During this past winter, I felt it was necessary to take a deeper dive into the history and current state of Higgins Lake. With assistance from the analytical lab at the Annis Water Resources Institute at Grand Valley State, we completed several analyses that provide context and new insights into the history of Higgins Lake and have added perspective to some recent observations. First, my graduate student Billy Mulligan collected temperature, dissolved oxygen (DO), and nutrient data during summer and fall 2020. His work was based on a review of data collected in 1930s, 1970s, 1980s, and 1990s. In combination with our 2020 data, these studies reveal that Higgins Lake has been changing during the past several decades and the trend is toward decreasing water quality.

The History-

Moffett and Brown (1940) provide a description of Higgins Lake during the late 1930's. They describe the sediment from 30 ft. to the 70-80 ft. contour as mostly sand and gravel, and in the "deeper water" it is primarily "muck", which would be the result of 7,000-8,000 years of natural processes and 30-50 years of the logging era which overlaps with about 100 years of shoreline development that is still occurring today. During August, 1939 when surface water was warmer than water at the bottom, they found that DO concentrations were higher near the bottom at depths of 85 and 98 ft. than DO concentrations at the surface of the lake. This follows the pattern we expect to see in an oligotrophic lake. In this case, cold water can hold more oxygen in solution than warm water, and organisms, particularly bacteria are not consuming large amounts of oxygen for their metabolism. At 100 ft. in the South Basin and 138 ft. in the North Basin they noted that DO at the bottom was 6.8 mg/L and 6.6 mg/L, approximately 1.7 mg/L less than at the surface. This suggests that microbes and other organisms were consuming a small amount of oxygen as they were metabolizing the “muck” at the deeper locations. Overall, Moffett and Brown conclude that the “abundant” oxygen supply was due to the lack of “extensive organic deposits”, that is, decaying organisms. During the 1970’s and 1980’s, Schultz and Fairchild (1983) found surface DO was similar to concentrations reported during the 1930s. In the deepest area of the North Basin, they only sampled to100 ft., but found DO concentrations similar to those noted at that depth in the late 1930s by Moffett and Brown. Although DO levels were similar at the 100 ft. contour and the surface we can only speculate about conditions below the 100 ft depth contour in the 1980s (see below). Both Studies sampled at approximately the same depth in the South Basin and reported similar results.

The Change-

In 2001, Minnerick reported a significant change in DO concentrations in the North Basin at 120 ft. and in the South Basin at 98 ft. DO concentrations at both locations dropped below 2 mg/L, a substantial chage from just 20 years earlier. During 2020, conditions were not quite as extreme in the North Basin at 136 ft. with August DO at 5.9 mg/L. However, DO concentration in the South Basin were similar to Minnericks’s (2001) at 1.86 mg/L. During September and October, DO in the South Basin rose slightly, but DO continued to decrease in the North Basin.

At other 2020 sample sites located around each basin (below 80 ft. in the South Basin and below 100 ft. in the North Basin), DO concentrations near the bottom decreased through the summer at many of our sites with deeper, colder water containing less DO than warmer surface water. These findings contrast with findings of Moffett and Brown (1940) who reported just the opposite during the 1930s, when colder deeper water contained more DO than warmer surface water.

The Cause-

Higgins Lake has accumulated a significant amount of organic sediment in deeper regions and at some shallower depths as well. Organic sediments are the result of biological material such as leaves and grass clippings entering the lake and aquatic organisms that sink to the bottom. Obviously, leaves from the surrounding terrestrial vegetation make their way into the lake on an annual basis and have for the past 7,000 to 8,000 years. But DO data from the late 1930s are exactly what you expect for an oligotrophic lake with modest amounts of organic sediment. However, that has been changing since at least the 1980s. If natural processes did not result in the accumulation of enough organic sediment to reduce DO concentration in 7,000-8,000 years, it seems unlikely that those same natural processes could reach this level in another 40 to 80 years. In this case, it is not unreasonable to suggest that the accumulation of organic material on the bottom of Higgins Lake is the result of human activity over the past few decades.

The decrease in DO concentrations would result from an increase in microbial respiration. As microbes metabolize accumulated organic material they consume DO; the more organic material, the more microbes there will be, and more DO will be consumed. A rapid change in DO concentrations below 80 ft. since the 1980s is the key indicator of an accelerated accumulation of organic material; the accumulation of organic material at a rate that has likely exceeded rates that occurred over the past few thousand years.

The Evidence-

We have analyzed sediment samples from the South and North Basins for organic content and found that the percentage of organic to inorganic material in surface sediments generally exceeds 50% and at some sample sites, exceeds 80%. That is, the deeper lake sediments are now generally more that 50% organic material – almost like good compost.

We have analyzed the same sediment samples for phosphorus and have found that the deeper lake sediments have accumulated large amounts of this nutrient. The ongoing addition of phosphorus to the lake from the surrounding watershed increases the production of biomass within the lake. As these organisms die, they sink to the bottom where they decompose due to microbial metabolism adding nutrients to the sediments. The data from Schultz and Fairchild illustrates this point. In the North Basin below the thermocline (49 ft), total phosphorus (TP) increased from 25 ug/L near the surface to 50 ug/L. Soluble phosphorus (SRP) was lower at 8 ug/L. This indicates that much of the phosphorus at that depth was tied up in organisms. At 86 ft., TP declines but SRP jumps to 20 ug/L. SRP would increase as dead organisms decompose while they sink to the bottom. In the South Basin TP accumulates at about 71 ft., hitting 120 ug/L. SRP at the same depth is slightly less than 20 ug/L. At 86 ft. the concentration of TP and SRP are nearly equal (just under 80 ug/L each or 160 ug/L total) and at 93 ft., most of the 160 ug/L of phosphorus is SRP indicating that decomposition is fairly complete. As long as there is sufficient DO, all of this phosphorus would tend to remain at the bottom associated with the sediments.

Several studies starting with Schultz and Fairchild have shown that phosphorus concentrations in nearshore areas are generally higher than in the offshore areas. The evidence of this added phosphorus can easily be seen in the level of biomass production along the drop off where some aquatic plant beds reach the same biomass as those in Muskegon Lake. The density of Zebra Mussels on plant stems and rocks also provide evidence of the amount of biomass production. Lastly, the amount of algal growth on and within the shallow, nearshore sediments provide strong evidence that nutrients, particularly in groundwater, are reaching the lake. In addition, the presence of nitrogen-fixing cyanobacteria in this zone indicate that phosphorus is entering the lake through groundwater.

The Outcomes-

In oligotrophic lakes, low nutrient concentrations limit the amount of biological growth and the limited amounts of organic material that settles to the bottom. The microorganisms can breakdown this small amount of material, and DO concentrations remain high near the bottom sediments. The presence of DO near the water-sediment interface chemically “locks” phosphorus within the sediment. This is the condition Moffett and Brown recorded in the 1930s.

The conditions and processes that lead to phosphorus release from sediments are well documented. Increasing nutrient concentrations in the lake result in an increase in the amount of biomass produced within the lake, e.g. algal growth and plant growth. Data from the 1980s (Schultz and Fairchild) illustrate the process that occurred as increased quantities of phosphorus were added to the lake. As nutrients support more biomass, the amount of biomass exceeds the ability of microorganism to break it all down on an annual basis, and organic material begins to accumulate and form organic sediment. Organic lake sediments provide a rich food source for microorganisms; as these organisms breakdown this rich biological material they reduce DO concentrations. As long as there is sufficient DO, phosphorus remains “locked” in the sediments, but as DO concentrations reach critical levels, a series of chemical reactions occur in the sediment making phosphorus more soluble and it begins to leach into the overlying water column. Although it is not generally available to the biological communities during stratification, fall and spring turnover may mix some of these nutrients throughout the water column making them available during early fall and spring. Observations of a nitrogen fixing cyanobacteria bloom in Higgins Lake during fall 2020 strongly suggests that phosphorus became available late in the summer in sufficient quantities to support an algal bloom during fall.

Not only are chemical reactions sensitive to DO concentrations, so are aquatic organisms. The areas of a lake that can be occupied by various fish species are defined by temperature and DO. For example, a recent Canadian study found that lake trout were distributed in a lake where the temperature was between 5^{o} and 13^{o} C, and DO ranged from 9-12 mg/L although they preferred temperature between 5° and 8° C and could tolerate lower DO. In the 1930s and early 1980s, lake trout could occupy from 36 ft. to over 100 ft. in the North Basin and from 36 ft. to the bottom in the South Basin using the Canadian temperature and DO criteria. During August and September 2020, in the deepest parts of the lake, lake trout would prefer depths between 40 ft. and 95 ft. in the North Basin and 46 ft. and 74 ft. in the South Basin. By October 2020, conditions at North Basin sites indicate that lake trout would prefer to occupy depths between 40 ft. and 83 ft. The combination of warmer temperatures at the surface and less DO at the bottom is reducing the amount of preferred conditions for the lake trout population.

The Conclusion-

Nearshore areas of Higgins Lake have higher phosphorus concentrations than offshore regions and the lake has accumulated a significant quantity of phosphorus associated with organic sediments, most likely within the last 40 to 80 years. Schultz and Fairchild calculated that Higgins Lake retains nearly 90% of all the phosphorus that enters the lake, and warned against the continued addition of phosphorus to the lake. Thus, the majority of phosphorus that entered the lake in the early 1980s is still in the lake. Although the cyanobacterial bloom last fall may be an infrequent event now, there is a very high likelihood that these kinds of cyanobacterial blooms will become more frequent in the future if summers continue to be warmer, winters shorter, and phosphorus continues to be added at the current rates. Add to this Zebra Mussels and its close relative, the recently introduced Quagga Mussel, both of which do not consume cyanobacteria, and the likelihood of cyanobacteria blooms become even greater. I have already reported regular and widespread cyanobacterial growth in the shallow nearshore regions; a clear indicator of elevated phosphorus levels in those areas. Reducing the chance of more regular and prolonged cyanobacterial blooms in the future will require minimizing or completely eliminating the addition of more anthropogenic phosphorus. The continued accumulation of organic material and declines in DO concentrations will further limit the areas of the lake that can be occupied by certain fish species such as lake trout.

There is no chemical fix, controlling anthropogenic phosphorus is the one tool available to reduce and hopefully reverse the conditions that have been created during the past several decades. The actions required to control phosphorus inputs are no mystery and the implementation simply requires acknowledging that Higgins Lake has and will continue to experience a trend toward lower water quality. The actions: 1) eliminate the use of fertilizers that contain phosphorus, 2) if a house is on septic, have it serviced regularly (every 2 to 3 years at least), 3) use household products that do not contain phosphorus (e.g., TSP), 4) develop ordinances that incorporate criteria for protecting groundwater and lake water quality, and 4) seriously consider a common wastewater treatment facility that will eliminate the possibility of phosphorus and nitrogen in sewage from reaching Higgins Lake now or in the future.

One of the most difficult challenges in circumstances like this is to persuade individuals to act when there is no perceived crisis. Those that have been long-time residents at Higgins Lake may acknowledge that the lake has changed, but it is easy to look at Higgins Lake and conclude that there is no "crisis". But controlling phosphorus loading to the lake should be the first priority. Waiting until there are regular cyanobacteria blooms or until some other obvious crisis arises will simply be too late.