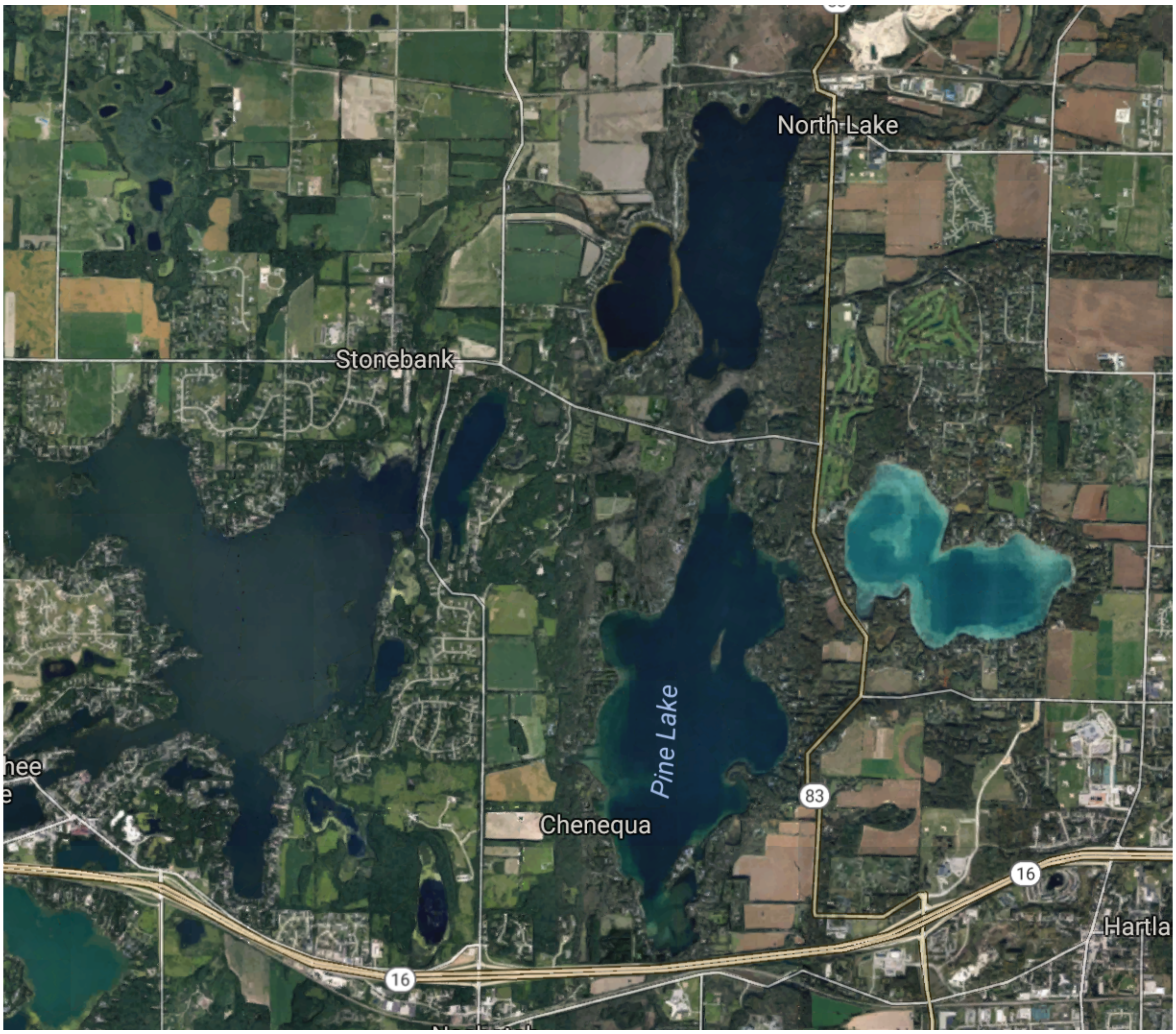
Beaver Lake

A “GEM” in the midst of Lake Country



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Introduction

Lakes have become a highly prized resource in North America as high quality fresh water becomes more and more scarce. Land adjacent to a lake provides a wide variety of aesthetic, psychological and physical benefits to its owners. Key to maintaining these treasured benefits are effective lake and watershed management.

Friends of Beaver Lake (FOBL) have been working together with the property owners around the lake to monitor the chemical parameters of the lake, manage aquatic plant communities and develop an exciting fishery. A group of concerned lake residents created this charitable volunteer organization in 2004. The early goals of the organization included monitoring high capacity well development and its effect on ground water input to the lake as well as obtaining a better understanding of key aspects of the watershed. Key challenges were identified such as algae blooms, reduction of nitrogen and phosphorous, water quality monitoring and managing aquatic plants and wildlife in the lake. Spring and fall water quality testing has been done annually since 2008. Fish cribs have been installed to improve fish habitat, game fish have been stocked and both fish and plant surveys have been done. This impressive array of lake management efforts is extremely beneficial to the future preservation of this "gem" in Waukesha County's lake country.

During the summer of 2017 FOBL contacted Wisconsin Lutheran College (WLC) Biology Department to explore a collaboration with students and professors at the college. WLC has performed a variety of studies on Wisconsin lakes over the past 20 years. Dr. Robert Anderson, an aquatic ecologist and fisheries biologist has guided students in tracking muskies on Pewaukee Lake, conducting plant surveys on a variety of Wisconsin lakes, chemical assessments and fish community studies. This study represents the beginning of this collaboration between FOBL and WLC.

The purpose of this study is to evaluate the results of FOBL's water quality monitoring over the past nine years and make recommendations regarding future management directions.

Water Quality Evaluation

Water quality data has been gathered by the Friends of Beaver Lake since 2008 and can be used as an indicator of lake health.

Beaver Lake is a "marl" lake. What is a marl lake and how does it alter water quality and fishing?

A lake is considered a "marl lake" when it is surrounded by soluble limestone and other rocks or soil that contain calcium. As water moves through the ground or across the surface it dissolves calcium from the rocks and soil and carries it into the lake as calcium ions (Ca^{++}). The calcium ions can combine with carbonate ions (CO_3^{--}) in the lake water to form solid calcium carbonate ($CaCO_3$) a white chalky substance called marl. Carbonate ions form in lake water when carbon dioxide (CO_2) from the atmosphere dissolves in water forming bicarbonate ions (HCO_3^-) and carbonate ions (CO_3^{--}). There is a continual balancing act between these ions resulting in the frequent formation of calcium carbonate (marl). Marl lakes are also considered hard water lakes that are more productive than soft water lakes. Hard water lakes are able to maintain more nutrients in solution which can act as fertilizer for algae which is the base of the lakes food web. Hard water lakes are also able to buffer pH levels such that acid rain does not have a significant impact on the lake. One drawback of marl lakes is that the precipitation of the marl can also lead to phosphorus precipitation resulting in this nutrient becoming unavailable for use by algae and aquatic plants. In marl lakes organic matter in the water can also be bound to the precipitate and drop out of suspension. As a result, the water of marl lakes is often extremely clear and has a blue tint to it. Despite this, many marl lakes are able to sustain an exciting sport fishery. Beaver Lake in particular, has traditionally been an excellent sport fishing lake for bass and panfish. In 2005, The Wisconsin Department of Natural Resources reported northern pike, largemouth bass, yellow perch, and bluegill to be present in the lake (SEWRPC 2014).

pH – Most recent measurement from Spring 2017 – 8.2

Why is this measurement taken?

The pH of a lake is a measure of the alkalinity or acidity of the water body. A pH of 7 is known as "neutral", below this level is considered "acidic", and above is considered "basic". The solubility of many chemical compounds in water is controlled by pH. If pH is too low, toxic metals are more soluble and can harm the local fish populations, and the formation of shells can be negatively impacted. When pH is too high, phosphorus can be released from the sediment, and ammonia levels can rise to toxic levels (Water & Environmental Analysis Laboratory at the University of Wisconsin-Stevens Point 2015).

What does this mean?

In Beaver Lake, the mineral composition of the watershed has led to a pH level in the basic range. Since 2008, when pH levels in spring and fall were around 8.16, pH levels have generally increased every year, peaking out around 8.44 in spring of 2016 before dropping in the fall of 2016 and the spring of 2017 (Figure 1). Although every pH level recorded in the lake falls within the typical Wisconsin Lake range, the increase in pH could be a result of increased algae that photosynthesize and remove more carbon dioxide from the water. It also may be a result of increased levels of calcium carbonate coming into the lake through ground water and surface runoff (Wetzel 1983). This somewhat elevated pH level provides a good buffer against acid rain (SEWRPC 2003) and poses no threat to the health of the lake.

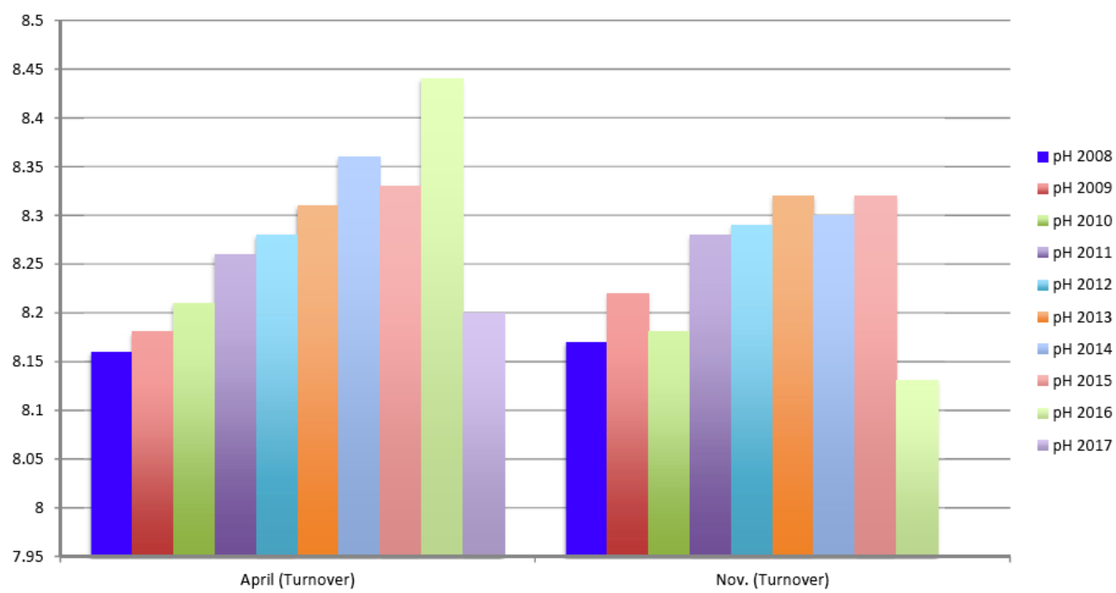

Figure 1: Beaver Lake pH readings during April and November 2008 – 2017.

Alkalinity – Most recent measurement from Spring 2017 ~170 mg/l of $CaCo_3$

Why is this measurement taken?

Alkalinity measures how resistant a lake is to pH changes. If a lake is more alkaline it will be more resistant. If a lake has less alkalinity, it is considered to be more susceptible to acidification (Water & Environmental Analysis Laboratory at the University of Wisconsin-Stevens Point 2015). Alkalinity is measured by determining the amount of $CaCo_3$ present in the water that can neutralize a strong acid (Wetzel 1983). This measurement can allow lake managers to understand a lake's potential vulnerability to acid rain.

What does this mean?

Beaver Lake alkalinity levels suggest that the lake is highly resistant to pH changes (Water & Environmental Analysis Laboratory at the University of Wisconsin-Stevens Point 2015). Measurements for each year since 2008 have remained between 160 and 200 (mg/l as $CaCo_3$) which is on the high end of typical Wisconsin lakes and falls in the normal "marl" lakes category (Figure 2). This high alkalinity reflects the limestone and dolomite in the glacial deposits of the Beaver Lake watershed (Figure 3). The consistent alkalinity levels indicate that the water moving into the lake through shallow aquifers and across the watershed has retained a similar balance over the years.

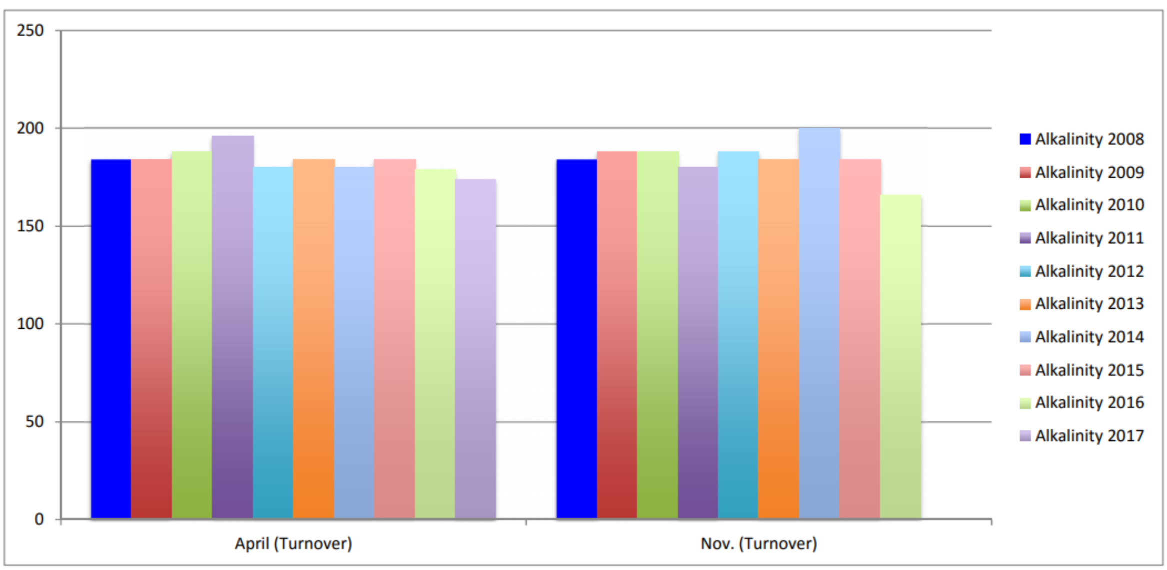

Figure 2: Beaver Lake alkalinity readings during April and November 2008 – 2017.

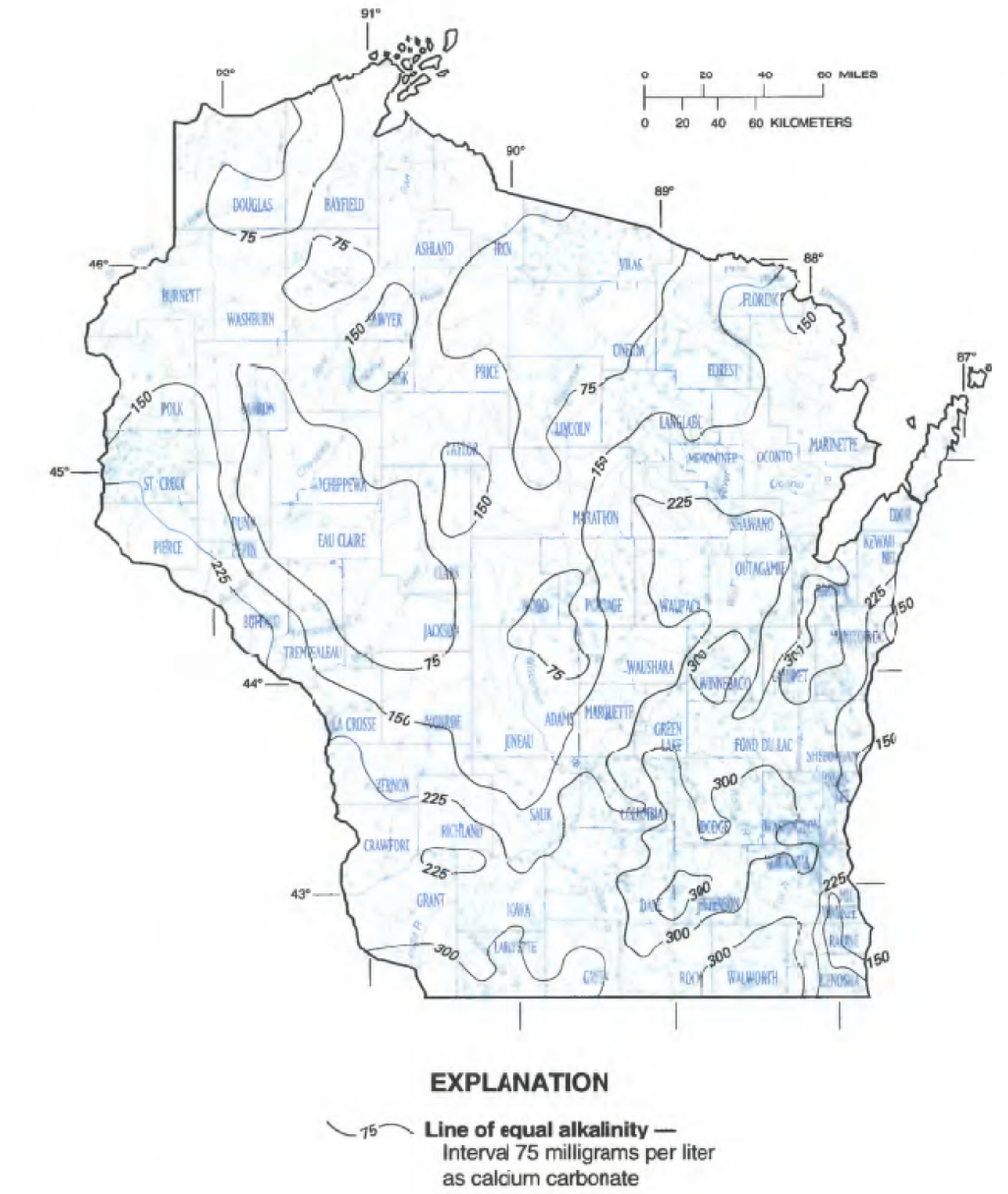

Figure 3: Distribution of alkalinity of water from Wisconsin's shallow aquifer system (Kammerer 1995).

Water Hardness – Most recent measurement in Spring 2017 ~305 mg/l as $CaCO_3$

Why is this measurement taken?

Water hardness is also a measure of the calcium and magnesium ion concentrations in the water. Although the units of measure (mg/l as $CaCO_3$) are the same for hardness and alkalinity, hardness is a measure of the total $CaCO_3$ in a liter of water while alkalinity is the quantity of $CaCO_3$ needed to neutralize a strong acid (Wetzel 1983). This measurement provides insight into the general character of the lake and informs management decisions. For example, hard water lakes have the ability to assimilate significant amounts of phosphorus without impacting algae or aquatic plant growth since phosphorus often precipitates out of the water column as marl (Horne & Goodman 1994). The phosphorous that precipitates from the water column then becomes part of the lake sediment. This can build up to a point where it begins to become soluble again. The lake then has an internal nutrient source that can drive algae blooms even if external input of phosphorous is low. In addition, hard water lakes tend to be more productive since more nutrients can be dissolved in the water allowing better algae and plant growth that are the basis of a healthy food web and habitat for fish (Water & Environmental Analysis Laboratory at the University of Wisconsin-Stevens Point 2015).

What does this mean?

Since 2008, water hardness in Beaver Lake has stayed relatively stable from 2008-2017 between 200 and 240 mg/l with the exception of a spike just above 300 mg/l in April 2017 (Figure 4). Beaver Lake falls at the upper end of the typical Wisconsin lake range (Water & Environmental Analysis Laboratory at the University of Wisconsin-Stevens Point 2015). The spike seen in 2017 is probably an anomaly but should be monitored. Based on the alkalinity and water hardness measurements, Beaver Lake could be characterized as a hard-water alkaline or marl lake (SEWRPC 2003).

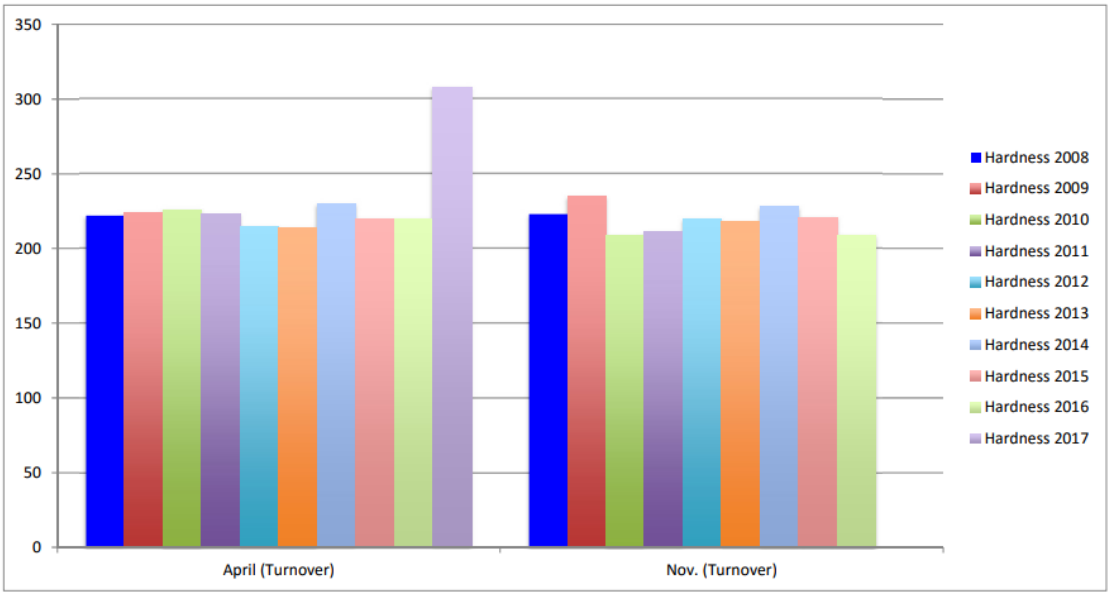

Figure 4: Beaver Lake water hardness during April and November 2008 – 2017.

Specific Conductance - Most recent measurement in Spring 2017 ~550 µS/cm

Why is this measurement taken?

Specific conductance indicates the concentration of dissolved ions in a lake (Table 1) that affects how well water conducts electricity. When more dissolved ions are present, specific conductance increases. Watersheds that receive high amounts of precipitation normally have low conductivity because rainwater does not contain many dissolved minerals. Specific conductance is highly affected by the geology near the lake. Lakes surrounded by easily dissolved rocks such as Beaver Lake have higher specific conductance (Water & Environmental Analysis Laboratory at the University of Wisconsin-Stevens Point 2015). Changes in specific conductance can reflect human activities around the lake such as removing vegetative cover that increases surface runoff, allowing exposed soil to be carried into the lake with rainwater and increased runoff from roads and parking lots. The ionic concentration influences the lake's ability to assimilate pollutants and maintain nutrients in solution.

Table 1: Relative percent of typical freshwater ions (Horne & Goodman 1994).

Anions	Percent	Cations	Percent
HCO_3^-	73%	Ca^{+2}	63%
SO_4^{-2}	16%	Mg^{+2}	17%
Cl^-	10%	Na^+	15%
		K^+	4%
other	< 1%	other	< 1%

What does this mean?

Beaver Lake specific conductance ranged between 500 and 620 µS/cm at any sampling time, which is at the high end of the spectrum for typical Wisconsin Lakes (Figure 5). This range is typical of hard water and what would be expected for a marl lake (Water & Environmental Analysis Laboratory at the University of Wisconsin-Stevens Point 2015). In times of thermal stratification, specific conductance can differ at different locations in the water column, however, since all sampling took place during lake turnover in the spring and fall, specific conductance would remain relatively the same at any depth (SEWRPC 2003). If specific conductance would begin to increase year after year it could be the result of increased development in the watershed causing higher runoff of pollutants like road salt from roads and parking lots (Water & Environmental Analysis Laboratory at the University of Wisconsin-Stevens Point 2015). A protective measure to reduce future impacts of surface runoff would be to increase the amount of natural vegetation near the lake shore through the development of rain gardens and planting of native emergent aquatic plant species.

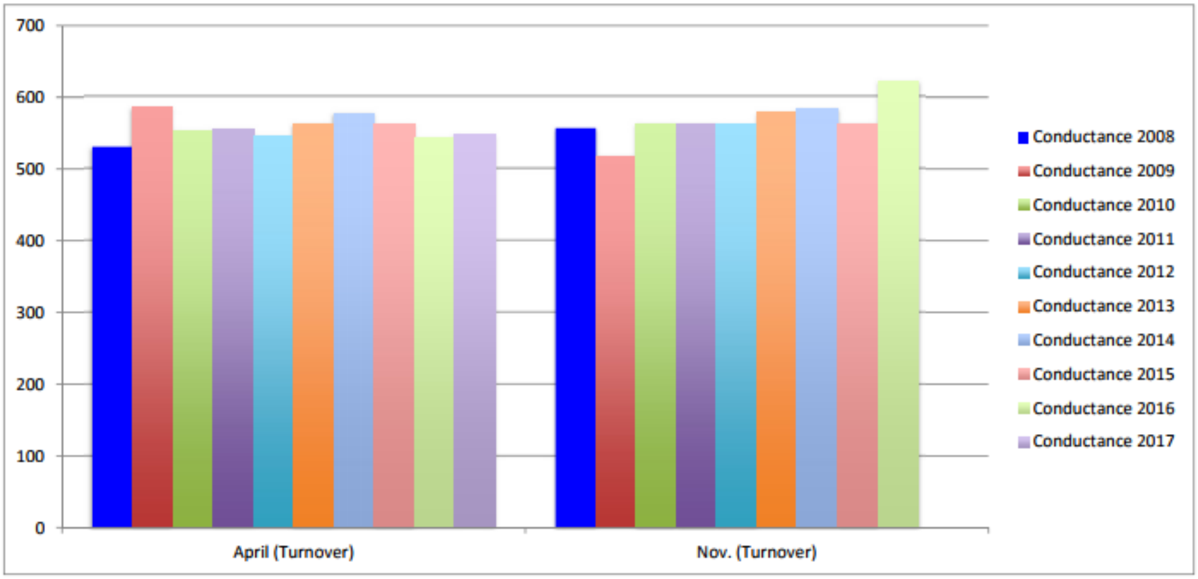

Figure 5: Beaver Lake specific conductance during April and November 2008 – 2017.

Turbidity - Most recent measurement in Spring 2017 – 3 Turbidity Units (TU)

Why is this measurement taken?

Turbidity measures suspended particles in the water that can make the water appear cloudy. The particles can come from suspended lake bottom sediment, soil or pollutants in surface water runoff and algae blooms. The turbidity measurement is a measurement of light reflected by the particles as a beam of light is shined through a water sample. The higher the units, the more particles are suspended in the water (Water & Environmental Analysis Laboratory at the University of Wisconsin-Stevens Point 2015). Turbidity varies greatly based on recent rainfall and activity on the lake. It is possible to have wide variation in readings that are taken only once or twice a year.

What does this mean?

The most recent measurement of 3 TU's in Beaver Lake from Spring 2017 falls within the lower part of the typical Wisconsin lake range, which is between 0 and 8 (Figure 6). In Spring of 2008 the turbidity was around 9, which is the highest measurement ever recorded for Beaver Lake. Since this level was only seen once and subsequent results have been much lower it should not be seen as a normal occurrence (Water & Environmental

Analysis Laboratory at the University of Wisconsin-Stevens Point 2015). Beaver Lake's status as a marl lake suggests that it would be a clear lake and this is reflected in the TU measurements since 2008. Additionally, it should be noted that an invasive species of mussel, zebra mussels, were found to be present in the lake in 2005. Zebra mussels are known to filter the water so much that it reduces turbidity. Given the consistently good water clarity in Beaver Lake, zebra mussels have not had a noticeable impact (SWERPC 2014).

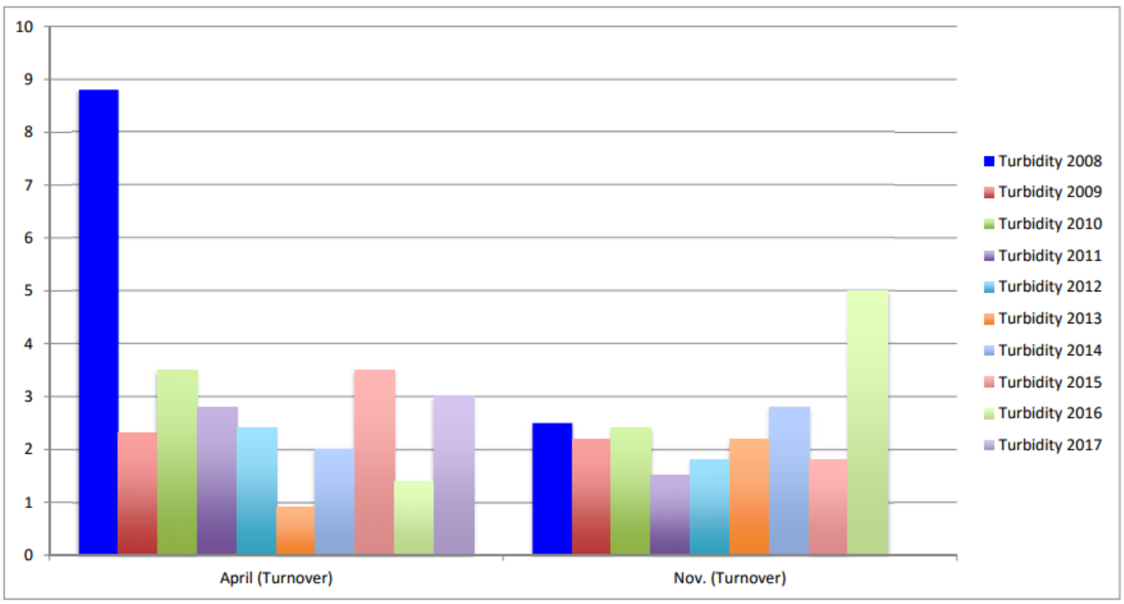

Figure 6: Beaver Lake turbidity during April and November 2008 – 2017.

Color - Most recent measurement in Spring 2017 - 4 Standard Units

Why is this measurement taken?

Lake color is measured by reflected light that is not absorbed by the water. Color can vary between blue, green, red, brown or a combination of any of those colors. The sample is filtered, in order to remove suspended particles. The measurement normally reflects how much organic matter is dissolved in the water. Waters with a higher color measurement are often surrounded by wetlands (Water & Environmental Analysis Laboratory at the University of Wisconsin-Stevens Point 2015).

What does this mean?

Beaver Lake has an extremely low "color" measurement ranging from 2.5 to 8.8 standard units (Figure 7). This is below the normal Wisconsin lake range of about 10 – 35 (Water & Environmental Analysis Laboratory at the University of Wisconsin-Stevens Point 2015). Although lake color measurements have been higher in other years, they have never exceeded 10 in Beaver Lake. These low measurements are likely the result of organic particles being carried out of the water column as marl is formed.

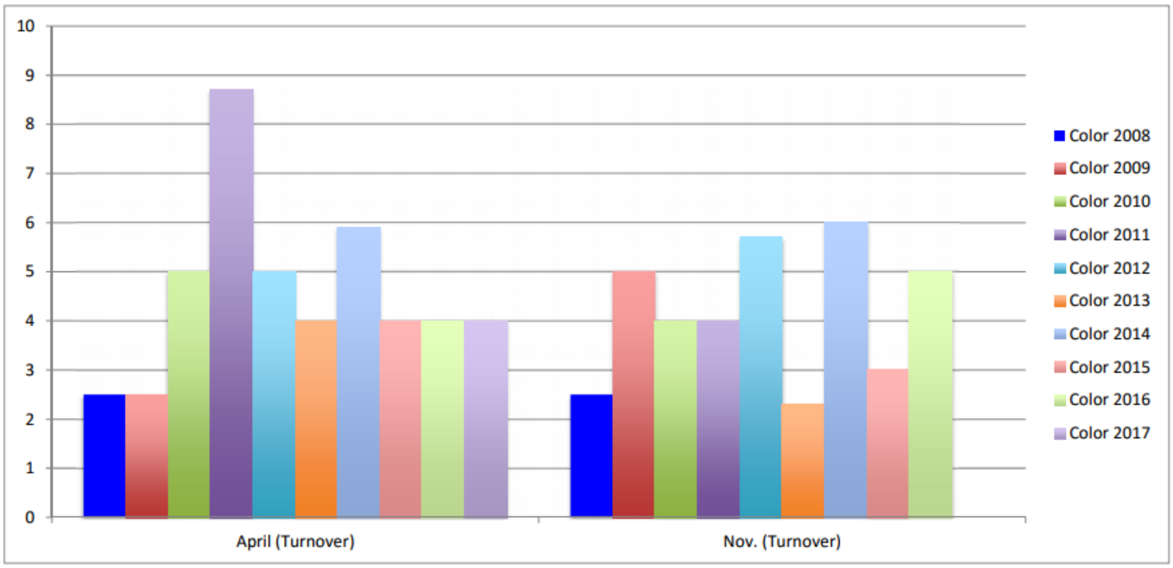

Figure 7: Beaver Lake color during April and November 2008 – 2017.

Potassium - Most recent measurement in Spring 2017~2.45 mg/l

Why is this measurement taken?

Potassium is an element that occurs naturally in rocks and lake vegetation. However, if potassium levels are high, it could be an indication of potassium chloride fertilizer use or the breakdown of organic matter or animal waste (Water & Environmental Analysis Laboratory at the University of Wisconsin-Stevens Point 2015). Potassium is used by aquatic plants during photosynthesis and can be depleted during algal blooms.

What does this mean?

Potassium measurements in Beaver Lake ranged between 1.5 and 2.5 mg/l (Figure 8) which falls within the typical Wisconsin lake range at the higher end of the spectrum. Both spring measurements in 2016 and 2017 display a slightly upward trend. If this trend continues it could indicate that potassium chloride fertilizer is running off into the lake (Water & Environmental Analysis Laboratory at the University of Wisconsin-Stevens Point 2015).

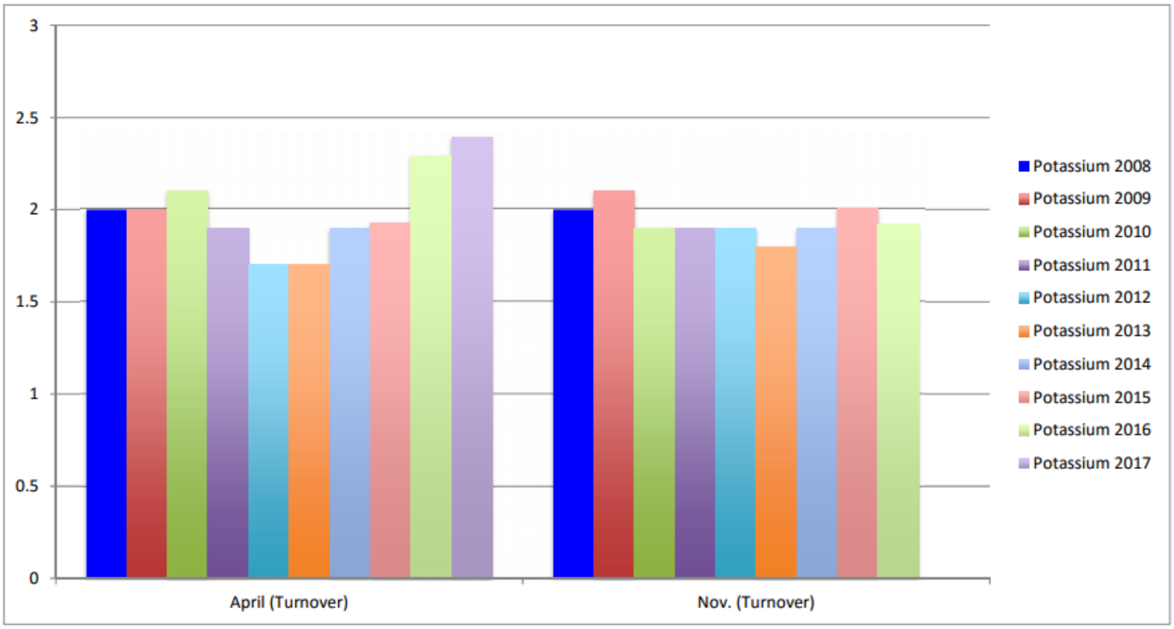

Figure 8: Beaver Lake potassium readings during April and November 2008 – 2017.

Sulfate- Most recent measurement in Spring 2017~51mg/l

Why is this measurement taken?

High levels of sulfate can result from springs bubbling into the lake from shallow water glacial till aquifers, naturally decaying organic material, acid rain, and use of sulfate based algaecide. USGS sulfate concentration distribution map of Wisconsin (Kammerer 1995) shows sulfate levels of 60 mg/l in the Waukesha County shallow aquifers (Figure 9). Sulfate is normally found in low concentrations except in lakes with high levels in nearby bedrock (Water & Environmental Analysis Laboratory at the University of Wisconsin-Stevens Point 2015). High levels of sulfate can also be an indicator of acid rain (SEWRPC 2014).

What does this mean?

Beaver Lake sulfate levels have remained around 20 mg/l every year except in the spring of 2017 when they exhibited a rise up to about 51 mg/l (Figure 10). The 2017 level is above the normal Wisconsin lake range of 1.6 to 30 (Water & Environmental Analysis Laboratory at the University of Wisconsin-Stevens Point 2015). Since this is the only reading in this range, further readings will need to be done in order to determine if it is a trend or an anomalous reading. If measurements remain above 50mg/l this could be an indicator that ground water input to the lake is increasing, a sulfate based algaecide is being used in the lake, or surface water runoff is coming from an area with organic decomposition.

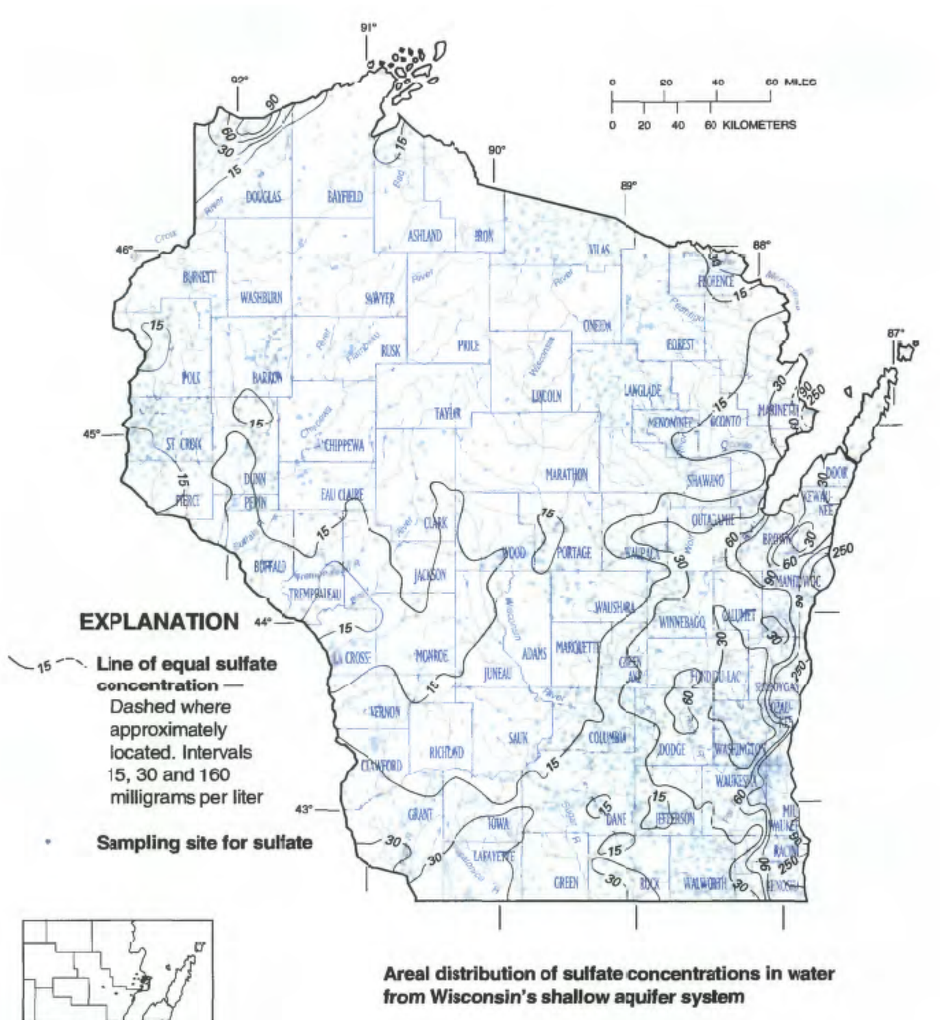

Figure 9: Distribution of sulfate concentrations in water from Wisconsin's shallow aquifer system (Kammerer 1995).

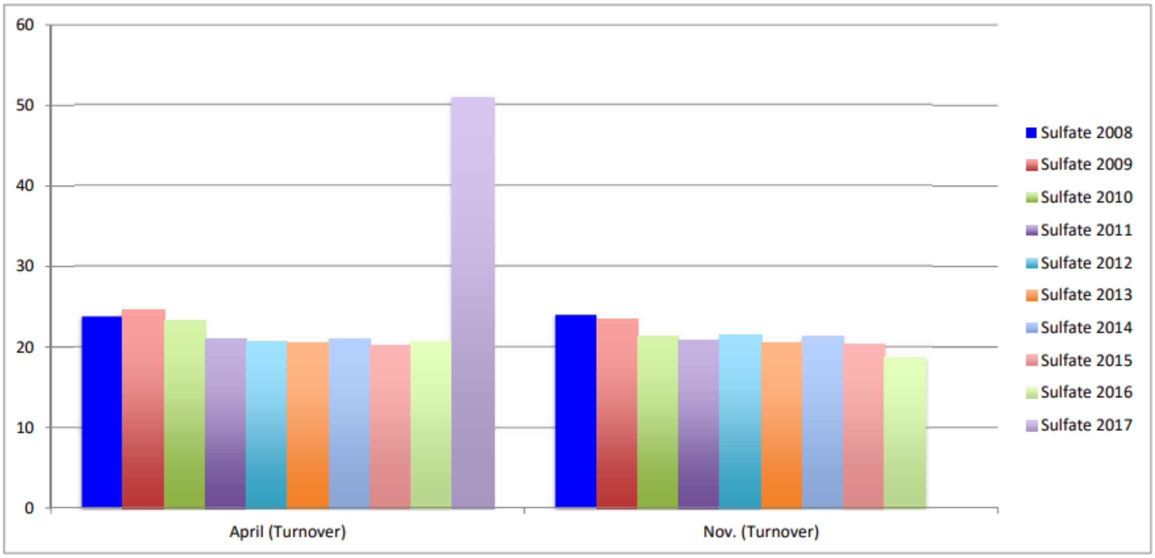

Figure 10: Beaver Lake sulfate readings during April and November 2008 – 2017.

Sodium and Chloride- Most recent measurements in Spring 2017 ~11 and 71 mg/l respectively.

Why is this measurement taken?

Sodium and chloride levels indicate the salinity of a lake and are impacted by road salt, table salt, and water softening salt that is washed into the lake (Water & Environmental Analysis Laboratory at the University of Wisconsin-Stevens Point 2015). Chloride levels in Beaver Lake became a concern in 1995 when road salts, water softener salt, and fertilizers containing potash contributed to high chloride levels. This occurred in most Southeastern Wisconsin Lakes, however in Beaver Lake the chloride measurements nearly tripled from 1975 to 1995 (SEWRPC 2014).

What does this mean?

The indicator level that chloride pollution will cause stress to plants and animals is near 250 mg/l. In 1995, Beaver Lake had a concentration of 44 mg/l, which although below 250 mg/l, was still a concern (SEWRPC 2014). Beaver Lake sodium and chloride levels have a relatively consistent increase between 2008 and 2017 (25 to 35 mg/l sodium and 45 to 80 mg/l chloride) with the exception of the 2017 spring sodium measurement that was around 12 mg/l Sodium (Figures 11&12). These levels (with the exception of the spring 2017 sodium measurement) are slightly above the typical Wisconsin Lake range (Water & Environmental Analysis Laboratory at the University of Wisconsin-Stevens Point 2015).

This trend is a continuation of the trend noted in 1995 (SEWRPC 2014) and should serve as a call to action to reduce the amount of salt runoff into the lake from local roads and parking lots. This problem can be addressed by encouraging rain gardens and storm water retention basins as well as working with state and local governments to identify approaches to reduce the use of road salt.

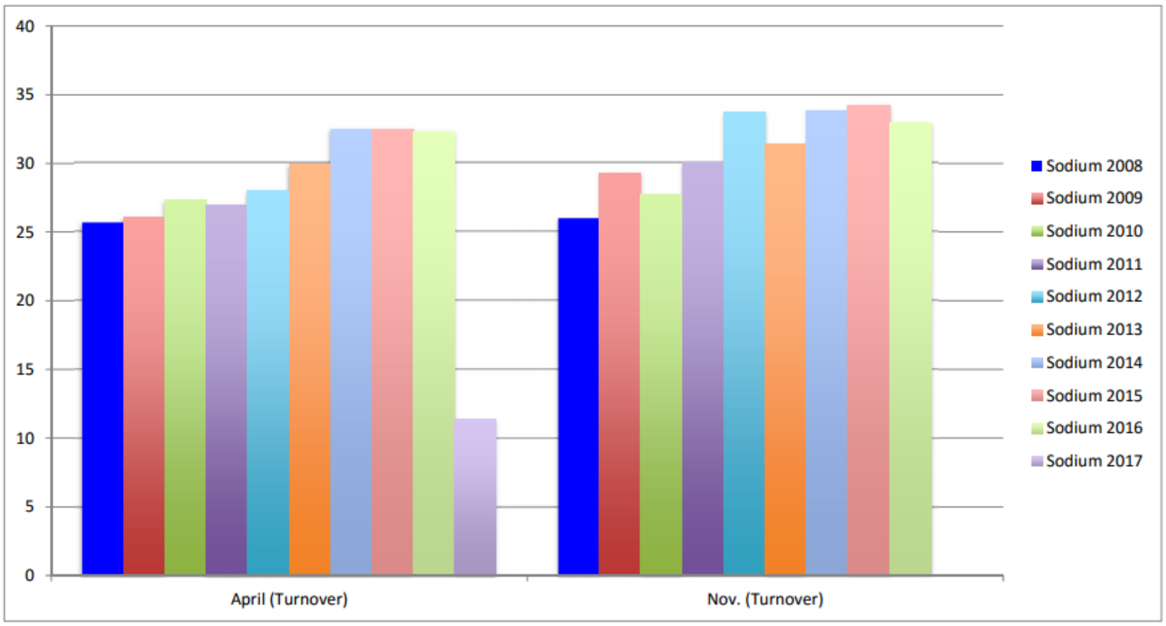

Figure 11: Beaver Lake sodium readings during April and November 2008 – 2017.

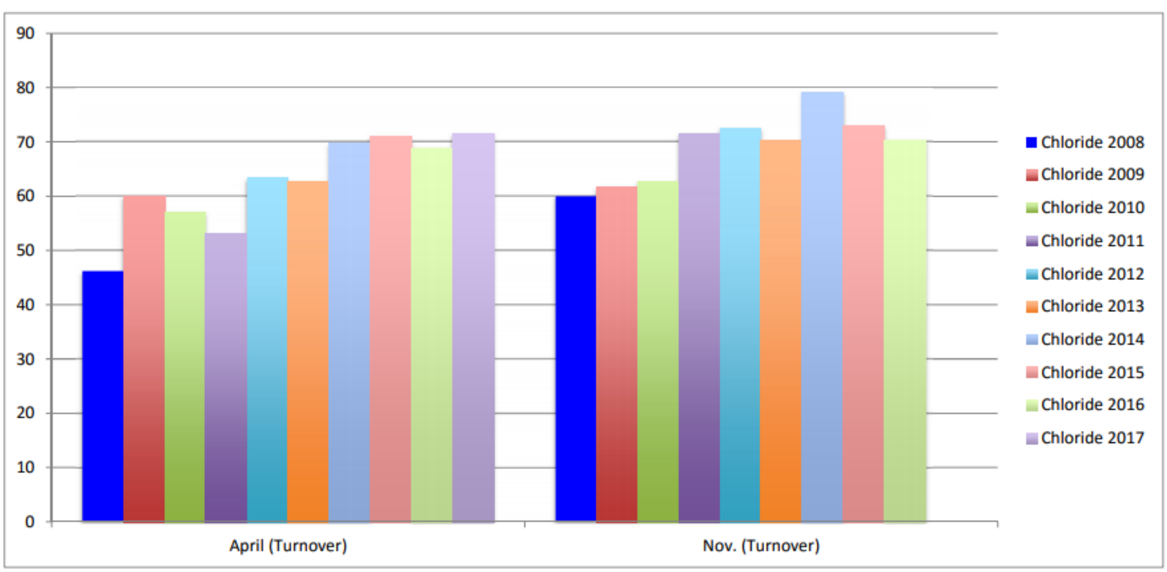

Figure 12: Beaver Lake chloride readings during April and November 2008 – 2017.

Nitrogen: Ammonium, Nitrite, Kjeldahl Nitrogen, Inorganic Nitrogen and Total Nitrogen - Most recent measurements in Spring 2017

Ammonium ~ .07 mg/l

Nitrite ~ .21 mg/l

Inorganic Nitrogen ~ .28 mg/l

Kjeldahl Nitrogen ~ .77 mg/l

Total Nitrogen ~ .98 mg/l

Why are these measurements taken?

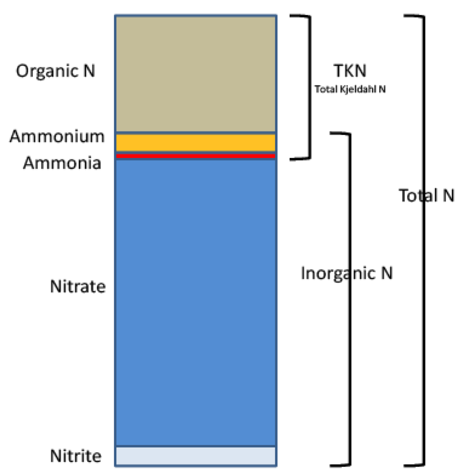

Figure 13: Relative amounts of nitrogen in Minnesota lakes (Wall 2013)

Ammonium, nitrite, inorganic nitrogen, and Kjeldahl nitrogen measurements are all used to calculate total nitrogen (Figure 13). Ammonia (NH_3) is the reduced form of nitrogen released from decomposing organic material or converted from Nitrogen (N_2) in the air by bacteria. Ammonia is also excreted by land and aquatic animals and is applied as a fertilizer on farms (Figure 14). Ammonia, which can be toxic at high levels combines with hydrogen ions to form ammonium (NH_4). If oxygen is present, ammonium is oxidized by microbes and forms nitrite (NO_2) and then nitrate (NO_3). As an intermediate product, nitrite is seldom elevated and is not a major concern in surface waters. Nitrate moves readily through soils and is carried into lakes with ground water. Nitrate is also a breakdown product of pet waste, leaf litter and grass clippings that can wash into lakes with surface water runoff. Nitrate and ammonium are used by plants and microbes as a nitrogen source and are nutrients that can control plant growth. Total Kjeldahl nitrogen is the sum of nitrogen bound in organic substances plus ammonia. The term Kjeldahl refers to the chemical process used to extract the nitrogen. In lakes that are located in areas dominated by agricultural production inorganic nitrogen is a much higher proportion of the total nitrogen than Kjeldahl nitrogen (Figure 13). In natural forested or grassland watersheds, lake water has higher Kjeldahl nitrogen than inorganic nitrogen since nitrate is very low in these areas (Wall 2013). Total nitrogen is most commonly used as an indicator of eutrophication (accelerated aging) of lakes along with total phosphorus.

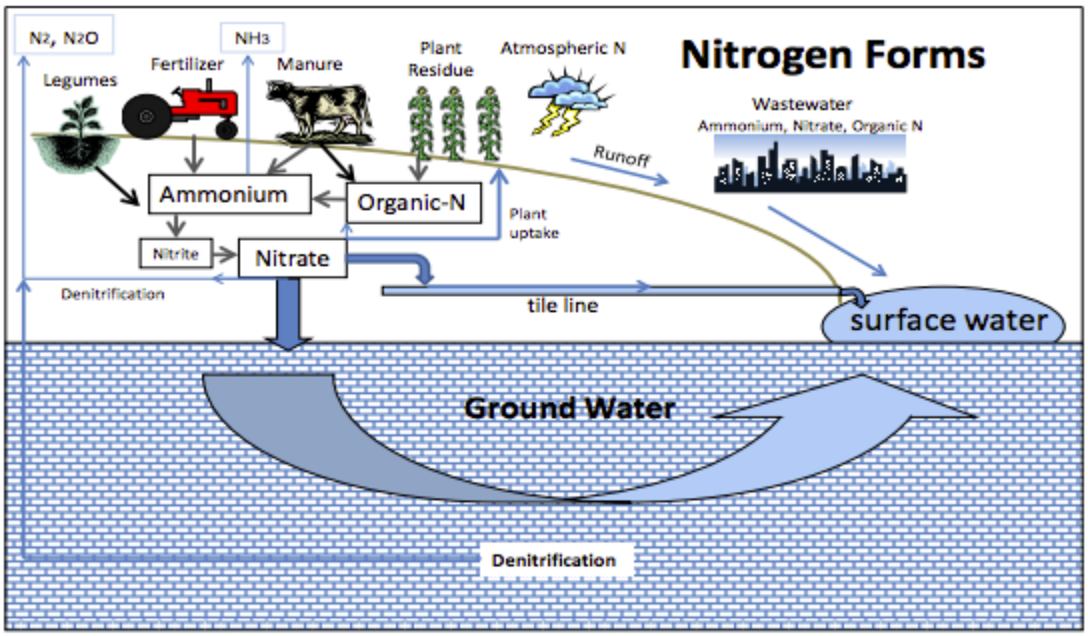

Figure 14: Nitrogen cycle, showing primary N sources, forms and routes to surface waters (Wall 2013).

What does this mean?

The various forms of nitrogen found in Beaver lake during 2008 – 2017 are indicative of a natural wooded or grassland environment watershed. The relative amount of inorganic nitrogen is less than half the contribution of Kjeldahl nitrogen since 2012 (Figures 15 & 16). Since 2012, inorganic nitrogen has been below 0.3 mg/l which reduces the potential for an algal bloom. An inorganic nitrogen level of 0.3 mg/l is needed to support a summer algal bloom.

Total nitrogen unfortunately provides a different picture for the Beaver Lake watershed. Between 2008 and 2017 total nitrogen levels ranged from 0.7 mg/l to 1.1 mg/l (Figure 19). In Wisconsin, total nitrogen levels below .6 milligrams/L help reduce nuisance algal growth (SEWRPC 2003). Since Beaver Lake total nitrate levels are above this value, plant and algae growth must be limited by another nutrient. Total nitrogen levels have also been exhibiting a slightly upward trend over the past 5-6 years indicating that increasing amounts of nitrogen are entering the lake and the organic form of nitrogen seems to be the culprit (Figure 15). This increase may be coming from an increase in the amount of impervious surfaces. Improvement of riparian buffers would be beneficial. All nitrogen levels should continue to be monitored in order to determine if the trend continues.

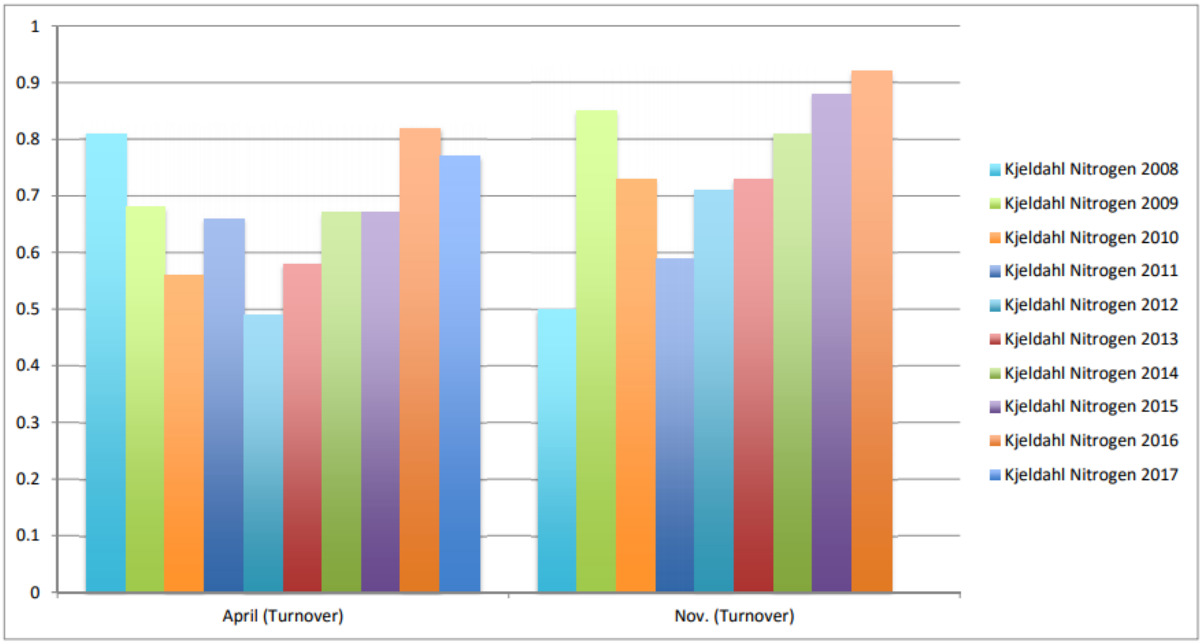

Figure 15: Beaver Lake Kjeldahl nitrogen (mg/l) during April and November 2008 – 2017.

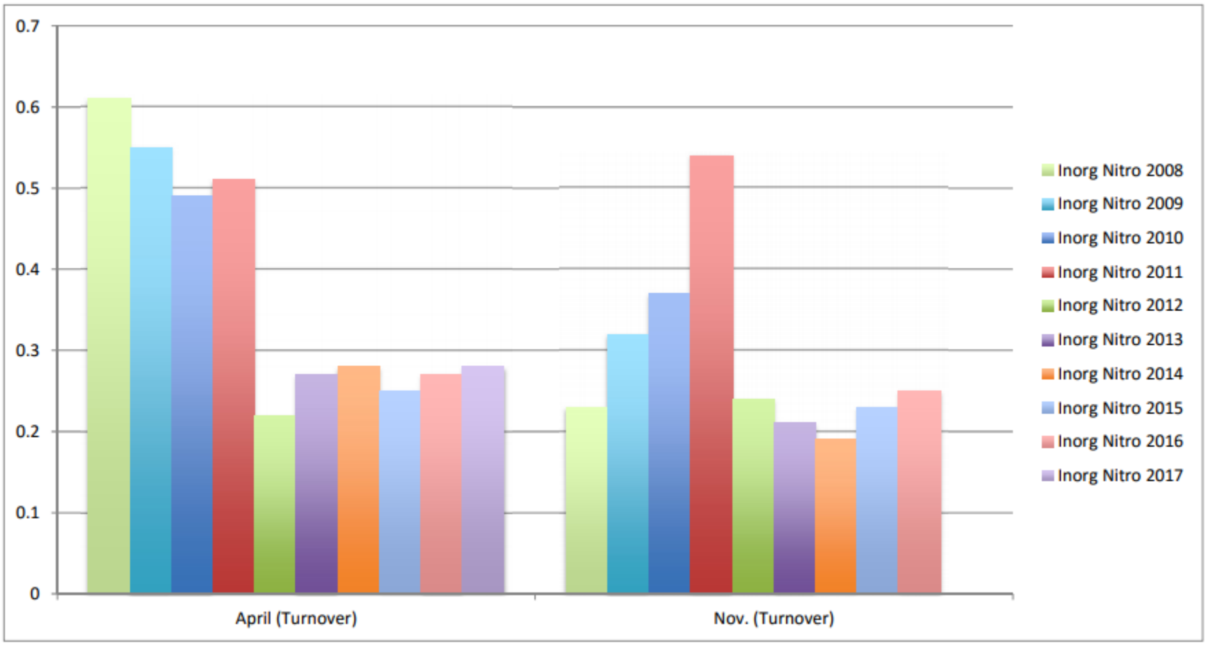

Figure 16: Beaver Lake inorganic nitrogen (mg/l) during April and November 2008 – 2017.

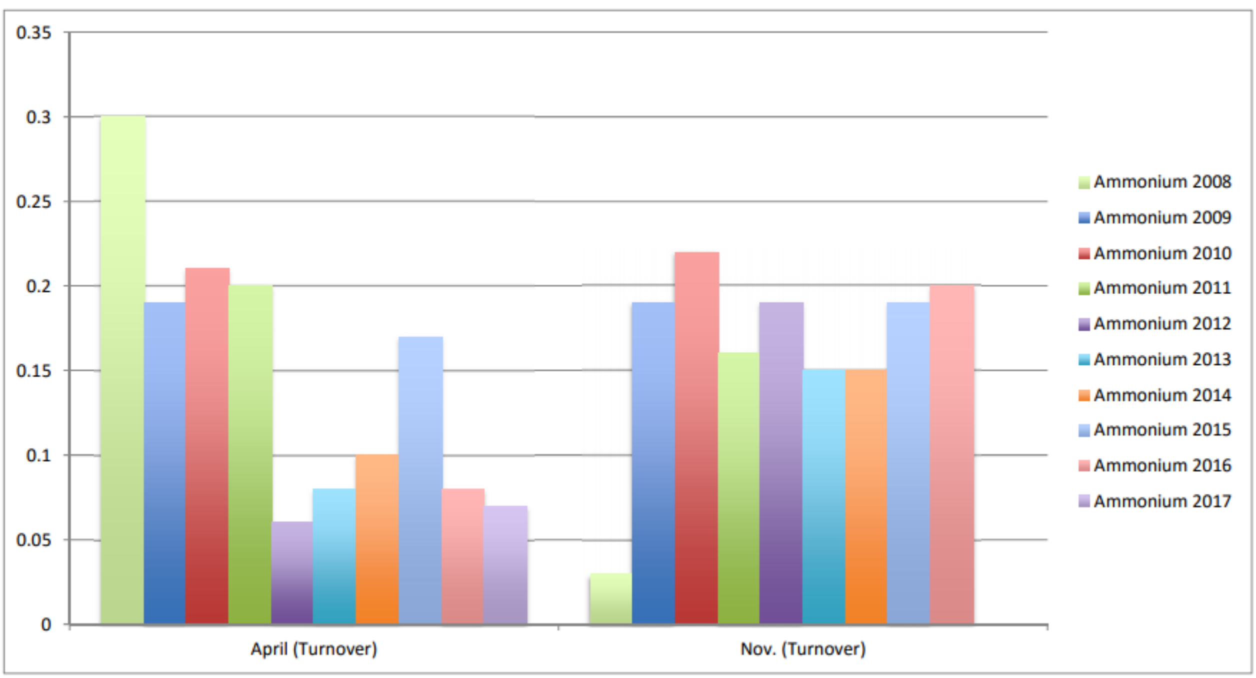

Figure 17: Beaver Lake ammonium (mg/l) during April and November 2008 – 2017.

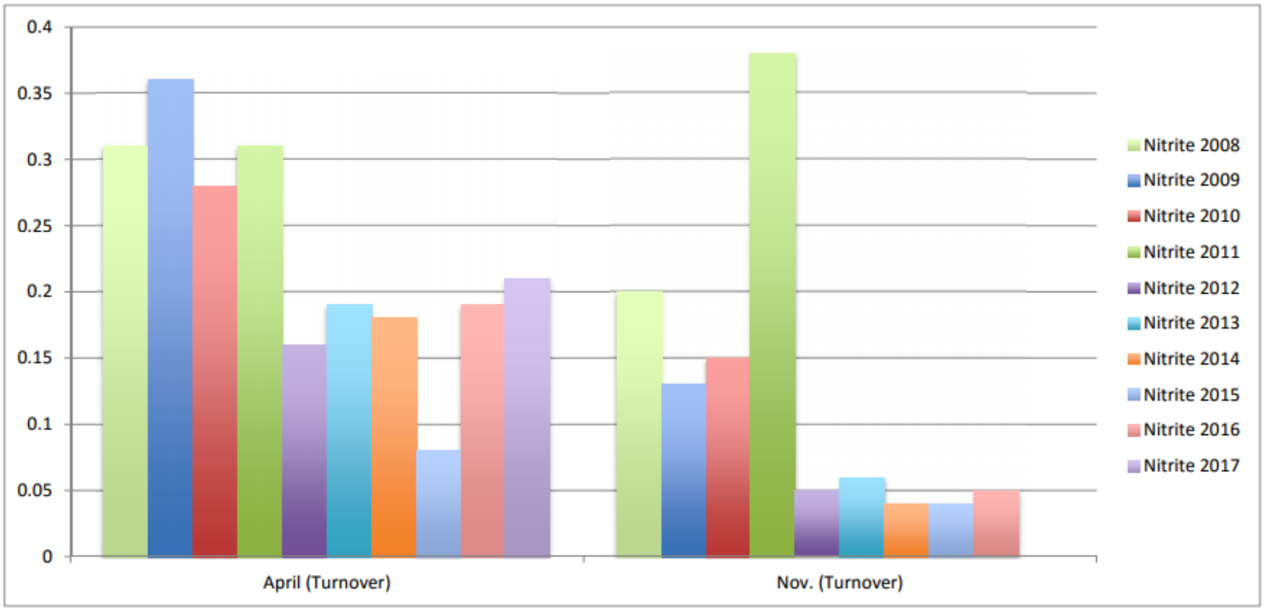

Figure 18: Beaver Lake nitrite (mg/l) during April and November 2008 – 2017.

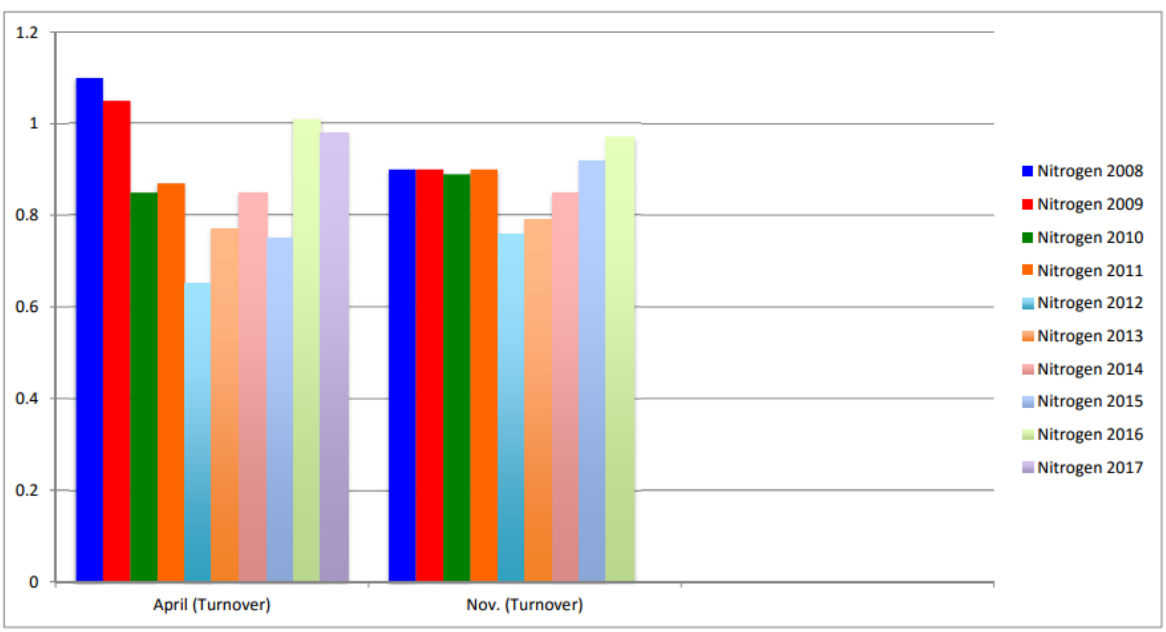

Figure 19: Beaver Lake nitrogen (mg/l) during April and November 2008 – 2017.

Phosphorus - Most recent measurement in Spring 2017~.01 mg/l

Why is this measurement taken?

Phosphorus is the key nutrient affecting plant and algae growth in 80% of Wisconsin's lakes. Phosphorus in lakes originates from many of the same sources as described for nitrogen. As mentioned in the first section of this report describing marl lakes, it is possible for a great deal of the phosphorus entering the lake to be carried to the sediment in the bottom of the lake along with the calcium carbonate. This presents a potential problem for the future since at some point the concentration of phosphorus in the sediment will become high enough that it will start to return to the water column. At this point it will be available to stimulate plant and algae growth and increase the nutrient levels in the lake.

Since phosphorus is normally the key limiting nutrient in lakes it may be responsible for increases in algae and aquatic plant growth. There are many different types of algae that can increase in growth when nutrients are added to a lake. An example of some types of algae that can form in lakes are filamentous algae and single celled phytoplankton. Filamentous algae are single celled algae that form chains, or filaments. They begin by forming along the bottom or on structures in the lake and form large mats on the surface. Filamentous algae generally do not have value in the lake food chain, and can be viewed as undesirable and are referred to as "pond scum". Phytoplankton are normally present at the surface of lakes, and millions can be present at a time. When there are enough phytoplankton to change the color of the surface water, it is termed an algal bloom. Some algal blooms can be beneficial to the pond food chain, but too much can deplete the oxygen in the water and kill fish. Other types of algae blooms can produce toxins. Before 2007, Beaver Lake experienced a blue-green or cyanobacteria algal bloom that produced surface scum on the lake and had the potential to produce a type of toxin called microcystin. Microcystin, which is produced by cyanobacteria, can have negative effects on plants, animals, and people. However, measurements taken in August 2007 revealed that the microcystin concentration (0.38 μg/l) was below the World Health Organization guidelines for potential toxicity. This suggested that the toxins were not present in a large enough quantity to cause negative effects on the plants, animals, or people. Since 2007, blue-green algae levels have been reduced, however nontoxic algal blooms have been reported by Village staff after 2007. Possible causes for algal blooms include unusually warm surface water, increased nutrients in runoff water, large rainfall events, higher water levels, and changes in runoff and groundwater structures (SEWRPC 2014). After algal increases, there can be lower water clarity, and depleted oxygen levels during algae decomposition (Water & Environmental Analysis Laboratory at the University of Wisconsin-Stevens Point 2015).

What does this mean?

In the mid 1970's, Beaver Lake phosphorus levels were around 24 µg/l. The Water Quality Index for total phosphorus for Wisconsin's natural lakes (Figure 20) places this in the "Good" category. In 1995, Phosphorus levels were found to be around 7 µg/l putting Beaver Lake in the "Very good" category (SEWRPC 2014). Recently, from 2008- 2017, phosphorus measurements from Beaver Lake have consistently remained below 15 µg/l which is also in the "Very good" category (Figure 21). This suggests that the lake is currently at low risk for periodic nuisance algae blooms, and that phosphorus levels have decreased since the mid 1970's. However, a slight upward trend has been evident in the past 7 years, and precautions should be taken to prevent nutrient runoff and algal blooms in the future. (SEWRPC 2003). Specific actions that can be taken are restricting pesticide use, control of litter and pet waste, proper disposal of motor vehicle fluids, and leaf collection. The largest areas of concern are impervious surfaces, such as parking lots. Where possible, stormwater runoff should be diverted to areas that can absorb the water such as rain gardens, instead of the water running directly into the lake. Additionally, property owners around the lake can maintain and expand riparian buffers around the lake shore in order to reduce excess phosphorus runoff into Beaver Lake (SEWRPC 2014).

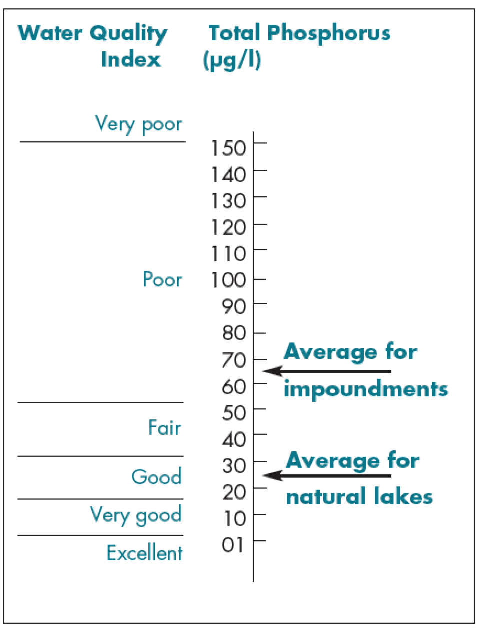

Figure 20: Wisconsin lakes total phosphorus concentrations (Shaw et al. 2004).

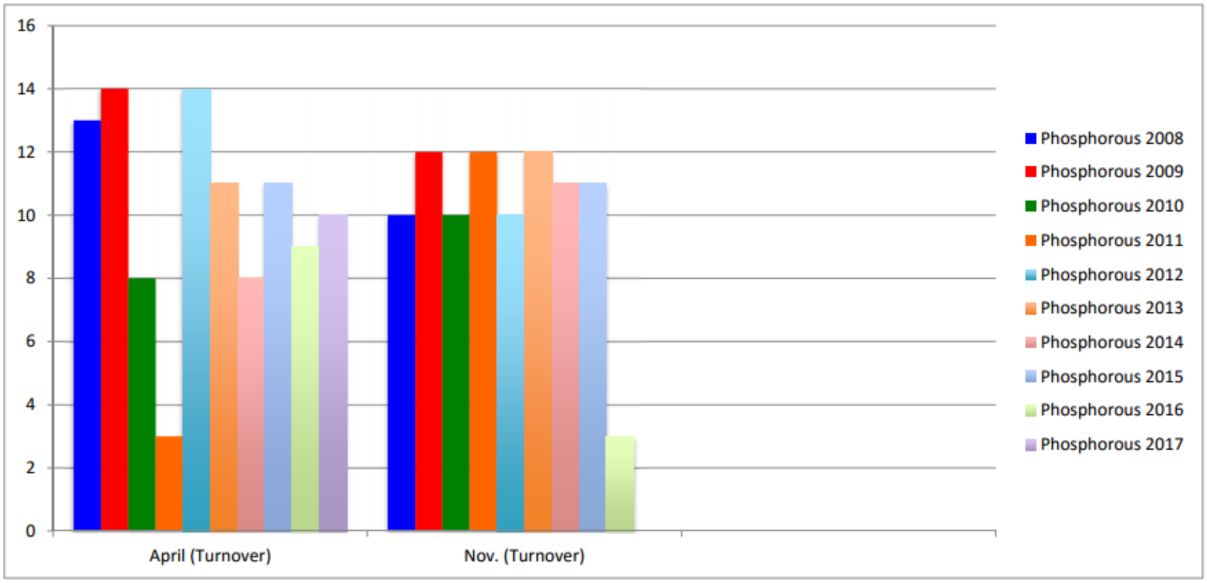

Figure 21: Beaver Lake phosphorus (µg/l) during April and November 2008 – 2017.

TN:TP- Most recent measurement in Spring 2017~99

Why is this measurement taken?

Since nitrogen and phosphorus are often the main limiting resources for plant growth in a lake, TN/TP is a ratio of "total nitrogen" to "total phosphorus" that indicates which one is more likely to be the limiting factor. When TN/TP is greater than 14:1, phosphorus is likely to be limiting. If the ratio is less than 10:1, nitrogen is most likely the limiting resource (SEWRPC 2003). Aquatics plants require phosphorus and nitrogen in order to grow. When either nitrogen or phosphorus is in short supply, plant growth is limited by that nutrient. Therefore, if the limiting nutrient increases, plant growth normally follows. In most lakes, phosphorus is the limiting nutrient, however in some lakes (such as Pine lake) nitrogen is the limiting nutrient. In an effort to reduce excess phosphorus runoff into lakes, phosphorus has been regulated in Wisconsin and taken out of some fertilizers. Additionally, measures to reduce stormwater runoff getting into lakes, rain gardens and native vegetation buffers along shoreline areas is being encouraged (SEWRPC 2014).

What does this mean?

With the exception of two years, the TN/TP in Beaver Lake has remained between 45:1 and 125:1which indicates that phosphorus is the limiting nutrient in Beaver Lake

(Figure 22). Since phosphorus is the limiting nutrient in the lake, excessive levels of phosphorus are likely to result in nuisance algal blooms and the creation of undesirable lake conditions (Table 2) (SEWRPC 2003)

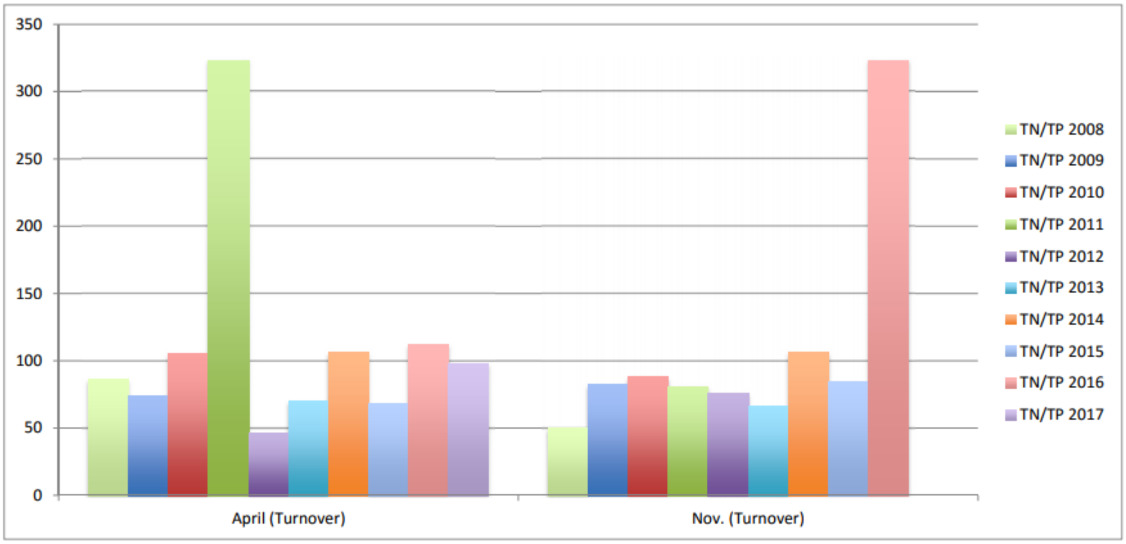

Figure 22: Beaver Lake TN:TP during April and November 2008 – 2017.

Table 2: Spring turnover nitrogen, phosphors, and TN:TP Ratio measurements in Beaver Lake, Waukesha County, WI from 2008-2017.

Year (Every reading taken in April)	Nutrient Levels		
	Nitrogen (mg/l)	Phosphorus (mg/l)	TN:TP Ratio
2008	1.1	.013	84.6:1
2009	1.05	.014	75:1
2010	.82	.008	102.5:1
2011	.83	.003	276.7:1
2012	.63	.014	45:1
2013	.68	.011	61.8:1
2014	.82	.008	102.5:1
2015	.67	.011	69.9:1
2016	1	.009	111.1:1
2017	.89	.010	89:1

Since nitrogen and phosphorus levels have been slightly increasing and could be a concern, how can runoff be prevented in order to preserve present lake conditions?

It is important to evaluate the future direction of development in the Beaver Lake watershed in order to take measures to retain good water quality in the lake. By the year 2035, the planned land usage around Beaver Lake is expected to consist of 69% urban use, and 31% rural use. Agricultural land is expected to cover around 63 acres of land, and residential land use is expected to cover around 1,201 acres. In comparing to 2010 land use statistics, the projected 2035 usage shows a large increase in urban usage and a significant decline in rural usage (Table 3). The decline in rural usage is mainly a reduction in agricultural and other open lands. It is important to take into consideration that the predicted land use is not reflective of a village of Chenequa ordinance that prevents cutting of trees and vegetation in residential areas if they are within 75 feet of a body of water. As a result, much of the "residential" land consists of covered canopy land that is not typical of many residential areas. Therefore the 2035 prediction is likely an overestimate for urban land use. If new development is consistent with Chapter NR 151 "Runoff Management" of the Wisconsin Administrative Code, which calls for an 80 percent reduction in total suspended sediment from areas of new development, the projections for phosphorus and sediment carried to the lake should be reduced (Table 4). Phosphorus loading in 2010 was 661 pounds and the projection for 2035 is 403.5 pounds (SEWRPC 2014). Even though the amount of phosphorus and other nutrient runoff may be reduced there is still a cumulative effect in the lake which argues for development of as many measures as possible to reduce nutrient input and extend the life of the lake.

Table 3: Beaver Lake watershed land use for 2010 and projections for 2035 (SEWRPC 2014).

Land Use Categories[a]	2010		2035	
	Acres	Percent of Total	Acres	Percent of Total
Urban[b]				
Residential	763	37.8	1,201	59.6
Commercial	1	<0.1	1	<0.1
Industrial	1	<0.1	2	0.1
Governmental and Institutional	27	1.3	71	3.5
Recreational	118	5.9	120	6.0
Subtotal	910	45.1	1,395	69.2
Rural				
Agricultural and Other Open Lands	541	26.8	63	3.1
Wetlands	25	1.3	25	1.3
Woodlands	213	10.6	208	10.3
Water	327	16.2	325	16.1
Extractive	- -	- -	- -	- -
Landfill	- -	- -	- -	- -
Subtotal	1,106	54.9	621	30.8
Total	2,016	100.0	2,016	100.0

Table 4: Existing and future pollution loads to Beaver Lake 2010 and 2035 (SEWRPC 2014).

Land Use Categories[a]	2010				2035 (no controls on new development loads)				2035 (NR 151 controls)[b]			
	Sediment (tons)	Phosphorus (pounds)	Copper (pounds)	Zinc (pounds)	Sediment (tons)	Phosphorus (pounds)	Copper (pounds)	Zinc (pounds)	Sediment (tons)	Phosphorus (pounds)	Copper (pounds)	Zinc (pounds)
Urban												
Residential	7.4	153	- -	7.6	11.7	240	- -	12.0	8.3	196.5	0.0	8.9
Commercial	0.4	1	0.2	1.5	0.4	1	0.2	1.5	0.4	1.0	0.2	1.5
Industrial	0.6	2	0.3	2.2	0.6	2	0.3	2.2	0.6	2.0	0.3	2.2
Governmental and Institutional	6.8	36	1.9	21.4	18.1	96	5.0	56.8	9.1	66.0	2.8	32.0
Recreational	1.4	32	- -	- -	1.4	32	- -	- -	1.4	32.0	0.0	0.0
Subtotal	16.6	222	2.4	32.7	32.2	371	5.5	72.5	19.8	297.5	3.3	44.6
Rural												
Agricultural and Other Open Lands	98.1	387	- -	- -	14.3	55	- -	- -	14.3	55.0	0.0	0.0
Wetlands	- -	1	- -	- -	<0.1	1	- -	- -	<0.1	1.0	0.0	0.0
Woodlands	0.4	9	- -	- -	0.4	8	- -	- -	0.4	8.0	0.0	0.0
Water	30.7	42	- -	- -	30.6	42	- -	- -	30.6	42.0	0.0	0.0
Subtotal	129.2	439	- -	- -	45.3	106	- -	- -	45.3	106.0	0.0	0.0
Total	145.8	661	2.4	32.7	77.5	477	5.5	72.5	65.1	403.5	3.3	44.6

[a] *Parking included in associated use.*

[b] *Assumes a level of control consistent with the requirements of Chapter NR 151, "Runoff Management," of the* Wisconsin Administrative Code, *which calls for an 80 percent reduction in total suspended sediment (TSS) from areas of new development. Consistent with that level of TSS reduction, a 50 percent reduction in total phosphorus and 70 percent reduction in metals was assumed.*

Runoff can have an enormous impact on the phosphorus and nitrogen levels, and 2017 has been an extremely rainy summer for Wisconsin, with some areas of the state receiving twice their normal summertime rain levels. Rain is normally nutrient poor, but once it encounters the ground and turns into runoff, it can pick up nutrients and sediment that is easily carried off into rivers and lakes. Wet summer weather along with runoff normally lead to poor visibility in lakes and algal blooms. Before European settlement in the United States, much of the land was uneven and composed of a variety of natural materials such as fallen trees, and few impervious surfaces. As a result, lake clarity was higher since runoff was slowed and would soak into the ground before reaching lakes or rivers. The landscape that currently surrounds most lakes is no longer like this. Heavy machinery has sculpted the land near lakes to quickly remove water into rivers and lakes to prevent flooding. Many of the land surfaces are compacted or paved over becoming impervious to the absorption of water into the ground. The addition of more water into a lake can cause waves to pick up shoreline nutrients that would normally be above the high-water mark adding even more nutrients to the water body. The addition of runoff along with summer sunshine and warm air are perfect conditions for algal blooms. Steps can be taken by homeowners to prevent runoff from going directly into the lake. The addition of rain barrels, French drains, rain gardens, shoreline buffers, and the removal of unneeded impervious surfaces can all help prevent excess phosphorus and nitrogen from entering the lake. The landscape in Wisconsin has been reshaped to quickly move runoff into waterbodies for over 150 years, the reversal of the process is going to take time, but positive steps must be taken in order to see the trend reversed (Olson 2017).

Secchi Disk Readings- 9 Year average -3.5 meters (11.5 feet)

Why is this measurement taken?

Secchi disk readings measure light penetration into the water as a rough estimate of water clarity. The disk is a round plastic or metal plate that is either all white, or has alternating white and black quarters. The plate is lowered into the water and the depth where it is just visible is recorded as the “Secchi disk depth” (Dodson 2005). When the water is turbid, there will be lower visibility, therefore, the deeper down the disk is visible, the more clear/less turbid the water is.

What does this mean?

From 2008-2016 the 9-year average Secchi disk reading for Beaver Lake was 3.5 meters, or 11.5 feet, which places the lake in the "oligotrophic" category (Table 5). An oligotrophic lake is characteristically located away from agriculture, has low primary productivity, high water quality, is extremely clear, and has low fish productivity (Dodson 2005). Although the oligotrophic category is suggested by the water clarity data, the fact that Beaver Lake is a marl lake changes this perspective. Given the nutrient data discussed earlier, Beaver Lake would fit more realistically in the mesotrophic category. It is encouraging to see that water clarity appears to be improving over the last nine years.

Table 5: Beaver Lake Secchi disk readings during May-September 2008 – 2016.

Date	2008	2009	2010	2011	2012	2013	2014	2015	2016	Average
May: Week 1	8.0	10.0	20.0	18.0	18.5	11.0	15.0	15.0	16.0	14.6
May: Week 2	8.0	12.0	17.0	12.5	18.0	7.5	15.0	14.0	12.0	12.9
May: Week 3	6.0	11.0	18.0	11.0	13.0	8.0	13.0	13.0	9.0	11.3
May: Week 4	7.0	9.0	14.0	10.5	15.0	8.0	12.0	14.0	11.0	11.2
May: Average	**7.3**	**10.5**	**17.3**	**13.0**	**16.1**	**8.6**	**13.8**	**14.0**	**12.0**	**12.5**
June: Week 1	7.0	9.0	14.0	9.5	12.0	12.0	9.0	12.0	14.0	10.9
June: Week 2	8.0	10.0	14.0	7.5	9.5	11.0	14.0	13.0	16.0	11.4
June: Week 3	10.0	10.0	14.0	9.0	9.5	13.0	15.0	15.0	21.0	12.9
June: Week 4	10.0	10.0	14.0	10.5	9.5	14.0	12.0	15.0	17.0	12.4
June: Average	**8.8**	**9.8**	**14.0**	**9.1**	**10.1**	**12.5**	**12.5**	**13.8**	**17.0**	**11.9**
July: Week 1	11.0	10.0	15.0	12.5	9.5	13.0	11.5	14.0	12.0	12.1
July: Week 2	9.0	12.0	10.0	8.5	8.0	11.5	12.0	12.0	10.0	10.3
July: Week 3	9.0	13.0	9.0	8.5	8.5	12.5	11.0	10.0	7.0	9.8
July: Week 4	10.0	10.0	8.0	9.0	7.0	11.5	11.5	9.0	7.0	9.2
July: Average	**9.8**	**11.3**	**10.5**	**9.6**	**8.3**	**12.1**	**11.5**	**11.3**	**9.0**	**10.4**
August: Week 1	10.0	11.0	6.0	10.5	7.0	14.5	12.0	10.0	7.0	9.8
August: Week 2	9.0	10.0	7.0	9.5	12.0	11.0	8.0	10.0	9.0	9.5
August: Week 3	10.0	10.0	7.0	11.0	13.0	10.0	10.0	11.0	11.0	10.3
August: Week 4	10.0	10.0	8.0	12.5	20.0	9.0	10.0	12.0	12.0	11.5
August: Average	**9.8**	**10.3**	**7.0**	**10.9**	**13.0**	**11.1**	**10.0**	**10.8**	**9.8**	**10.3**
September: Week 1	11.0	11.0	9.0	12.5	20.0	10.0	11.0	12.0	12.0	12.1
September: Week 2	10.0	11.0	10.0	12.0	20.0	10.0	11.0	11.0	10.0	11.7
September: Week 3	11.0	11.0	11.0	12.5	20.0	11.0	16.0	11.0	9.0	12.5
September: Week 4	10.0	10.5	10.0	12.0	20.0	12.0	15.0	12.0	12.0	12.6
September: Average	**10.5**	**10.9**	**10.0**	**12.3**	**20.0**	**10.8**	**13.3**	**11.5**	**10.8**	**12.2**
Seasonal Average	**9.2**	**10.5**	**11.8**	**11.0**	**13.5**	**11.0**	**12.2**	**12.3**	**11.7**	**11.5**

Monthly Low
Monthly High

Absolute Low **6.0 (2010)**
Absolute High **21.0 (2016)**

Note: 9 year average is 11.5 feet. 2016 average of 11.7 feet places it in the Oligotrophic category (very good).

Dissolved Oxygen and Temperature Profiles

Why are these measurements taken?

Dissolved oxygen and temperature measurements at different depths are taken in order to visualize lake productivity and survivability at certain depths of the lake (Wetzel 1983).

What do they mean?

Beaver Lake dissolved oxygen and temperature measurements were taken on August 14th, 2017 at two locations (Figure 25). The dissolved oxygen and temperature exhibited a "clinograde" curve, where temperature and dissolved oxygen decrease at the thermocline (an area where there is a steep temperature change). Since the measurements were taken in the middle of summer, the oxygen near the bottom of the lake, also known as the hypolimnion is used up as a result of bacterial decomposition of organic matter after spring turnover. Phytoplankton in the water column provide oxygen to the upper portion of the water column, and decomposition continues to remove oxygen from the lower portion of the water column. The portion of Beaver Lake above the thermocline had a very good dissolved oxygen concentration of 10 mg/l while the area below the thermocline (~6.5 meters/21 feet) dropped below levels that can support many animals and plants (Figures 23 and 24) until lake turnover occurs in the fall. (Wetzel 1983).

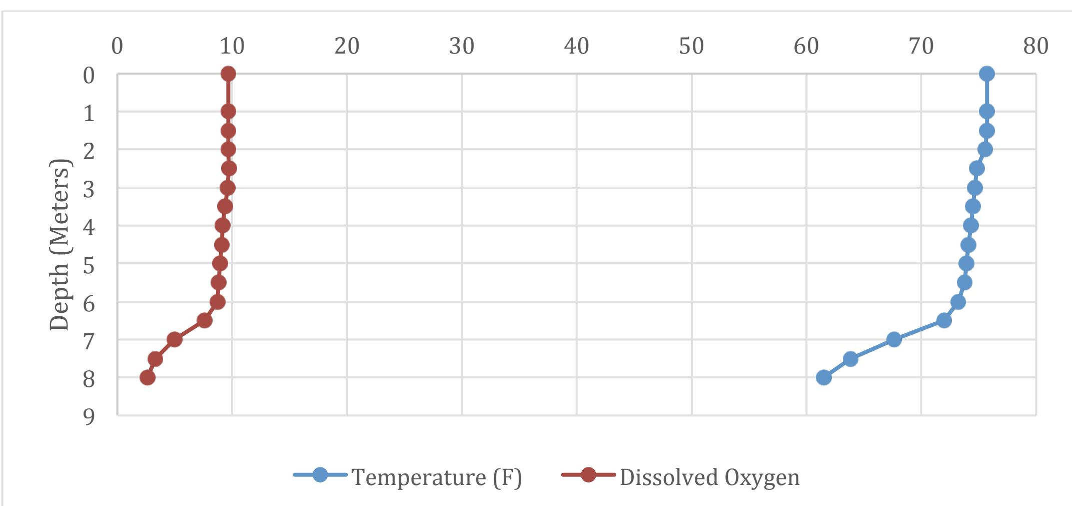

Figure 23: Beaver Lake Dissolved Oxygen (mg/l) and Temperature measurements taken on August 14th, 2017 at Beaver Lake (43.12875, -88.35905) in Waukesha County, WI (Location 1).

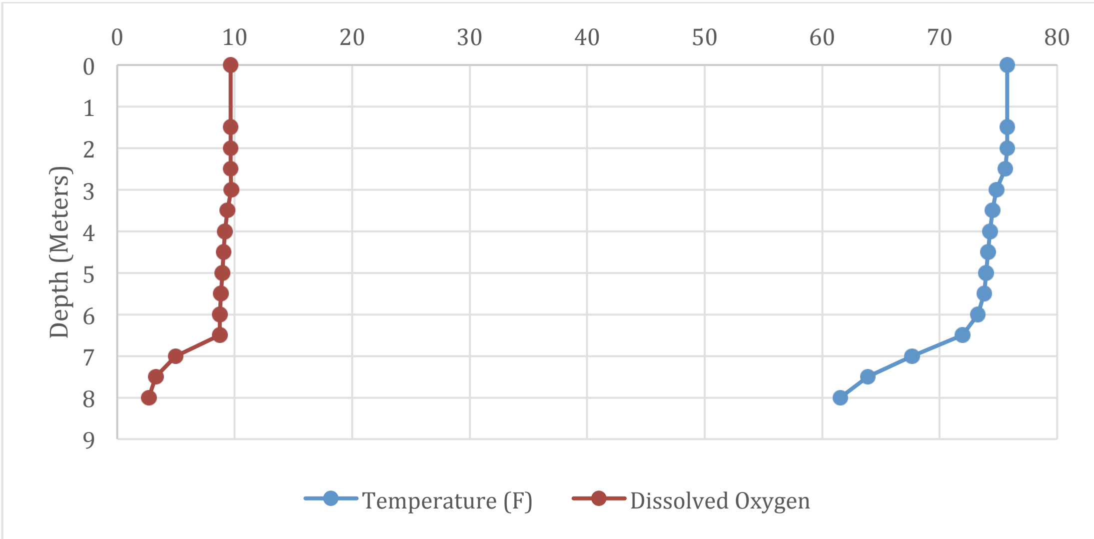

Figure 24: Beaver Lake Dissolved Oxygen and Temperature measurements taken on August 14th, 2017 at Beaver Lake (43.1315, -88.36862) in Waukesha County, WI (Location 2).

Figure 25: Location of dissolved oxygen and temperature measurements taken on August 14th, 2017 at Beaver Lake in Waukesha County, WI.

Recommendations

- Begin to include chlorophyll a measurements in the chemical analysis of Beaver Lake water so that a Trophic State Index can be developed for comparison to other lakes in the state. This index is based on total phosphorus, total nitrogen and chlorophyll a measurements
- Encourage development of natural shorelines with emergent vegetation. This will reduce turbulence in the lake by dampening wave action. This will also trap incoming nutrients washing in from surrounding land. This will also allow a greater diversity of submerged aquatic plants to grow in the lake and create habitat for fish.
- Initiate programs to assist land owners throughout the watershed to build rain gardens and other structures that will allow water to soak into the soil and become part of the shallow water aquifers that sustain the lake.
- Work with local municipalities to reduce the use of salt on roadways and in parking lots.
- Continue existing monitoring efforts in order to be alerted to both positive and negative trends in Beaver Lake's health.
- Develop shoreline and in-lake habitat for macroinvertebrates and fish through placement of fish cribs and natural woody structures near shore.
- Discourage boating activities that disturb the sediment in shallow areas of the lake. When these sediments are disturbed they release nutrients into the water column and decrease water clarity. Disturbing these sediments also uproots important aquatic plants and eliminates fish habitat.

Literature Cited

Dodson, S. I. (2005). Introduction to limnology. New York, NY: McGraw-Hill.

Horne, A.J. and C.R. Goldman. 1994. Limnology. 2nd edition. McGraw-Hill Co., New York, New York, USA

Kammerer, P.A. 1995. Ground-Water flow and quality in Wisconsin's shallow Aquifer system. U.S. Geological Survey Water-Resources Investigations Report 90-4171

Olson, E. 2017. Wetter Summer Weather Yields Water Woes. Lake Tides, 42, No. 3. Retrieved September 1, 2017, from https://www.uwsp.edu/cnr-ap/UWEXLakes/Documents/resources/newsletter/vol41-vol45/vol42-3summer2017websmall.pdf

SEWRPC (Southeastern Wisconsin Regional Planning Committee). 2003. A lake management plan for Pewaukee Lake, Waukesha County, Wisconsin. Community Assistance Planning Report No. 58 (2nd Edition), Waukesha, WI.

SEWRPC (Southeastern Wisconsin Regional Planning Committee). 2014. A water resources management plan for the Village of Chenequa, Waukesha county Wisconsin. Community Assistance Planning Report No. 315, Waukesha, WI.

Shaw, Byron, Chritine Mechenich and Lowell Klessig. 2004. Understanding Lake Data. Univ. of Wisconsin Extension publication G3582

Wall, David. 2013. Nitrogen in Waters: Forms and Concerns. Minnesota Pollution Control Agency. https://www.pca.state.mn.us/sites/default/files/wq-s6-26a2.pdf

Water & Environmental Analysis Laboratory at the University of Wisconsin-Stevens Point. 2015. Interpreting Your Wisconsin Lake Chemistry. Unpublished manuscript.

Wetzel, R. G. 1983. Limnology (3rd ed.). San Diego, CA: Academic Press.