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.

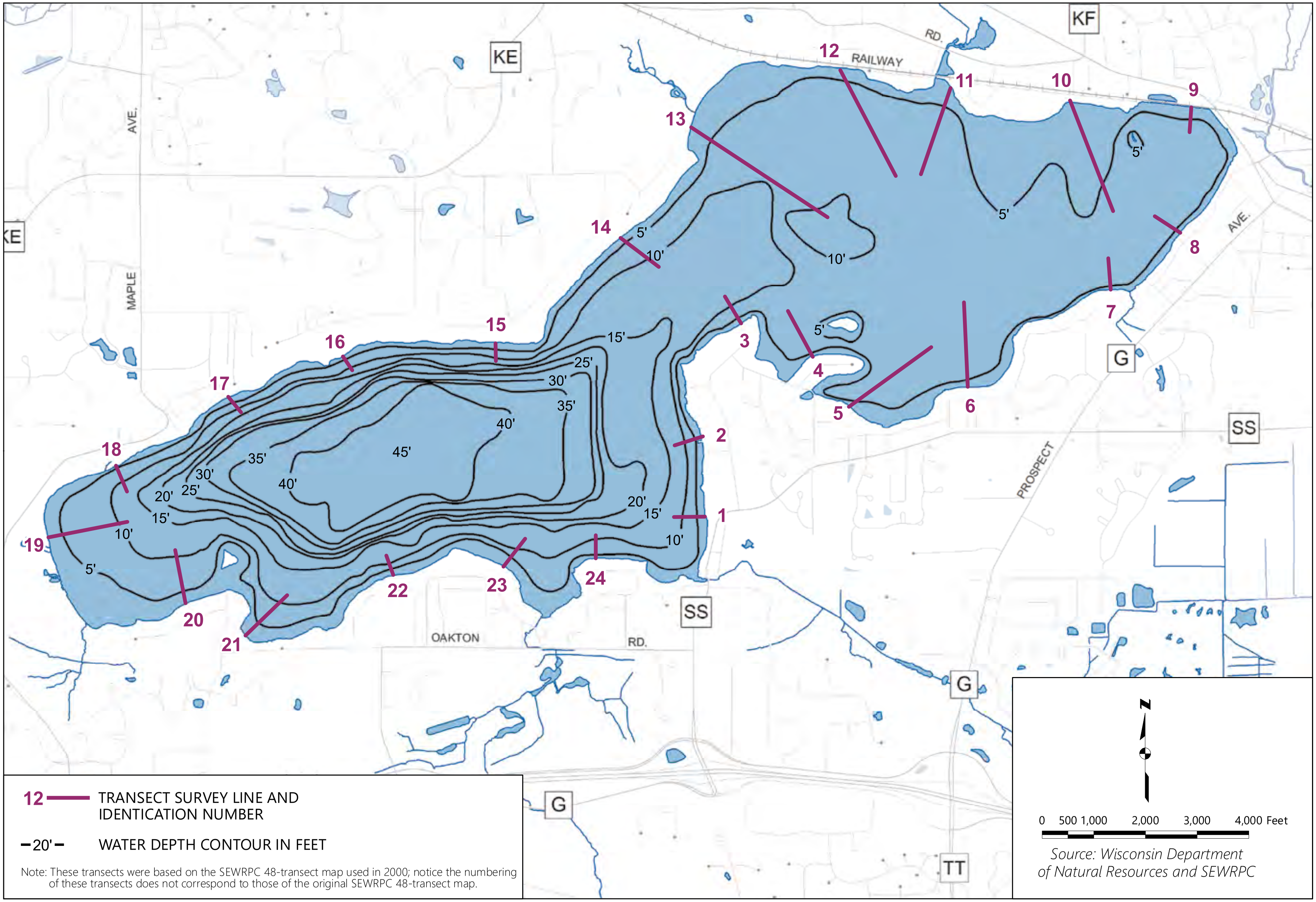
Surveys conducted in 2000-2010 and 2013-2014 used transect methodology; the 2011 and 2016 surveys used the grid-based point-intercept method. Additionally, surveys in 2006-2009 used the same transects; in 2010, the transect locations were shifted and the 2010, 2013 and 2014 surveys all used the shifted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

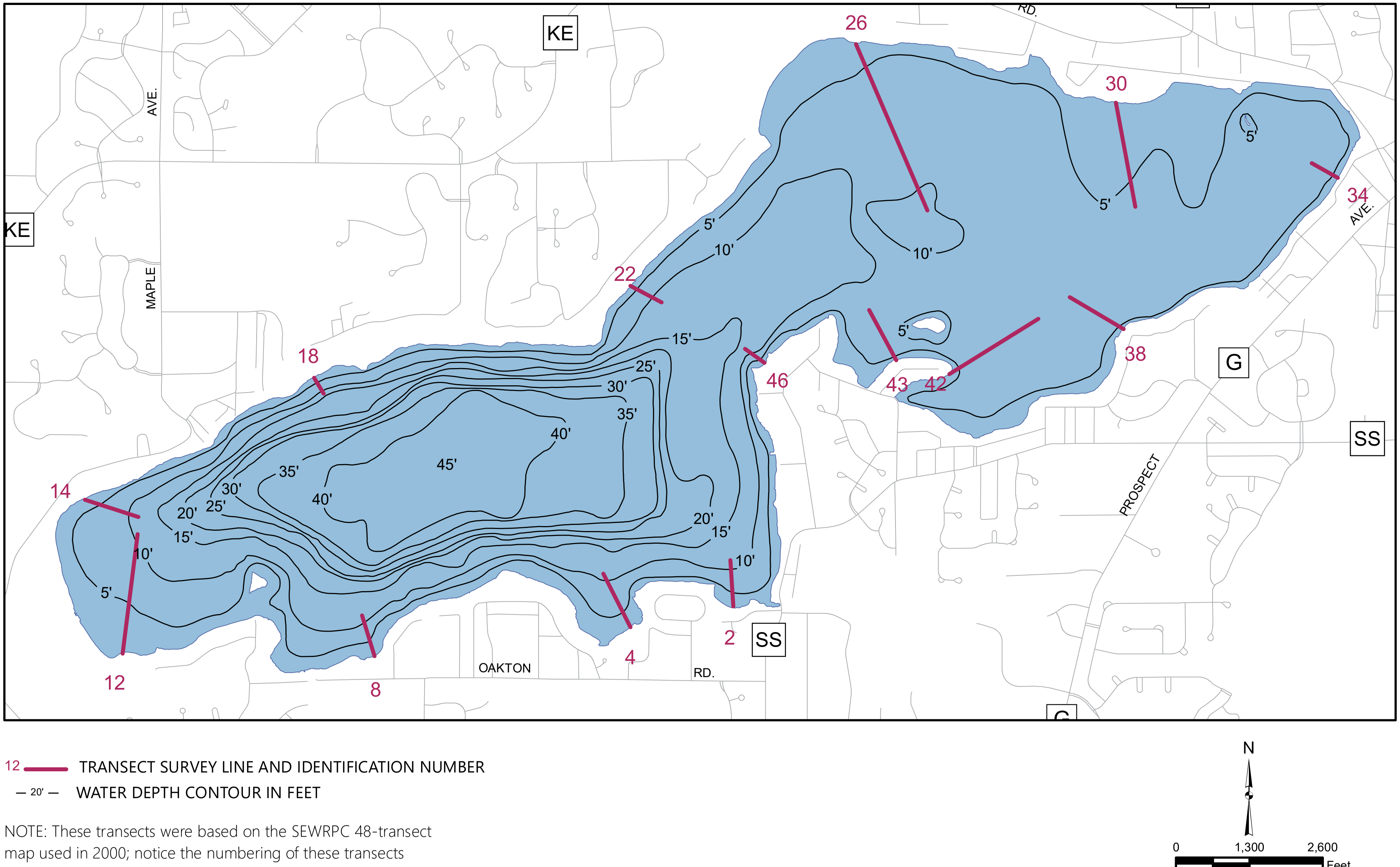
[b] *Considered a high-value aquatic plant species known to offer important values in specific aquatic ecosystems under Section NR 107.08 (4) of the* Wisconsin Administrative Code.

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



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.

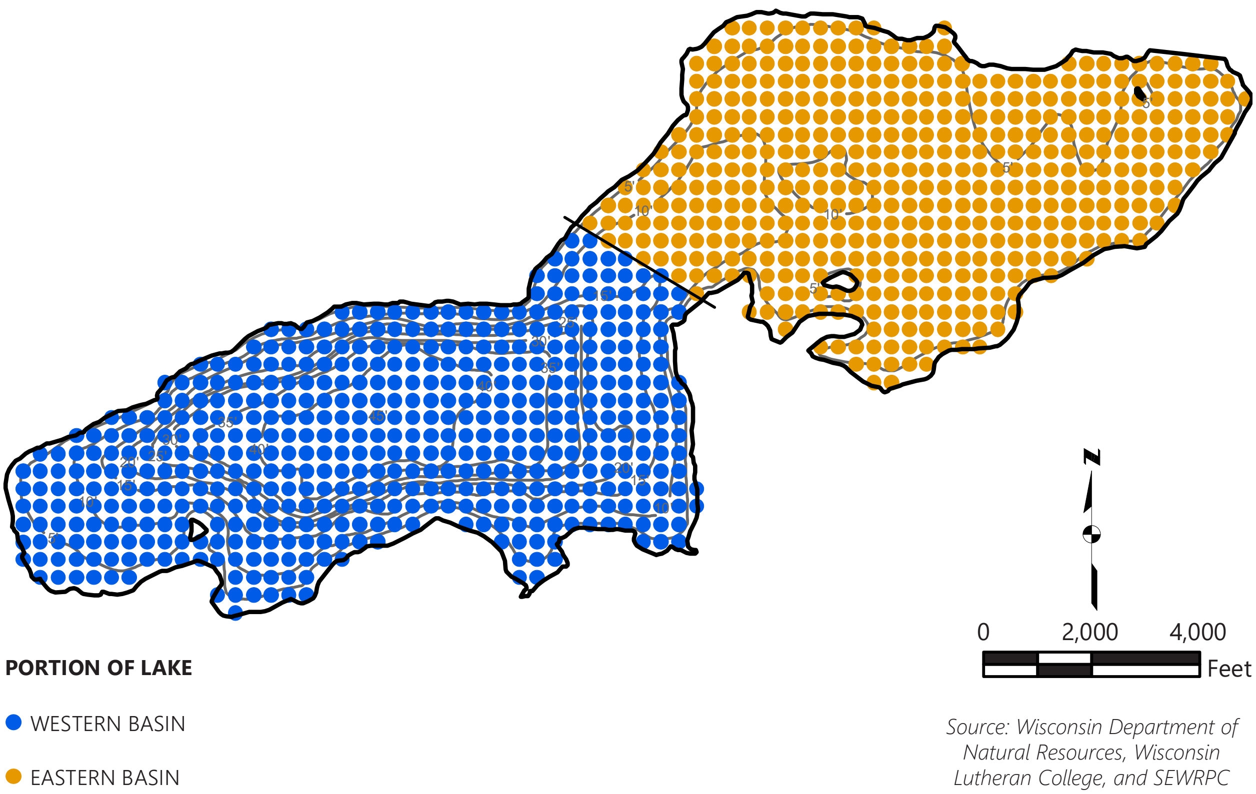
[a] *Designated as invasive and nonnative aquatic plant species pursuant to section NR 109.07 of the* Wisconsin Administrative Code.

[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

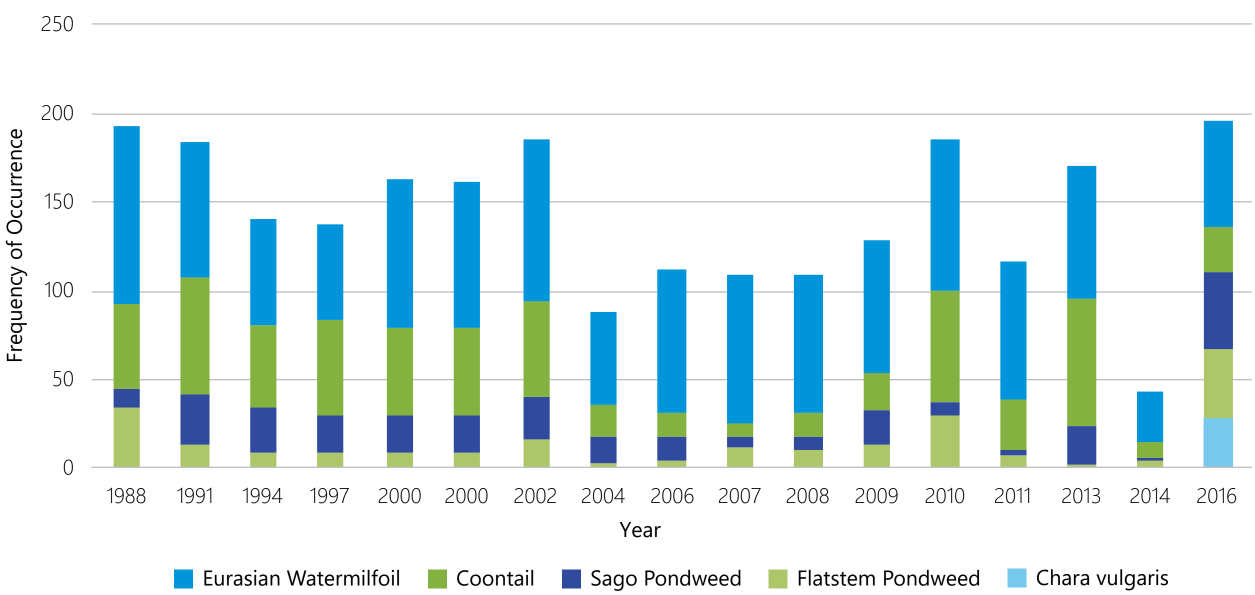
As stated earlier, Wisconsin Lutheran College conducted aquatic plant surveys on Pewaukee Lake in 2000, 2002, 2004, 2006-2011, 2013, 2014, and 2016; results of these surveys are presented in Table 2.24. The 2000 survey conducted by Wisconsin Lutheran College used different transect lines than the 2000 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.

<u>Changes in Species Distribution</u>

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

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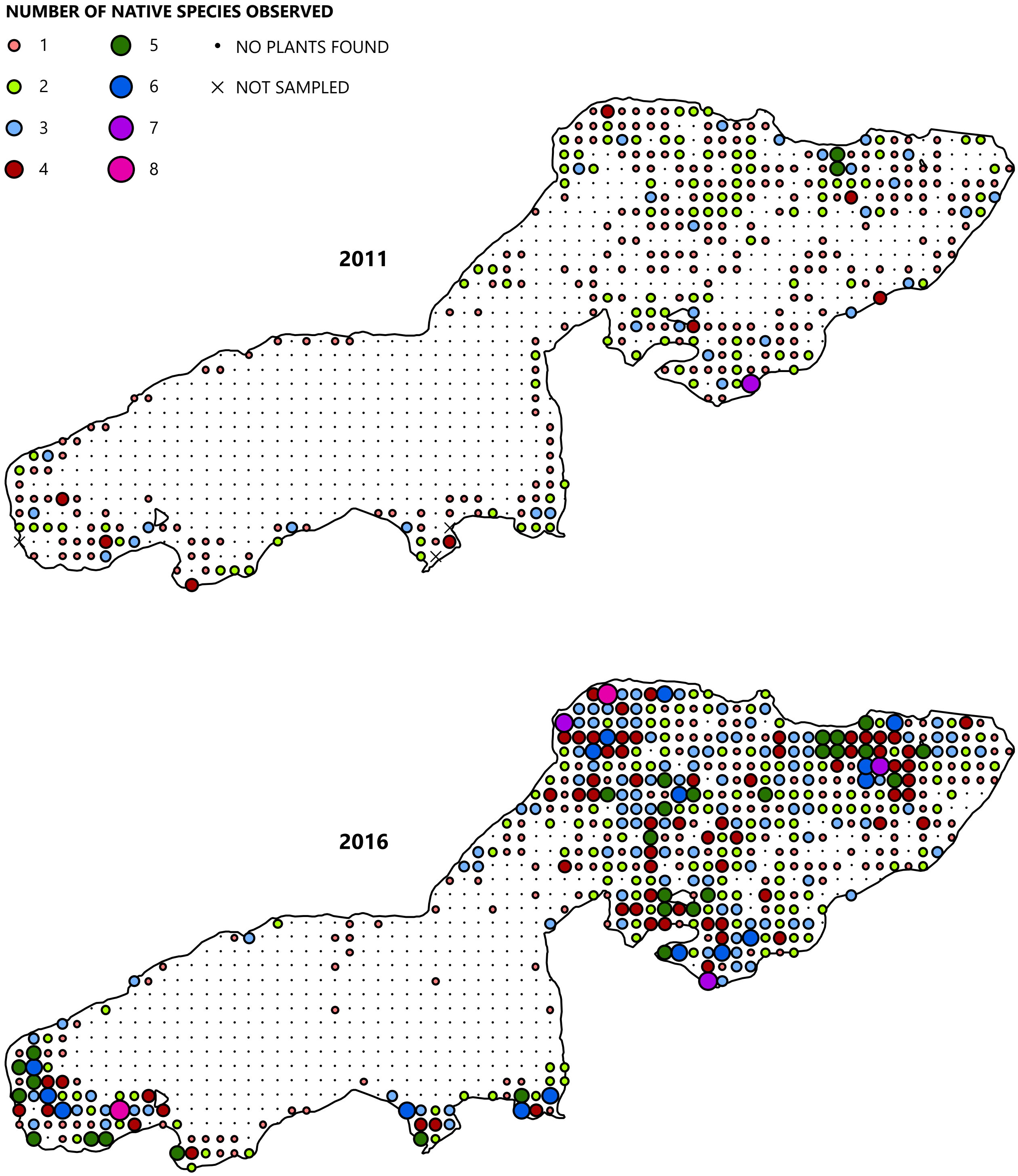
[158] *WDNR, 2010,* op. cit.

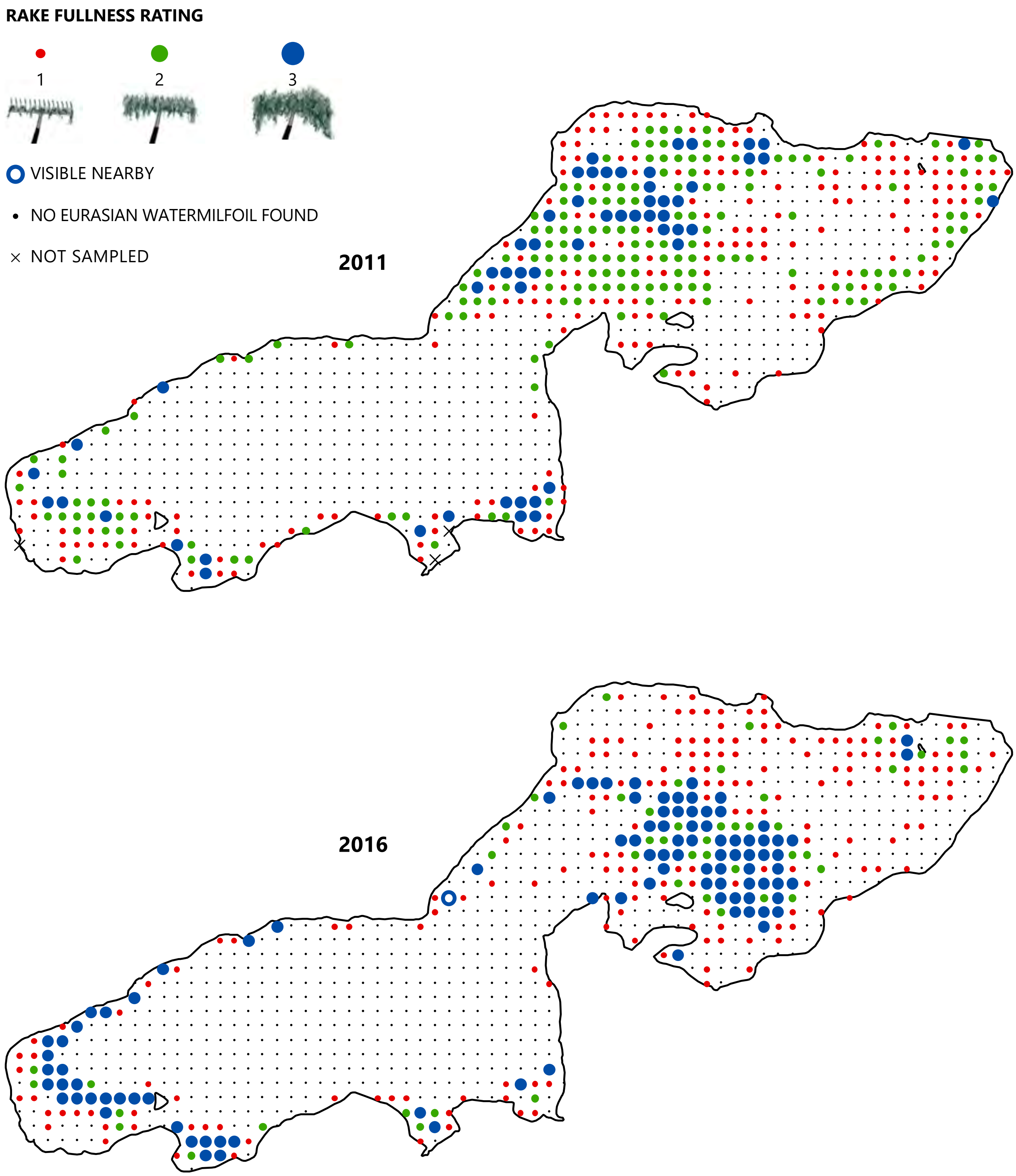
[159] *Wisconsin Lutheran College, 2011,* op. cit.

Figure 2.67
Pewaukee Lake Native Aquatic Plants Species Richness: 2011 Versus 2016



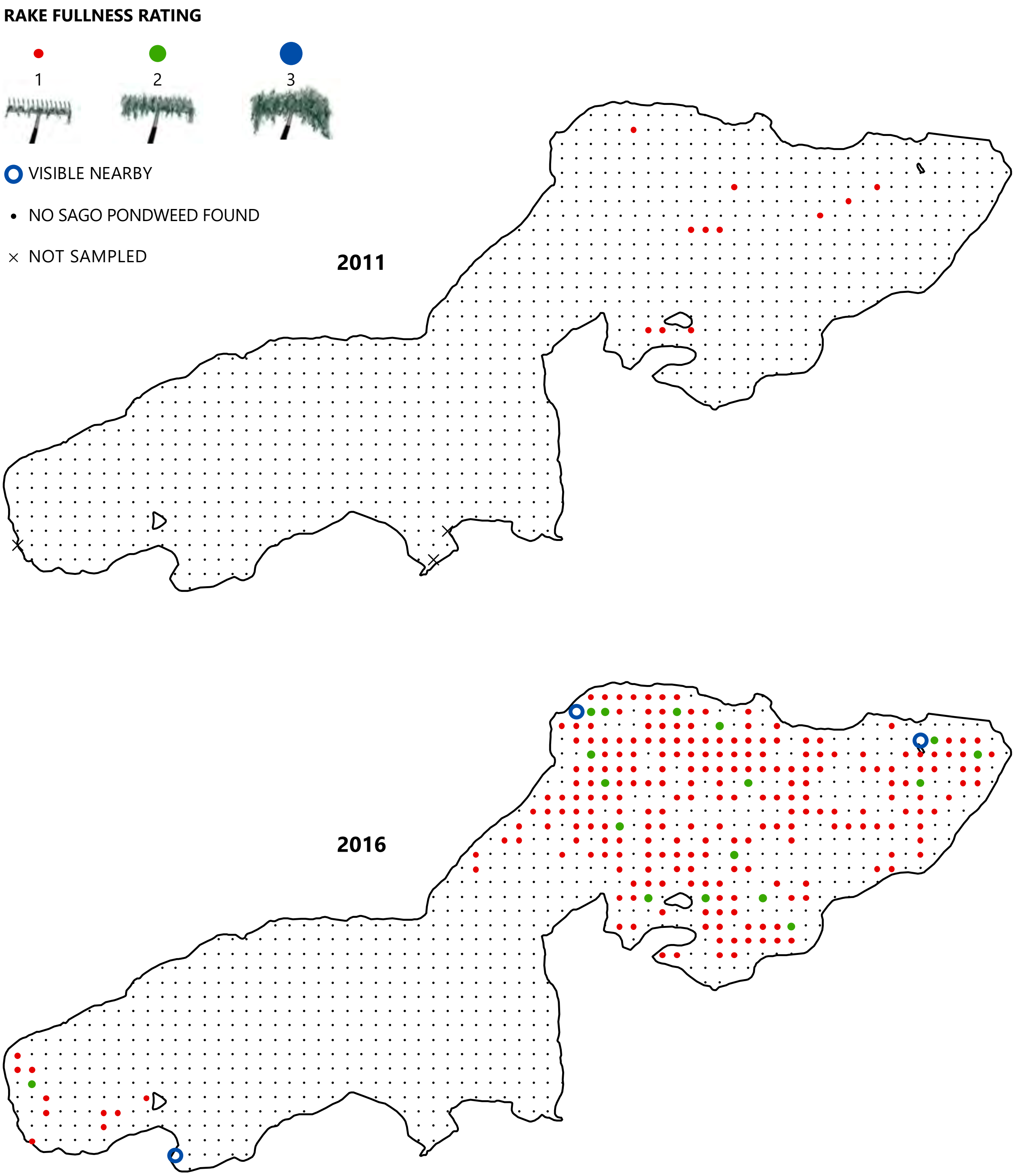
Source: Wisconsin Department of Natural Resources, Wisconsin Lutheran College, and SEWRPC

Figure 2.68
Eurasian Watermilfoil Occurrence in Pewaukee Lake: 2011 Versus 2016



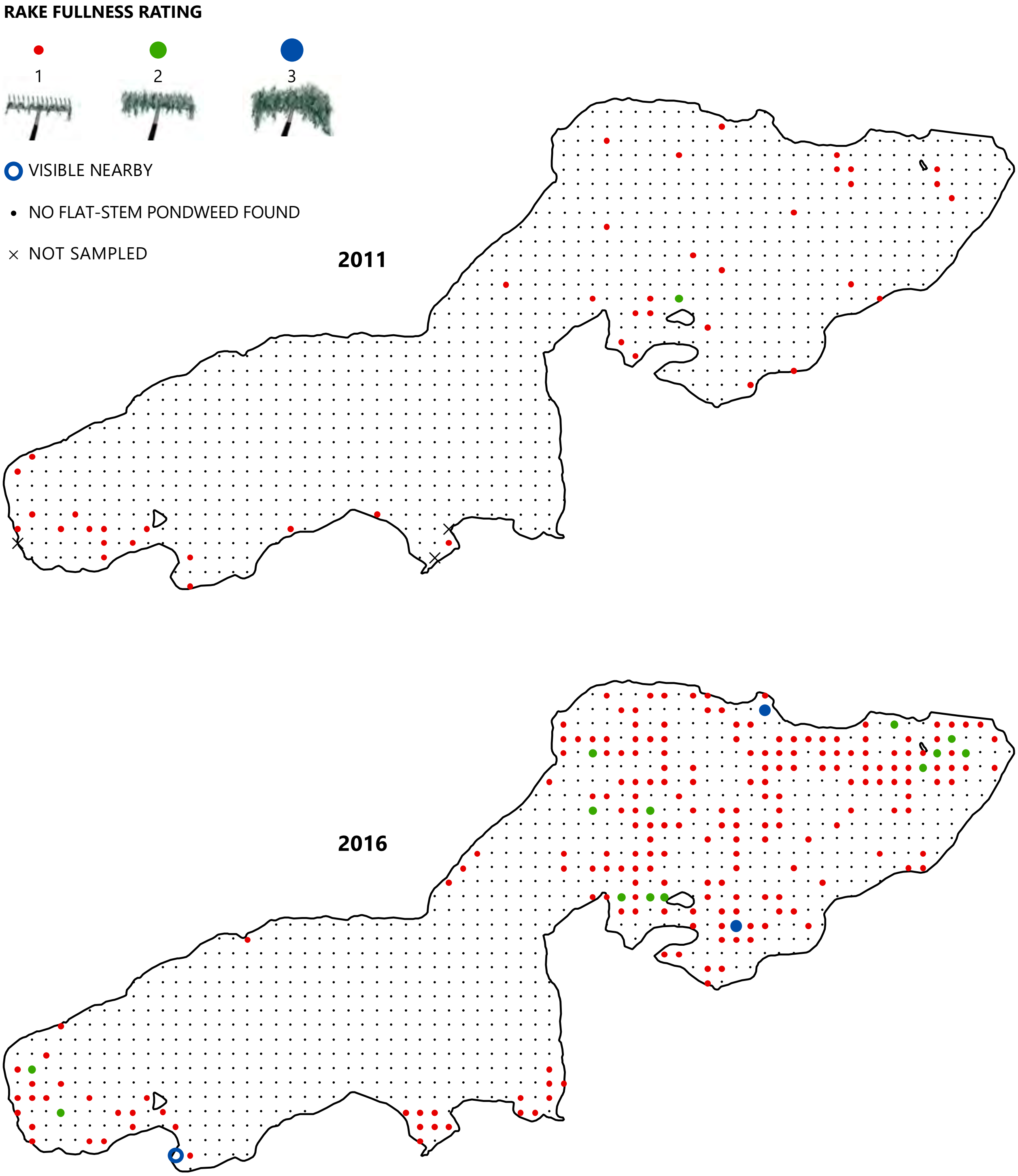
Source: Wisconsin Department of Natural Resources, Wisconsin Lutheran College, and SEWRPC

Figure 2.69
Sago Pondweed Occurrence in Pewaukee Lake: 2011 Versus 2016



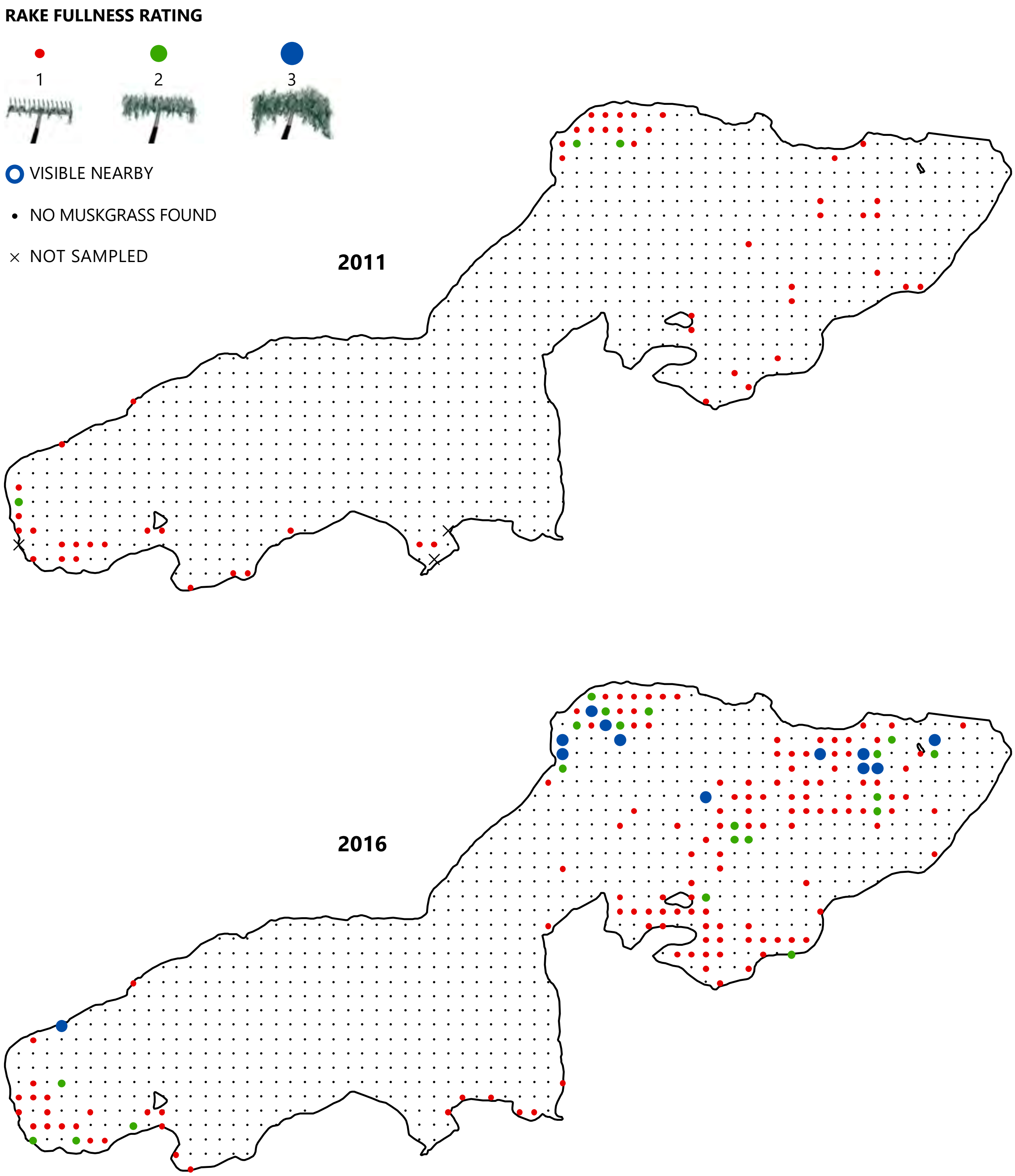
Source: Wisconsin Department of Natural Resources, Wisconsin Lutheran College, and SEWRPC

Figure 2.70
Flat-Stem Pondweed Occurrence in Pewaukee Lake: 2011 Versus 2016



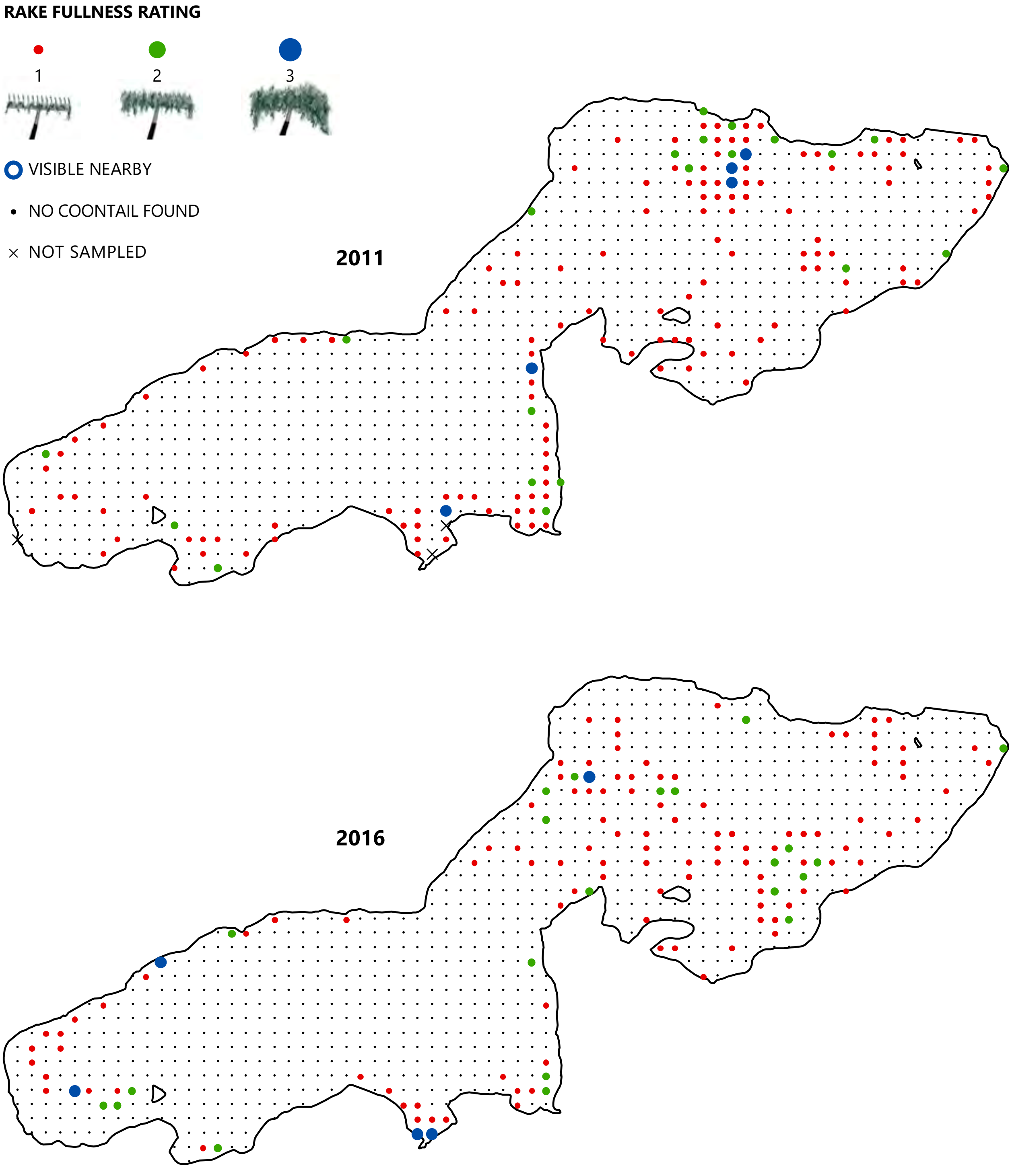
Source: Wisconsin Department of Natural Resources, Wisconsin Lutheran College, and SEWRPC

Figure 2.71
Muskgrass Occurrence in Pewaukee Lake: 2011 Versus 2016



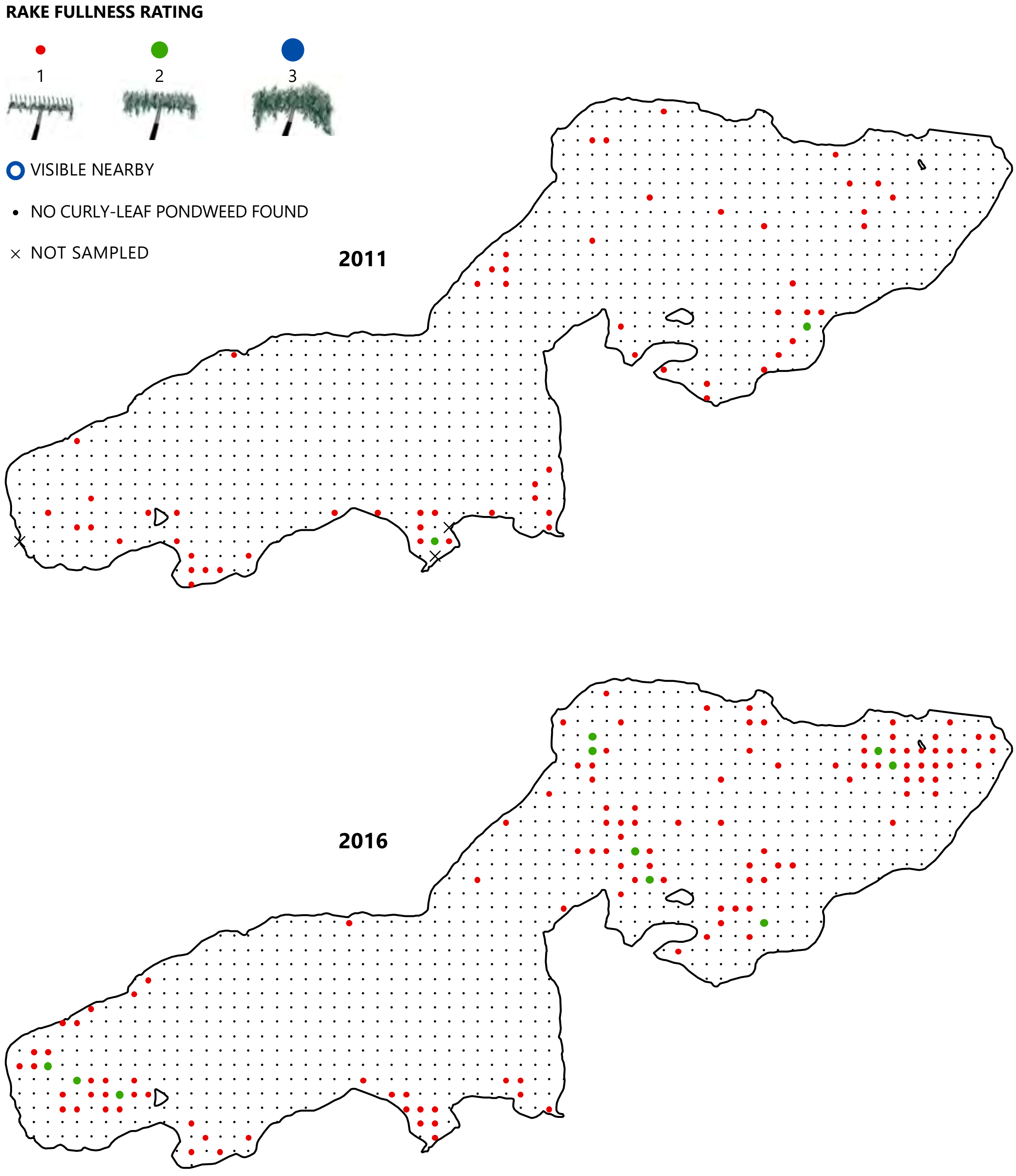
Source: Wisconsin Department of Natural Resources, Wisconsin Lutheran College, and SEWRPC

Figure 2.72
Coontail Occurrence in Pewaukee Lake: 2011 Versus 2016



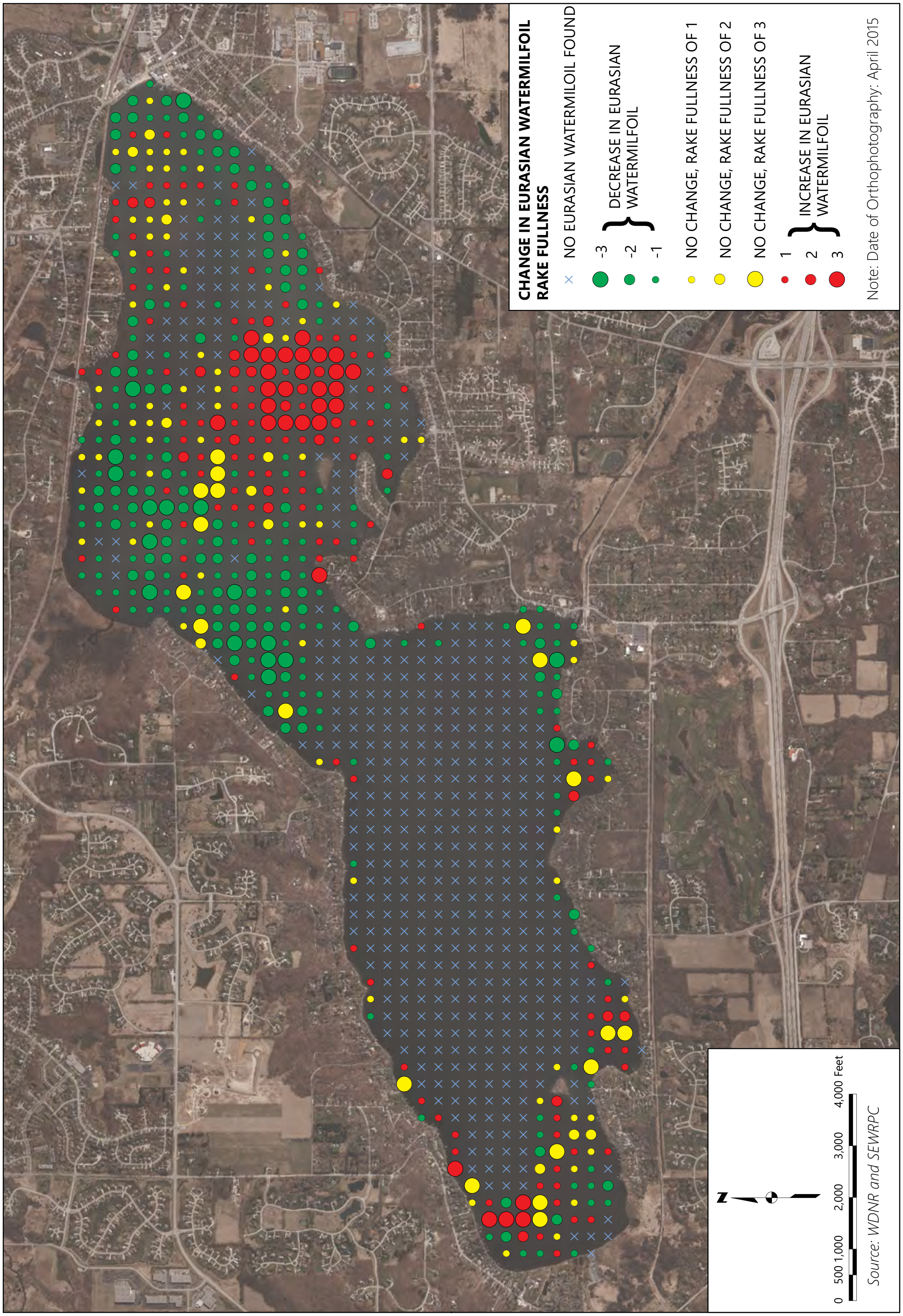
Source: Wisconsin Department of Natural Resources, Wisconsin Lutheran College, and SEWRPC

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.

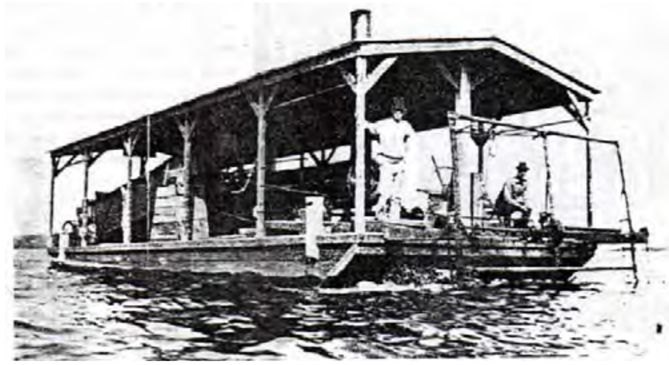
<u>History of Harvesting in Pewaukee Lake</u>

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]

[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]

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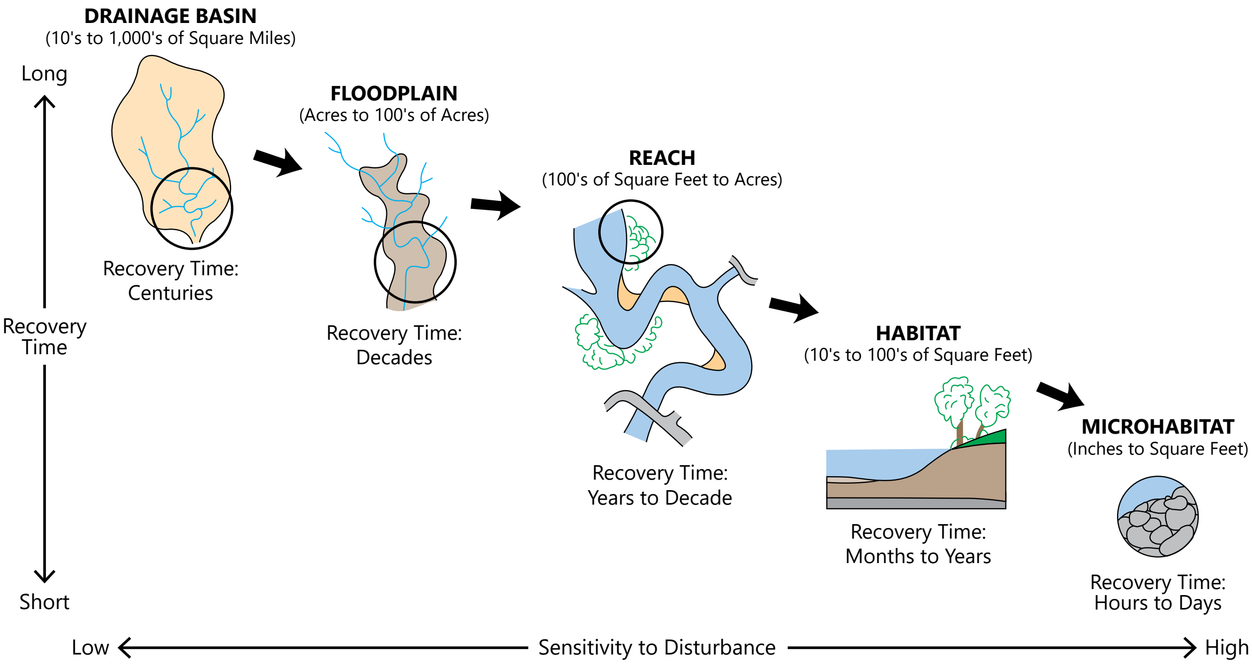
[179] *C.A. Frissell, W.J. Liss, C.E. Warren, and M.D. Hurley, "A Hierarchical Framework for Stream Classification: Viewing Streams in a Watershed Context,"* Journal of Environmental Management*, 10: 199-214, 1986.*

[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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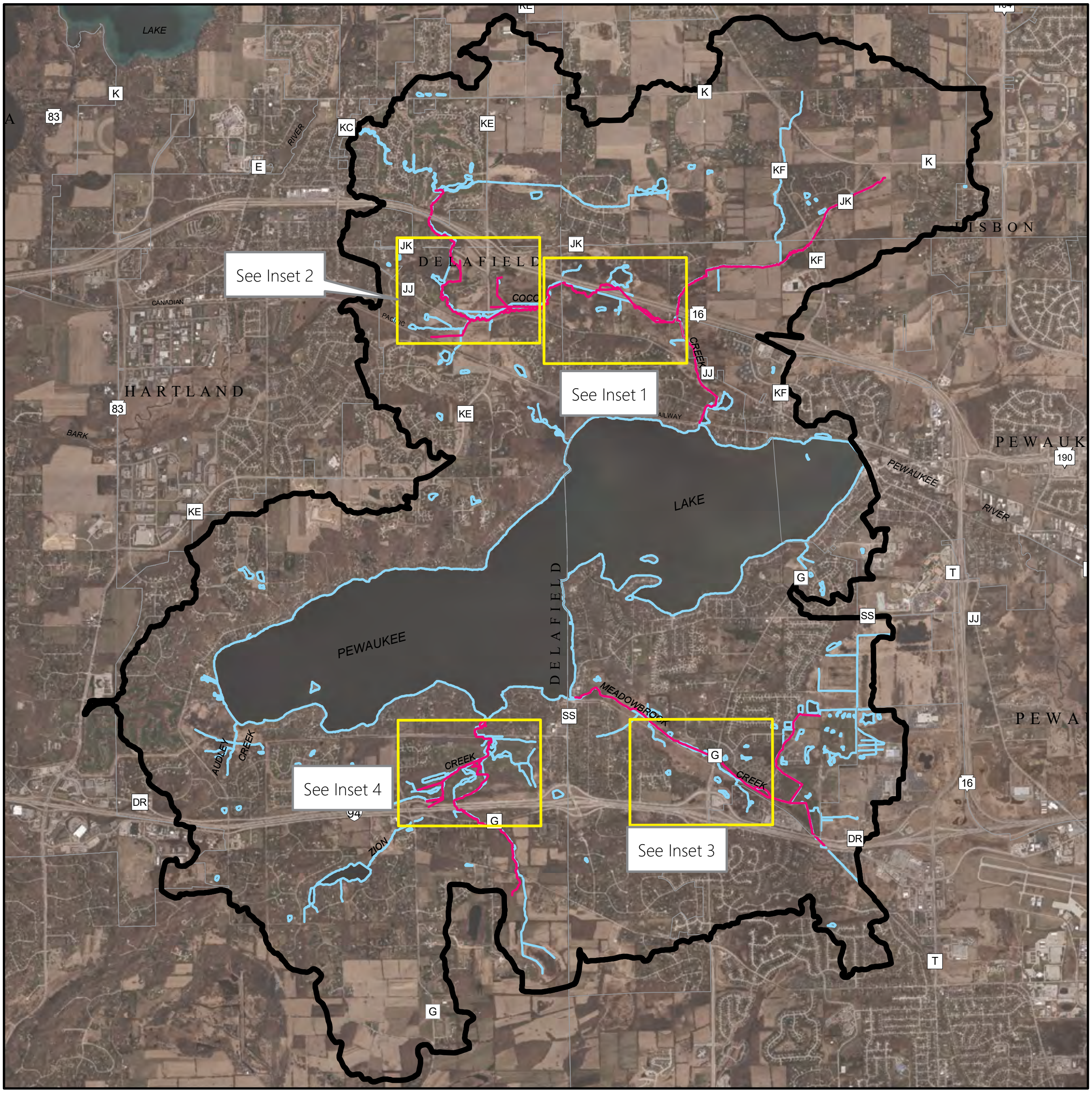
[184] *N.D. Gordon, et al.,* Stream Hydrology*, John Wiley and Sons, April 1993, page 318.*

[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

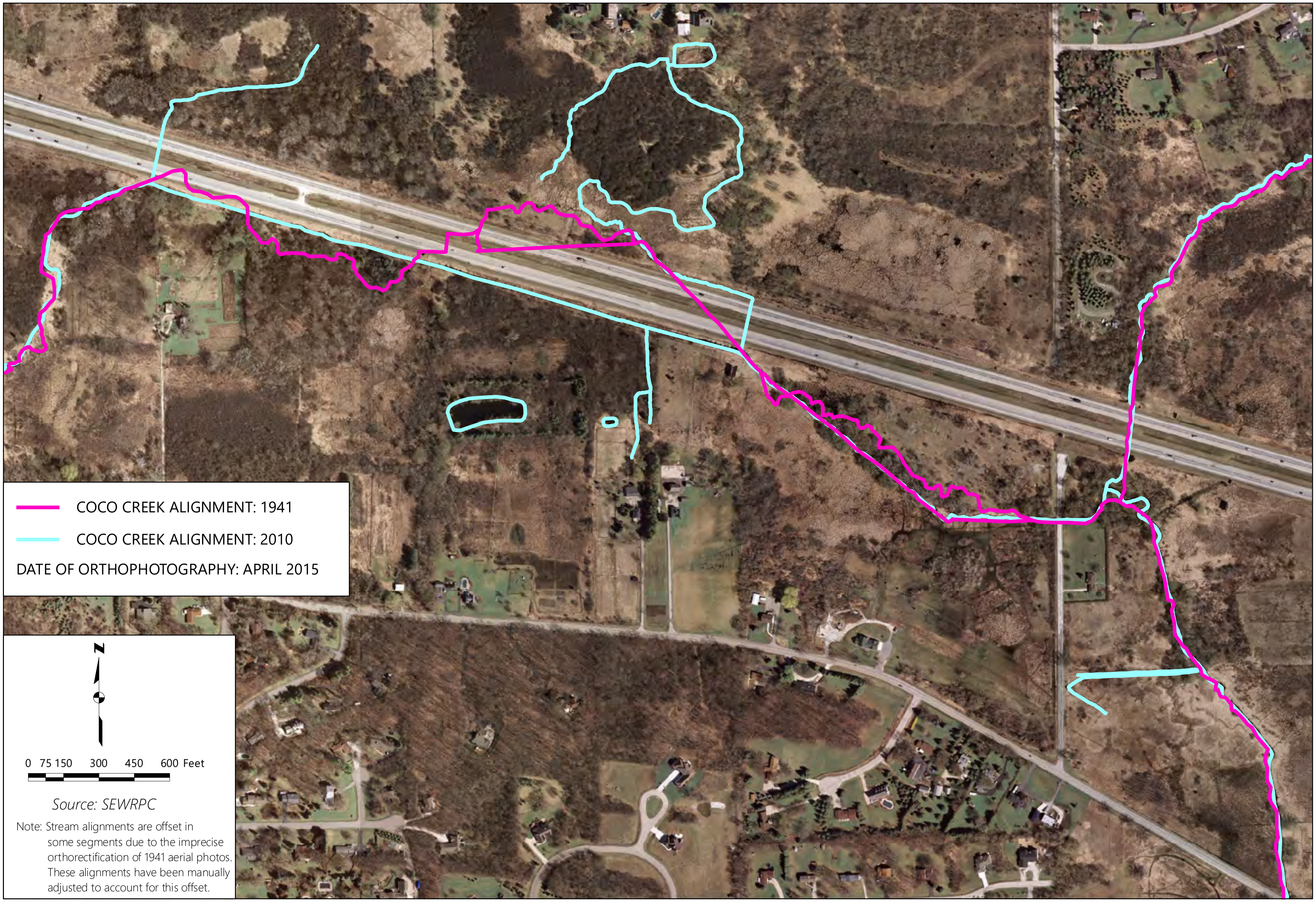
0 1,250 2,500 5,000 Feet

Source: SEWRPC

Note: Stream alignments are offset in some segments due to the imprecise orthorectification of 1941 aerial photos.

Date of Orthophotography: April 2015

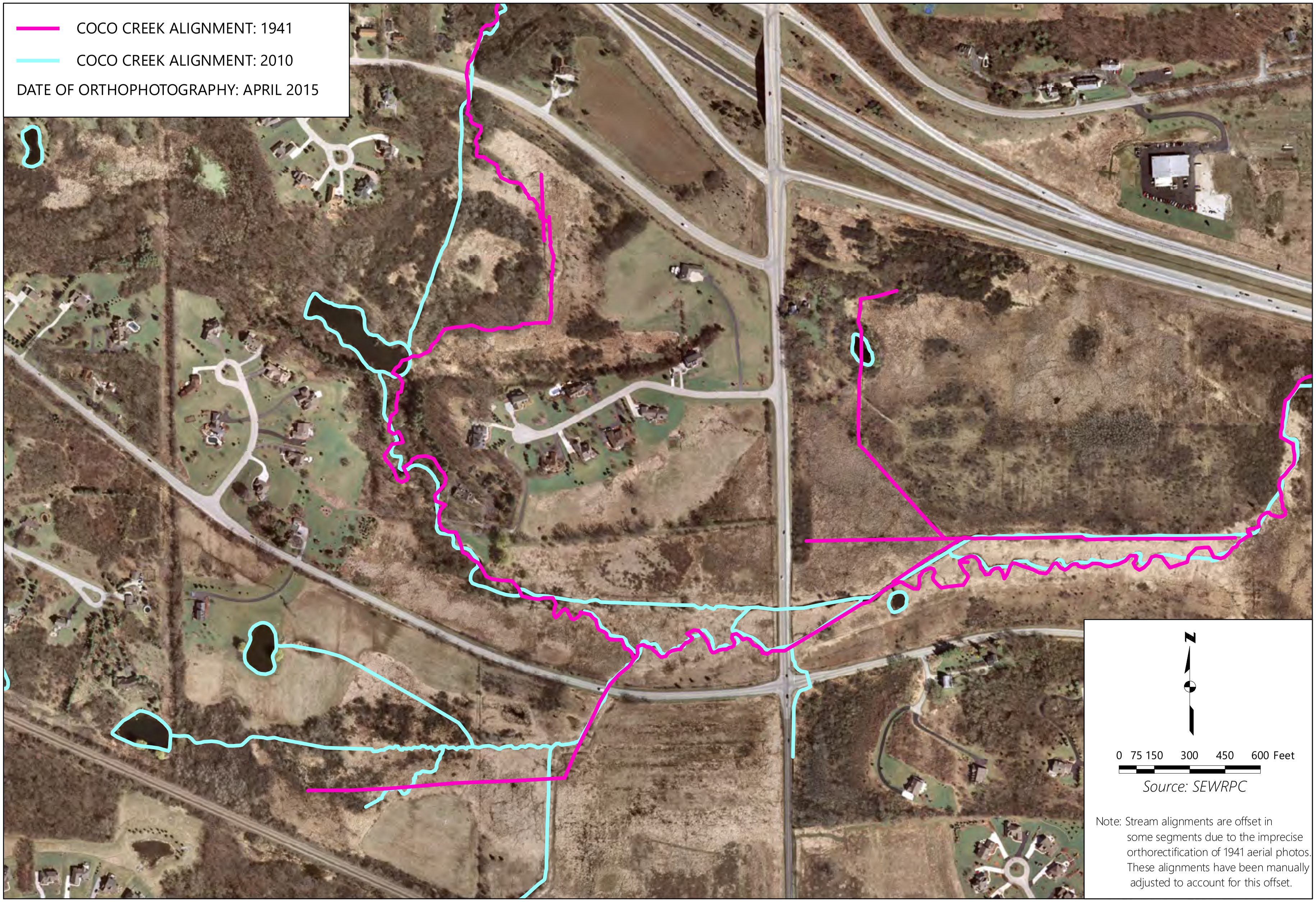
Map 2.30 – Inset 1
Upstream Coco Creek Stream Alignments: 1941 and 2010



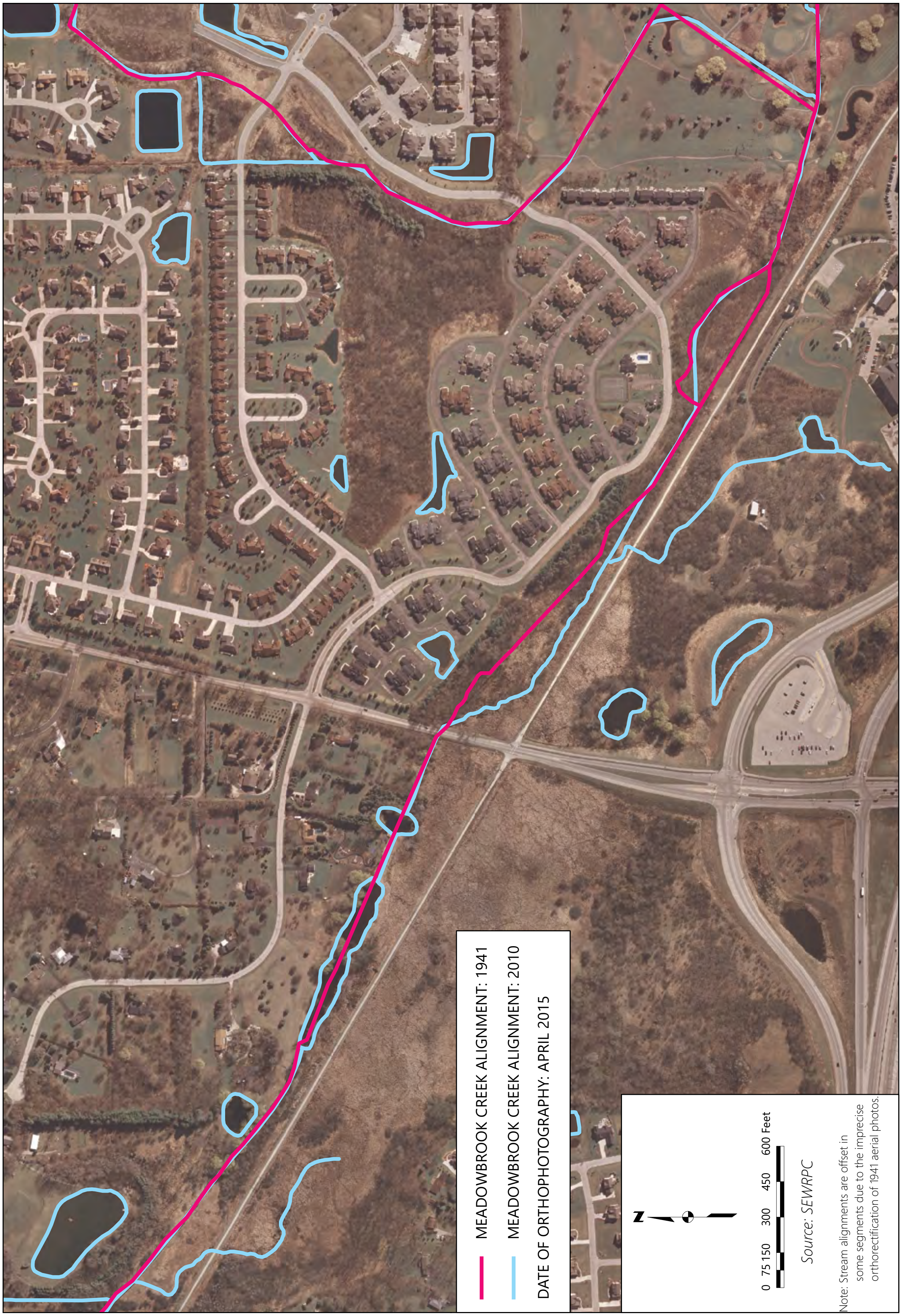
Source: SEWRPC

Note: Stream alignments are offset in some segments due to the imprecise orthorectification of 1941 aerial photos. These alignments have been manually adjusted to account for this offset.

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.

<u>Changes in Land Use</u>

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.

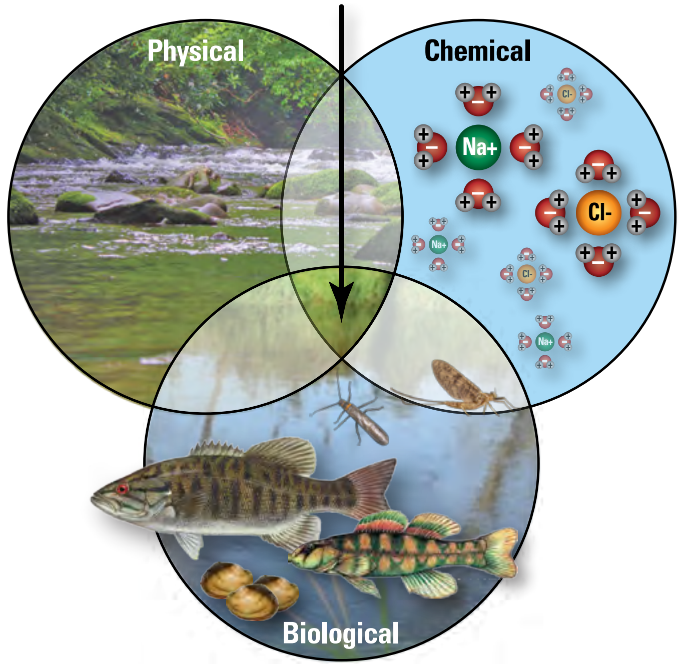
[186] *Ibid.*

- **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.

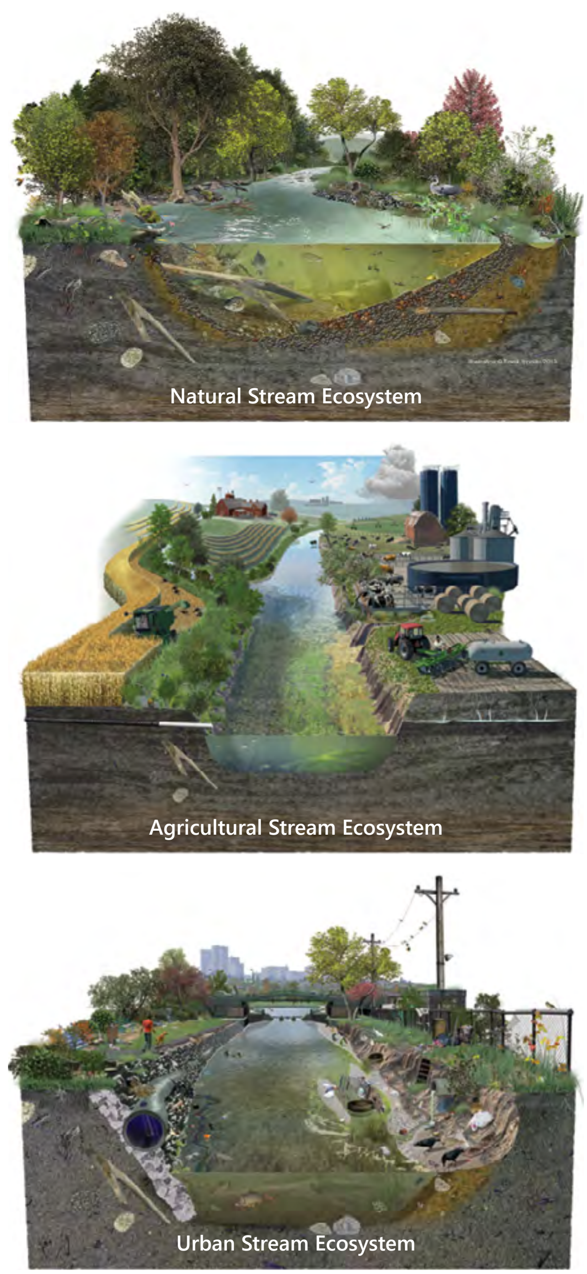
[187] *Personal Communication, Dr. Jeffrey J. Steuer, U.S. Geological Survey.*

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.*

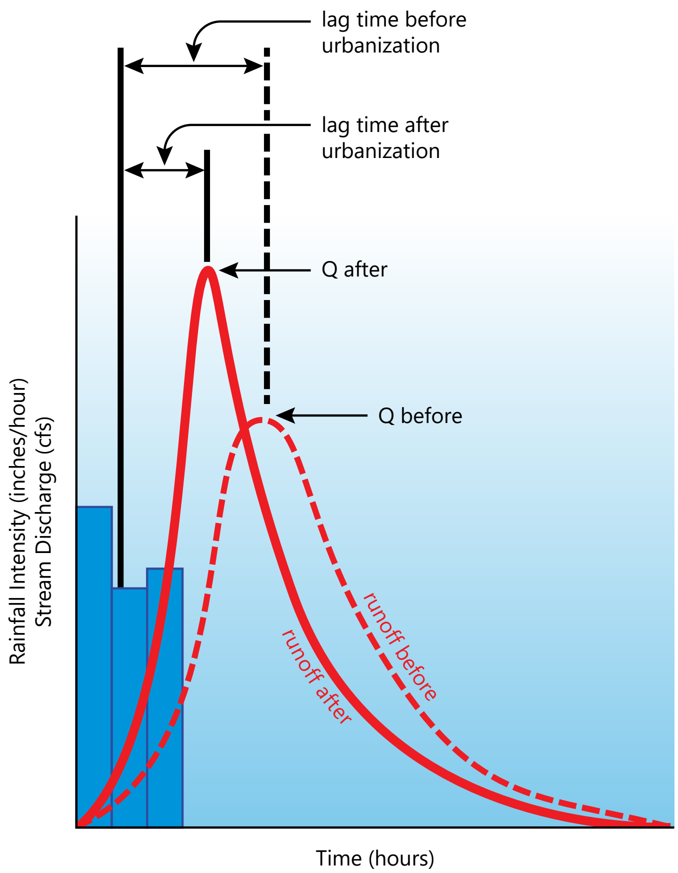
[189] *L. Wang, J. Lyons, P. Kanehl, and R. Bannerman, "Impacts of Urbanization on Stream Habitat and Fish Across Multiple Spatial Scales,"* Environmental Management*, 28: 255-266, 2001.*

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.

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.

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*

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)

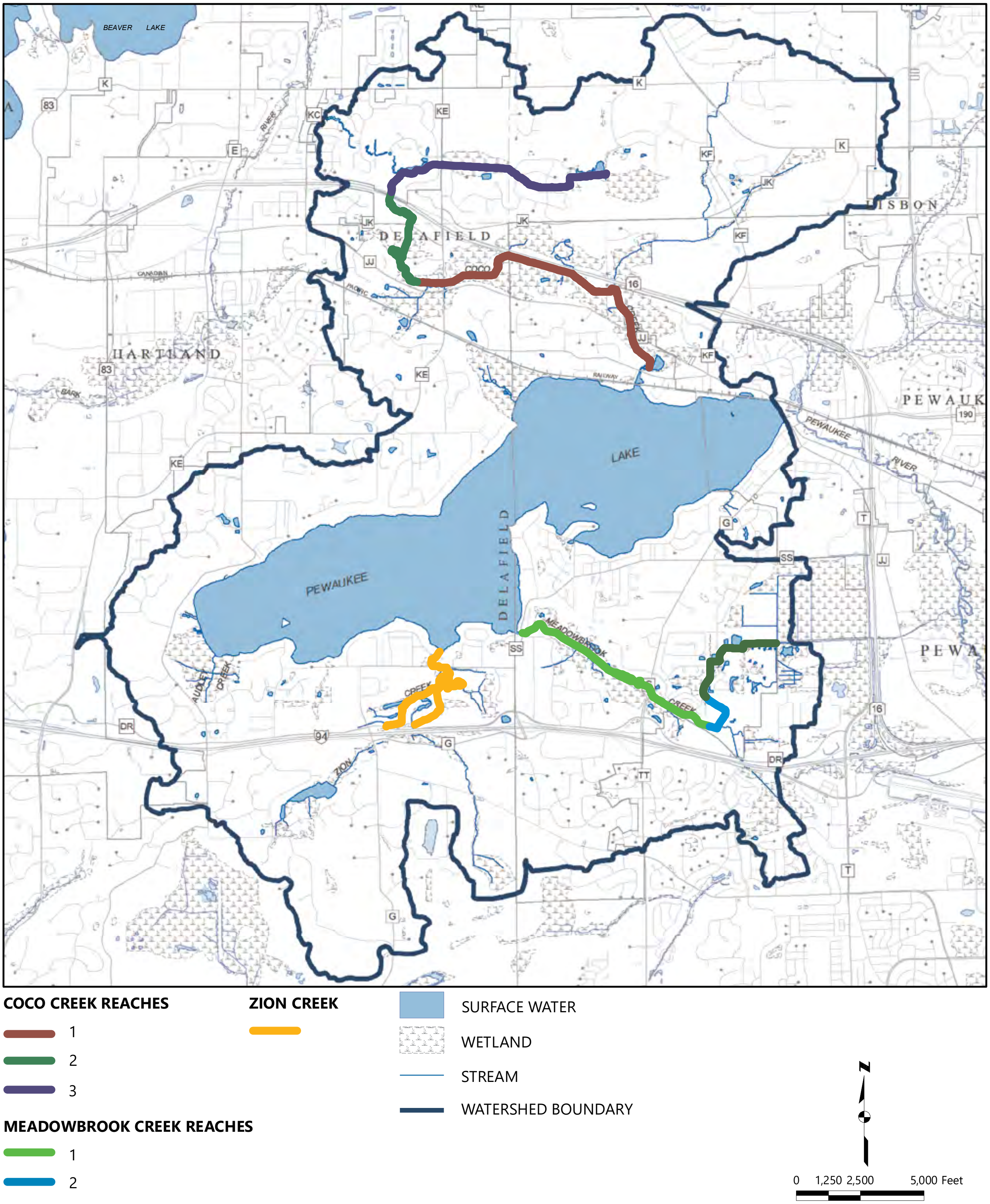
The distribution of these three habitat types, as surveyed primarily in Coco and Meadowbrook creeks, are shown on Map 2.32 (only a small reach of Zion Creek was surveyed, as indicated in the map). The diversity of the pool and riffle structure (i.e., number of pools compared to the number of riffles) 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



Source: SEWRPC

Table 2.27
Low-Gradient Stream Habitat Criteria Scores Within the Pewaukee Lake Watershed: 2012 and 2015

	Coco Creek			Meadowbrook Creek			Zion Creek
Habitat Criterion	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.

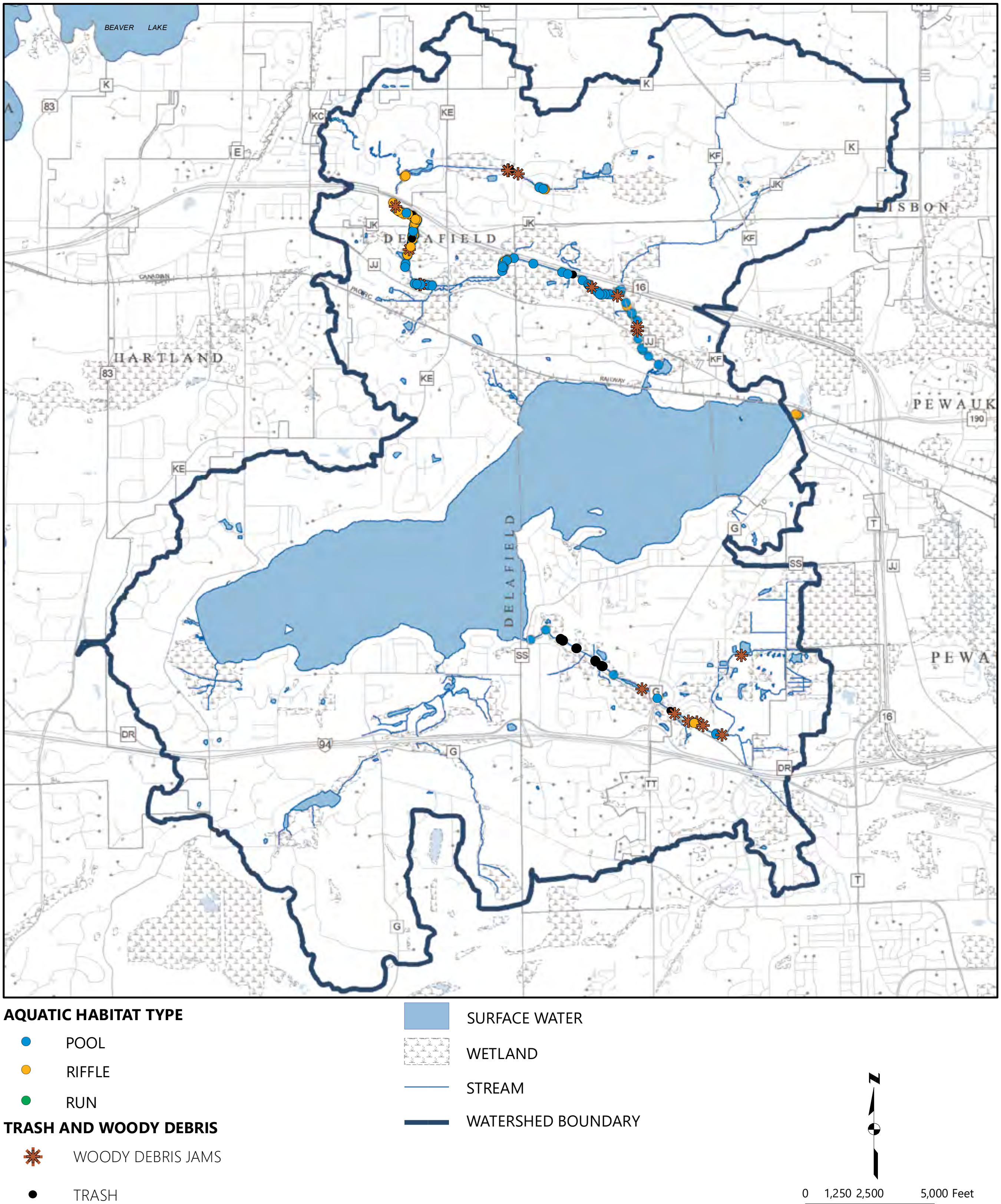
Pool habitats are the opposite of riffle habitats and are also important components of fish habitat in streams, especially for larger fish. On account of their greater depth, pools offer protection from predators, provide feeding areas, and provide refuge from high temperatures in the summer and cold 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

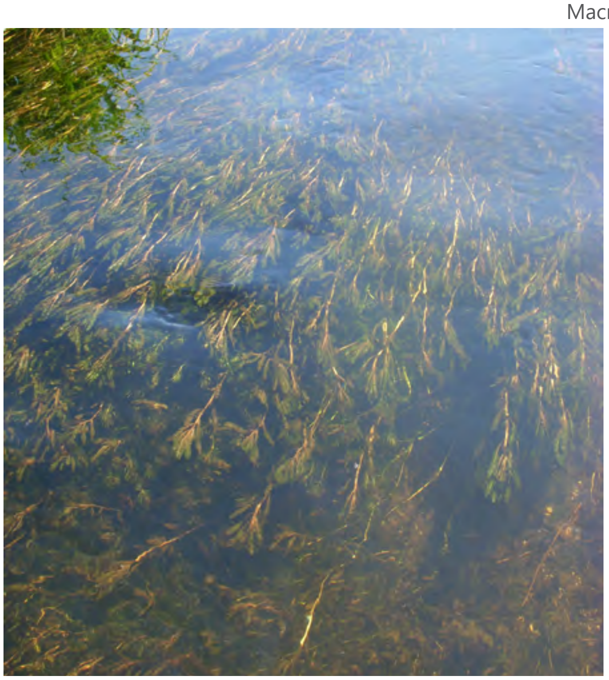
Overhanging Vegetation

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

[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

[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

	Bluegill		Bullhead		Crappie		Channel Catfish		Largemouth Bass		Muskellunge	
Year	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)

	Bluegill		Bullhead		Crappie		Channel Catfish		Largemouth Bass		Muskellunge	
Year	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)

Year	Muskellunge Hybrid		Northern Pike		Perch		Smallmouth Bass		Walleyed Pike		White Bass	
	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,

[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".

[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.

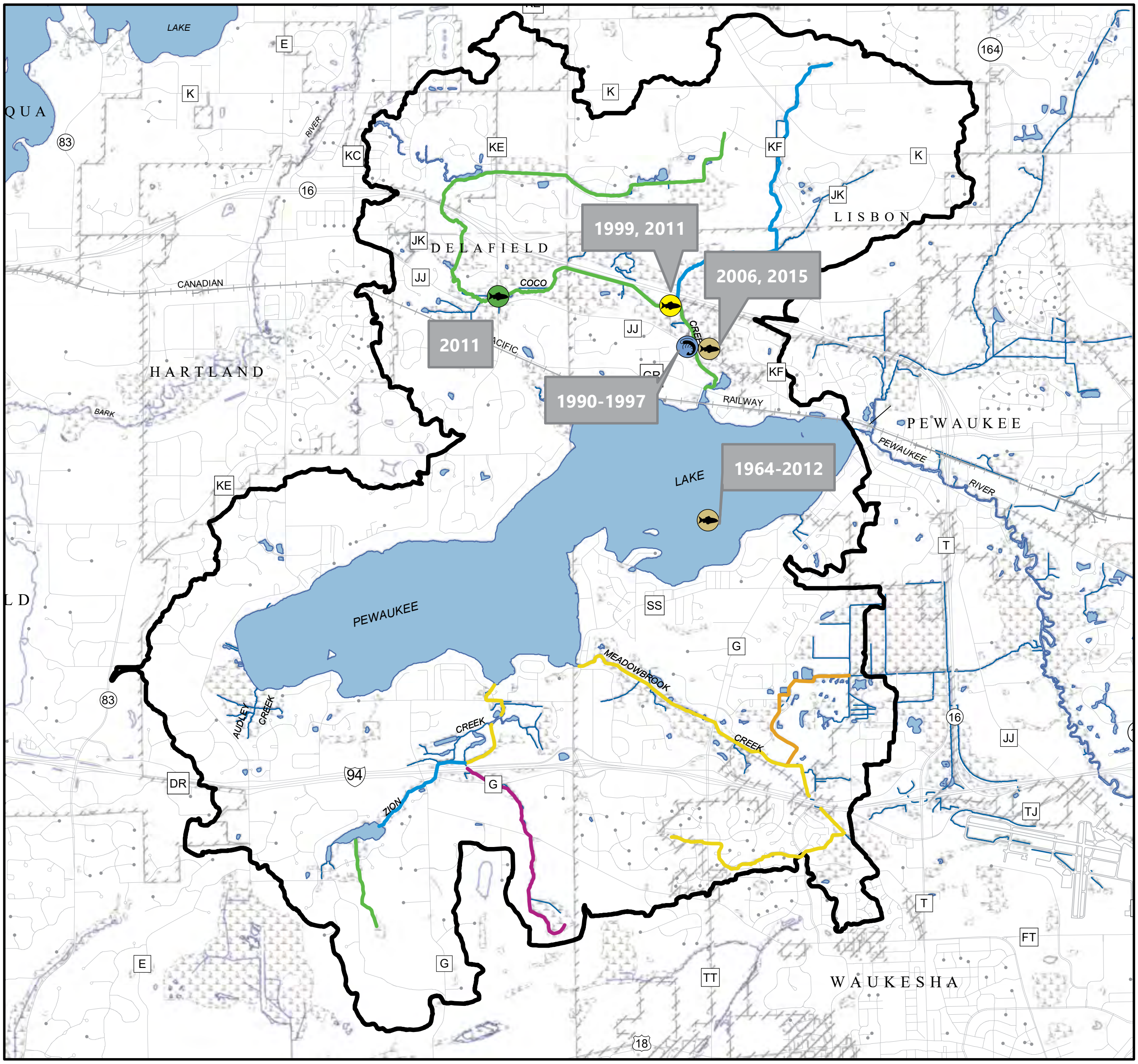
Zooplankton

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

		Date and Time				
Category	**Observation**	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

Activity	Percent Respondents Participating[a]						
	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.*

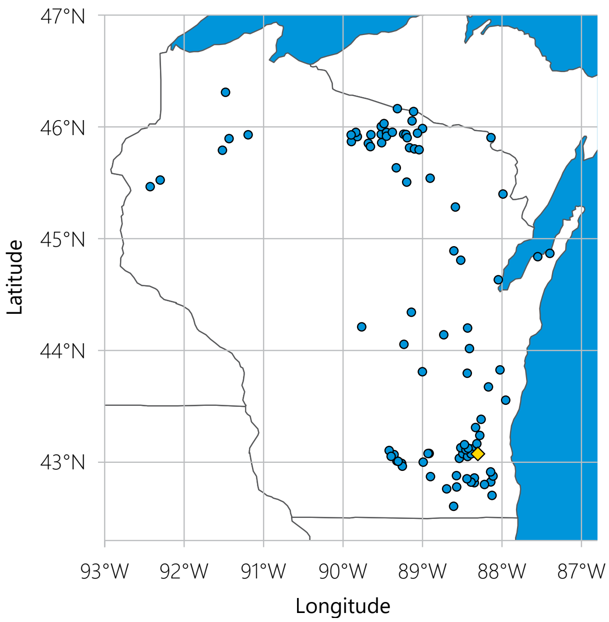
[244] *C. Houser, "Relative Importance of Vessel-Generated and Wind Waves to Salt Marsh Erosion in a Restricted Fetch Environment,"* Journal of Coastal Research, *262: 230-240, 2010.*

[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.

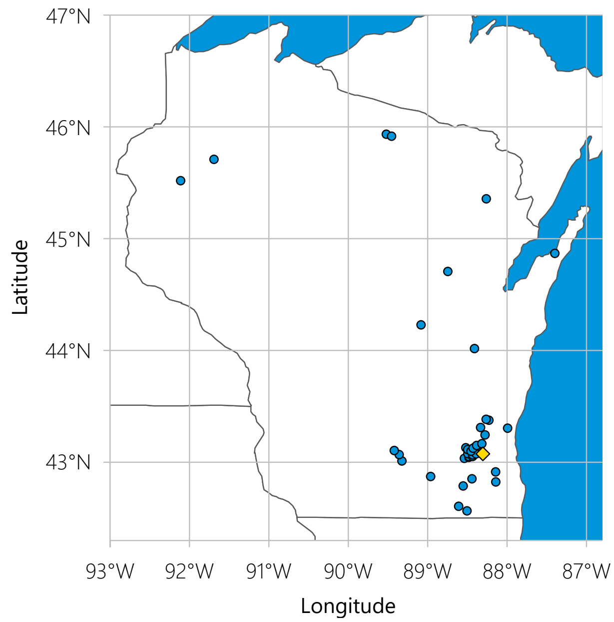
Figure 2.84
Waterbodies that Boaters Visited Before Visiting Pewaukee Lake



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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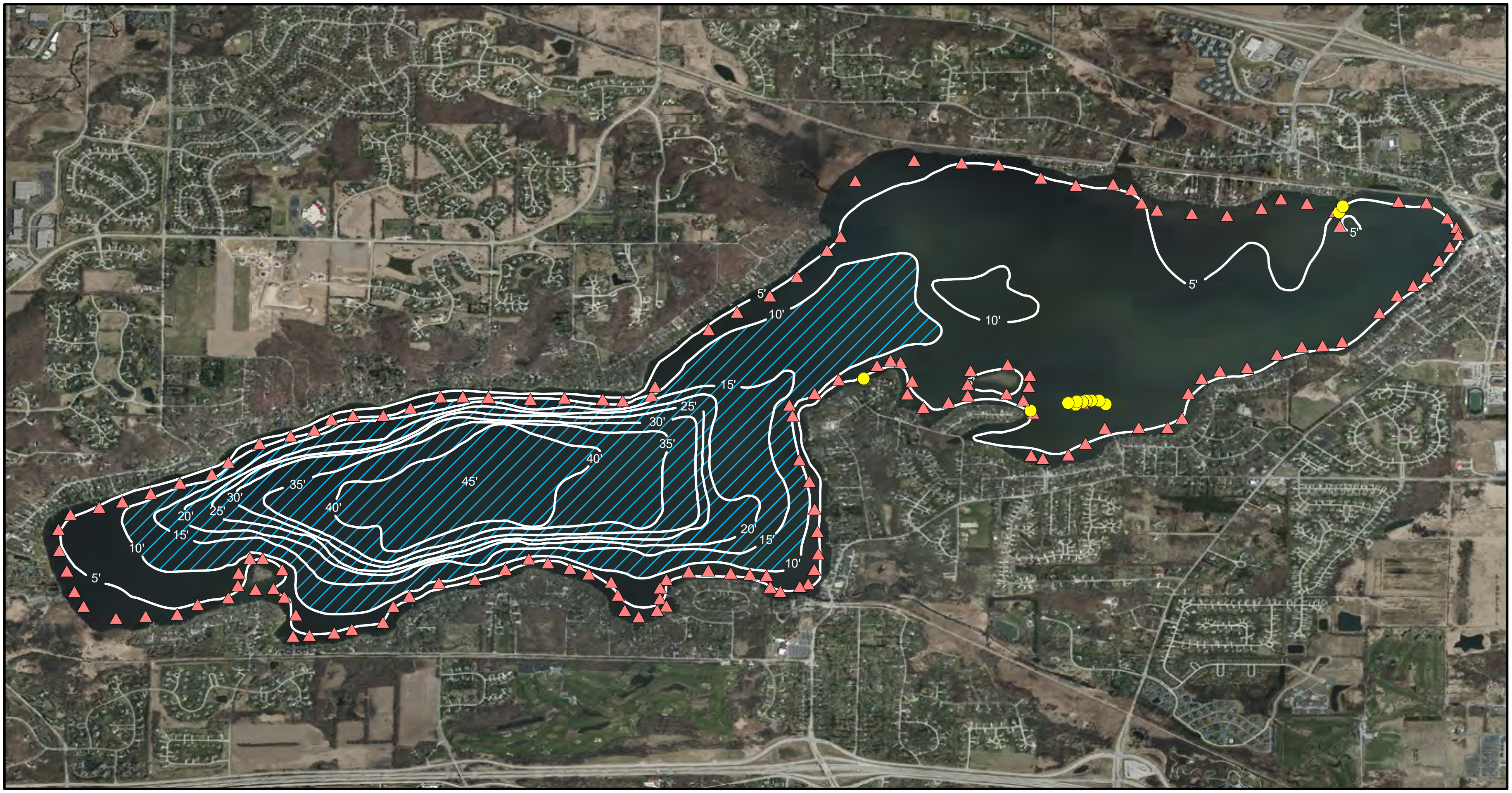
[256] *Keller, 2017,* op. cit.

[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



TYPE OF BUOY

ROCK

SHORELINE

RECOMMENDED HIGH-INTENSITY BOATING AREA

20' WATER DEPTH CONTOUR IN FEET

0 1,500 3,000 6,000 Feet

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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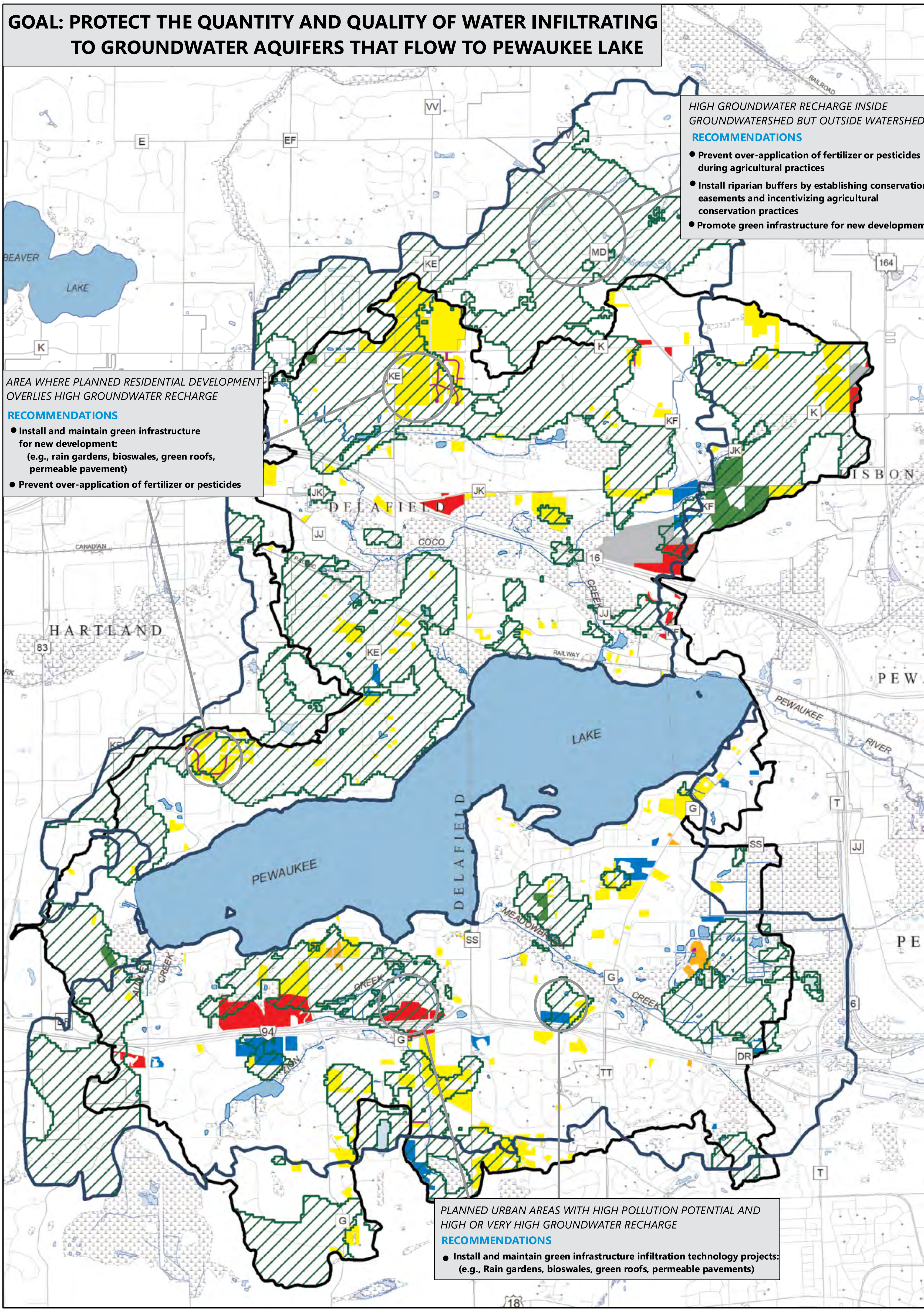
[259] *Detention features can be built that encourage infiltration of stored water and contribute to groundwater recharge. Such systems are one of only a few artificial methods that meaningfully reduce overall runoff volume. They are best situated in areas of high and very high groundwater recharge potential.*

[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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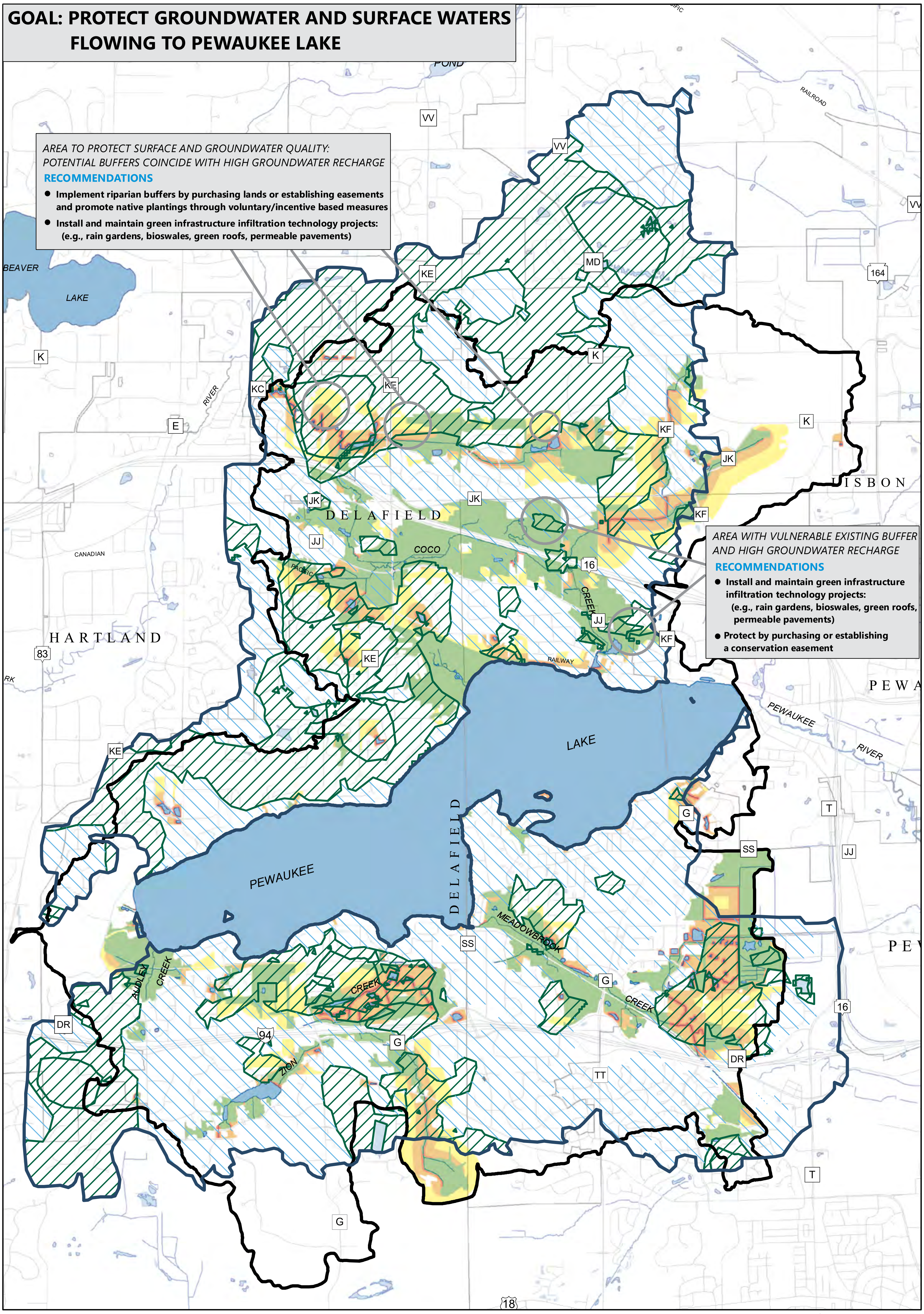
[262] *Personal communication, Daniel Naze, P. E., Village of Pewaukee Director of Public Works/Village Engineer, May 29, 2019.*

[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
- 75 FOOT MINIMUM BUFFER WIDTH
- 400 FOOT MINIMUM CORE HABITAT WIDTH
- 1,000 FOOT OPTIMAL CORE HABITAT WIDTH FOR WILDLIFE PROTECTION
- HIGH AND VERY HIGH GROUNDWATER RECHARGE POTENTIAL
- MODERATE GROUNDWATER RECHARGE POTENTIAL

MANAGEMENT IMPLICATIONS

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.

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).

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

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.

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[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.

[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.

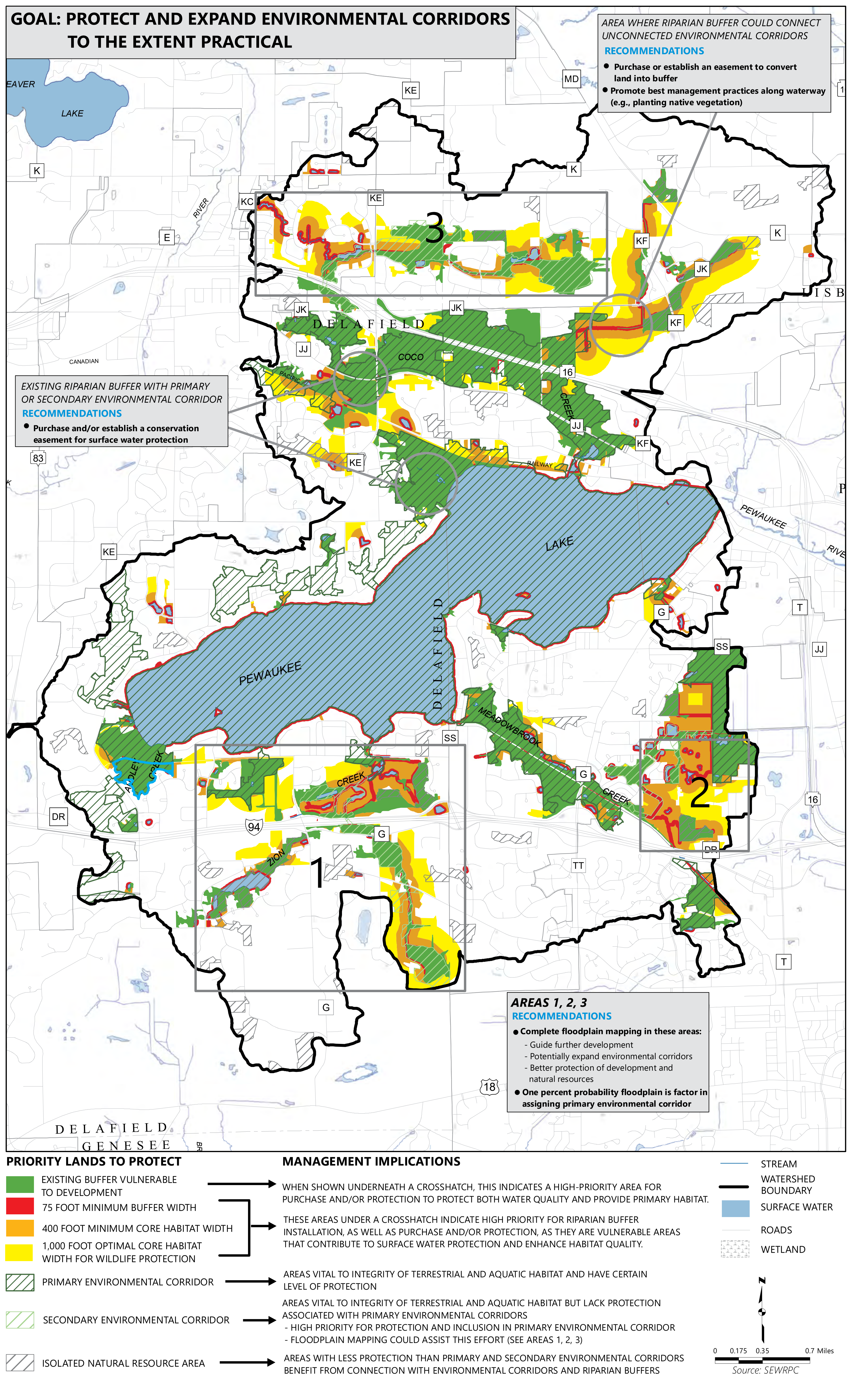
- Consider a shoreline BMP and shoreline buffer enhancement program. This program could encourage the development of rain gardens or buffers along shorelines. Combining rain gardens with buffer strips can enhance their benefit. The WDNR Healthy Lakes & Rivers grant program could help fund some of these 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).

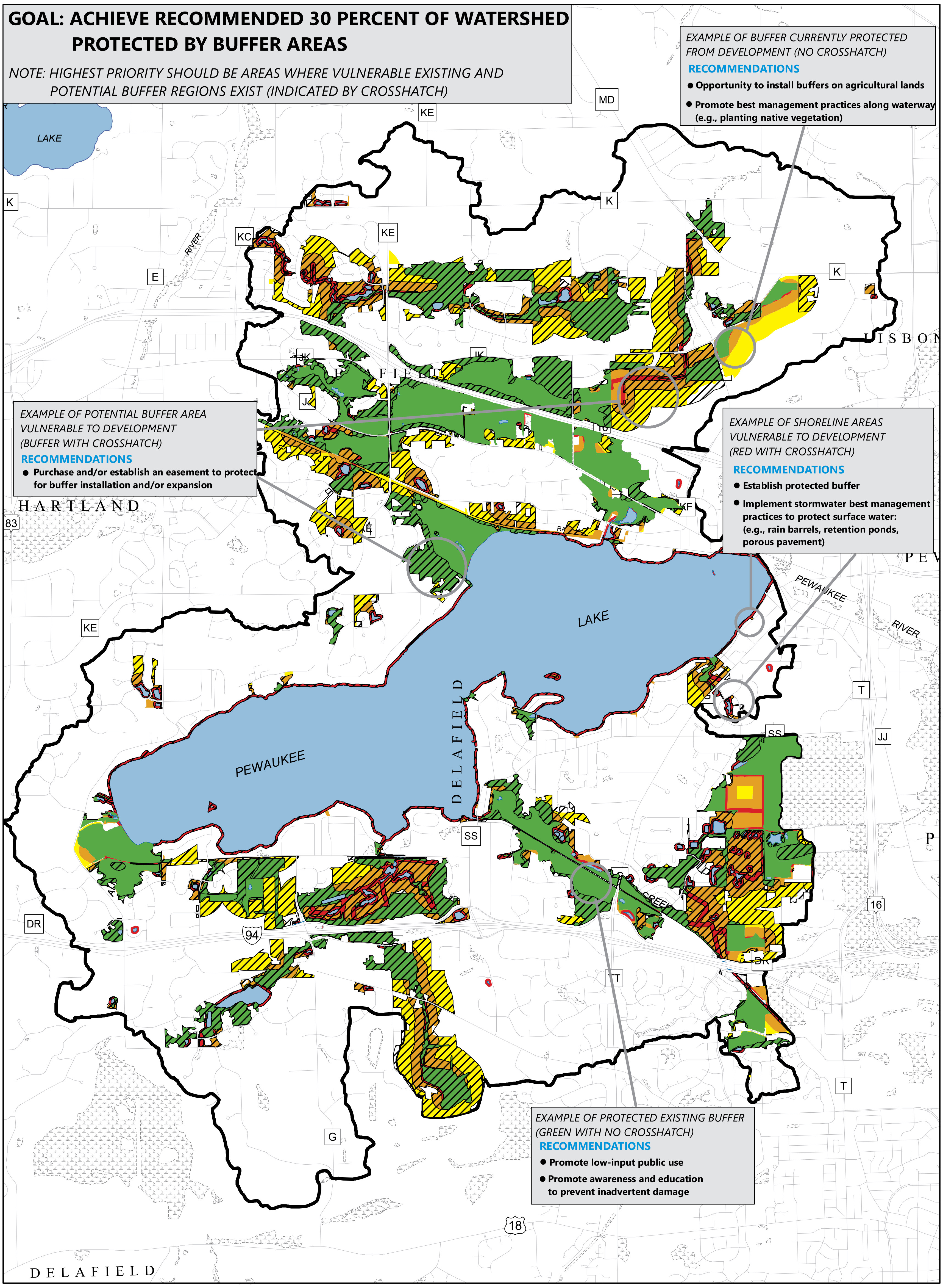
➤ **Recommendation 3.3: Protect buffer, wetland, and floodplain function**
Control invasive species that threaten the ecological value of buffers, wetlands, and floodplains. Additionally, relax human-imposed constraints placed upon watercourses. These efforts should be considered a <u>medium priority</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.

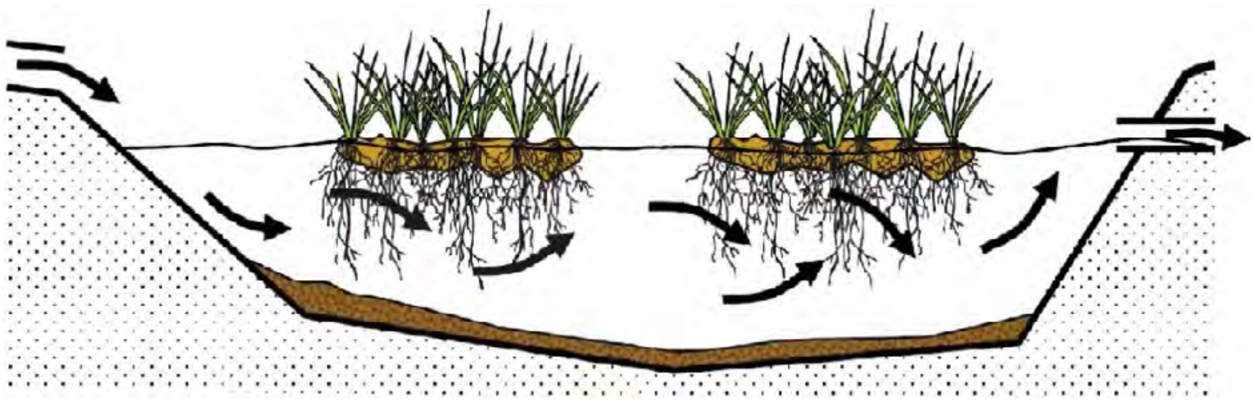
Sub-Basin Level Recommendations

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.

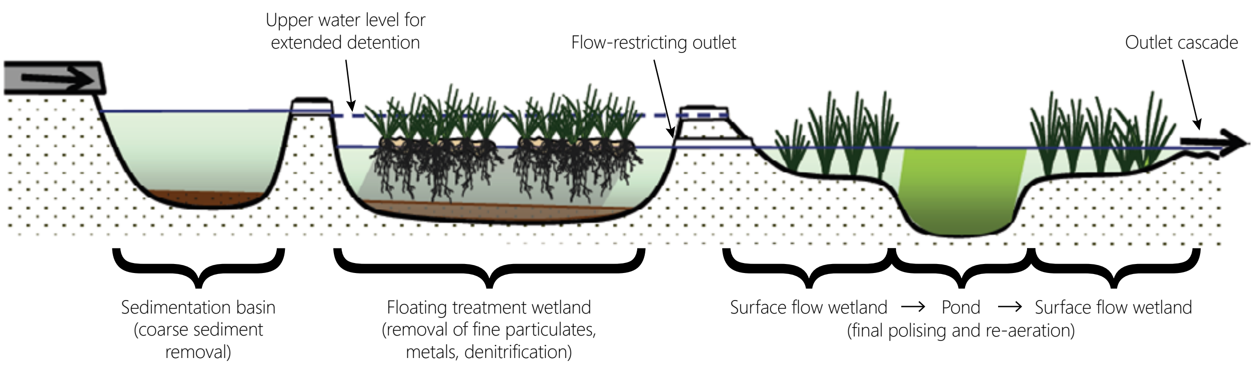
- **Recommendation 3.13: Tributaries should be prioritized regarding phosphorus load reduction goals**
  A study by Wisconsin Lutheran College and WDNR PRESTO model output indicate that Coco Creek is the major tributary phosphorus contributor to Pewaukee Lake. However, the PRESTO model shows Meadowbrook 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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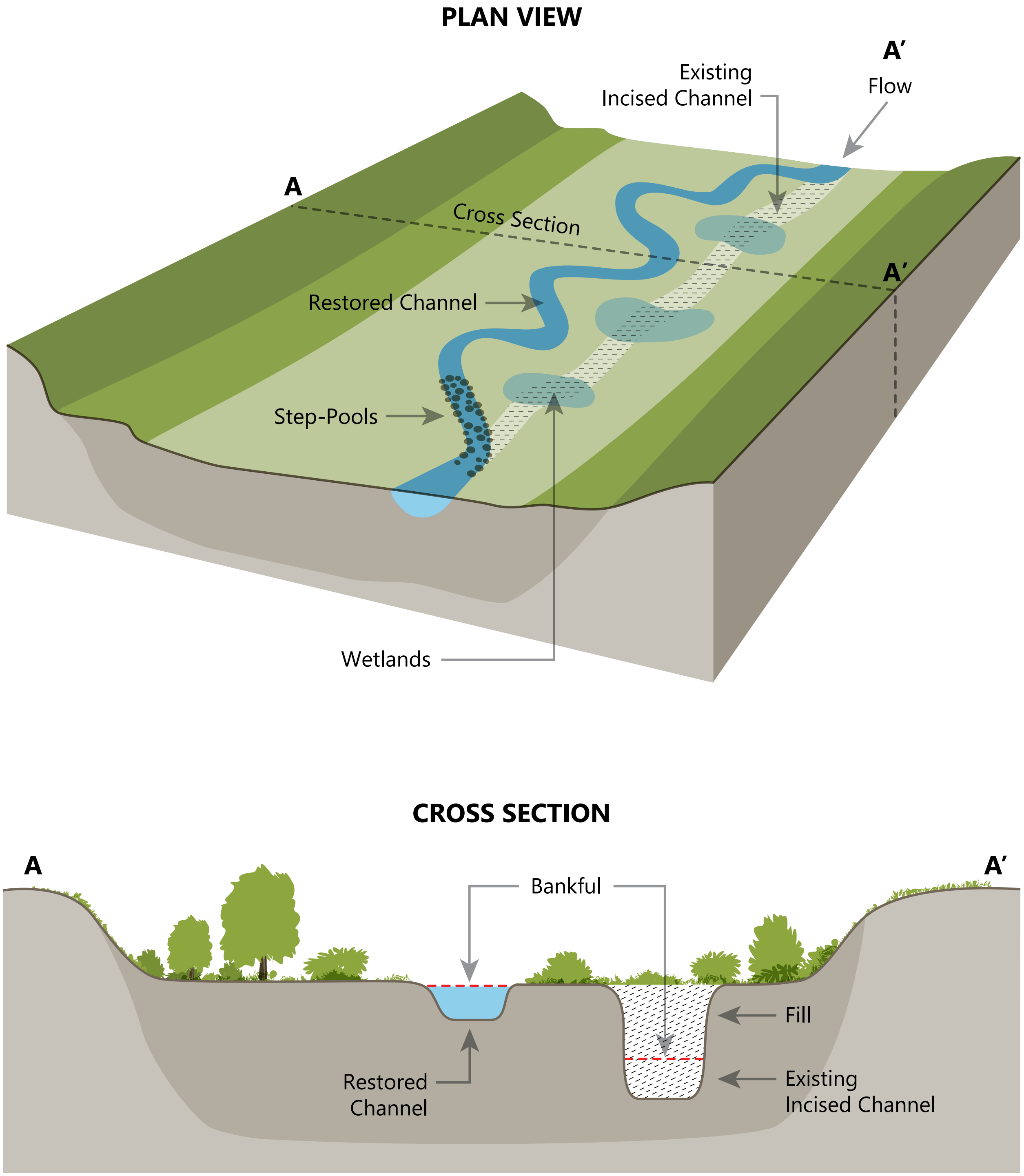
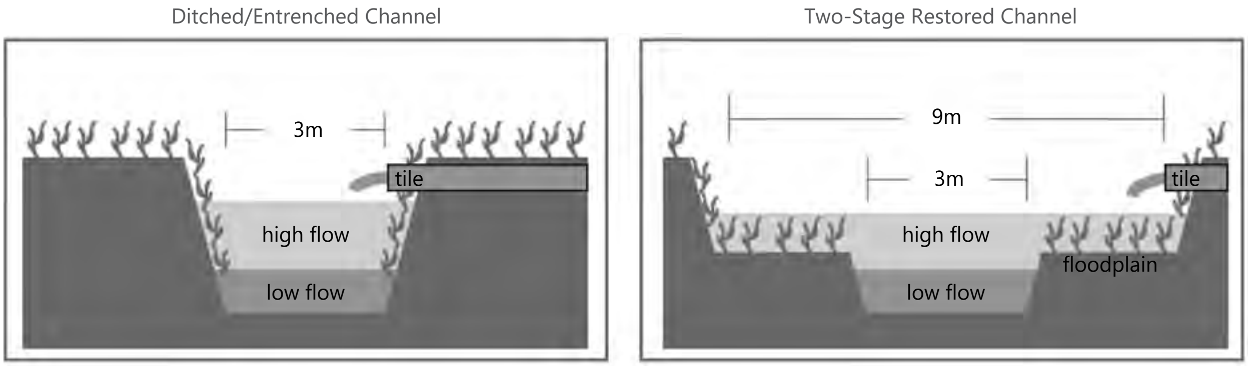
[281] *For more information, see healthylakeswi.com.*

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

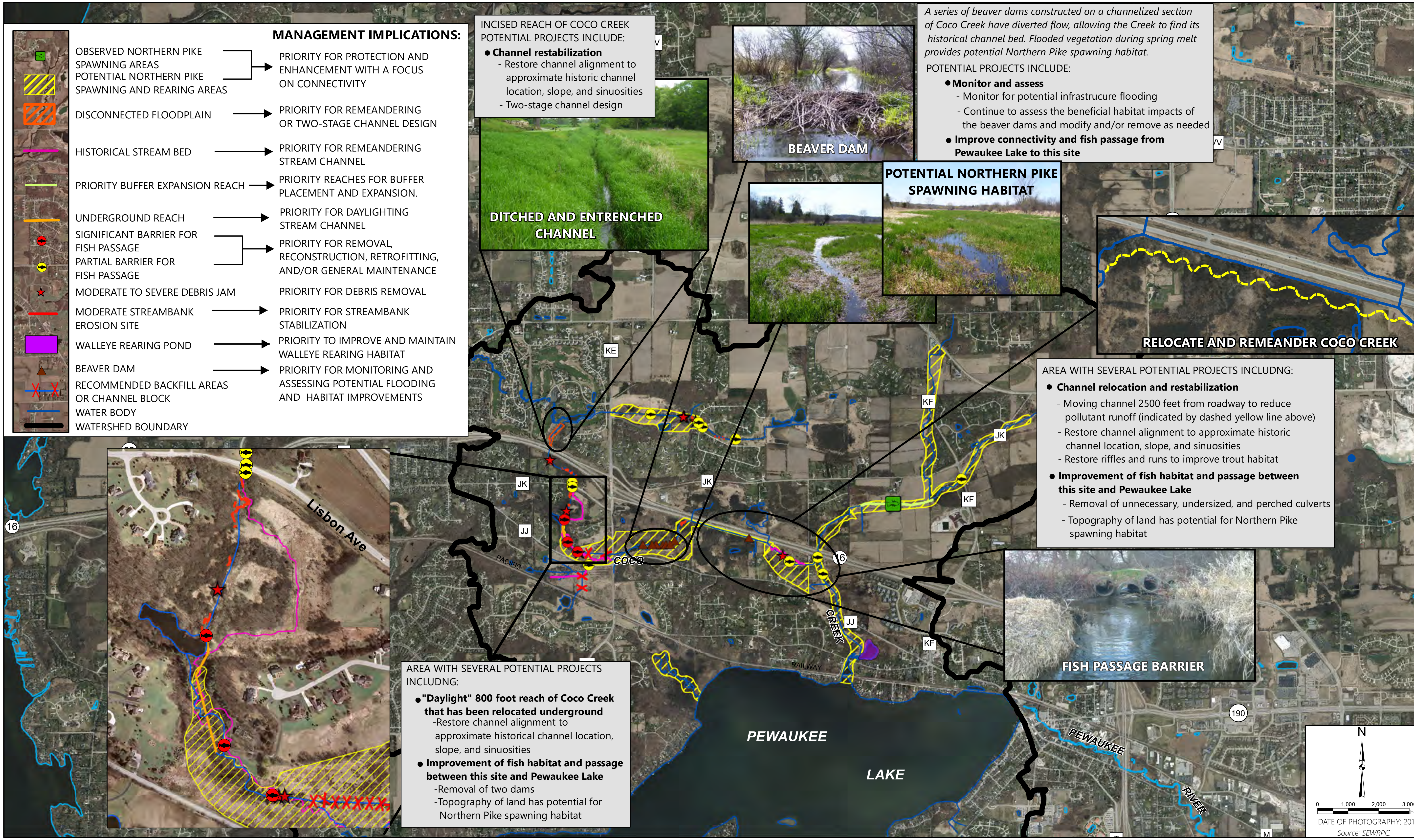
This section summarizes the information and recommendations needed to manage nuisance plant, Eurasian watermilfoil (EWM) (*Myriophyllum spicatum*), and curly-leaf pondweed (CLP) (*Potamogeton crispus*) growth in the Lake. Accordingly, it presents a range of alternatives that could potentially be used, 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.

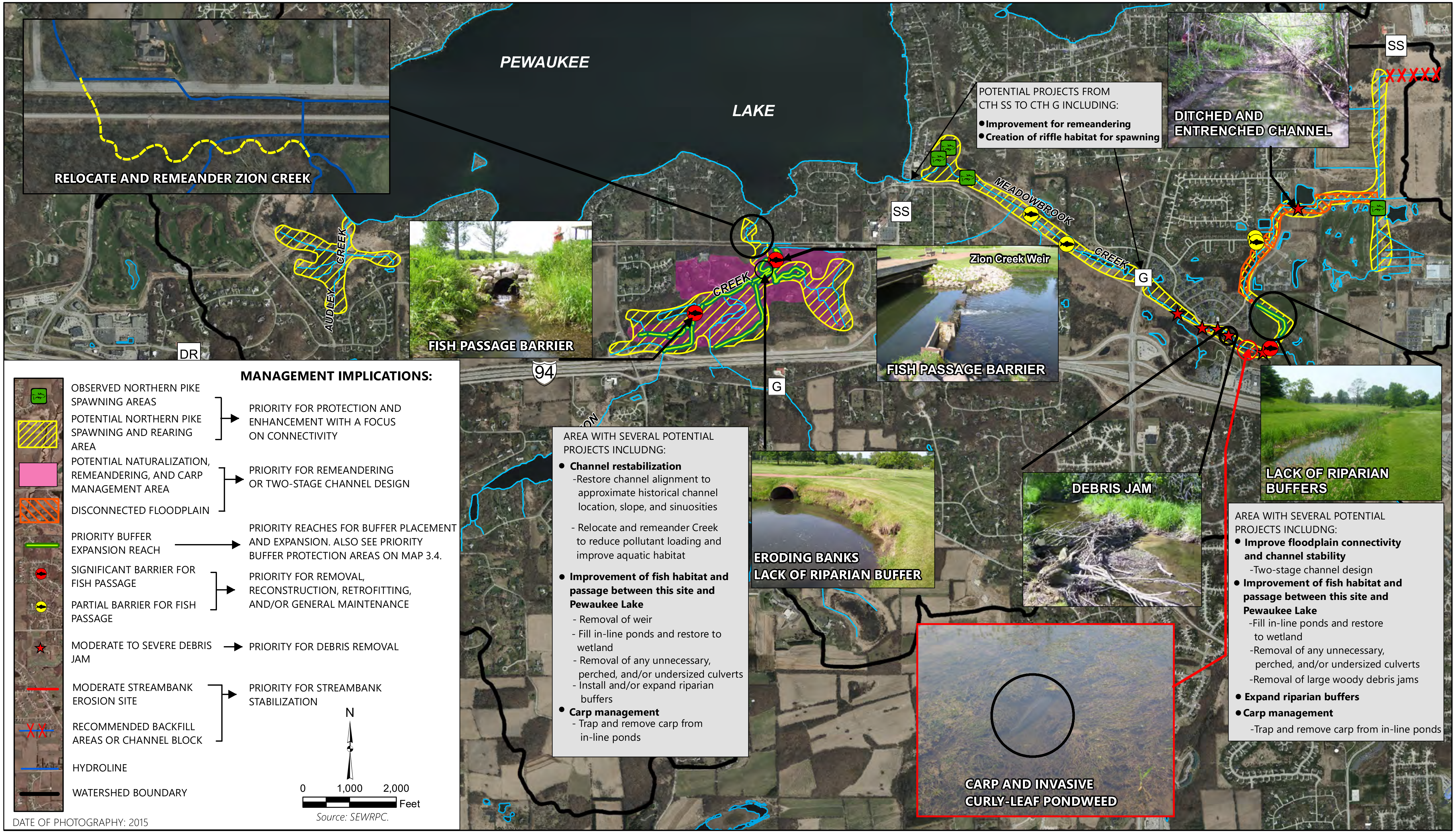
Aquatic Plants in Pewaukee Lake

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



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:

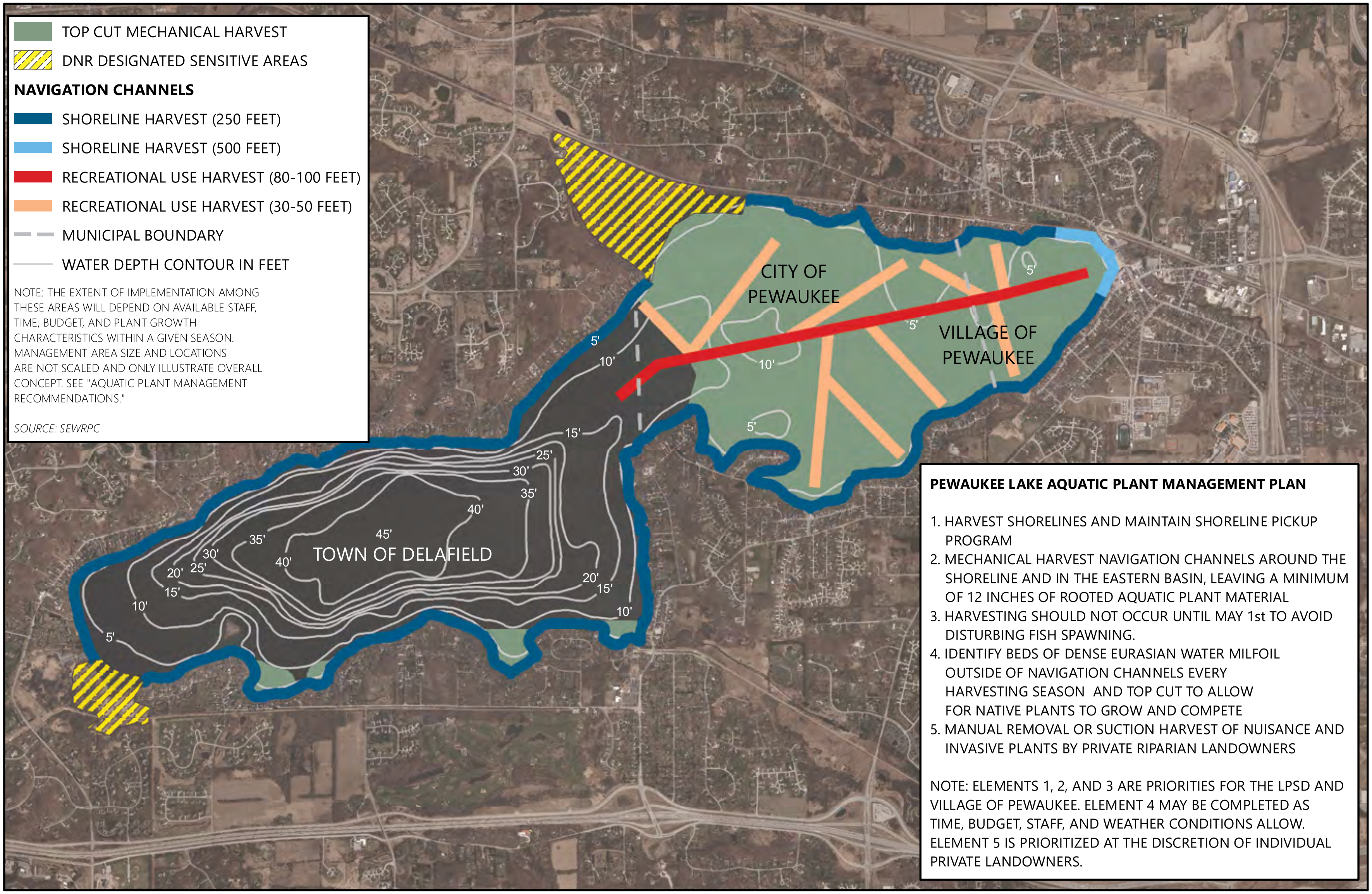
➤ **Recommendation 4.1: Mechanical harvesting of invasive and nuisance aquatic plants**
This recommendation should continue to be a high priority. Navigation channels should be maintained around the shoreline of Pewaukee Lake, excluding the WDNRdesignated Sensitive Areas as shown on Figure 3.5. These 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**

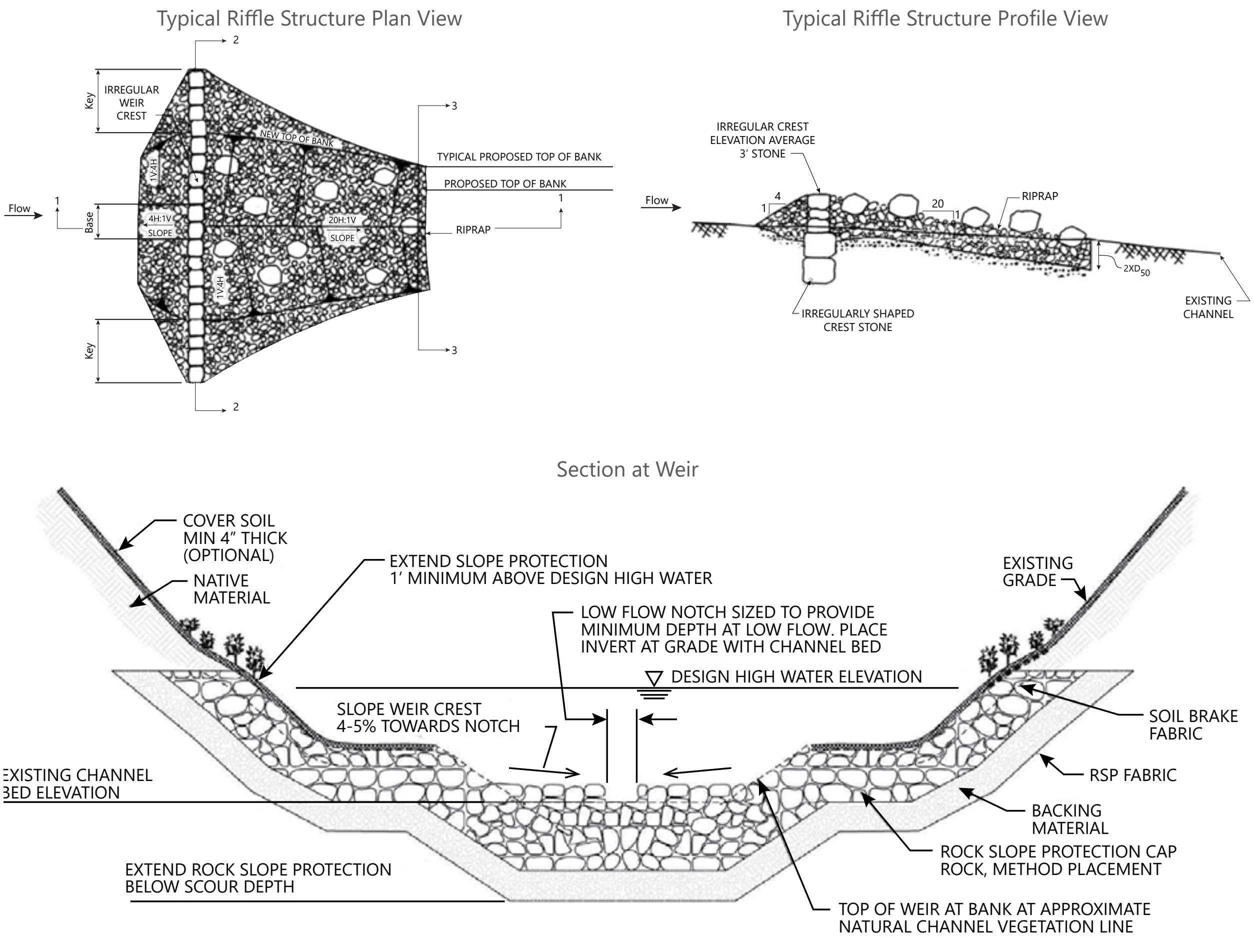
Stream flows are a fundamental part of stream health and actions to mitigate the negative consequences of channelization (especially to Meadowbrook Creek) and physical impediments to stream flow should be considered a medium priority. Other natural stream features, such as riffles, pools, and instream 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).

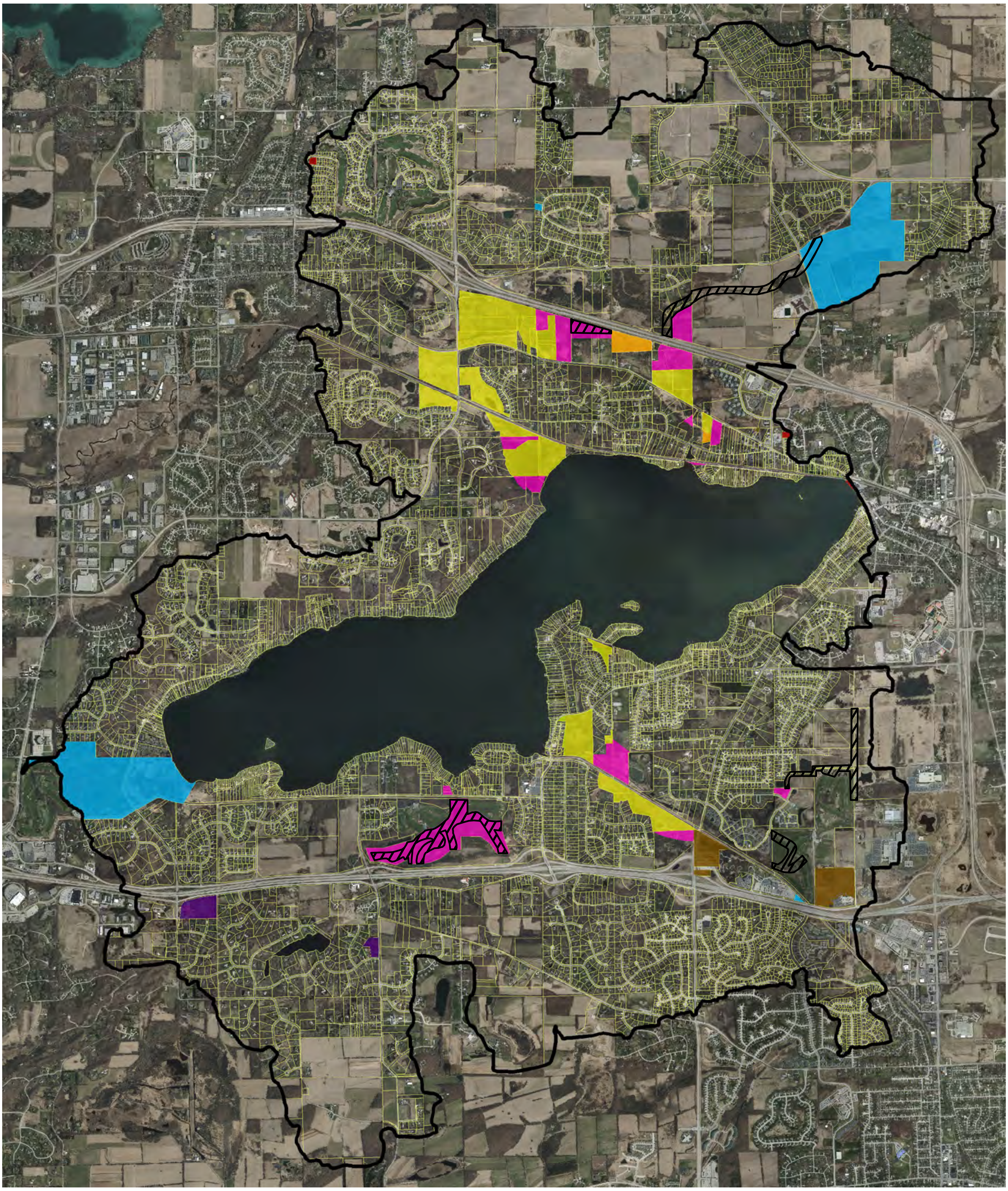
- **Recommendation 6.17: Continue to monitor fish and wildlife populations**
  In general, tracking the diversity and abundance of fish and wildlife would help future Lake managers detect change. Consequently, continued monitoring of fish populations and periodic recording of the types of animals found 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)

N

0 1,450 2,900 5,800 Feet

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.

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[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

INSTREAM HABITAT INVENTORY AMONG REACHES IN THE PEWAUKEE LAKE TRIBUTARIES: 2012 AND 2015

APPENDIX A

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				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)	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)

		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 (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.