Highland Lake Summary

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The following is a brief summary of the water quality history (1974 to 2016) of Highland Lake and of some of the efforts that have been taken to protect and improve that water quality. First there is a brief overview of the process of eutrophication. Next, a timeline is used to chronologically track relevant conditions and events. This is followed by discussions of the progression of water quality conditions in the lake and of the Total Maximum Daily Load Report (TMDL) that was completed in 2003.

Overview of Lake Eutrophication

Biological productivity refers to an ecosystem's ability to support life. The term ***eutrophication*** refers to the progression of a biological system from a lower level of productivity to a higher level of productivity, or, from a lower trophic state to a higher trophic state. Lakes with low levels of productivity are referred to as ***oligotrophic***, and lakes with high levels, ***eutrophic***.

The Statutory Water Classification for Maine lakes, ***Class GPA***, requires a stable or decreasing (improving) trophic state in lakes, and that lakes be free of culturally induced algal blooms that impair their use and enjoyment. In most instances the underlying reason for eutrophication of a system is an increase in the supply of essential nutrients to the system. In Maine lakes, the amount of phosphorus in the lake controls the amount of plant, particularly algae, production in the lake; the algae, as the primary food source in the system, control the amount of zooplankton and fish the system can support. Maine DEP considers late summer as ***baseline*** with respect to monitoring lakes for trophic stress.

The phytoplankton community in lakes changes with the seasons, a phenomenon referred to a as ***seasonal succession***. In the spring after ice out phosphorus, silica and other nutrients are mixed into the water column from the bottom. The combination of these nutrients, particularly dissolved silica, and increasing light in the period around the solstice, result in abundant growth of ***diatoms***, a type of algae where the cells

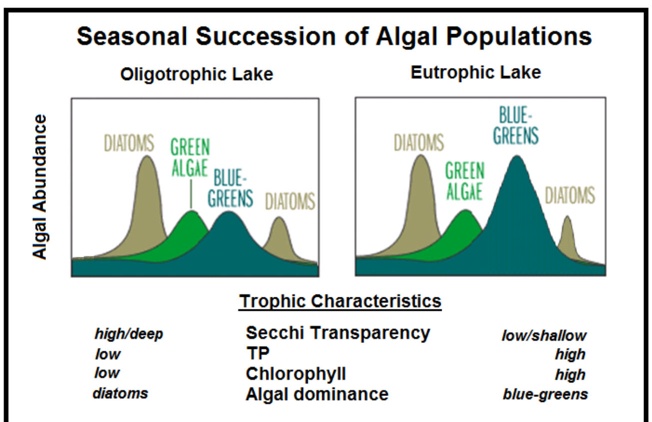


Figure 1. Differences between seasonal algal succession in oligotrophic and eutrophic lakes including trophic characteristics.

are covered with silica (glass) cases. The diatoms "***bloom***" until they run out of silica, and when they die or crash, they strip the water of some phosphorus. In low productivity and moderate productivity lakes, the spring and early summer diatom bloom is the most productive time of the year – the time when algal densities and nutrients are highest and Secchi transparencies lowest. This is followed by a summer with low productivity and high transparencies. As lakes eutrophy, mechanisms come into play that return phosphorus to the water column after the diatom crash, and the level of algal production in the summer equals or exceeds that of the spring diatom bloom. Figure 1 illustrates the differences in algal succession and trophic characteristics.

Timeline

- 1974 to 76. DEP/USGS study established baseline trophic quality (level of algal production). Mean annual Secchi Disc Transparency (SDT) ranged from 5.7 m to 6.6 m, mean annual Total Phosphorus (TP) ranged from 7.2 ppb to 9.8 ppb.

- 1974 to 1986. Trophic parameters remain relatively stable, with mean SDT generally in the 6.5m to 7.0 m range. Limited Temperature and Dissolved Oxygen (DO) profiles show late summer oxygen depletion in the water below the bottom of the warm, well mixed surface layer (epilimnion). During these years, the highest algal production (lowest SDT and highest TP) occurred in the spring due to diatom blooms (an algal species that takes advantage of cool weather and silica recirculating during overturn). This phenomenon is typical of low productivity (oligotrophic) lakes. Highly productivite (eutrophic) lakes generally support cyanobacteria blooms (also known as blue-green algae) during mid to late summer as illustrated in Figure 1.

- 1987 to 1989. Over this three year period, mean SDT drops to a low of 4.0 m in 1989. Unfortunately, there was little to no TP data obtained during this period. It is likely that the increase in trophic level was at least in part a response to the high level of growth in residential development in the watershed during the 1980s.

- 1990. Highland Lake was listed as impaired in the 1990 Integrated Water Quality Report to EPA because of the late summer DO depletion. The reason for the impairment was later changed to include documented trend of increasing trophic state (i.e. increasing levels of algal production) based on the long term trend of decreasing transparency.

- 1990 to 1993. Mean SDT rebounded quickly from the low in 1989 and peaked in 1993 with mean SDT similar to the mid-70s, and highlighted by a maximum 10 m SDT in July.

- 1994 to 2010. Average SDT dropped from the 1993 high to establish a new equilibrium condition at approximately 5.0 m, just above the state average. Mean TP appears to be stable around 10 ppb. The new equilibrium trophic condition is notably higher (more algae, lower SDT, higher TP) than in the baseline period in the 1970s and early 1980s and is characterized by generally more intense and quite severe depletion of deep water DO which starts earlier in the summer season. During most of this period, the highest algal production (lowest SDT and highest TP) continued to occur in the spring or fall, not in the summer, a condition typical of both low (oligotrophic) and moderate (mesotrophic) productivity lakes.

- 1997. Cumberland County SWCD working with Highland Lake Association volunteers performed a watershed survey which identified 104 erosion sites (phosphorus sources).

- 1999. Cumberland County SWCD incorporated the watershed survey into the Highland Lake Watershed Management Plan.

- 1999 to 2002. Cumberland County SWCD received and executed a DEP/EPA Nonpoint Source grant (Highland Lake, Phase 1) to install BMPs on both residential and road sites. The Highland Lake Youth Conservation Corps was established under this grant and installed BMPs on 88 sites from 2000 to 2002.

- 2003. DEP completed a required Total Maximum Daily Load Report (TMDL).

- 2004 to 2008. Cumberland County SWCD received and executed a DEP/EPA Nonpoint Source grant (Highland Lake, Phase 2) which addressed export of eroded sediment and phosphorus at 100 residential and road sites.

- 2005. Cumberland County completed an update of the Watershed Management Plan that incorporated all of the required elements of an EPA Watershed Based Plan and identified many new and/or additional sites that needed to be addressed in the watershed.

- 2008 to 2010. Cumberland County SWCD received and executed a DEP/EPA Nonpoint Source grant (Highland Lake, Phase 3) to implement BMPs on many of the sites identified in the updated Management Plan.

- 2010. DEP removed Highland Lake from the list of impaired waters because it had maintained a stable trophic state for more than 10 years, and thus met the statutory water quality criteria of having a stable or decreasing trophic state.

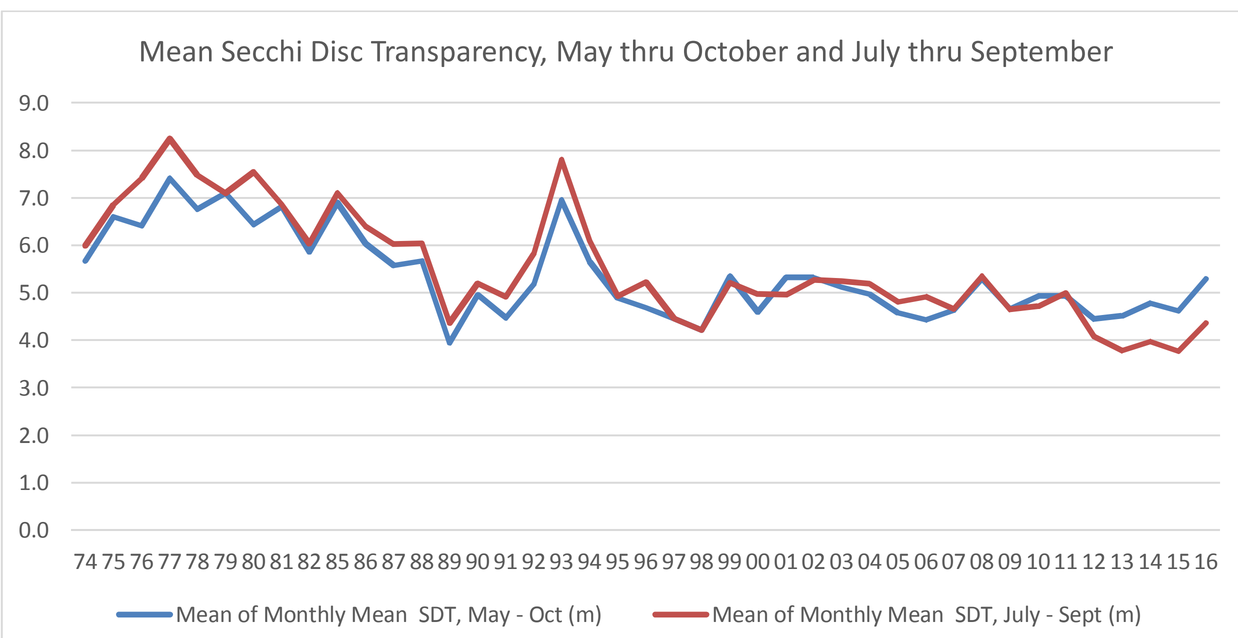
- 2007 to 2017. The seasonal timing of algal production shifted first to a condition where productivity appears relatively even throughout the seasons, then to a condition where the most productive period is during the summer months. This latter condition is typical of higher productivity (eutrophic) lakes. During the latter half of this period mean TP rose, reaching 12 ppb in some years.

- 2014 to 2017. Highland Lake develops short term blue green algal blooms that result in SDTs of less than 2.0 m. Based on microscopic analysis at UNH, the blooming alga in at least one of these years is a type of blue green algae that is very small (1.0 to 2.0 microns, referred to a picoplankton) and is mostly solitary cells dispersed throughout the water (as opposed to more typical blue green bloomers that are larger and colonial). The blooms consistently start in the 3rd or 4th week in July and end in 1st or 2nd week in August. They are bracketed by SDTs of 4 m or more. Given the consistency of the timing, appearance and duration of the blooms it is likely all four years were picoplankton blooms.

Understanding the progression of trophic state in Highland Lake

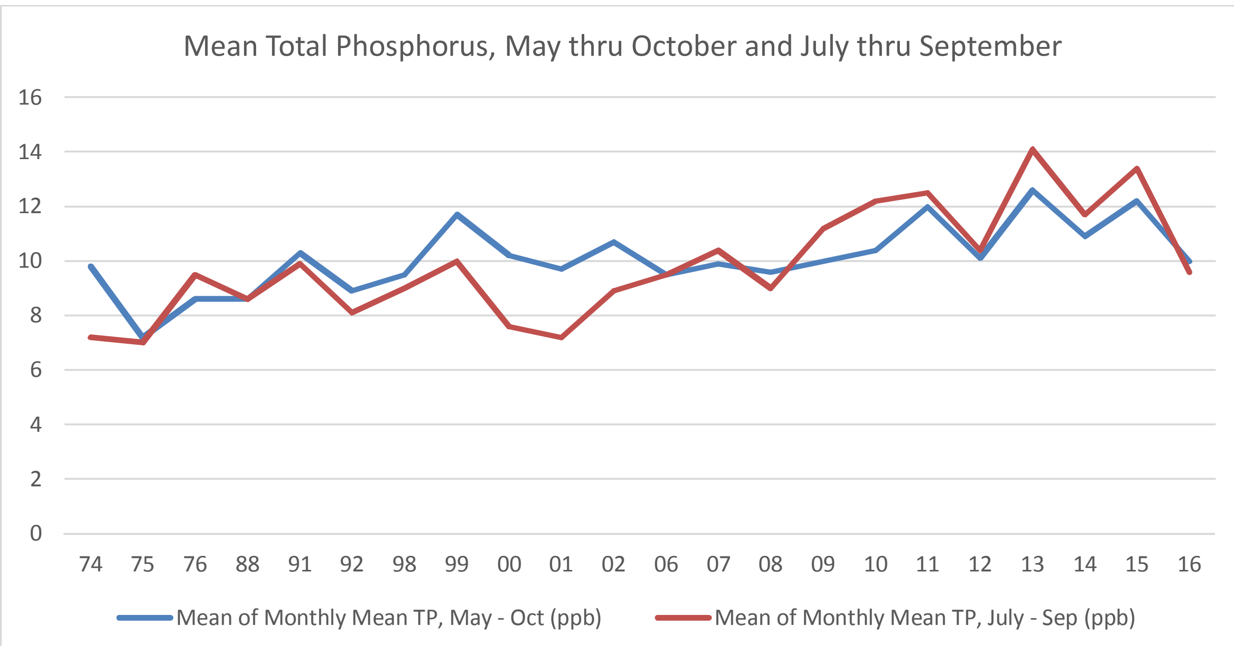
As can be seen in Figures 2 and 3 and in the timeline above, Highland Lake appears to have undergone significant eutrophication since 1974 when data was first collected on the lake. Some lakes have a natural trophic cycle that alternates between lower and higher states, but in this case, watershed development likely played and will continue to override any natural cycling. Secchi Disc Transparency is a strong, though indirect, measure of the amount of algae

Figure 2. Mean of Monthly Mean SDT in meters from 1974 to 2016.



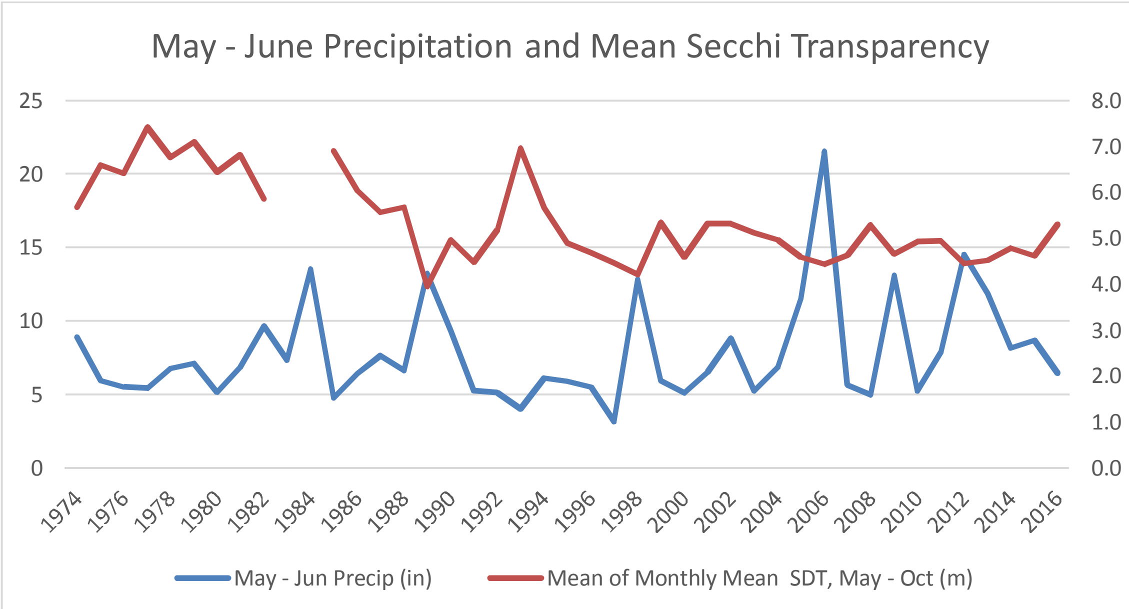
suspended in the water, called phytoplankton. The more transparent the water column, the less algae present in the lake. Figure 2 shows how average transparency has dropped over the period of record, from around 6.5 to 7 m down to less than 5 m. Figure 3 illustrates average phosphorus concentrations in the lake over the same period. The phosphorus record is less continuous than the Secchi record, but it is still a strong data set which shows the progression of average total phosphorus concentrations from around 8 ppb in the mid-1970s to 10 ppb or more in recent years.

Figure 3. Mean of Monthly Mean TP in ppb from 1974 to 2016 for years with data.



As is frequently the case with eutrophying lakes, the change is not smooth and continuous. Highland Lake appears to have moved from a relatively stable low trophic state in the 1970s and early 1980s through a period of transitions with a low in 1989 and a high in 1993 to settle into a new, stable condition from the mid-1990s to 2007. This is followed by a period of increasing trophic state culminating in what is assumed to be picoplankton blooms in 2014 through 2017. Some, though certainly not all, of the variations in this progression of trophic change can be explained by weather. Figure 4 plots average SDT against amount of precipitation in May and June for each year. Years with high rain in the spring are likely to provide more phosphorus to the system at a time when the algae can most take advantage of it as compared to years that have relatively dry springs. Thus, some of the relatively more productive (lower transparency) years align with higher precipitation and vice-versa.

Figure 4. Late Spring Precipitation and Mean SDT.



The change in seasonal succession is evident in the Highland Lake data set. In Figure 2, the blue line represents the average Secchi transparency for the period of May through October in each year. The red line represents the average for July through September. When the red line is above the blue line it indicates that the clearest water with the least algae is occurring during the summer months. When the blue line is on top the cloudiest water with the most algae is occurring during the summer. In the relatively stable period in the 1970s and early 1980's, the difference between the lines is large (in 1979 and 1981 there were no spring readings), with the clearest water in the summer time. As the lake transitions to the stable, but more productive period between 1995 and 2007, the clearest water is still generally in the summer, but the difference is much less. From 2008 to 2011 there is virtually no difference between the average summer transparencies and the spring and fall transparencies. After 2011, the summer becomes the least clear and most productive period, a seasonal succession pattern typical of high productivity lakes. In Figure 3, the phosphorus data suggests the same transition, with summer TP concentrations being lowest in the summer during the early years and highest during the summer in the recent years.

<u>The TMDL</u>

As mentioned in the Timeline, DEP completed a required Total Maximum Daily Load Report (TMDL) on Highland Lake in 2003. The purpose of the report was to determine (1) the phosphorus load that would result in the target in-lake phosphorus condition of 10 ppb and (2) the reduction in current load necessary to achieve and maintain that target concentration. The target lake concentration of 10 ppb was selected because the lake's phosphorus concentration over the previous decade had been stable at about 10 ppb (mean of 10.1 ppb) and the goal of the TMDL was to maintain this stable trophic condition.

Unfortunately, the TMDL misrepresented the situation. The report used a lake response model to estimate the target load, but a different model, a land use classification and coefficient model, to estimate the current load to the lake. Both of these models have substantial potential error associated with them, particularly the land use based model. Because the land-based model estimated the current load at 441 kg/yr, 53% higher the lake response model's estimate of the target load, the resulting TMDL indicated that in order to meet the target concentration of 10 ppb the load to the lake would have to be reduced by approximately 30%, despite the fact that the lake was already at the target concentration. Subsequent lake TMDLs on other lakes addressed this problem by using the same model to define the target load and the current load.

A more appropriate TMDL would have recognized that the current load as virtually equivalent to the target load, but, given expected growth in the watershed and associated increases in phosphorus loading to the lake, applied a reasonable margin of safety (a standard part of TMDL calculations) to make room for expected increases in load and recommended actions to lower the current phosphorus load to the lake. The Phosphorus Control Action Plan associated with the 2003 TMDL and the ensuing 2005 updated Watershed Based Plan do just that.

Final Thoughts

With the exception of data collected in 1974 through 1976, the great majority of the Secchi transparency and phosphorus data presented in this summary was collected by the Highland Lake volunteer monitors, particularly Ralph Johnston and Keith Williams. The relatively simple analysis presented here could be enhanced by the addition of some other data sets, particularly chlorophyll, and by a more in depth statistical evaluation, but, given recent events in the town and the watershed, it was deemed better to do a quick analysis with the data that was most available and get the information out where interested parties could use it. Our understanding of the nature of the picoplankton bloom is particularly weak, both in terms of its characterization and of the underlying factors which control it. More study on this front is needed in order to plot the best path forward for Highland Lake.