Lake Churchill Water Quality Sampling 2014
Germantown, Montgomery County, Maryland

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Project Introduction

Princeton Hydro completed another late summer water quality sampling event on August 28, 2014, the seventh such annual event and the third consecutive year in a row. These events have been conducted near the end of the growing season, a critical period when water quality tends to be at its lowest due primarily to high rates of biological activity, particularly algae growth. This type of single-event monitoring program, when conducted over a long period, is valuable in tracking changes to lake ecology and by focusing on the most critical time of year allows for the identification of the most pressing issues in the lake. It also allows for evaluation of the management activities undertaken at the lake or the watershed.

The same general water quality impairments have been identified during each monitoring event, chiefly high algae density, poor clarity, and high coloration, all of which are readily observable and apparent to lake users. A hidden, but measurable issue is the strong thermal stratification of the lake, a natural phenomenon in which the lake is vertically divided into zones of decreasing water temperature. Thermal stratification in this lake is driven by the shape of the basin, with relatively high depths relative to surface area, and landscape position, with the lake nestled in its valley, both of which decrease wind-driven mixing. Because the lake does not mix, it becomes anoxic at depth, or devoid of dissolved oxygen critical for maintaining the fishery, thus resulting in a very great loss of usable fish habitat. It also leads to other changes in water chemistry in the anoxic portions, particularly the storage of extremely high and toxic concentrations of ammonia as well as internal nutrient loading of phosphorus released from the sediments. Fortunately, the stratification appears quite stable and both the high nutrient levels, which could cause major algae blooms if released into the photic zone or shallow areas of algae/plant growth, and toxic ammonia are sequestered probably until late in the fall or even the winter when these releases are of considerably less concern.

2013 in many respects represented the highest water quality seen to date, particularly in the improved Secchi clarity and decreased algal biomass and nutrient concentrations. This was attributed partly to improvements within the watershed, particularly efforts to help stabilize the incoming tributaries and general stormwater management, and seasonal climatic factors, particularly increased and regular rainfall, which would alter lake flushing dynamics. Despite these improvements, the lake would still be considered eutrophic, or highly biologically productive, and characterized again by high nutrient concentrations and excessive algae and/or plant growth. In addition, it still demonstrated its usual thermal stratification and anoxia. The most troubling development in 2013 was the identification of the invasive plant Hydrilla, which was apparently previously identified and managed for in the lake. While only a few fragments of this plant were found, the reemergence was thought to be partially a product of increased clarity in the lake.

2014 was marked by decreased water quality and in effect a return to more typical conditions with lower Secchi depths and increased algae density, as well as the continuing long-term problems with stratification, anoxia, and ammonia and phosphorus buildup in the deep hypolimnion. Together these factors continue to characterize the lake as eutrophic. Part of this deterioration is likely a result of different seasonal climate patterns, particularly the very dry growing season of 2014. However, 2014 was also cooler than typical and this too is reflected in the in-situ water quality data and subtly altered patterns of thermal stratification. While there was a decline, as stated above, the measured water quality seemed to represent what could be thought of as average conditions, rather than a truly precipitous decline in water quality. The biggest issue of concern relative to past years was the major expansion of Hydrilla, which was found rooted in the eastern cove occupying an area of up to an acre, although the distribution was patchy. This occurred despite a reduction in Secchi clarity, although there are mitigating circumstances which explain the observed conditions to be discussed in detail below. Overall, the list of recommendations is mostly unchanged, but the urgency to deal with Hydrilla in the lake has increased significantly and action on this front is strongly encouraged.

The scope of services conducted in 2014 is similar to those of past efforts and identical to that of 2013 and consists of four distinct sampling services:

- In-situ water quality monitoring conducted with a water quality meter
- Discrete water quality sampling for laboratory analysis
- Plankton sampling
- Aquatic plant survey

All sampling was conducted at the previously established sampling stations. This type of station fidelity allows direct comparisons from year to year at specific sites, as well providing good spatial coverage of the lake and its two major tributaries. Station locations are listed below and mapped in Appendix I.

- East End of Lake
- South Cove
- Mid-Lake
- Spillway/Dam
- East Tributary
- South Tributary

In-Situ Water Quality Monitoring

In-situ water quality monitoring was conducted at each of the six stations in profile from the surface to the bottom in 1.0 meter intervals (3.3 ft). In-situ measurements were made with a calibrated multi-probe water quality meter. Calibration procedures followed manufacturer's guidance.

Temperature

Temperature is a critical water quality parameter and affects lake ecology in two significant ways. Temperature is very important in regulating the rate of chemical reactions and biological productivity, manifested primarily in increased growth of algae and plants with increasing temperature. A second important phenomenon related to temperature is thermal stratification. Thermal stratification occurs when the lake becomes vertically layered, with warmer water overlying cooler waters at depth; this is associated with changes in density which increases with decreasing temperature. When this occurs, these layers resist intermixing. Essentially, this cuts off the contact of the deep waters or hypolimnion with the atmosphere which is important in the exchange of gases, particularly oxygen. As such, the hypolimnion can become hypoxic or anoxic, an extreme depletion of dissolved oxygen caused by microbes consuming organic detritus (such as dead algae cells) at the sediment interface. This results in two specific impairments. First, most lake organisms, especially fish and zooplankton, cannot survive in hypoxic environments which results in a large loss of usable lake volume and important refuge habitat. The second, and perhaps more important impact, is that anoxia causes changes in water and sediment chemistry which results in internal nutrient loading of phosphorus and accumulation of certain compounds, such as ammonia, which normally oxidize to other compounds or are assimilated by autotrophs. When thermal stratification breaks down, this can cause a huge nutrient pulse which may spur tremendous algae blooms or release potentially toxic compounds such as ammonia. Fortunately, the lake seems to be quite stably stratified and the mixing, likely to occur in late autumn, probably occurs at a period when release of these compounds is mitigated by cold temperatures.

Surface temperatures were approximately 27°C (81°F) in the lake fairly typical of measured temperatures to date. As always, the tributaries were much cooler, below 70°F, because they are primarily discharging cool groundwater and flowing through a forested corridor. These temperatures were sufficiently high to promote a high degree of algae growth. As always, these temperatures indicate that the lake only supports a warmwater fishery, often characterized by Largemouth Bass and various sunfish species.

The lake, as usual, was highly thermally stratified. One interesting aspect of the temperature profile (Figure 1) is that from 3.0 m down to about 6.0 m, temperatures were significantly lower than previous temperature profiles. While this probably had no significant impact on water quality metrics at those depths, it is probably reflective of cooler summer temperatures on average and might indicate slightly lower levels of seasonal productivity, despite the surface measurements represented by the single “snapshot” water quality event. It may also indicate that stratification was achieved somewhat earlier in the spring, thus persisting longer.

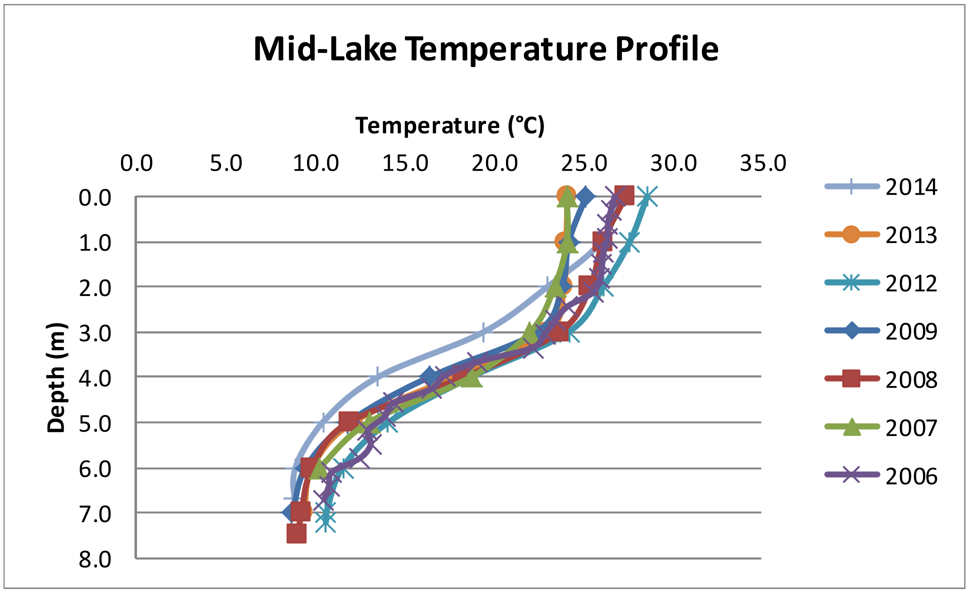


Figure 1: Multi-Year Temperature Profiles

Dissolved Oxygen

Dissolved oxygen plays an important role in many lake processes, as touched upon in the temperature section. In these types of studies it is primarily an indicator of biological productivity or the relative rate of the production of algal and plant biomass. High dissolved oxygen (DO) concentrations are reflective of high productivity, as oxygen is a by-product of photosynthesis, the process of fixing carbohydrates in all plants and algae, and thus is related to the quantity of biomass in the system. Very low DO concentrations can also be an indication of the same high levels of production, as all this biomass is also consumed by microbes which deplete oxygen during respiration or decomposition of the matter. DO can be very dynamic. On a spatial scale, there is often great variation from surface to bottom, driven by high levels of photosynthesis near the top and microbial decomposition on the bottom. On a temporal scale there can be dramatic changes in concentration from day to night. This diel cycling is driven by photosynthesis during the day and respiration at night. Respiring organisms include not only microbes but also by the plants and algae which also consume oxygen rather than produce it when it is dark and photosynthesis, a light dependent reaction, is halted. Furthermore, there can be wide seasonal shifts related to high levels of production during the growing season relative to the winter. Seasonal trends can be somewhat muted by temperature effects on DO concentrations. DO is found at a greater concentration in cooler water and at lower concentration in warm water (in the absence of biological processes). This is why DO level is often expressed as a percent concentration, which describes the concentration of DO at a certain temperature in water with atmospheric diffusion as the only source without biological sources (photosynthesis) or sinks (respiration).

The first measurable indication of increased algae or phytoplankton activity in 2014 was the increased surface DO concentrations ranging from 10.65 to 11.57 mg/L or 136 to 146 %

saturation. These are certainly high values by any accounting, the highest yet observed on the lake, but not unusual for a eutrophic to hypereutrophic lake system. DO % saturation hovered around 100% in the tributaries, ideal for flowing waters.

The profiles though, prove of more interest (Figure 2). As usual, because the lake was highly stratified, much of the lake is hypoxic or anoxic with hypoxia (DO < 2.0 mg/L) occurring at roughly 3.0 m and complete anoxia occurring at 4.0 m to the bottom, typical of the other years measured. One point of interest is that there is an observed spike in DO concentrations at 1.0 m at the mid-lake station and mirrored by the other in-lake stations. This is an indication of a sub-surface algae bloom. A similar occurrence can also be observed in the 2009 profile at 2.0 m, although of a lesser magnitude.

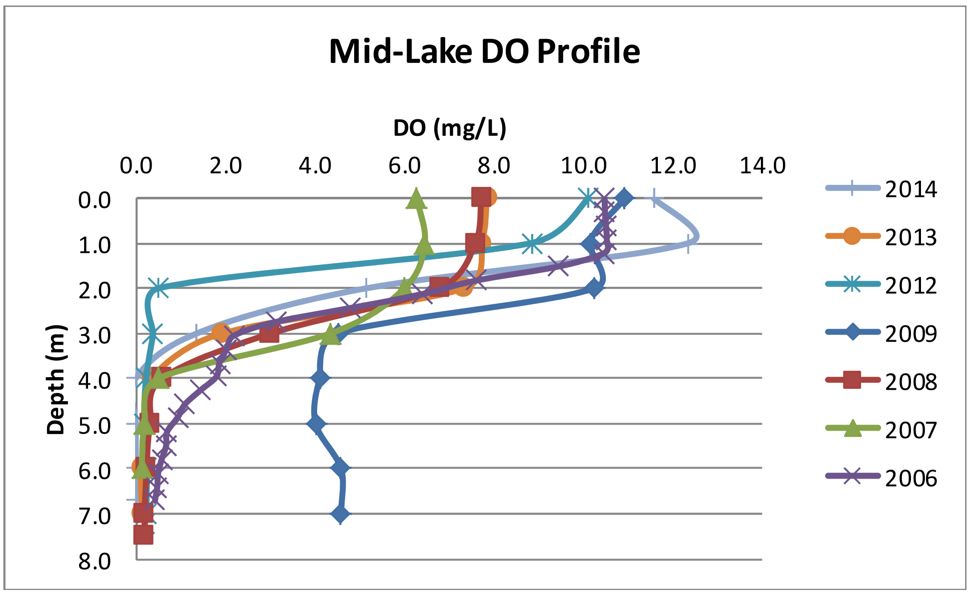


Figure 2: Multi-Year Dissolved Oxygen Profiles

Another interesting point in the DO data occurred at the eastern station. DO % saturation was quite high here, at nearly 140% at the surface; while supersaturated (DO % saturation > 100 %) conditions have been seen here before, this is the highest by a wide margin. Additionally, as with the other in-lake stations, the DO concentrations increase with depth, reflective of not only a sub-surface algae bloom, but also the quantity of rooted aquatic vegetation- mixed species but primarily Hydrilla in the vicinity.

Specific Conductance

Specific conductance is a proxy measure of dissolved solids loads in water. The primary sources of these dissolved solids are tributary influx, surface runoff, and groundwater loading although precipitation can also be an important source and hydrology can alter these values as well. A certain level of dissolved solids is necessary to support the biological function of the lake, but excessive conductance can cause shifts in biological community composition as well as indicate pollution. Conductance values averaged about 0.480 mS/cm in the surface waters, higher than previously measured, but within an acceptable range. Decreased precipitation leading to lower flushing and also the increased groundwater flow to the system is likely responsible for the increase. As usual the eastern tributary had a higher conductance than the south tributary, but both were within acceptable levels.

Specific conductance, as usual, increased with depth and reached 7.8 mS/cm at the bottom (Table 1). This is certainly a high value, but well within the range of previously measured conditions. Thermal stratification and increased exchange with groundwater increase conductance in the deeper portions of the lake. Because the lake is so strongly stratified, these high conductance waters are essentially sequestered from the biologically active portions of the lake.

Table 1: In-Situ Data

Lake Churchill, Montgomery County, MD - 8/28/2014												
Station	DEPTH		Secchi		Sample		Temperature		Conductivity	pH	Dissolved Oxygen	
	m	ft	m	ft	m	ft	(°C)	(°F)	(mS/cm)	(S.U.)	(mg/L)	%
East End of Lake	1.20	3.9	0.90	3.0	0.0	0.0	28.76	83.77	0.480	8.69	10.65	138.0
					0.5	1.6	28.05	82.49	0.478	8.84	11.64	149.0
					1.0	3.3	27.32	81.18	0.481	8.82	12.14	153.4
South Cove	2.60	8.5	1.00	3.3	0.0	0.0	27.73	81.91	0.476	8.86	10.81	137.6
					1.0	3.3	26.47	79.65	0.479	8.90	12.75	158.7
					2.0	6.6	23.56	74.41	0.548	7.33	5.87	69.3
					2.5	8.2	19.79	67.62	2.090	6.96	1.90	20.9
Mid-Lake	6.80	22.3	0.90	3.0	0.0	0.0	27.13	80.83	0.479	8.98	11.57	145.8
					1.0	3.3	26.07	78.93	0.481	8.86	12.37	155.3
					2.0	6.6	23.06	73.51	0.571	7.35	5.17	60.4
					3.0	9.8	19.49	67.08	2.600	6.79	1.37	15.0
					4.0	13.1	13.57	56.43	5.500	6.40	0.00	0.0
					5.0	16.4	10.49	50.88	6.980	6.52	0.00	0.0
					6.0	19.7	8.97	48.15	7.710	6.67	0.00	0.0
					6.7	22.0	8.90	48.02	7.790	6.78	0.00	0.0
Spillway	6.20	20.3	1.00	6.6	0.0	0.0	26.75	80.15	0.477	8.97	10.88	136.1
					1.0	3.3	26.00	78.80	0.485	8.88	12.35	152.4
					2.0	6.6	22.97	73.35	0.585	7.56	5.33	62.2
					3.0	9.8	19.79	67.62	2.090	6.94	1.90	20.9
					4.0	13.1	14.83	58.69	5.200	6.55	0.00	0.0
					5.0	16.4	10.32	50.58	6.970	6.58	0.00	0.0
					6.0	19.7	9.24	48.63	7.610	6.72	0.00	0.0
East Tributary	0.20	0.7	NA	NA	0.1	0.3	20.76	69.37	0.703	7.12	9.18	102.6
South Tributary	0.20	0.7	NA	NA	0.1	0.3	18.95	66.11	0.410	7.52	9.28	99.7

pH

pH describes the concentration of hydrogen ions in water, or more simply describes the acidity or basicity of water. pH of 7.0 is considered neutral; values greater than this are basic and values less than 7.0 are termed acidic. pH is controlled in aquatic systems by both abiotic and biotic processes. Watershed characteristics such as soils and geology are the primary determinants of pH, however this can be modified significantly by biological processes. For instance, highly productive lakes usually have higher pH values, whereas low productivity lakes or those dominated by decomposition of organic matter, such as some wetlands, may have low pH. Buffering capacity or alkalinity also influences pH and well buffered systems tend to have relatively stable pH, whereas poorly buffered systems show wide fluctuations, even within the course of a day.

pH approached 9.0 in the surface stations. This is much higher than in 2013, and among the highest pH values yet measured. This is another indicator of particularly high productivity because a consequence of photosynthetic activity is to raise pH values. In contrast to the in-lake stations, the tributaries were only slightly basic (7.1 to 7.5). This demonstrates that phytoplankton (algae) and plants increase pH in the lake relative to tributary waters by nearly 2.0 standard units.

Secchi Depth Transparency

The Secchi disk is a simple though powerful tool used to measure water transparency. Because of its simplicity and wide use a number of metrics use Secchi depth to predict or measure lake productivity. In most lakes transparency is affected primarily by inorganic suspended solids such as eroded soil particles, algae cells, and coloration. Generally, lakes with Secchi depths less than 2.0 m (6.6 ft) are considered eutrophic or highly productive. Eutrophic lakes are generally identified as having lower water quality than other lakes, especially if much of the productivity is related to anthropogenic activities and non-point source pollutant loading, as is typical of urbanized watersheds.

Secchi depth decreased to an average of 0.95 m in 2014, which represents a median of the seven year dataset. This places the lake in the eutrophic range and because TSS concentrations were so low in the tributary, the reduced clarity is almost wholly a function of algae density in the lake. The Secchi depth in the lake has long been considered a limiting factor for plant growth, thus making the lake a plankton dominated system. One of the factors contributing to the reduced Secchi clarity this year was the deeper algae bloom, specifically the density of cells at depth were effective in limiting Secchi clarity. In fact, the lake appeared less colored than usual, yet the Secchi clarity did not reflect this. A time-series chart of average Secchi depth is presented below as Figure 3.

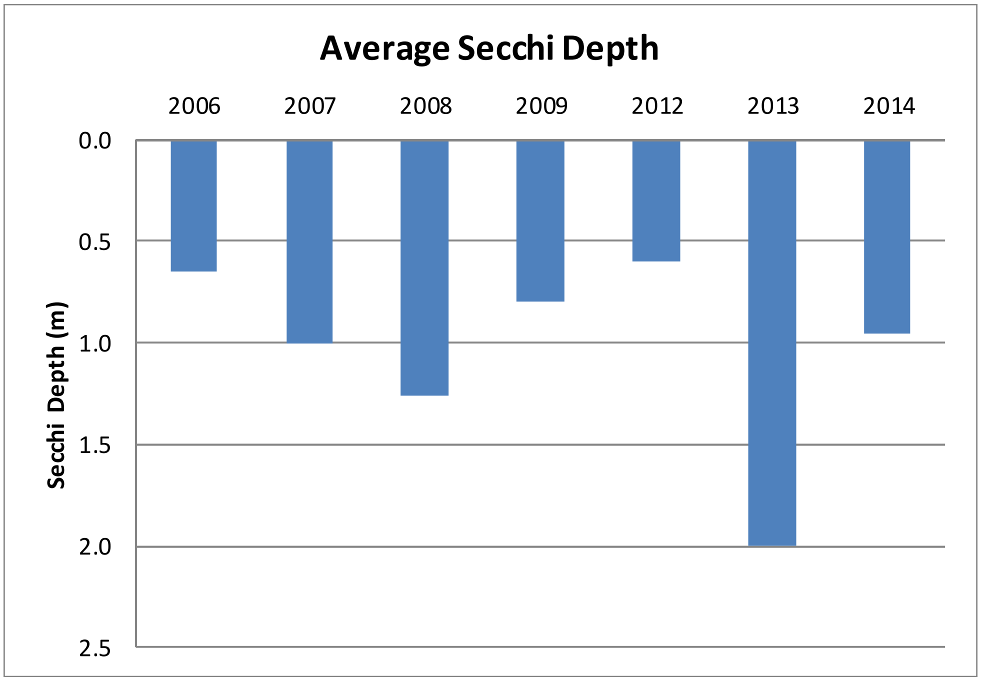


Figure 3: Multi-Year Secchi Depths

Discrete Water Quality Monitoring

Discrete samples were collected at all six sampling stations and transported to a certified aqueous chemistry laboratory for analysis. All samples were grab samples collected with a Van Dorn sampler approximately 0.5 m (1.6 ft) below the surface. An additional deep sample was taken immediately above the sediments at the Mid-Lake station.

Phosphorus Species

Phosphorus is the nutrient of greatest concern in most waterbodies in the region and the one most responsible for facilitating eutrophication of lakes. Phosphorus is often called the limiting nutrient, the one that is in shortest supply relative to biological demands. Small increases in this nutrient can therefore lead to major increases in biological production. There are a variety of sources of phosphorus including particulate material transported in stormwater and tributary inflow, probably the most common form, atmospheric deposition of dust, and groundwater, but in urbanized watersheds septic leachate, fertilizers, and other sources are also important. In addition, as touched upon above, internal loading or recycling of phosphorus can be very important. Decomposition of plants and algae is important, as is release from the sediments during anoxic conditions. Anoxia promotes changes in water and sediment chemistry and phosphorus that generally sinks or precipitates to the bottom and becomes bound in the sediments in a complex with iron can dissolve and reenter the water column. Generally, in stably stratified lakes this phosphorus is often unavailable in the photic zone where plants and algae grow near the lake surface, but if the lake mixes and stratification breaks down all this liberated phosphorus becomes mixed throughout the water column, becomes biologically available, and this can lead to significant algae blooms or major loading to points downstream.

Two phosphorus metrics were sampled. Total Phosphorus (TP) is the sum measure of all phosphorus species in both particulate and soluble forms, as well as organic and inorganic forms. Soluble Reactive Phosphorus (SRP) was also sampled and this parameter consists of inorganic soluble forms of phosphorus that are most easily biologically assimilated. This is also the form of phosphorus that is produced during internal sediment release. TP concentrations of as little as 0.03 mg/L can be high enough to support relatively dense algae blooms and concentrations above 0.06 mg/L are indicative of either dense algae blooms or imminent blooms. SRP concentrations tend to be usually quite low since this nutrient is so rapidly taken up, and concentrations in excess of 0.005 mg/L can be high enough to support relatively dense algae growth.

TP concentrations were actually moderate in the surface waters ranging from 0.02 to 0.04 mg/L, but were high enough to exceed the threshold to support bloom densities of phytoplankton. TP was very high at depth at 0.22 mg/L as a consequence of both internal nutrient loading under anoxic conditions and more generally the settling of senesced algae cells. TP in the east tributary was quite low at just 0.01 mg/L, considering that streams typically have higher TP concentrations than lakes because of the particulate load of flowing waters, but the lack of flow is probably a mitigating factor in this concentration. The true puzzlement was the high concentration of 0.22 mg/L in the south tributary, 90% of which is attributable to the exceedingly high SRP concentration of 0.200 mg/L. There have been high numbers recorded here in the past, as recently as 2012 with a concentration 0.054 mg/L, and other anomalies such as microbial mats. The concentration seems high enough to suggest a septic or gray water discharge, but the specific conductance values would probably need to be higher to firmly support this conclusion. It must also be pointed out that the water was extremely clear at this station as well, and overall is a puzzle. SRP was measurable at a low concentration in the east tributary, but within an acceptable range. All of the in-lake stations, even the deep station, were below detection limits with the exception of the south cove where the tributary discharge is influencing the SRP concentration in this locale.

Table 2: Discrete Data

Lake Churchill, Montgomery County, MD - 8/28/14								
Station	**Alkalinity**	**Hardness**	**NH3-N**	**NO3-N**	**SRP**	**TP**	**TSS**	**Chlorophyll *a***
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	µg/L
East End of Lake (IS-1)	50	88	0.02	0.22	ND <0.002	0.03	16	28.4
South Cove (IS-6)	40	86	0.05	0.15	0.002	0.02	11	31.3
Mid-Lake (IS-7)	46	88	0.03	0.18	ND <0.002	0.03	11	34.6
Mid-Lake Deep (IS-7)	NS	NS	11.60	1.00	ND <0.002	0.22	NS	NS
Spillway/DAM (IS-8)	46	86	0.04	0.20	ND <0.002	0.04	12	35.3
East Tributary	60	185	ND <0.01	2.90	0.006	0.01	3	NS
South Tributary	39	124	0.30	4.00	0.200	0.22	ND <3	NS

Nitrogen Species

While phosphorus is the most important nutrient, nitrogen is a close second and is the building block for proteins. Nitrogen is generally found at a greater concentration in the environment than phosphorus. Because of the extreme solubility of most nitrogen species, groundwater is a much more important vector than it is for phosphorus. Nitrate is the most common form of nitrogen, because other species of nitrogen tend to oxidize to nitrate and it is produced through microbial nitrification or denitrification. Nitrogen is also fixed from atmospheric nitrogen gas by various soil microbes and by blue-green algae. Other sources include atmospheric dryfall and wetfall, runoff enriched with fertilizers, and septic effluent. Nitrate is the most commonly utilized species of nitrogen by algae, and concentrations in excess of 0.05 mg/L are considered relatively high in lakes, although concentrations in streams are not considered high until they reach 1.0 mg/L. A second important species of nitrogen is ammonia. Ammonia is typically derived from the decomposition of organic matter, but is generally non-persistent in the environment because it is so rapidly assimilated or because it oxidizes to other forms. While ammonia is an important nutrient it can also be extremely toxic at high concentrations, but its toxicity varies greatly with both water temperature and pH. Acute lethal effects for fish can start as low as 0.20 mg/L up to 2.0 mg/L, and the EPA recommended criteria is 0.02 mg/L for freshwaters.

The in-lake surface concentrations of NO_3 were high, ranging from 0.15 to 0.22 mg/L; these values are somewhat higher than 2013. Again, this may be related to a lack of flushing in the lake and an increased groundwater signature as NO_3 is extremely mobile in groundwater. The concentration in the hypolimnetic sample was 1.00 mg/L. The tributaries, as in the case of SRP, were divergent although the concentrations were quite high at 2.90 and 4.00 mg/L in the eastern and southern coves respectively. The elevated concentrations are also likely related to increased groundwater flow rather than runoff within the stream channel because of the dry summer. The high NO_3 concentrations combined with the moderate TP concentrations are sufficiently high to spur major algae growth.

Surface ammonia concentrations in the lake were relatively low and are undoubtedly maintained in such a state by cellular uptake in algae. The south cove station was marginally higher than the other stations at 0.05 mg/L, and like SRP data, this is probably a consequence of loading from the south tributary. While the east tributary was below detection limits, NH_3 in the south tributary was measured at 0.30 mg/L. This is not a very high number, but combined with the SRP data certainly points to some type of loading that does not seem natural.

As usual, the hypolimnetic NH_3 concentration was an exceedingly high 11.6 mg/L, about half of the measured concentration in 2013 and 40% of the 2012 peak. The reduction overall is good news, but this is still a very high concentration, at least 5 fold higher than an acute lethal concentration. Fortunately, the stability of thermal stratification in the lake, at least throughout the growing season, maintains these concentrations in a part of the lake that is biologically inactive and does not pose a major risk; however, it is also thermal stratification that is directly responsible for the buildup of these concentrations as anaerobic decomposition of senesced phytoplankton cells is the main cause of such concentrations. It is also an indicator of greater issues of lake eutrophication providing such high senesced algal biomass. NH_3 accumulation in the lake is certainly a concern, but to date there has been no documented fishkills or other associated impact upon fall turnover, however monitoring the situation is important.

Total Suspended Solids

Total suspended solids (TSS) refers to all suspended particulate material in water, including inorganic soil particles as well as organic particles such as algae cells and decomposing organic detritus like leaf litter. This metric is distinct from settleable solids, generally coarser particles that are likely to quickly settle and would comprise much of the material accumulating at the tributary mouths. High solids concentrations can impact lakes by greatly increasing turbidity and color, contribute to some infilling and habitat loss, or in impairing fish respiration through interference with gill function. TSS is also correlated with phosphorus loading because phosphorus tends to bind to fine particles. Concentrations in excess of 25 mg/L are usually perceived as muddy by most lake users.

TSS concentrations showed a marked rise in 2014 relative to last year as a consequence of increased phytoplankton density. While the TSS load in the lake is almost wholly related to algae density, as evidenced by the much lower tributary concentrations, up to 3 mg/L, they are not wholly responsible. The eastern station had the highest measured TSS concentration at 16 mg/L that included suspended sediments that contributed to a brown coloration in this part of the lake. The identified culprit of the suspension of lake sediments in this part of the lake are Common Carp, which were observed feeding in the shallows. This process is called bioturbation; carp contribute to this by gulping in sediments, filtering out prey/forage items on the gill rakers, and exhausting the inorganic soils through the back of the gill plate.

Alkalinity and Hardness

Alkalinity and hardness are related, but separate metrics. Alkalinity can describe the buffering capacity of a waterbody or its ability to resist changes in pH. Specifically it is a measure of carbonates, bicarbonates, and hydroxides. Alkalinity values should range between 20 to 200 mg/L with optimal concentrations between 100 and 200 mg/L to protect against rapid pH swings. Alkalinity can also be used to gauge the approximate productivity of a system with higher values usually indicating increasing productivity. Hardness is a measurement of certain metallic ions such as calcium, magnesium, and iron. These compounds are essential in many biological functions including bone, scale, and shell production and various other metabolic reactions.

Alkalinity and hardness are little changed in the lake, as these tend to be less influenced by biological processes than many of the other measured parameters. Alkalinity is fairly low in the system, at less than 50 mg/L. This value is sufficient to maintain ecological functions, but does suggest that the lake is subject to rather rapid pH changes and also partially explains the difference in pH between the lake and the tributaries. The lake is moderately hard in the high 80 mg/L range. This hardness may help to mitigate some of the impacts of internal nutrient loading in the lake as suggested by the low concentration deep water SRP sample.

Chlorophyll a

Chlorophyll *a* describes a biological metric which can serve as a proxy measure of algal biomass. Specifically, it is the measure of the primary photosynthetic pigment common to all plants and algae. It is used primarily to estimate the trophic state and biological productivity of a lake. In general, concentrations in excess of 30 µg/L are indicative of bloom-like conditions, and persistent growing season concentrations of 6.0 µg/L or more are indicative of eutrophic waterbodies.

Chlorophyll concentrations more than doubled relative to 2013, averaging 32.4 µg/L. This was also accompanied by a halving of Secchi depth as illustrated in Figure 4. Increased chlorophyll, and by proxy algae density, is a function of higher nutrient concentrations in 2014. Another important factor is reduced flushing rate or conversely increased retention period, which aids in algal utilization of available nutrients through longer contact and a lack of direct loss of algal biomass through discharge over the spillway. Chlorophyll concentrations and algae density are measured at a rate reflective of hypereutrophy in the lake.

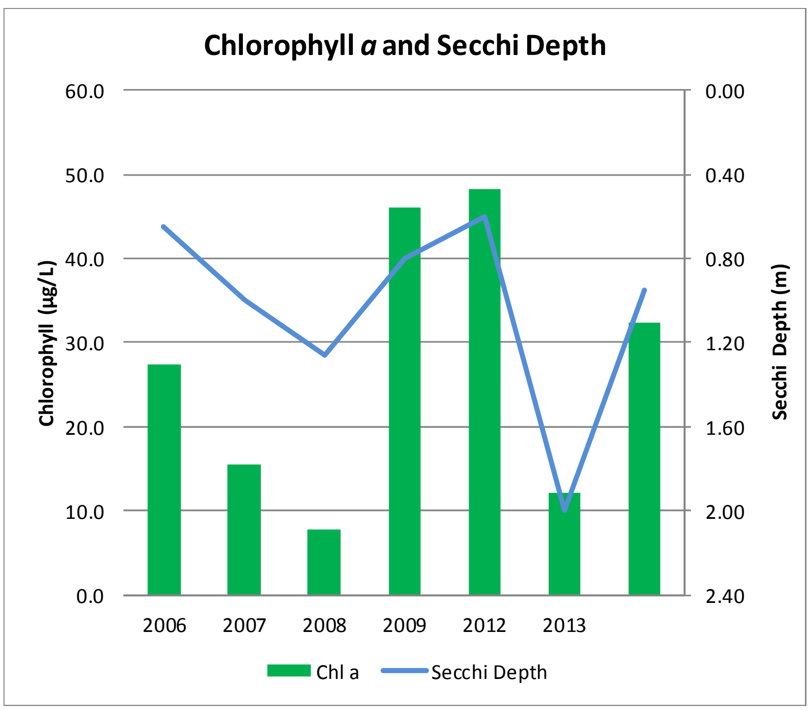


Figure 4: Chlorophyll a and Secchi Depth

Plankton Sampling

Plankton samples were collected from all in-lake stations. Phytoplankton samples were whole water samples, while zooplankton samples were collected with a plankton tow nets. All samples were preserved with Lugol's solution and processed in Princeton Hydro's in-house biological laboratory. Plankton data can be found in Appendix II.

Phytoplankton

Phytoplankton or algae are a functional group of microscopic plants and bacteria that form the base of many aquatic food webs. This consists of suspended or planktonic (free-floating), single cell and colonial algae, as well as benthic or filamentous algae growing near the bottom or forming dense surface mats. Algae are a necessary and important component of any lake system, but when they exhibit excessive growth leading to dense blooms, surface scum formation, or excessive mat growth they can cause a variety of impairments. This type of excessive growth or eutrophication is always a result of excessive nutrient concentrations that are usually linked to watershed pollutant loading, either diffuse non-point source pollutants such as those found in stormwater and groundwater or from point-sources such as treatment plants, or from internal nutrient loading or nutrient recycling attributable to the decomposition of plants and algae or release from the sediments under anoxic conditions. The impairments related to excessive growth can run a wide gamut from: i) aesthetic impairment including a loss of clarity, excessive coloration, and odors; ii) recreational impairments including impacted navigation and poor fishing and; iii) a variety of environmental damages including the production of harmful algae blooms (HABs) caused by blue-green algae producing cyanotoxins, oxygen depletion and accelerated internal nutrient generation, and loss of usable fish habitat among others. As mentioned above blue-green algae tend to be a particularly noxious group not only because they produce cyanotoxins, but also because they flourish in high phosphorus environments because they can utilize organic sources of phosphorus and fix atmospheric nitrogen, abilities that other algae do not possess, and because they are not grazed by zooplankton and thus lack a natural biological control mechanism.

The phytoplankton samples showed a poor community composition with low to moderate diversity and high density. The blue-green algae *Coelosphaerium* dominated the plankton. This is not a particularly noxious blue-green, but three other genera were reported as present or common, including *Microcystis*. *Microcystis* is one of the worst blue-greens prone to reaching bloom densities and producing the cyanotoxin microcystin, a hepatotoxin. This genus is often implicated in fishkills or even the death of livestock and wildlife utilizing bloom-impacted watering holes. While the density of this organism was low, emerging science points to this as a major concern as waterbodies continue to eutrophy highlighting the need for management. Other organisms included the green algae *Pediastrum,* several diatoms, and the dinoflagellate *Ceratium*. The overall community type represents a poor forage base for zooplankton. By the same token zooplankton cannot control blue-green algae numbers through grazing because of a number of defenses, including cyanotoxin production.

Zooplankton

Zooplankton are a diverse group of small planktonic animals that form the trophic level above phytoplankton in the food web. They consume a wide variety of food items, including bacteria, detritus, algae, and other zooplankters. Zooplankton, especially large-bodied herbivores, are crucial in maintaining algae at acceptable densities in lakes, however they are unable to graze blue-green algae for a variety of reasons. Zooplankton in turn are a crucial food source for zooplanktivorous fish and are an important part of the diet of almost all juvenile fish. Their numbers can be negatively affected by large anoxic zones, overgrazing by certain invasive fish such as Golden Shiners, certain pollutants, and copper algicides.

Despite the poor phytoplankton composition, the zooplankton displayed both moderate diversity and abundance. This may suggest that the observed dominance of blue-greens in the system may have been a recent development and furthermore may suggest better clarity in earlier parts of the growing season, which may also explain the expansion of plants in the system. All three major groups of freshwater zooplankton were represented: cladocerans (water fleas), copepods, and rotifers. Of particular interest was the presence of large-bodied herbivorous zooplankters, those forms which provide the highest grazing pressure on algae, including the cladocerans *Daphnia* and *Diaphanosoma* and the copepod *Diaptomus*. These forms were probably responsible for maintaining the non-blue-green algae in acceptable densities. As mentioned above, zooplankton are unable to effectively graze blue-greens because of their multiple defenses.

Macrophyte Survey

A macrophyte survey was also conducted by making a complete circuit of the shallow littoral zone of the lake near the shoreline and documenting any aquatic macrophytes and mat algae. Plants can form an important component of lake ecosystems, providing valuable habitat for fish and macroinvertebrates, uptake of nutrients, and stabilization of lake sediments. The major find in 2013 was the presence of several Hydrilla fragments in the lake, an extremely invasive plant that has been marching north for some time and a plant which had been identified and managed in the lake previously, although not found during any of Princeton Hydro's August sampling events to that point. Part of the recolonization in the lake was supposed related to excellent clarity of 2.0 m in the lake such that improved clarity lifts light limitation and allows rooted plants to grow in the limited littoral area of the lake. Despite a reduction in clarity observed in 2014, the eastern cove around the tributary delta was covered in a patchy distribution of rooted Hydrilla. There are several reasons for this expansion. First, last year established a germ stock of Hydrilla in the lake, either through rooted biomass, fragmentation and subsequent rerooting (a very common mechanism among aquatic vegetation), or the production of seed. Second, Hydrilla was only found in very shallow portions of the lake, less than a foot deep, and even with reduced Secchi depths there is insufficient light limitation to preclude the growth of aquatic macrophytes. Finally, some of the water quality data and general seasonal climatic conditions suggest that the lake may have been clearer for much of the summer relative to the sampling point. One of those indications was the presence of a deeper water algae bloom, so that even though Secchi depth was down to just 1.0 m, that upper meter itself may have been clearer than in a more typical surface weighted bloom situation.

Other plants observed include Brittle Naiad which was found in a density equal to the Hydrilla in the eastern cove. This plant was fairly widespread throughout the entire region this growing season. One or two stalks of a pondweed species (*Potamogeton* sp.) were also observed. Some minor Duckweed was observed around the margins of the entire lake. Additionally, there were a few very small patches of mat algae, primarily along the north shore.

Summary and Recommendations

Overall, the recommendations that have been advocated in the past continue to stand as fundamentally conditions at the lake have not shown significant or sustained movement in a particular direction; otherwise stated that interannual variability moves around a central tendency. The exception of course is with Hydrilla, which was first detected last year, and in 2014 showed a significant expansion. As such, the management of this plant will continue to be the top priority for the coming year. Otherwise, management recommendations are based on longer term items that should be preceded by more thorough study.

To summarize, the lake continues to exhibit symptoms of cultural eutrophication, namely poor clarity and high coloration as a result of dense planktonic algae growth, in turn resulting from sufficiently high nutrient concentrations to support such growth. As a consequence of lake basin morphometry and landscape position, the lake continues to exhibit strong thermal stratification. Because the lake is eutrophic however this leads to growing season anoxia from typically 3.0 m and below and a dangerous build-up of ammonia and phosphorus. At the same time, because the stratification is so stable, the potential growing season effects of a release of ammonia or phosphorus are contained, but at turnover some concerns still remain. While 2013 was probably the best year on record in terms of most water quality metrics, 2014 was a return to more normal conditions, summarized below.

- Average Secchi clarity of 0.95 m
- Surface pH of 8.9, a high value indicating dense phytoplankton growth
- Surface DO concentration exceeding 140%
- Average TP concentration surface climbing to 0.03 mg/L
- Increased average chlorophyll concentration to 32.4 µg/L.
- Poor phytoplankton community composition dominated by blue-green algae

Weather patterns again seem to be a major factor in ordering the observed condition, particularly the dry conditions which decrease lake flushing and probably allow for more efficient utilization of available nutrients and increases in algae density. The major concern for the year was the significant expansion of Hydrilla in the lake. In cases of plant invasion, early and significant action is the best course to eliminate it while it is manageable, i.e. before the establishment of a significant seedbank, as well as a major saving in long term management expenditure.

Hydrilla Response

Previously, an aquatic pesticide applicator had been retained to perform monitoring and treatment of hydrilla in the lake. This dual program was deemed quite effective as minimal amounts were identified in 2011 and none detected in 2012 through this monitoring program, prompting the discontinuation of these services in 2013. The discovery of the plant by PH in late August 2013 and its expansion to cover upward of an acre in 2014 is a certainly alarming and requires early action in 2015.

While hand pulling and other mechanical methods were recommended last year, the time for these kinds of actions has passed, and instead herbicide applications will be required. Herbicide applications will require hiring a certified applicator business which will file for a permit prior to treatment. As with all state-issued permits, there may be a lengthy review period so permits should be filed as soon as possible. For smaller patches a contact herbicide may be preferable, while a systemic herbicide may be required for higher densities. Continued monitoring of this plant will be necessary for several years. Additionally, plan on treating for several years. While the first year of application should eliminate all or nearly all live plants and further germ production, extant seed and root mass may continue to produce plants over the next several years, requiring treatment and monitoring throughout that period.

Increased Monitoring

Increased monitoring activity would be critical in understanding the seasonal dynamics of Lake Churchill. While sampling to this point has always occurred late in the summer when conditions are expected to be at their worst, it would be extremely useful to sample earlier in the season in order to determine when the lake stratifies or if it ever truly mixes. Sampling in the fall or winter would also be extremely helpful in determining the fate of ammonia in the system and if it in fact reaches lethal concentrations in the upper reaches of the lake.

At a minimum a seasonal sampling program should be established including spring, summer, and autumn sampling. While all six stations would remain consistent the collection of discrete samples would likely be limited to only the Mid-Lake station and the tributaries in order to cut costs. This type of sampling approach would allow for the thorough documentation of the lake throughout the growing season and greatly increase understanding of impacts over time as well as better identify the source of the impacts. Some degree of storm sampling should also be included to really understand the role of the tributaries in regard to pollutant and nutrient loading to the lake. Continued plant surveys would also be a critical component of such sampling and would be targeted on characterizing Hydrilla growth.

Phase I Diagnostic Feasibility Study

At this point in monitoring the lake it is necessary to complete a full-scale diagnostic feasibility study. The ultimate goal of this type of study is to fully characterize the lake and watershed system in order to develop and implement a meaningful and effective lake management plan that is specifically tailored to address the identified impairments and act upon both the root causes and the symptoms of lake impairments through a variety of management solutions and best management practices (BMP).

Typically, Princeton Hydro includes the following components in Phase I Studies:

- Bathymetry Study – A bathymetry study is crucial in understanding habitat quality, trophic state, and hydrology of a lake system. This task has already been completed in previous studies.
- Water Quality Study – A full scale water quality study would contain many of the elements in this study including in-situ and discrete water quality monitoring as well as storm sampling. This would likely be conducted on a monthly interval throughout the growing season as well as once in the winter. The same six stations would be retained.
- Aquatic Vegetation and Filamentous Algae Surveys – This component would be included as a component of the water quality study. Considering the recent discovery of hydrilla this task gains prominence.
- Hydrologic Modeling – Hydrology is definitely one of the most important factors in determining water quality especially in impoundments like Lake Churchill and would result in the development of a complete water budget describing precipitation, runoff from the watershed, groundwater flux, and seasonal storage/loss of water. This data in turn is used to develop trophic state models.
- Pollutant Load Modeling – Pollutant loading would be calculated using various models that rely on up-to-date geographic information system (GIS) data layers to describe how the land use, soils/geology, and climate impact pollutant loading in this system. These models are modified by empirical water quality data and hydrology data. In addition, a model would be developed for the lake to describe the impact of internal nutrient release.
- Trophic State Modeling – A variety of trophic state models would be calculated based on the pollutant load, hydrology, and water quality data to describe the trophic state or productivity of the lake. A number of models would be run and the one best describing the dynamics of this lake would then be selected. This model could then be used in a predictive capacity to understand how the implementation of certain management strategies would benefit the lake as well as track actual implementation and change over time.

- Management Recommendations – Once all data gathering and analysis is completed, a custom lake management plan would be written to improve the water quality and other values of Lake Churchill. These recommendations are always made with high regard to practical considerations, scientific integrity, budgetary concerns, and effectiveness.

Aeration/Destratification

This recommendation needs a full diagnostic/feasibility analysis before implementation, but could address many of the outstanding issues with the lake. Certainly it is known that the lake is subject to very strong thermal stratification with the attendant water quality impairments, chiefly nutrient loading from the sediments and extremely high ammonia concentrations. Aeration/destratification could ameliorate these effects. Presently, installing such a system is cautioned against because mixing dynamics in the lake are not well understood. Because the lake is strongly stratified in the late summer unnecessarily introducing mixing could impair conditions rather than maintaining high nutrient and ammonia concentrations in the hypolimnion where it is sequestered from the biologically active portions of the lake.

Destratification works by pumping compressed air from a shoreline compressor through air lines to diffuser heads. Newer style diffuser heads are very robust relative to older diffusers in that they are self-cleaning and nearly maintenance free. Micro-bubbles are released from the heads and serve as an air-lift mechanism that keeps the water column vertically mixed. The continuous mixing limits the development of thermal stratification, and more importantly would maintain DO levels in the hypolimnion thus preventing internal nutrient loading and ammonia storage as well as greatly increasing usable habitat volume. While the aeration or destratification does not directly limit algae growth (other than forms that require stable stratification) it instead works to limit nutrient cycling in the lake and thus reduce nutrient concentrations.

Additional Strategies

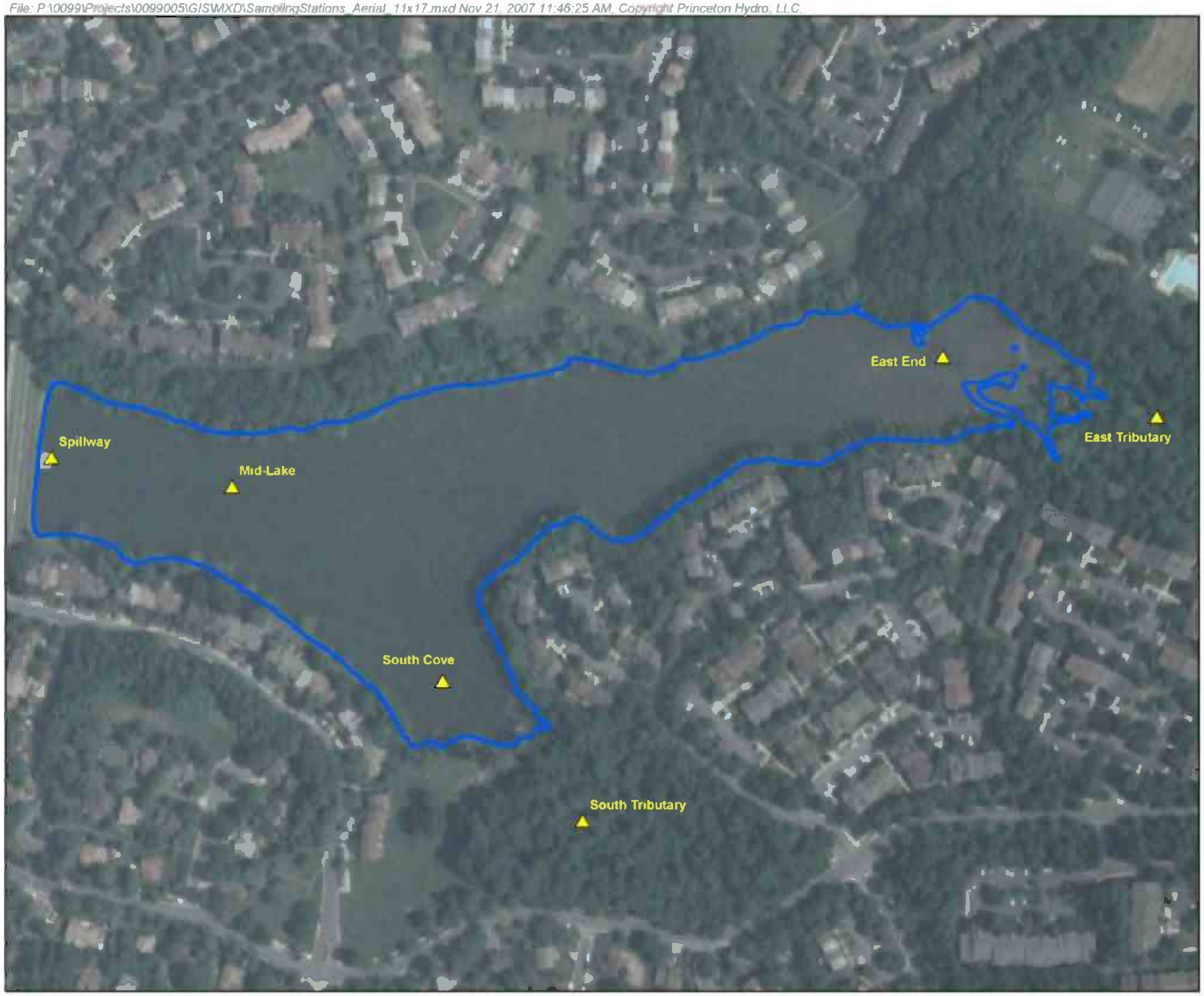
Several other strategies should also be considered. One of these is the application of alum or a similar product to induce nutrient inactivation. These products bind tightly to phosphorus and even particulates (somewhat dependent on where in the water column the material is applied), which then precipitate and settle on the bottom. This in effect makes the nutrient inactive and effectively reduces in lake concentrations with an expected decrease in biological productivity.

Finally, a series of simple management strategies could be implemented throughout the watershed to help control the loading of nutrients and solids. Certainly some steps have been made in this regard, particularly the stabilization of the tributaries upstream, but much smaller scale projects when implemented over a wide area and at a high rate can also be effective. This would include simple BMPs such as regular cleanout of catch basins followed by the installation of catch basin inserts that more effectively trap these types of pollutants.

Appendix I

Site Map

File: P:\0099\Projects\0099005\GIS\MXD\SamplingStations_Aerial_11x17.mxd Nov 21, 2007 11:46:25 AM, Copyright Princeton Hydro, LLC.



Princeton Hydro

MARYLAND COUNTY MAP

PRINCETON HYDRO, LLC.
1108 OLD YORK ROAD
P.O. BOX 720
RINGOES, NJ 08551

1 inch equals 200 feet
0 200
Feet

SOURCES:

1. Aerial photo as obtained from Maryland State GIS Depot
2. Sample locations field located using Trimble ProXRS GPS unit

SAMPLING LOCATION MAP

LAKE CHURCHILL
BATHYMETRIC RESURVEY
GERMANTOWN
MONTGOMERY COUNTY, MD

Legend

Lake Boundary

Sampling Stations

Appendix II

Plankton Data

Churchill - Dam Phyto / Zooplankton Community Composition - 8/28/14			
Phytoplankton		**Zooplankton**	
Organism	**Abundance**	**Organism**	**Abundance**
Chlorophytes		**Cladocerans**	
Pediastrum	C	*Bosmina*	C
		Daphnia	C
Diatoms		*Diaphanosoma*	C
Melosira	C		
Cylindrotheca	C	**Copepods**	
		Mesocyclops	P
Cyanobacteria		*Cyclops*	C
Aphanizomenon	C		
Anabaena	P	**Rotifers**	
Coelosphaerium	A-dominant	*Keratella*	P
		Brachionus	P

Churchill - Mid Lake Phyto / Zooplankton Community Composition - 8/28/14			
Phytoplankton		**Zooplankton**	
Organism	**Abundance**	**Organism**	**Abundance**
Chlorophytes		**Cladocerans**	
Pediastrum	C	*Daphnia*	C
Diatoms		**Copepods**	
Melosira	C	*Diaptomus*	C
Navicula	P	*Cyclops*	P
Cylindrotheca	P	nauplii	P
Cyanobacteria		**Rotifers**	
Aphanizomenon	C	*Keratella*	C
Anabaena	C		
Coelosphaerium	A-dominant		
Microcystis	P		
Dinoflagellates			
Ceratium	P		

Churchill - South Phyto / Zooplankton Community Composition - 8/28/14			
Phytoplankton		**Zooplankton**	
Organism	**Abundance**	**Organism**	**Abundance**
Chlorophytes		**Cladocerans**	
Pediastrum	P	*Bosmina*	C
		Daphnia	C
Diatoms		*Diaphanosoma*	P
Pinnularia	P		
		Copepods	
Cyanobacteria		*Diaptomus*	C
Aphanizomenon	C	*Cyclops*	C
Anabaena	C	nauplii	C
Coelosphaerium	A-dominant		
		Rotifers	
Dinoflagellates		*Keratella*	A
Ceratium	P		

Churchill - East Phyto / Zooplankton Community Composition - 8/28/14			
Phytoplankton		**Zooplankton**	
Organism	**Abundance**	**Organism**	**Abundance**
Chlorophytes		**Cladocerans**	
Pediastrum	C	*Bosmina*	C
		Daphnia	C
Diatoms			
Navicula	P	**Copepods**	
		Diaptomus	P
Cyanobacteria		nauplii	C
Coelosphaerium	A-dominant		
		Rotifers	
Dinoflagellates		*Keratella*	C
Ceratium	P		

Appendix III
Glossary

Glossary of Key Terms

- Acidity - The state of being acid that is of being capable of transferring a hydrogen ion in solution; solution that has a pH value lower than 7.

- Alkalinity - The capacity of water for neutralizing an acid solution. Alkalinity of natural waters is due primarily to the presence of hydroxides, bicarbonates, carbonates and occasionally borates, silicates and phosphates. It is expressed in units of milligrams per liter (mg/l) of $CaCO_3$ (calcium carbonate). Low alkalinity is the main indicator of susceptibility to acid rain. Increasing alkalinity is often related to increased algal productivity. Lakes with watersheds having a sedimentary carbonate rocks geology then to be high in dissolved carbonates (hard-water lakes), whereas those in a watershed with a granitic or igneous geology tend to be low in dissolved carbonates (soft water lakes).

- Anthropogenic activities – Impacted by, created by, or resulting from human activities.

- Aeration - A process which promotes biological degradation of organic matter in water. The process may be passive (as when waste is exposed to air), or active (as when a mixing or bubbling device introduces the air).

- Algae - Microscopic plants and other organisms which contain chlorophyll and live floating or suspended in water. Algae may also form dense colonies and mats. Algae also may be attached to structures, rocks, or other submerged surfaces. It serves as food for fish and small aquatic animals. Excess algal growths can impart tastes and odors to potable water. Algae produce oxygen during sunlight hours and use oxygen during the night hours. They can affect water quality adversely by lowering the dissolved oxygen in the water during the night or after die-off. See also phytoplankton.

- Alum Treatment - Process of introducing granular or liquid alum (aluminum sulfate) into the lake water, to create a precipitate or floc that is used to strip the water column of fine particles and algae or used to treat the bottom sediment for the purpose of limiting the internal recycling of phosphorus.

- Ammonia - A colorless gaseous alkaline compound that is very soluble in water, has a characteristic pungent odor, is lighter than air, and is formed as a result of the decomposition of most nitrogenous organic material. A key nutrient.

- Anoxic – Devoid of oxygen or dissolved oxygen. DO concentrations less than 1.0 mg/L are generally treated as anoxic.

- Autotroph – Autotrophs are primary producers that sustain their energy from photosynthesis. Phytoplankton and macrophytes are autotrophs.

- Bathymetry - The measurement and mapping of water depths and bottom contours.

- Best Management Practices - Schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of waters of the United States. BMPs also include but are not limited to treatment requirements, operating procedures, and practices to control plant site runoff, spillage or leaks, sludge or wastewater disposal, or drainage from raw material storage. Practices or structures designed to reduce the quantities of pollutants -- such as sediment, nitrogen, phosphorus, and animal wastes that are washed by rain and snow melt from farms into surface or ground waters.

- Chlorophyll *a* - A green pigment found in photosynthetic organisms; used as an indicator of algal biomass.

- Clarity - The transparency of a water column. Commonly measured with a Secchi disk

- Conductivity or Conductance – See Specific Conductivity.

- Cyanobacteria – This group of algae is also known as blue-green algae or cyanophytes. This taxon consists of algae that are prone to bloom formation. This is due to certain competitive advantages including the ability to fix atmospheric nitrogen and to utilize organic forms of phosphorus, traits which no other algae share. They are also not consumed by zooplankton. As a result they are not subject to nitrogen limitation, grazing, and can utilize other forms of phosphorus. Blooms produce foul odors and can deplete dissolved oxygen levels at night and upon senescence.

- Debris - A broad category of large manufactured and naturally occurring objects that are commonly discarded (e.g., construction materials, decommissioned industrial equipment, discarded manufactured objects, tree trunks, boulders).

- Detritus - Any loose material produced directly from disintegration processes. Organic detritus consists of material resulting from the decomposing organic materials or from terrestrial sources like leaves.

- Diel – Refers to the course of events over a day and includes both diurnal and nocturnal cycles. In limnology diel variations are measured in a variety of parameters.

- Dissolved oxygen – The concentration of the gas oxygen (O_2) present in water. Dissolved oxygen (DO) can be an indicator of the ecologic function of the waterbody. Oxygen is more soluble at lower temperatures and less soluble at higher temperatures. Contributors to DO in water include atmospheric diffusion and photosynthetic processes of algae and aquatic vegetation. Percent saturation refers to maximum concentration of DO per a given temperature due to atmospheric diffusion. Supersaturated conditions occur when excessive photosynthesis contributes more DO to a system than would occur through inorganic processes alone at a given temperature.

- Dredging - Removal of sediment from the bottom of a water body.

- Epilimnion- The upper layer of water in a thermally stratified lake or reservoir. This layer consists of the warmest water and has a fairly uniform (constant) temperature. The layer is readily mixed by wind action.

- Eutrophication - A process that occurs when a lake or stream becomes over-rich with nutrients; as a consequence it becomes overgrown in algae and other aquatic plants. These autotrophs senesce or die and are decomposed by microbes. This decomposition or respiration by microbes can significantly reduce dissolved oxygen levels to the impairment of other aquatic organisms. Eutrophication can be a natural process or it can be a cultural process accelerated by an increase of nutrient loading to a lake by human activity. Fertilizers, which drain from the fields, and nutrients from animal wastes and sewage are examples of cultural processes and are often the primary causes of the accelerated eutrophication of a waterbody.

- Erosion- The wearing away of land surface by wind or water. Erosion occurs naturally but can be caused by farming, residential or industrial development, mining, or timber-cutting.

- Fecal contamination - The presence in water bodies of living organisms (bacteria and viruses) or agents derived by fecal bacteria that can cause negative human health effects. Fecal contamination may be a result of wildlife, livestock, pet, waterfowl or septic and sewage discharges.

- Herbicides - A compound, usually a man-made organic chemical, used to kill or control plant growth.

- Hydrology - The occurrence, circulation, distribution, and properties of the waters of the earth, and their reaction with the environment. For lakes this is usually associated with the quantification of the water flow into and out of the system and the study of pollutant transport that occurs in concert with the inflow.

- Hypereutrophic - Pertaining to a lake or other body of water characterized by excessive nutrient concentrations such as nitrogen and phosphorous and resulting high productivity. Such waters are often shallow, with algal blooms and periods of oxygen deficiency. Slightly or moderately eutrophic water can be healthful and support a complex web of plant and animal life. However, such waters are generally undesirable for drinking water and other needs. Degrees of eutrophication typically range from oligotrophy (maximum transparency, minimum chlorophyll-a, minimum phosphorus) through mesotrophy, eutrophy, to hypereutrophy water (minimum transparency, maximum chlorophyll *a*, maximum phosphorus). Also see Trophic State.

- Hypolimnion - Bottom waters of a thermally stratified lake. This layer consists of colder, denser water. Temperatures may remain relatively constant year around and it may experience little or no mixing with the upper warmer layers of the water body, although almost all lakes of moderate depth (<100 feet) will periodically mix. The hypolimnion of a eutrophic lake is usually low or lacking in oxygen.

- Hypoxic – low or depressed dissolved oxygen concentrations generally less than 2.0 mg/L, but may be applied to DO concentrations less than 4.0 mg/L.

- In-situ water quality parameters - in place; in-situ measurements consist of measurements of water quality parameters in the field, rather than in a laboratory.

- Invasive species - A species whose presence in the environment causes economic or environmental harm or harm to human health.

- Limnology - The study of bodies of fresh water with reference to their plant and animal life, physical properties, geographical features, etc. The study of the physical, chemical, hydrological, and biological aspects of fresh water bodies.

- Littoral Zone - 1. That portion of a body of fresh water extending from the shoreline lakeward to the limit of occupancy of rooted plants. Sometimes characterized as twice the Secchi depth or at a depth equal to 1% of incident light penetration at the surface. 2. A strip of land along the shoreline between the high and low water levels.

- Land use/ Land cover - The arrangement of land units into a variety of categories based on the properties of the land or its suitability for a particular purpose. It has become an important tool in rural land-use planning.

- Macroinvertebrates – Large aquatic invertebrates. Generally applied to aquatic insects, mollusks, and crustaceans.

- Macrophyte – Vascular (higher order) plants that grow in water. Includes different growth forms such as emergents, submerged, rooted floating-leaf, and floating. Also known as submerged aquatic vegetation or aquatic weeds. Includes waterweeds, pondweeds, water lilies, and duck weed amongst others.

- Mesotrophic - Reservoirs and lakes which contain moderate quantities of nutrients and are moderately productive in terms of aquatic animal and plant life.

- Microbes – Bacteria, fungus, and other microscopic life forms. Generally responsible for the decomposition of organic materials.

- Morphometry or Lake Morphometry – The three-dimensional shape of lake including depth. This term is generally interchangeable with bathymetry. Lake morphometry is characterized by bathymetry surveys.

- Nitrate – The most common form of nitrogen nutrient in most aquatic ecosystems and the nitrogen species most often utilized by plants and algae. Nitrate is generally found in high supply relative to phosphorus and highly mobile in water.

- Nitrogen - An essential nutrient in the food supply of plants and the diets of animals. Animals obtain it in nitrogen-containing compounds, particularly amino acids. Although the atmosphere is nearly 80% gaseous nitrogen, very few organisms have the ability to use it in this form with the exception of cyanobacteria or blue-green algae. The higher plants normally obtain it from the soil after micro-organisms have converted the nitrogen into ammonia or nitrate, which they can then absorb. There are various forms of both oxidized and reduced nitrogen including ammonia and nitrate.

- Non-point source pollution – Non-point source pollution is the enrichment of pollutants or nutrients through stormwater runoff. Natural or human-induced pollution caused by diffuse, indefinable sources that are not regulated as point sources, resulting in the alteration of the chemical, physical, and biological integrity of the water.

- Oligotrophic - Deep lakes that have a low supply of nutrients and thus contain little organic matter. Such lakes are characterized by high water transparency and high dissolved oxygen.

- pH - A measure of the acidity or basicity of a material, or the concentration of the positive hydrogen ion, liquid or solid. pH is represented on a scale of 0 to 14 with 7 representing a neutral state, 0 representing the most acid and 14, the most basic.

- Periphyton abundance - Microscopic underwater plants and animals that are firmly attached to solid surfaces such as rocks, logs, and pilings. In smaller streams this can indicate nutrient and thermal enrichment.

- Phosphorus - An element that while essential to life, contributes to the eutrophication of lakes and other bodies of water. There are various species or forms of phosphorus including Total Phosphorus (sum of all species), Organic Phosphorus, and Dissolved Phosphorus amongst others. Soluble reactive phosphorus is a measure of soluble orthophosphates.

- Photic Zone – The upper layers of lake in which photosynthesis occurs. Generally depths less than twice the Secchi depth.

- Photosynthesis - The process by which plants and algae transform carbon dioxide and water into carbohydrates and other compounds, using energy from the sun captured by C

- Chlorophyll in the plant. The rate of photosynthesis depends on climate, intensity and duration of sunlight, nutrient availability, temperature, and carbon dioxide concentration.

- Phytoplankton - Very tiny, often microscopic, plants and other photosynthetic or autotrophic organisms found in fresh and saltwater. Phytoplankton drift near the surface of the water where there is plenty of sunlight for growth. Phytoplankton form the base for most lake food chains.

- Point-source pollution - Easily discernible source of water pollution such wastewater treatment plants and other facilities that directly discharge to waterways.

- Pollutant loading - The amount of polluting material that a transporting agent, such as a stream, a glacier, or the wind, is actually carrying at a given time.

- Residential discharge - Any flow of surface water or the collective flow of residential development generated in single and multi-family homes. May include storm water collected from the roof, lawn, driveway, a basement sump pump, or effluent from a malfunctioning septic system.

- Respiration – The consumption of organic materials by living organisms in a lake. All aquatic life forms, including microbes, algae, zooplankton, and fish respire organic materials. Respiration can lower pH values and for most organisms except certain bacteria requires dissolved oxygen.

- Secchi disk transparency - A flat, white disc lowered into the water by a rope until it is just barely visible. At this point, the depth of the disc from the water surface is the recorded Secchi disc transparency.

- Sedimentation - 1. Process of deposition of waterborne or windborne sediment or other material; also refers to the infilling of bottom substrate in a waterbody by sediment (siltation). 2. When soil particles (sediment) settles to the bottom of a waterway.

- Specific conductance - A rapid method of estimating the dissolved-solids content of a water supply. The measurement indicates the capacity of a sample of water to carry an electrical current, which is related to the concentration of ionized substances in the water. Also called conductance.

- Stormwater runoff - Stormwater runoff, snow melt runoff, and surface runoff and drainage; rainfall that does not infiltrate the ground or evaporate because of impervious land surfaces but instead flows onto adjacent land or watercourses or is routed into drain and sewer systems.

- Stratification - Formation of water layers each with specific physical, chemical, and biological characteristics. As the density of water decreases due to surface heating, a stable situation develops with lighter water overlaying heavier and denser water. During stratification there is no mixing between layers, establishing chemical as well as thermal gradients.

- Submerged aquatic macrophyte - Large vegetation that lives at or below the water surface; an important habitat for young fish and other aquatic organisms.

- Suspended solids - 1) Solids that either float on the surface or are suspended in water or other liquids, and which are largely removable by laboratory filtering. 2) The quantity of material removed from water in a laboratory test, as prescribed in standard methods for the examination of water and wastewater.

- Thermal Stratification – A natural phenomenon in which lakes of sufficient depth are divided into distinct depth zones of varying temperatures. In the summer months the coolest and densest water is located at the lake bottom. In winter months the upper depths of a lake may be warmer than the bottom. The maximum density of freshwater occurs at 39°F. Thermal stratification prevents the mixing of the entire water column.

- Thermocline - The middle layer in a thermally stratified lake or reservoir. In this layer there is a rapid decrease in temperature with depth. Also called the Metalimnion.

- Trophic State – Indicates the level of primary production as measured by photosynthetic activity or other metrics. Various models exist to describe trophic state. Perhaps the most widely used is Carlson's Trophic State Index (TSI) which relies on the use of summer average Chlorophyll, Secchi depth, and Total Phosphorus values.

- Tributary – A stream or other flowing waterbody discharging to a lake or a larger stream.

- Turbidity - A cloudy condition in water due to suspended silt or organic matter often attributable to algae blooms or increased sediment loads.

- Water quality - The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.

- Watershed management - A holistic approach applied within an area defined by hydrological, not political, boundaries, integrating the water quality impacts from both point and nonpoint sources. Watershed management has a premise that many water quality and ecosystem problems are better solved at the watershed scale rather than by examining the individual waterbodies or dischargers. Use, regulation and treatment of water and land resources of a watershed to accomplish stated objectives.

- Zooplankton - Tiny, sometimes microscopic, floating, aquatic animals and protozoans.

Zooplankton generally feed upon phytoplankton, organic detritus, microbes, and other zooplankters.