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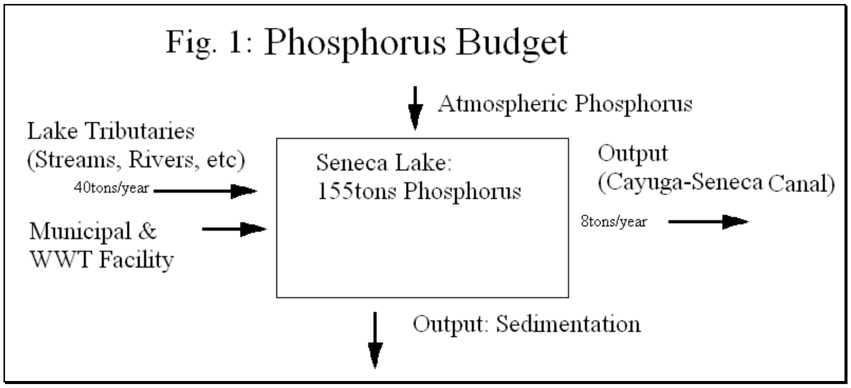
Active Phosphate Sequestration in the Seneca Lake Watershed

Seneca Lake, along with its neighboring Finger Lakes is suffering from nutrient loading as a result of the large percentage of agricultural land in each lakes watershed. With 39% of the Seneca Lake watershed classified as agricultural land [1], a significant percentage of the phosphate and nitrate loading into the lake can be attributed to agricultural practices. Nutrient loading is primarily the result of the use of high phosphate fertilizers during and before rain events, this practice results in runoff and phosphate loading in nearby streams and rivers that eventually drain into Seneca Lake. Numerous active and passive regulatory practices called Best Management Practices have been shown to positively affect the phosphate loading in nearby Conesus Lake and many are applicable to Seneca. However; BPMs, despite their effectiveness, are generally cost prohibitive, this paper aims to suggest alternative systems which can effectively reduce phosphate levels in Seneca Lake tributaries. These alternative schemes, in conjunctive with the implementation of agricultural BMPs can positively affect the phosphate budget of Seneca Lake, resulting in generally improved water quality, as indicated by a reduction of plant and algal biomass in the lake.

Nutrient loading in Seneca Lake

Like most freshwater bodies Seneca Lake is phosphate limited; this refers to phosphate as being in low concentrations relative to other essential components for algal and macrophyte growth, carbon and nitrogen. In a phosphate limited system the maximum amount of potential biomass in the lake is limited to the amount that would completely consume the available phosphate preventing additional productivity. For most algae these components are consumed in specific ratios. The C:N:P ratio for most algae is approximately 47:7.2:1 [2]. Although reducing the amount of carbon, nitrogen, or phosphate availability in a water body would effectively decrease turbidity and improve water quality, it is more effective to target which even nutrient is limiting in the specific water body.

Fig. 1: Phosphorus Budget



Approximate phosphate fluxes into and out of Seneca Lake [3]

Evaluating the phosphorus budget for a water body is a powerful tool in understanding the condition of a lake, and determining whether it experiencing nutrient loading. In the case of Seneca, the inflow of phosphates from streams, rivers, municipal waste water, and the atmosphere are greater than the combined outflows of phosphate, through the canal and deposition into the sediment on the lake bottom. Although values of inflow and outflow of phosphate from the town water system, and the atmosphere and into the sediment are not given, they are generally perceived to be small compared to the total phosphorus influx into the lake. Because inflow is greater than combined outflow the total phosphate concentration of Seneca is assumed to be increasing, this assumption is confirmed from annual averages of measured phosphate concentrations in the lake.

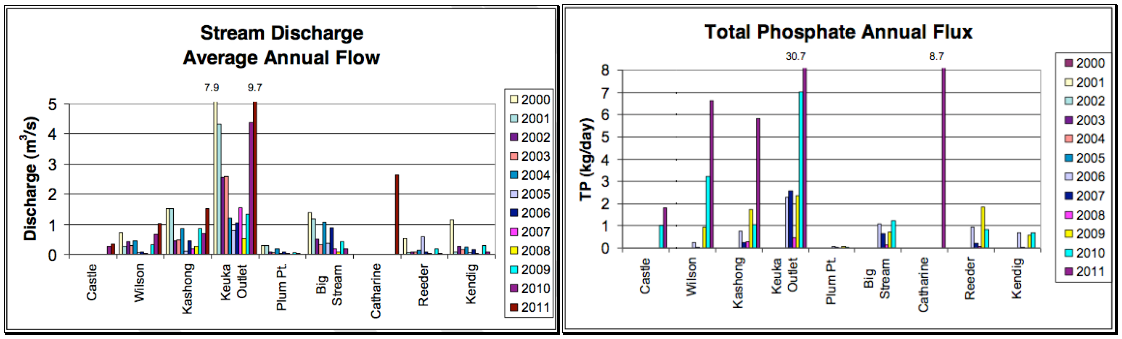


Fig 2: Average Annual flow of Seneca Lake tributaries, and
Average daily phosphate flux [5]

The average daily phosphate flux into Seneca from individual streams is below 2kg/day, however several tributaries have been shown to have significantly higher phosphate flux, for example Keuka Outlet and Catharine Creek had an annual average phosphate flux of

30.7kg/day and 8.7kg/day respectively during 2011[4]. The relatively high phosphate fluxes associated with Catherine Creek and the Keuka Outlet can be attributed primarily to two factors, the relative drainage size of each creek, and the large percentage of agricultural land within each sub-watershed. The Keuka Outlet drains the largest portion of the Seneca watershed into Seneca Lake; the Keuka sub-watershed includes the Keuka Lake watershed.

Effects of Nutrient Loading on Water Quality

It is sometime difficult to define the goals of a watershed management plan, to say that the goal is to improve the water quality is vague and insufficient do direct future efforts. The Seneca watershed is relatively free of heavy metal contaminants, and there are low levels of chemical pollutants when compared to other water bodies such as nearby Onondaga Lake. Therefore one could say the water quality in Seneca is higher than that of other Finger Lakes, this may be true, but chemical pollutants are not the only consideration when comparing water quality. Turbidity or clarity is the most apparent indicator of water quality. Turbidity is a result of suspended particulate matter in the water and is reflected by the apparent clarity of the water. The particulate matter is most often comprised of suspended solids, such a mineral or organic particulate or living organic matter such as phytoplankton and algae. Turbidity resulting from nutrient and silica loading of a lake often reflect the potential biological productivity of the lake and in many cases is preferable to having a more oligotrophic (nutrient deficient) water body. Clearer water then contains less nutrient and suspended material and is less capable of supporting large populations of macrophytes and aquatic organisms such as algae.

Seneca Lake is currently in an oligotrophic state, however increased phosphate loading into the lake, and regular cyclic changes in the lake’s nutrient profile can, and have historically pushed Seneca to a more productive state, high productivity increases water turbidity or conversely decreased water clarity. There exists data for the past 20 years reflecting water clarity in Seneca, in the form of measured secchi disk depths, where low values indicate increasing turbidity over the last 14 years.

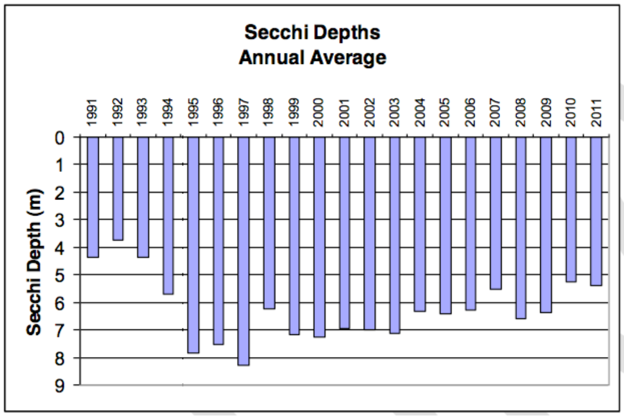


Fig. 3: Secchi Disk Depths indicating water clarity (turbidity)
low values indicate lower clarity [6]

Secchi depths are a reflection of water clarity, and directly related to the amount of suspended particulate and algae in the water column at the site being measured. Because clear water is generally more aesthetically appealing, and considered to be of higher quality than turbid water, it is generally the goal of watershed management schemes to improve water clarity, as would be reflected in increased secchi disk depths. Figure 3 shows a gradual decrease in water clarity over the last 14 years, this could be an indication that Seneca is moving into a more turbid period of increased productivity and decreased water clarity. The *Seneca Lake Watershed Management Plan* sites the recent increase in lake turbidity as being a result of the recent die off of the zebra mussel population in the lake. This introduced a large amount of previously sequester nutrients back into the water, and eliminated the largest mechanism through which nutrients had been previously removed from the water column. Whatever the cause, of increasing turbidity over the last 14 years, nutrient loading remains the primary source of additional phosphate into the lake, and provides enough nutrients through surface runoff to sustain large populations of algae and macrophytes within the lake.

Algae and water clarity are not the only indicators of nutrient loading, the abundance of aquatic plants in the lake littoral (depths below 30 feet or so) also indicate both the extent of nutrient loading, and the sites of highest phosphate flux into the water body. The recent increase in macrophyte growth, dominated by the exotic Eurasian water milfoil (Myriophyllum spicatum), has become a hot topic for local residents who have perceived an increased prevalence in milfoil growth throughout the lake littoral. The recent spike in macrophyte growth corresponded to the introduction of zebra mussels in the 1990's and the resulting increased water clarity [7]. This indicates that the growth of macrophytes such as milfoil is light limited as opposed to phosphate limited and therefore more dependent on water clarity and depth of macrophyte beds. Despite this it has been demonstrated in nearby Conesus Lake that the enactment of agricultural best management practices (BMPs) aimed at reducing nutrient loading into the lake, have at least marginally helped to reduce macrophyte population density and coverage in the areas where sub-watersheds have implemented BMPs.

Best Management Practices (BMPs)

Best Management Practices within the Conesus Lake watershed were focused primarily on dairy and row crop farms. The practices were intended to prevent erosion of surface soil, retain nitrate, organic nitrogen, and phosphorus. This was accomplished through structural BMPs such as constructing terraces, vegetation buffer strips, and sediment control basins. In comparison nonstructural (cultural) BMPs involved modification to practices intended to minimize site disturbance through planning and design, activities such as mandated regular soil testing, limited fertilizer application, and new tillage and crop sequencing practices [8]. A study of the effectiveness of BMPs in the Conesus Lake watershed found reductions in nutrient and sediment loading in many tributaries draining sub-watersheds in which BMPs had been implemented. The study also found the practices to have had an effect on lake macrophytes, and microbial communities in the lake littoral areas adjacent to tributaries draining into Conesus Lake. Although BMPs have been shown to be moderately effective at reducing nutrient and sedimentation of sub-watershed streams and Conesus Lake itself, they have yet to be implemented on a substantial enough scale to make a real difference in large watersheds comprised of a significant percentage of agricultural land. The primary reason for this has been the costs associated with implementing BMPs on a large scale. Structural BMPs can cost a significant amount to implement, and a continual cost to maintain. For row crop farmers, constructing BMPs such as vegetation buffer strips and sediment control basins requires valuable agricultural space that would otherwise be used for farming and accordingly results in a decrease in the farmable area of a given property. Nonstructural BMPs may be easier to mandate, but changing practices can be equally costly.

Active Phosphate Sequestration

It is apparent now that BMPs alone may not be sufficient to drastically improve or even maintain the water quality in Seneca Lake, however there maybe secondary ways to remove phosphorus from the tributaries of Seneca, preventing it from entering the lake. Ideally which ever process that removes phosphorus would also produce a useable byproduct. There are numerous systems that can actively remove phosphorus from water while stimulating growth of biomass that can be dried and burned, processed into diesel, converted into methane through decomposition, used for livestock feed, or as a natural fertilizer. One such system is the Algae Photo-Bioreactor, which uses large amounts of water to grow highly productive algae in an environment that allows the algae to grow more quickly than in open water. Bioreactors are currently being used to remove flume gases from fossil fuel burning power plants, the NO_2 and CO_2 laden gas from the power plant furnace is pumped through closed system of water filled tubes, within the tubes algae sequester the carbon and nitrogen and release clean oxygen. Algae consumes carbon, nitrogen, and phosphorus in the same C:N:P ratio cited above. In the case of using the bioreactor to scrub clean nitrogen and carbon from air, phosphorus would be added in abundance to ensure enough algae can be grown to effectively sequester the gaseous pollutants. In trying to remove phosphorus, nitrogen and carbon would need to be added (from the atmosphere) in substantial quantities so as to make phosphate the limiting component of the algae growth cycle. Algae consume nutrients in an approximate C:N:P mass ratio of 47:7.2:1 resulting in an approximate 55kg of algae biomass for every kilogram of phosphate consumed. Assuming such a system could be implemented along the Keuka Outlet, and was able to handle the large flow volume of the outlet, the bioreactor would effectively produce 1600kg of dry algae biomass per day of operation. It is however somewhat unrealistic to expect any bioreactor to handle the high discharge flow rate of Keuka Outlet, which can reach nearly $10m^3$/second. So instead only a small percentage of the total flow would be diverted to the bioreactor. Commercially available bioreactors for installation at power plants and waste water treatment facilities could be modified for the application of phosphate sequestration in freshwater tributaries. Several companies have units of various dimensions and capacities from $3.8m^2$ to $140m^2$ [9], and the design of most closed tubular units allow for the expansion necessary to increase water handling capacity and algae production. Although most bioreactors use specialized strands of algae to ensure maximum productivity for a given application, use of indigenous algae varieties would negate the potential ecological risks if foreign algae were to enter the Seneca Lake watershed.

Fig. 4: Example of a closed tubular bioreactor
and an open "pond" bioreactor [10]

Shown above are a picture of a small ~$4m^3$ capacity, commercially available, tubular bioreactor and an example of an open "pond" style bioreactor. Each unit has its own advantages and disadvantages. The tubular style bioreactor comes as a complete unit from the manufacture and has control and automation systems integrated to enable easy emptying and harvesting of algae, the tubular system can also easily be used indoors as would most likely be the case for a unit to be installed in Upstate New York. The open pond reactor is a much more simple design. The pond bioreactor only requires the construction of a shallow manmade pond, and the instillation of a mechanism for circulating the water within the system. The advantage of the pond style bioreactor is its lower cost and greater volume handling potential. The algae produced in bioreactors can be used for any number of applications, perhaps the most pertinent to the Finger Lakes region is as livestock feed. However the algae can be used as a biofuel through any different processing mechanisms. Dry algae can be turned into biodiesel, methane, or can be pelletized and burned in wood furnaces.

Although the true costs of implementing algae bioreactors capable of processing the volumes of water necessary to notably impact the phosphate levels in Seneca Lake have yet to be fully determined, this serves as a clear indicator of potential alternative watershed management schemes capable of improving the water quality in Seneca Lake. Unlike BMPs the use of active phosphate sequestration can produce a crop of algae for use in any number of applications, and may eventually be able to produce a return on the initial investment in technology and hardware for the water handling systems. A significant amount of research is still needed to ascertain the viability of algae based water treatment systems for controlling nutrient loading, however the availability of bioreactors for installation at municipal waste water treatment facilities provides and excellent starting point. Although the Geneva W.W.T. facility doesn't represent a significant source of phosphate loading into Seneca Lake, the application of bioreactor technology could effectively eliminate the nutrients that do make it into the lake from the WWT center while also producing algae to sell to local farmers or generate electricity onsite. Eventually it may be shown to be economically feasible to implement this technology on known sites of nutrient loading into Seneca, such as Reeder Creek, Catherine Creek, or the Keuka Outlet and effectively reduce the amount of phosphate loading into Seneca Lake attributed to these tributaries.

Sources

[1] 39% ag land in watershed
[2] CNP ratio
[3] Phosphate budget values
[4] phosphate flux from page 103
[5] phosphate flux and discharge graphs pg 104
[6] Secchi Disk depths (Halfman, 2012) pg 84
[7] Zebra mussles improve growing conditions for milfoil pg 93
[8] BMP definition page 24 The impact of agricultural best management practices on downstream systems: Soil loss and nutrient chemistry and flux to Conesus Lake, New York, USA
[9] AlgaeLink Systems http://www.algaelink.com/joomla/index.php?option=com_content&view=article&id=5&Itemid=7
[10] http://hrc.unlv.edu/renewable/biofuels/rd_Photobioreactor.html