using the low-range loading estimates for the reason discussed above, the Canfield-Bachmann 1981 model for natural lakes best fits observed conditions in Pewaukee Lake as the predicted surface water phosphorus concentrations (0.028 mg/l) most closely matched average concentrations (0.024 mg/l) in the Lake.

Using the WiLMS model, we predicted loading rates under three different land use scenarios: pre-settlement (circa 1830), year 2015, and planned conditions based on local government comprehensive plans. For 2015 land use, the WiLMS model predicts between 3,318 and 10,970 pounds of phosphorus could be delivered to Pewaukee Lake each year from nonpoint sources, with the most likely value at 6,284 pounds per year. The lowest WiLMS rate of 3,318 pounds per year is slightly lower than the predictions of 3,941 pounds per year from the UAL model and the combined 4,592 pounds per year from the Lake tributaries calculated by the WDNR PRESTO-lite model. These loading rates are two to three times greater than those predicted under presettlement land use (1,081 to 5,068 pounds per year). The planned land use estimates indicate that phosphorus loading rates to the Lake are most likely to remain stable or just slightly increase with anticipated changes in land use within the watershed, such as the shift from agricultural and pasture lands to low density residential use (see land use discussion in Section 2.2, "Lake and Watershed Physiography" for greater detail).

WiLMs model outputs suggest that before settlement, Pewaukee Lake's phosphorus concentrations averaged around 0.012 mg/l, suggesting that the Lake was an oligotrophic waterbody. Model outputs for year 2015 conditions suggest that phosphorus concentration should be 0.028 mg/l, a value slightly exceeding typical phosphorus concentrations detected in the Lake and indicative of a mesotrophic waterbody. The slightly lower phosphorus values detected in Lake water may be reflective of the relatively large mass of phosphorus removed from lake water by aquatic plant harvesting, and is thought to be a fairly good match for actual conditions. Using the model to look forward, land use changes are not expected to significantly change phosphorus values in the Lake for the next 30 years.

In-Lake Phosphorus Sources

Internal Loading

Phosphorus concentrations tend to vary widely in the deepest parts of the Lake. As shown in Figure 2.48, samples drawn from the Lake's deep water hypolimnion during the summer months commonly contain phosphorus concentrations more than ten times higher than near-surface lake water, with values averaging 0.173 mg/l, and ranging from 0.019 mg/l to 0.360 mg/l. Large discrepancies between surface and deep water phosphorus concentrations are an indication of internal loading. Under oxygenated conditions, phosphorus remains tightly bound to lake-bottom sediment; however, during anoxic conditions, geochemical reactions release this phosphorus from the bottom sediment into the water column where it is then free to mix throughout the entire water column during the next overturn period. Phosphorus released in stratified lakes in this condition is a well-documented phenomenon and can account for up to 39 percent of a lake's total phosphorus load;[127] indeed, concentrations of phosphorus as high as 1.0 mg/l (1000 ug/l) have been observed.[128]

Lake stratification can signal when internal loading is occurring. Hypolimnetic phosphorus concentrations rapidly increase immediately after the Lake stratifies (usually early to mid-June), commonly reaching their maximum values during July. This is a common occurrence on many lakes as biological productivity and attendant organic loading to hypolimnetic waters peaks in late spring. Temperature, DO, and specific conductivity profiles suggest that mixing between the hypolimnion and epilimnion typically occurs during late summer. Consequently, late summer hypolimnetic phosphorus concentrations are occasionally lower than midsummer concentrations. This peak in hypolimnetic phosphorus concentrations during summer stratification signals the occurrence of internal loading.

Exposure of sediment to anoxic (without oxygen) water can exacerbate internal loading issues. When anoxic conditions are present, the amount of exposed sediment is influenced by the shape of the lake basin. Even though two lakes may have equivalent maximum depths, a lake that has broad shallow areas and a small

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[127] *G.K. Nurnberg, and R.H. Peters, "The Importance of Internal Phosphorus Load to the Eutrophication of Lakes With Anoxic Hypolimnia: With 8 Figures in the Text,"* Verhandlung Internationale Vereinigung Limnologie*, 22(1): 90-194, 1984.*

[128] *B.K. Holstrom et al.,* Water resources data, Wisconsin, water years 1985-1991, *U.S. Geological Survey Water-Data Report WI-85-1 to WI-91-1, 1985-1992 (published annually).*

deep hole has less deep water bottom sediment area than an equal depth lake that is uniformly deep. Since sediment exposed to anoxic water can release phosphorus into the water column, lakes with more deep water sediment area are more susceptible to significant phosphorus internal loading. Moderate depth/size stratified lakes are among the most prone to internal phosphorus loading. Such lakes lack large water volumes, and, hence, have comparatively little stored oxygen in the hypolimnion, making them prone to anoxia. As discussed in Section 2.5, "Water Quality," summer anoxia forms in Pewaukee Lake below 25 feet depth in July and August most years, resulting in about 450 acres of anoxic lake bottom that could contribute to internal phosphorus loading (see Figure 2.31).

To evaluate the contribution of internal loading to total Lake phosphorus loads, we calculated the internal loading rate for Pewaukee Lake using the difference in spring and summer hypolimnetic phosphorus concentrations multiplied by the volume of anoxic water within the Lake. This calculation assumes that the hypolimnetic phosphorus concentrations are entirely driven by release of phosphorus from lake-bottom sediment, which may be an overestimation of these rates. Using the mean hypolimnetic phosphorus concentrations from 1973 to 2018, the internal loading rate for Pewaukee Lake was 1,818 pounds per year. However, the data used for this calculation was primarily collected prior to 2000, at which point the frequency of hypolimnetic sampling decreased. As surface water phosphorus concentrations have declined since 2000, it is possible that internal loading rates have declined as well, but there are not enough data available to support this hypothesis. In addition, the frequency of anoxic days has been declining in the Lake, which could also potentially reduce the impacts of internal loading.

Internal Recycling

Another process that can contribute significantly to a lake's phosphorus load is *internal recycling*. As rooted aquatic plants grow, they take up phosphorus from the lake sediment through their roots and incorporate it into the plant itself. Aquatic plants also absorb nutrients from the water column directly.[129] When the plant dies and decays, this phosphorus can then be released back into the water column. In a study done on Lake Wingra in Madison, Wisconsin,[130] internal recycling of Eurasian watermilfoil (EWM) (*Myriophyllum spicatum*) represented 47 percent of the annual external phosphorus input to the lake. In a study conducted on Whitewater and Rice lakes in 1991,[131] internal recycling was found to account for approximately 51 percent of the combined internal and external total phosphorus input to Whitewater Lake, equivalent to 582 pounds of phosphorus, and 82 percent of the total to Rice Lake, equivalent to 295 pounds of phosphorus. According to this study, "at Whitewater Lake, by late July, in-lake phosphorus mass had exceeded inputs by a factor of more than 3, and at Rice Lake, the in-lake phosphorus mass had exceeded the external inputs by a factor of more than 13." Clearly, internal loading (the release of phosphorus from bottom sediments through anoxic-stimulated chemical reactions), is not the only internal factor increasing lake phosphorus concentrations; internal recycling can play a key role as well. Just how important recycling of phosphorus is in Pewaukee Lake has yet to be determined and will require a separate study beyond the scope of this report.

There are other minor events and processes related to physical disruption of bottom sediments, especially in shallow lakes, that can cause phosphorus levels in a lake's water column to increase: movement through sediment by benthic organisms, propeller-caused stirring of bottom sediments by motorboats, and wind/wave action. Such physical disruptions tend to re-suspend bottom sediments and cause phosphorus concentrations in the water column to increase.

Pollution Mitigation Strategies

Properly implemented pollution mitigation strategies, such as managing stormwater, restoring wetlands, minimizing shoreline erosion, and creating riparian buffers, can reduce pollutant loading into lakes and streams. This subsection discusses these strategies and their implementation in the Pewaukee Lake watershed.

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[129] *G. Thiébaut, "Phosphorus and Aquatic Plants," In P.J. White and J.P. Hammond (eds), The Ecophysiology of PlantPhosphorus Interactions,* Plant Ecophysiology *7, 2008.*

[130] *C.S. Smith and M.S. Adams, "Phosphorus Transfer From Sediments by* Myriophyllum spicatum*,"* Limnology and Oceanography, *31(6): 1312-1321, 1986.*

[131] *G.L. Goddard and S.J. Field,* Hydrology and Water Quality of Whitewater and Rice Lakes in Southeastern Wisconsin, 1990-91, *U.S. Geological Survey Water-Resources Investigations Report 94-410, 1994.*

Stormwater Management

To meet the requirements of the Federal Clean Water Act, the WDNR developed a permit program under Wisconsin Administrative Code NR 216, "Storm Water Discharge Permits." A municipal separate storm sewer system (MS4) permit is required for a municipality that is either located within a Federally-designated urbanized area, has a population of 10,000 or more, or is designated for permit coverage by the WDNR. Municipal permits require stormwater management programs to reduce polluted stormwater runoff by implementing best management practices. Chapter NR 216 also requires certain types of industries to obtain stormwater discharge permits from the WDNR, but there are no industrial stormwater permits issued in the Pewaukee Lake watershed. The general permit requires an MS4 holder to develop, maintain, and implement stormwater management programs to prevent pollutants from the MS4 from entering State waters. Examples of stormwater best management practices (BMPs) used by municipalities to meet permit conditions include detention basins, street sweeping, filter strips, bioretention facilities, and rain gardens.

In cooperation with the WDNR, Waukesha County, and the Commission, storm sewer system inventory information was obtained from each of the MS4 municipalities, as well as from Waukesha County records, and combined into a composite map for the entire watershed (see Map 2.21). Under their MS4 permit, each of these communities is required to provide detailed and accurate inventories in a digital geographic information systems (GIS) software format for the following elements summarized below:

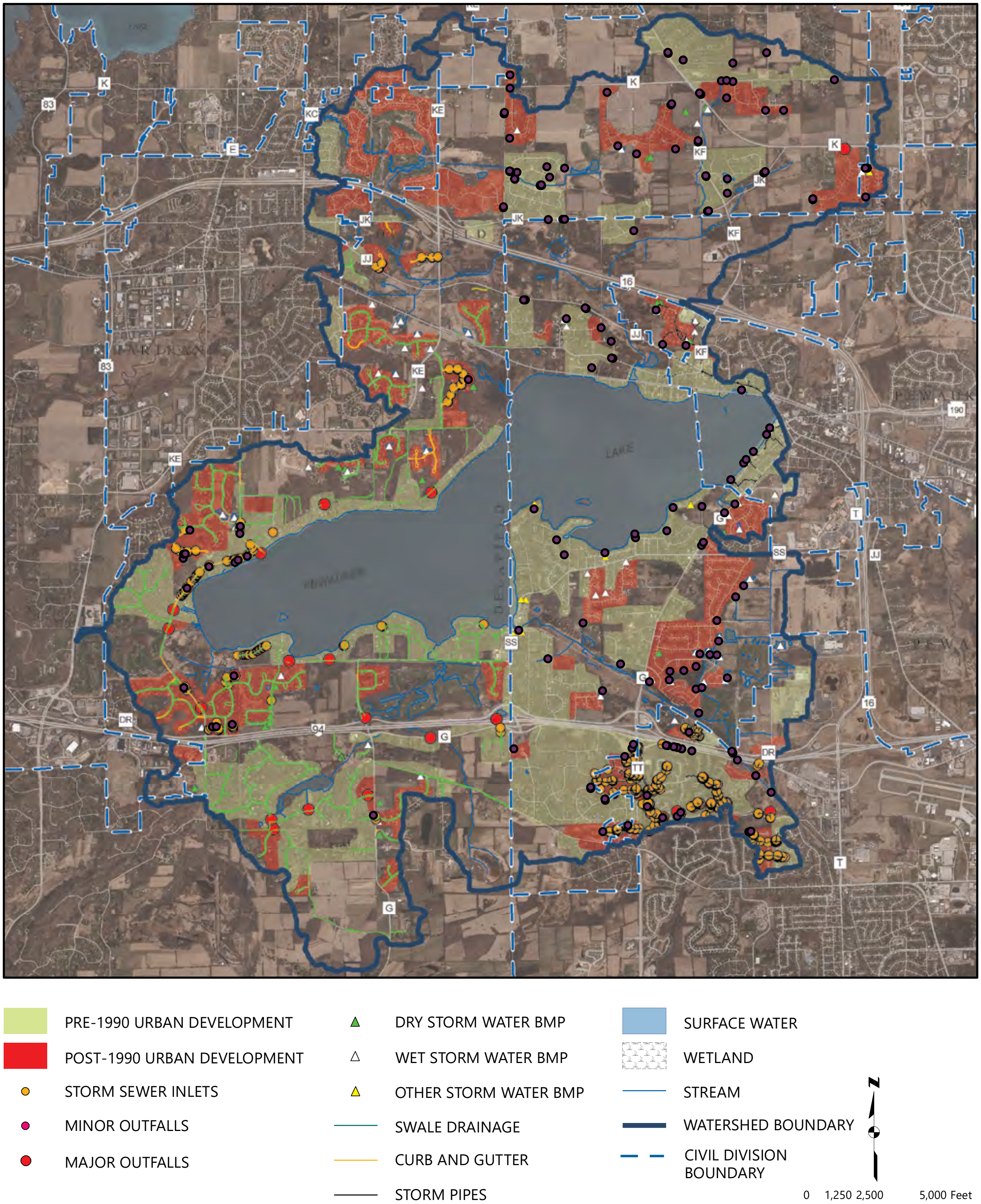
- Identification of all known MS4 outfalls discharging to waters of the State or another MS4 including minor outfalls and major outfalls[132]
- Location and permit number of any known discharge to the MS4 that has been issued Wisconsin Pollutant Discharge Elimination System permit coverage by the WDNR
- Location of structural stormwater facilities including detention basins, infiltration basins, and manufactured treatment devices
- Identification of publicly owned park and recreational areas and other open lands
- Location of municipal garages, storage areas and other public works facilities
- Identification of streets

Map 2.21 shows stormwater information throughout the watershed as reported from 2015 through 2018. The map is not intended to show every element of the stormwater infrastructure in each community. Information on specific characteristics of municipal stormwater management systems can be located in individual reports for each community as documented in Table 2.20.

Since each of the MS4 communities compiled its inventories using different digital formats and categories, the GIS data files were integrated to the extent practicable by Waukesha County staff. The main categories include major outfalls, minor outfalls, storm sewers, swale drainage, curb and gutter, and stormwater BMPs (wet basins and dry basins). Based upon this inventory data, there are a total of 18 major outfalls, 149 minor outfalls, 22 dry basins, and 24 wet basins (having a permanent pond) within the Pewaukee Lake watershed. The storm sewers shown on Map 2.21 include both culverts and storm sewers. In addition, some communities also mapped the sewer inlets, curb and gutter, and swale information, which helps to better understand how stormwater is routed across the landscape within portions of the watershed. The majority of the storm sewer inlets throughout the watershed are located in the Meadowbrook sub-basin in Waukesha, although some are located in the Pewaukee Lake sub-basin in the Town of Delafield. Those inlets are connected to numerous minor and major outfalls that discharge directly into Meadowbrook Creek and Pewaukee Lake (see Stream Inventory Conditions above and Appendix A). There are additional outfalls located directly adjacent to the Zion Creek in the Town of Delafield. As noted in the inventory summary

[132] *A major outfall is a municipal separate storm sewer outfall that meets one of the following criteria: 1) a single pipe with an inside diameter of 36 inches or more or equivalent conveyance (cross sectional area of 1,018 square inches), which is associated with a drainage area of more than 50 acres, or 2) an MS4 that receives stormwater runoff from lands zoned for industrial activity or from other lands with industrial activity that is associated with a drainage area of two acres or more.*

Map 2.21
Storm Drainage Systems Within the Pewaukee Lake Watershed



Source: SEWRPC

Table 2.20
MS4 Community Stormwater Infrastructure Inventory Within the Pewaukee Lake Watershed: 2010-2018

	Stormwater Management System Category					
		Outfalls		Best Management Practices (BMP)		
Community	Sewer Inlets	Minor	Major	Dry Basin	Wet Basin	Other
City of Pewaukee	0	56	0	5	6	1
City of Waukesha	222	21	15	1	0	0
Town of Delafield	121	17	18	16	25	0
Town of Lisbon	0	52	1	4	9	0
Village of Pewaukee	0	10	0	5	27	8
Village of Sussex	0	3	0	0	2	2
Total	343	149	34	31	69	11

Source: City of Pewaukee, AECOM; City of Waukesha, GRAEF; Town of Delafield, R.A. Smith National, Inc.; Town of Lisbon, Strand Associates, Inc.; Village of Pewaukee, STANTEC; Village of Sussex, Ruekert & Mielke, Inc.; Waukesha County PLU – Land Resources Division; and SEWRPC

section above, several of these outfalls may be good candidates for modification or improvement to reduce the volume of stormwater pollutants entering Meadowbrook Creek and, ultimately, Pewaukee Lake.

These data were projected over the total extent of urban lands under pre-1990 versus post-1990 conditions, because stormwater rules and practices began to be implemented more widely during the post-1990 period. Hence, nearly all of the stormwater BMPs on the landscape reside within the urban lands developed after 1990. Consequently, most of the stormwater BMPs directly around Pewaukee Lake within the Pewaukee Lake watershed consisted of storm sewers, curb and gutter, and swales. It is also important to note that there are several minor and major outfalls that discharge stormwater with limited treatment directly into Pewaukee Lake, and which could be contributing pollutants including sediments into nearshore areas of the Lake, especially in the west basin. Such outfalls might be good candidates for modification or improvement to reduce stormwater pollutants from entering the Lake.

In contrast, since many areas upstream of Pewaukee Lake in the Meadowbrook and Coco Creek sub-basins were developed after 1990, BMPs include the aforementioned practices, but wet and dry stormwater detention basins are much more prevalent among these sub-basins. Nearly 50 of these wet and dry basins have been constructed since about 1990 and more continue to be constructed with each new development throughout the watershed. These basins are designed to capture the stormwater runoff water and release it at a reduced rate. Wet basins allow the total suspended solids particles, nutrients, and associated materials to settle out. Dry basins generally provide little control of nonpoint source pollution, because they have no permanent pool for settling and subsequent storage of particulate pollutants. Stormwater is diverted into these basins prior to discharging into the surface water of the Lake or local tributaries and streams within the Pewaukee Lake system.

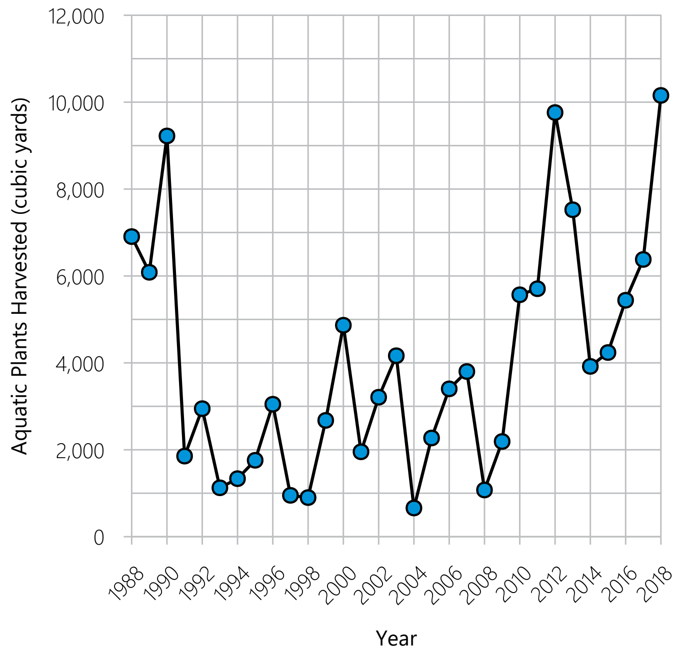
Phosphorus Removal Through Macrophyte Harvesting

A benefit of aquatic plant harvesting versus chemical treatment is that harvesting physically removes plant mass, and the nutrients contained therein, from the Lake. In some lakes, plant harvesting removes enough phosphorus to tangibly reduce lake phosphorus loads. Plant harvesting is already underway in the Lake for navigation purposes. The LPSD has kept records of the approximate amounts of harvested plants since at least 1988 (see Figure 2.58). In addition, the Village of Pewaukee harvested 1,000 yd^3 of plants in 2018. The Commission calculated the pounds of total phosphorus removed through harvesting by multiplying the annual mass of aquatic plant removed by the phosphorus concentration of those aquatic plants, with the following notes and assumptions:

- The amount of aquatic plants harvested is typically reported as a volume (often in cubic yards). To determine the mass removed, the density of the wet harvested plants was assumed to be 900 pounds per cubic yard.
- The amount of phosphorus contained by aquatic plants varies by species, lake, and time. The phosphorus content of harvested plants was estimated using information collected by the Wisconsin

Lutheran College (WLC) on Pewaukee Lake, the U.S. Geological Survey on Whitewater and Rice lakes (Whitewater-Rice), and a study conducted on a eutrophic lake in Minnesota (Minnesota). The WLC study assumed that plant dry weight is 6.7 percent of wet weight and that total phosphorus constitutes 0.2 percent of the total dry weight of the plant. The Whitewater-Rice and Minnesota studies assumed that dry weight is 15 and 7 percent of the wet weight, respectively, and phosphorus constituted 0.31 and 0.30 percent of the dry plant weight, respectively. Assumed values for the percent of dry weight to wet weight and the total phosphorus concentrations are similar to those found in other studies.[133,134]

Figure 2.58
Annual Aquatic Plant Volume Harvested in Pewaukee Lake: 1988-2018



Source: Lake Pewaukee Sanitary District, Village of Pewaukee, and SEWRPC

Using this method, the Commission estimates that aquatic plant harvesting removes an average of 786 to 2,729 lbs. of phosphorus each year, for a cumulative phosphorus removal of up to 52,348 lbs. since 1988 (see Figure 2.59). This phosphorus removal constitutes between 15 and 51 percent of the annual nonpoint source phosphorus loading into Pewaukee Lake. The cumulative impact of annually removing phosphorus from Pewaukee Lake through harvesting is significant. Improvements in water clarity, phosphorus, and chlorophyll-*a* measurements on the Lake since 1988 indicate that phosphorus removal through aquatic plant harvesting may be helping to offset phosphorus inputs.

Reducing Erosion Through Shoreline Protection

Many property owners abutting Pewaukee Lake are concerned with jointly maintaining the Lake's shorelines, recreational use, and aesthetic appeal without jeopardizing Lake health. This issue of concern is further emphasized by the fact that water quality, sedimentation, and aquatic plant growth can all be affected by shoreline maintenance practices.

Before discussing shoreline characteristics, it is important to understand the difference between two terms: *shoreline protection* and *buffers*.

- *Shoreline protection* encompasses various measures—engineered or natural—that shield the immediate shoreline (water-land interface) against the erosive forces of wave action
- *Buffers* are areas of plant growth—engineered or natural—in the riparian zone (lands immediately back from the shoreline) that trap sediment and nutrients emanating from upland and nearshore erosion

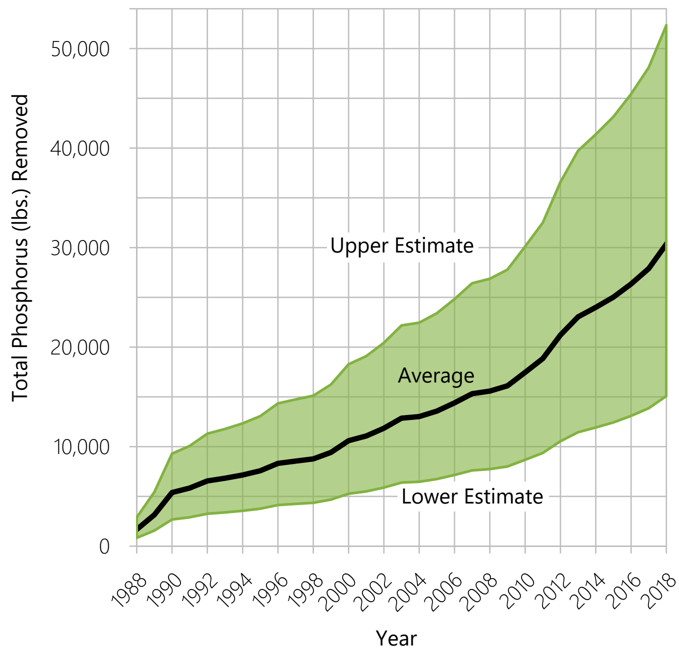
"Hard" engineered seawalls of stone, riprap, concrete, timbers, and steel, once considered "state-of-the-art" shoreline protection, are now recognized only as options to protect and restore a lake's water quality, wildlife, recreational opportunities, and scenic beauty. Indeed, the inability of hard shorelines to absorb wave energy can reflect that energy back into a lake, increasing wave energy in other portions of a lake. Manmade "hard" options available to home owners include: "bulkheads," where a solid *vertical* wall of erosion-

[133] *K.M. Carvalho and D.F. Martin, "Removal of Aqueous Selenium by Four Aquatic Plants," Journal of Aquatic Plant Management, 39: 33-36, 2001.*

[134] *G. Thiébaut, 2008,* op. cit.

resistant material (e.g., poured concrete, steel, or timber) is erected; "revetments," where a solid, *sloping* wall (usually asphalt, as in the case of a roadway, or poured concrete) is installed; "riprap," where loose stone material is placed along the shoreline. However, these options are only available with a WDNR permit.

Figure 2.59
Cumulative Mass of Phosphorus Removed by Aquatic Plant Harvesting from Pewaukee Lake: 1988-2018



Source: Lake Pewaukee Sanitary District, Village of Pewaukee, and SEWRPC

"Soft" shoreline protection techniques, such as vegetated shoreline protection, are increasingly required pursuant to Chapter NR 328, "Shore Erosion Control Structures In Navigable Waterways," of the *Wisconsin Administrative Code*. These techniques include natural shoreline, native planting, maintenance of aquatic plants along shorelines, and "fish sticks" (see Figure 2.58). Vegetative shoreline protection is becoming more popular as people living along lakes and streams become increasingly aware of the value of protecting their shorelines, improving overall aesthetic appeal of their shoreline, and promoting natural and nature-like habitat for both terrestrial and aquatic wildlife. Additionally, shorelines protected with vegetation help shield a lake from both land-based and shoreline pollution and sediment deposition. These "soft" techniques can be incorporated with "hard" shoreline protection in order to reduce erosion, mitigate pollutant loading, and improve aquatic habitat (see Figure 2.60). Examples of techniques that incorporate "hard" and "soft" techniques into "living" shorelines are presented in Appendix B on page 313.[135]

Given the benefits of "soft" shoreline protection measures, the WDNR no longer grants permits for construction of new "hard" structures in lakes that do not have extensive wave action threatening the shoreline, although existing structures may be repaired. Consequently, the recommendations in this plan related to shoreline restoration focus on "soft", vegetative shoreline protection measures. Beach areas, which by law need to be made from pea gravel,[136] are considered as a separate category. Placing pea gravel may be permitted; however, this must be evaluated by WDNR on a case-by-case basis.

It should be emphasized that shoreline protection need not always rely on manmade, engineered structures. Many types of natural shoreline offer substantial protection against erosive force. For example, the boulders and rock cliffs found along Lake Superior function as natural riprap or bulkheads checking excessive shoreline erosion. Additionally, marshlands containing areas of exposed cattail stalks and lily pads effectively mitigate shoreline erosive forces as exposed marshland plant stalks disperse and dampen waves and dissipate energy.

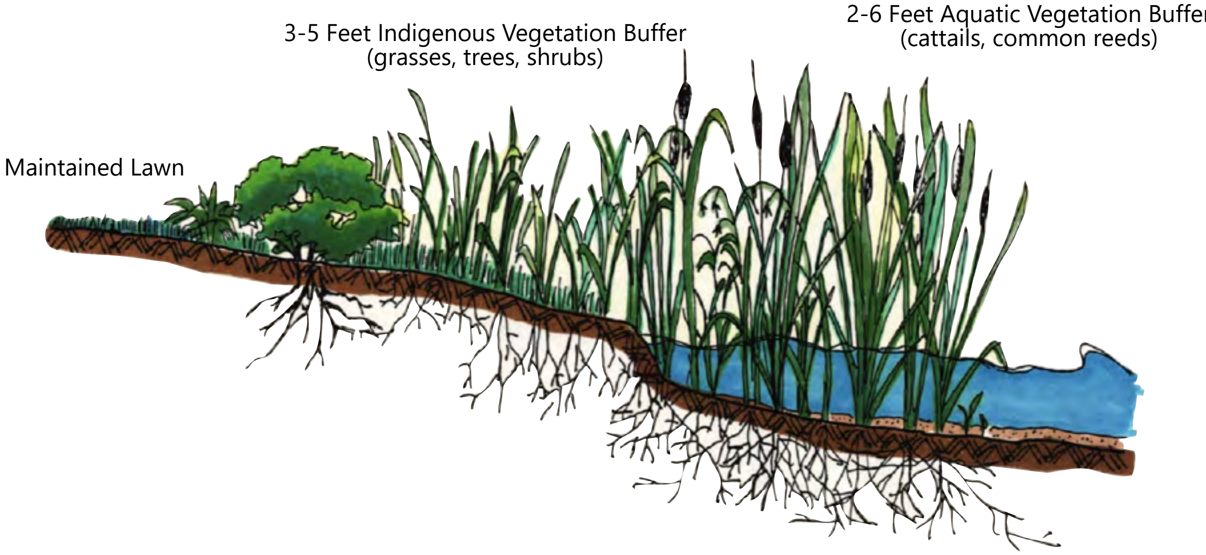
<u>Pewaukee Shoreline Conditions</u>

To help quantify the shoreline restoration and maintenance needs of Pewaukee Lake, and to help develop recommendations related to shoreline maintenance and pollution reduction, Commission staff surveyed the Lake's shoreline protection during the summer of 2015. The results of this survey are shown on Map 2.22 (with more detailed insets of this map displayed in Appendix C on page 323). As the map(s) illustrates, nearly all of Pewaukee Lake's shoreline is protected by "hard" structures of riprap or bulkhead (wooden, metal, or concrete). As previously noted, such structures are highly effective methods of shoreline

[135] *For more information on "living" shorelines, see www.habitatblueprint.noaa.gov/wp-content/uploads/2018/01/NOAA-Guidance-for-Considering-the-Use-of-Living-Shorelines_2015.pdf.*

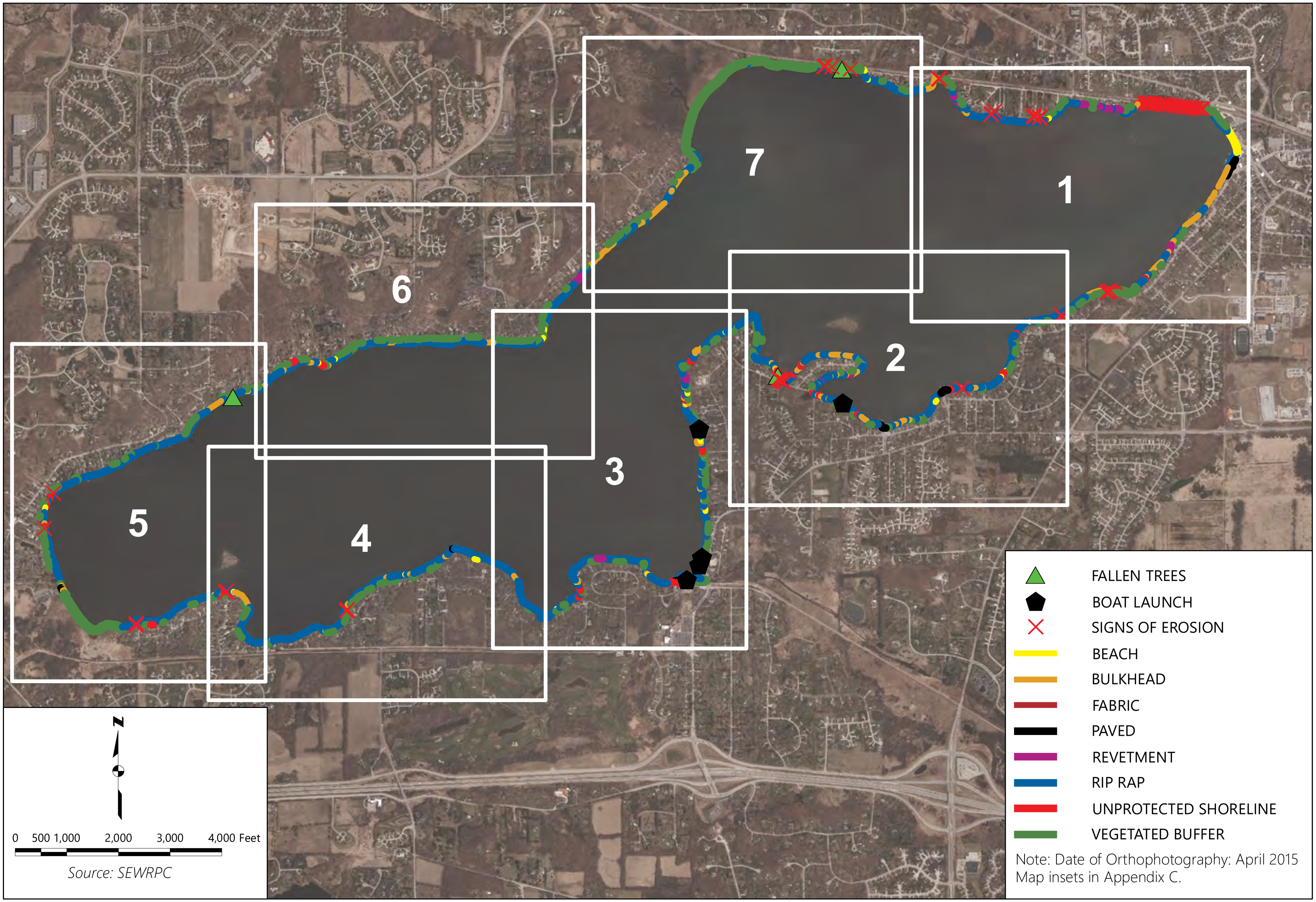
[136] *WDNR does not permit the use of sand because these materials quickly flow into a waterbody and contribute to the "fill-in" of the Lake.*

Figure 2.60
Natural Shoreline Buffers



Source: Washington County Planning and Parks Department and SEWRPC

Map 2.22
Pewaukee Lake Shoreline Conditions: 2015



erosion control, especially in areas of low banks and shallow waters. The majority of riparian properties on Pewaukee Lake that have riprap as shoreline protection have mowed lawns within the riparian zone behind the riprap protection. Although the rock placement protects against the actions of waves and ice, it does not effectively protect against nutrient and sediment runoff. Rock riprap should include natural, unmowed vegetation reinforcement on the upslope side of the riprap protection to help trap nutrients and sediment before they enter the Lake (see Figure 2.61).

Other methods of shoreline protection identified during the 2015 survey included beach, natural vegetation, and vegetated buffer strips within the riparian zone of the Lake. These are illustrated in Map 2.22 as *vegetated buffer*, which includes natural aquatic and riparian vegetation along the shoreline as well as portions of riparian land back from the immediate shoreline that utilize vegetation as a means of reducing sediment and pollution runoff.

Although the majority of the shoreline of Pewaukee Lake does have some form of protection, there were several areas around the Lake that were either unprotected (i.e., mowed lawn up to the water's edge) or exhibiting symptoms of erosion (see Appendix C). Given the desire of Lake users to promote long-term Lake health and the need to preserve recreational use and aesthetics of the Lake, priority should be given to adding natural shoreline protection to these areas that lack protection or are showing active erosion; repairing or maintaining already installed shoreline structure where feasible; and installing "soft" shoreline protection such as native vegetative shoreline protection wherever and whenever possible, as well as expanding riparian buffer. Shoreline maintenance and recommendations will be further discussed in Chapter 3.

Riparian Corridor Conditions

Healthy riparian corridors help to protect water quality, groundwater, fisheries and wildlife, and ecological resilience to invasive species, and can reduce potential flooding of structures and harmful effects of climate change.[137] The health of riparian corridors is largely dependent upon width and continuity. Therefore, efforts to protect and expand the remaining riparian corridor width and continuity are foundational elements for protecting and improving the fishery, wildlife, and recreation within the Pewaukee Lake watershed.

Riparian buffers are areas of plant growth—constructed or natural—in the *riparian zone* (those lands immediately back from the shoreline) that trap sediment and nutrients emanating from upland and nearshore erosion. The provision of buffer strips along waterways represents an important intervention that addresses anthropogenic sources of contaminants. Even relatively small buffer strips provide a degree of environmental benefit, as suggested in Table 2.21 and Figure 2.62.[138,139] The Wisconsin Buffer Initiative (WBI) further developed two key concepts that are relevant to this plan: 1) riparian buffers are very effective in protecting water resources and 2) riparian buffers need to be a part of a larger conservation system to be most effective.[140] However, it is important to note that the WBI limited its assessment and recommendations solely to the protection of water quality, and did not consider the additional values and benefits of riparian buffers. Research clearly shows that riparian buffers can have many potential benefits, such as flood mitigation, prevention of channel erosion, provision of fish and wildlife habitat, enhancement of environmental corridors, and water temperature moderation. However, the nature of the benefits and the extent to which the benefits are achieved is site-specific. Consequently, the ranges in buffer width for each of the buffer functions shown in Figure 2.62 are large. Buffer widths should be based on desired functions, as well as site conditions. For example, based upon a number of studies of sediment removal, buffer widths ranging from about 25 to nearly 200 feet achieved removal efficiencies of between 33 and 92 percent, depending upon local site differences such as soil type, slope, vegetation, contributing area, and influent

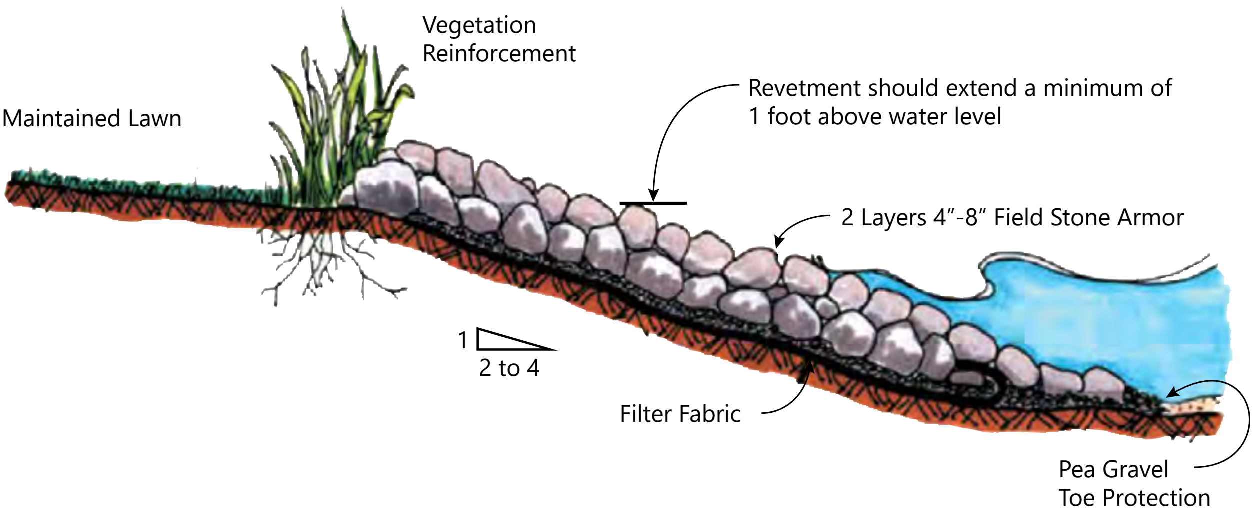
[137] *N.E. Seavy, et al., "Why Climate Change Makes Riparian Restoration More Important than Ever: Recommendations for Practice and Research,"* Ecological Restoration*, 27(3): 330-338, 2009;* "Association of State Floodplain Managers, Natural and Beneficial Floodplain Functions: Floodplain Management—More Than Flood Loss Reduction," 2008, *www.floods.org/NewUrgent/Other.asp*.

[138] *Data were drawn from A. Desbonnet, P. Pogue, V. Lee, and N. Wolff,* Vegetated Buffers in the Coastal Zone – A Summary Review and Bibliography*, CRC Technical Report No. 2064, Coastal Resources Center, University of Rhode Island, 1994.*

[139] *See www.sewrpc.org/SEWRPCFiles/Publications/ppr/rbmg-001-managing-the-waters-edge.pdf.*

[140] *University of Wisconsin-Madison, College of Agricultural and Life Sciences,* The Wisconsin Buffer Initiative*, December 2005.*

Figure 2.61
Incorporating Vegetation into Upslope Riprap Protection



Note: Design specifications shown herein are for typical structures. The detailed design of shoreline protection structures must be based upon analysis of local conditions.

Source: SEWRPC

Table 2.21
Effect of Buffer Width on Contaminant Removal

Buffer Width Categories (feet)	**Contaminant Removal Efficiency (percent)[a]** Sediment	Total Suspended Sediment	Nitrogen	Phosphorus	Nitrate-Nitrogen
1.5 to 25					
Mean	75	66	55	48	27
Range	37-91	31-87	0-95	2-99	0-68
Number of Studies	7	4	7	10	5
25 to 50					
Mean	78	65	48	49	23
Range	--	27-95	7-96	6-99	4-46
Number of Studies	1	6	10	10	4
50 to 75					
Mean	51	--	79	49	60
Range	45-90	--	62-97	0-99	--
Number of Studies	5	--	2	2	1
Greater than 75					
Mean	89	73	80	75	62
Range	55-99	23-97	31-99	29-99	--
Number of Studies	6	9	8	7	1

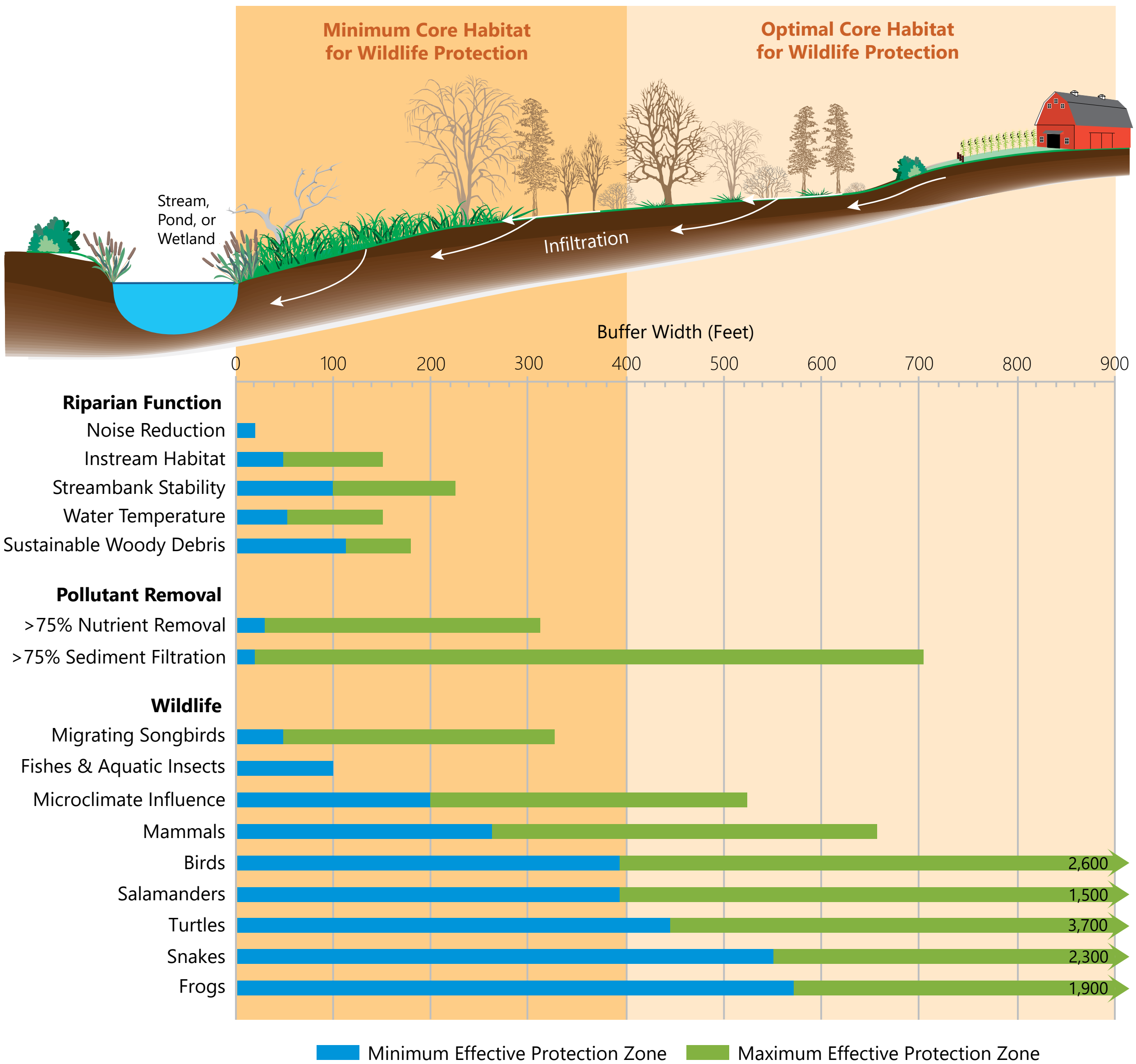
[a] *Removal efficiency measured in surface runoff.*

Source: University of Rhode Island Sea Grant Program

concentrations, to name a few. Figure 2.62 shows that for any particular buffer width, for example 75 feet, the buffer can provide multiple benefits, ranging from water temperature moderation to enhancement of wildlife species diversity. Benefits not shown in the figure include bank stabilization, which is an important concept in utilizing buffers for habitat protection.

While it is clear from the literature that wider buffers can provide a greater range of values for aquatic systems, the need to balance human access and use with the environmental benefits to be achieved suggests that a 75-foot-wide riparian buffer provides a minimum width necessary to contribute to good water quality

Figure 2.62
Buffer Widths Providing Specific Conservation Functions



Source: SEWRPC

and a healthy aquatic ecosystem. In general, most pollutants are removed within a 75-foot buffer width. However, from an ecological point of view, 75-foot-wide buffers are inadequate for the protection and preservation of groundwater recharge or wildlife species. Riparian buffer strips greater than 75 feet in width provide significant additional physical protection of streams, owing to their function in intercepting sediment and other contaminants mobilized from the land surface as a result of natural and anthropogenic activities. These wider buffers also serve to sustain groundwater recharge and discharge relationships, and biological benefit, as a result of the habitat available within the shoreline and littoral areas associated with streams and lakes.[141]

For example, the highest quality environmental corridors, natural areas, and vegetation communities are located within and adjacent to the riparian buffer network throughout the Pewaukee Lake watershed as

[141] *See, for example, B.M. Weigel, E.E. Emmons, J.S. Stewart, and R. Bannerman, Buffer Width and Continuity for Preserving Stream Health in Agricultural Landscapes*, Wisconsin Department of Natural Resources Research and Management Findings, Issue 56, *December 2005.*

shown on Map 2.20. In other words, riparian buffers are a vital conservation tool that provides connectivity among landscapes to improve the viability of wildlife populations within the habitats comprising the primary and secondary environmental corridors and isolated natural resource areas.[142]

As previously mentioned, healthy and sustained aquatic and terrestrial wildlife diversity is dependent upon adequate riparian buffer width and habitat diversity. Specifically, recent research has found that the protection of wildlife species is determined by the preservation or protection of core habitat within riparian buffers with widths ranging from a minimum of 400 feet to an optimal 900 feet or greater. These buffer areas are essential for supporting healthy populations of multiple groups of organisms, including birds, amphibians, mammals, reptiles, and insects and their various life stages. For example, some species of birds, amphibians, turtles, snakes, and frogs have been found to need buffer widths as great as 2,300 feet, 1,500 feet, 3,700 feet, 2,300 feet, and 1,900 feet, respectively, for at least part of their life histories. Hence, preservation of riparian buffers to widths of up to 1,000 feet or greater represents the optimal condition for the protection of wildlife in the Pewaukee Lake watershed.[143]

Map 2.16 shows the major natural cover types both within and outside of the existing riparian buffers distributed throughout the Pewaukee Lake watershed. This inventory shows that the riparian buffers are comprised of a variety of wetland (emergent/wet meadow, flats, forested, and scrub/shrub) and upland (brush, grassland, upland conifer, and deciduous) vegetation communities. Each of these habitats is necessary to support the life history requirements of multiple wildlife species. For example, amphibians and reptiles have been reported to utilize numerous habitat types that include seasonal (ephemeral) wetlands, permanent wetlands (lakes, ponds, and marshes), wet meadows, bogs, fens, small and large streams, springs and seeps, hardwood forest, coniferous forest, woodlands, savannahs, grasslands, and prairies.[144] Hence, it is this mosaic of habitats and the ability of organisms to travel between them at the correct times in their lives to survive, grow, and reproduce, which is essential to support an abundant and diverse wildlife community throughout this watershed.

The development patterns and infrastructure that humans create on the landscape lead to a number of obstructions that can limit both the availability of wildlife habitat as well as the ability for organisms to travel between habitats. These obstructions are primarily a result of roadways, railways, and buildings that fragment the natural landscape. Therefore, an effective management strategy to protect wildlife abundance and diversity in the Pewaukee Lake watershed would be to maximize critical linkages between habitat areas on the landscape, ensuring the ability of species to access these areas. Examples of critical linkages include the following:

- Water's edge (lake, pond, river, wetland) to terrestrial landscapes (i.e., riparian buffer width)
- Water's edge to water's edge (e.g., river to ephemeral pond, lake to ephemeral pond, permanent pond to ephemeral pond)
- Habitat complexes or embedded habitats-wetland to upland (e.g., seep to prairie) and upland to upland (e.g., grassland to woodland)

In addition, connecting the secondary environmental corridor (SEC) lands and multiple isolated natural resource areas (INRAs) throughout the Pewaukee Lake watershed to the larger primary environmental corridor (PEC) areas, as well as building and expanding upon the existing protected lands, represent sound approaches to enhancing the corridor system and wildlife areas within the watershed.

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[142] *P. Beier and R.F. Noss, "Do Habitat Corridors Provide Connectivity?,"* Conservation Biology, *12(6): 1241-1252, 1998.*

[143] *The shoreland zone is defined as extending 1,000 feet from the ordinary high water mark of lakes, ponds, and flowages and 300 feet from the ordinary high water mark of navigable streams, or to the outer limit of the floodplain, whichever is greater. To be consistent with this concept and to avoid confusion, the optimum buffer width for wildlife protection is defined as extending 1,000 feet from the ordinary high water mark on both sides of the lakes, ponds, and navigable streams in the watershed.*

[144] *B.A. Kingsbury and J. Gibson (eds.),* Habitat Management Guidelines for Amphibians and Reptiles of the Midwestern United States, *Partners in Amphibian and Reptile Conservation Technical Publication HMG-1, 2nd Edition, 2012.*

Potential Restorable Wetlands

Wetlands provide a number of benefits such as water quality improvement, wildlife habitat, and flood mitigation. According to the USEPA, a typical one-acre wetland can store about one million gallons of water.[145] Restoring wetlands in the watershed area would provide water storage and reduce sediment and phosphorus loading. Establishing restored wetlands, particularly as riparian buffers, can help reduce pollution loads from tile drains, barnyards, and upland runoff, and can be implemented in areas where frequent crop damage occurs due to flooding. Although modeling load reductions associated with wetland restorations was beyond the scope of this report, constructed wetlands have been reported to reduce median pollutant loads by 73 percent for total suspended solids, 38 percent for total phosphorus, 69 percent for particulate phosphorus, 30 percent for total nitrogen, 70 percent for metals (zinc and copper), 60 percent for bacteria, and, 80 percent for hydrocarbons.[146]

Hydric soils characteristic of wetland conditions form under settings where the ground is saturated with water for long enough periods of time to cause changes in the soil properties. These unique soils and growing conditions foster a suite of plant species that thrive in wet, oxygen-deprived soil. Hence, the majority of the wetlands remaining in the Pewaukee Lake watershed are found along the tributaries. Wetlands currently comprise a total of 8.6 percent of the Pewaukee Lake watershed. This falls below a standard of 10 percent established by Environment Canada for the minimum recommended level of wetland area needed to provide protection for a major watershed. This minimum requirement also includes meeting a level of 6 percent wetland for each subwatershed.[147] None of the sub-watersheds meet this recommended level of wetland protection. The Coco Creek watershed has the highest level of protection at 4 percent. The Audley Creek and Pewaukee Lake watersheds both have extremely low levels of protection at 0.6 percent each. Therefore, there is a good potential to restore wetlands throughout the Pewaukee Lake watershed, which could be a key component to address nonpoint source soil erosion and associated pollutant load reductions in this basin.

Potentially restorable wetland areas are also good candidate sites for constructed floodplain benches associated with re-meandering ditched reaches within the Lake tributary network network and/or opportunities to modify tile drainage to reduce pollution loads. Therefore, any potential restorable wetland areas that are located within the existing floodplain boundary would be a high priority for conversion to wetland, because their location would facilitate a higher level of protection to reduce the amount of pollutants entering Pewaukee Lake. Onsite evaluation of potential wetland restoration sites will be necessary prior to design and implementation.

Existing and Potential Riparian Buffers

Map 2.23 shows the current status of existing and potential riparian buffers at the 75-foot, 400-foot, and 1,000-foot widths along the Pewaukee Lake and its major tributary streams. Buffers were primarily developed from 2015 digital orthophotographs and the 2010 WDNR Wisconsin Wetland Inventory, and from Commission inventories of PEC, SEC, and INRA. Polygons were created using geographic information system (GIS) techniques to delineate contiguous natural lands (i.e., nonurban and nonagricultural lands) comprised of wetland, woodland, and other open lands adjacent to waterbodies. Those lands comprise a total of about 2,204 acres, or 16 percent, of the total land area (not including water area) within the Pewaukee Lake watershed.

The most extensive existing buffers were found within the Coco Creek and Meadowbrook Creek sub-basins that together comprised about 75 percent (1,649 acres) of the total buffered lands within the Pewaukee Lake watershed (see Figure 2.63). Existing buffers comprise between 18 to 27 percent of the total land area within these sub-basins. The remaining three sub-basins of Pewaukee Lake, Zion Creek, and Audley Creek contain 25 percent (555 acres) of the total buffered lands within the watershed, which ranged from a total of 9 to 11 percent of existing buffers of the total land area within each of their respective sub-basins.

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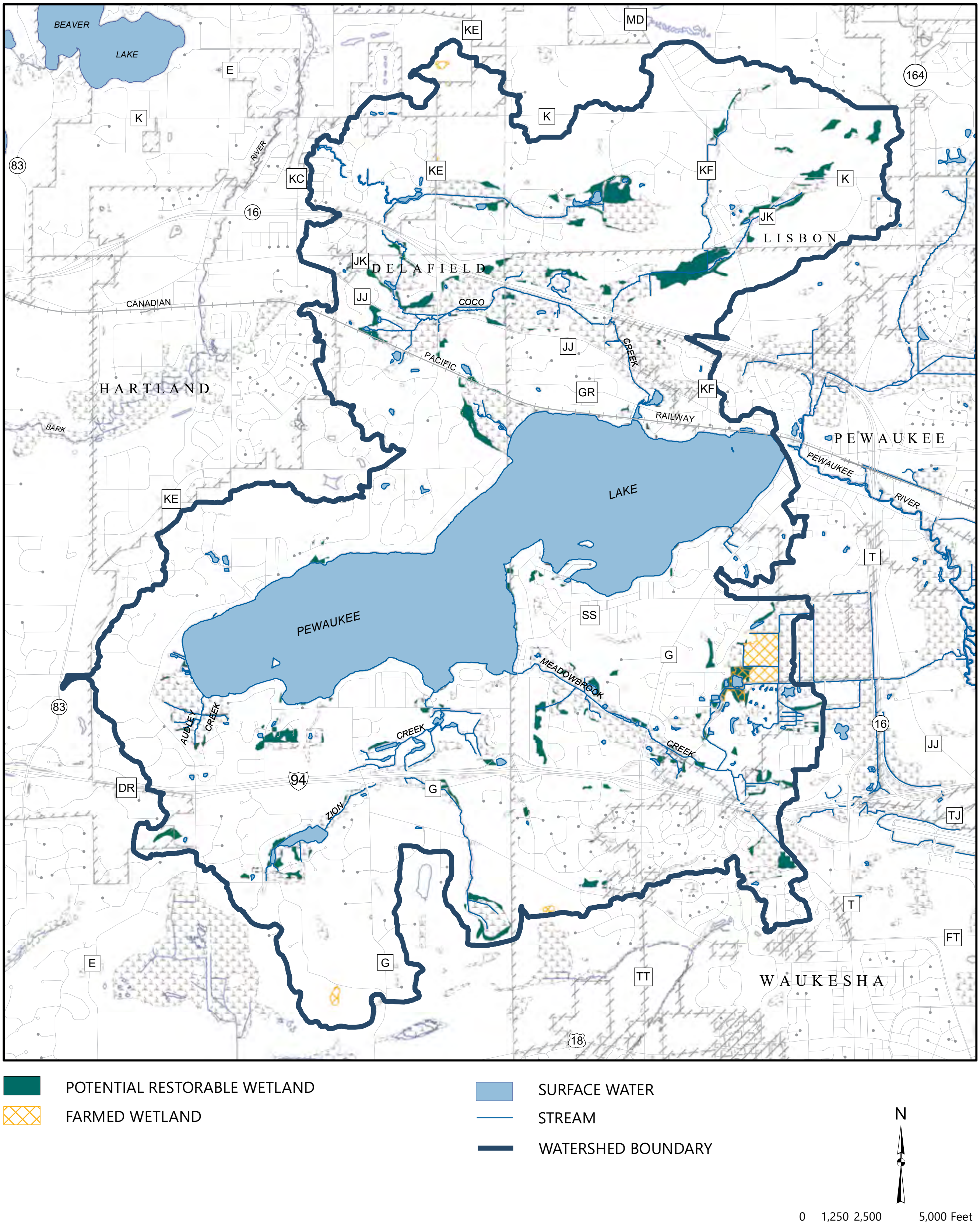
[145] *U.S. Environmental Protection Agency (USEPA),* Wetlands: Protecting Life and Property from Flooding*, May 2006, USEPA843-F-06-001, Website: water.epa.gov/type/wetlands/outreach/upload/Flooding.pdf.*

[146] *Minnesota Pollution Control Agency, Minnesota Stormwater Manual website, stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs.*

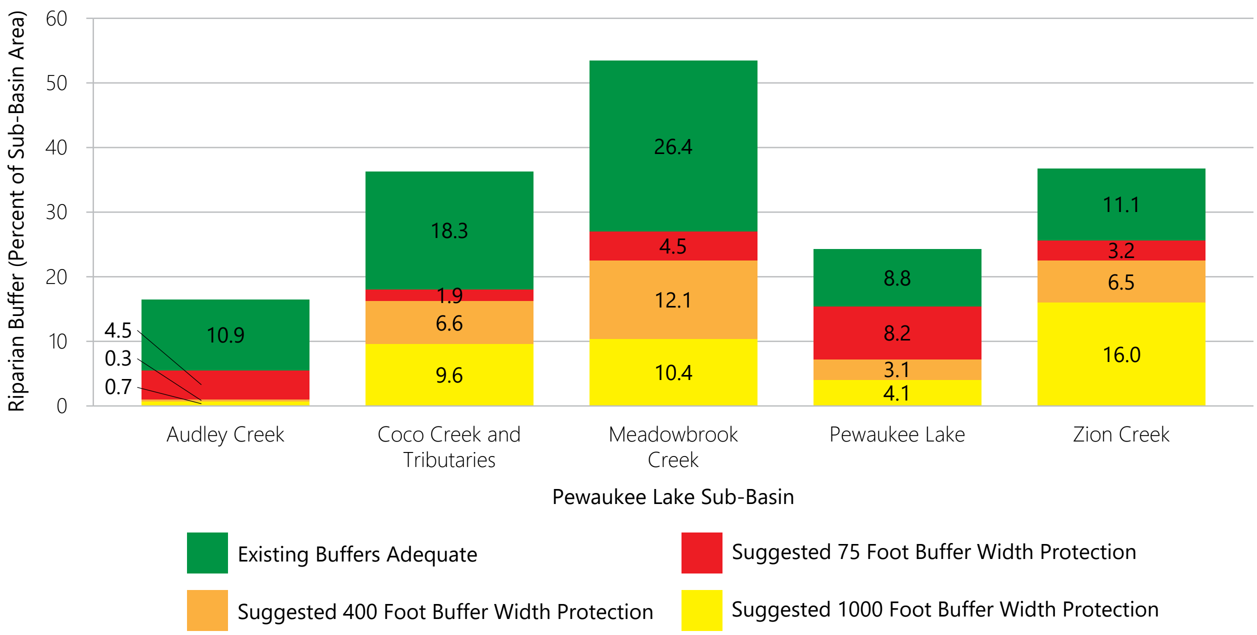
[147] *Environment Canada,* How Much Habitat is Enough? Third Edition, *Environment Canada, Toronto, Ontario, 2013, www.documentcloud.org/documents/2999368-THUNDER-BAY-How-Much-Habitat-Is-Enough-3rd-Ed-2013.html.*

Map 2.23
Potentially Restorable and Farmed Wetlands Within the Pewaukee Lake Watershed



Source: Wisconsin Department of Natural Resources and SEWRPC

Figure 2.63
Existing and Suggested Riparian Buffer Width by Watershed Sub-Basin



Source: SEWRPC

Comparison between the existing buffers versus the potential buffers at the 75-foot, 400-foot, and 1,000-foot widths throughout the Pewaukee Lake watershed indicates that some areas contain existing buffers at 75-foot, 400-foot, and 1,000 feet widths from the edge of the stream, which indicates they are providing a good level of water quality and wildlife protection. However, there are multiple locations in both urban and agricultural areas throughout the watershed that show encroachments into the 75-foot and 400-foot riparian zones (see Map 2.20), including the Pewaukee Lake shoreline perimeter. It is important to note that there are about 8.8 linear miles (46,943 feet) of non-buffered riparian shoreline around Pewaukee Lake. That distance represents 63 percent of the total shoreline length. Based upon this analysis, there are many opportunities to improve the amount of riparian buffers to protect water quality and wildlife (at the 75-foot, 400-foot, and 1,000-foot widths) while reducing pollutant loading, both within the tributary network and the Pewaukee Lake shoreline.

Pollutant Loadings Summary

There are no significant point sources of pollution in the Pewaukee Lake watershed. Anticipated changes in land use between existing and planned conditions in the Lake's watershed are expected to result in an overall decrease in sediment loading to the Lake of about 400,000 pounds per year as 1,800 acres of rural lands (mainly agricultural) are converted to urban use (mostly residential). This conversion of existing rural lands to urban uses is also expected to produce an increase in the predicted amounts of metal loading to Pewaukee Lake: copper is expected to increase about 160 pounds (from 609 pounds in 2015 to 769 pounds) and zinc is expected to increase nearly 1,100 pounds (from 4,119 pounds in 2015 to 5,205 pounds). A very small net decrease in the amount of phosphorus entering the Lake is expected as well, as most of the decrease in phosphorus from a decline in rural land uses (mostly agricultural) is offset by increases in phosphorus due to an increase in urban uses (residential). While there may not be a pollution input source problem with total phosphorus in the Lake, data show that there is a great deal of phosphorus in the bottom sediments that is released under anoxic conditions (i.e., internal loading). In addition, recycling of phosphorus, while shown to be a significant part of the nutrient load in other Wisconsin lakes, has yet to be determined for Pewaukee Lake and will require a separate study. Coco Creek and Meadowbrook Creek are the two main tributary contributors of phosphorus to Pewaukee Lake, at 1,343 pounds annually and 1,209 pounds annually, respectively, followed by Zion Creek. Nuisance levels of aquatic plants in Pewaukee Lake have been managed since the 1970s using chemicals initially and then transitioning to mechanical harvesting in the 1980s. Data have shown that harvesting has played a key role in removing at least 13,000 pounds of phosphorus from Pewaukee Lake since 1988 with higher estimates in excess of over 50,000 pounds. Aquatic plant harvesting, combined with stormwater management practices, protection of wetlands, and key riparian buffered lands, are contributing to the improvement (i.e., reduced phosphorus loads) of Pewaukee Lake. Recommendations regarding management to mitigate pollutant loading are provided in Section 3.4, "Pollutant and Sediment Sourced Loads."

2.7 AQUATIC PLANTS

This section presents data from aquatic plant surveys completed on Pewaukee Lake. It should be used to gain a better understanding of the plant communities within the Lake, determine changes in the Lake's plant communities over time, and guide aquatic plant management, particularly as it relates to invasive species.

It is important to note that all healthy lakes have plants. In fact, in a nutrient-rich lake such as Pewaukee Lake, it is normal to have luxuriant plant growth in shallow areas (e.g., the east end of Pewaukee Lake, in particular). Nutrient-rich lakes are common in Southeastern Wisconsin due to nutrient-rich soil. Native aquatic plants form a foundational part of a lake ecosystem. Aquatic plants form an integral part of the aquatic food web, converting sediments and inorganic nutrients present in the water into organic compounds that are directly available as food to other aquatic organisms. In this process, known as *photosynthesis*, plants utilize energy from sunlight and release the oxygen required by many other aquatic life forms into the water. Aquatic plants also serve a number of other valuable functions in a lake ecosystem, including:

- Improving water quality by filtering excess nutrients from the water
- Providing habitat for invertebrates and fish
- Stabilizing lake bottom substrates
- Supplying food for waterfowl and various lake-dwelling animals

It is also important to note that even though aquatic plants may hinder human use and/or access to a lake, aquatic plants should not necessarily be eliminated or even significantly reduced in abundance because they often support many other beneficial functions. For example, white water lily (found commonly throughout Southeastern Wisconsin) plays a major role in providing shade, habitat, and food for fish and other important aquatic organisms. It also helps prevent damage to the lakeshore by dampening the power of waves that could otherwise erode the shoreline. Additionally, the shade that this plant provides helps reduce the growth of undesirable plants (e.g., invasive EWM) because it limits the amount of sunlight reaching the lake bottom. Given these benefits, large-scale removal of native plants that may be perceived as a nuisance (especially white water lilies) should be avoided when developing plans for aquatic plant management.

Phytoplankton and Macrophytes

Aquatic plants include microscopic algae ("phytoplankton") and larger plants ("macrophytes"). Macrophytes are often described using the terms *submerged, floating-leaf, free-floating,* and *emergent,* depending on where the plant is found in the lake ecosystem. *Submerged* plants are found in the main lake basin and, although most are rooted in the bottom substrate, some species, such as coontail (*Ceratophyllum demersum*) can become free-floating. *Floating-leaf* plants, such as water lilies, generally have large, floating leaves and are usually found in shallow water areas a few feet in depth or less that contain loose bottom sediments. *Free-floating* plants, such as duckweed (*Lemna* spp.), have small leaves, are not rooted to the sediment, and are often wind-blown around the waterbody. *Emergent* plants, which have leaves that emerge above the water, are commonly found along the shoreline areas of a lake, such as bulrushes and cattails. All four types have significant roles to play in the overall working of a lake's ecosystem.

Maintaining a rich and diverse community of native species is important for every ecosystem as this:

- Helps sustain and increase the robustness of the existing system
- Increases the ability of an ecosystem to adapt to environmental changes
- Provides a spectrum of options for future decisions regarding the management of that system

Many factors—including lake configuration, depth, water clarity, nutrient availability, bottom substrate, wave action, and type and size of fish populations—determine the distribution and abundance of aquatic macrophytes in lakes, with most waterbodies within Southeastern Wisconsin naturally supporting abundant and diverse aquatic plant communities.

Depending on their types, distribution, and abundance, aquatic macrophytes can be either beneficial or a nuisance. Plants growing in the proper locations and in reasonable densities in lakes are beneficial in maintaining lake fisheries and wildlife populations, and in providing habitat for a variety of aquatic organisms. Aquatic plants also may remove nutrients from the water that otherwise would contribute to excessive algal growth. They can become a nuisance when their densities become so great as to interfere with swimming and boating activities, when their growth forms limit habitat diversity, or when the plants reduce the aesthetic appeal of the resource.

Phytoplankton

Phytoplankton is the term for a group of microscopic organisms that includes bacteria, protists, and algae. These organisms are aquatic and can all actively photosynthesize. Maintaining a healthy community of phytoplankton is essential for lake health, as these species form the foundation of the lake's food web and create oxygen required by other organisms, such as zooplankton and fish. However, an overabundance of phytoplankton, generally caused by excessive nutrient loads, can impair lake health by decreasing water clarity and reducing hypolimnetic oxygen. Phytoplankton were most recently surveyed in the Lake during 1976 by WDNR and 2002 by Wisconsin Lutheran College. Blue-green algae were noted to be the dominant algal group in the Lake in both surveys[148].

Since phytoplankton and rooted plants compete for nutrients, an abundance of rooted aquatic plants means fewer nutrients (usually phosphorus) available to algae, in turn reducing the abundance of free-floating algae and increasing water clarity. Conversely, when rooted aquatic plants senesce or die, the subsequent return of nutrients to the water column can increase algal populations and decrease water clarity; algae blooms occur during large die-offs of aquatic plants. Thus, it is important to appreciate the balance that exists between rooted aquatic plants and algae in a Lake; the over-suppression of one can often lead to an over-abundance of the other. For example, the elimination of too many rooted plants in an attempt to achieve a "weed-free lake" can result in a condition of chronic algae blooms, supersaturated oxygen levels in night time surface waters, and summer fish kills.

Native Plants

Aquatic plants live in community with one another. They develop complex interactions and mutual dependencies that are of great significance in how these dynamic communities function within a lake. Native aquatic plant species are specifically adapted to local aquatic environments and many kinds of wildlife depend on the presence of specific native plant species for survival. For example, the seeds and tubers of Sago pondweed (*Stuckenia pectinata*) are an important food source for migratory waterfowl.

In Wisconsin, the presence of native pondweeds is generally considered to be indicative of a healthy lake with good habitat for fish and aquatic life. Pondweeds provide good habitat and serve as food and shelter for a variety of aquatic organisms and waterfowl. Of the pondweeds that occur in the Region, white-stem pondweed (*Potamogeton praelongus*) is of special importance because of its sensitivity to changes in water quality and intolerance of turbidity. It is considered a valuable water quality indicator species, since its disappearance from a lake can be due to deteriorating water quality. Conversely, its presence in a lake is an indicator of good water quality.[149] White-stem pondweed was first recorded as present in Pewaukee Lake (albeit, in small numbers) in 2000 and has also been observed (in small numbers) in surveys conducted in 2007, 2008, 2011, 2014, and 2016.

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[148] *For a greater description of the phytoplankton community, see SEWRPC Community Assistance Planning Report No. 58, 2nd Edition,* op. cit.

[149] *Wisconsin Lakes Partnership, Through the Looking Glass...A Field Guide to Aquatic Plants, University of Wisconsin-Extension.*

Community Changes Over Time

Aquatic plant communities undergo cyclical and periodic changes that reflect community responses to interannual climatic conditions as well as long-term changes in a lake's "hydroclimate." Interannual changes, occurring between three to seven years, can include surface water elevations, water temperature, as well as ice-off and ice-on dates. These factors can promote the short-term growth of certain species, such as curly-leaf pondweed (CLP) (*Potamogeton crispus*) being more abundant in years with earlier ice-off. Long-term factors affecting plant communities—those which occur over a decade or longer—can include nutrient loading, sedimentation rates, recreational use patterns, and natural stressors. Natural stressors can include biological stressors, such as herbivory and disease, as well as climatic and limnological factors, such as insulation, water temperature, and lake circulation patterns. For example, EWM populations have been observed to increase rapidly upon introduction, but decline following this explosive initial growth[150], which may be partly attributed to herbivory by native milfoil weevils. Additionally, aquatic plant management can reduce the abundance of nonnative species over time, although total eradication from the community is unlikely in many cases. Examining changes in aquatic plant communities over time can reveal the factors promoting or inhibiting the growth of specific species, informing management options to control the abundance of those species in the Lake.

Aquatic Nonnative and Invasive Species (AIS)

The terms "nonnative" and "invasive" are often confused and incorrectly assumed to be synonymous. *Nonnative* is an overarching term describing living organisms introduced to new areas beyond their native range with intentional or unintentional human help. Nonnative species may not necessarily harm ecological function or human use values in their new environments. *Invasive* species, on the other hand, are the subset of nonnative species that have damaging impacts on the ecological health of their new environments and/or are considered a nuisance to human use values. In summary, invasive species are non-native but not all non-native species are invasive.

Introducing invasive species, either plants or animals, can severely disrupt both terrestrial and aquatic natural systems. Since invasive species often have no natural predators to control their growth, they are often able to reproduce prolifically and outcompete native species for space and other necessary resources. This can have devastating effects on native species that have well developed dependencies on the availability of native plants and animals**.**

The most common and destructive invasive species in Wisconsin lakes are EWM and CLP; both are declared nuisance species identified in Chapters NR 40 and NR 109 of the *Wisconsin Administrative Code* and both species have been recorded as present in Pewaukee Lake since at least 1967. Invasive species of high concern are continuously changing due to new introductions and successful management of past invasions. Waukesha County recently adopted a strategic aquatic invasive species (AIS) plan with the goals of monitoring AIS populations, educating water users about AIS, preventing the spread of AIS, and managing existing AIS populations.[151] As part of this effort, the County is maintaining an updated, online database of recorded AIS populations.[152]

The WDNR officially lists three invasive aquatic plant species as having been verified and vouchered in Pewaukee Lake: EWM, CLP, and starry stonewort (*Nitellopsis obtusa*). Another species, yellow floating heart (*Nymphoides peltata*) was listed as verified in 2011, with observations in two ponds adjacent to Coco Creek. The LPSD completed an AIS early detection and response project in 2011 to eradicate the population; no new observations have been recorded since completion of this project. Hybrid Eurasian/northern watermilfoil, commonly found in nearby lakes, may also be present but the WDNR does not currently list it as verified in the Lake.[153]

[150] *S.R. Carpenter, "The Decline of* Myriophyllum spicatum *in a Eutrophic Wisconsin (USA) Lake,"* Canadian Journal of Botany, *58(5): 527-535, 1980.*

[151] *For more information, see SEWRPC Community Assistance Planning Report No. 333,* Waukesha County Aquatic Invasive Species Strategic Plan*, February 2018.*

[152] *See www.waukeshacounty.gov/AISStrategicPlan.*

[153] *See dnr.wi.gov/lakes/invasives/AISLists.aspx?species=MILFOIL_HYBRID&location=68.*

Eurasian Watermilfoil

While eight milfoil species are found in Wisconsin, EWM (see Figure 2.64) is the only nonnative, or *exotic*. EWM was first observed in Pewaukee Lake in 1966. As an exotic species, EMW has few natural enemies that can inhibit its growth. Thus, EWM can grow abundantly in suitable conditions, particularly in mesotrophic or eutrophic hard-water lakes or where the lake bottom has been disturbed, such as following dredging. Unless its growth is anticipated and controlled, EWM populations can displace native plant species and interfere with the aesthetic and recreational use of waterbodies; this plant has been known to cause severe ecological and recreational problems within Southeastern Wisconsin lakes.

EWM can quickly reproduce through the rooting of plant fragments, which can unintentionally be created during lake recreational activities. For example, boat propellers can fragment EWM plants, which are able to generate new root systems from fragments, causing the plant to become more widespread within the lake. Additionally, these fragments allow EWM to disperse to new lakes, as they cling to boats, trailers, motors, and/or bait buckets and can stay alive for weeks. As EWM can become a dominant plant species within two years of arriving in a new waterbody, it is very important to remove all vegetation from boats, trailers, and other equipment after removing them from the water and prior to launching in other waterbodies.

Curly-Leaf Pondweed

CLP (see Figure 2.64) is the only non-native pondweed (*Potamogeton* spp.) found within Wisconsin. This species is predominantly found in disturbed, eutrophic lakes, where it exhibits a peculiar split-season growth cycle that provides a competitive advantage over native plants and makes management of this species difficult. This species reproduces using turions, a type of plant bud utilized by some aquatic plants. The turions are produced in late summer and lie dormant in lake sediment until cooler fall water temperatures trigger the turions to germinate. Over the winter, the turions produce winter foliage that thrives under the ice. In spring, when water temperatures begin to rise again, the plant has a head start on the growth of native plants and quickly grows to full size, producing flowers and fruit earlier than its native competitors. CLP begins to die-off in midsummer, releasing phosphorus that reduces lake water quality. It can grow in more turbid waters than many native plants, so protecting or improving water quality is an effective method of control of this species, as clearer waters in a Lake can help native plants compete more effectively.

Starry Stonewort

A new potentially invasive macrophytic algal species, starry stonewort (see Figure 2.64), was identified in Pewaukee Lake in 2019. This species can form extremely dense mats, which may affect the species richness of the aquatic plant community and cause recreational use impediments. Overgrowth of starry stonewort can also reduce the movement of fish and other animals, as well as reduce fish spawning.[154] Starry stonewort is indigenous to Eurasia and first appeared in the United States in 1978 along the St. Lawrence River. As of the writing of this report, starry stonewort has been found in Indiana, Michigan, Minnesota, New York, Pennsylvania, Vermont, and Wisconsin.[155] The first observation of this species in Wisconsin was during 2014 in Little Muskego Lake. Subsequently, starry stonewort has been observed in Big Muskego Lake, Bass Bay, Lower Nemahbin Lake, and Okauchee Lake in Waukesha County; Green Lake, Little Cedar Lake, Pike Lake and Silver Lake in Washington County; Long Lake and Wind Lake in Racine County; and Geneva Lake in Walworth County. No methods have yet been found to successfully manage its growth.

Pewaukee Lake Surveys

Nuisance levels of aquatic plants, especially in the east basin of Pewaukee Lake, have long been a part of the Lake. Beginning with the construction of the first dam in 1838 that flooded the wetland at the east end, the Lake has experienced abundant aquatic plant growth. Abundance levels of plant growth in the Lake were viewed mainly within the context of their impact on commerce by competing ice companies who depended on clear lake waters for the production of contact-grade ice. Not until the 1960s were attempts

[154] "Aquatic Invasive Species Quick Guide: Starry Stonewort (*Nitellopsis obtusa L.*)", *Golden Sands Resource Conservation and Development Council, Inc. This Quick Guide is part of a series on aquatic invasive species, and may be reproduced for educational purposes. Visit uwsp.edu/cnr/uwexlakes/clmn or goldensandsrcd.org/our-work/water to download this series of handouts. Developed by Golden Sands Resource Conservation & Development Council, Inc. as part of an AIS education program, supported by a grant from the Wisconsin Department of Natural Resources. Maintained and updated by the Wisconsin Citizen Lake Monitoring Network.*

[155] USGS Nonindigenous Aquatic Species Database, Gainesville, FL. *nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=1688*.

Figure 2.64
Invasive Aquatic Plants Verified and Vouchered in Pewaukee Lake: 2019

Eurasian watermilfoil (*Myriophyllum spicatum*)

Curly-leaf pondweed (*Potamogeton crispus*)

Starry Stonewort (*Nitellopsis obtusa*)

Starry stonewort bulbil

Source: Paul Skawinski and SEWRPC

made to produce meaningful aquatic plant surveys, but even then these surveys relied mainly on subjective anecdotal descriptions rather than objective quantifications (see Table 2.22). It wasn't until the 1980s that aquatic plant surveys in Pewaukee Lake began to utilize more objective and scientific survey protocols to accurately describe, quantify, and document aquatic plant communities (see Table 2.23).

Aerial photography has been a useful tool for documenting abundant plant growth in Pewaukee Lake. Beginning in the early 1970s, aerial views of the Lake were taken as part of the US Department of Agriculture Farm Service Agency program. These aerial photographs indicate Lake areas that have historically had abundant plant growth, as shown on Map 2.24. In addition, Map 2.24 lists the years corresponding to times of peak abundances in those areas as shown by aerial photographs. These aerial surveys reinforce the ground-level observations and in-lake surveys documenting areas of greatest aquatic plant abundance in the Lake.

Aquatic plant surveys on Pewaukee Lake have been conducted by various agencies over a number of years, including 1967, 1976, 1986, 1988, 1991-92, 1994, 1997, 2000-02, 2004-11, and 2013-16. In 2000, it was observed that Pewaukee Lake was experiencing the greatest level of aquatic plant growth since 1990. According to LPSD records, from 1985 to 2004, native aquatic plant populations in Pewaukee Lake increased as milfoil density decreased. In 2016, species richness in the Lake was the highest observed in the past 25 years, associated with a decline in abundance of EWM and an increased abundance of native species.

Table 2.22
Aquatic Plant Species Present in Pewaukee Lake: 1967 and 1976

Area	Common Name	Scientific Name	Relative Abundance 1967 (lakewide)	Relative Abundance 1976 (area)
1	Stonewort	*Chara* sp.	Sparse	Moderate
	Eurasian Watermilfoil[a]	*Myriophyllum spicatum*	Abundant	Moderate
	Large-Leaf Pondweed	*Potamogeton amplifolius*	None	Very sparse
	Sago Pondweed	*Stuckenia pectinata*	Sparse	Sparse
	Soft-Stem Bulrush	*Scirpus validus*	Very sparse	Very sparse
	Bur Reed	*Sparganium eurycarpum*	Very sparse	Very sparse
	Broadleaf Cattail	*Typha latifolia*	Very sparse	Very sparse
	Purple Bladderwort	*Utricularia purpurea*	Very sparse	Sparse
2	Stonewort	*Chara* sp.	Sparse	Abundant
	Eurasian Watermilfoil[a]	*Myriophyllum spicatum*	Abundant	Abundant
	Clasping-Leaf Pondweed	*Potamogeton richardsonii*	None	Very sparse
	Sheathed Pondweed	*Stuckenia vaginata*	None	Very sparse
3	Eurasian Watermilfoil[a]	*Myriophyllum spicatum*	Abundant	Abundant
	Curly-Leaf Pondweed[a]	*Potamogeton crispus*	Sparse	Very sparse
	Sago Pondweed	*Stuckenia pectinata*	Sparse	Sparse
	Sheathed Pondweed	*Stuckenia vaginata*	None	Very sparse
4	Eurasian Watermilfoil[a]	*Myriophyllum spicatum*	Abundant	Abundant
	Sago Pondweed	*Stuckenia pectinata*	Sparse	Very sparse
5	Eurasian Watermilfoil[a]	*Myriophyllum spicatum*	Abundant	Very abundant
	Yellow Water Lily	*Nuphar* sp.	Very sparse	Very sparse
	Curly-Leaf Pondweed[a]	*Potamogeton crispus*	Sparse	Moderate
	Sago Pondweed	*Stuckenia pectinata*	Sparse	Very sparse
6	Eurasian Watermilfoil[a]	*Myriophyllum spicatum*	Abundant	Very abundant
	Curly-Leaf Pondweed[a]	*Potamogeton crispus*	Sparse	Very sparse
	Sago Pondweed	*Stuckenia pectinata*	Sparse	Sparse
	Sheathed Pondweed	*Stuckenia vaginata*	None	Very sparse
7	Water Weed	*Elodea canadensis*	Very sparse	Very sparse
	Eurasian Watermilfoil[a]	*Myriophyllum spicatum*	Abundant	Abundant
	Slender Naiad	*Najas flexilis*	None	Very sparse
8	Eurasian Watermilfoil[a]	*Myriophyllum spicatum*	Abundant	Moderate
	Slender Naiad	*Najas flexilis*	None	Very sparse
	Sheathed Pondweed	*Stuckenia vaginata*	None	Very sparse
9	Eurasian Watermilfoil[a]	*Myriophyllum spicatum*	Abundant	Very abundant
	Slender Naiad	*Najas flexilis*	None	Very sparse
	Curly-Leaf Pondweed[a]	*Potamogeton crispus*	Sparse	Moderate
	Sago Pondweed	*Stuckenia pectinata*	Sparse	Very sparse
	Sheathed Pondweed	*Stuckenia vaginata*	None	Very sparse
10	Eurasian Watermilfoil[a]	*Myriophyllum spicatum*	Abundant	Very abundant
	Slender Naiad	*Najas flexilis*	None	Very sparse
	Curly-Leaf Pondweed	*Potamogeton crispus*	Sparse	Very sparse
	Sago Pondweed	*Stuckenia pectinata*	Sparse	Very sparse
11	Eurasian Watermilfoil[a]	*Myriophyllum spicatum*	Abundant	Abundant
	Curly-Leaf Pondweed[a]	*Potamogeton crispus*	Sparse	Very sparse
	Sago Pondweed	*Stuckenia pectinata*	Sparse	Very sparse
	Sheathed Pondweed	*Stuckenia vaginata*	None	Sparse
12	Stonewort	*Chara* sp.	Sparse	Very sparse
	Eurasian Watermilfoil[a]	*Myriophyllum spicatum*	Abundant	Moderate
	Sago Pondweed	*Stuckenia pectinata*	Sparse	Very sparse

Table continued on next page.

Table 2.22 (Continued)

Area	Common Name	Scientific Name	Relative Abundance 1967 (lakewide)	Relative Abundance 1976 (area)
13	Eurasian Watermilfoil[a]	*Myriophyllum spicatum*	Abundant	Very abundant
	Slender Naiad	*Najas flexilis*	None	Very sparse
	Yellow Water Lily	*Nuphar* sp.	Very sparse	Very sparse
	Water Lily	*Nymphaea* sp.	Sparse	Very sparse
	Curly-Leaf Pondweed[a]	*Potamogeton crispus*	Sparse	Very sparse
	Sago Pondweed	*Stuckenia pectinata*	Sparse	Moderate
	Sheathed Pondweed	*Stuckenia vaginata*	None	Sparse
	Soft-Stem Bulrush	*Scirpus validus*	Very sparse	Very sparse
	Bur Reed	*Sparganium eurycarpum*	Very sparse	Very sparse
	Broadleaf Cat-Tail	*Typha latifolia*	Very sparse	Very sparse
14	Water Weed	*Elodea canadensis*	Very sparse	Very sparse
	Eurasian Watermilfoil[a]	*Myriophyllum spicatum*	Abundant	Abundant
	Slender Naiad	*Najas flexilis*	None	Very sparse
	Curly-Leaf Pondweed[a]	*Potamogeton crispus*	Sparse	Very sparse
	Sago Pondweed	*Stuckenia pectinata*	Sparse	Very sparse
15	Eurasian Watermilfoil[a]	*Myriophyllum spicatum*	Abundant	Very abundant
	Slender Naiad	*Najas flexilis*	None	Very sparse
	Curly-Leaf Pondweed[a]	*Potamogeton crispus*	Sparse	Very sparse
	Sago Pondweed	*Stuckenia pectinata*	Sparse	Very sparse
	Soft-Stem Bulrush	*Scirpus validus*	Very sparse	Very sparse
	Bur Reed	*Sparganium eurycarpum*	Very sparse	Very sparse
	Broadleaf Cattail	*Typha latifolia*	Very sparse	Very sparse

[a] *Nonnative or alien species.*

Source: Wisconsin Department of Natural Resources and SEWRPC

Aquatic Plant Survey Methods

There have also been several different methods of sampling the types, distribution, and relative abundance of aquatic macrophytes in Pewaukee Lake over the years, which complicates empirical comparisons from one year to another. For example, the WDNR aquatic plant survey in 1967 was conducted "lake wide", while the 1976 survey divided the shoreline areas of the Lake into "areas". In the absence of a consistent, objective measuring method, these two surveys relied on descriptors such as "abundant" or "sparse" to describe the abundance of each plant species (see Table 2.22).

Transect Methodology

Starting in 1986, most aquatic plant surveys of Pewaukee Lake were conducted utilizing the modified Jesson and Lound method. This methodology is based on a series of numbered transect lines located at regular intervals around the shoreline of the lake (see Figure 2.65). Along each transect line extending directly out from shore, a series of four sampling points are located based on pre-determined water depths of 1.5, 5, 9 and 11 feet. At each sampling point, four rake hauls are made and a record is made of each species observed in each haul, with no consideration for the relative abundance of each species: the species is identified as either *present* or *absent* in each haul. For example, if a species is present in three of the rake hauls, it is assigned a density rating of "3" and described as "moderate" in abundance.[156] This approach can be quantified so that empirical comparisons can be made between successive surveys over time.

Figure 2.65 shows the locations of the 24 transect lines utilized during surveys conducted by the WDNR during 1988, 1991, 1994, and 1997. A survey conducted in 2000 by the Commission utilized 48 transects created by inserting an additional transect line approximately halfway between the 24 lines previously used (see Map 2.25). Table 2.23 shows the results of these surveys.

[156] *Wisconsin Lutheran College, Biology Department Technical Bulletin 013,* Southeast Wisconsin's Pewaukee Lake Aquatic Plant Survey 2010, *April 2011.*

Table 2.23
Aquatic Plant Mean Species Density in Pewaukee Lake: 1988-2000

Aquatic Plant Species	Mean Species Density				
	1988[a,b]	1991[a,b]	1994[a,b]	1997[a,b]	2000[b]
Ceratophyllum demersum (coontail)	2.75	2.97	2.22	2.40	2.57
Chara vulgaris (muskgrass)	1.77	1.03	1.50	1.13	2.15
Elodea canadensis (waterweed)	0.56	0.65	1.25	1.65	1.86
Heteranthera dubia (water stargrass)	0.75	0.75	0.63	0.67	2.00
Myriophyllum sp. (native watermilfoil)	--	--	1.20	1.91	1.00
Myriophyllum spicatum (Eurasian watermilfoil)[c]	3.62	2.96	2.76	2.47	3.27
Najas flexilis (slender naiad)	2.07	1.47	1.79	0.63	2.61
Najas guadalupensis (southern naiad)	--	--	--	1.72	--
Potamogeton amplifolius (large-leaf pondweed)[d]	1.50	0.50	0.40	1.17	1.50
Potamogeton crispus (curly-leaf pondweed)[c]	1.82	1.58	0.88	--	1.00
Potamogeton filiformis (thread-leaf pondweed)	--	0.75	--	--	--
Potamogeton illinoensis (Illinois pondweed)[d]	--	--	--	--	0.60
Potamogeton natans (floating-leaf pondweed)	--	--	--	--	0.60
Potamogeton praelongus (white-stem pondweed)[d]	--	--	--	--	1.20
Potamogeton richardsonii (clasping-leaf pondweed)[d]	--	0.42	0.25	--	1.00
Potamogeton zosteriformis (flat-stemmed pondweed)	0.75	0.80	1.05	1.48	1.60
Potamogeton spp. (pondweed)	1.90	0.25	0.25	0.63	--
Stuckenia pectinata (Sago pondweed)[d]	0.94	1.56	1.24	1.13	1.56
Utricularia sp. (bladderwort)	0.25	--	0.88	0.75	1.00
Vallisneria americana (water celery)[d]	0.77	0.79	1.16	1.50	2.51

Note: Species mean density for all sample points including sample points where a particular species did not occur in Pewaukee Lake: Abundant (density rating equals 4 to 5), Common (density rating equals 2 to 3), Scarce (density rating equals 1), and Absent (density rating equals 0).

[a] *Survey conducted by Wisconsin Department of Natural Resources as part of the Long-Term Trend Monitoring Program.*

[b] *Maximum density equals 5.0.*

[c] *Designated as invasive and nonnative aquatic plant species pursuant to section NR 109.07 of the* Wisconsin Administrative Code.

[d] *Considered a high-value aquatic plant species known to offer important values in specific aquatic ecosystems under Section NR 107.08 (4) of the* Wisconsin Administrative Code.

Source: Wisconsin Department of Natural Resources and SEWRPC

In 2001 and 2002, aquatic plant *reconnaissance* surveys were also conducted in which only a smaller subset of the original 24 transects were used; these reconnaissance surveys were intended only to provide abbreviated follow-ups to the comprehensive 2000 survey. To avoid confusion, and because these data were not collected as part of a comprehensive survey, the resultant data and a map of these transect lines was not included in this report.

Transect methodology was continued by Wisconsin Lutheran College during aquatic plant surveys conducted by the college from 2000 through 2014 (see Table 2.24 for results). Map 2.26 shows approximate locations of the transects used for the 2000 - 2009 Wisconsin Lutheran College surveys, while Map 2.27 shows locations of the transects used during the 2010, 2013, and 2014 surveys; note that both are based on the transect locations and numbering system of the 48-transect map used during the 2000 Commission survey. The 2011 and 2016 survey data shown in Table 2.25 were the result of surveys conducted using point-intercept methodology.

Point-Intercept Methodology

In 2010, the WDNR adopted a grid-based point-intercept approach for conducting aquatic plant surveys.[157] In this method, sampling sites are based on predetermined global positioning system (GPS) location points that are arranged in a grid pattern across the entire surface of a lake (see Map 2.28). At each grid point sampling site, a single rake haul is taken and a qualitative assessment of the rake fullness, on a scale of zero

[157] *Wisconsin Department of Natural Resources, Publication No. PUB-SS-1068 2010,* Recommended Baseline Monitoring of Aquatic Plants in Wisconsin: Sampling Design, Field and Laboratory Procedures, Data Entry and Analysis, and Applications*, 2010.*

Map 2.24
Extent of Chronically Dense Plant Growth, Pewaukee Lake: 1972-2006

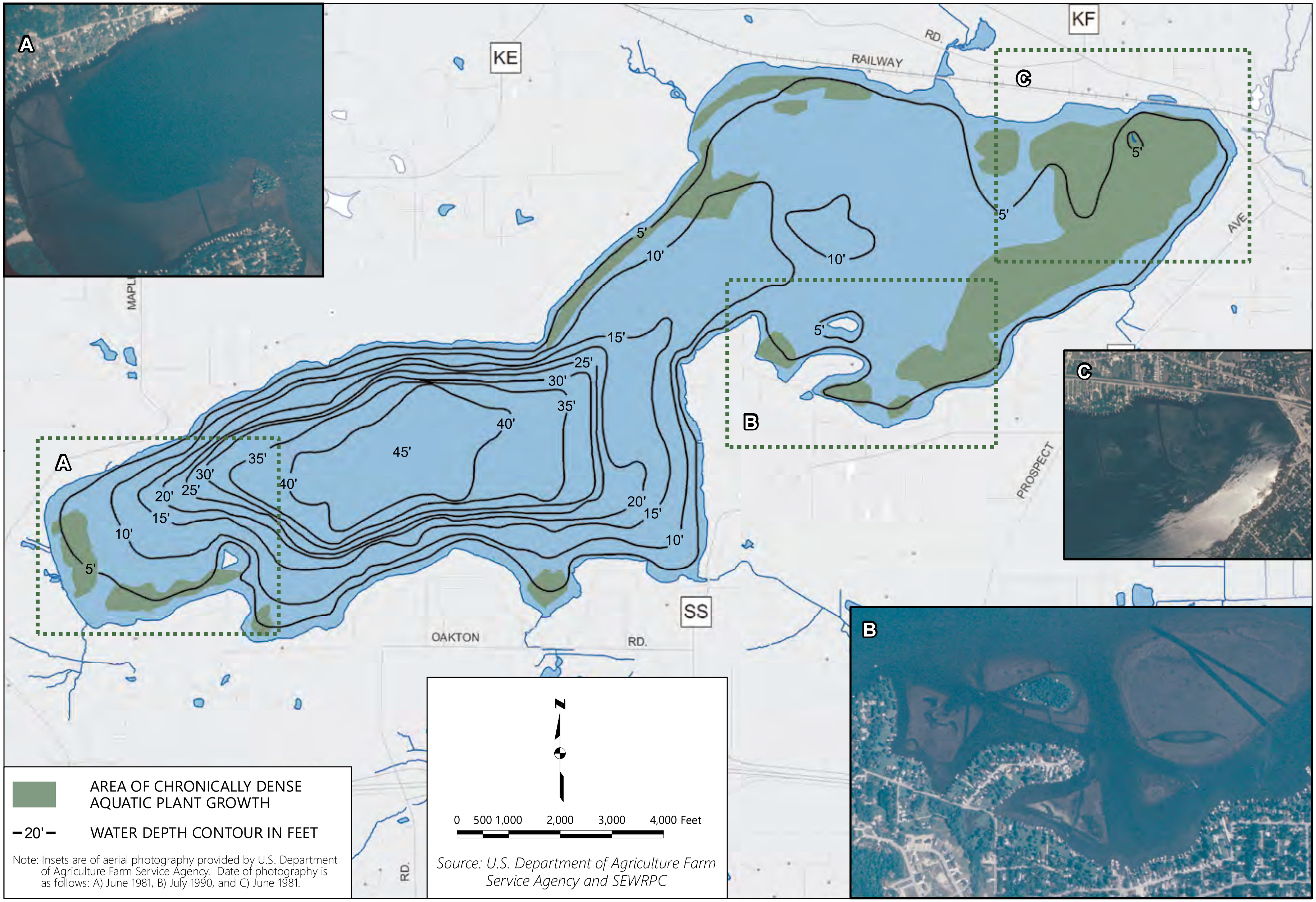
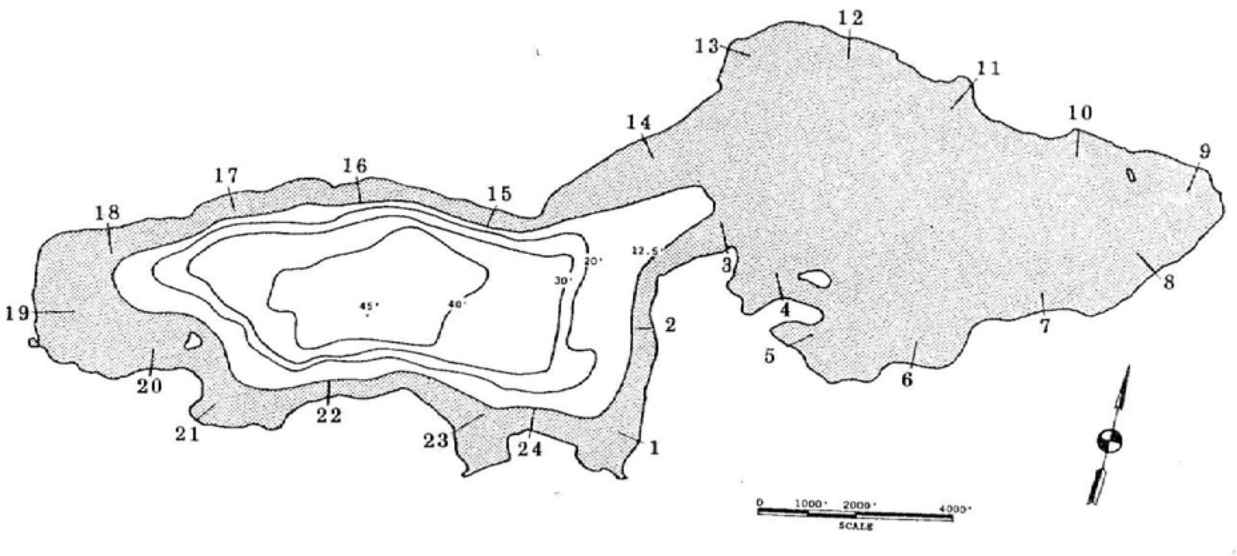


Figure 2.65
Wisconsin Department of Natural Resources Aquatic Plant Transects on Pewaukee Lake: 1988, 1991, 1994, and1997



Source: Wisconsin Department of Natural Resources and SEWRPC

to three, is made for each species identified. The 2011 and 2016 Wisconsin Lutheran college aquatic plant surveys of Pewaukee Lake were conducted using the grid-based point-intercept method.

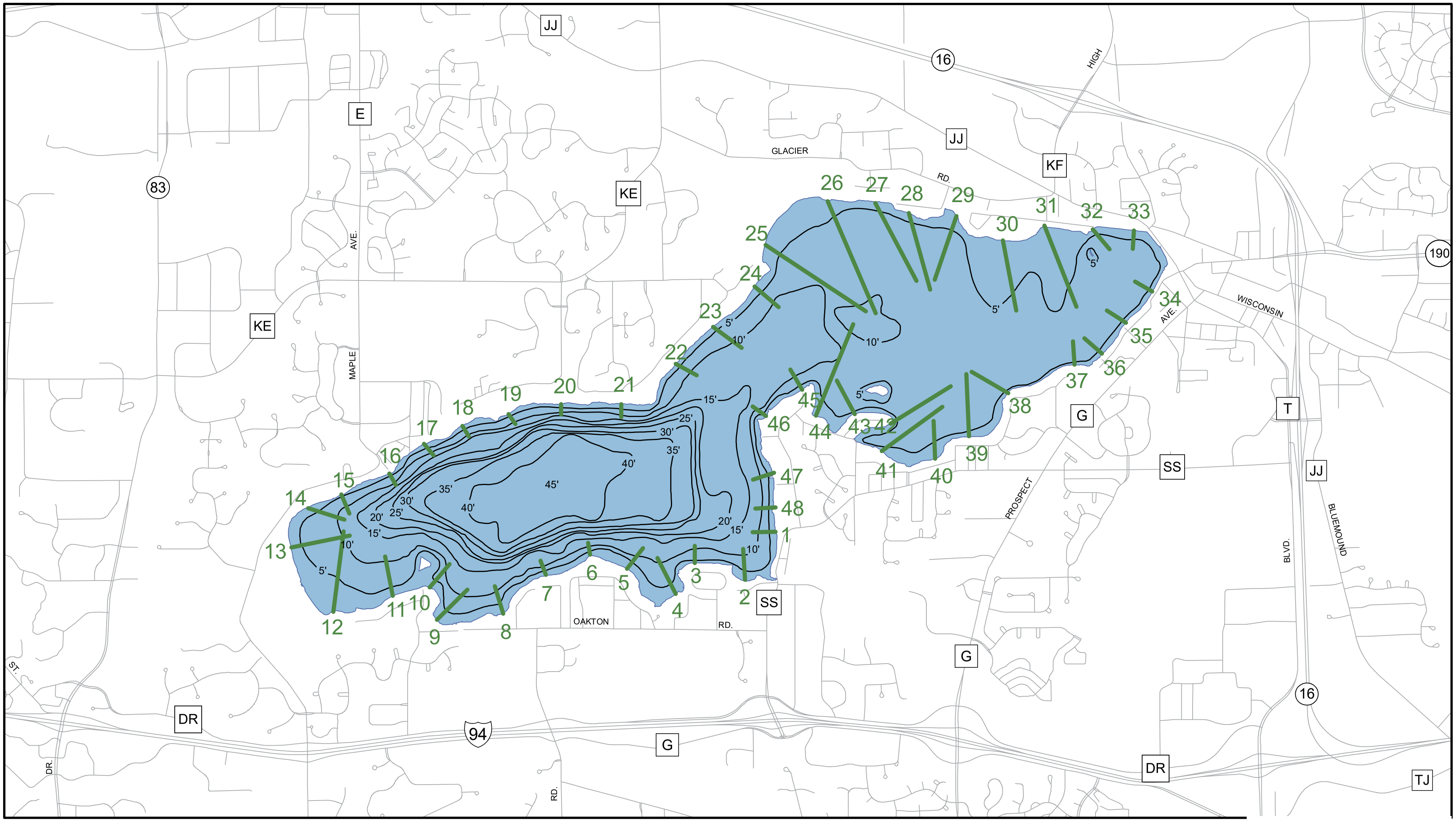
1967-2016 Transect Surveys

Table 2.22 presents a comparison of the macrophyte communities surveyed during 1976 with those noted to have been present within the Lake during 1967 based on 15 different sampling areas in the Lake. As described above, rather than use objective quantitative data to indicate the abundance of the various plant species observed, narrative descriptors were used. Notwithstanding, it is clear that the dominant plant species in Pewaukee Lake at the time of both the 1967 and 1976 plant surveys was EWM. Indeed, this plant was the dominant species in every area of the Lake during both the 1967 and 1976 surveys. So dominant was EWM that in nearly every area observed during the 1967 survey, it was described as either "abundant" or "very abundant." Every other plant species was assessed as either "sparse" or "very sparse" by comparison. This pattern of dominance was mostly the same during the 1976 survey as well. Other macrophytes observed during both the 1967 and 1976 surveys (albeit in small numbers compared to EWM) included: muskgrass (*Chara vulgaris*), waterweed (*Elodea canadensis*), CLP, and Sago pondweed.

Aquatic plant surveys conducted by the WDNR from 1988 through 1997 and by Commission staff in 2000 are summarized in Table 2.23 and illustrated in Figure 2.66. Throughout this period, the relative densities of EWM and CLP appeared to be steadily declining. With this decline, some native species, particularly waterweed, watermilfoil (*Myriophyllum* sp.), water celery or eelgrass (*Vallisneria americana*), and flat-stemmed pondweed (*Potamogeton zosteriformis*), increased in abundance with decreased competitive pressure from EWM. However, other native species did not indicate a clear trend, fluctuating in abundance between years.

In 2000, it was observed that Pewaukee Lake was experiencing the greatest level of aquatic plant growth since 1990. Indeed, the amount of plant material harvested by the LPSD during 2000 was surpassed only one time during the previous 15 years. Aquatic plant surveys were conducted by Commission staff, in association with staff from the LPSD, during July to August 2000 and in August 2001. During these surveys, plant growth occurred throughout most of the Lake where the water depth was less than 15 feet. Seventeen species of submergent aquatic plants were identified. EWM and CLP continued to be present in the Lake, while EWM, coontail, wild celery (*Vallisneria americana*), and muskgrass (*Chara* spp.) appeared to be the dominant species. At the same time, healthy populations of pondweeds (*Potamogeton* spp.) appeared to be scattered throughout the Lake. They were most commonly found at depths of between five and 10 feet.

Map 2.25
Pewaukee Lake Aquatic Plant Survey Transect Locations: SEWRPC 2000



12 TRANSECT SURVEY LINE AND IDENTIFICATION NUMBER

— 20' — WATER DEPTH CONTOUR IN FEET

NOTE: A subset of these transects was used for the 2001 and 2002 reconnaissance surveys conducted by SEWRPC staff.

N

0 2,000 4,000 Feet

Source: SEWRPC

Table 2.24
Frequency of Occurrence for Aquatic Plant Species in Pewaukee Lake: 2000-2016

Aquatic Plant Species	2000	2002	2004	2006	2007	2008	2009	2010	2011	2013	2014	2016
Ceratophyllum demersum (coontail)	49.4	54.2	17.4	13.7	7.8	13.7	21.7	63.0	29.3	71.4	8.2	24.5
Chara sp. (muskgrasses)	--	--	--	--	--	--	--	--	--	--	--	28.3
Chara vulgaris (muskgrass)	23.5	22.9	4.3	21.6	9.8	11.8	13.0	39.0	10.1	6.1	3.8	0.0
Elodea canadensis (waterweed)	13.3	18.8	1.9	2.0	--	2.0	10.9	54.0	8.4	--	0.9	7.2
Heteranthera dubia (water stargrass)	14.5	12.5	5.6	--	--	--	--	48.0	0.0	26.5	0.9	18.5
Myriophyllum heterophyllum (various-leaved watermilfoil)	--	--	--	--	--	--	--	--	--	--	--	2.3
Myriophyllum sibiricum (northern water milfoil)	--	--	--	--	--	--	--	--	--	--	--	15.7
Myriophyllum sp. (native watermilfoil)	0.6	--	--	21.6	19.6	3.9	--	74.0	13.5	79.6	34.6	--
Myriophyllum spicatum (Eurasian watermilfoil)[a]	82.5	91.7	53.4	80.4	84.3	78.4	73.9	85.0	78.1	75.5	28.3	60.4
Najas flexilis (slender naiad)	43.4	50.0	4.3	9.8	--	3.9	23.9	7.0	8.1	--	0.9	--
Najas guadalupensis (southern naiad)	--	--	--	--	--	--	--	--	--	--	--	3.9
Najas marina (spiny naiad)[a]	--	--	--	--	--	--	--	4.0	--	--	--	--
Nitella flexilis (nitella)	--	--	--	--	--	--	--	2.0	--	--	--	--
Nymphaea odorata (White water lily)	--	--	--	--	--	--	--	0.0	--	--	--	0.4
Potamogeton amplifolius (large-leaf pondweed)[b]	4.8	8.3	1.9	7.8	13.7	17.6	17.4	9.0	2.7	--	0.2	3.0
Potamogeton crispus (curly-leaf pondweed)[a]	2.4	6.3	1.9	5.9	2.0	2.0	6.5	46.0	10.9	10.2	0.3	22.5
Potamogeton diversifolius (water-thread pondweed)	--	--	--	--	--	--	--	7.0	--	--	--	--
Potamogeton foliosus leafy pondweed)	--	--	--	--	--	--	--	--	1.3	--	--	--
Potamogeton friesii (Fries' pondweed)	--	--	--	--	--	--	--	2.0	--	--	--	--
Potamogeton gramineus (variable-leaf pondweed)[b]	--	--	6.2	--	--	--	--	7.0	0.4	2.0	--	--
Potamogeton hillii (Hill's pondweed)	--	--	--	--	--	--	--	2.0	--	--	--	--
Potamogeton illinoensis (Illinois pondweed)[b]	--	--	--	2.0	--	7.8	--	9.0	--	12.2	--	0.7
Potamogeton natans (floating-leaf pondweed)	--	--	--	--	--	--	--	2.0	--	2.0	--	0.5
Potamogeton nodosus (long-leaf pondweed)	--	--	--	--	--	--	--	2.0	--	--	--	0.2
Potamogeton praelongus (white-stem pondweed)[b]	3.0	--	--	--	2.0	2.0	--	--	1.8	--	1.3	7.0
Potamogeton pusillus (small pondweed)	--	--	--	--	--	--	--	2.0	5.8	2.0	0.4	1.4
Potamogeton richardsonii (clasping-leaf pondweed)[b]	0.6	2.1	--	--	--	--	--	--	4.1	--	--	5.1
Potamogeton robbinsii (Robbin's pondweed)	--	--	--	--	--	--	--	--	0.2	4.1	--	1.9
Potamogeton zosteriformis (flat-stemmed pondweed)	9.0	16.7	2.5	3.9	11.8	9.8	13.0	30.0	7.9	2.0	3.7	38.7
Potamogeton sp. (pondweed)	--	--	--	--	--	--	--	--	--	--	--	--
Ranunculus longirostris (stiff water crowfoot)	--	--	--	--	--	--	--	--	--	--	--	1.8
Stuckenia pectinata (Sago pondweed)[b]	20.5	22.9	15.5	13.7	5.9	7.8	19.6	7.0	1.9	22.4	2.4	44.0
Utricularia sp. (bladderwort)	1.2	--	--	--	--	--	--	9.0	0.5	--	--	--
Utricularia vulgaris (common bladderwort)	--	--	--	--	--	--	--	--	--	--	--	0.7
Vallisneria americana (water celery)[b]	25.9	33.3	--	13.7	15.7	13.7	19.6	33.0	6.8	48.9	12.7	21.0
Wolffia borealis (northern watermeal)	--	--	--	--	--	--	--	--	--	--	--	0.5
Zannichellia palustris (horned pondweed)	--	--	8.1	--	--	--	--	--	--	--	--	--

Table continued on next page.

Table 2.24 (Continued)

Aquatic Plant Species	2000	2002	2004	2006	2007	2008	2009	2010	2011	2013	2014	2016
Total Number of Species	18	12	12	13	10	13	10	23	18	15	14	24
Total Number of Native Species	16	10	10	11	8	11	8	20	16	13	12	22
Total Number of Nonnative Species	2	2	2	2	2	2	2	3	2	2	2	2

Note: Frequency of Occurrence is the number of occurrences of a species divided by the number of samplings with vegetation, expressed as a percent; it is the percentage of times a particular species occurred when there was aquatic vegetation present.

Surveys conducted in 2000-2010 and 2013-2014 used transect methodology; the 2011 and 2016 surveys used the grid-based point-intercept method. Additionally, surveys in 2006-2009 used the same transects; in 2010, the transect locations were shifted and the 2010, 2013 and 2014 surveys all used the shifted transects. Surveys using similar methodology are grouped by background color.

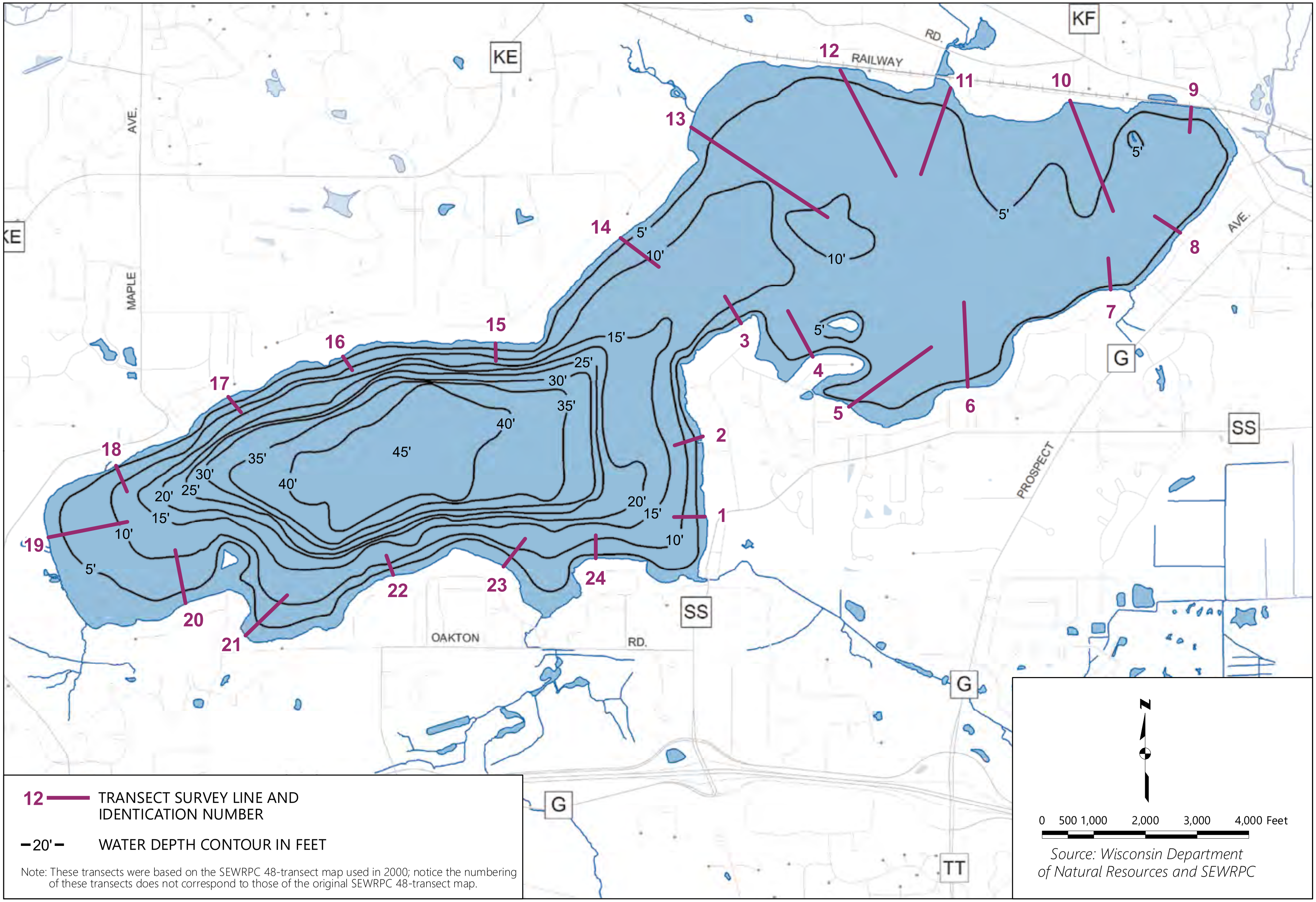
[a] *Designated as invasive and nonnative aquatic plant species pursuant to section NR 109.07 of the* Wisconsin Administrative Code.

[b] *Considered a high-value aquatic plant species known to offer important values in specific aquatic ecosystems under Section NR 107.08 (4) of the* Wisconsin Administrative Code.

Source: Wisconsin Department of Natural Resources, Wisconsin Lutheran College, and SEWRPC

Map 2.26

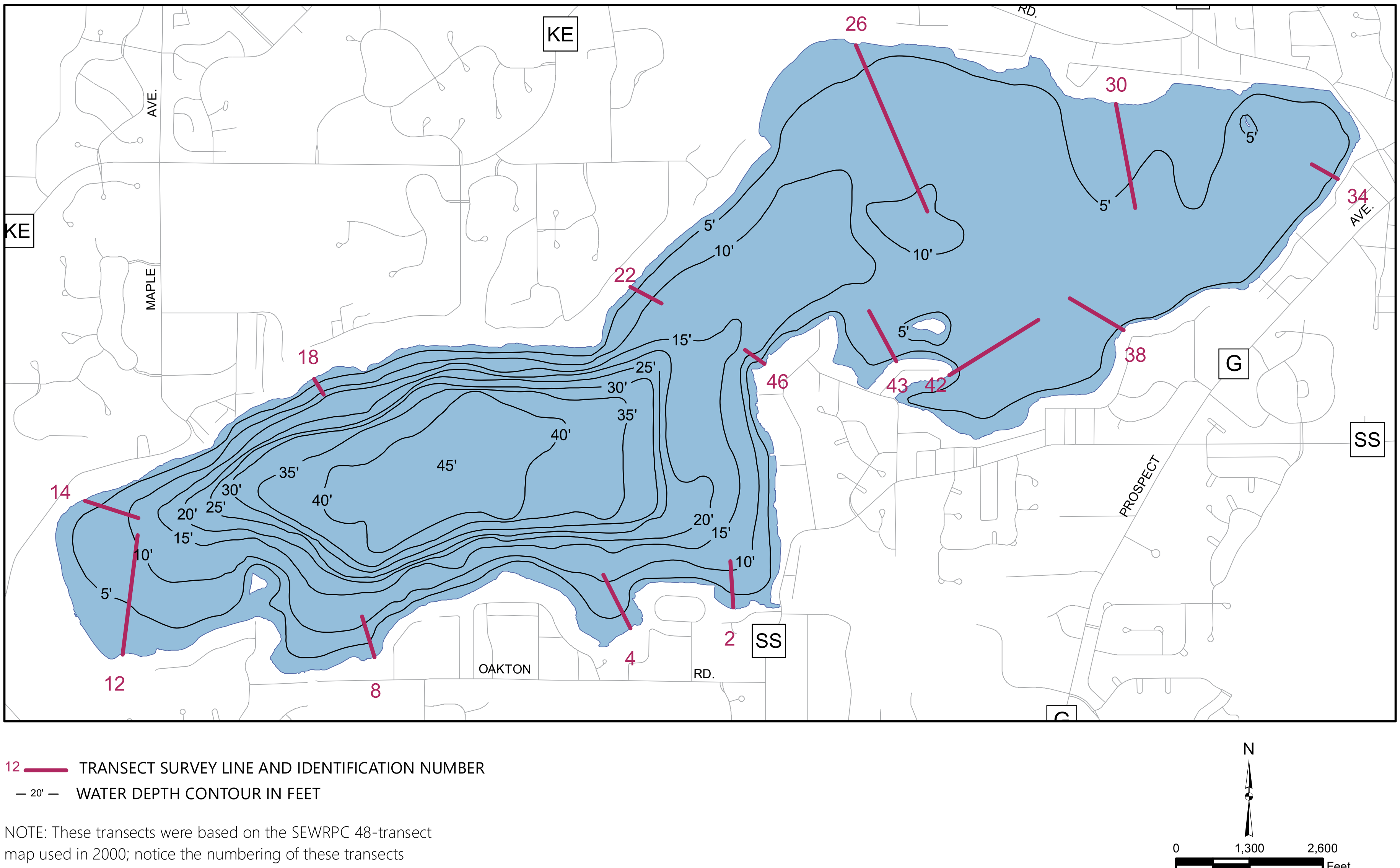
Transect Lines Used for Pewaukee Lake Aquatic Plant Surveys by Wisconsin Lutheran College: 2000, 2002, 2004, 2006, 2007, 2008, and 2009



Note: These transects were based on the SEWRPC 48-transect map used in 2000; notice the numbering of these transects does not correspond to those of the original SEWRPC 48-transect map.

Source: Wisconsin Department of Natural Resources and SEWRPC

Map 2.27
Transect Lines Used for Pewaukee Lake Aquatic Plant Surveys by Wisconsin Lutheran College: 2010, 2013, and 2014



NOTE: These transects were based on the SEWRPC 48-transect map used in 2000; notice the numbering of these transects corresponds to those of the original SEWRPC 48-transect map.

Source: Wisconsin Lutheran College and SEWRPC

Table 2.25
Aquatic Plant Species Frequency of Occurrence in Pewaukee Lake East Basin Versus West Basin: 2011 and 2016

	2011			2016		
Aquatic Plant Species	East	West	Whole Lake	East	West	Whole Lake
Ceratophyllum demersum (coontail)	24.0	43.4	29.3	22.8	29.4	24.5
Chara sp. (muskgrasses)	8.4	14.5	10.1	30.4	22.4	28.3
Elodea canadensis (waterweed)	7.2	11.8	8.4	6.8	8.4	7.2
Heteranthera dubia (water stargrass)	--	--	--	24.5	0.7	18.5
Myriophyllum heterophyllum (various-leaved watermilfoil)	--	--	--	--	9.1	2.3
Myriophyllum sibiricum (northern watermilfoil)	17.5	3.3	13.5	10.4	31.5	15.7
Myriophyllum spicatum (Eurasian watermilfoil)[a]	77.8	79.0	78.1	57.4	69.2	60.4
Najas flexilis (slender naiad)	9.9	3.3	8.1	--	--	--
Najas guadalupensis (southern naiad)	--	--	--	2.8	7.0	3.9
Nymphaea odorata (White water lily)	--	--	--	0.3	0.6	0.4
Potamogeton amplifolius (large-leaf pondweed)[b]	2.5	3.3	2.7	1.7	9.1	3.5
Potamogeton crispus (curly-leaf pondweed)[a]	7.4	20.4	10.9	19.8	30.8	22.5
Potamogeton foliosus (leafy pondweed)	1.7	--	1.3	--	--	--
Potamogeton gramineus (variable-leaf pondweed)[b]	0.5	--	0.4	--	--	--
Potamogeton illinoensis (Illinois pondweed)[b]	--	--	--	--	2.8	0.7
Potamogeton natans (floating-leaf pondweed)	0.0	0.7	0.2	0.5	0.7	0.5
Potamogeton nodosus (long-leaf pondweed)	0.0	0.0	0.0	0.4	--	0.2
Potamogeton praelongus (white-stem pondweed)[b]	2.2	0.7	1.8	7.8	4.9	7.0
Potamogeton pusillus (small pondweed)	7.4	1.3	5.8	--	5.6	1.4
Potamogeton richardsonii (clasping-leaf pondweed)[b]	4.2	4.0	4.1	6.8	--	5.1
Potamogeton robbinsii (Robbin's pondweed)	0.3	--	0.2	0.2	7.0	1.9
Potamogeton zosteriformis (flat-stemmed pondweed)	6.7	11.2	7.9	42.1	28.7	38.7
Ranunculus longirostris (stiff water crowfoot)	--	--	--	1.9	1.4	1.8
Stuckenia pectinata (Sago pondweed)[b]	2.7	--	1.9	55.8	9.1	44.0
Utricularia vulgaris (common bladderwort)	0.7	--	0.5	0.2	2.1	0.7
Vallisneria americana (water celery)[b]	6.4	7.9	6.8	20.9	21.0	21.0
Wolffia borealis (northern watermeal)	--	--	--	0.7	--	0.5
Total Number of Species	18	14	18	20	21	24
Total Number of Native Species	16	12	16	18	19	22
Total Number of Nonnative Species	2	2	2	2	2	2

Note: Frequency of Occurrence is the number of occurrences of a species divided by the number of samplings with vegetation, expressed as a percent; it is the percentage of times a particular species occurred when there was aquatic vegetation present.

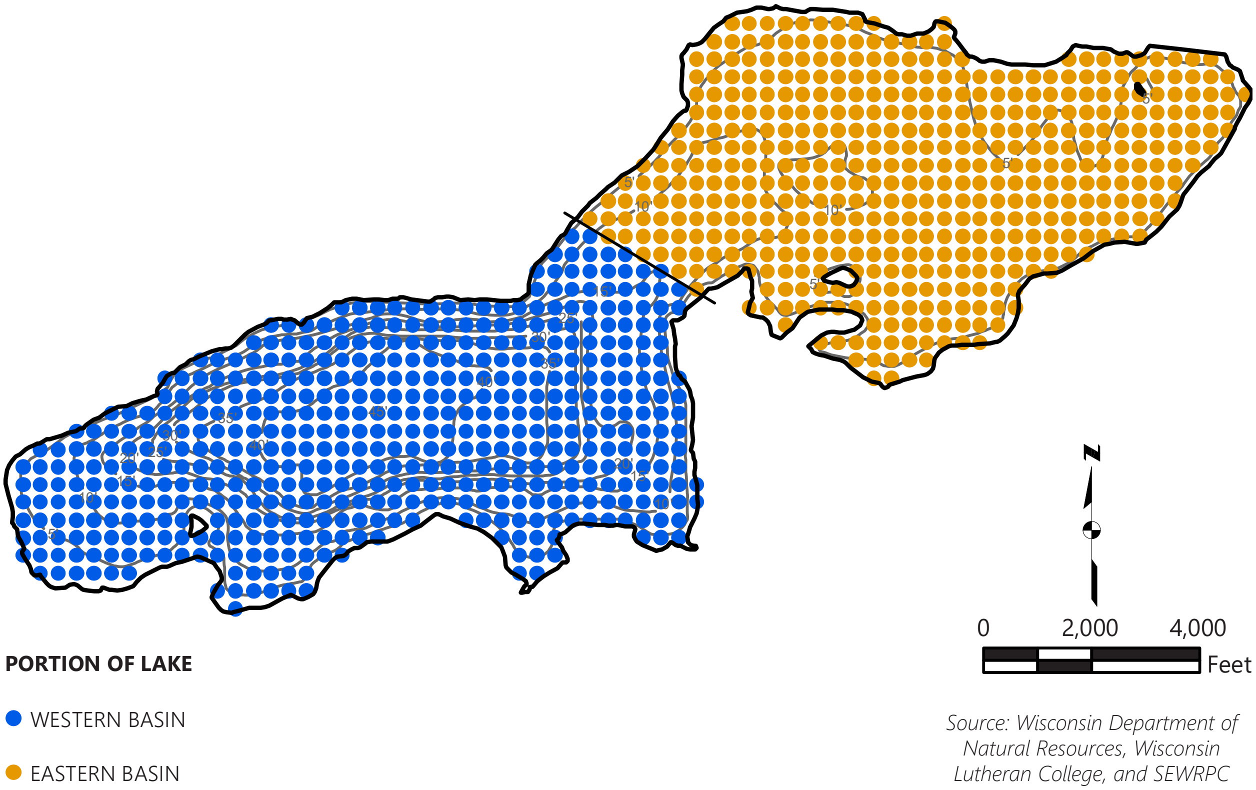
[a] *Designated as invasive and nonnative aquatic plant species pursuant to section NR 109.07 of the* Wisconsin Administrative Code.

[b] *Considered a high-value aquatic plant species known to offer important values in specific aquatic ecosystems under Section NR 107.08 (4) of the* Wisconsin Administrative Code.

Source: Wisconsin Lutheran College, and SEWRPC

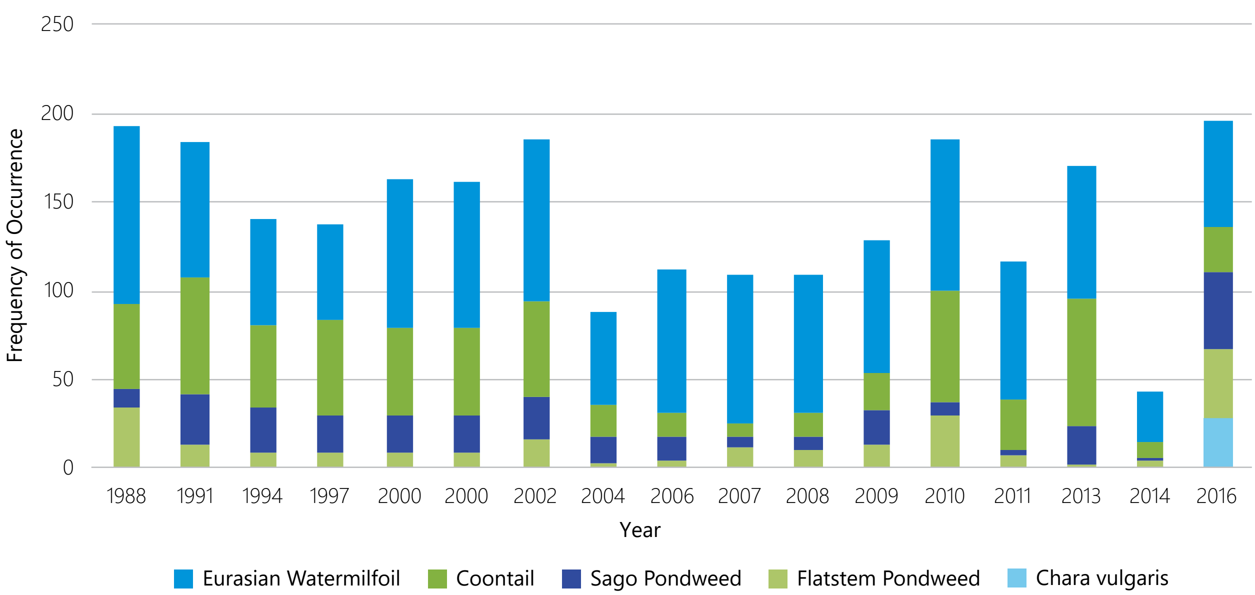
As stated earlier, Wisconsin Lutheran College conducted aquatic plant surveys on Pewaukee Lake in 2000, 2002, 2004, 2006-2011, 2013, 2014, and 2016; results of these surveys are presented in Table 2.24. The 2000 survey conducted by Wisconsin Lutheran College used different transect lines than the 2000 Commission survey, but the results were largely similar. EWM was still the most dominant plant throughout the Lake in the 2000 survey, reaching an areal extent similar to that reported during 1988, but largely confined to areas of the Lake with depths of between five and 15 feet. Nevertheless, the growths of EWM in the Lake during the year 2000 were among the heaviest in recent years. These growths created nuisance conditions in much of the eastern basin of the Lake and in the western basin of the Lake in areas where depths were less than 12 feet. It has been postulated that this resurgence of EWM within the Lake may have reflected the cyclical nature of the climatic regime within the Region and the tolerance of the EWM to colder water temperatures than those generally tolerated by native aquatic plant species.

Map 2.28
WDNR Point-Intercept Survey Points Used in the East-West Comparison of Pewaukee Lake: 2011 and 2016



Source: Wisconsin Department of Natural Resources, Wisconsin Lutheran College, and SEWRPC

Figure 2.66
Frequency of Occurrence Trends of Five Species Abundant in Pewaukee Lake: 1988-2016



Note: Two separate surveys were conducted in 2000, one by SEWRPC, and the other by Wisconsin Lutheran College.

Source: Wisconsin Lutheran College and SEWRPC

From 2000 to 2004, EWM continued to be the dominant plant in Pewaukee Lake. Coontail, wild celery and muskgrass also were consistently among the top five most dominant plants in the Lake. EWM continued to be the most dominant plant in the Lake during the period from 2006 through 2011. In 2013, EWM was not the most numerous plant in the Lake for the first time since 1991, but in 2016 the plant re-emerged as the most dominant species. In addition, native water milfoils (*Myriophyllum* spp.), Sago pondweed, muskgrass (*Chara* spp.), and the non-native CLP all became more abundant in the Lake throughout this time.

2011 and 2016 Point-Intercept Surveys

A grid-based point-intercept system instead of the transect methodology was utilized for surveys conducted in 2011 and 2016. These surveys were both conducted using the same GPS sampling points and followed the point-intercept survey protocol.[158] Thus, these surveys can more accurately indicate changes in species distributions within the Lake as well as changes in community composition over time.

Species richness is a count of the number of species identified. Generally, lake-wide species richness was higher in 2016 (23 species) than 2011 (18 species), with both values exceeding the average richness of 15 for Southeastern Wisconsin lakes (see Figure 2.67). Additionally, the presence of species associated with less disturbed lake conditions, such as white-stem pondweed (*Potamogeton praelongus*) and Robbins' pondweed (*Potamogeton robbinsii*), and higher Floristic Quality Index values (26) than the regional average (20) are also indicators of improving lake health.[159] Similarly, species diversity, calculated using the Simpson diversity index, was higher in 2016 (0.89) than in 2011 (0.76), indicating that there were more equal proportions of species in 2016. This increase in richness and diversity shows a positive trend for the aquatic plant community of Pewaukee Lake. Communities with high species richness and diversity are more robust, provide a wider variety of habitat and food, and are indicative of healthier ecosystems.

Overall species composition and distribution did not change significantly between 2011 and 2016, as four of the most dominant species in 2011 (EWM, muskgrass, coontail, and CLP) were also dominant in 2016 (see Table 2.25). The six most dominant plants in the 2016 survey, in order of decreasing dominance, were:

1. EWM (most dominant in 2011)
2. Sago pondweed (coontail was second-most dominant in 2011)
3. Flat-stem pondweed (Robbins' pondweed was third-most dominant in 2011)
4. Muskgrass (northern milfoil was fourth-most dominant in 2011)
5. Coontail (CLP was fifth-most dominant in 2011)
6. CLP (muskgrass was sixth-most dominant in 2011)

Figures 2.68 through 2.73 compare the distribution of the six most dominant plants in Pewaukee Lake in 2011 with their distribution in 2016. Appendix D contains distribution maps for all the aquatic plant species observed during the 2016 point-intercept survey of Pewaukee Lake.

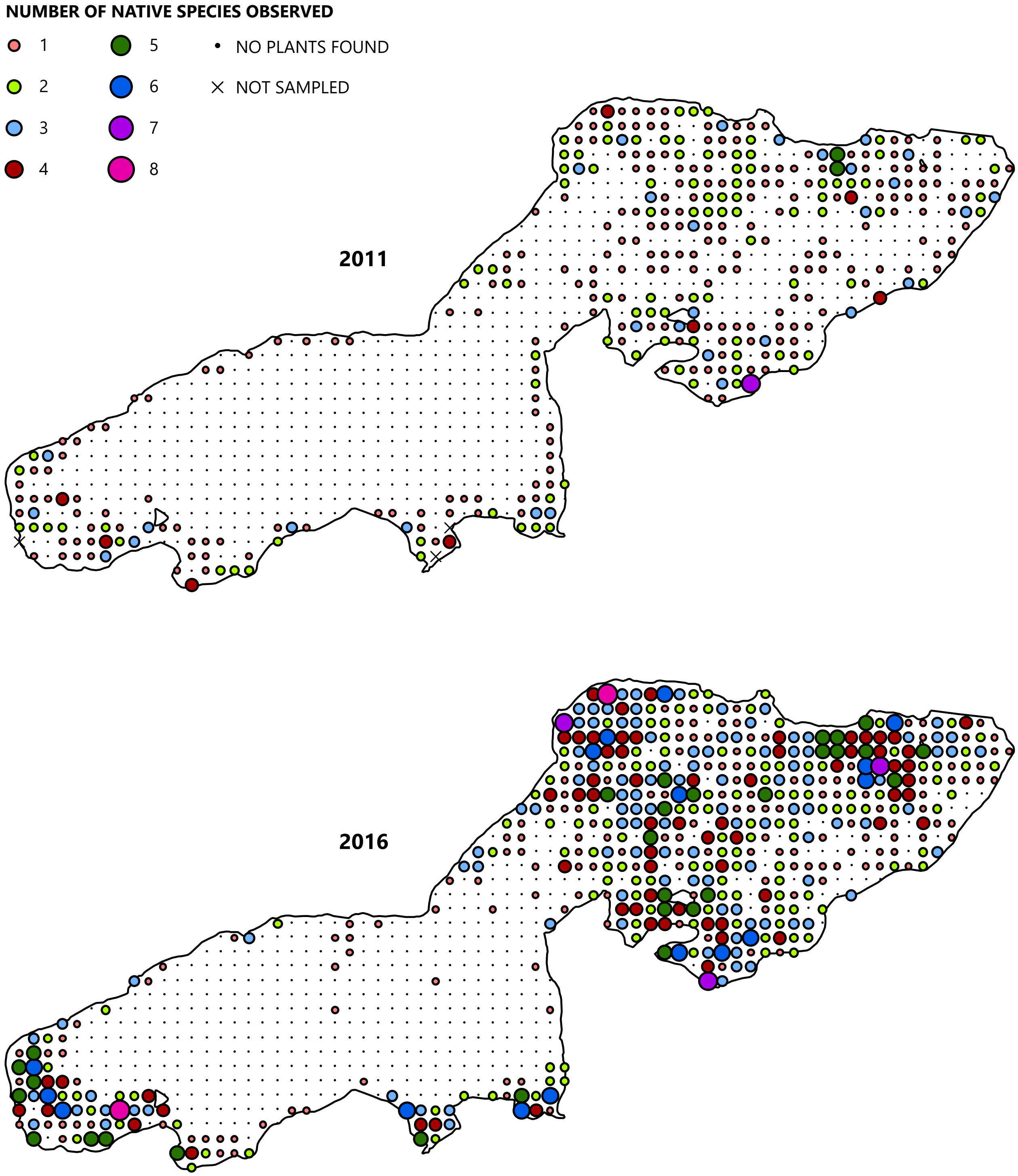
Changes in Species Distribution

EWM was the most dominant plant in both 2011 and 2016, and was especially abundant in the east basin of the Lake, as shown in Figure 2.68. This is no surprise since aquatic plant growth in Pewaukee Lake is, in general, more abundant in the east basin than in the west basin. The species was most abundant in generally the same areas in both 2011 and 2016: widespread throughout the east basin with large concentrations in the mid- to northwest portions, at the far west end of the Lake, and in the three prominent bays along the southern shoreline of the west basin. Lake-wide EWM frequency of occurrence decreased from 78.1 percent in 2011 to 60.4 percent in 2016 (see Table 2.25). Declines of EWM were largest along the western and southeastern portions of the east basin, as shown on Map 2.29. However, a large area in the east basin

[158] *WDNR, 2010,* op. cit.

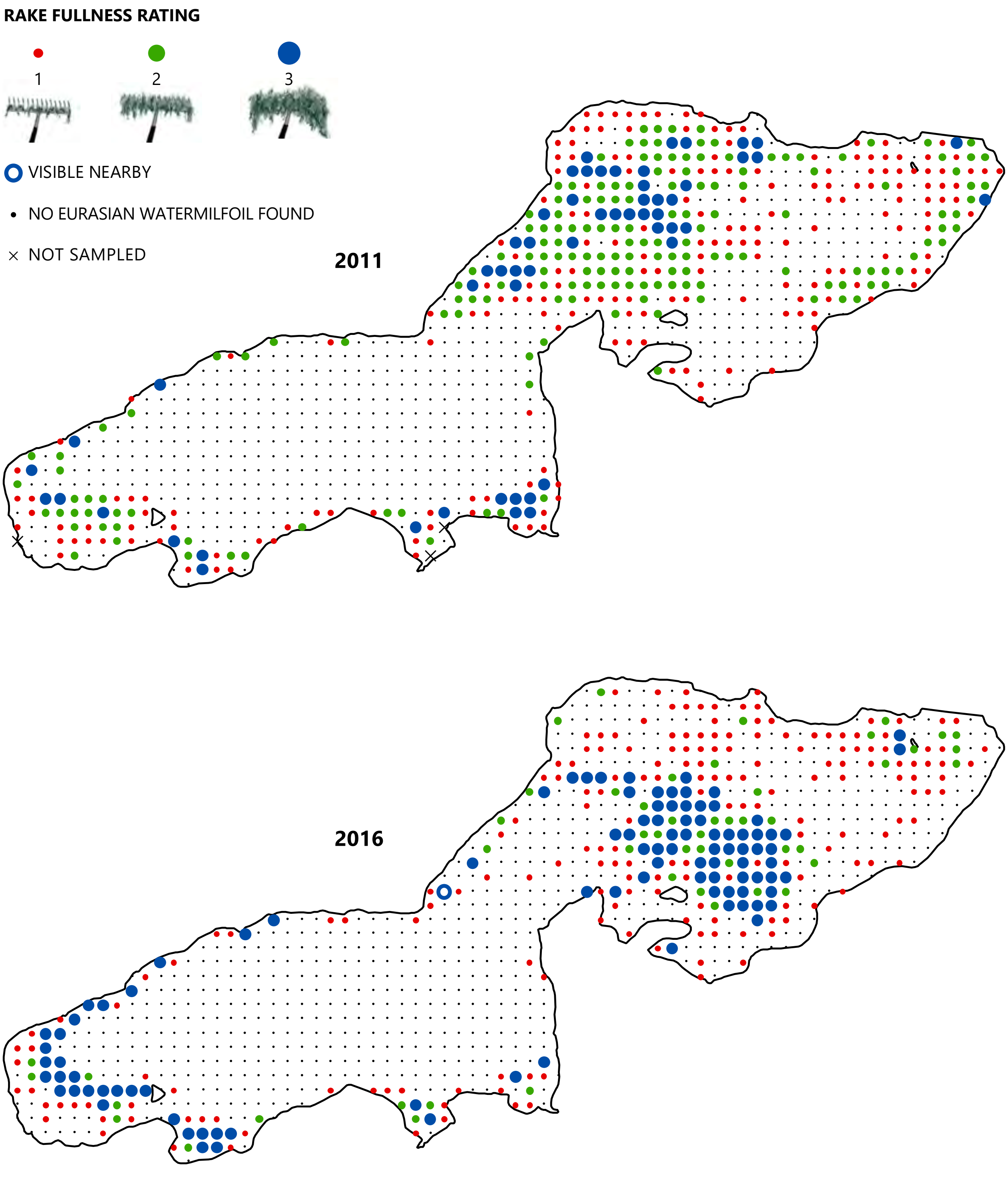
[159] *Wisconsin Lutheran College, 2011,* op. cit.

Figure 2.67
Pewaukee Lake Native Aquatic Plants Species Richness: 2011 Versus 2016



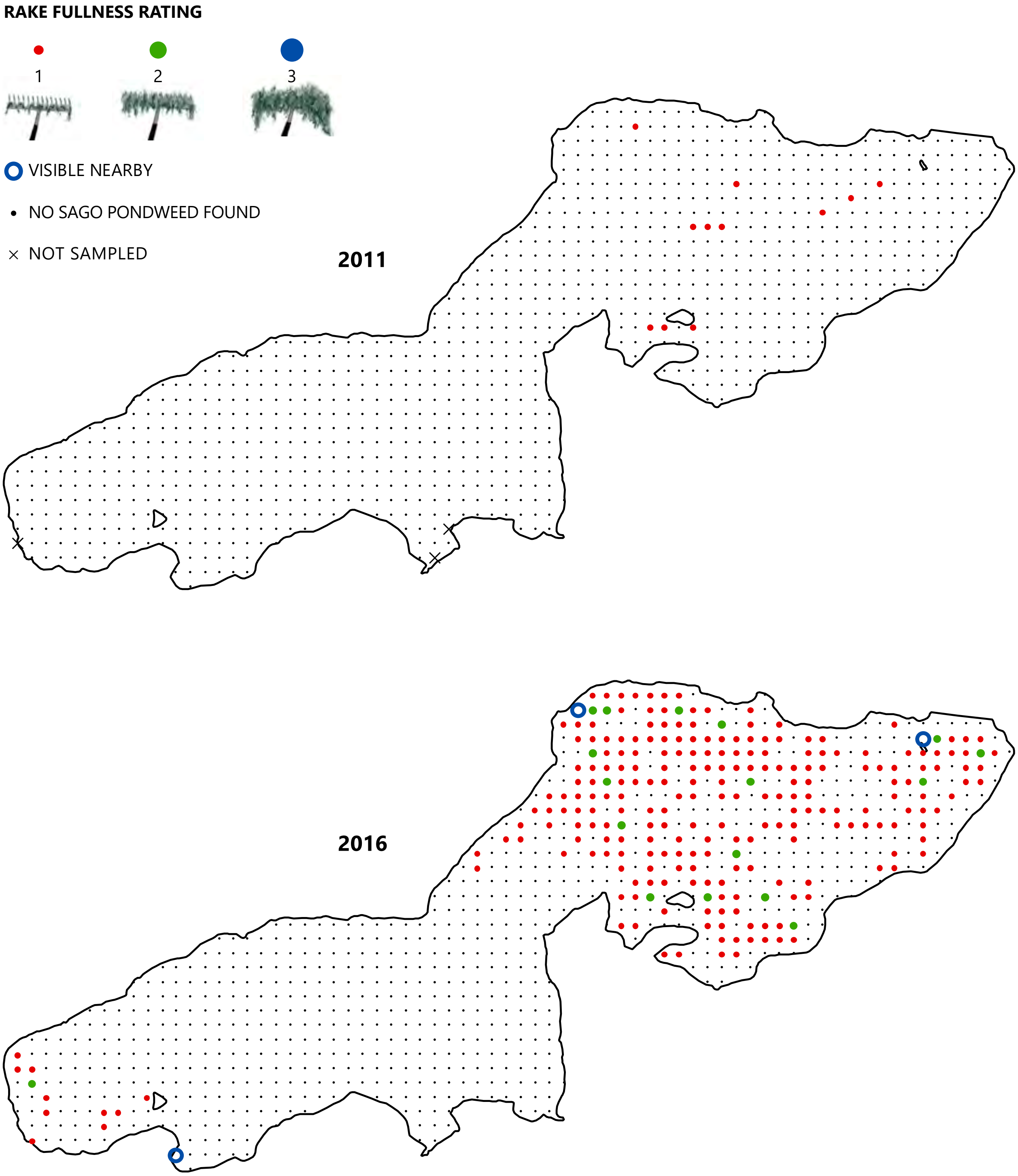
Source: Wisconsin Department of Natural Resources, Wisconsin Lutheran College, and SEWRPC

Figure 2.68
Eurasian Watermilfoil Occurrence in Pewaukee Lake: 2011 Versus 2016



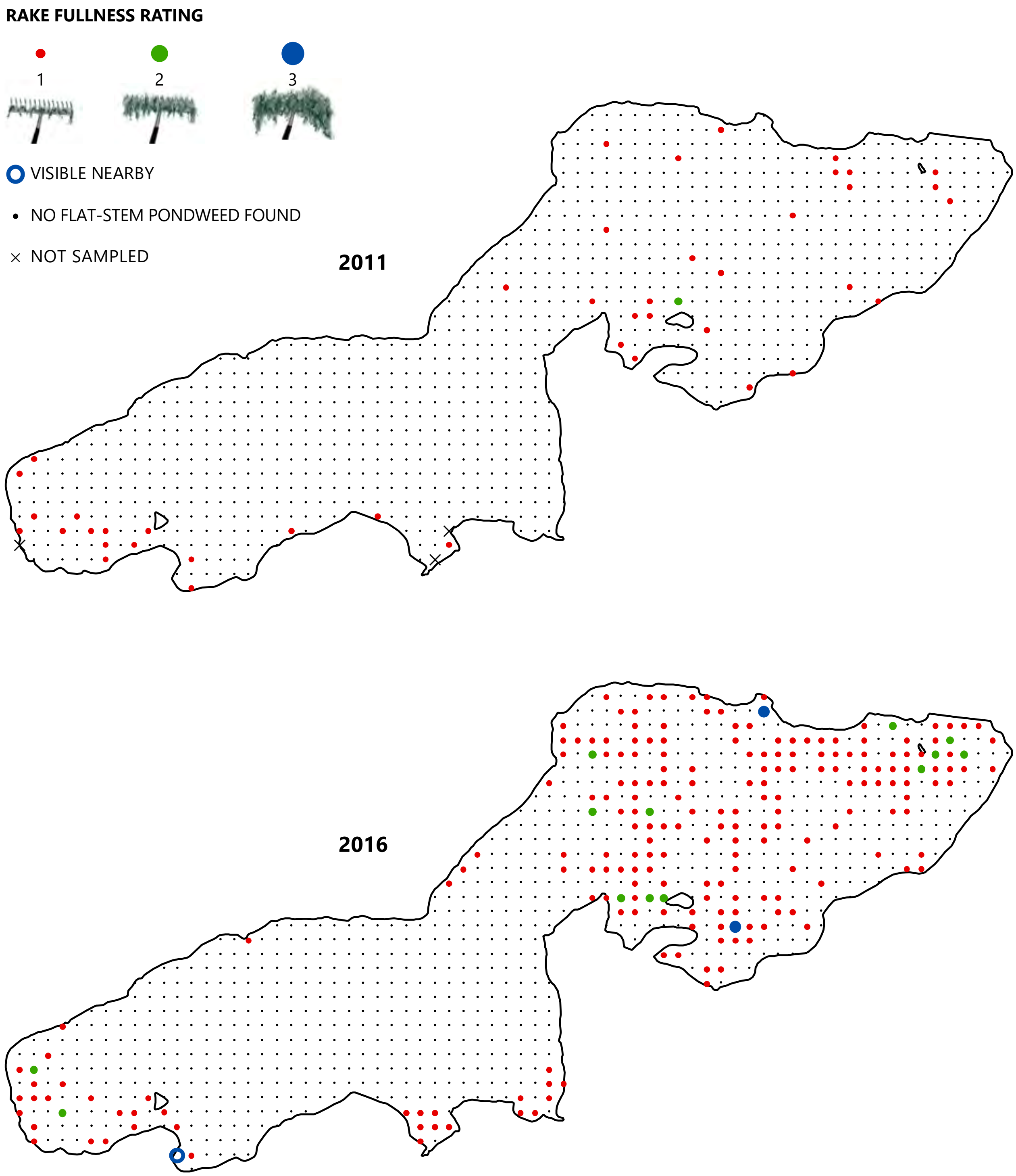
Source: Wisconsin Department of Natural Resources, Wisconsin Lutheran College, and SEWRPC

Figure 2.69
Sago Pondweed Occurrence in Pewaukee Lake: 2011 Versus 2016



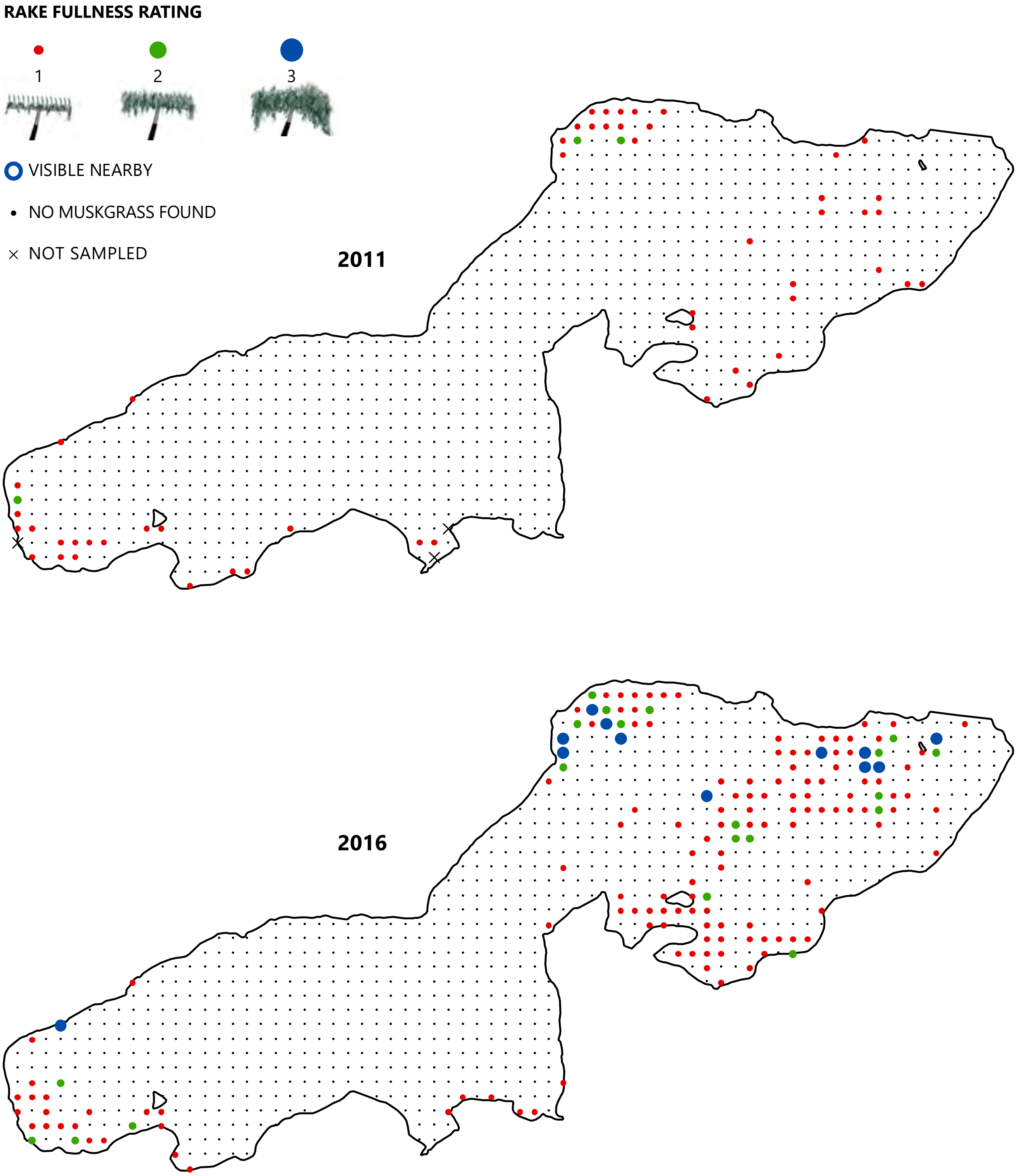
Source: Wisconsin Department of Natural Resources, Wisconsin Lutheran College, and SEWRPC

Figure 2.70
Flat-Stem Pondweed Occurrence in Pewaukee Lake: 2011 Versus 2016



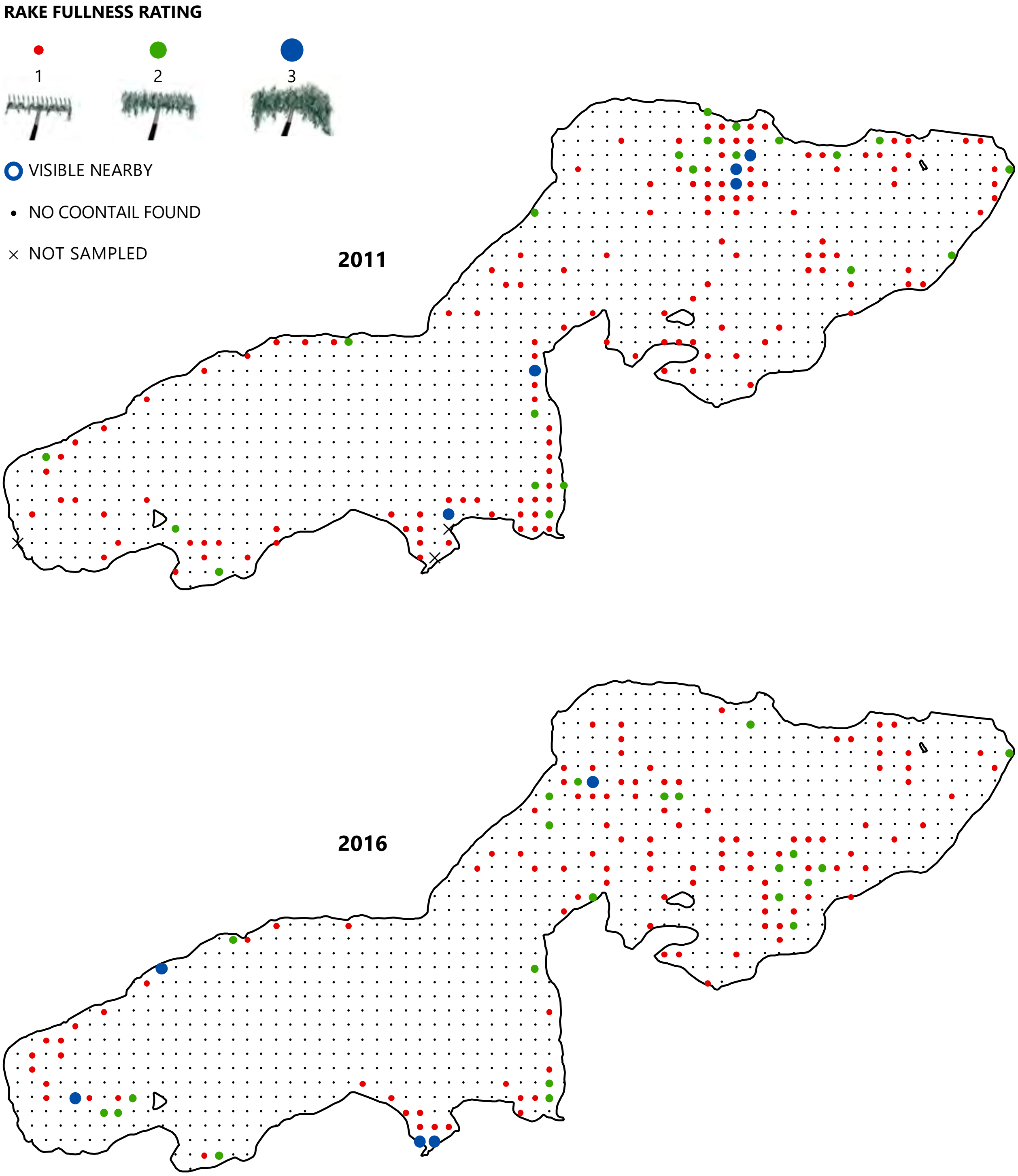
Source: Wisconsin Department of Natural Resources, Wisconsin Lutheran College, and SEWRPC

Figure 2.71
Muskgrass Occurrence in Pewaukee Lake: 2011 Versus 2016



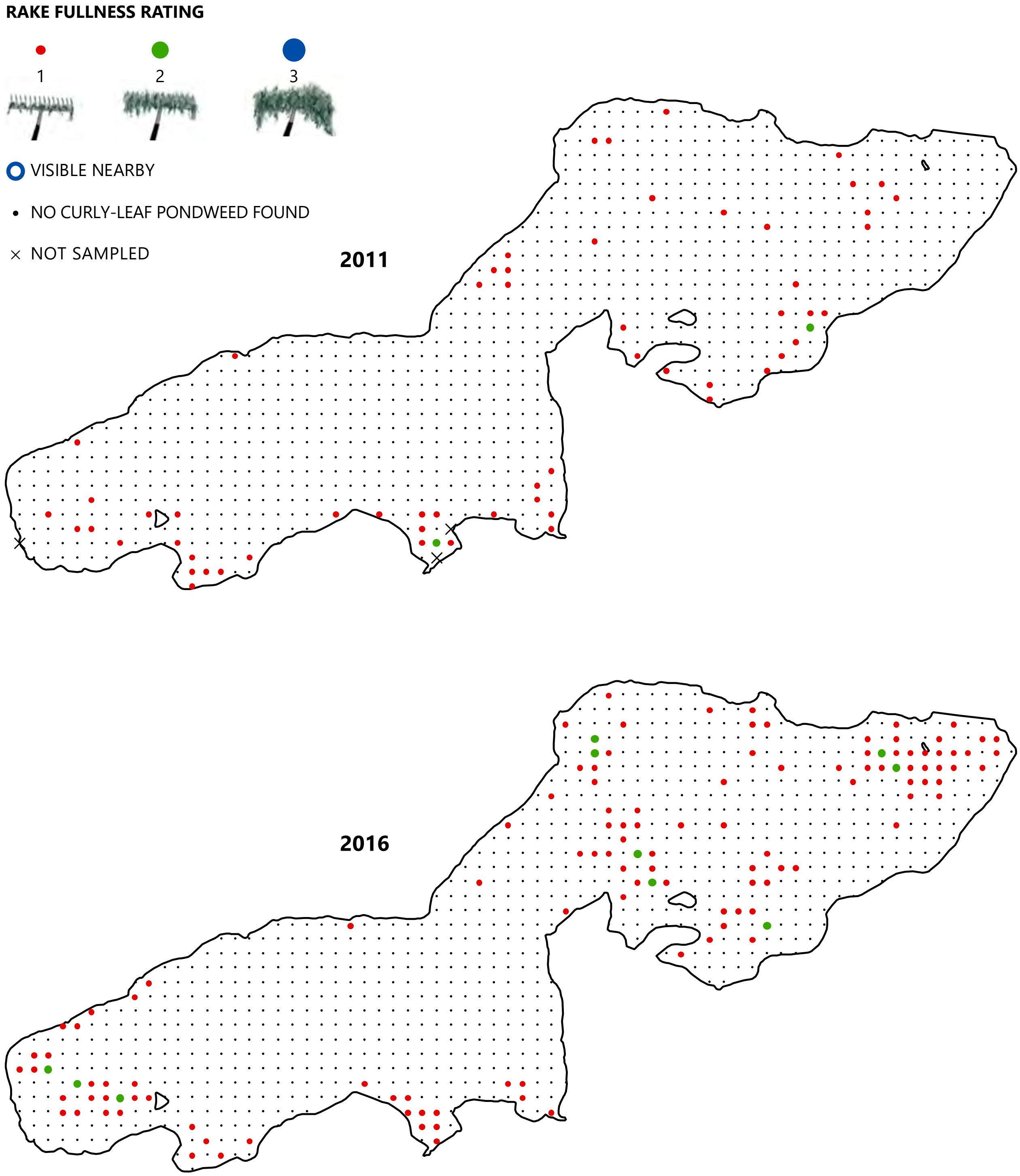
Source: Wisconsin Department of Natural Resources, Wisconsin Lutheran College, and SEWRPC

Figure 2.72
Coontail Occurrence in Pewaukee Lake: 2011 Versus 2016



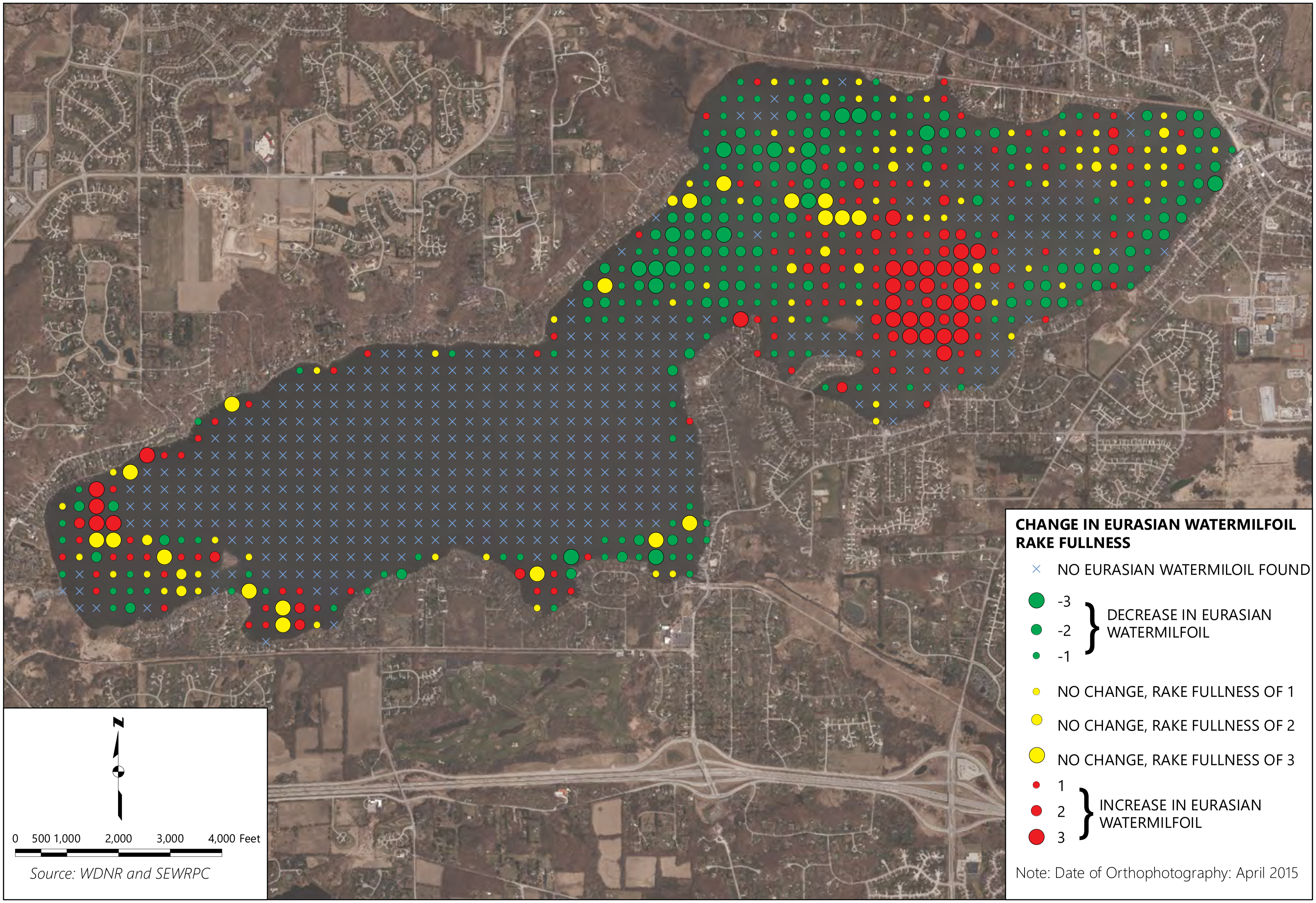
Source: Wisconsin Department of Natural Resources, Wisconsin Lutheran College, and SEWRPC

Figure 2.73
Curly-leaf Pondweed Occurrence in Pewaukee Lake: 2011 Versus 2016



Source: Wisconsin Department of Natural Resources, Wisconsin Lutheran College, and SEWRPC

Map 2.29
Change in Eurasian Watermilfoil Rake Fullness in Pewaukee Lake: 2011 and 2016



has had little change in EWM cover or abundance. According to the LPSD, harvesting in this area has been limited by time and budget constraints. However, decreases in EWM density and distribution have been observed that may not have been captured in the survey.

Sago pondweed, a native species, was the second most dominant plant in the 2016 survey (Table 2.25). This species was not among the six most dominant species in 2011 but, as shown in Figure 2.69, was observed widely distributed throughout almost the entire east basin in 2016. The lowest abundance of this plant since 2000 were recorded in 2011, so it could be that the plant was in a "down cycle" during the 2011 survey since abundance data for 2000, 2004, 2006, 2009, and 2013 all show significantly larger amounts of Sago pondweed (in 2016, the highest amounts of this species since 2000 were recorded). It is well known that most species of aquatic plants, especially the pondweeds, tend to exhibit abundance in multiyear cycles. Since the presence of pondweeds is generally considered a sign of a healthy aquatic plant community, an established population of Sago pondweed is a positive aspect for the Pewaukee Lake aquatic plant community.

Flat-stemmed pondweed, another native species, was the third most dominant species in the 2016 survey. Somewhat similar to the pattern of abundance observed with Sago pondweed, flat-stemmed pondweed also showed relatively widely-scattered and low abundances in 2011, but significant increase in abundance in 2016, especially in the east basin (see Figure 2.70).

Muskgrass (*Chara* spp.), an important native genus, was the fourth most dominant plant in the 2016 survey. As shown in Figure 2.71, in 2011 the plant was concentrated more in the northwest corner of the east basin, in the westernmost tip of the Lake, and in the bays along the south shore of the Lake. In 2016, the plant was still found in most of the same locations as 2011, but in greater abundance, especially in the east basin of the Lake. A type of macroalgae, muskgrass is another valuable native plant due to its ability to assist in stabilizing bottom sediments and precipitating phosphorus (a nutrient that can cause algal blooms when in excess) out of the water column.

Coontail (*Ceratophyllum demersum*), a common native species, was the fifth most abundant plant in 2016 and the second most abundant plant in 2011. Its distribution in the Lake was similar between 2011 and 2016—more abundant in the east basin of the Lake, but generally found along most of the Lake's nearshore depths (see Figure 2.72). A non-rooted native plant, coontail is widely found throughout most of the lakes in Southeastern Wisconsin, where it is often among the most abundant species within a lake.

CLP was the sixth most abundant plant in the 2016 survey and the fifth most abundant plant in 2011. As shown in Figure 2.73, this species was somewhat more abundant in 2016, mostly in the east basin of the Lake, the westernmost tip of the Lake, and the three main bays along the south shore of the west basin. This species tends to reach maximum abundance early in the growing season.

East and West Basin Comparisons

As is clear from Map 2.7, the bathymetry of the east and west basins of Pewaukee Lake is markedly different. The east basin has gently sloped bottom contours and a maximum depth of about ten feet; the western basin contains much steeper bottom contours and has a maximum depth of about 45 feet. Such contrasting physical conditions in the two basins of the Lake undoubtedly influence the plant growth in these respective areas and produce differences in the two plant communities. Consequently, each basin poses a unique challenge for aquatic plant management in the Lake. Table 2.25 presents data comparing details of the plant growth in the east and west basins (see Map 2.28) as recorded during the point-intercept surveys of 2011 and 2016.

In the 2011 report of the aquatic plant survey conducted by Wisconsin Lutheran College[160], it was noted that:

> "Seven more species were found in the East Basin than in the West Basin [...]Seven species including coontail, curly-leaf pondweed, musk grass, Elodea and flat-stem pondweed occurred more frequently in the West Basin of the Lake. The majority of plants were found at the five-foot depth in the East Basin and the ten-foot depth in the West Basin. Maximum depth of plant colonization found was 17 ft. in the West Basin and 14 ft. in the East Basin. Eurasian watermilfoil was denser in the East Basin, and

[160] *Wisconsin Lutheran College, 2011,* op. cit.

especially concentrated in the northwestern part of the basin. Northern water milfoil, slender naiad, and the density of flat stem was greater in the East Basin than in the West Basin. As expected based on the difference in morphology of the basins, plants were distributed much more evenly across the East Basin than the West Basin."

Data from the 2016 aquatic plant survey indicates that the number of species in the east and west basins in 2016 was about equal, with 19 species in the east basin and 21 species in the west basin; both basins showing an increase in the number of native species since the 2011 survey. The proportions of plant species are remarkably similar between east and west basins, with a general slight increase in abundance in the west basin. There was a greater diversity and abundance of plant species overall compared to 2011. The proportions of plant species are remarkably similar between the east and west basins, with a slight decrease in overall species richness in the west basin. In both basins, the high abundance of EWM may be limiting overall aquatic plant species richness by outcompeting other plants for space, nutrients, and light.

Aquatic Plant Management in Pewaukee Lake

The residents of Pewaukee Lake have worked hard over the years to meet the challenges presented by the aquatic plant growth in the Lake. As knowledge of how lakes actually function as living systems has developed, management strategies have adapted. Today's management strategies attempt to strike the difficult balance between recreational desires and the long-term healthy functioning of the Lake. That the Lake is, in fact, a dynamic system makes finding a lasting strategy something of a moving target; what works today is not guaranteed to work tomorrow.

Even though the Lake has a healthy aquatic plant community, the presence of EWM, CLP, and starry stonewort pose risks to the plant community if not effectively managed. Dense beds of milfoil, along with some nuisance plant growth, impedes Lake access in the east basin. Consequently, the LPSD and the Village of Pewaukee's Public Works Department engage in aquatic plant management activities, including mechanical harvesting. This subsection discusses the history of aquatic plant management in the Lake as well as current and alternative management measures.

Aquatic plant management techniques can be classified into five groups:

- *Physical measures* – including lake bottom coverings
- *Biological measures* – which include the use of organisms, including herbivorous insects
- *Manual measures* – physical removal of plants by individuals using hand-held rakes or by hand
- *Mechanical measures* – including harvesting and removing aquatic plants with a machine known as a harvester or by suction harvesting
- *Chemical measures* – including use of aquatic herbicides to kill nuisance and nonnative aquatic plants.

More information regarding these alternatives is provided below. All control measures are stringently regulated and most require a State of Wisconsin permit. Chemical controls, for example, require a permit and are regulated under Chapter NR 107, "Aquatic Plant Management," of the *Wisconsin Administrative Code*, while placing bottom covers (a physical measure) requires a WDNR permit under Chapter 30 of the *Wisconsin Statutes*. All other aquatic plant management practices are regulated under Chapter NR 109, "Aquatic Plants: Introduction, Manual Removal and Mechanical Control Regulations," of the *Wisconsin Administrative Code*.

The aquatic plant management elements described below consider alternative management measures consistent with the provisions of Chapters NR 103, "Water Quality Standards for Wetlands," NR 107, and NR 109 of the *Wisconsin Administrative Code*. Furthermore, the alternative aquatic plant management measures are consistent with the requirements of Chapter NR 7, "Recreational Boating Facilities Program," and with the public recreational boating access requirements relating to eligibility under the State cost-share grant programs set forth in Chapter NR 1, "Natural Resources Board Policies," of the *Wisconsin Administrative Code*.

Physical Measures

Lake-bottom covers and light screens provide limited control of rooted plants by creating a physical barrier that reduces or eliminates plant-available sunlight. Various materials such as pea gravel or synthetics like polyethylene, polypropylene, fiberglass, and nylon can be used as covers. The longevity, effectiveness, and overall value of some physical measures is questionable. Whatever the case, the WDNR does not permit these kinds of controls. Consequently, lake-bottom covers are not a viable aquatic plant control strategy for Pewaukee Lake.

Biological Measures

Biological controls offer an alternative approach to controlling nuisance or exotic plants. Biological control techniques traditionally use herbivorous insects that feed upon nuisance plants. This approach has been effective in some Southeastern Wisconsin lakes.[161] Milfoil weevils (*Eurhychiopsis lecontei)* do best in waterbodies with balanced panfish populations,[162] and under conditions that include dense EWM beds where the plants reach the surface and are close to shore, natural shoreline areas where leaf litter provides habitat for over-wintering, and little boat traffic. However, Pewaukee Lake has highly developed shore areas, high boat activity, and an abundance of panfish. Additionally, milfoil weevils are not currently commercially available. For these reasons, milfoil weevils are not likely well suited for application at Pewaukee Lake and not a viable option.

Manual Measures

Manual removal of specific types of vegetation provides a highly selective means of controlling nuisance aquatic plant growth, including invasive species such as EWM and CLP. Two common manual removal methods are used: raking and hand-pulling. Each relies on physically removing target plants from the Lake. Removing plant material from the Lake reduces nutrient loads to the lake along with the volume of plant materials that would normally have contributed to the accumulation of lake-bottom sediment. Hence, both of these conditions help to incrementally maintain water depths and improve water quality. Furthermore, removing target plants reduces their reproductive potential.

Raking with specially designed hand tools is particularly useful in shallow nearshore areas. This method allows nonnative plants to be removed and also provides a safe and convenient aquatic plant control method in deeper nearshore waters around piers and docks. Advantages of this method include:

- Tools are relatively inexpensive ($100 to $150 each)
- The method is easy to learn and use
- Results are immediately apparent
- Plant material is immediately removed from a lake (including seeds and plant fragments)

Should Pewaukee Lake residents decide to implement this method of control, an interested party could acquire a number of these specially designed rakes for riparian owners to use on a trial basis. If those rakes satisfy users' needs and objectives, additional property owners could be encouraged to purchase rakes. In areas where other management efforts are not feasible, raking is a viable option to manage overly abundant or undesirable plant growth.

The second manual control method—hand-pulling whole plants (stems, roots, leaves, and seeds) where they occur in isolated stands—provides an alternative means of controlling plants such as EWM and CLP. This method is particularly helpful when attempting to target nonnative plants in the high growth season, when native and nonnative species often coexist and intermix**.** Since the LPSD and the Village already

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[161] *B. Moorman, "A Battle with Purple Loosestrife: A Beginner's Experience with Biological Control,"* LakeLine*, 17(3): 20-37, 1997; see also, C.B. Huffacker, D.L. Dahlsen, D.H. Janzen, and G.G. Kennedy,* Insect Influences in the Regulation of Plant Population and Communities*, pp. 659-696, 1984; and C.B. Huffacker and R.L. Rabb (eds.),* Ecological Entomology*, John Wiley, New York, New York, USA.*

[162] *Panfish such as bluegill and pumpkinseed are predators of herbivorous insects. High populations of panfish lead to excess predation of milfoil weevils.*

conduct plant pick-up services, homeowners would not have to haul these manually pulled plants away (see below). This method is more highly selective than rakes, mechanical removal, and chemical treatments, and if carefully applied, is less damaging to native plant communities. Given these advantages, hand-pulling EWM and CLP is considered a viable option in Pewaukee Lake, where practical. Volunteers or homeowners could employ this method as long as they are properly trained to identify EWM, CLP, or any other invasive plant species of interest. WDNR provides a wealth of guidance materials, including an instructional video describing manual plant removal, to help educate volunteers and homeowners.

Pursuant to Chapter NR 109 of the *Wisconsin Administrative Code*, aquatic plants may be raked or hand pulled without a WDNR permit under the following conditions:

- EWM, CLP, and purple loosestrife (*Lythrum salicaria*) may be removed if the native plant community is not harmed in the process.
- No more than 30 lineal feet of shoreline may be cleared. However, this total must include shoreline lengths occupied by docks, piers, boatlifts, rafts, and areas undergoing other plant control treatment. In general, regulators allow vegetation to be removed up to 100 feet out from the shoreline.
- Plant material that drifts onto the shoreline must be removed.
- The shoreline is not a designated sensitive area.
- Raked, hand-cut, and hand-pulled plant material must be removed from the lake.

Any other manual removal program requires a State permit, unless specifically used to control designated nonnative invasive species such as EWM. In general, State manual aquatic plant removal permits call for all hand-pulled material to be removed from the lake. Mechanical equipment (e.g., dragging equipment such as a rake behind a motorized boat or the use of weed rollers) is not authorized for use in Wisconsin at this time.

Mechanical Measures

Two methods of mechanical harvesting are currently permitted and employed in Wisconsin. These methods include use of an aquatic plant harvester (mechanical harvesting) and suction harvesting. More details about each are presented below.

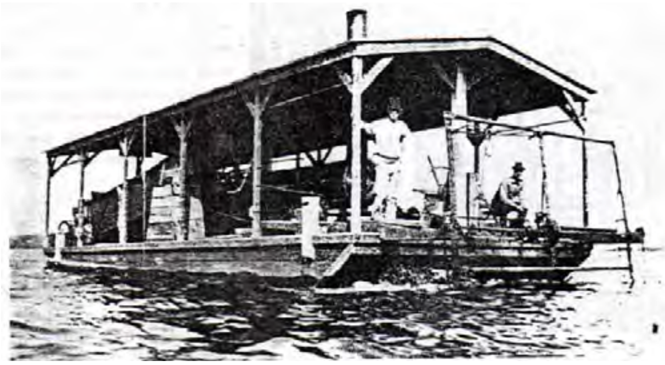
History of Harvesting in Pewaukee Lake

The first written records of mechanical efforts to control aquatic plants growth on Pewaukee Lake date back to 1888, when lake plants were cut to provide passageway for the mail boat operating on the Lake at that time. Ice companies, in order to maintain the clarity and purity of winter ice, utilized steam-powered cutters on the Lake as early as 1898 (see Figure 2.74). The LPSD began the cutting of aquatic plants in 1944. In 1945, the State Board of Health conducted investigations into alleged problems, such as cut plants floating into navigation lanes in the Lake. As a result, the State Board of Health began requiring cut plants to be removed from the Lake. In response, in 1947, Matt Grinwold designed and built the first lake *harvester* (a floating machine that cut and removed the cut plants from the Lake) and in 1947, the LPSD began harvesting aquatic plants in Pewaukee Lake along with a chemical treatment program (as described later in this section).

In 1947, a combination of mechanical and chemical methods were used and continued until the mid-1960s at which time the use of chemicals was greatly diminished. Since 1984, the LPSD has relied solely on a comprehensive program of plant harvesting to control nuisance levels of aquatic plants in Pewaukee Lake. Detailed records have been kept since 1988 regarding the amounts of plant material removed and the areas harvested. In 1990, the Pewaukee Lake Citizens Advisory Committee was formed and developed a report that contained a number of recommendations, including the harvesting of plants rather than using chemical treatments.

The aquatic plant removal program that is in place today focuses on removal of nuisance levels of plants, especially EWM, with the long-term goal in mind of improving the recreational opportunities for lake users and improving habitat for native aquatic plants and other life. Harvesting shoreline areas helps make it possible for people to engage in nearshore activities such as swimming and fishing from their piers and shorelines. Harvesting channels not only provides access to the main body of the Lake for boaters, but also cruising lanes for predator fish to forage. Removing aquatic plants physically from a lake reduces the amount of potential nutrients available for future plant growth (see Sections 2.6, "Pollutant Loads" and 3.3, "Water Quality"). Given appropriate conditions, harvesting of aquatic plants is generally believed to be an environmentally sound method of managing nuisance levels of aquatic plants.

Figure 2.74
Early Weed Cutter on Pewaukee Lake: 1898



Weeds in Pewaukee Lake have always been a problem. Coping with them in 1898 was this engine-powered weed cutter which helped to reduce them temporarily.

Source: Lake Pewaukee Sanitary District and SEWRPC

Mechanical Harvesting

Modern harvesters are sophisticated machines for cutting and gathering aquatic plant material. Harvesters consist of an adjustable depth cutting apparatus that can remove plants from the surface down to about five feet below the water surface. The cut plants are then gathered with a collection system (e.g., a conveyor and a basket) that picks up most cut plant material. Mechanical harvesting can be a practical and efficient means of controlling nuisance plant growth as well as reducing in-lake nutrient recycling, sedimentation, and target plant reproductive potential. In other words, harvesting removes plant biomass, which would otherwise decompose and release nutrients, sediment, and seeds or other reproductive structures (e.g., turions, bulbils, plant fragments) into a lake. Mechanical harvesting is particularly effective for large-scale projects.

An advantage of mechanical harvesting is that the harvester, when properly operated, "mows" aquatic plants and, therefore, typically leaves enough living plant material in the lake to provide shelter for aquatic wildlife and to stabilize lake-bottom sediment. None of the other aquatic plant management methods leave living plant material in place after treatment. Aquatic plant harvesting also has been shown to facilitate growth of native aquatic plants by allowing light to penetrate to the lakebed and stimulate growth of suppressed native plants. This is particularly effective when controlling invasive plant species that commonly grow very early in the season when native plants have not yet emerged or appreciably grown. Finally, harvesting does not kill native plants in the way that other control methods do. Instead, this method simply trims them back.

A disadvantage of mechanical harvesting is that the harvesting process may fragment plants and thereby unintentionally facilitate the spread of EWM, which utilizes fragmentation as a means of propagation. Recent small-scale greenhouse trials found that EWM fragments remained buoyant from about two to four days in summer, with greater buoyancy in fall (i.e., average of up to 5.4 days).[163] EWM are particularly successful in areas where plant roots have been removed. This further emphasizes the need to prevent harvesting that removes native plant roots. Harvesting may also agitate bottom sediments in shallow areas, thereby increasing turbidity and resulting in deleterious effects such as smothering of fish breeding habitat and nesting sites. Agitating bottom sediment also increases the risk of nonnative species recolonization, as invasive species tend to thrive on disrupted and/or bare lake bottom. To this end, most WDNR-issued permits do not allow deep-cut harvesting in water less than three feet deep,[164] which limits the utility of this alternative in many littoral areas. Nevertheless, if employed correctly and carefully under suitable conditions, harvesting can benefit navigation lane maintenance and can ultimately reduce regrowth of nuisance plants while maintaining, or even enhancing, native plant communities.

[163] *J.D. Wood and M.D. Netherland, "How Long do Shoot Fragments of Hydrilla (*Hydrilla verticillata*) and Eurasian Watermilfoil (*Myriophyllum spicatum*) Remain Buoyant*?," Journal of Aquatic Plant Management*, 55: 76-82, 2017.*

[164] *Deep-cut harvesting is harvesting to a distance of only one foot from the lake bottom. This is not allowed in shallow areas, because it is challenging to properly ensure that the harvester does not hit the lake bottom in these areas.*

Currently, the LPSD operates three harvesters (Figure 2.75) that are used for cutting from the ends of the piers to about two hundred feet from shore. These harvesters cut to a depth of five feet and cut a nine-foot wide path. In 2014, two new harvesters were added; one of the older machines was converted into a "shallow water harvester" and the other reserved as a back-up.

Some cut plant fragments can escape the harvester's collection system. This negative side effect is fairly common. To compensate for this, most harvesting programs include a plant pickup program—the LPSD and the Village of Pewaukee have such a collection system. The plant pickup program gathers significant accumulations of floating plant debris as well as arranges regular pickup from the docks of lakefront property owners who actively rake plant debris into piles on their docks and shorelines.[165] The LPSD operates three transport units (Figure 2.76) for picking up plant material from on-lake harvesters and transporting them to shore conveyers; several shore conveyers for loading plant material from transports into a dump truck; and three shore units (Figure 2.77) to pick up floating fragments around piers and along shorelines. The shore units are unique to Pewaukee Lake and were designed by LPSD staff; they have no cutter bars and are specially designed to operate in small areas to pick up floating debris. Plant pickup programs, when applied systematically, can reduce plant propagation from plant fragments and can help alleviate the negative aesthetic consequences of plant debris accumulating on shorelines. However, it is important to note that plant fragments from normal boating activity on Pewaukee Lake (particularly during weekends) create far more plant fragments than generated from the harvesting operations, with significant accumulations occurring in the east basin due to prevailing wind conditions.[166] Therefore, this plant pickup program is essential for the protection of the Lake—even in areas where harvesting has not recently occurred—and plant pickup efforts should be initiated early in the week (i.e., within two days after a weekend) before floating plant debris begins to sink to the bottom of the lake.

Suction Harvesting (DASH)

An alternative aquatic plant harvesting method has emerged called Diver Assisted Suction Harvesting (DASH). First permitted in 2014, DASH (also known as suction harvesting) is a mechanical process where divers identify and pull select aquatic plants by their roots from the lakebed and then insert the entire plant into a suction hose that transports the plant to the lake surface for collection and disposal. The process is essentially a more efficient and wide-ranging method for hand-pulling aquatic plants. Such labor-intensive work by skilled professional divers is, at present, a costly undertaking and long-term monitoring will need to evaluate the efficacy of the technique. Nevertheless, many apparent advantages are associated with this method, including: 1) lower potential to release plant fragments when compared to mechanical harvesting, raking, and hand-pulling, thereby reducing spread and regrowth of invasive plants like EWM; 2) increased selectivity in terms of plant removal when compared to mechanical and hand harvesting, thereby reducing the loss of native plants; and 3) lower potential for disturbing fish habitat.

Both mechanical harvesting and suction harvesting are regulated by WDNR and require a permit.[167] Non-compliance with permit requirements is an enforceable violation of Wisconsin law and may lead to fines and/or complete permit revocation. The information and recommendations provided in this report will help frame permit requirements. Permits can cover up to a five-year period.[168] At the end of that period, it would be necessary to develop a new plant management plan. The updated plan must consider the results of a new aquatic plant survey and should evaluate the success, failure, and effects of earlier plant management activities that occurred in the lake.[169] These plans and plan execution are overseen by the WDNR AIS coordinator for the region.[170]

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[165] *The plant pick-up program by the LPSD and the Village of Pewaukee collects plant material generated by landowner raking and/or hand pulling along their own shoreline.*

[166] *Personal Communication, Thomas H. Koepp, P.E. LEED AP, Lake Pewaukee Sanitary District, Manager/Superintendent.*

[167] *Permits for mechanical harvesting can be dependent on the type of harvesters utilized. The Lake Pewaukee Sanitary District uses an Aquarius HS-620 while the Village of Pewaukee Public Works Department uses an Aquarius HM-420S and an Aquarius HM-220.*

[168] *Five-year permits allow a consistent aquatic plant management plan to be implemented over a significant length of time. This process allows the selected aquatic plant management measures to be evaluated at the end of the permit cycle.*

[169] *Aquatic plant harvesters must document harvesting activities as one of the permit requirements.*

[170] *Information on the current AIS coordinator is found on the WDNR website.*

Chemical Measures

Aquatic herbicides sodium arsenite, diquat, endothall, and 2,4-D have all been applied to Pewaukee Lake to control aquatic macrophyte growth. Diquat and endothall (Aquathol) are contact herbicides and kill plant parts exposed to the active ingredient. Diquat use is restricted to the control of duckweed (*Lemna* spp.), milfoil (*Myriophyllum* spp.), and waterweed (*Elodea* spp.). However, this herbicide is non-selective and will kill many other aquatic plants, such as pondweeds (*Potamogeton* spp.), bladderwort (*Utricularia* sp.), and naiads (*Najas* spp.). Endothall primarily kills pondweeds, but does not control such nuisance species as EWM. The herbicide 2,4-D is a systemic herbicide that is absorbed by the leaves and translocated to other parts of the plant; it is more selective than the other herbicides listed above and is generally used to control EWM. However, it will also kill species such as water lilies (*Nymphaea* sp. and *Nuphar* sp.).

In 1944, the LPSD first contacted the Wisconsin State Health Department regarding the possible use of chemical pesticides in Pewaukee Lake. In 1945, chemical treatments in Pewaukee Lake by the LPSD began with the use of sodium arsenite and copper compounds. Sodium arsenite would be eventually discontinued in 1963, two years before the WDNR banned the use of sodium arsenite statewide in 1965, and four years before the Wisconsin legislature banned the use of sodium arsenite statewide in 1969. Over the 17 years that sodium arsenite was used in Pewaukee Lake, the Lake received over 165 tons of the chemical—the most of any Wisconsin lake.

The LPSD first used the chemical 2,4-D in 1968. In 1985, all chemical herbicide treatments for aquatic plants in Pewaukee Lake by the LPSD were discontinued, although some private chemical treatments of aquatic plants continued in the Lake until 1989. Since 1985, there have been numerous news articles in local newspapers containing both positive and negative perspectives toward the use of chemical herbicides in Pewaukee Lake. Table 2.26 presents a list of chemical treatments used to manage aquatic plants in Pewaukee Lake from 1950 to the time the use of chemicals in the Lake was discontinued in 1989.

In addition to the chemical herbicides used to control large aquatic plants, algaecides have also been applied to Pewaukee Lake. Copper

Figure 2.75
Lake Pewaukee Sanitary District Aquatic Plant Harvester

Source: Lake Pewaukee Sanitary District and SEWRPC

Figure 2.76
Lake Pewaukee Sanitary District Aquatic Plant Transport Barge

Source: Lake Pewaukee Sanitary District and SEWRPC

Figure 2.77
Lake Pewaukee Sanitary District Small-Scale Aquatic Plant Harvester

Source: Lake Pewaukee Sanitary District and SEWRPC

Table 2.26
Aquatic Plant Chemical Control Agents Applied to Pewaukee Lake: 1950-2018

		Algae Control			Macrophyte Control				
Year	Total Acres Treated	Copper Sulfate (pounds)	Blue Vitriol (pounds)	Cultrine or Cutrine-Plus	Sodium Arsenite (pounds)	2, 4-D (gallons)	Diquat (gallons)	Endothal (gallons)	Aquathol (gallons)
1950-1969	882.9	66,105.0	16,680.0	2,525.0 gallons	217,040.0	--	--	--	--
1960	375.8	--	6,600.0	1,500.0 pounds	19,680.0	--	--	--	--
1961	364.4	--	6,750.0	--	21,600.0	--	--	--	--
1962	257.0	7,600.0	--	322.6 pounds	5,124.0	53.0	--	--	--
1963	361.0	6,215.0	--	4,665.0 pounds	23,334.0	--	--	--	--
1964	413.0	5,450.0	--	--	21,792.0	--	--	--	--
1965	1,282.6	6,150.0	--	--	17,982.0	--	--	--	--
1966	240.4	2,464.0	--	--	2,280.0	--	48.4	--	52.4
1967	104.0	200.0	--	--	5,400.0	15.0	--	--	11.0
1968	404.8	1,250.0	--	--	--	465.0	--	--	700.0
1969	127.0	200.0	--	--	--	90.0	--	--	100.0
1970[a]	129.5	1,805.0	--	--	--	15.0	--	5.0	240.0
1971	56.6	240.0	--	--	--	45.0	5.0	--	--
1972	59.3	140.0	--	--	--	--	10.0	--	25.0
1973	168.4	--	--	--	--	578.0	--	--	135.0
1974	32.1	--	--	--	--	175.0	--	--	--
1975	25.8	--	--	--	--	124.0	--	--	--
1976	2.0	--	--	--	--	8.0 5.0 pounds	--	--	--
1977	56.9	--	--	--	--	227.2	--	--	--
1978	--	--	--	--	--	--	--	--	--
1979	--	--	--	--	--	--	--	--	--
1980	33.7	--	--	--	--	163.0	--	--	--
1981	49.7	--	--	--	--	303.0	--	--	--
1982	1.4	--	--	--	--	9.0	--	--	--
1983	--	--	--	--	--	--	--	--	--
1984	16.2	--	--	--	--	45.0	--	--	--
1985	37.8	--	--	--	--	70.0	--	--	--
1986	2.8	10.0	--	5.0 gallons	--	5.0	--	--	--
1987	0.4	--	--	2.0 gallons[b]	--	--	--	--	--
1988	0.5	--	--	--	--	10.0 pounds[b]	--	--	30.0 pounds[b]
1989	0.1	--	--	--	--	30.0 pounds[b]	--	--	--
1990-2000	--	--	--	--	--	--	--	--	--
Post 2000	--	--	--	--	--	--	--	--	--
Total	--	97,829.0	30,030.0	6,492.6 pounds, 2,532.0 gallons	334,232	2,390.2 gallons, 45.0 pounds	63.4	5.0	1,163.4 gallons, 30.0 pounds

[a] *120 pounds of lime were applied in 1970.*

[b] *Private chemical treatments of aquatic plants.*

Source: Wisconsin Department of Natural Resources sulfate (Cutrine Plus) has been applied to Pewaukee Lake, on occasion. Copper, the active ingredient in many algaecides including Cutrine Plus, may accumulate in the bottom sediments. Excessive levels of copper may be toxic to fish and benthic organisms, but, generally, have not been found to be harmful to humans.[171]

Today, use of chemical herbicides in aquatic environments is stringently regulated and requires a WDNR permit and WDNR staff oversight during application. Chemical herbicide treatment is a short-term method to control heavy growths of nuisance aquatic plants. Chemicals are applied to growing plants in either liquid or granular form. The advantages of using chemical herbicides to control aquatic plant growth include relatively low cost as well as the ease, speed, and convenience of application. Disadvantages associated with chemical control include:

1. **Unknown and/or conflicting evidence about long-term effects of chemicals on fish, fish food sources, and humans**—Chemicals approved by the U.S. Environmental Protection Agency as aquatic plant herbicides have been studied to rule out short-term (acute) effects on humans and wildlife. Additionally, some studies also examine long-term (chronic) effects of the chemical on animals (e.g., the effects of being exposed to these herbicides for many years). However, it is often impossible to conclusively state that no long-term effects exist due to the animal testing protocol, time constraints, and other issues. Additionally, long-term studies have not addressed all potentially affected species.[172] For example, conflicting studies/opinions exist regarding the role of the chemical 2,4-D as a human carcinogen.[173] Some lake property owners judge the risk of using chemicals as being too great, despite legality of use. Consequently, the concerns of lakefront owners should be considered whenever chemical treatments are proposed. Additionally, if chemicals are used, they should be applied as early in the season as practical and possible. This helps assure that the applied chemical decomposes before swimmers and other lake users begin to actively use the lake.[174]

2. **An increased risk of algal blooms**—Water borne nutrients promote growth of aquatic plants and algae. As explained in Chapter 2, if rooted aquatic plants are not the primary user of water-borne nutrients, algae tends to be more abundant. Action should be taken to avoid both loss of native plants and excessive chemical use, which can compromise the health of a lake's native plant community and reduce the ability of rooted aquatic plants to compete with algae for limiting nutrients. Balance must be maintained between rooted aquatic plants and algae—when the population of one declines, the other may increase in abundance to nuisance levels. In addition to decreasing competition for water-borne nutrients, the death and decomposition of aquatic plants can increase nutrient levels in lake water. Higher nutrient concentrations fuel aquatic plant and algal growth.

3. **A potential increase in organic sediments, and associated anoxic conditions, can stress aquatic life and cause fish kills**—When chemicals are used to control large mats of aquatic plants, the dead plant material generally settles to the bottom of a lake and subsequently decomposes. This process leads to an accumulation of organic-rich sediment and can deplete oxygen from the water column as bacteria decompose plant remains. Stratified lakes, such as Pewaukee Lake, are particularly vulnerable to oxygen depletion, especially in summer in the deeper areas of the Lake. Excessive oxygen loss can inhibit a lake's ability to support certain fish and can trigger chemical processes that release phosphorus from bottom sediment, further increasing lake nutrient levels. These concerns emphasize the need to limit chemical control to early spring, when EWM has not yet formed dense mats.

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[171] *J.A. Thornton and W. Rast, "The Use of Copper and Copper Compounds as Algicides," in H. Wayne Richardson,* Handbook of Copper Compounds and Applications*, Marcel Dekker, New York, 1997, pp. 123-142.*

[172] *U.S. Environmental Protection Agency, EPA-738-F-05-002, 2,4-D* RED Facts*, June 2005.*

[173] *M.A. Ibrahim, et al., "Weight of the Evidence on the Human Carcinogenicity of 2,4-D,"* Environmental Health Perspectives*, 96: 213-222, 1991.*

[174] *Though the manufacturers indicate that swimming in 2,4-D-treated lakes is allowable after 24 hours, it is possible that some swimmers may want more time following application to ensure that they receive less exposure to the chemical. Consequently, allowing for extra time is recommended, so that residents and lake users can feel comfortable that they are not being unduly exposed.*

4. **Adverse effects on desirable aquatic organisms due to loss of native species**—Native plants, such as pondweeds, provide food and spawning habitat for fish and other wildlife. A robust and diverse native plant community is a foundational element to the overall conditions a lake needs to provide and host desirable gamefish populations since fish, and the organisms fish eat, require aquatic plants for food, shelter, and oxygen. If native plants are unintentionally lost due to insensitive herbicide application, fish and wildlife populations often suffer. Consequently, if chemical herbicides are applied to the Lake, these chemicals must preferentially target EWM or CLP. Such chemicals should be applied in early spring when native plants have not yet emerged.

5. **A need for repeated treatments due to re-emergence of target plants from existing seed banks and/or plant fragments**—As mentioned previously, chemical treatment is not a one-time solution. The fact that the treated plants such as EWM are not actively removed from the Lake increases the potential for viable seeds/fragments to remain after treatment, thereby allowing for resurgence of the target species later in the season and/or the next year. For example, underwater monitoring of auxin herbicide (Triclopyr or 2,4-D) treated EWM and hybrid EWM infested areas within Gun Lake, Michigan, revealed recovery and survival of severely injured plants in the forms of shoot formation, root crowns, and rooting of settled vegetative fragments within four weeks after treatment.[175] Additionally, leaving large areas void of plants (both native and invasive) creates a disturbed area without an established plant community. EWM in disturbed areas. In summary, applying chemical herbicides to large areas can provide opportunities for reinfestation, which in turn necessitates repeated herbicide applications.

6. **Hybrid water milfoil's resistance to chemical treatments**—Hybrid water milfoil[176] complicates management, since research suggests that certain strains may have higher tolerance to commonly utilized aquatic herbicides such as 2,4-D and Endothall and those differences may be heritable among different genotypes.[177] Consequently, further research on the efficacy and impacts of herbicides on hybrid water milfoil needs to be conducted to better understand the appropriate dosing applied within lakes, which will require increased time and cost.

7. **Effectiveness of small-scale chemical treatments**—Small-scale treatments of 2,4-D on EWM have proven to have highly variable results. A study completed in 2015 concluded that less than 50 percent of the 98 treatment areas were effective, or had more than a 50 percent reduction in EWM.[178] In order for a treatment to be effective it must meet a certain exposure time while maintaining a target concentration; however, due to the dissipation of chemicals (e.g., wind and wave action) target concentrations are often not met. Therefore, when deciding to implement small-scale chemical treatments the variability in results together with the cost of treatment need to be considered.

Aquatic Plant Summary

Aquatic plants—especially native species—are a necessary part of the healthy functioning of a lake; they provide a number of benefits to other organisms that live in the lake as well as, even if indirectly, benefitting human activities. However, when levels of plants become such that recreational and other human activities that take place in or on the lake are impaired, the management of aquatic plants becomes necessary.

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[175] *R.A. Thum, S. Parks, J.N. McNair, P. Tyning, P. Hausler, L. Chadderton, A. Tucker, and A. Monfils, "Survival and vegetative regrowth of Eurasian and hybrid watermilfoil following operational treatment with auxinic herbicides in Gun Lake, Michigan",* Journal of Aquatic Plant Management*, 55: 103-107, 2017.*

[176] *In recent years, it has become evident that EWM and native (or northern) water milfoil have begun to hybridize; the resultant hybrid strains – and they are many – cannot be reliably identified based on physical appearance alone, thus making identification and selection of the appropriate control method problematic.*

[177] *L.L. Taylor, J.N. McNair, P. Guastello, J. Pashnick, and R.A. Thum, "Heritable variation for vegetative growth rate in tem distinct genotypes of hybrid watermilfoil",* Journal of Aquatic Plant Management*, 55: 51-57, 2017; E.A. LaRue, et al., "Hybrid Watermilfoil Lineages are More Invasive and Less Sensitive to a Commonly Used Herbicide than Their Exotic Parent (Eurasian Watermilfoil)",* Evolutionary Applications*, 6: 462-471, 2013; and, L.M. Glomski, M.D. Netherland, "Response of Eurasian and Hybrid Watermilfoil to Low Use Rates and Extended Exposures of 2,4-D and Triclopyr",* Journal of Aquatic Plant Management*, 48: 12-14, 2010.*

[178] *M. Nault, S. Knight, S.V. Egeren, et al., "Control of Invasive Aquatic Plants on a Small Scale,"* LakeLine, 35(1): *35-39, 2015.*

Pewaukee Lake has a long history of human activities designed to manage perceived nuisance levels of aquatic plants in the Lake, which has been further complicated by the dominance of nonnative, invasive species. Since 1967, EWM has consistently been one of the most dominant species in the aquatic plant community of the Lake. Both chemical and mechanical methods have been used to manage nuisance aquatic plant levels, with a more recent shift toward utilizing solely mechanical means.

This shift in plant management has been accompanied by increases in species richness, growth of disturbance-sensitive species, and other signs indicating a healthier plant community. Plant species richness in the Lake is at the highest it has been in the past 25 years. EWM has been declining in recent years, with a dramatic increase in native plants including native milfoil, coontail, muskgrass, waterweed, flat-stemmed pondweed and water celery. In general, Pewaukee Lake supports what appears to be an increasingly healthy and diverse aquatic macrophyte community. Management recommendations for maintaining this community are provided in Section 3.5 "Aquatic Plants."

2.8 STREAM HABITAT

This section provides detail on the ecosystem services that streams provide, environmental factors that influence streams including human manipulation, and the current conditions of stream habitat in the Pewaukee Lake watershed.

Stream Function, Form, and Processes

Streams actively transport water *and* sediment. Streams continually erode, transport, and deposit sediment causing stream channels to change over time. When the amount of sediment load delivered to a stream is equal to what is being transported downstream, and when stream widths, depths, and length remain consistent over time, it is common to refer to such a stream as being in a state of "dynamic equilibrium." In other words, the stream retains its overall physical dimensions but those physical features may shift or migrate over time. It is not uncommon for low-gradient streams in Southeastern Wisconsin to migrate more than one foot within a single year.

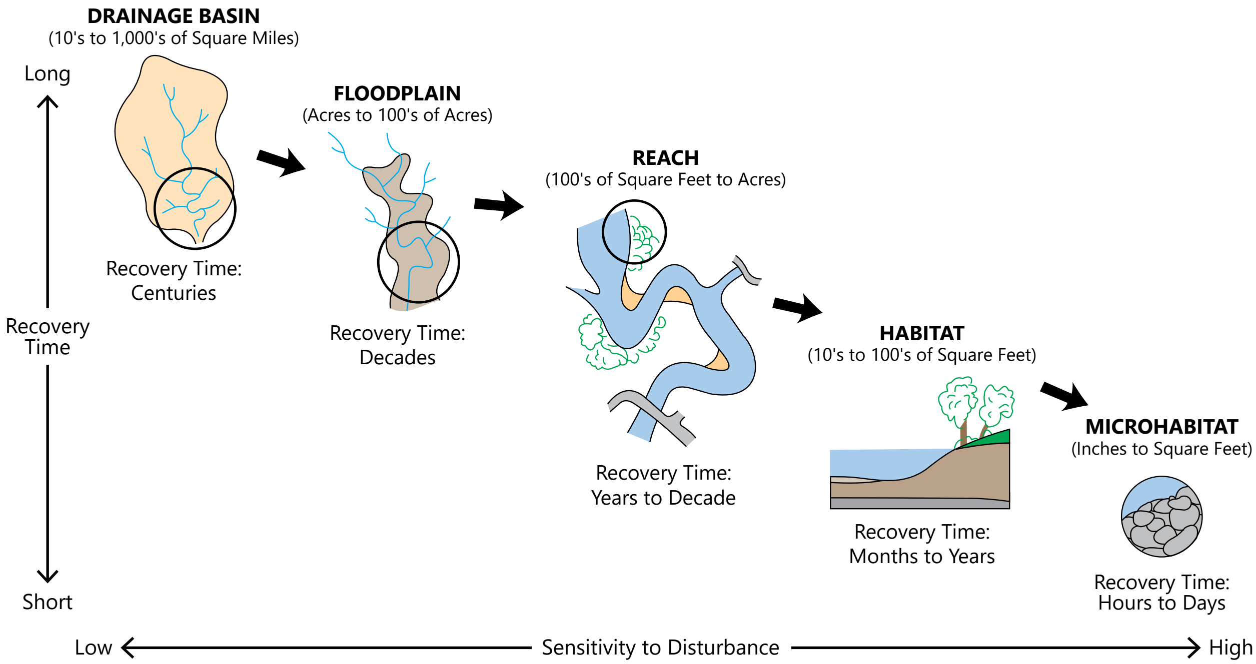
Stream channel characteristics, such as slope, length, and sinuosity are the product of many disparate factors including geology (e.g., soil gradation and permeability, topography); flora, fauna, and their interplay; weather; and human manipulation (e.g., ditching, impoundments, changed hydrology). Many healthy streams naturally meander and migrate across a landscape over time. Sinuosity is a measure of how much a stream meanders and is defined as the ratio of channel length between two points on a channel to the straight-line distance between the same two points. Sections of streams that have been artificially straightened typically have low sinuosity values (a value closer to one).

To better understand stream systems and what influences their conditions, it is important to understand the effects of both spatial and temporal scales. Streams can theoretically be subdivided into a spectrum of habitat disturbance sensitivity and recovery time (see Figure 2.78).[179] Microhabitats, such as a small patch of gravel or the cover provided by a particular tree, are most susceptible to disturbance, while entire river systems and watersheds are least susceptible. Furthermore, events that affect smaller-scale habitat characteristics may not affect larger-scale system characteristics, whereas large disturbances can directly influence both large- and smaller-scale features of streams. For example, sediment deposition may occur simultaneously with scour at another nearby site, but the overall characteristics of the reach do not significantly change. In contrast, a large-scale disturbance, such as results from an extremely large flood event, is initiated at the segment level and reflected at all lower hierarchal levels (reach, habitat, and microhabitat). Similarly, on a temporal scale, siltation of microhabitats may disturb the biotic community over the short term. However, if the disturbance is of limited scope and intensity, the system may recover quickly to pre-disturbance levels.[180]

[179] *C.A. Frissell, W.J. Liss, C.E. Warren, and M.D. Hurley, "A Hierarchical Framework for Stream Classification: Viewing Streams in a Watershed Context,"* Journal of Environmental Management*, 10: 199-214, 1986.*

[180] *G.J. Niemi, P. DeVore, N. Detenbeck, et al., "An Overview of Case Studies on Recovery of Aquatic Systems From Disturbance,"* Journal of Environmental Management*, 14: 571-587, 1990.*

Figure 2.78
Relation Between Recovery Time and Sensitivity to Disturbance for Different Hierarchical Spatial Scales Associated with Stream Systems



Source: Adapted from C.A. Frissell, W.J. Liss, C.E. Warren, and M.D. Hurley, "A Hierarchical Framework for Stream Habitat Classification: Viewing Streams in a Watershed Context," Environmental Management 10: 199-214, *1986, and SEWRPC*

The two most important stream system fundamentals are listed below.

- A fluvial system is an integrated series of physical gradients. Downstream areas are longitudinally linked and dependent upon the upstream segments.
- Streams are intimately connected to their adjacent terrestrial setting. Land-stream interaction is crucial to healthy stream ecosystem processes and this connectivity does not diminish in importance with stream size. In this regard, human land use and manipulation significantly influence stream channel condition and associated biological integrity.[181]

Physical Stream Habitat

Physical stream habitat includes streambed substrates, water temperature, and large woody structure from streamside vegetation. Streambed substrates include bedrock, boulders, cobbles, gravel, silt, clay, and a wide range of organic materials ranging from muck to submerged trees. Streambed sediment composition varies on account of stream gradient, channel form, vegetation type and abundance, hydrology, and local geology. Streambed substrates provide living space for many stream organisms. Stable substrates, such as cobbles and boulders, shelter organisms from the stream's current and protect organisms from being washed downstream during high flows. Streams with abundant cobbles and boulders commonly support greater biological diversity than do streams dominated by less stable substrates (e.g., muck, sand and silt).

Water temperature directly influences aquatic organism metabolism, respiration, feeding rate, growth, and reproduction. Most aquatic species have a unique and specific optimal temperature range for growth and

[181] *L. Wang, J. Lyons, P. Kanehl, and R. Gatti., "Influences of Watershed Land Use on Habitat Quality and Biotic Integrity in Wisconsin Streams,"* Fisheries*, 22(6): 6-12, 1997; J.S. Stewart, L. Wang, J. Lyons, et al., "Influences of Watershed, Riparian-Corridor, and Reach-Scale Characteristics on Aquatic Biota in Agricultural Watersheds,"* Journal of the American Water Resources Association*, 37(6): 1475-1487, 2001; F.A. Fitzpatrick, B.C. Scudder, B.N. Lenz, and D.J. Sullivan, "Effects of Multi-Scale Environmental Characteristics on Agricultural Stream Biota in Eastern Wisconsin,"* Journal of the American Water Resources Association*, 37(6): 1489-1507, 2001.*

reproduction. Therefore, the spatial and temporal distributions of aquatic organisms are largely dictated by temperature differences created by regional differences in climate and elevation along with more local effects from riparian (stream corridor) shading and groundwater influence. Water temperature also influences many chemical processes, such as the solubility of oxygen in water. Cold water holds more oxygen than warm water.

The riparian zone is land directly adjacent to and abutting streams. Plant and animal communities in riparian zones commonly rely on moisture and nutrients delivered by streams. The size and character of riparian zones have a major influence on the amount of shelter and food available to aquatic organisms and the amount of sunlight reaching the stream through the tree canopy, which influences water temperature and the amount of energy available for photosynthesis. Riparian zones also influence the amount and quality of runoff reaching streams.

Human Manipulation

Scientists have found that stream health suffers throughout the nation when streams are located in both agricultural and urban areas.[182] Of the three aquatic biological communities (algae, macroinvertebrates, and fish), at least one was altered at least 80 percent of the time. Nevertheless, almost 20 percent of streams found in agricultural and urban areas were relatively healthy. Ecological health of a stream system was found to be directly related to the degree of human-induced change to streamflow characteristics and water quality (nutrients, sediments, and other human-sourced pollutants). Major findings and important implications of this study include:

- The presence of healthy streams in watersheds with substantial human influence suggests that it is possible to maintain and restore healthy stream ecosystems in landscapes occupied and modified by humans.

- Water quality is not independent of water quantity. Flow volumes are a fundamental part of stream health. Because the flow regimen is modified in so many streams and rivers, many water-quantity based management and protection strategies commonly can enhance stream health.

- Efforts to understand the causes of reduced stream health should consider the possible effect of nutrients, sediment, chloride, heavy metals, organic pollutants, and pesticides, particularly in agricultural and urbanized settings.

<u>Impacts of Stream Channelization</u>

Straightening meandering stream channels (sometimes labelled ditching or channelization) was once a widely practiced technique thought to speed runoff. Many streams (especially smaller first and second order streams) draining intensely farmed or highly developed areas were ditched. The U.S. Department of Agriculture National Resources Conservation Service (NRCS) (formerly Soil Conservation Service) cost-shared such activities until the early 1970s in Southeastern Wisconsin.[183] The objectives of channelization were:

- To reduce local flooding by conveying stormwater runoff more rapidly downstream

- To drain low-lying land thereby increasing the value of land to agriculture and development

- To relocate streams to allow more efficient farming in rectangular fields and simplify site drainage in developing areas

Channelization shortens overall channel length between two points. As such, the distance water travels to descend a set amount is decreased, and the resultant channel slope increases and water velocity increases. Streams with higher slopes and faster moving water have a greater ability to move sediment, both in terms of sediment volume and particle size. Increasing stream slope commonly destabilizes natural bed substrate and channel forms that have equilibrated to a lower slope channel. Channelized stream segments

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[182] *D.M. Carlisle, M.R. Meador, T.M. Short, et al.,* The Quality of Our Nation's Waters—Ecological Health in the Nation's Streams, 1993-2005, *U.S. Geological Survey Circular 1391, 2013, http:// pubs.usgs.gov/circ/1391/.*

[183] *Personal Communication, Gene Nimmer, NRCS engineer.*

commonly erode their beds and/or banks, and, through sediment erosion or deposition, can propagate instability in adjacent unaltered stream segments.

In many cases, drain tiles and supplemental drainage ditches were installed to complement and facilitate water movement off fields and reduce the incidence of shallow saturated soil. To facilitate drainage, many channelized stream reaches were commonly dredged much deeper and wider than the pre-existing stream channel provide a discharge point for drainage ditches and tiles. Such modification tends to produce slow moving, essentially, stagnant waterways during low flow. Many channelized reaches became long straight pools or areas of sediment deposition and accumulation, as velocities within these reaches are too low to carry suspended materials. This is why many channelized reaches frequently contain uniformly deep, fine-grained, organic-rich sediments as their predominant substrate type.

Channelization often leads to a long series of unintentional negative changes in stream form and function. Channelized streams experience instream hydraulic changes that compromise the stream's ability to access floodplain areas during high runoff periods. This break in stream and floodplain connectivity has numerous detrimental impacts, including:

- Reduces the stream's and riparian community's ability to filter sediment and pollutant from floodwater
- Reduces floodwater storage, increasing downstream flood volumes and elevations
- Increases the erosive and sediment carrying capacity of water within the ditched segment
- Destabilizes stream channels at the point of modification as well as upstream and downstream of the modified reach

Channelization often destroys shade-providing riparian vegetation, increasing summer water temperatures. Furthermore, channelization can alter instream sedimentation rates and paths of sediment erosion, transport, and deposition. For example, the most heavily channelized sections of the streams assessed in this study contained some of the greatest amounts of unconsolidated sediment deposition, particularly Meadowbrook Creek.

In addition to the loss of stream length, channel straightening significantly reduces the number of pool and riffle features within a stream system. Pool-riffle sequences are often found in meandering streams, where pools occur at meander bends and riffles at crossover stretches.[184] Pools and riffles are important refuge, reproduction, feeding, and nursery areas for a wide variety of aquatic life, and encourage hyporheic flow,[185] which benefits in-stream habitat and overall water quality. Therefore, channelization, as traditionally accomplished without mitigating features, generally creates an unravelling effect on stream form, can exacerbate flooding and water quality problems in downstream reaches, and diminishes suitability of instream and riparian habitat for fish and wildlife.

<u>Channelization of Lake Tributaries</u>

Comparing aerial photographs from 1941 to 2010 reveals stream-mile loss in Coco Creek, Meadowbrook Creek, and Zion Creek (see Map 2.30, including insets 1 through 4). The actual distance of stream channel lost from the pre-settlement period is likely significantly greater, but because detailed maps or aerial photographs are not available before 1941, the original stream channel location can only be estimated by unnaturally straight stream form. After 1941, stretches of Coco Creek were channelized to facilitate construction of STH 16, as well as for the expansion of local roadways (see "Inset 1" and "Inset 2" to Map 2.30). A series of inline ponds on Meadowbrook Creek were constructed sometime between 1963 and 1970. These ponds remain today.

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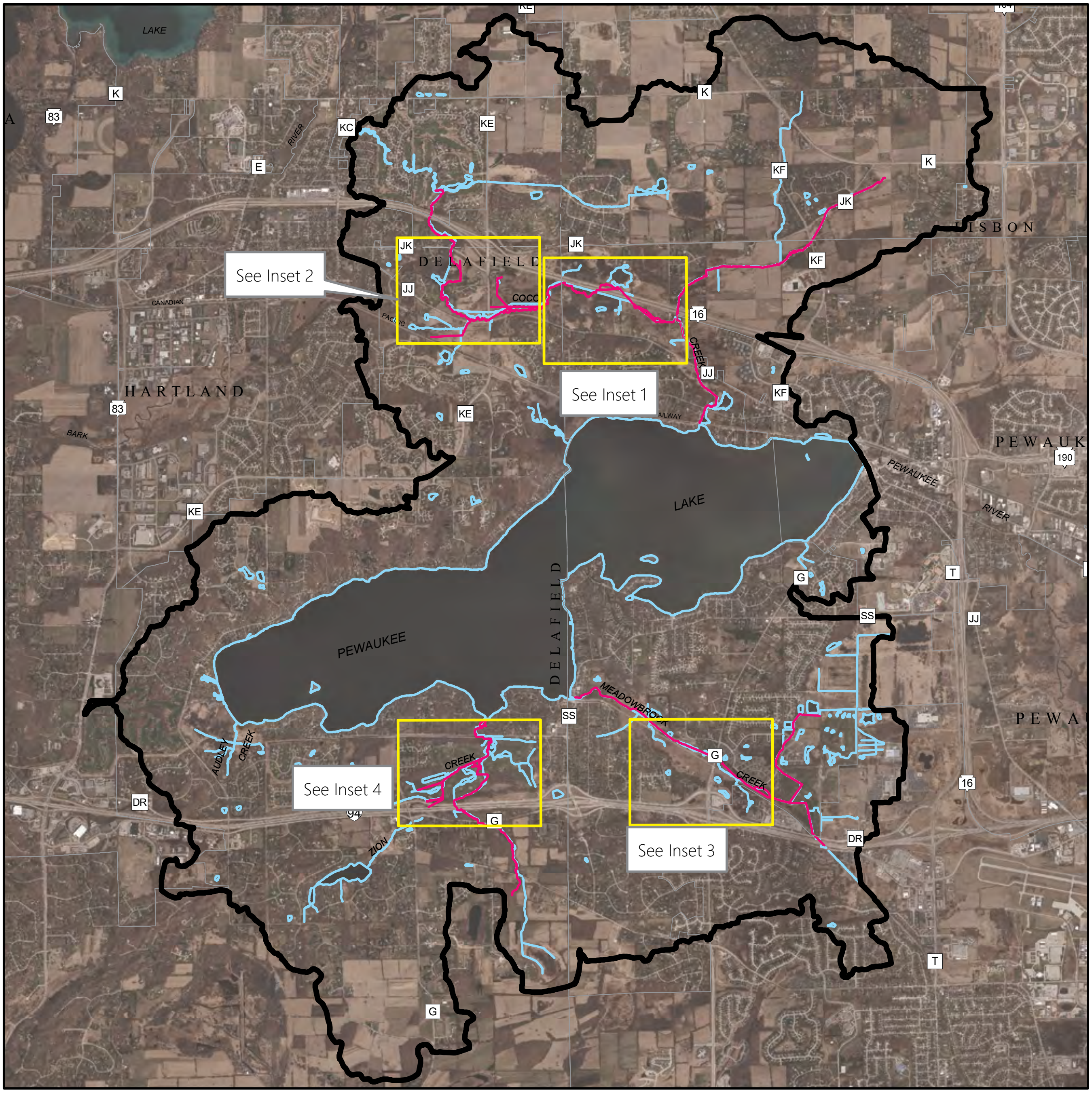
[184] *N.D. Gordon, et al.,* Stream Hydrology*, John Wiley and Sons, April 1993, page 318.*

[185] *Hyporheic flow is water moving into, out of, and within sediment below and alongside a stream bed that frequently enters and exits the stream's main flow channel. Hyporheic flow stimulates favorable geochemical reactions, supports life in the stream bed, and helps stabilize stream temperatures.*

Map 2.30
Stream Alignments Within the Pewaukee Lake Watershed: 1941 and 2010



1941 STREAM

2010 STREAM

WATERSHED BOUNDARY

N

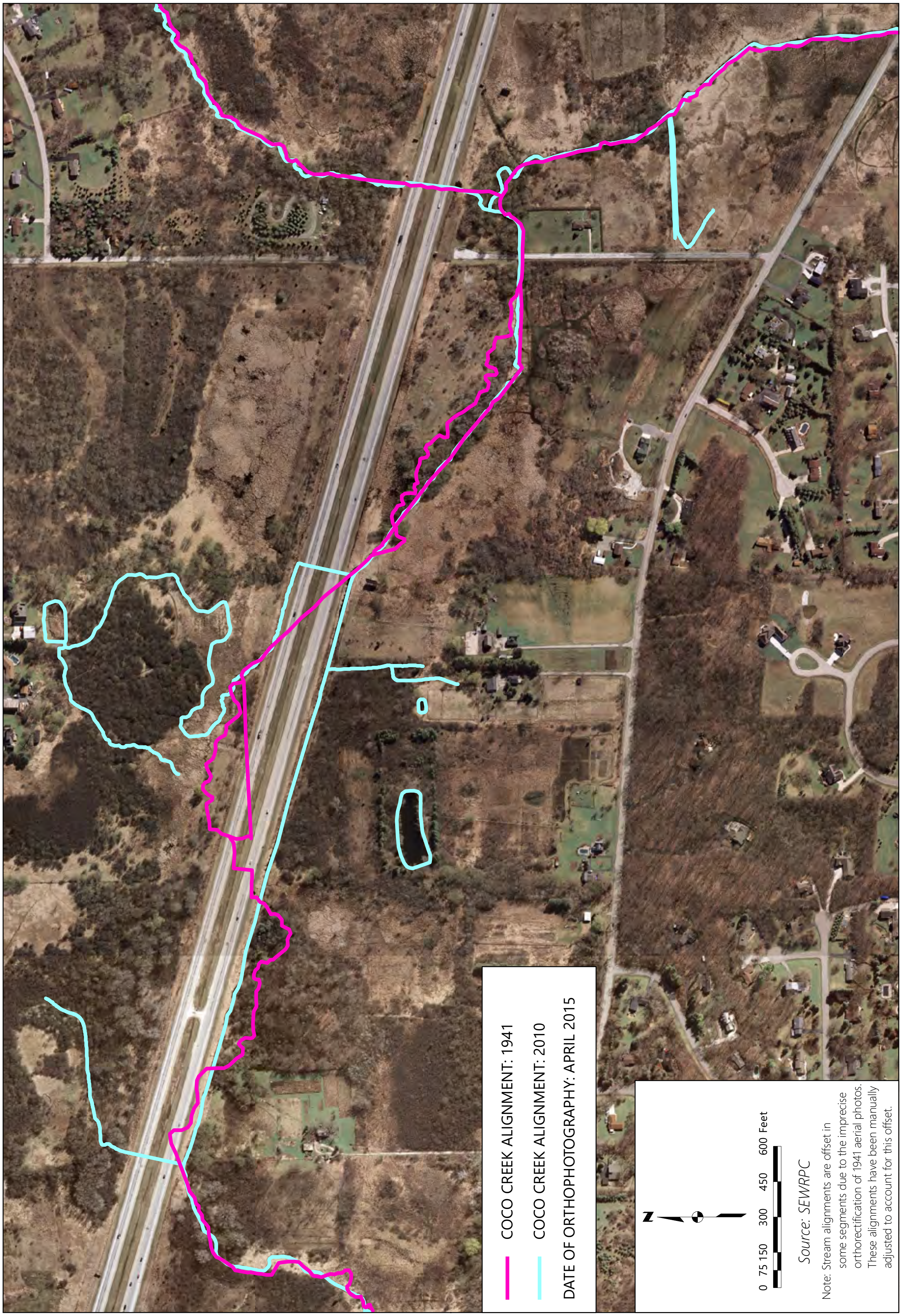
0 1,250 2,500 5,000 Feet

Note: Stream alignments are offset in some segments due to the imprecise orthorectification of 1941 aerial photos.

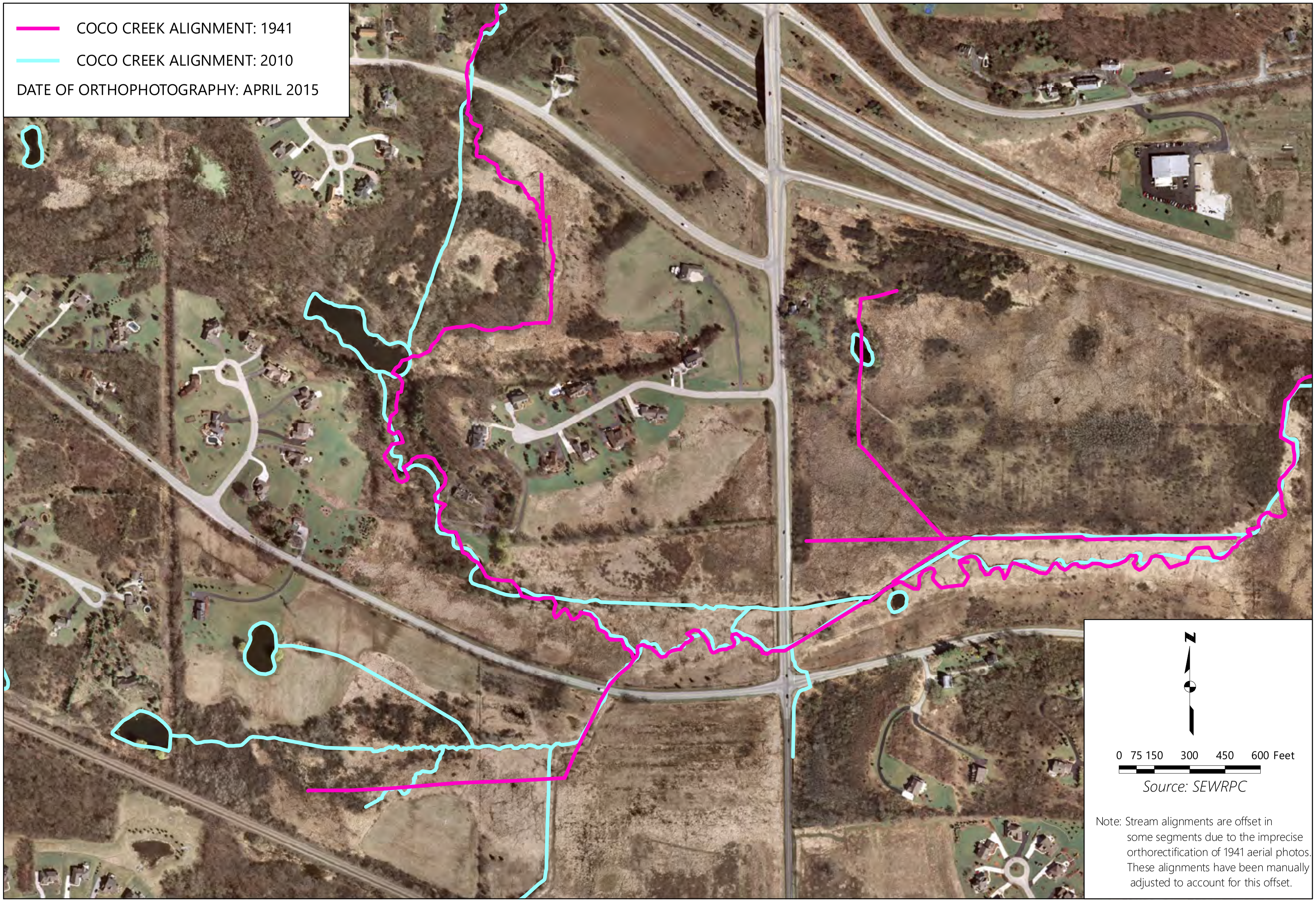
Date of Orthophotography: April 2015

Source: SEWRPC

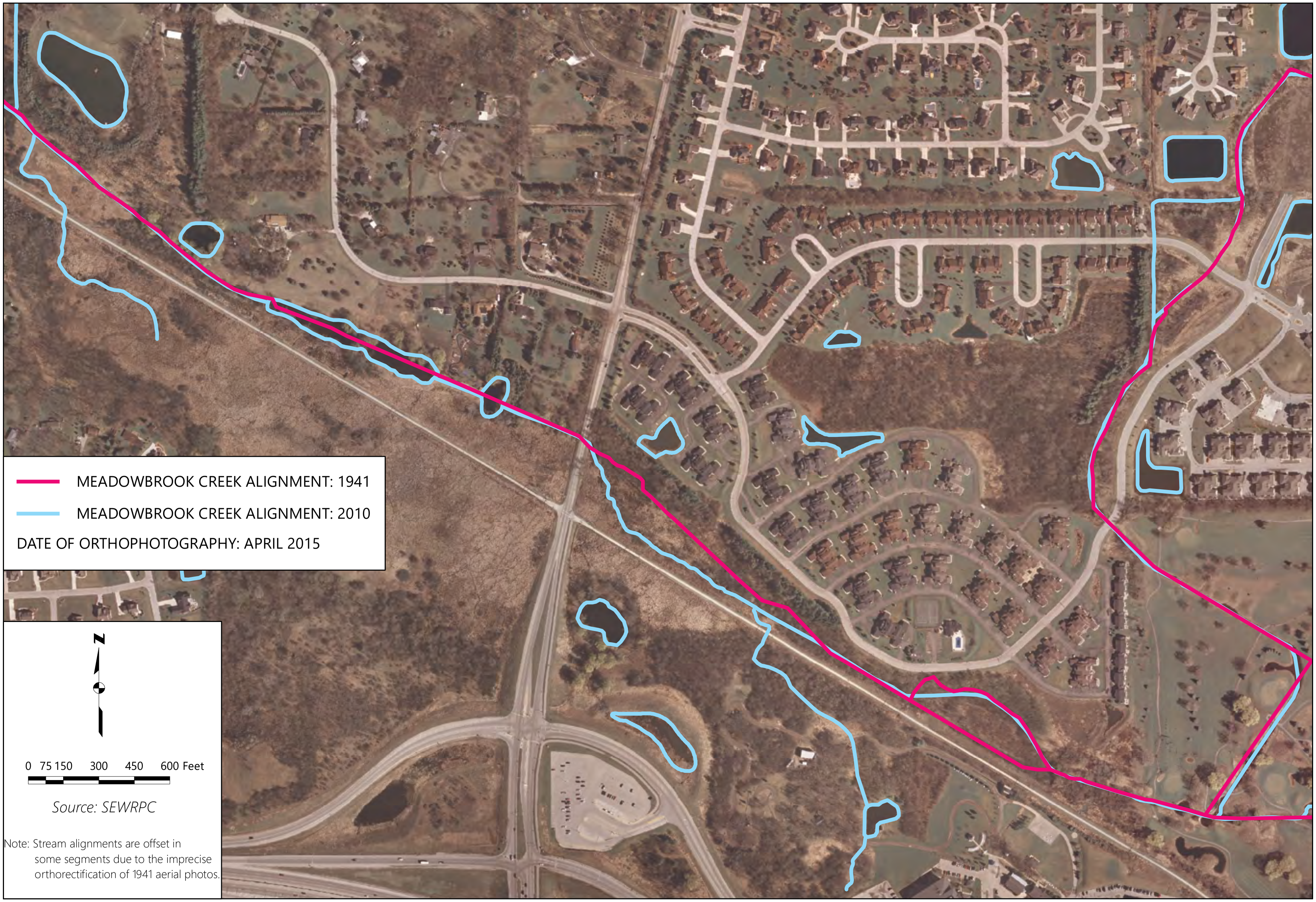
Map 2.30 – Inset 1
Upstream Coco Creek Stream Alignments: 1941 and 2010



Map 2.30 – Inset 2
Downstream Coco Creek Stream Alignments: 1941 and 2010



Map 2.30 – Inset 3
Meadowbrook Creek Stream Alignments: 1941 and 2010



Map 2.30 – Inset 4
Zion Creek Stream Alignments: 1941 and 2010

As of 2010, Coco Creek's sinuosity ranged from 1.13 to 3.86, while the sinuosity of Meadowbrook Creek ranged from 1.26 to 3.26. Both creeks have channelized and qausi-natural segments. Comparing 1941 versus 2010 stream alignments shows that this system, while already channelized in many reaches during 1941, was more sinuous in 1941 than 2010. Before 1941, the loss in sinuosity chiefly resulted from drainage projects facilitating agriculture. In contrast, after 1941, most ditching accommodated road construction and urban development. Non-channelized reaches still exhibit healthy meanders that have migrated only slightly over the nearly seventy years between 1941 and 2010.

Despite having more than 70 to 100 years to recover from channelization, these reaches have not been able to redevelop more natural or appropriate sinuosities. Therefore, the only reasonable way to restore stream function within these systems is to physically reconstruct them. Reconstructing meanders or restoring a more natural sinuosity, particularly in low gradient systems, is one of the most effective ways to restore instream habitat and the ability of this system to transport sediment and to function more like a healthy stream system. In particular, the highest priority or best locations to restore stream function are where the pre-existing channel lengths that were cut off during channel straightening still exist. For example, there are several extensive reaches within Coco Creek where the previous channel lengths appear to exist but are separated from the current channel, as shown on Map 2.30 (see insets 1 and 2). Even if the old stream channel has been buried or cannot be determined, there are many opportunities to rehabilitate or increase stream sinuosities and associated habitat and stream function within these channelized sections of stream.

Changes in Land Use

The land- and water-use activities associated with agricultural and urban land uses have been demonstrated to influence the hydrological and chemical factors of streams. The effects manifested upon streams are often carried to and manifested within connected lakes. These factors are summarized below and are illustrated in Figure 2.79.[186]

Hydrologic Factors

The timing, variability, and volume of streamflow influence, and even control, many key physical, chemical, and biological characteristics and processes of stream systems. For example, recurring high flows from seasonal rainfall or snowmelt organize and shape the basic structure of a river's channel shape, structure, and its physical habitats, which in turn influence the types of aquatic organisms that can thrive. For many aquatic organisms, low flows impose basic constraints on the availability and suitability of habitat, such as water depths and the amount of wetted streambed. The life cycles of many aquatic organisms are synchronized with the variation and timing of stream flows. For example, the reproductive period of some common fish species (e.g., northern pike (*Esox lucius*) and white sucker *(Catostomus commersoni*)) is triggered by the onset of heavy, cold runoff created by early spring snowmelt and associated rainfall.

In general, human activities in Southeastern Wisconsin's agricultural settings alter the natural flow regimen of streams and rivers through a number of ways, including the following examples.

- **Vegetation and soil changes.** Clearing natural vegetation and intensive cropping typically reduces soil's ability to absorb runoff. This in turn can lower water tables, reduce the landscape's ability to detain water, provide groundwater recharge, and sustain water features during extended dry weather periods, and can rapidly deliver both surface-water runoff and groundwater to nearby streams.

- **Enhanced and artificial drainage.** This includes features such as drain tiles, French drains, artificial ditches, straightened and/or deepened streams, and storm sewers. As with vegetation and soil changes, enhanced and artificial drainage can lower water tables, reduce the landscape's ability to detain water, provide groundwater recharge, and sustain water features during extended dry weather periods, and can rapidly deliver both surface-water runoff and groundwater water to nearby streams.

- **Groundwater pumping,** which can deplete groundwater systems feeding lakes, streams, springs, and wetlands. Water exported from a watershed has the greatest impact to local groundwater flow systems. Export can include supplying a use outside the local watershed or water consumptively used and not returned to the groundwater system.

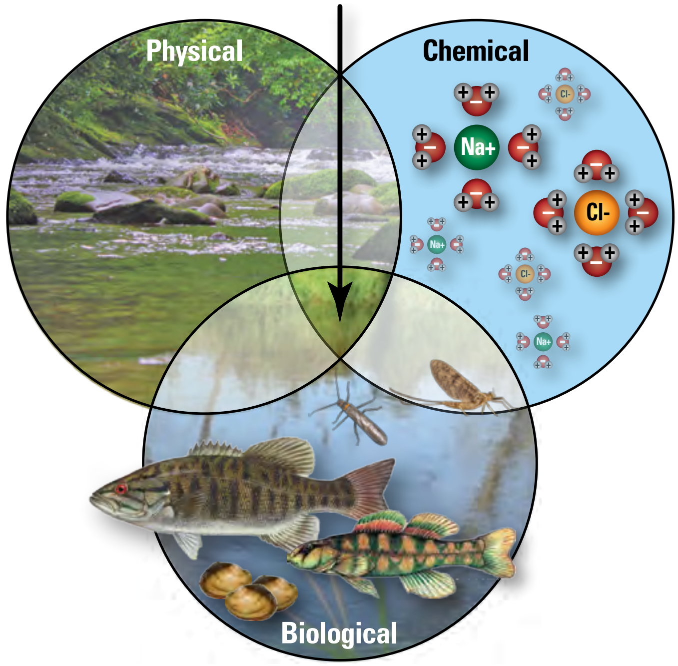
[186] *Ibid.*

- **Irrigation.** Irrigation can supplement natural soil moisture and increase groundwater recharge. If irrigation water is sourced beyond the local watershed, irrigation can increase the supply of groundwater to local water bodies.

Since agricultural practices and stream system characteristics are diverse (see Figure 2.80, "Agricultural Stream"), the net effect of agriculture upon stream ecosystems can be highly variable.

One of the most profound changes humans make in urban settings is greatly increasing the amount of impervious land cover (e.g., rooftops and pavement). Impervious surfaces restrict infiltration of precipitation into the soil, decreasing groundwater recharge and increasing the volume of water reaching streams as stormwater runoff. Engineered stormwater conveyance systems are often installed to manage increased runoff volumes. These systems rapidly convey runoff to lakes and streams, and, if unmitigated by careful design, compromise a watershed's ability to store runoff and remove sediment and pollutants entrained in runoff. This situation also increases storm runoff rates, decreases stormwater retention, and leads to higher and more variable peak stream flows, generating "flashy" streams that convey large volumes of water immediately after rainfall or snowmelt occurs, but which exhibit very low flow during dry periods. High peak flows scour the bed and banks of stream and degrade channel morphology. More nutrients, sediment, and pollutants reach stream channels, reducing water quality (see Figures 2.80 and 2.81).

Figure 2.79
Illustrations of the Dynamic Components of Natural, Agricultural, and Urban Stream Ecosystems



This simple diagram shows that a stream's ecological health (or "stream health") is the result of the interaction of its biological, physical, and chemical components. Stream health is intact if (1) its biological communities (such as algae, macroinvertebrates, and fish) are similar to what is expected in streams under minimal human influence and (2) the stream's physical attributes (such as streamflow) and chemical attributes (such as salinity or dissolved oxygen) are within the bounds of natural variation.

Source: Modified from Carlisle, D.M., Meador, M.R., Short, T.M., Tate, C.M., Gurtz, M.E., Bryant, W.L., Falcone, J.A., and Woodside, M.D., 2013, The Quality of our Nation's Waters—Ecological Health in the Nation's Streams, 1993–2005, *U.S. Geological Survey Circular 1391, p. 2, pubs.usgs.gov/circ/1391, and SEWRPC*

Reduced infiltration to groundwater reduces stream flow during dry weather. This issue is particularly pronounced in headwater streams where groundwater supplies most dry-weather streamflow. In addition, larger human populations, industry, and commercial endeavors commonly increase overall water demand in urbanized areas. Many urbanized areas in Southeastern Wisconsin draw their water supply from aquifers underlying watersheds, excluding those with access to Lake Michigan's surface water. Increased groundwater withdrawal reduces the volume of water emitted by natural discharge points (e.g., springs and seeps), which in turn affects natural stream flow regimens, water quality, and stream ecology.

Recent research has shown that average flow volume, high flow volume, high flow event frequency, high flow duration, and rate of change of stream cross-sectional area were the hydrologic variables most consistently associated with changes in algal, invertebrate, and fish communities.[187] In the Pewaukee Lake watershed, the amount of urban development is great enough to negatively affect water quality and quantity. Moreover, the amount of urban development is projected to increase, a factor that could intensify the impact of this issue. Therefore, the hydrology of this urbanizing stream system within the Pewaukee Lake watershed is a major determinant of stream dynamics and is a vital component of habitat for fishes and other organisms.

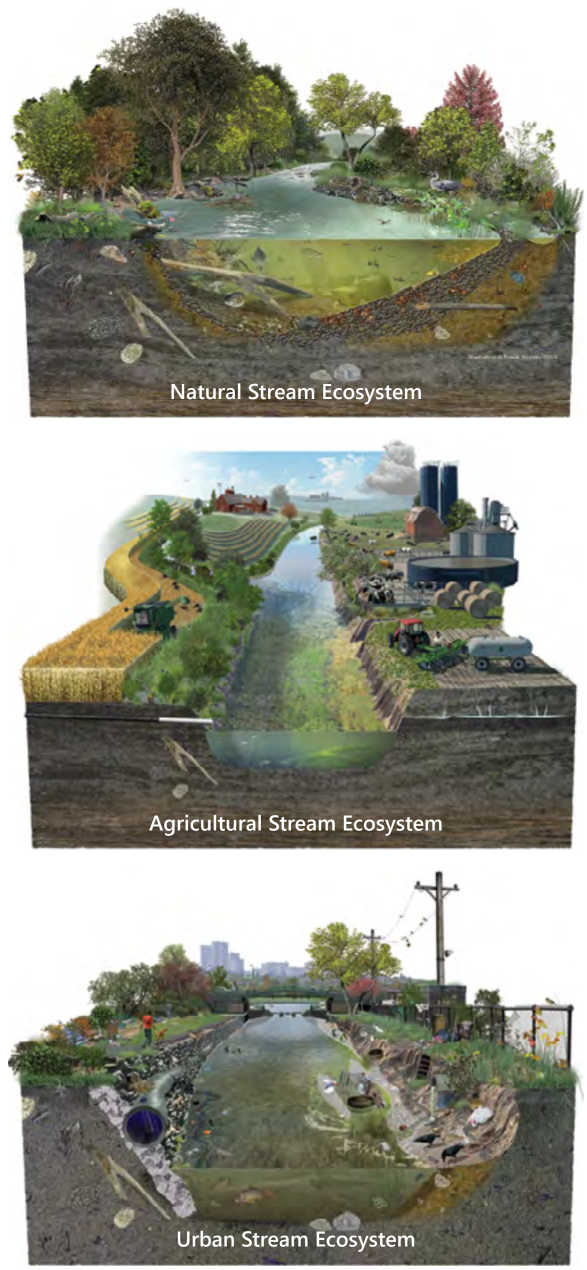
[187] *Personal Communication, Dr. Jeffrey J. Steuer, U.S. Geological Survey.*

To some degree, the negative effects of impervious surface can be mitigated with traditional storm water management practices and emerging green infrastructure technologies, such as pervious pavement, green roofs, rain gardens, bioretention, and infiltration facilities. Modern stormwater management practices manage runoff using a variety of techniques, including those focused on detention, retention, and conveyance. Emerging technologies, in contrast, differ from traditional modern stormwater practices in that they seek to mimic the disposition of precipitation on an undisturbed landscape by retaining and infiltrating stormwater onsite. A number of nontraditional, emerging low impact development (LID) technologies that have been implemented throughout the Region, including disconnecting downspouts; installing rain barrels, green roofs, and rain gardens; and constructing biofiltration swales in parking lots and along roadways. Experience has shown that these emerging technologies can be effective. For example, recent research has demonstrated that bioretention systems can work in clayey soils with proper sizing, remain effective in the winter, and contribute significantly to groundwater recharge, especially when such facilities utilize native prairie plants.[188]

The location of impervious surfaces also determines the degree of direct impact they will have upon a stream. For example, impervious surfaces located close to a stream are more damaging than those more distant, since less time and distance is available to attenuate runoff volume and pollutant loads. A study of 47 watersheds in Southeastern Wisconsin found that one acre of impervious surface located near a stream could have the same negative effect on aquatic communities as 10 acres of impervious surface located farther from the stream.[189]

Since urban lands located adjacent to streams have a greater impact on the biological community, an assumption could be made that riparian buffer strips located along streams could be instrumental in attenuating the negative runoff effects attributed to urbanization. Yet, riparian buffers may not be the complete answer since most urban stormwater is delivered directly to the stream via piped storm sewers or engineered channels, and therefore enters the stream without first passing through riparian buffers.

Figure 2.80
Components of Ecological Stream Health



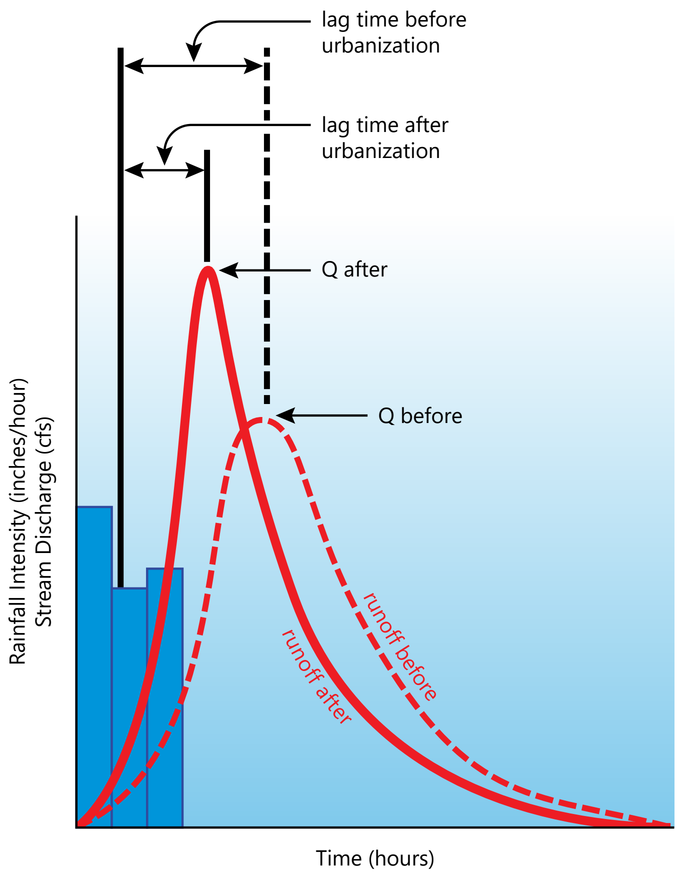
Source: Illustration by Frank Ippolito, www.productionpost.com. Modified from Carlisle, D.M., Meador, M.R., Short, T.M., Tate, C.M., Gurtz, M.E., Bryant, W.L., Falcone, J.A., and Woodside, M.D., 2013, The Quality of our Nation's Waters—Ecological Health in the Nation's Streams, 1993–2005, *U.S. Geological Survey Circular 1391, p. 28, pubs.usgs.gov/circ/1391, and SEWRPC*

[188] *R. Bannerman, WDNR and partners;* Menasha Biofiltration Retention Research Project*, Middleton, WI, 2008; N.J. LeFevre, J.D. Davidson, and G.L. Oberts,* Bioretention of Simulated Snowmelt: Cold Climate Performance and Design Criteria*, Water Environment Research Foundation (WERF), 2008; W.R. Selbig and N. Balster,* Evaluation of Turf Grass and Prairie Vegetated Rain Gardens in a Clay and Sand Soil: Madison, Wisconsin, Water Years 2004-2008*, In cooperation with the City of Madison and Wisconsin Department of Natural Resources, U.S. Geological Survey Scientific Investigations Report, in draft.*

[189] *L. Wang, J. Lyons, P. Kanehl, and R. Bannerman, "Impacts of Urbanization on Stream Habitat and Fish Across Multiple Spatial Scales,"* Environmental Management*, 28: 255-266, 2001.*

Riparian buffers need to be combined with other management practices, such as detention basins, grass swales, and infiltration facilities to adequately mitigate the effects of urban stormwater runoff. Combining practices into such a "treatment train" can provide a much higher level of pollutant removal than can single, stand-alone practices. Stormwater and erosion treatment practices vary in their function, which in turn influences their level of effectiveness. Location of a practice on the landscape, as well as proper construction and continued maintenance, greatly influences the level of pollutant removal and runoff volume management.

Figure 2.81
Stream Hydrographs Before and After Urbanization



Note: The lag time is the time it takes to reach peak flow for the watershed since the highest rainfall intensity. Q is the stream flow discharge.

Source: *Federal Interagency Stream Restoration Working Group (FISRWG),* Stream Corridor Restoration: Principles, Processes, and Practices, *p. 15, October 1998*

Chemical Factors

The unique water chemistry requirements and tolerances of each aquatic plant and animal species defines their natural abundance and distribution in streams. Many naturally occurring chemical substances are vital to normal growth, development, and reproduction. For example, sufficient DO is necessary for normal respiration. DO concentration in streams and rivers is determined, in part, by physical aeration processes that are influenced by the slope and depth of the stream, the amount of oxygen used in the stream to support respiration and decomposition of organic matter, as well as the water temperature. Similarly, nominal amounts of nutrients and minerals (e.g., nitrogen, phosphorus, calcium, and silica) must be available to sustain stream ecological health.

Human activities often contribute additional amounts of naturally occurring substances as well as other synthetic (manmade) chemicals to streams from point and nonpoint sources. Runoff from agricultural lands (see "Agricultural Stream Ecosystem" in Figure 2.79) may contain 1) eroded soil; 2) nutrients and organic matter adhering to the soil or resulting from the application of fertilizer and manure; 3) chloride and other salts from soil amendments; 4) pesticides used to control insects, weeds, rodents, bacteria, fungi, or other unwanted organisms; and 5) other synthetic compounds used for varying purposes along with their degradants. Runoff from urban lands (see "Urban Stream Ecosystem" in Figure 2.79) may contain 1) sediment from construction and other activities; 2) organic matter from trees, lawns, urban animals, and pets; 3) nutrients and pesticides applied to lawns and recreational areas; and 4) petroleum compounds, organic toxins, and deicing salts from roads and parking lots. Point sources include municipal and industrial wastewater effluent that, depending on the sources of wastewater and level of treatment, may contain various amounts of nutrients and other contaminants.

Current Stream Conditions

Commission staff examined conditions in the Pewaukee River, including Coco, Meadowbrook, and Zion Creeks, in spring of 2012 and late spring and summer of 2015. A comprehensive report was subsequently prepared that discusses watershed issues, presents and interprets field data, discusses the importance of the data in detail, and provides recommendations to improve the stability and ecological health of the River and its tributaries.[190] The reader is encouraged to review a copy of the Pewaukee River report, particularly the section discussing Pewaukee Lake and its tributaries.

[190] *SEWRPC Community Assistance Planning Report No. 313,* op. cit.

Commission staff examined the three largest tributaries (Coco, Meadowbrook, and Zion Creeks) between March and May, 2012 and April, May, and August of 2015 (see Map 2.31 for surveyed stream reaches). Both quantitative and qualitative measures were largely based upon the WDNR Baseline Monitoring protocols for instream fisheries habitat assessment.[191] Cross sectional surveys were completed throughout the watershed. Additional water depths were recorded in pool habitats to assess number and quality in order to supplement information between cross sections where the full complement of data was collected. Physical parameters that were measured include water and sediment depth, substrate composition, undercut bank, bank slopes, and channel width. The remaining cover parameters were each qualitatively estimated as none, low, moderate, and high percent abundances based upon categories as defined by the low gradient stream habitat methodology.[192]

Meadowbrook, Coco, and Zion Creeks comprise a low-gradient stream system, characterized by a gradient of about 0.005 feet/foot or lower. High quality, low gradient streams tend to lack riffles and have relatively slow currents, small substrate particle sizes, and well developed meandering (i.e., high sinuosity) channel morphology. Such systems often flow through wetlands and may have very soft, unconsolidated (i.e., organic) substrates and poorly defined channels in some cases. Such characteristics have made low-gradient streams candidates for channelization for agricultural development along with installation of tiles to improve drainage, which is what has occurred to a large extent in this stream system.

The stream reaches examined during 2012 and 2015 yielded low gradient stream habitat criteria scores that were fair-good (Coco Creek) and poor-fair (Meadowbrook Creek). As shown in Table 2.27, these criteria include several habitat variables that are well established as strongly influencing fish communities and biotic integrity. Those habitat criteria include channelization percent and age, instream cover, bank erosion, sinuosity, standard deviation of thalweg depth, and buffer vegetation. It is important to note that the lowest habitat scores were always associated with highly channelized stream reaches. Although the streams continue to recover from past channelization, channelized stream segments clearly continue to limit overall habitat quality. These channelized reaches will not likely recover in a reasonable amount of time without further human intervention.

The overall distribution of instream habitat types is characterized by:

- Pools (deep water and slower water velocities)
- Riffles (shallow water, large substrates, and higher water velocities)
- Runs (intermediate depth and water velocities)

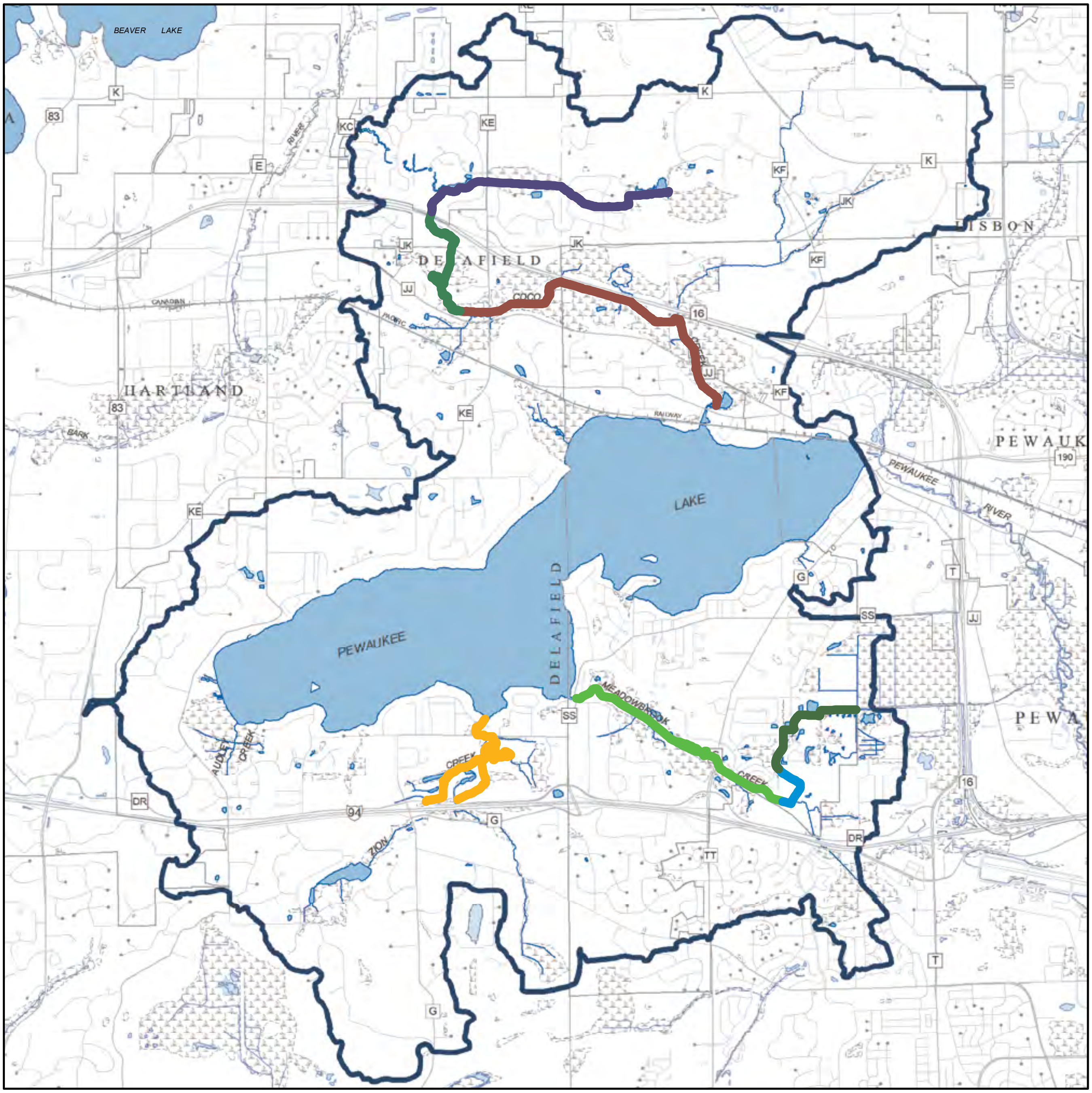
The distribution of these three habitat types, as surveyed primarily in Coco and Meadowbrook creeks, are shown on Map 2.32 (only a small reach of Zion Creek was surveyed, as indicated in the map). The diversity of the pool and riffle structure (i.e., number of pools compared to the number of riffles) is very limited in the lower reaches of Meadowbrook and Coco Creeks. This is not particularly surprising, since these streams are still adjusting to the increased water elevation of the Lake caused by the outlet dam. The mouths of these streams essentially drowned and now act as estuaries. It will take many years for these streams to transport sufficient sediment to form firm granular bed channels to the Lake's margins, and the large clasts that anchor riffles will not likely be transported to these reaches without human intervention. Natural deposits of large clasts have been buried by post dam construction sediment, and will not be a factor in future riffle formation unless the outlet dam is removed.

In the studied sections of the creeks, 35 riffles were found in Coco Creek and only two were found in the lowermost reaches of Meadowbrook Creek. Riffle habitat availability was found to be extremely limited

[191] *Wisconsin Department of Natural Resources,* Guidelines for Evaluating Habitat of Wadable Streams*, Bureau of Fisheries Management and Habitat Protection, Monitoring and Data Assessment Section, Revised June 2000; T. Simonson, J. Lyons, and P. Kanehl,* Guidelines for Evaluating Fish Habitat in Wisconsin Streams*, Wisconsin Department of Natural ResourcesGeneral Technical Report NC-164, 1995; and L. Wang, "Development and Evaluation of a Habitat Rating System for Low-Gradient Wisconsin Streams,"* North American Journal of Fisheries Management*, 18, 1998.*

[192] *Ibid.*

Map 2.31
Pewaukee Lake Tributary Stream Reaches Used in Instream Habitat Surveys: 2012 and 2015



COCO CREEK REACHES

1
2
3

MEADOWBROOK CREEK REACHES

1
2
3

ZION CREEK

SURFACE WATER
WETLAND
STREAM
WATERSHED BOUNDARY

0 1,250 2,500 5,000 Feet

Source: SEWRPC

Table 2.27
Low-Gradient Stream Habitat Criteria Scores Within the Pewaukee Lake Watershed: 2012 and 2015

Habitat Criterion	Coco Creek			Meadowbrook Creek			Zion Creek
	1	2	3	1	2	3	1
Channelization (percent)	61-100	10-60	61-100	61-100	61-100	61-100	61-100
Channelization (age)	>20	>20	>20	>20	>20	>20	>20
Instream Cover (percent)	5-10	11-14	5-10	11-14	5-10	5-10	<5
Bank Erosion (percent)	<7	7-50	<7	<7	<7	<7	<7
Sinuosity (ratio)	<1.05	1.05-1.20	<1.05	<1.05	<1.05	<1.05	<1.05
Thalweg Depth (standard deviation)	>0.40	>0.40	>0.40	>0.40	0.05-0.25	0.05-0.25	0.05-0.25
Buffer Vegetation (percent)	51-90	>90	20-50	51-90	<20	51-90	<20

Note: Background colors indicate the low-gradient stream habitat score given to each tributary reach: Poor (red), Fair (yellow), Good (green), and Excellent (blue). See Map 2.31 for the location of each tributary reach.

Source: SEWRPC

within the lower reaches, but was more common upstream. Although both of these tributaries were heavily channelized long before 1941, Coco Creek exhibits a much better relationship between width and depth and overall habitat quality than Meadowbrook Creek. Excessively wide and deep features associated with the lower portion of Meadowbrook Creek are likely the result of dam construction flooding the original stream floodplain and/or overly aggressive channel deepening and widening during the time of channelization. The lowermost portions of Meadowbrook Creek will likely never recover within a reasonable time frame from the effects of outlet dam construction and channelization without further human intervention.

The maximum depths of pool, riffle, and run habitats change along the course of a stream from its headwaters to its confluence with another waterbody. These differences indicate that although they may be nominally the same types of habitat areas, the pools, riffles, and runs in the upper portions of a stream effectively form smaller habitat areas than the corresponding habitat areas in the lower reaches of the watershed. These differences can affect and determine the biological community type, abundance, and distribution present within distinct hydrologic reaches, which, in effect, can result in significant differences in species composition within each of the reaches. The upstream reaches naturally contain a lower abundance and diversity of fishes compared to the downstream reaches because these reaches contain less water volume. However, it is also important to note that these upstream areas provide vital spawning and nursery habitat needed to sustain the quality and productivity of the entire fishery.

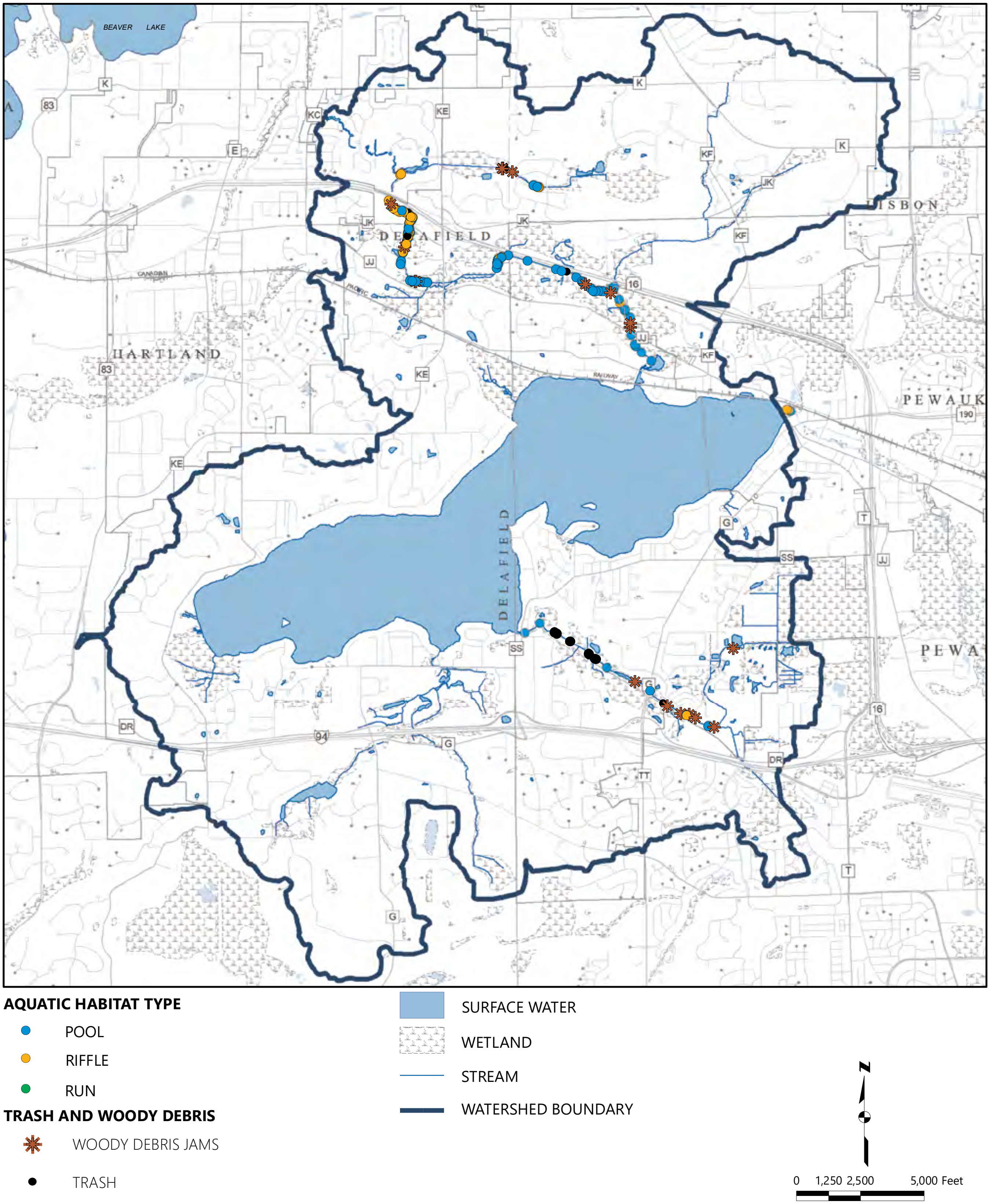
Pool habitats are the opposite of riffle habitats and are also important components of fish habitat in streams, especially for larger fish. On account of their greater depth, pools offer protection from predators, provide feeding areas, and provide refuge from high temperatures in the summer and cold temperatures in the winter. As shown in Map 2.32, only three pools are found in the surveyed reaches of Meadowbrook Creek. Coco Creek has many more pools. Pools are often monitored to track the effect of enhancement projects and natural stream processes, but variations of water depth with discharge can complicate assessment of changes in the depth and volume of pools.

Low gradient stream habitat criteria also include various types of instream cover and bank erosion. Coco and Meadowbrook Creeks had instream cover scores of Fair to Good, while Zion Creek had a score of Poor. All reaches of all three creeks had Excellent scores for bank erosion, aside from reach two of Coco Creek. This analysis indicates that although a number of modifications were made to the tributary system of Pewaukee Lake, opportunities exist to improve habitat quantity and quality throughout the Lake's watershed.

Instream Cover

Instream cover is an essential component of a healthy stream ecosystem. It provides shelter for aquatic organisms, prevents excessively high water temperatures, and inhibits eutrophication. The type and amounts of riparian vegetation are significant drivers of the types and amounts of instream cover. Examples of instream cover are shown in Figure 2.82. Instream woody structures are an important component of stream ecosystems, providing essential food and habitat for aquatic organisms. Woody structures can affect

Map 2.32
Aquatic Habitat Types, Woody Debris, and Trash Accumulations Identified in the Pewaukee Lake Tributaries: 2012 and 2015



Source: SEWRPC

Figure 2.82
Example of Instream Cover Within the Pewaukee Lake Watershed

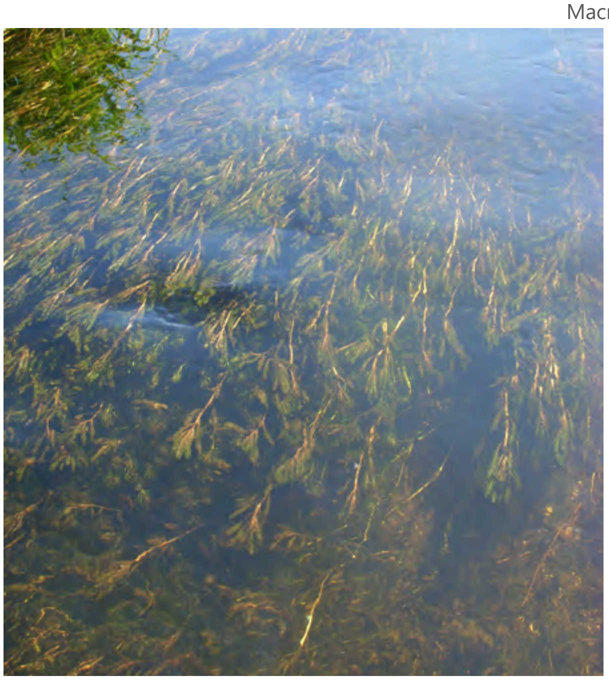
Overhanging Vegetation

Emergent Vegetation

Wood Debris

Boulders and Cobble

Macrophytes



Source: SEWRPC

channel morphology forming pools; retain organic matter, gravel, and sediment; influence invertebrate abundance; and provide cover and velocity refuge for fish.[193]

Woody structures are present, albeit mostly in relatively low amounts, along Coco and Meadowbrook creeks. Cover was ranked from low to high based on the degree and areal extent of shading. Low to moderate abundance cover dominates Coco Creek, accounting for 93 percent of all cover types. The remaining 7 percent are high abundance cover types. Cover on Meadowbrook Creek was comprised of about 78 percent low to moderate abundance cover and about 22 percent high abundance cover.

Excessive woody structures can sometimes accumulate, causing debris jams that can function like a dam.[194] Debris jams may significantly disrupt stream sediment dynamics, compromise the water carrying capacity of the channel, lead to localized flooding and bank stability problems, and disrupt aquatic organism migration. Therefore, it is important to periodically monitor debris accumulations and either partially remove or completely remove them, as well as address any streambank erosion issues, when appropriate. Map 2.32 and Appendix A show the results of the 2012 and 2015 surveys of Coco and Meadowbrook creeks regarding the relative amounts of obstruction in each.

Buffer Vegetation

Riparian buffer vegetation is another important dimension included within the low gradient stream scoring criteria to assess instream habitat quality. The buffer vegetation is quantified as the percent of the area within 10 meters of the stream that is covered by undisturbed vegetation, such as woodlands, shrubs, meadows, or wetland. Stream reaches flanked by extensive wooded riparian areas are more shaded. Shaded areas commonly have less algae and macrophyte growth, whereas unshaded areas can host excessively dense aquatic plant growth. Coco Creek has about 80 percent more riparian shading than Meadowbrook Creek. Consequently, significantly less macrophyte and algae growth was noted in Coco Creek.

Undercut Streambanks

Undercut streambanks provide fish cover and resting areas and are important habitat quality features. The 2012 and 2015 surveys of Coco and Meadowbrook Creeks found only one instance of deeply undercut banks (>1.0 foot) in Coco Creek. Coco Creek did have evidence of moderate streambank undercutting while Meadowbrook Creek had only shallow (<0.5 feet) undercutting.

Trash and Tires

Watershed urbanization can lead to the intentional and unintentional accumulation of trash and debris in waterways and associated riparian lands. Although accumulated trash and debris are not part of the low gradient stream scores summarized above, these materials degrade waterbody aesthetics and can physically and/or chemically compromise habitat quality and its value to aquatic and terrestrial wildlife. Debris can accumulate to such an extent that it limits recreation, passage of aquatic organisms, and/or leads to streambank erosion.

Commission staff recorded and mapped significant trash and debris deposits encountered along Coco and Meadowbrook Creeks while completing the 2012 and 2015 comprehensive surveys (see Map 2.32 and Appendix A, Maps A.5 and A.6). The majority of trash observed in Coco Creek was general rubbish. Construction materials, fencing, automobile tires were commonly found in Meadowbrook Creek.

Stream Crossings and Dams

Bridges and culverts can affect a stream's overall water conveyance capacity, stream width/depth, stream form, water velocity, and channel substrates. These structures can create physical and/or behavioral barriers to fish and other aquatic organisms. Therefore, in 2012 and 2015, Commission staff inventoried structures along Coco, Meadowbrook, and Zion Creeks. The structure inventory is summarized in Appendix E, including

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[193] *B. Mossop and M.J. Bradford, "Importance of Large Woody Debris for Juvenile Chinook Salmon Habitat in Small Boreal Forest Streams in the Upper Yukon River Basin, Canada,"* Canadian Journal of Forestry Resources*, 35: 1955-1966, 2004.*

[194] *Human influence factors can cause streams to contain unnaturally high amounts of woody structures. For example, introduced tree diseases can cause the entire tree canopy to die. When these trees fall, an enormous amount of woody structures can be contributed to a stream over a very short period of time.*

descriptions and photographs (see Figure E.1), maps (see Map E.1), conditions, as well as a fish passage and navigation hazard ratings (see Table E.1). Based upon this assessment, eleven structures were identified to be passable, but seven structures were considered partial barriers. None of these structures were considered navigation hazards.

Because of the number of culverts within the Pewaukee Lake tributaries, their combined impact on fish communities could potentially be significant.[195] Culverts tend to have a destabilizing influence on stream morphology that can create temporal, species selective barriers to fish migration because swimming abilities vary substantially among species and size-classes of fish, affecting their ability to traverse the altered hydrologic regime within the culverts.[196] Fish of all ages require freedom of movement to fulfill life-cycle critical needs (feeding, growth, spawning, refuge). Such needs generally cannot be found in only one particular area of a stream system. These movements may be upstream or downstream and occur over an extended period of time, especially in regard to feeding. In addition, before winter freeze-up, many types of fish tend to move downstream to deeper pools for overwintering. Fry and juvenile fish also require access up and down the stream system while seeking rearing habitat for feeding and protection from predators. Recognizing that fish populations are often adversely affected by culverts has resulted in numerous designs and guidelines that help allow better fish passage and help ensure a healthy naturally sustainable fisheries community.[197]

Beaver Activity

Beavers alter aquatic environments to a greater extent than any other mammal except humans. Their ability to increase landscape heterogeneity by felling trees and constructing impoundments and canals goes beyond their immediate needs for food and shelter. This animal can dramatically alter nutrient cycles and food webs in aquatic and terrestrial ecosystems by modifying hydrology and selectively removing riparian trees.[198] Beaver activity in streams is an example of a naturally altered ecosystem structure and dynamics. Beaver activity may alter habitat in many ways.[199] For example, beaver activity may:

- Modify channel geomorphology and hydrology
- Increase retention of sediment and organic matter
- Create and maintain wetlands
- Alter soil moisture, creating anaerobic zones in soils and sediments and thereby modifying nutrient cycling and decomposition dynamics
- Modify the riparian zone, including the species composition and growth form of plants
- Influence the character of water and materials transported downstream
- Modify instream aquatic habitat and water quality factor, which ultimately influences community composition (e.g., fish and macroinvertebrates) and diversity

Beaver dams are not permanent structures. Without constant maintenance, the dams will breach and fail. In addition, dams are frequently abandoned when beavers migrate to new areas for better food and habitat

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[195] *T.M. Slawski and T.J. Ehlinger, "Fish Habitat Improvement in Box Culverts: Management in the Dark?"* North American Journal of Fisheries Management*, 18: 676-685, 1998.*

[196] *Stream Enhancement Research Committee,* Stream Enhancement Guide, *Province of British of Columbia and the British Columbia Ministry of Environment, Vancouver, 1980.*

[197] *B.G. Dane,* A Review and Resolution of Fish Passage Problems at Culvert Sites in British Columbia*, Canada Fisheries and Marine Sciences Technical Report 810, 1978; Chris Katopodis*, Introduction to Fishway Design*, Freshwater Institute Central and Arctic Region Department of Fisheries and Oceans, January, 1992.*

[198] *A.M. Ray, A.J. Rebertus, and H.L. Ray, "Macrophyte Succession in Minnesota Beaver Ponds,"* Canadian Journal of Botany*, 79: 487-499, 2001.*

[199] *R.J. Naiman, J.M. Melillo, and J.E. Hobbie, "Ecosystem Alteration of Boreal Forest Streams by Beaver (*Castor canadensis*),"* Ecology*, 67: 1254-1269, 1986.*

conditions. Beavers do not inhabit an area for a set time frame. Dams have been noted to be maintained over long periods of time, while others are only used seasonally. Beaver dams are likely fish passage barriers for many native species under fair weather flow conditions. Although most fish species can migrate downstream without significant issue, upstream passage is likely restricted for many native fish by physical and behavioral limitations associated with each fish species.

Beaver dams can affect stream form and function on watershed wide scales. When beavers impound streams by building dams, they substantially alter stream hydraulics in ways that benefit many fish species.[200] Early research suggested that beaver dams might be detrimental to fish, primarily by hindering fish passage, and it has been demonstrated that beaver dams seasonally restrict movement of fishes.[201] Until recently, it was common for fish managers to remove beaver dams. However, more than 80 North American fish species have been documented in beaver ponds, including 48 species that commonly use these habitats, and the beaver ponds' overall benefit to numerous fish species has been well documented, causing managers to rethink the practice of removing beaver dams.[202] In agricultural areas, beaver dams may impound water and submerge drain tile outlets, reducing the effectiveness of the tile systems and adversely affecting crops. For the reasons cited above, beaver management is a complicated and controversial issue, and decisions to remove beaver dams should be addressed on a case-by-case basis.

Meadowbrook Creek contained two beaver dams (Appendix A, Map A.6 on page 312). Beaver dams can positively affect overall stream health in some instances. For example, beaver dams can reconnect stream channels to floodplains, which in turn can help enhance the stream's ability to detain floodwater and retain sediment and nutrients in off-channel areas. However, beaver dams can also potentially limit fish passage, particularly for species that lack leaping behavior while migrating to spawning areas (e.g., northern pike (*Esox lucius*)). Therefore, it is important to continue to monitor beaver activity and take action when and where appropriate. Those efforts should be particularly focused in the following locations: along migratory routes for northern pike spawning migrations, particularly Meadowbrook Creek and Coco Creek to their confluence with Pewaukee Lake; locations where structures may threaten to flood important infrastructure; and, where aquatic organism passage can become obstructed, particularly at culverts, bridges, small dams, fords, and intentional/unintentional channel filling.

Habitat Quality Indicators Through Stream Macroinvertebrates

Macroinvertebrates are organisms without backbones that inhabit the substrates such as sediments, debris, logs, and plant vegetation in the bottom of a stream or creek for at least part of their life cycle. Macroinvertebrates are visible to the naked eye, are abundant in freshwater systems, and include insect larvae such as leeches, worms, crayfish, shrimp, clams, mussels, and snails. Since macroinvertebrates develop and grow within the water, they are affected by local changes in water quality.

The majority of macroinvertebrates tend to be found within the shallow, fast flowing riffle habitats of streams compared to deeper and slower flowing pool or run habitats. Riffles can range from uneven bedrock or large boulders to sand substrates. However, the optimum riffle substrates for macroinvertebrates are characterized by particle diameters ranging from gravels (one inch) to cobbles (ten inches). Water flowing through these areas provides plentiful oxygen and food particles. Riffle-dwelling communities are made up of macroinvertebrates that generally require high dissolved oxygen levels and clean water, and most are intolerant of pollution. For example, mayflies (Ephemeroptera), stonefly larvae (Plecoptera), and caddisfly larvae (Trichoptera) tend to be found in cold, clear flowing water with a gravel or stone bottom and high dissolved oxygen concentrations. Caddisfly larvae, in particular, are sensitive to pollution and oxygen depletion.[203]

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[200] *J.W. Snodgrass and G.K. Meffe, "Influence of Beavers on Stream Fish Assemblages: Effects of Pond Age and Watershed Position,"* Ecology *79: 926-942, 1998.*

[201] *I.J. Schlosser, "Dispersal, Boundary Processes, and Trophic-Level Interactions in Streams Adjacent to Beaver Ponds,"* Ecology*, 76: 908-925, 1995.*

[202] *M.M. Pollock, G.R. Pess, T.J. Beechie, and D.R. Montgomery, "The Importance of Beaver Ponds to Coho Salmon Production in the Stillaguamish River Basin, Washington, USA,"* North American Journal of Fisheries Management*, 24: 749-760, 2004.*

[203] *D.L. Osmond, D.E. Line, J.A. Gale, et al.,* WATERSHEDSS: Water, Soil and Hydro-Environmental Decision Support System*h2osparc.wq.ncsu.edu, North Carolina State University Water Quality Group, 1995, see website at www.water.ncsu.edu/watershedss/info/macroinv.html.*

Macroinvertebrate Biotic Indices

Macroinvertebrates are useful indicators of water quality because they spend much of their life in the waterbody, they are not mobile, they are easily sampled, and the references needed to identify them to a useful degree of taxonomic resolution are readily available. In addition, the differences among macroinvertebrate species in habitat preferences, feeding ecology, and environmental tolerances allow the quality of water and habitat in a waterbody to be evaluated based upon the identity of the groups that are present and their relative abundances. The differences among macroinvertebrate species in feeding ecology are often represented through the classification of species into functional feeding groups based upon the organisms' principal feeding mechanisms.[204] Several groups have been described. Scrapers include herbivores and detritivores that graze on microflora, microfauna, and detritus attached to mineral, organic, or plant surfaces. Shredders include detritivores and herbivores that feed primarily on coarse particulate organic matter. Collectors feed on fine particulate organic matter. This group includes filterers that remove suspended material from the water column and gatherers that utilize material deposited on the substrate.

A variety of metrics have been developed and used for evaluating water quality based upon macroinvertebrate assemblages.[205] These include metrics based on taxa richness, trophic function, relative abundance of the dominant taxa, and diversity, as well as more complicated metrics. Most of these metrics have been developed for stream systems, though some macroinvertebrate metrics are being developed for other aquatic environments, such as wetlands.[206] The Hilsenhoff Biotic Index (HBI), and the percent of individuals detected consisting of members of the insect orders Ephemeroptera, Plecoptera, and Trichoptera (percent EPT) were used to classify the historic and existing macroinvertebrate data and to evaluate the environmental quality of the stream system using survey data from various sampling locations in the Pewaukee Lake watershed.[207]

The HBI represents the average weighted pollution tolerance values of all arthropods present in a sample. It is based upon the macroinvertebrate community's response to high loading of organic pollutants and reductions in the concentration of dissolved oxygen. It is designed for use with samples collected from riffles and runs, and may not be reliable for interpreting data collected from other stream environments. For example, macroinvertebrate data from samples collected from snags tend to be more variable and give higher HBI values than data from samples collected in riffles.[208] Lower values of the HBI indicate better water quality conditions while higher values indicate worse water quality conditions.

The percent EPT consists of the percentage of individuals detected in a sample that are members of the insect orders Ephemeroptera, Plecoptera, and Trichoptera. These taxa represent the organisms in streams and rivers that are less tolerant of organic pollution. Higher values of percent EPT indicate better water quality. Lower values indicate worse water quality. Low values of percent EPT may result from a variety of stressors including high loadings of organic pollution, low concentrations of dissolved oxygen, biologically active concentrations of toxic substances, disruption of stream flow regime, and increases in water temperature.

Tributary Macroinvertebrate Conditions

Macroinvertebrate analyses were conducted by the WDNR in Coco Creek in 1990, 1997, and 2015 and in Zion Creek in 2015. As noted above, the number and type of macroinvertebrates present in a stream can provide an indicator of water quality. Hence, the HBI, species richness, and percent EPT were used to classify macroinvertebrate and environmental quality in Coco and Zion Creek. All three surveys in Coco Creek indicated fair to good macroinvertebrate community conditions with improvement between 1990 and 2015, as the HBI shifted from fair (5.3) to good (4.8) and percent EPT increased from 18 to 31 percent. In Zion

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[204] *K.W. Cummins, "Trophic Relations of Aquatic Insects,"* Annual Review of Entomology*, 18: 183-206, 1973; K.W. Cummins and M.J. Klug, "Feeding Ecology of Stream Invertebrates,"* Annual Review of Ecology and Systematics*, 10: 147-172, 1979.*

[205] *R.A. Lillie, S.W. Szczytko, and M.A. Miller,* Macroinvertebrate Data Interpretation Manual*, Wisconsin Department of Natural Resources, PUB-SS-965 2003, Madison, Wisconsin, 2003.*

[206] *R.A. Lillie, "Macroinvertebrate Community Structure as a Predictor of Water Duration in Wisconsin Wetlands,"* Journal of the American Water Resources Association*, 39: 389-400, 2003.*

[207] *W.L. Hilsenhoff, "Rapid Field Assessment of Organic Pollution With a Family-Level Biotic Index,"* Journal of the North American Benthological Society*, 7(1): 65-68, 1988.*

[208] *Lillie, Szczytko, and Miller, 2003,* op. cit.

Creek, the macroinvertebrate community is in fair condition (HBI of 5.4), with relatively low species richness (13 species) but a moderate percent EPT (31 percent).

Both the Coco and Zion Creek macroinvertebrate surveys were conducted in highly channelized reaches, where the naturally meandering stream channel and associated riffle habitats have been removed. Channelization has likely contributed to the fair conditions of Coco Creek in 1990 as well as current conditions of Zion Creek. Riffle habitats produce the highest abundance and diversity of macroinvertebrate food, such as Ephemeroptera, Trichoptera, and Diptera, for insectivorous fish species, such as brown and brook trout, compared to other instream habitats. Thus, restoring the historic meandering channel patterns and associated riffle and pool habitats presents great potential to improve macroinvertebrate quality and the associated trout fishery.

Despite this channelization, the most recent surveys indicate that Coco Creek has improved to good conditions. This improvement likely reflects improvements in water quality, with lower stream temperature and greater dissolved oxygen concentrations allowing pollutant intolerant macroinvertebrate species to persist in channelized reaches. In contrast, the warm water temperatures and low dissolved oxygen concentrations of Zion Creek are impairing macroinvertebrate habitat, reducing the abundance and diversity of intolerant species. Reducing pollutant loading, lowering stream water temperatures, and improving dissolved oxygen concentrations by implementing riparian buffers and improving in-stream habitat can improve macroinvertebrate and fish communities in both tributaries.

Habitat Quality Summary

Pewaukee Lake and its tributaries have been heavily altered by human manipulation. Dam construction, stream channelization, as well as agricultural and urban development have transformed the landscape, degrading habitat quality for plants and wildlife. However, preservation and restoration of environmental corridors, construction of riparian and shoreline buffers, and re-meandering of streams has been improving habitat quality throughout the watershed. As the majority of the lakeshore is armored, incorporating soft shoreline protection measures with these hard measures may improve water quality and mitigate pollutant loading. Despite the channelization of the streams, there are still areas of moderate habitat for fish spawning that should be protected. Recommendations for the management and protection of lake and stream habitat quality are presented in Section 3.4, "Pollutant and Sediment Sources and Loads" as well as Section 3.7, "Fish and Wildlife."

2.9 FISHERIES

This section describes the historical and current conditions and management of fish populations in the Pewaukee Lake watershed, including a history of fish stocking and management in Pewaukee Lake followed by a description of the current fishery. The fisheries and conditions of the tributary streams are also detailed.

Pewaukee Lake

Pewaukee Lake contains a large variety of naturally reproducing warmwater fish species as well as northern pike, muskellunge, and walleye, which are largely contributed via stocking. The WDNR lists muskellunge, northern pike, largemouth bass, smallmouth bass, and panfish as "common", and walleye as "present", in Pewaukee Lake.[209] The extensive expanse of soft fine-grained sediment and abundant aquatic plant growth in the Lake's east basin formerly made Pewaukee Lake an excellent longnose gar lake. The Wisconsin Conservation Bulletin in 1937 noted that longnose gar were once abundant in the Lake, with gar observed "loafing about" at the surface of the water and a 56 inch gar reportedly caught.[210] However, the longnose gar population in Pewaukee Lake was reportedly purposely eliminated since it was thought that gar were competing with muskellunge. About 10,000 pounds of gar were removed from the Lake. While longnose gar have been observed in more recent surveys, it does not appear that they have returned to their historic abundance.

Wisconsin's high-quality warmwater fisheries are characterized as having many native species. Cyprinids, darters, suckers, sunfish, and percids typically dominate the fish assemblage. Pollution intolerant species

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[209] *Wisconsin Department of Natural Resources publication PUB-FH-800*, Wisconsin Lakes, *2005.*

[210] *G.C. Becker, "The Fishes of Pewaukee Lake,"* Wisconsin Academy of Sciences, Arts, and Letters*, 53: 19-27, 1964.*

(species that are particularly sensitive to water pollution and habitat degradation) are also common in such high-quality warmwater systems.[211] Pollution tolerant fish species (species that are capable of persisting under a wide range of degraded conditions) are typically present, but they do not dominate the fish fauna of these systems. Insectivores (fish that feed primarily on small invertebrates) and top carnivores (fish that feed on other fish, vertebrates, or large invertebrates) are generally common. Omnivores (fish that feed on both plant and animal material) also are generally common, but do not dominate. Simple lithophilous spawners (species that lay their eggs directly on large substrate, such as clean gravel or cobble without building a nest or providing parental care for the eggs) are generally common.

Stocking

Fish have been stocked in Pewaukee Lake since at least to the late 1800s, when walleye, bass, rainbow trout, and white bass were planted in the Lake, and when brook trout were stocked in some of the Lake's tributary streams.[212] Fish stocking records in Pewaukee Lake are presented in Table 2.28. Between 1895 and 1905, walleye was the predominant species stocked in Pewaukee Lake, with nearly 2,000,000 walleye stocked during this time period. In addition, 6,000 smallmouth bass were stocked in 1895 with another 5,000 stocked in 1903. In 1937, muskellunge, largemouth bass, crappie, bullhead, and bluegill were stocked into Pewaukee Lake for the first time.

A muskellunge management program, consisting of the stocking of muskellunge and *hybrid* (or, "tiger") muskellunge, and subsequent creel censi and surveys, was initiated during 1967. Since 1967, muskellunge and/or tiger muskellunge fingerling have been stocked into the Lake each year (aside from 1974, 1978, and 1979). The muskellunge stock program has been enthusiastically accepted by Southeastern Wisconsin anglers as the WDNR has demonstrated the Lake to be a remarkably productive muskellunge fishery. This survey led to the WDNR continuing and expanding the Lake's muskellunge management program.

Northern pike were stocked into the Lake nearly every year between 1991 through 2000, but only once since then, in 2014. Large numbers of walleye pike have been stocked on a fairly regular basis nearly every other year since 1980.

The Pewaukee chapter of Walleyes for Tomorrow (WFT) first met in May 2013 and currently has over 170 members and 15 local sponsors. WFT coordinates with the WDNR and operates to provide for stocking programs (such as the "Walleye Wagon") as well as to protect and improve habitat for walleye and northern pike in Pewaukee Lake through various fundraising events, activities, and community involvement. Since 2014, the WFT stocking efforts have included annual stocking of walleye fry as well as alternate year large fingerling walleye stocking.[213] Recognizing that Pewaukee Lake was suffering from a lack of young of the year walleye and northern pike, WFT members joined forces with the WDNR to approach the problem on several fronts. A "Walleye Wagon" was constructed that would become a portable fish hatchery where walleyes netted from the Lake would be used to gather and fertilize eggs; the newly hatched fry could then be released into the Lake. In addition, a strong emphasis was placed on improving fish habitat and providing suitable spawning sites in Pewaukee Lake through off-shore placement of rock structures, woody debris, and the first "fish sticks" project completed in Southeastern Wisconsin. Informational and educational programing has also been a part of the WFT program in Pewaukee Lake, as the organization has sponsored fish contests that promote "catch-and-release" practices.

Fish Surveys

Fishery surveys suggest that Pewaukee Lake contains a diverse and abundant fish community.[214] The Lake has been observed to contain a warmwater assemblage of about 32 species and a transitional or coolwater assemblage of about 13 species, including two designated species of special concern (banded killifish and lake chubsucker) and one threatened species (pugnose shiner) (see Table 2.29).

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[211] *J. Lyons,* Using the Index of Biotic Integrity (IBI) to Measure Environmental Quality in Warmwater Streams of Wisconsin*, United States Department of Agriculture, General Technical Report NC-149, 1992.*

[212] *Wisconsin Commissioners of Fisheries*, Biennial Report of the Commissioners of Fisheries of Wisconsin, *Democrat Printing Company, State Printer, 1884-1914.*

[213] *Personal Communication, Benjamin Heussner, WDNR, to Michael Borst, SEWRPC,* July 28, 2016.

[214] *See Table 25, SEWRPC Community Assistance Planning Report No. 58, 2nd Edition,* op. cit.

Table 2.28
Fish Stocked in Pewaukee Lake: 1937-2015

Year	Bluegill		Bullhead		Crappie		Channel Catfish		Largemouth Bass		Muskellunge	
	Number	Size[a]	Number	Size[a]	Number	Size[a]	Number	Size[a]	Number	Size[a]	Number	Size[a]
1937	21,750	Fingerling	5,000	Fingerling	3,750	Fingerling	--	--	24,500	Fingerling	145,400	Fry
1938	90	Adult	--	--	10,000	Fingerling	--	--	32,000	Fingerling	115	Fingerling
1938	44,000	Fingerling	--	--	--	--	--	--	--	--	--	--
1939	24,000	Fingerling	--	--	--	--	--	--	20,702	Fingerling	50	Fingerling
1939	--	--	--	--	--	--	--	--	--	--	60,000	Fry
1940	--	--	--	--	--	--	--	--	20,700	Fingerling	60,000	Fry
1941	2,000	Fingerling	--	--	--	--	--	--	25,000	Fingerling	--	--
1941	--	--	--	--	--	--	--	--	600	Yearling	--	--
1942	10,000	Fingerling	6,000	Fingerling	--	--	--	--	16,000	Fingerling	--	--
1942	350	Yearling	--	--	--	--	--	--	350	Yearling	--	--
1943	--	--	50,000	Fingerling	--	--	--	--	15,000	Fingerling	--	--
1944	200	Adult	10,000	Fingerling	--	--	--	--	10,000	Fingerling	--	--
1944	10,000	Fingerling	--	--	--	--	--	--	--	--	--	--
1945	6,000	Fingerling	--	--	--	--	--	--	7,000	Fingerling	--	--
1946	5,000	Fingerling	--	--	--	--	--	--	8,000	Fingerling	--	--
1947	--	--	--	--	--	--	--	--	13,000	Fingerling	--	--
1948	--	--	--	--	--	--	--	--	10,000	Fingerling	--	--
1949	--	--	--	--	--	--	--	--	--	--	--	--
1950	--	--	--	--	--	--	--	--	15,325	Fingerling	--	--
1951	--	--	--	--	--	--	--	--	2,000	Fingerling	--	--
1952	--	--	--	--	--	--	--	--	--	--	--	--
1953	--	--	--	--	--	--	--	--	9,192	Fingerling	--	--
1954-1955	--	--	--	--	--	--	--	--	--	--	--	--
1956	--	--	--	--	--	--	--	--	--	--	--	--
1957-1966	--	--	--	--	--	--	--	--	--	--	--	--
1967	--	--	--	--	--	--	--	--	--	--	2,400	Fingerling
1968	--	--	--	--	--	--	--	--	--	--	1,250	Fingerling
1969	--	--	--	--	--	--	--	--	--	--	1,200	Fingerling
1970	--	--	--	--	--	--	--	--	--	--	1,200	Fingerling
1971	--	--	--	--	--	--	--	--	--	--	2,000	Fingerling
1972	--	--	--	--	--	--	--	--	--	--	1,942	Fingerling
1973	--	--	--	--	--	--	--	--	--	--	2,864	Fingerling
1974	--	--	--	--	--	--	--	--	--	--	--	--
1975	--	--	--	--	--	--	--	--	--	--	--	--
1976	--	--	--	--	--	--	--	--	--	--	--	--
1977	--	--	--	--	--	--	--	--	--	--	--	--
1978-1979	--	--	--	--	--	--	--	--	--	--	--	--

Table continued on next page.

Table 2.28 (Continued)

Year	Bluegill		Bullhead		Crappie		Channel Catfish		Largemouth Bass		Muskellunge	
	Number	Size[a]	Number	Size[a]	Number	Size[a]	Year	Number	Size[a]	Number	Size[a]	Number
1980	--	--	--	--	--	--	--	--	--	--	1,470	Fingerling
1981	--	--	--	--	--	--	--	--	--	--	487	Fingerling
1982	--	--	--	--	--	--	--	--	--	--	1,250	Fingerling
1983	--	--	--	--	--	--	--	--	--	--	--	--
1984	--	--	--	--	--	--	--	--	--	--	1,550	Fingerling
1985	--	--	--	--	--	--	--	--	--	--	1,253	Fingerling
1986	--	--	--	--	--	--	--	--	--	--	2,090	Fingerling
1987	--	--	--	--	--	--	--	--	--	--	2,137	Fingerling
1988	--	--	--	--	--	--	--	--	--	--	3,000	Fingerling
1989	--	--	--	--	--	--	--	--	--	--	2,450	Fingerling
1990	--	--	--	--	--	--	4,000	Fingerling	--	--	1,033	Fingerling
1991	--	--	--	--	--	--	--	--	3,200	Fingerling	2,966	Fingerling
1992	--	--	--	--	--	--	--	--	--	--	6,236	Fingerling
1993	--	--	--	--	--	--	--	--	--	--	2,935	Fingerling
1994	--	--	--	--	--	--	--	--	--	--	893	Fingerling
1995	--	--	--	--	--	--	--	--	--	--	100	Fingerling
1996	--	--	--	--	--	--	--	--	--	--	5,381	Fingerling
1997	--	--	--	--	--	--	--	--	--	--	425	Fingerling
1998	--	--	--	--	--	--	--	--	--	--	2,484	Fingerling
1999	--	--	--	--	--	--	--	--	--	--	4,628	Yearling
2000	--	--	--	--	--	--	--	--	--	--	1,430	Fingerling
2001	--	--	--	--	--	--	--	--	--	--	5,000	Fingerling
2002	--	--	--	--	--	--	--	--	--	--	5,000	Fingerling
2003	--	--	--	--	--	--	--	--	--	--	2,497	Fingerling
2004	--	--	--	--	--	--	--	--	--	--	2,500	Fingerling
2005	--	--	--	--	--	--	--	--	--	--	2,500	Fingerling
2006	--	--	--	--	--	--	--	--	--	--	2,500	Fingerling
2007	--	--	--	--	--	--	--	--	--	--	550	Fingerling
2008	--	--	--	--	--	--	--	--	--	--	1,667	Fingerling
2009	--	--	--	--	--	--	--	--	--	--	2,500	Fingerling
2010	--	--	--	--	--	--	--	--	--	--	1,055	Fingerling
2011	--	--	--	--	--	--	--	--	--	--	4,874	Fingerling/ Yearling
2012	--	--	--	--	--	--	--	--	--	--	4,986	Fingerling
2013	--	--	--	--	--	--	--	--	--	--	2,612	Fingerling/ Yearling
2014	--	--	--	--	--	--	--	--	--	--	1,346	Fingerling
2015	--	--	--	--	--	--	--	--	--	--	1,780	Fingerling

Table continued on next page.

Table 2.28 (Continued)

Year	Muskellunge Hybrid		Northern Pike		Perch		Smallmouth Bass		Walleyed Pike		White Bass	
	Number	Size[a]	Number	Size[a]	Number	Size[a]	Number	Size[a]	Number	Size[a]	Number	Size[a]
1937	--	--	2,250	Fingerling	18,375,000	Fry	65	Adult	7,071,300	Fry	--	--
1937	--	--	--	--	19,975	Fingerling	--	--	--	--	--	--
1937	--	--	--	--	9,000	Adult	--	--	--	--	--	--
1938	--	--	233,824	Fry	15,482,880	Eggs	--	--	5,835,000	Fry	--	--
1938	--	--	5,000	Fingerling	148,000	Fingerling	--	--	--	--	--	--
1939	--	--	143,000	Fry	--	--	--	--	6,944,800	Fry	--	--
1940	--	--	219,210	Fry	--	--	--	--	6,432,760	Fry	--	--
1941	--	--	--	--	--	--	--	--	6,400,000	Fry	--	--
1942	--	--	--	--	--	--	--	--	3,500,000	Fry	--	--
1943	--	--	--	--	4,000	Fingerling	--	--	5,000,000	Fry	12,000	Fingerling
1944	--	--	--	--	--	--	--	--	1,500,000	Fry	--	--
1945	--	--	--	--	--	--	--	--	2,000	Fingerling	--	--
1945	--	--	--	--	--	--	--	--	1,150,000	Fry	--	--
1946	--	--	--	--	--	--	--	--	2,000	Fingerling	--	--
1946	--	--	--	--	--	--	--	--	5,200,000	Fry	--	--
1947	--	--	--	--	--	--	--	--	5,200,000	Fry	--	--
1948	--	--	--	--	--	--	--	--	5,200,000	Fry	--	--
1949	--	--	--	--	--	--	--	--	5,250	Fingerling	--	--
1950	--	--	--	--	--	--	--	--	--	--	--	--
1951	--	--	--	--	--	--	--	--	7,250	Fingerling	--	--
1952	--	--	500	Fingerling	--	--	--	--	41,064	Fingerling	--	--
1953	--	--	--	--	--	--	--	--	--	--	--	--
1954-1955	--		--	--	--	--	--	--	--	--	--	--
1956	--	--	--	--	--	--	--	--	9,400	Fingerling	--	--
1957-1966	--	--	--	--	--	--	--	--	--	--	--	--
1967	--	--	--	--	--	--	--	--	--	--	--	--
1968	--	--	--	--	--	--	--	--	--	--	--	--
1969	--	--	--	--	--	--	--	--	--	--	--	--
1970	--	--	--	--	--	--	--	--	--	--	--	--
1971	--	--	--	--	--	--	--	--	--	--	--	--
1972	--	--	--	--	--	--	--	--	--	--	--	--
1973	--	--	--	--	--	--	--	--	--	--	--	--
1974	--	--	--	--	--	--	--	--	--	--	--	--
1975	1,850	Fingerling	--	--	--	--	--	--	--	--	--	--
1976	3,678	Fingerling	--	--	--	--	--	--	--	--	--	--
1977	4,272	Fingerling	--	--	--	--	--	--	--	--	--	--
1978-1979	--	--	--	--	--	--	--	--	--	--	--	--
1980	850	Fingerling	--	--	--	--	--	--	37,473	Fingerling	--	--
1981	2,550	Fingerling	--	--	--	--	--	--	3,000,000	Fry	--	--

Table continued on next page.

Table 2.28 (Continued)

	Muskellunge Hybrid		Northern Pike		Perch		Smallmouth Bass		Walleyed Pike		White Bass	
Year	Number	Size[a]	Number	Size[a]	Number	Size[a]	**Year**	Number	Size[a]	Number	Size[a]	Number
1982	1,963	Fingerling	--	--	--	--	--	--	101,925	Fingerling	--	--
1983	3,500	Fingerling	--	--	--	--	--	--	89,124	Fingerling	--	--
1984	1,280	Fingerling	1,970	Fingerling	--	--	--	--	2,500,000	Fry	--	--
1985	3,528	Fingerling	--	--	--	--	--	--	103,643	Fingerling	--	--
1986	1,250	Fingerling	--	--	--	--	--	--	66,488	Fingerling	--	--
1987	1,000	Fingerling	--	--	--	--	--	--	10,080	Fingerling	--	--
1988	1,000	Fingerling	--	--	--	--	--	--	--	--	--	--
1989	1,000	Fingerling	--	--	--	--	--	--	38,185	Fingerling	--	--
1990	--	--	--	--	--	--	--	--	100,000	Fingerling	--	--
1991	--	--	2,500	Fingerling	--	--	--	--	70,000	Fingerling	--	--
1992	--	--	2,500	Fingerling	--	--	--	--	106,886	Fingerling	--	--
1993	--	--	2,500	Fingerling	--	--	--	--	--	--	--	--
1994	--	--	1,560	Fingerling	--	--	--	--	98,296	Fingerling	--	--
1995	--	--	--	--	--	--	--	--	--	--	--	--
1996	--	--	2,105	Fingerling	--	--	--	--	100,000	Fingerling	--	--
1997	--	--	--	--	--	--	--	--	--	--	--	--
1998	--	--	4,754	Fingerling	--	--	--	--	235,468	Fingerling	--	--
1999	--	--	2,360	Fingerling	--	--	--	--	--	--	--	--
2000	4	Yearling	--	--	--	--	--	--	249,300	Fingerling	--	--
2001	--	--	--	--	--	--	--	--	--	--	--	--
2002	--	--	--	--	--	--	--	--	69,888	Fingerling	--	--
2003	--	--	--	--	--	--	--	--	--	--	--	--
2004	--	--	--	--	--	--	--	--	107,516	Fingerling	--	--
2005	--	--	--	--	--	--	--	--	--	--	--	--
2006	--	--	--	--	--	--	--	--	87,513	Fingerling	--	--
2007	--	--	--	--	--	--	--	--	--	--	--	--
2008	--	--	--	--	--	--	--	--	--	--	--	--
2009	--	--	--	--	--	--	--	--	--	--	--	--
2010	--	--	--	--	--	--	--	--	87,255	Fingerling	--	--
2011	--	--	--	--	--	--	--	--	--	--	--	--
2012	--	--	--	--	--	--	--	--	87,255	Fingerling	--	--
2013	--	--	--	--	--	--	--	--	--	--	--	--
2014	--	--	2,500	Fingerling	--	--	--	--	36,984	Fingerling	--	--
2015	--	--	5,450	Fingerling	--	--	--	--	4,540,000	Fry	--	--

[a] *A fry is a newly hatched fish, a fingerling is a fish in its first year, and a yearling is an immature fish.*

Source: Wisconsin Department of Natural Resources and SEWRPC

Table 2.29
Fish Species Physiological Tolerance by Stream and Reach Within the Pewaukee Lake Watershed: 1964-2015

Fish Species According to Their Relative Tolerance to Pollution	Stream Reach or Lake (see Map 2.33)					
	Coco Creek					Pewaukee Lake
	2006[a]	1999	2011	2011	2015	1964-2012
Coldwater						
Intermediate						
Brown Trout[b]	--	--	--	X	X	--
Transitional						
Sensitive						
Blackchin Shiner	--	--	--	--	--	X
Blacknose Shiner	--	--	--	--	--	X
Muskellunge	--	--	--	--	--	X
Northern Pike	--	--	--	--	--	X
Pugnose Shiner[c]	--	--	--	--	--	X
Intermediate						
Johnny Darter	--	--	--	--	X	X
Northern Pike x Muskellunge Hybrid	--	--	--	--	--	X
Walleye	--	--	--	--	--	X
Yellow Perch	--	X	X	X	--	X
Tolerant						
Brook Stickleback	--	--	--	--	--	X
Central Mudminnow	X	X	X	X	X	X
Creek Chub	--	X	--	--	--	X
White Sucker	--	X	X	X	--	X
Warmwater						
Sensitive						
Rock Bass	--	--	--	--	--	X
Smallmouth Bass	--	--	--	--	--	X
Spottail Shiner	--	--	--	--	--	X
Intermediate						
Banded Killifish[d]	--	--	--	--	--	X
Bigmouth Shiner	--	--	--	--	--	X
Black Crappie	--	--	--	--	--	X
Bluegill	--	X	X	X	X	X
Bowfin	--	--	--	--	--	X
Brook Silverside	--	--	--	--	--	X
Brown Bullhead	--	--	--	--	--	X
Common Shiner	--	X	--	--	--	X
Emerald Shiner	--	--	--	--	--	X
Freshwater Drum	--	--	--	--	--	X
Grass Pickerel	--	--	--	--	--	X
Hornyhead Chub	--	X	--	--	--	--
Lake Chubsucker[d]	--	--	--	--	--	X
Largemouth Bass	--	--	--	X	--	X
Longnose Gar	--	--	--	--	--	X
Mimic Shiner	--	--	--	--	--	X
Pumpkinseed	--	--	X	X	X	X
Spotfin Shiner	--	--	--	--	--	X
Tadpole Madtom	--	--	--	--	--	X
Warmouth	--	--	--	--	--	X
White Bass	--	--	--	--	--	X
White Crappie	--	--	--	--	--	X

Table continued on next page.

Table 2.29 (Continued)

Fish Species According to Their Relative Tolerance to Pollution	Stream Reach or Lake (see Map 2.33)					
	Coco Creek					Pewaukee Lake
	2006[a]	1999	2011	2011	2015	1964-2012
Warmwater (continued)						
Tolerant						
Black Bullhead	--	--	--	--	--	X
Bluntnose Minnow	X	--	--	--	--	X
Common Carp	--	--	--	--	--	X
Fathead Minnow	--	X	--	--	--	X
Golden Shiner	--	--	X	--	--	X
Goldfish	--	--	--	--	--	X
Green Sunfish	--	--	X	X	X	X
Yellow Bullhead	--	X	--	--	--	X
Total Number of Species	2	9	7	8	6	45
Warmwater IBI Qualitative Score	--	--	--	--	--	--
Cool-Cold Transition IBI Qualitative Score	--	Fair	Fair	Good	Good	--
Coldwater IBI Qualitative Score	--	Very poor	Very poor	Fair	Fair	--

[a] *Sampling at this site was for a study focused on minnow species. Other non-minnow species sampled at for this site were not recorded.*

[b] *This species is stocked by Wisconsin Department of Natural Resources fisheries management staff.*

[c] *Designated threatened species.*

[d] *Designated species of special concern.*

Source: Wisconsin Department of Natural Resources, Wisconsin Lutheran College, and SEWRPC

Wisconsin Lutheran College conducted a fish survey of Pewaukee Lake during July through October, 2006.[215] Sampling was done at 13 locations within 30 feet of shore around the Lake with one additional station located in Coco Creek. Nearly 1,100 fish were collected with the most abundant species being bluntnose minnow. Among those species not part of the minnow and small fish assemblage, bluegill were the most abundant.

The WDNR has completed numerous fish surveys, including creel surveys, in Pewaukee Lake dating back at least to 1944. The WDNR Lake Use Report (FX-2) for Pewaukee Lake includes a 1964 WDNR survey. Other WDNR survey reports include a 1982 published report of a creel survey, a 1987 creel survey reported on in Fish Management Report Number 131, a 1991 published survey (FM-800-91), electrofishing reports from 1993 and 1999, and a 1998 comprehensive fish survey. Highlights from recent (2011-2012) WDNR comprehensive surveys targeting muskellunge, walleye, largemouth bass, smallmouth bass, northern pike and panfish are summarized below.[216]

- Muskellunge, a fish not native to inland waters of Southeastern Wisconsin, are entirely dependent on an intensive stocking program. Similarly, walleye and northern pike populations appear to be significantly supported by stocking.

- Stocking efforts have produced a muskellunge population density well above the Wisconsin statewide average. The 2011-2012 assessment resulted in a muskellunge population estimate of 0.62 fish per acre which is one-tenth of a fish per acre higher than the previous estimate performed during the 1998 comprehensive assessment. The current assessment indicates muskellunge size structure is fairly balanced with the vast majority of fish measuring 30-39 inches. Fish below 30 inches or over 40 inches were infrequently captured during the 2011-2012 assessment. The highlight of these fish was a 50.2 inch female muskellunge captured in 2012 that weighed over 40 pounds. Muskellunge in Pewaukee Lake grow at a rate faster than the Wisconsin statewide average. Mortality for muskellunge was calculated to be 46.6 percent beginning at age five or, 33.5 inches.

[215] *Wisconsin Lutheran College,* Minnow and Small Fish Assemblages of Pewaukee Lake, Wisconsin, *2006.*

[216] *B. Heussner, S. Gospodarek, and A. Notbohm,* Comprehensive Survey Report of Pewaukee Lake, Waukesha County (WBIC 772000), *Wisconsin Department of Natural Resources, 2012.*

Although this length is below the 40-inch minimum for angler harvest, angling pressure could contribute to this mortality rate as a result of added stress during warm water months when musky are frequently targeted and susceptible to hooking mortality.

- Walleye populations in Pewaukee Lake have historically been low. Unfortunately, the 2011-2012 assessment showed little change as the number of adult walleye per acre was calculated to be 0.4 per surface acre. This estimate is lower than those of the 1998 and 1977 assessments and is likely a result of inconsistent stocking during the past decade. Average lengths, proportional stock density (PSD) and relative stock density (RSD) indicate a top heavy walleye size structure stemming from a majority of older fish in the system. According to the 2011-2012 assessment, walleye grow quickly until age six where growth appears to slow significantly. The estimated annual walleye mortality rate is 51 percent beginning at age six or 21.1 inches.

- Largemouth bass were captured with mild success during the spring 2011 portion of the two year comprehensive assessment. Average length and size structure has increased since the 1998 assessment but the largemouth in Pewaukee Lake are still of average size when compared to other Waukesha County lakes that have been surveyed recently. Like most species in Pewaukee Lake, largemouth bass grow at a rate that is faster than the Wisconsin statewide average.

- Smallmouth bass were also captured in spring of 2011, but catch rates were lower when compared to largemouth. Average size and size structure have increased since the 1998 assessment. Pewaukee Lake's smallmouth are some of the largest in Waukesha County. Over 70 percent were at or above the 14-inch minimum length limit for angler harvest and several fish between 18 to 21 inches were captured.

- Northern pike fyke netting catch was low, indicating a significant drop in northern numbers since the 1998 assessment. An absence of stocking is likely the culprit for this reduction of northern pike numbers, although competition with muskellunge and a lack of spawning habitat may be contributing factors.

- Panfish were plentiful, but size structures were small during the 2011-2012 assessment. Small panfish size structure and over-abundance is a common problem in lakes, such as Pewaukee, that contain dense EWM beds. In addition to thick milfoil, angler selective harvest of larger panfish may also be a contributing factor.

In the spring of 2013, northern pike were observed to have migrated upstream from Pewaukee Lake to spawn in the unnamed eastern branch of Coco Creek, as well as upstream to the unnamed tributary in the headwaters of Meadowbrook Creek. These observations indicate how good connections between the Lake and tributaries can facilitate production of northern pike in this system. Refer to Chapter 3 for management recommendations geared towards safeguarding these spawning stocks to protect and enhance the natural reproduction of these populations.

Tributary Classification

The Pewaukee Lake watershed contains both warmwater (Meadowbrook Creek, Zion Creek) and coldwater (Coco Creek) tributary streams. Coldwater systems are characterized by few native species, with salmonids (trout) and cottids (sculpin) dominating, and they lack many of the taxonomic groups that are important in high-quality warmwater streams. An increase in fish species richness in coldwater fish assemblages often indicates environmental degradation. When degradation occurs, the small number of coldwater species is replaced by a larger number of more physiologically tolerant cool and warmwater species, which is the opposite of what tends to occur in warmwater fish assemblages.

A stream model has recently been developed by the WDNR to classify stream reaches into their biotic community by fish occurrence and abundance, as well as the ecological conditions that largely determine the biotic community (i.e., stream flow and water temperature).[217] Although this model has some limitations,

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[217] *J. Lyons, "Patterns in the Species Composition of Fish Assemblages Among Wisconsin Streams,"* Environmental Biology of Fishes, *45: 329-341, 1996.*

it does provide an objective, standardized, and ecologically meaningful framework to classify streams.[218] The proposed natural community classification has eleven natural community classes, as summarized in Table 2.30.[219]

Results of the stream model corroborate the coldwater classification on Coco Creek as shown on Map 2.33. The cool headwater (cold transitional) classification was predicted by the model for the unnamed east branch of Coco Creek, which was also generally supported by water temperature data summarized above. Zion Creek was classified as a cold headwater fishery to a cool headwater fishery. Although no temperature data are available for the headwaters of this system, the temperatures from the lower reaches of this creek indicate that this is more appropriately classified as a warm headwater stream (see Section 2.5, "Water Quality" for discussion of stream temperatures). In addition, the entire unnamed eastern branch of Zion Creek was ranked with a macroinvertebrate classification, which is probably appropriate, but no information exists to verify this classification. The stream model also predicted that Meadowbrook Creek transitions from a warm headwater to a cool headwater classification, but more information would need to be collected in order to verify these classifications.

Fish Communities

A review of the fish data collected in Coco Creek between 2011 and 2012 indicates that the lower portions of Creek were found to have between seven and nine species per survey. As previously mentioned, healthy coldwater streams are comprised of a lower number of species compared to healthy warmwater streams, so this low number of species is a good sign for Coco Creek. The surveys also indicate that this fishery contains a mixture of warmwater tolerant, transitional or coolwater species, and one sensitive coldwater species. The warmwater tolerant and intermediate species include yellow bullhead, green sunfish, golden shiner, fathead minnow, bluntnose minnow, pumpkinseed, largemouth bass, bluegill, common shiner, and hornyhead chub. Yellow bullhead, green sunfish, pumpkinseed, bluegill, and largemouth bass species are not usually found in high-quality coldwater streams, but since these are found in high abundance in Pewaukee Lake it is not unusual for these species to migrate up into the lower reaches of Coco Creek. The transitional or coolwater species observed in Coco Creek include white sucker, creek chub, central mudminnow, and yellow perch. Finally, brown trout were the only coldwater sensitive species found in Coco Creek.

Fish Index of Biotic Integrity

Coco Creek was sampled in 1999 and 2011, and achieved fair-good cool-cold IBI scores and very poor-fair coldwater IBI scores. These results indicate that Coco Creek has a cool to coldwater fish assemblage, except for the absence of brook trout in these samples. Since brook trout are the only native stream-dwelling salmonid in Wisconsin, the presence and abundance of brook trout dramatically improves the IBI score. The cool water temperature data and the presence of brook trout indicate the capacity to support salmonids. Brook trout may be absent from Coco Creek due to their displacement by brown trout, which may be favored by competition, degradation of habitat, and lack of parasites.[220] No fish surveys have been conducted on other tributaries of Pewaukee Lake, so the IBI cannot be assessed for these tributaries.

Fisheries Summary

Pewaukee Lake contains the most diverse and abundant fish community within the Pewaukee River watershed. The Lake has a long history of stocking and a reputation for a good sport fishery, largely the result of the efforts of local sport fishing and other groups. The Lake's tributaries also play a significant role in the health of the Pewaukee Lake fishery, providing habitat for warm, cool, and coldwater species as well as for northern pike spawning. As increased urbanization pressure occurs in the Lake's watershed, continued vigilance and proactive measures will be necessary to protect this valuable natural resource for future generations. Management recommendations for the protections of Pewaukee Lake watershed fisheries are provided in Section 3.7, "Fish and Wildlife".

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[218] *J. Lyons,* An Overview of the Wisconsin Stream Model*, Wisconsin Department of Natural Resources, 2007.*

[219] *J. Lyons,* Proposed Temperature and Flow Criteria for Natural Communities for Flowing Waters*, Wisconsin Department of Natural Resources, February 2008, updated October 2012.*

[220] *Wisconsin Department of Natural Resources Bureau of Fisheries Management,* Wisconsin Inland Trout Management Plan 2020-2029*, 2019.*

Table 2.30
Water Temperature and Flow Criteria Defining Natural Stream Community Type and Biotic Integrity

Natural Community	Maximum Daily Mean Water Temperature (°F)	Annual 90 Percent Exceedence Flow (ft^3/s)	Primary Index of Biotic Integrity
Ephemeral	Any	0.0	N/A
Macroinvertebrate	Any	0.0-0.03	Macroinvertebrate
Cold Headwater	<69.3	0.03 -1.0	Coldwater Fish
Cold Mainstem	<69.3	>1.0	Coldwater Fish
Cool (Cold-Transition) Headwater	69.3-72.5	0.03-3.0	Headwater Fish
Cool (Cold-Transition) Mainstem	69.3-72.5	>3.0	Cool-Cold Transition Fish
Cool (Warm-Transition) Headwater	72.6-76.3	0.03-3.0	Headwater Fish
Cool (Warm-Transition) Mainstem	72.6-76.3	>3.0	Cool-Warm Transition Fish
Warm Headwater	>76.3	0.03-3.0	Headwater Fish
Warm Mainstem	>76.3	3.0-110.0	Warmwater Fish
Warm River	>76.3	>110.0	River Fish

Note: for further information on stream natural community types, visit the WDNR's webpage explaining stream natural communities: dnr.wi.gov/topic/rivers/naturalcommunities.html.

Source: References for IBIs: Macroinvertebrate–Weigel 2003; Coldwater Fish–Lyons et al. 1996; Headwater Fish–Lyons 2006; Coolwater Fish–Lyons, in preparation; Warmwater Fish–Lyons 1992; River Fish–Lyons et al. 2001

2.10 OTHER WILDLIFE

A healthy wildlife population, including deer, amphibians, birds, small mammals, etc. is the ultimate indication of a healthy watershed. Although the quality of lakes, streams, and rivers is often assessed based on measures of the chemical or physical properties of water, a more comprehensive perspective is obtained if resident biological communities (including wildlife) are also assessed. Guidelines to protect human health and aquatic life have been established for specific physical and chemical properties of water and have become useful yardsticks with which to assess water quality. Biological communities provide additional crucial information because they live within the watershed for weeks to years and therefore integrate through time the effects of changes to their chemical or physical environment.[221]

In addition, biological communities are a direct measure of waterbody health—an indicator of the ability of a waterbody to support aquatic life. Thus, the condition of biological communities, integrated with key physical and chemical properties, provides a comprehensive assessment of waterbody health. The presence and abundance of species in a biological community are a function of the inherent requirements of each species for specific ranges of physical and chemical conditions. Therefore, when changes in land and water use in a waterbody cause physical or chemical properties to exceed their natural ranges, vulnerable aquatic species are eliminated, which ultimately impairs the biological condition and waterbody health.[222]

Aquatic and terrestrial wildlife communities have educational and aesthetic values, perform important functions in the ecological system, and are the basis for certain recreational activities. The location, extent, and quality of fishery and wildlife areas and the type of fish and wildlife characteristic of those areas are important determinants of the overall quality of the environment in the Pewaukee Lake watershed.

Aquatic Animals

Aquatic animals include microscopic zooplankton; benthic, or bottom-dwelling, invertebrates; fish; reptiles and amphibians; mammals; and waterfowl and other birds that inhabit the Lake and its shorelands. These make up the primary and secondary consumers of the food web.

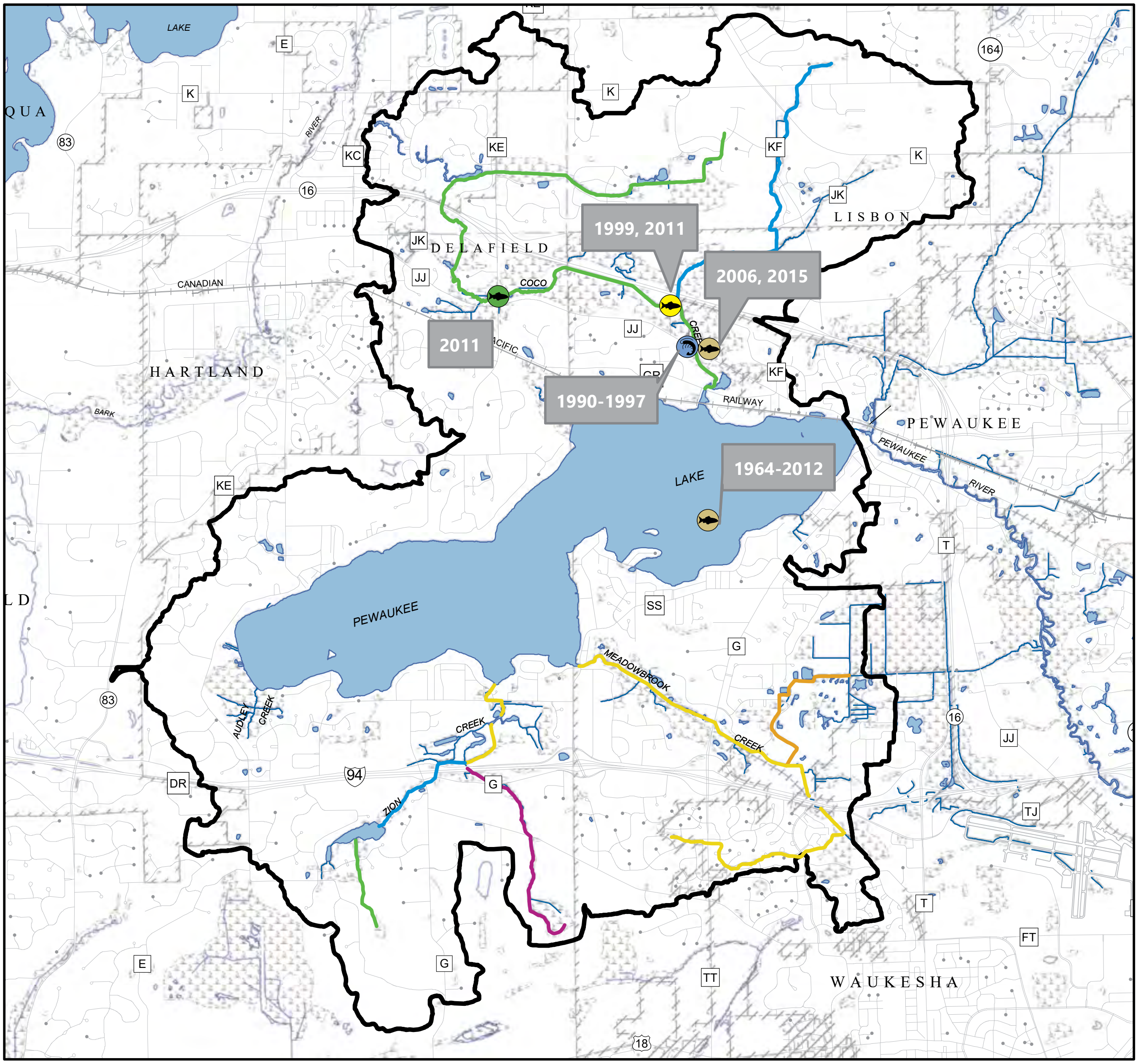
Zooplankton

Zooplankton are microscopic animals that inhabit the same environment as phytoplankton, the microscopic plants. An important link in the food chain, zooplankton feed mostly on algae and, in turn, are a good

[221] *Carlisle et al., 2013,* op. cit.

[222] *Ibid.*

Map 2.33
Pewaukee Lake Tributary Stream Classification with Fish and Macroinvertebrate Biotic Index Surveys: 1964-2015



FISH IBI RATING AND SITE ID

- GOOD
- FAIR
- UNRATED

AQUATIC BUGS HBI RATING AND SITE ID

- GOOD TO VERY GOOD

- COLD HEADWATER
- COOL (COLD TRANSITION) HEADWATER
- COOL (WARM TRANSITION) HEADWATER
- WARM HEADWATER
- MACROINVERTEBRATE
- SURFACE WATER
- UNCLASSIFIED STREAM
- WATERSHED BOUNDARY
- WETLAND

N

0 3,200 6,400 Feet

Note: The text box indicates the survey year.

Source: Wisconsin Department of Natural Resources, Wisconsin Lutheran College, and SEWRPC

food source for fish. Zooplankton surveys were conducted on the Lake in 1976, 1986, 2000, and 2002. A study conducted in 1976 reported crustacean zooplankton in varying abundances in Pewaukee Lake with populations of most zooplankton species peaking during spring and fall.[223] Additional sampling of zooplankton was done at three sites on Pewaukee Lake by the Wisconsin Lutheran College, during July and August 2000.[224] Fourteen different types of zooplankton were identified in this study.

Lake Benthic Invertebrates

The benthic, or bottom dwelling, faunal communities of lakes include such organisms as sludge worms, midges, and caddisfly larvae. These organisms are an important part of the food chain, acting as processors of organic material that accumulates on the lake bottom. Some benthic fauna are opportunistic in their feeding habits, while others are predaceous. The diversity of benthic faunal communities can be used as an indicator of lake trophic status. In general, a reduced or limited diversity of organisms present is indicative of a eutrophic lake; however, there is no single "indicator organism." Rather, the entire community must be assessed to determine trophic status as populations can fluctuate widely through the year and between years as a consequence of season, climatic variability, and localized water quality changes.

The benthic fauna population of Pewaukee Lake was sampled during the early spring of 1976 and 1977 prior to metamorphosis and emergence of adult benthic organisms.[225] At the time of the 1976 and 1977 surveys, Pewaukee Lake had a relatively diverse benthic fauna.[226]

The benthic fauna of Pewaukee Lake also were sampled by the Wisconsin Lutheran College during June, July and August of 2000. This study found 18 types of macroinvertebrates including mayfly nymphs, scuds, and midge and phantom midge larvae.

Nonnative and Invasive Aquatic Animals

The introduction of nonnative aquatic animals to a waterbody can disturb food webs, ultimately impacting water quality, habitat, and potentially recreational use. However, not all nonnative animals are invasive or cause severe negative impacts to lake ecosystems. This subsection describes the environmental impacts of the three nonnative animal species found in Pewaukee Lake. Methods for managing invasive species are described in Chapter 3.

Zebra Mussels

Populations of zebra mussel (*Dreissena polymorpha* – see Figure 2.83), a nonnative species of mussel, have been verified in Pewaukee Lake since 2004. Zebra mussels are small fingernail-size clams with D-shaped shells. Adults typically range from one-quarter to one and one-half inch in size. The shells commonly have yellow and brownish stripes. This invasive species reproduces rapidly (females can produce up to a half million eggs per year) forming colonies on nearly any clean, hard, flat underwater surface. This behavior has caused the zebra mussel to become a costly nuisance to humans as massive populations of the mollusk have clogged municipal water intake pipes and fouled underwater equipment. Zebra mussels feed by filtering small plants, animals, and particles from the water column, an action that deprives native zooplankton (small aquatic animals that form an important food source for many larger organisms), native mussels, juvenile and larval fish, and many other organisms of key food sources.

The filter feeding proclivity of zebra mussels has led to improved water clarity in many lakes. Ironically, improved water clarity has sometimes, in turn, increased growth of rooted aquatic plants, including EWM. A

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[223] *For a more detailed description of the results of this study, see SEWRPC Community Assistance Planning Report No. 58, 2nd Edition,* op. cit.

[224] *A.L. Schmoldt and R.C. Anderson,* Southeast Wisconsin's Pewaukee Lake Biological Evaluation 2000, *Wisconsin Lutheran College, Biology Department, Technical Bulletin 002, May 2001.*

[225] *Samples were collected in the deep basin in the western portion of the Lake, and processed by sieving through a 60-mesh sieve; samples were preserved in 95 percent ethyl alcohol. The larvae were picked from the debris, counted, and classified. Chironomid larvae, however, were not reared to adult stages and, therefore, species identification must be considered tentative.*

[226] *For a more detailed description of the results of this study, see SEWRPC Community Assistance Planning Report No. 58, 2nd Edition,* op. cit.

curious interplay between zebra mussels, water clarity, EWM, and native aquatic plants has been observed within Southeastern Wisconsin. Zebra mussels have been observed to attach themselves to stems of the EWM plants (see Figure 2.83). The increased weight of the shells and live mussels drags the plant deeper below the surface and partially out of the *photic zone* (the depth to which sufficient sunlight penetrates lake water to support photosynthesis). This interferes with the competitive strategy of the EWM plants and has sometimes contributed to regrowth of beneficial native aquatic plants. In other instances, decreased EWM has led to nuisance growths of filamentous algae (which is too large to be ingested by the zebra mussels). Regardless of the seemingly beneficial impact of zebra mussels on water clarity, the overall environmental, aesthetic, and economic tolls of invasive aquatic animals on lake ecosystems and recreational resource values generally outweigh positive factors.

Figure 2.83
Zebra Mussels Attached to Eurasian Watermilfoil

Source: SEWRPC

Chinese Mystery Snail

Native to eastern Asia, Chinese mystery snails have been found in many Wisconsin waterbodies following their introduction to the Great Lakes area in the 1930s or 40s. However, not much is known about the impacts of these species to lake ecosystems, except that they may have a negative effect on native snail populations.[227] These animals prefer soft sediment, which they scrape and consume from the lake bottom. The presence of Chinese mystery snails in Pewaukee Lake was verified by WDNR on April 1, 2010.

Other Wildlife

Although a quantitative field inventory of amphibians, reptiles, birds, and mammals was not conducted as a part of the current Pewaukee Lake study, a list of species observed during past field visits in the area of the Pewaukee Lake watershed includes: whitetail deer, beaver, raccoon, opossum, squirrel, chipmunk, rabbit, green frog, Blanding's turtle, sandhill cranes, great blue herons, wild turkeys, and various songbirds. Also, it is possible, by polling naturalists and wildlife managers familiar with the area, to complete a list of amphibians, reptiles, birds, and mammals that may be expected to be found in the area under existing conditions. The technique used in compiling the wildlife data involved obtaining lists of those amphibians, reptiles, birds, and mammals known to exist, or known to have existed, in the Pewaukee Lake area, associating these lists with the historic and remaining habitat areas in the Pewaukee Lake area as inventoried, and projecting the appropriate amphibian, reptile, bird, and mammal species into the Pewaukee Lake area. The net result of the application of this technique is a listing of those species that were probably once present in the drainage area, those species that may be expected to still be present under currently prevailing conditions, and those species that may be expected to be lost or gained as a result of urbanization within the area.

Amphibians and Reptiles

Amphibians and reptiles are vital components of ecosystems within the Pewaukee Lake watershed. Table 2.31 lists those amphibian and reptile species normally expected to be present in the Pewaukee Lake watershed under present conditions and identifies those species most sensitive to urbanization.

Most amphibians and reptiles have definite habitat requirements that are adversely affected by advancing urban development, as well as by certain agricultural land management practices. The major detrimental factors affecting the maintenance of amphibians in a changing environment is the destruction of breeding ponds, urban development occurring in migration routes, and changes in food sources brought about by urbanization.

[227] *See nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=1044.*

Table 2.31
Amphibians and Reptiles Likely Present Within the Pewaukee Lake Watershed

Common Name	Scientific Name	Species Reduced or Dispersed with Complete Urbanization	Species Lost with Complete Urbanization
Amphibians			
Proteidae Family			
Mudpuppy	*Necturus maculosus maculosus*	X	--
Ambystomatidae Family			
Blue-Spotted Salamander	*Ambystoma laterale*	--	X
Spotted Salamander	*Ambystoma maculatum*	X	X
Eastern Tiger Salamander	*Ambystoma tigrinum tigrinum*	X	--
Salamandridae Family			
Central Newt	*Notophthalmus viridescens louisianensis*	X	--
Bufonidae Family			
American Toad	*Bufo americanus americanus*	X	--
Hylidae Family			
Western Chorus Frog	*Pseudacris triseriata triseriata*	X	--
Blanchard's Cricket Frog[a,b]	*Acris blanchardi*	X	--
Northern Spring Peeper	*Hyla crucifer crucifer*	--	X
Gray Tree Frog	*Hyla versicolor*	--	X
Ranidae Family			
American Bullfrog[c]	*Lithobates catesbeiana*	--	X
Green Frog	*Lithobates clamitans melanota*	X	--
Northern Leopard Frog	*Lithobates pipiens*	--	X
Pickerel Frog[c]	*Lithobates palustris*	--	X
Reptiles			
Chelydridae Family			
Common Snapping Turtle	*Chelydra serpentina serpentina*	X	--
Kinosternidae Family			
Musk Turtle (stinkpot)	*Sternotherus odoratus*	X	--
Emydidae Family			
Western Painted Turtle	*Chrysemys picta belli*	X	--
Midland Painted Turtle	*Chrysemys picta marginata*	X	--
Blanding's Turtle[d]	*Emydoidea blandingii*	--	X
Trionychidea Family			
Eastern Spiny Softshell	*Trionyx spiniferus spiniferus*	X	--
Colubridae Family			
Northern Water Snake	*Nerodia sipedon sipedon*	X	--
Midland Brown Snake	*Storeria dekayi wrightorum*	X	--
Northern Red-Bellied Snake	*Storeria occipitomaculata occipitomaculata*	X	--
Eastern Garter Snake	*Thamnophis sirtalis sirtalis*	X	--
Chicago Garter Snake	*Thamnophis sirtalis semifasciatus*	X	--
Butler's Garter Snake[d]	*Thamnophis butleri*	X	--
Eastern Hognose Snake	*Heterodon platirhinos*	--	X
Smooth Green Snake	*Opheodrys vernalis vernalis*	--	X
Eastern Milk Snake	*Lampropeltis triangulum triangulum*	--	X

[a] *Likely to be extirpated from the watershed.*

[b] *State-designated endangered species.*

[c] *State-designated special concern species.*

[d] *State-designated threatened species.*

Source: Gary S. Casper, Geographical Distribution of the Amphibians and Reptiles of Wisconsin, 1996, Wisconsin Department of Natural Resources, Kettle Moraine State Forest, Lapham Peak Unit; and SEWRPC

Birds and Mammals

A large number of birds, ranging in size from large game birds to small songbirds, may also be found in the Pewaukee Lake area. Table 2.32 lists those birds that normally occur in the watershed. Each bird is classified as to whether it breeds within the area, visits the area only during the annual migration periods, or visits the area only on rare occasions. The Pewaukee Lake watershed supports a significant population of waterfowl, including mallard and teal. Larger numbers of birds move through the drainage area during migrations when most of the regional species may also be present; ospreys and loons are notable migratory visitors.

Because of the mixture of natural lands still present in the area, along with the favorable summer climate, the area supports many other species of birds. Hawks, owls, swallows, whippoorwills, woodpeckers, nuthatches, flycatchers, robins, red-winged blackbirds, orioles, cardinals, kingfishers, and mourning doves provide valuable ecological roles and many serve as subjects for bird watchers and photographers. Threatened species migrating in the vicinity of Pewaukee Lake include the Cerulean warblers, the Acadian flycatcher, great egret, and the Osprey. Endangered species migrating in the vicinity of Pewaukee Lake include the common tern, Caspian tern, Forster's tern, and the loggerhead shrike.

A variety of mammals, ranging in size from large animals like the northern white-tailed deer to small animals like the least shrew, can be expected to be found in the Pewaukee Lake area. Mink, muskrat, beaver, white-tailed deer, red and grey fox, grey and fox squirrel, and cottontail rabbits are mammals reported to frequent the area. Table 2.33 lists those mammal species whose ranges are known to extend into the Pewaukee Lake area.

Species of Concern

While Southeastern Wisconsin has historically supported a wide variety of plant communities and attendant wildlife species, increased pressure from urban development and agriculture have had significant and adverse impacts on local biota. Many habitat types have been virtually eliminated and most have been seriously degraded. As habitat is lost, so, typically, are the species dependent on that habitat. The result for many species has been local and regional elimination, and for some, even extirpation. Table 2.34 lists those species of vertebrate animals that have been documented as having existed at the time of initial European settlement but have since disappeared from the Region.

The vertebrate animal (mammal, bird, reptile, amphibian, and fish) and vascular plant species found in Southeastern Wisconsin that were officially listed by the WDNR, Bureau of Endangered Resources, on the "Wisconsin Natural Heritage Working List" were identified in SEWRPC Planning Report Number 42. Within the Region, the List identified 20 plant and 19 vertebrate animal species as Endangered, 25 plant and 17 animal species as Threatened, and 69 plant and 61 animal species as Special Concern. This compilation of species is intended to be dynamic, reflecting the most updated ecological information regarding these species. Since preparation of SEWRPC Planning Report No. 42, the Bureau of Endangered Resources has updated its list periodically, adding or removing species and changing the status of other species as more knowledge is obtained about native species, as species become more or less rare, and as the degree of endangerment increases or decreases. Accordingly, the regional list should be updated to reflect these changes. Currently, 18 vertebrate animal species of the Region are listed as endangered; 20 are listed as threatened; and 59 are listed as special concern. Table 2.35 lists the revisions that have been made in the status of the Region's critical vertebrate animal species.

Wildlife Summary

The Pewaukee Lake watershed is home to a wide variety of fauna, supported by the extensive aquatic, riparian, and upland habitat found in its environmental corridors and natural areas. Some of these species, such as zooplankton and benthic invertebrates, enhance water quality and support the Lake fishery. Others, such as white-tail deer and waterfowl, provide recreational use like wildlife viewing and hunting. While the majority of this fauna are native species contributing to healthy, functioning ecosystems, there are aquatic invasive species present that may be impairing these communities. Recommendations for monitoring and management of these species and their habitat are discussed in Section 3.7, "Fish and Wildlife."

Table 2.32
Birds Likely Present Within the Pewaukee Lake Watershed

Common Name	Breeding	Wintering	Migrant
Gaviidae Family			
Common Loon[a]	--	--	X
Podicipedidae Family			
Pied-Billed Grebe	X	--	X
Horned Grebe	--	--	X
Phalacrocoracidae Family			
Double-Crested Cormorant	--	--	X
Ardeidae Family			
American Bittern[a]	X	--	X
Least Bittern[a]	X	--	X
Great Blue Heron[a]	X	R	X
Great Egret[b]	--	--	X
Cattle Egret[a,c]	--	--	R
Green Heron	X	--	X
Black-Crowned Night Heron[a]	--	--	X
Anatidae Family			
Tundra Swan	--	--	X
Mute Swan[c]	X	X	X
Snow Goose	--	- -	X
Canada Goose	X	X	X
Wood Duck	X	- -	X
Green-Winged Teal	--	- -	X
American Black Duck[a]	--	X	X
Mallard	X	X	X
Northern Pintail[a]	--	--	X
Blue-Winged Teal	X	--	X
Northern Shoveler	--	--	X
Gadwall	--	--	X
American Widgeon[a]	--	--	X
Canvasback[a]	--	--	X
Redhead[a]	--	--	X
Ring-Necked Duck	--	--	X
Lesser Scaup[a]	--	--	X
Greater Scaup	--	--	R
Common Goldeneye[a]	--	X	X
Bufflehead	--	--	X
Red-Breasted Merganser	--	--	X
Hooded Merganser[a]	R	--	X
Common Merganser[a]	--	--	X
Ruddy Duck	--	--	X
Cathartidae Family			
Turkey Vulture	X	--	X
Accipitridae Family			
Osprey[a]	--	--	X
Bald Eagle[a,d]	--	--	R
Northern Harrier[a]	X	R	X
Sharp-Shinned Hawk	X	X	X
Cooper's Hawk[a]	X	X	X
Northern Goshawk[a]	--	R	X
Red-Shouldered Hawk[b]	R	--	X
Broad-Winged Hawk	R	--	X
Red-Tailed Hawk	X	X	X
Rough-Legged Hawk	--	X	X
American Kestrel	X	X	X
Merlin[a]	--	--	X

Table continued on next page.

Table 2.32 (Continued)

Common Name	Breeding	Wintering	Migrant
Phasianidae Family			
Grey Partridge[c]	R	R	--
Ring-Necked Pheasant[c]	X	X	--
Wild Turkey	X	X	--
Rallidae Family			
Virginia Rail	X	--	X
Sora	X	--	X
Common Moorhen	X	--	X
American Coot	X	R	X
Gruidae Family			
Sandhill Crane	X	--	X
Charadriidae Family			
Black-Bellied Plover	--	--	X
Semi-Palmated Plover	--	--	X
Killdeer	X	--	X
Scolopacidae Family			
Greater Yellowlegs	--	--	X
Lesser Yellowlegs	--	--	X
Solitary Sandpiper	--	--	X
Spotted Sandpiper	X	--	X
Upland Sandpiper[a]	R	--	X
Semi-Palmated Sandpiper	--	--	X
Pectoral Sandpiper	--	--	X
Dunlin	--	--	X
Common Snipe	R	--	X
American Woodcock	X	--	X
Wilson's Phalarope	--	--	X
Laridae Family			
Ring-Billed Gull	--	--	X
Herring Gull	--	X	X
Common Tern[e]	--	--	R
Caspian Tern[e]	--	--	R
Forster's Tern[e]	--	--	R
Black Tern[a]	X	--	X
Columbidae Family			
Rock Dove[c]	X	X	--
Mourning Dove	X	X	X
Cuculidae Family			
Black-Billed Cuckoo	X	--	X
Yellow-Billed Cuckoo[a]	X	--	X
Strigidae Family			
Eastern Screech Owl	X	X	--
Great Horned Owl	X	X	--
Snowy Owl	--	R	--
Barred Owl	X	X	--
Long-Eared Owl[a]	--	X	X
Short-Eared Owl[a]	--	R	X
Northern Saw-Whet Owl	--	--	X
Caprimulgidae Family			
Common Nighthawk	X	--	X
Whippoorwill	--	--	X
Apodidae Family			
Chimney Swift	X	--	X
Trochilidae Family			
Ruby-Throated Hummingbird	X	--	X

Table continued on next page.

Table 2.32 (Continued)

Common Name	Breeding	Wintering	Migrant
Alcedinidae Family			
Belted Kingfisher	X	X	X
Picidae Family			
Red-Headed Woodpecker[a]	X	R	X
Red-Bellied Woodpecker	X	X	--
Yellow-Bellied Sapsucker	--	R	X
Downy Woodpecker	X	X	--
Hairy Woodpecker	X	X	--
Northern Flicker	X	R	X
Tyrannidae Family			
Olive-Sided Flycatcher	--	--	X
Eastern Wood Pewee	X	--	X
Yellow-Bellied Flycatcher[a]	--	--	X
Acadian Flycatcher[b]	R	--	X
Alder Flycatcher	R	--	X
Willow Flycatcher	X	--	X
Least Flycatcher	R	--	X
Eastern Phoebe	X	--	X
Great Crested Flycatcher	X	--	X
Eastern Kingbird	X	--	X
Alaudidae Family			
Horned Lark	X	X	X
Hirundinidae Family			
Purple Martin[a]	X	--	X
Tree Swallow	X	--	X
Northern Rough-Winged Swallow	X	--	X
Bank Swallow	X	--	X
Cliff Swallow	X	--	X
Barn Swallow	X	--	X
Corvidae Family			
Blue Jay	X	X	X
American Crow	X	X	X
Paridae Family			
Tufted Titmouse	R	R	--
Black-Capped Chickadee	X	X	X
Sittidae Family			
Red-Breasted Nuthatch	R	X	X
White-Breasted Nuthatch	X	X	--
Certhiidae Family			
Brown Creeper	--	X	X
Troglodytidae Family			
Carolina Wren	--	--	R
House Wren	X	--	X
Winter Wren	--	--	X
Sedge Wren[a]	X	--	X
Marsh Wren	X	--	X
Regulidae Family			
Golden-Crowned Kinglet	--	X	X
Ruby-Crowned Kinglet[a]	--	--	X
Blue-Gray Gnatcatcher	X	--	X
Eastern Bluebird	X	--	X
Veery[a]	X	--	X
Gray-Cheeked Thrush	--	--	X
Swainson's Thrush	--	--	X
Hermit Thrush	--	--	X
Wood Thrush[a]	X	--	X
American Robin	X	X	X

Table continued on next page.

Table 2.32 (Continued)

Common Name	Breeding	Wintering	Migrant
Mimidae Family			
Gray Catbird	X	--	X
Brown Thrasher	X	--	X
Bombycillidae Family			
Bohemian Waxwing	--	R	--
Cedar Waxwing	X	X	X
Laniidae Family			
Northern Shrike	--	--	X
Loggerhead Shrike[e]	--	--	R
Sturnidae Family			
European Starling[c]	X	X	X
Vireonidae			
Bell's Vireo	--	--	R
Solitary Vireo	--	--	X
Yellow-Throated Vireo	X	--	X
Warbling Vireo	X	--	X
Philadelphia Vireo	--	--	X
Red-Eyed Vireo	X	--	X
Parulidae Family			
Blue-Winged Warbler	X	--	X
Golden-Winged Warbler[a]	R	--	X
Tennessee Warbler[a]	--	--	X
Orange-Crowned Warbler	--	--	X
Nashville Warbler[a]	--	--	X
Northern Parula	--	--	X
Yellow Warbler	X	--	X
Chestnut-Sided Warbler	--	--	X
Magnolia Warbler	--	--	X
Cape May Warbler[a]	--	--	X
Black-Throated Blue Warbler	--	--	X
Yellow-Rumped Warbler	--	R	X
Black-Throated Green Warbler	--	--	X
Cerulean Warbler[b]	R	--	R
Blackburnian Warbler	--	--	X
Palm Warbler	--	--	X
Bay-Breasted Warbler	--	--	X
Blackpoll Warbler	--	--	X
Black-and-White Warbler	--	--	X
Prothonotary Warbler[a]	--	--	R
American Redstart	X	--	X
Ovenbird	X	--	X
Northern Waterthrush	--	--	X
Connecticut Warbler[a]	--	--	X
Mourning Warbler	R	--	X
Common Yellowthroat	X	--	X
Wilson's Warbler	--	--	X
Kentucky Warbler[b]	--	--	R
Canada Warbler	R	--	X
Hooded Warbler[b]	R	--	R
Thraupidae Family			
Scarlet Tanager	X	--	X
Cardinalidae Family			
Northern Cardinal	X	X	--
Rose-Breasted Grosbeak	X	--	X
Indigo Bunting	X	--	X

Table continued on next page.

Table 2.32 (Continued)

Common Name	Breeding	Wintering	Migrant
		Emberizidae Family	
Dickcissel[a]	R	--	X
Eastern Towhee	X	--	X
American Tree Sparrow	--	X	X
Chipping Sparrow	X	--	X
Clay-Colored Sparrow	R	--	X
Field Sparrow	X	--	X
Vesper Sparrow[a]	X	--	X
Savannah Sparrow	X	--	X
Grasshopper Sparrow[a]	X	--	X
Henslow's Sparrow[b]	R	--	X
Fox Sparrow	--	R	X
Song Sparrow	X	X	X
Lincoln's Sparrow	--	--	X
Swamp Sparrow	X	X	X
White-Throated Sparrow	--	R	X
White-Crowned Sparrow	--	--	X
Dark-Eyed Junco	--	X	X
Lapland Longspur	--	R	X
Snow Bunting	--	R	X
		Icteridae Family	
Bobolink[a]	X	--	X
Red-Winged Blackbird	X	X	X
Eastern Meadowlark[a]	X	R	X
Western Meadowlark[a]	R	--	X
Yellow-Headed Blackbird	X	--	X
Rusty Blackbird	--	R	X
Common Grackle	X	X	X
Brown-Headed Cowbird	X	R	X
Orchard Oriole[a]	R	--	R
Baltimore Oriole	X	--	X
		Fringillidae Family	
Purple Finch	--	X	X
Common Redpoll	--	X	X
Pine Siskin[a]	--	X	X
American Goldfinch	X	X	X
House Finch	X	X	X
Evening Grosbeak	--	X	X
		Passeridae Family	
House Sparrow[c]	X	X	--

Note: Total number of bird species: 219
Number of alien, or nonnative, bird species: 7 (3 percent)

Breeding: Nesting species
Wintering: Present January through February
Migrant: Spring and/or fall transient

X – Present, not rare; R – Rare

[a] *State-designated species of special concern. Fully protected by Federal and State laws under the Migratory Bird Act.*

[b] *State-designated threatened species.*

[c] *Alien, or nonnative, bird species.*

[d] *Federally designated threatened species.*

[e] *State-designated endangered species.*

Source: Samuel D. Robbins, Jr., Wisconsin Bird Life, Population & Distribution, Past and Present, *1991; John E. Bielefeldt, Racine County Naturalist; Zoological Society of Milwaukee County and Birds Without Borders-Aves Sin Fronteras,* Report for Landowners on the Avian Species Using the Pewaukee, Rosendale and Land O' Lakes Study Sites, *April-August, 1998; Wisconsin Department of Natural Resources; and SEWRPC*

2.11 RECREATION

Essentially all Lake residents and users want to ensure that Pewaukee Lake continues to support conditions favoring recreation and, relatedly, property value. This issue of concern relates to many of the topics discussed in this chapter (e.g., aquatic plants, water quality, algal blooms, water quantity, and wildlife) because each can affect different recreational uses.

Lake Shorelines

Maintaining Pewaukee Lake's aesthetic appeal, recreational use, and overall health is a shared responsibility of riparian land owners, those who live within the Pewaukee Lake watershed, and those who visit and use the Lake. Water quality, sedimentation, aquatic plant growth, and aquatic habitat are all affected by shoreline conditions and maintenance practices.

Most of Pewaukee Lake's shoreline is devoted to residential land use. A few commercial properties are found on the Lake, most of which cater to Lake users (e.g., restaurants, bait shops, etc.) Significant expanses of wetland remain along the Lake's shoreline: one on the southwestern shore near the County boat landing and the other on the northwestern shoreline of the eastern portion of the Lake. A public beach, picnic area, and fishing pier are located at the eastern end of the Lake in the vicinity of the outlet. Recreational facilities development along the lake front at the eastern extreme of the Lake has been the subject of a recreational use plan prepared by the Regional Planning Commission.[228] This plan is currently being implemented by the Village of Pewaukee.

Public Access

Public access to Pewaukee Lake includes several parks, fishing piers, and boat launch sites. There are three public boat launch sites on Pewaukee Lake. The City of Pewaukee operates a two-laned concrete ramp at the end of Lakeview Boulevard on the south side of the east basin that accommodate 6 to 10 vehicles and has portable restrooms.[229] The City charges $3 daily or $30 annually to use the launch. The Village of Pewaukee and City of Pewaukee jointly maintain the Laimon Family Lakeside Park on the eastern shore of the east basin off of Park Avenue, which features a single-laned concrete boat launch and a parking lot that can accommodate 10 truck and trailer spots or 20 regular vehicles.[230] No

[228] *SEWRPC Memorandum Report No. 56,* A Lakefront Recreational Use and Waterway Protection Plan for the Village of Pewaukee, Waukesha County, Wisconsin*, March 1996.*

[229] *dnrmaps.wi.gov/LF_ShowDetails/boats.aspx?ID=119.*

[230] *Personal communication with Nick Phalin, Director of Parks & Recreation for City of Pewaukee, on January 21st, 2020.*

Table 2.33
Mammals Likely Present Within the Pewaukee Lake Watershed

Common Name	Scientific Name
Didelphidae Family	
Virginia Opossum	*Didelphis virginiana*
Soricidae Family	
Cinereous Shrew	*Sorex cinereus*
Short-Tailed Shrew	*Blarina brevicauda*
Least Shrew	*Cryptotis parva*
Vespertilionidae Family	
Little Brown Bat	*Myotis lucifugus*
Silver-Haired Bat	*Lasisoncteris octivagans*
Big Brown Bat	*Eptesicus fuscus*
Red Bat	*Lasiurus borealus*
Hoary Bat	*Lasiurus cinereus*
Leporidae Family	
Cottontail Rabbit	*Sylvilgus floridanus*
Sciuridae Family	
Woodchuck	*Marmota monax*
Thirteen-Lined Ground Squirrel (gopher)	*Spermophilus tridencemilineatus*
Eastern Chipmunk	*Tamias striatus*
Grey Squirrel	*Sciurus carolinensis*
Western Fox Squirrel	*Sciurus niger*
Red Squirrel	*Tamiasciurus hudsonicus*
Southern Flying Squirrel	*Glaucomys volans*
Castoridae Family	
American Beaver	*Castor canadensis*
Cricetidae Family	
Woodland Deer Mouse	*Peromyscus maniculatus*
Prairie Deer Mouse	*Peromyscus leucopus bairdii*
White-Footed Mouse	*Peromyscus leucopus*
Meadow Vole	*Microtus pennsylvanicus*
Common Muskrat	*Ondatra zibethicus*
Muridae Family	
Norway Rat (introduced)	*Rattus norvegicus*
House Mouse (introduced)	*Mus musculus*
Zapodidae Family	
Meadow Jumping Mouse	*Zapus hudsonius*
Canidae Family	
Coyote	*Canis latrans*
Eastern Red Fox	*Vulpes vulpes*
Gray Fox	*Urocyon cinereoargenteus*
Procyonidae Family	
Raccoon	*Procyon lotor*
Mustelidae Family	
Least Weasel	*Mustela nivalis*
Short-Tailed Weasel	*Mustela erminea*
Long-Tailed Weasel	*Mustela frenata*
Mink	*Mustela vison*
Badger (occasional visitor)	*Taxidea taxus*
Striped Skunk	*Mephitis mephitis*
Otter (occasional visitor)	*Lontra canadensis*
Cervidae Family	
White-Tailed Deer	*Odocoileus virginianus*

Source: H.T. Jackson, Mammals of Wisconsin*, 1961, U.S. Department of Agriculture Integrated Taxonomic Information System, National Museum of Natural History, Smithsonian Institute, and SEWRPC* restrooms are available on site, but the adjacent business Beachside Boat & Bait does have a restroom and offer boat rentals when open. This launch has daily launch fees of $7.00, an annual resident launch pass for $50.00, and an annual nonresident launch pass for $75.00. The County Department of Parks and Land Use operates the Pewaukee Lake Boat Ramp on the west side of the west basin, off of Maple Avenue in the Town of Delafield.[231] This concrete plank launch is ADA complaint, has flush toilets, and can accommodate 21 to 25 vehicles. The carry-in rate is 6.00 or $6.50 for trailered boats. On weekends and holidays, the rate for trailered boats is $8.00. Annual passes are also available for $80.00.

Table 2.34
Animals Extirpated from the Region

Common Name	Scientific Name
Mammals	
Bison	*Bison bison*
Gray Wolf	*Canis lupus*
Elk	*Cervus canadensis*
Cougar	*Felis concolor*
Lynx	*Lynx canadensis*
Fisher	*Pekania pennanti*
Indiana Bat	*Myotis sodalis*
Black Bear	*Ursus americanus*
Birds	
Carolina Parakeet (extinct)	*Conuropsis carolinensis*
Passenger Pigeon (extinct)	*Ectopistes migratorius*
Swallow-Tail Kite	*Elanoides forficatus*
Whooping Crane	*Grus americana*
Long-Billed Curlew	*Numenius americanus*
Trumpeter Swan	*Olor buccinators*
White Pelican	*Pelecanus erythrorhynchos*
Fish	
Longjaw Cisco	*Coregonus alpenae*
Deepwater Cisco	*Coregonus johannae*
Blackfin Disco	*Coregonus nigripinnis*
Creek Chubsucker	*Erimyzon oblongus*
Black Redhorse	*Moxostoma duguesnei*

Source: Wisconsin Natural Heritage Inventory Working List; Wisconsin Department of Natural Resources, 1990, and SEWRPC

Recreational Activities

The most popular recreational activities on Pewaukee Lake during the summer of 2016, both during the week and on the weekends, were visiting the park, beach swimming, and high and low speed cruising (see Table 2.36). Both high speed and low speed cruising were more popular on the weekends than during the week.

Commission staff conducted a watercraft census along the Pewaukee Lake shoreline in 2016 to identify variability in watercraft type and Lake use. Four hundred and four watercraft were observed during the census, either moored in the water or stored on land in the shoreland areas around the Lake: 204 powerboats, 41 fishing boats, 21 personal watercraft, 16 paddle boards, 12 sailboats, and 25 kayaks. About 51 percent of all docked or moored boats were motorized, with pontoon boats and powerboats being the most common boat types. The remaining 49 percent of all docked or moored boats were non-motorized (e.g., kayaks, rowboats, canoes, and pedal-boats/paddleboats). The number of moored or docked boats would generally suggest that about nine to twenty-three of these moored or docked watercraft would be found on the Lake during high-use periods.[232]

Commission staff counted the number, type, and use of watercraft on Pewaukee Lake on randomly selected weekdays and weekends during the summer of 2016, as shown on Table 2.36. These data provide insight into the primary recreational boat uses of the Lake. The recreational survey revealed at least twenty-eight and as many as 199 boats on the Lake at any given time. Fishing and low-speed cruising are the most popular weekend boating activities on Pewaukee Lake. However, the overall most popular boat-related recreational activities on both the weekends and weekdays were pleasure cruising, using shoreland park facilities, and swimming at the beach. This finding emphasizes the need to encourage boating access to the Lake without risking aesthetic beauty and the opportunity to swim.

Southeastern Wisconsin Boating Surveys

The type of boating taking place varies by the day of the week, time of day, and prevailing weather conditions. According to a Statewide survey that subdivided results by region,[233] boaters in Southeastern Wisconsin took to the water in the greatest numbers during August, with slightly lower numbers of boaters found on the water during June and July. These months account for approximately two-thirds of the total number of boater-days logged in the Region for the entire year. About two to three times as many boaters use their

[231] *dnrmaps.wi.gov/LF_ShowDetails/boats.aspx?ID=117.*

[232] *At any given time it is estimated that between about 2 percent and 5 percent of the total number of watercraft docked and moored will be active on the Lake.*

[233] *L.J. Penaloza,* Boating Pressure on Wisconsin's Lakes and Rivers, Results of the 1989-1990 Wisconsin Recreational Boating Study, Phase 1, *Wisconsin Department of Natural Resources Technical Bulletin 174, 1991.*

Table 2.35
Status of the State of Wisconsin-Designated Rare Animals

Common Name	Scientific Name	Status as Listed in PR-42	Current Status
		Mammals	
Red-Backed Vole	*Clethrionomys gapperi*	Special Concern	Not listed
Bobcat	*Lynx rufus*	Special Concern	Not listed
Thompson's Pigmy Shrew	*Sorex thompsonii*	Special Concern	Not listed
Southern Bog Lemming	*Synaptomys cooperi*	Special Concern	Not listed
		Birds	
Bewick's Wren	*Thryomanes bewickii*	Endangered	Not listed
Bald Eagle	*Haliaeetus leucocephalus*	Threatened	Special Concern
Henslow's Sarrow	*Ammodramus henslowii*	Special Concern	Threatened
Pine Siskin	*Carduelis pinus*	Special Concern	Not listed
Evening Grosbeak	*Coccothraustes vespertinus*	Special Concern	Not listed
Yellow Rail	*Coturnicops noveboracensis*	Special Concern	Threatened
Blackburnian Warbler	*Dendroica fusca*	Special Concern	Not listed
Orchard Oriole	*Icterus spurius*	Special Concern	Not listed
Common Merganser	*Mergus merganser*	Special Concern	Not listed
Red-Breasted Merganser	*Mergus serrator*	Special Concern	Not listed
Tennessee Warbler	*Vermivora peregrina*	Special Concern	Not listed
Canada Warbler	*Wilsonia canadensis*	Uncommon	Special Concern
Blue-Winged Warbler	*Vermvora pinus*	Uncommon	Special Concern
Nashville Warbler	*Vermivora ruficapilla*	Uncommon	Special Concern
Wood Thrush	*Hylocichia mustelina*	Uncommon	Special Concern
Red Crossbill	*Loxia curvirostra*	Uncommon	Special Concern
White-Eyed Vireo	*Vireo griseus*	Uncommon	Special Concern
Great Blue Heron	*Ardea herodias*	Uncommon	Special Concern
Whip-Poor-Will	*Caprimulgus vociferous*	Uncommon	Special Concern
Least Flycatcher	*Empidonax minimus*	Uncommon	Special Concern
Willow Flycatcher	*Empidonax traillii*	Uncommon	Special Concern
Veery	*Catharus fuscescens*	Uncommon	Special Concern
American Woodcock	*Scolopax minor*	Uncommon	Special Concern
Golden-Winged Warbler	*Vermivora chrysoptera*	Uncommon	Special Concern
		Reptiles And Amphibians	
Four-Toed Salamander	*Hemidactylium scutatum*	Uncommon	Special Concern
Butler's Garter Snake	*Thamnophis butleri*	Uncommon	Threatened
		Fish	
Lake Herring	*Coregonus artedii*	Special Concern	Not listed

Source: Wisconsin Natural Heritage Inventory Working List; Wisconsin Department of Natural Resources, 2007, and SEWRPC

boats on weekends than weekdays (see Table 2.37), corresponding with the results from the Commission's 2016 Pewaukee Lake boat count.

Fishing was by far the most popular activity in Southeastern Wisconsin in both spring and fall, and remains a leading reason for boat use throughout the summer (Table 2.38). Again, the data produced by the Commission's 2016 boat count corresponds quite well with regional averages, suggesting that Pewaukee Lake's boating activity is fairly represented by regional averages. The typical boat used on inland lakes in Southeastern Wisconsin is an open hulled vessel measuring approximately 18 feet long powered by a motor producing approximately 90 horsepower (Tables 2.39 and 2.40). Sailboats comprise approximately 24 percent of boat traffic (15 percent non-powered and 9 percent powered), while other non-powered boats comprise only 2 percent of boats found on waterbodies in the region.

Only a few respondents to the WDNR boating survey felt that excessive boat traffic was present on Southeastern Wisconsin lakes.[234] Studies completed in Michigan attempt to quantify desirable levels of boat traffic on an array of lakes used for a variety of purposes. This study concluded that 10 to 15 acres of *useable lake area*[235] per boat provides a reasonable and conservative average maximum desirable boating density,

[234] *Ibid.*

[235] *Useable lake area is the size of the open water area that is at least 100 feet from the shoreline.*

Table 2.36
Pewaukee Lake Recreational Boating Survey: Summer 2016

Category	Observation	Date and Time				
		10:00 a.m. – Noon Friday, June 24	4:00 – 6:00 p.m. Tuesday, August 2	10:00 a.m. – Noon Sunday, July 10	Noon – 2:00 p.m. Saturday, July 16	10:00 a.m. – Noon Sunday, July 10
Watercrafts Observed on Pewaukee Lake						
Type of Watercraft (number in use)	Power/Ski Boat	4	6	43	40	111
	Pontoon Boat	8	12	9	17	39
	Fishing Boat	9	3	8	10	11
	Personal Watercraft	1	4	3	3	10
	Kayak/Canoe	6	0	11	6	2
	Paddle Board	0	3	0	13	0
	Sailboat	0	0	0	0	12
	Utility Boat	1	0	0	0	0
Activity of Watercraft (number engaged)	Motorized Cruise/Pleasure	4	7	32	118	408
	Low Speed	2	3	10	66	189
	High Speed	2	4	22	52	219
	Anchored	6	5	6	6	0
	Fishing	9	3	8	23	24
	Skiing/Tubing	0	4	6	46	74
	Sailing/Windsurfing	0	0	0	0	34
Total	On Water	29	28	74	89	185
	In High-Speed Use	2	4	22	17	54
Recreational Activities Observed on Pewaukee Lake						
Activity (average number of people)	Park Goer	286	13	72	100	0
	Beach Swimming	40	68	31	31	50
	Boat/Raft Swimming	8	0	18	0	8
	Canoeing/Kayaking	6	3	11	6	4
	Sailboating	0	0	0	0	34
	Fishing From Boats	17	13	12	23	21
	Fishing From Shore	12	13	16	0	3
	Low-Speed Cruising	15	30	45	66	189
	High-Speed Cruising	16	10	59	52	219
	Skiing/Tubing	3	8	19	46	74
	Personal Watercraft Operation	1	5	4	3	10
	Total Number of People	404	163	287	327	612

Source: SEWRPC

and covers a wide variety of boat types, recreational uses, and lake characteristics.[236] Use rates above this threshold are considered to negatively influence public safety, environmental conditions, and the ability of a lake to host a variety of recreational pursuits. High-speed watercraft require more space, necessitating boat densities less than the low end of the range. The suggested density for a particular lake is:

Minimum desirable acreage per boat = 10 acres + (5 acres x (high-speed boat count/total boat count))

Table 2.37
Day-of-the-Week Boat Use in the Region: 1989-1990

Day of the Week	Percent Respondents Participating[a]
Sunday	46
Monday	16
Tuesday	14
Wednesday	16
Thursday	13
Friday	17
Saturday	46

[a] *Respondents may have participated in more than one day.*

Source: Wisconsin Department of Natural Resources

The Commission's 2016 recreational survey demonstrates that highest boat use occurs during weekends. Most boats in use during peak periods were capable of high-speed operation; however, no more than half were being operated at high speed. If one assumes that no more than half of the boats could potentially be operating at high speed during high-use periods, the formula described in the preceding paragraph suggests that 11.2 or more acres of useable open water should be available per boat. Given that roughly 1,937 useable acres are available for boating in Pewaukee Lake, no more than 173 boats should be present on the lake at any one time to avoid use problems. The number of boats actually observed on Pewaukee Lake was nearly always better than the optimal maximum density. However, boat density appears to meet or be slightly worse than the optimal maximum density during heavy use periods (weekends and holidays). This means that the potential for use conflicts, safety concerns, and environmental degradation is slightly higher than desirable on Pewaukee Lake during a few weekends and holidays. Management recommendations regarding boating pressure are provided in Chapter 3.

Boater Movement

The WDNR has collected survey data through the Clean Boats, Clean Waters program regarding lakes that boat users of Pewaukee Lake had visited up to five days before and after traveling to Pewaukee Lake (see Figures 2.84 and 2.85, respectively).[237] Visitors to Pewaukee Lake had traveled to 93 other waterbodies in Wisconsin before coming to Pewaukee and they traveled to 39 other waterbodies after visiting Pewaukee. Visitors to the Lake had traveled to lakes across Wisconsin, indicating the ability for the Lake to draw visitors from the entire state. However, this also showcases the potential spread of aquatic invasive species that are present in other parts of Wisconsin. In addition, these data show that there is substantial traffic among the lakes in Waukesha County, highlighting the potential for spread of starry stonewort in the Region.

Boating Impacts and Concerns

Boat wakes have been shown to have erosive effects on shorelines,[238] scour and disrupt lake bottom sediment,[239] damage aquatic vegetation, disrupt faunal communities,[240] and temporarily decrease water clarity.[241] However, boat wake energy is event-dependent and is influenced by the vessel length, water

[236] *A.E. Progressive,* Four Township Recreational Carrying Capacity Study, Pine Lake, Upper Crooked Lake, Gull Lake, Sherman Lake, *Study prepared for Four Township Water Resources Council, Inc. and the Townships of Prairieville, Barry, Richland, and Ross, May 2001.*

[237] *dnrmaps.wi.gov/H5/?viewer=Lakes_AIS_Viewer.*

[238] *D.M. Bilkovic, J. Mitchell, E. Daviset al.,* Review of Boat Wake Wave Impacts on Shoreline Erosion and Potential Solutions for the Chesapeake Bay, *STAC Publication Number 17-002, Edgewater, MD, 2017.*

[239] *T.R. Asplund,* The Effects of Motorized Watercraft on Aquatic Ecosystems, *PUBL-SS-948-00, University of Wisconsin–Madison, Water Chemistry Program, 2000.*

[240] *T.R. Asplund, C.M. and Cook, "Effects of Motor Boats on Submerged Aquatic Macrophytes,"* Lake and Reservoir Management, *13(1): 1-12, 1997.*

[241] *U. S. Army Corps of Engineers,* Cumulative Impacts of Recreational Boating on the Fox River - Chain O' Lakes Area in Lake and McHenry Counties, Illinois: Final Environmental Impact Statement, *Environmental and Social Analysis Branch, U.S. Army Corps of Engineers, Chicago, IL., 1994; T.R. Asplund,* Impacts of Motorized Watercraft on Water Quality in Wisconsin Lakes, *Wisconsin Department of Natural Resources Bureau of Research,, Madison, WI, PUBL-RS-920-96, 1996.*

Table 2.38
Boat User Activity in the Region by Month: 1989-1990

	Percent Respondents Participating[a]						
Activity	April	May	June	July	August	September	October
Fishing	68	57	49	41	44	42	49
Cruising	29	39	42	46	46	47	43
Water Skiing	3	9	20	27	19	16	8
Swimming	2	4	18	31	25	19	5
Average boating party size: 3.4 people							

[a] *Respondents may have participated in more than one activity.*

Source: Wisconsin Department of Natural Resources

depth, channel shape, and boat speed.[242] Wakes are most destructive in shallow and narrow waterways because wake energy does not have the opportunity to dissipate over distance.[243] Although boat wakes are periodic disturbances, in comparison to natural wind-generated waves, they can be a significant source of erosive wave force, due to their longer wave period and greater wave height.[244] Even small recreational vessels within 500 feet of the shoreline are capable of producing wakes that can cause shoreline erosion and increased turbidity.[245]

Shoreline conditions can also affect boat wave-induced water quality interactions within a lake. For example, armored shorelines can protect natural shoreline sediment, which can thereby prevent shoreline sediments from eroding into the lake. However, armoring potentially can increase bottom resuspension or erosion along other shoreline reaches through wave reflection/refraction. This is particularly prevalent along reaches armored with artificial materials such as concrete, masonry, or steel seawalls or steeply sloped riprap walls. Hence, promoting natural shorelines and/or properly (i.e., gently) sloped riprap walls can help absorb wave energy as opposed to reflecting it back across the lake. Such actions in turn can improve water quality.[246] Vegetated shorelines can effectively attenuate waves in certain settings; however, there is a limit to this capacity particularly if there is frequent exposure to boat wakes.[247]

Table 2.39
Boat Hull Types in the Region: 1989-1990

Hull Type	**Percent Respondents Participating[a]**
Open	68
Cabin	17
Pontoon	9
Other	6
Average length: 18.4 feet Average beam width: 6.4 feet	

[a] *Respondents may have participated in more than one day.*

Source: Wisconsin Department of Natural Resources

Table 2.40
Propulsion Types in the Region: 1989-1990

Propulsion Type	**Percent Respondents Participating[a]**
Outboard	53
Inboard/Outboard	14
Inboard	6
Other (powered)	1
Sail	15
Sail with Power	9
Other (nonpowered)	2
Average horse power: 86.5	

[a] *Respondents may have participated in more than one day.*

Source: Wisconsin Department of Natural Resources

[242] *STAC Publication Number 17-002, 2017,* op. cit.

[243] *Ibid.*

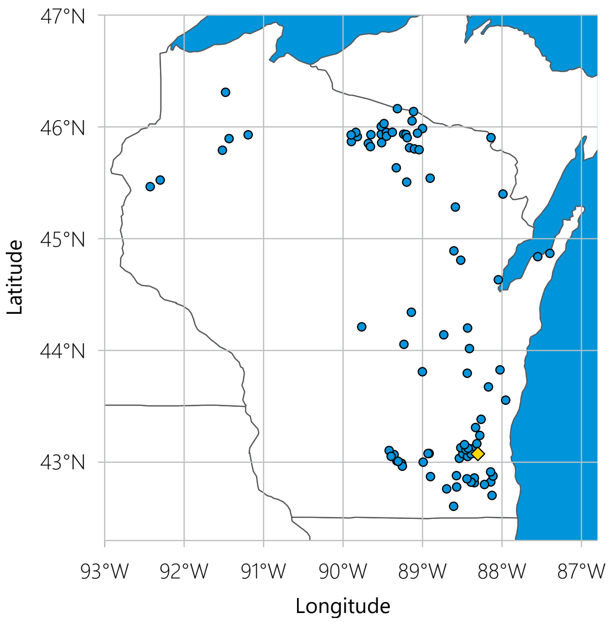
[244] *C. Houser, "Relative Importance of Vessel-Generated and Wind Waves to Salt Marsh Erosion in a Restricted Fetch Environment,"* Journal of Coastal Research, *262: 230-240, 2010.*

[245] *STAC Publication Number 17-002, 2017,* op. cit.

[246] *H. Harwood, "Protecting Water Quality & Resuspension Caused by Wakeboard Boats,"* LakeLine *37: 3, 2017.*

[247] *STAC Publication Number 17-002, 2017,* op. cit.

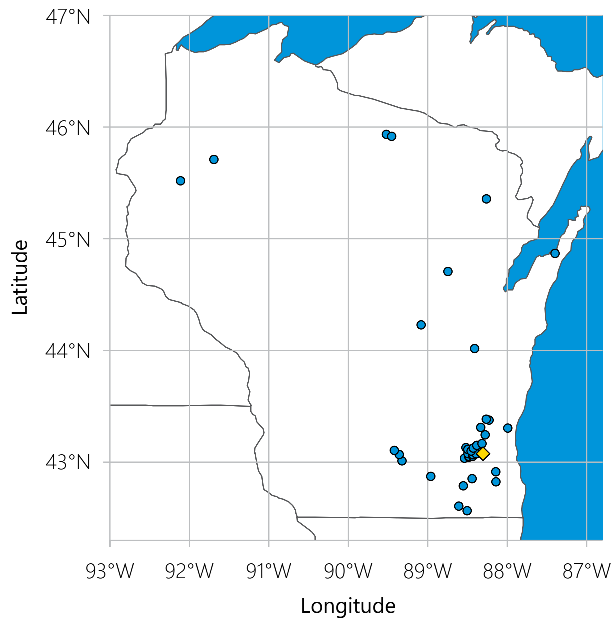
Figure 2.84
Waterbodies that Boaters Visited Before Visiting Pewaukee Lake



Note: Yellow diamond shows location of Pewaukee Lake.

Source: Wisconsin Department of Natural Resources and SEWRPC

Figure 2.85
Waterbodies that Boaters Visited After Visiting Pewaukee Lake



Note: Yellow diamond shows location of Pewaukee Lake.

Source: Wisconsin Department of Natural Resources and SEWRPC

Bladder boats, also known as wake boats, are a significant issue of concern in regards to recreational use on Pewaukee Lake.[248] The popularity of bladder boats has increased over the years with waterskiing, wakeboarding, and wake-surfing becoming common summertime sports.[249] Since wake boats produce larger wakes than non-wake boats, their operation creates more potential for erosion on shorelines compared to other motorboats.[250] Ballast-laden wake boats are capable of producing wave heights and frequencies that may exceed those produced during the most intense summer thunderstorms and/or high winds for the majority of inland lakes in Southeastern Wisconsin.[251,252] In addition, due to the specific design of wake boats, the stern of the boats is lowered through ballast placement or mechanical means. Since the propeller runs deeper in the water compared to other motorboats,[253] wake boats have a greater potential boats to disrupt bottom sediments. Even if the propeller does not come in direct contact with the bottom sediments, the turbulence from the propeller can reach as deep as 10 feet.[254] Greater bottom-sediment disruption increases water turbidity and suspends phosphorus from the lake bed, decreasing water quality.[255] The deeper running propellers of wake boats also have a greater chance to uproot and or fragment aquatic vegetation, which can promote the spread of undesirable plant species and degrade the Lake's aquatic

[248] *Wake boats are a type of inboard motorboat specially designed to increase wave height for specific water sports (i.e., wakeboarding and wake-surfing). To accomplish this, the hull is shaped to achieve maximum wake and many have a hydrofoil device and/or built-in ballast tanks to displace more water and create a larger wave.*

[249] *M. Smith and E. Jarvie,* Wakeboarding in Michigan: Impacts and Best Practices*, Michigan Chapter, North American Lake Management Society, 2015.*

[250] *Smith and Jarvie, 2015,* op. cit.*; Asplund, 2000,* op. cit.

[251] *STAC Publication Number 17-002, 2017,* op. cit.

[252] *In March 2019, Sawyer County proposed a resolution/ordinance that proposes a 700-foot buffer from the shore specifically for boats creating enhanced wakes to minimize shoreline. See more information at www.cola-wi.org/news.*

[253] *D. Keller, "Low-Speed Boating... Managing the Wave,"* LakeLine*, 37(3), 2017.*

[254] *Ibid.*

[255] *Harwood, 2017,* op. cit.

plant community.[256] Fragmentation by propellers favors invasive species, such as EWM, over native species, potentially leading to an increased spread of invasives. In addition, there also is an increased potential of introduction of new invasive species to the Lake via water pumped from wake boat ballast tanks. For example, quagga mussel (*Dreissena bugensis*) larvae, fish pathogens, or invasive plant fragments have been known to be introduced to new locations via water pumped from ship ballast tanks.

Ordinances

Boating and in-lake ordinances regulate the use of the Lake in general, and, when implemented properly, can help prevent inadvertent damage to the Lake such as excessive noise and wildlife disturbance, severe shoreline erosion from excessive wave action reaching the shoreline, and agitation of sediment and aquatic vegetation in shallow areas. Controls on boat traffic are currently set forth in *Chapter 21* of the Village of Pewaukee Code of Ordinances, and include a 10-mph speed limit restriction between one half hour after sunset and one half hour before sunrise and a 5 mph limit within 200 feet of any shore, swimmer, marked public swimming area, diving flag, canoe, rowboat, sailboat, non-operating motor boat, bridge, public landing, or anchorage.[257] These ordinances are generally enforced by the officers of the Water Safety Patrol Unit of the joint jurisdiction of the Town of Delafield, the Village of Pewaukee and the City of Pewaukee, or by a law enforcement officer.

Historically, 180 buoys were used to mark the slow-no-wake zone, 200 feet from the shoreline, and shallow rocks within Pewaukee Lake. The buoy locations were marked using GPS coordinates and missing buoys were replaced annually. However, in recent years the condition of the buoy chains has deteriorated and the missing buoys have not been replaced. Missing buoys present a safety hazard for recreation on Pewaukee Lake, as boaters may not be aware of their proximity to the slow-no-wake zone or rocks. During installation of the buoys in the spring of 2019, their condition and location were marked with GPS coordinates as a record for future monitoring and maintenance. A map of the buoy type and their locations is presented on Map 2.34.

Recreation Summary

Given that boaters (including fishermen), swimmers, and individuals who enjoy the aesthetics of the Lake are the primary users of the Lake, maintaining these primary uses should be considered a priority. Consequently, all of the recreation-related recommendations included in Section 3.8, "Recreational Use and Facilities," intend to ensure full use of the Lake. Since accommodating some lake users is not always advantageous or desirable to other lake users, the recommendations contained in Chapter 3 seek to encourage compromise between conflicting users so that all users may gain access to the Lake for their intended legal purpose.

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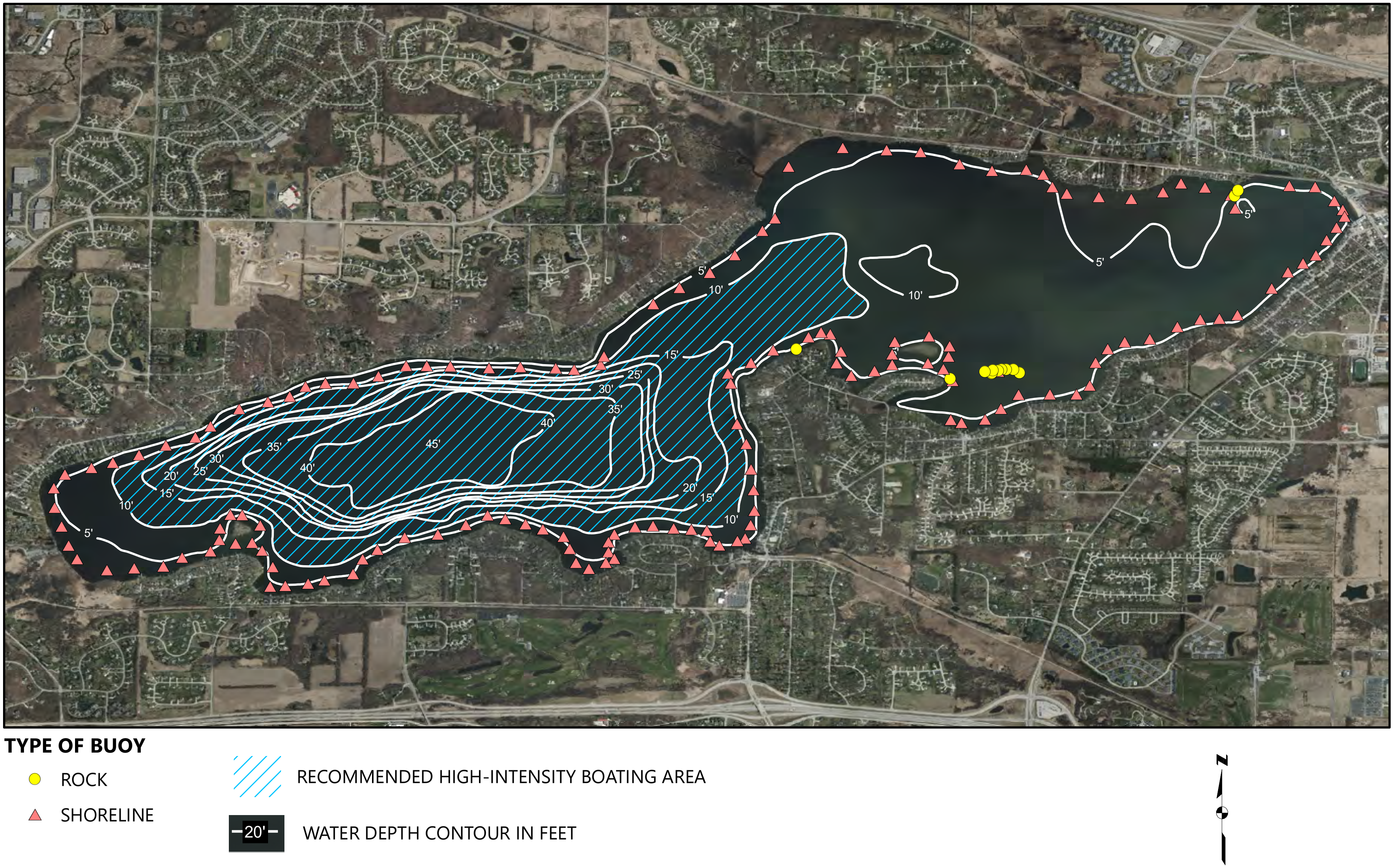
[256] *Keller, 2017,* op. cit.

[257] *Ordinance No. 2010-09 "Ordinance To Create Chapter 21 Of The Code Of Ordinances Regarding Lake Pewaukee Regulation," 2010.*

Map 2.34
Pewaukee Lake Shoreline and Rock Warning Buoy Deployment: 2019



Source: Village of Pewaukee Lake Patrol and SEWRPC

MANAGEMENT RECOMMENDATIONS AND PLAN IMPLEMENTATION 3

Credit: SEWRPC Staff

3.1 INTRODUCTION

Pewaukee Lake is a valuable resource to lake residents and visitors, contributes to the economy and quality of living in the local area, and is an important asset to the overall hydrology and ecology of the Pewaukee River watershed. This chapter provides actionable suggestions that help maintain and enhance the health of the Lake and encourage its continued enjoyment. Because of the Lake's great value to the nearby community and overall watershed, the Lake Pewaukee Sanitary District (LPSD) requested, and was subsequently awarded, a grant to study issues perceived to harm or threaten the Lake, and to suggest solutions to these problems. The resultant recommendations are listed in Table 3.1, and are based upon the interests and priorities of the stakeholder group,[258] analysis of available data, practicality, and the potential for successful implementation. Implementing these recommendations helps maintain and enhance the health of the Lake and improves its ability to provide short- and long-term benefit to the overall community.

The recommendations made in this chapter cover a wide range of programs and seek to address a broad array of factors and conditions that significantly influence the health, aesthetics, and recreational use of Pewaukee Lake. Since the plan addresses a wide scope of issues, it may not be feasible to implement every recommendation in the immediate future. To promote efficient plan implementation, the relative importance and significance of each recommendation is noted to help Lake managers prioritize plan elements. Nevertheless, all recommendations should eventually be addressed, subject to possible revision based on analysis of yet-to-be collected data (e.g., future aquatic plant surveys and water quality monitoring results), project logistics, and/or changing or unforeseen conditions.

Those responsible for Lake planning and management should actively conceptualize, seek, and promote projects and partnerships that enable the recommendations of the plan to be implemented. The measures presented in this chapter focus primarily on those that can be implemented through collaboration between local organizations, watershed property owners, and others who have a vested interest in the Lake's long-term health. Examples include the LPSD, the City of Pewaukee, the Town of Delafield, the Village of Pewaukee,

[258] *The Lake Pewaukee Sanitary District, Waukesha County, the City of Pewaukee, the Town of Delafield, the Village of Pewaukee, other nearby communities, the Wisconsin Department of Natural Resources (WDNR), members of the general public, grass-roots organizations, and other agencies.*

Table 3.1
Summary of Recommendations Grouped by Issues

Recommendation Number	Recommendation	Priority
	HYDROLOGY/WATER QUANTITY	
	Surface Water Monitoring and Management	
1.1	Continue to monitor Pewaukee Lake's water surface elevation	High
1.2	Continue to monitor and quantify the volume of water delivered to the Lake from the various (tributary) sub-basins	Medium
1.3	Retrofitting the Pewaukee Lake outlet dam so that it remains operational throughout the year	High
1.4	Pursue revision of current Pewaukee Lake level policy	High
1.5	Install infrastructure to prevent entrainment of beach sand into the Lake outlet	High
	Groundwater Monitoring and Protection	
1.6	Encourage local units of government to use the USGS Upper Fox River Basin groundwater model	High
1.7	Implement measures promoting stormwater storage and infiltration in existing urban areas	Low/High[a]
1.8	Reduce the impact of existing land use and future urban development on groundwater supplies	Low-High[a]
	WATER QUALITY	
	Pewaukee Lake Monitoring	
2.1	Continue and enhance comprehensive water quality monitoring within Pewaukee Lake	High
	Tributary Monitoring	
2.2	Level 1 WAV monitoring in Coco, Meadowbrook, and Zion creeks should be continued	High
2.3	Consider expanding up to Level 2 WAV monitoring to install programmable water temperature logging devices in these tributaries	Medium
	Phosphorus Management	
2.4	Reduce nonpoint source external phosphorus loads	High
2.5	Manage in-Lake phosphorus sources	High
2.6	Removing nutrients through aquatic plant harvesting	High
2.7	Promoting conditions conducive to muskgrass growth	High
2.8	Increasing the frequency of hypolimnetic phosphorus sampling	High
	Chloride Management	
2.9	Reduce private and public salt applications by practicing smart salt management	High
2.10	Optimize water softeners for water use and hardness levels and upgrade to high-efficiency softeners when practical	High
	POLLUTANT AND SEDIMENT SOURCES AND LOADS	
	Watershed Level	
3.1	Identify "hot spots" where sediment is entering Pewaukee Lake due to severe ditch erosion and/or retention pond failure	High
3.2	Protect and enhance buffers, wetlands, and floodplains	High
3.3	Protect buffer, wetland, and floodplain function	Medium
3.4	Protect remaining woodlands	Medium
3.5	Maintain stormwater detention basins	High
3.6	Promote urban nonpoint source abatement	High
3.7	Promote native plantings in and around existing and new stormwater detention basins	High
3.8	Retrofitting existing and enhancing planned stormwater management infrastructure to benefit water quality	High
3.9	Combine riparian buffers with other structures and practices	High
3.10	Stringently enforce construction site erosion control and stormwater management ordinances and creative employment of these practices	High
3.11	Encourage pollution source reduction efforts through best management practices	High
3.12	Collect leaves in urbanized areas	Medium
	Sub-Basin Level	
3.13	Tributaries should be prioritized regarding phosphorus load reduction goals	High
3.14	Relax human-imposed constraints on tributary streams	High
	Shoreline Maintenance Level	
3.15	Maintain shoreline protection and prevent streambank erosion	High
3.16	Reduce refracted wave energy	High
3.17	Encourage pollution source reduction efforts along shorelines through BMPs	High
3.18	Enforce ordinances	High

Table continued on next page.

Table 3.1 (Continued)

Recommendation Number	Recommendation	Priority
	AQUATIC PLANTS	
	Aquatic Plant Management	
4.1	Mechanical harvesting of invasive and nuisance aquatic plants	High
4.2	Inspect all cut plants for live animals. Live animals should be immediately returned to the water	Medium
4.3	Harvesting should not occur until May 1st	High
4.4	All harvester operators must successfully complete WDNR approved training to help assure adherence to harvesting permit specifications and limitations	High
4.5	The harvesting program should continue to include a comprehensive plant pickup program that all residents can use	High
4.6	All plant debris collected from harvesting activities should be collected and disposed of at the designated disposal sites	High
4.7	Continue to conduct annual winter "under the ice" aquatic plant monitoring	Medium
4.8	Enhance support of mechanical harvesting program	High
4.9	Manual removal of nuisance plant growth and invasive plants in near-shore areas	High
4.10	DASH could be employed by individuals to provide relief on nuisance native and nonnative plants around piers	Low
4.11	Chemical treatment could be employed by individuals to provide relief from nonnative plants around piers	Low
4.12	Manage access lanes with modified existing harvesting equipment	Low
	Native Plant Community and Invasive Species	
4.13	Protect native aquatic plants to the highest degree feasible through careful implementation of aquatic plant management and water quality recommendations	High
4.14	Actively manage invasive species to protect native plants and wildlife	High
4.15	Avoid disrupting bottom sediment or leaving large areas of bottom sediment devoid of vegetation	High
4.16	Implement control methods in early spring	High
4.17	Prevent the introduction of new invasive species	High
	Enhancing Aquatic Plant Management Coordination	
4.18	Greater communication and coordination between management operations	High
4.19	Establish a northeastern unloading site for the LPSD harvesting operation	High
4.20	Investigate sharing use of the North Shore Drive disposal site	Medium
4.21	Enhance coordination of pile pick-up services	High
4.22	Avoiding harvesting on Fridays when possible	Medium
	CYANOBACTERIA AND FLOATING ALGAE	
5.1	Reduce Lake water phosphorus concentrations	High
5.2	Continue to monitor algal abundance	Low/High[a]
5.3	Warn residents not to enter the water in the event of an algal bloom	High
5.4	Maintain or improve overall water quality	High
5.5	Maintain a healthy aquatic plant community to compete with algal growth	High
	FISH AND WILDLIFE	
	Habitat Quality	
6.1	Continue efforts to protect and enhance a sustainable coldwater habitat (brook trout fishery) in Coco Creek, as well as coolwater (northern pike, walleye) and warmwater (largemouth bass, musky) and associated aquatic community, habitat, and water quality in Meadowbrook Creek, Zion Creek, and Pewaukee Lake	High
6.2	Identify and remove instream barriers to passage of fish and other aquatic organisms	High
6.3	Preserve and expand wetland and terrestrial wildlife habitat, while making efforts to ensure connectivity between such areas	High
6.4	Follow WDNR guidelines for protecting WDNR-designated Sensitive Areas	High
6.5	Preserve and enhance instream features that provide important fish spawning and rearing habitats	Medium
6.6	Restore natural meanders and improve floodplain connectivity to Coco Creek, Zion Creek, and Meadowbrook Creek	Low
6.7	Mitigate streambank erosion	Medium
6.8	Improve aquatic habitat in Pewaukee Lake by maintaining and adding large woody debris and/or vegetative buffers along the Lake's edge	Medium
6.9	Mitigate water quality stress on aquatic life and maximize areas habitable to desirable fish	High/ Medium[a]

Table continued on next page.

Table 3.1 (Continued)

Recommendation Number	Recommendation	Priority
	FISH AND WILDLIFE (CONTINUED)	
	Habitat Quality (continued)	
6.10	Promote aquatic plant management plan implementation to avoid inadvertent damage to native species	High
6.11	Continue the Wetland Conservancy Fund program of purchasing and protecting wetlands	High
6.12	Preserve natural areas of countywide and local significance, as those of critical species habitat	High
6.13	Incorporate upland conservation and restoration targets into management and policy decisions	High
	Population Management	
6.14	Continue current fish rearing (musky and walleye) and stocking practices consistent with WDNR recommendations	Medium
6.15	Current fishing practices and ordinances should continue to be enforced	Medium
6.16	Encourage adoption of best management practices to improve wildlife populations	Medium
6.17	Continue to monitor fish and wildlife populations	Medium
	RECREATIONAL USE AND FACILITIES	
7.1	Encourage safe boating practices and boating pressure on navigable portions of the Lake	Medium
7.2	Maintain and enhance swimming through engaging in "swimmer-conscious" management efforts	Medium
7.3	Maintain and enhance fishing by protecting and improving aquatic habitat and ensuring the fish community remains viable	Medium
7.4	Maintain public boat launch sites	High
7.5	Existing boating regulations should be reviewed for compatibility with current conditions and expectations and ordinances should be conscientiously enforced	Low-High[a]
7.6	Consider increasing launch fees during peak use periods	Medium
7.7	Track and maintain shoreline and rock buoys stationed across Pewaukee Lake	High
7.8	Take action to reduce conditions leading to powerboat-induced shoreline erosion	Medium
	PLAN IMPLEMENTATION	
8.1	Actively share this plan and work with municipalities to adopt it by maintaining and enhancing relationships with County, municipal zoning administrators, directors of public works/municipal engineers, and law enforcement officers	High
8.2	Keep abreast of activities within the watershed that can affect the Lake	High
8.3	Educate watershed residents about relevant ordinances. Update ordinances as necessary to face evolving use problems and threats	High
8.4	Encourage key players to attend meetings, conferences, and/or training programs to build their lake management knowledge	Medium
8.5	Continue to ensure inclusivity and transparency with respect to all Lake management activities	High
8.6	Foster and monitor management efforts to communicate actions and achievements to future lake managers	Medium
8.7	Apply for grants when available to support implementation of programs recommended in this plan	Medium
8.8	Integrate lake users and residents in future management efforts	High
8.9	Continue to actively monitor management efforts	High
8.10	Foster open relationships with potential project partners	High
8.11	Continue to expand stormwater stenciling program throughout the watershed	Medium
8.12	Educate shoreline property owners on the importance and role of shoreline buffers	Medium
8.13	Educate property owners, organizations, municipal officials, and nearby business owners and golf course managers on the importance of preventing and stabilizing streambank erosion	High
8.14	Continue to install "This is Our Watershed" and "Adopt a Highway" signage throughout the watershed	Medium
8.15	Consider the development of an awards program or approved applicators program	Medium
8.16	Consider re-establishing a "New Lake Resident" welcome package	Medium
8.17	Coordinate with local stakeholder groups and organizations in developing communication mechanisms	Medium
8.18	Develop brochures informing homeowners about their responsibility for maintenance of the storm water drainage systems	Medium

Note: This summary of recommendations is a compiled list of items the Lake Pewaukee Sanitary District, the Town of Delafield, the City of Pewaukee, the Village of Pewaukee, the residents of the Pewaukee Lake watershed, and riparian owners, working together with volunteers and other nonprofit organizations, could implement to improve Pewaukee Lake and its watershed.

[a] *The priority is based on the sub recommendations.*

Source: SEWRPC

the residents of the Pewaukee Lake watershed, and riparian owners, working together with volunteers and other nonprofit organizations. Additionally, collaborative partnerships formed among other stakeholders (e.g., other agencies within the Wisconsin Department of Natural Resources (WDNR), developers, non-governmental organizations (NGOs), and other watershed municipalities) help promote efficient, affordable, and sustainable actions to assure the long-term ecological health of Pewaukee Lake.

As a planning document, this chapter provides concept-level descriptions of activities that may be undertaken to help protect and enhance Pewaukee Lake and its watershed. It is important to note that plan recommendations provide stakeholders and implementing entities with guidance regarding the type and nature of projects to pursue to meet plan goals. These recommendations and project suggestions do not constitute detailed technical specifications. The full logistical and design details needed to implement most recommendations must be more fully developed in the future when individual recommendations are implemented. Grants are often available to take concepts and produce actionable design drawings and plans.

In summary, this chapter provides 1) a context for understanding what needs to be done and the relative importance of plan elements and 2) information that will enable those implementing the plan to better envision what such efforts may look like and to more fully comprehend the overall intent. Such concepts can be invaluable for building coalitions and partnerships, writing competitive and meaningful grant requests, and initiating project design work.

3.2 HYDROLOGY/WATER QUANTITY

General Concepts

All waterbodies gain and lose water through various means. The source of all water supplied to the Region's waterbodies is precipitation. Although some waterbodies derive most water from runoff, tributary streams, and groundwater, these sources also ultimately depend upon precipitation. Waterbodies lose water in a number of ways including evaporation, plant transpiration, outflow, infiltration into beds and banks, and human withdrawal. When water inflow and outflow are not balanced, water elevations and streamflow fluctuate. If water supply is less than water demand, lake elevations can fall and stream flows can be reduced or eliminated. During heavier than normal precipitation, lake and river levels may rise.

Humans modify water dynamics in a drainage basin. In particular, two human activities significantly affect the hydrology of a region:

- Installing impermeable surfaces and stormwater infrastructure hastens runoff, increases runoff volume, and discourages groundwater recharge. This in turn typically increases the volume of water reaching lakes and rivers during wet weather, and decreases flow to waterbodies during dry weather.

- Pumping water from wells disrupts natural groundwater flow systems. If most of the pumped water is returned as groundwater after use, overall impact may be minimal. However, when water is either consumptively used (e.g., evaporated) or exported from the local groundwater flow system (carried by sanitary sewers that discharge effluent outside of the surface-watershed and groundwatershed), groundwater elevations may fall and discharge to and flow in surface-water features can be reduced or eliminated.

Such changes are generally detrimental to waterbody health. Therefore, management actions should attempt to reduce the impact of human-induced hydrologic change on waterbodies.

The Pewaukee Lake watershed is found at the periphery of the Milwaukee metropolitan area and is home to considerable numbers of people. As such, the watershed has significant amounts of impervious land cover and large areas drained by stormwater collection and conveyance networks. Additionally, all water supply systems depend on groundwater, and large volumes of groundwater are exported from the watershed, reducing the volume of groundwater available to feed surface water features. Reduced recharge and high human water demand stresses the watershed's surface water and groundwater resources, and the situation will likely intensify as the area continues to develop.

To maintain waterbody health and provide sustainable water supplies, action should be taken to counteract human activities that compromise sustainable, high quality, water supplies. In general, management actions aim to slow runoff, maintain or increase groundwater recharge, and reduce the volume of water removed from flow systems feeding Pewaukee Lake. Examples of such approaches are described in the following paragraphs.

- **Detain stormwater**. Urban development often involves manipulation of the landscape in ways that increase the volume and speed of runoff and decrease groundwater infiltration. Actions can be taken to detain and more slowly release runoff, reduce peak runoff rates, and better approximate natural rainfall/runoff patterns. When water is detained, physical and biological processes commonly reduce pollutant and sediment loads. Many features on the natural landscape detain runoff (e.g., wetlands, floodplains, closed depressions). Efforts should focus on protecting and enhancing natural stormwater detention areas. If the capacity of natural features is insufficient to achieve the desired goals, stormwater can be detained in purpose-built artificial structures (e.g., stormwater detention basins, ditch checks, swales). Artificial detention features should be installed to service new developments or retrofitted to infrastructure in developed areas. With careful and holistic planning, it can sometimes be feasible to build detention features as part of new development that also serve existing development.

- **Infiltrate stormwater**. The most basic approach to maintain stormwater infiltration and groundwater recharge is to protect or enhance high and very high groundwater recharge potential areas. Map 3.1 compares areas of planned development with current groundwater recharge potential. Areas of planned development in areas of high and very high groundwater recharge potential should be required to design and install infrastructure maintaining, or enhancing, overall stormwater infiltration.

  To maintain or enhance infiltration, water should not be allowed to rapidly leave the land surface and soil health should be maintained or enhanced. Intensive development, drainage ditches, tiling and other soil drainage schemes, storm sewers, and soil compaction should be avoided, particularly in high and very high groundwater recharge potential areas and/or the impact of such modifications should be carefully mitigated by restoring or enhancing natural detention features with good connections to groundwater flow systems.[259] Positive action should be taken to promote soil health throughout the area contributing surface and/or groundwater to the Pewaukee Lake watershed. Healthy soils are more porous, are less prone to erosion, and, therefore, help improve baseflow and water quality.[260]

  Given the significant quantity of groundwater exported from the watershed via sanitary sewers, maintaining, or more desirably increasing, surface water infiltration is very important. This action not only protects surface-water features and ecological health, but also helps safeguard the water supplies that humans in the Region depend upon for drinking water and other uses.

- **Reduce net groundwater demand.** Groundwater supplies all residential, commercial, and industrial water demands in the Pewaukee Lake watershed and surrounding areas. Additionally, public sanitary sewers that export wastewater from the watershed serve much of the area. Therefore, much of the water drawn from local aquifers is exported from the watershed and no longer can supply baseflow to surface-water features. This is a vexing problem that has few solutions. However, action can be taken to reduce current and future net groundwater demand placed on local aquifers. Examples of such concepts are provided below.

  - Promote enhanced infiltration of stormwater runoff.

  - Institute a water conservation campaign that focuses on water demands that are now discharged to sanitary sewers.

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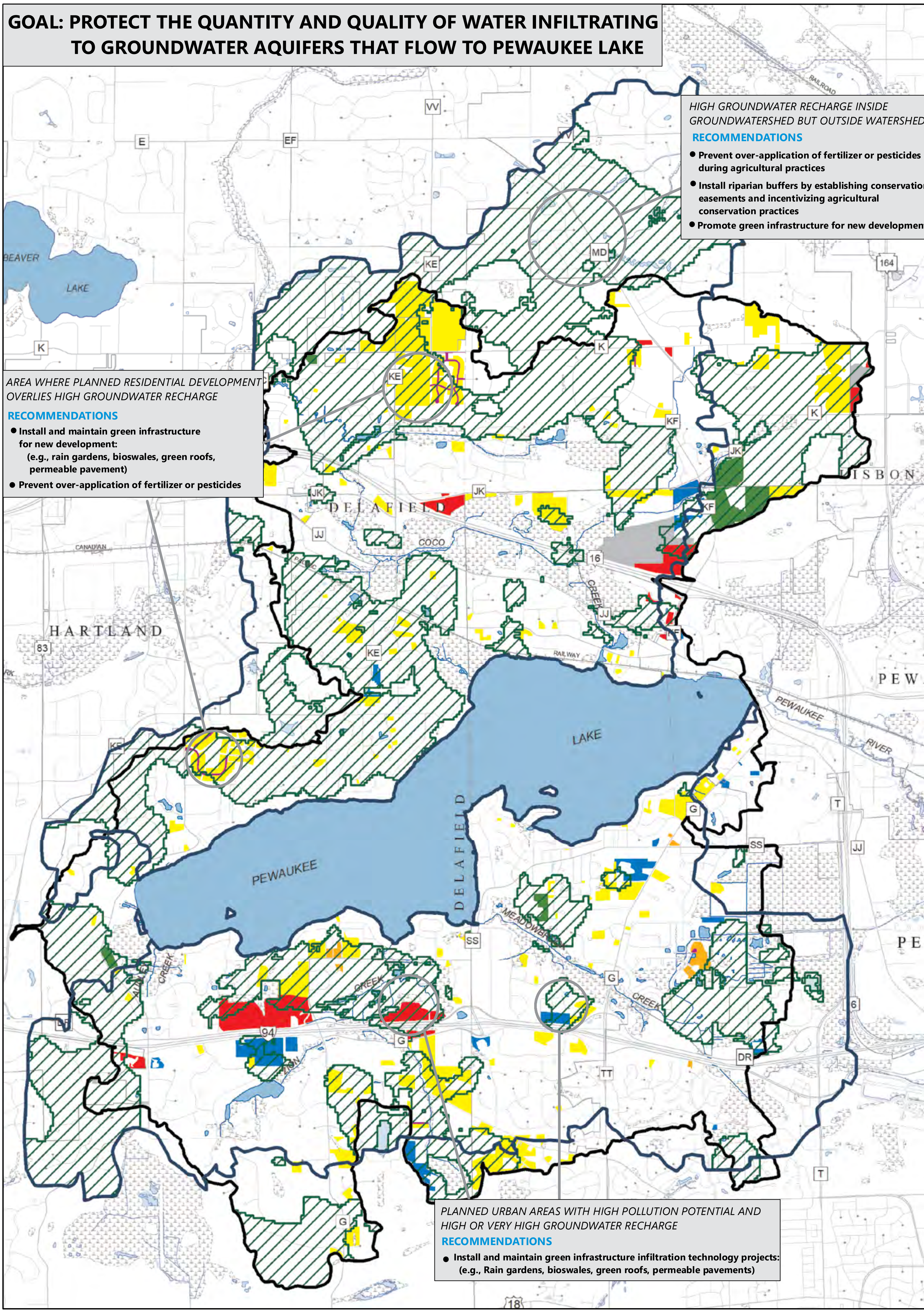
[259] *Detention features can be built that encourage infiltration of stored water and contribute to groundwater recharge. Such systems are one of only a few artificial methods that meaningfully reduce overall runoff volume. They are best situated in areas of high and very high groundwater recharge potential.*

[260] *More information regarding soil health can be obtained from many sources including the following website: www.nrcs.usda.gov/wps/portal/nrcs/main/national/soils/health.*

Map 3.1
High Groundwater Recharge Protection Priority Areas and Planned Urban Development Areas Within the Pewaukee Lake Watershed



PLANNED LAND USE

- SINGLE-FAMILY RESIDENTIAL
- MULTI-FAMILY RESIDENTIAL
- COMMERCIAL
- INDUSTRIAL
- GOVERNMENTAL AND INSTITUTIONAL
- RECREATIONAL
- TRANSPORTATION, COMMUNICATION, AND OTHER UTILITIES

- HIGH AND VERY HIGH GROUNDWATER RECHARGE AREAS
- SURFACE WATER
- WETLAND
- STREAM
- GROUNDWATERSHED BOUNDARY
- WATERSHED BOUNDARY

MANAGEMENT IMPLICATIONS

AREAS SHOWN UNDER A CROSSHATCH INDICATE A HIGH-PRIORITY AREA FOR IMPLEMENTING INFILTRATION TECHNOLOGY IN PLANNED DEVELOPMENT, AS THESE AREAS CURRENTLY ALLOW WATER TO ENTER (I.E., SEEP) INTO THE LAKE THROUGH GROUNDWATER RECHARGE. MAINTAINING GROUNDWATER RECHARGE IS ESSENTIAL TO PROTECTING WATER QUALITY AND QUANTITY.

Note: Planned land use is based on comprehensive plans adopted by local governments located within the Pewaukee Lake watershed.

0 850 1,700 3,400 Feet

Source: SEWRPC

- Evaluate if clean-water discharges now directed to sanitary sewers or discharge points outside the watershed can be discharged to areas within the area contributing surface water and groundwater to Pewaukee Lake. An example would be redirecting non-contact cooling water drawn from onsite wells that has not been treated in any way.[261]

  Groundwater recharge occurring outside of the groundwatershed of Pewaukee Lake does not support baseflow to the Lake. Nevertheless, groundwater recharge does support baseflow in neighboring lakes and streams. For example, water infiltrating from detention features in the Village of Hartland east of the Bark River supports groundwater systems discharging to Coco Creek and Pewaukee Lake.

The strategies promoting the quantity, timing, and quality of water reaching surface water features are most efficiently applied to specific areas to have the desired effect. The complex interplay of surface water and groundwater flow systems creates a situation where different geographic areas have differing potential to protect and enhance water supply and quality. These areas are described below and are located in Map 3.2.

- The area within the Lake's watershed but outside of the recharge area of shallow groundwater flow systems feeding Pewaukee Lake is best suited to strategies that focus on detaining stormwater runoff and enhancing runoff water quality.

- Areas outside of the surface watershed but within the recharge area of the shallow groundwater flow systems feeding Pewaukee Lake are best suited to strategies that aim to increase stormwater infiltration and reduce net groundwater demand.

- Projects executed in the area that is within both the Lake's watershed and groundwatershed can benefit both the Lake's surface water and groundwater supply. Projects in this area can use a combination of detention, infiltration, and net groundwater demand reduction.

Management Strategies

A management strategy addressing water quantity within the watershed water supply should be able to identify opportunity, quantify change, and evolve. Monitoring efforts are essential to provide the data necessary to make informed management decisions. The following recommendations for monitoring and management of surface waters and groundwater will help protect water resources throughout the watershed.

Surface Water Monitoring and Management

➤ **Recommendation 1.1: Continue to monitor Pewaukee Lake's water surface elevation**

The reference point elevation must be related to a known datum to allow comparison to data collected in the past and the future. Continued monitoring is necessary, so that any issues can be detected early and a long-term Lake level record obtained. Automated lake level systems are available and may be useful to link to public websites. Real time surface water elevation data would be useful for adapting the discharge rate to current weather conditions as well as better enforcement of boating ordinances. This recommendation is a high priority.

➤ **Recommendation 1.2: Continue to monitor and quantify the volume of water delivered to the Lake from the various (tributary) sub-basins**

At a minimum, stream flow should be quantified when water quality samples are collected. Additional measurements should be made to help quantify flow during fair weather, periods of heavy runoff, and dry weather. Runoff estimates can be made using empirical formulae or models. Additional measurements and modeling require substantial amounts of labor and/or cost. This recommendation is a medium priority.

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[261] *In some cases, municipal water supplies are treated with compounds (e.g., orthophosphate) that helps reduce corrosion in lead pipes. Additionally, disinfectants, fluoride, and other compounds are often added to municipal water supplies. These additives may be detrimental if discharged to surface water or groundwater.*

- **Recommendation 1.3: Retrofitting the Pewaukee Lake outlet dam so that it remains operational throughout the year**
  Currently, the bottom draw gate can be blocked by debris or locked into place by ice, removing the capacity to control lake surface water elevations and prepare for high precipitation events. Retrofitting the dam with an aerator, heating coil, or a similar piece of equipment to keep the gate operable in winter will greatly increase the dam operator's ability to maintain lake levels and adapt to inclement winter weather conditions. This recommendation is a high priority.

- **Recommendation 1.4: Pursue revision of current Pewaukee Lake level policy**
  Revising the policy to a more dynamic policy that mimics more closely the natural flow regime of the Lake levels, especially in regards to post-high precipitation events, transition protocols for seasonal change (winter to spring, etc.), and during times of high flooding events. A more natural flow would better enhance the ecology of the Lake and the Pewaukee River. This recommendation is a high priority.

- **Recommendation 1.5: Install infrastructure to prevent entrainment of beach sand into the Lake outlet**
  The Lakefront Park beach has lost sand to entrainment from the Lake outlet dam, requiring supplemental sand to be spread.[262] Installing infrastructure (e.g., a fishing pier) between the beach and the dam may help prevent sand entrainment from the beach and the subsequent accumulation of sand in the Pewaukee River.[263] This recommendation is a high priority.

Groundwater Monitoring and Protection

- **Recommendation 1.6: Encourage local units of government to use the U.S. Geological Survey (USGS) Upper Fox River Basin groundwater model**
  Local governments should use this model to investigate different development scenarios to help communities make future land use decisions in order to balance water supply needs, water quality needs, and possibly recreational needs. This is a high priority.

- **Recommendation 1.7: Implement measures promoting stormwater storage and infiltration in existing urban areas**
  Implementing this recommendation could involve:

  - **Enhancing the ability of rainfall and snowmelt to be detained, filtered, and/or infiltrated into soils**. This could be most easily achieved by installing modern stormwater best management practices (BMPs) associated with low-impact development, including rain gardens and other stormwater infrastructure specifically designed and carefully located to slow runoff, improve water quality, and promote infiltration.[264] Examples of simple infiltration measures include voluntarily directing stormwater to areas of permeable soil and favorable topography or minimizing impermeable surfaces. An example of redirecting stormwater is disconnecting roof downspouts from storm sewers. Such initiatives can be promoted by active educational outreach, providing instructions and supplies to property owners, and/or through subsidies. Some practices and projects, especially on public property, may qualify for partial funding through the WDNR Healthy Lakes & Rivers program. Given the relatively low cost and relative ease of implementation, this recommendation should be given a high priority throughout the watershed, with particular emphasis given to the portion of the watershed that is also within the groundwatershed.

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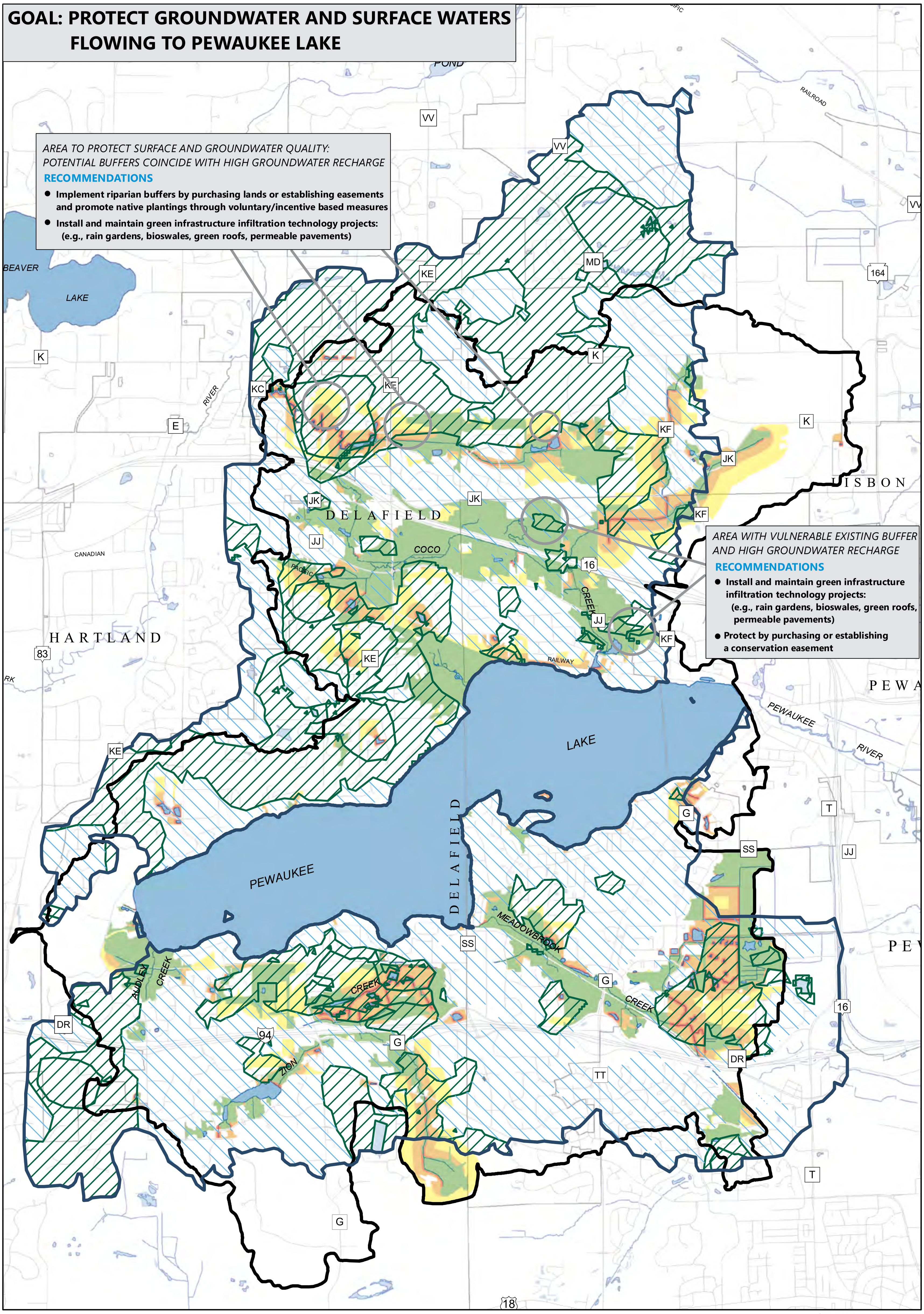
[262] *Personal communication, Daniel Naze, P. E., Village of Pewaukee Director of Public Works/Village Engineer, May 29, 2019.*

[263] *For more information, see SEWRPC Community Assistance Planning Report No. 313,* Pewaukee River Watershed Protection Plan, *2013.*

[264] *Rain gardens are depressions that retain water, are vegetated with native plants, and help water infiltrate into the ground rather than enter the Lake through surface runoff. Rain gardens can help reduce erosion and the volume of unfiltered pollution entering the Lake and can also help augment baseflow to the Lake.*

Map 3.2
Proposed Riparian Buffer Protection Areas and Groundwater Recharge Protection Areas Within the Pewaukee Lake Watershed



PRIORITY LANDS TO PROTECT

- EXISTING BUFFER VULNERABLE TO DEVELOPMENT → WHEN SHOWN UNDERNEATH A CROSSHATCH, THIS INDICATES A HIGH-PRIORITY AREA FOR PURCHASE AND/OR PROTECTION AS THESE AREAS ALLOWING WATER TO ENTER (I.E., SEEP) INTO THE LAKE THROUGH GROUNDWATER RECHARGE.
- 75 FOOT MINIMUM BUFFER WIDTH
- 400 FOOT MINIMUM CORE HABITAT WIDTH
- 1,000 FOOT OPTIMAL CORE HABITAT WIDTH FOR WILDLIFE PROTECTION

→ THESE AREAS UNDER A CROSSHATCH INDICATE HIGH PRIORITY FOR RIPARIAN BUFFER INSTALLATION, AS WELL AS PURCHASE AND/OR PROTECTION, AS IT CONTRIBUTES TO WATER ENTERING BACK INTO THE LAKE THROUGH GROUNDWATER RECHARGE AND HAS THE POTENTIAL TO PROTECT THE SURFACE WATER FROM POLLUTION (IF BUFFER REGION IS DEVELOPED).

- HIGH AND VERY HIGH GROUNDWATER RECHARGE POTENTIAL
- MODERATE GROUNDWATER RECHARGE POTENTIAL

MANAGEMENT IMPLICATIONS

Note: Areas of very high, high, and moderate groundwater recharge potential are modeled estimates based in part on land uses at the time the model was created. Land uses may have changed in some areas since the model was created. This factor should be taken into consideration when interpreting groundwater recharge potential on a finer scale.

- STREAM
- GROUNDWATERSHED BOUNDARY
- WATERSHED BOUNDARY
- SURFACE WATER

N

0 0.2 0.4 0.8 Miles

Source: SEWRPC

- **Integrating advanced stormwater management practices into local permitting processes.** A step toward a more comprehensive approach that benefits human habitation and waterbody health would be an ordinance requiring onsite stormwater management practices such as detention, permeable conveyance, limits to impervious surface, porous pavement, or other measures as a condition of issuance of a building permit affecting the overall impermeable surface area of a parcel. Such ordinances should be actively enforced when they exist, or should be incorporated into existing ordinances. This should be considered a high priority.

- **Retrofitting existing stormwater management systems with features that enhance water quality and/or modulate runoff rates.** Public works projects can be completed within existing urban development. Elements such as stormwater retention/infiltration basins, bioswales, permeable conveyance, and other infrastructure elements can help reduce the impact of existing development on water quality and quantity. In certain instances, stormwater infrastructure built for new development can be located and sized to manage stormwater runoff from existing development. Such projects are commonly difficult to execute and costly. Therefore, this recommendation should be generally assigned a low priority. Nevertheless, some retrofits can be easily integrated into system updates and should be considered whenever practical.

➤ **Recommendation 1.8: Reduce the impact of existing land use and future urban development on groundwater supplies**

This recommendation can be implemented by:

- **Promoting water conservation initiatives**. Additionally, avoiding discharge of potable water to sanitary sewers, instead discharge to soils, storm sewers, or surface water features.

- **Carefully controlling new development in the watershed's best groundwater recharge potential areas**. This helps assure local and sometimes regional groundwater flow systems are protected. Control can include excluding certain types of development, maintaining recharge potential through thoughtful design, and minimizing impervious surface area. Consider purchasing or obtaining protective or conservation easements on open lands with high and very high groundwater recharge potential. Promote policies that protect or enhance infiltration on public lands. The recommended priorities for preserving recharge areas are:

    - High priority should be given to areas identified as having high and very high groundwater recharge potential within the groundwatershed feeding Pewaukee Lake.

    - Medium priority should be given to moderate groundwater recharge potential areas within the groundwatershed feeding the Lake and its tributaries.

    - Low priority should be assigned to low groundwater recharge potential areas within the groundwatershed feeding the Lake and all areas outside the groundwatershed feeding the Lake.

    In addition, groundwater recharge protection efforts should be prioritized among sub-basins in this order:

    1. Coco Creek

    2. Zion Creek

    3. Meadowbrook Creek

- **Requiring compliance with the infiltration and groundwater management regulations and recommendations found in municipal ordinances** (high priority).

- **Encouraging developers to actively incorporate infiltration in new stormwater infrastructure** (high priority)**.** Such infrastructure is best located on area of high and very high recharge potential. Infiltrating water must be of good quality. Prioritize locations within the three main tributary watersheds (Coco, Meadowbrook, and Zion creeks) that are not fitted with stormwater quantity/quality infrastructure.

- **Encouraging local government to consider groundwater recharge and groundwater demand as an integral part of new development and infrastructure replacement proposals.** Some Southeastern Wisconsin communities have promulgated ordinances that require integrated analysis of groundwater and surface water impact in the process through which developers obtain permission to build new buildings and subdivisions (high priority).[265]

- **Critically examining proposals that export water from the groundwatershed** (high priority).

- **Promote good soil health.** This is most widely applicable to the agricultural lands within the watershed, but the principles can also be applied to other lands such as parks and lawns (high priority). Consider offering advice and, possibly, financial incentives. While all agricultural land can benefit from these practices, applying these practices to lands closest to waterbodies tributary to Pewaukee Lake will likely benefit the Lake's water quality the most.

- **Purchase land or conservation easements** on agricultural and other open lands within Pewaukee Lake's groundwatershed that are identified as having very high or high groundwater recharge potential (medium priority).

- **Continue to protect wetlands and uplands with an emphasis on preserving groundwater recharge to the Lake by enforcing town, village, and city zoning ordinances**. This recommendation should be given a high priority.

As with the other recommendations made in this chapter, any unanticipated, long-term, or large future changes in the tributaries' flow or the water elevation of Pewaukee Lake would spur the need for re-evaluation of these recommendations. Consequently, flow and water elevation data should be periodically examined and the suitability of water quantity recommendations should be re-evaluated. This process should be assigned a high priority.

3.3 WATER QUALITY

Water quality is one of the key parameters used to determine the overall health of a waterbody. The importance of good water quality can hardly be overestimated, as it impacts not only various recreational uses of a lake, but also nearly every facet of the natural balances and relationships that exist in a lake between the myriad of abiotic and biotic elements present. Because of the importance water quality plays in the functioning of a lake ecosystem, careful monitoring of this lake element represents a fundamental management tool. The fact that Lake residents are concerned with various water-quality-related issues (e.g., sources of pollution in the watershed, the volume of aquatic plant growth, algal growth) suggests that water quality management is warranted on the Lake.

Pewaukee Lake Monitoring

Water quality monitoring is an important tool that helps quantify the Lake's current condition, understand long term change, and provides insight into why changes are occurring. Currently, the WDNR monitors water quality four times each year (since 2000) at the deep hole in the west basin of Pewaukee Lake as part of their long-term monitoring program. The LPSD also monitors biweekly profiles for temperature, dissolved oxygen concentrations, salinity, and conductivity at five foot intervals in the west basin (i.e., deep hole) as well as Secchi depths in the west and east basins of the Lake. Recommendations to continue and enhancing these monitoring efforts are described in the following text.

[265] *The Village of Richfield in Washington County is such an example. More information may be found at the Village's website: www.richfieldwi.gov/index.aspx?NID=300.*

➤ **Recommendation 2.1: Continue and enhance comprehensive water quality monitoring within Pewaukee Lake**

This recommendation is a high priority. At a minimum, water quality samples should be analyzed for the following parameters:

- **Field measurements**
  - Water clarity (i.e., Secchi depth)
  - Temperature (profiled over the entire water depth range at the deepest portion of the Lake with more frequent readings near the thermocline)
  - Dissolved oxygen (profiled over the entire water depth range at the deepest portion of the Lake with more frequent readings near the thermocline)
  - Specific conductance (near-surface sample, profiles with depth if equipment is available)
  - pH (near-surface sample, profiles with depth if equipment is available)
- **Laboratory samples**
  - Total phosphorus (near-surface sample with supplemental samples collected during summer near the deepest portions of the Lake)
  - Total nitrogen (near-surface sample)
  - Chlorophyll-*a* (near-surface sample)
  - Chloride (near-surface sample)
  - Alkalinity (near-surface sample)

Laboratory tests quantify the amount of a substance within a sample under a specific condition at a particular moment in time, and provide valuable benchmark and trend-defining values. Phosphorus, nitrogen, and chlorophyll-*a* analyses are the basic suite of parameters used to determine and track overall lake health. These parameters are tested almost universally and are useful to contrast the Lake's health to other waterbodies of interest. Chloride is of particular concern in the Region, and is the focus of an ongoing Commission study.[266] Excessive chloride concentrations are indicative of heavy human influence and are commonly associated with environments more favorable to undesirable aquatic invasive species. Alkalinity is of particular importance to the process that drives phosphorus sequestration. Maintaining high alkalinity levels is instrumental to the Lake's ability to sequester phosphorus.

Field measurements can often serve as reasonable surrogates for common laboratory tests. For example, water clarity decreases when total suspended solids and/or chlorophyll-*a* concentrations are high, samples with high concentrations of total suspended solids commonly contain more phosphorus, and water with higher specific conductance commonly contains more salt and, therefore, more chloride. Periodically sampling water and running a targeted array of laboratory and field tests not only provides data for individual points in time, but can also allow laboratory results to be correlated with field test results. Once a relationship is established between laboratory and field values, this relationship can be used as an inexpensive means to estimate the concentrations of key water quality indicators normally quantified using laboratory data.

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[266] *SEWRPC Planning Report No. 57,* A Chloride Impact Study for the Southeastern Wisconsin Region*, in progress.*

Citizen Lake Monitoring

The Citizen Lakes Monitoring Network (CLMN) provides training and guidance regarding monitoring lake health.[267] Volunteers commonly monitor water clarity, temperature, and dissolved oxygen throughout the open water season (preferably every 10 to 14 days) and basic water chemistry (i.e., phosphorus and chlorophyll-*a* concentrations) four times per year (two weeks after ice off and during the last two weeks of June, July, and August). Volunteers enrolled in CLMN gather data at regular intervals on water clarity through the use of a Secchi disk. Because pollution tends to reduce water clarity, Secchi disk measurements are generally considered one of the key parameters in determining the overall quality of a lake's water, as well as a lake's trophic status. Expanded CLMN monitoring includes collection of water samples to measure total phosphorus and chlorophyll-*a*, which are also important for understanding trophic status.

Supplemental temperature/oxygen profiles collected at other times of the year (e.g., other summer dates, nighttime summer, fall, winter) can be helpful. For example, temperature/oxygen profiles collected during midsummer nights, just before sunrise, help evaluate diurnal oxygen saturation swings. Additionally, oxygen/temperature profiles should occasionally be measured in other portions of the Lake during summer to help evaluate the homogeneity of temperature and oxygen concentrations throughout the Lake. The locations of such supplemental sampling points need to be carefully documented.

Conductivity profiles collected during late fall, winter, and early spring would also help quantify the impact of road deicing on the Lake. In addition, the Lake's chloride concentration should also be monitored at least once per year when the Lake is fully mixed. Monitoring chloride concentrations allows the rate of concentration increase over time to be quantified. This will help discern the overall impact of cultural influence on the Lake and to evaluate if chloride concentrations are approaching levels that could foster negative changes in the Lake's ecosystem.

As part of the Long Term Trend Monitoring program, WDNR staff have been collecting detailed water quality information on Pewaukee Lake, including sampling during a spring turnover, monthly summer samples, and temperature and dissolved oxygen profiles at the deep hole, since 1986.[268] It is recommended that this WDNR monitoring be continued on Pewaukee Lake.

In addition to the University of Wisconsin-Division of Extension (UWEX) volunteer-based CLMN program, University of Wisconsin-Stevens Point (UW-SP) also offers several volunteer-conducted water quality sampling programs. Under these latter programs, volunteers collect water samples and send them to the UW-SP Water and Environmental Analysis Laboratory for analysis. The USGS also offers an extensive water quality monitoring program under their Trophic State Index monitoring program. Under this program, USGS field personnel conduct a series of approximately five monthly samplings beginning with the spring turnover. The Wisconsin State Laboratory of Hygiene analyzes these samples for an extensive array of physical and chemical parameters. Utilization of this program is also a viable option, if WDNR monitoring were to be terminated.

Monitoring Funding Opportunities

The basic UWEX CLMN program is available at no charge, but does require volunteers to be committed to taking Secchi disk measurements at regular intervals throughout the spring, summer, and fall. The Expanded Self-Help Program requires additional commitment by volunteers to take a more-extensive array of measurements and samples for analysis, also on a regular basis. The WDNR offers small grant cost-share funding within the NR 193 Surface Water Grant Program that can be applied for to defray the costs of laboratory analysis and sampling equipment. As with any volunteer-collected data, despite the implementation of standardized field protocols, individual variations in levels of expertise due to background and experiential differences, can lead to variations in data and measurements from lake-to-lake and from year-to-year for the same lake, especially when volunteer participation changes.

The UW-SP turnover sampling program requires only a once-a-year sampling, thereby requiring a smaller time commitment by the volunteers. However, there is a modest charge for the laboratory analysis and

[267] *More information regarding the CLMN may be found at the following website: uwsp.edu/cnr-ap/UWEXLakes/Pages/programs/clmn/default.aspx.*

[268] *See WDNR website for more information at: dnrx.wisconsin.gov/swims/public/reporting.o?type=10&action=post&stationNo=683143&year1=2017&format=html.*

since volunteers perform the sampling, the data is subject to those variations identified above. Additionally, since samples need to be taken as closely as possible to the actual turnover period, which occurs only during a relatively short window of time, volunteers need to monitor lake conditions as closely as possible to be able to determine when the turnover period is occurring.

In contrast, the USGS program does not require volunteer sampling. USGS personnel provide all sampling and analysis using standardized field techniques and protocols. As a result, a more standardized set of data and measurements may be expected. However, the cost of the USGS program is significantly higher than the UW-SP program. State cost-share funds may be available to the LPSD under the NR 193 Surface Water Planning grant program.

Tributary Monitoring

Since tributaries can play a significant role in determining a lake's water quality, it is recommended that water quality measurements continue to be taken in the three main tributaries: Coco, Meadowbrook, and Zion creeks. Recommendations for tributary monitoring are as follows:

➤ **Recommendation 2.2: Level 1 Water Action Volunteer (WAV) monitoring in Coco, Meadowbrook, and Zion creeks should be continued**

UWEX maintains WAV, a stream monitoring program that is the analogue of CLMN for lakes. Volunteers in the Pewaukee Lake watershed should continue to actively monitor the Lake's tributaries through the WAV program. Monitoring of water temperature, dissolved oxygen, as well as total phosphorus, transparency, chlorides, conductivity, and pH should be included; comparisons of internal loading in Pewaukee Lake and loads from the tributaries can be done to determine the proportional contributions of each. Water chemistry monitoring in the tributaries should occur *concurrently with flow data*. This recommendation is a high priority.

➤ **Recommendation 2.3: Consider expanding up to Level 2 WAV monitoring to install programmable water temperature logging devices in these tributaries**

The continuous monitoring provided by temperature logging devices can provide substantially more information about stream conditions and suitability for fish species. However, participation in this program requires greater time commitment, including training, equipment calibration, and data entry. This recommendation is a medium priority.

If electronic monitoring is not feasible at this time, grab samples should be collected to represent a cross section of flow events (i.e., low, medium and high). The sampler should record the current and recent weather conditions, a qualitative description of flow and water quality (e.g., "creek is very high and muddy"), and the exact location, date and time where the sample was collected. Sampling parameters should include the following:

- Stream flow
- Water clarity (transparency tubes, see below)
- Total phosphorus
- Total nitrogen
- Chloride
- Temperature
- Dissolved oxygen

Flow rate information allows the actual mass load of phosphorus contributed from the tributaries and the areas they drain to be quantified and compared. The amount of water delivered from each tributary can also be estimated using empirical formulae (e.g., the Rational Method) and models (e.g., TR 55, SWMM). These flow estimates can be combined with water quality information collected in the tributary streams to estimate mass loadings from each stream. Calculating mass loading using modeled flow rates should be considered a high priority. This information can then be used to target priority tributaries, seasons, and events for water quality analyses.

Parameters and sampling frequency may be adjusted as necessary to focus resources on the sub-basins identified to have the greatest impact to the Lake's water quality. Depending upon the sub-basin and sample results, action should be taken to help reduce pollutant loadings. For example, if phosphorus was detected in high concentrations in a tributary draining residential areas, efforts to communicate BMPs to homeowners should be reinforced, stormwater management infrastructure inspected, actions to protect and expand wetlands and buffers increased, and other factors considered. Intensified and/or expanded monitoring may help pinpoint source areas for particular attention.

Regular water quality monitoring helps Lake managers identify variations in the Lake's water quality and improves the ability to understand problems and propose solutions. Given the changing landscape in which Pewaukee Lake is situated, water quality and the conditions influencing water quality can change. Regular review and revision of water quality monitoring recommendations should be considered a high priority.

Phosphorus Management

All indicators of trophic state suggest that Pewaukee is transitioning from often eutrophic conditions to consistent mesotrophic conditions. This improvement in water quality is a testament to phosphorus load reduction efforts made within the watershed. Implementing these recommendations will continue to improve water quality within Pewaukee Lake, resulting in clearer water, fewer algal blooms, and reduced weedy plant growth.

- **Recommendation 2.4: Reduce nonpoint source external phosphorus loads**
  Pewaukee Lake can receive substantial sediment and pollutant loads from the drainages that discharge directly to the Lake. Nonpoint phosphorus loads should be reduced to the maximum extent practicable, and reduction strategies should be assigned high priority. This issue is discussed in more detail, and strategies to reduce loads are presented, under Section 3.4, "Pollutant and Sediment Sources and Loads."

- **Recommendation 2.5: Manage in-Lake phosphorus sources**
  The available evidence suggests that phosphorus internal loading is a substantial contributor to total phosphorus loading at 1,818 pounds per year. Therefore, actions taken to reduce internal phosphorus cycling can also have a profound effect on water quality and aquatic plant/algae abundance. Overall water quality and habitat value could likely be enhanced by decreasing the Lake's limiting plant nutrient (phosphorus). This in turn would help the Lake be less eutrophic, reduce the incidence and severity of algal blooms, lessen stress on the Lake's fish and aquatic life communities, help assure that natural plant-induced phosphorus sequestration processes continue, and sustain a high-quality ecosystem with more long-term resilience. Reducing excess phosphorus is key to this dynamic; therefore, managing in-Lake phosphorus is important. Additional data, particularly hypolimnetic phosphorus concentrations, may need to be collected to more fully evaluate internal loading dynamics and monitor effectiveness. This recommendation is a high priority.

While a large variety of techniques can be used to reduce internal recycling of phosphorus, two or three approaches appear to be most promising for Pewaukee Lake. It should be remembered that a combination of approaches, as opposed to choosing a single strategy, will typically provide the best results. Additional details regarding each approach are provided below:

- **Recommendation 2.6: Removing nutrients through aquatic plant harvesting**
  This should be considered a high priority in Pewaukee Lake. Plant harvesting has the potential to remove significant amounts of phosphorus from the Lake, offsetting phosphorus loading from precipitation and other sources, and potentially reducing the availability of legacy phosphorus. Chemical treatments should be avoided, since they allow nutrients to remain in the Lake in the form of dead plant material. A new small aquatic plant harvester specially designed for tight quarters and shallow waters may be a good alternative in areas inaccessible to current harvesting equipment. See the Section 3.5, "Aquatic Plants" for additional information.

➤ **Recommendation 2.7: Promoting conditions conducive to muskgrass growth**

This should be considered a high priority. Muskgrass (*Chara* spp.) growth sequesters phosphorus, and is a significant factor in some lakes' ability to absorb high phosphorus loads yet maintain good water quality. Muskgrass commonly favors areas of groundwater discharge, therefore, the volume of groundwater discharge to the Lake must be maintained. Clearer water can contribute to muskgrass growth, forming a positive self-reinforcing feedback loop.

➤ **Recommendation 2.8: Increasing the frequency of hypolimnetic phosphorus sampling**

Increased sample frequency would allow updated monitoring of internal loading within the Lake and is therefore recommended as a high priority. The reported internal loading rate was primarily calculated using data prior to 2000 due to lack of hypolimnetic phosphorus sampling since then. Declines in total phosphorus within the Lake surface water suggest that internal loading has likely declined as well, but this is not possible to measure without enhanced hypolimnetic monitoring.

Chloride Management

Chloride concentrations in the Lake have increased over time, consistent with many other lakes within Southeastern Wisconsin. Elevated chloride concentrations have been observed in Coco, Meadowbrook, and Zion Creeks, indicating that chloride loading is an issue affecting the entire watershed. Chloride is a conservative pollutant meaning that there are no natural processes that will break it down within the Lake. Additionally, remove of chloride from waterbodies is prohibitively expensive in most cases. Thus, reduction of chloride inputs is the most effective management strategy to maintain low chloride concentrations in the Lake. Many of the recommendations in Section 3.4, "Pollutant and Sediment Loading", such as implementation of vegetated buffer strips and retrofitting stormwater systems, mitigate pollutant runoff into surface waters, including chloride. However, the following recommendations specifically address chloride management:

➤ **Recommendation 2.9: Reduce private and public salt applications by practicing smart salt management**

Private salt application, such as to parking lots and personal sidewalks, can contribute substantial amounts of chloride to surface waters if the application rates are not properly managed. Using salt best management practices, such as calibrating salt spreading equipment, using road salt alternatives when practicable, and storing materials away from surface waters, should be encouraged. Salt applicators should also be encouraged to undergo winter salt certification training, hosted by Wisconsin Salt Wise.[269] This recommendation is a high priority.

➤ **Recommendation 2.10: Optimize water softeners for water use and hardness levels and upgrade to high-efficiency softeners when practical**

Residential and commercial water softeners have been shown to be a major chloride source, particularly in areas with hard water such as Southeastern Wisconsin.[270] Water softeners should be optimized for their water use and hardness levels, which can reduce their chloride discharge by up to 50 percent. Other municipalities and their associated wastewater treatment facilities within the Pewaukee Lake watershed should consider adopting the approach utilized by the City of Waukesha, which is cost-sharing water softener optimization with local water conditioning companies. Subsequently, the City's residents only need to pay a nominal $10 copayment to optimize their water softeners.[271] Residents of the watershed whose softeners discharge to the Waukesha sewer system can already take advantage of this program (see Map 2.11 on page 45). When water softeners are too old for optimization to have much effect, replacing the old softeners with high-efficiency softeners should be considered to reduce chloride discharge. This recommendation is a high priority.

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[269] *For a more complete list of salt best management practices and information on the Wisconsin Salt Wise winter salt certification program, see www.wisaltwise.com.*

[270] *A. Overbo, S. Heger, S. Kyser, et al.,* Chloride Concentrations from Water Softeners and Other Domestic, Commercial, Industrial, and Agricultural Sources to Minnesota Waters, *Minnesota Water Quality Association, 2019.*

[271] *For more information on the City of Waukesha's Water Softener Salt Program, see https://waukesha-wi.gov/1763/Softener-Salt-Program.*

3.4 POLLUTANT AND SEDIMENT SOURCES AND LOADS

Pewaukee Lake has relatively good water quality and no significant point sources of pollution in its watershed. Coco Creek, Zion Creek, and Meadowbrook Creek are the three main tributary contributors of phosphorus to Pewaukee Lake. Future conversion of agricultural land use to residential development will likely impact the Lake's water quality in a number of ways, including an overall decrease in sediment loading to the Lake and an increase in the amounts of metal loading. Data show that there is a great deal of phosphorus in the bottom sediments that is released under anoxic conditions (i.e., internal loading); the role recycling of phosphorus may be playing in Pewaukee Lake has yet to be determined and will require a separate study.[272]

Dedicated management continues to reduce phosphorus loading to the Lake. Promoting riparian and shoreline buffers as well as purchasing of conservation easements in riparian areas reduces sediment and phosphorus loading from runoff. Mechanical harvesting of aquatic plants in Pewaukee Lake removed between 18,000 and 52,000 pounds of phosphorus from the Lake since 1988. Finally, keeping leaves from collecting on residential streets through prompt leaf collection has been shown to be a critical part of reducing external phosphorus from residential areas. The recommendations presented below are intended to enhance ongoing efforts to reduce phosphorus and sediment loading at different scales: the entire Lake watershed, its sub-basins, and along the Lake shoreline.

Riparian Buffer Protection and Prioritization Strategies

All riparian buffers provide some level of protection that is greater than if there were no buffer at all. However, wider buffers provide a greater number of functions (infiltration, temperature moderation, and species diversity) than narrower buffers. Therefore, it is important that existing buffers be protected and expanded where possible. The riparian buffer network out to the 75-foot, 400-foot, and 1,000-foot widths as summarized in Section 2.6, "Pollutant Loads" provides the framework upon which to protect and improve water quality and wildlife within the Pewaukee Lake watershed. This framework can be achieved through a combination of strategies that include land acquisition, regulation, and best management practices.

Land Acquisition

The prioritization for acquisition of these lands (including PEC, SEC, and INRA, and natural areas (NAs)) should be based upon the following order of importance (from highest to lowest priority):

1. Existing riparian buffer (protect what exists on the landscape)

2. Potential riparian buffer lands up to 75 feet wide (minimum level of protection for pollutants)

3. Potential restorable wetlands within 1,000 feet of Pewaukee Lake or its tributaries (see Map 2.23 on page 137) or the one-percent-annual-probability-floodplain (see Map 2.9 on page 35), whichever is greater (priority for pollutant removal and wildlife habitat protection)

4. Potential riparian buffer lands up to 400 feet wide (minimum for wildlife protection)

5. Potential riparian buffer lands up to 1,000 feet wide (optimal for wildlife protection)

In addition, special consideration should be given to 1) acquiring riparian buffers in locations designated as having high to very high groundwater recharge potential as shown on Map 2.10 (page 42), and 2) connecting and expanding critical linkages among habitat complexes to protect wildlife abundance and diversity. Furthermore, connecting the SEC lands and multiple INRAs throughout the Pewaukee Lake watershed to the larger PEC areas, as well as building and expanding upon the existing protected lands as shown in Map 2.17 on page 64, represents a sound approach to enhance the corridor system and wildlife areas within the watershed.

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[272] *See Section 2.6, "Pollutant Loads" of this report for a detailed description of phosphorus recycling.*

Regulatory and Other Opportunities

Chapter NR 115, "Wisconsin's Shoreland Protection Program," of the *Wisconsin Administrative Code* establishes a minimum 75-foot development setback from the ordinary high water mark of navigable lakes, streams, and rivers. There also is a required minimum tillage setback standard of five feet from the top of the channel of surface waters in agricultural lands called for under Section NR 151.03 of the *Wisconsin Administrative Code*. Instream field observations in the watershed and orthophotograph interpretation indicate that Pewaukee Lake and its tributaries flowing through agricultural lands were not meeting the five-foot tillage setback. As summarized above, not having an adequate buffer between a field and a waterway can contribute to significant sediment and phosphorus loading to the waterway and can significantly limit wildlife habitat. In addition, based upon the water quality and wildlife goals for this watershed, neither the 5-foot tillage setback nor the 75-foot buffer requirement are adequate to achieve the pollutant load reduction goals and resource protection concerns.

It is important to note that crop yield losses have been found to be greatest along the edges of drainage ditches that tend to get flooded. Therefore, adding a buffer to these areas would not be taking prime production areas. Fields with high slopes (see Map 2.2 on page 15) and high soil erodibility, fields where the minimum riparian buffer width of 75 feet is not being met (see Map 2.20 on page 119) and/or crop land is located within the 1-percent-annual probability-floodplain (see Map 2.9 on page 35), and fields containing potentially restorable wetlands within 1,000 feet of a waterway could be considered priority fields for installation of riparian buffers. In addition, in expanded riparian buffers on cropland, the 75 feet adjacent to the waterway are envisioned to be harvestable buffers, so that farmers can periodically harvest the grasses to feed livestock. Expansion of riparian buffers to the 400- and 1,000-foot widths, or greater to the extent practicable, are not likely to be achievable until such time that the agricultural land is converted to urban uses. At that time, it may be possible to design portions of the development to accommodate such buffer widths. Hence, that will likely be the last chance to establish such critical protective boundaries and/or open space and habitat connections around waterways before urban structures and roadway networks are constructed.

Primary environmental corridors (PEC) have a greater level of land use protections compared to secondary corridors, isolated natural resource areas, or designated natural areas outside of PEC. Therefore, the regulatory strategy to expand protections for vulnerable existing and potential riparian buffers would be to increase the extent of designated primary environmental corridor lands within the Pewaukee Lake watershed. In particular, there are PEC polygons in the Pewaukee Lake watershed along the tributaries that are separated in areas where development has encroached between them (see Map 2.17 on page 64). For example, the PEC polygon along the western reaches of Coco Creek is entirely separated from that corridor around Coco Creek's eastern reaches near Ryan Road (CTH KF) in Pewaukee. Expanding connections between these PEC areas presents the greatest opportunity to expand primary environmental corridor in this watershed. Since these two areas already meet the minimum size requirements for designation as a PEC, any lands with sufficient natural resource features adjacent or connecting to this existing PEC could potentially be incorporated into this designation. For example, if connections could be made between the PEC and either SEC or INRA, these might be upgraded to PEC. This has the greatest potential where tributaries connect with Pewaukee Lake, and where expansion of riparian buffer lands could be used to create connections and expand natural corridors.

Wetlands located within PEC lands have been designated as Advanced Delineation and Identification (ADID) wetlands under Section 404(b)(1) of the Federal Clean Water Act and are deemed generally unsuitable for the discharge of dredge and fill material. In addition, the nonagricultural performance standards set forth in Section NR 151.125 of the *Wisconsin Statutes*, require establishment of a 75-foot impervious surface protective area adjacent to these higher-quality wetlands. This designated protective area boundary is measured horizontally from the delineated wetland boundary to the closest impervious surface.[273] Hence, these wetlands would have additional protections from being filled and from being encroached upon by future development, enabling retention of their riparian buffer functions.

[273] *Runoff from impervious surfaces located within the protective area must be adequately treated with stormwater BMPs.*

Best Management Practices and Programs for Riparian Buffers

A large portion of the existing and potential riparian buffers are privately owned within urban and agricultural areas of the watershed. It is the private landowner's choice to establish a buffer. In addition, although riparian buffers can be effective in mitigating the negative water quality effects attributed to urbanization and agricultural management practices, they cannot on their own address all of the pollution problems associated with these land uses. Therefore, riparian buffers need to be combined with other management practices, such as infiltration facilities, wet detention basins, porous pavements, green roofs, and rain gardens to mitigate the effects of urban stormwater runoff. To mitigate the effects of agricultural runoff, riparian buffers need to be combined with other management practices, such as barnyard runoff controls, manure storage, filter strips, nutrient management planning, grassed waterways, and reduced tillage. Therefore, the BMPs to improve and protect water quality in both agricultural and urban areas are essential elements for the protection of water quality and quantity and wildlife within the Pewaukee Lake watershed.

Recent research has indicated that converting up to eight percent of cropland at the field edge from production to wildlife buffer habitat leads to increased yields in the cropped areas of the fields, and this positive effect becomes more pronounced with time.[274] As a consequence, despite the initial loss of cropland for habitat creation, overall yields for an entire field can be maintained, and even increased, for some crops compared to control areas. Although it took about four years for the beneficial effects on crop yield to manifest themselves in this research project, this increase in yields was largely attributed to an increased abundance and diversity of crop pollinators within the wildlife habitat areas. Such results suggest that at the end of a five-year crop rotation, there would be no adverse impact on overall yield in terms of monetary value or nutritional energy, and that in subsequent years, pre-buffer yields would be maintained or increased. Hence, establishment of buffers or sacrificing marginal cropland edges to create wildlife buffer habitat or potential restorable wetland within the Pewaukee Lake watershed may actually lead to increased crop yields, so this practice may be economically feasible over the long-term. More importantly, these results also demonstrate that lower yielding field edges within Pewaukee Lake can be better used as non-crop habitats to provide services supporting enhanced crop production, benefits for farmland biodiversity, and protection of water and soil health.[275]

In Wisconsin, the USDA offers technical assistance and funding to support installation of riparian buffers and wetlands on agricultural lands. A 14- to 15-year contract must be entered into by the landowner or operator and the land is only eligible under certain conditions, but normally must be recently in agricultural production or use. Because the program requires a lengthy contract, it is often difficult to get farmers and/or landowners to commit to installing and maintaining riparian buffer strips. To overcome this, a custom program that offers a shorter time commitment, potentially five years, with a yearly payment incentive greater than what the USDA program offers, has found favor in other counties in the State, and could potentially be developed for the Pewaukee Lake watershed.

Watershed Level Recommendations

Since certain land use features naturally filter or remove pollutants prior to entering a lake system, it is important to evaluate where such features exist within the Lake's watershed and to what degree they may be able to mitigate pollutant loading of metals, nutrients, or sediment. It should be noted that these features can overlap and may provide multiple benefits.

- **Recommendation 3.1: Identify "hot spots" where sediment is entering Pewaukee Lake due to severe ditch erosion and/or retention pond failure**

  Areas of severe erosion can deliver significant amounts of sediment to the Lake during heavy precipitation events. For example, a wash-out gully at the west end of Pewaukee Lake near the Crystal Springs property has recently been identified (see Figure 3.1). In such cases, creative mitigation efforts, such as "Regenerative Stormwater Conveyance" systems[276] could be investigated. A collaborative effort involving

[274] *R. Pywell, M.S. Heard, B.A. Woodcock, et al., "Wildlife-Friendly Farming Increases Crop Yield: Evidence for Ecological Intensification,"* Proceedings of the Royal Society B: Biological Sciences, *282(1816), 2015.*

[275] *Ibid.*

[276] *www.wafscm.org/wp-content/uploads/Cizek The-Role-of-Regenerative-Stormwater-Conveyance reduced.pdf.*

Figure 3.1
Debris and Runoff from the Hills Behind the Crystal Springs Property to Pewaukee Lake: 2017

From culvert entering Crystal Springs

Flow entering pond

Flow exiting pond to Pewaukee Lake

Source: Lake Pewaukee Sanitary District and SEWRPC

local property owners, non-government organizations, Town, and County levels is recommended as a high priority to mitigate such problems, with funding sought through grants.

➤ Recommendation 3.2: Protect and enhance buffers, wetlands, and floodplains

Protecting these features helps safeguard areas that already benefit the Lake and require little to no additional inputs of money and labor. For this reason, protecting such areas should be considered high priority. Enhancing these features is often a cost-efficient way of increasing the level of lake protection and should be considered a medium priority. Efforts should begin by targeting direct residential inflow sources, (i.e., the Lake shoreline properties) and various sources from properties adjacent to the tributaries. Efforts may extend to adjacent properties as suitable. Implementation of this recommendation could involve:

- Continue to carefully control and limit development in Commission-delineated primary environmental corridors to protect existing natural buffers, floodplains, and wetlands systems. (see Map 3.3). Such development limitations are required under Chapter NR 121, "Areawide Water Quality Management Plans," of the *Wisconsin Administrative Code*, and they may be accomplished through local zoning.

- Continue to enforce zoning standards set forth in Chapter NR 115, "Wisconsin's Shoreland Protection Program," of the *Wisconsin Administration Code* (i.e., 75 feet from the ordinary high water mark along navigable waters) in the watershed.[277]

- Provide information to shoreland property owners and landowners along mapped tributaries. This information should describe the benefits near-shore aquatic and terrestrial buffers provide to the Lake, and help encourage landowners to protect buffers where they still occur and enhance, restore, or create buffers in other favorable areas where none remain. This information could include installation instructions and typical costs. Such programs would be most productive if accompanied by an incentive program that helps share the cost of installation or provides tax incentives.

  Two examples of programs that could enhance buffers in the watershed include installing rain gardens in residential areas and utilizing Farm Service Agency programs such as the Conservation Reserve Program (CRP) and affiliated Conservation Reserve Enhancement Program (CREP) in agricultural areas. Both of these initiatives use vegetation to slow and filter stormwater runoff. If thoughtfully designed and located, groundwater recharge may also be enhanced. Grants may also be obtained for novel initiatives such as cropped buffers, where farmers receive a compensatory payment for growing crops that help filter runoff.

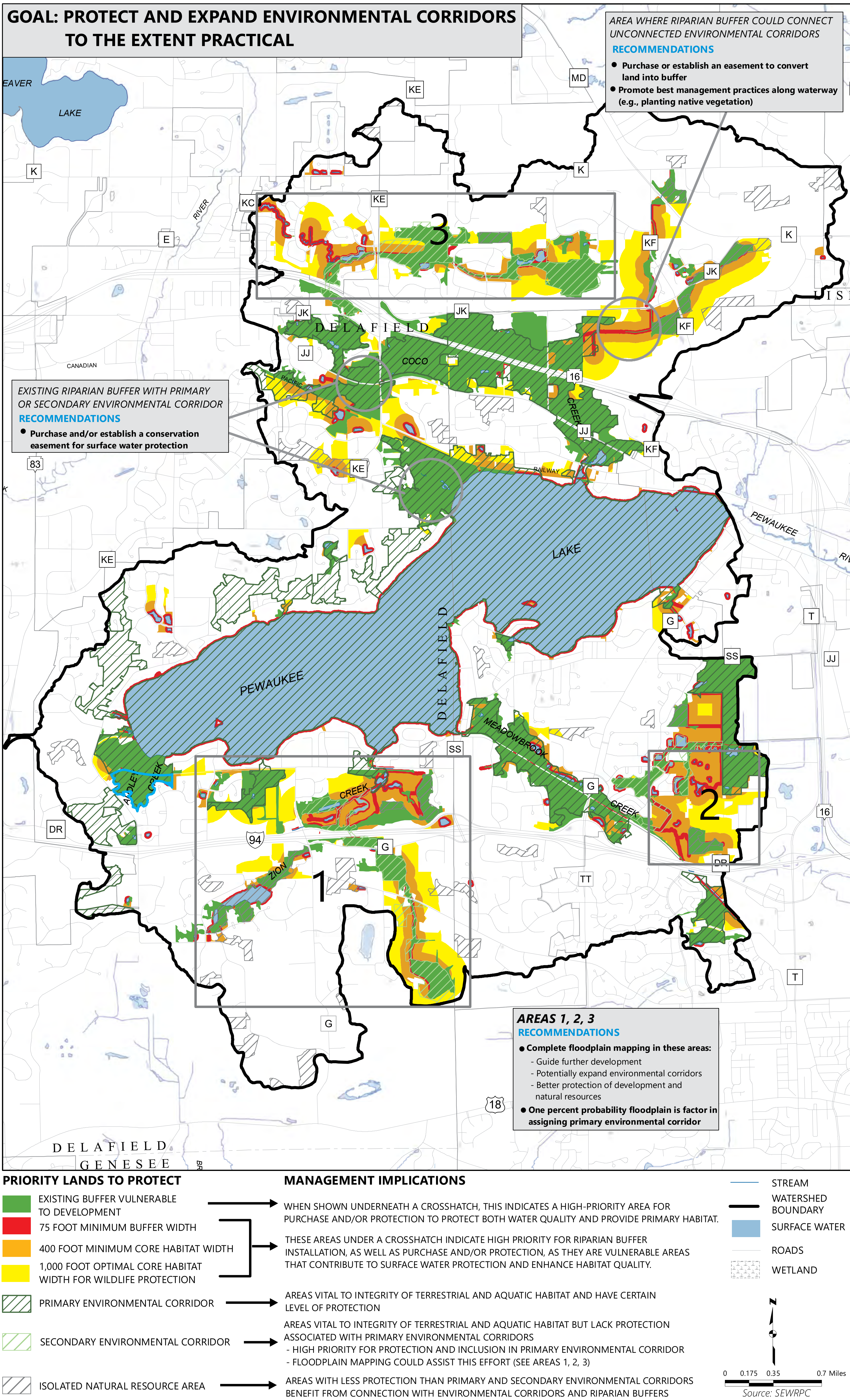
- Consider a shoreline BMP and shoreline buffer enhancement program. This program could encourage the development of rain gardens or buffers along shorelines. Combining rain gardens with buffer strips can enhance their benefit. The WDNR Healthy Lakes & Rivers grant program could help fund some of these efforts (see Section 3.9, "Plan Implementation" for more detail).

- Consider obtaining conservation easements and continue purchasing wetlands, floodplains, and uplands in key areas. Buffers can be preserved indefinitely and can have their ecological value enhanced to improve their habitat, filtering, and hydrologic functions (see Map 3.4).

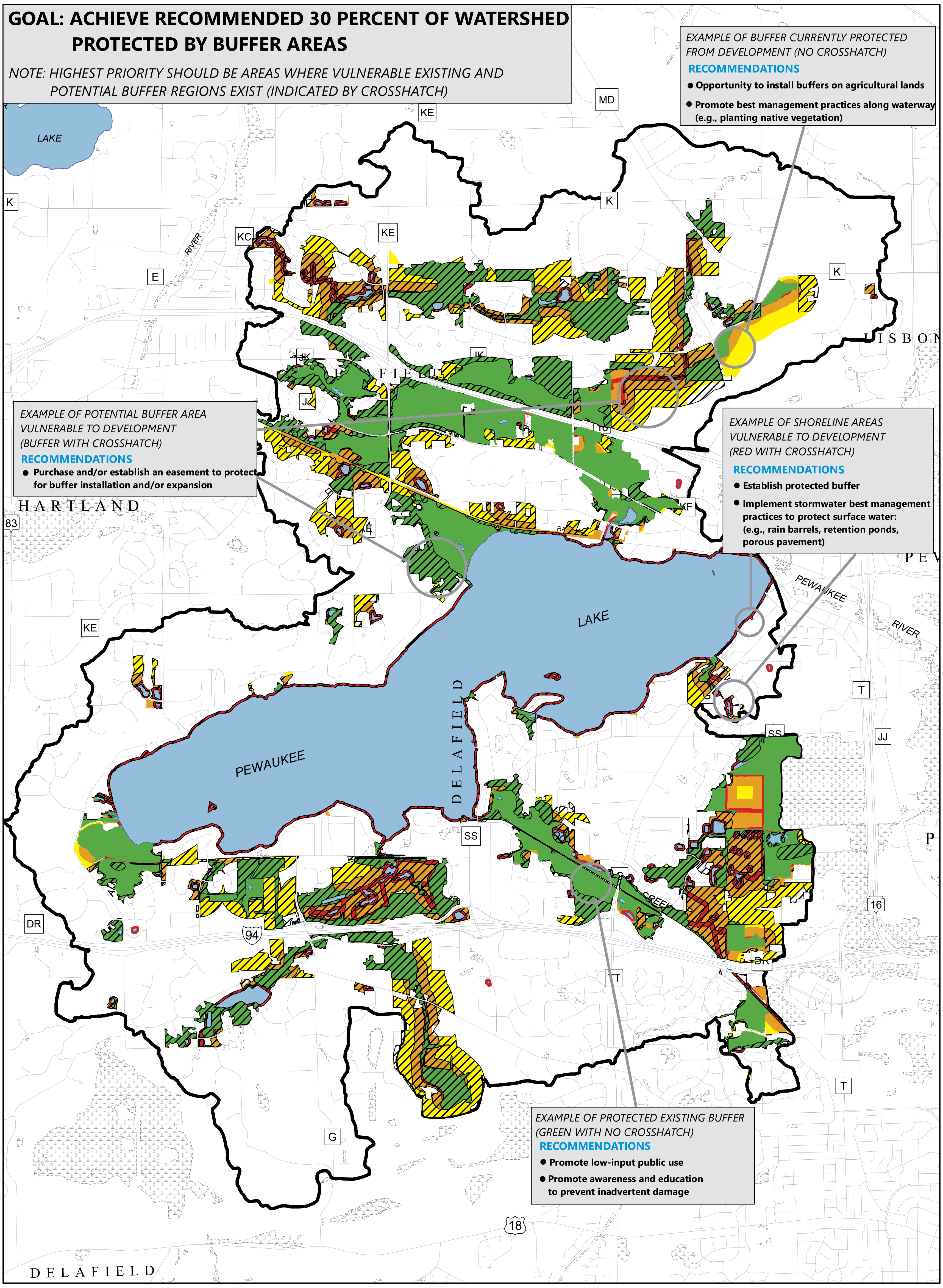
➤ **Recommendation 3.3: Protect buffer, wetland, and floodplain function**
Control invasive species that threaten the ecological value of buffers, wetlands, and floodplains. Additionally, relax human-imposed constraints placed upon watercourses. These efforts should be considered a <u>medium priority</u>. An example invasive species recommendation is to monitor and control reed canary grass in wetlands and shorelands. This species, a two- to nine-foot tall grass spreads and quickly displaces native wetland plants that help treat polluted water and which provide valuable wildlife habitat. Consequently, a visual survey of appropriate watershed and shoreline locations is recommended

[277] *The Wisconsin Legislature enacted significant changes to shoreland zoning laws in the 2011, 2013, and 2015 legislative sessions. These changes have generally resulted in a more limited role for the WDNR and counties, and a greater role by the State legislature in directly establishing shoreland standards. Of particular importance are 2011 Wis. Act 167, 2013 Wis. Act 80, 2015 Wis. Act 41, 2015 Wis. Act 55, 2015 Wis. Act 167, and 2015 Wis. Act 391. Previously, county ordinances were required to meet minimum standards set by the WDNR, but counties could enact stricter standards. That began to change with the 2011 Wisconsin Act 170, which prevented counties from adopting stricter standards than those in NR 115 for nonconforming structures and substandard lots. Since 2011, the trend of enhancing the role of the State legislature in the development of shoreland zoning has continued. For example, some of the more stringent standards adopted by counties, such as setbacks in excess of 75 feet, are no longer valid. Currently, under 2015 Wis. Act 55, a shoreland zoning ordinance may not regulate a matter more restrictively than it is regulated by a State shoreland-zoning standard unless the matter is not regulated by a standard in Chapter NR 115, "Wisconsin's Shoreland Protection Program," of the* Wisconsin Administrative Code*. (Examples of unregulated matters may involve wetland setbacks, bluff setbacks, development density, and stormwater standards.) In addition, under Act 55, a local shoreland zoning ordinance may not <u>require</u> establishment or expansion of a vegetative buffer on already developed land through mitigation; counties must allow property owners to establish 35-foot wide "viewing corridors" within each 100 feet of shoreland buffer zone and allow multiple viewing corridors to run consecutively in cases where shorelines run in excess of 100 feet; and, whereas the impervious surfaces standard remains at no more than 15 percent of the lot area, sidewalks, public roadways, and areas where runoff is treated by a device or system or is discharged to an internally drained pervious area, must not be included in the calculation of impervious surface and there are exceptions to the 15 percent standard for highly developed areas. According to the Wisconsin Legislative Council, 2015 Wis. Act 41 "authorizes towns to enact zoning ordinances that apply in shorelands, except that it generally prohibits a town zoning ordinance from imposing restrictions or requirements with respect to matters regulated by a county zoning ordinance that affect the same shorelands."*

Map 3.3
Proposed Riparian Buffer Protection Areas and Environmental Corridors Within the Pewaukee Lake Watershed



Map 3.4
Proposed Riparian Buffer Protection Areas Within the Pewaukee Lake Watershed



LANDS UNDER PROTECTION

- EXISTING RIPARIAN BUFFER → AREAS THAT PROTECT WATERWAYS FROM POLLUTION AND ARE UNDER SOME FORM OF PROTECTION FROM DEVELOPMENT
- 75 FOOT MINIMUM BUFFER WIDTH
- 400 FOOT MINIMUM CORE HABITAT WIDTH
- 1,000 FOOT OPTIMAL CORE HABITAT WIDTH FOR WILDLIFE PROTECTION

→ AREAS FOR RIPARIAN BUFFER EXPANSION THAT ARE UNDER SOME FORM OF PROTECTION FROM DEVELOPMENT

LANDS TO BE PROTECTED (CROSSHATCHED)

- EXISTING RIPARIAN BUFFER → AREAS THAT CURRENLTLY PROTECT WATERWAYS FROM POLLUTION AND ARE VULNERABLE TO DEVELOPMENT. THESE ARE HIGH PRIORITY AREAS FOR PURCHASE AND/OR PROTECTION
- 75 FOOT MINIMUM BUFFER WIDTH
- 400 FOOT MINIMUM CORE HABITAT WIDTH
- 1,000 FOOT OPTIMAL CORE HABITAT WIDTH FOR WILDLIFE PROTECTION

→ AREAS FOR RIPARIAN BUFFER EXPANSION THAT ARE VULNERABLE TO DEVELOPMENT. THESE ARE HIGH PRIORITY AREAS FOR PURCHASE AND/OR PROTECTION

MANAGEMENT IMPLICATIONS

SURFACE WATER
WATERSHED BOUNDARY
STREAM
ROADS
WETLAND

0 0.175 0.35 0.7 Miles

Source: SEWRPC

NOTE: FOR THE PURPOSE OF THIS ANALYSIS, FORMS OF PROTECTION INCLUDE:
- FEMA 1000 YEAR FLOODWAY ZONE
- ADID WETLANDS
- OPEN SPACE LAND UNDER PUBLIC OWNERSHIP

to determine whether reed canary grass is a problem. If it is found to be an issue, the infestation should be promptly eradicated.[278] Human-imposed constraints commonly manifest themselves as stream reaches that are ditched, aggressively eroding, and debris choked, incised, and or diked. Such reaches should be targeted for naturalization.

- **Recommendation 3.4: Protect remaining woodlands**

  Perhaps the largest threat posed to woodlands in Southeastern Wisconsin is the combined problem of 1) diseases and insects that destroy the native tree canopy and 2) invasive plants such as buckthorn (common buckthorn (*Rhamnus cathartica*) and glossy buckthorn (*Frangula alnus*)) that inhibit or prevent native tree regeneration. Introduced pests have attacked ash, elm, butternut, and oak species. New pests are on the horizon that target black walnut, beech, and other trees. Existing woodlands should be kept free of invasive plant species and actions can be taken to prepare the woodland for the arrival of pests. For example, increasing the diversity of tree species through careful stand management and/or planting can help assure that complete canopy loss does not occur in the future. Actively employing these recommendations should be assigned a medium priority. State programs are available to assist woodland owners with stand management, tax implications, and professional forestry advice.[279]

- **Recommendation 3.5: Maintain stormwater detention basins**

  This should be considered a high priority, especially given the planned increase in urban land use. Maintenance of stormwater basins includes managing aquatic plants, removing and disposing of flotsam or jetsam, ensuring adequate water depth to settle and store pollutants, and actively and aggressively managing excess sediment. Specifications associated with the design of stormwater detention basins and maintenance requirements ensure that basins are functioning properly.[280] It is important to remember that stormwater detention basins occasionally require dredging to maintain characteristics that protect the Lake. The frequency of dredging is highly variable and is dependent upon the design of the basin and the characteristics of the contributing watershed. Regulatory entities should complete basin inspection in a manner consistent with current practices; however, ensuring that the owners of these basins know the importance of meeting these requirements through educational outreach can help ensure continued proper functioning of the ponds. Coordinating with municipalities and neighborhood associations can play an important role.

- **Recommendation 3.6: Promote urban nonpoint source abatement**

  In addition to local stormwater ordinances and stormwater management planning, another way to promote cost-effective nonpoint source pollution abatement is for all municipalities within the Pewaukee Lake watershed to work toward satisfying all conditions required by the Wisconsin Pollutant Discharge Elimination System municipal separate storm sewer system (MS4) discharge permitting process. This should be considered a high priority issue, with particular focus on Lake direct tributary areas.

- **Recommendation 3.7: Promote native plantings in and around existing and new stormwater detention basins**

  The use of native plants in these situations will improve filtration of detention waters, reduce pollutant loading, and provide wildlife habitat. In addition, detention basin management practices should be modified to reduce or eliminate fertilizing basin slopes and limiting herbicide application and cutting to invasive species only. This should be considered a high priority.

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[278] *Reed canary grass can be controlled through burning, modifying hydrology (e.g., flooding), tilling, grazing, mulching, shading (with tree and shrub plantings), manual removal, mowing, and/or chemical treatment. These methods are commonly used in appropriate combination. More information can be found at the following website: dnr.wi.gov/topic/forestmanagement/documents/pub/FR-428.pdf.*

[279] *The following website provides an overview of WDNR forestry information and programs: dnr.wi.gov/topic/ForestLandowners.*

[280] *Technical standards for design and maintenance of wet detention basins and other stormwater management practices can be found at dnr.wi.gov/topic/stormwater/standards/postconst_standards.html.*

- **Recommendation 3.8: Retrofit existing and enhance planned stormwater management infrastructure to benefit water quality**
  Water quality can benefit by extending detention times, spreading floodwater, and using features such as grassed swales to convey stormwater. Implementing such works requires close coordination with the municipalities within the Pewaukee Lake watershed. This recommendation should be considered a high priority.

- **Recommendation 3.9: Combine riparian buffers with other structures and practices**
  A much higher level of pollution removal can be achieved through the use of "treatment trains" combining riparian buffers with better-managed detention basins or new practices such as floating island treatments (see Figure 3.2), grassed swales, and infiltration facilities. This layering of practices and structures is a more effective way to mitigate the effects of urban stormwater runoff than such practices being used in isolation. This action should be assigned a high priority.

- **Recommendation 3.10: Stringently enforce construction site erosion control and stormwater management ordinances and creative employment of these practices**
  Ordinances must be enforced by the responsible regulatory entities in a manner consistent with current practices; however, local citizens can help by reporting potential violations to the appropriate authorities. This recommendation should be considered a high priority.

- **Recommendation 3.11: Encourage pollution source reduction efforts through BMPs**
  This recommendation should be considered a high priority. Examples of relevant BMPs for Pewaukee Lake include reducing fertilizer use on lawns, creating rain gardens, and properly storing salts and other chemicals to prevent them from washing into the Lake.

- **Recommendation 3.12: Collect leaves in urbanized areas**
  This recommendation should be assigned a medium priority. Leaves have been shown to be a very large contributor to total external phosphorus loading to lakes in urban settings. Stockpiling leaves in the street where they may be crushed and washed into the Lake or burning leaves in shoreline and ditch areas can create situations where a strong pulse of phosphorus is delivered to the Lake by late autumn rains. Residents should be encouraged to take advantage of the yard waste collection and leaf disposal programs in existence in those municipalities in the watershed that conduct such programs.

Agricultural land use is forecast to transition to largely residential use. Whereas this may have been perceived as a negative to Lake health in the past, stormwater management practices used in urbanizing landscapes can tangibly lessen pollutant loads and positively modulate runoff volumes when compared to existing agricultural land use. Therefore, if carefully and stringently enforced, stormwater management practices in the watershed areas planned for urban development may reduce the overall pollutant loads to the Lake and enhance dry weather baseflow. Moreover, future stormwater detention basins can be designed and located to enhance value beyond the requisite pollutant trapping and runoff detention value (e.g., when a pond is located adjacent to a natural area, a stormwater basin can provide valuable habitat function). Similarly, stormwater detention basins can be located in areas prone to contribute to groundwater recharge, helping sustain valuable groundwater-derived baseflow to local lakes, streams and wetlands. Bioswales, unlined ditches, and a battery of other "green" stormwater management practices can add to the overall positive effect of modern stormwater management.

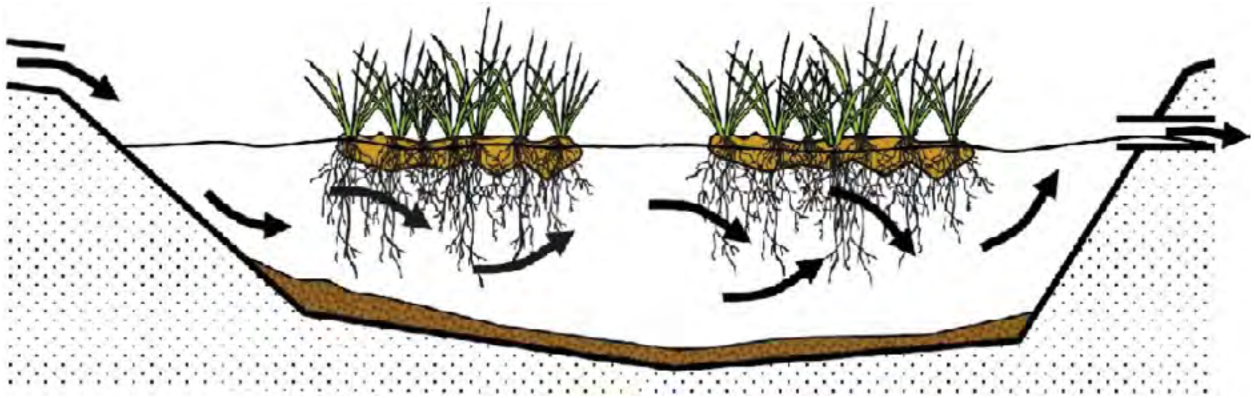
Sub-Basin Level Recommendations

Since some sub-basins bring more sediment and pollutants into the Lake system than others, it is important to develop specific goals to mitigate potential pollutant loading from each sub-basin.

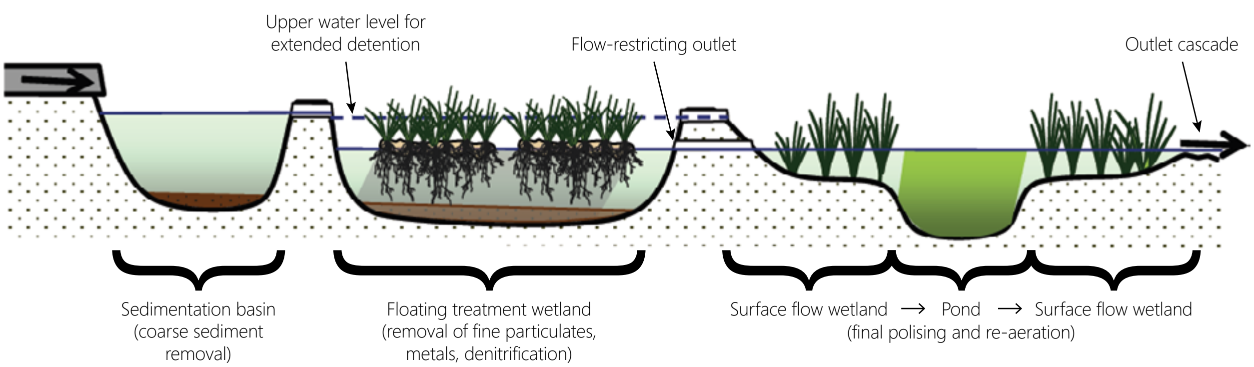
- **Recommendation 3.13: Tributaries should be prioritized regarding phosphorus load reduction goals**
  A study by Wisconsin Lutheran College and WDNR PRESTO model output indicate that Coco Creek is the major tributary phosphorus contributor to Pewaukee Lake. However, the PRESTO model shows Meadowbrook Creek contributing almost as much phosphorus as Coco Creek, while Zion Creek and Audley Creek contribute much less. In light of this model output, these streams should be prioritized regarding receiving pollutant load reduction actions according to the following order:

Figure 3.2
Schematic of Floating Treatment Wetland Design Applications

Emergent plants are grown within a floating artificially constructed material within a wet detention stormwater basin. The roots are directly in contact with the water column and can intercept suspended particles. The roots also provide a high surface area for microbiological activity that aid in adsorbing pollutants.



Conceptual longitudinal cross-section through a "newly designed" stormwater treatment system incorporating floating wetlands, ponds, and surface flow wetlands (not to scale).



Source: I. Dodkins, A. Mendzil, and L. O'Dea, Floating Treatment Wetlands (FTWs) in Water Treatment: Treatment Efficiency and Potential Benefits of Activated Carbon, *FROG Environmental LTD., March 2014; T.R. Headley and C.C. Tanner, "Constructed Wetlands With Floating Emergent Macrophytes: An Innovative Stormwater Treatment Technology,"* Critical Reviews in Environmental Science and Technology, *42: 2261-2310, 2012 and SEWRPC*

1. Coco Creek
2. Meadowbrook Creek
3. Zion Creek
4. Audley Creek

Such an order would deliver pollutant mitigating actions first to where the need is greatest. This should be considered a high priority.

Pollutant mitigating actions in the tributaries should be stream-specific. The three main tributaries to Pewaukee Lake have some features in common, but also have individual characteristics that make it necessary to consider somewhat different mitigation protocols for each. Draft proposals regarding stream-specific actions have been developed by Tom Koepp of LPSD that include: Coco Creek – riparian buffers, groundwater recharge protection, and bank stabilization; Zion Creek – riparian buffers, carp management, and fish passage enhancement; and, Meadowbrook Creek – riparian buffers, spawning habitat enhancement, riffle construction, and bank stabilization. It is important to note that pollutant loads from these streams can be reduced by reconnecting historical stream channels (i.e., remeandering) and reconstructing new channels and/or two-stage channel systems (see Figures 3.3 and 3.4). Such stream-specific activities to reduce pollutant loads should be considered high priority.

➤ **Recommendation 3.14: Relax human-imposed constraints on tributary streams**
Over many years of development in the watershed of Pewaukee Lake, the Lake's tributaries have been greatly altered to accommodate human preferences for land use. Actions such as ditching, straightening of natural stream meanders, and destruction of streambank woodlands, have resulted in greatly damaged systems suffering an inability to function properly as part of the greater Pewaukee Lake ecosystem. Taking corrective actions such as those presented in Maps 3.5 and 3.6 would do much to restore the natural habitat and proper functioning of these streams; this should be considered a high priority.

Shoreline Maintenance Level Recommendations

Maintaining shorelines and streambanks can reduce sediment and phosphorus loading associated with erosion and/or runoff into the Lake and its tributaries.

➤ **Recommendation 3.15: Maintain shoreline protection and prevent streambank erosion**
As described in Chapter 2 of this report, the majority of Pewaukee Lake's shoreline is protected by "hard" (wood, metal, or concrete) manmade structures of riprap or bulkhead. Such structures are highly effective methods of protecting against the erosive nature of wave action (especially in areas of low banks and shallow waters) and these structures need to be adequately maintained. However, shoreline protection needs to also protect against sediment and nutrient runoff. In this regard, incorporating vegetated buffer strips into "hard" shoreline protection is highly recommended.

Shoreline property owners need to better understand how vegetated riparian buffers can prevent shoreline erosion and reduce the amount of polluted runoff reaching the Lake. This is especially important in those areas where the shoreline is unprotected (e.g., where mowing of grass occurs up to the water's edge). Map 2.22 on page 131 indicates those specific areas where erosion and unprotected stretches of shoreline exist. In general, priority should be given to adding natural shoreline protection to the areas that lack protection or are showing active erosion, repairing or maintaining already installed shoreline structure where feasible, installing "soft" shoreline protection such as native vegetative shoreline protection wherever feasible, and expanding riparian buffers.

➤ **Recommendation 3.16: Reduce refracted wave energy**
Shorelines armored with concrete walls, wood, and other straight and hard materials tend to reflect wave energy back into the Lake. This refracted energy eventually reaches another shoreline, where it is either absorbed or again refracted back into the Lake. Such conditions can magnify the erosive power of waves. Many actions can be taken to reduce wave energy refraction. Examples include using irregular materials and surfaces that help absorb and dissipate wave energy, planting emergent or floating leaf plants to dissipate energy before it reaches the shoreline, and substituting hard shoreline armor for plants and woody structure. Perhaps the most practical way of approaching this issue is to require wave-energy absorbing features in new or repaired shoreline protection plans. This recommendation is a high priority.

➤ **Recommendation 3.17: Encourage pollution source reduction efforts along shorelines through BMPs**
Such efforts would include developing goals consistent with the guidelines of the Healthy Lakes & Rivers program.[281] This recommendation is a high priority.

➤ **Recommendation 3.18: Enforce ordinances**
Ordinances concerning building setbacks, mitigation measures, boat lifts, and piers should be enforced. This is considered a high priority.

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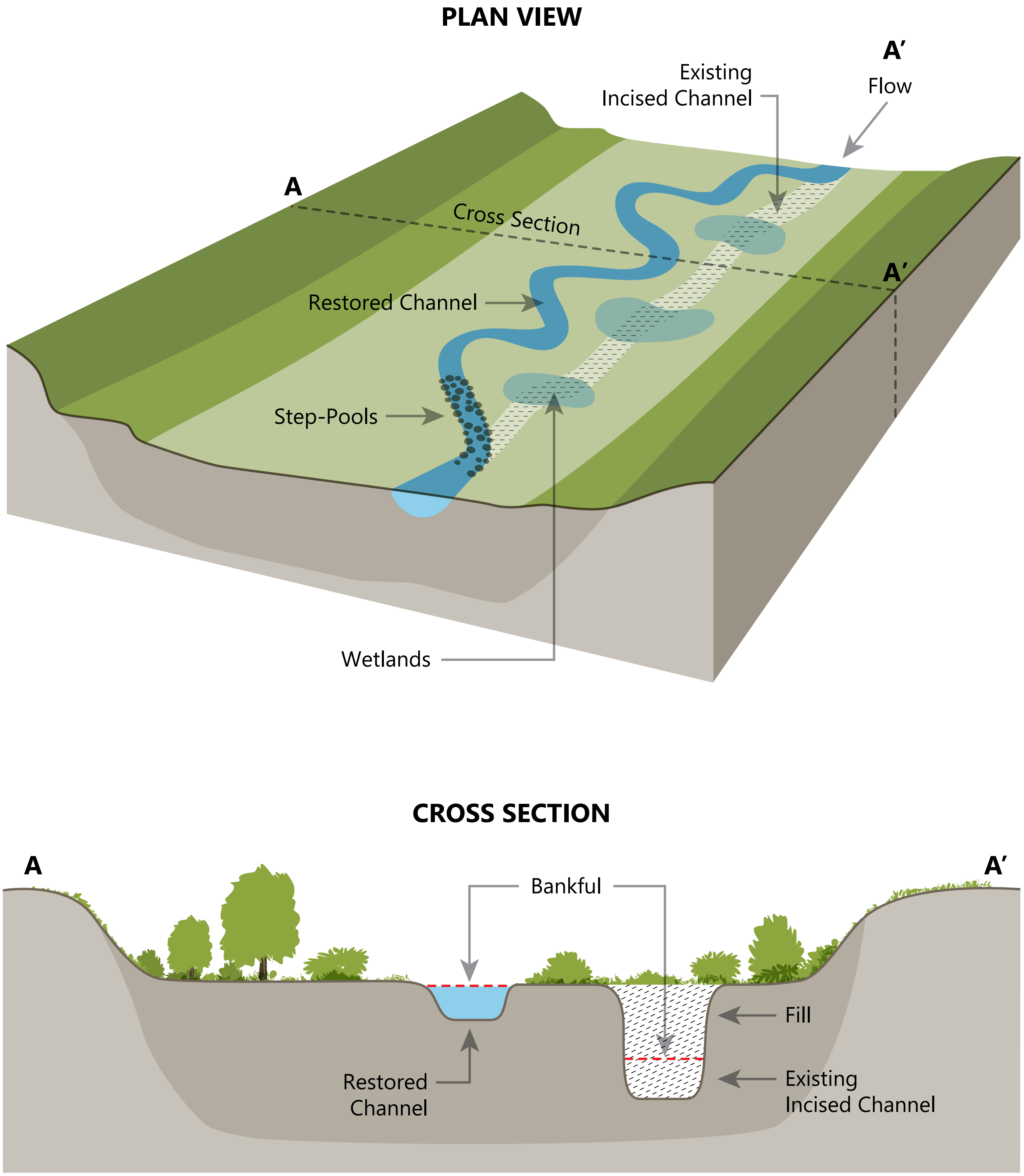
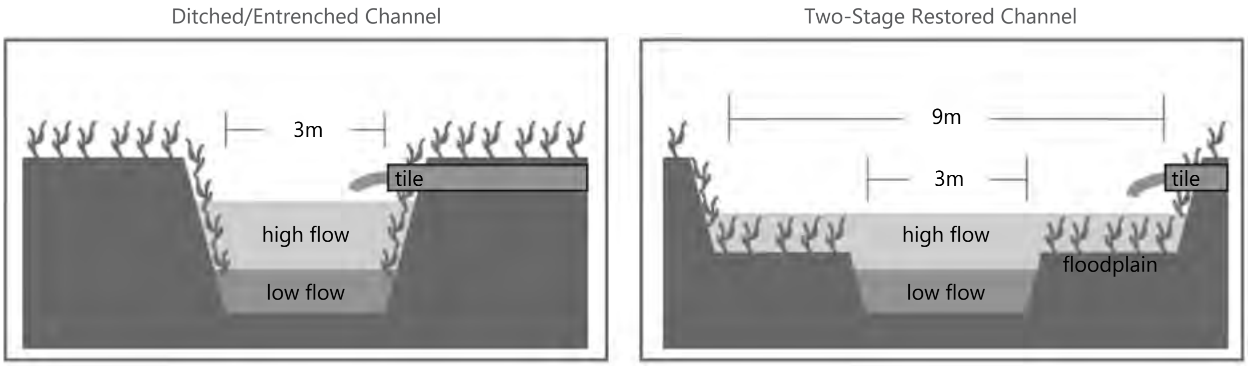
[281] *For more information, see healthylakeswi.com.*

Figure 3.3
Potential Stream Restoration Design Example for Pewaukee Lake Tributaries to Improve Stream Function



Source: Modified from W. Harman, R. Starr, M. Carter, et al., A Function-Based Framework for Stream Assessments and Restoration Projects, *US Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC, EPA 843-K-12-006, p. 36, 2012 and SEWRPC*

Figure 3.4
Schematic of a Two-Stage Design Channel



Note: The two-stage ditch design: a) Trapezoidal channel, with steep slopes, lack of floodplain connectivity, and drain tile, prior to floodplain restoration; b) restored two-stage ditch, with drain tiles cut back. The dark gray represents water levels during base flow and the light gray represents water levels during stormflow.

Source: Modified from S.S. Roley, J.L. Tank, and M.A. Williams, "Hydrologic Connectivity Increases Denitrification in the Hyporheic Zone and Restored Floodplains of an Agricultural Stream," Journal of Geophysical Research, *117(G3), p. 2, 2012 and SEWRPC*

3.5 AQUATIC PLANTS

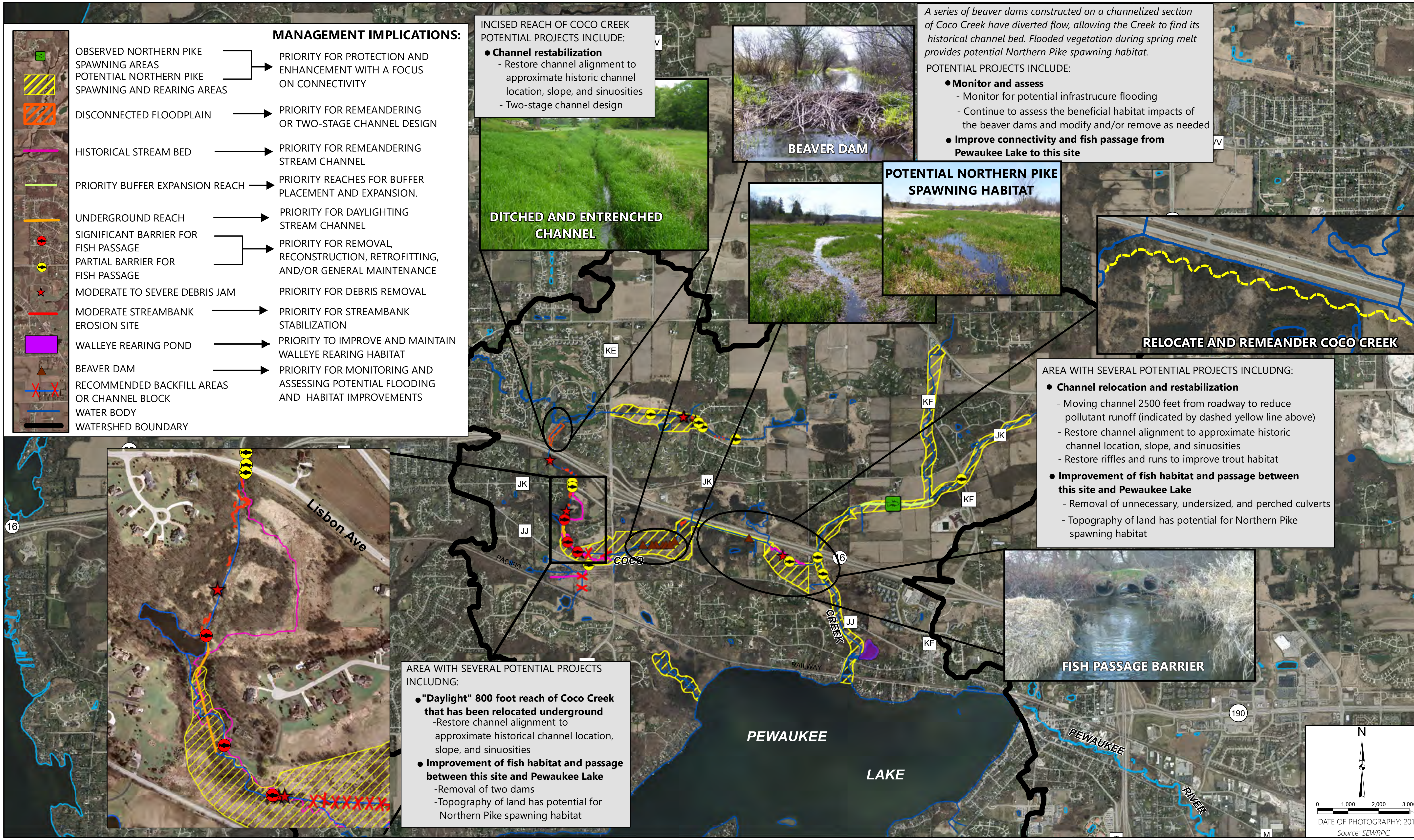
This section summarizes the information and recommendations needed to manage nuisance plant, Eurasian watermilfoil (EWM) (*Myriophyllum spicatum*), and curly-leaf pondweed (CLP) (*Potamogeton crispus*) growth in the Lake. Accordingly, it presents a range of alternatives that could potentially be used, and provides specific recommendations related to each alternative. The measures discussed focus on those that can be implemented by the LPSD and the Village of Pewaukee in collaboration with the WDNR and Lake residents. The aquatic plant management component of this report is limited to approaches that monitor and control nuisance aquatic plant growth in the Lake after growth has already occurred. Other sections in this chapter will describe other management strategies that can help prevent degradation of the Lake's water quality and aquatic plant community. Examples of such management actions include strategies to reduce phosphorus loads to the Lake and measures to prevent accidental introduction of new invasive plants and animals. In short, this section helps interested parties understand the particular plant management measures to be used in and around Pewaukee Lake, and can be a valuable resource when developing future aquatic plant management efforts and requisite permit applications.

Any aquatic plant management activities need to involve more than a short-term fix. Balances have to be struck between human recreational (and other) uses and the long-term ecological health of the lake. Considerations have to be given to not only controlling those volumes of plants and algae that deter recreational use, but also to the existence of invasive species like EWM, the long-term stability of the native aquatic plant community, the role of the plant community in the Lake's water quality, and the importance of keeping a balance between aquatic plants and algae – since both compete for the same nutrients, elimination of one will result in the over-abundance of the other. It is also important to remember that *native* aquatic plants form a foundational part of a lake ecosystem; large-scale removal of native plants that may be perceived as a nuisance (e.g., white water lilies) should be avoided when developing plans for aquatic plant management.

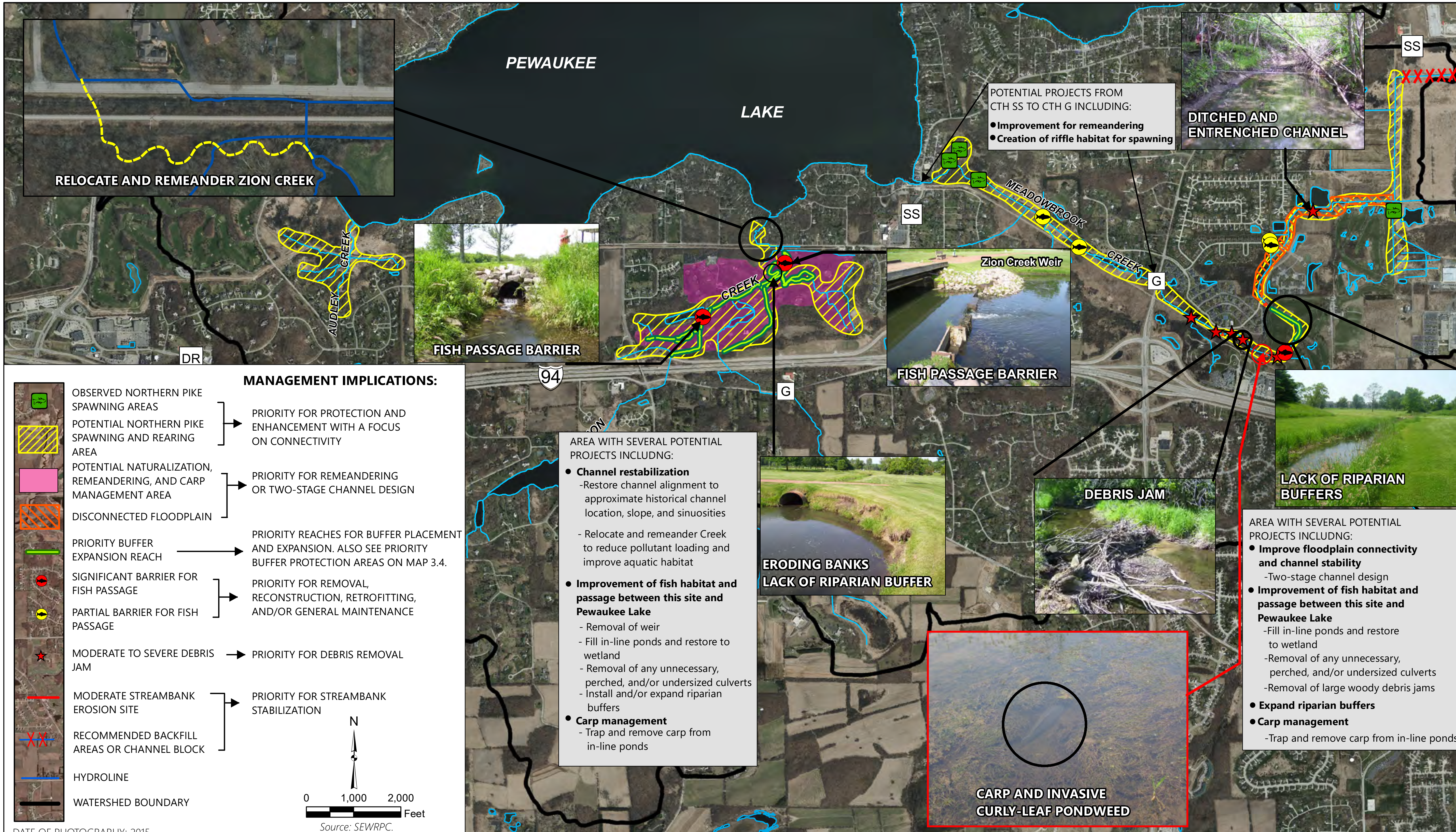
Aquatic Plants in Pewaukee Lake

Even though the Lake has a healthy aquatic plant community, the presence of EWM, CLP, and the introduction of starry stonewort (*Nitellopsis obtusa*), pose risks to the plant community if not effectively managed. EWM, in particular, has been a consistent problem over the years. Dense beds of EWM, along with other nuisance plant growth, impede Lake access in the eastern basin. Consequently, the LPSD and the Village of Pewaukee's Public Works Department engage in aquatic plant management activities; both rely principally on mechanical harvesting.

Map 3.5
Proposed Aquatic Habitat Recommendations Within the Coco Creek Subwatershed



Map 3.6
Proposed Aquatic Habitat Recommendations Within the Meadowbrook Creek and Zion Creek Subwatersheds



DATE OF PHOTOGRAPHY: 2015

Source: SEWRPC.

The WDNR has designated two Sensitive Areas in the Lake (see Figure 3.5).[282] All Sensitive Areas trap sediment and nutrients and thereby help protect the Lake's water quality. They also provide spawning, nursery and foraging opportunities to native fish and are excellent habitat for waterfowl, furbearers, and herptiles. However, protecting these areas requires limitations and restrictions be placed upon aquatic plant management.

The individual recommendations presented below, and which collectively constitute the recommended aquatic plant management plan, balance three major goals. These goals include:

1. Improving navigational access within the Lake

2. Protecting the native aquatic plant community

3. Controlling CLP, EWM, and hybrid watermilfoil populations

Plan provisions also ensure that current recreational use of the Lake (e.g., swimming, boating, and fishing) is maintained to the greatest extent practical. The plan recommendations described below consider common, State-approved, aquatic plant management alternatives, including manual, biological, physical, chemical, and mechanical measures.

Aquatic Plant Management Recommendations

Certainly, the contrasting physical conditions of the east and west basins of Pewaukee Lake impact the nature of the aquatic plant communities in them and present significant challenges regarding the effective management of aquatic plants in the Lake. The most effective plans rely on a *combination* of methods and techniques. A "silver bullet" single-approach strategy rarely produces the most efficient, most reliable, or best overall result. Therefore, to enhance access to, and the health of, Pewaukee Lake, this plan recommends five aquatic plant management techniques as described below:

- **Recommendation 4.1: Mechanical harvesting of invasive and nuisance aquatic plants**

  This recommendation should continue to be a high priority. Navigation channels should be maintained around the shoreline of Pewaukee Lake, excluding the WDNRdesignated Sensitive Areas as shown on Figure 3.5. These channels should continue to be cut to a maximum of 250 feet in width, with the exception of Pewaukee Beach where the width can extend to a maximum of 500 feet. Channels should also continue to be cut in the east basin for recreational use including boat access for travel routes, fishermen, and to serve as predation channels for the fishery. A main channel down the middle of the east basin should be 80 to 100 feet wide with the off-shoot channels ranging from 30 to 50 feet in width as necessary. Where the water depth allows, all channels can be cut down to a depth of 3 to 5 feet. Pewaukee Lake has a history of dense EWM beds particularly in the shallower, east basin. These areas should continue to be defined each season and be top-cut as time and budget allows to enable native aquatic plants to grow and compete against the invasive milfoil. All harvesting must maintain a minimum of 12 inches of rooted aquatic plant material at the bottom of the Lake.

- **Recommendation 4.2: Inspect all cut plants for live animals. Live animals should be immediately returned to the water**

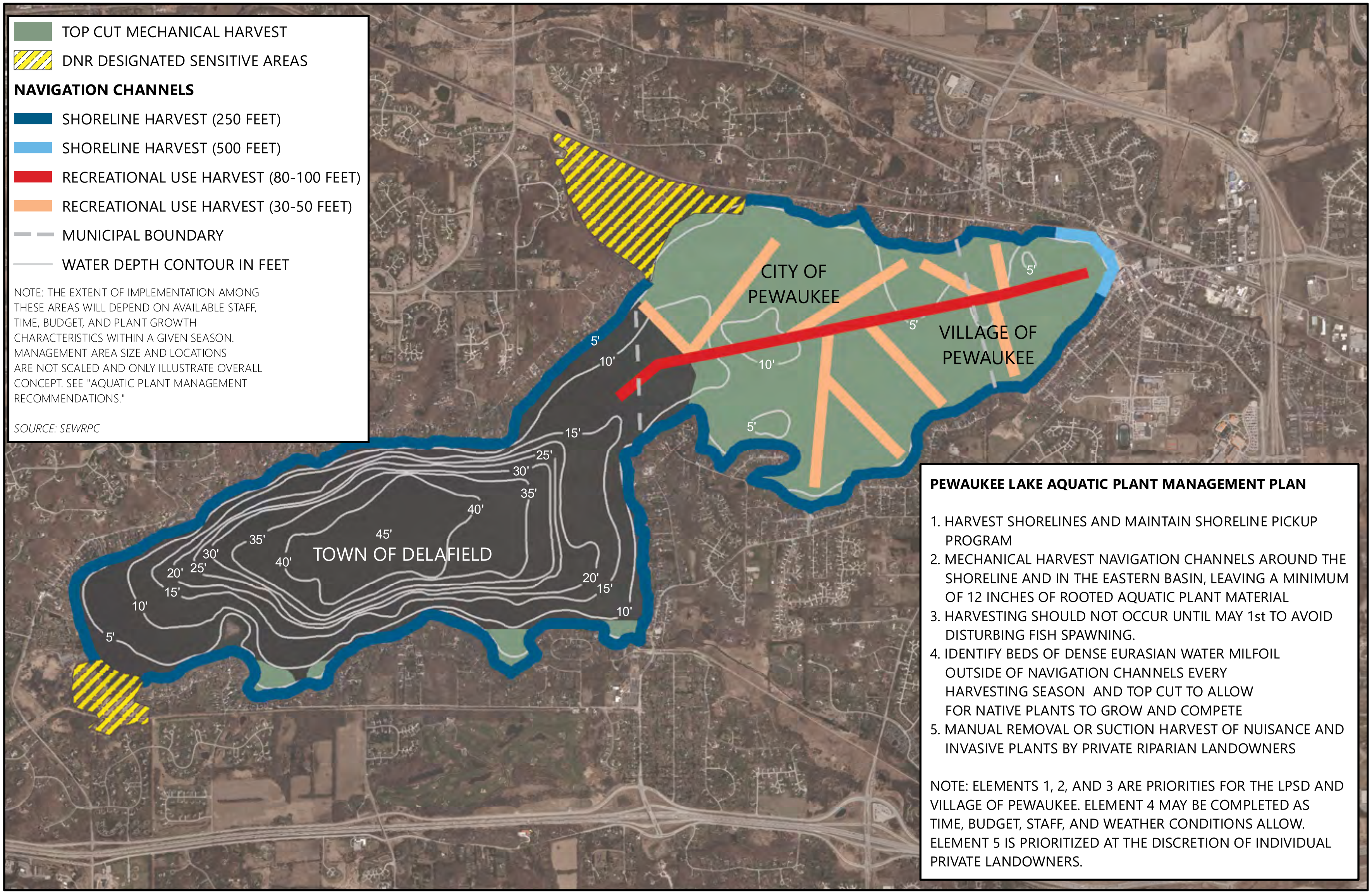
  This should be considered a medium priority. The WDNR recommends that a second staff person equipped with a net accompany and assist the harvester operator. Animals can get caught in the harvester and harvested plants, particularly when cutting larger plant mats. However, if a second staff person is not feasible, the harvester operator should stop the harvester to remove caught animals such as turtles, gamefish, and amphibians.

- **Recommendation 4.3: Harvesting should not occur until May 1st**

  This recommendation is a high priority to avoid disturbing fish spawning. Many fish species spawn in early spring. Studies suggest that spawning can be significantly disturbed by harvesting activities. Thus, avoiding harvesting during this time can benefit the Lake's fishery.

[282] *The WDNR is granted authority to define sensitive areas under Section NR 107.05(3)(i) of the* Wisconsin Administrative Code.

Figure 3.5
Aquatic Plant Management Plan for Pewaukee Lake: 2017-2021



- **Recommendation 4.4: All harvester operators must successfully complete training course to help assure adherence to harvesting permit specifications and limitations**

  The regional WDNR aquatic invasive species coordinator and/or LPSD or the Village of Pewaukee's Public Works Department should continue to provide training to all summer harvester operators. At a minimum, training should cover 1) "deep-cut" versus "shallow-cut" techniques and when to employ each in accordance with this plan, 2) review of the aquatic plant management plan and associated permits with special emphasis focused on the need to restrict cutting in shallow areas, 3) identification of and regulations pertaining to WDNR-designated Sensitive Areas, and 4) plant identification to encourage preservation of native plant communities. Additionally, this training course should reaffirm that all harvester operators are legally obligated to record their work for inclusion in annual reports that are required under harvesting permits. This recommendation is a high priority.

- **Recommendation 4.5: The harvesting program should continue to include a comprehensive plant pickup program that all residents can use**

  Harvesting and boating activity can fragment plants. Plant fragments may float in the Lake, accumulate on shorelines (particularly within the east basin of the Lake), and help spread undesirable plants. This helps assure that harvesting does not create a nuisance for Lake residents. The program includes residents raking plants, placing them in a pile in a convenient location accessible to the harvester (e.g., the end of a pier) for regularly scheduled pickup of cut plants by the LPSD and Village of Pewaukee harvester operators. This effort should be as collaborative as practical and harvester operators should consider focusing pickup efforts in the east basin after weekends, because plant fragments tend to accumulate throughout this area due to normal prevailing wind patterns. This recommendation is a high priority.

- **Recommendation 4.6: All plant debris collected from harvesting activities should be collected and disposed of at the designated disposal sites**

  Designated disposal sites are shown on Appendix F. Disposing of any aquatic plant material within identified floodplain and wetland areas is prohibited, and special care should be taken to assure that plant debris is not disposed of in such areas (high priority).

- **Recommendation 4.7: Continue to conduct annual winter "under the ice" aquatic plant monitoring**

  Conducting this monitoring with video cameras in March can be useful to determine potential problem areas, particularly of EWM growth, and prioritize harvesting activities in spring (medium priority).

- **Recommendation 4.8: Enhance support of mechanical harvesting program**

  Pewaukee Lake has an established harvesting program with LPSD, and historically the operation has been very successful in managing the Lake. However, the LPSD harvesting operation could be more effective with a second harvester off-load site on the northeastern shoreline of the Lake (assuming a suitable cost effective site could be found), as the size of Pewaukee Lake can inhibit the efficiency of the program. Efforts should be made to maintain proper funding/capital for future equipment purchases such as harvesters and aquatic plant transporters. This is recommended as a high priority.

- **Recommendation 4.9: Manual removal of nuisance plant growth and invasive plants in nearshore areas**

  This recommendation should be considered a priority for landowners as the LPSD does not cut between piers. "Manual removal" is defined as control of aquatic plants by hand or using hand-held non-powered tools. Given what is known of plant distribution, this option is given a high priority. Riparian landowners *do not need to* obtain a permit for manually removing aquatic plants if they meet the following criteria:

  - They confine this activity within a total distance of 30 feet along the shoreline (including the recreational use area such as a pier)
  - They do not extend this activity out from the shoreline more than 100 feet into the Lake
  - They remove all resulting plant materials from the Lake[283]

[283] *The manual removal area limitation for nearshore aquatic plants applies to shorelines where native plants are present. The removal area limitation does not apply to areas populated solely with nonnative and invasive plants.*

A permit *is* required if the property owner lives adjacent to a sensitive area or if another group actively engages in such work.[284] Prior to the "hand-pulling" season, an educational campaign should be actively promoted to help assure that shoreline residents appreciate the value of native plants, understand the relationship between algae and plants (i.e., more algae will grow if fewer plants remain), know the basics of plant identification, and the specifics about the actions they are allowed to legally take to "clean up" their shorelines.[285]

- **Recommendation 4.10: DASH could be employed by individuals to provide relief on nuisance native and nonnative plants around piers**

If an individual landowner chooses to implement DASH, the activity is typically confined to the same width of 30 feet of shoreline and cannot extend more than 100 feet into the Lake as described previously regarding manual harvest. However, given how costly DASH can be and how widespread the EWM is across the Lake, DASH is not considered a viable control option for managing EWM throughout Pewaukee Lake. Any use of DASH requires a NR 109 permit. This recommendation is a low priority.

- **Recommendation 4.11: Chemical treatment could be employed by individuals to provide relief from nonnative plants around piers**

Currently, the LPSD and the Village of Pewaukee will not be sponsoring a chemical treatment program for access/navigation lanes. However, property owners may pursue a NR 107 permit in order to treat shoreline areas. When employed, a physical barrier (e.g., turbidity barrier)[286] should be used to reduce chemical dispersal. The LPSD and/or Village of Pewaukee may consider a rapid response chemical treatment for an NR 40 prohibited species (not restricted species), where appropriate, if such a species (e.g., hydrilla, *Hydrilla verticillata*) were to appear in Pewaukee Lake in the future. This recommendation is a low priority.

As discussed earlier, other factors complicate chemical herbicide application in lakes, namely coincident growth of EWM and native species, the physical similarities between native water milfoil and EWM, and the presence of hybrid watermilfoil. Hybrid watermilfoil has not been verified to exist in Pewaukee Lake, but is likely to occur. Since EWM tends to grow early in the season, early spring chemical application is an effective way to target the EWM while minimizing impact to desirable native plants. Early spring application has the advantage of being more effective due to the colder water temperatures, a condition enhancing herbicidal effects and reducing the dosing needed for effective treatment. Early spring treatment also reduces human exposure (swimming is not particularly popular in very early spring) and limits the potential for unintentional damage to native species.

Considering the expanse of EWM in the east basin of Pewaukee Lake and the cost of chemical treatment, a whole lake treatment or large spot treatment in that basin is not recommended.[287] This is also supported by the efficiency and effectiveness of the harvesting operations, along with the added benefit to the ecology and water quality of Pewaukee Lake compared to chemical application. However, small spot treatments enclosed with a barrier (e.g., turbidity barrier) could be a viable alternative for treating shoreline areas and navigation lanes if determined feasible by the LPSD. Whatever the case, monitoring should continue to ensure that EWM populations do not become more problematic. If further monitoring suggests a dramatic change in these invasive species populations, management recommendations should be reviewed.

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[284] *If a lake district or other group wants to remove invasive species along the shoreline, a permit is necessary under Chapter NR 109, "Aquatic Plants: Introduction, Manual Removal and Mechanical Control Regulations," of the* Wisconsin Administrative Code, *as the removal of aquatic plants is not being completed by an individual property owner along his or her property.*

[285] *Commission and WDNR staff could help review documents developed for this purpose.*

[286] *A turbidity barrier (or curtain) is a mechanical device that consists of a curtain of material hanging suspended below floatation, similar in some respects to the silt barriers commonly seen around land-based construction sites.*

[287] *WDNR has been studying the efficacy of spot treatments versus whole lake treatments for the control of EWM and it has been found that spot treatments are not an effective measure for reducing EWM populations, while whole lake treatments have proven effective depending on conditions.*

- **Recommendation 4.12: Manage access lanes with modified existing harvesting equipment**
  Although small, shallow-draft harvesters (e.g., Inland Lakes ILH5x4 – 1—"Mini" Series or equivalent model) are available for harvesting in shallow areas, there is a desire to maintain at least 12 inches of rooted plant material to stabilize Lake-bottom sediments. Therefore, the LPSD is modifying a harvester to cut in shallow areas. This harvester will be maneuvered slowly in shallow areas to minimize sediment disturbance and will only be operated by senior staff (e.g., an individual with at least one year of harvesting experience) to ensure proper cutting techniques. This recommendation is a low priority.

Native Plant Community and Invasive Species Recommendations

A number of actions should be taken to retain native aquatic plants whenever practical and focus control efforts on aquatic invasive plants. All are considered high priority. These recommendations include:

- **Recommendation 4.13: Protect native aquatic plants to the highest degree feasible through careful implementation of aquatic plant management and water quality recommendations**
  Pewaukee Lake supports a wide array of aquatic plant species that provide excellent wildlife habitat and are an integral part of the Lake's ecosystems. Muskgrass growth is particularly beneficial as it enhances marl formation and sequestration of phosphorus from the water column.

- **Recommendation 4.14: Actively manage invasive species to protect native plants and wildlife**
  Invasive species are highly damaging to native plant and wildlife communities and are a nuisance to Lake recreation. Consequently, invasive species management is recommended. The most problematic invasive species currently in, or around, Pewaukee Lake are CLP, EWM, reed canary grass (*Phalaris arundinacea*), non-native phragmites (*Phragmites australis*), purple loosestrife (*Lythrum salicaria*), and starry stonewort (*Nitellopsis obtusa*). Mechanical and chemical aquatic plant control methods should follow BMPs to avoid spreading invasive plants and to lower the stress imposed by invasive species on the native plant community. Purple loosestrife can also be biologically controlled with purple loosestrife beetles.[288]

- **Recommendation 4.15: Avoid disrupting bottom sediment or leaving large areas of bottom sediment devoid of vegetation**
  Disturbance of the lake bottom increases the risk of recolonization of nonnative species; EWM in particular thrives in such areas. For this reason, care should be taken to judiciously and sensitively remove vegetation from problem areas.

- **Recommendation 4.16: Implement control methods in early spring**
  EWM, hybrid watermilfoil, and CLP grow extremely early in the season, earlier than most native aquatic plants. Implementing control methods as early as practical in the spring can help minimize damage to native aquatic plant communities; however, care should be taken to avoid harvesting in known fish spawning areas until after May 1. Moreover, early spring chemical applications are more effective due to colder water temperatures, a condition enhancing the herbicidal effect and reducing the concentrations needed for effective treatment. Early spring chemical treatment also helps reduce human exposure through lower human contact with Lake water when temperatures are still cold. Lastly, early season eradication of CLP helps lower production of turions (a dormant plant propagule), the dominant reproductive method of this plant.

- **Recommendation 4.17: Prevent the introduction of new invasive species**
  The introduction of new invasive species is a constant threat. Preventing their introduction is crucial to maintaining healthy lakes. To help decrease the chance of introducing new invasives the following recommendations are given a high priority:

  - **Educate residents** as to how they can help prevent invasive species from entering the Lake.

  - **Continue to participate in the Clean Boats, Clean Waters program** (a State program targeting invasive species prevention) to proactively encourage Lake users to clean boats and equipment before launching and using them in Pewaukee Lake.[289]

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[288] *More information about purple loosestrife beetles, and how to join a biocontrol program to grow and release beetles can be found on the WDNR website: dnr.wi.gov/topic/Invasives/loosestrife.html.*

[289] *Further information about Clean Boats, Clean Waters can be found on the WDNR website at: dnr.wi.gov/lakes/cbcw.*

- **Target launch sites**. Since boat launches are likely entry points for alien species, boat launch sites should be targeted for focused aquatic plant control.

- **Take immediate action to evaluate and eradicate newly identified invasive species.** If a new alien species infestation is found in the Lake, efforts to eradicate the new species should immediately be evaluated and, if possible, be employed to help prevent establishment. The WDNR has funding that can aid in early eradication efforts, particularly as it pertains to aquatic plants (see Table 3.2). Therefore, citizen monitoring for new invasive species is recommended. The CLMN provides training to help citizens participate in these efforts.

- **The aquatic plant management plan must be re-evaluated every five years**. This requires a new point-intercept survey and thoughtful re-examination of aquatic plant species composition and abundance.

Enhancing Aquatic Plant Management Coordination

These recommendations are made in the interest of improving operational efficiency and effectiveness by promoting greater coordination between the aquatic plant management operations of the LPSD and the Village of Pewaukee.

➤ **Recommendation 4.18: Greater communication and coordination between management operations**

The LPSD and the Village of Pewaukee should continue to enhance and formalize communication and information-sharing regarding aquatic plant management operations. In the short-term, shared contact information and equipment (e.g., a set of two-way radios) between the harvesting crews could facilitate better communication during operations. In the long-term, greater coordination on program goals, seasonal schedules, and daily operations between the LPSD and the Village of Pewaukee can improve the efficiency and effectiveness of aquatic plant management on the Lake, improved services to lake residents, and improved recreational experiences and quality for all users. This recommendation is a high priority.

➤ **Recommendation 4.19: Establish a northeastern unloading site for the LPSD harvesting operation**

The LPSD should continue to pursue establishing a northeastern unloading site for their aquatic plant harvesting operations. A northeastern unloading site would not only reduce excessive travel time and cost to the current unloading site, but also reduce the travel time and cost from the unloading site to the disposal site. Eliminating this unnecessary travel would yield more time and funds devoted to harvesting, shoreline clean up, and pile pick-up. This recommendation is a high priority.

➤ **Recommendation 4.20: Investigate expanding harvested plant disposal sites and opportunities to spread harvested plants on local farms**

The Village of Pewaukee's temporary disposal site at the Village Department of Public Works waste yard rapidly fills its capacity during the harvesting season. If necessary, the LPSD should consider sharing their disposal site with the Village of Pewaukee to provide temporary relief and allow the Village's harvesting operations to continue. The Village harvests approximately 1000 cubic yards annually, equaling a 10 to 20 percent increase in the annual plant volume stored at the LPSD disposal site. However, the Village should consider expanding their asphalt pad to accommodate more harvested plants. Additionally, both entities should investigate opportunities to spread harvested plants on local farms near the Lake, ensuring that their temporary disposal sites will be available during the growing season. This recommendation is a medium priority.

➤ **Recommendation 4.21: Enhance coordination of pile pick-up services**

Following Labor Day, both the LPSD and the Village of Pewaukee generally experience staffing shortages that reduce the capacity of their management operations. However, aquatic plants continue to grow and shoreline owners continue to pile harvested vegetation. The Village of Pewaukee and the LPSD should coordinate their pile pick-up services. If either entity does not maintain enough staff to continue pick-up services, a cooperative agreement could be formed to share staff and equipment in order to continue pick-up services through October. This recommendation is a high priority.

Table 3.2
Example WDNR Grant Programs Supporting Lake Management Activities

Category	Program	Grant Program	Maximum Grant Award	Minimum Grantee Match (percent)	Application Due Date
Water	Surface Water Grants	Aquatic Invasive Species (AIS) Prevention and Control	Clean Boats, Clean Waters: **$24,000**	25	November 1
			Established Population Control: **$150,000**	25	November 1
			Early Detection and Response: **$25,000**	25	Year-Round
			Research and Development annual funding limit: **$500,000**	25	November 1
		Surface Water Education	**$5,000** per project **$50,000** per waterbody	33	November 1
		Surface Water Plan	**$10,000**	33	November 1
		Comprehensive Management Plan	**$25,000**	33	November 1
		County Lake Grant	**$50,000**	33	November 1
		Ordinance Development	**$50,000**	25	November 1
		Management Plan Implementation	Lakes: **$200,000** Rivers: **$50,000**	25	November 1
		Healthy Lakes & Rivers	**$1,000** per practice **$25,000** per waterbody	25	November 1
		Surface Water Restoration	Lakes: **$50,000** Rivers: **$25,000**	25	November 1
		Land Acquisition and Easement	Lakes: **$200,000** Rivers: **$50,000**	25	November 1
	Citizen-Based Monitoring Partnership Program	--	**$5,000**	None	Spring
	Targeted Runoff Management	--	Small-Scale: **$225,000**	30	May 15
			Large-Scale: **$600,000**	30	May 15
	Urban Nonpoint Source & Stormwater Management	--	Planning: **$85,000** Property Acquisition: **$50,000** Construction: $**150,000**	50	May 15
Conservation and Wildlife	Knowles-Nelson Stewardship Program	Habitat Areas	--	50	March 1
		Natural Areas	--	50	March 1
		Streambank Protection	--	50	March 1
		State Trails	--	50	March 1
Boating	Boat Enforcement Patrol	--	Up to **75% reimbursement**	None	Various
	Boating Infrastructure Grant	--	Up to **$200,000 per state**	50	June 1
Recreation	Knowles-Nelson Stewardship Program	Acquisition and Development of Local Parks	--	50	May 1
		Acquisition of Development Rights	--	50	May 1
		Urban Green Space	--	50	May 1
		Urban Rivers	--	50	May 1
	Sport Fish Restoration	Boat Access	Varies annually	25	February 1
		Fishing Pier	Varies annually	25	October 1

Note: This table incorporates information from NR 193, which was made effective on June 1st, 2020. More information regarding these example grant programs may be found online at the following address: dnr.wi.gov/aid/grants.html. Additional federal, state, and local grant opportunities are available. Eligibility varies for each grant program.

Source: Wisconsin Department of Natural Resources and SEWRPC

- **Recommendation 4.22: Avoiding harvesting on Fridays when possible**
  Aquatic plant harvesting should generally be avoided on Fridays, with efforts instead focused on pile pick-up and shoreline cleanup before heavy recreational use during the weekends. Exceptions could be made for seasons with exceptionally excessive aquatic plant growth. This recommendation is a medium priority.

3.6 CYANOBACTERIA AND FLOATING ALGAE

The presence of algae is generally a healthy component of any aquatic ecosystem. Algae are primary building blocks of a lake food chain and can produce oxygen in the same way as rooted plants. Many forms of algae exist, from filamentous algae to cyanobacteria. The majority of algae strains are beneficial to lakes in moderation. However, excessive growth of algae or the presence of toxic strains should be considered an issue of concern. As with aquatic plants, algae generally grow at faster rates in the presence of abundant dissolved phosphorus (particularly in stagnant areas). Consequently, when toxic or high volumes of algae begin to grow in a lake it often indicates a problem with phosphorus enrichment or pollution.

Preventative Recommendations

Floating algae and blue green (i.e., "cyano") bacteria are ongoing issues of concern for Pewaukee Lake residents, although the Lake does not have a history of documented chronic nuisance-level algal blooms. To maintain desirable algal populations, this section recommends monitoring algal growth, helping Lake residents recognize and respond to excessive algae, and taking management actions that help prevent undesirable algal growth in the future. The five recommendations are listed below.

- **Recommendation 5.1: Reduce Lake water phosphorus concentrations**
  Algal growth in the Lake is limited by available phosphorus. Several techniques are discussed in the Section 3.3, "Water Quality" to help maintain or lower phosphorus concentrations in the Lake. Related issues are discussed in Section 3.4, "Pollutant and Sediment Sources and Loads", Section 3.5, "Aquatic Plants", and Section 3.7, "Fish and Wildlife". Lower phosphorus concentrations generally decrease the potential for algal blooms. Implementing these recommendations is critical to maintaining healthy algal populations and such implementation is assigned a high priority.

- **Recommendation 5.2: Continue to monitor algal abundance**
  This effort should focus on monitoring chlorophyll-*a*, as was described in the water quality monitoring recommendation (high priority). If large amounts of suspended or floating algae are found in the future (e.g., "pea soup" green water), samples should be collected to allow algal types, particularly toxic strains, to be identified. This can be considered a low priority at present, but if algae becomes abundant, it should be elevated to a high priority.

- **Recommendation 5.3: Warn residents not to enter the water in the event of an algal bloom**
  This should be considered a high priority unless testing positively confirms the absence of toxic algae. Therefore, methods for rapidly communicating unhealthful water conditions that are not conducive to body contact should be developed.

- **Recommendation 5.4: Maintain or improve overall water quality**
  Implementing recommendations provided in Section 3.3, "Water Quality" to improve water quality and reduce the risk of algal blooms developing. This should be assigned a high priority.

- **Recommendation 5.5: Maintain a healthy aquatic plant community to compete with algal growth**
  This can be promoted by implementing recommendations provided in Section 3.5, "Aquatic Plants." This should be assigned a high priority.

Implementing the above recommendations will help prevent excessive algal growth in Pewaukee Lake and should not preclude or significantly inhibit Lake use. If future monitoring reveals excessive or greatly increased algal growth, or should toxic algae be identified, these recommendations should be reevaluated (high priority). Reevaluation should include rethinking all relevant Lake management efforts.

Potential Corrective Measures

If excessive algae growth were to occur in the future, in-lake measures and manual removal methods could also be implemented. Implementation of these measures is not currently recommended, but a few examples are summarized below for possible future reference.

- **In-lake treatments** – Suspended and floating algae use dissolved or suspended nutrients to fuel growth. If water-column nutrient levels are reduced, the abundance of algae can be controlled. Water quality enhancement recommendations presented as feasible in Section 3.3, "Water Quality" should be the primary measures implemented to help control algal abundance. Supplemental activities that are not recommended for general water quality management, but which may be considered as a finite-term solution to counter severe algae problems are described below.

  - **Alum treatments** – Alum treatment involves dispersing a chemical (alum: hydrated potassium aluminum sulfate) throughout a lake. This chemical forms a flocculent solid that sinks, carrying algae and other solids to the lake bottom, allowing water to clear and rooted aquatic plants to grow at greater depth. Additional rooted aquatic plants compete with algae for nutrients, and can help clear lake water in the longer term. Alum-bound phosphorus precipitated to the lake bottom does not become soluble under anoxic water conditions and can help form a cap to reduce internal phosphorus loading. These effects can help lower lake water phosphorus concentrations, and, therefore, reduce algal blooms. An alum treatment is not necessary for Pewaukee Lake at the present time, would only be suggested to manage excessive or toxic algae problems, and is not discussed further in this report.

  - **Hypolimnetic withdrawal and on-shore treatment** – Much of the phosphorus available to fuel warm-season algal growth is released from Lake bottom sediment during summer, is available to fuel algal growth when conditions are right, and is returned to the Lake bottom where it remains available to fuel future algal growth. At least some of this stored phosphorus is likely a legacy from the time period where heavy phosphorus loads were directed to the Lake from wastewater treatment systems. Since the Lake has a finite capacity to flush pollutants downstream, actions to actively and permanently remove phosphorus from the Lake can help decrease future nutrient levels. Hypolimnetic withdrawal and on-shore treatment would use pumps or gravity to remove nutrient-rich waters from deep within the Lake during the summer, treat the water on shore, and then allow the treated water to pass downstream or re-enter the Lake. This approach can be designed at a variety of scales, with the most intensive approaches yielding the quickest results. Less costly low-intensity approaches can operate essentially indefinitely and lead to incremental water quality improvement over decades.

  - **Aeration** – This process involves pumping air to the bottom of a lake to disrupt stratification and limit the extent of anoxic conditions forming in the deep portion of the Lake. This in turn reduces internal loading (i.e., the release of phosphorus from deep sediments) and may reduce the severity of algal blooms during mixing periods. This method has produced mixed results in various lakes throughout Wisconsin and appears to be most successful in smaller water bodies such as ponds. If not properly designed or operated, aeration can increase nutrient levels and intensify and/or prolong algal blooms.

- **Manual removal** – Manual removal of algae using suction devices has recently been tested within the Region. This measure, though legal, is currently in the early stages of development and application. Additionally, algal "skimming" has been tried by lake managers with little success. Consequently, such measures should be further investigated and tested before investing significant time or funds into implementation.

All of the above measures are commonly only implemented when algal blooms become so profuse that recreational use is impaired. This is often because each method is only temporarily effective, and repeated implementation of these measures can be cost prohibitive. Since Pewaukee Lake has had only relatively minor issues with algal blooms in the past, these methods are not recommended at this time. The more permanent methods of algal control discussed above (i.e., pollution control and plant community maintenance) are considered most viable for Pewaukee Lake.

Harmful Algal Blooms

As a final note about algae, the U.S. EPA Office of Water has recently released a suite of materials that is available to states and communities to protect public health during harmful cyanobacteria algal blooms. Since some types of cyanobacteria blooms are capable of releasing toxic chemicals into the water, public health officials and outdoor water recreation managers can use the EPA's online resources to develop monitoring programs and communicate any potential health risks to the public. The City/Village of Pewaukee Joint Park and Recreation Department is the entity taking care of the public beaches. They already monitor *E. coli* concentrations and post results on their website as well as on signs placed on the lifeguard tower and two lifeguard chairs that signify the current status of the beach water quality. A green sign indicates good water conditions according to the EPA's guidelines. A yellow sign indicates that the *E. coli* levels are elevated, but do not warrant closing the beach. A red sign indicates the beach is closed, because the *E. coli* counts are too high for safe swimming. Therefore, a similar method to quickly communicate water conditions adverse to body contact should be developed for harmful algal blooms, possibly as per the U.S. EPA online resources as described above.

3.7 FISH AND WILDLIFE

Biological communities are a direct measure of waterbody health—an indicator of the ability of a waterbody to support aquatic life. The Pewaukee Lake fishery is well known throughout the Region and, through stocking efforts supported by the WDNR stocking program, as well as through efforts of volunteer organizations, has become a popular "musky lake" that also supports excellent panfish stock, as well as largemouth bass, walleyed pike, and northern pike populations. The Lake is a popular fishing destination for anglers during all seasons of the year. Additionally, the watershed supports numerous wildlife species in its varied upland, wetland, and aquatic habitats.

Fish and wildlife depend upon the health of the Lake, its tributaries, and the environmental corridors found throughout the watershed. The presence of fish and wildlife increases the Lake's recreational use, aesthetic appeal, overall enjoyment by humans, and the functionality of the Lake as an ecosystem. To enhance fish and wildlife quality and abundance within the Pewaukee Lake watershed, the following recommendations are made.

Habitat Quality

Preserving and enhancing habitat quality is essential to promoting healthy fish and wildlife populations within the watershed. Recommendations to improve habitat quality are as follows:

- **Recommendation 6.1: Continue efforts to protect and enhance a sustainable coldwater habitat (brook trout fishery) in Coco Creek, as well as coolwater (northern pike, walleye) and warmwater (largemouth bass, musky) and associated aquatic community, habitat, and water quality in Meadowbrook Creek, Zion Creek, and Pewaukee Lake**

  This recommendation is a high priority. Map 3.5 indicates proposed aquatic habitat recommendations for Coco Creek that include: channel restabilization and alignment, improvement of fish habitat and passage, removal of two dams, identifying potential northern pike spawning habitat, and monitoring/assessing the beneficial habitat impacts of beaver dams. Map 3.6 presents proposed aquatic habitat recommendations for Meadowbrook and Zion creeks that include: channel restabilization, removal of dams, filling in of ponds to restore lost wetlands, removal of unnecessary or perched culverts, removal of carp, and relocating stream reaches away from roads.

- **Recommendation 6.2: Identify and remove instream barriers to passage of fish and other aquatic organisms**

  This recommendation is a high priority. Even ephemeral streams, which only flow seasonally, can provide fish passage and two-way access to spawning and nursery grounds. Coco Creek, Zion Creek, and Meadowbrook Creek are life-cycle critical resources to some fish species and are a favored resource for many. For example, temporarily flooded grassy areas can be favored spawning areas for northern pike. Fish species known or likely to use the tributaries include white suckers, walleye pike, northern pike, and other forage fish.

Fish passage barriers are often categorized by scale. Small scale barriers include debris jams, sediment and railroad ballast accumulations, and overgrowth of invasive plants. Such barriers are commonly not recognized as problems, but can significantly affect fishery vitality. Large scale barriers include dams and culverts that are perched, too narrow, or too long. These barriers vary greatly in their ease of removal. BMPs include prioritization of barrier removal along a single stream, with highest habitat benefits and highest ease of removal given the highest rank for remediation. Ozaukee County's Fish Passage Program is highly developed and is a good information resource.[290] Removing fish passage barriers in Pewaukee Lake tributaries should be considered a medium priority. Fish passage projects often require frequent communication and active collaboration with private land owners, municipalities, and highway departments.

Coco Creek and Meadowbrook Creek both contain beaver dams; these structures have the potential to limit fish passage, particularly by northern pike trying to migrate into upstream tributaries to lay their eggs. Therefore, it is important to continue to monitor beaver activity and take action where appropriate. Those efforts should be particularly focused in the following locations: along migratory routes for northern pike spawning habitat, particularly Meadowbrook Creek and Coco Creek to the confluence with Pewaukee Lake; where structures may become threatened with flooding; and where navigation can become obstructed, particularly at culverts and bridges. Because the removal of beaver dams is a complicated and controversial issue, decisions to remove beaver dams should be addressed on a case-by-case basis.

➤ **Recommendation 6.3: Preserve and expand wetland and terrestrial wildlife habitat, while making efforts to ensure connectivity between such areas**

Expanding habitat connectivity could be achieved by implementing the buffer and wetland protection recommendations provided in Section 3.4, "Pollutant and Sediment Sources and Loads." Benefit could also be accrued by hydraulically reconnecting floodplains to ditched and straightened tributary streams. These reconnected floodplains detain floodwater, improve water quality, may promote groundwater recharge, and provide seasonally wet areas that are of great value for a wide range of birds, fish, amphibians, insects, and terrestrial animals. This should be assigned a high priority.

➤ **Recommendation 6.4: Follow WDNR guidelines for protecting WDNR-designated Sensitive Areas**

This recommendation is a high priority. The WDNR established two Sensitive Areas on Pewaukee Lake reflecting the particularly valuable habitat they provide and the number and importance of plant and animal species depending on these areas for survival (see Figure 3.5). The WDNR established guidelines regarding a number of issues that impact these areas including regulation of recreational traffic, permissible types of aquatic plant management, and the types of shoreline protection.

➤ **Recommendation 6.5: Preserve and enhance instream features that provide important fish spawning and rearing habitats**

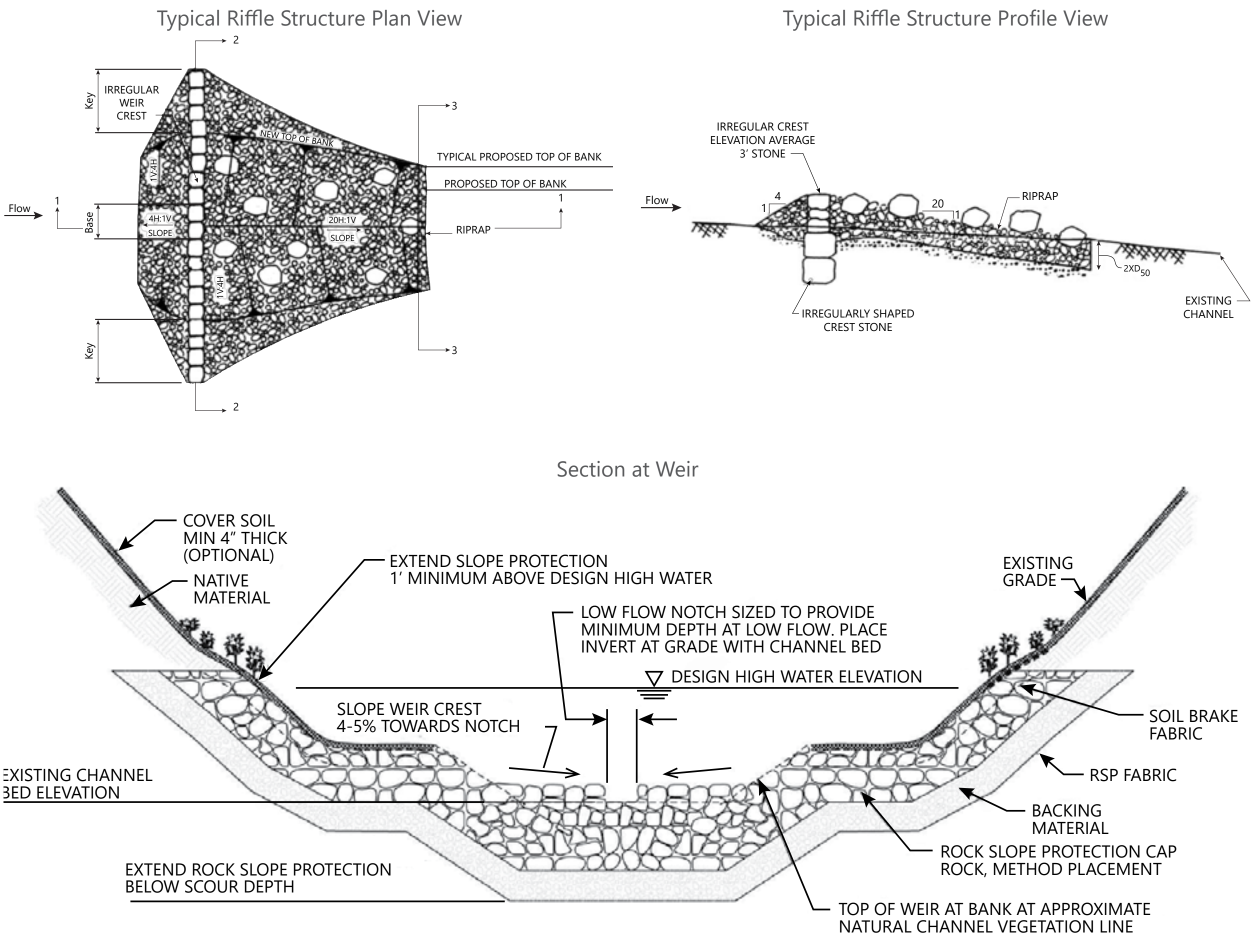
Stream flows are a fundamental part of stream health and actions to mitigate the negative consequences of channelization (especially to Meadowbrook Creek) and physical impediments to stream flow should be considered a medium priority. Other natural stream features, such as riffles, pools, and instream large and small woody debris (not severe enough to cause blockage) should be preserved and, depending on the situation, restored, in order to provide valuable fish habitat, protection from predators, feeding areas, and refuges from summer and winter temperature extremes. The use of natural channel design structures such as naturalized grade control or series of constructed riffle habitats might be a potential alternative (see Figure 3.6). Although undercut banks can reduce streambank stability, these are also areas of overhead protection for fish that are ranked as an important habitat quality feature. Finally, greater extent or width of riparian stream side vegetation should be encouraged.

➤ **Recommendation 6.6: Restore natural meanders and improve floodplain connectivity to Coco Creek, Zion Creek, and Meadowbrook Creek**

Channelization has been extensive throughout portions of the Coco Creek and Meadowbrook Creek tributaries. Due to the low slopes or energies within these streams, the only way to restore stream function is to physically reconstruct them. Reconstructing meanders or restoring a more natural sinuosity,

[290] *See website at www.co.ozaukee.wi.us/619/Fish-Passage.*

Figure 3.6
Example Design Elements – Naturalized Channel Grade Control Concepts



Note: Avoid excessive use of stone - avoid pavement-like or armored appearance. All installations must include choker material to bind and seal streambed. Coarse wood structure may be used to supplant stone in some applications. Grade control elements must be able to withstand high flow – key pieces must be sized to remain immobile and structures must extend beyond flood-prone width. Distribute vertical fall over several short (e.g., < 6-inch tall) riffles, and avoid channel sections with > 2 feet of vertical fall over 100 feet of channel length.

Source: Modified from D.T. Williams, David T. Williams and Associates; W. White, J. Beardsley, and S. Tomkins, Waukegan River Illinois National Nonpoint Source Monitoring Program Project, *Illinois State Water Survey, January 2011; Caltrans,* Fish Passage Design for Road Crossings: An Engineering Document Providing Fish Passage Design Guidance for Caltrans Project, *May 2007 and SEWRPC*

particularly in low gradient systems, is one of the most effective ways to restore instream habitat and the ability of this system to transport sediment and to function more like a healthy stream system. In particular, the highest priority or best locations to restore stream function are where the pre-existing channel lengths that were cut off during channel straightening still exist. Even if the old stream channel has been buried or cannot be determined, there are many opportunities to rehabilitate or increase stream sinuosities and associated habitat and stream function within these channelized sections of stream. Due to the potential cost, this should be considered a low priority.

➤ **Recommendation 6.7: Mitigate streambank erosion**

Streambank erosion destroys aquatic habitat, spawning, and feeding areas; contributes to downstream water quality degradation by releasing sediments to the water; and provides material for subsequent sedimentation downstream, which, in turn, covers valuable benthic habitats, impedes navigation, and fills wetlands. These effects may potentially be mitigated by sound land use planning combined with utilization of proper stormwater management practices. Such actions are considered a medium priority.

- **Recommendation 6.8: Improve aquatic habitat in Pewaukee Lake by maintaining and adding large woody debris and/or vegetative buffers along the Lake's edge**
  Most of the Lake's shorelines have been sanitized through traditional landscaping practices, a situation that reduces habitat value for aquatic organisms. Implementing this recommendation could take the form of educational or incentive-based programs to encourage riparian landowners to leave fallen trees in the water, and to develop buffer systems along the shoreline. In recent years, manmade structures, such as fish cribs and woody debris ("fish sticks", see Figure 3.7) have been part of an ongoing program to develop and improve aquatic habitat in the Lake. This should be considered a medium priority. WDNR grant money is available through the Healthy Lakes & Rivers program on a competitive basis for implementing additional "fish sticks" projects. Installing buffers will provide the added benefits of deterring geese populations from congregating on shoreline properties and promoting better water quality.

- **Recommendation 6.9: Mitigate water quality stress on aquatic life and maximize areas habitable to desirable fish**
  The primary ongoing in-Lake issue affecting aquatic organisms is the low summertime oxygen (anoxia) concentrations found in the Lake. However, the frequency of anoxic days has been decreasing. Since Coco and Meadowbrook Creeks are important spawning and nursery areas for the Lake's fish population, action should also be taken to protect water quality in these tributaries. For example, relocating reaches away from roads can reduce road salt and other pollutant runoff from entering the Creeks, while remeandering the relocated reaches can improve fish and macroinvertebrate habitat (see Maps 3.5 and 3.6). The water quality recommendations discussed earlier in this chapter call for measures to address these conditions. Implementation of those recommendations should be considered a high priority. Other stressors may develop in the future (e.g., new invasive species and other water quality concerns) and conditions should be carefully monitored for their impact on aquatic life (medium priority).

- **Recommendation 6.10: Promote aquatic plant management plan implementation to avoid inadvertent damage to native species**
  Native aquatic plant species can help protect water quality and provide food and shelter for fish and wildlife. Avoiding inadvertent damage to native species is essential to maintaining a clean and healthy lake. This should be assigned a high priority.

- **Recommendation 6.11: Continue the Wetland Conservancy Fund program of purchasing and protecting wetlands**
  Target wetlands in the watershed that are of special significance of preserving wildlife habitat as well as the natural functioning of the Lake-watershed relationship (see Map 3.7). This should be considered a high priority.

- **Recommendation 6.12: Preserve natural areas of countywide and local significance, particularly those with critical species habitat**
  Critical species habitats are essential for protecting rare native species, including those on the state's endangered and threatened species list (see Table 2.12 on page 68 and Map 2.18 on page 66). This recommendation is a high priority.

- **Recommendation 6.13: Incorporate upland conservation and restoration targets into management and policy decisions**
  Upland areas provide a wide range of ecosystem services, but are often among the first targeted for urban development (see Map 2.16 on page 63). This recommendation is a high priority.

Population Management

Through careful monitoring and management, Pewaukee Lake has become renowned for its sport fishing. The following recommendations can help maintain healthy populations of fish and wildlife:

- **Recommendation 6.14: Continue current fish rearing (musky and walleye) and stocking practices consistent with WDNR recommendations**
  The "Walleyes for Tomorrow" rearing program (with the "Walleye Wagon") and the musky rearing program, as integral parts of the Pewaukee Lake stocking initiatives, help assure that the fishery is maintained while efforts to better support natural fish propagation are developed and implemented. This recommendation is a medium priority.

Figure 3.7
Fish Cribs and Sticks Being Constructed and Placed on Pewaukee Lake

Source: Lake Pewaukee Sanitary District and SEWRPC

- **Recommendation 6.15: Current fishing practices and ordinances should continue to be enforced**
  As the current fishery appears healthy, this requires no direct change, and would therefore be a medium priority. Prioritization should be reconsidered if the fishery characteristics or recreational uses tangibly change.

- **Recommendation 6.16: Encourage adoption of best management practices to improve wildlife populations**
  This should be a medium priority, although this should increase to a higher priority if wildlife populations decline. The acceptance and employment of BMPs can be fostered through voluntary, educational, or incentive-based programs for properties adjacent to the shoreline, and by directly implementing these practices on public and protected lands. Special interest non-governmental organizations ("NGOs", e.g., Pheasants Forever, Ducks Unlimited, Trout Unlimited, Walleyes for Tomorrow, etc.) exist to foster habitat improvement projects, some of which collaborate with land owners to install beneficial projects. If this recommendation is implemented, a complete list of BMPs and relevant NGOs should be compiled and provided to landowners (see Figure 3.8 for examples of enhancing herptile habitats).

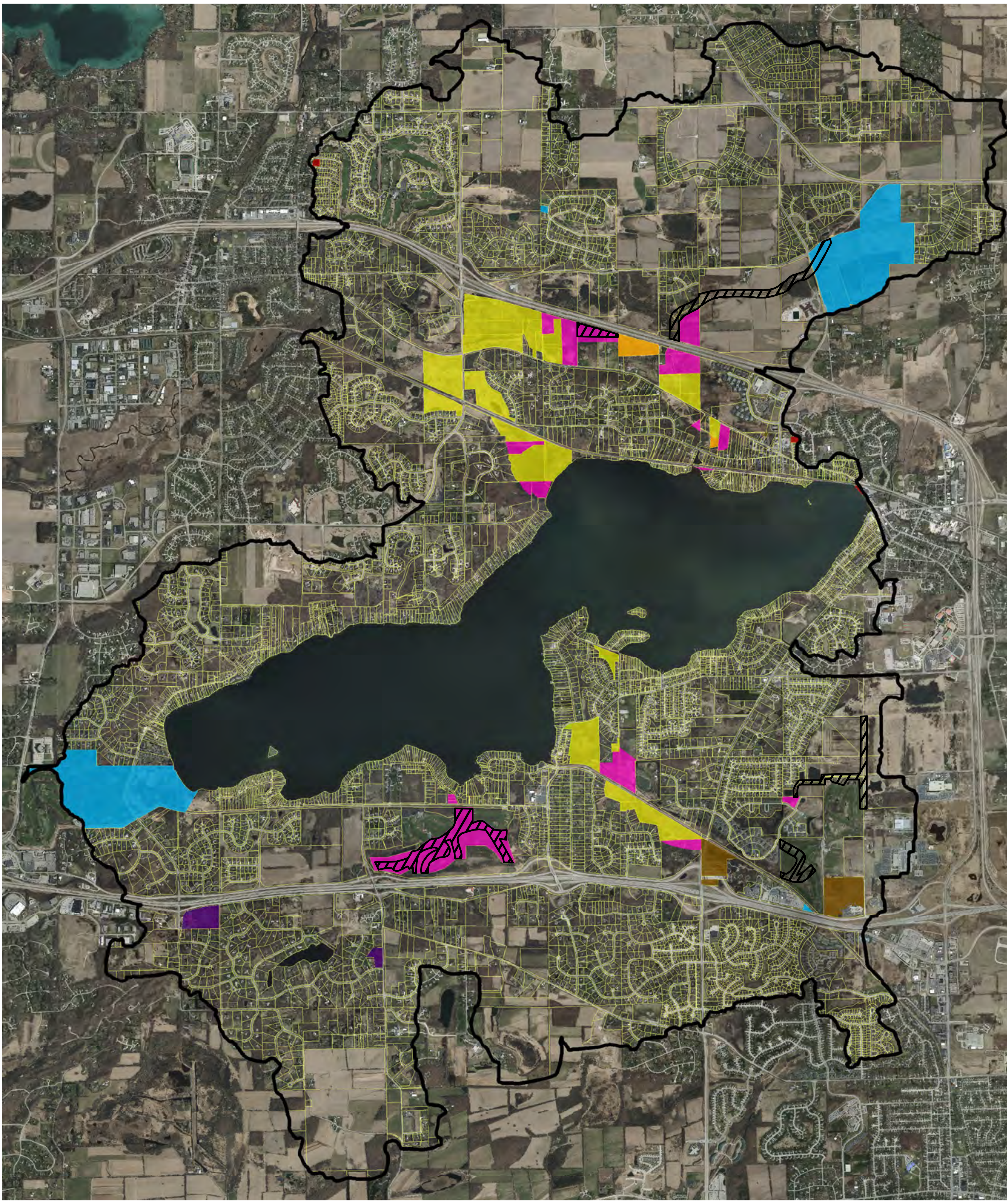
- **Recommendation 6.17: Continue to monitor fish and wildlife populations**
  In general, tracking the diversity and abundance of fish and wildlife would help future Lake managers detect change. Consequently, continued monitoring of fish populations and periodic recording of the types of animals found on and in the Lake and within its watershed is also a medium priority. Monitoring data can be collected from government agencies, non-governmental organizations (e.g., Audubon Society), and from volunteers around the Lake and throughout the watershed.

3.8 RECREATIONAL USE AND FACILITIES

Pewaukee Lake supports diverse recreational activities, such as swimming, kayaking, water-skiing, high-speed boating, cruising, and fishing. Maintaining the Lake's ability to provide safe, high quality recreational pursuits is a priority issue. In support of this goal, the following recommendations are made:

- **Recommendation 7.1: Encourage safe boating practices and boating pressure on navigable portions of the Lake**
  Although use conflicts, safety concerns, and environmental degradation were not presented as issues of concern during the preparation of this plan, if boat densities increase to undesirable levels in the future, boating ordinances and regulations should be reviewed, and if necessary, modified. Such ordinances and regulations should be conscientiously enforced to help reduce the potential for problems related to boat overcrowding during periods of peak boat traffic. Since problems are not known to currently exist, but because boat densities are relatively high during peak periods, this should be considered a medium priority issue.

Map 3.7
Existing and Proposed High Priority Lands to Protect Within the Pewaukee Lake Watershed



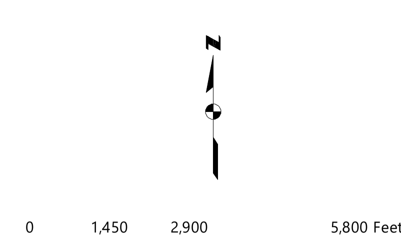
EXISTING PROTECTED LANDS

- EXISTING LPSD LAND (347 ACRES)
- EXISTING STATE LAND (56 ACRES)
- EXISTING COUNTY LAND (366 ACRES)
- EXISTING VILLAGE LAND (3 ACRES)
- EXISTING TOWN LAND (24 ACRES)
- EXISTING CITY LAND (18 ACRES)

PROPOSED PROTECTED LANDS

- PROPOSED GOVERNMENT OWNERSHIP/CONSERVATION EASEMENT (203 ACRES)

- PEWAUKEE LAKE WATERSHED BOUNDARY (15,878 ACRES)
- PROPERTY BOUNDARY
- HIGH PRIORITY STREAM BUFFER/ENVIRONMENTAL EASEMENT LANDS (139 ACRES)



Source: LPSD and SEWRPC

Figure 3.8
Examples of Habitat Improvement Projects in Agricultural and Urban Landscapes for Amphibians and Reptiles

Recreation or Reconnection of Wetland and Upland Habitats

Removing Obstacles and/or Placing Signage Can Improve Safety and Effectiveness of Travel Between Habitats

Burning Can Be an Effective Management Tool

Roadside Fences Can Reduce Mortality

Source: Partners in Amphibian and Reptile Conservation (PARC), Habitat Management Guidelines for Amphibians and Reptiles of the Midwestern United States, *Technical Publication HMG-1, 2nd Edition, 2012 and SEWRPC*

- **Recommendation 7.2: Maintain and enhance swimming through engaging in "swimmer-conscious" management efforts**

  This can be achieved by adopting the aquatic plant management recommendations made earlier in this chapter (see Section 3.5, "Aquatic Plants"), improving water quality (see Section 3.3, "Water Quality"), and controlling algae (see Section 3.6, "Cyanobacteria and Floating Algae"). This should be considered a medium priority issue.

- **Recommendation 7.3: Maintain and enhance fishing by protecting and improving aquatic habitat and ensuring the fish community remains viable**

  This recommendation can be achieved by implementing the aquatic wildlife recommendations provided in Section 3.7, "Fish and Wildlife." This is a medium priority issue.

- **Recommendation 7.4: Maintain public boat launch sites**

  Boat traffic on Pewaukee Lake is highly variable throughout the season and from weekday to weekend. The Lake is popular not only with boaters who live on the Lake, but also with those who trailer watercraft to the Lake. For this reason, launch site maintenance should be considered a high priority. This could include incorporating elements that help reduce the chance of spreading invasive species such as deploying trained volunteers to inspect boats and distributing literature (Clean Boats, Clean Waters program) during high use periods. Such activities could help reduce the chance of spreading invasive species.

- **Recommendation 7.5: Existing boating regulations should be reviewed for compatibility with current conditions and expectations and ordinances should be conscientiously enforced**

  Boat counts suggest that Pewaukee Lake is generally within desirable use levels, but may exceed these levels during peak use periods, such as weekends and holidays. Excessive boat density decreases the ability of the Lake to safely, sustainably, and satisfactorily support a wide range of activities. This means that the potential for use conflicts, safety concerns, and environmental degradation is slightly higher than desirable on Pewaukee Lake during some weekends and holidays. Existing boating ordinances should be reviewed for compatibility with current Lake conditions (medium priority). Given the variability of boating density, stringent ordinance enforcement should be considered a low priority for week days, but a high priority for weekends and holidays.

- **Recommendation 7.6: Consider increasing launch fees during peak use periods**

  Demand for power boating on Pewaukee Lake may meet or slightly exceed optimal use during weekends and holidays. Common economic theory suggests that demand can be reduced if costs increase. Launch fees can include the basic price paid to launch a boat and other factors such as convenience.[291] Certain changes can be made that both benefit the long-term health of the Lake and may place negative pressure on demand. Examples of such changes include the following:

  - Maintain motorized boat launch fees at the maximum permissible rate during weekends and holidays. Consider launch surcharges (such as the following), particularly on weekends and holidays, to adjust fees:

    - Twenty per cent surcharge for launch sites with toilet facilities. Potentially also apply to weekday rates to enhance revenue available for providing weekend/holiday launch attendants.

    - Large boat surcharges. An attendant would need to be on site for effective application. Allowable large boat surcharges are 30 percent for boats 20 to 26 feet long, and 60 percent for boats longer than 26 feet.

    - Have an attendant on duty during all summer weekends and holidays. The attendant's primary duty would be to implement Clean Boats, Clean Waters watercraft inspections and distribute literature to help Lake users understand invasive species issues. A surcharge of 20 percent may be charged when an attendant is on duty, and the attendant can also be responsible for launch surcharges for large boats.

[291] *See* Wisconsin Administrative Code *NR 1, Natural Resources Board Policies, for more information. NR 1.91, Public Boating Access Standards, describes permissible fee structures in great detail.*

- Increasing launch fees is assigned an overall medium priority, the implementation of which is dictated by the desires of the boat launch owner (City of Pewaukee or Waukesha County) and the needs and perceptions of Lake users.

➤ **Recommendation 7.7: Track and maintain shoreline and rock buoys stationed across Pewaukee Lake**
Poorly maintained or missing shoreline and rock buoys to indicate boaters when they are within the slow-no-wake zone or alert boaters to dangerous rock shoals nearby. Keeping an updated list of buoys with their coordinates can assist in identifying buoys that need to be replaced. This recommendation is a high priority.

➤ **Recommendation 7.8: Take action to reduce conditions leading to powerboat-induced shoreline erosion**
This recommendation is a medium priority. A number of ordinances are already enforced that are designed to protect shoreline and shallow areas around the Lake. To help minimize the ecological and environmental impacts of wake boats/surf boats, the LPSD should encourage boat operators to take the following actions:

- Avoid high speed operation within 500 feet of Lake shorelines.
- Avoid unnecessary ballast water or adding other extra weight to boats.
- Operate boats at speeds equal to or less than slow-no-wake in water less than 10 feet deep. Avoid operating wake boats in shallow water or near natural shorelines (see Map 2.34 on page 226).
- Avoid turning boats in tight circles as they increase wave height and frequency.
- Seek deeper water to minimize contact with vegetation. Encourage boats to operate outside EWM control areas to reduce fragmentation and spread of this invasive species.
- Adopt practices to stop the movement or transport of aquatic invasive species by draining water from, drying, and decontaminating all parts of the boat that come into contact with water.

Recreational uses range from noncontact, passive recreational activities such as picnicking and walking along the shoreline, to full-contact, active recreational activities such as swimming, boating, and waterskiing. To accommodate this range of uses, the State of Wisconsin has developed water use objectives for the surface waters of the State, and has promulgated these objectives in Chapters NR 102 and NR 104 of the *Wisconsin Administrative Code*. The scope of recreational uses engaged in on Pewaukee Lake is sufficiently broad to be consistent with the recommended use objectives of full recreational use and the support of a healthy warmwater sport fishery.

3.9 PLAN IMPLEMENTATION

The methods to implement this plan vary with recommendation type. For example, several important recommendations relate to enforcing of current ordinances (e.g., shoreline setbacks, zoning, construction site erosion control, and boating). Public agencies often have limited resources available to monitor compliance and effect enforcement. Consequently, the following recommendations are aimed at local citizens and management groups and are made to enhance the ability of the responsible entities to monitor compliance and enforce regulations.

➤ **Recommendation 8.1: Actively share this plan and work with municipalities to adopt it by maintaining and enhancing relationships with County, municipal zoning administrators, directors of public works/municipal engineers, and law enforcement officers**
This helps build open relationships with responsible entities and facilitates efficient communication and collaboration whenever needed. This should be assigned a high priority.

- **Recommendation 8.2: Keep abreast of activities within the watershed that can affect the Lake**
  Certain activities (e.g., construction, filling, erosion) could potentially affect the Lake. Maintaining good records (e.g., notes, photographs) and judiciously notifying relevant regulatory entities of problems when deemed appropriate is recommended as a high priority.

- **Recommendation 8.3: Educate watershed residents about relevant ordinances. Update ordinances as necessary to face evolving use problems and threats**
  This helps assure that residents know why rules are important, that permits are required for almost all significant grading or construction, and that such permits offer opportunity to regulate activities that could harm the Lake. This should be considered a high priority.

In addition to regulatory enforcement, a number of voluntary and/or incentive-based programs should be considered. These require proactive efforts to protect and manage the Lake. A number of factors hinder the ability of local citizens and management groups to effectively execute lake management projects. Consequently, the following actions are suggested to enable tangible action:

- **Recommendation 8.4: Encourage key players to attend meetings, conferences, and/or training programs to build their lake management knowledge**
  These actions as recommended as a medium priority as they will enhance institutional capacity. Some examples of capacity-building events are the Wisconsin Lakes Conference (which targets local lake managers) and the "Lake Leaders" training program (which teaches the basics of lake management and provides ongoing resources to lake managers). Both are hosted by UWEX. Additionally, courses, workshops, on-line training, regional summits, and general meetings can also be used for this purpose. Attendance at these events should include follow-up documents and meetings so that the lessons learned can be shared with the larger lake group.

- **Recommendation 8.5: Continue to ensure inclusivity and transparency with respect to all Lake management activities**
  If stakeholders do not fully understand the aims and goals of a project, or if they do not trust the process, excess energy can be devoted to conflict, a result that benefits no one. For this reason, this element is assigned high priority. These efforts should be implemented through public meetings and consensus building so that conflicts can be discussed, addressed and mitigated prior to implementing projects.

- **Recommendation 8.6: Foster and monitor management efforts to communicate actions and achievements to future lake managers**
  Institutional knowledge is a powerful tool that should be preserved whenever possible. Actions associated with this are sometimes imbedded in organization bylaws (e.g., minutes) and are therefore assigned medium priority. Open communication helps increase the capacity of lake management entities. This may take the form of annual meetings, website, newsletters, emails, reports and any number of other means that help compile and report action, plans, successes, and lessons learned. These records should be kept for future generations. The LPSD has done an excellent job preserving these records and is encouraged to continue to share historic and new reports and studies concerning Pewaukee Lake through its website, newsletters, and other outlets.

- **Recommendation 8.7: Apply for grants when available to support implementation of programs recommended under this plan**
  This is recommended as a medium priority. Table 3.2 provides a sample of WDNR grant opportunities that can potentially be used to implement plan recommendations. The LPSD, City of Pewaukee, Village of Pewaukee, and the Town of Delafield should all be aware that other local, State, and Federal agencies likely have grant opportunities that could assist with plan implementation.

- **Recommendation 8.8: Integrate lake users and residents in future management efforts**
  This is recommended as a high priority. The aim of this effort is to add to the donor and volunteer base working toward improving the Lake (see Figure 3.9). Private donations and volunteer time can be used as cost match for some grants.

- **Recommendation 8.9: Continue to actively monitor management efforts**
  Such monitoring provides valuable feedback as to the effectiveness of management actions and helps to communicate lessons learned. This is recommended as a high priority.

- **Recommendation 8.10: Foster open relationships with potential project partners**
  Continue to partner with and maintain good relations with volunteer groups, municipalities, and governing bodies, which promotes effective solutions to issues shared in common. This is recommended as a high priority.

- **Recommendation 8.11: Continue to expand stormwater stenciling program throughout the watershed**
  These efforts help to bring attention and raise environmental awareness among the general public. This is recommended as a medium priority.

- **Recommendation 8.12: Educate shoreline property owners on the importance and role of shoreline buffers**
  Programs, such as Healthy Lakes & Rivers, can provide valuable information and education for helping shoreline property owners understand the critical role they can play in controlling shoreline erosion and helping improve the overall condition of the Lake. This is recommended as a medium priority.

- **Recommendation 8.13: Educate property owners, organizations, municipal officials, and nearby business owners and golf course managers on the importance of preventing and stabilizing streambank erosion**
  The importance of maintaining streambank integrity cannot be overemphasized when protecting the water quality of Pewaukee Lake. All those who can play a role need to be made aware of the critical nature of this issue and be educated as to actions they can take to mitigate problems of this nature. This is recommended as a high priority.

Figure 3.9
Volunteer Activities Around Pewaukee Lake

Prairie Maintenance: 2014

Removing Phragmites: 2015

Boy Scouts Wood Duck Project

Source: Lake Pewaukee Sanitary District and SEWRPC

- **Recommendation 8.14: Continue to install "This is Our Watershed" and "Adopt a Highway" signage throughout the watershed**
  Such signs should be placed along sub-watershed tributaries and along major transportation routes as a means of raising awareness for environmental concerns. Increased awareness usually leads to increased involvement as more of the general public begins to see themselves as stakeholders in maintaining the quality of the natural resources around them. This is recommended as a medium priority.

- **Recommendation 8.15: Consider the development of an awards program or approved applicators program**
  Development of such a program or an approved applicators program in partnership with municipalities can be a powerful tool for promoting proper application strategies and practices for fertilizers and herbicides around the shorelines and tributaries of Pewaukee Lake. This is recommended as a medium priority.

➤ **Recommendation 8.16: Consider re-establishing a "New Lake Resident" welcome package**
Oftentimes, new residents are unaware of the special responsibilities they now have as property owners in a lake community. New shoreline property owners, in particular, have a need to be educated and "brought up to speed" on the various programs, rules, activities, and opportunities associated with lakefront ownership. This is recommended as a medium priority.

➤ **Recommendation 8.17: Coordinate with local stakeholder groups and organizations in developing communication mechanisms**
This is recommended as a medium priority. The Pewaukee Lake area contains a rich and varied cadre of volunteer organizations that are involved in the betterment of the Lake and its watershed, including:

- The Pewaukee Women's Club, which assists in prairie restoration, wetland purchases, and invasive species control

- The Pewaukee River Partnership, which is involved with native plant sales, boardwalks, and canoe launches

- The Pewaukee chapter of Walleyes for Tomorrow, which provides resources and volunteers for the Fish Sticks program, building and placing of fish cribs, habitat and streambank stabilization efforts, and walleye stocking and education (Walleye Wagon)

- The Pewaukee School District, which is involved in the 6th grade river restoration work and boat trips, and the 8th science classes take part in invasive species control through its River Keepers Club, wetland planting and maintenance, and trail development

- The Pewaukee Kiwanis, which conducts the annual Clean Water Festival

- The Boy Scouts of America, which has been involved in building wood duck boxes

- The Badger Fisherman's League, which conducts fishing clinics for kids and supports the fisheries improvement projects

➤ **Recommendation 8.18: Develop brochures informing homeowners about their responsibility for maintenance of the storm water drainage systems**
This is recommended as a medium priority.

As a final note, a major recommendation to promote implementation of this plan is education of lake residents, users, and governing bodies regarding the content of this plan. A campaign to communicate relevant information should therefore be given a high priority.

3.10 SUMMARY

The future will bring change to Pewaukee Lake and its watershed. Projections suggest that some of the agricultural land use in the watershed of today will give way to urban residential land use. It is critical that proactive measures be pursued to lay the groundwork for effectively dealing with and benefiting from future change. Working relationships with appropriate local, County, and State entities need to be nurtured now and in the future to help protect critical natural areas in the watershed during development, to initiate actions (such as residential street leaf litter pickup and disposal), and to instill attitudes among current and future residents that will foster cooperation and coordination of effort on many levels.

To help implement plan recommendations, Table 3.1 summarizes all recommendations and their priority level. The maps provided in this chapter indicate where recommendations should be implemented. These guides will provide current and future Pewaukee Lake managers with a visual overview of where to target management efforts.

As stated in the introduction, this chapter is intended to stimulate ideas and action. Therefore, these recommendations should provide a starting point for addressing the issues identified in Pewaukee Lake and its watershed. Successfully implementing this plan requires vigilance, cooperation, and enthusiasm, not only from local management groups, but also from State and regional agencies, Waukesha County, municipalities, and Lake residents, Lake users, and the general public. Implementation of the recommended measures will provide the water quality and habitat protection necessary to maintain or establish conditions in the watershed that are suitable for maintaining and improving the natural beauty and ambience of Pewaukee Lake and its ecosystem. This, in turn, benefits the Region's human population today and in the future.

APPENDICES

APPENDIX A

INSTREAM HABITAT INVENTORY AMONG REACHES IN THE PEWAUKEE LAKE TRIBUTARIES: 2012 AND 2015

Table A.1
Quantitative Instream Cover Characteristics Among Habitat Types in the Pewaukee Lake Tributaries: 2012 and 2015

Reach	Survey ID[a] (Maps A.1,2)	Sample Date	Longitude[b]	Latitude[b]	Habitat Type[c]	Water Velocity	Amount of Cover (rank)	Woody Debris (rank)	Macrophytes (rank)	Algae (rank)	Shading (rank)
Coco Creek	1	23-May-12	--	--	Pond	Slow	2	0	3	1	0
Coco Creek	2	23-May-12	--	--	Pond	Slow	1	0	1	2	1
Coco Creek	3	23-May-12	2458212.6512	401642.8848	Run	Slow	2	1	1	2	1
Coco Creek	4	23-May-12	2458468.5818	401572.0352	Run	Slow	1	1	1	1	3
Coco Creek	5	23-May-12	2458531.6266	401726.2960	Run	Slow	1	1	0	1	0
Coco Creek	6	23-May-12	2458577.117340	401920.649286	Deep pool	--	--	--	--	--	--
Coco Creek	7	23-May-12	2458407.0465	402102.7772	Run	Slow	1	1	1	1	0
Coco Creek	8	24-May-12	2458203.369070	402238.901930	Deep pool	--	--	--	--	--	--
Coco Creek	9	24-May-12	2458127.2449	402308.9920	Run	Slow	1	1	1	1	0
Coco Creek	10	24-May-12	2457968.428260	402496.210143	Deep pool	--	--	--	--	--	--
Coco Creek	11	24-May-12	2457954.9447	402523.4637	Run	Slow	1	1	0	0	0
Coco Creek	12	24-May-12	2457937.657000	402564.877985	Deep pool	--	--	--	--	--	--
Coco Creek	13	24-May-12	2457875.9337	402755.7766	Run	Slow	2	2	1	0	3
Coco Creek	14	24-May-12	2457794.596260	402941.201379	Deep pool	--	--	--	--	--	--
Coco Creek	15	24-May-12	2457811.2386	403135.9995	Run	Slow	2	2	0	0	1
Coco Creek	16	24-May-12	2457755.9812	403632.4369	Pool	Slow	2	2	0	0	1
Coco Creek	17	24-May-12	2457593.4126	403863.3406	Run	Moderate	1	1	1	0	0
Coco Creek	18	24-May-12	2457546.370380	403898.030830	Deep pool	--	--	--	--	--	--
Coco Creek	19	24-May-12	2457556.785710	403930.572760	Deep pool	--	--	--	--	--	--
Coco Creek	20	24-May-12	2457350.7618	404205.0456	Riffle	Fast	2	2	0	0	3
Coco Creek	21	24-May-12	2457323.147070	404338.252719	Deep pool	--	--	--	--	--	--
Coco Creek	22	24-May-12	2457281.2157	404608.3591	Run	Moderate	3	3	0	0	3
Coco Creek	23	24-May-12	2457112.287920	404761.279432	Deep pool	--	--	--	--	--	--
Coco Creek	24	24-May-12	2457073.3999	404778.4795	Run	Moderate	3	3	2	0	3
Coco Creek	25	25-May-12	2457052.424190	404771.695093	Deep pool	--	--	--	--	--	--
Coco Creek	26	25-May-12	2456968.4916	404646.5566	Run	Moderate	2	2	2	0	2
Tributary To Coco Creek	27	24-May-12	2457061.919250	404794.560861	Run	Moderate	1	1	0	0	2
Tributary To Coco Creek	28	24-May-12	2457121.201280	404813.530639	Riffle	Fast	1	1	0	0	3
Tributary To Coco Creek	29	25-May-12	2457135.105780	404846.326178	Deep pool	--	--	--	--	--	--
Tributary To Coco Creek	30	25-May-12	2457137.778020	404881.949794	Run	Slow	1	1	0	0	2
Coco Creek	31	15-Apr-15	--	--	Run	Moderate	**2**	**2**	**0**	**0**	1
Coco Creek	32	15-Apr-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	33	15-Apr-15	--	--	Pool	--	--	--	--	--	--
Coco Creek	34	15-Apr-15	--	--	Run	Moderate	**1**	**1**	**0**	**0**	0
Coco Creek	35	17-Apr-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	36	17-Apr-15	--	--	Run	Moderate	**1**	**2**	**0**	**0**	0
Coco Creek	37	17-Apr-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	38	17-Apr-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	39	17-Apr-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	40	17-Apr-15	--	--	Deep Pool	--	--	--	--	--	--

Table continued on next page.

Table A.1 (Continued)

Reach	Survey ID[a] (Maps A.1,2)	Sample Date	Longitude[b]	Latitude[b]	Habitat Type[c]	Water Velocity	Amount of Cover (rank)	Woody Debris (rank)	Macrophytes (rank)	Algae (rank)	Shading (rank)
Coco Creek	41	17-Apr-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	42	17-Apr-15	--	--	Run	Moderate	**1**	**2**	**0**	**0**	1
Coco Creek	43	17-Apr-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	44	17-Apr-15	--	--	Run	Slow	**2**	**2**	**0**	**0**	1
Coco Creek	45	17-Apr-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	46	17-Apr-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	47	17-Apr-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	48	17-Apr-15	--	--	Run	Slow	**1**	**1**	**0**	**0**	0
Coco Creek	49	23-Apr-15	--	--	Run	Slow	**1**	**1**	**0**	**0**	0
Coco Creek	50	23-Apr-15	--	--	Run	Moderate	**1**	**1**	**0**	**0**	1
Coco Creek	51	23-Apr-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	52	23-Apr-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	53	23-Apr-15	--	--	Run	Slow	**1**	**1**	**0**	**0**	0
Coco Creek	54	24-Apr-15	--	--	Run	Slow	**1**	**2**	**1**	**1**	0
Coco Creek	55	24-Apr-15	--	--	Run	Slow	**1**	**1**	**1**	**1**	1
Coco Creek	56	24-Apr-15	--	--	Run	Slow	**1**	**1**	**0**	**0**	1
Coco Creek	57	18991230	--	--	Run	Slow	**1**	**1**	**0**	**0**	1
Coco Creek	58	24-Apr-15	--	--	Run	Slow	**1**	**1**	**0**	**0**	0
Coco Creek	59	24-Apr-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	60	27-Apr-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	61	27-Apr-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	62	27-Apr-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	63	27-Apr-15	--	--	Riffle	Fast	**3**	**2**	**0**	**0**	3
Coco Creek	64	27-Apr-15	--	--	Pool	--	--	--	--	--	--
Coco Creek	65	27-Apr-15	--	--	Run	Slow	**2**	**2**	**0**	**0**	1
Coco Creek	66	27-Apr-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	67	27-Apr-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	68	27-Apr-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	69	27-Apr-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	70	27-Apr-15	--	--	Run	Slow	**1**	**1**	**0**	**0**	0
Coco Creek	71	27-Apr-15	--	--	Run	Slow	**1**	**2**	**2**	**2**	1
Coco Creek	72	28-Apr-15	--	--	Run	Moderate	**2**	**2**	**2**	**2**	2
Coco Creek	73	28-Apr-15	--	--	Run	Slow	**2**	**2**	**1**	**1**	0
Coco Creek	74	28-Apr-15	--	--	Run	Slow	**1**	**2**	**1**	**1**	2
Coco Creek	75	28-Apr-15	--	--	Pool	Slow	**2**	**2**	**2**	**2**	1
Coco Creek	76	4-May-15	--	--	Run	Slow	**2**	**2**	**2**	**2**	1
Coco Creek	77	4-May-15	--	--	Run	Slow	**1**	**1**	**1**	**1**	0
Coco Creek	78	4-May-15	--	--	Run	Slow	**2**	**2**	**1**	**1**	1
Coco Creek	79	4-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	80	4-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	81	4-May-15	--	--	Deep Pool	--	--	--	--	--	--

Table continued on next page.

Table A.1 (Continued)

Reach	Survey ID[a] (Maps A.1,2)	Sample Date	Longitude[b]	Latitude[b]	Habitat Type[c]	Water Velocity	Amount of Cover (rank)	Woody Debris (rank)	Macrophytes (rank)	Algae (rank)	Shading (rank)
Coco Creek	82	4-May-15	--	--	Run	Moderate	**1**	**1**	**1**	**1**	0
Coco Creek	83	6-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	84	6-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	85	6-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	86	6-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	87	6-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	88	6-May-15	--	--	Run	Moderate	**2**	**3**	**0**	**0**	2
Coco Creek	89	6-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	90	6-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	91	6-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	92	7-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	93	7-May-15	--	--	Run	Slow	**2**	**3**	**1**	**1**	1
Coco Creek	94	7-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	95	7-May-15	--	--	Pond	--	--	--	--	--	--
Coco Creek	96	7-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	97	7-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	98	7-May-15	--	--	Riffle	Fast	**1**	**1**	**0**	**0**	1
Coco Creek	99	7-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	100	7-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	101	7-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	102	8-May-15	--	--	Riffle	Fast	**2**	**2**	**1**	**1**	1
Coco Creek	103	8-May-15	--	--	Run	Slow	**1**	**1**	**0**	**0**	3
Coco Creek	104	8-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	105	8-May-15	--	--	Run	Slow	**2**	**1**	**0**	**0**	1
Coco Creek	106	8-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	107	8-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	108	8-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	109	8-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	110	8-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	111	8-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	112	8-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	113	8-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	114	8-May-15	--	--	Riffle	Moderate	**2**	**2**	**0**	**0**	1
Coco Creek	115	8-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	116	8-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	117	8-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	118	12-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	119	12-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	120	12-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	121	12-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	122	12-May-15	--	--	Run	Moderate	**2**	**1**	**1**	**1**	0

Table continued on next page.

Table A.1 (Continued)

Reach	Survey ID[a] (Maps A.1,2)	Sample Date	Longitude[b]	Latitude[b]	Habitat Type[c]	Water Velocity	Amount of Cover (rank)	Woody Debris (rank)	Macrophytes (rank)	Algae (rank)	Shading (rank)
Coco Creek	123	12-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	124	12-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	125	12-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	126	12-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	127	12-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	128	12-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	129	12-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	130	12-May-15	--	--	Riffle	Moderate	**2**	**2**	**0**	**0**	3
Coco Creek	131	13-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	132	13-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	133	13-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	134	13-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	135	13-May-15	--	--	Pool	Slow	**3**	**2**	**1**	**1**	3
Coco Creek	136	13-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	137	13-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	138	13-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	139	13-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	140	14-May-15	--	--	Run	Slow	**1**	**2**	**0**	**0**	3
Coco Creek	141	14-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	142	14-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	143	14-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	144	14-May-15	--	--	Run	Moderate	**1**	**2**	**0**	**0**	2
Coco Creek	145	14-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	146	14-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	147	14-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	148	15-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	149	15-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	150	15-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	151	15-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	152	15-May-15	--	--	Riffle	Fast	**2**	**2**	**0**	**0**	2
Coco Creek	153	15-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	154	15-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	155	15-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	156	15-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	157	15-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	158	15-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	159	15-May-15	--	--	Run	Slow	**1**	**2**	**0**	**0**	2
Coco Creek	160	15-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	161	15-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	162	26-May-15	--	--	Run	Moderate	**2**	**1**	**1**	**1**	1
Coco Creek	163	26-May-15	--	--	Run	Moderate	**2**	**1**	**1**	**1**	1

Table continued on next page.

Table A.1 (Continued)

Reach	Survey ID[a] (Maps A.1,2)	Sample Date	Longitude[b]	Latitude[b]	Habitat Type[c]	Water Velocity	Amount of Cover (rank)	Woody Debris (rank)	Macrophytes (rank)	Algae (rank)	Shading (rank)
Coco Creek	164	26-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	165	26-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	166	26-May-15	--	--	Run	Moderate	**1**	**0**	**1**	**1**	1
Coco Creek	167	26-May-15	--	--	Run	Moderate	**1**	**0**	**1**	**1**	1
Coco Creek	168	26-May-15	--	--	Run	Slow	**2**	**0**	**1**	**1**	1
Coco Creek	169	26-May-15	--	--		--	--	--	**1**	**1**	--
Coco Creek	170	26-May-15	--	--	Run	Slow	**1**	**0**	**1**	**1**	1
Coco Creek	171	29-May-15	--	--	Run	Slow	**2**	**1**	**1**	**1**	2
Coco Creek	172	18-May-15	--	--	Pond	Slow	**2**	**1**	**2**	**2**	1
Coco Creek	173	18-May-15	--	--	Run	Slow	**2**	**3**	**2**	**2**	3
Coco Creek	174	18-May-15	--	--	Run	Slow	**1**	**3**	**1**	**1**	2
Coco Creek	175	18-May-15	--	--	Run	Slow	**2**	**3**	**0**	**0**	2
Coco Creek	176	20-May-15	--	--	Run	Moderate	**1**	**1**	**0**	**0**	1
Coco Creek	177	20-May-15	--	--	Run	Moderate	**0**	**2**	**0**	**0**	1
Coco Creek	178	20-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	179	20-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	180	20-May-15	--	--	Deep Pool	--	--	--	--	--	--
Coco Creek	181	20-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	182	20-May-15	--	--	Riffle	--	--	--	--	--	--
Coco Creek	183	20-May-15	--	--	Riffle	Moderate	**2**	**1**	**0**	**0**	1
Coco Creek	184	20-May-15	--	--	Run	Slow	**1**	**2**	**0**	**0**	1
Meadowbrook	185	22-May-12	2453324.6511	391273.0121	Estuary	Slow	**2**	**1**	**2**	**0**	0
Meadowbrook	186	22-May-12	2453377.6829	391282.9199	Estuary	Slow	**2**	**1**	**2**	**0**	0
Meadowbrook	187	22-May-12	2453634.0186	391253.1194	Pool	Slow	**3**	**2**	**3**	**0**	1
Meadowbrook	188	22-May-12	2453839.6255	391390.8619	Run	Slow	**2**	**2**	**2**	**1**	3
Meadowbrook	189	22-May-12	2453995.4762	391436.8432	Run	Slow	**2**	**1**	**2**	**2**	2
Meadowbrook	190	22-May-12	2454226.5571	391646.8867	Pool	Slow	**3**	**1**	**3**	**2**	1
Meadowbrook	191	17-May-12	2454432.5246	391401.8088	Run	Slow	**2**	**2**	**2**	**0**	1
Meadowbrook	192	17-May-12	2454860.1851	391291.0577	Run	Slow	3	1	3	0	1
Meadowbrook	193	17-May-12	2455400.8150	390918.4659	Run	Slow	3	1	3	1	1
Meadowbrook	194	17-May-12	2455935.0239	390625.0187	Run	Slow	3	1	3	1	0
Meadowbrook	195	22-May-12	2456450.1150	390218.8361	Run	Slow	3	0	3	2	0
Meadowbrook	196	22-May-12	2456846.646387	389896.495841	Deep pool	--	--	--	--	--	--
Meadowbrook	197	22-May-12	2457290.5146	389687.4277	Pond	Slow	1	1	1	1	1
Meadowbrook	198	22-May-12	2457410.0327	389617.5535	Pond	Slow	2	2	1	1	1
Meadowbrook	199	22-May-12	2457716.5718	389463.0617	Pond	Slow	1	1	1	1	1
Meadowbrook	200	22-May-12	2457909.0901	389393.3728	Run	Slow	2	1	1	0	0
Meadowbrook	201	22-May-12	2458105.8286	389328.7266	Pond	Slow	1	1	1	2	1
Meadowbrook	202	22-May-12	2458340.5282	389220.4316	Run	Slow	2	2	1	0	3
Meadowbrook	203	22-May-15	--	--	Deep Pool						
Meadowbrook	204	22-May-15	--	--	Run	Slow	2	3	2	1	1

Table continued on next page.

Table A.1 (Continued)

Reach	Survey ID[a] (Maps A.1,2)	Sample Date	Longitude[b]	Latitude[b]	Habitat Type[c]	Water Velocity	Amount of Cover (rank)	Woody Debris (rank)	Macrophytes (rank)	Algae (rank)	Shading (rank)
Meadowbrook	205	22-May-15	--	--	Run	Slow	2	3	3	1	2
Meadowbrook	206	22-May-15	--	--	Run	Slow	2	3	2	1	2
Meadowbrook	207	3-Jun-15	--	--	Run	Slow	1	2	1	1	3
Meadowbrook	208	3-Jun-15	--	--	Run	Slow	1	2	2	1	2
Meadowbrook	209	3-Jun-15	--	--	Run	Slow	1	2	0	0	3
Meadowbrook	210	3-Jun-15	--	--	Riffle	--	--	--	--	--	--
Meadowbrook	211	3-Jun-15	--	--	Deep Pool	--	--	--	--	--	--
Meadowbrook	212	3-Jun-15	--	--	Riffle	--	--	--	--	--	--
Meadowbrook	213	3-Jun-15	--	--	Run	Slow	1	2	1	0	3
Meadowbrook	214	4-Jun-15	--	--	Run	Slow	1	2	2	1	2
Meadowbrook	215	4-Jun-15	--	--	Deep Pool	--	--	--	--	--	--
Meadowbrook	216	4-Jun-15	--	--	Deep Pool	--	--	--	--	--	--
Meadowbrook	217	9-Jun-15	--	--	Pond	Slow	3	1	3	1	0
Meadowbrook	218	9-Jun-15	--	--	Run	Slow	2	1	3	2	0
Meadowbrook	219	9-Jun-15	--	--	Run	Slow	1	3	1	1	2
Meadowbrook	220	8-Jun-15	--	--	Run	Slow	1	2	0	0	3
Meadowbrook	221	8-Jun-15	--	--	Run	Slow	2	2	3	0	2
Meadowbrook	222	10-Jun-15	--	--	Run	Slow	1	3	1	1	3
Meadowbrook	223	10-Jun-15	--	--	Run	--	2	3	1	1	3
Meadowbrook	224	10-Jun-15	--	--	Run	Slow	1	3	0	0	3
Zion Creek	225	24-Jun-15	--	--	Run	Slow	1	0	2	1	0
Zion Creek	226	24-Jun-15	--	--	Run	Moderate	2	0	0	0	1
Tributary to Meadowbrook	404	18-May-12	2454109.615770	391625.588183	Run	Slow	2	1	0	0	0
Tributary to Meadowbrook	405	18-May-12	2454104.897280	391643.857832	Run	Slow	2	1	1	1	0
Tributary to Meadowbrook	406	18-May-12	2454103.203380	391731.302867	Run	Moderate	1	1	1	0	2

Note: Instream cover variable rank numbers are defined as follows: 0 = None or Nearly Absent (< 5.0 percent), 1 = Low Abundance (5 to 25 percent), 2 = Moderate Abundance (25 to 75 percent), and 3 = High Abundance (greater than 75 percent).

Sample dates collected in 2012 and reported in CAPR 313 were renumbered in this Report.

[a] *Cross-section surveys were not conducted in every pool habitat location, however maximum pool depths were recorded.*

[b] *These coordinates are in North American Datum (NAD) 1927 State Plane Wisconsin South Federal Information Processing Standard (FIPS) 4803.*

[c] *The table is color coded by instream habitat type- Pools (blue), Riffles (tan), and Runs (green).*

Source: SEWRPC

Table A.2
Quantitative Streambank and Bankfull Characteristics Among Habitat Types in the Pewaukee Lake Tributaries: 2012 and 2015

		Left Bank				Right Bank				Bankfull							
Reach[a]	Survey ID[b] (Maps A.1,2)	Length (feet)	Height (feet)	Slope	Undercut (feet)	Length (feet)	Height (feet)	Slope	Undercut (feet)	Width (feet)	Depth-1 (feet)	Depth-2 (feet)	Depth-3 (feet)	Depth-4 (feet)	Depth-5 (feet)	Mean Depth (feet)	Max. Depth (feet)
Coco Creek (2012)	1	--	--	--	--	0.0	--	--	--	--	--	--	--	--	--	--	0.0
Coco Creek (2012)	2	--	--	--	--	0.0	--	--	--	--	--	--	--	--	--	--	0.0
Coco Creek (2012)	3	--	--	--	--	0.0	--	--	--	--	--	--	--	--	--	--	0.0
Coco Creek (2012)	4	--	--	--	--	0.0	--	--	--	--	--	--	--	--	--	--	0.0
Coco Creek (2012)	5	0.2	2.1	10.50	--	0.6	1.7	2.83	--	25.8	2.2	2.4	2.5	2.7	2.0	2.40	2.7
Coco Creek (2012)	6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2012)	7	0.5	1.8	3.60	--	0.8	1.5	1.88	--	18.8	2.8	2.9	2.7	2.9	1.9	2.60	2.9
Coco Creek (2012)	8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2012)	9	0.5	1.5	3.00	0.8	0.5	13.6	27.20	0.4	13.6	2.5	2.6	3.2	3.2	2.5	2.80	3.2
Coco Creek (2012)	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2012)	11	0.4	1.7	4.25	0.7	0.5	1.9	3.80	0.5	12.1	1.9	2.0	2.1	2.1	2.0	2.00	2.1
Coco Creek (2012)	12	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2012)	13	0.4	1.4	3.50	--	0.0	1.1	--	--	17.0	2.1	2.3	2.3	2.1	2.1	2.20	2.3
Coco Creek (2012)	14	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2012)	15	0.3	1.1	3.67	--	0.6	1.1	1.83	--	15.2	2.2	2.3	2.5	2.7	2.1	2.40	2.7
Coco Creek (2012)	16	0.5	1.7	3.40	--	0.8	2.1	2.63	0.5	11.8	2.2	2.7	3.0	2.9	2.6	2.70	3.0
Coco Creek (2012)	17	0.3	2.0	6.67	--	1.2	1.5	1.25	--	11.4	2.3	2.4	2.3	2.3	2.2	2.30	2.4
Coco Creek (2012)	18	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2012)	19	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2012)	20	2.2	2.1	0.95	--	3.6	2.1	0.58	--	18.4	2.3	2.3	2.3	2.3	2.3	2.30	2.3
Coco Creek (2012)	21	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2012)	22	1.7	2.2	1.29	--	2.3	2.0	0.87	--	16.2	2.6	2.5	2.9	3.0	2.5	2.70	3.0
Coco Creek (2012)	23	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2012)	24	0.7	1.7	2.43	--	1.4	1.7	1.21	--	20.1	1.9	1.9	1.7	2.1	2.6	2.00	2.6
Coco Creek (2012)	25	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2012)	26	1.2	1.4	1.17	--	2.4	1.2	0.50	--	17.5	1.6	1.7	1.7	1.6	1.5	1.60	1.7
Tributary to Coco Creek (2012)	27	0.6	1.1	1.83	--	0.6	1.2	2.0	--	5.7	1.6	1.6	1.4	--	--	1.53	1.6
Tributary to Coco Creek (2012)	28	1.2	1.1	0.92	--	1.5	1.3	0.87	--	3.6	1.3	1.3	1.2	--	--	1.27	1.3
Tributary to Coco Creek (2012)	29	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Tributary to Coco Creek (2012)	30	0.4	1.7	4.25	--	0.7	1.5	2.14	--	8.6	2.4	2.7	2.5	--	--	2.53	2.7
Coco Creek (2015)	31	1.2	1.0	1.2		1.2	1.1	1.1		13.5	1.5	1.8	2.0	1.9	1.9	1.8	2.0
Coco Creek (2015)	32	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	33	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	34	0.2	1.7	0.1	1.0	0.3	1.8	0.2	0.6	8.3	2.2	2.4	2.4	2.3	2.1	2.3	2.4
Coco Creek (2015)	35	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	36	0.1	2.0	0.1	1.0	0.2	1.1	0.2		8.6	2.4	2.6	2.2	1.9	1.3	2.1	2.6
Coco Creek (2015)	37	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	38	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	39	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table continued on next page.

Table A.2 (Continued)

Reach[a]	Survey ID[b] (Maps A.1,2)	Left Bank Length (feet)	Left Bank Height (feet)	Left Bank Slope	Left Bank Undercut (feet)	Right Bank Length (feet)	Right Bank Height (feet)	Right Bank Slope	Right Bank Undercut (feet)	Bankfull Width (feet)	Bankfull Depth-1 (feet)	Bankfull Depth-2 (feet)	Bankfull Depth-3 (feet)	Bankfull Depth-4 (feet)	Bankfull Depth-5 (feet)	Bankfull Mean Depth (feet)	Bankfull Max. Depth (feet)
Coco Creek (2015)	40	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	41	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	42	2.1	1.5	1.4		0.1	2.2	0.0	1.0	11.4	1.8	2.1	2.1	2.3	2.4	2.1	2.4
Coco Creek (2015)	43	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	44	2.0	1.3	1.5		2.0	1.7	1.2		17.0	2.8	2.0	2.2	2.3	2.1	2.3	2.8
Coco Creek (2015)	45	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	46	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	47	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	48	0.1	1.7	0.1	--	0.3	2.2	0.1	1.0	10.0	2.3	2.9	2.8	2.8	2.4	2.6	2.9
Coco Creek (2015)	49	2.0	1.0	2.0	--	3.3	1.1	3.0	0.0	19.0	2.0	2.1	2.0	2.0	1.8	2.0	2.1
Coco Creek (2015)	50	0.6	1.9	0.3	--	1.1	1.8	0.6	0.0	13.6	1.7	1.6	1.6	1.7	1.7	1.7	1.7
Coco Creek (2015)	51	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	52	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	53	1.2	2.5	0.5	--	--	2.8	0.0	--	13.6	2.5	2.7	2.8	2.6	2.5	2.6	2.8
Coco Creek (2015)	54	0.4	2.2	0.2	1.0	1.0	1.3	0.8	--	12.5	2.4	2.8	2.7	2.4	2.5	2.6	2.8
Coco Creek (2015)	55	--	--	0.0	0.7	0.6	1.8	0.3	--	9.6	1.3	1.9	2.3	2.5	2.3	2.1	2.5
Coco Creek (2015)	56	0.3	1.5	0.2		0.1	1.8	0.1	0.7	9.5	1.9	2.2	2.6	2.5	2.1	2.3	2.6
Coco Creek (2015)	57	0.3	1.5	0.2		0.1	1.8	0.1	0.7	9.5	1.9	2.2	2.6	2.5	2.1	2.3	2.6
Coco Creek (2015)	58	0.4	1.8	0.2	0.6	0.2	1.8	0.1	0.0	8.0	2.2	2.3	2.3	2.3	2.1	2.2	2.3
Coco Creek (2015)	59	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	60	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	61	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	62	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	63	0.5	1.1	0.5	--	0.2	1.1	0.2	0.6	14.2	1.3	1.4	1.5	1.5	1.4	1.4	1.5
Coco Creek (2015)	64	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	65	0.2	1.6	0.1	0.5	0.3	1.4	0.2	0.6	9.3	1.5	2.0	2.1	2.1	1.9	1.9	2.1
Coco Creek (2015)	66	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	67	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	68	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	69	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	70	0.3	1.5	0.2	0.6	0.6	1.7	0.4	0.6	8.7	1.7	2.0	2.2	2.2	1.9	2.0	2.2
Coco Creek (2015)	71	0.3	1.4	0.2	0.4	0.2	1.2	0.2	0.6	10.4	1.5	1.7	1.8	1.7	1.4	1.6	1.8
Coco Creek (2015)	72	0.8	1.2	0.7		0.6	0.8	0.8		6.7	1.5	1.9	1.3			1.6	1.9
Coco Creek (2015)	73	0.4	1.8	0.2	0.6	0.5	2.1	0.2	0.8	9.2	1.7	2.1	2.3	2.3	2.2	2.1	2.3
Coco Creek (2015)	74	1.0	1.1	0.9	--	0.9	1.7	0.5	0.6	12.8	1.4	2.0	2.4	2.4	2.0	2.0	2.4
Coco Creek (2015)	75	0.3	0.8	0.4	--	0.7	1.7	0.4	0.5	11.5	1.1		1.5	2.0	2.5	1.8	2.5
Coco Creek (2015)	76	0.1	1.2	0.1	--	0.3	0.4	0.8	--	4.6	0.8	1.1	1.3	--	--	1.1	1.3
Coco Creek (2015)	77	0.1	1.3	0.1	0.4	0.2	1.5	0.1	--	4.4	1.2	1.6	1.5	--	--	1.4	1.6
Coco Creek (2015)	78	0.4	0.7	0.6		0.1	1.5	0.1	--	6.4	0.7	1.7	1.9	1.9	1.5	1.5	1.9
Coco Creek (2015)	79	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table continued on next page.

Table A.2 (Continued)

Reach[a]	Survey ID[b] (Maps A.1,2)	Left Bank Length (feet)	Left Bank Height (feet)	Left Bank Slope	Left Bank Undercut (feet)	Right Bank Length (feet)	Right Bank Height (feet)	Right Bank Slope	Right Bank Undercut (feet)	Bankfull Width (feet)	Bankfull Depth-1 (feet)	Bankfull Depth-2 (feet)	Bankfull Depth-3 (feet)	Bankfull Depth-4 (feet)	Bankfull Depth-5 (feet)	Bankfull Mean Depth (feet)	Bankfull Max. Depth (feet)
Coco Creek (2015)	80	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	81	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	82	0.2	1.4	0.1	0.6	0.4	1.5	0.3	0.6	6.6	1.9	2.0	2.0	1.9	1.7	1.9	2.0
Coco Creek (2015)	83	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	84	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	85	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	86	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	87	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	88	0.6	0.8	0.8	--	0.4	0.9	0.4	--	12.2	1.4	1.7	2.3	2.0	1.6	1.8	2.3
Coco Creek (2015)	89	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	90	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	91	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	92	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	93	0.8	1.4	0.6	0.4	0.4	1.2	0.3	0.3	15.0	1.7	2.0	1.8	1.4	1.4	1.7	2.0
Coco Creek (2015)	94	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	95	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	96	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	97	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	98	1.9	1.8	1.1	--	1.1	1.7	0.6	--	9.6	1.9	1.8	1.7	--	--	1.8	1.9
Coco Creek (2015)	99	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	100	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	101	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	102	0.6	1.4	0.4	--	0.6	1.5	0.4	--	7.8	1.5	1.6	1.6	--	--	1.6	1.6
Coco Creek (2015)	103	0.2	1.4	0.1	0.4	0.4	1.3	0.3	--	9.3	1.5	1.8	1.7	1.9	1.6	1.7	1.9
Coco Creek (2015)	104	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	105	1.5	1.8	0.8	--	0.9	2.7	0.3	1.0	8.6	2.1	2.5	2.7	--	--	2.4	2.7
Coco Creek (2015)	106	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	107	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	108	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	109	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	110	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	111	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	112	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	113	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	114	0.7	1.7	0.4	--	1.4	2.7	0.5	1.8	12.7	2.2	2.2	2.4	2.5	2.7	2.4	2.7
Coco Creek (2015)	115	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	116	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	117	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	118	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	119	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table continued on next page.

Table A.2 (Continued)

Reach[a]	Survey ID[b] (Maps A.1,2)	Left Bank				Right Bank				Bankfull							
		Length (feet)	Height (feet)	Slope	Undercut (feet)	Length (feet)	Height (feet)	Slope	Undercut (feet)	Width (feet)	Depth-1 (feet)	Depth-2 (feet)	Depth-3 (feet)	Depth-4 (feet)	Depth-5 (feet)	Mean Depth (feet)	Max. Depth (feet)
Coco Creek (2015)	120	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	121	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	122	0.6	1.2	0.5	0.3	1.7	1.0	1.7	--	6.6	1.6	1.4	1.2	0.0	--	1.1	1.6
Coco Creek (2015)	123	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	124	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	125	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	126	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	127	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	128	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	129	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	130	0.2	1.4	0.1	0.6	1.2	1.5	0.8	--	13.0	1.7	1.8	1.9	1.6	1.7	1.7	1.9
Coco Creek (2015)	131	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	132	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	133	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	134	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	135	0.2	1.6	0.1	--	0.3	1.4	0.2	--	12.3	2.0	2.8	2.1	1.8	1.7	2.1	2.8
Coco Creek (2015)	136	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	137	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	138	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	139	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	140	0.6	1.6	0.4	--	1.5	1.7	0.9	--	11.2	1.8	1.6	1.6	1.8	1.8	1.7	1.8
Coco Creek (2015)	141	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	142	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	143	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	144	1.5	1.8	0.8	--	2.1	1.8	1.2	--	11.5	2.1	2.1	2.0	0.0	0.0	1.2	2.1
Coco Creek (2015)	145	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	146	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	147	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	148	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	149	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	150	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	151	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	152	0.8	1.4	0.6	--	1.0	1.5	0.7	--	12.4	1.7	1.6	1.7	1.6	1.6	1.6	1.7
Coco Creek (2015)	153	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	154	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	155	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	156	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	157	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	158	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	159	2.2	2.0	1.1	--	1.1	2.1	0.5	--	12.3	2.2	2.3	2.5	2.2	2.2	2.3	2.5

Table continued on next page.

Table A.2 (Continued)

Reach[a]	Survey ID[b] (Maps A.1,2)	Left Bank Length (feet)	Left Bank Height (feet)	Left Bank Slope	Left Bank Undercut (feet)	Right Bank Length (feet)	Right Bank Height (feet)	Right Bank Slope	Right Bank Undercut (feet)	Bankfull Width (feet)	Depth-1 (feet)	Depth-2 (feet)	Depth-3 (feet)	Depth-4 (feet)	Depth-5 (feet)	Mean Depth (feet)	Max. Depth (feet)
Coco Creek (2015)	160	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	161	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	162	6.1	1.9	3.2	--	1.0	1.8	0.6	--	13.0	1.9	2.8	2.1	0.0		1.7	2.8
Coco Creek (2015)	163	4.7	2.7	1.7	--	1.7	1.5	1.1	--	11.3	1.9	2.2	2.4	0.0		1.6	2.4
Coco Creek (2015)	164	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	165	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	166	0.6	2.0	0.3	0.7	0.8	1.4	0.6	--	5.4	2.1	2.4	2.3	0.0	--	1.7	2.4
Coco Creek (2015)	167	0.2	1.2	0.2	--	0.2	0.6	0.3	--	3.7	1.3	1.3	0.9	0.0	--	0.9	1.3
Coco Creek (2015)	168	0.4	0.3	1.3	--	0.0	0.3	0.0	--	19.3	0.8	1.2	1.5	1.0	0.9	1.1	1.5
Coco Creek (2015)	169	0.5	0.8	0.6	--	2.0	0.9	2.2	--	33.4	1.6	1.8	1.8	1.7	1.4	1.7	1.8
Coco Creek (2015)	170	0.5	0.2	2.5	--	1.9	0.5	3.8	--	20.0	1.0	0.8	1.2	0.0	--	0.8	1.2
Coco Creek (2015)	171	0.8	0.7	1.1	--	0.6	0.6	1.0	--	5.2	1.0	1.2	0.8	0.0	--	0.8	1.2
Coco Creek (2015)	172	0.5	0.7	0.7	--	0.3	0.3	1.0	--	15.3	1.7	2.4	2.5	2.1	1.8	2.1	2.5
Coco Creek (2015)	173	1.0	0.5	2.0	--	0.5	0.3	1.7	--	10.9	0.7	0.7	0.9	0.7	0.6	0.7	0.9
Coco Creek (2015)	174	2.0	0.5	4.0	--	1.0	0.5	2.0	--	12.2	0.6	0.8	0.9	0.9	0.8	0.8	0.9
Coco Creek (2015)	175	9.4	1.1	8.5	--	6.5	0.9	7.2	--	10.5	1.0	1.1	1.1	0.0	--	0.8	1.1
Coco Creek (2015)	176	0.4	1.1	0.4	--	0.7	0.9	0.8	--	4.3	1.4	1.7	1.3	0.0	--	1.1	1.7
Coco Creek (2015)	177	2.5	1.1	2.3	--	2.2	1.1	2.0	--	8.2	1.2	1.2	1.2	0.0	--	0.9	1.2
Coco Creek (2015)	178	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	179	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	180	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	181	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	182	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	183	3.2	1.3	2.5	--	0.5	1.2	0.4	--	7.3	1.5	1.5	1.4	0.0	0.0	0.9	1.5
Coco Creek (2015)	184	1.5	0.6	2.5	--	0.8	0.8	1.0	--	5.1	0.8	0.9	1.0	0.0		0.7	1.0
Meadowbrook (2012)	185	--	--	--	--	0.0	--	--	--	--	--	--	--	--	--	--	0.0
Meadowbrook (2012)	186	--	--	--	--	0.0	--	--	--	--	--	--	--	--	--	--	0.0
Meadowbrook (2012)	187	0.0	2.2	--	--	1.4	1.3	0.93	--	47.5	2.2	2.1	2.1	2.3	1.8	2.10	2.3
Meadowbrook (2012)	188	1.8	0.9	0.50	--	6.9	1.0	0.14	--	35.6	2.2	2.6	2.1	1.6	1.2	1.90	2.6
Meadowbrook (2012)	189	--	--	--	--	0.0	--	--	--	--	--	--	--	--	--	--	0.0
Meadowbrook (2012)	190	--	--	--	--	0.0	--	--	--	--	--	--	--	--	--	--	0.0
Meadowbrook (2012)	191	0.4	1.5	3.75	--	1.2	1.8	1.50	--	24.5	1.7	2.0	2.3	2.4	2.3	2.10	2.4
Meadowbrook (2012)	192	0.3	1.2	4.0	--	1.6	1.0	0.62	--	28.5	1.5	1.6	1.7	1.6	1.6	1.60	1.7
Meadowbrook (2012)	193	0.4	1.0	2.50	--	0.8	1.0	1.25	--	34.4	1.2	1.5	1.4	1.2	1.0	1.30	1.5
Meadowbrook (2012)	194	0.3	1.5	5.0	--	0.4	1.3	3.25	--	18.9	1.7	1.9	2.1	2.1	1.8	1.90	2.1
Meadowbrook (2012)	195	0.3	1.6	5.33	--	1.4	1.3	0.93	--	16.7	1.8	1.9	2.0	1.8	1.7	1.80	2.0
Meadowbrook (2012)	196	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Meadowbrook (2012)	197	--	--	--	--	0.0	--	--	0.8	--	--	--	--	--	--	--	0.0
Meadowbrook (2012)	198	--	--	--	0.2	0.0	--	--	0.8	--	--	--	--	--	--	--	0.0
Meadowbrook (2012)	199	--	--	--	--	0.0	--	--	--	--	--	--	--	--	--	--	0.0

Table continued on next page.

Table A.2 (Continued)

Reach[a]	Survey ID[b] (Maps A.1,2)	Left Bank				Right Bank				Bankfull							
		Length (feet)	Height (feet)	Slope	Undercut (feet)	Length (feet)	Height (feet)	Slope	Undercut (feet)	Width (feet)	Depth-1 (feet)	Depth-2 (feet)	Depth-3 (feet)	Depth-4 (feet)	Depth-5 (feet)	Mean Depth (feet)	Max. Depth (feet)
Meadowbrook (2012)	200	0.3	1.6	5.33	0.2	0.7	1.6	2.29	--	21.4	1.8	2.0	2.5	2.5	2.2	2.20	2.5
Meadowbrook (2012)	201	--	--	--	--	0.0	--	--	--	--	--	--	--	--	--	--	0.0
Meadowbrook (2012)	202	2.1	1.2	0.57	--	2.1	1.0	0.48	--	15.3	1.3	1.5	1.5	1.4	1.3	1.40	1.5
Meadowbrook (2015)	203	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Meadowbrook (2015)	204	1.0	1.0	1.0	--	3.6	2.1	1.7	--	13.0	1.1	1.3	1.3	1.2	1.0	1.2	1.3
Meadowbrook (2015)	205	2.7	1.0	2.7	--	0.8	0.9	0.9	--	16.0	1.3	1.2	1.2	1.5	1.2	1.3	1.5
Meadowbrook (2015)	206	0.4	1.2	0.3	--	1.1	1.1	1.0	--	20.2	1.7	1.6	1.6	1.6	1.5	1.6	1.7
Meadowbrook (2015)	207	2.1	1.4	1.5	--	1.2	1.5	0.8	--	12.2	2.1	2.4	2.5	2.3	1.8	2.2	2.5
Meadowbrook (2015)	208	2.1	1.3	1.6	--	2.4	1.6	1.5	--	14.6	1.8	1.9	1.8	1.8	1.7	1.8	1.9
Meadowbrook (2015)	209	2.3	2.1	1.1	--	1.1	1.9	0.6	--	15.1	2.2	2.3	2.4	2.4	2.3	2.3	2.4
Meadowbrook (2015)	210	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Meadowbrook (2015)	211	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Meadowbrook (2015)	212	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Meadowbrook (2015)	213	1.9	1.9	1.0	--	1.6	1.8	0.9	--	15.3	2.6	3.2	3.1	2.5	2.1	2.7	3.2
Meadowbrook (2015)	214	2.7	1.4	1.9	--	2.1	1.4	1.5	--	16.4	1.7	2.0	2.0	1.8	1.5	1.8	2.0
Meadowbrook (2015)	215	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Meadowbrook (2015)	216	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Meadowbrook (2015)	217	0.7	0.6	1.2	--	0.7	0.7	1.0	--	17.7	0.9	1.2	1.3	1.1	1.1	1.1	1.3
Meadowbrook (2015)	218	1.1	1.7	0.6	--	1.4	0.7	2.0	--	10.3	0.7	1.2	0.9			0.9	1.2
Meadowbrook (2015)	219	0.6	1.8	0.3	--	2.0	2.0	1.0	--	13.9	2.2	2.4	2.4	2.3	2.2	2.3	2.4
Meadowbrook (2015)	220	2.8	2.5	1.1	--	3.2	2.5	1.3	--	17.4	2.6	2.7	2.8	2.8	2.6	2.7	2.8
Meadowbrook (2015)	221	2.3	1.8	1.3	--	1.7	2.1	0.8	--	15.3	1.9	2.1	2.2	2.2	2.2	2.1	2.2
Meadowbrook (2015)	222	1.0	1.2	0.8	--	0.8	1.2	0.7	--	10.5	1.3	1.4	1.6	1.4	1.3	1.4	1.6
Meadowbrook (2015)	223	0.3	0.8	0.4	--	0.7	0.6	1.2	--	9.6	1.1	1.2	1.0			0.8	1.2
Meadowbrook (2015)	224	1.6	1.5	1.1	--	2.4	1.4	1.7	--	13.8	1.7	1.9	2.1	2.0	1.7	1.9	2.1
Zion Creek (2015)	225	0.4	1.4	0.3	--	1.2	1.7	0.7	--	10.2	1.7	1.7	1.6	--	--	1.7	1.7
Zion Creek (2015)	226	0.2	1.2	0.2	--	0.6	1.1	0.5	--	5.4	1.3	1.3	1.3	--	--	1.3	1.3
Tributary to Meadowbrook (2012)	404	0.4	1.0	2.50	--	0.5	1.2	2.40	--	2.7	1.3	1.4	1.4	--	--	1.37	1.4
Tributary to Meadowbrook (2012)	405	0.2	1.1	5.50	--	0.5	10.9	21.80	--	10.3	1.0	1.2	1.0	1.0	1.1	1.06	1.2
Tributary to Meadowbrook (2012)	406	0.7	1.7	2.43	--	4.5	0.8	0.18	--	4.6	0.9	1.0	0.9	--	--	0.93	1.0

[a] *The table is color coded by instream habitat type- Pools (blue), Riffles (tan), and Runs (green).*

[b] *Cross-section surveys were not conducted in every pool habitat location, however maximum pool depths were recorded.*

Source: SEWRPC

Table A.3
Quantitative Instream Low Flow Characteristics Among Habitat Types in the Pewaukee Lake Tributaries: 2012 and 2015

Reach[a]	Survey ID[b] (Maps A.1,2)	Low Flow (feet) Width	Depth-1	Depth-2	Depth-3	Depth-4	Depth-5	Depth-6	Depth-7	Depth-8	Depth-9	Depth-10	Mean Depth	Max. Depth
Coco Creek (2012)	1	--	1.2	2.2	1.6	0.9	1.0	0.8	0.9	0.9	0.8	0.5	1.10	2.2
Coco Creek (2012)	2	--	1.7	2.3	1.3	0.5	0.6	--	--	--	--	--	1.30	2.3
Coco Creek (2012)	3	--	1.0	1.6	2.3	1.8	1.1	--	--	--	--	--	1.60	2.3
Coco Creek (2012)	4	--	0.6	1.6	1.8	1.7	1.4	--	--	--	--	--	1.40	1.8
Coco Creek (2012)	5	25.0	1.4	1.7	2.0	2.1	1.4	--	--	--	--	--	1.70	2.1
Coco Creek (2012)	6	--	--	--	--	--	--	--	--	--	--	--	--	3
Coco Creek (2012)	7	17.5	2.1	2.3	2.0	2.1	1.0	--	--	--	--	--	1.90	2.3
Coco Creek (2012)	8	--	--	--	--	--	--	--	--	--	--	--	--	3.2
Coco Creek (2012)	9	12.6	1.7	1.8	2.4	2.3	1.6	--	--	--	--	--	2.00	2.4
Coco Creek (2012)	10	--	--	--	--	--	--	--	--	--	--	--	--	2.9
Coco Creek (2012)	11	11.4	1.2	1.3	1.3	1.3	1.2	--	--	--	--	--	1.30	1.3
Coco Creek (2012)	12	--	--	--	--	--	--	--	--	--	--	--	--	2.2
Coco Creek (2012)	13	16.7	1.2	1.5	1.5	1.2	1.1	--	--	--	--	--	1.30	1.5
Coco Creek (2012)	14	--	--	--	--	--	--	--	--	--	--	--	--	2.4
Coco Creek (2012)	15	14.3	1.3	1.5	1.7	1.8	1.2	--	--	--	--	--	1.50	1.8
Coco Creek (2012)	16	10.7	1.0	1.6	1.9	1.7	1.4	--	--	--	--	--	1.50	1.9
Coco Creek (2012)	17	9.9	1.0	1.1	1.0	1.0	0.9	--	--	--	--	--	1.00	1.1
Coco Creek (2012)	18	--	--	--	--	--	--	--	--	--	--	--	--	1.6
Coco Creek (2012)	19	--	--	--	--	--	--	--	--	--	--	--	--	3
Coco Creek (2012)	20	12.6	0.4	0.4	0.4	0.4	0.3	--	--	--	--	--	0.40	0.4
Coco Creek (2012)	21	--	--	--	--	--	--	--	--	--	--	--	--	1.5
Coco Creek (2012)	22	12.5	0.5	0.5	1.0	1.0	0.6	--	--	--	--	--	0.70	1.0
Coco Creek (2012)	23	--	--	--	--	--	--	--	--	--	--	--	--	2.1
Coco Creek (2012)	24	17.7	0.5	0.4	0.2	0.6	1.0	--	--	--	--	--	0.50	1.0
Coco Creek (2012)	25	--	--	--	--	--	--	--	--	--	--	--	--	2.8
Coco Creek (2012)	26	13.8	0.4	0.6	0.6	0.5	0.4	--	--	--	--	--	0.50	0.6
Tributary to Coco Creek (2012)	27	5.7	0.5	0.5	0.3	--	--	--	--	--	--	--	0.43	0.50
Tributary to Coco Creek (2012)	28	3.6	0.3	0.3	0.1	--	--	--	--	--	--	--	0.23	0.30
Tributary to Coco Creek (2012)	29	--	--	--	--	--	--	--	--	--	--	--	--	2
Tributary to Coco Creek (2012)	30	8.6	1.5	1.9	1.7	--	--	--	--	--	--	--	1.70	1.90
Coco Creek (2015)	31	10.9	0.6	0.9	1.1	1.1	1.0	--	--	--	--	--	0.9	1.1
Coco Creek (2015)	32	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	33	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	34	7.6	1.3	1.5	1.5	1.4	1.2	--	--	--	--	--	1.4	1.5
Coco Creek (2015)	35	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	36	7.0	1.5	1.7	1.3	0.9	0.3	--	--	--	--	--	1.1	1.7
Coco Creek (2015)	37	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	38	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	39	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	40	--	--	--	--	--	--	--	--	--	--	--	--	--

Table continued on next page.

Table A.3 (Continued)

Reach[a]	Survey ID[b] (Maps A.1,2)	Low Flow (feet)												
		Width	Depth-1	Depth-2	Depth-3	Depth-4	Depth-5	Depth-6	Depth-7	Depth-8	Depth-9	Depth-10	Mean Depth	Max. Depth
Coco Creek (2015)	41	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	42	8.8	0.4	0.8	0.7	1.0	1.1	--	--	--	--	--	0.8	1.1
Coco Creek (2015)	43	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	44	12.5	0.5	0.7	0.7	0.9	0.6	--	--	--	--	--	0.7	0.9
Coco Creek (2015)	45	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	46	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	47	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	48	9.3	1.0	1.6	1.7	1.7	1.3	--	--	--	--	--	1.5	1.7
Coco Creek (2015)	49	12.6	1.1	1.3	1.2	1.2	0.9	--	--	--	--	--	1.1	1.3
Coco Creek (2015)	50	11.6	1.0	0.9	0.9	1.0	1.0	--	--	--	--	--	1.0	1.0
Coco Creek (2015)	51	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	52	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	53	12.5	1.3	1.6	1.8	1.7	1.6	--	--	--	--	--	1.6	1.8
Coco Creek (2015)	54	11.1	1.5	2.0	1.9	1.6	1.6	--	--	--	--	--	1.7	2.0
Coco Creek (2015)	55	9.0	0.4	1.0	1.4	1.6	1.4	--	--	--	--	--	1.2	1.6
Coco Creek (2015)	56	8.8	0.8	1.1	1.6	1.5	1.0	--	--	--	--	--	1.2	1.6
Coco Creek (2015)	57	8.8	0.8	1.1	1.6	1.5	1.0	--	--	--	--	--	1.2	1.6
Coco Creek (2015)	58	7.2	1.1	1.1	1.1	1.1	0.8	--	--	--	--	--	1.0	1.1
Coco Creek (2015)	59	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	60	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	61	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	62	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	63	11.6	0.3	0.4	0.5	0.5	0.4	--	--	--	--	--	0.4	0.5
Coco Creek (2015)	64	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	65	8.1	0.8	1.3	1.4	1.4	1.2	--	--	--	--	--	1.2	1.4
Coco Creek (2015)	66	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	67	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	68	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	69	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	70	7.4	0.8	1.1	1.4	1.4	1.1	--	--	--	--	--	1.2	1.4
Coco Creek (2015)	71	9.6	1.0	1.3	1.4	1.3	1.0	--	--	--	--	--	1.2	1.4
Coco Creek (2015)	72	4.7	0.8	1.2	0.6	--	--	--	--	--	--	--	0.9	1.2
Coco Creek (2015)	73	8.0	1.0	1.4	1.5	1.5	1.4	--	--	--	--	--	1.4	1.5
Coco Creek (2015)	74	10.8	0.5	1.2	1.7	1.7	1.3	--	--	--	--	--	1.3	1.7
Coco Creek (2015)	75	10.5	0.5		1.0	1.4	1.8	--	--	--	--	--	1.2	1.8
Coco Creek (2015)	76	4.2	0.5	0.7	1.0	--	--	--	--	--	--	--	0.7	1.0
Coco Creek (2015)	77	4.1	0.7	1.1	1.0	--	--	--	--	--	--	--	0.9	1.1
Coco Creek (2015)	78	6.0	0.3	1.4	1.6	--	--	--	--	--	--	--	1.2	1.6
Coco Creek (2015)	79	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	80	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	81	--	--	--	--	--	--	--	--	--	--	--	--	--

Table continued on next page.

Table A.3 (Continued)

Reach[a]	Survey ID[b] (Maps A.1,2)	Low Flow (feet)												
		Width	Depth-1	Depth-2	Depth-3	Depth-4	Depth-5	Depth-6	Depth-7	Depth-8	Depth-9	Depth-10	Mean Depth	Max. Depth
Coco Creek (2015)	82	5.6	1.0	1.1	1.1	1.0	0.8	--	--	--	--	--	1.0	1.1
Coco Creek (2015)	83	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	84	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	85	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	86	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	87	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	88	10.9	0.8	1.0	1.7	1.3	0.9	--	--	--	--	--	1.1	1.7
Coco Creek (2015)	89	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	90	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	91	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	92	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	93	13.8	0.6	1.0	0.9	0.5	0.5	--	--	--	--	--	0.7	1.0
Coco Creek (2015)	94	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	95	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	96	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	97	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	98	6.5	1.9	0.2	0.1	--	--	--	--	--	--	--	0.7	1.9
Coco Creek (2015)	99	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	100	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	101	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	102	6.2	0.2	0.2	0.1			--	--	--	--	--	0.2	0.2
Coco Creek (2015)	103	8.4	0.3	0.6	0.5	0.6	0.3	--	--	--	--	--	0.5	0.6
Coco Creek (2015)	104					--	--	--	--	--	--	--	--	--
Coco Creek (2015)	105	6.0	0.4	0.9	1.1	--	--	--	--	--	--	--	0.8	1.1
Coco Creek (2015)	106	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	107	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	108	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	109	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	110	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	111	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	112	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	113	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	114	5.5	0.0		0.1	0.2	0.4	--	--	--	--	--	0.2	0.4
Coco Creek (2015)	115	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	116	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	117	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	118	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	119	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	120	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	121	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	122	4.0	0.7	0.6	0.3	0.0	--	--	--	--	--	--	0.4	0.7

Table continued on next page.

Table A.3 (Continued)

Reach[a]	Survey ID[b] (Maps A.1,2)	Low Flow (feet)												
		Width	Depth-1	Depth-2	Depth-3	Depth-4	Depth-5	Depth-6	Depth-7	Depth-8	Depth-9	Depth-10	Mean Depth	Max. Depth
Coco Creek (2015)	123	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	124	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	125	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	126	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	127	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	128	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	129	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	130	10.6	0.3	0.3	0.5	0.2	0.2	--	--	--	--	--	0.3	0.5
Coco Creek (2015)	131	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	132	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	133	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	134	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	135	11.5	0.6	1.4	0.7	0.3	0.3	--	--	--	--	--	0.7	1.4
Coco Creek (2015)	136	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	137	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	138	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	139	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	140	8.9	0.3	0.1	0.0	0.2	0.2	--	--	--	--	--	0.2	0.3
Coco Creek (2015)	141	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	142	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	143	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	144	7.6	0.3	0.3	0.1	0.0	0.0	--	--	--	--	--	0.1	0.3
Coco Creek (2015)	145	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	146	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	147	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	148	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	149	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	150	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	151	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	152	9.7	0.3	0.2	0.3	0.2	0.2	--	--	--	--	--	0.2	0.3
Coco Creek (2015)	153	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	154	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	155	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	156	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	157	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	158	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	159	8.3	0.2	0.3	0.5	0.3	0.2						0.3	0.5
Coco Creek (2015)	160	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	161	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	162	6.0	0.1	1.1	0.5	0.0	--	--	--	--	--	--	0.4	1.1
Coco Creek (2015)	163	4.6	0.4	0.8	1.1	0.0	--	--	--	--	--	--	0.6	1.1

Table continued on next page.

Table A.3 (Continued)

Reach[a]	Survey ID[b] (Maps A.1,2)	Low Flow (feet)												
		Width	Depth-1	Depth-2	Depth-3	Depth-4	Depth-5	Depth-6	Depth-7	Depth-8	Depth-9	Depth-10	Mean Depth	Max. Depth
Coco Creek (2015)	164	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	165	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	166	3.8	1.0	1.4	1.3	0.0	--	--	--	--	--	--	0.9	1.4
Coco Creek (2015)	167	3.4	1.0	1.0	0.5	0.0	--	--	--	--	--	--	0.6	1.0
Coco Creek (2015)	168	14.7	0.4	0.8	1.1	0.5	0.4	--	--	--	--	--	0.6	1.1
Coco Creek (2015)	169	31.1	1.1	1.3	1.3	1.2	0.9	--	--	--	--	--	1.2	1.3
Coco Creek (2015)	170	15.7	0.6	0.4	0.9	0.0	--	--	--	--	--	--	0.5	0.9
Coco Creek (2015)	171	3.5	0.4	0.7	0.2	0.0	--	--	--	--	--	--	0.3	0.7
Coco Creek (2015)	172	14.2	1.4	2.2	2.2	1.8	1.5	--	--	--	--	--	1.8	2.2
Coco Creek (2015)	173	8.1	0.3	0.3	0.6	0.4	0.2	--	--	--	--	--	0.4	0.6
Coco Creek (2015)	174	8.0	0.2	0.3	0.3	0.3	0.2	--	--	--	--	--	0.3	0.3
Coco Creek (2015)	175	4.5	0.1	0.2	0.1	0.0	--	--	--	--	--	--	0.1	0.2
Coco Creek (2015)	176	3.0	0.4	0.8	0.3	0.0	--	--	--	--	--	--	0.4	0.8
Coco Creek (2015)	177	2.9	0.2	0.1	0.1	0.0	--	--	--	--	--	--	0.1	0.2
Coco Creek (2015)	178	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	179	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	180	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	181	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	182	--	--	--	--	--	--	--	--	--	--	--	--	--
Coco Creek (2015)	183	2.8	0.1	0.2	0.1	0.0	0.0	--	--	--	--	--	0.1	0.2
Coco Creek (2015)	184	2.3	0.2	0.2	0.3	0.0	--	--	--	--	--	--	0.2	0.3
Meadowbrook (2012)	185	--	1.3	1.5	2.7	2.5	2.7	2.5	2.5	2.4	2.3	1.4	2.20	2.7
Meadowbrook (2012)	186	--	1.1	1.3	2.0	2.2	2.7	2.5	2.5	2.6	2.0	1.0	2.00	2.7
Meadowbrook (2012)	187	45.9	1.1	1.3	1.3	1.4	0.9	--	--	--	--	--	1.20	1.4
Meadowbrook (2012)	188	26.8	1.5	1.9	1.4	0.9	0.4	--	--	--	--	--	1.20	1.9
Meadowbrook (2012)	189	--	0.6	0.7	0.7	1.4	0.7	--	--	--	--	--	0.80	1.4
Meadowbrook (2012)	190	--	1.0	1.7	3.5	2.2	1.0	--	--	--	--	--	1.90	3.5
Meadowbrook (2012)	191	23.2	0.7	1.1	1.3	1.5	1.2	--	--	--	--	--	1.20	1.5
Meadowbrook (2012)	192	26.7	0.9	1.1	1.1	1.0	0.9	--	--	--	--	--	1.00	1.1
Meadowbrook (2012)	193	33.2	1.0	1.2	1.1	0.8	0.7	--	--	--	--	--	1.00	1.2
Meadowbrook (2012)	194	18.3	1.2	1.4	1.6	1.5	1.2	--	--	--	--	--	1.40	1.6
Meadowbrook (2012)	195	15.2	0.8	0.9	1.0	0.8	0.6	--	--	--	--	--	0.80	1.0
Meadowbrook (2012)	196	--	--	--	--	--	--	--	--	--	--	--	--	2.2
Meadowbrook (2012)	197	--	1.3	1.8	2.2	2.1	1.7	--	--	--	--	--	1.80	2.2
Meadowbrook (2012)	198	--	0.7	1.4	1.8	2.0	1.3	--	--	--	--	--	1.40	2.0
Meadowbrook (2012)	199	--	1.2	2.1	2.0	1.7	1.0	--	--	--	--	--	1.60	2.1
Meadowbrook (2012)	200	20.5	0.5	0.8	1.3	1.2	0.8	--	--	--	--	--	0.90	1.3
Meadowbrook (2012)	201	--	1.4	2.5	2.1	1.6	1.0	--	--	--	--	--	1.70	2.5
Meadowbrook (2012)	202	10.9	0.3	0.5	0.6	0.5	0.5	--	--	--	--	--	0.50	0.6
Meadowbrook (2015)	203	--	--	--	0.0	0.0	--	--	--	--	--	--	0.0	0.0
Meadowbrook (2015)	204	6.4	0.2	0.3	0.3	0.3	0.1	--	--	--	--	--	0.2	0.3

Table continued on next page.

Table A.3 (Continued)

Reach[a]	Survey ID[b] (Maps A.1,2)	Low Flow (feet)												
		Width	Depth-1	Depth-2	Depth-3	Depth-4	Depth-5	Depth-6	Depth-7	Depth-8	Depth-9	Depth-10	Mean Depth	Max. Depth
Meadowbrook (2015)	205	10.1	0.3	0.2	0.2	0.5	0.2	--	--	--	--	--	0.3	0.5
Meadowbrook (2015)	206	14.7	0.4	0.4	0.3	0.3	0.2	--	--	--	--	--	0.3	0.4
Meadowbrook (2015)	207	8.8	0.8	1.1	1.2	0.3	0.4	--	--	--	--	--	0.8	1.2
Meadowbrook (2015)	208	9.5	0.5	0.5	0.4	0.4	0.2	--	--	--	--	--	0.4	0.5
Meadowbrook (2015)	209	10.7	0.2	0.3	0.5	0.4	0.2	--	--	--	--	--	0.3	0.5
Meadowbrook (2015)	210	--	--	--	--	--	--	--	--	--	--	--	--	--
Meadowbrook (2015)	211	--	--	--	--	--	--	--	--	--	--	--	--	--
Meadowbrook (2015)	212	--	--	--	--	--	--	--	--	--	--	--	--	--
Meadowbrook (2015)	213	11.8	0.9	1.5	1.4	0.9	0.5	--	--	--	--	--	1.0	1.5
Meadowbrook (2015)	214	11.4	0.4	0.8	0.7	0.5	0.3	--	--	--	--	--	0.5	0.8
Meadowbrook (2015)	215	--	--	--	--	--	--	--	--	--	--	--	--	--
Meadowbrook (2015)	216	--	--	--	--	--	--	--	--	--	--	--	--	--
Meadowbrook (2015)	217	13.3	0.3	0.6	0.6	0.3	0.3	--	--	--	--	--	0.4	0.6
Meadowbrook (2015)	218	6.0	0.2	0.6	0.4	--	--	--	--	--	--	--	0.4	0.6
Meadowbrook (2015)	219	10.4	0.3	0.5	0.5	0.5	0.3	--	--	--	--	--	0.4	0.5
Meadowbrook (2015)	220	11.0	0.2	0.4	0.5	0.6	0.4	--	--	--	--	--	0.4	0.6
Meadowbrook (2015)	221	10.8	0.2	0.4	0.5	0.4	0.3	--	--	--	--	--	0.4	0.5
Meadowbrook (2015)	222	5.2	0.0	0.1	0.3	0.2	0.0	--	--	--	--	--	0.1	0.3
Meadowbrook (2015)	223	5.0	0.3	0.4	0.2		0.0	--	--	--	--	--	0.2	0.4
Meadowbrook (2015)	224	7.3	0.2	0.4	0.6	0.4	0.2	--	--	--	--	--	0.4	0.6
Zion Creek (2015)	225	7.3	0.3	0.3	0.3	--	--	--	--	--	--	--	0.3	0.3
Zion Creek (2015)	226	3.8	0.2	0.2	0.2	--	--	--	--	--	--	--	0.2	0.2
Tributary to Meadowbrook (2012)	404	2.7	0.5	0.5	0.6	--	--	--	--	--	--	--	0.53	0.6
Tributary to Meadowbrook (2012)	405	10.3	0.3	0.4	0.3	0.2	0.3	--	--	--	--	--	0.30	0.4
Tributary to Meadowbrook (2012)	406	4.6	0.2	0.3	0.2	--	--	--	--	--	--	--	0.23	0.3

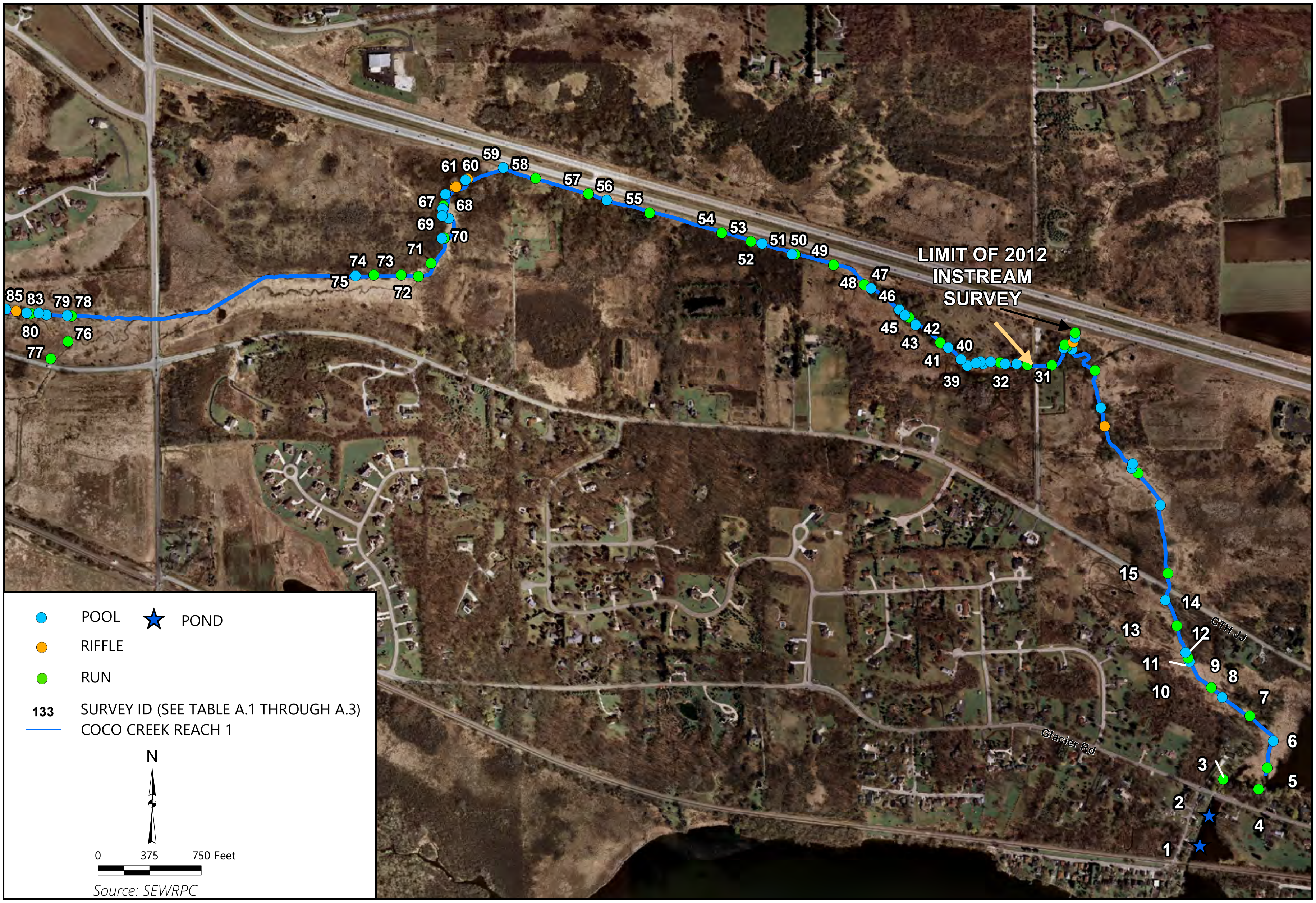
Note: The number of points at which water depths were measured within a cross-section was dependent upon stream width. In general, if wetted width was less than 10 feet, only three points per transect were taken; for widths ranging from 10 to 75 feet, five to 10 points per transect were taken; and where width was greater than 75 feet, 10 points were taken.

[a] *The table is color coded by instream habitat type- Pools (blue), Riffles (tan), and Runs (green).*

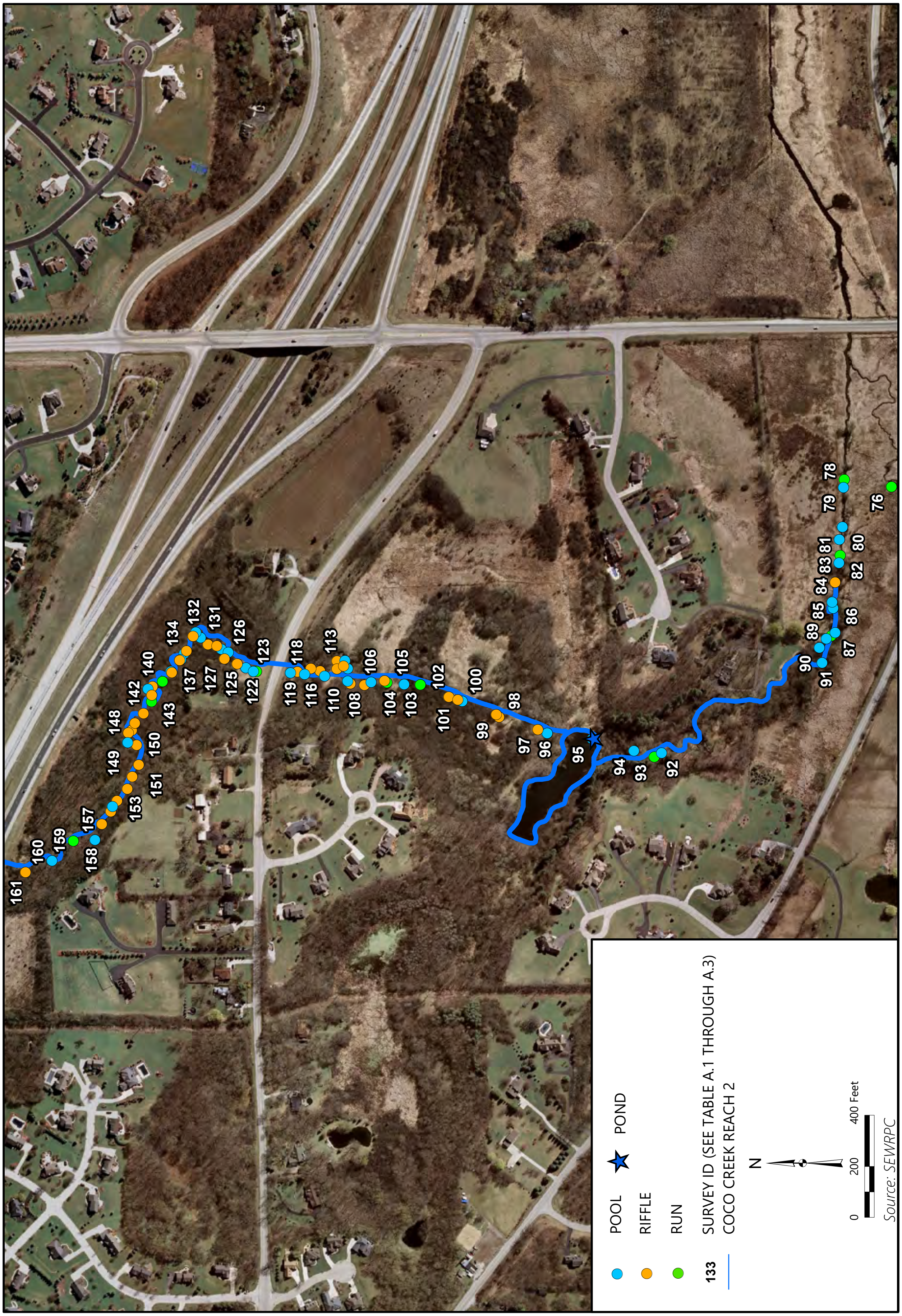
[b] *Cross-section surveys were not conducted in every pool habitat location, however maximum pool depths were recorded.*

Source: SEWRPC

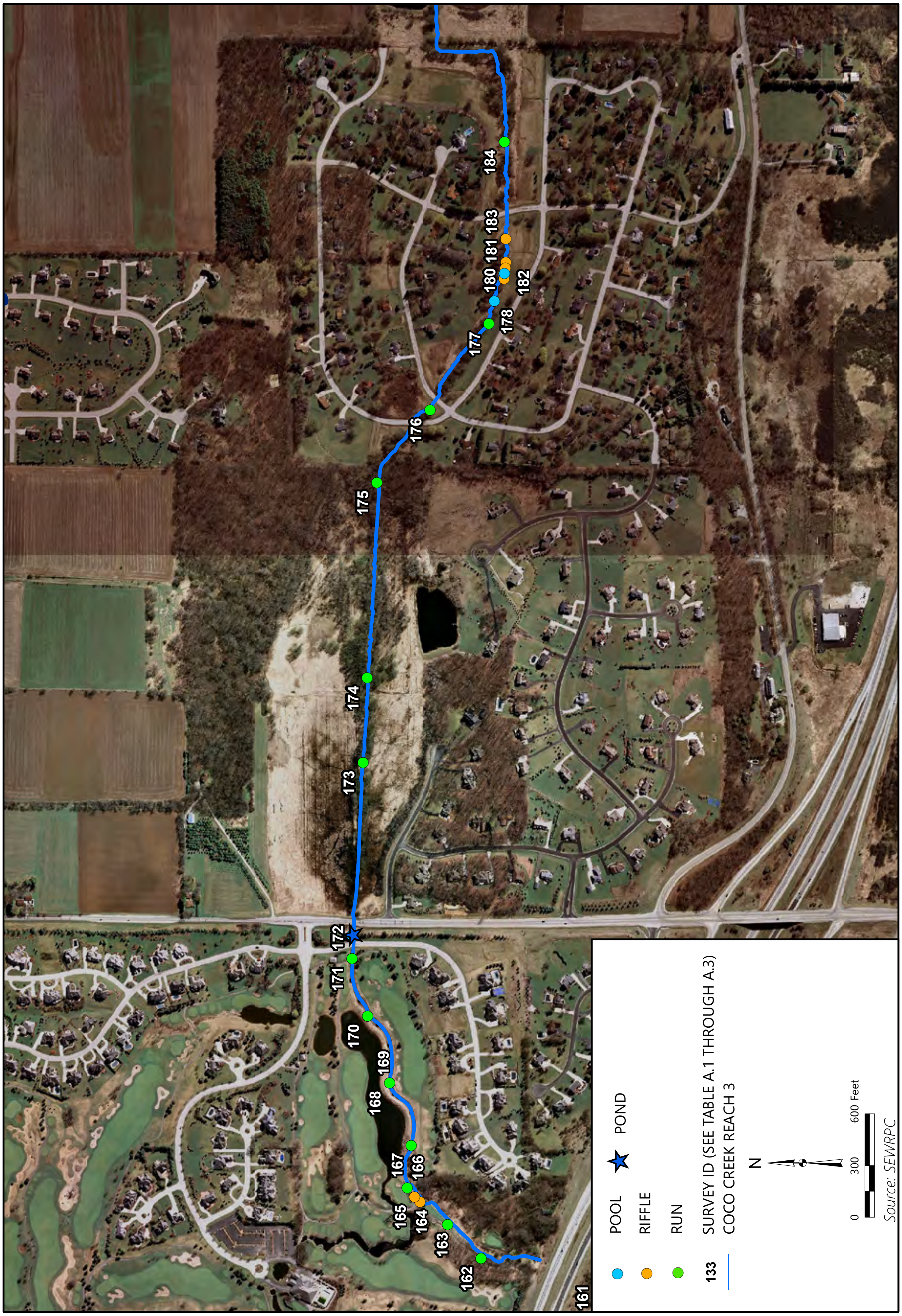
Map A.1
Aquatic Habitat Type Within Coco Creek Stream Reach 1: 2012 and 2015



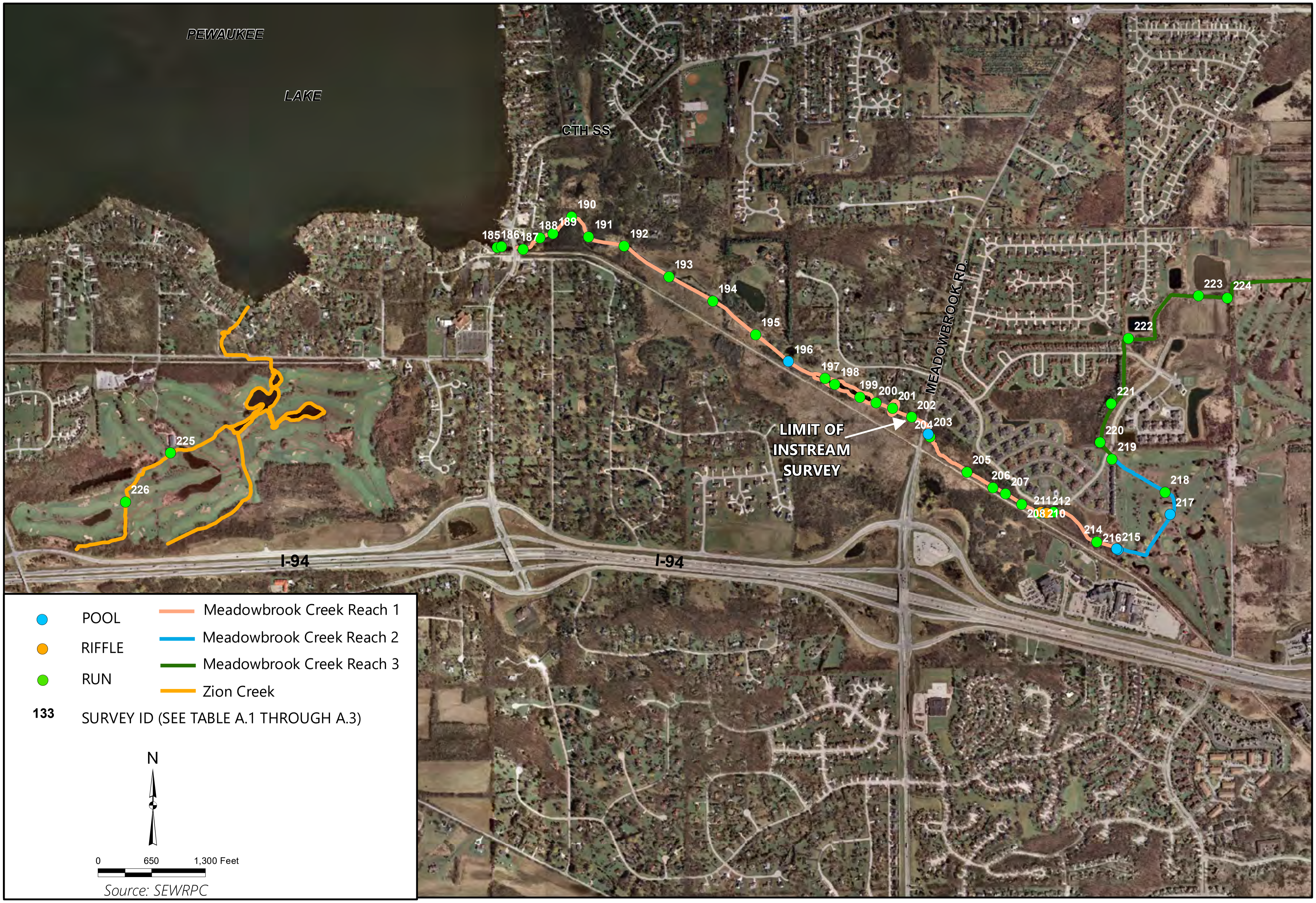
Map A.2
Aquatic Habitat Type Within Coco Creek Stream Reach 2: 2012 and 2015



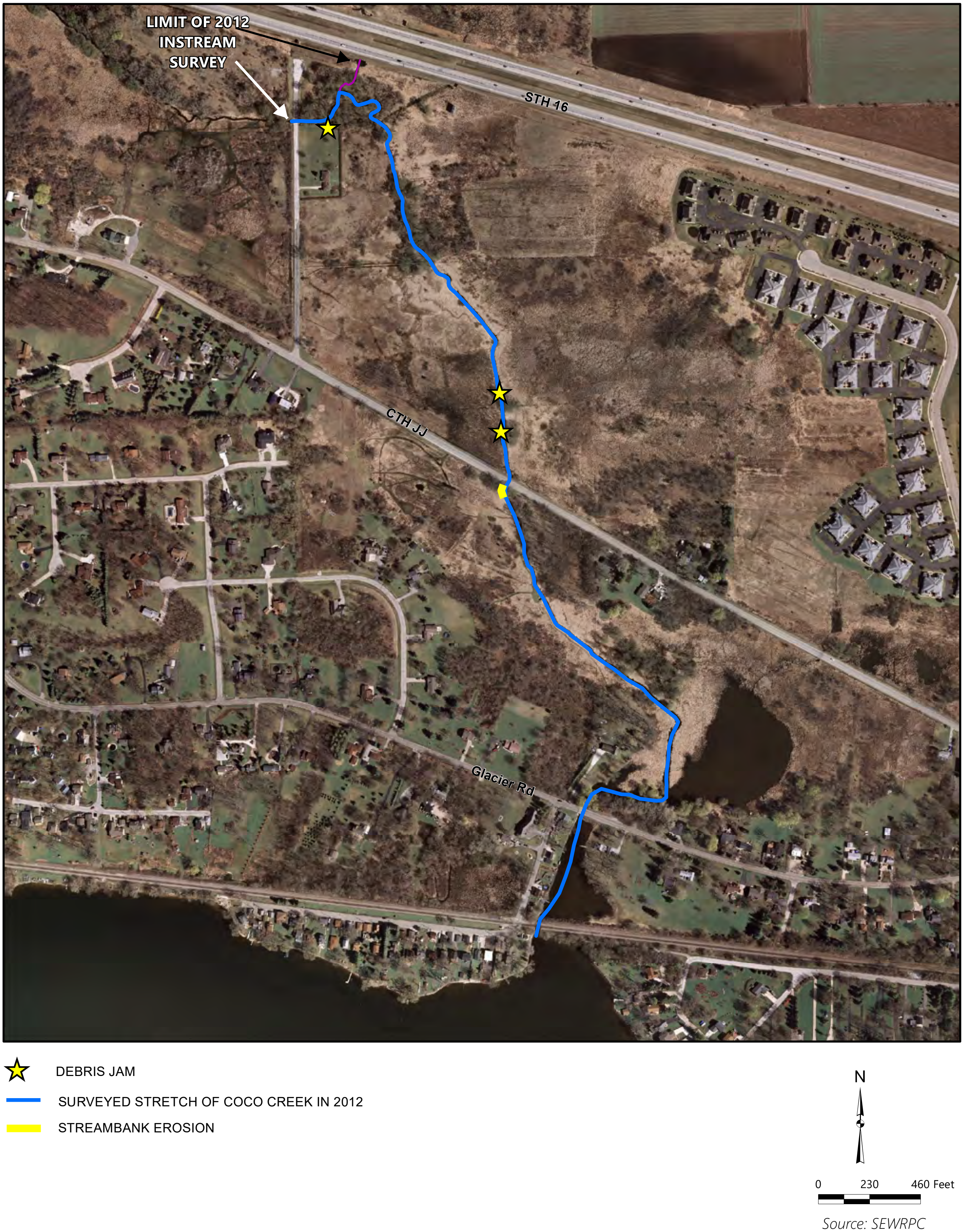
Map A.3
Aquatic Habitat Type Within Coco Creek Stream Reach 3: 2012 and 2015



Map A.4
Aquatic Habitat Type Within the Meadowbrook and Zion Creek Stream Reaches: 2012 and 2015

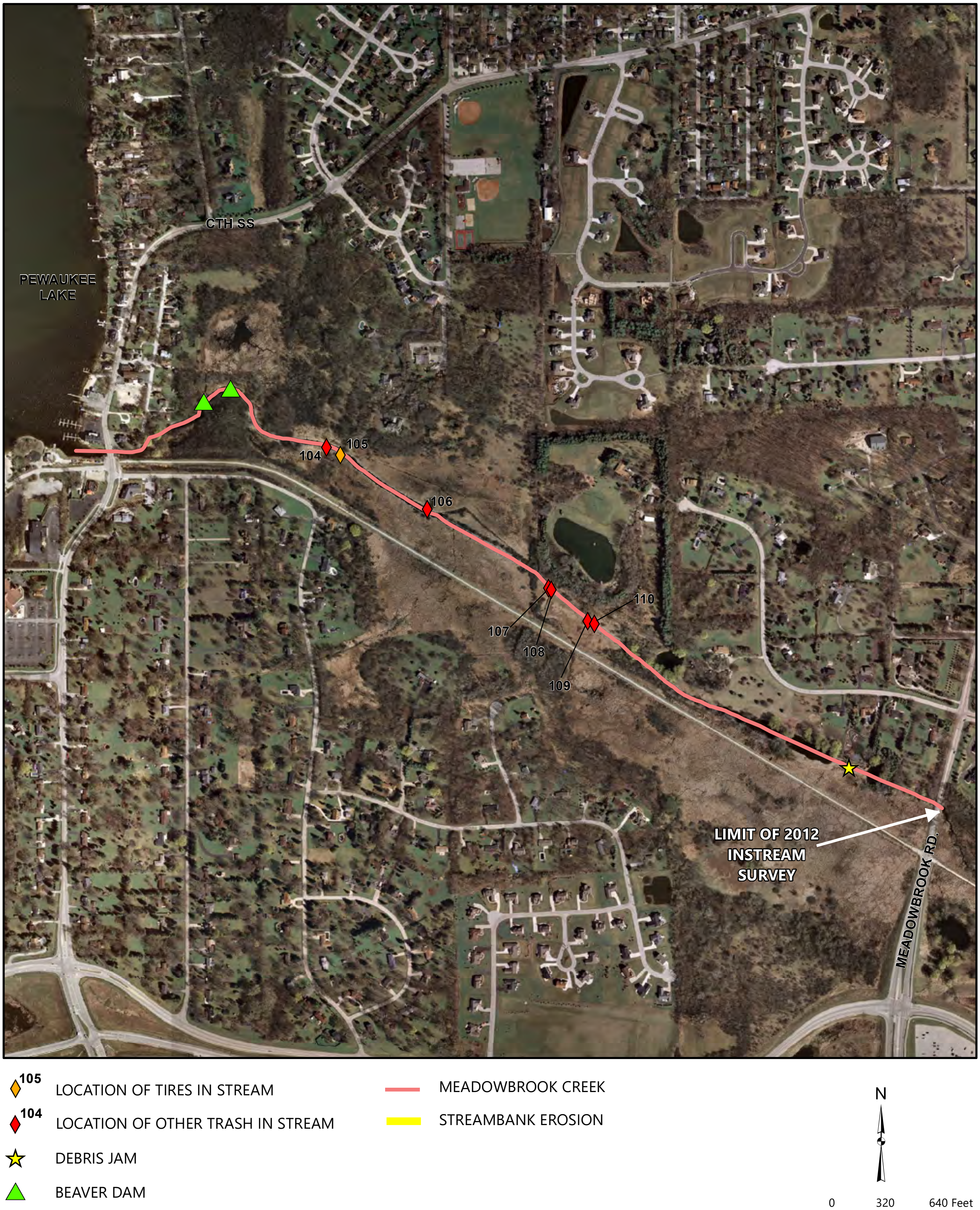


Map A.5
Debris Jams and Streambank Erosion Within the Coco Creek Stream Reach: 2012



Source: SEWRPC

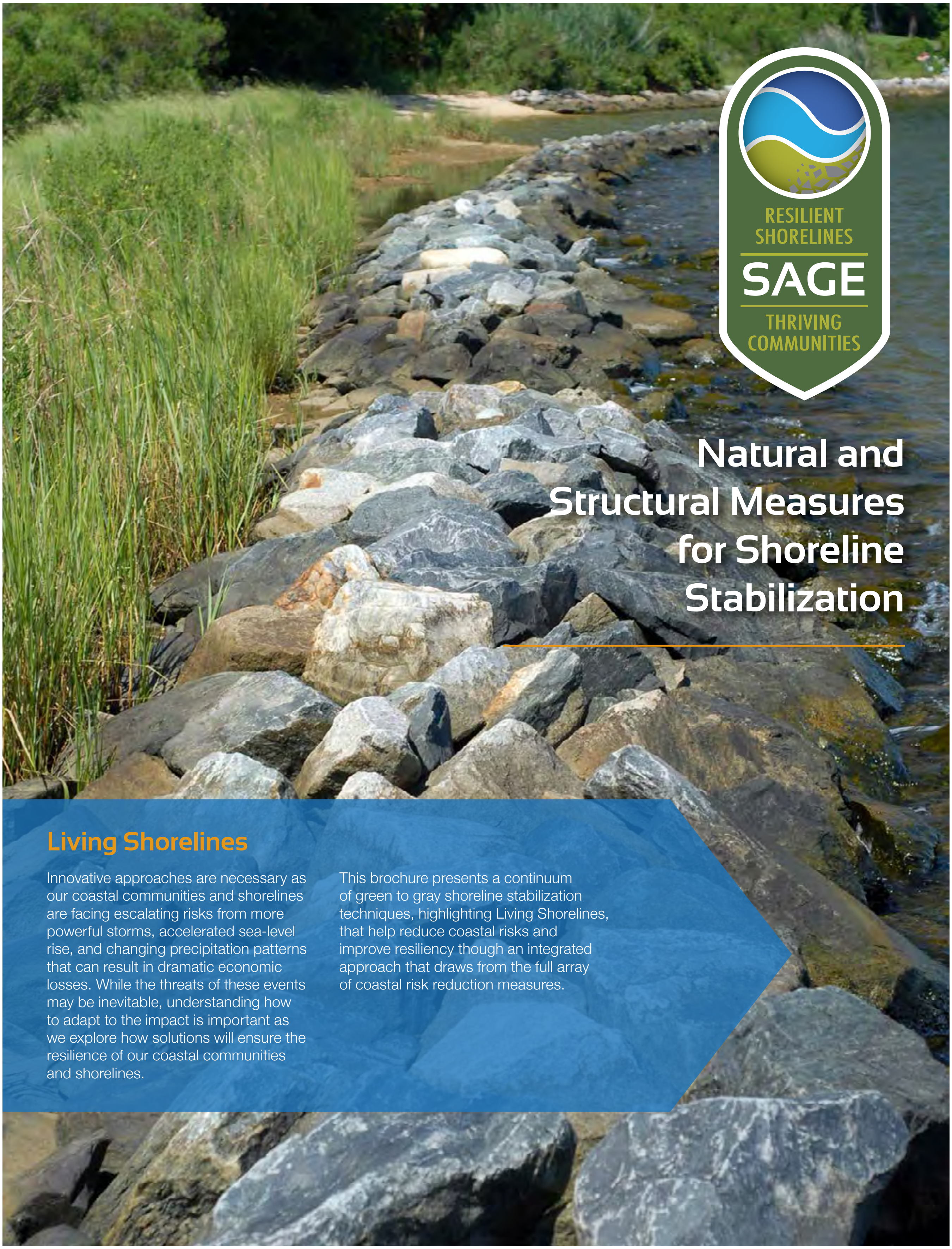
Map A.6
Trash, Debris Jams, Beaver Dams, and Streambank Erosion Within the Meadowbrook Creek Stream Reach: 2012



Source: SEWRPC

NATURAL AND STRUCTURAL MEASURES FOR SHORELINE STABILIZATION

APPENDIX B



Natural and Structural Measures for Shoreline Stabilization

Living Shorelines

Innovative approaches are necessary as our coastal communities and shorelines are facing escalating risks from more powerful storms, accelerated sea-level rise, and changing precipitation patterns that can result in dramatic economic losses. While the threats of these events may be inevitable, understanding how to adapt to the impact is important as we explore how solutions will ensure the resilience of our coastal communities and shorelines.

This brochure presents a continuum of green to gray shoreline stabilization techniques, highlighting Living Shorelines, that help reduce coastal risks and improve resiliency though an integrated approach that draws from the full array of coastal risk reduction measures.

Coastal Risk Reduction and Living Shorelines

Coastal Risk Reduction

Coastal systems typically include both natural habitats and man-made structural features. The relationships and interactions among these features are important variables in determining coastal vulnerability, reliability, risk and resilience.

Coastal risk reduction can be achieved through several approaches, which may be used in combination with each other. Options for coastal risk reduction include:

- Natural or nature-based measures: Natural features are created through the action of physical, biological, geologic, and chemical processes operating in nature, and include marshes, dunes and oyster reefs. Nature-based features are created by human design, engineering, and construction to mimic nature. A living shoreline is an example of a nature-based feature.
- Structural measures: Structural measures include sea walls, groins and breakwaters. These features reduce coastal risks by decreasing shoreline erosion, wave damage, and flooding.
- Non-structural measures: Includes modifications in public policy, management practices, regulatory policy and pricing policy (e.g., structure acquisitions or relocations, flood proofing of structures, implementing flood warning systems, flood preparedness planning, establishment of land use regulations, emergency response plans).

The types of risk reduction measures employed depend upon the geophysical setting, the desired level of risk reduction, objectives, cost, reliability, and other factors.

SAGE – Systems Approach to Geomorphic Engineering

USACE and NOAA recognize the value of an integrated approach to risk reduction through the incorporation of natural and nature-based features in addition to non-structural and structural measures to improve social, economic, and ecosystem resilience. To promote this approach, USACE and NOAA have engaged partners and stakeholders in a community of practice called SAGE, or a Systems Approach to Geomorphic Engineering. This community of practice provides a forum to discuss science and policy that can support and advance a systems approach to implementing risk reduction measures that both sustain a healthy environment and create a resilient shoreline.

SAGE promotes a hybrid engineering approach that integrates soft or ‘green’ natural and nature-based measures, with hard or ‘gray’ structural ones at the landscape scale. These stabilization solutions include “living shoreline” approaches which integrate living components, such as plantings, with structural techniques, such as seawalls or breakwaters.

Living Shorelines achieve multiple goals, such as:

- Stabilizing the shoreline and reducing current rates of shoreline erosion and storm damage;
- Providing ecosystem services (such as habitat for fish and other aquatic species) and increasing flood storage capacity; and
- Maintaining connections between land and water ecosystems to enhance resilience.

In order to determine the most appropriate shoreline protection technique, several site-specific conditions must be assessed. The following coastal conditions, along with other factors, are used to determine the combinations of green and gray solutions for a particular shoreline.

REACH: A longshore segment of a shoreline where influences and impacts, such as wind direction, wave energy, littoral transport, etc. mutually interact.

RESILIENCE: The ability to avoid, minimize, withstand, and recover from the effects of adversity, whether natural or man made, under all circumstances of use. This definition also applies to engineering (i), ecological (ii), and community resilience (iii).

FETCH: A cross shore distance along open water over which wind blows to generate waves. For any given shore, there may be several fetch distances depending on predominant wind direction.

PHYSICAL CONDITIONS: The slope of the foreshore or beach face, a geologic condition or bathymetry offshore.

TIDAL RANGE: The vertical difference between high tide and low tide.

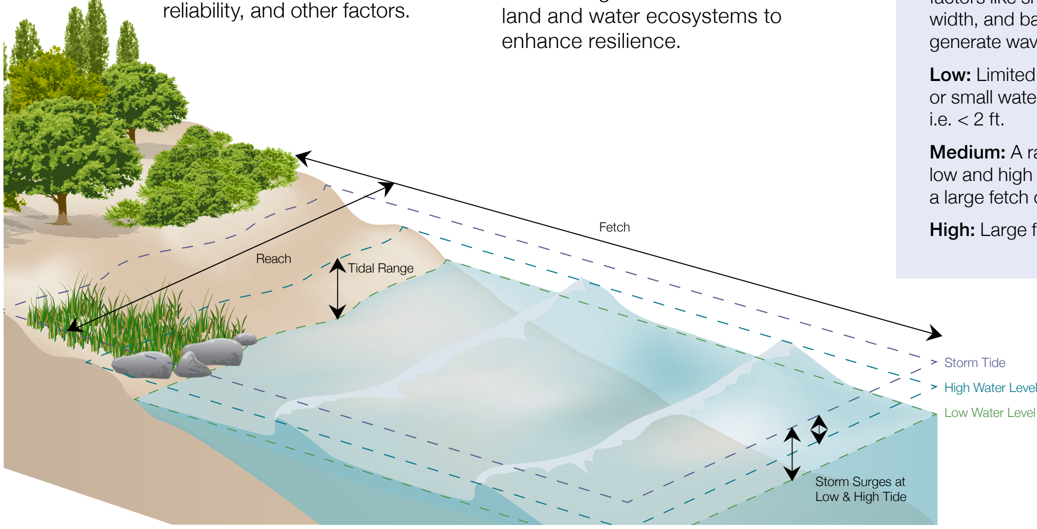
STORM SURGE: The resulting temporary rise in sea level due to the action of wind stress on the water surface and low atmospheric pressure created during storms which can cause coastal flooding. Surge is the difference from expected tide level. Storm tide is the total water level.

WAVE ENERGY: Wave energy is related to wave height and describes the force a wave is likely to have on a shoreline. Different environments will have lower or higher wave energy depending on environmental factors like shore orientation, wind, channel width, and bathymetry. Boat wakes can also generate waves.

Low: Limited fetch in a sheltered, shallow or small water body (estuary, river, bay) i.e. < 2 ft.

Medium: A range that combines elements of low and high energy (e.g., shallow water with a large fetch or partially sheltered) i.e. 2 - 5 ft.

High: Large fetch, deep water (open ocean).



HOW GREEN OR GRAY SHOULD YOUR SHORELINE SOLUTION BE?

GREEN - SOFTER TECHNIQUES

Small Waves | Small Fetch | Gentle Slope | Sheltered Coast

LIVING SHORELINE

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VEGETATION ONLY

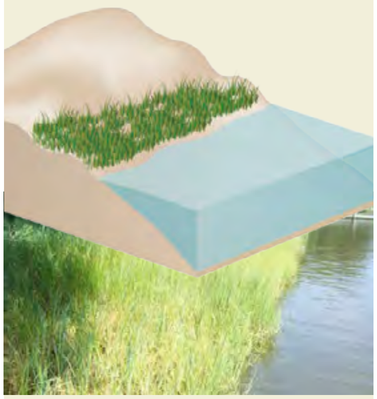

Photo Credit: Maryland Department of Natural Resources - Shoreline Conservation Service

Roots hold soil in place to reduce erosion. Provides a buffer to upland areas and breaks small waves.

Suitable For

Low wave energy environments.

Material Options

- Native plants*

Benefits

- Dissipates wave energy
- Slows inland water transfer
- Increases natural storm water infiltration
- Provides habitat and ecosystem services
- Minimal impact to natural community and ecosystem processes
- Maintains aquatic/terrestrial interface and connectivity
- Flood water storage

Disadvantages

- No storm surge reduction ability
- No high water protection
- Appropriate in limited situations
- Uncertainty of successful vegetation growth and competition with invasive

Initial Construction: ●
Operations & Maintenance: ●

EDGING

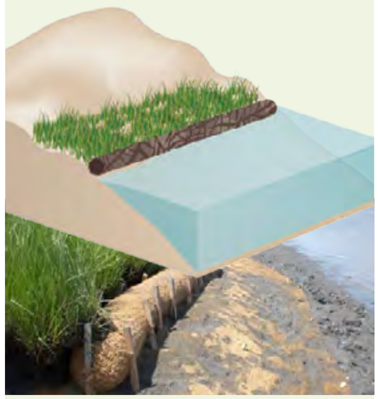

Photo Credit: Partnership for Delaware Estuary

Structure to hold the toe of existing or vegetated slope in place. Protects against shoreline erosion.

Suitable For

Most areas except high wave energy environments.

Vegetation* Base with Material Options

(low wave only, temporary)
- “Snow“ fencing
- Erosion control blankets
- Geotextile tubes
- Living reef (oyster/mussel)
- Rock gabion baskets

Benefits

- Dissipates wave energy
- Slows inland water transfer
- Provides habitat and ecosystem services
- Increases natural storm water infiltration
- Toe protection helps prevent wetland edge loss

Disadvantages

- No high water protection
- Uncertainty of successful vegetation growth and competition with invasive

Initial Construction: ●●
Operations & Maintenance: ●

SILLS

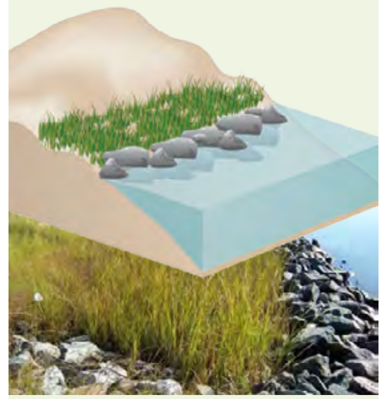

Photo Credit: Maryland Department of Natural Resources - Shoreline Conservation Service

Parallel to existing or vegetated shoreline, reduces wave energy and prevents erosion. A gapped approach would allow habitat connectivity, greater tidal exchange, and better waterfront access.

Suitable For

Most areas except high wave energy environments.

Vegetation* Base with Material Options

- Stone
- Sand breakwaters
- Living reef (oyster/mussel)
- Rock gabion baskets

Benefits

- Provides habitat and ecosystem services
- Dissipates wave energy
- Slows inland water transfer
- Provides habitat and ecosystem services
- Increases natural storm water infiltration
- Toe protection helps prevent wetland edge loss

Disadvantages

- Require more land area
- No high water protection
- Uncertainty of successful vegetation growth and competition with invasive

Initial Construction: ●●
Operations & Maintenance: ●

* Native plants and materials must be appropriate for current salinity and site conditions.

Initial Construction: ● = up to $1000 per linear foot, ●● = $1001 - $2000 per linear foot, ●●● = $2001 - $5000 per linear foot, ●●●● = $5001 - $10,000 per linear foot
Operations and Maintenance (yearly for a 50 year project life): ● = up to $100 per linear foot, ●● = $101 - $500 per linear foot, ●●● = over $500 per linear foot

HOW GREEN OR GRAY SHOULD YOUR SHORELINE SOLUTION BE?

GREEN - SOFTER TECHNIQUES

Small Waves | Small Fetch | Gentle Slope | Sheltered Coast

LIVING SHORELINE

CONTINUED FROM LAST PAGE

BEACH NOURISHMENT ONLY

Photo Credit: USACE New York District Public Affairs

Large volume of sand added from outside source to an eroding beach. Widens the beach and moves the shoreline seaward.

Suitable For

Low-lying oceanfront areas with existing sources of sand and sediment.

Material Options

- Sand

Benefits

- Expands usable beach area
- Lower environmental impact than hard structures
- Flexible strategy
- Redesigned with relative ease
- Provides habitat and ecosystem services

Disadvantages

- Requires continual sand resources for renourishment
- No high water protection
- Appropriate in limited situations
- Possible impacts to regional sediment transport

Initial Construction: ●●●
Operations & Maintenance: ●●

BEACH NOURISHMENT & VEGETATION ON DUNE

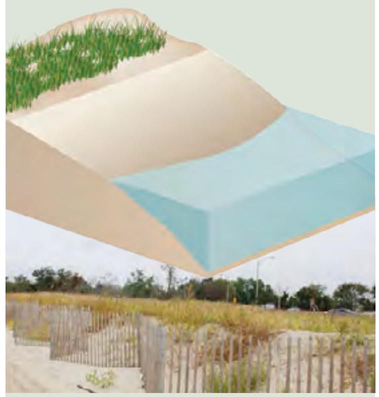

Photo Credit: USACE New York District Public Affairs

Helps anchor sand and provide a buffer to protect inland area from waves, flooding and erosion.

Suitable For

Low-lying oceanfront areas with existing sources of sand and sediment.

Material Options

Sand with vegetation
Can also strengthen dunes with:

- Geotextile tubes
- Rocky core

Benefits

- Expands usable beach area
- Lower environmental impact
- Flexible strategy
- Redesigned with relative ease
- Vegetation strengthens dunes and increases their resilience to storm events
- Provides habitat and ecosystem services

Disadvantages

- Requires continual sand resources for renourishment
- No high water protection
- Appropriate in limited situations
- Possible impacts to regional sediment transport

Initial Construction: ●●●
Operations & Maintenance: ●●

Initial Construction: ● = up to $1000 per linear foot, ●● = $1001 - $2000 per linear foot, ●●● = $2001 - $5000 per linear foot, ●●●● = $5001 - $10,000 per linear foot
Operations and Maintenance (yearly for a 50 year project life): ● = up to $100 per linear foot, ●● = $101 - $500 per linear foot, ●●● = over $500 per linear foot

4

HOW GREEN OR GRAY SHOULD YOUR SHORELINE SOLUTION BE?

GRAY - HARDER TECHNIQUES

Large Waves | Large Fetch | Steep Slope | Open Coast

COASTAL STRUCTURE

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BREAKWATER

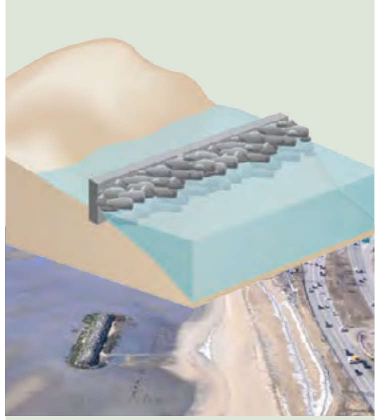


Photo Credit: USACE New York District Public Affairs

Offshore structures intended to break waves, reducing the force of wave action and encourages sediment accretion. Can be floating or fixed to the ocean floor, attached to shore or not, and continuous or segmented. A gapped approach would allow habitat connectivity, greater tidal exchange, and better waterfront access.

Suitable For

Most areas except high wave energy environments often in conjunction with marinas.

Material Options

- Grout-filled fabric bags
- Armorstone
- Pre-cast concrete blocks
- Living reef (oyster/mussel) if low wave environment
- Wood
- Rock†

Benefits

- Reduces wave force and height
- Stabilizes wetland
- Can function like reef
- Economical in shallow areas
- Limited storm surge flood level reduction

Disadvantages

- Expensive in deep water
- Can reduce water circulation (minimized if floating breakwater is applied)
- Can create navigational hazard
- Require more land area
- Uncertainty of successful vegetation growth and competition with invasive
- No high water protection
- Can reduce water circulation
- Can create navigation hazard

GROIN

Photo Credit: USACE New York District Public Affairs

Perpendicular, projecting from shoreline. Intercept water flow and sand moving parallel to the shoreline to prevent beach erosion and break waves. Retain sand placed on beach.

Suitable For

Coordination with beach nourishment.

Material Options

- Concrete/stone rubble†
- Timber
- Metal sheet piles

Benefits

- Protection from wave forces
- Methods and materials are adaptable
- Can be combined with beach nourishment projects to extend their life

Disadvantages

- Erosion of adjacent sites
- Can be detrimental to shoreline ecosystem (e.g. replaces native substrate with rock and reduces natural habitat availability)
- No high water protection

† Rock/stone needs to be appropriately sized for site specific wave energy.

GRAY CAN BE GREENER: e.g., 'Living Breakwater' using oysters to colonize rocks or 'Greenwall/Biowall' using vegetation, alternative forms and materials

Breakwater	Groin
Initial Construction: ●●●●	Initial Construction: ●●●
Operations & Maintenance: ●●●	Operations & Maintenance: ●●

Initial Construction: ● = up to $1000 per linear foot, ●● = $1001 - $2000 per linear foot, ●●● = $2001 - $5000 per linear foot, ●●●● = $5001 - $10,000 per linear foot

Operations and Maintenance (yearly for a 50 year project life): ● = up to $100 per linear foot, ●● = $101 - $500 per linear foot, ●●● = over $500 per linear foot

HOW GREEN OR GRAY SHOULD YOUR SHORELINE SOLUTION BE?

GRAY - HARDER TECHNIQUES

Large Waves | Large Fetch | Steep Slope | Open Coast

COASTAL STRUCTURE

CONTINUED FROM LAST PAGE

REVETMENT

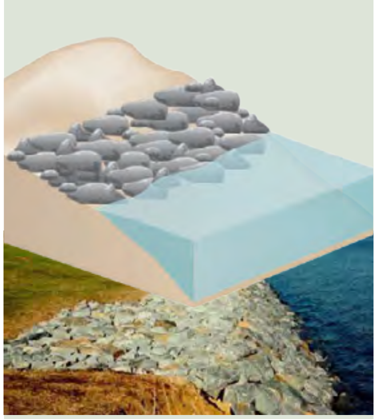


Photo Credit: Maryland Department of Natural Resources - Shoreline Conservation Service

Lays over the slope of a shoreline. Protects slope from erosion and waves.

Suitable For

Sites with pre-existing hardened shoreline structures.

Material Options

- Stone rubble[‡]
- Concrete blocks
- Cast concrete slabs
- Sand/concrete filled bags
- Rock-filled gabion basket

Benefits

- Mitigates wave action
- Little maintenance
- Indefinite lifespan
- Minimizes adjacent site impact

Disadvantages

- No major flood protection
- Require more land area
- Loss of intertidal habitat
- Erosion of adjacent unreinforced sites
- Require more land area
- No high water protection
- Prevents upland from being a sediment source to the system

[‡] Rock/stone needs to be appropriately sized for site specific wave energy.

BULKHEAD

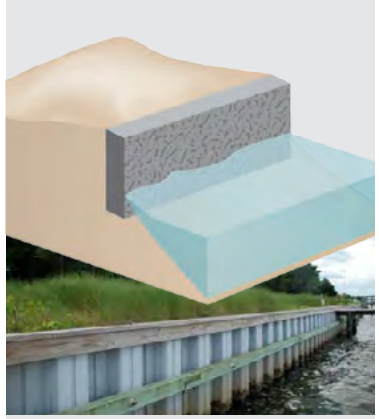


Photo Credit: North Carolina Department of Environment and Natural Resources

Parallel to the shoreline, vertical retaining wall. Intended to hold soil in place and allow for a stable shoreline.

Suitable For

High energy settings and sites with pre-existing hardened shoreline structures. Accommodates working water fronts (eg: docking for ships and ferries).

Material Options

- Steel sheet piles
- Timber
- Concrete
- Composite carbon fibers
- Gabions

Benefits

- Moderates wave action
- Manages tide level fluctuation
- Long lifespan
- Simple repair

Disadvantages

- No major flood protection
- Erosion of seaward seabed
- Erosion of adjacent unreinforced sites
- Loss of intertidal habitat
- May be damaged from overtopping oceanfront storm waves
- Prevents upland from being a sediment source to the system
- Induces wave reflection

SEAWALL

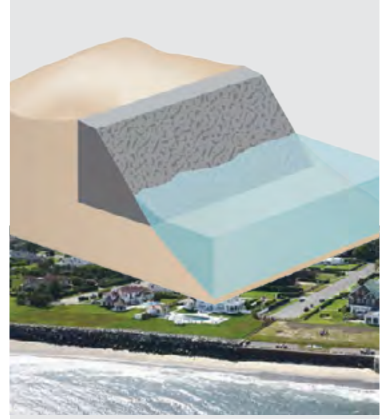


Photo Credit: USACE New York District Public Affairs

Parallel to shoreline, vertical or sloped wall. Soil on one side of wall is the same elevation as water on the other. Absorbs and limits impacts of large waves and directs flow away from land.

Suitable For

Areas highly vulnerable to storm surge and wave forces.

Material Options

- Stone
- Rock
- Concrete
- Steel/vinyl sheets
- Steel sheet piles

Benefits

- Prevents storm surge flooding
- Resists strong wave forces
- Shoreline stabilization behind structure
- Low maintenance costs
- Less space intensive horizontally than other techniques (e.g. vegetation only)

Disadvantages

- Erosion of seaward seabed
- Disrupt sediment transport leading to beach erosion
- Higher up-front costs
- Visually obstructive
- Loss of intertidal zone
- Prevents upland from being a sediment source to the system
- May be damaged from overtopping oceanfront storm waves

GRAY CAN BE GREENER: e.g., 'Living Breakwater' using oysters to colonize rocks or 'Greenwall/Biowall' using vegetation, alternative forms and materials

	Revetment	Bulkhead	Seawall
Initial Construction	●●●●	●●●	●●●●
Operations & Maintenance	●●	●●	●●●

Initial Construction: ● = up to $1000 per linear foot, ●● = $1001 - $2000 per linear foot, ●●● = $2001 - $5000 per linear foot, ●●●● = $5001 - $10,000 per linear foot
Operations and Maintenance (yearly for a 50 year project life): ● = up to $100 per linear foot, ●● = $101 - $500 per linear foot, ●●● = over $500 per linear foot

Is a Living Shoreline a Good Fit for What I Need?

Living Shorelines achieve multiple goals such as:

- Stabilizing the shoreline and reducing current rates of shoreline erosion and storm damage
- Providing ecosystem services, such as habitat for fish and other aquatic species and increasing flood storage capacity
- Maintaining connections between land and water ecosystems to enhance resilience

Site-specific conditions will influence your choice of shoreline protection technique (ex: wave energy level, fetch lengths, rate and pattern of erosion, etc). Here are some additional factors to keep in mind as you consider Living Shorelines.

WHAT ARE THE BENEFITS?

- Erosion control and shore stabilization.
- Restored and enhanced habitat which supports fish and wildlife populations.
- Increased property values.
- Enhanced community enjoyment.
- Opportunities for education.
- Improved public access to waterfront through recreational activities such as fishing, boating and birding. Can be used to satisfy zoning and permitting requirement for waterfront development projects.
- Complemented natural shoreline dynamics & movement; increased resilience and absorption of wave energy, storm surge and floodwaters; and an adaptive tool for preparation of sea level rise.
- Improved water quality from settling or trapping sediment (e.g. once established, a marsh can filter surface water runoff or oysters can provide coastal water filtration).

WHAT ARE SOME CHALLENGES?

- Uncertainty in risk because of lack of experience of techniques.
- Public funds are often tied to government permit compliance.
- Permitting processes can be lengthy and challenging. The existing regulatory process is centered on traditional "gray" or "hard" techniques. Regulators and project sponsors alike are learning how to design living shorelines projects. Talk with someone about your state's permitting process or to hear about their experiences.
- It takes time to develop and test new shoreline protection methods.
- There may be land ownership constraints. Consider where federal and state jurisdiction for the water body starts and ends.
- In urban environments, there is limited land (bulkheads may seem like the only option), a variety of upland uses (industrial past use may have left legacy contaminants) and high velocity waters.
- The overall sediment system needs to be taken into account to protect neighboring properties from experiencing starved down drift shorelines or other consequences as a result of a project.
- Lack of public awareness of performance and benefits of living shorelines.
- Not all techniques have the same level of performance or success monitoring. Less practiced techniques may require more monitoring.

WHAT INFLUENCES COST?

- The materials chosen for the project influence cost.
- Including green techniques can be cheaper than traditional gray techniques.
- Sometimes it's possible to install the project yourself, other times you will need help from a professional.
- Long term maintenance is required as any landscape project (e.g. replanting may be needed after a storm).

HOW TO FIND OUT MORE

If you have a Living Shorelines permitting question, contact your state's office of Environmental Protection, Conservation or Natural Resources, your coastal zone manager such as your state's Department of State, as well as your local U.S. Army Corps of Engineers (USACE) district office.

If you would like science or engineering advice, or to talk to people who have experience studying or constructing living shorelines, reach out to some of the following: your local universities, your City's Department of Planning and Department of Parks, Sea Grant Chapter, Littoral Society, The Nature Conservancy, The Trust for Public Land, The Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA), USACE, engineering firms and other organizations that focus on your local waterfront.

These and other websites are good references to learn more about Living Shorelines:

SAGE
www.SAGEcoast.org

NOAA Restoration
www.habitat.noaa.gov/livingshorelines

USACE Engineer Research Development Center, Engineering with Nature
el.erdc.usace.army.mil/ewn

USACE North Atlantic Division, National Planning Center of Expertise for Coastal Storm Damage Reduction
www.nad.usace.army.mil/About/NationalCentersofExpertise/CoastalStormDamageReduction(Planning).aspx

Virginia Institute of Marine Science (VIMS) Center for Coastal Resources Management
ccrm.vims.edu/livingshorelines/index.html

Coasts, Oceans, Ports & Rivers Institute (COPRI)
www.mycopri.org/livingshorelines

The Nature Conservancy
www.nature.org/ourinitiatives/habitats/oceanscoasts/howwework/helping-oceans-adapt-to-climate-change.xml

US Army Corps of Engineers®

Developed with support and funding from SAGE, NOAA and USACE; February 2015

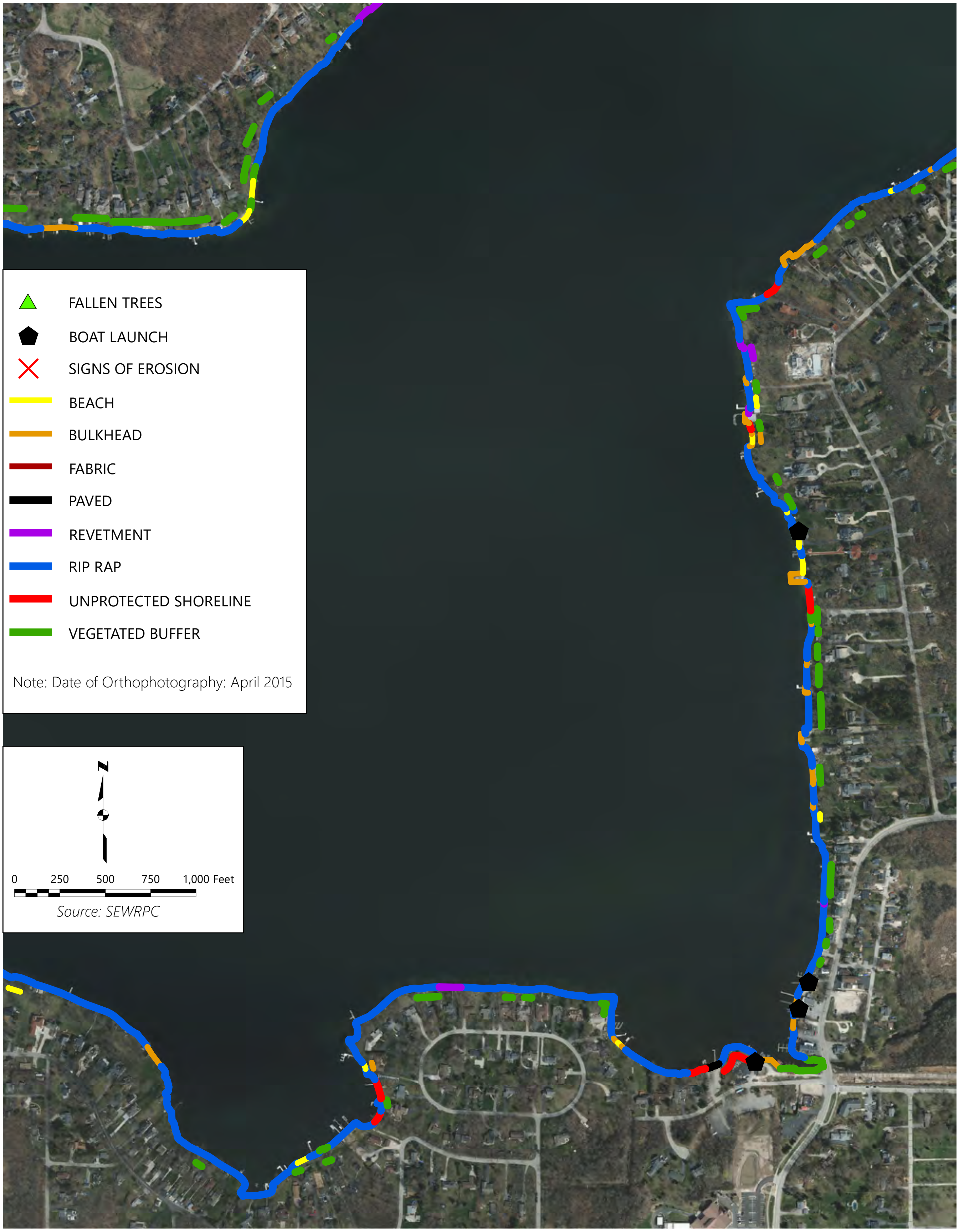
APPENDIX C

SHORELINE ASSESSMENT INSETS

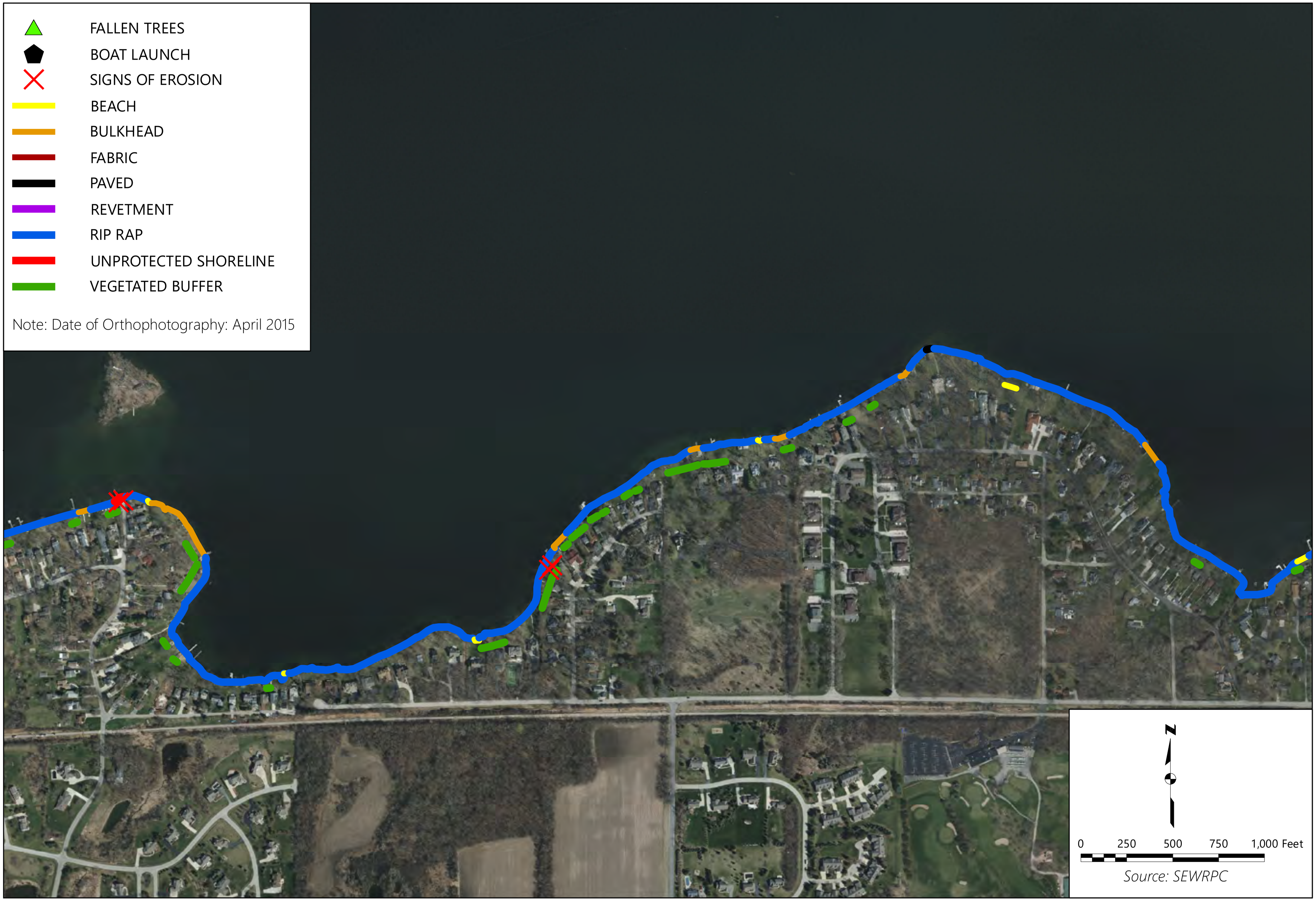
Map C.1
Map 2.22 – Inset 1 (Eastern Pewaukee Lake Shoreline Conditions: 2015)

Map C.2
Map 2.22 – Inset 2 (Southeastern Pewaukee Lake Shoreline Conditions: 2015)

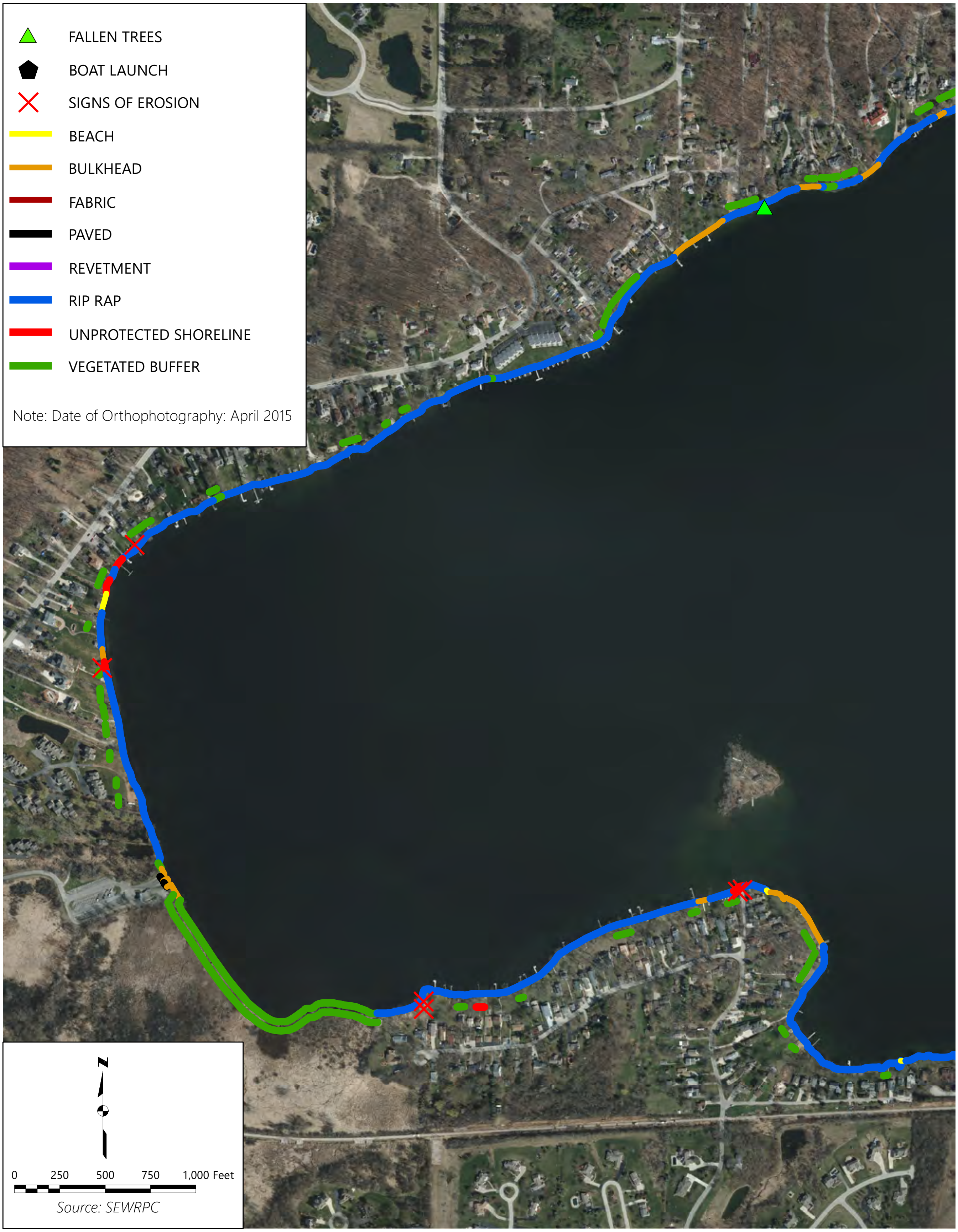
Map C.3
Map 2.22 – Inset 3 (Central Pewaukee Lake Shoreline Conditions: 2015)



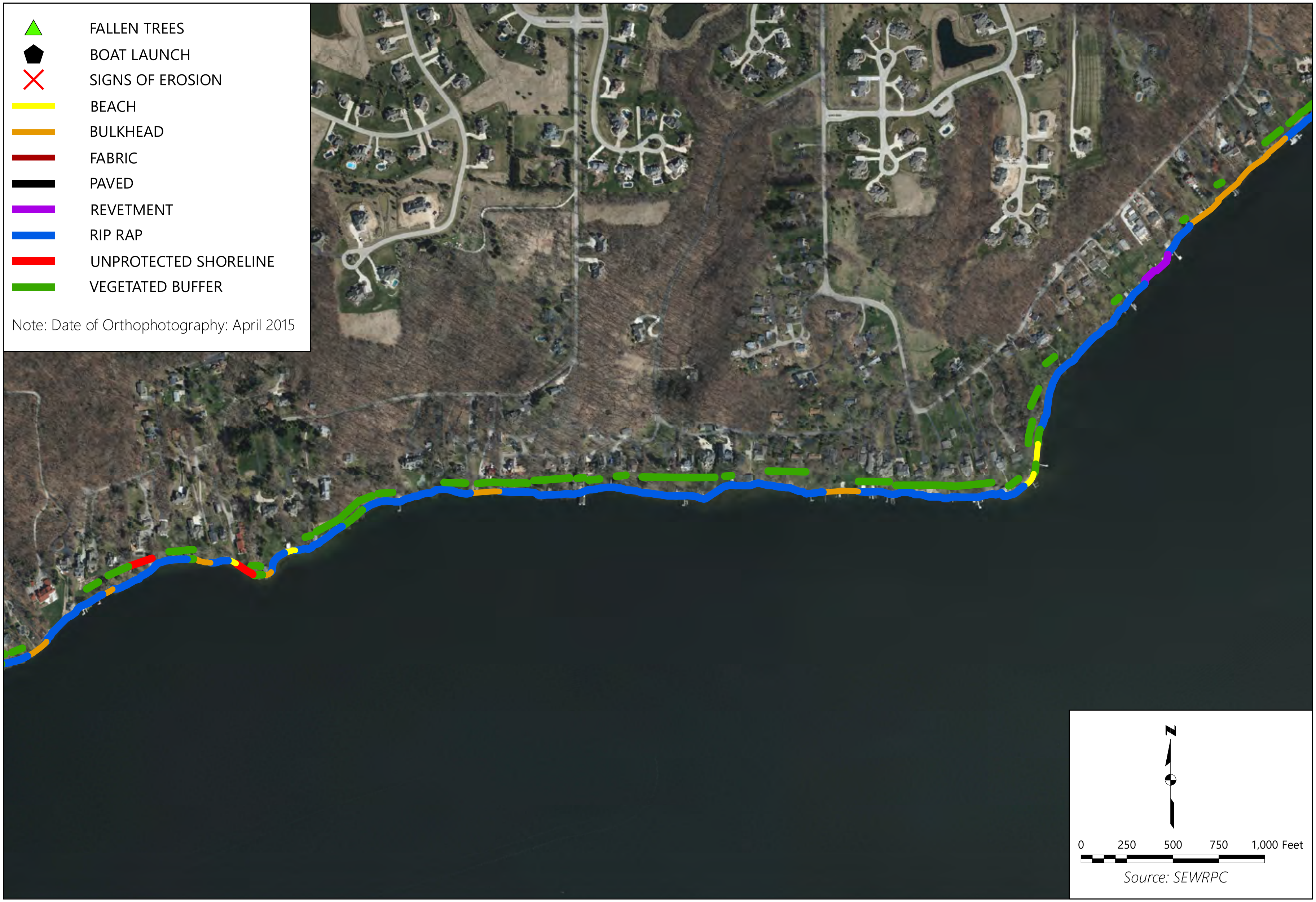
Map C.4
Map 2.22 – Inset 4 (Southwestern Pewaukee Lake Shoreline Conditions: 2015)



Map C.5
Map 2.22 – Inset 5 (Western Pewaukee Lake Shoreline Conditions: 2015)



Map C.6
Map 2.22 – Inset 6 (Northwestern Pewaukee Lake Shoreline Conditions: 2015)

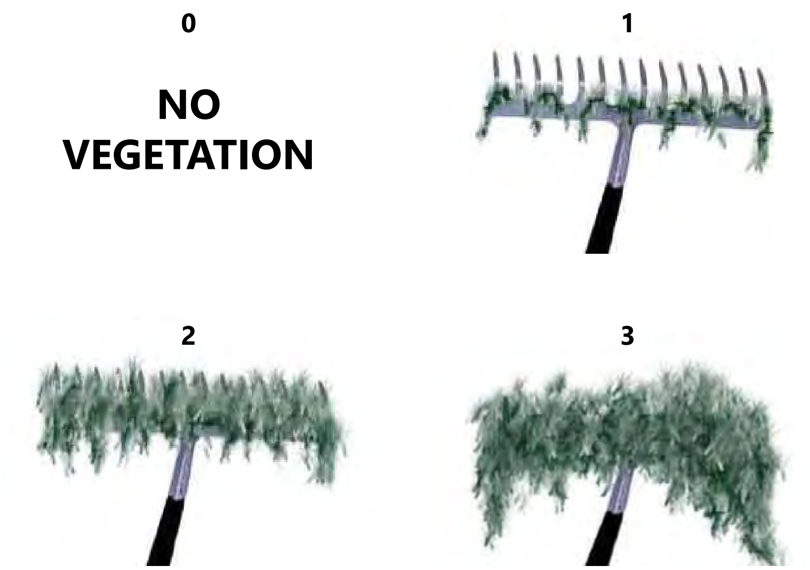


Map C.7
Map 2.22 – Inset 7 (Northeastern Pewaukee Lake Shoreline Conditions: 2015)

APPENDIX D

PEWAUKEE LAKE AQUATIC PLANT SPECIES DETAILS

Figure D.1
Rake Fullness Ratings



Source: Wisconsin Department of Natural Resources and SEWRPC

SOURCES OF INFORMATION:

Borman, S., Korth, R., & Temte, J. (2014). Through the Looking Glass: A Field Guide to Aquatic Plants, Second Edition. Stevens Point, WI, USA: Wisconsin Lakes Partnership.

Robert W. Freckman Herbarium: wisplants.uwsp.edu

Skawinski, P. M. (2014). Aquatic Plants of the Upper Midwest: A Photographic Field Guide to Our Underwater Forests, Second Edition. Wausau, Wisconsin, USA: Self-Published.

University of Michigan Herbarium: michiganflora.net/home.aspx

UW-System WisFlora. 2016. wisflora.herbarium.wisc.edu/index.php

Ceratophyllum demersum — Coontail

Native

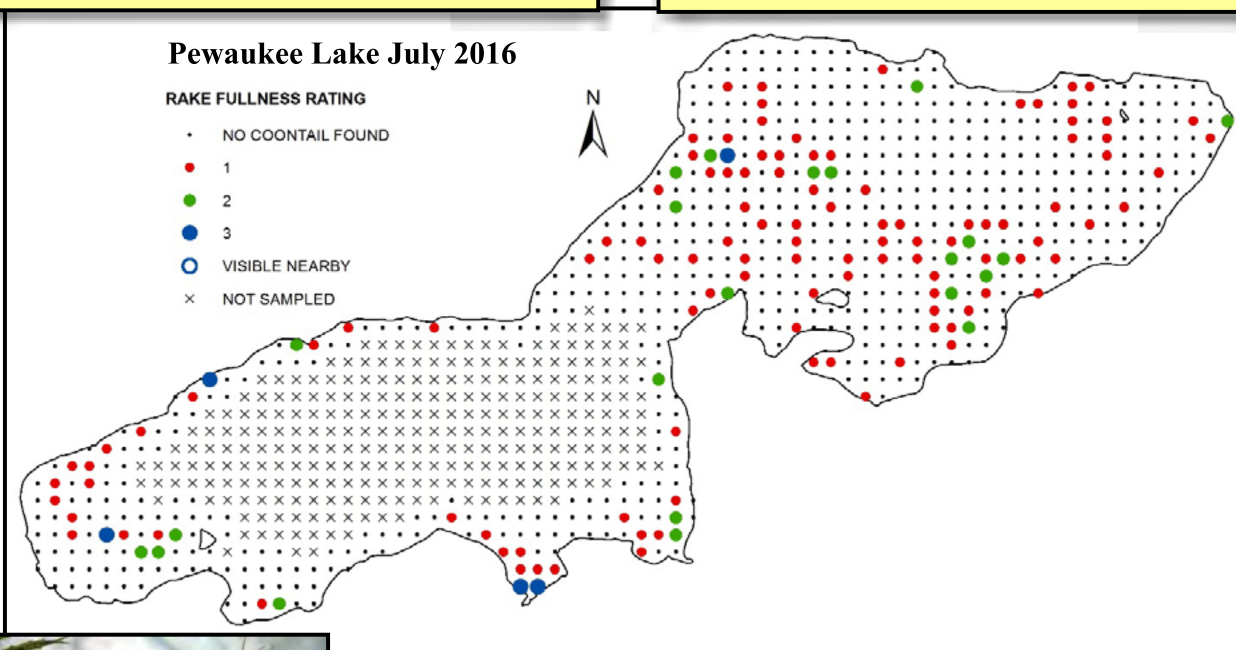
Identifying Features

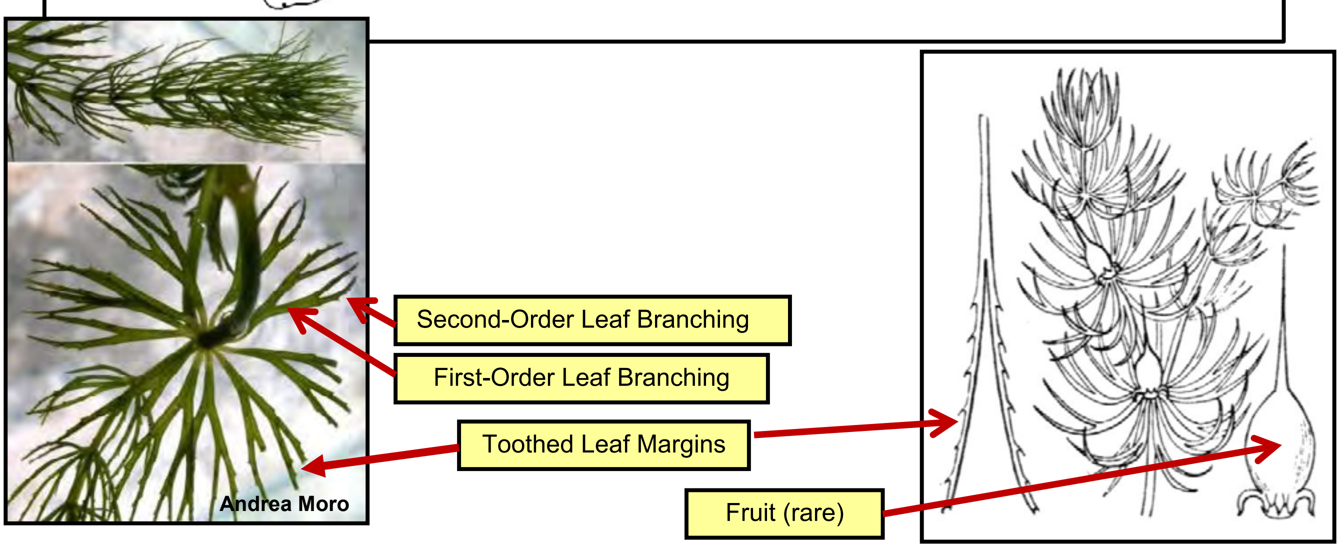
- Often bushy near tips of branches, giving the raccoon tail-like appearance (“coontail”)
- Whorled leaves with one to two orders of branching and small teeth on their margins
- Flowers (rare) small and produced in leaf axils

Coontail is similar to spiny hornwort (*C. echinatum*) and muskgrass (*Chara* spp.), but spiny hornwort has some leaves with three to four orders of branching, and coontail does not produce the distinct garlic-like odor of muskgrass when crushed

Ecology

- Common in lakes and streams, both shallow and deep
- Tolerates poor water quality (high nutrients, chemical pollutants) and disturbed conditions
- Stores energy as oils, which can produce slicks on the water surface when plants decay
- Anchors to the substrate with pale, modified leaves rather than roots
- Eaten by waterfowl, turtles, carp, and muskrat





Ceratophyllum echinatum — Spiny Hornwort
Native

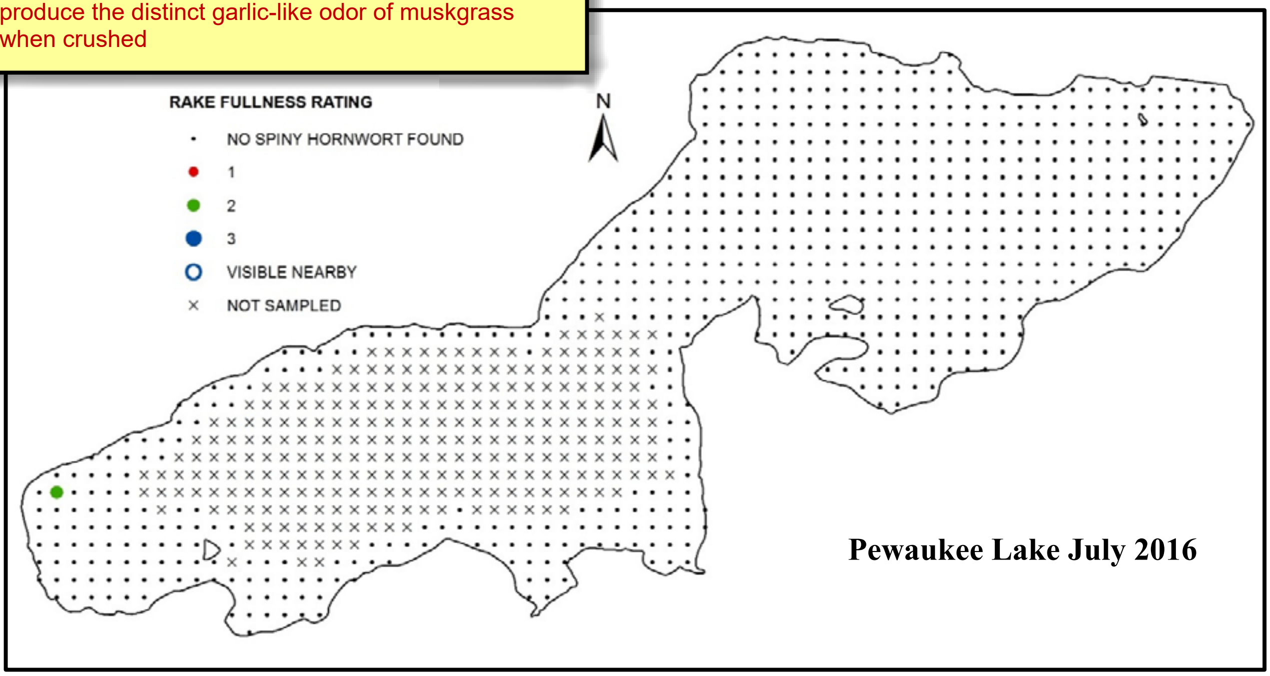
Identifying Features

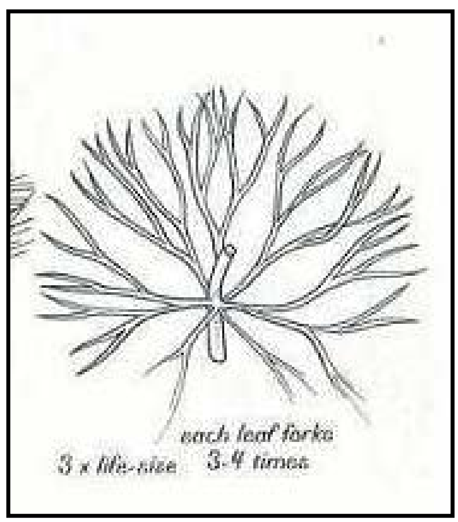
- Often heavily branched
- Delicate whorled leaves branch 3 to 4 times
- Edges of leaves toothless but with some spines
- Fruits have rough surface and several spines of varying lengths around margin

Spiny hornwort is similar to coontail (*C. demersum*) and muskgrass (*Chara* spp.), but spiny hornwort has some leaves that are delicate and have three to four orders of branching, and spiny hornowort does not produce the distinct garlic-like odor of muskgrass when crushed

Ecology

- Uncommon and found in acidic, soft water lakes and ponds
- Anchors to the substrate with pale, modified leaves rather than roots
- Bushy stems harbor many invertebrates and provide shelter and foraging for fish





Chara spp. — Muskgrasses

Native

Algae (not vascular plants)

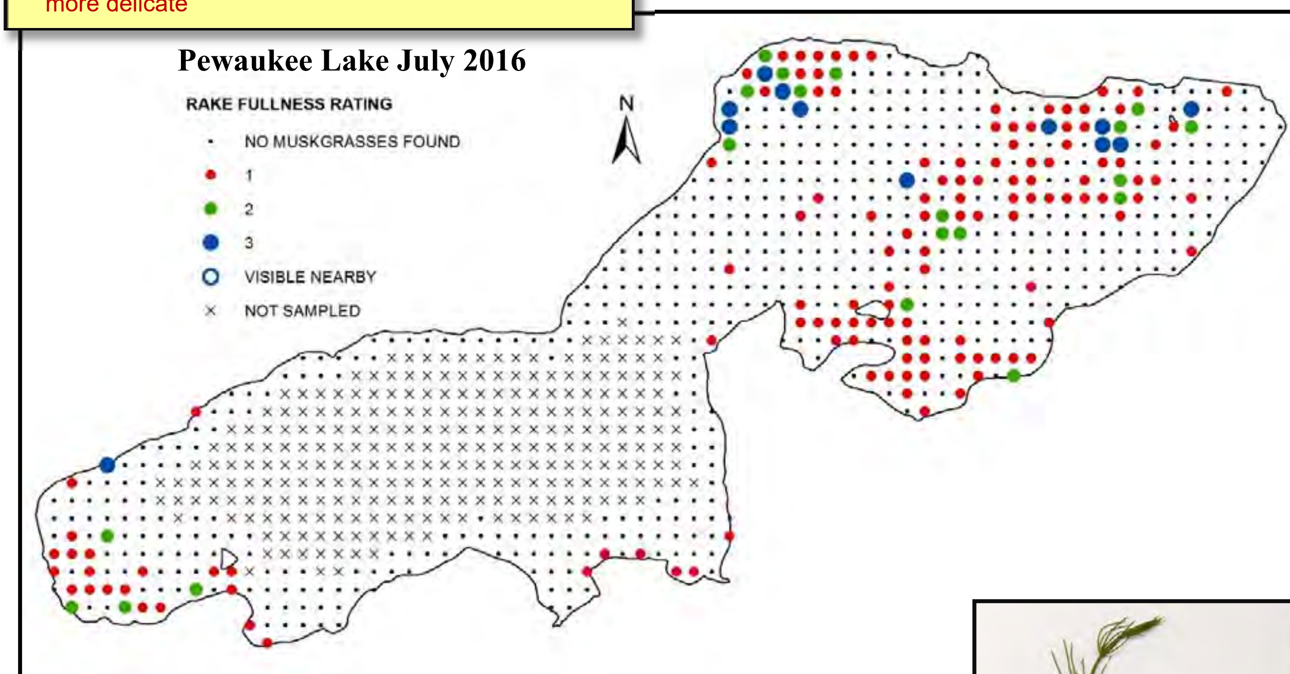
Identifying Features

- Leaf-like, ridged side branches develop in whorls of six or more
- Often encrusted with calcium carbonate, which appears white upon drying (see photo on left, below)
- Yellow reproductive structures develop along the whorled branches in summer
- Emits a garlic-like odor when crushed

Stoneworts (*Nitella* spp.) are similar large algae, but their branches are smooth rather than ridged and more delicate

Ecology

- Found in shallow or deep water over marl or silt, often growing in large colonies in hard water
- Overwinters as rhizoids (cells modified to act as roots) or fragments
- Stabilizes bottom sediments, often among the first species to colonize open areas
- Food for waterfowl and excellent habitat for small fish



Elodea canadensis — Common Waterweed

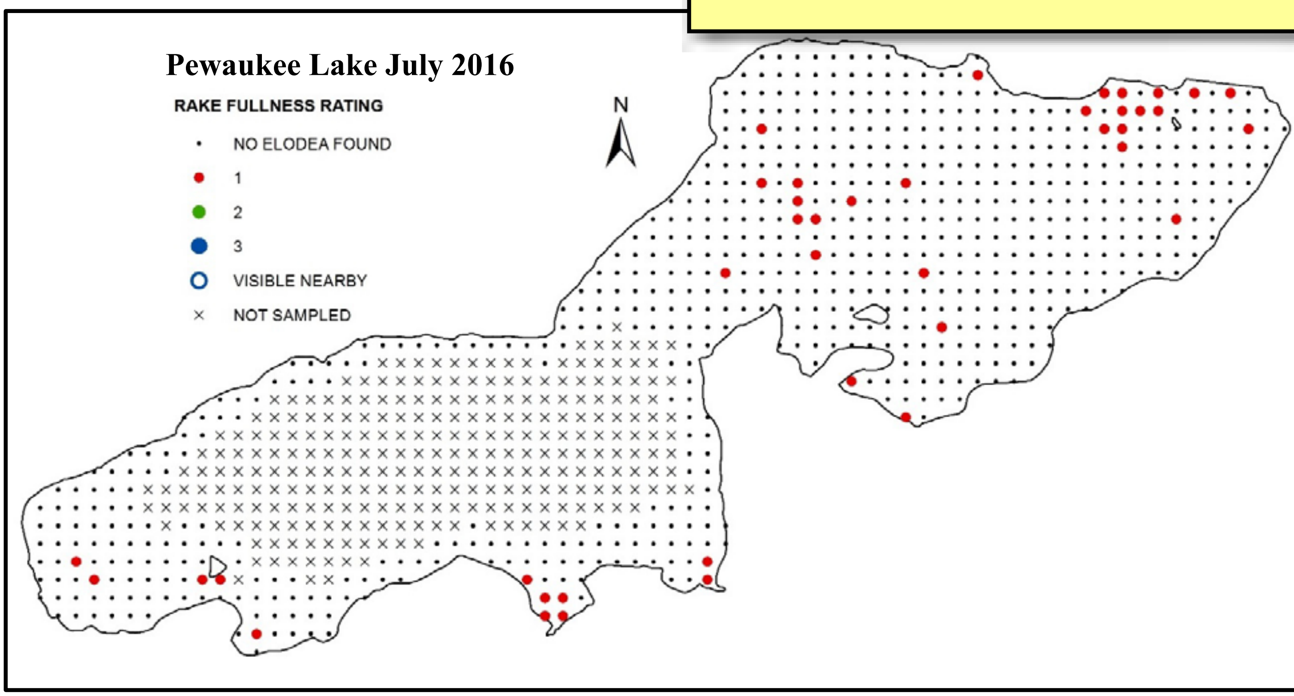
Native

Identifying Features

- Slender stems, occasionally rooting
- Leaves lance-shaped, in whorls of three (rarely two or four), 6.0 to 17 mm long and averaging 2.0 mm wide
- When present, tiny male and female flowers on separate plants (females more common), raised to the surface on thread-like stalks

Ecology

- Found in lakes and streams over soft substrates tolerating pollution, eutrophication and disturbed conditions
- Often overwinters under the ice
- Produces seeds only rarely, spreading primarily via stem fragments
- Provides food for muskrat and waterfowl
- Habitat for fish or invertebrates, although dense stands can obstruct fish movement



Heteranthera dubia — Water Stargrass

Native

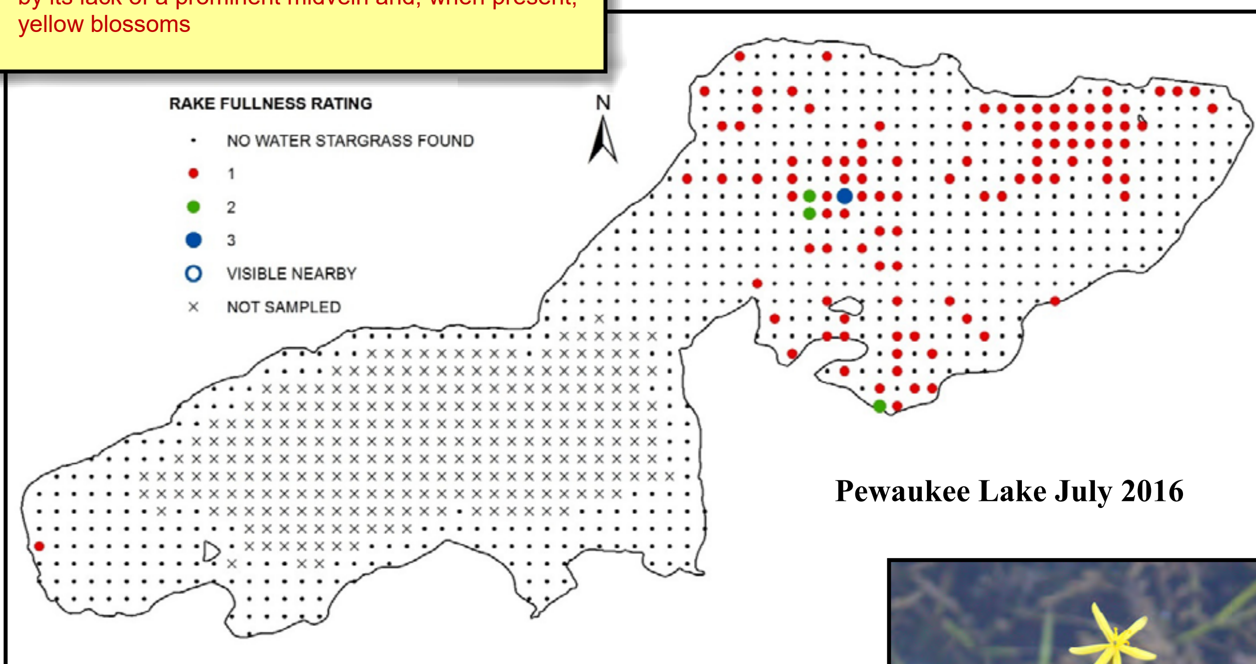
Identifying Features

- Stems slender, slightly flattened, and branching
- Leaves narrow, alternate, with no stalk, and lacking a prominent midvein
- When produced, flowers conspicuous, yellow, and star-shaped (usually in shallow water) or inconspicuous and hidden in the bases of submersed leaves (in deeper water)

Yellow stargrass may be confused with pondweeds that have narrow leaves, but it is easily distinguished by its lack of a prominent midvein and, when present, yellow blossoms

Ecology

- Found in lakes and streams, shallow and deep
- Tolerates somewhat turbid waters
- Overwinters as perennial rhizomes
- Limited reproduction by seed
- Provides food for waterfowl and habitat for fish



Myriophyllum sibiricum — Northern Water Milfoil

Native

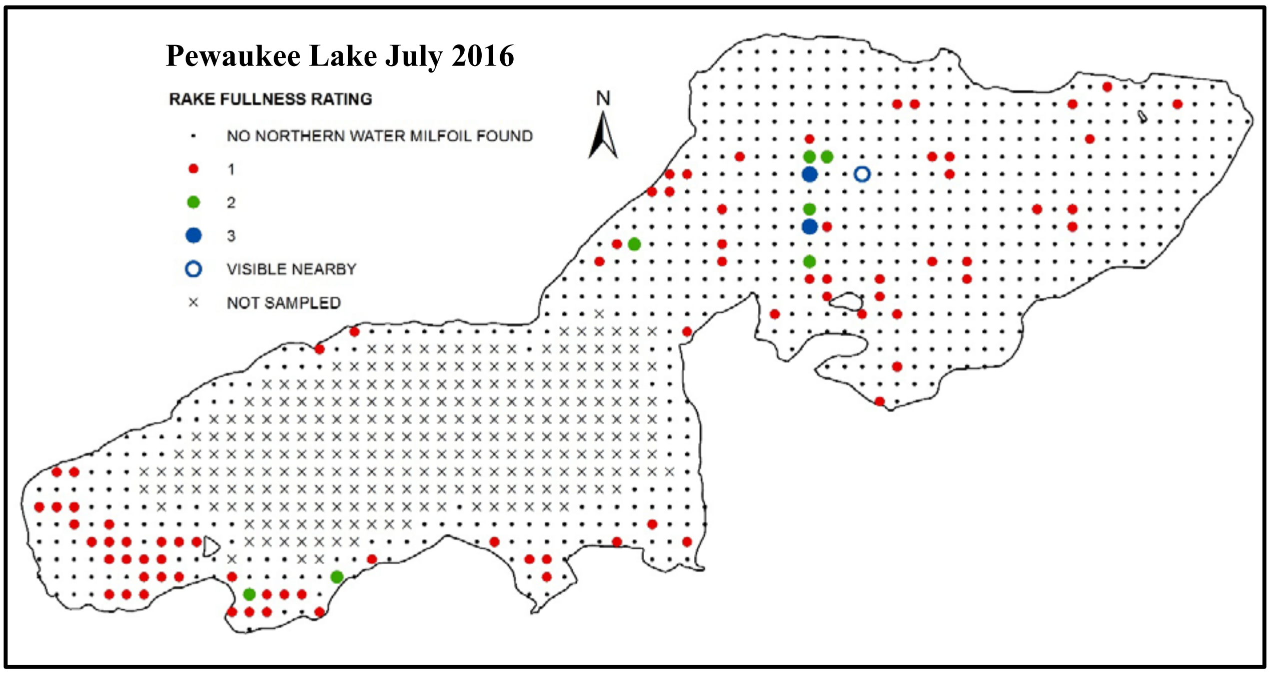
Identifying Features

- Light-colored, stout stems
- Leaves in whorls of four to five, divided into four to 12 pairs of leaflets, lower leaflets longer than the upper ones
- Forms winter buds (turions) in autumn

Northern water milfoil is similar to other water milfoils. Eurasian water milfoil (*M. spicatum*) tends to produce more leaflets per leaf and have more delicate, pinkish stems

Ecology

- Found in lakes and streams, shallow and deep
- Overwinters as winter buds and/or hardy rootstalks
- Consumed by waterfowl
- Habitat for fish and aquatic invertebrates
- Hybridizes with Eurasian water milfoil, resulting in plants with intermediate characteristics



Myriophyllum heterophyllum
Native

Various-leaved Water Milfoil

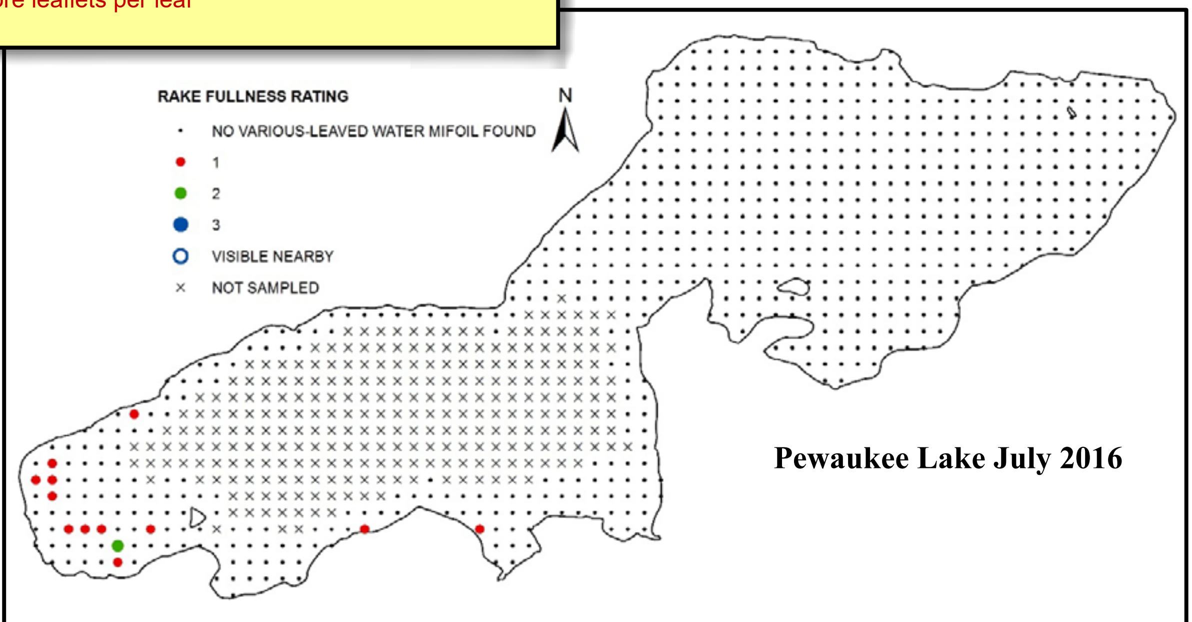
Identifying Features

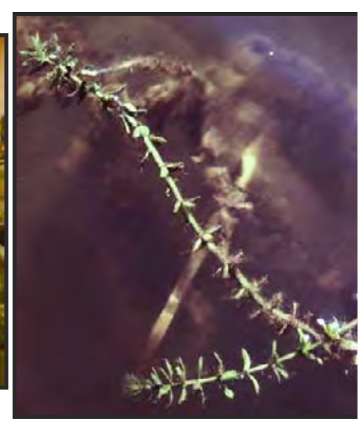
- Very short internodes lead to very bushy appearance
- Leaves in whorls of four to six, with some scattered on stem, divided into seven to 14 pairs of leaflets
- No winter buds are formed
- Flower bracts are larger than flowers and have smooth or slightly serrated edges

Various-leaved water milfoil is similar to other water milfoils. Eurasian water milfoil (*M. spicatum*) tends to be less bushy, limp out of water, and produce more leaflets per leaf

Ecology

- Found in lakes and streams, up to 15 feet but mostly shallower
- Plants on wet shorelines may produce deeply serrate "terrestrial" leave or bracts
- Consumed by waterfowl
- Provides habitat for aquatic invertebrates and shade, shelter, and foraging for fish





Myriophyllum spicatum
Nonnative/Exotic

Eurasian Water Milfoil

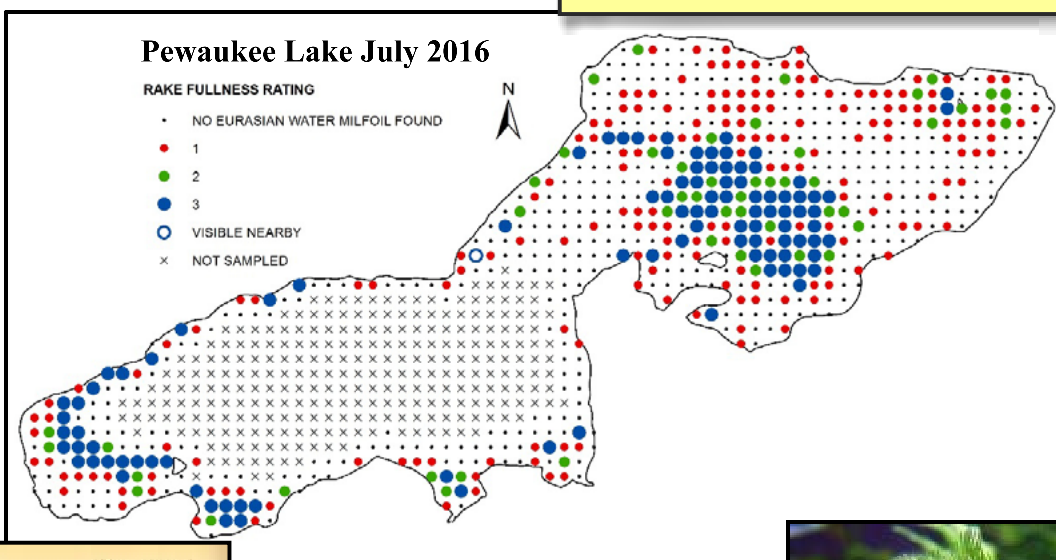
Identifying Features

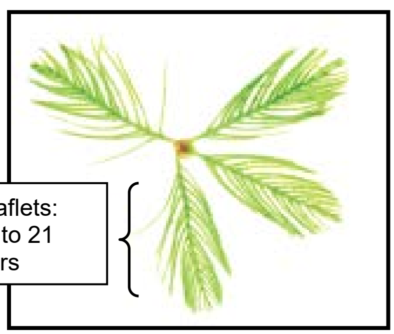
- Stems spaghetti-like, often pinkish, growing long with many branches near the water surface
- Leaves with 12 to 21 pairs of leaflets
- Produces no winter buds (turions)

Eurasian water milfoil is similar to northern water milfoil (*M. sibiricum*). However, northern water milfoil has five to 12 pairs of leaflets per leaf and stouter white or pale brown stems

Ecology

- Hybridizes with northern (native) water milfoil, resulting in plants with intermediate characteristics
- Invasive, growing quickly, forming canopies, and getting a head-start in spring due to an ability to grow in cool water
- Grows from root stalks and stem fragments in both lakes and streams, shallow and deep; tolerates disturbed conditions
- Provides some forage to waterfowl, but supports fewer aquatic invertebrates than mixed stands of aquatic vegetation





Najas guadalupensis — Southern Naiad

Native

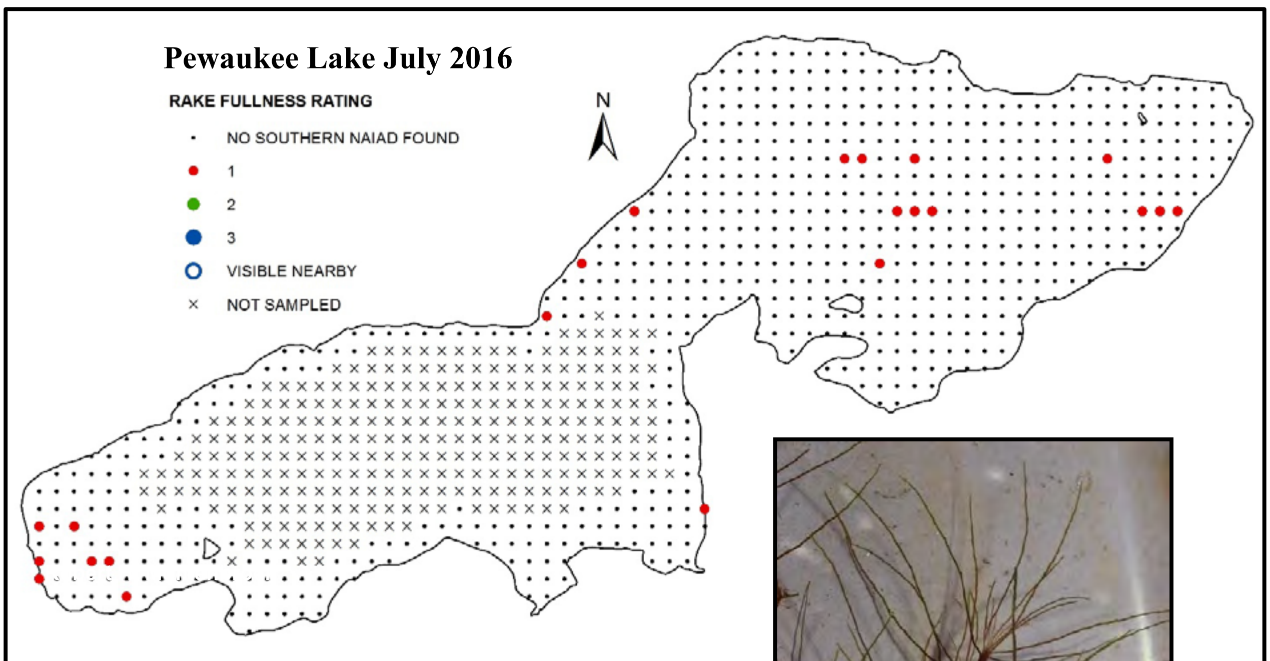
Identifying Features

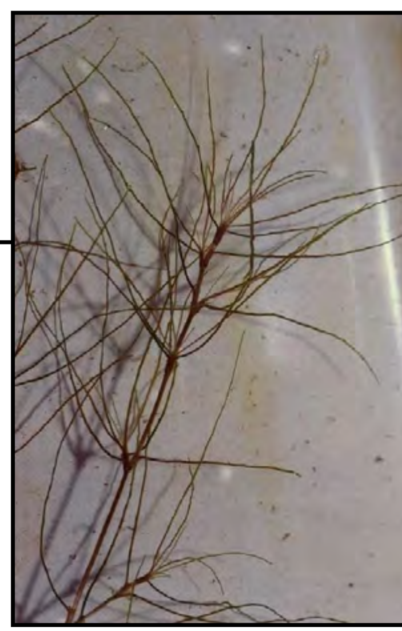
- Leaves 0.2 to 2.0 mm wide and blunt with slight shoulder bases where they attach to the stem and finely serrated margins
- Flowers, when present, tiny and located in leaf axils
- Leaves opposite and may appear loosely whorled

Two other *Najas* occur in southeastern Wisconsin. Slender naiad (*N. flexilis*) has narrower leaves (to 0.6 mm) with a pointed tip. Spiny naiad (*N. marina*) has coarsely toothed leaves with spines along the midvein below

Ecology

- In shallow to deep lakes and sandy, gravelly soil
- An annual plant that completely dies back in fall and regenerates from seeds each spring; also spreading by stem fragments during the growing season





Nymphaea odorata — White Water Lily

Native

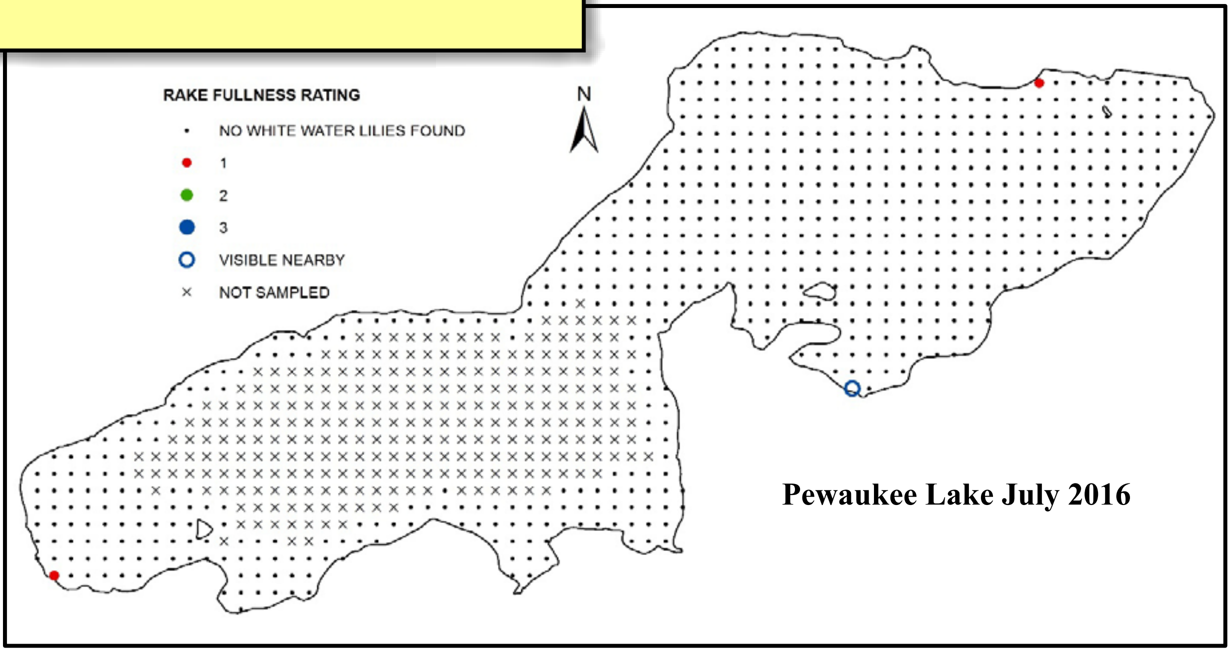
Identifying Features

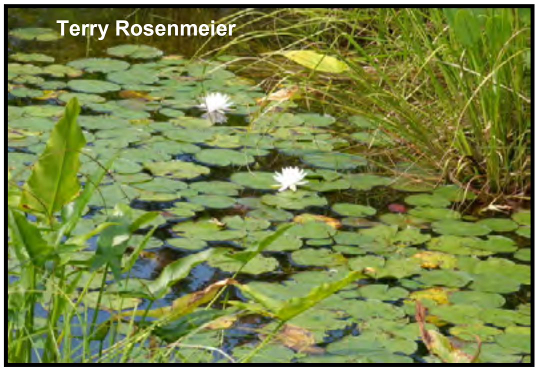
- Leaf stalks round in cross-section with four large air passages
- Floating leaves round (four to 12 inches wide under favorable conditions), *with a notch* from the outside to the center, and reddish-purple underneath
- Flowers white with a yellow center, three to nine inches wide

Pond lilies (*Nuphar* spp.) are superficially similar, but have yellow flowers and leaves somewhat heart-shaped. American lotus (*Nelumbo lutea*) is also similar, but its leaves are *unnotched*

Ecology

- Found in shallow waters over soft sediments
- Leaves and flowers emerge from rhizomes
- Flowers opening during the day, closing at night
- Seeds consumed by waterfowl, rhizomes consumed by mammals





Potamogeton amplifolious — Large-Leaf Pondweed

Native

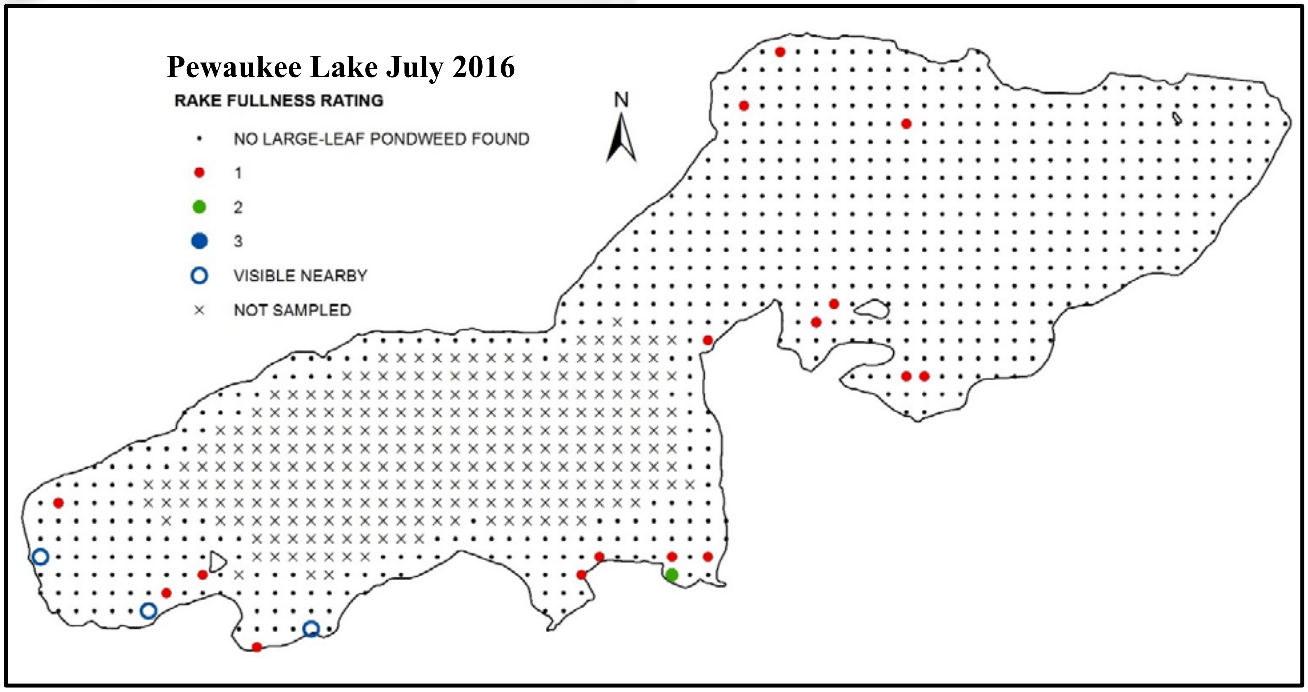
Identifying Features

- When produced, floating leaves 2-23 cm long *with 27-49 veins* and petiole longer than leaf blade
- Submersed leaves large and sickle-shaped, 4-7 cm wide, 8-20 cm long, *with more than 19 veins*, and folded upwards along the sides
- White stipules up to 12 cm long

Large-leaf pondweed may be distinguished from Illinois pondweed (*P. illinoensis*) by the greater number of veins on submersed and floating leaves.

Ecology

- Soft substrate, shallow and deep lakes
- Emerges in spring from buds formed along rhizomes
- Provides food for waterfowl, muskrat, beaver, and deer
- Provides habitat and/or food for fish, muskrat, waterfowl, and insects



Potamogeton crispus — Curly-Leaf Pondweed

Nonnative/Exotic

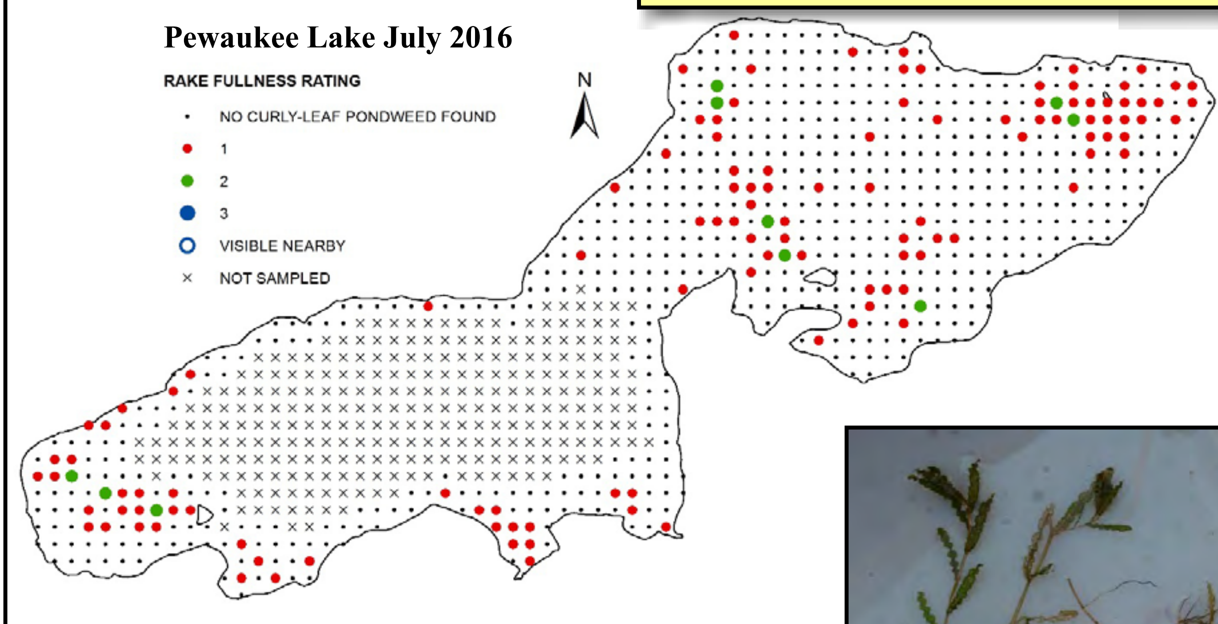
Identifying Features

- Stems slightly flattened and both stem and leaf veins often somewhat pink
- Leaf margins very wavy and finely serrated
- Stipules (3.0 to 8.0 mm long) partially attached to leaf bases, disintegrating early in the season
- Produces pine cone-like overwintering buds (turions)

Curly-leaf pondweed may resemble clasping-leaf pondweed (*P. richardsonii*), but the leaf margins of the latter are not serrated

Ecology

- Found in lakes and streams, both shallow and deep
- Tolerant of low light and turbidity
- Disperses mainly by turions
- Adapted to cold water, growing under the ice while other plants are dormant, but dying back during mid-summer in warm waters
- Produces winter habitat, but mid-summer die-offs can degrade water quality and cause algal blooms
- Maintaining or improving water quality can help control this species, because it has a competitive advantage over native species when water clarity is poor




Zofia Noe


Zofia Noe

Potamogeton illinoensis — Illinois Pondweed
Native

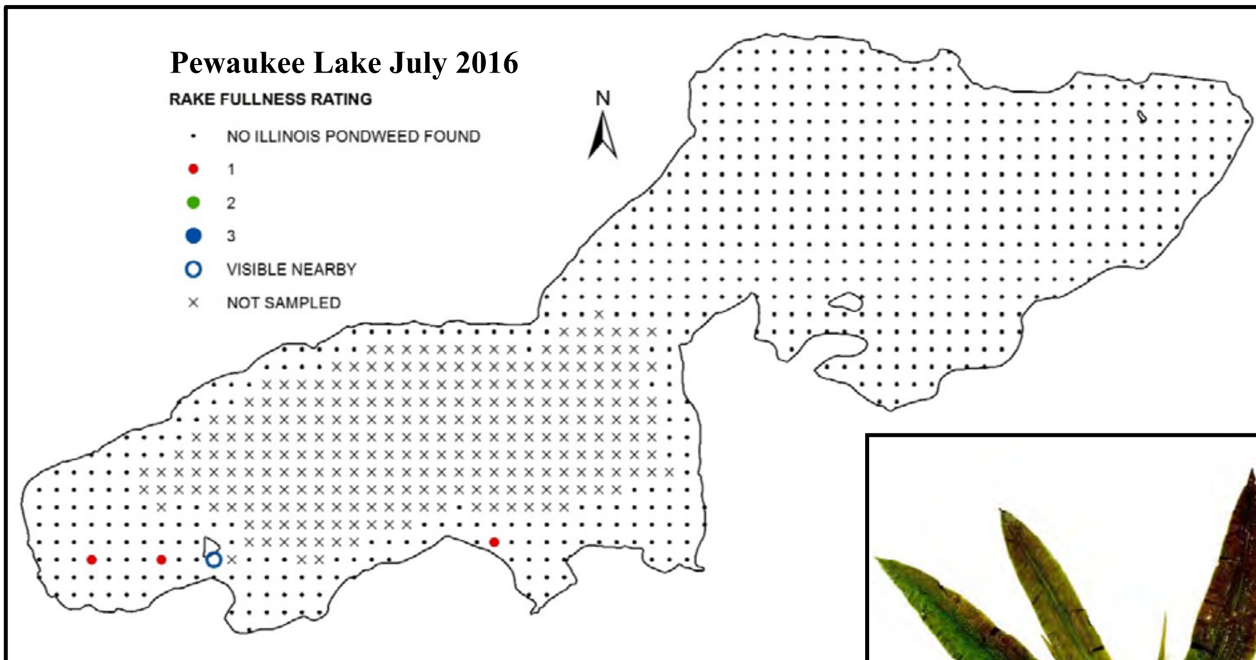
Identifying Features

- Stout stems up to 2.0 m long, often branched
- Submerged leaves with nine to 19 veins (midvein prominent) on short stalks (up to 4.0 cm) or attached directly to the stem
- Floating leaves, if produced, elliptical, with 13 to 29 veins
- Often covered with calcium carbonate in hard water

Variable pondweed (*P. gramineus*) is similar to Illinois pondweed, but differs in having three to seven veins on submerged leaves

Ecology

- Lakes with clear water, shallow or deep, neutral or hard, over soft sediments
- Overwinters as rhizomes or remains green under the ice
- Provides food for waterfowl, muskrat, deer, and beaver
- Provides excellent habitat for fish and aquatic invertebrates



Potamogeton natans — Floating-Leaf Pondweed

Native

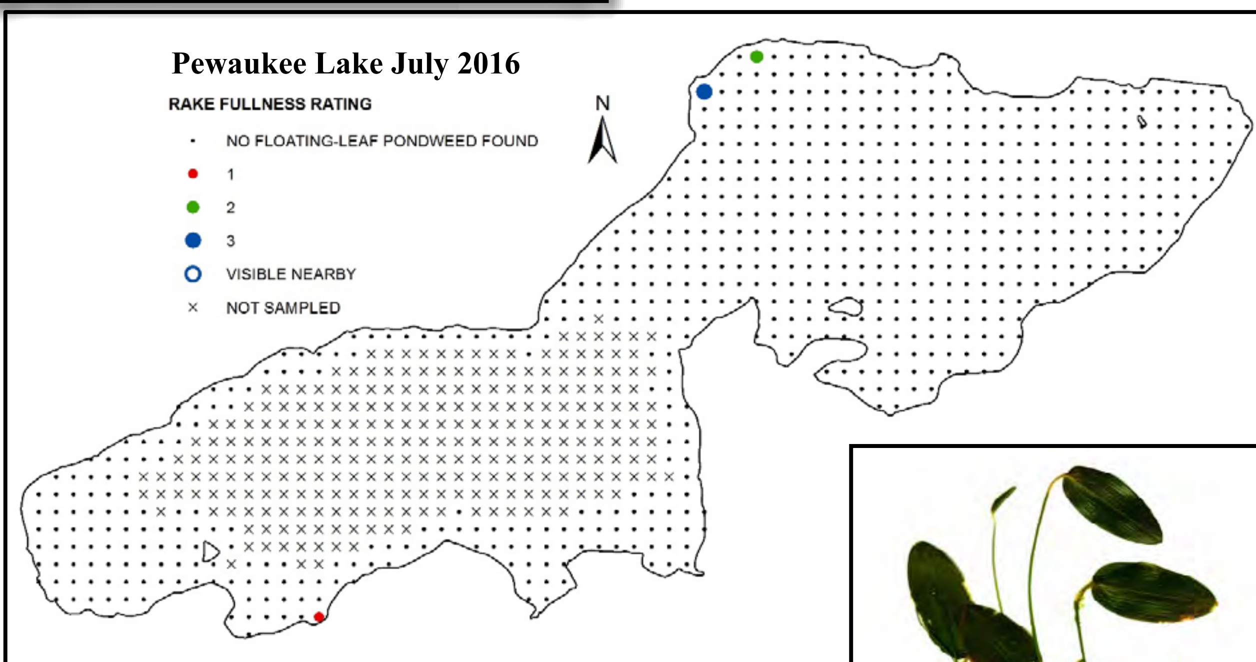
Identifying Features

- Floating leaves (5.0 to 10 cm long) with heart-shaped bases and 17 to 37 veins
- Floating leaf stalks bent where they meet the leaf, causing the leaf to be held at roughly a 90-degree angle to the stalk
- Submersed leaves (1.0 to 2.0 mm wide) linear and stalk-like, with three to five veins

Floating-leaf pondweed is similar to Oakes' pondweed (*P. oakesianus*) and spotted pondweed (*P. pulcher*). Oake's pondweed is smaller, with floating leaves 2.5 to 6.0 cm long and submersed leaves 0.25 to 1.0 mm wide. Spotted pondweed differs in having small black spots on its stems and leaf stalks and lance-shaped submersed leaves with wavy margins

Ecology

- Usually in shallow waters (<2.5 m) over soft sediment
- Emerges in spring from buds formed along rhizomes
- Provides food for waterfowl, muskrat, beaver, and deer
- Holds fruit on stalks until late in the growing season, which provides valuable feeding opportunities for waterfowl
- Provides good fish habitat



Potamogeton nodosus
Native

Long-Leaf Pondweed

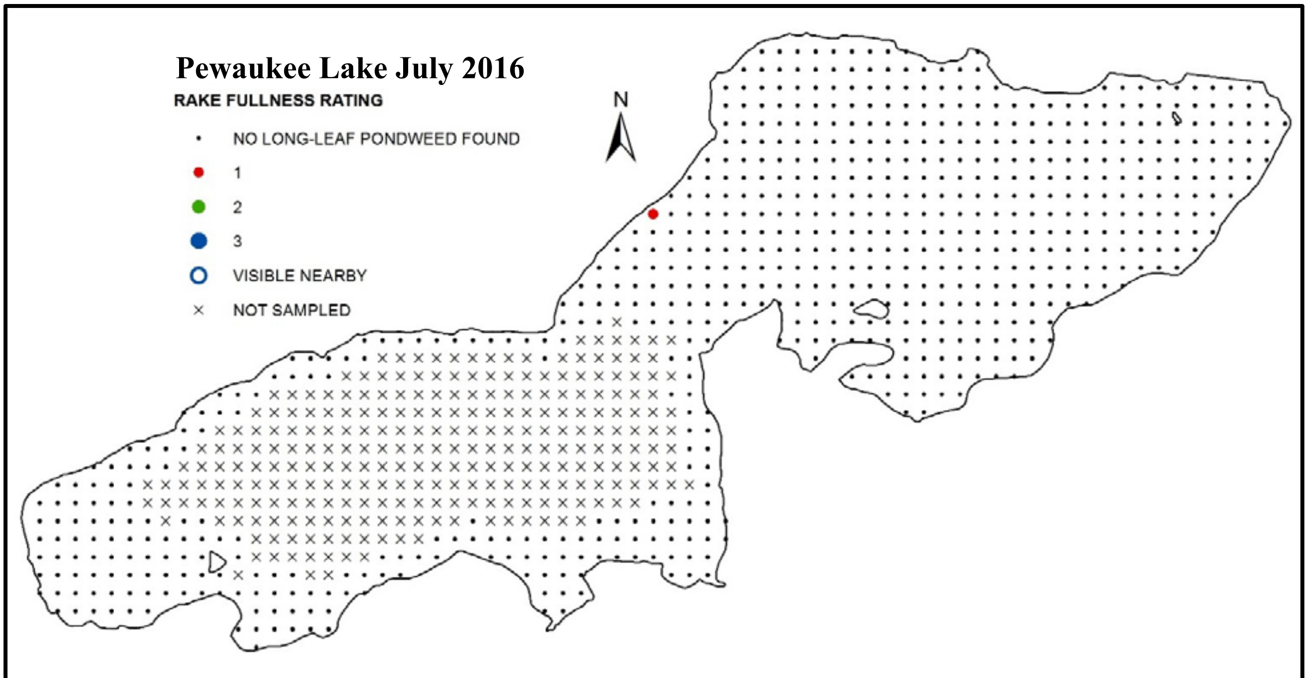
Identifying Features

- Floating leaves 5.0 to 13 cm long, tapering to leaf stalks that are longer than the attached leaf blades
- Submersed leaves up to 30 cm long and 1.0 to 2.5 mm wide, with seven to 15 veins, and long leaf stalks
- Stipules 4.0 to 10 cm long, free from the leaves, disintegrating by mid-summer

Long-leaf pondweed may be distinguished from other pondweeds that have similar floating leaves (e.g. *P. illinoensis* and *P. natans*) by the long leaf stalks of its submersed leaves. The floating leaves of *P. natans* also differ by having a heart-shaped base and by being held to the leaf stalks at roughly 90-degree angles. In *P. illinoensis* the stalks of floating leaves, if produced, are shorter than the leaf blades

Ecology

- Streams and lakes, shallow and deep, but more often in flowing water
- Emerges in spring from buds formed along rhizomes
- Provides food for waterfowl, muskrat, beaver, and deer
- Harbors large numbers of aquatic invertebrates, which provide food for fish



Potamogeton praelongus — White-Stem Pondweed

Native

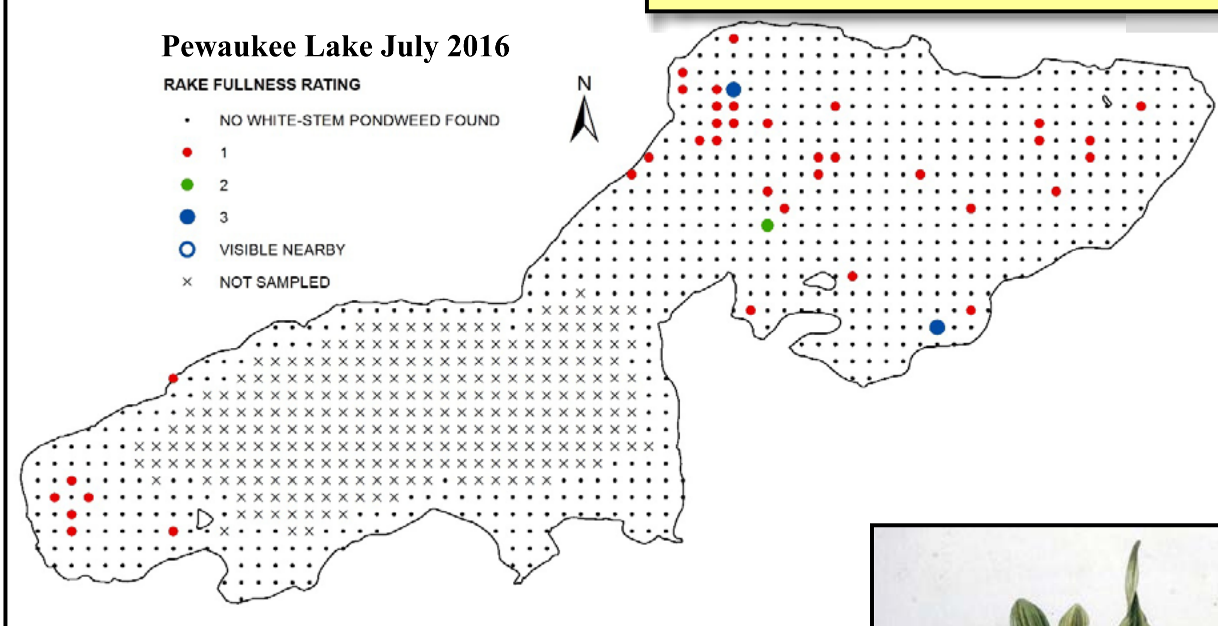
Identifying Features

- Stems usually pale and zig-zagging
- Leaves clasping, alternate, with three to five prominent veins and 11 to 35 smaller ones, with boat-shaped tips that often split when pressed between fingers

White-stem pondweed is similar to clasping pondweed (*P. richardsonii*), but the leaves of clasping pondweed do not have boat-shaped tips that split when pressed

Ecology

- Found in clear lakes in water three to 12 feet deep over soft sediments
- *"Indicator species"* due to its sensitivity to water quality changes; its disappearance indicating degradation; requires more natural areas that receive little disturbance
- Sometimes remains evergreen beneath the ice
- Provides food for waterfowl, muskrat, beaver, and deer
- Provides habitat for trout and muskellunge



Potamogeton pusillus — Small Pondweed

Native

Identifying Features

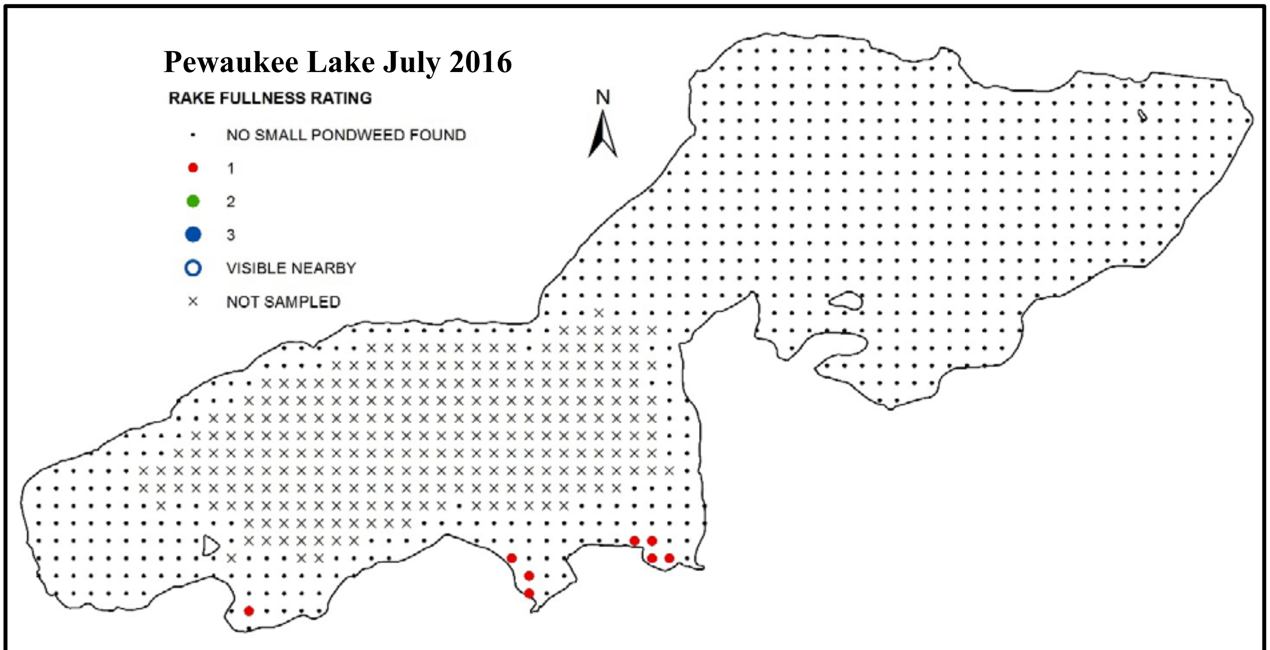
- Narrow, submersed leaves (1-7 cm long and 0.2-2.5 mm wide), attaching directly to the stem, with 3 veins, leaf tips blunt or pointed, and often with raised glands where the leaf attaches to the stem
- Produces no floating leaves
- Numerous winter buds (turions) produced with rolled, inner leaves resembling cigars
- Flowers and fruits produced in whorls spaced along slender stalk

Small pondweed is similar to leafy pondweed (*P. foliosus*), when not in flower and fruit. However, unlike leafy pondweed, it often has raised glands where the leaves meet the stem. The flowers and fruits of small pondweed are also borne on longer, more slender stalks and in whorls that are spaced apart.

Ecology

- Shallow or deep waters over soft sediments in lake and streams
- Overwinters as rhizomes or winter buds (turions)
- Food for waterfowl, muskrat, deer, and beaver
- Cover for invertebrates and fish

USDA-NRCS PLANTS Database
Britton, N.L., and A. Brown. 1913. Illustrated flora of the northern states and Canada. Vol. 1: 84.



Potamogeton richardsonii — Clasping-Leaf Pondweed

Native

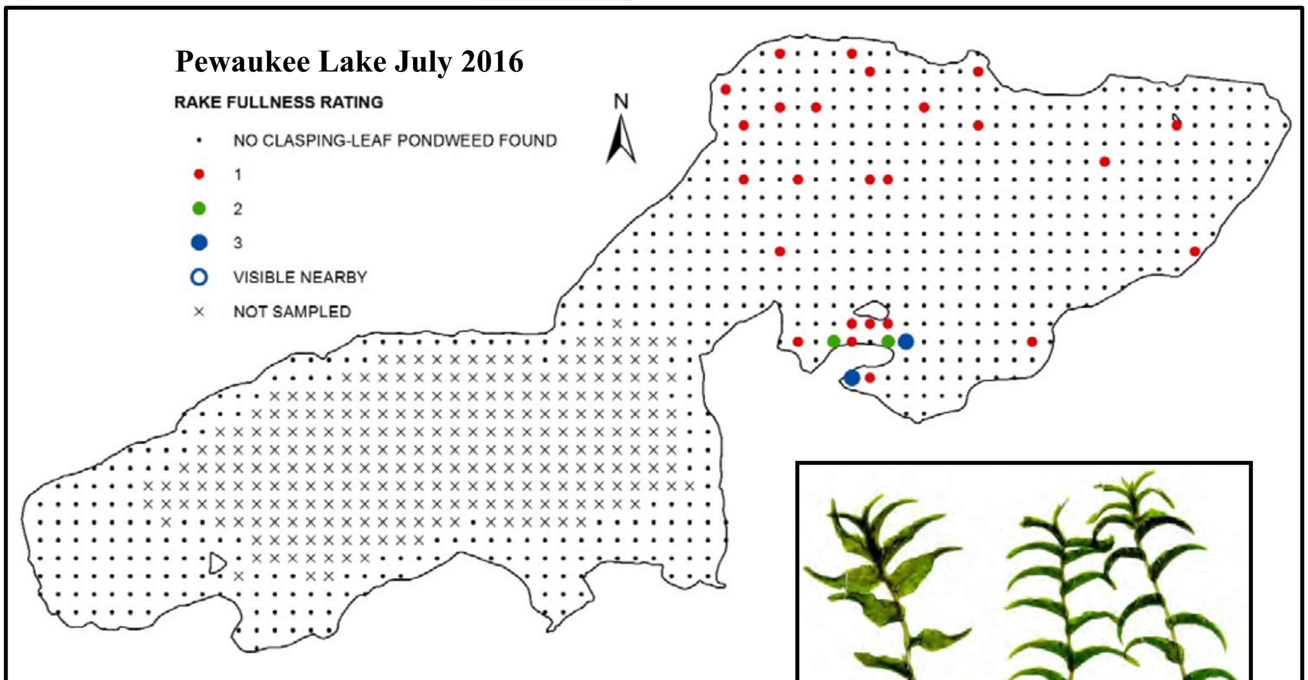
Identifying Features

- Leaves alternating along and clasping the stem, with wavy edges, coming to a point at the tip, and often with three to five veins prominent among many more that are faintly visible
- Produces no floating leaves

Clasping pondweed is similar to white-stem pondweed (*P. praelongus*), but the latter has boat-shaped leaf tips that split when pressed between one's fingers. The exotic curly-leaf pondweed (*P. crispus*) may appear similar, but differs by having serrated leaf margins

Ecology

- In lakes and streams, shallow and deep, often in association with coontail
- Tolerant of disturbance
- Fruits a food source for waterfowl and plants browsed by muskrat, beaver, and deer
- Stems emerging from perennial rhizomes



Potamogeton robbinsii — Robbins Pondweed or Fern Pondweed

Native

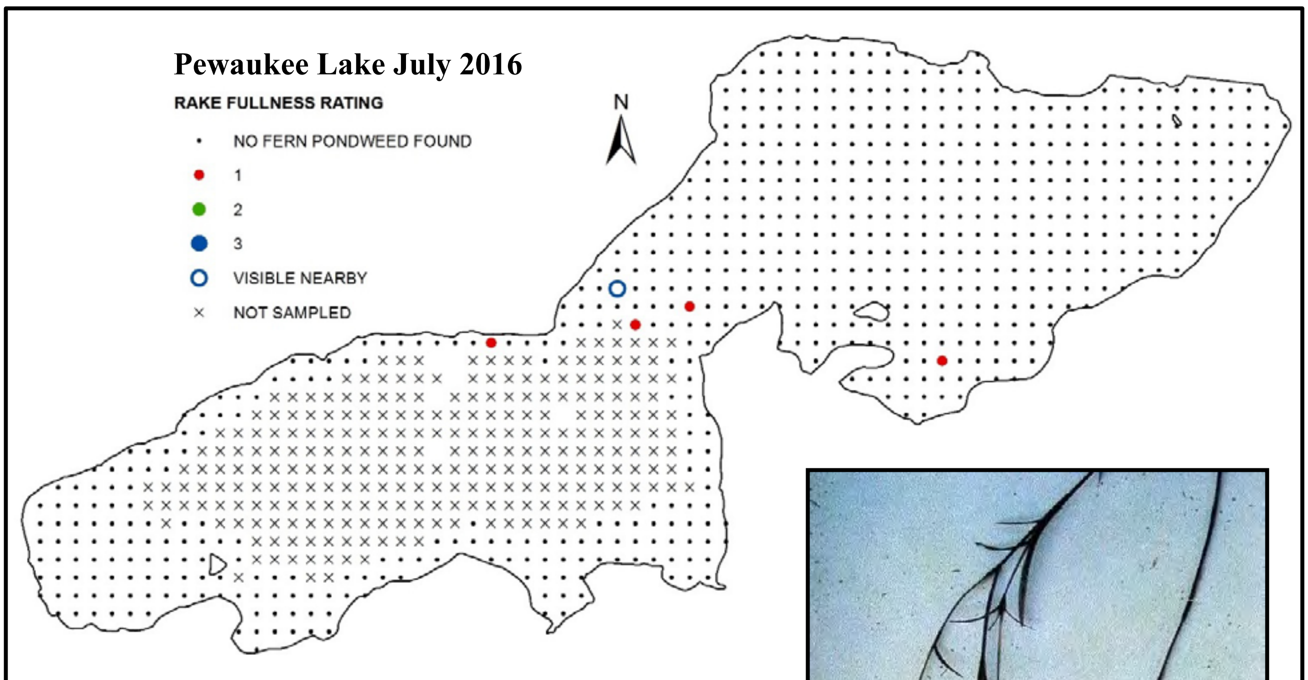
Identifying Features

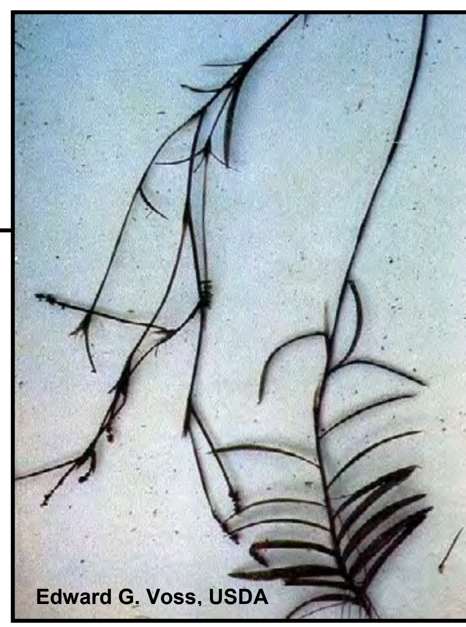
- Robust stems; stems and leaves often dark green to brown
- Leaves two-ranked (in opposite directions) along the stem, long and pointed, wrapping around the stem at the base, with edges finely serrated
- No floating leaves

Robbins pondweed is similar to flat-stem pondweed (*P. zosteriformis*) and water stargrass (*Zosterella dubia*), but is distinguished from both by its round stem

Ecology

- Lakes, often deeper than other pondweeds; requires more natural areas that receive little disturbance
- Plants often remaining green over the winter
- Regenerates from rhizomes and winter buds (turions), fruit only rarely produced
- Provides food for waterfowl
- Provides habitat for invertebrates and fish, particularly pike





Edward G. Voss, USDA

Potamogeton zosteriformis — Flat-Stem Pondweed

Native

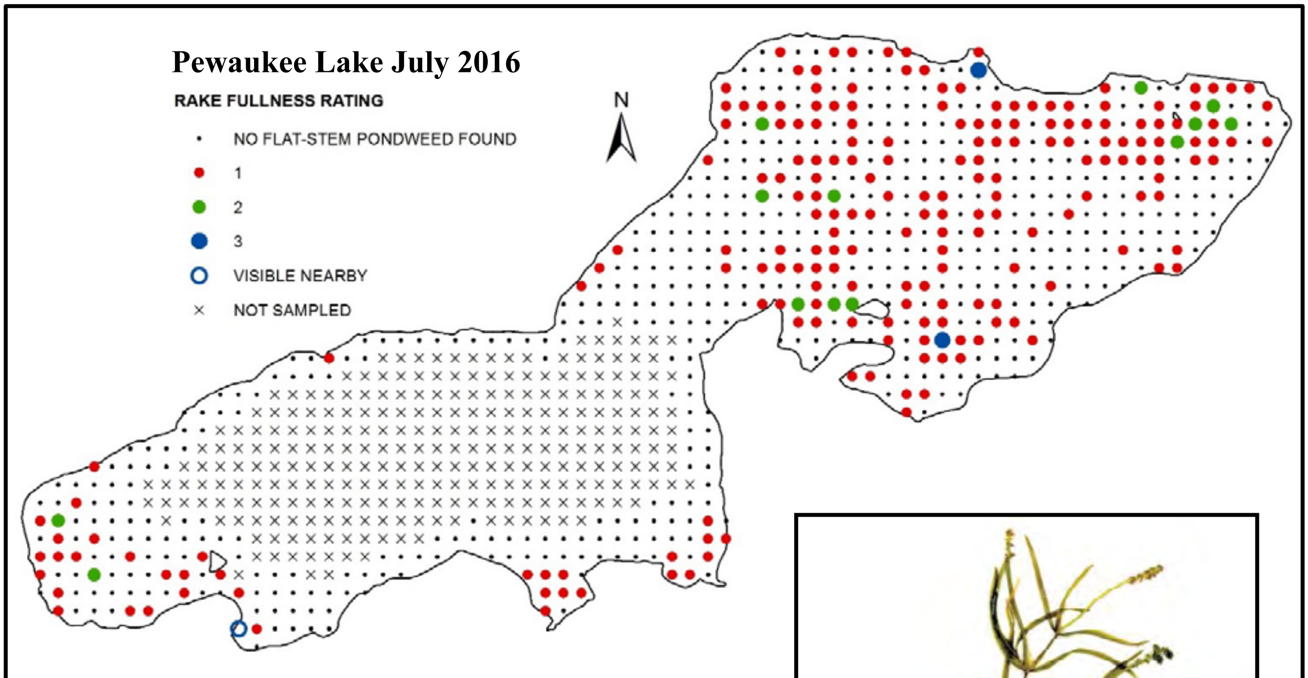
Identifying Features

- Stems strongly flattened
- Leaves up to four to eight inches long, pointed, with a prominent midvein and many finer, parallel veins
- Stiff winter buds consisting of tightly packed ascending leaves

Flat-stem pondweed may be confused with yellow stargrass (*Zosterella dubia*), but the leaves of yellow stargrass lack a prominent midvein.

Ecology

- Found at a variety of depths over soft sediment in lakes and streams
- Overwinters as rhizomes and winter buds
- Has antimicrobial properties
- Provides food for waterfowl, muskrat, beaver, and deer
- Provides cover for fish and aquatic invertebrates



Ranunculus aquatilis — White Water Crowfoot

Native

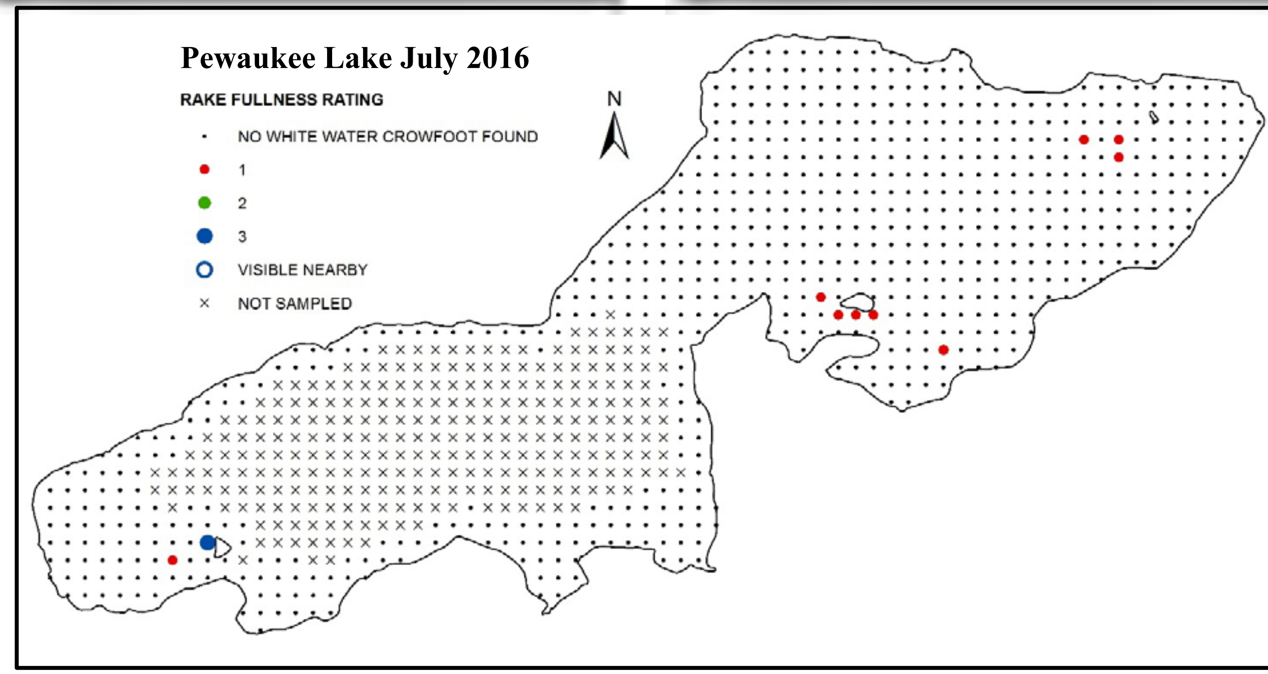
Identifying Features

- Submersed leaves finely divided into thread-like sections, and arranged alternately along the stem
- Flowers white, with five petals
- May or may not produce floating leaves

White water crowfoot is similar to other aquatic *Ranunculus* spp. However, the latter have yellow flowers and leaf divisions that are flat, rather than thread-like

Ecology

- Shallow water in lakes or streams, often with high alkalinity
- Often forms dense patches near springs or sand bars
- Emerges from rhizomes in the spring
- Fruit and foliage consumed by waterfowl and upland birds alike
- Habitat for invertebrates that are food for fish like trout



Stuckenia pectinata — Sago Pondweed

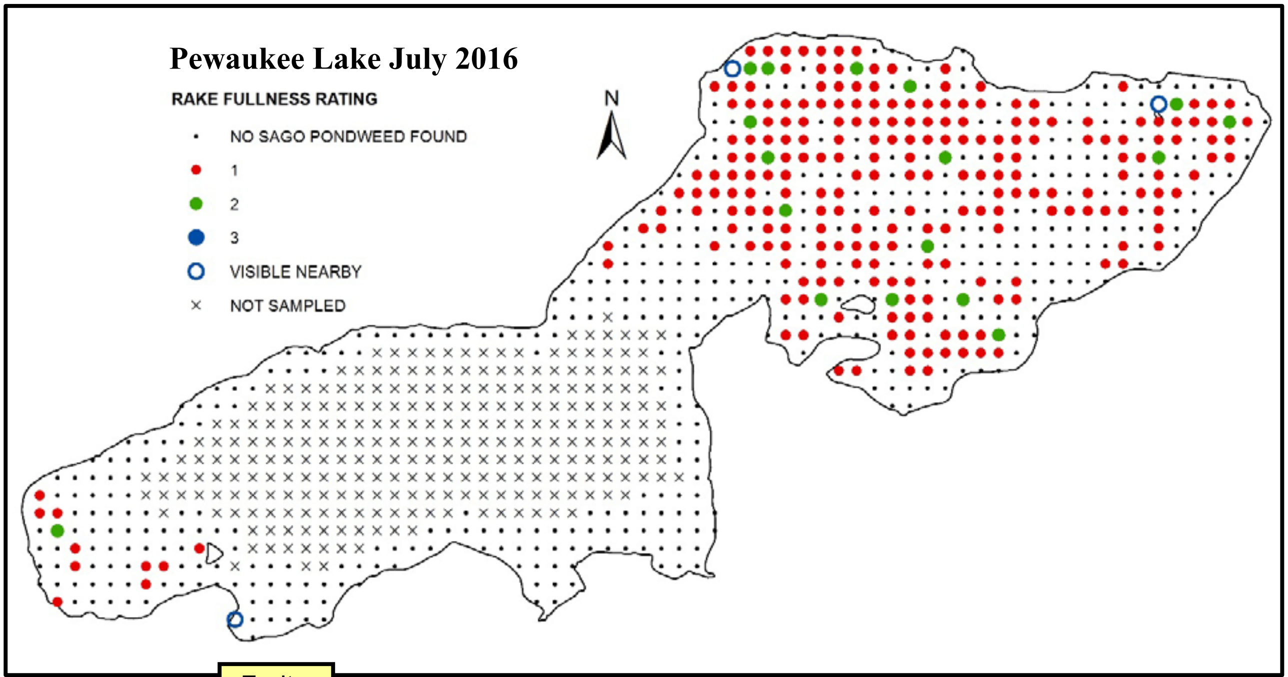
Native

Identifying Features

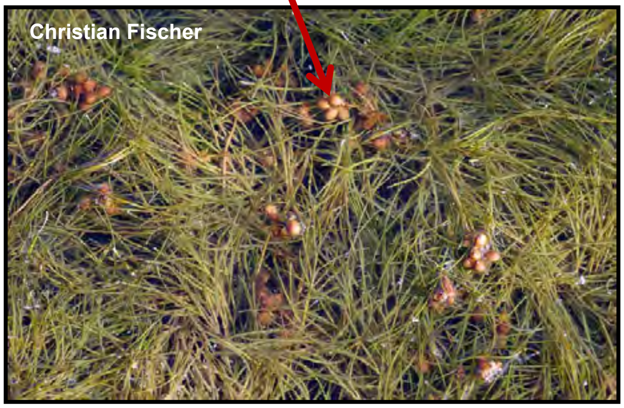
- Stems often *slightly zig-zagged* and forked multiple times, yielding a fan-like form
- Leaves one to four inches long, very thin, and ending in a sharp point
- Whorls of fruits spaced along the stem may appear as beads on a string

Ecology

- Lakes and streams
- Overwinters as rhizomes and starchy tubers
- Tolerates murky water and disturbed conditions
- Provides abundant fruits and tubers, which are an *important food for waterfowl*
- Provides habitat for juvenile fish



Fruits



Utricularia spp. — Bladderworts

Native

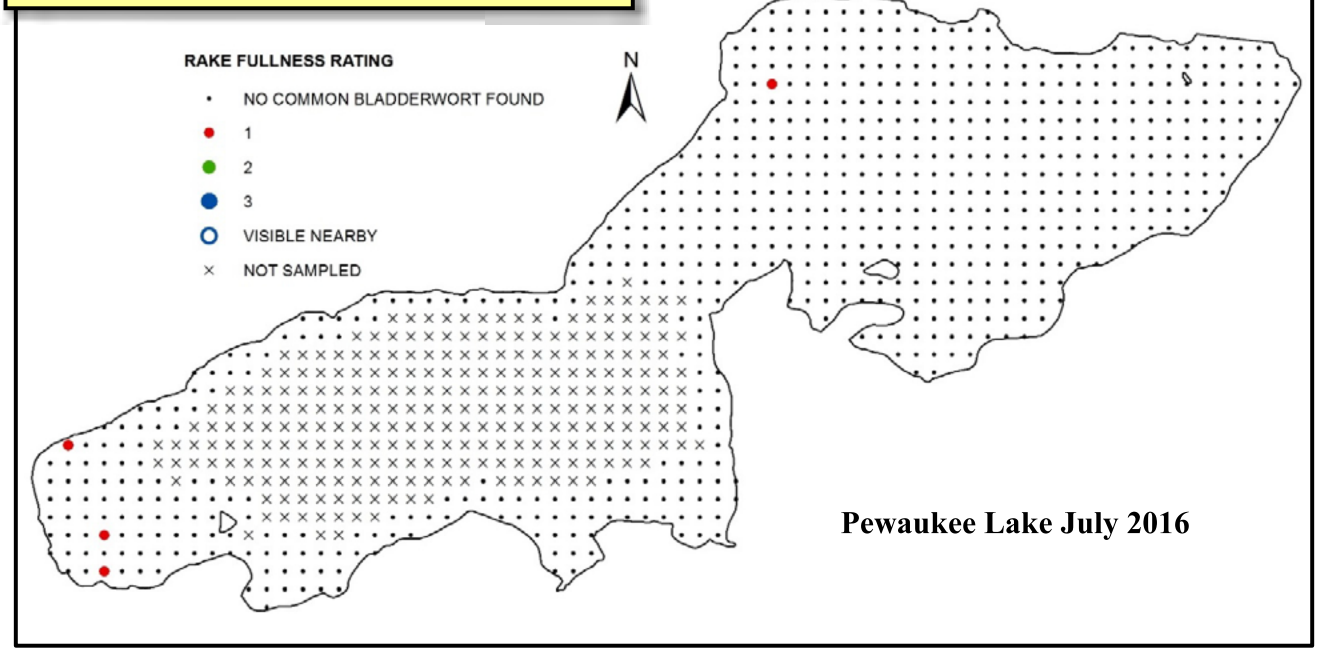
Identifying Features

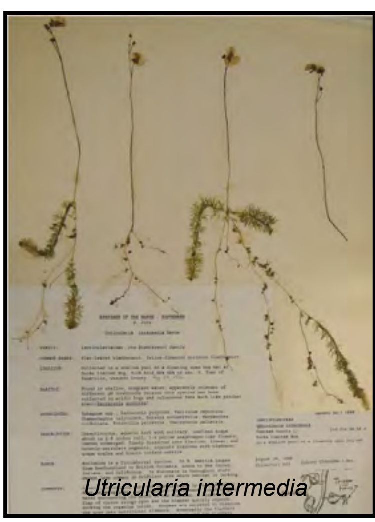
- Flowers snapdragon-like, yellow or purple, held on stalks above the water surface
- *Producing bladders* (small air chambers on the stem) that capture prey and give buoyancy to the stem
- Stems either floating (due to air bladders) or anchored in the substrate; branches finely divided, if floating

Several similar bladderworts occur in southeastern Wisconsin

Ecology

- Most species found in quiet shallows and along shores, but common bladderwort (*Utricularia vulgaris*) sometimes occurring in water several feet deep
- Provides forage and cover for a wide range of aquatic organisms
- Bladders capture and digest prey, including small invertebrates and protozoans





Utricularia intermedia

Utricularia gibba
David Midgley

Utricularia vulgaris
Kirill Ignatyev

Utricularia purpurea

Vallisneria americana — Eelgrass

Native

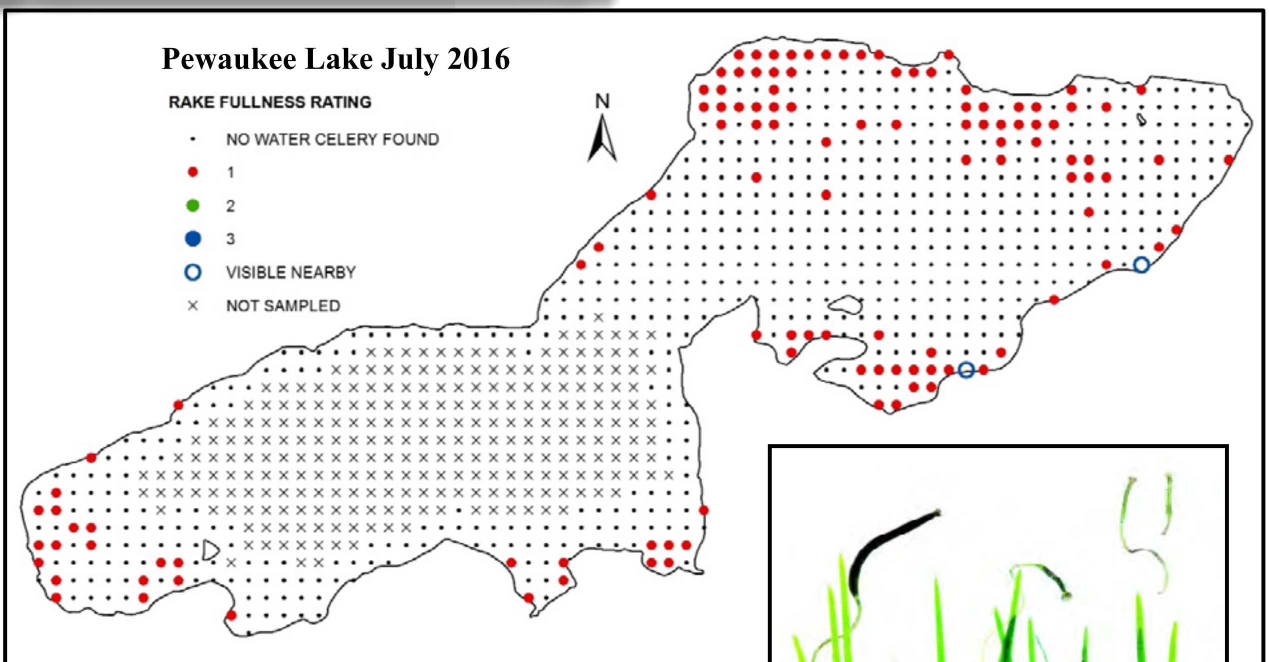
Identifying Features

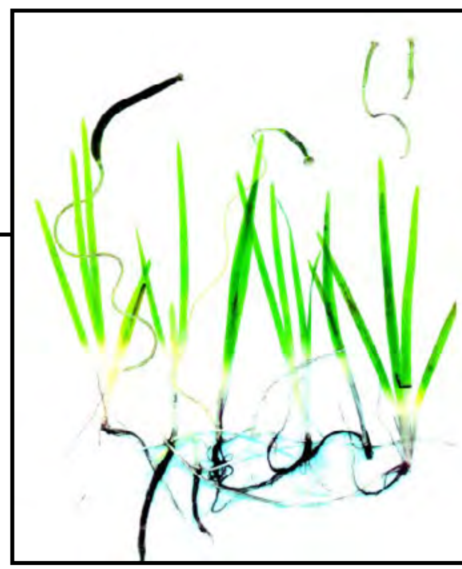
- Leaves ribbon-like, up to two meters long, with a prominent stripe down the middle, and emerging in clusters along creeping rhizomes
- Male and female flowers on separate plants, female flowers raised to the surface on spiral-coiled stalks

The foliage of eelgrass could be confused with the submersed leaves of bur-reeds (*Sparganium* spp.) or arrowheads (*Sagittaria* spp.), but the leaves of eelgrass are distinguished by their prominent middle stripe. The leaves of ribbon-leaf pondweed (*Potamogeton epihydrus*) are also similar to those of eelgrass, but the leaves of the former are alternately arranged along a stem rather than arising from the plant base

Ecology

- Firm substrates, shallow or deep, in lakes and streams
- Spreads by seed, by creeping rhizomes, and by offsets that break off and float to new locations in the fall
- All portions of the plant consumed by waterfowl; an especially important food source for Canvasback ducks
- Provides habitat for invertebrates and fish





APPENDIX E

STREAM CROSSING DESCRIPTION, LOCATION, CONDITION, FISH PASSAGE, AND NAVIGATION RATING ASSESSMENT IN THE PEWAUKEE LAKE TRIBUTARIES: 2012 AND 2015

Table E.1
Structure Description, Location, Condition, Fish Passage and Navigation Rating Assessment Within the Pewaukee Lake Watershed: 2012 and 2015

Structure Number on Map E.1 and Figure E.1	Description	Road Crossing	River Mile	Culvert/ Bridge Length (feet)	Ditch Erosion	General Condition	Limiting Water Depth (feet)[a]	Embedded Depth (feet)	Priority Rating and Recommendation Summary for Site			
									Fish Passage Rating	Recommended Actions	Navigation Hazard	Survey Year
Coco Creek												
1	Metal and concrete bridge with abutments	Canadian Pacific Railway	0.00	40.9	Minor	Fair	3.3	--	Passable	None	No	2012
2	Concrete bridge with abutments	Glacier Road	0.11	36.5	Stable	Good	2.6	--	Passable	None	No	2012
3	Three seven-foot-wide, 4.7-foot-high corrugated metal pipe arch culverts	CTH JJ	0.52	46.0	Minor	Lannon stone wall surrounding culvert is failing	0.3	0.4	Passable	Debris removal, general maintenance	N/A	2012
4	One three-foot-diameter; one four-foot-diameter round corrugated metal culverts	Private culverts	0.81	14.0	Stable	Fair	0.4	0.0	Partial barrier at low flows	Remove	N/A	2012
6	One 5.6-foot-wide, 3.2-foot-high; one 5.6-foot-wide, two-foot-high corrugated metal pipe arch culverts	Yench Road	1.00	34.0	Stable	Lannon stone wall surrounding culvert is failing	1.0	0.5	Passable	General maintenance on structure headwall	N/A	2012
7	Four-3.0-foot-diameter concrete round projecting culverts	City of Pewaukee Private crossing	1.13	17.0	Moderate	Poor	0.9	0.0	Restricted Passage	Remove. All flow directed in culvert 2. Culverts 1, 3, and 4 are perched at inlet and outlet	N/A	2015
8	Span wood foot bridge	City of Pewaukee Private crossing	1.86	5.0	Moderate	Fair	--	--	Passable	Replace	N/A	2015
9	One eight-foot-wide, four-foot-high concrete box culvert	CTH KE Primary culvert	2.43	48.0	Stable	Good	1.0	1.5	Passable	None	N/A	2012
10	One eight-foot-wide, four-foot-high concrete box culvert	CTH KE Secondary culvert	2.43	48.0	Stable	Good	1.0	1.5	Passable	None	N/A	2015
12	Wood foot bridge with abutment on one side	Abandoned private crossing	2.69	8.0	Moderate	Fair	--	--	Passable	Remove, not necessary	N/A	2015
13	Three 3.5-foot-diameter smooth concrete headwall culverts	Underground	2.94	N/A	Minor	Fair	--	--	Barrier	Remove and daylight that stretch of stream	N/A	2015
14	One 12.4-foot-wide, six-foot-high concrete box culvert	CTH JK (Lisbon Avenue)	3.20	84.6	Stable	Good	0.2	0.0	Partial barrier at low flows	Remove or reconstruct rock weir	N/A	2012
15	Wood span walking bridge	Private crossing	3.54	--	Moderate	Poor	--	--	Passable	None	N/A	2015
16	Two eight-foot-wide, six-foot-high concrete box culverts	STH 16	3.56	298.0	Stable	Good	0.2	0.0	Passable	Debris removal at inlet	N/A	2012
17	One three-foot-diameter round smooth concrete culvert with apron	Juniper Drive	4.09	68.0	Stable	Fair	--	0.7	Passable	Replace culvert with more appropriate capacity	N/A	2015
18	One three foot diameter plastic round corrugated pipe at inlet. One three foot-wide, 2.5 foot-high square concrete culvert at outlet	Jungbluth Road	4.12	60.0	Stable	Fair	--	0.0	Passable	Replace culvert with more appropriate capacity	N/A	2015
19	One three-foot-diameter round smooth concrete culvert completely exposed	No Road	4.37	16.0	Stable	Poor. Split at seams	--	0.0	Passable	Remove, not necessary	N/A	2015

Table continued on next page.

Table E.1 (Continued)

Structure Number on Map E.1 and Figure E.1	Description	Road Crossing	River Mile	Culvert/ Bridge Length (feet)	Ditch Erosion	General Condition	Limiting Water Depth (feet)[a]	Embedded Depth (feet)	Priority Rating and Recommendation Summary for Site: Fish Passage Rating	Recommended Actions	Navigation Hazard	Survey Year
						Coco Creek (continued)						
20	Two three-foot-diameter round corrugated metal culverts	South Willow Creek Drive	4.68	43.0	Minor	Fair	--	0.2	Partial barrier at low flows	General maintenance	N/A	2015
21	Two three-foot-diameter round corrugated metal culverts	North Courtland Circle	4.72	44.0	Stable	Fair	--	0.3	Partial barrier at low flows	General maintenance	N/A	2015
22	Two three-foot-diameter round corrugated metal culverts	Lynndale Lane	4.95	41.0	Stable	Fair	--	0.5	Partial barrier at low flows	General maintenance	N/A	2015
						Tributary to Coco Creek						
5	Four five-foot-diameter round concrete culverts	STH 16	0.04	200.0	Stable	Good	1.6	0.6	Partial barrier	Replace culverts with more appropriate capacity	N/A	2012
11	One three-foot-diameter round corrugated metal culvert	CTH JJ (Capitol Drive)	0.18	35.5	Stable	Good	--	0.4	Partial barrier at low flows	Reconstruct around apron	N/A	2015
23	Two four-foot-diameter round corrugated metal culverts	CTH KF (Ryan Road)	1.34	94.0	Minor	Fair	0.2	0.2	Partial barrier at low flows	Remove boulder/ cobble pile at inlet	N/A	2012
						Meadowbrook Creek						
24	One 10-foot-wide, seven-foot-high corrugated metal pipe arch culvert	CTH SS	0.00	38.0	Moderate	Fair	1.6	0.0	Passable	General maintenance, erosion control at inlet	N/A	2012
25	One 5.3-foot-wide, 5.9-foot-high ellipse corrugated metal culvert	CTH G	1.11	58.7.0	Minor	Concrete wall surrounding culvert is failing	3.0	0.1	Passable	General maintenance, debris clearing downstream of outlet	N/A	2012
25a (not pictured)	Man-made weir made of riprap and cobble	Man-made weir	1.45	--	--	--	--	--	Partial barrier at low flows	Removal	N/A	2012
25b (not pictured)	Man-made weir made of riprap and cobble	Man-made weir	1.64	--	--	--	--	--	Partial barrier at low flows	Removal	N/A	2012
26	One four-foot-wide, 3.4-foot-high ellipse corrugated metal culvert	Pewaukee Golf Club bridge #1	1.68	20.0	Moderate	Fair	--	0.0	Passable	General maintenance, inlet has minor lip, restricted flow	N/A	2015
27	One four-foot-diameter round corrugated metal culvert	Pewaukee Golf Club bridge #2	1.76	20.0	Stable	Poor, crushed	--	1.0	Barrier	Replace, severely crushed in center. Inlet end raised.	N/A	2015
28	One three-foot-diameter round corrugated metal culvert	Pewaukee Golf Club bridge #3	1.82	20.0	Minor	Poor, rusted through	--	0.3	Passable	Replace	N/A	2015
29	One three-foot-diameter round corrugated metal culvert	Pewaukee Golf Club bridge #4	1.92	20.0	Stable	Fair	--	0.1	Passable	None	N/A	2015
30	One three-foot-diameter round corrugated metal culvert	Pewaukee Golf Club bridge #5	2.02	20.0	Stable	Poor, rusted through	--	0.0	Passable	Replace	N/A	2015
31	One 10-foot-wide, six-foot-high concrete box culvert	Fieldhack Drive	2.10	65.0	Stable	Good	0.3	0.9	Passable	General maintenance, debris removal upstream	N/A	2012
32	One 10-foot-wide, six-foot-high concrete box culvert	Milkweed Lane	2.35	65.0	Minor	Good	0.1	0.2	Partial barrier at low flows	Erosion control at inlet	N/A	2012

Table continued on next page.

Table E.1 (Continued)

Structure Number on Map E.1 and Figure E.1	Description	Road Crossing	River Mile	Culvert/ Bridge Length (feet)	Ditch Erosion	General Condition	Limiting Water Depth (feet)[a]	Embedded Depth (feet)	Priority Rating and Recommendation Summary for Site: Fish Passage Rating	Recommended Actions	Navigation Hazard	Survey Year
Meadowbrook Creek (continued)												
33	One three-foot-diameter round corrugated metal culvert at inlet. Outlet is cement	Private crossing	2.55	20.0	Moderate	Fair	--	0.0	Passable	Remove, not necessary	N/A	2015
Zion Creek												
34	Two six-foot-wide, 4.8-foot-high corrugated metal pipe arch culverts	Louis Avenue	0.04	35.7	Minor	Fair	1.7	0.5	Passable	Erosion control at inlet	N/A	2012
35	One eight-foot-wide, five-foot-high concrete box culvert	Oakton Avenue	0.19	52.6	Stable	Good	0.3	0.0	Passable	Monitor condition of adjacent Lannon stone walls	N/A	2012
36	Metal weir at span golf cart bridge	Western Lakes Golf Club	0.32	--	--	--	--	--	Barrier	Remove	N/A	2015
37	One 4.7-foot-wide, 3.0-foot-high ellipse corrugated metal culvert	Western Lakes Golf Club	0.53	30.0	Minor	Fair	--	0.0	Passable	None	N/A	2015
38	One 4.7-foot-wide, 3.0-foot-high ellipse corrugated metal culvert	Western Lakes Golf Club	0.57	24.0	Moderate	Fair, bent inlet	--	0.0	Passable	General maintenance, remove wooden ledge from inlet	N/A	2015
39	One 4.7-foot-wide, 3.0-foot-high ellipse corrugated metal culvert	Western Lakes Golf Club	0.64	24.0	Minor	Fair	--	0.0	Passable	None	N/A	2015
40	One 3.0-foot-wide, 2.0-foot-high ellipse corrugated metal culvert	Western Lakes Golf Club	0.74	30.0	Minor	Fair	--	0.0	Barrier	Reconstruct, outlet perched 0.7-feet, inlet is being undercut; above streambed	N/A	2015
41	One 3.0-foot-wide, 2.0-foot-high ellipse corrugated metal culvert	Western Lakes Golf Club	0.84	30.0	Minor	Fair	--	0.0	Passable	None	N/A	2015
42	One 12-foot-wide, six-foot-high concrete box culvert	Gof Road and Interstate 94	1.00	250.0	Minor	Good	--	0.2	Passable	None	N/A	2015

Note: The yellow and red colors indicate moderate and high priority ratings or problems to address fish passage and navigation hazards in the watershed.

[a] *The 2015 instream survey data does not contain limiting water depth.*

Source: SEWRPC

Figure E.1
Stream Crossings and Dam Locations in the Pewaukee Lake Tributaries: 2012 and 2015

1- CANADIAN PACIFIC RAILWAY
COCO CREEK (RM 0.00)

2-GLACIER ROAD
COCO CREEK (RM 0.11)

3- CTH JJ
COCO CREEK (RM 0.52)

4- PRIVATE CULVERTS
COCO CREEK (RM 0.81)

5- STH 16
COCO CREEK **TRIBUTARY** (RM 0.04)

6- YENCH ROAD
COCO CREEK (RM 1.00)

7- CITY OF PEWAUKEE CROSSING
COCO CREEK (RM 1.13)

8- PRIVATE WALKING BRIDGE
COCO CREEK (RM 1.86)

9- CTH KE PRIMARY CULVERT
COCO CREEK (RM 2.43)

10- CTH KE **SECONDARY** CULVERT
COCO CREEK (RM 2.43)

11 CTH JJ
COCO CREEK **TRIBUTARY** (RM 0.18)

12- ABANDONED PRIVATE CROSSING
COCO CREEK (RM 2.69)

Figure E.1 (Continued)

13- UNDERGROUND CULVERTS
COCO CREEK (RM 2.94)

14- CTH JK (LISBON AVENUE)
COCO CREEK (RM 3.20)

15-PRIVATE WALKING BRIDGE
COCO CREEK (RM 3.54)

16- STH 16
COCO CREEK (RM 3.56)

17- JUNIPER WAY
COCO CREEK (RM 4.09)

18- JUNGBLUTH ROAD
COCO CREEK (RM 4.12)

19- ABANDONED CULVERT
COCO CREEK (RM 4.37)

20- S. WILLOW CREEK DRIVE
COCO CREEK (RM 4.68)

21- N. COURTLAND CIRCLE
COCO CREEK (RM 4.72)

22- LYNNDALE LANE
COCO CREEK (RM 4.95)

23- CTH KF (RYAN ROAD)
COCO CREEK **TRIBUTARY** (RM 1.34)

24- CTH SS
MEADOWBROOK (RM 0.00)

Figure E.1 (Continued)

25- CTH G
MEADOWBROOK (RM 1.11)

26- PEWAUKEE GOLF CLUB BRIDGE 1
MEADOWBROOK (RM 1.68)

27- PEWAUKEE GOLF CLUB BRIDGE 2
MEADOWBROOK (RM 1.76)

28- PEWAUKEE GOLF CLUB BRIDGE 3
MEADOWBROOK (RM 1.82)

29- PEWAUKEE GOLF CLUB BRIDGE 4
MEADOWBROOK (RM 1.92)

30- PEWAUKEE GOLF CLUB BRIDGE 5
MEADOWBROOK (RM 2.02)

31- FIELDHACK DRIVE
MEADOWBROOK (RM 2.10)

32- MILKWEED LANE
MEADOWBROOK (RM 2.35)

33- PRIVATE CULVERT
MEADOWBROOK (RM 2.55)

34- LOUIS AVENUE
ZION CREEK (RM 0.04)

35- OAKTON AVENUE
ZION CREEK (RM 0.19)

36- WESTERN LAKES GOLF CLUB WEIR
ZION CREEK (RM 0.32)

Figure E.1 (Continued)

37- WESTERN LAKES GOLF CLUB CULVERT 1 ZION CREEK (RM 0.53)

38- WESTERN LAKES GOLF CLUB CULVERT 2 ZION CREEK (RM 0.57)

39-WESTERN LAKES GOLF CLUB CULVERT 3 ZION CREEK (RM 0.64)

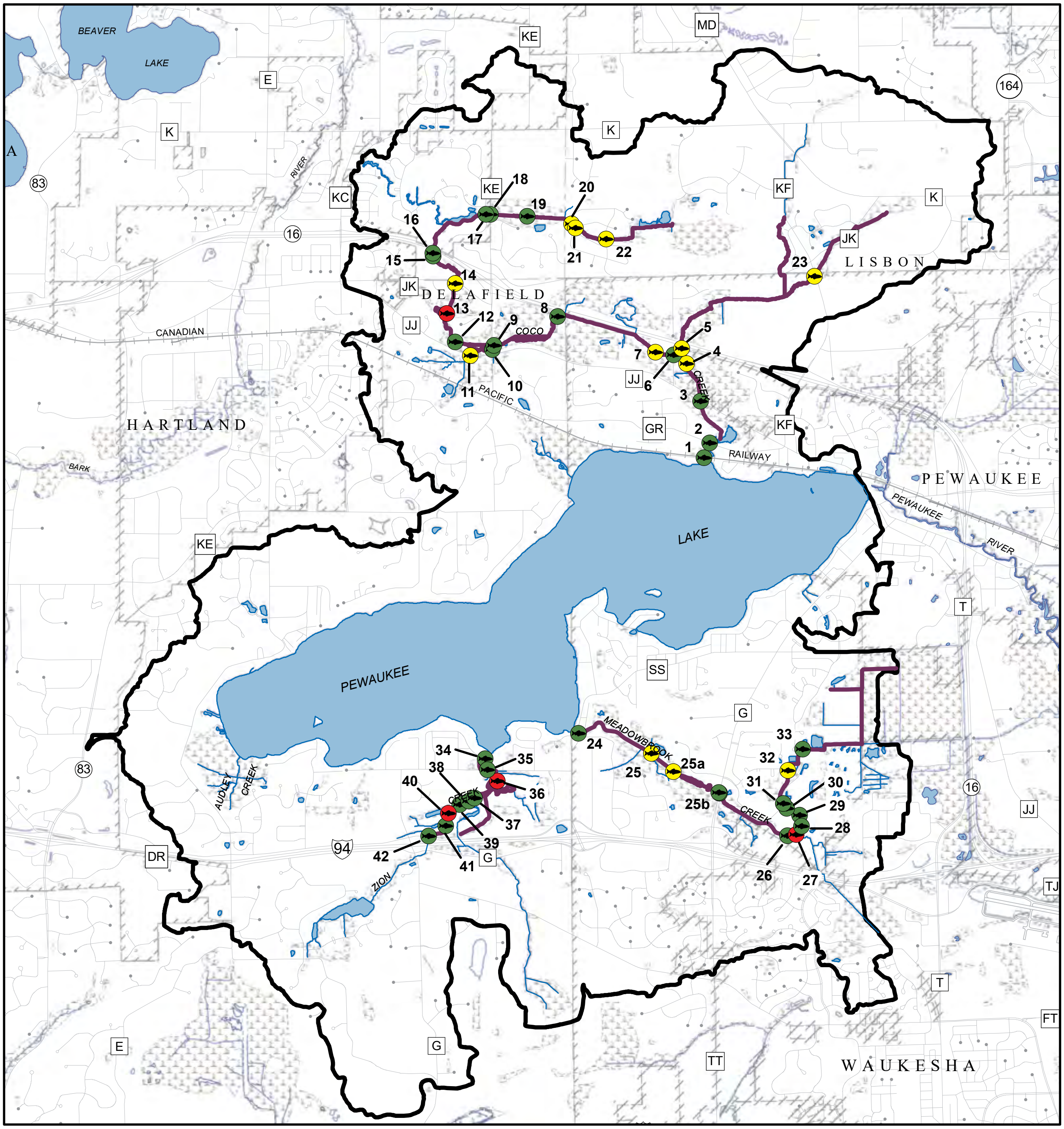
40- WESTERN LAKES GOLF CLUB CULVERT 4 ZION CREEK (RM 0.74)

41- WESTERN LAKES GOLF CLUB CULVERT 5 ZION CREEK (RM 0.84)

42- I-94 ZION CREEK (RM 1.00)

Source: SEWRPC

Map E.1
Fish Passage Assessments at Stream Crossings in the Pewaukee Lake Tributaries: 2012 and 2015



FISH PASSAGE RATING:
(see Table E.1 and Figure E.1 for details of each crossing)

3 PASSABLE

7 PARTIAL BARRIER AT ALL TIMES OR DURING LOW FLOW PERIODS

13 SIGNIFICANT BARRIER

SURFACE WATER

STREAM (NOT SURVEYED)

WATERSHED BOUNDARY

WETLAND

STREAM (SURVEYED)

N

0 1,250 2,500 5,000 Feet

Source: SEWRPC

Note: Structures were surveyed during the summer of 2012 and 2015, indicating fish passage ratings may have changed since the survey was taken.

TYPES OF CROSSINGS[1]

- The number of stream crossings should be minimized.

- If a crossing is necessary, structures that maintain to the extent possible the existing streambed and bank conditions are preferable; therefore, bridges spanning streams are preferable to other structures.

- If a culvert is necessary, open bottom structures are preferable to closed bottom structures.

- If a closed bottom culvert is necessary, box culverts, elliptical, or pipe arch culverts are preferable to round pipe culverts, because round pipes generally reduce stream width to a much larger degree than the aforementioned structures, causing long term upstream and downstream passage limitations (see physical considerations below).

- Offsetting Multiple Culverts—If multiple culverts are necessary, it is recommended that the culvert inverts be offset vertically and only one culvert be designed to provide passage during low flow conditions and the additional culverts be used to pass the higher flow events (see Figure E.2). Therefore, the low flow culvert will be the only culvert, in a series of two or more culverts, designed to provide fish passage during low flows and shall meet the physical requirements of passage above.

BIOLOGICAL CONSIDERATIONS[2]

- Contact the area WDNR fisheries manager prior to design and construction to minimize impacts.[3]

- Species of fish present (coldwater, warmwater, threatened, endangered, species of special concern).

- Life stages to potentially be impacted (e.g., egg development within substrates should be avoided).

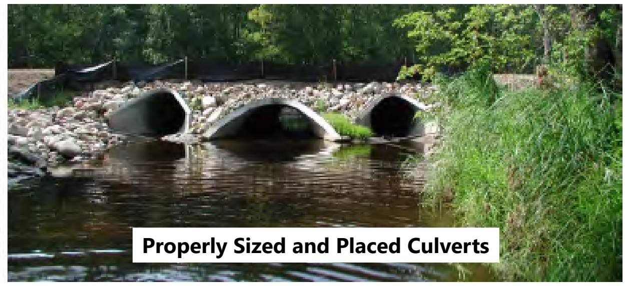
- Migration timing of affected species/ life stages (e.g., adult spawning times should be avoided).

PHYSICAL CONSIDERATIONS[4]

It is important to note that in order to achieve the minimum physical criteria outlined below, the culvert(s) will need to be oversized as part of the design to ensure adequate long-term fish passage as well as the ability to pass the design period rainfall event.

It is understood that it may not be possible to achieve some of the minimum passage criteria below based upon specific on-site conditions or constraints, however, the closer the designed and completed culvert can meet these criteria the better the long-term passage and overall sustainability of the fishery will be achieved in this region.

Figure E.2
Considerations for Culvert Design and Placement



Source: Minnesota Department of Natural Resources

Provide Adequate Depth

- Slope—Culvert should be installed with a slope that matches the riffle slope as measured in the thalweg[5] (see Minnesota DNR guidelines)[6]

- Water Depth and Velocity—Water depths and velocities should be comparable to those found in the natural channel at a variety of flows. Depths should maintain the determined thalweg depth at any point within the culvert during low flow periods (see Minnesota DNR guidelines).

- Installation Below Grade—The culvert should be installed so that the bottom of the structure is buried to a depth equal to 1/6th the bankfull width of the stream (up to two feet) below the natural grade line elevation of the stream bottom (see Minnesota DNR guidelines). The culvert should then be filled to stream grade with natural substrates. The substrates should consist of a variety of gravel ranging from one to four inches in diameter and either mixed with nonuniformly laid riprap or uniformly placed alternate riprap baffles, large enough to be stable during the culvert design discharge, which will ensure stability of substrates during high flow events.

Provide Adequate Width and Openness

- Crossing Span (see Massachusetts Stream Crossings Handbook):[7]

  - General—Spans channel width (a minimum of 1.2 times the bankfull with of the stream).

  - Optimum—Spans the streambed and banks (at least 1.3 times the bankfull width) with sufficient capacity to provide dry passage for wildlife (see Figure E.3). Culvert width shall match the bankfull width (minimum) of the existing channel.

- Openness (see Massachusetts Stream Crossings Handbook):[8]

  - General—Openness ratio (cross sectional area/crossing length) of at least 0.82 feet. The crossing should be wide and high relative to its length.

  - Optimum—Openness ratio of at least 1.64 feet and minimum height of six feet. If conditions significantly reduce wildlife passage near a crossing (e.g. steep embankments, high traffic volumes, or other physical barriers), maintain a minimum height of eight feet and openness ratio of 2.46 feet.

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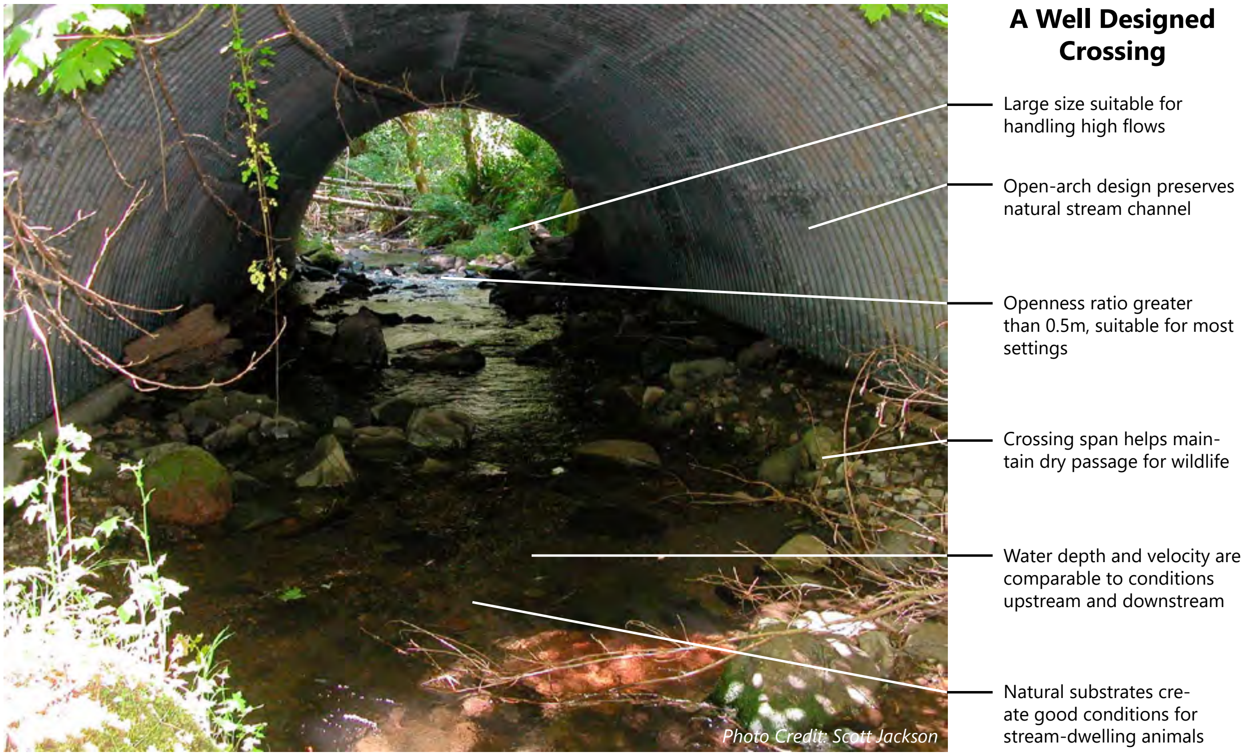
[5] *The thalweg is the lowest point of the streambed.*

[6] *Minnesota DNR,* Best Practices for Meeting DNR General Public Waters Work Permit GP *2004-0001, March 2006.*

Figure E.3
Key Features that Promote Fish and Wildlife Passage



Source: Department of Fish and Game, Massachusetts Stream Crossings Handbook, *June 2012*

Provide Adequate Resting Areas

- Length—Culverts that exceed more than 75 feet in length need to provide additional resting areas (e.g., installation of baffles or weirs) within the culvert to facilitate passage.[9]

Inlet and Outlet Protection

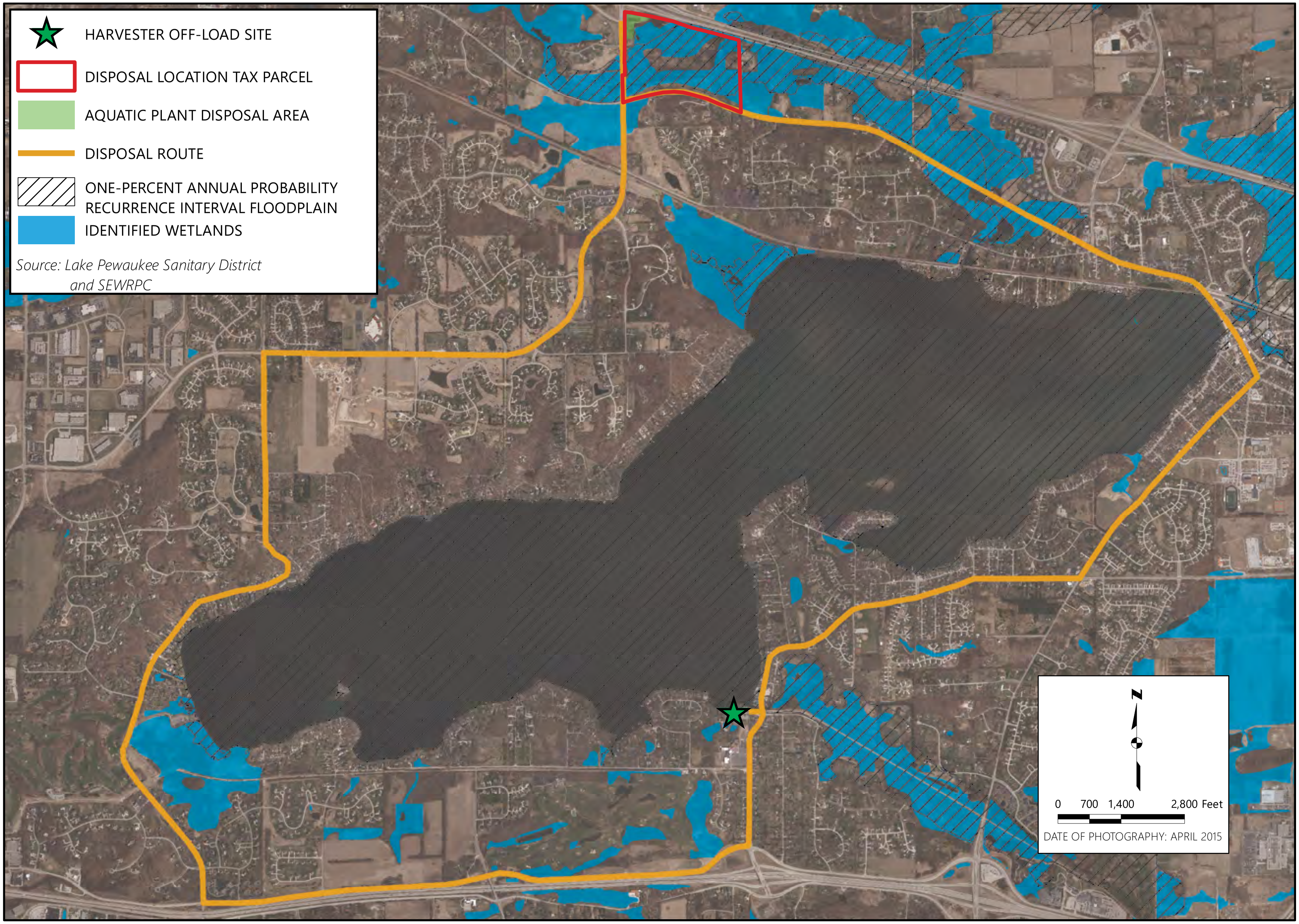
- Align the culvert with the existing stream alignment (e.g., 90 degree bends at the inlet or outlet should be avoided, even though this will increase culvert length, see Minnesota DNR guidelines).[10]
- The low flow culvert should be centered on the thalweg of the channel to ensure adequate depths inside the culvert.
- Provide grade control where there is potential for head-cuts that could degrade the channel.
- It may be necessary to install riprap protection on the outside bank below the outlet to reduce bank erosion during high flow events.

[9] *Thomas Slawski and Timothy Ehlinger, "Habitat Improvement in Box Culverts: Management in the Dark?,"* North American Journal of Fisheries Management, *Volume 18:676-685, 1998.*

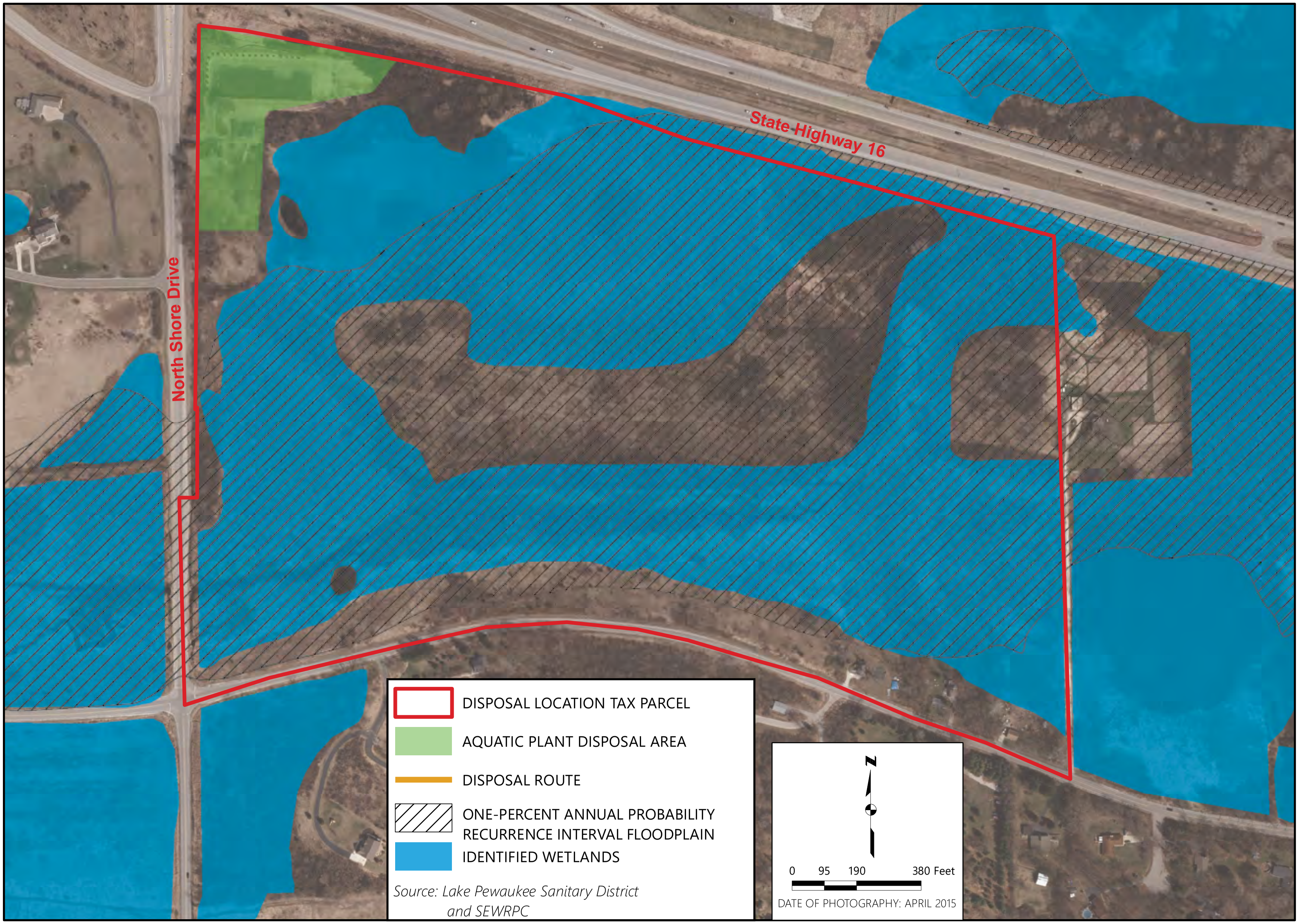
HARVESTING INFORMATION

APPENDIX F

Map F.1
Mechanical Harvesting Disposal Site Location, Off-Load Site, and Haul Routes for Lake the Pewaukee Sanitary District, Pewaukee Lake: 2017-2021

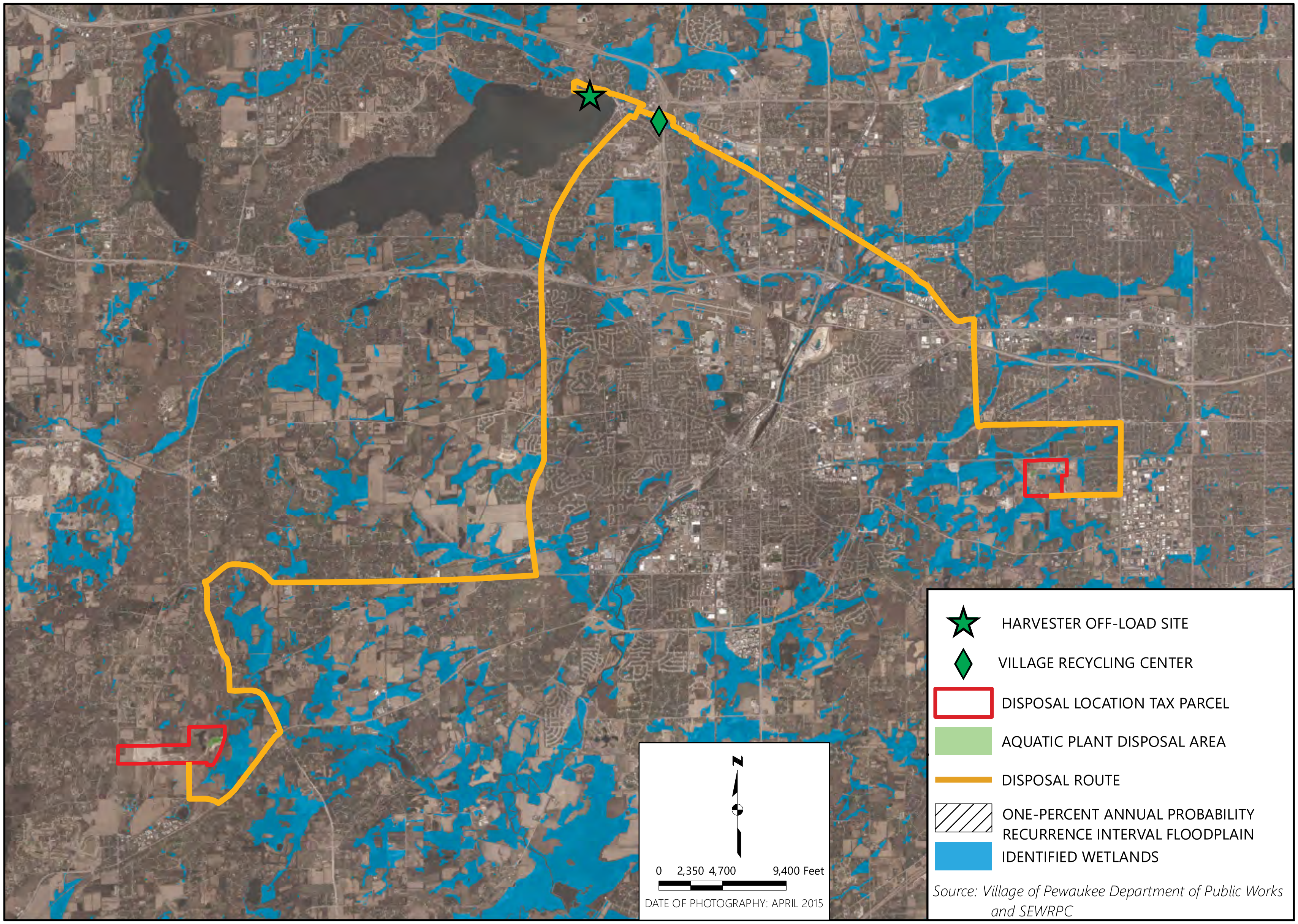


Map F.2
Mechanical Harvesting Disposal Site Location for the Lake Pewaukee Sanitary District, Pewaukee Lake: 2017-2021



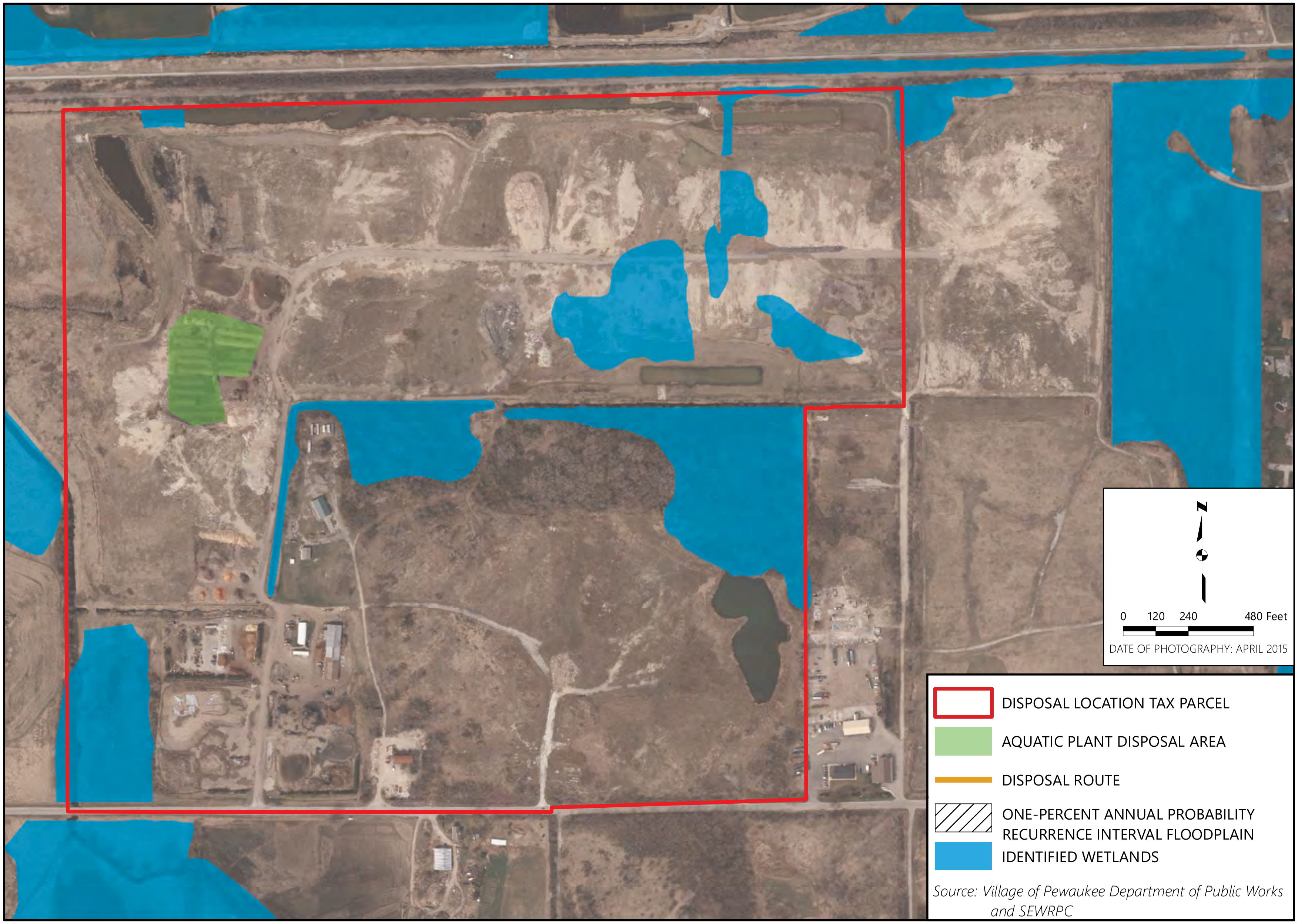
Source: Lake Pewaukee Sanitary District and SEWRPC

Map F.3
Mechanical Harvesting Disposal Site Location, Off-Load Site, and Haul Routes for the Village of Pewaukee Department of Public Works, Pewaukee Lake: 2017-2021



Source: Village of Pewaukee Department of Public Works and SEWRPC

Map F.4
Southeastern Mechanical Harvesting Disposal Site Location for the Village of Pewaukee Department of Public Works, Pewaukee Lake: 2017-2021



Source: Village of Pewaukee Department of Public Works and SEWRPC

Map F.5
Southern Mechanical Harvesting Disposal Site Location for the Village of Pewaukee Department of Public Works, Pewaukee Lake: 2017-2021