B. REGIONAL ASSESSMENT: water quality and nutrients 2006

Secchi Transparency

Measuring the Secchi depth records the relative transparency or clarity of the water as it appears to an observer above the lake surface. Transparency can be affected by water color (which relates to the concentration of large organic molecules called “humic acids”), phytoplankton abundance and species present, and turbidity caused by other suspended particles, such as clay and detritus. Secchi transparency readings can also be affected by wind and waves, as well as by light reflections off the water surface. The sampling protocol calls for measurements to be made in the same fashion each time, on the shady side of the boat, with records of wind and sun conditions, in order to evaluate the data.

Transparency changes often mirror changes in algal abundance, which may be due either to changes in growth rates from nutrient availability or in grazing rates by zooplankton. It can also indicate major inputs of silt and detritus, such as soils dislodged by large storms or moved into the water as a result of human activities. Transparency measurements compared across years may indicate correlations with specific events known to have occurred or can point to land use changes over time.

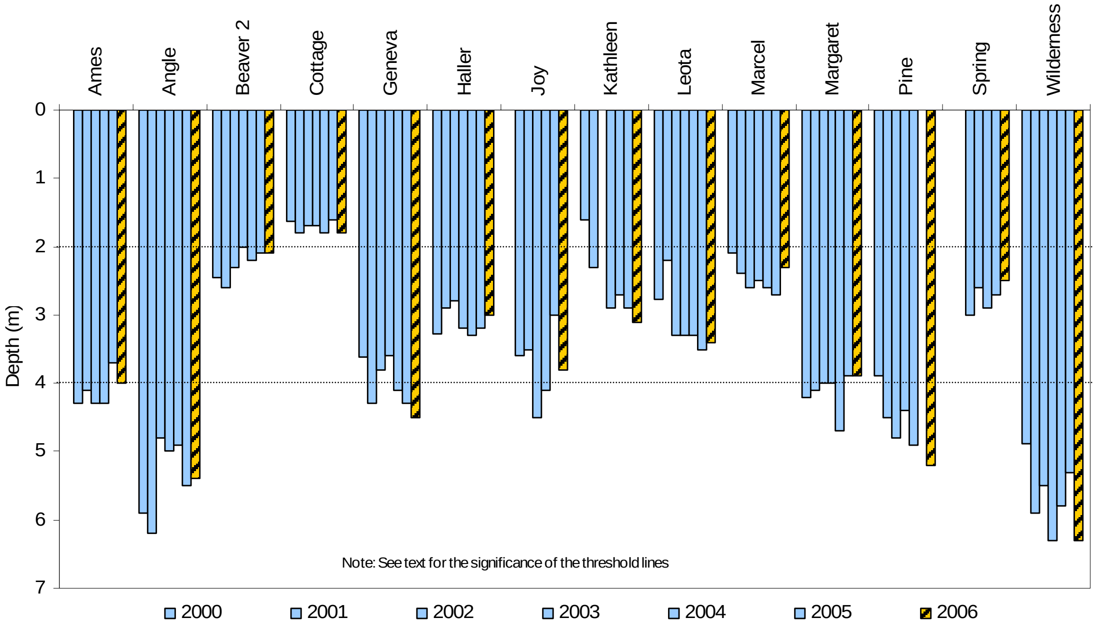
Secchi Depth 2006

Average annual Secchi depths for lakes measured by the Level I volunteers over the last five years (Figure B-1) can be evaluated by the relationship with the Trophic State Indicator (TSI) thresholds, which are based on water clarity and its relationship to algal abundance (see dotted lines in the figure). A Secchi reading of 2 meters in produces a TSI value of 50, which represents the threshold between mesotrophic (medium) and eutrophic (high) algal productivity, while a Secchi reading of 4 meters produces a TSI of 40, which marks the change from oligotrophic (low) to mesotrophic productivity.

The annual mean Secchi values for each lake with complete records over the past seven years show a consistency between values over time, although there are major differences between lakes around the county. Lakes with clarity generally deeper than 4m include Angle, Pine, and Wilderness. For the last two years, Lake Margaret has been below the 4m threshold, but was at or above it for the five previous years. Ames Lake has also showed a similar threshold pattern of recent decreases in clarity. In contrast, Lake Geneva has been increasing in clarity over the last three years, hovering around the 4m threshold.

Seven lakes were between 2 to 4m in average clarity, and there were few large fluctuations from year to year among them, although Lake Joy appeared to vary more than the others. Kathleen appeared to be increasing in clarity over the years, as does Marcel, although 2006 showed a decrease. Transparencies at Spring Lake were deeper than the 2m threshold, but declined over time, as did Beaver-2. Cottage Lake was the only water body in which transparencies were shallower than the 2m threshold for all the years shown.

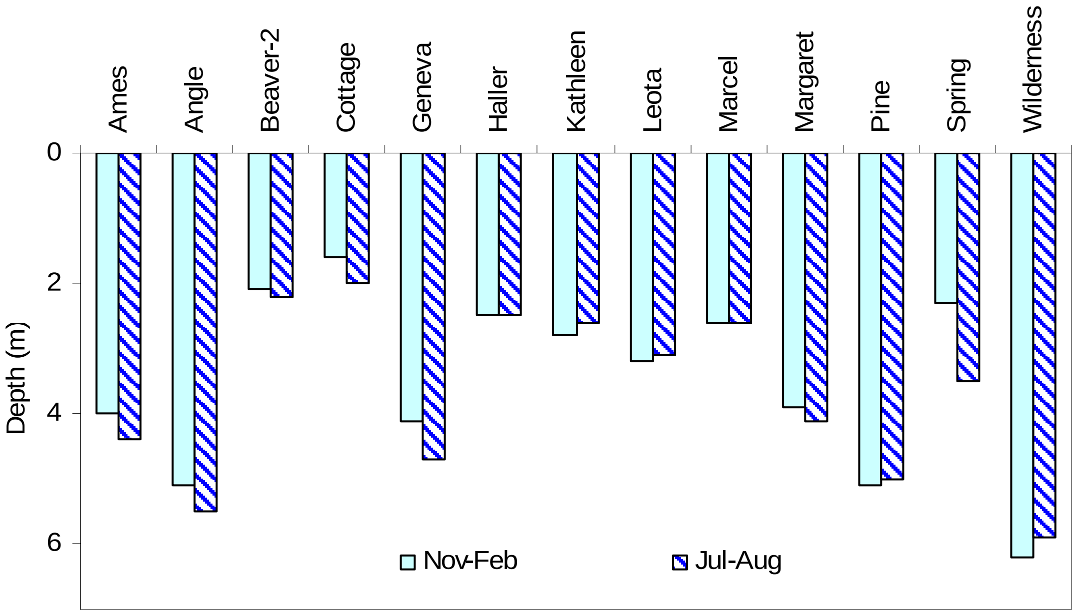
Figure B-1. Average annual water clarity (Secchi transparency), measured at weekly intervals.



In some cases, shallower Secchi depths may be caused by particle inputs from storm water runoff rather than algal abundances. In addition to storm water inputs, wave action (due to strong winds) and low light levels during the winter months can also be important factors influencing shallower average Secchi depth measurements. To evaluate these possibilities, two specific time periods were examined from the Level I Secchi data (Figure B-2) to see if wet season effects (November-February) could be separated from influences associated with summer algal blooms (July-August). Spring and autumn data were not included in this analysis because both major storm events and large phytoplankton blooms can occur during those seasons, thus confusing any possible interpretation.

During the wet months, significantly smaller transparencies were observed for 6 of the 13 lakes with comprehensive annual data for Secchi depth, indicating that storm water runoff or winter seasonal effects probably influenced water clarity in these lakes to a greater degree than the summer algal populations. These lakes included Ames, Angle, Cottage, Geneva, Margaret, and Spring. Two lakes, Kathleen and Wilderness, had decreased transparencies in the summer, indicating algal blooms might be impacting water clarity. Five lakes had essentially equivalent transparency for both periods, including Beaver-2, Haller, Leota, Marcel, and Pine.

Figure B-2. Average November-February Secchi transparency compared to average July-August values.



Water color

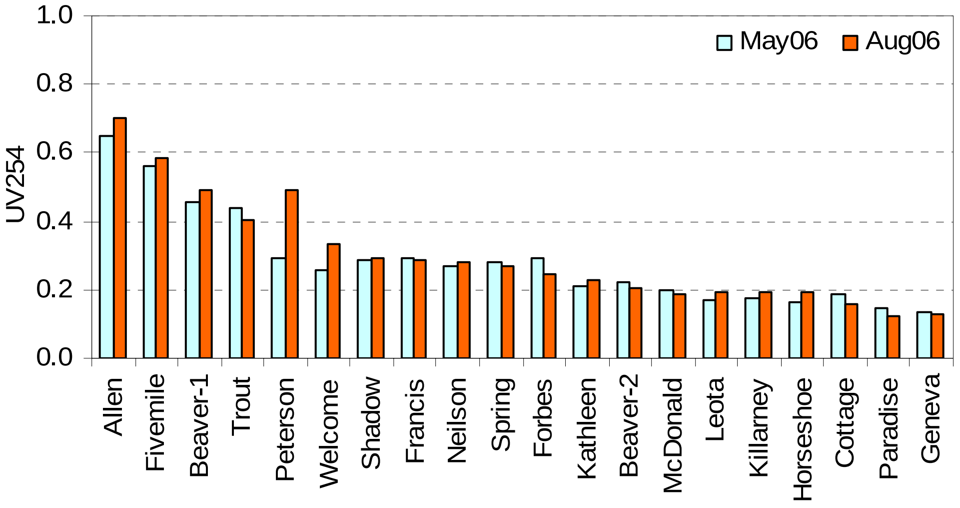
The water molecule has very little color by itself, but pure water will usually appear to be somewhat blue due to the scattering of light penetrating the water. Lake water can appear to be highly colored, due to the other substances dissolved in the water, such as large organic molecules from sources such as wetlands and bogs, algae present in the plankton, clays and silt in suspension (glacial lakes), and other chemicals such as iron compounds or calcium carbonate.

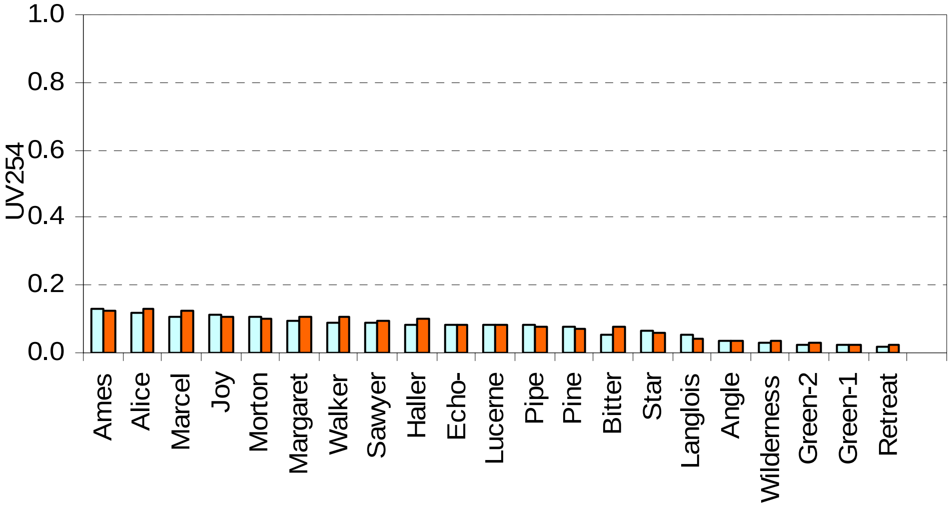
Generally, lakes with adjacent or nearby wetlands will have more color because of the leaching of undecomposed organic substances from the wetland into the lake. The hummocky glacial topography of the Puget lowlands creates many such wetlands, and quite a few lakes in the county have “tea” colored water as a result. Area soils can also contribute, particularly when there is little impermeable surface from development.

Color due to organic molecules (yellow to brown) can be measured by the amount of light energy the molecules absorb in the ultraviolet frequencies (Figure B-3). Lakes with large amounts of organic molecules will have less water clarity, and the differences in light penetration and dissolved organic matter will affect the species of algae that can grow well.

Water color was measured in May and July, with little difference seen between measurements for most of the lakes. Allen and Fivemile were the most highly colored lakes, and both have extensive wetlands in direct contact with the lake water. Beaver-1, which was also highly colored, has a nearby high quality sphagnum peat bog that feeds directly into the lake, as well as wetlands along its western margin. Beaver-2 has much less color, but receives water from sources in addition to water flowing from Beaver-1.

Figure B-3. Amount of color in lake water due to organic compounds, measured by UV254 absorbance for samples taken in May and August.





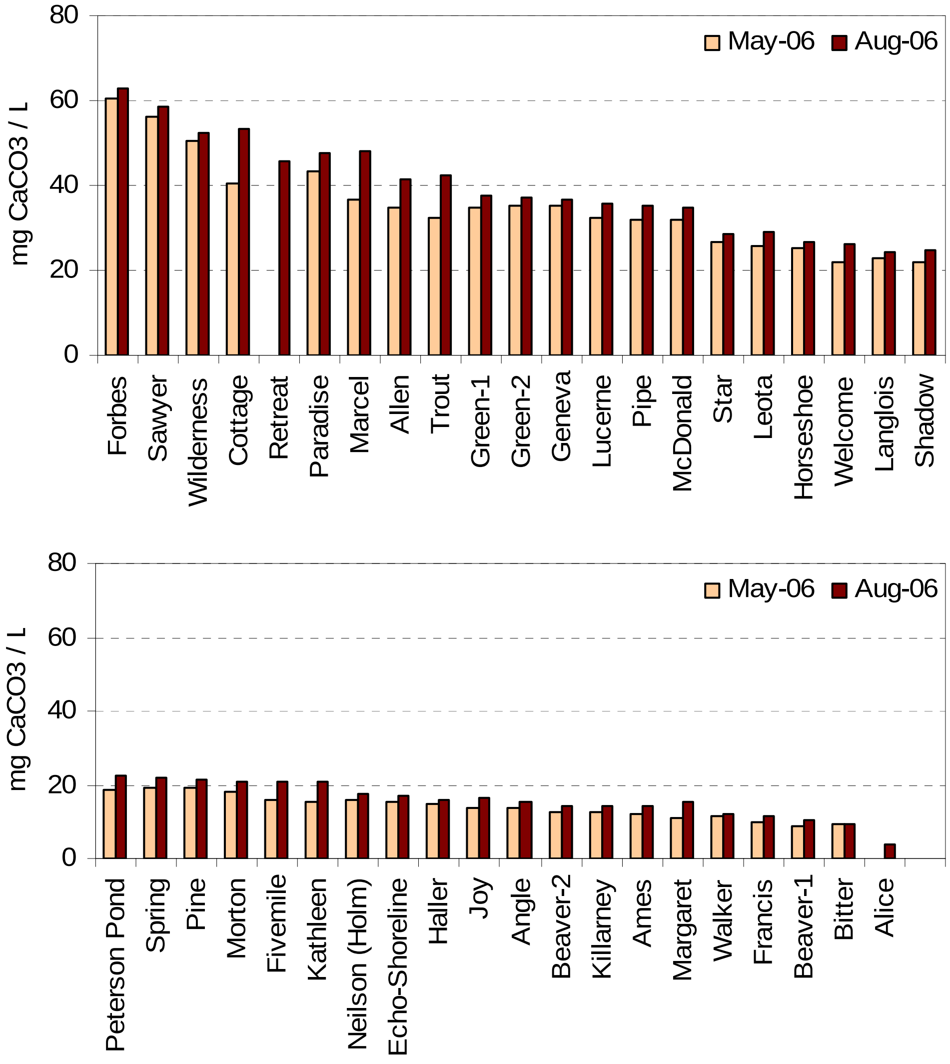
Other lakes with distinctly colored water (around 0.2 or above on the scale) generally also had associated wetlands or were situated in relatively undeveloped watersheds containing wetlands. Forbes Lake was an exception, since it is well-colored and has associated wetlands, but is located in a highly developed area of Kirkland.

Some rural lakes with little watershed development, even those with associated wetlands, were fairly light in color. These included Alice, Marcel, and Langlois. Most lakes in urban areas had relatively little color, possibly due to the filling and displacement of natural wetlands in the area, as well as little percolation of run-off water into watershed soils. Pine Lake originally had a wetland feeding into the lake, which was diverted in the late 1980s to control phosphorus inputs.

Total Alkalinity

Total alkalinity is the capacity of the lake water to absorb hydrogen ions without changing the pH of the water. It is also known as acid neutralizing capacity. This is usually related to the amount of carbonate and bicarbonate anions in the water, balanced by cations such as calcium, magnesium, and sodium. Soft water lakes that contain small concentrations of these dissolved elements and molecules can change pH rapidly, which modifies one of the environmental conditions for plants and animals living in the lake. Hard water lakes have more dissolved salts, and pH does not change so quickly. Total alkalinity was measured at the same times as water color, in May and August (Figure B-4).

Figure B-4. Total alkalinity at1m, measured in May and August.



The Puget lowlands are blanketed by glacial drift left by receding land glaciers, and very little bedrock is exposed on the surface. This means that, unlike in areas with limestone bedrock in direct contact with soils, surface waters and shallow aquifers are in general rather soft. Areas that have undergone more development and areas that have been mined for coal usually yield more dissolved salts and ions, so lakes in those areas of the region may have higher alkalinities. However, none of the values are as high as waters in limestone areas, such as the Midwestern USA, where alkalinities can be 150mg/L or higher.

Lakes monitored in the program ranged from the low of 4 mg/L in Lake Alice to over 60 mg/L in Forbes Lake. Most of the low alkalinity lakes are rural, with relatively small watersheds. However, several are quite urban in character, including Bitter, Killarney, Angle, and Haller, with high percentages of impervious surface in their catchments. However, these lakes tend to have fairly small watersheds as well, so that much of the water coming into these lakes is from direct precipitation.

It can be seen on the charts that in nearly every case, the alkalinity derived in August is slightly higher than that measured in May. This is probably due to two different factors. One is the lack of dilution by rainwater due to the dry summer climate of the region. The other is that nutrient uptake by growing algae tends to drive the chemical balance of the dissolved ions in the water towards an increase in carbonic acid anions. Data from other lake studies has shown that alkalinities drop in winter and rise in summer on a regular cyclical basis in the region.

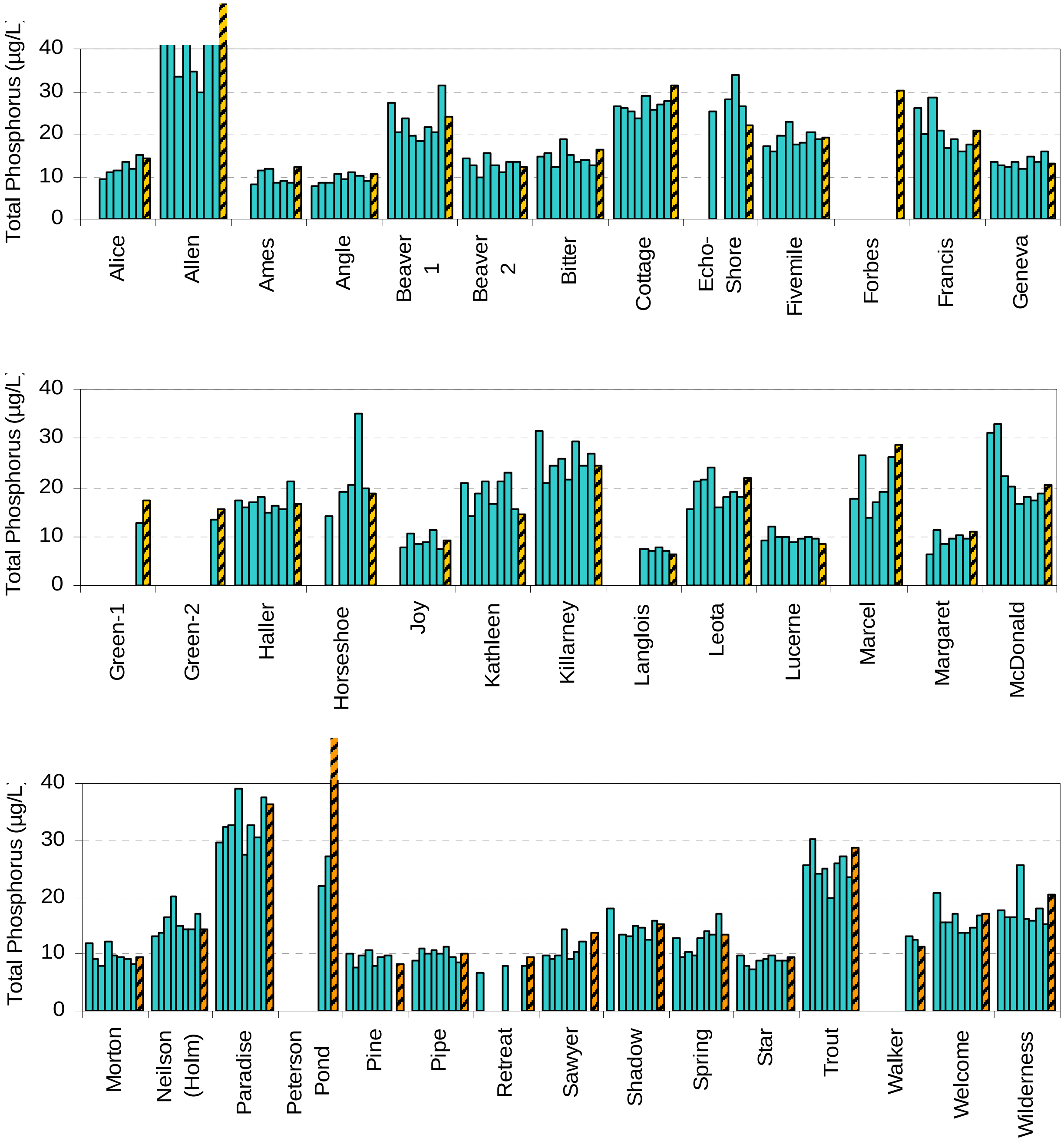
Total Phosphorus

Many water quality problems in lakes can be related to high concentrations of nutrients that stimulate the growth of algae and aquatic plants beyond what is considered beneficial for human use. In temperate freshwater systems, the nutrient that limits algae growth is most often phosphorus, although phytoplankton can also be occasionally limited by nitrogen concentrations or even by silica or iron availability. Before trying to manage a water quality problem, it is important to know which nutrient is limiting plant growth most frequently in the lake and which one can be most easily managed to bring growth into line with the beneficial uses envisioned for the lake.

Since phosphorus is generally considered to be the nutrient in shortest supply in this geographic region for algae growing in lake water, keeping track of phosphorus concentrations during the growing season is considered essential to a basic water quality monitoring program.

Many lakes have little variation in phosphorus levels from year to year, although some variation can be expected to occur due to the many factors that impact phosphorus inputs. Nine consecutive years of phosphorus measurements were examined for the lakes monitored in 2006 (Figure B-5). Several differing methods of analysis were employed to search for overall trends or changes over time.

Figure B-5. Average phosphorus concentrations at 1m depth, May – October.



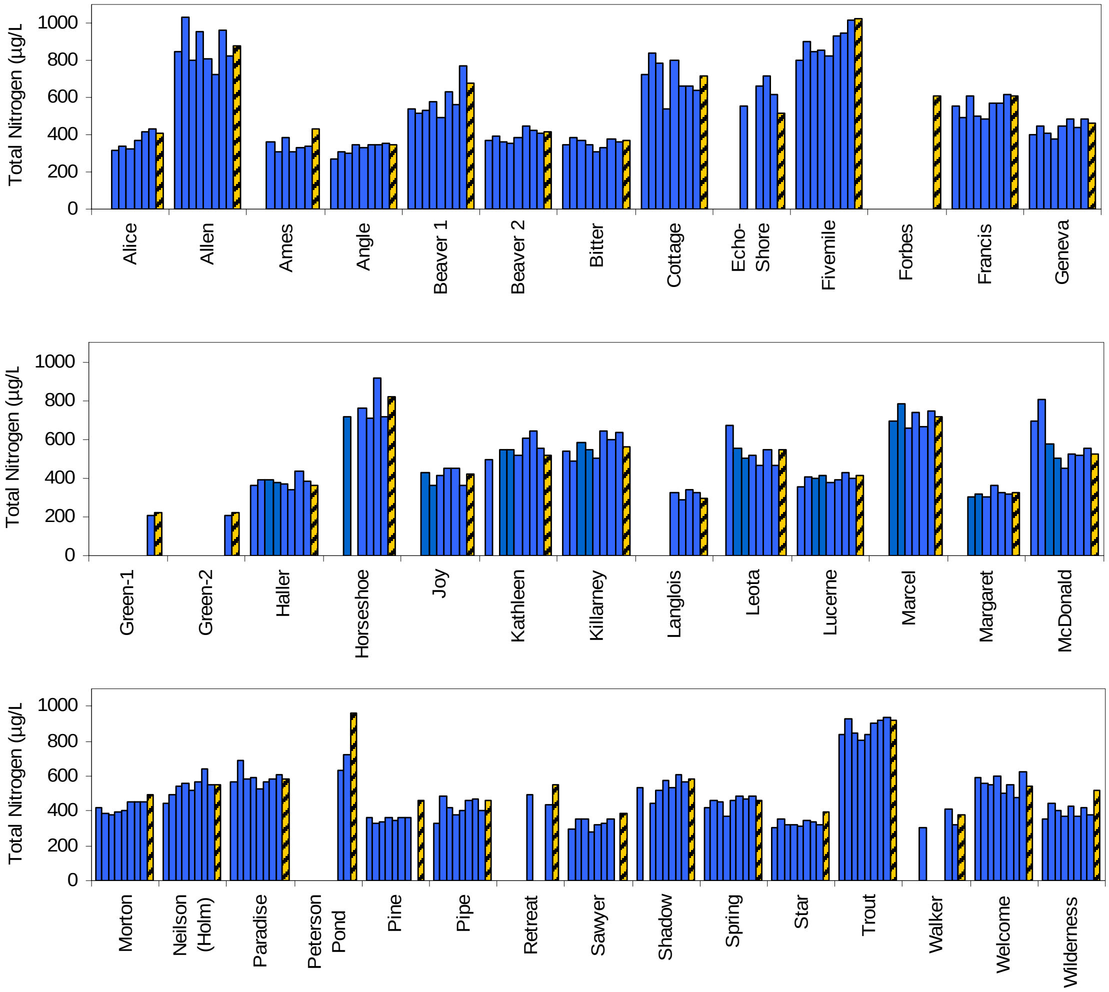
Thirty-one of the 38 lakes with multiple years of data yielded average total phosphorus concentrations over the interval without any marked trend of increase or decrease. Several lakes had large swings in phosphorus between years, including Allen, Killarney, Paradise, and Marcel. Lakes with more decreases than combined increases and remaining steady included Beaver-1, Beaver-2, Boren, Geneva, Killarney, and Trout. Lakes with more increases in phosphorus than combined decreases and holding steady included Allen, Francis, Leota, and Marcel. Lakes that showed a potential for increasing over time (more increases than decreases) included Alice, Cottage, Margaret, Neilson (Holm), Sawyer, Shadow, and Spring.

Forbes, Green (stations 1 and 2), Retreat and Walker will need more years of data collection before patterns begin to emerge.

Total Nitrogen

Nitrogen is usually more than ten times more abundant by weight in the environment than phosphorus, but can become the limiting nutrient on occasion when phosphorus inputs increase. In addition, the ratio of nitrogen to phosphorus can be a good indicator of which algal species will do well in a body of water because of their differing needs.

Figure B-6. Average nitrogen concentrations at 1m, May – October.



Similar analyses to those for phosphorus were carried out on nitrogen concentrations for monitored lakes (Fig B-6). Twenty-five of the 38 lakes with multiple years of data yielded average total nitrogen concentrations over past years without any marked trend of increase or decrease. Several lakes had large swings in nitrogen between years, including

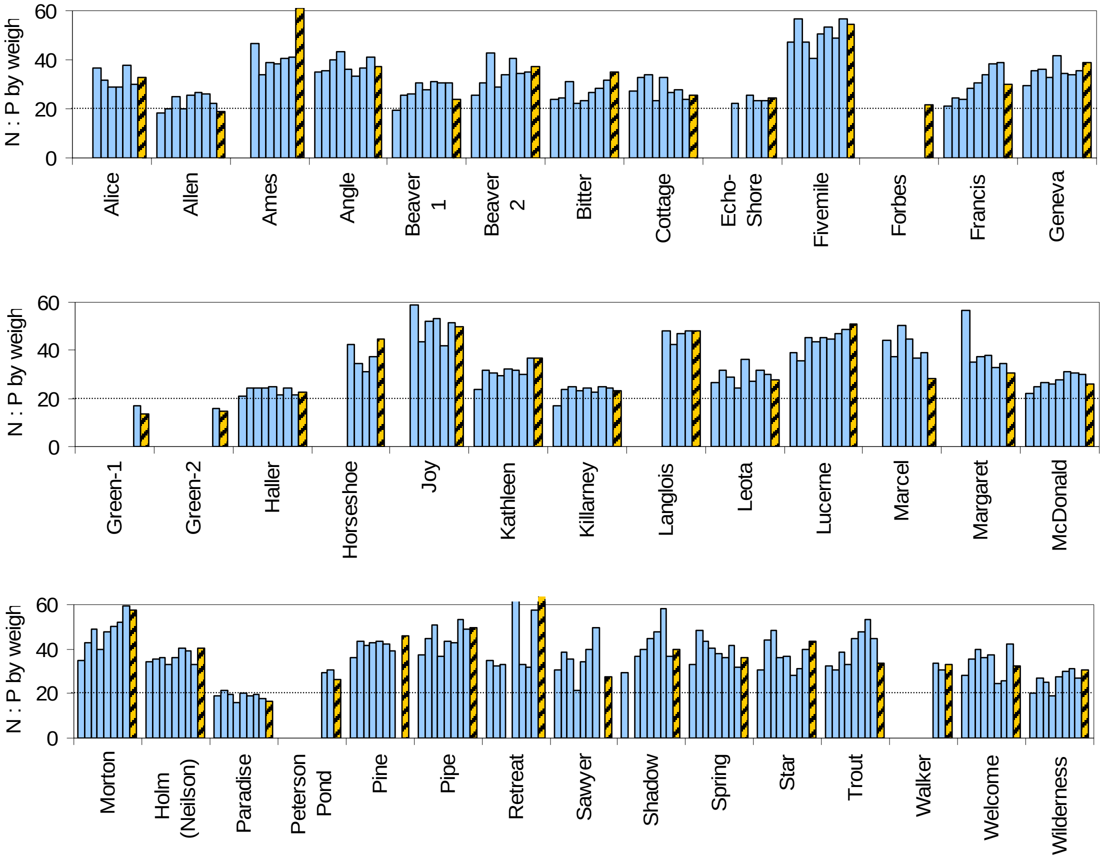
Allen, Cottage, Echo-Shoreline, and Horseshoe. Lakes Killarney and Leota had total nitrogen that decreased somewhat steadily while Welcome Lake may be decreasing, but the pattern was not clear-cut. Lake McDonald decreased in total nitrogen in the late 1990s and has been stable since then. Lakes with steadily increasing nitrogen concentrations included Neilson, Sawyer, and Shadow. Lakes that showed a possibility of increase over time included Angle, Alice, Beaver-1, Fivemile, Morton, and Neilson (Holm).

Forbes and Green Lakes reported Level II data for the first or second time, and these lakes will need more years of data collection before patterns begin to emerge.

Nitrogen: Phosphorus Ratios

One way to make a quick nutrient assessment of a lake is to calculate nitrogen to phosphorus ratios (N:P, Figure B-7).

Figure B-7. Average ratio of N to P at 1m, May – October.



Generally, nitrogen to phosphorus ratios of 17:1 or greater indicate that phosphorus availability is limiting algal growth (Carroll and Pelletier 1991). Within each lake, the ratio varies throughout the growing season. Some lakes are primarily phosphorus limited, but occasionally may be nitrogen limited. Others are solely governed by one nutrient, which is in the shortest supply through the season. Lower nitrogen to phosphorus ratios can favor bluegreens over other algal species, because some bluegreen species are able to use nitrogen from the air, unlike other algae, so they are limited by nitrogen available in the water. A ratio of 20:1 or below is generally indicative of potentially advantageous conditions for bluegreen growth.

A biological wrinkle in using N:P ratios to assess the potential for algal growth is that some algae can take up phosphorus and store it for use later in the season when phosphorus concentrations have become very low in the epilimnion (so-called "luxury uptake"). Thus, the population growth rates of such algae may be reflecting earlier conditions of phosphorus availability rather than the period during which they are being measured.

Several lakes averaged N:P ratios below 20 for the period of May-October 2006, including Allen, Green, and Paradise. Lakes with values near 20 or with records of many values near 20 over time include Echo-Shoreline, Forbes, Green, Haller, Killarney, and Paradise. Only Green and Paradise Lakes had seasonal averages below 17 in 2006, suggesting nitrogen limitation for at least part of the May – October period.

A number of lakes with ratios averaging ratios above 20, experienced distinct periods during the sample season with ratio values at or below the threshold. Most of these were characterized by declines in early fall to levels at or below the 20 threshold. Lakes in this group included Ames, Beaver-1, Bitter, Cottage, Geneva, Leota, Marcel, McDonald, Sawyer, Shadow, Spring, and Wilderness. These distinct periods of low N:P ratios could have encouraged growth by nuisance bluegreen species, even if the entire season was not characterized by low ratios.

Upward trends in N:P ratios through time can be seen for lakes Bitter, Beaver-2, Francis, Lucerne, Morton and Pipe, while apparent declines (lower ratios) were seen in Spring and Margaret lakes, both of which have relatively good water quality to date. Average ratios in other lakes either changed greatly from year to year or showed no particular trend or directionality.

The increase in average N:P ratios overall suggest that nutrient conditions for bluegreen algae are becoming less favorable in a general sense, thus potentially reducing the possibility of toxic bluegreen blooms on a region-wide basis, although many lakes may still be at risk, particularly during the fall.

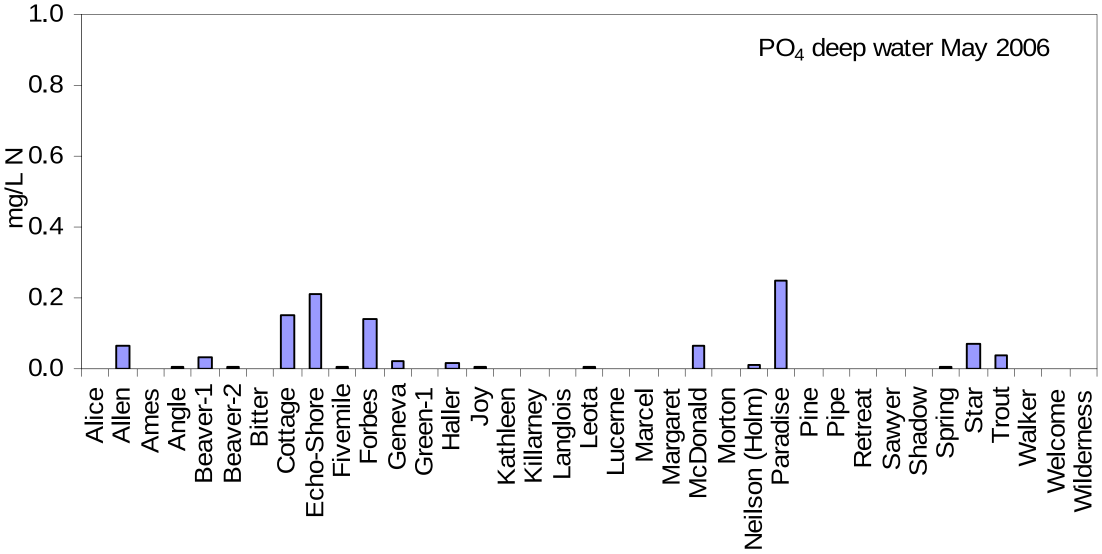
Deep water nutrients

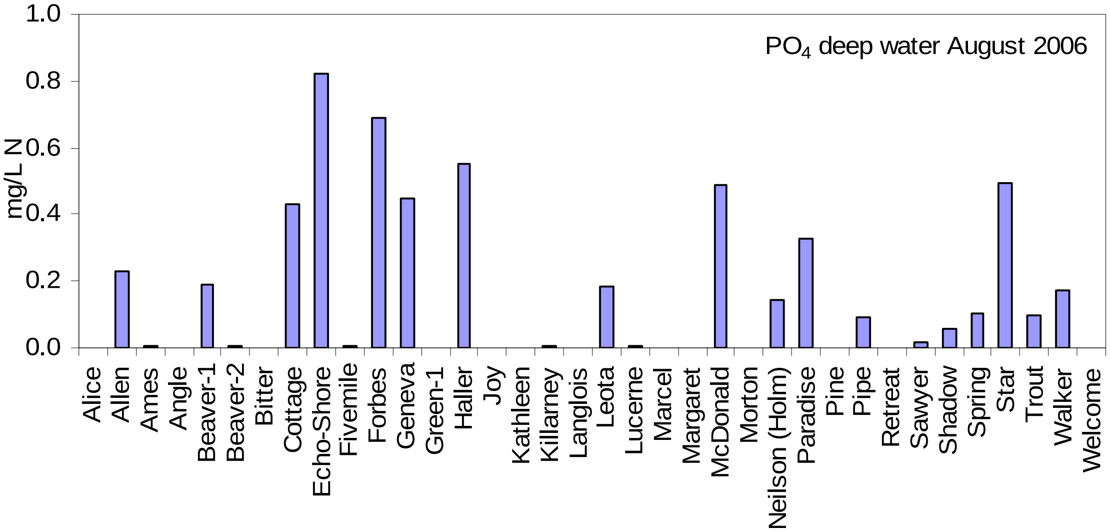
If lake water remains stratified thermally for a significant period of time, such as over the summer months, the deep water of the hypolimnion is cut off from oxygen entering the lake through contact with the atmosphere, thus making recharge impossible during that period of time. This means that animals living in deep water and decomposers such as bacteria in the sediment gradually deplete the dissolved oxygen content through their metabolic needs. In some lakes, this means the water in the hypolimnion can become anoxic (without oxygen, referring to the dissolved gaseous oxygen in the water), which makes it unlivable for most animals while the condition persists.

In addition to making the water inhospitable for animals, anoxia also changes the chemical environment at the deep water / sediment interface. This leads to phosphorus release from the lake sediments back into the water, which is then recycled throughout the lake in the fall when thermal mixing occurs. Higher amounts of dissolved inorganic orthophosphate (OPO_4) can be found in deep water in late summer when this happens (Figure B-8).

Deep water was measured twice in most of the lakes: once in late May, which was considered to be the beginning of summer, and again in late August, which was considered to be a time before mixing down had occurred. Some lakes were too shallow to be sampled for deep water, including Francis, Horseshoe, and Peterson Pond.

Figure B-8. Concentrations of orthophosphate found in deep water samples in late May and late August.

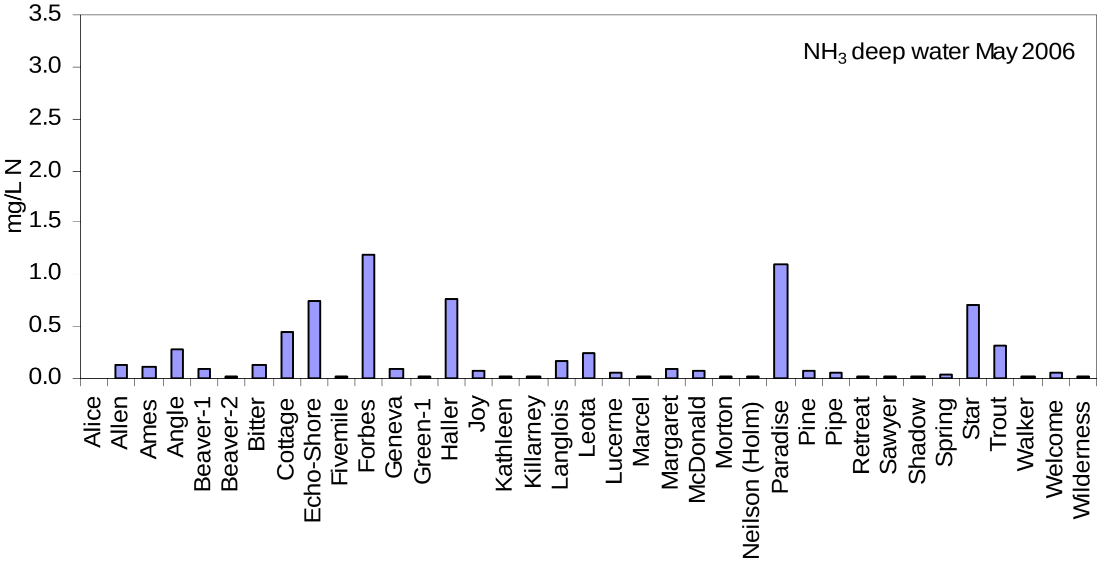


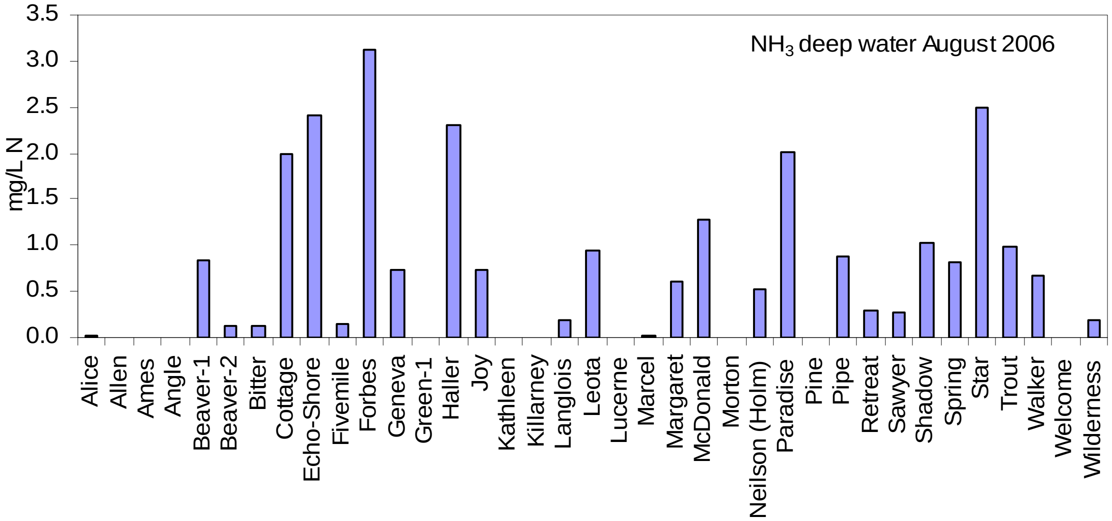


The difference in the amount of orthophosphate present in the deep water between May and August is very large for a number of King County lakes, including Cottage, Echo-Shoreline, Forbes, Geneva, Haller, McDonald, Paradise, and Star. Lakes Allen, Beaver-1, Leota, Neilson (Holm), Pipe, Sawyer, Shadow, Spring, Trout, Walker and Wilderness also experienced an increase in orthophosphate through the summer, but on a low to moderate scale, thus suggesting that internal loading due to sediment release is a smaller component of the phosphorus inputs for those lakes than for the ones with large orthophosphate concentrations in the deep water towards the end of summer.

Ammonia (NH_3) is another chemical whose presence indicates little or no dissolved oxygen in deep water (Figure B-9).This is because the nitrogen that is generally present in molecules combined with oxygen (NO_2 and NO_3) will convert to ammonia in the absence of oxygen in the water column.

Figure B-9. Concentrations of ammonia found in deep water samples in late May and late August.





Similar to phosphorus, the concentrations of ammonia increase greatly for some lakes between May and August, and in general it is the same lakes experiencing the increase. However, they are not always proportionally equivalent, and that can be related to the differences in nitrogen and phosphorus cycles for each lake. Nitrogen is also generally much more abundant by weight than phosphorus in lake water, and that is reflected in the different Y-axis scales between phosphorus and nitrogen in the charts.

Lakes with large amounts of ammonia in the deep water by the end of summer include Cottage, Echo-Shoreline, Forbes, Haller, McDonald, Paradise, Shadow, and Star. Lakes with more moderate amounts include Allen, Beaver-1, Geneva, Joy, Leota, Margaret, Neilson (Holm), Pipe, Spring, Trout, and Walker. Some lakes had slightly larger amounts of ammonia in May than in August, for example Allen, Ames and Pine, but these numbers were always at very low levels and may be within the error of the measurements.

It should be noted that the deep sample from Lake Langlois was not from 1m above the absolute bottom of the lake because the lake is meromictic and rarely if ever mixes all the way through the water column. Instead, the deepest sample from Lake Langlois was taken from a meter above the chemocline (the depth at which dissolved materials increase enormously in concentration, marking the bottom of the actual mixing zone in the lake).

Conclusions

From a regional perspective, the water quality of King County lakes remains good, supporting beneficial uses through the recreational season and causing little cause for concern as a whole. One area of continued concern is late summer through fall blooms of bluegreen algae, fueled by mixing up of deep water nutrients with the change of seasons.

Several lakes may profit from close attention to changes over time. Green Lake, which has low overall phosphorus concentrations as a result of an alum treatment, is expected to increase in phosphorus over time because external sources are difficult to control in the watershed. The timeframe for this to occur is not known, so monitoring should fill the knowledge gap. Because nitrogen is relatively low in this lake, bluegreen algae are greatly benefited by phosphorus increases due to their ability to fix nitrogen from the air.

Cottage, Spring and Margaret Lakes are increasing in phosphorus over time, while nitrogen is remaining more or less steady, thus decreasing the N: P ratio. Cottage Lake is listed on the EPA 303d list for phosphorus impairment and there is currently a project to underway to reduce phosphorus inputs to the lake through community education and shoreline restoration projects. While both Spring and Margaret currently have good water quality, Spring Lake has had some bluegreen algae blooms in the fall and should be watched for increased frequency of these occurrences. Good water quality in Lake Margaret is of special importance because of its use as a domestic water supply reservoir, so it should be tracked closely as well.

Lakes that have increased in both phosphorus and nitrogen include Alice, Neilson (Holm), Sawyer and Shadow. The N:P ratios for all of these lakes have remained essentially the same. One lake, Morton, has increased in nitrogen while phosphorus has remained steady. Both Sawyer and Shadow have experienced fall bluegreen blooms and should be watched closely. Sawyer has a TMDL for phosphorus similar to Cottage Lake and a set goal of a summer average of 16 μg/L total phosphorus, which it has met since 1998.