VOLUNTEER MONITORING: Introduction, Methods, and Bibliography

Purpose of Report

Monitoring water quality of the small lakes in King County was initiated in the 1970s by the Municipality of Metropolitan Seattle (METRO) and has been carried out regularly since 1993 by the Lake Stewardship Program of the King County Water and Land Resources Division. The program relies on the help of citizens who are trained to act as volunteer stewards, providing the manpower for field sampling and on-site observations necessary for carrying out such an ambitious program.

The intent of the data collection and analysis is to provide nearby residents, scientists, lake managers, jurisdictions, and interested individuals with current information on the water quality and physical conditions for lakes monitored throughout the County. Lakes within city boundaries are also included through inter-local agreements between King County and interested cities.

For many lakes, these data may represent the only reliable source of information for assessing current water quality and addressing questions regarding the characteristics and ecology of a particular lake. The information on the Lake Stewardship Program's web pages can help to guide lake protection and stewardship activities in King County and may also be used to plan further work to address specific questions about conditions in or near a particular lake.

Website Layout

Data reporting and analyses are in three different sections on this website, which are all in formats compatible with downloading. This replaces the program's annual report, last published for 2004 data, that was available both as a hard copy edition and as a pdf online.

This introduction provides basic information on the volunteer monitoring program, includes some general commentary on processes that occur in lakes, and discusses the collection and analytical protocols used by the program. It will only be updated as methods change or as the direction of the program is modified in any major way.

Regional results and analysis will be contained in three subsections published in annual editions, beginning with 2005. The subsections will include comparative climatic information, physical measurements made at the lakes, and regionally-based reporting on lake water quality, including comparisons and long term trend analyses.

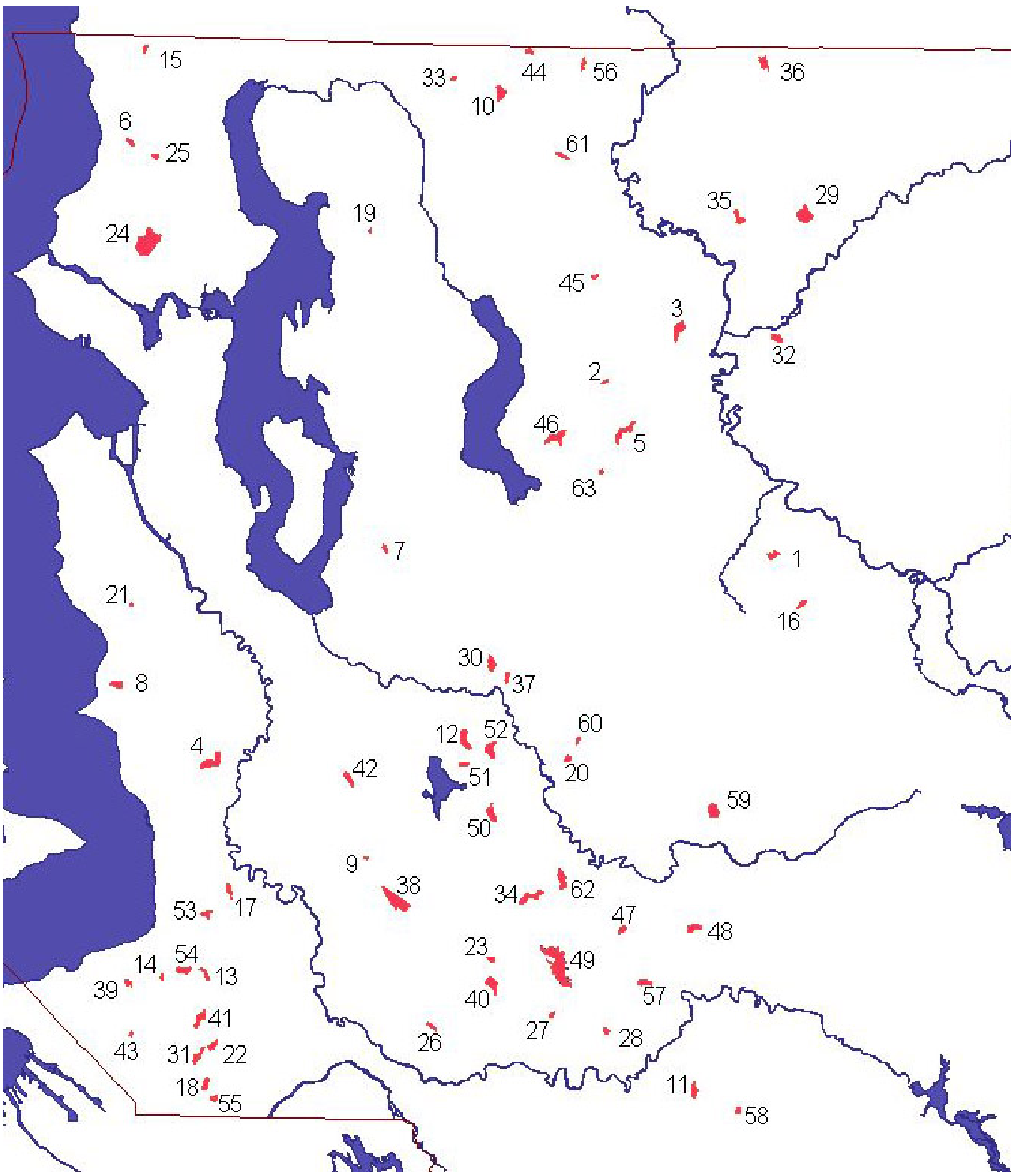
Data for each lake can be viewed in tabular or graphic formats or downloaded from:

http://www.metrokc.gov/dnrp/wlr/water-resources/small-lakes/data/default.aspx

Maps and discussion of the conditions found at each lake are also available at this link.

Over sixty small lakes (Figure 1) have had at least some data collected since 1993, and many have data that spans this time period. This means that a solid foundation of background data is available for examining any changes that occur in terms of the expected normal range of variation for that lake. In addition, a picture of the lakes in the region as a whole is beginning to emerge, which should have important benefits in the future when climate changes appear to be affecting ecological processes.

Figure 1. Small lakes with monitoring data collected by the Lake Stewardship Program and citizens volunteers. Key to numbered lakes follows.



Key to lake names and sizes for Figure 1:

Key#	Lake Name	Acres
1	Alice	32
2	Allen	11
3	Ames	76
4	Angle	103
5	Beaver	71
6	Bitter	18
7	Boren	16
8	Burien	40
9	Clark Lake	7
10	Cottage	63
11	Deep	39
12	Desire	69
13	Dolloff	21
14	Easter	11
15	Echo - Shoreline	11
16	Echo Lake	19
17	Fenwick	21
18	Fivemile	35
19	Forbes	6
20	Francis	16
21	Garrett (Hicks)	5

Key#	Lake Name	Acres
22	Geneva	28
23	Grass	15
24	Green	256
25	Haller	14
26	Holm (Neilson)	20
27	Horseshoe	10
28	Jones	15
29	Joy	108
30	Kathleen	48
31	Killarney	29
32	Langlois	41
33	Leota	9
34	Lucerne	69
35	Marcel	33
36	Margaret	53
37	McDonald	16
38	Meridian	153
39	Mirror	18
40	Morton	66
41	North	51
42	Panther	34

Key#	Lake Name	Acres
43	Panther	8
44	Paradise	18
45	Peterson Pond	7
46	Pine	86
47	Ravensdale	18
48	Retreat	51
49	Sawyer	286
50	Shadow	49
51	Shady (Mud)	21
52	Spring (Otter)	65
53	Star	33
54	Steel	46
55	Trout	16
56	Tuck	12
57	Twelve	41
58	Walker	12
59	Walsh	73
60	Webster	10
61	Welcome	16
62	Wilderness	66
63	Yellow	9

Why Monitor?

The collection of data on lakes varies from one program to another, depending on the objectives of the program. For the King County Lake Stewardship Program, the objectives of data collection include: (1) gathering baseline data with the intent of assessing long-term trends; (2) defining seasonal and water column variability; (3) identifying potential problems, proposing possible management solutions when feasible, or pinpointing additional studies to be made; (4) educating lake residents, lake users, and policy makers regarding lake water quality and its protection; and (5) providing a foundation of knowledge that can be used for long-term stewardship of the smaller lakes in King County.

Every lake is a unique body of water, reflecting the characteristics and hydrology of its watershed. Water quality is affected by the sources and quantity of water inflows, as well as by the amounts and types of nutrients originating from the watershed, in particular nitrogen and phosphorus. For example, when the surface area of a lake makes up a relatively large percentage of the total watershed, much of the precipitation falling in the basin goes directly into the lake, not passing first over hard surfaces or through soils, wetlands or constructed drainage systems. Thus, in this case relatively pure rain water makes up a significant proportion of the total water 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 over the course of a 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.

To maximize information obtained for the effort, the Volunteer Monitoring Program offers two different programs: Level I monitors collect data all year on precipitation, lake level, surface water temperature, and water clarity. The main emphasis in this effort is on the hydrological balance between the lake and its watershed, as well as temperature ranges and the impacts of inputs on water clarity.

Level II monitors also measure temperature and clarity, in addition to collecting samples for water chemistry from May through October. The main emphasis in this effort is on nutrient balances and algal communities. Level II sampling coincides with much of the primary recreational period for lakes in the Pacific Northwest, which is the chief beneficial use of most of the regional lakes from the human standpoint. During the summer, water chemistry and temperature vary with depth in most lakes. On each sampling trip, volunteer monitors collect samples from a depth of one meter. In early summer and again in late summer, Level II samples are collected from the surface (1m), middle, and one meter above the bottom from the deepest part of the lake to define changes found in the vertical profiles of the parameters.

Most of the more than 700 lakes and ponds located in King County have never been monitored, and only a few have long monitoring records. However, by concentrating on the small lakes found throughout the inhabited portion of King County, the Lake Stewardship Program hopes to provide a basis for assessing impacts of development and human activities on the ecology of the small lakes in the region, as well as to their beneficial uses.

WATER QUALITY

Lake Classification and Eutrophication

Lakes can be classified by measurements of both potential and actual biological activity, also known as “trophic state.” Lakes with high concentrations of nutrients and algae, which are generally accompanied by low water transparencies, are termed eutrophic or highly productive. Lakes with low concentrations of nutrients and algae, most often accompanied by high transparencies, are categorized as oligotrophic or low in productivity. Lakes intermediate between eutrophic and oligotrophic are termed mesotrophic. A commonly used index of water quality for lakes is the Trophic State Index (TSI) originally developed by Robert Carlson (1977), which separates lakes into the three different categories by scoring water clarity and concentrations of phosphorus and chlorophyll *a*, relating them to a scale based on the amount of phytoplankton biovolume present. This index and its application to King County lakes are discussed further in the subsection of the annual regional report entitled “Chlorophyll and TSI”.

Each lake’s productivity is influenced by a variety of natural factors that interact, including watershed size and geology, lake depth and surface area, climate, direction and strength of the prevailing winds, the quality and quantity of water entering and leaving the lake and catastrophic events such as earthquakes and volcanic eruptions. At any particular point in time, lakes may be naturally eutrophic, mesotrophic, or oligotrophic, based on the characteristics and stability of the surrounding watershed.

Increases in a lake’s biological activity over time (“eutrophication”) may occur naturally in some lakes, but can be hastened by human activities in others. Natural eutrophication, when it occurs, probably happens on a time scale of thousands of years and is generally not observable in a lifetime. Lakes in a region may naturally exhibit a variety of degrees of productivity without human-induced (cultural) impacts. However, the effects of human-induced eutrophication can be seen in as little as a decade, speeding up substantially what may often be a very slow process in a natural environment.

Land use activities, including home building and habitation, commercial and industrial development, agriculture, forestry, resource extraction, landscaping, gardening, and animal keeping all have the potential to contribute increased concentrations of nutrients into surface and ground waters and change sediment movements. Increases in impervious surfaces associated with land development also result in distinct changes in surface water runoff patterns. This surface water, as it enters lakes and streams, can increase biological productivity by increasing the concentrations of nutrients available for plant growth. Additional sediment input associated with increased surface water runoff can also impact lakes in various other ways, such as delta building and decreased light penetration.

Lakes can also be characterized by the frequency of algal blooms and the type of algae present. Large amounts of algae can affect swimming, fishing, boating, wildlife, aesthetics, and other uses. Eutrophic lakes, for example, may have frequent nuisance algal blooms dominated by bluegreen algae (cyanobacteria). These blooms can form surface scums, give off noxious odors, and may occasionally produce toxins that have direct health impacts on animals as well as people.

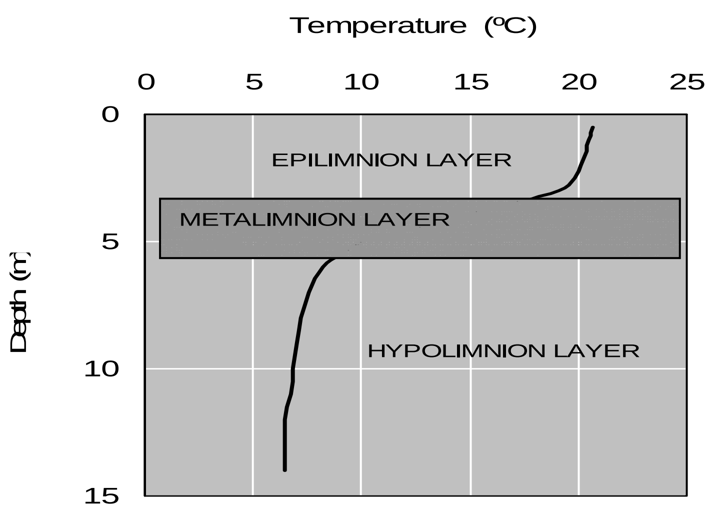
Excessive growth of rooted aquatic plants can also impact boating, fishing, and swimming. A lake need not be eutrophic to support a large amount of aquatic plant life. Many aquatic plants are rooted in the sediments, from which they can draw nutrients. An additional important factor is the depth to which light can penetrate in the lake, affecting how much of the lake bottom is within that depth range. Clear lakes with large areas of shallow water can support aquatic plant growth over a larger area than deep or colored water lakes, but plants may be less dense because of smaller amounts of nutrients available in the lake sediments.

Seasonal Patterns in Water Quality

Lakes are complex ecosystems with many kinds of living organisms interacting with each other and their environment. External factors such as solar radiation, wind, air temperature and water inflows combine with internal forces such as evaporation rates, currents, nutrient release from sediments, nutrient uptake by algae, and plant-animal interactions to produce an intricate web of relationships.

An annually occurring process known as thermal stratification occurs when the water column, warmed by sunshine at the surface, separates into layers divided by temperature difference (Figure 2), which usually persist through the warm seasons. During late fall and winter, water temperatures remain essentially uniform from top to bottom, and water circulates evenly throughout the lake. As the days lengthen in spring, the surface water warms faster than heat can move downward through the water column, either by diffusion or by wind mixing. This is aided by the density differences of water at differing temperatures. Cool water is denser than warm, so it takes more energy to mix it up from the bottom. Eventually, these thermal and density differences stabilize into three layers: the upper warm epilimnion, the lower cool hypolimnion, and a zone of rapid temperature change in between them, termed the metalimnion.

Figure 2. Thermal stratification schematic drawing.



Water does not readily move across the boundaries because of the density differences, and as a result, overall water chemistry is different in each layer through the summer. The differences are related to the biological activities and physical processes taking place in each level. The epilimnion stays warm, light is present, and algae continue to grow and reproduce until the nutrient supply is depleted. A hiatus in algal increase then occurs until cool air temperatures in the autumn cause the sharply defined thermal layers to begin mixing together, circulating the nutrients previously held in the deep hypolimnion back up to water near the surface. This sometimes stimulates an autumn burst of algal growth, but this is generally short-lived, eventually limited by the onset of colder weather and shorter days.

The amount of oxygen contained in the hypolimnion is affected by both the persistence of thermal stratification and the productivity level of the lake. Oxygen enters the waters of a lake in several different ways: by mixing into the surface water from the air, given off as a by-product of photosynthesis by algae, and contained in water flowing into the lake. It disperses through water mixing and diffusion. Once thermal stratification is established, oxygen is no longer supplied to the hypolimnion because the lower water is cut off from contact with the atmosphere, few algae can live and grow in the dark, deep water, and most inlets empty in the shallow water.

The demand for oxygen continues from the animals that live in deep waters such as fish, as well as from the bacterial decomposers that break down the organic material that sinks to the bottom (e.g.: algal remains and organic detritus). If a lake is eutrophic, the large amount of algal remains will stimulate massive decomposition activity. Oxygen concentrations in the water can get very low and may even be totally used up by the bacteria before the end of summer. When this happens, it can have an enormous impact on fish such as salmonids, who need cool temperatures and prefer the safety of deep water, but who may be forced upwards towards the surface by the lack of available oxygen. Warm surface water temperatures can stress fish, pushing them to move into the limited zone between warm surface water and oxygen deprived bottom water. This area narrows through the summer, creating hardships for the population. Heat and oxygen stressed fish are also more susceptible to disease, sometimes leading to die-offs.

Very low oxygen concentrations also affect nutrient availability in future seasons. In the absence of oxygen, a chemical reaction in the sediments facilitates the release of more phosphorus back into the water column than would otherwise occur if oxygen levels remained high. This means that more phosphorus is available in the water for algal growth in the next growing season, and the lake is likely to be even more productive than before.

The Lake Stewardship Volunteer Monitoring 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. As funds have allowed, additional sampling has been performed to characterize the water chemistry of the deeper lake layers. This vertical sampling has provided some data that is useful in understanding the general nutrient cycling and water column relationships in individual lakes.

Methods

Level I Data Collection

Level I data collection occurs daily and weekly, and is compiled by the 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..

Lake level is recorded daily by volunteers by reading a gauge (a porcelain-glazed steel metric ruler) attached permanently to a rigid dock or other fixed structure in the lake, usually near the volunteer's home. Many of these meter sticks have not yet been calibrated to elevation above sea level, so the vertical measurements taken are relative to the stick position rather than to mean sea level.

Precipitation is also recorded daily, with rain collected in a calibrated rain gauge installed in an area exposed to direct rainfall, located away from overhanging objects such as trees or buildings. Some volunteers now have residential weather stations installed on the house roof and report these data for daily precipitation accumulation.

Water clarity (Secchi depth) and surface water temperature are measured weekly. Secchi depth generally is 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. It is important to try to read this at the same time of day because the angle of the sun can change light penetration into the water. Other factors include glare from sky cover reflecting in the water and the amount of chop caused by wind. The reading must be taken without using sunglasses, especially of the polarized variety. There is some variation between viewers in how far into the water they can see the disk, but this simple method produces remarkably similar data when people conduct side-by-side measurements.

Volunteers measure water temperature at the same location as Secchi depth readings. The method calls 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. The protocol calls for special thermometers that change very slowly, so that the lag between bringing the thermometer up from 1m and reading the value will not impact the reading.

Further details on Level I volunteer monitoring sampling methods are supplied in the *Lake Stewardship Program Volunteer Lake Monitor Sampling Manual*, which is updated periodically and can be found as a pdf file in the volunteer monitoring section of the Lake Stewardship website at:
http://dnr.metrokc.gov/wlr/waterres/smlakes/monitor.htm#manual.

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. All original data are available for downloading on the Lake Stewardship Program website at:

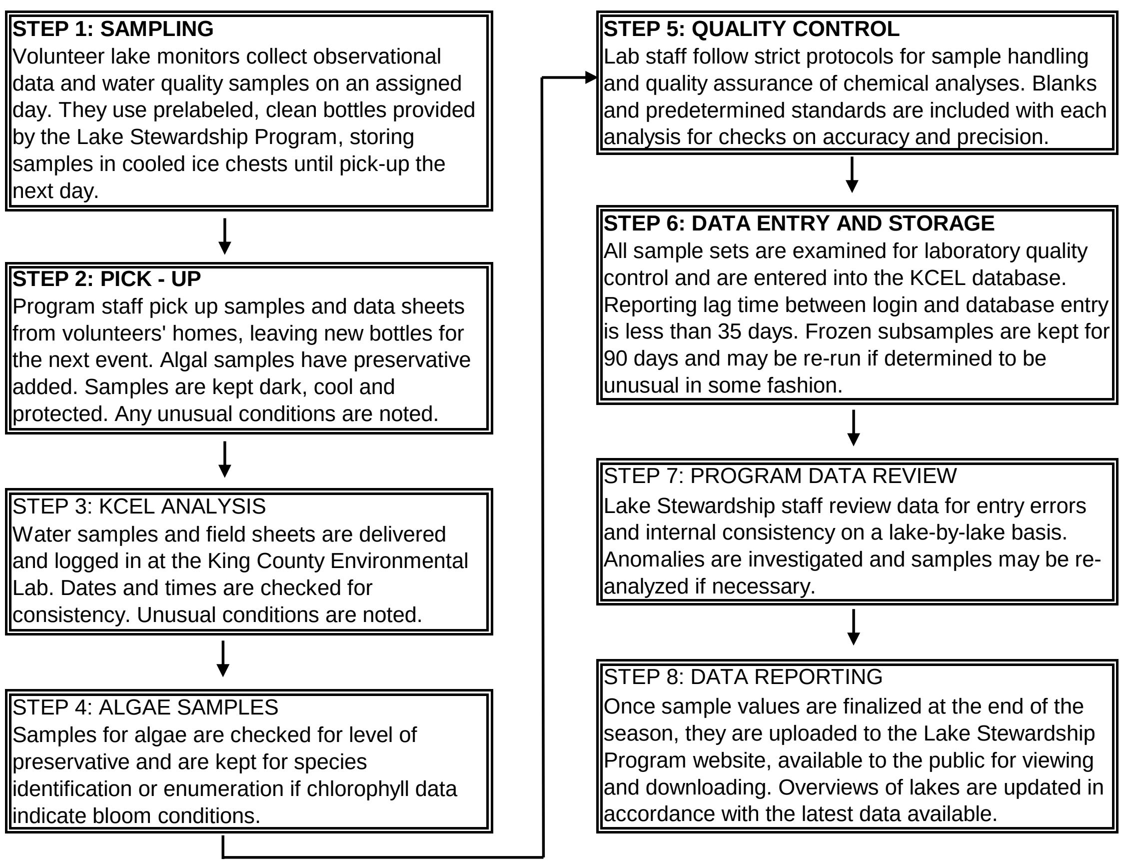
http://www.metrokc.gov/dnrp/wlr/water-resources/small-lakes/data/default.aspx

Level II Data Collection

Level II volunteer monitoring activities occur twelve times a season from early May through October on a predetermined schedule. Water samples are collected from one meter depth on every sampling date, and volunteers also collect deeper samples twice during the period, usually at mid-depth as well as at one meter from the lake bottom.

For most lakes, volunteers are able to collect data for the entire period (May through October), although there a couple of lakes that occasionally become too shallow to launch a boat to get to the sample station (examples are Grass and Horseshoe). Gaps and anomalies are noted by lake when analyzing data. A flow chart of the entire sampling and data production process shows how samples are treated (Figure 3).

Figure 3. How lake samples are collected and processed.



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

On the two dates when vertical profiles were sampled, samples are taken at one meter, mid-depth, and one meter from the lake bottom. Temperature is measured at each depth using the thermometer mounted inside the sampler, and water samples for total phosphorus and total nitrogen are collected at all three depths. Chlorophyll *a* and phytoplankton analyses are 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. Samples for total alkalinity, water color, orthophosphate, and nitrate (plus nitrite) are also collected from specific depths during the profile events. Water is also filtered through a polycarbonate filter with opens of 0.45 microns, and the dried filters are kept for future reference. Color of the filters is also rated using the Munsell color chips from the Geological Society of America's Rock Color charts.

The water samples are analyzed at the EPA approved King County Environmental Laboratory, using standard methods and protocols, as well as accredited quality assurance and quality control procedures. Phytoplankton (algae) identifications and qualitative estimates are carried out by a combination of a qualified consultant and King County staff with extensive phytoplankton experience, when analysis is determined to be warranted based on the chlorophyll concentrations or if other questions arise.

Physical and chemical values for each lake and date are available as downloadable data or in customized charts. Phytoplankton data are available upon request. Further details on Level II volunteer monitoring sampling methods are described in the *Lake Stewardship Program Volunteer Lake Monitor Sampling Manual.*

Other parameters

While on the lake, many monitors also rate particle abundance. This is often helpful in determining the relationship between Secchi readings and reported chlorophyll concentrations. The Secchi disc is lowered 6" under the water surface and a rough estimate of particles visible in the 2 white sections is made. At 6" depth, the two sections correspond to a total of 2 liters of water volume. Water is rated as having less than 10 particles, 10 to 100, and greater than 100. This assessment is not meant to be a quantitative measurement, but rather as a general indication of how many particles are present at a particular time.

Some volunteers also keep track of the numbers of Canada geese found on their lakes. They have two methods from which to choose, but must stay consistently with their chosen method in order to make comparisons reliable. They can either keep track daily of the maximum number of geese that are seen on the lake at one time during the day, or they can keep track of the maximum seen at any one time on a weekly basis.

Data Analysis

Minimum, maximum, and average values for temperature and Secchi depth are determined for the Level I volunteer monitoring data. Annual lake level range and accumulated precipitation are also determined for each participating lake with complete data sets.

For Level II water quality measurements, the minimum, maximum, and average values are 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.

The Trophic State Index or TSI for water clarity, chlorophyll-a, and total phosphorus (Carlson 1977) are calculated for Level II volunteer monitoring data. TSI values are computed based on a regression that was derived by comparing values of the parameter to the algal bio-volume of a suite of lakes and then transformed into a number on a scale of 0 to 100, based on the relationship. Numbers on this scale can be used to compare water quality over time and between lakes.

The nitrogen to phosphorus ratios (N:P) are also calculated since, if nutrient limitation of algal growth is likely to be operating, 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 the overall on the website.

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