9353 Hill Road • Swartz Creek, MI 48473
(810) 635-4400 • Fax (810) 635-4404
www.lakeproinc.com

2017 Forest Lake Water Quality Review

Introduction

The goals of this testing protocol were to monitor various water quality parameters of the lake, compare results to historical data, and identify any potential risks to the health of Forest Lake. Water samples were taken at two different locations and tested for 14 parameters. Tests were conducted on a monthly basis from April through August. Tests were conducted with a Hanna Multiparameter Water Quality Meter or LaMotte SMART2 Colorimeter.

Test results were compared to historical data from the report "2016 Forest Lake Water Quality Review" by LakePro, Inc.

In this report, we included historical data from Water Quality Investigators. Their report provided annual averages for many of the parameters from 2002 to 2009. Including this data allows us to see more accurate trends in the water quality data. In order to make the analysis easier, we displayed annual averages and trendlines on the graphs. The trend lines revealed which direction each water quality parameter moved over the past fourteen years.

Results

Parameter	2017 Season Average	Target Range	Status
Temperature	71.6 ˚F	Less Than 75 ˚F	Healthy
Dissolved Oxygen	7.7 mg/L	4.0 – 12.0 mg/L	Healthy
Total Phosphorus	100 ppb	0 – 100 ppb	Acceptable
Phosphate	49 ppb	0 – 100 ppb	Healthy
Nitrate	475 ppb	0 – 1,000 ppb	Healthy
Chlorophyll-a	5.2 ppb	0 – 7.3 ppb	Healthy
Transparency	11.5 feet	More than 6.5 feet	Healthy
pH	7.5 S.U.	7.0 – 9.0 S.U.	Healthy
Total Dissolved Solids	556 ppm	0 – 1,000 ppm	Healthy
Conductivity	1,092 ppm	0 – 1,500 ppm	Healthy
Alkalinity	132 ppm	100 – 250 ppm	Healthy
Sulfate	16.5 ppm	3 – 30 ppm	Healthy
Fluoride	0.08 ppm	0.01 – 0.30 ppm	Healthy
Chloride	323 ppm	0 – 230 ppm	High

Year-End Discussion

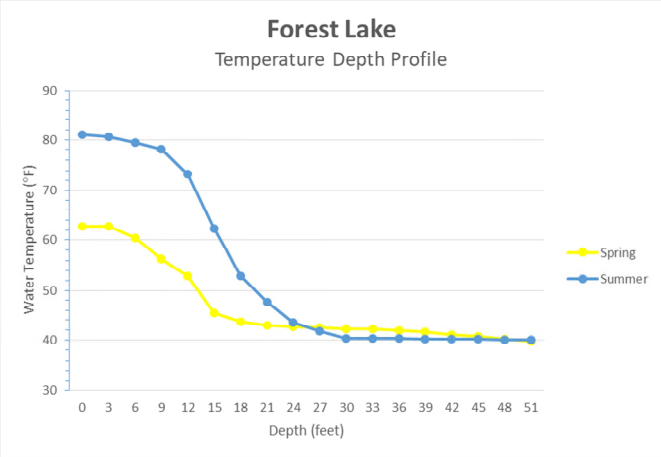
Forest Lake's water quality was very good throughout 2017. The season average for most parameters were within the target ranges. Total phosphorus was at the top end of the target range and chloride was high, as discussed below.

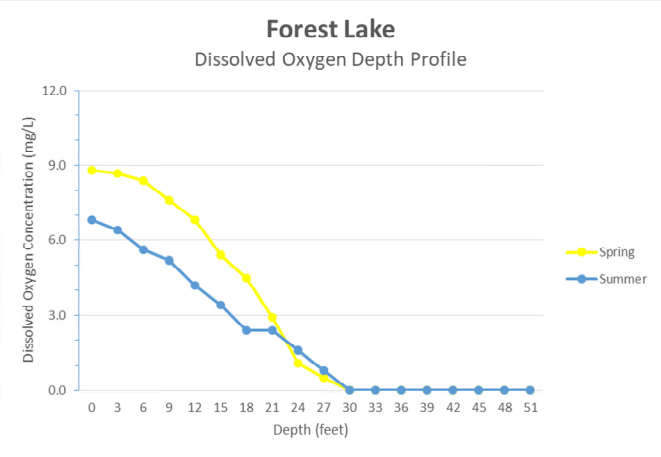
9353 Hill Road • Swartz Creek, MI 48473
(810) 635-4400 • Fax (810) 635-4404
www.lakeproinc.com

Temperature and Dissolved Oxygen

The average surface water temperature this year was similar to previous years. The preceding winter was cold and most Michigan lakes had average ice and snow cover. This led to cooler water temperatures in the spring. Summer temperatures rose sharply in June. As a result, the water temperatures later in the summer barely reached the 80's. Cooler water can hold more oxygen, so lower temperatures are preferable.

We also measured temperature at different depths to create a profile. This data shows how the temperature changed with depth and whether or not a thermocline was present in the lake. During the spring test, there was not a defined thermocline. By the summer sampling, the water was stratified and water temperatures decreased sharply from 12 to 21 feet. The thermocline was near 17 feet.





There is a limit on how much dissolved oxygen can be in the water, which depends upon water temperature. Despite the warmer temperatures in late summer, Forest Lake had excellent dissolved oxygen concentrations throughout the summer. Dissolved oxygen is vital for a healthy aquatic ecosystem, so this year's concentrations were a positive for lake.

The depth profile protocol was followed and measurements were taken for dissolved oxygen. The data showed how the oxygen concentration changed throughout the water column. A concentration of 3.0 milligrams per liter is a general limit for fish, so this graph shows there was enough oxygen to support fishes in the water down to 15 feet.

Nutrients, Plant Production, and Transparency

Nutrients in the water are the fuel for plant growth. Nutrient concentrations can be interpretted as the potential for nuisance plant growth. Phosphorus is a main nutrient necessary for aquatic plant growth, so it is important that this nutrient remains low in the lake. The total phosphorus fluctuated in and out of the target range during the summer. The season average was at the upper limit of the target range, showing there was an overall decrease since last year. Phosphate, the active form of phosphorus, was within the target range for all tests this year.

Nitrate is another major nutrient for aquatic plant growth. The nitrate concentrations remained within the target range across all tests. It is important that residents fertilize and use their land responsibly to prevent additional nutrients from entering the lake.

We also measured Chlorophyll concentrations because it is a direct indicator of plant production. The target for chlorophyll is below 7.2 parts per billion. In July, the concentration was above the target range at the west site. All other tests were within the target range, along with the annual average.

One of the most important effects of plant growth on the lake is the reduction of water clarity. Before algae forms the green mats of "scum" on the surface, it is suspended in the water column. Algae floating in the water can decrease water clarity, even before you see a tint of green. This year, the water clarity averaged over 10 feet.

In order to better understand the relationship between nutrients, plant production, and clarity, limnologists use Trophic State Indices (TSI) to score each category and examine the relationship between them. In general, lower scores indicate a less productive lake. The TSIs for Forest Lake this year were:

Category	Water Quality Parameter	Trophic State Index (season average)	Classifciation
Nutrients	Total Phosphorus	70	Hypereutrophic
Plant Production	Chlorophyll	46	Mesotrophic
Clarity	Transparency	42	Mesotrophic

The TSI for Total Phosphorus classified the lake as hypereutrophic, or extremely productive. This is based on the availability of abundant nutrients to fuel plant productivity. The TSI for Chlorophyll, however, is lower than the nutrient score. This suggests that despite the availability of nutrients, the plants did not grow to the levels supported by the nutrients. Another factor is that the aggressive plant management helped control the nuisance plant and algae growth. The TSI for Transparency even lower, classifying the lake as mesotrophic. This shows that the water clarity was better than expected from the chlorohpyll.

Water Chemistry Parameters

It is important to monitor the basic water chemistry of the lake water. Shifts in these parameters indicate major changes to the lake that may need to be further investigated.

The pH of the lake remained within the target range for the entire summer. The Total Dissolved Solids (TDS) showed there were moderate amounts of dissolved substances in the water. This parameter includes nutrients, salts, and other substances, so it is a positive that this parameter has remained within the target range.

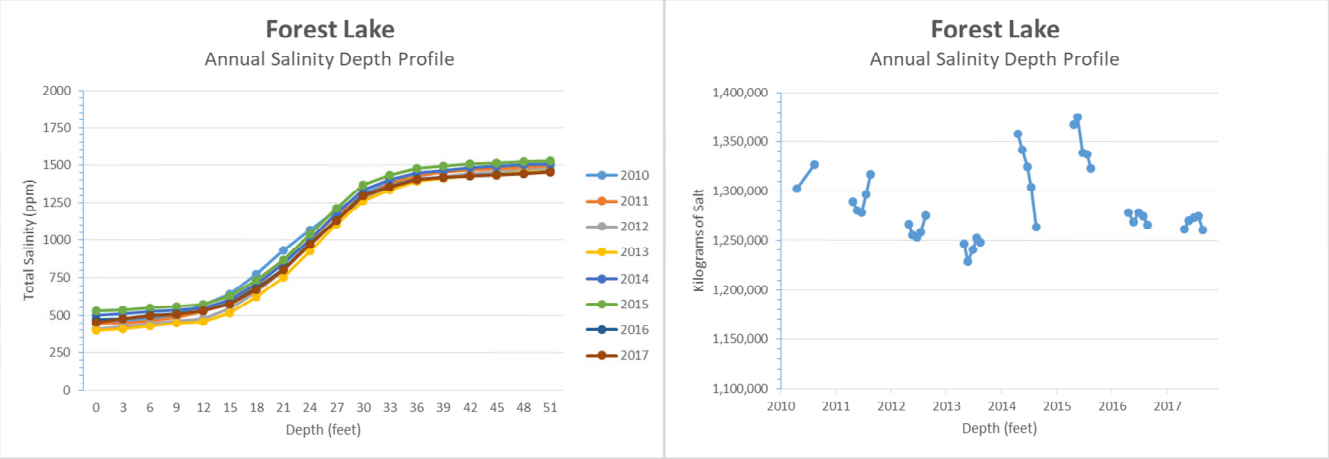
Conductivity, which measures ionic molecules in the water, usually follows the TDS. This parameter measures the ability of molecules in the water to conduct electricity. Thus, it is particularly sensitive to salts, which are excellent conductors. The conductivity was in the middle of the target range this year.

Alkalinity measures the concentration of one salt, Calcium Carbonate, which is beneficial to the aquatic ecosystem. The carbonate ions are able to accept protons from acids, making it a natural buffer. This means that as acidic substances enter the lake, the carbonate is able to buffer against severe changes in pH that could pose a threat to the ecosystem. This year the Alkalinity was at a healthy level for all tests.

Pollutants

Finally, the lake is tested for Sulfate, Fluoride, and Chloride as indicators of pollution. These molecules should be present in the water naturally, but elevevated levels can indicate pollution from within the watershed and may pose a risk to the ecosystem. Throughout the year, the sulfate and fluoride concentrations were within their target ranges. Chloride was above the target range for all of 2017, but improved over the course of summer.

Chloride is a main constituent of total salinity. The depth profile protocol was followed and measurements were taken for salinity. This allowed us to see how this parameter changed throughout the water column. We also used the readings and volume at each depth to calculate a volume weighted load.

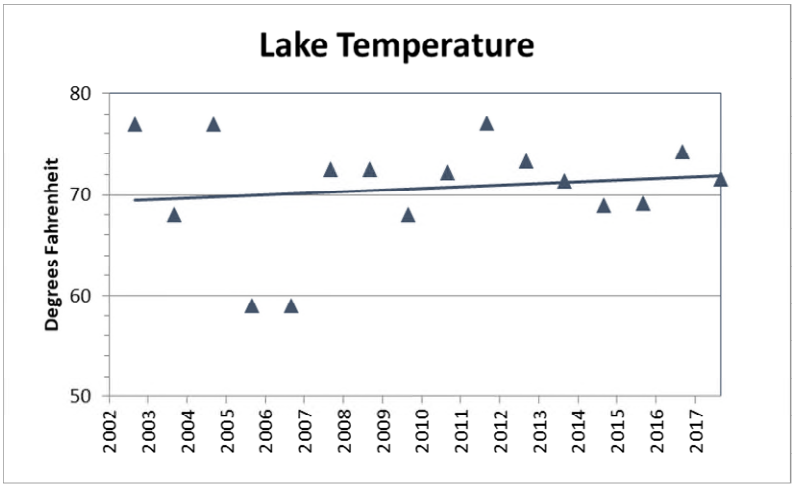


The first graph shows the average annual salinity at 3-foot depth intervals. This graph shows the salinity increases with depth and ranges from about 500 parts per million at the surface to about 1,500 parts per million in the deepest portion of the lake.

Based on the amount of water at each depth interval and the concentration of salts, we are able to calculate a total salt load for the lake. The second graph shows those calculated loads during each testing event. The salinity was relatively consistent through the summer. The salt decreased by the end of the summer, showing some improvement. The most likely cause for the improvement was the rain late in the summer that helped flush salt from the surface water.

9353 Hill Road • Swartz Creek, MI 48473
(810) 635-4400 • Fax (810) 635-4404
www.lakeproinc.com

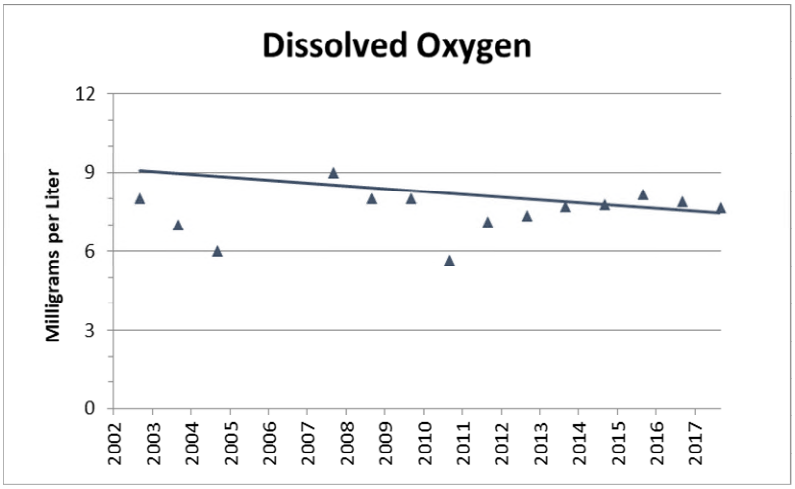
Historical Data & Trends



Lake Temperature (°F)					
	April	May	June	July	August
West	62.7	63.2	72.6	79.0	81.0
East	62.7	63.2	72.5	79.0	79.7
			Season Average		71.6

Discussion

The long term trend for water temperature is slightly upward. This year was below the trend, which helped to flatten it. Water temperature depends upon air temperatures and the dates selected for testing. For that reason, LakePro tries to select similar dates for testing each year. Cooler water is able to hold more oxygen, so lower temperatures are better for the ecosystem.

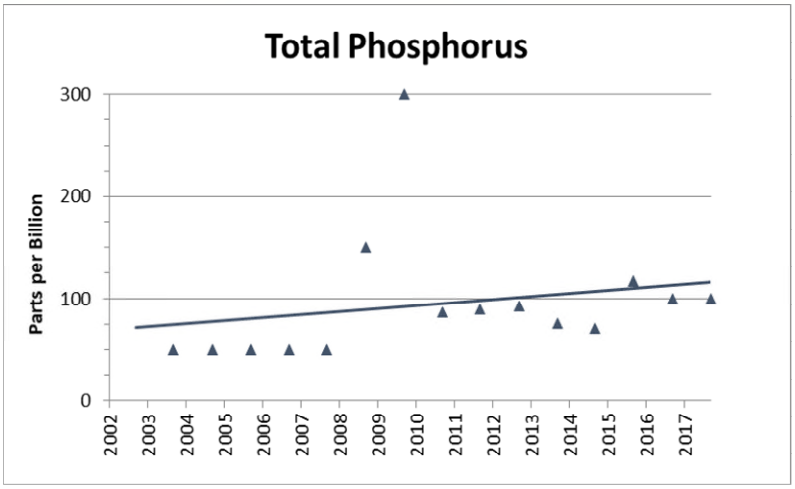


Dissolved Oxygen (mg/L)					
	April	May	June	July	August
West	8.8	8.4	7.2	7.3	6.8
East	9.1	8.6	7.6	6.8	6.2
			Season Average		7.7

Discussion

As expected with increasing temperatures, the dissolved oxygen trend is slightly downward. As water temperature increased, the oxygen solubility decreased. This has been a negative change for the lake, but oxygen concentrations remained adequate to support a healthy ecosystem. The 2017 average was above the trend line, which helped to flatten it. We will look for the downward trend to eventually flatten in the future.

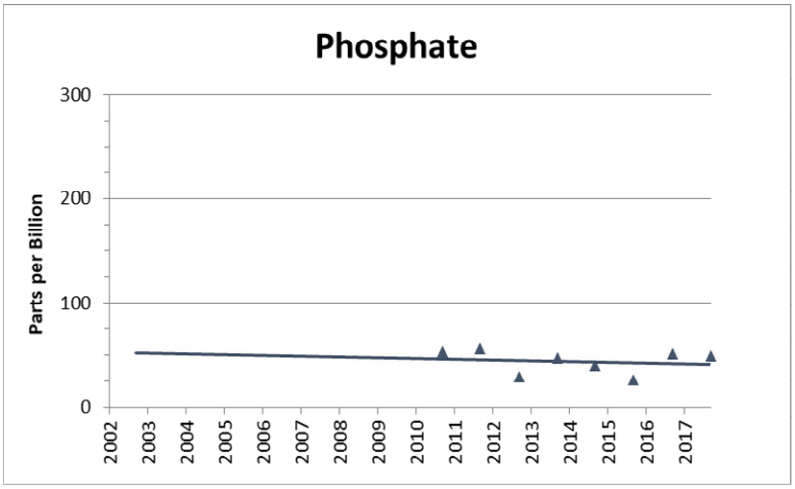
9353 Hill Road • Swartz Creek, MI 48473
(810) 635-4400 • Fax (810) 635-4404
www.lakeproinc.com



Total Phosphorus (ppb)					
	April	May	June	July	August
West	80	110	110	90	120
East	100	90	90	100	110
			Season Average		100
			Trophic State Index		70

Discussion

Generally, lakes tend to accumulate the substances that flow into it. Since testing began in 2003, the trend for Total Phosphorus has increased slightly. The 2008 and 2009 concentrations were much higher than all other years of testing, worsening the trend. There are ways to rid a lake of phosphorus, such as mechanical harvesting and heavy rain events that create excess flow. However, it is much easier to prevent excess nutrients from entering the lake. For this reason, it is vital that residents around the lake fertilize and use their land responsibly so as to prevent phosphorus from reaching the lake.

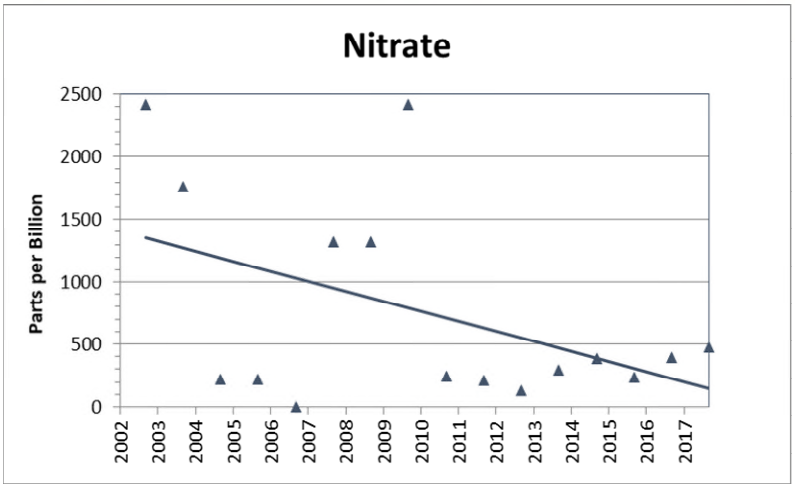


Phosphate (ppb)					
	April	May	June	July	August
West	40	60	50	40	60
East	50	50	40	50	50
			Season Average		49

Discussion

As more total phosphorus accumulates in the lake, so too will the phosphates. There is no historical data available for phosphates, so the trendline reflects the changes only since 2010. The trend is slightly downward and the phosphate concentrations remained below the target threshold.

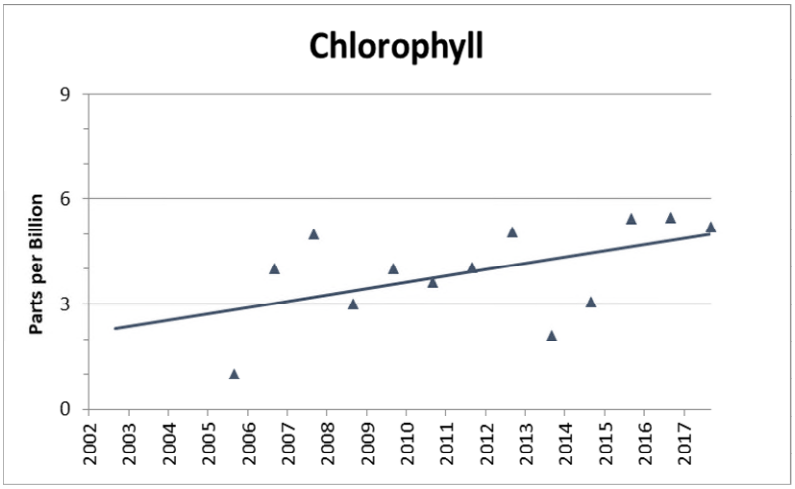
9353 Hill Road • Swartz Creek, MI 48473
(810) 635-4400 • Fax (810) 635-4404
www.lakeproinc.com



Nitrate (ppb)					
	April	May	June	July	August
West	484	528	528	484	484
East	528	440	484	396	396
			Season Average		475

Discussion

The nitrate season averages fluctuated widely over the testing history. The trend is downward, but recent results show a slight upward trend, but remain within the target range. It is important that residents around the lake fertilize and use their land responsibly to prevent additional nitrate from reaching the lake.

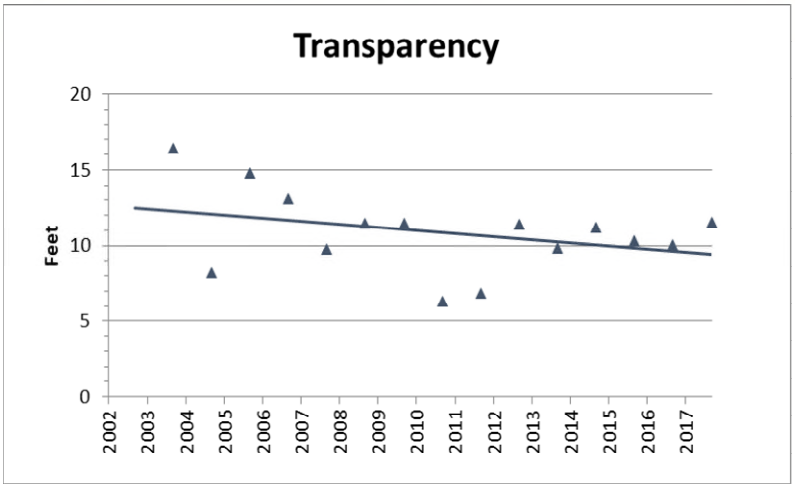


Chlorophyll (ppb)					
	April	May	June	July	August
West	3.8	4.2	6.4	7.8	5.7
East	3.4	3.9	5.4	6.7	5.0
				Season Average	5.2
				Trophic State Index	46

Discussion

Chlorophyll trended upward over the testing history. This was most likely a product of increasing phosphorus concentrations and sufficient nitrates. For now, the annual chlorophyll averages remained within the target range. Continuing to mechanically harvest will remove plant biomass and the nutrients within it. Responsible land management by residents around the lake will help stifle the source of excess nutrients, preventing further worsening of the plant growth.

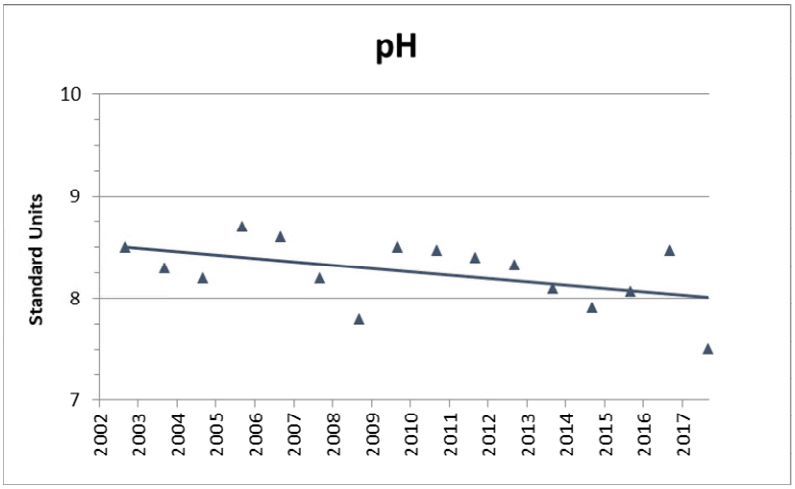
9353 Hill Road • Swartz Creek, MI 48473
(810) 635-4400 • Fax (810) 635-4404
www.lakeproinc.com



Transparency (feet)					
	April	May	June	July	August
West	11.0	10.2	14.1	12.7	9.4
East	11.3	10.3	13.4	13.1	9.9
			Season Average		11.5
			Trophic State Index		42

Discussion

Chlorophyll is used as an indicator of plant growth, including algae that clouds the water. Therefore, the increasing chlorophyll concentrations lead to lower transparency over the testing history. The decreasing water clarity could also be due to higher dissolved solids or higher suspended solids (e.g. sediment). Although the clarity trended downward, it was still above the target depth this summer.

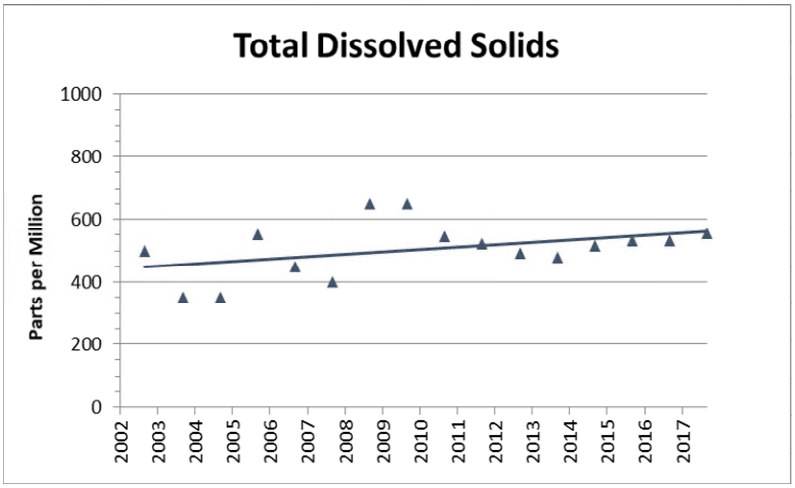


pH (Standard Units)					
	April	May	June	July	August
West	7.9	7.6	7.3	7.3	7.5
East	7.7	7.7	7.4	7.3	7.4
			Season Average		7.5

Discussion

The pH decreased slightly over the testing history. The shift moved annual values closer to 8, the middle of the target range. This change has not had a major impact on the lake, but any sharp changes may need to be quickly investigated.

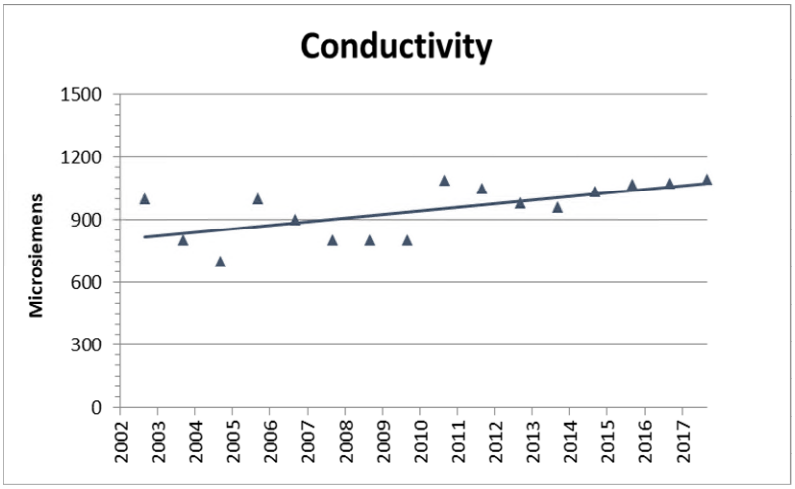
9353 Hill Road • Swartz Creek, MI 48473
(810) 635-4400 • Fax (810) 635-4404
www.lakeproinc.com



Total Dissolved Solids (ppm)					
	April	May	June	July	August
West	548	531	553	563	586
East	546	534	552	563	581
			Season Average		556

Discussion

The total dissolved solids increased over the testing history, showing that the lake is accumulating more substances. The increase was slow and the averages remained within the target range. Recent years were flat, possibly due to increased precipitation, which helped to flush the lake.

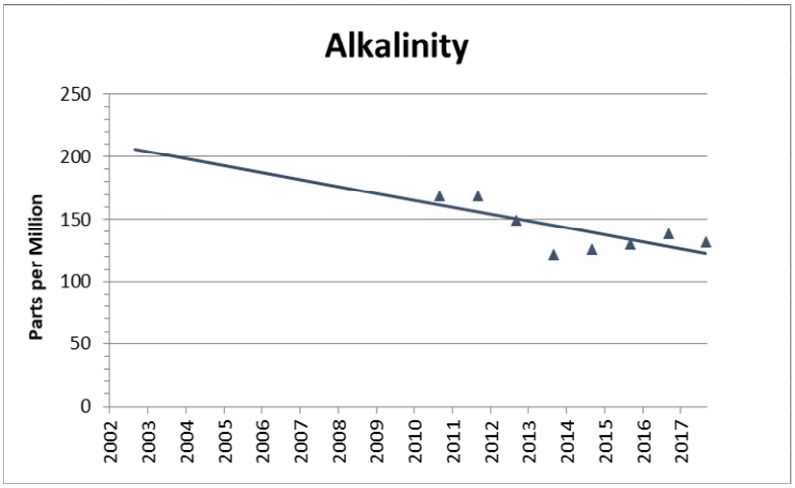


Conductivity (µS)					
	April	May	June	July	August
West	1,095	1,063	1,106	1,027	1,173
East	1,091	1,068	1,115	1,025	1,160
			Season Average		1,092

Discussion

Like the TDS, conductivity increased over the testing history. Conductivity is an extension of TDS and measures the amount of ionic molecules in the water (which conduct electricity, usually salts). We will look for this trend to slow in future years of testing.

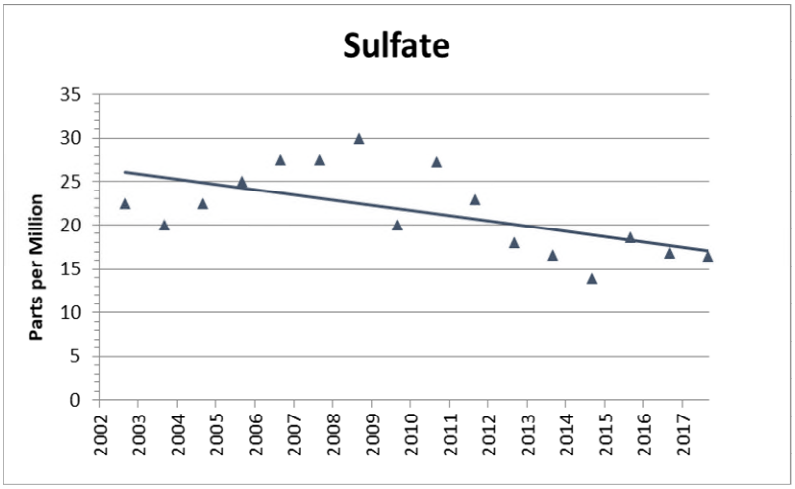
9353 Hill Road • Swartz Creek, MI 48473
(810) 635-4400 • Fax (810) 635-4404
www.lakeproinc.com



Alkalinity (ppm)					
	April	May	June	July	August
West	142	137	122	118	125
East	150	142	128	124	131
				Season Average	132

Discussion

Alkalinity was first included in the testing in 2010, so the historical data is more abbreviated. Alkalinity slowly decreased during the past five years, but remained within the target range.

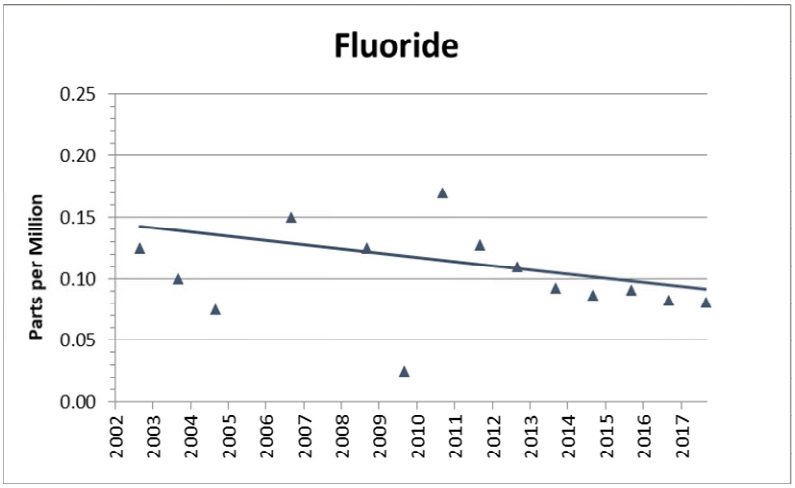


Sulfate (ppm)					
	April	May	June	July	August
West	17.8	15.9	16.2	17.0	16.6
East	17.4	15.6	16.0	16.5	16.2
				Season Average	16.5

Discussion

Sulfate fluctuated over the course of testing but the overall trend is slightly downward. It is important that this parameter stay within the target range.

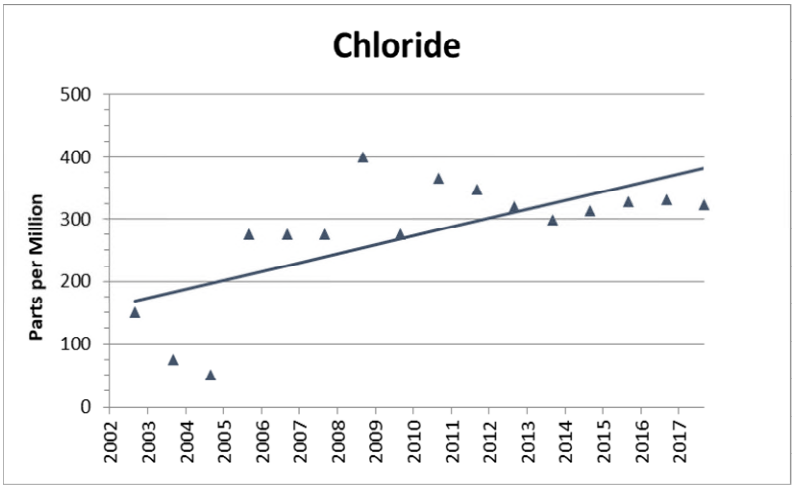
9353 Hill Road • Swartz Creek, MI 48473
(810) 635-4400 • Fax (810) 635-4404
www.lakeproinc.com



Fluoride (ppm)					
	April	May	June	July	August
West	0.08	0.08	0.08	0.08	0.08
East	0.08	0.08	0.08	0.09	0.08
			Season Average		0.08

Discussion

Fluoride has fluctuated widely over the testing history, but showed an overall decline. It is important that this parameter stay within the target range.



Chloride (ppm)					
	April	May	June	July	August
West	338	328	328	321	319
East	325	320	322	315	310
			Season Average		323

Discussion

The trend line for Chloride is upward. The data shows a large increase in 2005, which put to concentrations over the target threshold. Since then, the trend is only slightly upward and recent years helped to flatten the trend.

LakePro Inc.
9353 Hill Road • Swartz Creek, MI 48473
(810) 635-4400 • Fax (810) 635-4404
www.lakeproinc.com

Analysis Information

Temperature:	The water temperature directly affects the amount of oxygen that is able to dissolve into the water. The temperature of surface waters is not indicative of the entire water column.
Dissolved Oxygen:	D.O. is a measure of the amount of oxygen dissolved in the water. This oxygen is available to fish and other animals for respiration. Vegetation generally increases DO, particularly during the day and early evening. Animals and other respiring organisms consume the oxygen, mostly during the day. Oxygen is also added to the lake through wave action, rain, fountains and aerators.
Total Phosphorus:	Phosphorus is an essential nutrient for plant growth. However, concentrations exceeding 100 ppb can impair the water and results in nuisance vegetation growth.
Phosphates:	Phosphate is the form of phosphorous that is most readily available to plants and algae.
Nitrate:	Nitrogen is also essential for plant growth. Nitrate is the predominant form of nitrogen in water. Excessive nitrate concentrations may also result in pollution and increased vegetation.
Chlorophyll-a:	Chlorophyll-a is a direct measurement of the amount of green pigment produced by plants and phytoplankton. This indicates the amount of plant growth and is used to calculate a Trophic State Index.
Transparency:	The ability of light to penetrate the water column is determined by the amount of dissolved and suspended particles in the water. Although aesthetically desirable, transparent water allows increased light to reach the lake bed and may result in vegetation growth.
pH:	pH is a measure of acidity or alkalinity. pH is a general measure of lake health and can roughly indicate the range of other measurements such as alkalinity and hardness.
TDS:	Total Dissolved Solids is the amount of all organic and inorganic substances in the water in a molecular or ionized state. Higher values generally indicate richer and more productive water. Lower values usually indicate cleaner and less productive water.
Conductivity:	Conductivity is a measure of the ability of water to conduct electricity. Dissolved ions in the water increase conductivity, thus TDS and Conductivity are closely related.
Alkalinity:	Alkalinity refers to the ability of the water to neutralize acids, mainly through the hydrogenation of carbonate ions. This is why the alkalinity is expressed as "ppm as $CaCO_3$". However, other basic molecules in the water can also contribute to alkalinity.
Sulfate:	Sulfate occurs naturally as minerals, such as calcium sulfate and magnesium sulfate. In fresh water, sulfate is usually the second or third most abundant anion. Other sources of sulfate include water material from pulp mills, steel mills, food processing operations, and municipal wastes. Under low oxygen conditions, sulfate can by reduced to hydrogen sulfide gas, which smells like rotten eggs.
Fluoride:	Fluoride may occur naturally or be added to public drinking water supplies.
Chloride:	Chloride is one of the major anions found in water and sewage. The presence of chlorides may be due to water passing through salt formations in the earth or pollution from industrial processes, domestic wastes, or road salt. The salt content of water affects the distribution of plant and animal life in an aquatic system, based on the amount of slat they can tolerate.

9353 Hill Road • Swartz Creek, MI 48473
(810) 635-4400 • Fax (810) 635-4404
www.lakeproinc.com

Trophic States

Oligotrophic: Water is very clear. Nutrient levels are generally low. Plant and algae productivity is also low. Sufficient dissolved oxygen in the bottom, cooler waters allows cold-water fish to survive, such as salmon and trout.

Mesotrophic: Water is moderately clear. Nutrient levels are slightly elevated. Plant and algae productivity is present, but generally not a nuisance. Oxygen and temperature in the lower portion of the lake allow walleye and perch to survive.

Eutrophic: Water is not clear due to high nutrients levels, increased turbidity, and excessive algal growth. There is no oxygen in the bottom, cooler waters, restricting the lake to warm water species, such as bass and bluegill.

Hypereutrophic: Nutrient levels are extremely high, promoting very high algae productivity. Blue-green algae blooms are likely. High turbidity and algae growth make the water opaque. Little plant growth is restricted to invasive plants. The only fish that can survive this environment are rough fish, such as carp, catfish, and mudminnows.

Sample Sites: