Section 1
Introduction

Purpose of Report

This report is the ninth in a series that summarizes data collected by volunteer lake monitors annually. This volume, covering water year 2003 (October 2002 through September 2003) and extending into October 2003 for water quality measurements, provides citizens, scientists, lake managers, and other interested individuals with current information on King County lake water quality and physical conditions for lakes monitored by participating citizens.

For many lakes, these data represent the only reliable source of information for assessing current water quality and addressing questions regarding the characteristics of a particular lake. The information in this report can help to guide lake protection and stewardship activities in King County and can be used to plan further work to address specific questions about a lake's conditions.

Report Layout

While content has remained substantially the same as in the past, the 2003 report has been reorganized to make the information more accessible as a Web-based publication. The new format includes three sections, which will be available for downloading on the Lake Stewardship Web site at *http://dnr.metrokc.gov/wlr/waterres/smlakes/reports.htm*. Section 1 unites the introduction and methods chapter from earlier reports, but omits the extensive discussion of processes in lakes and human impacts that was repeated annually. Section 2 contains annual and comparative climatic information and the regionally-based reporting, analyses, and comparisons that were formerly found in Chapter 5. Section 3 combines the individual lake reports from the former Chapter 3 with Appendices A and B. All of the data tables, charts, and discussion for each lake will be included in subsections that are divided by lake, available for downloading on an individual basis. The chapter on freshwater algae has been omitted, since it also was repeated annually. Appendix C, which contained lake bathymetric maps, will now be available on the Web site to download as needed. Plans are being made to combine deleted portions with regionally specific information on geography, geologic history, and biology into a guidebook for King County Lakes that will not need annual updating.

Why Monitor?

The specific data that is collected on lakes varies from one program to another, depending on the chosen objectives of the program. For the King County Lake Stewardship Program, the overarching objectives of data collection have included: (1) gathering baseline data and assessing long-term trends, particularly for lakes that do not have other organized assessment efforts focused on them; (2) defining seasonal and water column variability over time to establish normal ranges; (3) identifying potential problems, proposing possible management solutions and alternatives, or pinpointing additional studies to be made to accomplish such goals; (4) educating lake residents, lake users, and policy makers regarding lake water quality and its protection; and (5) providing a solid, reliable, cost-effective foundation of knowledge that can be used for long-term stewardship of King County lakes.

Every lake is a unique body of water, reflecting the characteristics and hydrology of the watershed. Water quality is affected by the sources and relative quantity of water inflows, including the amounts and types of nutrients originating from the watershed, in particular nitrogen and phosphorus. For example, when the surface area of a lake represents a relatively large percentage of the total watershed, much of the precipitation falling in the basin goes directly into the lake, not passing first through soils, wetlands or constructed drainage systems. Thus, in this case relatively pure water makes up a significant proportion of the total input to the lake. In other cases where direct precipitation makes up a smaller proportion of the water input, land use practices throughout the watershed become very important influences on conditions as well as changes within lakes.

Water chemistry and physical characteristics in lakes vary seasonally as well as by depth at certain times of the year. The most dynamic period for lakes is during the “growing season” of mid-spring through early autumn when lake dwelling organisms are most active. This coincides with much of the primary recreational period for lakes in the Pacific Northwest.

Most of the more than 700 lakes and ponds in King County have never been monitored, and only a few have long term monitoring records. In 2003, the Lake Stewardship Program staff worked with volunteer monitors in the collection of Level I data on 38 lakes and Level II data on 51 lakes. Volunteers on 36 lakes completed five or more years of water quality monitoring, thus building a solid body of information for use in the future.

The Program has focused on the monitoring of water chemistry in the upper water layers during the growing season in order to characterize lake trophic state. However, during the summer, water chemistry and temperature vary with depth in most lakes. As funds have allowed, additional sampling has been performed to characterize the water chemistry of the deeper lake layers. This vertical sampling has provided data that is useful in understanding the general nutrient cycling and water column relationships in individual lakes. On two dates in water year 2003, Level II samples were collected from the surface, middle, and one meter above the bottom in the deepest part of the lake to define changes found in the vertical profiles of the parameters.

Land use analysis of 2002 aerial photographs was conducted for the catchment basins of the small lakes monitored in 2003, as part of an internship work program. The work as a whole will be posted as a report on the Lake Stewardship Program Web site when completed (Nora Kammer, 2004), but pertinent data were included with the discussion of the individual lake results for the year and a regional chart comparing land use for all the lakes has been included in Section 2.

Program Summary and Outlook

The 2003 monitoring program, which ran from October 2002 through October 2003, represented the ongoing effort by King County to expand the information available on the smaller lakes within its boundaries. The program attempted to maximize limited resources amid the changing jurisdictions within King County, while the staff remained committed to making the most of the volunteer monitors' time and effort. Changes may continue to occur for both the methods of collection and reporting as adjustments are made in response to volunteer requests and staff observations. Some parameters may be discontinued, while others may be added to the program if the information gained is considered to be important in assessing the condition of the lakes.

The Lake Stewardship Program's Web site, **http://dnr.metrokc.gov/wlr/waterres/smlakes**, continues to feature lake management information, as well as electronic copies of many of our publications. In addition, the site highlights the efforts of our volunteer monitors and provides information to people interested in joining the data collection program. Due to budget cutbacks, paper copies of the annual report may be discontinued except for regional libraries, as well as a set of selected portions to be mailed to volunteer monitors. The entire report will continue to be available to download for our Web site.

Previous versions of the annual report have featured a section in the introduction which included a discussion of many important physical and biological processes in lakes, including notes on how development of land within watersheds and expanding human activities can impact lake ecosystems. Rather than the repeated publication of the same material every year, the program has planned to publish a regional guidebook that includes the information in the future. However, in the interim please refer to past editions of this report to find such information. These can be found on the Lake Stewardship Program Web site (referenced in the previous paragraph) under the publications link or alternatively, paper copies are available at King County regional libraries.

The Lake Stewardship Program staff provides volunteers with technical assistance and answers to questions relating to limnological processes and conditions found at specific lakes. Please give us a call with concerns and feedback. We always enjoy hearing from you.

Methods

Volunteer monitors sampled 53 lakes for the Lake Stewardship Program in water year 2003 **(Fig 1-1)**. Aside from Lake Sammamish, lakes sampled ranged in surface area from 10 acres to 279 acres and in maximum depth from seven feet to 98 feet. Lake Sammamish has a maximum depth of 105 feet and a surface area of 4,893 acres. These lakes spanned all trophic classifications and degrees of urbanization in their watersheds.

The Lake Stewardship Volunteer Monitoring Program is split into two levels of data collection: Level I and Level II. Throughout the year, the Level I participants measure precipitation, lake level, surface water temperature, and clarity (Secchi depth). The Level II participants collect water samples for water quality analysis, while also measuring water temperature and clarity, from the end of April through October.

Level I Data Collection

Level I data collection occurs both daily and weekly, and is compiled by water year, which begins with October and ends in September. The water year differs from the calendar year because it is based on annual precipitation and hydrologic patterns.

In water year 2003, 34 lakes participated in the Level I program for most or all of the water year. For several lakes, volunteers were not able to complete this commitment or were recruited later in the year, so the data are incomplete.

Figure 1-1: Lake locations for western King County

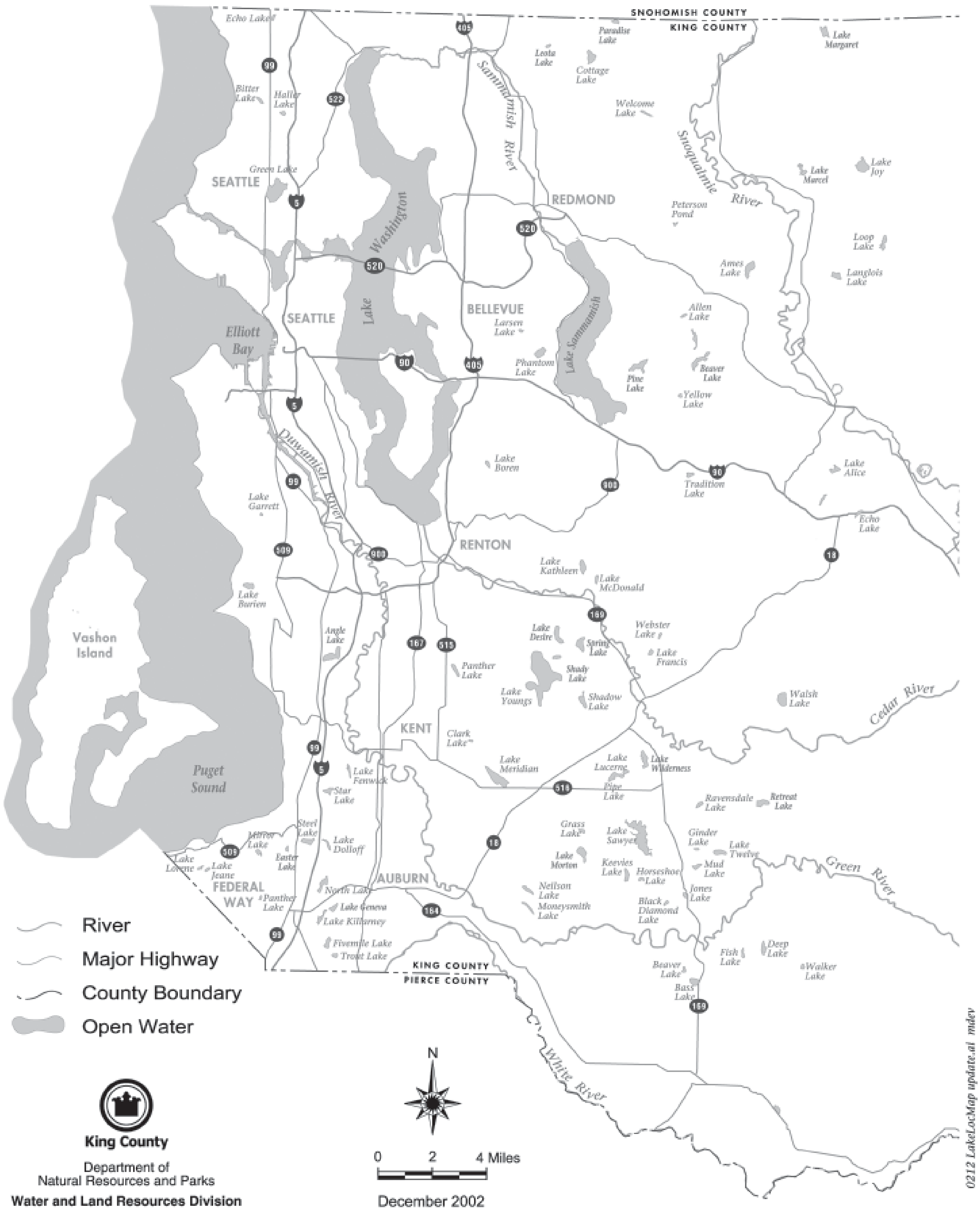


Figure 1-2: How lake samples are collected and processed

STEP 1: Sampling
Volunteer lake monitors collect observational data and water quality samples on an assigned day. They use prelabeled, clean bottles provided by the Lake Stewardship Program.

STEP 2: Pick-Up
Lake Stewardship Program staff pick up samples and data sheets from volunteers' homes and leave new bottles for the next sample date. Phytoplankton samples are preserved at the time of pick up and samples are kept cool and protected. Any unusual conditions are noted.

STEP 3: Environmental Lab Analysis
Data sheets and water samples for chemistry analysis are delivered and logged into the King County Environmental Laboratory. Sample dates and times are checked for consistency. Any unusual conditions are noted.

STEP 4:
Phytoplankton Sample Analysis
Phytoplankton samples are mailed to Water Environmental Services, Inc., a consulting group, that then identifies algae in each sample, measures cell sizes and estimates numbers. The data are summarized and sent to the county to be entered into spreadsheets for analysis and graphing. The consultant cleans the sample bottles and returns them to King County for re-use.

STEP 5: Quality Control
The lab chemistry staff follow strict protocol for sample holding times and quality assurance of chemical analysis. Staff include "blanks," "standards," and "spikes," — predetermined sample values — in all batches being analyzed to test reliability of the chemical analyses and ensure quality.

STEP 6: Data Entry & Storage
After lab analysis, all sample values are examined for consistency. Once its quality is assured, data are entered into a King County database for further analysis. The time between receiving samples and database entry is less than 30 days. Excess water samples are frozen and kept for 90 days, for further analysis as needed.

STEP 7: Data Review
Using the King County database, Lake Stewardship Program staff review data for entry errors and internal consistency on a lake-by-lake basis. Anomalies are discussed with the Environmental Lab and if necessary, samples are re-analyzed.

STEP 8: Data Reporting
At the end of the season, sample values are finalized for the year. Graphs are made of the data parameters and compared with previous years, with the results published herein. The King County Lake Monitoring Report is distributed to volunteers, libraries, scientists, government and environmental agencies and other stakeholders interested in the water quality of King County's small lakes.

Lake level and precipitation measurements were recorded daily by volunteers. Lake level was recorded by reading a gauge (a porcelain-glazed aluminum metric ruler) attached permanently to a rigid dock or other fixed structure in the lake, usually near the volunteer's home. Often the meter sticks have not been calibrated to elevation, so the measurements are relative to the stick position rather than sea level. Precipitation was collected in a plastic rain gauge installed in an area exposed to direct rainfall and away from overhanging objects such as trees or buildings.

Water clarity (Secchi depth) and surface water temperature were measured weekly. Secchi depth generally was measured over the lake's deepest point (Wolcott 1961, USGS 1976). The method involves lowering an eight-inch disk painted with alternating black and white quadrants over the shaded side of the boat until the disk disappears from view, then lifting it until it reappears again. The depths at each point are noted and, if different, are averaged.

Volunteers measured water temperature at the same location as Secchi depth. The method called for submerging a Celsius thermometer in the water to about one meter below the water surface for two minutes, then bringing it to the surface and reading the temperature to the nearest 0.5 degrees. Further details on Level I volunteer monitoring sampling methods are supplied in the *Lake Stewardship Program Volunteer Lake Monitor 2003 Sampling Manual* (King County 2003).

Daily data are transformed either by summation (precipitation) or by averaging (water levels) into weekly values when all or nearly all daily values were measured, while the parameters measured weekly are reported directly (Section 3). All original data are available upon request to King County Water and Land Resources Division.

Level II Data Collection

Level II volunteer monitoring activities were performed every two weeks from late April through October on a predetermined schedule. Water samples were collected at one meter depth on every sampling date, and volunteers also collected deeper samples twice during the period, usually at mid-depth as well as at one meter from the lake bottom.

In water year 2003, 51 lakes had volunteers who participated in the Level II program. For most lakes, volunteers were able to collect data for the entire period (May through October). Gaps and anomalies are noted by lake in the individual text. A flow chart of the sampling process has been included to show how samples are treated after collection **(Fig 1-2)**.

Volunteers anchored at a specified location, generally over the lake's deepest point. For each date, volunteers recorded the time and weather, as well as making observations on unusual conditions or activities on the lake. Secchi depth was measured using the same methods as described for Level I. Water samples were collected using a Van Dorn vertical water sampler at one meter depth. Temperature was read from a thermometer installed inside the sampler, after which water was saved in special containers for further analysis, generally for total phosphorus, total nitrogen, chlorophyll *a*, and phytoplankton.

On the two dates when vertical profiles were sampled, samples were taken at one meter, mid-depth, and one meter from the lake bottom. Temperature was measured at each depth using the thermometer mounted inside the sampler, and water samples for total phosphorus and total nitrogen were collected at all three depths. Chlorophyll *a* and phytoplankton analyses were generally collected for the one meter and mid-depth samples only, but there were some exceptions in cases when the bathymetry or history of the lake suggested that large deep water phytoplankton concentrations might occur.

The water samples were analyzed at the King County Environmental Laboratory (approved by the Environmental Protection Agency) for total phosphorus, total nitrogen, and chlorophyll *a*, using standard protocols and quality assurance and quality control procedures. Phytoplankton (algae) identifications and enumerations were carried out by a private consultant to the Lake Stewardship Program.

Physical and chemical values for each date are detailed in Section 3. Phytoplankton data for individual dates are available upon request. Further details on Level II volunteer monitoring sampling methods are described in the *Lake Stewardship Program Volunteer Lake Monitor 2002 Sampling Manual* (King County 2003).

Data Analysis

Minimum, maximum, and average values for temperature and Secchi depth were determined for the Level I volunteer monitoring data. Annual lake level range and total precipitation were determined for each participating lake with complete data sets. The data are illustrated in charts for each individual lake (Section 3).

For Level II water quality measurements, the minimum, maximum, and average values were determined for the sampling period. The values found throughout the sample season are charted for each lake, with total nitrogen and total phosphorus on the same chart for comparison (Section 3).

The Trophic State Index or TSI (Carlson 1977) and the nitrogen to phosphorus ratios (N:P) were calculated for Level II volunteer monitoring data. TSI values are derived from a regression that compared values of a parameter such as total phosphorus, chlorophyll *a* or Secchi transparency to the algal bio-volume of a suite of lakes and assigned a number on a scale of 0 to 100, based on the relationship found. This scale can be used to compare water quality over time and between lakes (see discussion in Section 2C and data for individual lakes in section 3). If nutrient limitation of algal growth is likely to occur, the nitrogen to phosphorus ratio may be used to identify the nutrient that is in shortest supply. Generally lakes with an N:P ratio of less than 20 may be experiencing limitations by both nitrogen and phosphorus at times during the growing season. The results of these analyses for the lakes are presented in both Section 2 and Section 3.

Section 2
Regional Assessment

SECTION 2A: CLIMATE AND HYDROLOGY

Introduction

Regional water quality patterns found in the lakes of the inhabited areas of King County can be produced by comparing the data from all the lakes in water year 2003, as well as examining data for each lake over time. In addition, because of the wide range in local rainfall received through the year, measuring precipitation at each lake makes it possible to look at particular changes in lake level relative to the rainfall received in that watershed. Level I monitoring data on precipitation, water levels, and Secchi transparency (water clarity) are compared for all the lakes measured in 2003, including Lake Sammamish. The discussion of Level II monitoring covers the similar comparisons for average phosphorus and chlorophyll, Trophic State Indices (TSI), and nitrogen to phosphorus ratios.

Precipitation

While Level I volunteer monitors collected precipitation data at 38 lakes throughout King County in water year 2002, only 22 lakes had comprehensive rainfall records for the period. If the precipitation records for a lake had some gaps, but had data for at least 330 days, estimated values for the missing days were inserted by averaging all available data from the other lake sites in the county for that day. Discussion of the data set as a whole is limited to the 22 lakes with the most complete data.

Water Year 2003 Precipitation Data

The sum of accumulated rainfall at Sea-Tac International Airport for the 2003 water year totaled 822 millimeters (mm), which is below the 50-year average of 972mm. This can be visualized by comparing it to the last six years and to the mean accumulation

Figure 2-1: Comparative cumulative rainfall for SeaTac weather station, 1996-2003

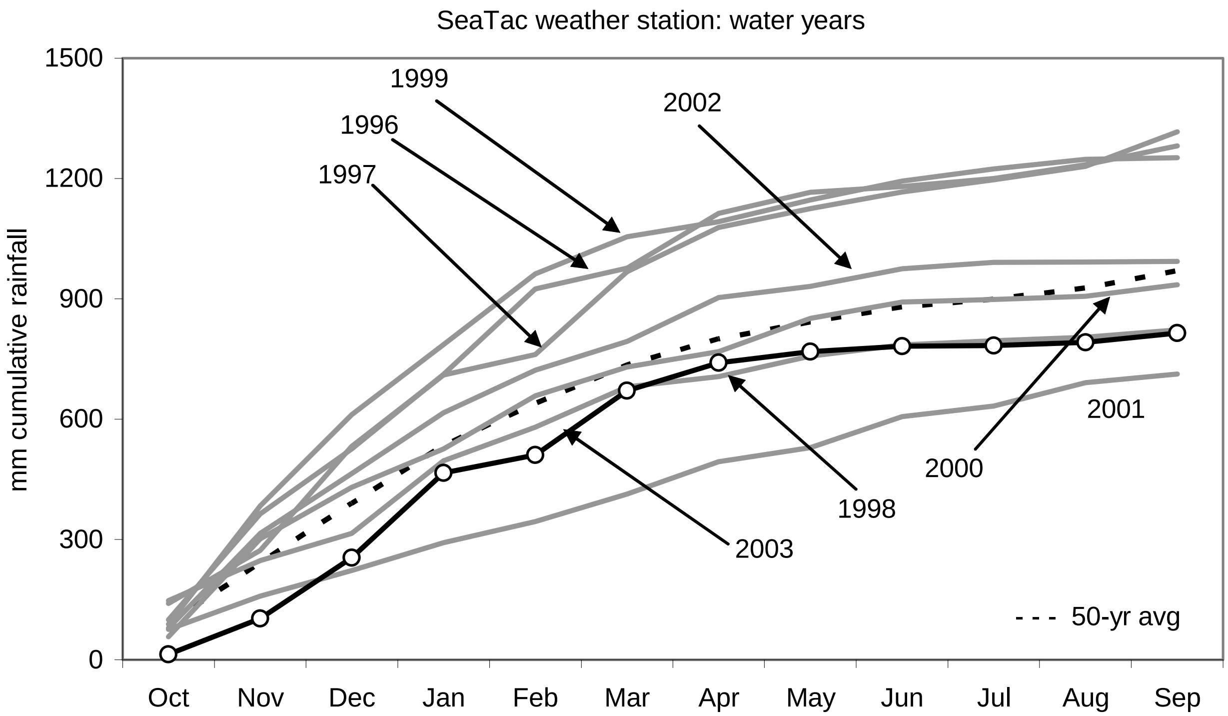
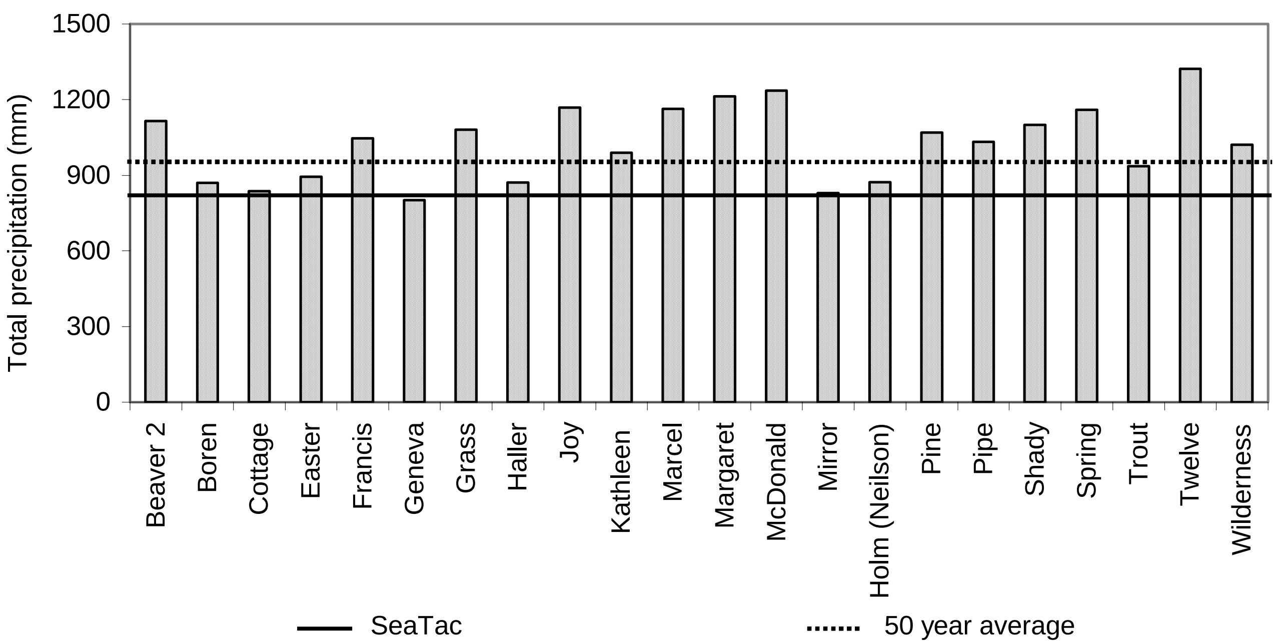


Figure 2-2: Total rainfall at individual lakes for WY 2003



rate for the last 50 years at the Sea-Tac weather station **(Fig. 2-1)**. The accumulation rate over the 2003 water year remains below the average consistently throughout the entire year, very similar to 1998, but substantially higher than water year 2001, which was one of the lowest totals on record.

Annual precipitation totals for water year 2003 for the 22 lake sites when compared to that for Sea-Tac **(Fig. 2-2)** show that almost all the lake sites received greater precipitation than the international airport site (solid line across chart). The differences between the various sites illustrate the influence that location has on both daily and annual precipitation values. A variety of factors, including rain gauge placement, adherence to protocols, local topography and storm cell intensity, as well as the patterns of weather movement between the Olympic and the Cascade Ranges (the "convergence zone"), all influence the precipitation recorded at each location.

If the monthly totals for each lake during the year are plotted together with the Sea-Tac data on a single chart (Fig. 2-3), it becomes clear that the Sea-Tac station ranks in the lower range of the monthly precipitation accumulations recorded at all the locations covered by King County volunteers in 2003.

Lake Level

Fluctuations of water level in lakes are affected both directly and indirectly by area precipitation. Other major influences include: (1) watershed size (also called the "catchment basin"); (2) land use within the watershed boundaries; (3) vegetation types and coverage; (4) nearby or adjacent wetlands; (5) soil structures and types, as well as specific geology of the area; (6) surface and subterranean hydrology; (7) outlet type or structure, with or without management; and (8) the volume of water the lake holds relative to the size of the watershed that receives the rain. These factors combine to give each lake a pattern of water level change that is unique.

Nonetheless, some common fluctuation patterns can be found among lakes. In general, lakes in urbanized watersheds commonly respond to precipitation events more quickly and have greater fluctuations in water level than lakes in undeveloped watersheds. This is largely due to the increase in impervious surfaces, as well as the collection and channelization of surface runoff for quick removal from developed properties. Lakes with large watersheds may have a delayed response to precipitation because of the distance that runoff travels before entering the lake. Lakes with large surface areas or volumes relative to the size of the watershed are often less responsive than other lakes in general because they do not receive very much water from a storm event relative to the volume they already contain.

Sometimes other factors become important in water level changes. Beavers building dams on outlet streams can keep lake levels high through the summer, while human destruction of such dams can cause sudden drops in water level and unexpected surges of water downstream. Adjustable heights of weirs on outlet streams can also account for unusual patterns in lake levels.

Lake Level Fluctuations 2003

Seasonal fluctuations in lake levels were observed at most of the lakes with complete data sets. Water levels were typically at the lowest stand during fall (the end of the water year) and steadily increased during late fall/early winter as precipitation increased (see Section 3 for individual lake results). During the fall and winter, many lakes also showed the greatest fluctuation in daily lake level readings, as storm runoff from watersheds with saturated soils quickly flowed to the lakes instead of percolating through soil horizons. This type of runoff pattern caused peaks in water levels to mirror large precipitation events closely, which can be seen in records for individual lakes.

Figure 2-3: Monthly rainfall totals

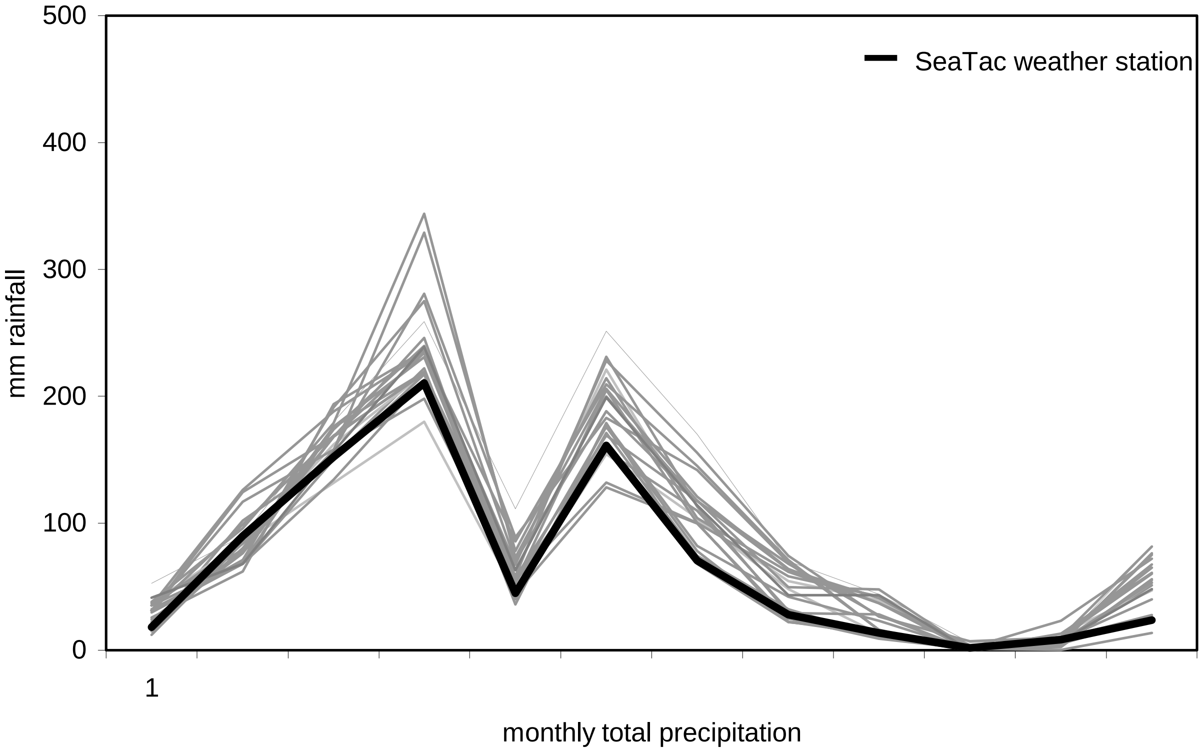
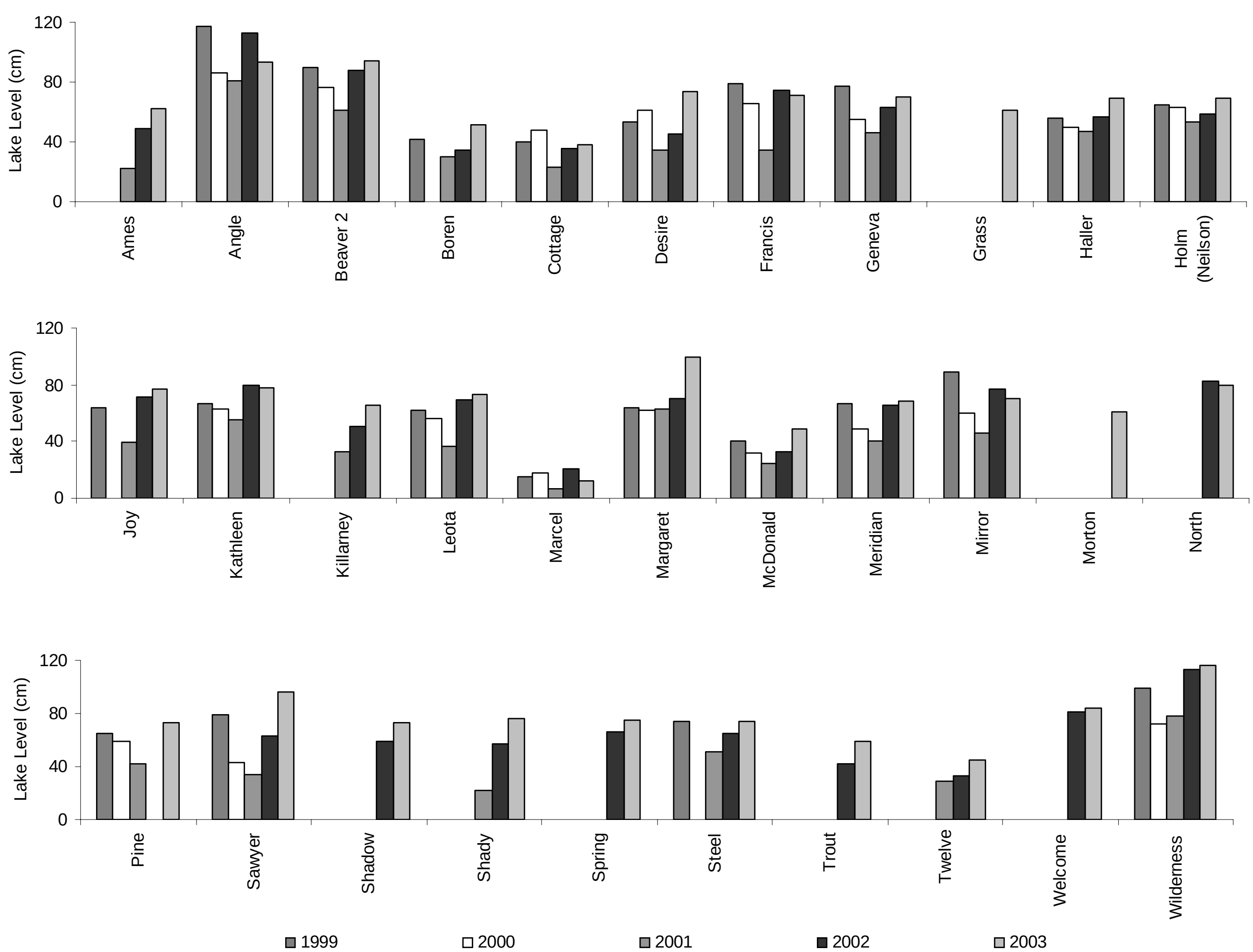


Figure 2-4: Annual water level range for 1999-2003

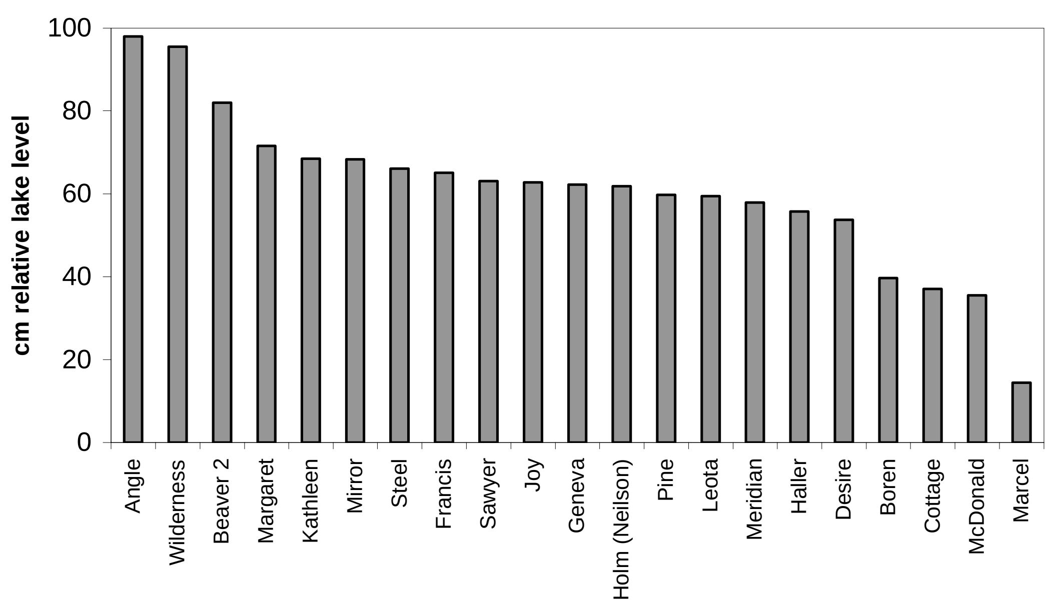


The range in water level is the difference between the maximum and minimum stands over the entire water year. Changes in a particular lake from year to year can be compared as well as comparing records between lakes. Lakes with large fluctuations often show their high sensitivities to winter precipitation and runoff, as well as to evaporation through summer. Lakes with small variations in water level probably receive a higher percentage of ground water inputs, which are a steadier source of water through the year than rainfall. Some lakes are managed at the outlet for desired water levels, but this does not necessarily mean that the annual range will be small. For example, Lake Margaret is kept lower in the winter as a buffer against high levels following rainstorms and is allowed to rise to high levels in the spring in order to store water for domestic use by homeowners in the area. Its fluctuation is controlled for the benefit of the community.

Where essentially complete records were available for comparison, it was noted that lake level ranges in nearly every case were higher than for water years 2001 and 2002. Some of the recorded annual ranges were close to the highest over the last five years for many of the lakes **(Fig 2-4)**, including Ames, Beaver 2, Boren, Desire, Haller, Joy, Margaret, Sawyer, Shady, and Wilderness. The lakes with the widest average fluctuation over the last five years **(Fig. 2-5)** included Angle, Wilderness, and Beaver 2. Most of the lakes had a more moderate variation, but several showed little average change through the season, including Boren, Cottage, McDonald, and Marcel. Several lakes with suggestive data such as Killarney and North had few recent years of record.

Analyzing records of annual maximum high water level can indicate whether or not a lake was at its capacity for water storage (at or above the threshold of the outlet) at the beginning of the dry season each year. It also indicates if a lake rose to unusual heights at any point during the wet season **(Fig. 2-6)**. The values for high water levels cannot be compared from lake to lake because the measurements for each lake are relative, based on the waterline on a fixed meter stick used to make the measurement. However, an idea can be gained of whether or not the lake was at capacity by comparing high precipitation years with low ones; for this report the best years to contrast would be 1999 (the first bar) with 2001

Figure 2-5: Mean annual range over the last 5 years for lakes with at least 4 years of data

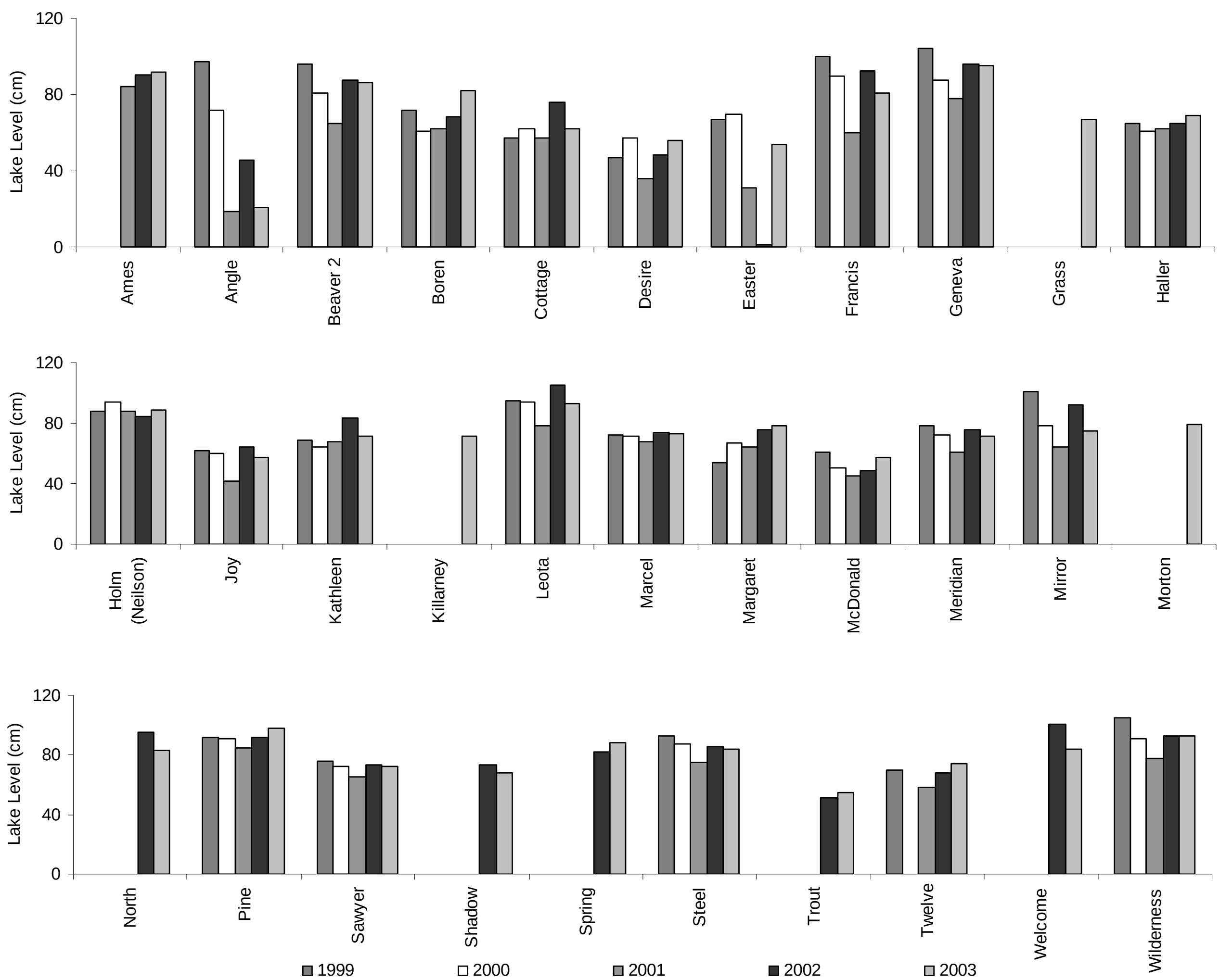


(middle bar). As an example, Haller Lake had a relatively constant maximum level for the last five years, suggesting that inputs were balanced by water flowing out rapidly enough to maintain the winter level at a stable height. On the other hand, Lake Geneva had a higher stand in 1999 than in the other four years, suggesting that it may have a rapid response to large rainfall events that can lead to a larger fluctuation over the season and from year to year.

Conclusion

Many volunteers recorded higher ranges of lake level fluctuations in 2003 than in the previous 5 years, but this was not matched by higher maximum stands. This suggests that the higher ranges were due to summer low stands, due either to increased evaporation or to lower ground water inputs. Continued volunteer observation will be important for determining how changes in natural conditions, management activities, or watershed development all affect individual lake levels. Ongoing monitoring will help lakeside residents, citizens in nearby communities, and city and county officials to understand more thoroughly the trends and relationships of water level fluctuations with precipitation, thus leading to more effective drainage management.

Figure 2-6: Maximum water levels over the last 5 years



SECTION 2B: NUTRIENTS

Secchi Transparency

The Secchi depth measures the relative transparency of water to an observer above the lake surface. Transparency can be affected by water color (which is affected by concentrations of large organic molecules called “humic acids”), phytoplankton abundance and the particular species present, and turbidity caused by suspended particles from other origins. Secchi transparency readings can also be affected by wind and waves, as well as by light glare off the water surface. The sample protocol calls for measurements to be made in the same fashion each time, with records of wind and sun conditions, in order to compare values.

Transparency changes often mirror changes in algal abundance, 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 water as a result of human activities. Transparency measurements compared across years may indicate correlations with specific events known to have occurred.

Secchi Depth 2003

Average annual Secchi depths for lakes measured by the Level I volunteers over the last five years can be grouped by the Trophic State Indicator (TSI) value, which is based on the depth measurements **(Fig. 2-7)**. A Secchi reading of 2m equates to a TSI value of 50, which is on the threshold between mesotrophic and eutrophic productivity, while a Secchi reading of 4m equates to a TSI of 40, which marks the change from oligotrophic to mesotrophic productivity. The dotted lines in Fig. 2-7 mark these thresholds.

The annual mean Secchi values for the lakes

Figure 2-7: Average annual Secchi transparency for the last 5 years

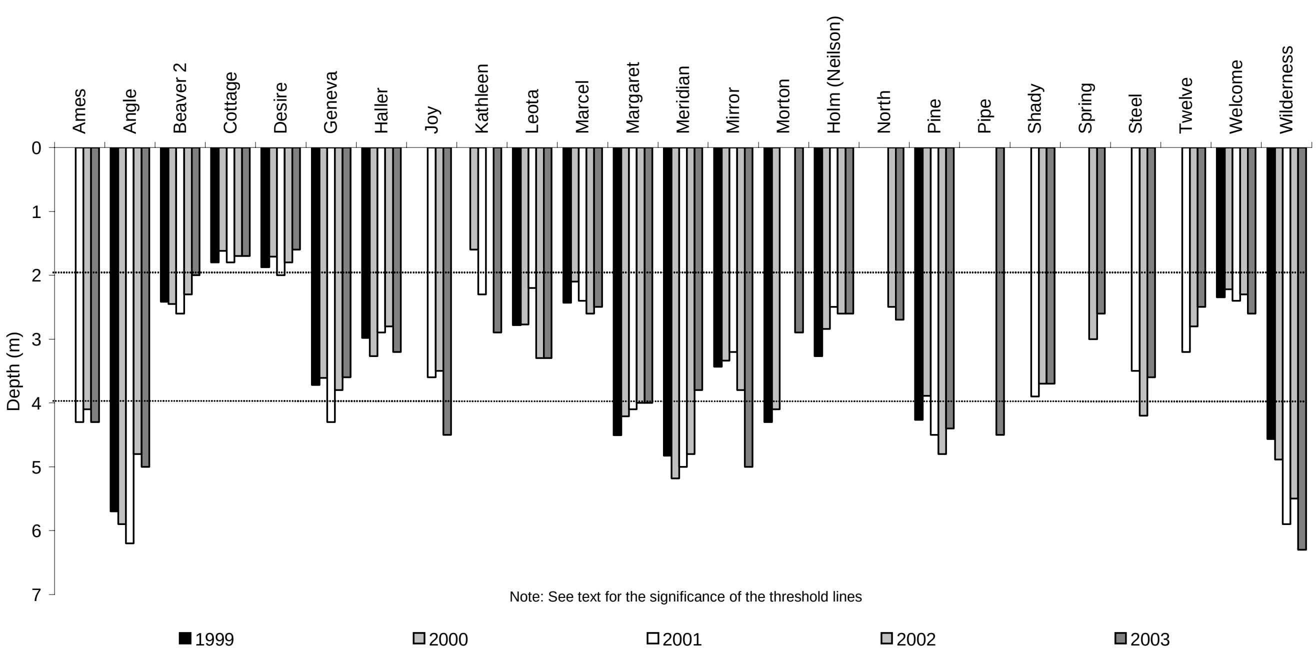
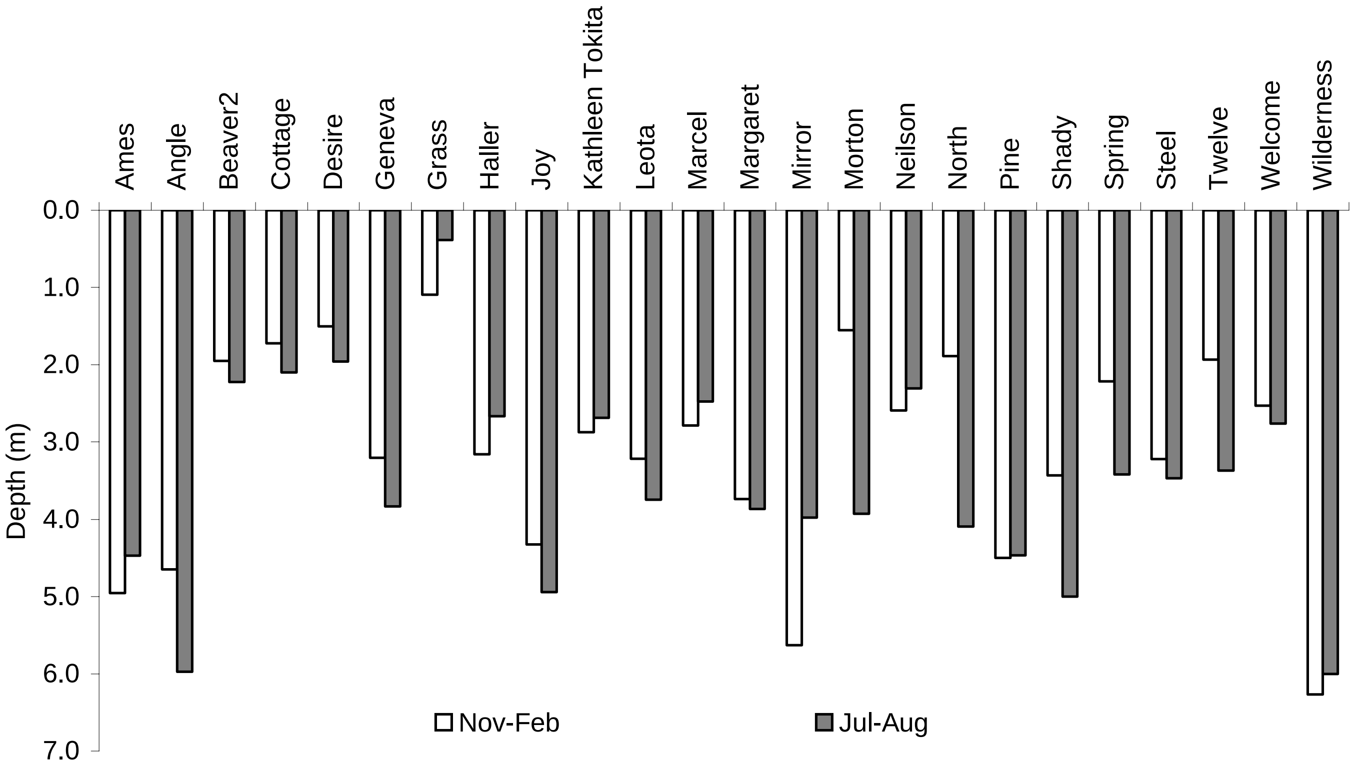


Figure 2-8: Wet/dry season Secchi comparisons



with complete records over the past five years show a range of values over time. Lakes with clarity usually deeper than 4m include Ames, Angle, Margaret, Meridian, Pine, and Wilderness. However, Margaret appears to be decreasing in clarity over the last five years and in both 2002 and 2003 was right on the threshold between oligotrophy and mesotrophy. Conversely, transparencies in Joy and Mirror Lakes have been generally below the 4m threshold, but in 2003 had deeper average values above 4m. Most lakes were between 2 to 4m in average clarity, and there were few large fluctuations from year to year among them. Other possible trends towards decreasing clarity can be observed in Beaver 2, Holm (Neilson), and Twelve. Two lakes, Cottage and Desire, remained below the 2m threshold for all the years depicted.

In some cases, lower Secchi depths may be caused by particle inputs from storm water runoff. To evaluate this possibility, Level I Secchi depths for 2003 were divided into two time periods **(Fig.2-8)** to see if the influence of storm water runoff (November-February) could be separated from influences associated with summer algal blooms (July-August). Spring and autumn data were not included because both major storm events and large phytoplankton blooms can occur during those seasons, thus confusing the interpretation.

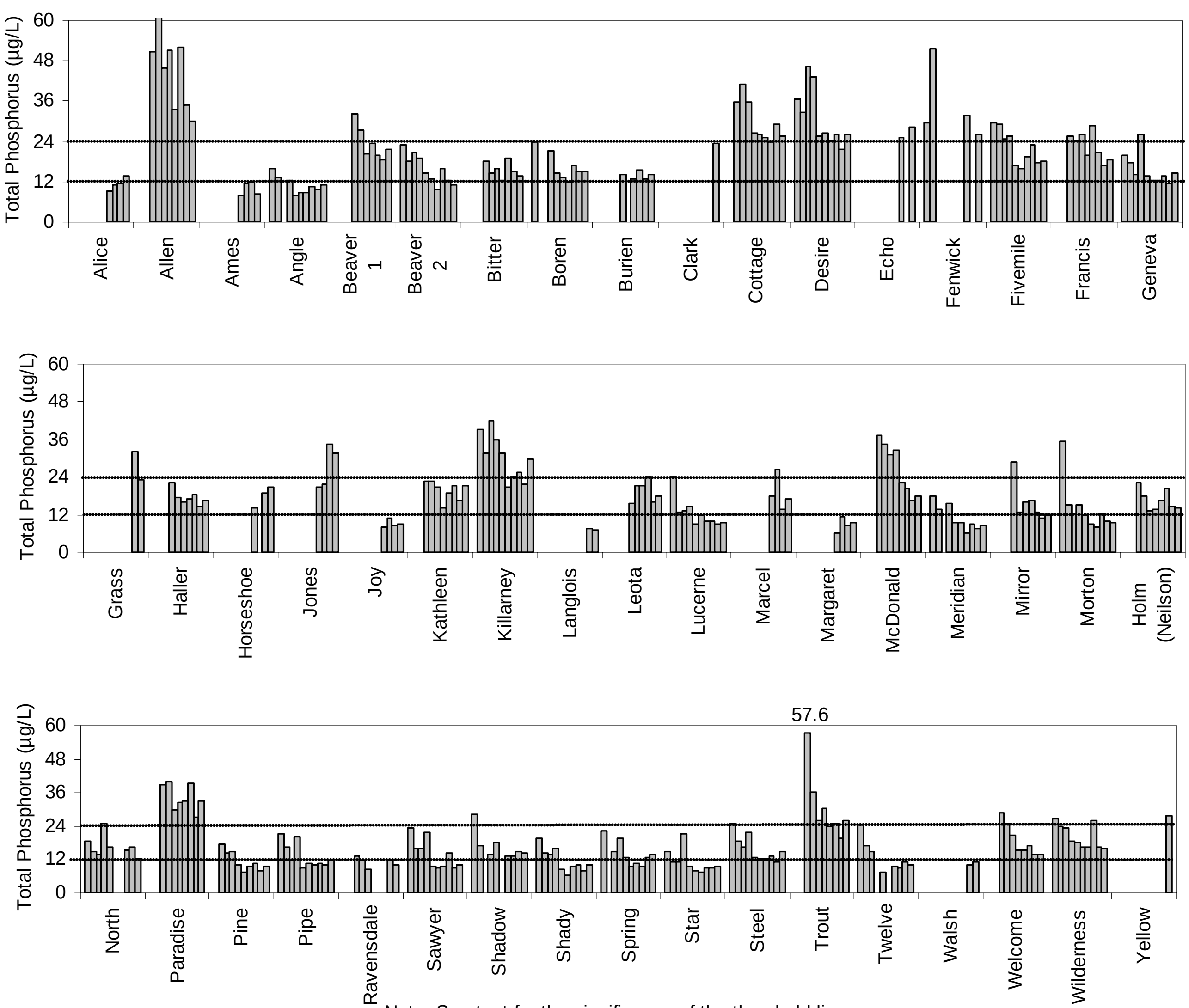
During the wet months, significantly lower transparencies were observed for 12 of the 24 lakes in the program with comprehensive annual data for Secchi depth, indicating that storm water runoff may influence water clarity in these lakes to a greater degree than summer algal populations. In addition to storm water inputs, wave action (due to strong winds) and low light levels during the winter months may be an important factor influencing lower average Secchi depth measurements. Five of the lakes had significantly lower transparencies in the summer, indicating algal blooms could be impacting water clarity. These included Ames, Grass, Haller, Marcel, and Mirror. Most of the lakes with large differences between winter and summer were lower in transparency in the winter, including North, Shady, Spring, and Twelve.

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

Many lakes have similar mean phosphorus levels from year to year, with some variation expected to occur. Thirty-three of the 45 lakes with three or more years of Level II data yielded similar average total phosphorus over past years, or showed a step-drop in 1998 that may be related to a change in King County laboratory analysis procedures **(Fig 2-9)**. However, total phosphorus has been dropping steadily over the last five years in eight lakes, including Beaver-1, Beaver-2, Fivemile, Francis, McDonald, Trout, Welcome, and Wilderness. Total phosphorus in Allen Lake has varied widely over the past five years, but has dropped steadily over the past three years. It should be noted that there were multi-year gaps in the data for Fenwick, North and Ravensdale Lakes that made interpretation more difficult.

Clark, Echo (Shoreline), Grass, Langlois,

Figure 2-9: 1994-2003 average total phosphorus, May-October



Note: See text for the significance of the threshold lines

Walsh, and Yellow 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.

Several lakes showed a steady increase of phosphorus over time, including Alice, Horseshoe, and Jones. Holm (Neilson) increased four years in a row, but decreased in 2002 and 2003. Margaret may also be increasing over time, but the rate is too low to be sure that the data is not merely reflecting inter-annual variability. No lakes have increased in total phosphorus over a long enough period of time for trends to be considered statistically significant. However, the increases do point to lakes that should have careful attention paid to them over the next few years.

Nitrogen: Phosphorus Ratios

Many water quality problems in lakes can be related to high concentrations of nutrients that stimulate the growth of algae and aquatic plants. In temperate freshwater systems, the nutrient that limits algae growth is most often phosphorus, although phytoplankton can be occasionally limited by nitrogen concentrations or even by silica or iron. Before trying to manage a water quality problem, it is important to know which nutrient is limiting plant growth most frequently in the lake.

To make a quick nutrient assessment, nitrogen to phosphorus ratios (N:P) are calculated for individual lakes. Generally, nitrogen to phosphorus ratios of 17:1 or greater suggest that phosphorus limits 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. 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.

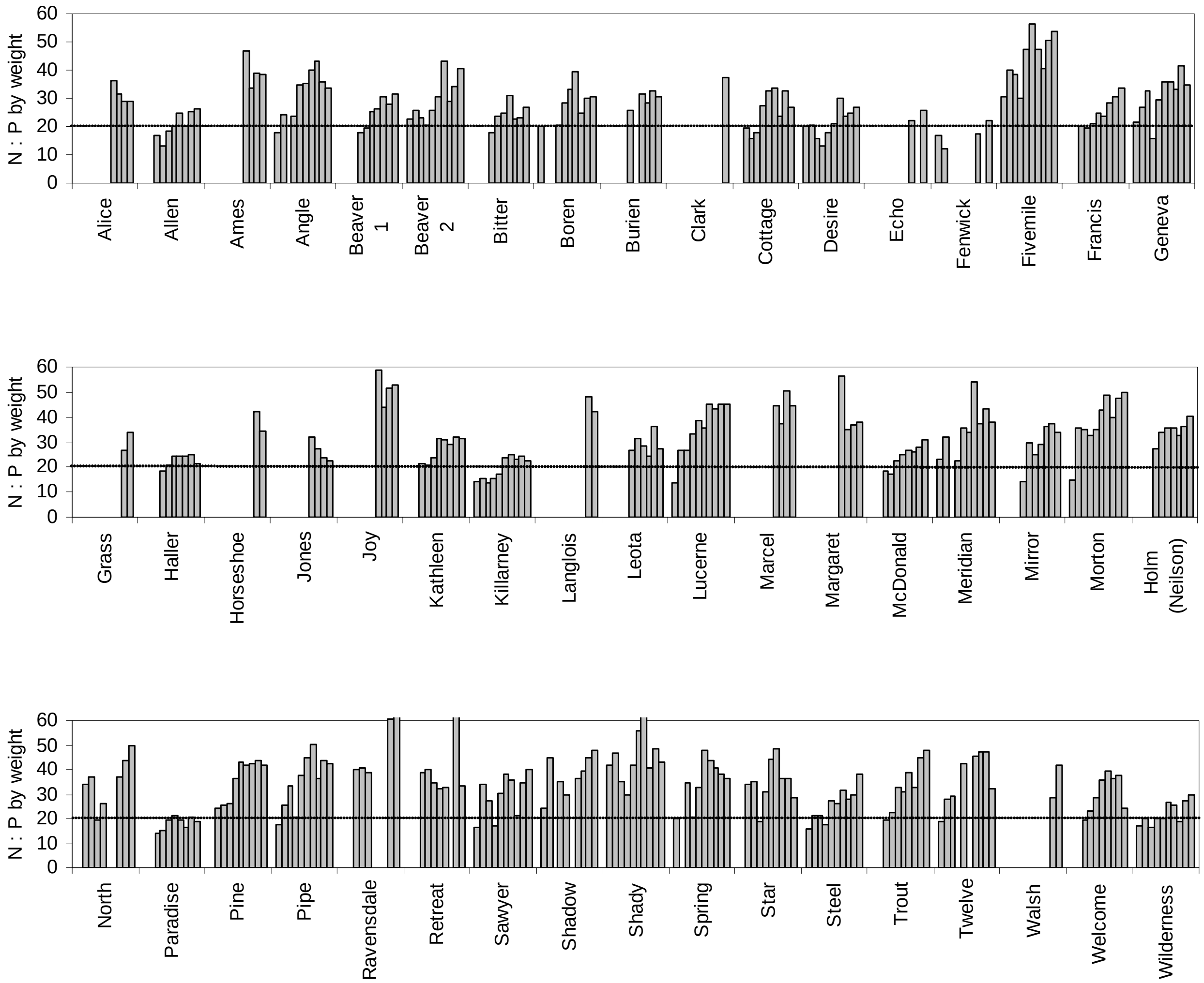
2003 Ratios

No Level II lakes had an average N:P ratio less than 20 for the period of May-October 2003 **(Fig. 2-10)**, although individual values below 20 have been common in certain lakes over the past ten years. Many of the lakes have had lower average ratios than they have now, suggesting that algae in these lakes could have experienced nitrogen limitation at some time during the growing seasons in past years. Upward trends through time in N:P ratios can be seen for 17 of the 51 lakes, which could signal a change in direction away from domination by bluegreen populations in the future. The average ratio in other lakes has changed greatly from year to year or has shown no particular trend or directionality.

Lakes that ranked as oligotrophic by their TSI indicators generally also had higher N:P ratios, while eutrophic lakes had lower N:P ratios. One lake which was contrary in this regard is Fivemile, which had generally high N:P ratios although ranked as mid- to high-range mesotrophic, with a eutrophic TSI-Secchi likely due to water color.

Several lakes had N:P ratios that hovered near the threshold of 20 throughout the season. These included Haller, Jones, Killarney, and Paradise. Some lakes had averages well above 20, but experienced periods during the sample

Figure 2-10: 1994-2003 N:P ratio



season with values at or below the threshold. Several lakes had higher N:P ratios in spring, which either dropped steadily through the summer or declined more abruptly in late summer to levels at or below 20. Lakes in this group included Boren, Cottage, Desire, Sawyer, Steel, Walsh, and Wilderness. Lake McDonald had the opposite pattern of starting low and then rising to a higher level the rest of the season. Two lakes, Echo (Shoreline) and Fenwick, started low, rose in mid summer, and then dropped again. Lake Marcel had the opposite pattern of high values with a low period in mid summer. Any of these periods of low N:P ratio could have encouraged a growth increase by bluegreen species.

Conclusion

For the majority of lakes in King County, average May-October phosphorus concentrations have either remained steady or have declined in recent years, including 2003. Only three lakes in the monitoring program have shown steady gains recently, and these should be watched to see if there are other indicators of deterioration in water quality. N:P ratios for the lakes suggest that conditions for bluegreen algae are becoming less favorable overall, thus reducing the possibility of toxic bluegreen blooms on a region-wide basis, although several lakes are still at risk, particularly at specific times of year.

Lake Stratification and Chemistry Profiles

Seasonal changes in the water chemistry of each lake relate in part to physical differences that occur with changes in water temperature. These chemical changes are much more pronounced in thermally stratified lakes. During spring and early summer, the combination of heat from sunlight and movement of the near surface water in the lake causes more warming in the upper portions of the water column than in the lower depths. This results in thermal “stratification” of a lake into stable layers of water with differing temperatures and densities. Deeper lakes generally remain stratified throughout the summer, while shallow lakes exposed to wind either never fully stratify thermally or else develop transient thermal stratification that breaks down often.

Effects of Stratification

Temperature patterns and thermal stratification influence fundamental processes in lakes, such as changes in dissolved oxygen concentrations, nutrient release, and algal growth. Oxygen enters the water (dissolves) through contact with the atmosphere at the surface. Once a lake stratifies, deep water (the hypolimnion) is no longer mixing with shallow water and therefore the atmosphere is only in contact with upper water. This means that the dissolved oxygen in deeper water may be exhausted by the demands of bottom dwelling animals and bacteria some time after stratification has occurred. Such anoxic (no oxygen) waters can greatly stress fish like trout and salmon that require cool, oxygenated waters in order to survive.

In addition, chemical reactions related to anoxia cause the sediments to release phosphorus back into the deep water. When this water mixes with the surface waters in autumn as cooling occurs, an algal bloom can result from the sudden influx of nutrients into surface waters from the bottom. Monitoring water chemistry differences between the epilimnion and hypolimnion during summer provides a way to assess the role that internal nutrient cycling plays in lake water chemistry.

Chlorophyll measurements can act as analogues for algae distribution in the water column. Since algae need sunlight to photosynthesize, as well as nutrients to build the organic molecules necessary for growth and reproduction, the largest populations should be found at the point where the best compromise between these two needs is found. When sunlight is very intense, it can actually cause photo-damage to algal cells, cause growth inhibition at shallow depths. However, in lakes with highly colored water or such densely blooming algae that shading by other algae can occur, inhibition may not be found. Great concentrations of algae can sometimes be found much deeper in the water column, where enough light can penetrate to the thermocline and below, to the nutrient rich hypolimnion. In shallow lakes, large amounts of algae can be found above the bottom for the similar reasons.

2003 Profiles

Depending on the maximum depth of each lake, samples were taken by Level II volunteer monitors at two or three depths for measuring temperature, chlorophyll *a*, total phosphorus, and total nitrogen **(Table 2-1)**. The precise sampling depths were based on the actual depth measured at the sampling site, with samples taken from 1m from the surface, the middle of the water column, and 1m above the measured bottom. These samples were collected in mid May and again in early September in order to characterize changes in the water column over the summer during the most probable period of stratification. Lakes with stable thermal stratification usually show the most dramatic differences in water chemistry between the top and bottom samples in late summer.

In the Pacific Northwest, most lakes that stratify have already done so by May and retain

Table 2-1: Summer profile data

Name	date	Secchi	depth-m	degC	Chlor-A	TP ug/L	TN ug/L
Alice	5/18/2003	4.3	1	15.0	2.49	12.7	297
			8	NR	5.41	13.9	285
	9/8/2003	4.0	1	22.0	5.77	13.8	402
			8	21.0	10.40	15.4	419
Allen	5/19/2003	0.8	1	15.0	4.01	32.3	684
			2	11.5	2.61	42.9	706
			3.5	9.5	6.13	103.0	731
	9/8/2003	1.3	1	20.0	4.23	17.9	621
			2	18.5	5.31	21.4	646
			3.5	15.0	74.60	148.0	729
Ames	5/19/2003	4.0	1	16.0	2.94	8.0	286
			4	13.0	8.68	11.5	356
			7	9.0	5.83	18.3	393
	9/7/2003	4.5	1	22.5	1.90	9.8	303
			4	21.5	3.07	11.1	319
			7	14.0	11.50	38.6	534
Angle	5/19/2003	4.8	1	15.0	3.20	11.5	360
			5.5	14.5	4.49	24.3	398
			10.5	9.5		20.8	377
	9/8/2003	3.8	1	22.0	<detect	7.9	315
			8	21.0	<detect	10.2	329
			13.5	8.0		131.0	1930
Beaver-1	5/20/2003	1.3	1	15.5	17.00	28.0	737
			7	5.5	0.92	22.6	543
			14	5.0		85.0	814
	9/8/2003	1.5	1	19.5	4.41	13.4	536
			7	7.0	<detect	36.2	620
			14	5.0		202.0	1210
Beaver-2	5/18/2003	2.6	1	14.0	5.45	15.1	500
			7	8.0	1.72	16.9	448
			14	7.0		23.1	492
	9/7/2003	2.8	1	21.0	2.94	11.5	401
			7	9.0	2.39	17.3	393
			14	7.0		96.3	824
Bitter	5/18/2003	4.2	1	16.5	2.49	12.2	280
			4	15.5	4.14	11.8	273
			8	10.0	21.50	72.4	851
	9/7/2003	3.2	1	22.0	4.81	17.1	375
			4	21.5	7.74	14.8	318
			7	14.0	30.70	137.0	1900
Boren	5/18/2003	3.7	1	11.5	4.41	18.0	595
			5	NR	4.81	19.7	843
			9	4.0		36.1	828
	9/7/2003	4.1	1	22.0	3.60	17.8	313
			5	18.5	13.80	22.8	438
			9	8.0	21.40	156.0	1540
Burien	5/18/2003	6.0	1	16.5	1.60	11.4	325
			8	11.0	4.21	17.8	381
	9/7/2003	2.5	1	23.0	3.20	17.2	428
			7.5	19.0	40.90	37.4	563
Clark	5/19/2003	2.0	1	15.4	4.31	74.0	936
			3	9.5	3.00	17.4	851
			6	7.0	1.40	54.4	1220
	9/8/2003	1.5	1	21.5	16.60	25.9	672
			3	16.7	67.20	88.3	1340
			6	7.6	4.21	24.1	516
Cottage	5/19/2003	1.5	1	15.0	13.70	25.1	821
			3	13.0	17.80	27.3	808
			6.5	9.0	3.73	124.0	683
	9/8/2003	1.2	1	21.0	19.50	32.0	785
			3	20.0	24.20	33.7	719
			6.5	11.0	16.80	983.0	2700
Desire	5/18/2003	2.2	1	15.5	5.38	62.4	648
			5	12.0	1.10	37.5	480
	9/7/2003	1.2	1	24.0	28.80	25.1	851
			5	22.5	31.70	173.0	649
Echo Shoreline	5/18/2003	2.0	1	17.0	9.93	29.1	598
			3.5	15.0	13.80	34.8	654
			7	10.0	4.17	87.5	1100
	9/8/2003	2.0	1	22.0	20.90	26.9	574
			4	20.0	10.40	29.0	462
			8.5	9.0	46.10	946.0	3170
Fenwick	5/19/2003	2.5	1	15.0	15.20	28.0	492
			4	9.0	26.80	27.0	458
			8	7.0	9.21	182.0	705
	9/9/2003	3.2	1	20.5	7.01	19.0	496
			4	15.0	195.00	113.0	593
			8	8.0	22.50	212.0	953
Fivemile	5/18/2003	1.5	1	16.0	5.13	24.4	1040
			5	9.0	<detect	18.7	1070
			9	7.0		39.9	1130
	9/7/2003	1.0	1	22.0	3.70	24.3	938
			5	10.0	<detect	19.3	893
			8	7.0		58.8	1190
Frances	5/19/2003	2.7	1	14.0	1.6	9.6	406
	9/7/2003	1.5	1	20.0	11.20	25.8	664
Geneva	5/18/2003	3.6	1	14.5	11.00	16.4	537
			7	7.5	9.73	15.5	739
			13	6.0		254.0	952
	9/7/2003	4.5	1	21.5	2.00	14.4	428
			7	11.0	20.20	25.5	386
			13	6.0	3.50	446.0	1660

Table 2-1: Continued.

Name	date	Secchi	depth-m	degC	Chlor-A	TP ug/L	TN ug/L
Grass	5/18/2003	1.3	1	11.0	4.49	14.9	619
Haller	5/18/2003	4.0	1	16.0	5.93	26.4	378
			6	6.0	16.00	66.4	931
			9	4.5		220.0	1550
	9/7/2003	3.0	1	21.5	3.60	19.4	332
			6	10.0	7.48	60.0	491
			9	5.0		765.0	3280
Horseshoe	5/18/2003	3.0	1	14.0	9.61	21.8	566
	9/8/2003	NR	1	20.0	6.23	32.7	1010
Jones	5/18/2003	NR	1	14.0	33.4	45.8	958
	9/7/2003	2.0	1	22.5	3.87	23.0	531
Joy	5/18/2003	5.0	1	15.0	1.40	13.0	603
			7	7.0	1.10	10.7	648
			11	6.0		37.6	768
	9/7/2003	4.5	1	24.0	3.00	9.6	352
			5.5	15.0	2.60	13.0	460
			11	6.0		78.6	1170
Kathleen	5/18/2003	2.1	1	15.0	3.52	15.6	495
			5	11.0	5.93	29.6	681
	9/7/2003	3.1	1	21.5	6.54	17.8	599
			3	20.5	3.87	22.8	585
Killarney	5/18/2003	1.8	1	16.5	64.90	61.3	922
			2.5	15.0	28.80	55.0	929
	9/7/2003	2.4	1	22.0	3.74	28.2	611
			2.5	21.8	4.41	25.1	584
Langlois	5/19/2003	6.5	1	13.0	2.86	8.8	309
			14	4.5	3.43	8.8	474
			28	4.0		5350.0	57100
	9/8/2003	7.2	1	20.5	<detect	5.9	264
			7	15.0	<detect	5.9	250
			20	4.5		243.0	4570
Leota	5/18/2003	4.0	1	11.0	1.10	18.9	556
			3	4.5	1.60	25.8	553
			6	2.5		141.0	1290
	9/7/2003	4.0	1	17.0	3.60	15.0	385
			3	12.5	14.80	21.0	344
			6	1.5		307.0	3110
Lucerne	5/18/2003	2.3	1	15.0	6.14	18.1	481
			6	8.0	4.11	11.2	643
			10	6.5		22.8	562
	9/8/2003	4.0	1	22.5	<detect	5.9	341
			6	17.0	<detect	8.5	362
			9	9.0		42.7	1410
Marcel	5/18/2003	2.5	1	14.0	6.64	20.5	1100
			3.5	11.2	37.80	35.0	940
	9/7/2003	2.0	1	21.2	20.20	19.3	473
			4	19.2	8.81	24.1	670

Name	date	Secchi	depth-m	degC	Chlor-A	TP ug/L	TN ug/L
Margaret	5/18/2003	3.5	1	14.5	13.80	12.2	495
			6	9.5	3.20	11.5	435
			11.5	7.0		13.6	512
	9/7/2003	3.5	1	21.5	2.00	7.7	240
			5.5	13.0	4.65	10.5	245
			11	7.0		5.9	612
McDonald	5/18/2003	1.0	1	13.5	10.50	25.1	496
			7	6.5	7.32	26.0	626
			13	5.0		218.0	721
	9/8/2003	NR	1	NR	9.21	16.9	576
			7				
			13	NR		194.0	915
Meridian	5/20/2003	5.0	1	15.0	2.52	9.0	281
			13	7.0	2.80	10.5	414
			25	6.0		35.0	513
	9/8/2003	5.5	1	23.0	<detect	9.7	374
			13	7.0	<detect	86.1	2000
			25	6.0		200.0	901
Mirror	5/19/2003	5.5	1	18.0	1.30	10.0	317
			5	16.5	3.20	14.0	357
	9/8/2003	3.6	1	23.5	10.70	12.5	412
			5	23.0	10.40	15.8	422
Morton	5/18/2003	4.5	1	15.0	6.18	12.2	493
			4	14.0	9.50	11.6	523
	9/7/2003	4.4	1	23.5	1.60	10.1	386
			4	23.0	1.20	11.5	462
Neilson	5/18/2003	3.1	1	14.5	8.01	18.3	547
			4	7.8	2.00	15.3	597
			8	5.6		31.6	671
	9/7/2003	2.4	1	22.0	3.30	11.8	542
			4	13.0	20.80	21.3	503
			8	7.0		79.3	1030
North	5/18/2003	1.7	1	17.0	11.40	15.8	542
			5	12.0	25.70	17.5	481
			8	9.0	7.57	24.5	665
	9/9/2003	3.8	1	24.0	2.80	8.1	504
			5	18.0	48.10	13.5	406
			8	10.0	73.20	21.8	1260
Paradise	5/19/2003	1.5	1	13.0	86.80	47.7	715
			4.5	9.0	1.95	17.6	703
			7.5	5.5		217.0	722
	9/7/2003	3.3	1	18.5	27.40	29.2	369
			4	12.0	27.50	32.7	354
			7.5	14.0		801.0	2680

Table 2-1: Continued.

Name	date	Secchi	depth-m	degC	Chlor-A	TP ug/L	TN ug/L
Pine	5/18/2003	5.5	1	15.0	2.67	8.0	303
			6	10.0	13.00	13.6	392
			10	8.0		45.1	641
	9/7/2003	3.8	1	22.0	2.40	8.7	320
			6	19.5	12.20	11.8	358
			10	9.5		32.3	659
Pipe	5/19/2003	3.6	1	16.5	6.52	10.2	466
			8	7.5	2.05	8.6	560
			17	5.5		15.9	680
	9/8/2003	6.1	1	22.5	<detect	8.8	371
			10	18.0	<detect	8.7	357
			18	8.5		12.5	391
Ravensdale	5/18/2003	5.3	1	8.0	2.52	11.5	731
			2.3	8.0	4.14	12.9	745
			4				
	9/7/2003	4.4	1	12.5	1.68	10.0	607
			2	10.0			
			4	8.0	2.72	10.3	616
Sawyer	5/18/2003	2.5	1	13.0	9.84	12.6	470
			8	6.0	4.12	15.7	608
			16.5	5.5		38.4	659
	9/7/2003	4.1	1	21.0	1.70	8.9	211
			8	7.0	7.21	23.7	359
			14.5	8.0		74.4	548
Shadow	5/19/2003	2.1	1	15.0	10.10	20.1	594
			6.5	7.0	8.15	17.0	872
			12	6.0		17.7	905
	9/8/2003	3.7	1	22.0	<detect	18.6	518
			6	11.0	41.90	27.5	490
			11.5	6.5		40.8	736
Shady	5/19/2003	2.5	1	15.5	17.40	15.8	529
			6	7.5	6.64	10.9	572
			12	5.4		40.0	1160
	9/8/2003	4.6	1	21.1	3.60	7.2	388
			6	13.5	3.80	11.0	344
			11	6.0		18.8	1710
Spring	5/18/2003	1.3	1	15.0	17.50	16.1	519
			4	10.5	5.45	14.7	595
			8	8.0		43.7	665
	9/7/2003	3.4	1	23.0	1.90	10.9	433
			4	15.0	8.21	41.0	412
			8	8.0		195.0	1690
Star	5/19/2003	5.8	1	18.0	4.46	8.5	330
			7	10.0	6.41	12.3	448
			14	8.0		322.0	2270
	9/8/2003	5.9	1	24.0	2.14	8.1	295
			7	19.0	7.01	12.0	353
			13	8.5		201.0	1810

Name	date	Secchi	depth-m	degC	Chlor-A	TP ug/L	TN ug/L
Steel	5/19/2003	5.0	1	16.0	2.00	10.4	298
			6	14.0	6.89	18.5	328
	9/8/2003	2.5	1	22.0	5.61	15.4	430
			6	21.0	40.40	12.5	1970
Trout	5/19/2003	1.8	1	15.0	4.14	28.7	1090
			4	6.5	1.10	29.9	1120
			7	5.0		93.3	1300
	9/8/2003	2.2	1	19.0	7.61	19.9	766
			4	10.0	14.00	62.7	821
			7	5.0		264.0	1730
Twelve	5/19/2003	3.5	1	15.0	3.09	10.5	507
			6	6.5	63.30	16.1	690
	9/8/2003	2.0	1	21.5	10.20	11.8	434
			6.5	NR	103.00	16.1	721
Walsh	5/18/2003	3.8	1	13.0	5.95	11.2	518
			5	8.0	6.87	13.4	549
			10	5.5		19.5	467
	9/7/2003	5.7	1	23.0	2.27	11.3	173
			5	20.0	3.87	12.8	206
			10	7.0		18.7	360
Welcome	5/18/2003	2.2	1	14.5	5.26	15.7	644
			3.5	11.0	1.49	15.3	650
	9/7/2003	3.0	1	22.0	2.94	17.3	470
			3.5	19.4	12.20	15.2	417
Wilderness	5/18/2003	6.3	1	NR	2.52	18.8	493
			6	9.0	108.00	63.1	772
			8.5	6.5		110.0	475
	9/7/2003	7.5	1	22.5	4.33	14.5	236
			6	18.0	2.00	23.8	186
			7.8	12.0	9.21	89.0	452
Yellow	9/7/2003	1.1	1	22.5	7.21	33.5	983
			1.9	22.0	6.61	34.0	1030

the stratification until some time in October. Water temperatures will reflect this if comparisons are made between the top and bottom values. Shallow lakes such as Alice, Allen, Burien, Desire, Frances, Kathleen, Killarney, Marcel, Mirror, Morton, Steel and Welcome show very little difference between the temperatures at the top and bottom, or sometimes a difference on only one of the two dates, suggesting that stratification, if occurring, is probably of short duration.

Lake Langlois represents an unusual case because it is extraordinarily deep relative to its surface area, which can lead to semi-permanent isolation of the deepest water, a condition called meromixis. In lakes like this, the wind, sun and air temperature influences on the surface water do not provide enough energy to mix the water all the way to the bottom of the basin. The very different characteristics of the Langlois deep water indicate that it does not mix to the bottom annually, unlike all the other monitored lakes in the county. This leads to permanent anoxia and a build-up of sulfides and nutrients that do not mix up into the shallow water, but remain in place and generally increase in concentration over time with influx of settling material. The profile sample taken at 28m in mid May supports this with the extremely high values of phosphorus and nitrogen. The September profile sample was taken at a shallower depth, above the zone of meromixis, in order to look at the deepest water nutrient concentrations that were likely to mix up in the fall.

For many lakes, total phosphorus levels were typically larger in bottom water samples by August compared to 1m and mid-depth concentrations, suggesting that release of phosphorus from the sediments was occurring over the summer months. The measurement of the total amount of phosphorus is not a direct measure of the phosphorus that is available for algal uptake, since the phosphorus contained in particles both organic and inorganic will be included in the assay. However, major differences in bottom sample phosphorus concentrations between May and September do suggest that some release from the sediments is occurring.

There are several possible sources of errors in phosphorus measurements of the bottom samples. If any bottom sediments were disturbed during sampling, they could be incorporated in the sample, and measured levels could be very high, but would not reflect what was actually present and available for phytoplankton growth. Volunteers were instructed to discard the water if it appeared to include any bottom sediments and to collect another sample. Another check on this possibility was instituted in 2003 by filtering particles from a subsample of collected water and retaining the filter in case of questions about the samples.

Another potential source for error in shallow lakes might be incorporation of material originating from rooted aquatic plants in the deep sample. By August, several of the shallower lakes can have aquatic plants growing up from the bottom all across the lake, including at the sample site. Material sinking from the shallow water can get caught in these plants and then disturbed when the sampler is dropped through the water, thus incorporating extra particulate matter into the sample water. This would then give a high reading similar to the bottom sediments that would not be at all related to chemical release of sedimentary phosphorus.

Very high concentrations of total phosphorus (> 200 µg/L) on one or both profile dates were found in the bottom samples of lakes Beaver-1, Cottage, Echo (Shoreline), Fenwick, Geneva, Haller, Langlois, Leota, McDonald, Meridian, Paradise, Star, and Trout, or 13 out of the 51 lakes that were monitored. For these lakes, phosphorus release from the sediments likely increased the potential for algal growth in the fall or into the next spring, and could also be increasing the values of the Trophic State Indicators as well. For most of the other lakes, the process of internal phosphorus recycling due to anoxia in the hypolimnion probably did not contribute significantly to the phosphorus budget in 2003.

Total nitrogen showed very similar patterns, but not precisely the same relationships from lake to lake. Nitrogen chemistry is more complex than phosphorus, and it is usually of less concern for management strategies in the Pacific Northwest because it is not generally the nutrient in least supply for algae in the lakes of King County. However, it does affect the nitrogen to phosphorus ratio present in each lake, which gives some algae an advantage over other species. Nitrogen is often about an order of magnitude higher in concentration than phosphorus in freshwater. Lakes which had very high concentrations of total nitrogen (>1500 µg/L) on one or more dates included Angle, Beaver-1, Bitter, Boren, Cottage, Echo (Shoreline), Geneva, Haller, Langlois, Leota, McDonald, Meridian, Paradise, Shady, Spring, Star, Steel, and Trout. This added up to 18 of the 51 lakes.

Chlorophyll *a* was measured at the same depths as phytoplankton samples were taken, usually at the surface and mid-depth. However, for some lakes chlorophyll was also measured in the deep sample. There were some lakes in which chlorophyll was much greater at the surface than at mid-depth on one or both dates, including Beaver-1, Cottage, Jones, Killarney, Margaret, Paradise, Shady and Spring. More lakes showed the reverse pattern of greater chlorophyll *a* in deep water than at 1m, and for some of them the difference was quite large. Lakes with this pattern on one or both dates included Alice, Allen, Ames, Bitter, Boren, Burien, Clark, Fenwick, Geneva, Haller, Holm (Neilson), North, Pine, Steel, Trout, Twelve, Welcome, and Wilderness.

Conclusions

Many lakes in King County exhibit some degree of thermal stratification by the beginning of summer. Some of the shallow lakes remain unstratified or stratify only for brief periods due to the diffusion of heat through the water column and mixing actions by wind. In most lakes with stable thermoclines, nutrient concentrations were higher in the bottom samples during one or both profile sampling dates. While some lakes had higher chlorophyll *a* content at the surface, more lakes had higher chlorophyll concentrations in the deeper samples than in the 1m sample.

SECTION 2C: TROPHIC STATE INDEX AND LAND USE

Trophic State Index

The productivity of lakes can be classified using numbers that predict biological activity by calculating the Trophic State Index (TSI) based on conditions in the lake. TSI values provide a standard measure to rate lakes on a scale of 0 to 100. Each major division (10, 20, 30, etc.) correlates the doubling of algal biovolume 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 amounts of dissolved organic matter may produce erroneously high TSI ratings for Secchi transparency. The shape and size of phytoplankton species can also influence the Secchi reading, as well as the chlorophyll ratings, since small, diffuse algae cloud the water more than large, dense algal colonies and species of algae vary in the amount of chlorophyll they contain. Additionally, it is important to note that the total phosphorus measure is most reliable for lakes that are strictly phosphorus limited in algal nutrition, and the relationship often falls apart when nitrogen is the limiting nutrient. Although no lakes in King County have been identified as limitation, there are several lakes in which nitrogen appears to be limiting at times through the season or in which phosphorus and nitrogen limitations are occasionally combined.

2003 TSI Ratings

TSI values were calculated for the three parameters measured on each sampling date for the 51 lakes monitored by Level II volunteers, and the average for each was produced for the season (**Fig 2-11**). 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 over the past nine years for each lake are included in the individual lake descriptions (Section 3).

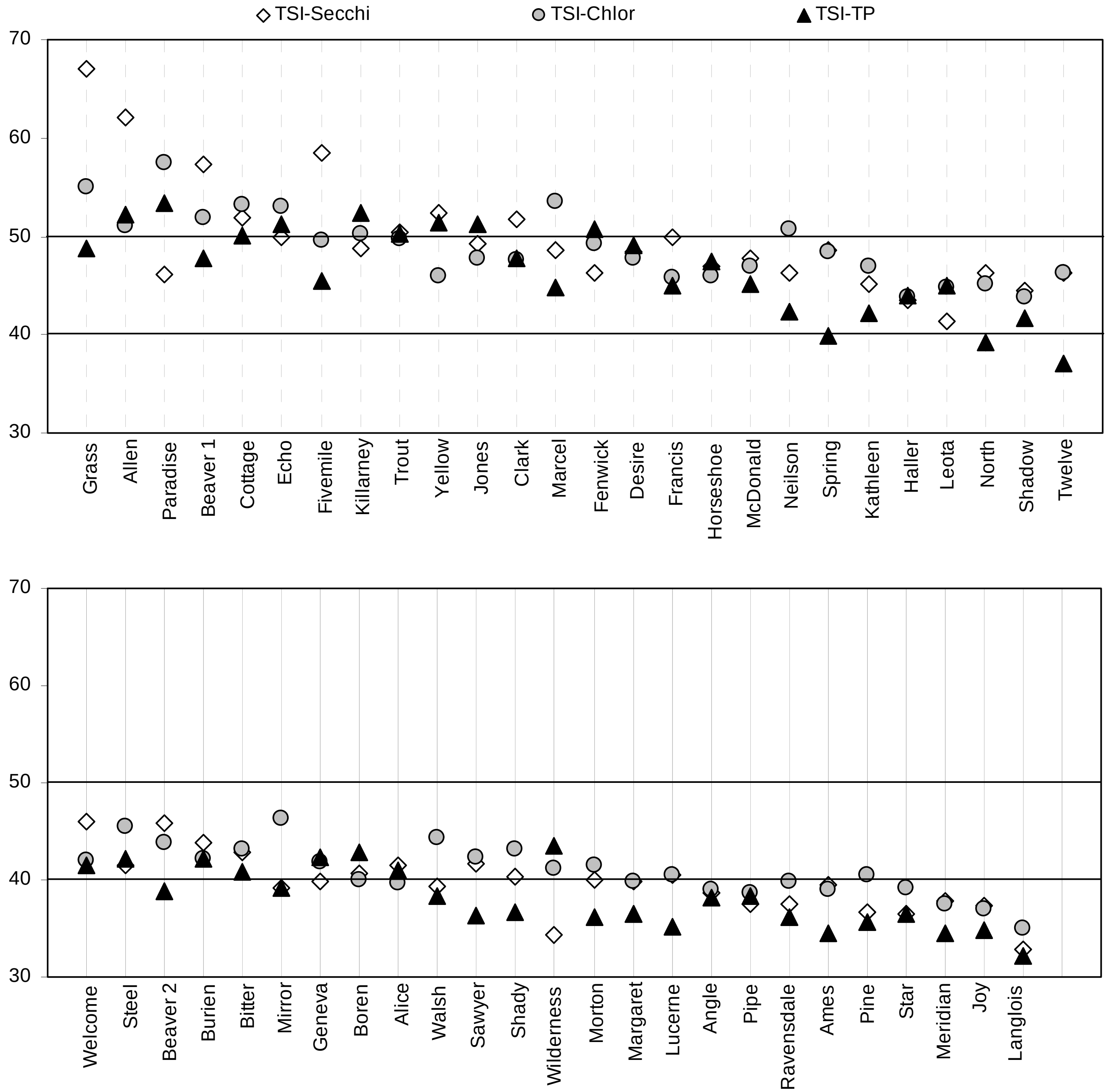
Carlson (1977) points out that if all the assumptions are correct, the TSI values produced from the three different parameters should be very close to each other. Many King County lakes follow this prediction, but several have values that are not very close, suggesting that some different conditions or processes are active at those lakes. When lakes have two close TSI values and one very different one, the outlying value could be excluded from consideration if a reasonable hypothesis is put forward to explain the differing value. For example, there are four King County lakes in 2003 whose trophic assignment could be reassessed, based on the difference between the TSI-Secchi and the other values: Allen, Fivemile, Grass, and Wilderness. Grass and Fivemile are easy to evaluate because the TSI-TP and TSI-chlor are closer together, while the TSI-Secchi is much higher. The color of the water in both lakes is yellow (King County, 2002), which is likely to cause the TSI-Secchi values to predict higher lake productivities than actually exist. Both Grass and Fivemile should then be evaluated on the basis of the other two indicators. Without the TSI-Secchi value included, Fivemile productivities is assessed as mesotrophic rather than eutrophic. However, for Grass Lake all three indicators are more or less equidistant and make excluding any of them difficult.

In contrast, Lake Wilderness has two TSI values that range in the middle of mesotrophic, but the TSI-Secchi places well below the oligotrophic threshold. If the phytoplankton data are compared to the Secchi data, it is apparent that the bluegreens *Aphanizomenon* and *Gloeotrichia* dominated the phytoplankton during the time of higher transparency in the spring and fall. *Aphanizomenon* makes dense, long and narrow colonies resembling blades of grass, while *Gloeotrichia* makes dense balls of filaments. Neither shape interferes with clarity to the same extent as more diffuse colonies of algae or myriads of individual cells. Thus, the Secchi readings might not reflect the higher productivity during those times when the bluegreens were abundant, and productivity would likely be better represented by the chlorophyll *a* and total phosphorus TSI values. This puts Lake Wilderness in the middle range of mesotrophy.

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. Nine lakes met this criterion for all three calculations of TSI at or below the threshold: Langlois, Joy, Meridian, Star, Ames, Ravensdale, Pipe, Angle, and Margaret. Four other lakes had two out of three TSI values below 40: Pine, Lucerne, Mirror, and Morton.

Mesotrophic lakes have TSI ratings between 40 and 50. They are considered to be transitional between being relatively nonproductive and very productive biologically. In 2003, with two out of three indicators above the threshold or all three very near the threshold, the transitional lakes included Alice, Walsh, Sawyer, Shady, Boren and Geneva. Lakes slightly more productive, but considered in the lower range of mesotrophy included Beaver-2, Bitter, Burien, Steel, Welcome, Twelve, Shadow, North, Leota, and Haller. The middle to high range

Figure 2-11: Trophic state charts



mesotrophic lakes, with all three indicators in or very close to the 40-50 range included Kathleen, Spring, Holm (Neilson), McDonald, Horseshoe, Francis, and Marcel. Fivemile is a special case and should be considered as part of this group also.

Lakes that have TSI values greater than 50 are considered eutrophic, characterized by high biological productivity. Seven lakes were on the threshold between mesotrophy and eutrophy, including Clark, Jones, Paradise, Beaver-1, Yellow, Trout, and Killarney. Four lakes were rated clearly eutrophic in 2003: Allen, Cottage, Echo (Shoreline), and Grass.

Chlorophyll *a*

Variability is often much greater from year to year in chlorophyll *a* concentrations than it is for total phosphorus or the N:P ratio. This is not surprising, since the phytoplankton populations in a lake can be concentrated by wind and water movements and so may not be evenly distributed at the time of sampling. In addition, algal species present in a lake can change from year to year, and algae differ in the amount of chlorophyll per cell by species. The amount of chlorophyll *a* per cell can vary with the health and age of the population as well. For example, large blooms of cyanobacteria (bluegreens) may yield less chlorophyll than equivalent volumes of chlorophytes (green algae) because many bluegreens have accessory pigments in addition to the chlorophyll that are used to capture light for photosynthesis. 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 chrysophytes and diatoms, may sink down towards the thermocline, out of the surface water.

Even with all the variables that come into play on each sampling date, the annual May-October averages of chlorophyll (**Fig 2-12**) demonstrate that most of the lakes in the program have generally similar average concentrations from year to year or else vary within a certain range. This is particularly true of lakes with lower average concentrations, of which there are many: Alice, Ames, Angle, Bitter, Boren, Burien, Geneva, Haller, Horseshoe, Joy, Langlois, Lucerne, Margaret, Meridian, Morton, Pine, Pipe, Ravensdale, Sawyer, Shadow, Shady, Star, Walsh, and Wilderness.

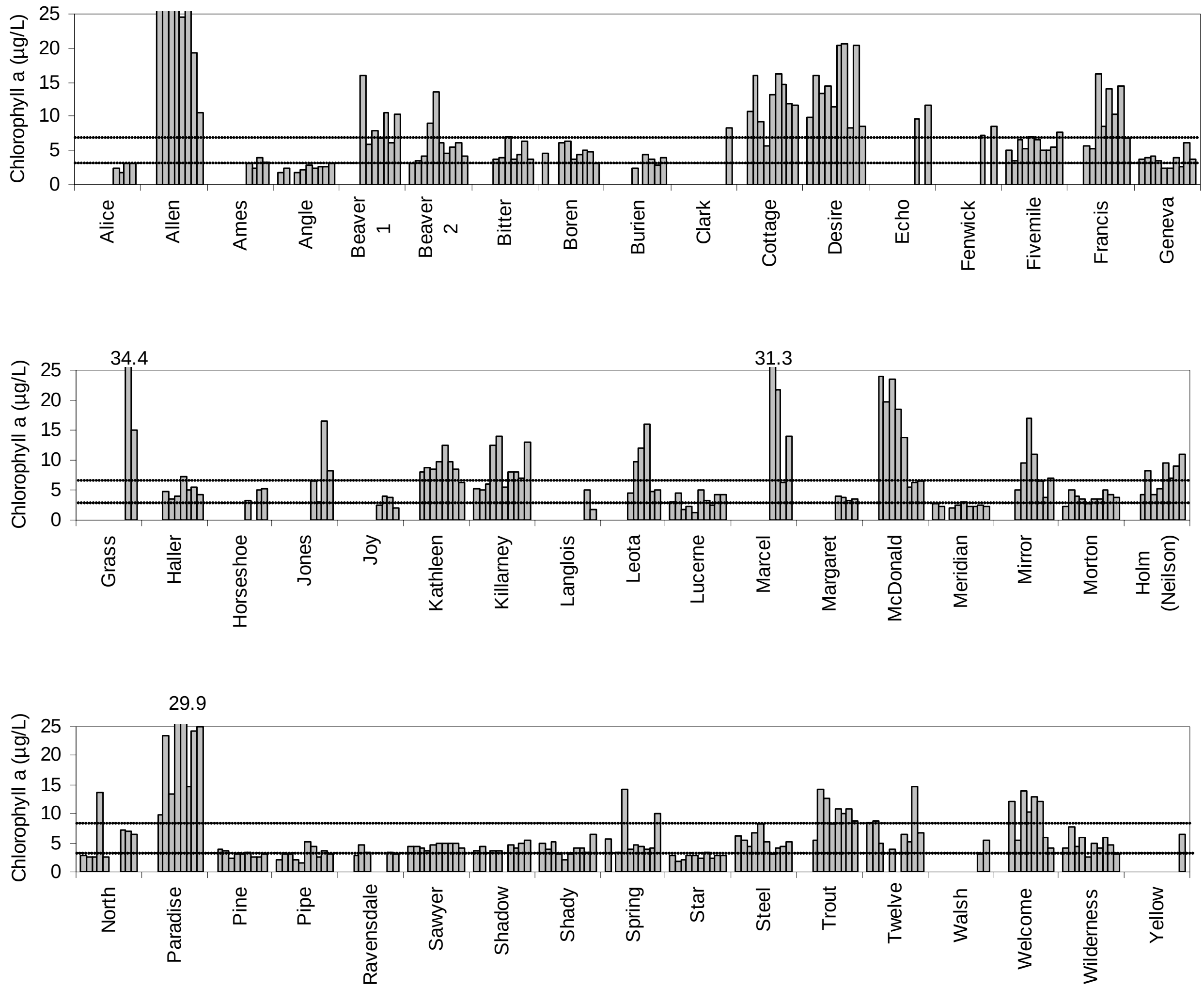
Average chlorophyll concentrations in Allen Lake vary a great deal from year to year, but in the past have always been much higher than in the other lakes participating in the program, with the exceptions of Grass, Marcel, and Paradise. Several other lakes which are also consistently higher than others include Cottage, Desire, Francis, Kathleen, Killarney, Paradise, Trout, and Welcome. Marcel has decreased sharply over the three years of monitoring. McDonald decreased steadily from 1998 to 2001, but have remained stable since then. Mirror had a peak in 1999 and has decreased since then. Welcome may also be decreasing, with a sharp decline in 2002. Leota appeared to be increasing, but dropped in 2002 and remained low in 2003.

A few lakes have one or two significantly higher years, such as Beaver-1 and Beaver-2 (oddly enough, these are in different years), North in 1997, or Lake Killarney in 1998. Alternatively, there may be one or two lower years, such as 2001 for Lake Desire. Such values can be anomalous and not repeated in the future, or could also be indications of regular, but ephemeral blooms that coincided with a sampling date in a particular year, but was missed in others because of the two-week gap between sample collections.

Conclusion

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 that are not representative of the lake as a whole, being

Figure 2-12: 1994-2003 average chlorophyll, May-October



Note: See text for the significance of the threshold lines

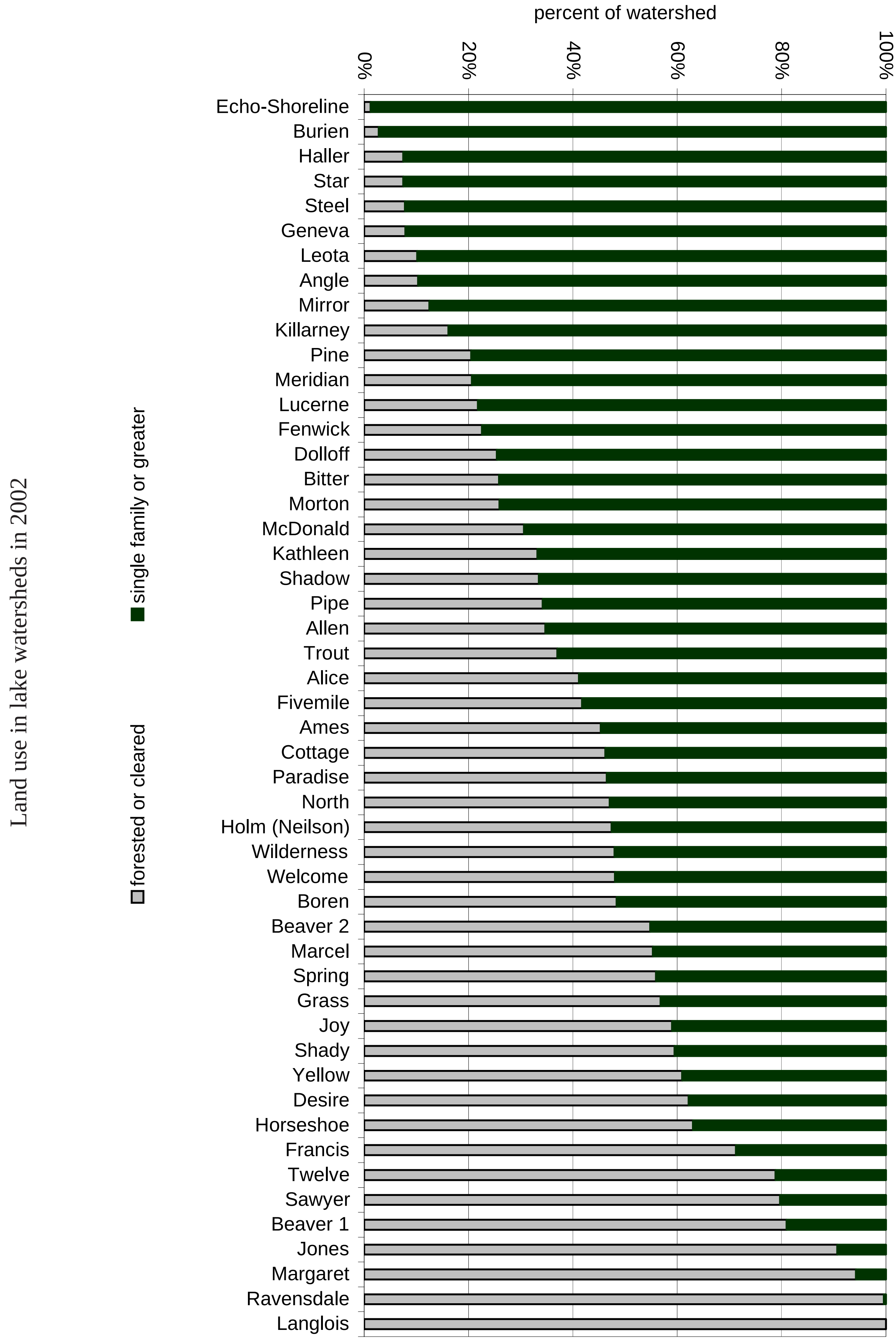
either too high or too low, but these tend to average out over a season. In practice, chlorophyll concentrations are rarely high at lakes with low overall productivity, and the yearly averages generally appear to be within a constant range. Chlorophyll tends to vary more at lakes with high phytoplankton abundances, such as at Allen. As a measure of productivity, chlorophyll may be subject to more variation than either Secchi or TP.

Land Use Analysis

A project to look at land use within the watersheds of monitored lakes was undertaken by Nora Kammer, a King County summer intern, who was enrolled in graduate school at the University of Washington in the civil engineering program. Kammer used a suite of aerial photographs taken in 2002 that had western King County coverage and overlaid the natural boundary watershed lines for the lakes in the program. Although some of the boundaries have undoubtedly been changed by developments and drainage projects, the project became impossible to complete within the time frame if all changes were tracked down and incorporated, while likely yielding little difference in the results.

Four different categories were chosen, with specified criteria, and all land was classified using ArcView 3.1 software. The categories

Figure 2-13: Land use in watersheds, based on 2002 aerial photographs



were collapsed into two for charting purposes: (1) forested or cleared land; and (2) development at or above the scale of suburban single family residences. For more information on the process or the results, please contact Sally Abella at 206-296-8382.

The percentage within each watershed of each of these two summary categories can be calculated and ordered by descending percentages of development **(Fig 2-13)**. This data can then be compared to the trophic status of the lakes to see if there is a general correlation with development and productivity.

While there are some easy agreements, such as oligotrophic lakes Langlois, Ravensdale, and Margaret located in relatively undeveloped watersheds and eutrophic Echo Lake in the city of Shoreline. There are many that do not fit this simple paradigm, which illustrates the complex nature of the relationship between land use, land configurations and lakes. There are clearly a range of other factors at work, such as adjacent highly productive wetland systems, the number of nearby septic systems, agricultural practices, degradation of associated wetlands, sewer system installations, even loss of wetland territory inside highly developed city boundaries. However, this set of data will certainly aid in future research on these effects and will be available to help answer some questions about changes noted in particular lakes in the future.