2019

Lake Study Report
Silver Lake – Portage, Wisconsin
WBIC #107700

Final Report
to Columbia County, City of Portage and
Wisconsin Department of Natural Resources

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SILVER LAKE STUDY RESULTS

ABOUT SILVER LAKE

To understand a lake and its water quality, fish and wildlife, and recreational opportunities, we need to understand its physical characteristics and setting within the surrounding landscape. Silver Lake is located in the city of Portage, with one public boat landing located on the east side of the west basin. Silver Lake is a 74-acre spring lake with groundwater, surface runoff and precipitation contributing most of its water and the water leaving through a wetland complex on the east side of the lake. The maximum depth is 42 feet in the west basin and 16 feet in the east basin; the lakebed has a moderate slope (Figure 1) and its bottom sediments are mostly muck with areas of sand.

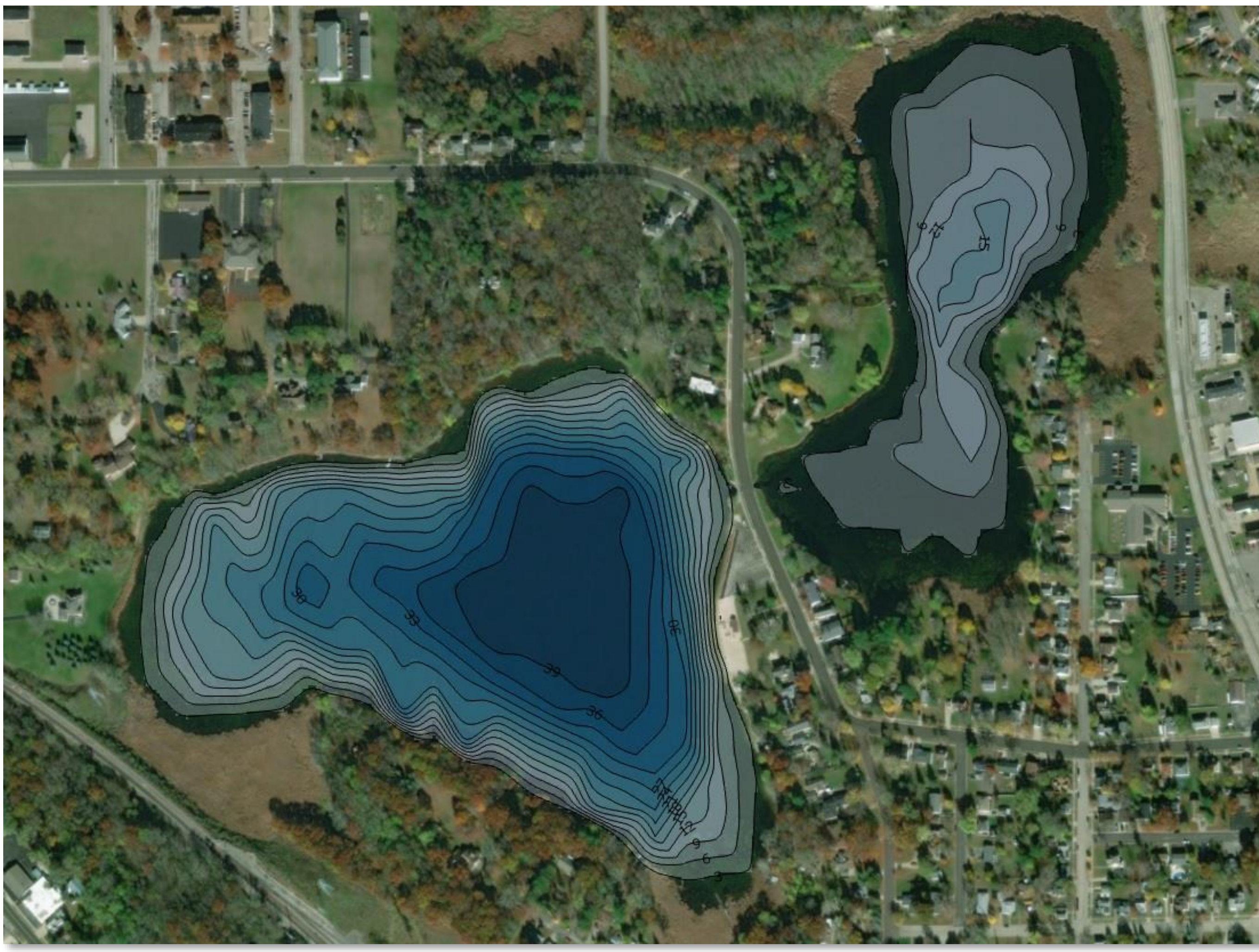


FIGURE 1. CONTOUR MAP OF THE SILVER LAKE BASIN.

WHERE IS THE WATER COMING FROM? - WATERSHEDS AND LAND USE

The water quality in Silver Lake is a reflection of the land that drains to it. The water quality, the amount of algae, aquatic plants, the fishery and other animals in the lake are all affected by natural and manmade characteristics. Natural characteristics that affect a lake include the amount of land that drains to the lake, the hilliness of the landscape, types of soil, extent of wetlands, and the type of lake. Within the lake's watershed, alterations to the landscape, the types of land use, and the land management practices are examples of how people may affect the lake.

It is important to understand where Silver Lake's water originates in order to understand the lake's health. During snowmelt or a rainstorm, water moves across the surface of the landscape (runoff) towards lower elevations such as the lake itself or adjacent wetlands. The land area that contributes runoff to Silver Lake is called a surface watershed. Groundwater also moves into Silver Lake; the groundwater also originates in precipitation although this is that fraction of the precipitation that moves into the ground and is not taken up by plants. The groundwater also moves to lower elevations and ultimately discharges to the lake itself or adjacent wetlands. The land area that contributes groundwater to Silver Lake is the groundwater watershed and its land area may be slightly different from the surface watershed. The surface watershed and groundwater watershed are shown in Figure 2 and Figure 5.

The capacity of the land in the watershed to shed or hold water and contribute or filter particles determines the amount of erosion and nutrient runoff that may occur, the amount of groundwater feeding a lake, and ultimately, the lake's water quality and quantity. Essentially, landscapes with a greater capacity to infiltrate water during rain events and snowmelt help to slow the delivery of the water to the lake. Less runoff is desirable because it allows more water to recharge the groundwater, which feeds the lake year-round - even during dry periods or when the lake is covered with ice.

Land use and land management practices within a lake's watershed can affect both its water quantity and quality. Undisturbed forests and grasslands usually allow much of the precipitation to soak into the ground, resulting in more groundwater, less surface runoff and better water quality, other types of land uses may result in increased runoff and less groundwater recharge, and may be sources of pollutants that can impact the lake and its inhabitants. Areas of land with exposed soil can produce soil erosion. Soil entering the lake can make the water cloudy and cover fish spawning beds. Soil also contains nutrients such as phosphorus that increase the growth of algae and aquatic plants. Development of the land can change natural drainage patterns, alter vegetation and increase pollutant movement. Impervious (hard) surfaces such as roads, rooftops, and compacted soil prevent rainfall from soaking into the ground, which may result in more runoff that carries pollutants to the lake. Sources of these pollutants include animal waste, and fertilizers. Increased runoff of nutrients contributes nutrients that enhance the growth of algae and aquatic plants in the lake.

Although development can increase the transfer of nutrients from land to water, there are a variety of land management practices that can be put in place to help reduce impacts to our lakes. Some practices are designed to reduce runoff. These include protecting/restoring wetlands, installing rain gardens, swales, rain barrels, and routing drainage from pavement and roofs away from the lake so that they can infiltrate. Some practices are used to help reduce nutrients from moving across the landscape towards the lake. Examples include manure management practices, eliminating/reducing the use of fertilizers, increasing the distance between the lake and a septic drain field, protecting/restoring native vegetation in the shoreland, and using erosion control practices. Columbia County staff and other professionals can work with landowners to determine which practices are best suited to a particular property.

View looking northeast of cattails in the south bay of the West Basin-Silver Lake.

The surface watershed for Silver Lake is approximately 483 acres (Figure 2). The dominant types of land use in the watershed are urban/residential (49%), forest (22%), and barren land (9%). The land closest to the lake often has the greatest impact on water quality and habitat; Silver Lake's shoreland is surrounded primarily by developed land, wetlands, and forest.

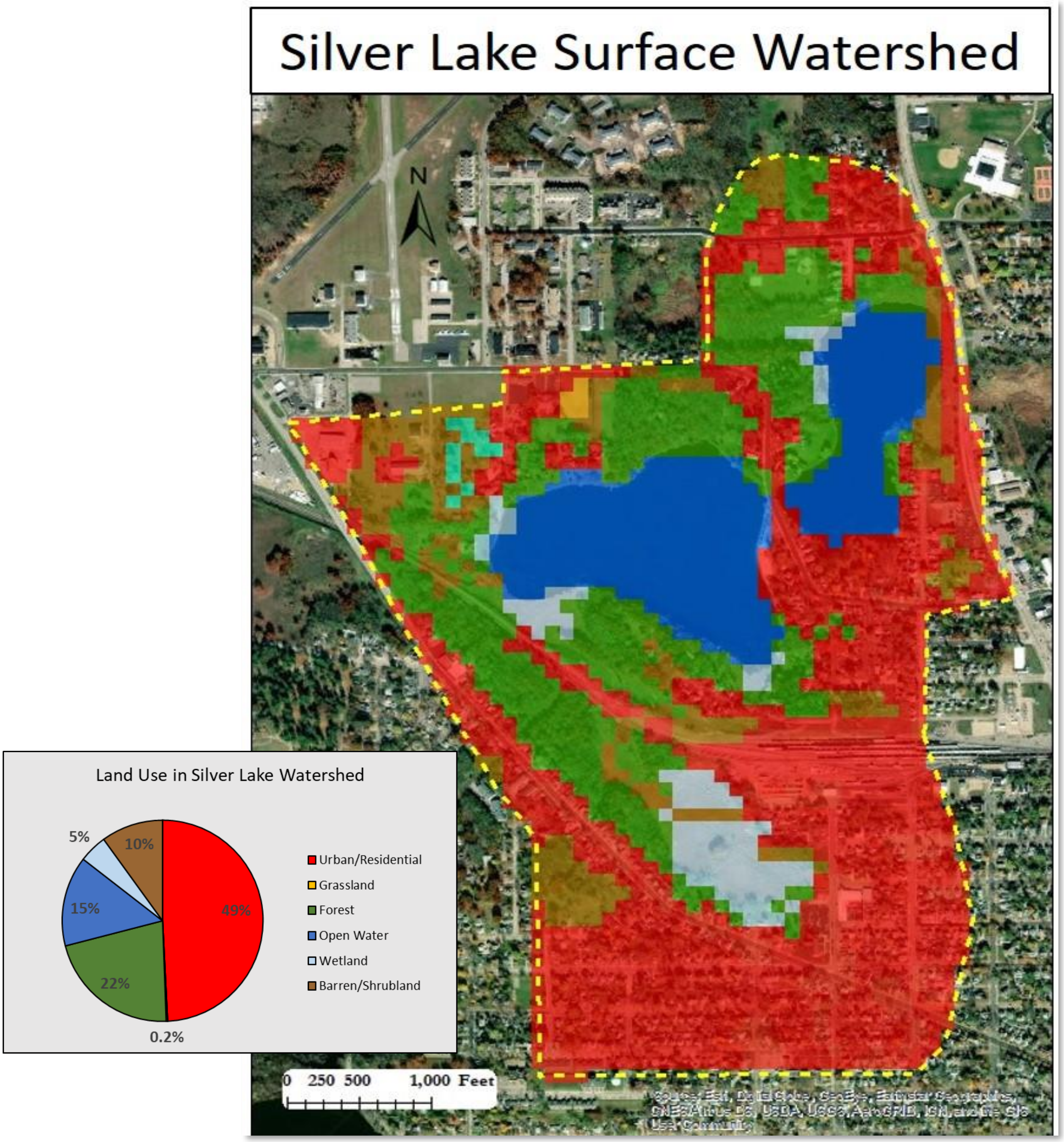


FIGURE 2. LAND USE IN THE SILVER LAKE SURFACE WATERSHED.

Silver Lake's surface watershed was delineated using a combination of elevation data, storm sewer maps and site reconnaissance. An important part of the surface watershed is the area that drains to the South Wetland in Figure 3. Although there is a large railroad embankment between the wetland and Silver Lake, monitoring of water levels and field reconnaissance was used to determine if the wetland was internally drained or was directly connected to surface water within the lake basin itself and the wetland located east of Silver Lake across New Pinery Road (Figure 2).

FIGURE 3. WETLANDS ADJACENT TO SILVER LAKE.

Pressure transducers were deployed in the South (Inlet) Wetland, West Basin and East (Outlet) Wetland to record water level changes during June-July 2019. The results are shown in Figure 3. Very close correlation is obvious between the Lake Basin and the Outlet Wetland to the east as they rise together with each storm event, then drain almost as quickly. Correlation to storm events is also seen in the Inlet Wetland, but with a much slower release following each storm. There is a small open channel from the South Wetland that leads through a culvert under the railroad embankment and continues north-northeast and then disappears into the thick cattail marsh just before reaching the lake. It appears that the south wetland acts as a stormwater detention basin which stores (water level increases) and then slowly releases water to the lake. It is reasonable to assume that the slowing of the flow leads to retention of sediment in the wetland complex and high evapotranspiration may reduce the volume of water that enters the lake in summer. While wetlands are useful for treating urban stormwater, additional investigation could explore how effective it is in storing nutrients such as phosphorus over the long-term and how much it might contribute in spring and fall when the vegetation is less active. In addition, if any future hydrologic alternations are proposed for the wetland area, consideration to how that might alter its water quality benefits could be considered.

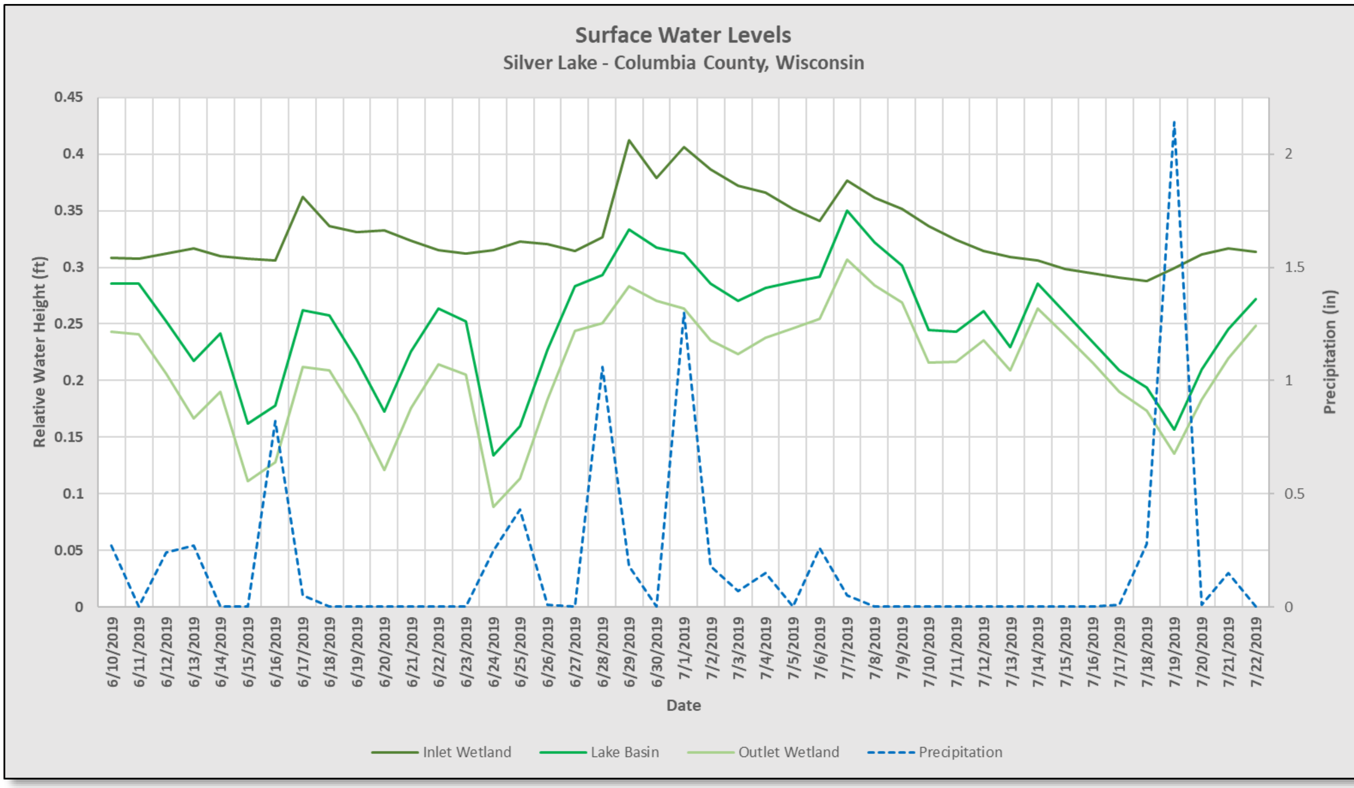


FIGURE 4. SURFACE WATER LEVELS AND PRECIPITATION - JUNE-JULY 2019.

Groundwater is water that infiltrates through the soil and then moves into the local lake and streams. Because this water passes through soil and the groundwater aquifer, the more groundwater that enters a lake, the more influence the local geology has on the lake. Groundwater can spend years to decades in the

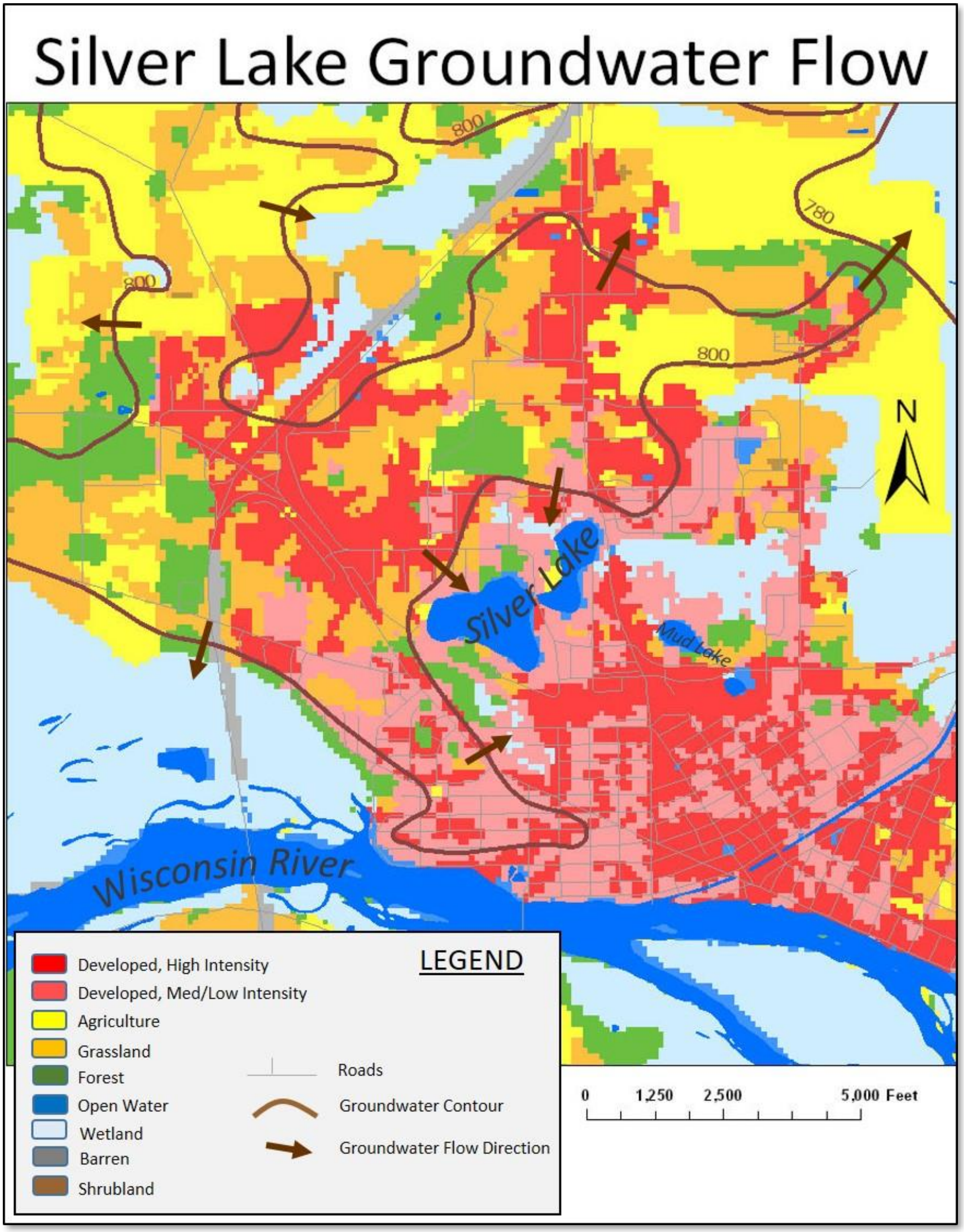


FIGURE 5. GROUNDWATER FLOW DIRECTION NEAR SILVER LAKE.

ground from the time it enters to the time it discharges to the lake or stream. This length of time means that the groundwater temperature is near constant year-round; during the summer, groundwater entering Silver Lake is cooler than the water temperature. In the winter, groundwater entering the lake is warmer than the water and leads to areas of the lake that may freeze later or thaw earlier.

Groundwater flows below ground from areas of higher to lower water elevations and ultimately discharges to the wetlands and lake. The groundwater feeding the lakes in Columbia County originates nearby as this area is located along a groundwater (and surface water) divide between water heading toward the Wisconsin/Mississippi Rivers and the Gulf of Mexico and water heading toward the Fox River and Great Lakes. This results in a relatively small groundwater contributing area to the lake (roughly from the airport to the north and the interstate to the west) and a lake that is responsive to groundwater level fluctuations. As the water table moves up and down following years of higher or lower precipitation, respectively, the lake level will also be expected to vary in elevation. The approximate groundwater contributing area can be observed in Figure 5. The brown arrows in Figure 5 indicate the general direction of groundwater flow (groundwater entering Silver Lake enters from the north and west).

Water levels in a lake fluctuate naturally as a result of seasonal and long-term variations in precipitation and runoff. These natural fluctuations are an inherent feature of lake ecosystems, essential for the survival and well-being of many species that have evolved to suit their life cycle to those fluctuations, and needed for a range of ecosystem services (Gasith and Gafny 1990, Wantzen et al. 2008). They can result in changes to water clarity, water quality, aquatic plant assemblages, etc.

Silver Lake water level data (referenced to a staff gauge located on the bridge abutment between the two basins) between 2009 and 2018 is shown (black circles) in Figure 6 below. The data indicates nearly 3 feet in water level fluctuation with a high of almost 9 feet on the gauge in 2009 and a low of almost 6 feet in late 2011.

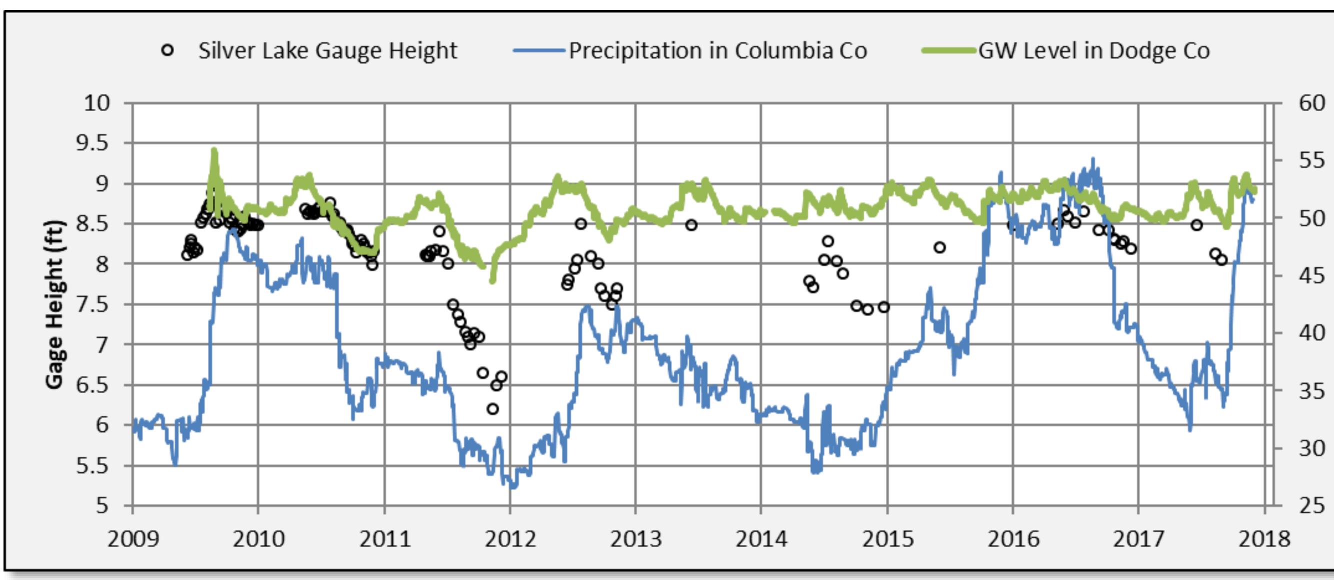
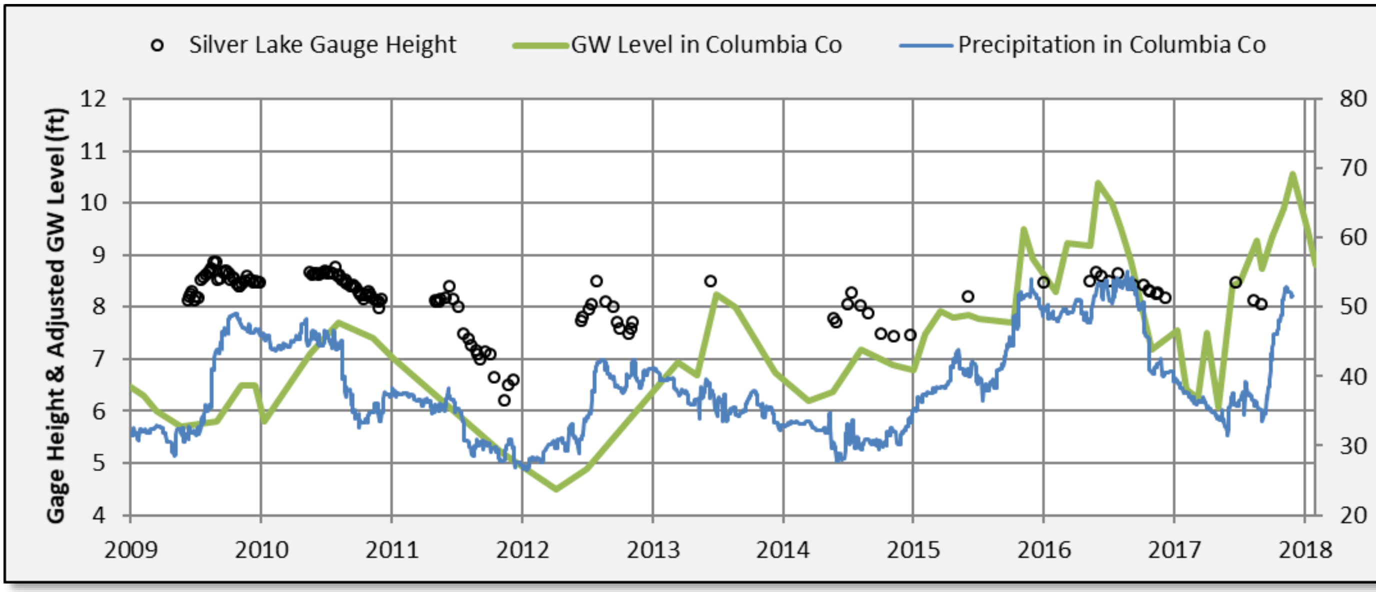
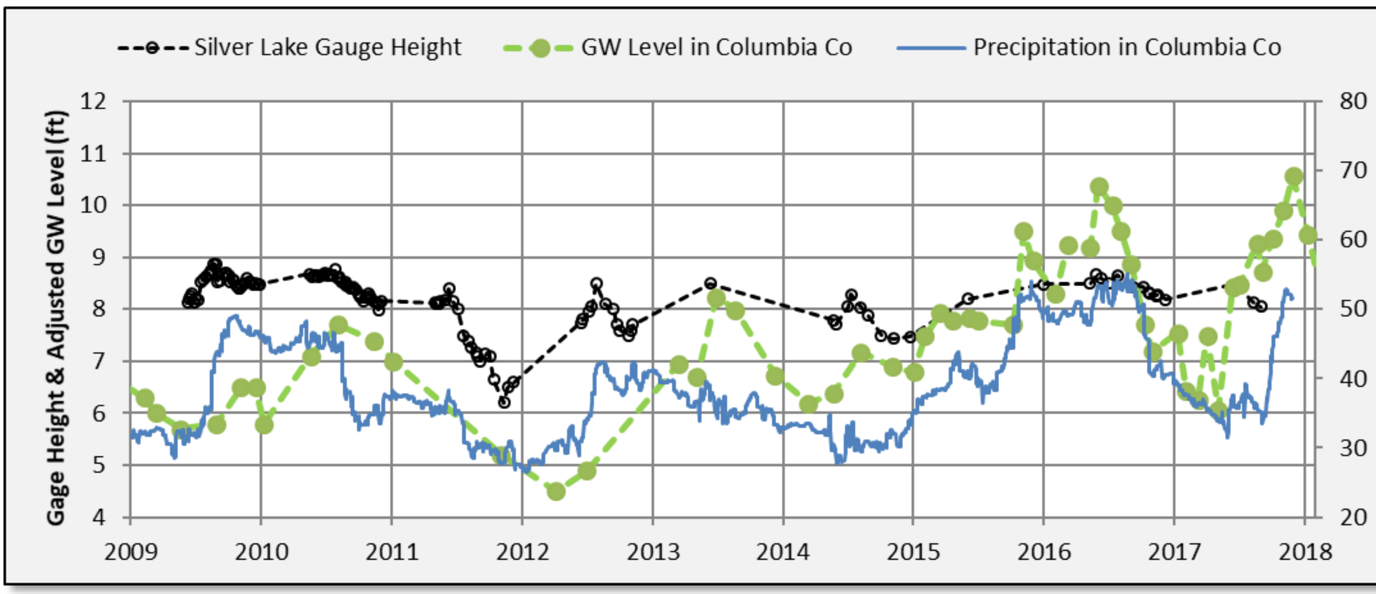


FIGURE 6. WATER LEVELS AND PRECIPITATION, 2009-2018. PRECIPITATION SHOWN AS TOTAL FOR THE PREVIOUS 365 DAYS (RIGHT AXIS), GROUNDWATER LEVEL RECORDED AT WELL USGS CO-12/09E/27-0620 IN THE SANDSTONE AQUIFER AND WATER LEVEL ADJUSTED BY ADDING 39 FEET TO FIT GRAPH SCALE (LEFT AXIS).

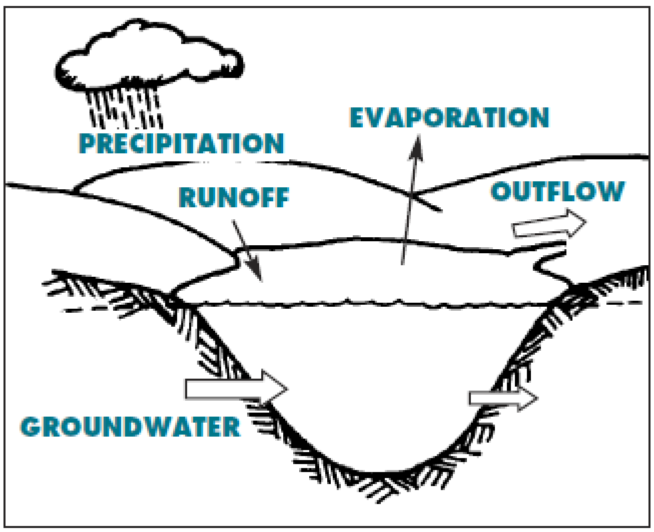




There is good correlation between the trend in annual precipitation (blue line) and water levels in Silver Lake for this time period which illustrates the lake's response to these contributions. For further comparison, water level data from a monitoring well (green line) in Columbia County shows that water table elevations also show a similar trend with a low in early 2012 and high water levels in 2016 and late 2017.

Flow out of the lake was 1.5 cubic feet per second (cfs) in fall, 2019. That is consistent with a groundwater contributing area of approximately 1,000 acres. The groundwater and surface water runoff into the lake lead to water inflow rate that varies over time. The groundwater provides a base flow into the lake which is less variable than the inflow that results from large precipitation events when surface runoff enters the lake.

Lake water quality is a result of many factors including the local geology, the climate, and land management. Assessing lake water quality allows us to evaluate current lake health and to make comparisons with the historical observations. We can then identify what is needed to achieve a more desirable state or preserve an existing state based on aesthetics, recreation, wildlife and the fishery. During this study, water quality in Silver Lake was assessed by measuring different characteristics including temperature, dissolved oxygen, water clarity, water chemistry, and algae.



The source of a lake's water supply is important in determining its water quality and choosing management practices to preserve or influence that quality. Silver Lake is classified as a groundwater drainage lake (Figure 7). Drainage lakes receive water primarily through groundwater, and to lesser extents direct runoff and precipitation. Drainage lakes generally have higher concentrations of minerals such as calcium and magnesium, which are picked up by groundwater moving through soil and rock. Drainage lakes are also vulnerable to contamination moving towards the lake in the groundwater. Examples for Silver Lake may include septic systems, agriculture, and road salt.

FIGURE 7. ILLUSTRATION SHOWING INFLOW AND OUTFLOW OF WATER IN A DRAINAGE (SPRING) LAKE.

1The geologic composition that lies beneath a lake has the ability to influence the temperature, pH, minerals, and other properties in a lake. As groundwater moves, some substances are filtered out, but some materials in the soil dissolve into the groundwater. Minerals such as calcium and magnesium in the soil around Silver Lake are dissolved in the water (Shaw et al., 2000).

TABLE 1. MINERALS AND PHYSICAL MEASUREMENTS IN SILVER LAKE, 2017-2019.

Silver Lake-West	**Alkalinity** (mg/L)	**Calcium** (mg/L)	**Magnesium** (mg/L)	**Color** (SU)	**Turbidity** (NTU)
Average Value	124.5	34	8.6	21	1.2
Silver Lake-East	**Alkalinity** (mg/L)	**Calcium** (mg/L)	**Magnesium** (mg/L)	**Color** (SU)	**Turbidity** (NTU)
Average Value	117	29.05	8.8	24	2.6

The average hardness for Silver Lake during the 2017-2019 sampling period was 125 mg/L, which is considered hard (Table 1). Hard water provides calcium necessary for building bones and shells for animals in the lake. The average alkalinity was 124.5 mg/L in the west basin and 117 mg/L in the east basin; higher alkalinity in inland lakes can support higher species productivity. Hardness and alkalinity also play a role in the type of aquatic plants that are found in a lake (Wetzel, 2001).

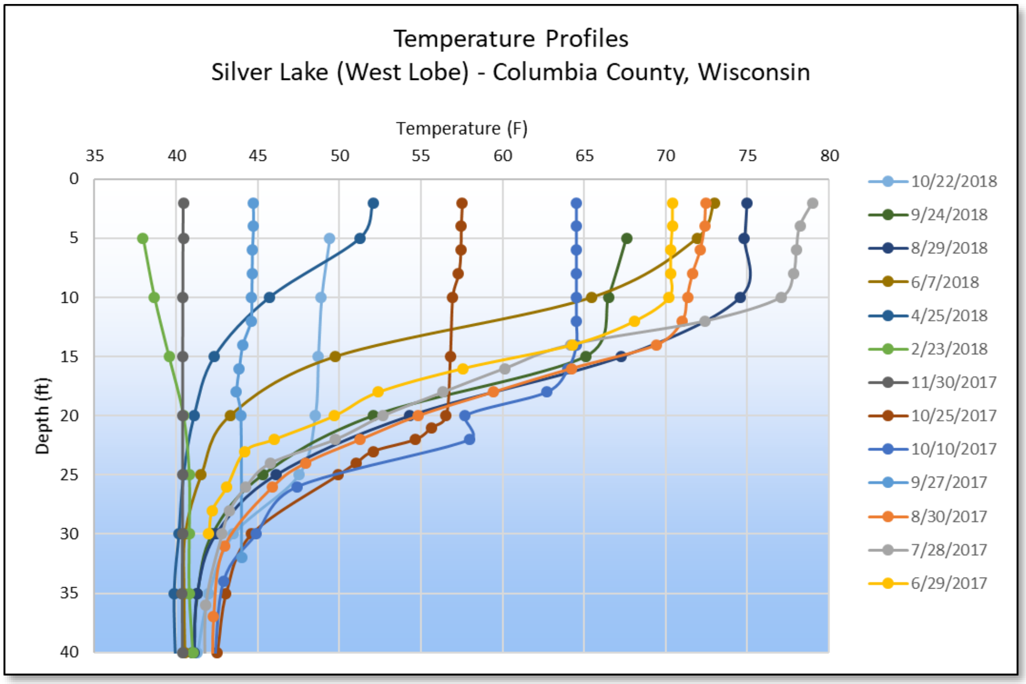
Chloride concentrations, and to lesser degrees sodium and potassium concentrations, are commonly used as indicators of how a lake is being impacted by human activity.

Silver Lake had elevated chloride and sodium concentrations over the monitoring period (Table 2). These concentrations are below concentrations that should be harmful to aquatic organisms but are an indication that land use is impacting the lake. In Silver Lake, the higher chloride and sodium concentrations are most likely the result of road-salting chemicals applied in the surface and groundwater watersheds.

TABLE 2. AVERAGE WATER CHEMISTRY IN SILVER LAKE, 2017-2019.

Silver Lake-West	Average Value			Reference Value		
	Low	Medium	High	Low	Medium	High
Potassium (mg/L)			1.8	<.75	0.75-1.5	>1.5
Chloride (mg/L)			50.3	<3	3.0-10.0	>10
Sodium (mg/L)			33.2	<2	2.0-4.0	>4
Silver Lake-East	**Average Value**			**Reference Value**		
	Low	**Medium**	**High**	**Low**	**Medium**	**High**
Potassium (mg/L)			1.52	<.75	0.75-1.5	>1.5
Chloride (mg/L)			53.5	<3	3.0-10.0	>10
Sodium (mg/L)			34.9	<2	2.0-4.0	>4

In a lake, the water temperature changes throughout the year and may vary with depth. Water temperature was measured in each basin of Silver Lake from the surface to the bottom at the time of sample collection (Figure 8). During the 2017-2019 study, temperature data illustrated a typical deep lake profile in the west basin with a well-developed thermocline by June between 15 and 25 feet. Spring and fall overturn profiles are apparent with temperatures between 37 and 42 degrees maintained with depth. The east basin illustrates typical profiles of a shallow, mixed lake that maintain a similar temperature from surface to bottom. During the summer months, a period of slight stratification develops as surface temperatures warm.



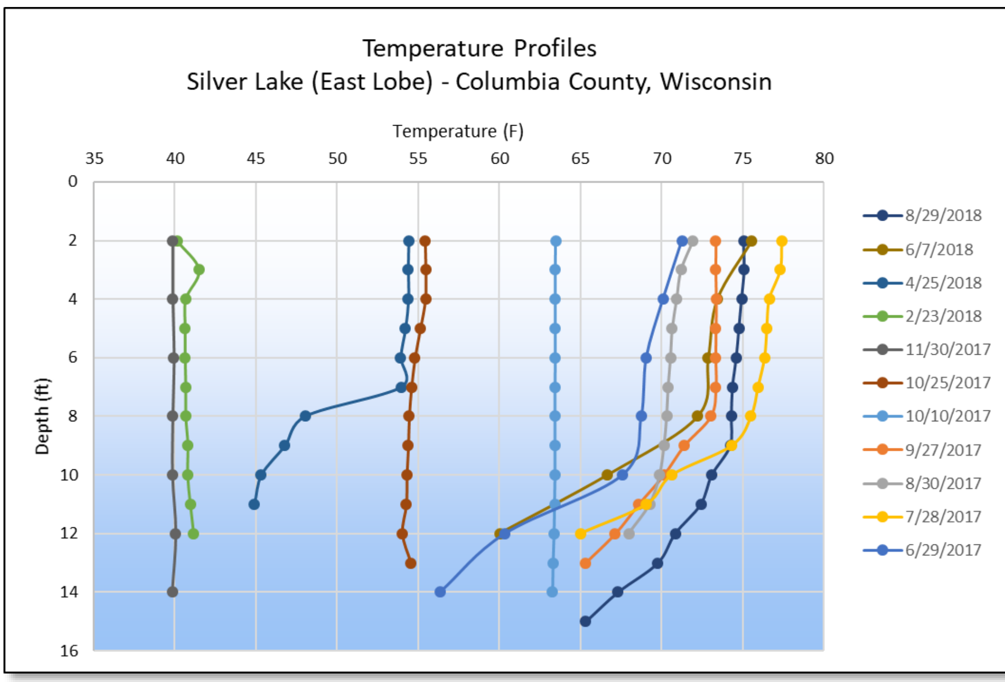
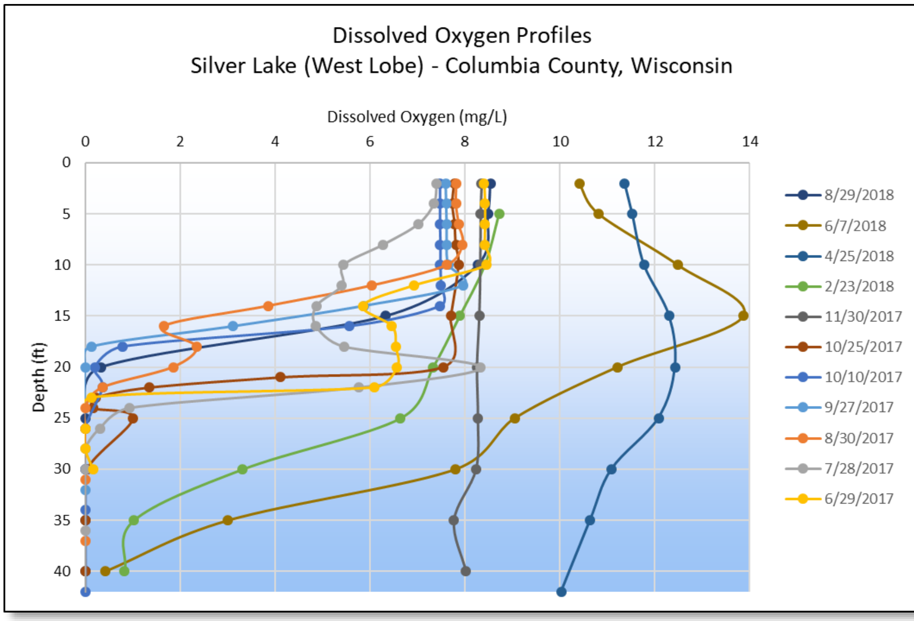


FIGURE 8. TEMPERATURE PROFILES IN SILVER LAKE, 2017-2019.

Dissolved oxygen is an important measure in aquatic ecosystems because a majority of organisms in the water depend on oxygen to survive. Oxygen is dissolved into the water from contact with the air, which is increased by wind and wave action. Algae and aquatic plants also produce oxygen when sunlight enters the water, but the decomposition of dead plants and algae reduces oxygen in the lake. Some forms of iron and other metals carried by groundwater can also consume oxygen when the groundwater discharges to the lake. During winter and summer when lakes stratify (layer), the amount of dissolved oxygen is often lower towards the bottom of the lake. Dissolved oxygen concentrations below 5 mg/L stress some species of cold-water fish and over time can reduce the amount of available habitat for sensitive cold-water species of fish and other aquatic organisms.

Dissolved oxygen was measured in each basin of Silver Lake from the surface to the bottom at the time of sample collection. During the 2017-2019 study, dissolved oxygen data in the west basin illustrated a typical profile for a deep, stratified lake with moderate levels of nutrients. Most the year, these concentrations start near saturation at the surface and drop off significantly as depths reach the thermocline between 10 and 25 feet. During the summer, there is low oxygen concentrations below the thermocline. During spring and fall overturn, mixing of the lake leads to oxygen concentrations that are relatively uniform from surface to bottom (Figure 9). The bumps in concentration during the June, July and August 2017 profiles (west basin) at 20 feet are indicative of algae blooms at depth. This is largely absent in the east basin where more plants are available to outcompete algae for nutrients.



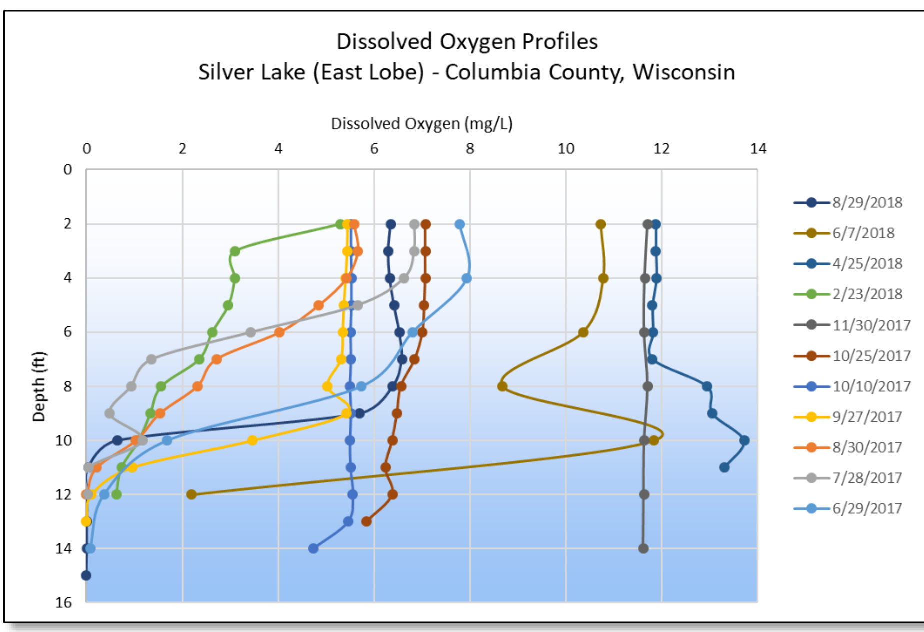
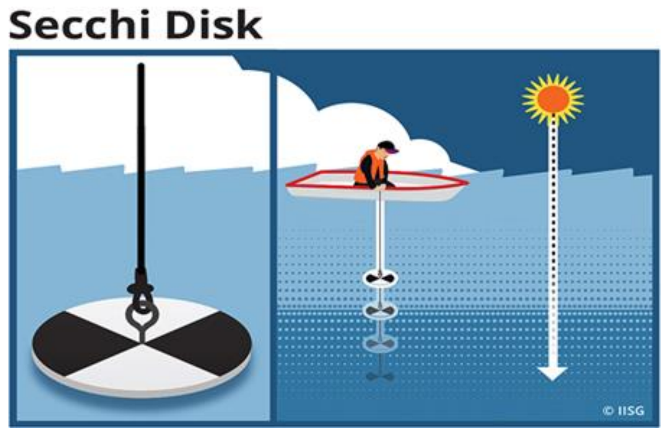


FIGURE 9. DISSOLVED OXYGEN PROFILES IN SILVER LAKE, 2017-2019.

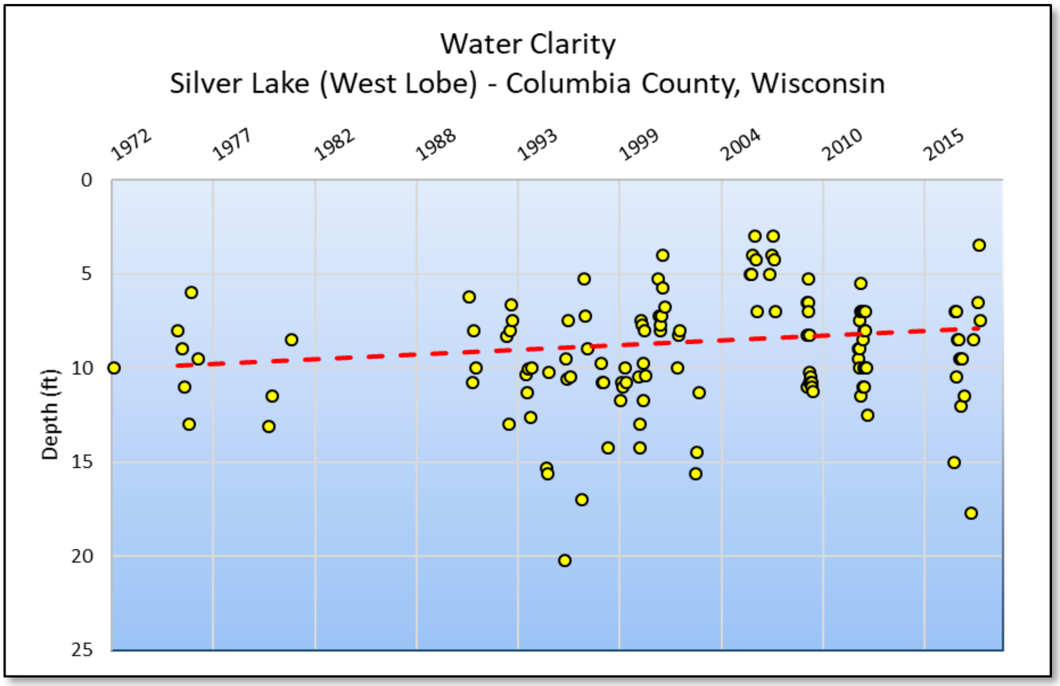
Water clarity is a measure of the depth that light can penetrate the water. It is an aesthetic measure and is also related to the depth that rooted aquatic plants can grow. Water clarity is affected by water color, turbidity (suspended sediment), and algae, so it is normal for water clarity to change throughout the year and from year to year.



In Silver Lake, color was low. High speed boating is not really possible in the east basin due to plant density and is rare in the west basin where depths in most areas are great enough that sediment is unlikely to be resuspended. As a result, the variability in transparency observed throughout the year is likely due primarily to fluctuating algae concentrations. Water clarity measured during the study in each basin was generally considered good.

The west basin, which generally has slightly deeper secchi depths than the east basin, observed depths ranging from 7 feet to 17.7 feet during the study (Figure 10) and shows a decreasing trend over the long term (based on July/August data). When compared with past data as far back as the early 1970s, the average water clarity measured during the study was similar in all sampled months except. Water clarity in Silver Lake was typically reduced during the late summer and early fall.

The east basin has a far more limited data set with only a few measurements prior to this study. Secchi depths ranged from 7 feet to 13 feet during the study (Figure 11). When compared with past data, the average water clarity measured during the study was better in all sampled months. Water clarity in Silver Lake was typically reduced during the late summer and early fall.



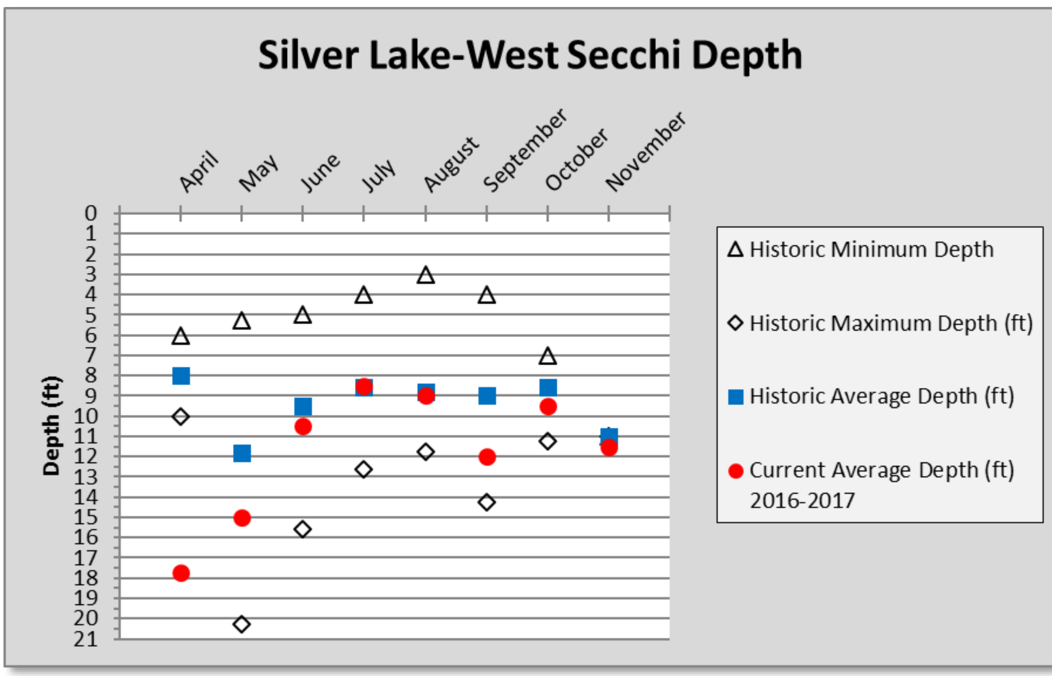
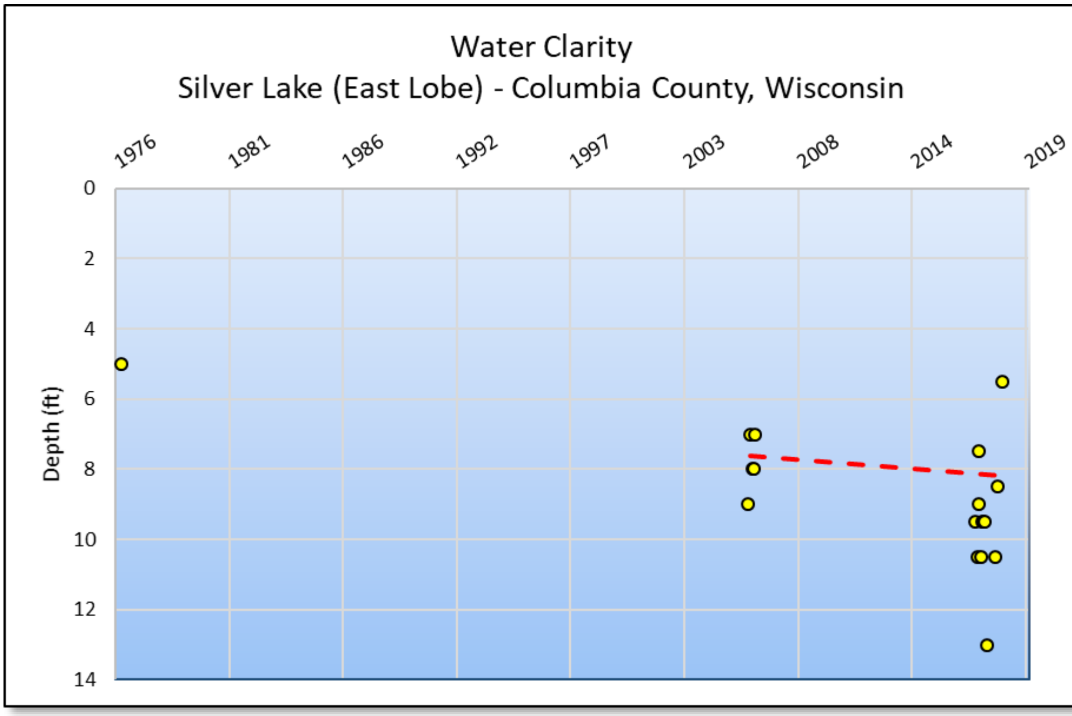


FIGURE 10. WATER CLARITY IN SILVER LAKE-WEST.



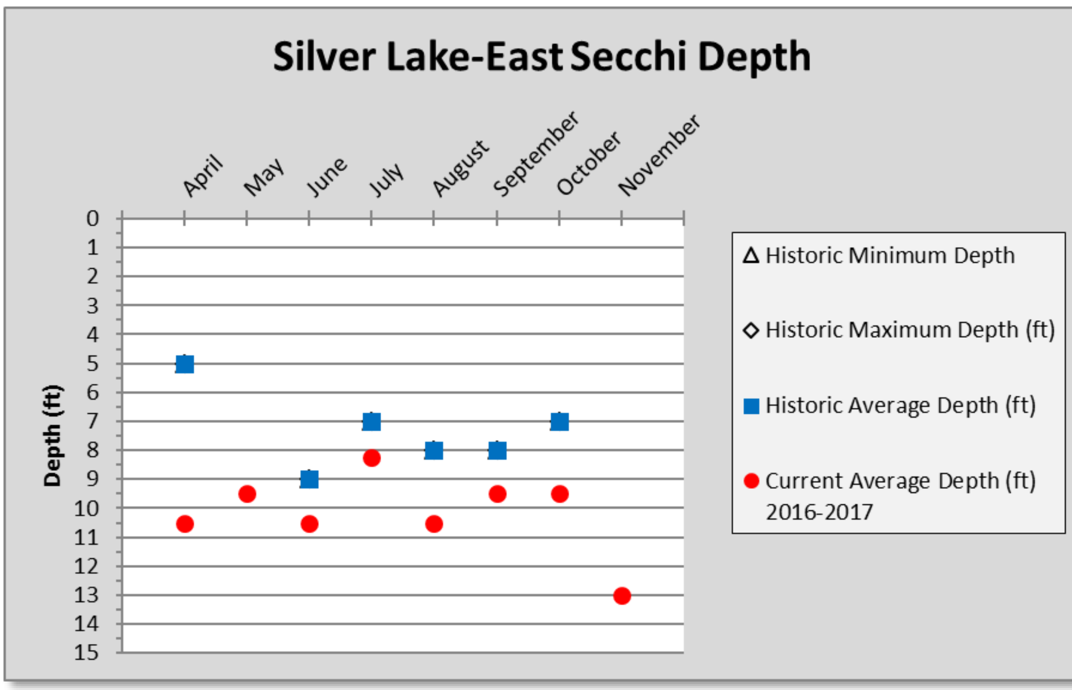


FIGURE 11. WATER CLARITY IN SILVER LAKE-EAST.

Nutrients (phosphorus and nitrogen) are used by algae and aquatic plants for growth. Phosphorus is present naturally throughout the watershed in soil, plants, animals and wetlands. Common sources from human activities include soil erosion, animal waste, fertilizers and septic systems.

It is most common for phosphorus to move from the land to the water through surface runoff, but it can also travel to the lake in groundwater. Once in a lake, a portion of the phosphorus becomes part of the aquatic system in the form of plant and animal tissue, and sediment. The phosphorus continues to cycle within the lake for many years.

During the study, total phosphorus concentrations in Silver Lake (West) ranged from a high of 51 ug/L April 2019 to a low of 14.7 ug/L in July 2018 (Table 3). The summer median total phosphorus concentrations were 24.5 ug/L, 23.8 ug/L and 16.7 ug/L in 2017, 2018 and 2019, respectively. This is just above Wisconsin's phosphorus standard of 20 ug/L for deep seepage lakes and just below 30 ug/L for drainage lakes (Figure 12). Silver Lake is a headwater drainage lake that likely has a large seepage component to its behavior. So, though the 3-year growing season average is technically below standard, it is at levels that are approaching threshold levels. Inorganic nitrogen concentrations in Silver Lake were within the natural background range for lakes in Columbia County.

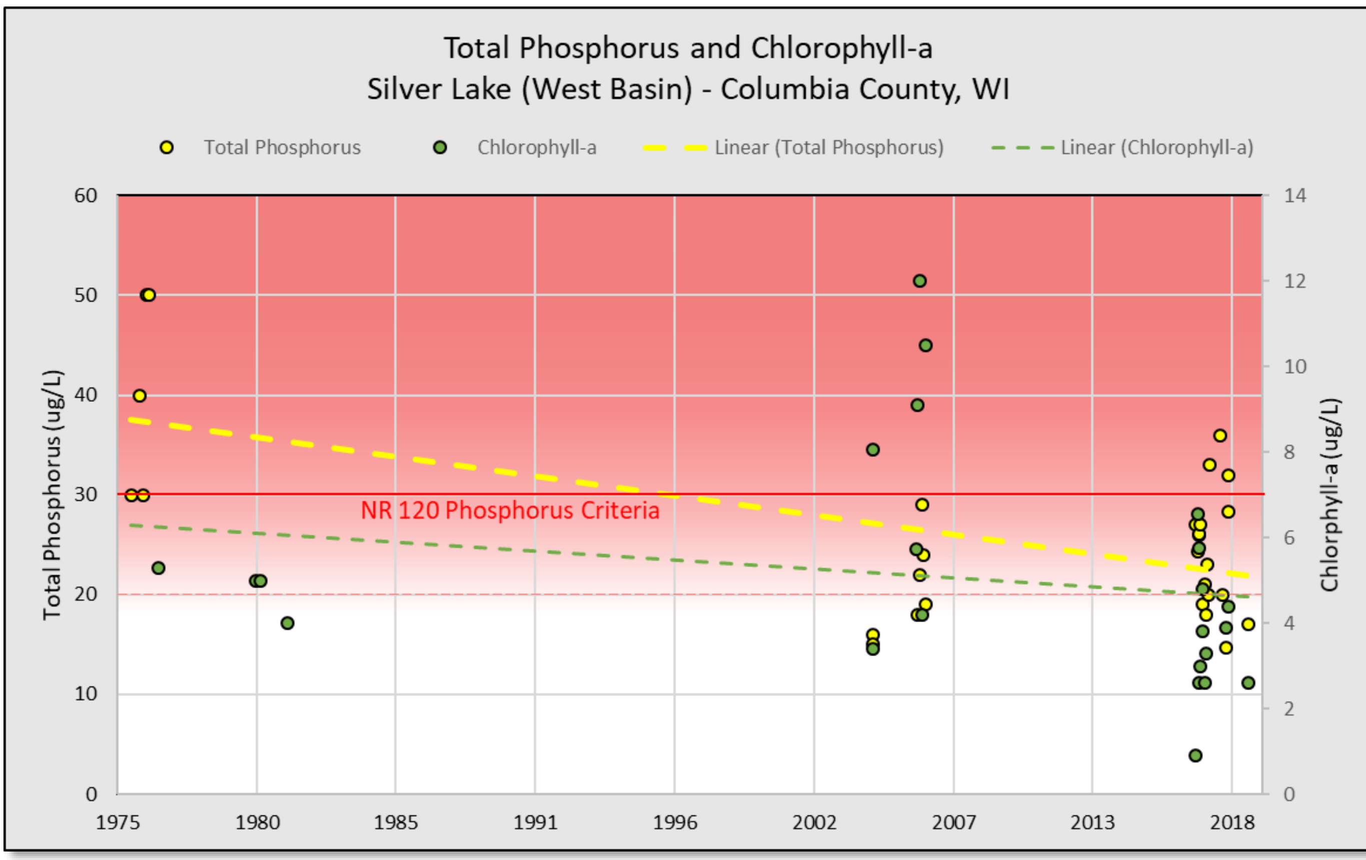


FIGURE 12. TOTAL PHOSPHORUS AND CHLOROPHYLL-A.

Chlorophyll *a* is a measurement of algae in the water. Chlorophyll *a* concentrations in Silver Lake varied only slightly throughout the monitoring period ranging from a high of 6.5 ug/L in June 2017 to a low of 0.9 ug/L in May 2017. The average over the monitoring period was 3.7 ug/L. It should be noted that the standard Wisconsin Department of Natural Resources sample acquisition protocol was followed, collecting integrated samples of the upper six feet of water. Dissolved oxygen concentrations suggest that algae below the six feet depth are also important in Silver Lake and these were not accounted for in these analyses.

TABLE 3. SEASONAL SUMMARY OF NUTRIENT CONCENTRATIONS IN SILVER LAKE, 2017-2019.

Silver Lake-West	Inorganic Nitrogen (mg/L)			Soluble Reactive Phosphorus (ug/L)			Total Phosphorus (ug/L)		
	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max
Fall	0.02	0.20	0.61	5	5.5	6	20	23	33
Spring	0.13	0.21	0.29	nd	2	4	27	38	51
Summer	nd	0.07	0.09	2	3	4	14.7	23	32

Estimates of phosphorus from the landscape can help to understand the phosphorus sources to Silver Lake. Land use in the surface watershed was evaluated and used to populate the Wisconsin Lakes Modeling Suite (WILMS) model. In general, each type of land use contributes different amounts of phosphorus in runoff and through groundwater. The types of land management practices that are used and their distances from the lake also affect the contributions to the lake from a parcel of land. Based on modeling results, developed land and grassland had the greatest percentages of phosphorus contributions from the watershed to Silver Lake (Figure 13).

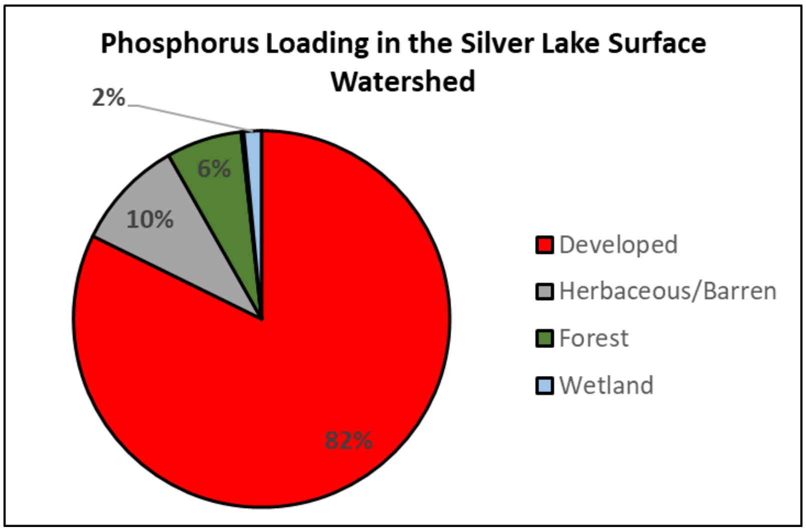


FIGURE 13. ESTIMATED DISTRIBUTION OF PHOSPHORUS LOADING FROM LAND USES IN THE SILVER LAKE WATERSHED.

The phosphorus contributions by land use category, called phosphorus export coefficients, are shown in Table 4. The phosphorus export coefficients have been obtained from studies throughout Wisconsin (Panuska and Lillie, 1995).

TABLE 4. DATA USED TO MODEL PHOSPHORUS INPUTS FROM LAND USES IN THE SILVER LAKE WATERSHED.

Silver Lake Watershed Land Use	Phosphorus Export Coefficient (lbs/acre-yr)	Land Use Area Within the Watershed		Estimated Phosphorus Load	
		Acres	%	Pounds	%
Water	0	70	15%	0	0%
Developed	0.5	239	49%	120	82%
Herbaceous/Barren	0.3	46	9.5%	14	10%
Forest	0.09	105	22%	9	6%
Hay/Pasture/Grassland	0.3	1	0.2%	0.3	0.2%
Wetland	0.1	22	5%	2	2%

Once phosphorus is in a lake, some continues through the system dissolved in water while the rest is taken up by plants at the bottom of the food chain, then moves up through phytoplankton, fish and wildlife. When these organisms die, their nutrient rich remains join soil particles and become part of the lake's substrate.

Based on some general assumptions, estimates of phosphorus residing in the lake were made (Table 5) along with an estimate of phosphorus removed via plant harvesting. Modeling above estimates 150 lbs of phosphorus loading to the lake per year. The estimate below suggests about 113 lbs of phosphorus removed each year for a net loading of about 37 lbs/year of phosphorus due to harvesting.

West Lobe	**Water**			**Sediment**			**Submersed Plants**			**Emergent Plants**			**Harvested Plants**	
	Volume	900	acre-ft	Area	47	acre	Area	5	acre	Area	8	acre	**(Based on 2018 Harvest Report)**	
	Volume	39204000	cubic feet	Area	190299.6728	m2	Area	20244.65	m2	Area	32391.43	m2		
	Volume	1108469578	liters	Sed depth	0.25	meter	Biomass Density	50	dry gram/m2	Biomass Density	700	g/m2		
	P Conc	24	ug/l	P Conc	200	mg/kg	P Content	0.003	fraction	P Content	0.002	fraction		
								0.3	%		0.2	%		
				Sed Density	0.5	g/cm3								
				Sed Density	31.2	lb/ft3								
				Sed Density	500	kg/m3								
				P Mass	4.76E+06	gram	P Mass	3036.7	gram	P Mass	45348.0	gram	46800	lbs wet weight
	P Mass	26.60	kg		4757.5	kg		3.04	kg		45.35	kg	2925	lbs dry weight
	P Mass	**59**	**lb**	**P Mass**	**10479**	**lb**	**P Mass**	**7**	**lb**	**P Mass**	**100**	**lb**	**8.775**	**lbs P content**
					25	mg/m2								
East Lobe	**Water**			**Sediment**			**Submersed Plants**			**Emergent Plants**				
	Volume	250	acre-ft	Area	31	acre	Area	17.5	acre	Area	13.5	acre		
	Volume	10890000	cubic feet	Area	125516.8055	m2	Area	70856.26	m2	Area	54660.54	m2		
	Volume	307908216	liters	Sed depth	0.25	meter	Biomass Density	150	dry gram/m2	Biomass Density	700	g/m2		
	P Conc	24	ug/l	P Conc	200	mg/kg	P Content	0.003	fraction	P Content	0.002	fraction		
								0.3	%		0.2	%		
				Sed Density	0.5	g/cm3								
				Sed Density	31.2	lb/ft3								
				Sed Density	500	kg/m3								
				P Mass	3.14E+06	gram	P Mass	31885.3	gram	P Mass	76524.8	gram	559000	lbs wet weight
	P Mass	7.39	kg		3137.9	kg		31.89	kg		76.52	kg	34937.5	lbs dry weight
	P Mass	**16**	**lb**	**P Mass**	**6912**	**lb**	**P Mass**	**70**	**lb**	**P Mass**	**169**	**lb**	**104.8125**	**lbs P content**
					25	mg/m2								

TABLE 5. ESTIMATES OF PHOSPHORUS CONTENT IN SILVER LAKE.


Aquatic plants in Silver Lake

Aquatic plants play important roles in a lake's ecosystem. They provide habitat for the fishery and other aquatic organisms, stabilize the sediment, reduce erosion, buffer temperature changes and waves, and infuse oxygen into the water. Aquatic plants near shore provide food, shelter and nesting material for shoreland mammals, shorebirds and waterfowl. It is not unusual for otters, beavers, muskrats and deer to be seen along a shoreline in their search for food or nesting material. The aquatic plants that attract the animals to these areas contribute to the beauty of the shoreland and lake.

The rapid and dominant growth of aquatic invasive plants, such as Eurasian watermilfoil (EWM), can reduce the recreational value of a lake. Aquatic invasive plants may also outcompete and cause a decline in native vegetation, which degrades habitat diversity and can alter the aquatic ecosystem.

An aquatic plant survey was conducted on Silver Lake in July 2017 by staff from the Center for Watershed Science and Education. Using the 'point-intercept' method, results and statistics from this survey can be compared to future surveys to assess change. Twenty-one species of aquatic plants were found in Silver Lake, with two additional species observed visually (Table 6). The greatest diversity of aquatic plants occurred in the shallows bordering the lake (Figure 14). Eighty-two percent (113 of 138) of the sites visited had vegetative growth (Figure 15). The greatest depth at which aquatic plant growth was found was 16 feet.


EWM observed in Silver Lake.

The dominant plant species found in Silver Lake was Eurasian water-milfoil (*Myriophyllum spicatum*), followed by coontail (*Ceratophyllum demersum*) and largeleaf pondweed (*Potamogeton amplifolius*). Eurasian water-milfoil (EWM) is the most predominant invasive species in Wisconsin lakes. It can reproduce from fruiting bodies and from fragmentation, making it hard to control once established. Coontail is an important food source for a wide range of waterfowl species. A number of invertebrate and fish species use the bushy stems and stiff whorls of leaves of the coontail as habitat, especially in the winter when other aquatic plants have died back. The broad leaves of largeleaf pondweed offer shade, shelter and foraging opportunities for fish. The fruits are produced in abundance and are a valuable food for waterfowl.

The Floristic Quality Index (FQI) evaluates how close a plant community is to undisturbed conditions. Each plant is assigned a coefficient of conservatism value (C-value) that reflects its sensitivity to disturbance, and these numbers are used to calculate the FQI. C-values range from 0 to 10. The lower the number, the more tolerant the plant is to disturbance. Having more plants with low C-values than high C-values is an indicator of disturbance, as the lower C-value plants better tolerate the stresses caused by disturbance. A C-value of 0 is assigned to exotic species. The FQI is an index that combines C-values of the plants observed with their relative abundance. The FQI for Silver Lake was 21.7.

In Silver Lake, C-values ranged from 0 to 8 (Table 6). Four of the twenty-four species found in Silver Lake had a C-value of 8, indicating good health in the aquatic plant community. The species with the highest frequency of occurrence within vegetated areas was common waterweed, with a C-value of 3. One invasive plant species was sampled, Eurasian watermilfoil (EWM), which has a C-value of 0.

Two species of invasive aquatic plants exist in Silver Lake. Curly-leaf pondweed (CLP) and EWM were both first reported in Silver Lake in 1994. EWM can hybridize with native milfoil, and the hybrid (HWM) was confirmed in Silver Lake by professionals from the Wisconsin Department of Natural Resources in 2012. During the 2017 survey, EWM/HWM was found in 73% of vegetated areas and accounted for a large portion of the plant biomass in the lake (Figure 16). EWM/HWM can create dense beds that can damage boat motors, make areas non-navigable, stunt or alter the fishery, create problems with dissolved oxygen, and prevent activities like fishing and swimming. This plant can produce a viable seed; however, its primary mode of reproduction and spread is fragmentation. A one-inch fragment is enough to start a new plant, making EWM/HWM very successful at reproducing. CLP was found (during a special survey in May 2018) in 12% of vegetated areas (Figure 17). CLP likes cold water and starts growing early in the season beneath the ice with Iis lifecycle wrapping up by early June. This mass of decaying plants right as the water is warming up can often lead to increased phosphorus and nuisance algae blooms.

The Simpson Diversity Index (SDI) quantifies biodiversity based on a formula that uses the number of species surveyed and the number of individuals per site. The SDI uses a decimal scale from 0 to 1; values closer to one represent higher amounts of biodiversity. The Silver Lake SDI for the 2017 survey was 0.88.

TABLE 6. AQUATIC PLANT SPECIES IDENTIFIED AND COEFFICIENT OF CONSERVATISM VALUES FOR SPECIES PRESENT IN SILVER LAKE, 2017.

Scientific name	Common name	Sampled	Visuals	C-value
Ceratophyllum demersum	coontail	x		3
Chara spp.	muskgrasses	x	x	7
Elodea canadensis	common waterweed	x	x	3
Elodea nuttallii	slender waterweed	x		7
Heteranthera dubia	water stargrass	x		6
Myriophyllum sibiricum	northern water milfoil	x	x	6
Myriophyllum spicatum	Eurasian water milfoil	x	x	0
Najas flexilis	slender naiad	x		6
Najas guadalupensis	southern naiad	x	x	8
Nitella spp.	stoneworts	x		7
Nymphaea odorata	white water lily		x	6
Potamogeton amplifolius	large-leaf pondweed		x	7
*Potamogeton crispus**	Curly-leaf pondweed*	x	x	0
Potamogeton foliosus	leafy pondweed	x		6
Potamogeton friesii	Fries' pondweed	x	x	8
Potamogeton gramineus	variable pondweed	x	x	7
Potamogeton illinoensis	Illinois pondweed	x	x	6
Potamogeton natans	floating-leaf pondweed	x	x	5
Potamogeton praelongus	white-stem pondweed	x	x	8
Potamogeton pusillus	small pondweed	x		7
Potamogeton strictifolius	stiff pondweed	x	x	8
Potamogeton zosteriformis	flat stem pondweed	x	x	6
Stuckenia pectinata	sago pondweed	x	x	3
Vallisneria americana	water celery	x	x	6
	filamentous algae	x		-
*CLP was mapped during a special survey conducted in May 2018.				

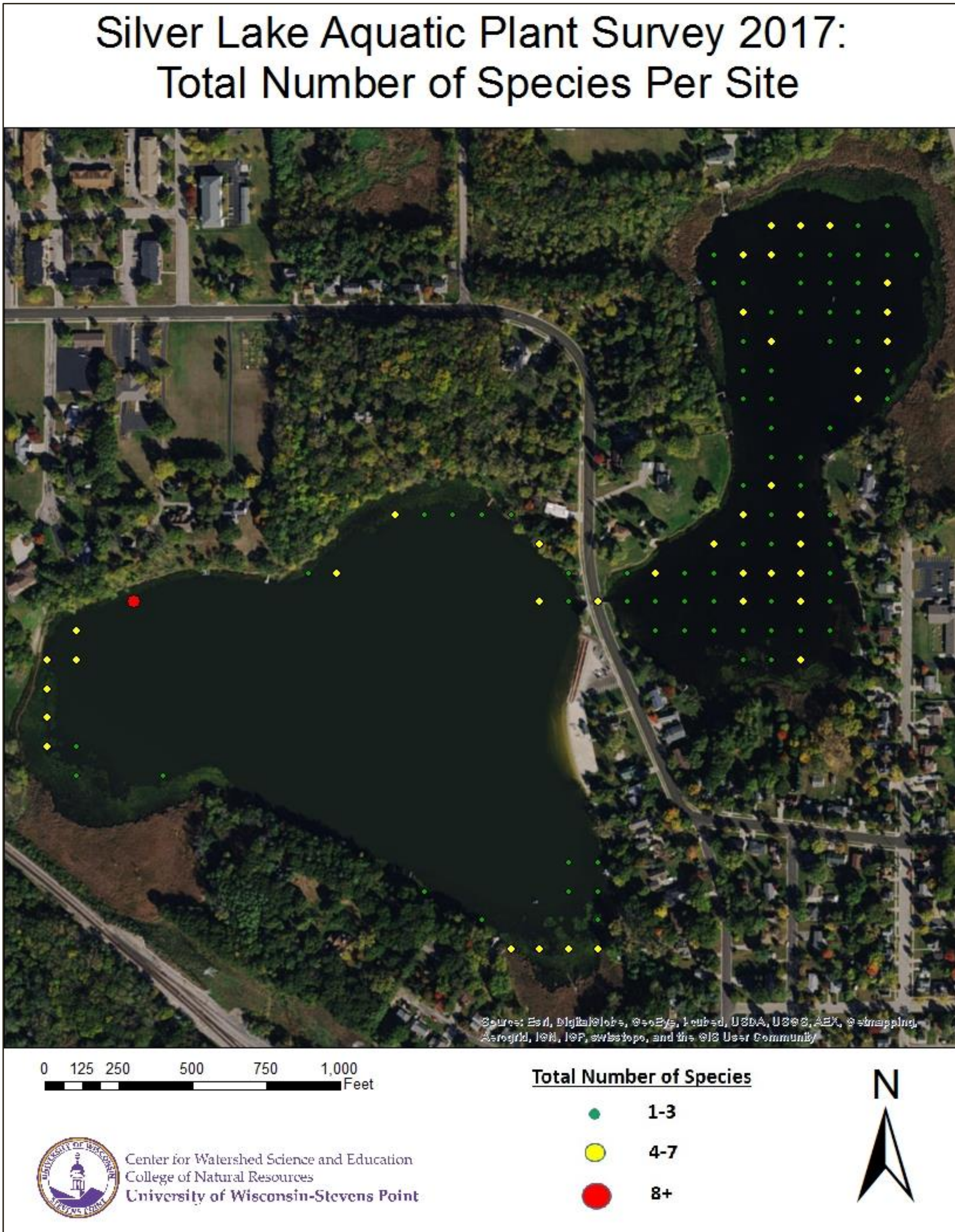


FIGURE 14. NUMBER OF AQUATIC PLANT SPECIES OBSERVED AT EACH SAMPLE SITE IN SILVER LAKE, 2017.

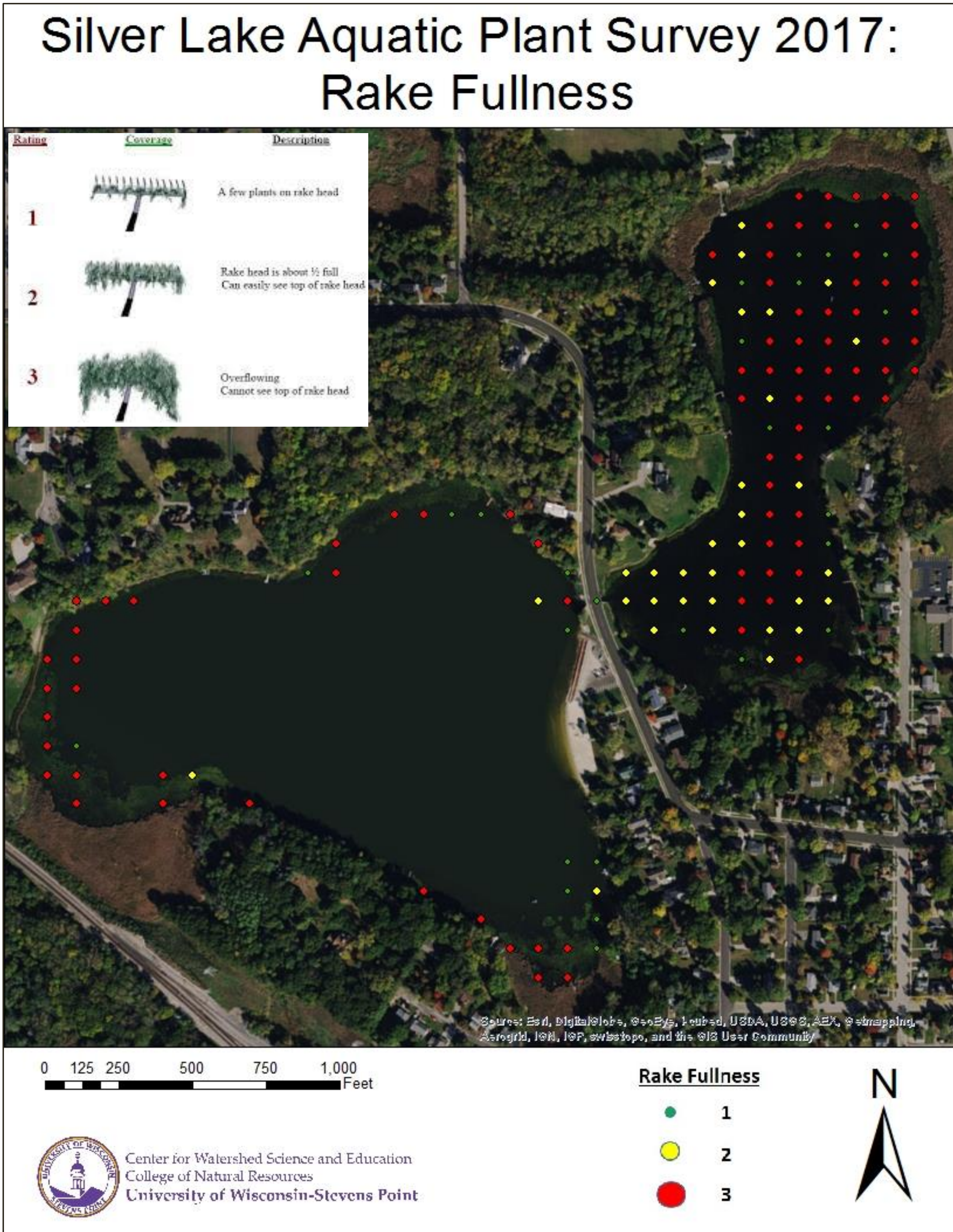


FIGURE 15. RAKE FULLNESS AT SAMPLE SITES IN SILVER LAKE, AUGUST 2017.

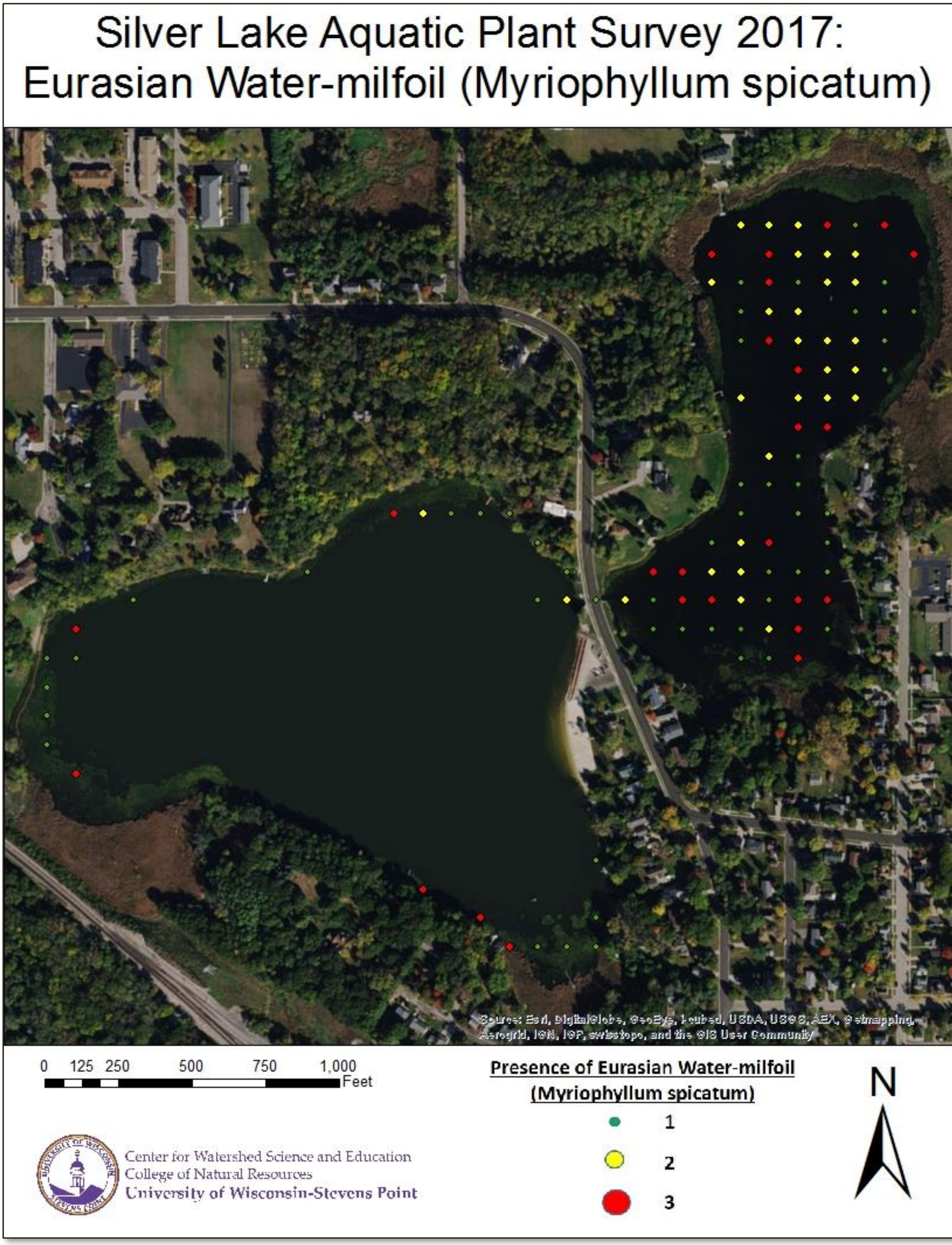


FIGURE 16. LOCATIONS AND ABUNDANCE OF EURASIAN WATERMILFOIL (EWM/HWM) AT SAMPLE SITES IN SILVER LAKE, AUGUST 2017.

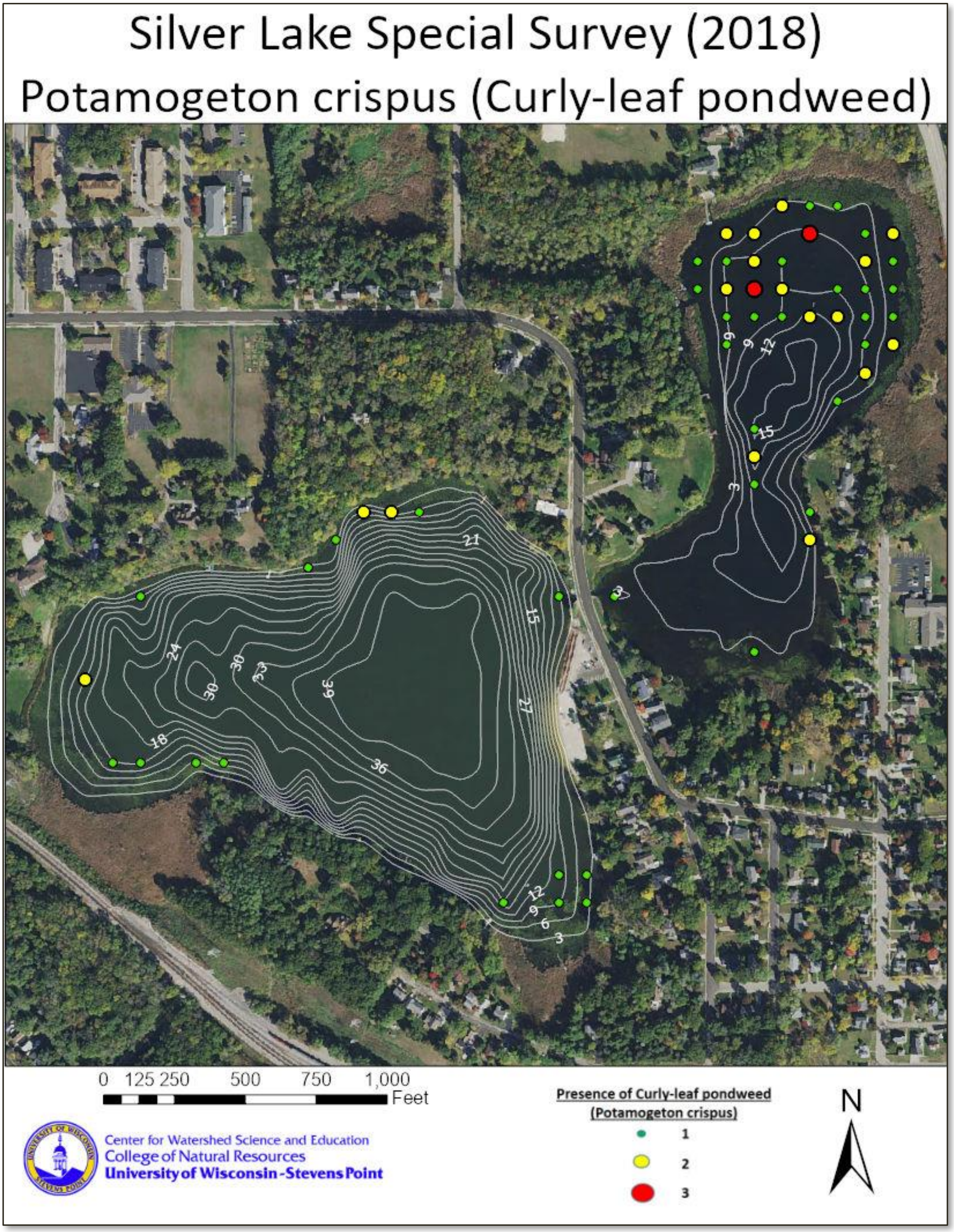


FIGURE 17. LOCATIONS AND ABUNDANCE OF CURLY-LEAF PONDWEED (CLP) AT SAMPLE SITES IN SILVER LAKE, JUNE 2018.

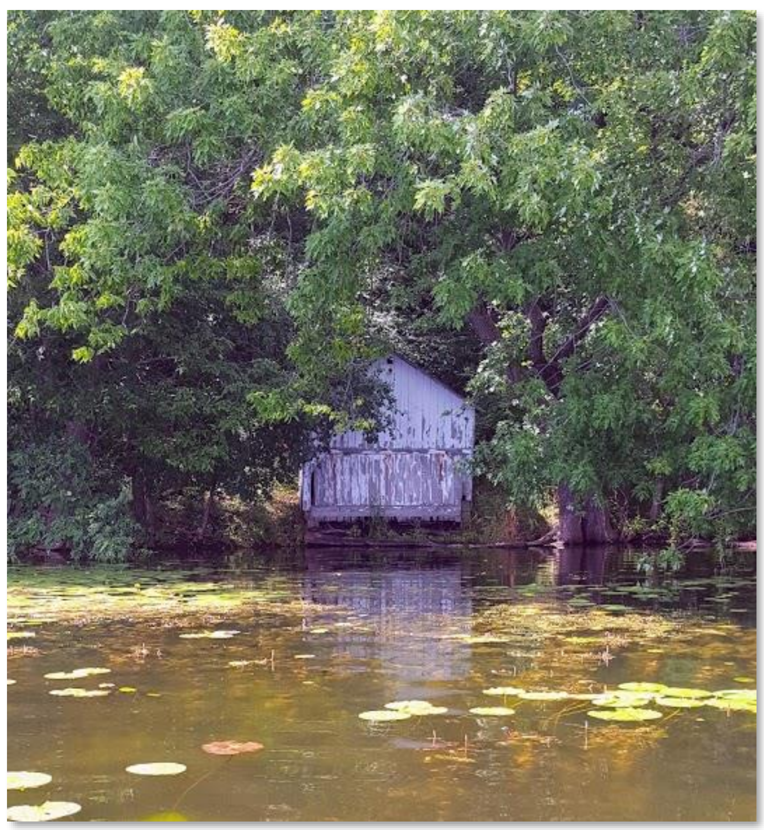
Shoreland vegetation is critical to a healthy lake's ecosystem. It provides habitat for many aquatic and terrestrial animals including birds, frogs, turtles, and many small and large mammals. It also helps to improve the quality (or reduce the quantity) of the runoff that is flowing across the landscape towards the lake. Healthy shoreland vegetation includes a mix of tall grasses/flowers, shrubs and trees which extend at least 35 feet landward from the water's edge.

To better understand the health of Silver Lake, shorelands were evaluated by professionals from the Center for Land Use Education and Columbia County. The survey inventoried the type and extent of shoreland vegetation. Areas with erosion, rip-rap, barren ground, seawalls, structures and docks were also inventoried.

A summary of the shoreland survey around Silver Lake is displayed in Figure 18. The shorelands were color-coded to show their overall health based on natural and physical characteristics. Black shorelands identify healthy shorelands with sufficient vegetation and few human disturbances. Red shorelands indicate locations where changes in management or mitigation may be warranted. Some portions of Silver Lake's shorelands are in good condition; however, large portions of the shore have challenges that should be addressed. Table 7 lists disturbances within 15 feet of the shore. 37% of Silver Lake's shoreland was ranked as poor.   A summary of shoreland disturbance is displayed in Table 7 and Table 8.

TABLE 7. DISTURBANCES WITHIN 15 FEET OF SHORE AROUND SILVER LAKE, 2017.

Modifications, Structures, Erosion	Measured Occurrence
Artificial Beach	293 ft
Rip Rap	302 ft
Sea Wall	1,040 ft
Impervious Surface	359 ft
Mowed Lawn	4,228 ft
Erosion	121 ft
Nonconforming Buildings	8
Piers	38
Coarse Woody Habitat	22 logs/mile



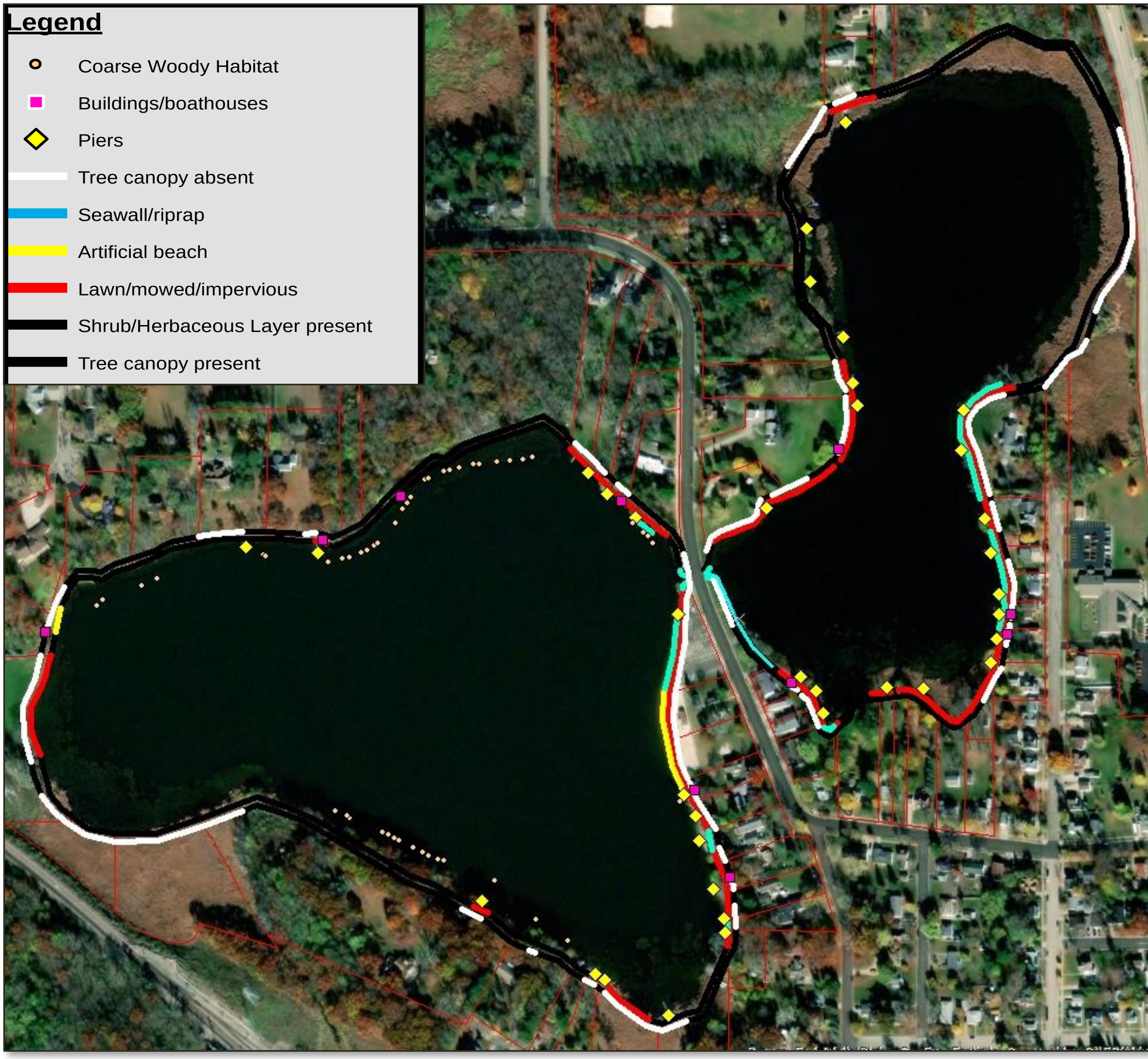


FIGURE 18. OVERALL SHORELAND HEALTH AROUND SILVER LAKE, 2017.

TABLE 8. SILVER LAKE SHORELAND DISTURBANCE SUMMARY, 2017.

Silver Lake Shoreland Disturbance					
Total lakefront footage	No. Riparian lots	Total allowable (NR115) disturbed shoreland-feet	Total allowable (NR115) disturbed shoreland-%	Measured shoreland disturbance-feet	Measured shoreland disturbance-%
11,589	59	1,770	15	4,277	37

CONCLUSIONS & RECOMMENDATIONS

Water quality measurements in Silver Lake provided a picture of a healthy lake, mixed with indications of impacts from land management in the water chemistry, near shore and in the watershed.

- During the study, total phosphorus concentrations in Silver Lake ranged from 51 ug/L to 14.7 ug/L. The summer median total phosphorus concentrations were 24.5 ug/L, 23.8 ug/L and 16.7 ug/L in 2017, 2018 and 2019, respectively. This is just above Wisconsin's phosphorus standard of 20 ug/L for deep seepage lakes and just below 30 ug/L for drainage lakes. Silver Lake is a headwater drainage lake that likely has a large seepage component to its behavior. So, though the 3-year growing season average is technically below standard, it is at levels that are approaching threshold levels.
- Silver Lake had elevated chloride and sodium concentrations relative to background. While these concentrations are not harmful to aquatic organisms, they indicated that pollutants are entering the lake from land management practices near shore and in the watershed. The major source of chloride and sodium in the Silver lake watershed is likely road-salting.
- Atrazine, an herbicide commonly used on corn, was below the detection limit in the samples that were analyzed from Silver Lake.
- Natural background concentrations of inorganic nitrogen were present in Silver Lake.
- Dissolved oxygen was plentiful in the upper 15 feet of water in Silver Lake.
- Routine monitoring of water quality can help to track changes in Silver Lake. A monitoring plan should be designed and implemented.

In general, each type of land use contributes different amounts of phosphorus, nitrogen, and pollutants in runoff and through groundwater. The types of land management practices that are used and their distances from the lake affect the contributions to the lake from a parcel of land.

- Identifying and taking steps to maintain or improve water quality in Silver Lake depends upon understanding the sources of nutrients to the lake and identifying those that are manageable. Based on modeling results, developed land had the greatest percentage of phosphorus contributions from the watershed to Silver Lake. In urban settings, such as Silver Lake, direct drainage of stormwater runoff to the water body via storm gutters, storm sewers and impervious surfaces is significantly increased versus that of a natural setting. However, this infrastructure also creates opportunities for filtering, treatment, or rerouting of stormwater before it enters the waterbody. The most cost-effective approach to this is increasing infiltration within the watershed using rain gardens, rainwater catchment, swales, etc.
- Over-application of chemicals and nutrients should be avoided. Landowners in the watershed should be made aware of their connection to the lake and should work to reduce their impacts through the implementation of water quality-based best management practices.

Shoreland health is critical to a healthy lake's ecosystem. Silver Lake's shoreland was assessed for the extent of vegetation and disturbances. Shoreland vegetation provides habitat for many aquatic and terrestrial animals, including birds, frogs, turtles, and many small and large mammals. Vegetation also helps to improve the quality of the runoff that is flowing across the landscape towards the lake. Healthy shoreland vegetation includes a mix of tall grasses/flowers, shrubs and trees extending at least 35 feet inland from the water's edge. Alone, each manmade disturbance may not pose a problem for a lake, but on developed lakes, the collective impact of these disturbances can be a problem for lake habitat and water quality.

- A few portions of Silver Lake's shorelands are in moderately good condition; however, large portions of the shore have challenges that should be addressed. Much of Silver Lake's shoreland was ranked as poor with respect to aquatic habitat.
    - Structures such as seawalls, rip-rap (rocked shoreline), and artificial beach can result in habitat loss.
    - Erosion can contribute sediment to the lake, which can alter spawning habitat and carry nutrients into the lake.
    - Unmanaged runoff from rooftops of structures located near shore can also contribute sediment to the lake.
    - Docks and artificial beaches can result in altered in-lake habitat. Denuded lakebeds provide opportunities for invasive species to become established and reduce habitat that is important to fish and other lake inhabitants.
- Strategies should be developed to ensure that healthy shorelands remain intact and efforts should be made to improve shorelands that have disturbance. Depending upon the source of the disturbances, erosion should be controlled, vegetation should be restored, and/or excess runoff should be minimized.
- Dissemination of relevant information to property owners is the recommended first step towards maintaining healthy shorelands.

- The Columbia County Land Conservation Department and Natural Resources Conservation Service (NRCS) have professional staff available to assist landowners interested in learning how they can improve water quality through changes in land management practices.

Aquatic plants are the forested landscape within a lake. They provide food and habitat for a wide range of species including fish, waterfowl, turtles, and amphibians, as well as invertebrates and other aquatic animals. They improve water quality by releasing oxygen into the water and utilizing nutrients that would otherwise be used by algae. A healthy lake typically has a variety of aquatic plant species that creates the diversity needed to make the aquatic plant community more resilient and help prevent the establishment of non-native aquatic species.

- The diversity of an aquatic plant community is defined by the type and number of species present throughout the lake. Twenty-three species of aquatic plants were observed in Silver Lake.
- Four high quality aquatic plant species (C-value 8 or greater) were found in Silver Lake.
- Two species of invasive aquatic plants exist in Silver Lake. Curly-leaf pondweed (CLP) and Eurasian watermilfoil (EWM) were first reported in 1994.
- EWM can hybridize with native milfoil; the presence of the hybrid (HWM) was confirmed in Silver Lake in 2012 by professionals from the Wisconsin Department of Natural Resources. HWM can be more resistant than EWM to chemical treatments.
    - During the 2017 survey, EWM/HWM was found in 73% of vegetated areas and accounted for a large portion of the plant biomass in the lake.
    - EWM/HWM can create dense beds that can damage boat motors, make areas non-navigable, stunt or alter the fishery, create problems with dissolved oxygen, and prevent activities like fishing and swimming.

    - This plant can produce a viable seed; however, its primary mode of reproduction and spread is fragmentation. A one-inch fragment is enough to start a new plant, making EWM/HWM very successful at reproducing.
- The amount of disturbed lakebed from raking or pulling plants should be minimized, since these open spaces are "open real estate" for aquatic invasive plants to establish.
- Early detection of aquatic invasive species (AIS) can help to prevent their establishment should they be introduced into the lake. Boats and trailers that have visited other lakes can be a primary vector for the transport of AIS.
- Programs are available to help volunteers learn to monitor for AIS and to educate lake users at the boat launch about how they can prevent the spread of AIS.

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GLOSSARY OF TERMS

Algae: One-celled (phytoplankton) or multicellular plants either suspended in water (plankton) or attached to rocks and other substrates (periphyton). Their abundance, as measured by the amount of chlorophyll a (green pigment) in an open water sample, is commonly used to classify the trophic status of a lake. Numerous species occur. Algae are an essential part of the lake ecosystem and provide the food base for most lake organisms, including fish. Phytoplankton populations vary widely from day to day, as life cycles are short.

Atrazine: A commonly used herbicide. Transports to lakes and rivers by groundwater or runoff. Has been shown to have toxic effects on amphibians.

Blue-Green Algae: Algae that are often associated with problem blooms in lakes. Some produce chemicals toxic to other organisms, including humans. They often form floating scum as they die. Many can fix nitrogen (N2) from the air to provide their own nutrient.

Calcium (Ca++): The most abundant cation found in Wisconsin lakes. Its abundance is related to the presence of calcium-bearing minerals in the lake watershed. Reported as milligrams per liter (mg/1) as calcium carbonate (CaCO3), or milligrams per liter as calcium ion (Ca++).

Chloride (Cl-): The chloride ion (Cl-) in lake water is commonly considered an indicator of human activity. Agricultural chemicals, human and animal wastes, and road salt are the major sources of chloride in lake water.

Chlorophyll *a*: Green pigment present in all plant life and necessary for photosynthesis. The amount present in lake water depends on the amount of algae and is therefore used as a common indicator of algae and water quality.

Clarity: See "Secchi disk."

Color: Color affects light penetration and therefore the depth at which plants can grow. A yellow-brown natural color is associated with lakes or rivers receiving wetland drainage. Measured in color units that relate to a standard. The average color value for Wisconsin lakes is 39 units, with the color of state lakes ranging from zero to 320 units.

Concentration units: Express the amount of a chemical dissolved in water. The most common ways chemical data is expressed is in milligrams per liter (mg/l) and micrograms per liter (ug/l). One milligram per liter is equal to one part per million (ppm). To convert micrograms per liter (ug/l) to milligrams per liter (mg/l), divide by 1000 (e.g. 30 ug/l = 0.03 mg/1). To convert milligrams per liter (mg/l) to micrograms per liter (ug/l), multiply by 1000 (e.g. 0.5 mg/l = 500 ug/l).

Cyanobacteria: See "Blue-Green Algae."

Dissolved oxygen: The amount of oxygen dissolved or carried in the water. Essential for a healthy aquatic ecosystem in Wisconsin lakes.

Drainage basin: The total land area that drains runoff towards a lake.

Drainage lakes: Lakes fed primarily by streams and with outlets into streams or rivers. They are more subject to surface runoff problems, but generally have shorter residence times than seepage lakes.

Emergent: A plant rooted in shallow water and having most of its vegetative growth above water.

Eutrophication: The process by which lakes and streams are enriched by nutrients, and the resulting increase in plant and algae. The extent to which this process has occurred is reflected in a lake's trophic classification: oligotrophic (nutrient poor), mesotrophic (moderately productive), and eutrophic (very productive and fertile).

Groundwater drainage lake: Often referred to as a spring-fed lake, it has large amounts of groundwater as its source and a surface outlet. Areas of high groundwater inflow may be visible as springs or sand boils. Groundwater drainage lakes often have intermediate retention times with water quality dependent on groundwater quality.

Hardness: The quantity of multivalent cations (cations with more than one +), primarily calcium (Ca^{++}) and magnesium (Mg^{++}) in the water expressed as milligrams per liter of $CaCO_3$. Amount of hardness relates to the presence of soluble minerals, especially limestone or dolomite, in the lake watershed.

Intermittent: Coming and going at intervals, not continuous.

Macrophytes: See "Rooted aquatic plants."

Marl: White to gray accumulation on lake bottoms caused by precipitation of calcium carbonate ($CaCO_3$) in hard water lakes. Marl may contain many snail and clam shells. While it gradually fills in lakes, marl also precipitates phosphorus, resulting in low algae populations and good water clarity. In the past, marl was recovered and used to lime agricultural fields.

Mesotrophic: A lake with an intermediate level of productivity. Commonly clear water lakes and ponds with beds of submerged aquatic plants and mediums levels of nutrients. See also "eutrophication".

Nitrate (NO_3^-): An inorganic form of nitrogen important for plant growth. Nitrate often contaminates groundwater when water originates from manure, fertilized fields, lawns or septic systems. In drinking water, high levels (over 10 mg/L) are dangerous to infants and expectant mothers. A concentration of nitrate-nitrogen (NO_3-N) plus ammonium-nitrogen (NH_4-N) of 0.3 mg/L in spring will support summer algae blooms if enough phosphorus is present.

Oligotrophic: Lakes with low productivity, the result of low nutrients. Often these lakes have very clear waters with lots of oxygen and little vegetative growth. See also "eutrophication".

Overturn: Fall cooling and spring warming of surface water increases density, and gradually makes lake temperatures and density uniform from top to bottom. This allows wind and wave action to mix the entire lake. Mixing allows bottom waters to contact the atmosphere, raising the water's oxygen content. Common in many lakes in Wisconsin.

Phosphorus: Key nutrient influencing plant growth in more than 80% of Wisconsin lakes. Soluble reactive phosphorus is the amount of phosphorus in solution that is available to plants. Total phosphorus includes the amount of phosphorus in solution (reactive) and in particulate form.

Rooted aquatic plants (macrophytes): Refers to higher (multi-celled) plants growing in or near water. Macrophytes are beneficial to lakes because they produce oxygen and provide substrate for fish habitat and aquatic insects and provide food for many aquatic and terrestrial animals. Overabundance of such plants, especially problem species, is related to shallow water depth and high nutrient levels.

Secchi disk: An 8-inch diameter plate with alternating quadrants painted black and white that is used to measure water clarity (light penetration).

Sedimentation: Materials that are deposited after settling out of the water.

Stratification: The layering of water due to differences in density. As water warms during the summer, it remains near the surface while colder water remains near the bottom. Wind mixing determines the thickness of the warm surface water layer (epilimnion), which usually extends to a depth of about 20 feet. The narrow transition zone between the epilimnion and cold bottom water (hypolimnion) is called the metalimnion. Common in many deeper lakes in Wisconsin.

Watershed: See "Drainage basin."