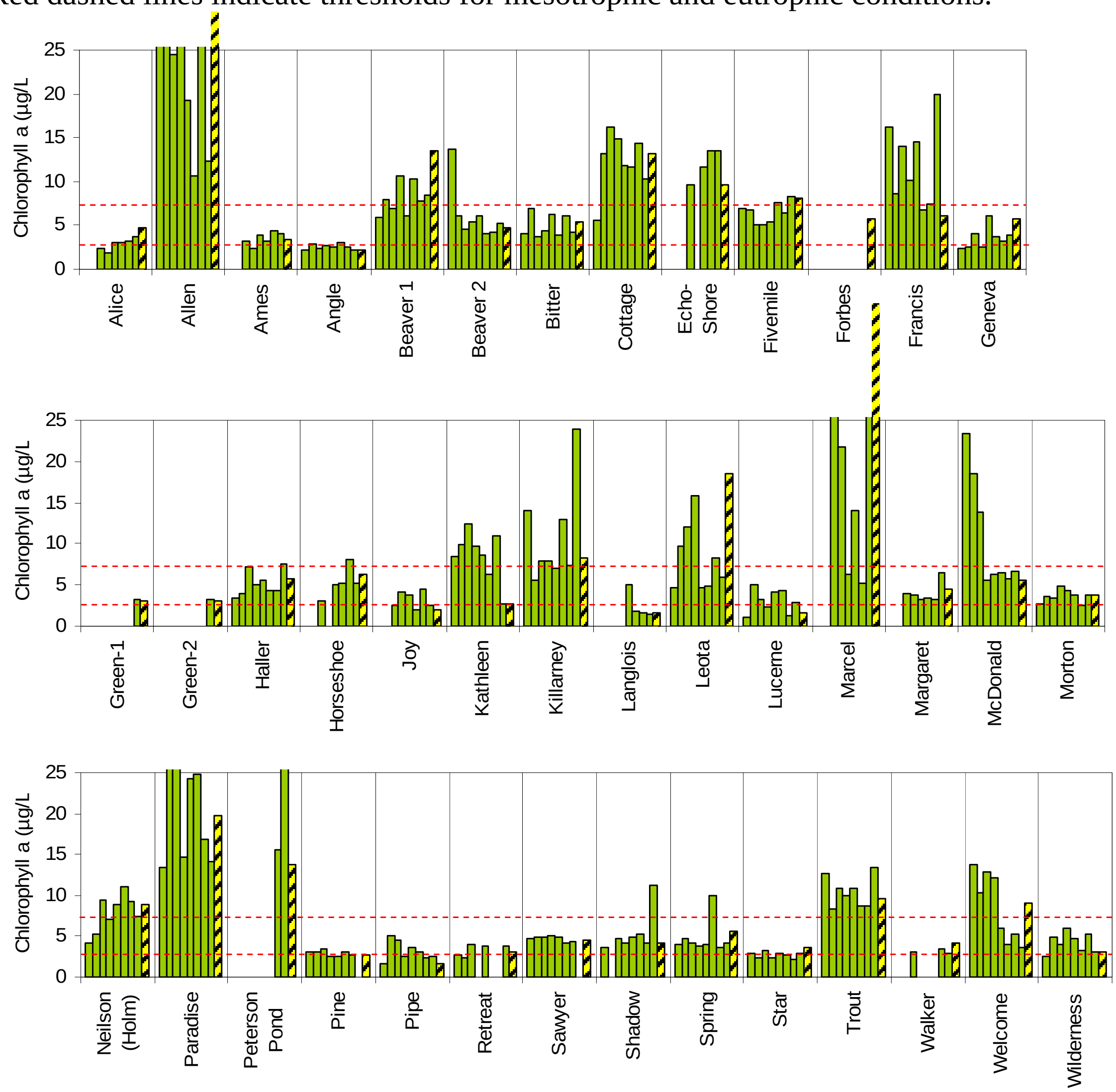
C. REGIONAL ASSESSMENT: chlorophyll and trophic state index 2006

Chlorophyll a

Variability is often much greater from year to year in chlorophyll *a* concentrations (Figure C-1) than it is for nutrients or the N: P ratio. This is not surprising because many different factors can influence algae concentrations at the time a water sample is taken. For example, the phytoplankton populations in a lake can be concentrated into an area by wind and water movements and so may not be evenly distributed at the time of sampling. Lack of wind can cause bluegreens to float up to the surface, concentrating them at the top of the water column, while other species, such as chlorophytes and diatoms, may sink down towards the thermocline, out of the surface water.

Figure C-1. Average chlorophyll-a concentrations at 1m, May – October, 1998-2006. Red dashed lines indicate thresholds for mesotrophic and eutrophic conditions.



In addition, algal species present in a lake can change from year to year, and species differ in the amount of chlorophyll per cell, thus leading to variation in the relationship between chlorophyll concentrations and algal biovolumes. For example, large blooms of bluegreens (cyanobacteria) may yield less chlorophyll than equivalent volumes of green algae (chlorophytes) because many bluegreens have accessory pigments that are used to capture light for photosynthesis. The amount of chlorophyll *a* per cell can also vary with the health and age of the population as well.

The dashed lines on the chart mark the thresholds for Trophic State Indicators. The lower line marks the transition between oligotrophic and mesotrophic, while the upper dashed line marks the change from mesotrophic to eutrophic.

Even with all the variables that come into play for each sampling date, the annual May-October averages of chlorophyll compared over time demonstrate that most of the lakes in the program have generally similar average concentrations from year to year or else vary within a definable range. This is particularly true of lakes in the lower range of average concentrations, hovering at or below the mesotrophic threshold, including: Alice, Ames, Angle, Geneva, Joy, Langlois, Lucerne, Margaret, Morton, Pine, Pipe, Star, Walker, and Wilderness. Lakes Alice and Geneva may be increasing over time, while Pipe appears to be declining. Green Lake chlorophyll levels are currently low as a result of the alum treatment done in 2004.

While lakes with lower overall chlorophyll averages tend not to vary a great deal, some lakes in the middle of the distribution may have one or two years in which chlorophyll was significantly higher than in the other years. Single year high averages may be anomalous and not repeated in the future, or could also be indications of regularly occurring, but ephemeral, blooms that coincide with a sampling date in a particular year, but may be missed in others because of wind moving blooms around the lake or the two-week gap between sample collections. Lakes with this pattern include Beaver-1, Beaver-2, Bitter, Fivemile, Haller, Horseshoe, Leota, Neilson (Holm), Sawyer, Spring, and Welcome. Lakes that appear to have increased chlorophyll over time include Beaver-1, Fivemile, and Neilson (Holm). Lake McDonald, which has had high chlorophyll concentrations in 1998, has dropped to a moderate amount in the last 6 years. Welcome Lake may be showing a similar pattern as well.

Average annual chlorophyll values for lakes with higher concentrations of chlorophyll often varied a great deal from year to year, but were generally considerably higher than other lakes in the program. These lakes included Allen, Cottage, Echo-Shoreline, Francis, Kathleen, Killarney, Marcel, Paradise, Peterson Pond, and Trout.

Discussion

Average concentrations of chlorophyll *a* may vary a great deal from year to year, particularly in lakes with large amounts of algae. Concentration of algae by wind and water movements can lead to samples being taken that are not representative of the lake as a whole, being either too high or too low. However, chlorophyll concentrations from the center of the lake are rarely high at lakes with low over-all productivity, and the yearly averages over time generally appear to be within a constant range for any one lake. Chlorophyll tends to vary more at lakes with generally high phytoplankton abundances, such as at Allen. As a measure of productivity, chlorophyll may be subject to more variability than either Secchi or TP.

Most lakes within the volunteer monitoring program either remained steady in 2006 relative to past years or continued a pattern of unpredictable variability from year to year. Lakes that may be showing downward trends over recent years include Beaver-2, Kathleen, Pipe, McDonald, and Welcome. Lakes that may be showing upward trends, although some are small in magnitude, include Alice, Beaver-1, Fivemile, Geneva, and Neilson (Holm).

Trophic State Index

The productivity of lakes can be classified using calculated values that predict biological activity called the Trophic State Index (TSI), based on measured conditions in the lake. TSI values provide a standardized way to rate lakes on a scale of 0 to 100. Each major division (10, 20, 30, etc.) correlates with a doubling of algal biovolume and its relationship to various measurable parameters by linear regression and re-scaling (Carlson, 1977). The indices are based on the summer mean values (May through October) of three commonly measured lake parameters: Secchi depth, total phosphorus, and chlorophyll *a*.

The relationships are not always straightforward. Carlson points out that highly colored lakes containing large amount of dissolved organic matter may produce erroneously high TSI ratings for Secchi transparency, since the clarity is impacted by water color. The shape and size of dominant phytoplankton species can also influence the Secchi reading, as well as the chlorophyll values, since small, diffuse algae cloud the water more than large, dense algal colonies, and the species of algae can vary in the amount of chlorophyll they contain.

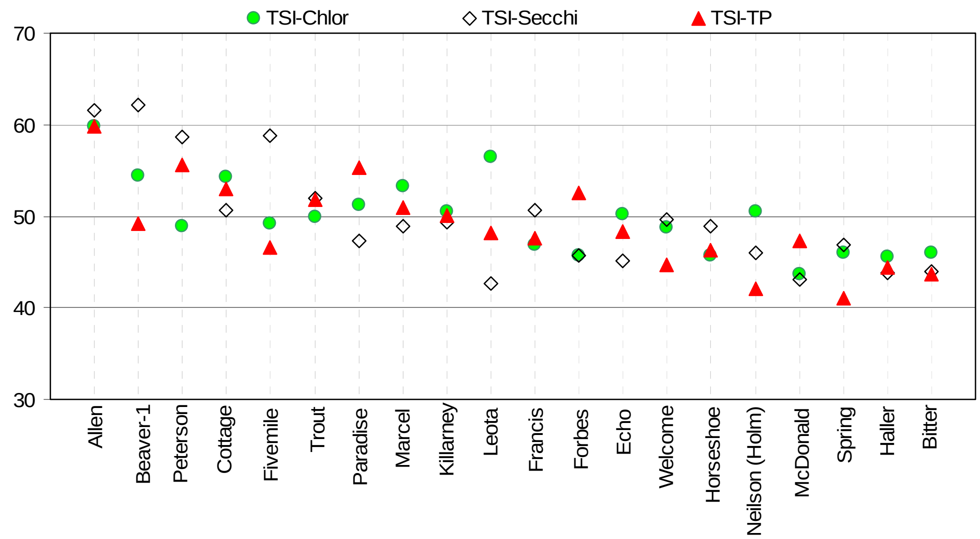
It is important to note that the total phosphorus measure is most reliable for lakes that are strictly phosphorus limited for algal nutrition, and the TSI relationships may not be validated when nitrogen is the limiting nutrient instead. Although no lakes in King County have been identified as solely governed by nitrogen limitation, there are several lakes in which nitrogen appears to be limiting at times through the season or in which phosphorus and nitrogen limitations occasionally alternate or operate together.

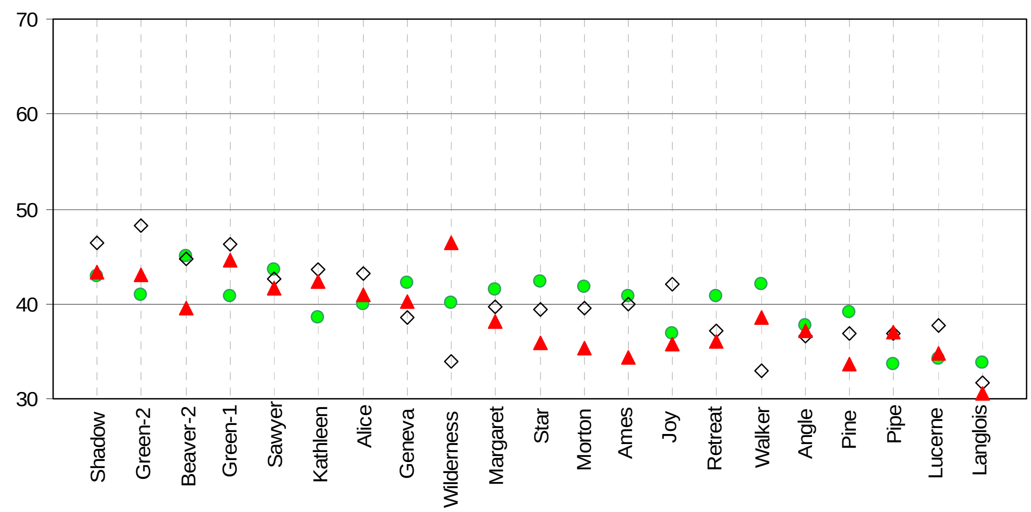
2006 TSI Ratings

TSI values were calculated for the three parameters measured on each sampling date for the lakes monitored by Level II volunteers (Figure C-2), and the average over the season for each was plotted. The lakes were arranged by the average of all three TSI values in descending order to show the range of values found for monitored lakes in the county. TSI values calculated over the past nine years for each lake are included in the individual lake descriptions (see Section 3).

Carlson (1977) points out that if all the assumptions are correct, the TSI values produced for the three different parameters should be very close to each other. Many King County lakes follow this prediction, but several have values that are not very close, suggesting that some different conditions or processes are active at those lakes. When lakes have two close TSI values and one very different one, the outlying value might be excluded from consideration if a reasonable explanation is put forward for the differing value.

Figure C-2. Average TSI values at 1m for three parameters for each lake measured in 2006.





Lakes Allen, Fivemile, Beaver-1, Trout, and Peterson could be reassessed because of water color (see discussion in section B on water color and measurements). Of these, both Allen and Trout actually show fairly good agreement between the three indices, but the TSI-Secchi values for Beaver-1, Fivemile, and Peterson are clearly higher than the other TSI values, which is probably related to the color of the water. Leaving out the TSI-Secchi value, Fivemile productivity is assessed as mesotrophic rather than eutrophic, while both Beaver-1 and Peterson are still above the threshold for eutrophy.

Several lakes had TSI-Secchi values lower than the other three indicators, suggesting unexpected water clarity. This can happen when the dominant algal species make large colonies that appear in the water as particles rather than creating cloudiness. Lakes which showed this pattern included Leota, Paradise, Walker, and Wilderness.

Oligotrophic lakes with TSI values less than 40 are considered to have low biological activity, with high clarity and low concentrations of chlorophyll *a* and total phosphorus. Five lakes met this criterion with all three TSI values at or below the threshold: Angle, Langlois, Lucerne, Pine, and Pipe. Eight lakes had two out of three TSI values at or below 40: Ames, Geneva, Joy, Margaret, Morton, Retreat, Star, and Wilderness.

Mesotrophic lakes have TSI ratings between 40 and 50. They are considered to be transitional between being relatively nonproductive and very productive biologically. In 2006, with two out of three indicators above the threshold or all three in the midrange or below, the lakes included Alice, Beaver-2, Green, Kathleen, and Sawyer. Lakes with all three indicators in the middle to upper range included Bitter, Haller, McDonald, and Shadow and Spring.

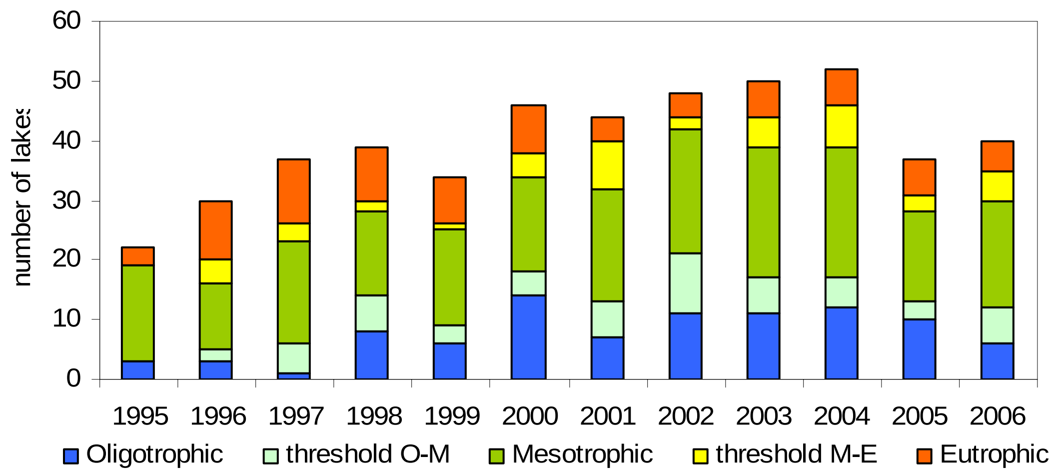
Higher range mesotrophic lakes, with all TSI values near the upper limit of mesotrophy, or with one of the three over the threshold of eutrophy, included Echo-Shoreline, Francis, Forbes, Horseshoe, Leota, Neilson (Holm), and Welcome. Fivemile is a special case because of water color, and it should be considered as part of this group as well.

Lakes that have TSI values greater than 50 are considered eutrophic, characterized by high biological productivity. Lakes with TSI values that suggested they were on the threshold of eutrophic conditions include Killarney, Marcel, Paradise and Trout. Lakes more solidly in the eutrophic classification included Allen, Beaver-1, Cottage, and Peterson Pond.

Discussion

Although the suite of lakes measured is not precisely the same from year to year, the years can be compared in a general way to look for regional conditions and trends (Figure C-3).

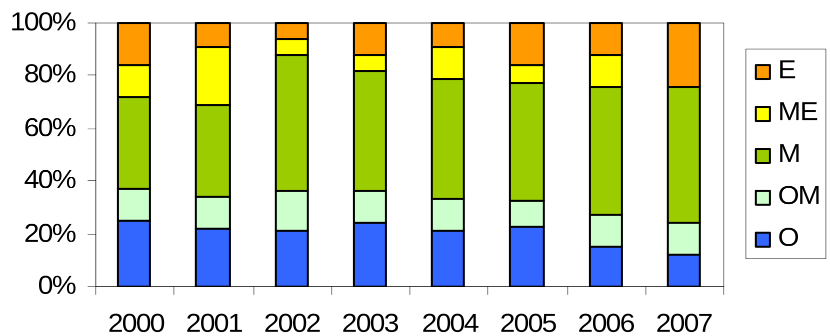
Figure C-3. Numbers of lakes monitored in each trophic state category, including threshold evaluations, between 1995 and 2006.



As in recent years, the majority of the lakes monitored in King County fall into the mesotrophic range for algal productivity, although the number of lakes measured varies from year to year. Slightly more lakes were measured in 2006 than in 2005, both down from the larger number of lakes participating in 2003-2004. The number of lakes in the oligotrophic category decreased between 2005 and 2006, while the lakes on the threshold between oligotrophy and mesotrophy increased. This may have to do with relatively warm conditions in early fall that allowed larger than usual populations of algae to persist. In any case, small changes from year to year may be expected in these numbers because of changes in the list of lakes included in the program, as well as annual variation in climate conditions.

A suite of 32 lakes that have been monitored regularly since 2000 were chosen to look for regional trends without the complication added of the addition and subtraction of lakes to the program each year (Figure C-4)

Figure C-4. Percentages by year of trophic state categories achieved by 32 lakes regularly monitored by Lake Stewardship Program and citizen volunteers, 2000 – 2006.



It is clear from looking at the percentages of lakes in each category over the last seven years that, while small changes are seen from year to year, no major regional trends are being observed in nutrient and algae concentrations in the small lakes of King County. However, it is quite possible that this picture may change with the accumulated impacts of increasing development in the watersheds and global climate change. Lakes can be sensitive integrators of everything that happens in their watersheds, and if major changes occur in the future, it is likely that those changes will be reflected in lake ecosystems.