Green Lake Water Quality:
Water Quality Monitoring Results for Water Year 2013

March 2014

King County

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The City of Seattle

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King County Lakes and Streams Monitoring Group
King County Water and Land Resources Division
Department of Natural Resources and Parks

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OVERVIEW

The King County Lakes and Streams Monitoring Group and its predecessor the Lake Stewardship Program have worked with volunteer monitors on Green Lake since 2005 to track water quality, which has been of particular interest after the alum treatment of the lake was carried out in 2004 to control phosphorus concentrations in the water column. Volunteers undergo training and use equipment owned and maintained by King County.

Two water quality sampling stations in the lake were established in 2005 and measurements were taken at both sites in the years 2005 – 2008. Beginning in 2009 and continuing through 2013, the station near East green lake was monitored for water quality, while some year-round physical monitoring occurred at the fishing dock at East Green Lake and water levels were checked at the Meridian outlet structure.

Green Lake is surrounded by a public park, and car-top boats can be launched at various points around the lake. It has a history of milfoil infestation, for which control efforts have been undertaken from time to time.

Green Lake has also been closed to recreation for bluegreen algae (cyanobacteria) accumulations and blooms several times. In the fall of 2013, warnings were again posted concerning downwind accumulations of toxic algae along the shorelines, although the lake remained open to recreation well away from those areas.

The lake has been treated with alum to reduce available phosphorus for algae control in 1991 and again in 2004. The most recent treatment reduced nutrients and immediately improved the water quality of the lake. The 2013 data indicate that Green Lake as a whole continues to have low to moderate algal productivity (lower mesotrophic, see definition in "What We Measure") with good water quality, aside from the small amounts of cyanobacteria. Information from the current monitoring project is used to assess the longevity of the alum treatment's effect.

The discussion in this report focuses on the 2013 water year. The specific data used to generate the charts in this report can be downloaded from the King County Lakes and Streams Monitoring data website at:

http://your.kingcounty.gov/dnrp/wlr/water-resources/small-lakes/data/default.aspx

Data can also be provided in the form of excel files upon request.

Further introduction and a discussion of the philosophy of the volunteer lake monitoring program and the parameters measured can be found on-line at:

http://your.kingcounty.gov/dnrp/library/archive-documents/wlr/waterres/smlakes/2006_Intro.pdf

1.0 WHAT WE MEASURE AND WHY

Measurements that were taken at all of the lakes in the small lakes monitoring program are discussed in this section to introduce the parameters and give context to the discussions of the data that follow.

Lake level is a relative measure of the water level that is measured daily using a staff plate installed on either a pole or a fixed height dock . These data can be used to look at the annual fluctuation of water levels in the lake, as well as response to increased water coming in due to storm events and the rate at which it drains. While most of the installed staff plates at lakes around the county are not surveyed to tie the data in with sea level, this could be done in the future to give actual elevations.

Daily **precipitation** is measured at the same time as lake water level in order to relate the lake level to inputs from the watershed. These data are collected either through a plastic rain gage provided by King County that can be emptied after reading each day or by a recording weather station if the volunteer chooses to purchase a reliable unit.

Both Level 1 and Level II volunteers measure Secchi transparency and water temperature. Level I volunteers do this weekly throughout the year while Level II volunteers measure between May and October when they collect water samples for laboratory analysis.

Secchi transparency is a common method used to assess and compare water clarity. It is a measure of the water depth at which a black and white disk disappears from view when lowered from the water surface. Factors in the water that affect Secchi readings include the number and size of particles present, such as algae and silt, as well as water color from dissolved organic molecules. Other factors that affect the readings are the amount of glare, choppiness of the water, shade from tall trees or the boat, and variation in the vision of the observers.

Water temperature is usually measured using an alcohol-based thermometer that holds a specific temperature long enough to allow the observer to read the value after retrieving the thermometer from the water.

Phosphorus and nitrogen are naturally occurring elements necessary for growth and reproduction in both plants and animals. However, many activities associated with residential development can increase these nutrients in water beyond natural levels. In lakes of the Puget Sound lowlands, phosphorus is often the nutrient in least supply, meaning that biological productivity is most often limited by the amount of available phosphorus. Increases in phosphorus can lead to more frequent and dense algae blooms – a nuisance to residents and lake users, and a potential safety threat if blooms become dominated by cyanobacteria (bluegreen algae) that can produce toxins.

Total phosphorus (TP) and **total nitrogen (TN)** are both measured every time the level II volunteers collect water at the 1m depth. More specific forms of nitrogen and phosphorus are measured twice during the sampling period, when water is collected from 3 depths at the station: 1 m, the middle depth of the water column, and 1 m from the lake bottom. These include nitrate-nitrite, ammonia, and soluble reactive phosphorus, and the data can be used to infer the amount of oxygen present in deep water, as well as the presence of internal loading of nutrients from the sediments back into the lake water.

The **ratio of total nitrogen to total phosphorus (N:P)** can be used to determine if nutrient conditions are favorable for the growth of cyanobacteria (bluegreen algae), which can negatively impact uses of the lake and potentially produce toxins. When N:P ratios are near or below 25, nitrogen is as likely to be the limiting nutrient as phosphorus. Cyanobacteria may then be able to dominate the algal community due to their ability to take up nitrogen from air.

Chlorophyll-*a* concentrations indicate the abundance of phytoplankton in the lake. Although different species of algae contain varying amounts of chlorophyll, all algae use it in order to complete the photosynthetic pathway by which they store energy. For example, some cyanobacteria have other light-catching pigments and thus have relatively little chlorophyll compared to their biovolume.

Pheophytin is a product of chlorophyll decomposition and is generally measured along with chlorophyll as an indicator of how fresh or viable the phytoplankton in the sample are. Bottom sediments will contain a large amounts of pheophytin compared to chlorophyll, while actively-growing algae from surface waters will have very little pheophytin present.

A common method of tracking water quality trends in lakes is by calculating the **Trophic State Index (TSI)**, developed and first presented by Robert Carlson in a scientific paper dated 1977. TSI values predict the biological productivity of the lake based on three parameters that are easily measured: water clarity (Secchi), total phosphorus, and chlorophyll-*a.* The values are scaled from 0 to 100, which allow them to be used for comparisons of water quality over time and between lakes. If all of the operating assumptions about a lake ecosystem are met, the 3 TSI values should be very close together for a particular lake. When they are far apart in value, lake conditions and measurements should be examined to understand what special conditions exist at the lake or to evaluate the data for errors.

The Index relates to three commonly used categories of productivity:

- *oligotrophic* (low productivity, below 40 on the TSI scale - low in nutrient concentrations, small amount of algae growth);
- *mesotrophic* (moderate productivity, between 40 and 50 on TSI scale – moderate nutrient concentrations, moderate growth of algae growth); and
- *eutrophic* (high productivity, above 50 – high nutrient concentrations, high level of algae growth).

A lake may fall into any of these categories naturally, depending on the conditions in the watershed, climate characteristics, vegetation, and rock and soil types, as well as the shape and volume characteristics of the lake basin. Activities of people, such as land development, sanitary waste systems, and agricultural practices, can also increase productivity, which is known as "cultural eutrophication."

2.0 PHYSICAL PARAMETERS

Methodical precipitation records were compiled for the 2013 water year by a Level I volunteer (Figure 1). However, lake level records were not obtained for water year 2013. In the past there has been a small amount of variation in the water level of the lake through the year, which in the past has related well to the precipitation record. This is because both stormwater inputs and the water level in Green Lake are managed by Seattle Parks Department and Seattle Public Utilities to maximize water quality and recreational opportunities.

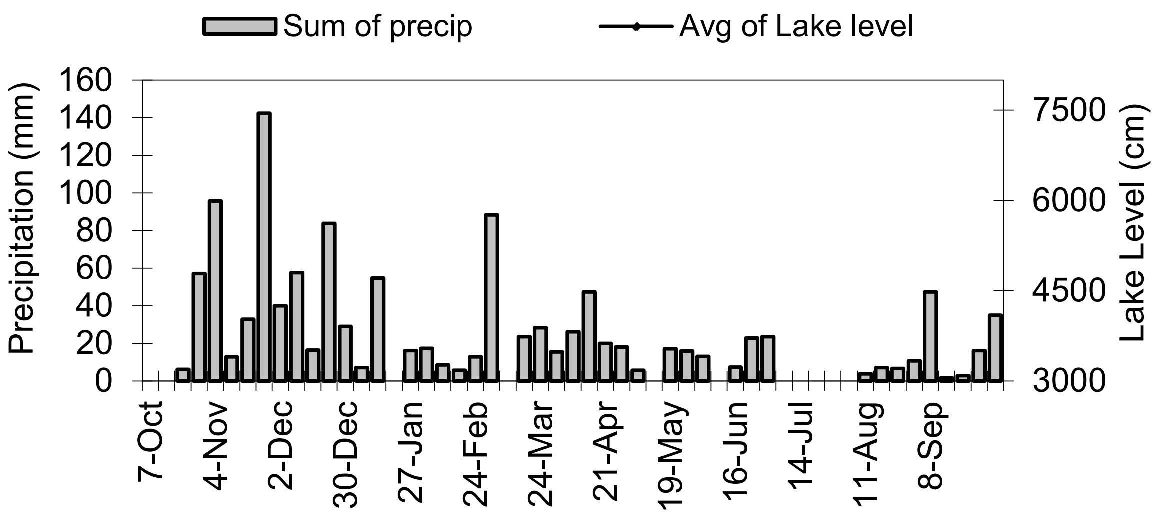

Figure 1. Green Lake precipitation records for water year 2013.

Secchi transparencies measured by the Level II volunteers at the open water station ranged between 1.2 and 5.0 m from May through October, averaging 3.7 m, while Level I measurements made from the dock at East Green Lake ranged between 1.7 and 4.3 m, averaging 3.0 m between May – October and 2.9 m from January – September (Figure 2).

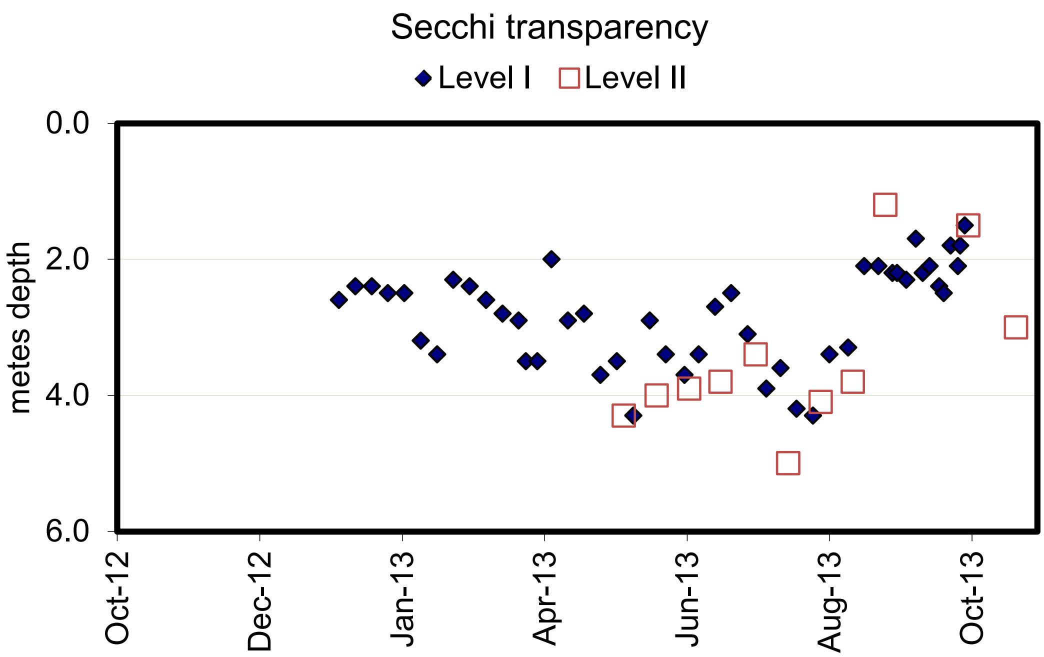

Figure 2. WY 2013 open water (Level II) and East Dock (Level I) Secchi transparency.

The differences between the readings at the sampling site and the dock may be understood by taking into account factors that can bias a Secchi measurement, such as direction and strength of wind, differing visual acuities between observers, light reflection off the water, depth of water at the site, and location on the lake. In some years, the shallow water column at the dock site has limited the depth to which the Secchi disk could be lowered, and the depth recorded sometimes may have been a minimum value because the Secchi reached the lake bottom before it disappeared from view. Therefore, the dock readings perhaps should be viewed as a minimum estimate of the value. In addition, prevailing winds are from the southwest and often algae will be blown shoreward by the wind, concentrating in the area of the dock, which increases the turbidity of the water and lowers the Secchi depth.

The period in Autumn of cyanobacteria dominance was reflected in both the open water and dock Secchi measurements, with significantly lower clarity recorded by both observers.

At the open water station (Level II), surface water temperatures from May through October ranged between 16 and 23.5 degrees Celsius with an average temperature of 19.2 °C (Figure 3). At the East Dock, temperatures over the entire year ranged from 4.0 to 23.0 °C with an annual average of 13.8 °C (57 ° F), while the May – October average was 20.2 °C (68 °F). Green Lake is in the lower third for summer maxima recorded among the lakes monitored by King County in 2013.

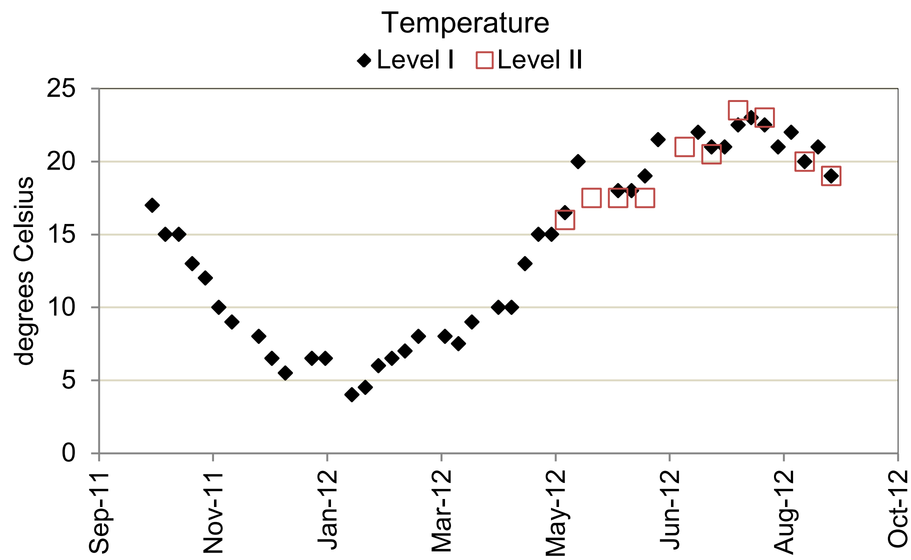

Figure 3. WY 2013 Green-1 (Level II) and East Dock (Level I) temperatures.

Mean summer water temperatures over the time period that Green Lake has been monitored show a statistically weak trend towards increase over time (Figure 4). The correlation coefficient is 0.265, which suggests that just over a quarter of the variability between years can be explained by an increasing trend. A shallow water temperature increase over time has not been detected in other small lakes monitored throughout King County, but because conditions can vary in watershed size, land use, hydrological conditions and basin configurations between lakes, comparing trends over time may not yield a great deal of information about global climate change in the region.

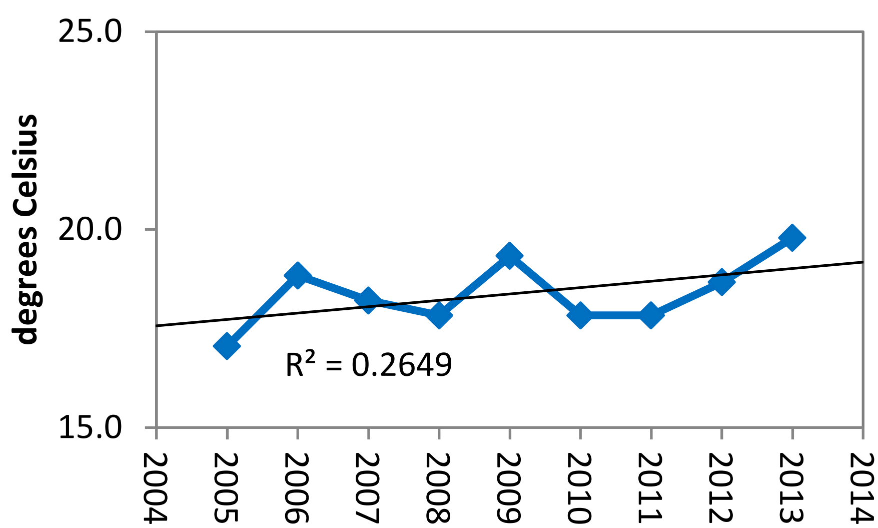

Figure 4. Mean May – October 1m water temperatures for Green Lake at the mid-lake station (Green-1) since 2005. The increasing trend line has a correlation coefficent of 0.2649.

3.0 NUTRIENT AND CHLOROPHYLL ANALYSIS

Samples to be analyzed for total phosphorus (TP) and total nitrogen (TN) were collected by volunteers at a depth of one meter during the months of May through October. Samples were taken from additional depths in May and August on two dates.

Nutrient concentrations remained fairly stable throughout the monitoring period (Figure 5). Total nitrogen dipped slightly in early summer and then increased slightly through October. Total phosphorus had even less variability over the season. This lack of seasonal response is consistent with past years and suggests that limitation of phytoplankton by phosphorus may be occurring before monitoring begins in May.

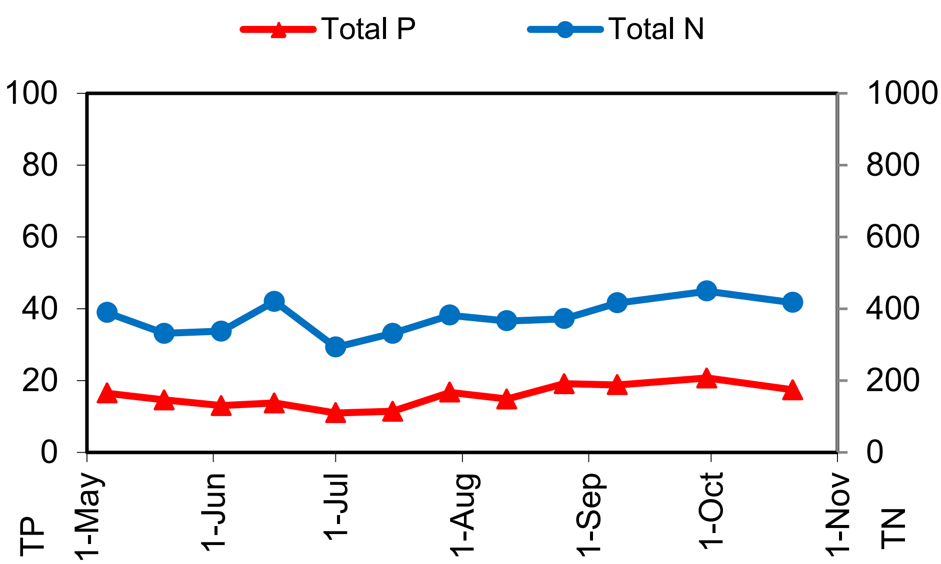

Figure 5. Green Lake Total P (TP) and Total N (TN) in µg/L, summer 2013.

In Green Lake, phosphorus and nitrogen remained in relatively constant proportion to each other through the sampling period, with the N:P ratio ranging from 19.5 to 30.7, averaging 24.4 (Figure 6). The ratio reached a maximum in mid-June, during which P was likely the limiting nutrient. However, during most of the sampling period N:P levels hovered around 25, indicating that both phosphorus and nitrogen could have been co-limiting production by the phytoplankton, and conditions might have been favorable for competition by cyanobacteria. From late August through October, the ratio was below 25, which coincided with the cyanobacterial bloom that contained species producing toxins.

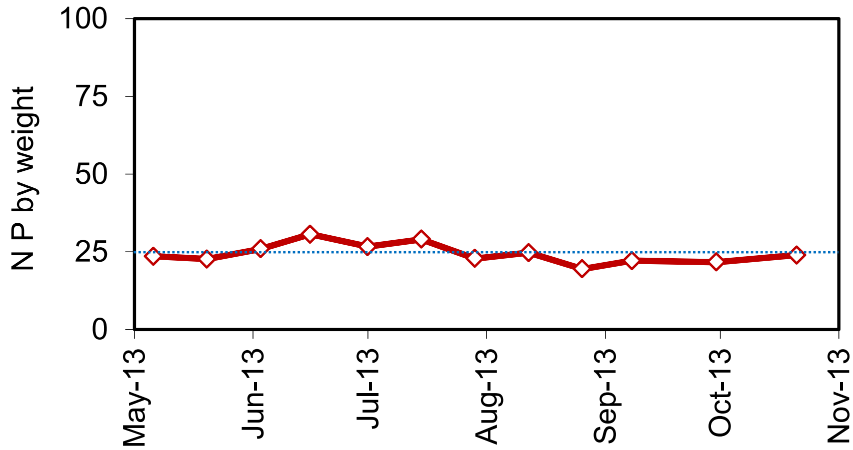

Figure 6. Green Lake N:P ratios, 2013. Values at and below the blue line indicate a potential nutrient advantage for cyanobacteria.

Since 2005, the average N:P ratio over the sampling period appears to be changing in Green Lake and, with 9 straight years of data, a test for directional trend could be applied to the values (Figure 7) . A correlation coefficient of 0.459 suggests that an increasing trend explains approximately half of the variation seen over time, which is a relatively robust indicator for directional change in lake data.

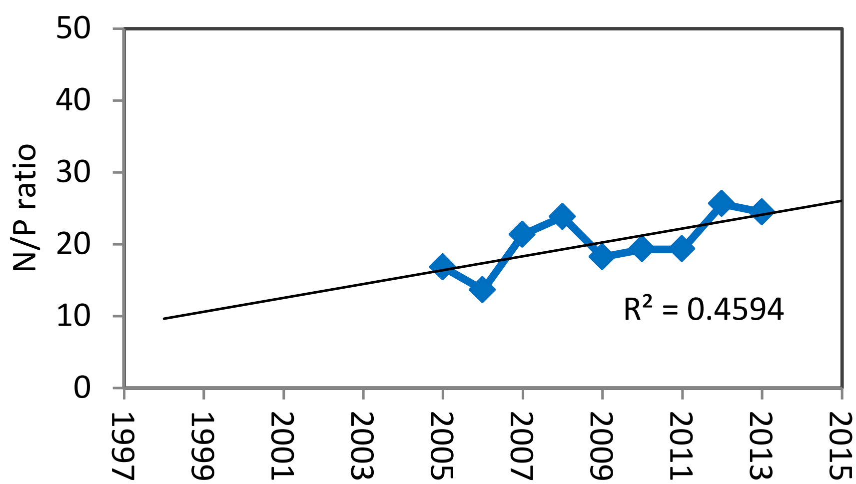

Figure 7. Green Lake N:P ratios over time with trend line, including coerrelation coefficient.

This increasing N:P trend appears to be due to an increase in nitrogen in the lake rather than a decrease in phosphorus (Figure 8). Average summer concentrations over time were tested for trends since 2004. An increasing trend for total nitrogen was validated with a correlation coefficient of 0.7928, which is very robust, indicating that nearly 80% of the variability between years can be explained by an increasing trend. The trend line for total phosphorus is flat, with a very low correlation coefficient of 0.0004, indicating that greater than 99% of the variability is random and not related to a trend.

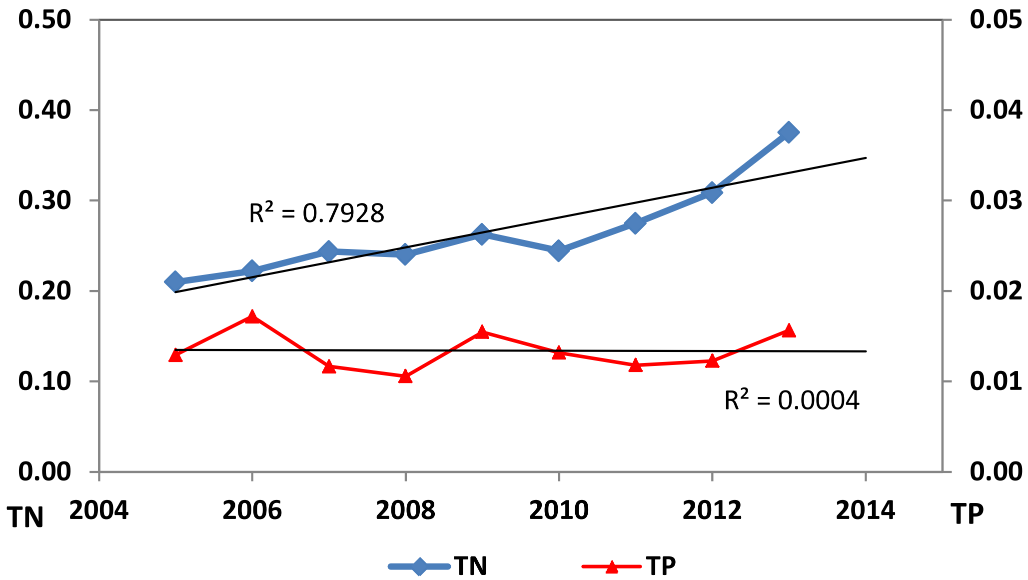

Figure 8. **Average total nitrogen and total phosphorus concentrations May – October over time, with trend lines calculated, including correlation coefficients. Note that the TN scale is 10x higher than the scale for TP.**

Concentrations of chlorophyll-*a* in Green Lake declined slightly from May through late July, when a high value was recorded (Figure 9). There was a sharp decline in August, followed by a major increase in early October, and another decrease at the end of the sampling season. Pheophytin, a degradation product of chlorophyll, was generally above detection levels throughout the season, but remained low.

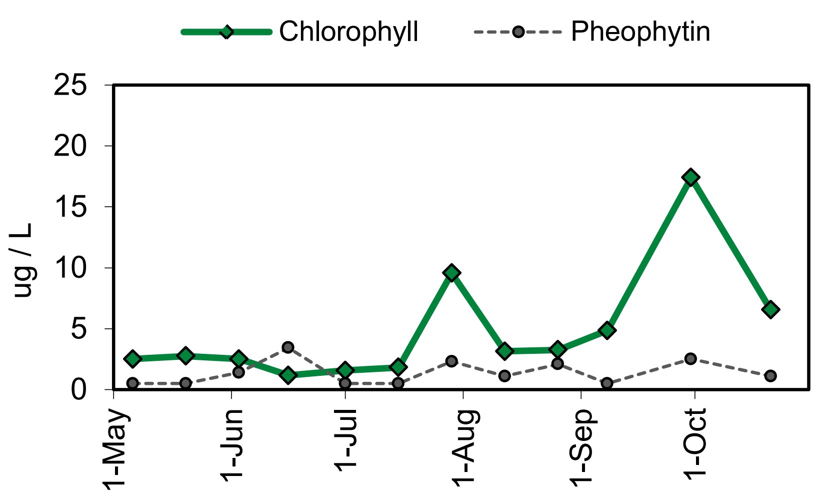

Figure 9. **Chlorophyll and pheophytin concentrations for Green Lake, May-October 2013.**

4.0 ALGAL TOXICITY

Between August and December 2013 large cyanobacterial colonies accumulated in places against the lake shorelines, pushed by light waves and wind. Buoyant cyanobacteria can be easily moved across expanses of water to produce scum accumulations, even when there is little "bloom" in the sense of an overall large abundance of phytoplankton in a lake.

Extensive testing was carried out in 2013 for toxins in water taken from visually determined scums, as well as from clear water outside of areas of high cyanobacterial concentration. Samples were submitted to the Washington Department of Ecology Algae Program (Table 1). Microcystin was analyzed on every occasion. Anatoxin-a was spot-checked until the end of October, when the analysis was dropped because no anatoxin had been detected in any of the previous samples.

Table 1. Green Lake cyanobacterial toxicity sampling under the WDOE algae program in 2013. All values in µg/L. < MDL signifies below the minimum detection limit. Samples above the recreational guideline (6 µg/L) are highlighted in yellow and orange.

Date	Microcystin	Anatoxin-a	Scum?	Location and notes
2/27/2013	7.10	<MDL	no	Dock at East Green Lake
3/4/2013	<MDL	<MDL	YES	Dock at East Green Lake
3/18/2013	<MDL		no	Dock at East Green Lake
8/26/2013	21.3	<MDL	YES	Densmore drain by wading pool
9/4/2013	21.5	<MDL	no	NE cove by boat rental; large colony in sample
9/4/2013	19.4	<MDL	YES	small craft center
9/10/2013	295		YES	small craft center
9/10/2013	<MDL		no	Duck Island beach
9/18/2013	21.4		YES	small craft center
9/18/2013	23.5		YES	NE cove by boat rental & fishing dock
9/18/2013	0.92		no	East bathing beach
9/24/2013	295	<MDL	YES	small craft center
9/24/2013	<MDL	<MDL	no	NE cove by boat rental
10/1/2013	0.50	<MDL	no	small craft center
10/1/2013	0.24		no	Duck Island beach
10/7/2013	14.2	<MDL	YES	small craft center
10/7/2013	78.1	<MDL	no	NE cove near dock; large colony in sample
10/15/2013	295		YES	NE cove by boat rental
10/15/2013	<MDL		no	west beach
10/22/2013	<MDL	<MDL	no	west beach
10/22/2013	4.03	<MDL	no	small craft center
10/29/2013	3.40		no	NE cove by boat rental
10/29/2013	<MDL		no	West Beach
11/5/2013	2.60		YES	small craft center
11/5/2013	<MDL		no	west beach
11/12/2013	73.8		YES	south of east swimming beach
11/19/2013	2.50		YES	west swimming beach
11/25/2013	6.40		YES	east beach
12/2/2013	3.90		YES	Densmore darin beach

Three samples were submitted in January – March of 2013, with the first sample slightly over the provisional state guideline of 6 µg/ L for microcystin, but samples taken subsequently were below detection. This is comparable to 2012, in which winter samples produced similar traces of microcystin.

No further scums were reported until late August, when a scum was sampled along the shoreline of the small cove north of the dock by the East Green Lake swimming beach The level of microcystin in this sample was considerably above the provisional state guideline, and more samples were taken as soon as the value was validated. The data from October 2nd showed that outside of scum accumulations, microcystin values were quite low, but the highly concentrated algae within the scums could pose health and safety risks.

Weekly samples were taken from around the lake from that time until values were at or below the recreational guideline for three weeks in a row.

While Green Lake is not producing substantial lake-wide algae blooms, relatively concentrated amounts of toxin-producing algae can accumulate downwind and pose a localized health threat to dogs drinking heavily from a scum containing the algae (Figure 10). Accumulations were often found near or among Eurasian watermilfoil fragments, also pushed by the wind against the downwind shorelines.

Figure 10. Accumulation of algae along the north shoreline in Fall 2013.

Signage was posted on sandwich boards at points around the lake shore that warned park users about health threats to both pets and people (Figure 11). Sandwich boards were used so that the signs could be moved to areas of frequent accumulations as the wind shifted. Some were also posted on information kiosks and nearby community centers to make pet owners aware of the danger and keep pets away from patches of scum accessible from the shore.

Figure 11. Sign prepared by King County for posting by Seattle Parks Department around Green Lake during the period of toxic algae accumulation along the shoreline.

The King County swimming beach program included samples at the west swimming beach for the bluegreen algal toxins microcystin and anatoxin-a, as well as fecal coliform bacteria concentrations, from late May through September in 2013. All spring and early summer toxin results were below the minimum detection level at the swimming beaches, but from August through September, several small concentrations of microcystin were detected (below 1 µg/L). This suggests that the bathing beaches can host some limited cyanobacteria accumulations as well as in the coves. King County swimming beach data can be viewed at:

http://green.kingcounty.gov/swimbeach/

5.0 WATER COLUMN PROFILES

Profile data (Table 2) from the open water station indicate that the lake was fairly well mixed thermally throughout the sampling season. The lack of temperature differences between shallow and deep water supports the idea that thermocline development was most likely transitory, as it generally has been in the past in Green Lake.

Table 2. Green Lake profile results. Secchi and Depth in meters. Temperature in degrees Celsius. Chlorophyll and Pheophytin in µg/L. Nitrogen, phosphorus, and alkalinity in mg /L. UV254 is in absorption units. Sample values below minimum detection level (MDL) are marked in bold, red font with the MDL value.

Lake name	Date	Secchi	Depth	DegC	Chlor-a	Pheo	Total N	NH3	Total P	OPO4	UV254	Total Alk
Green	5/20/13	4.0	1	18.0	2.8	0.5	0.331	**0.009**	0.0146	**0.0020**	0.0487	40.9
Green			3	17.5	3.3	**0.5**	0.375		0.0210			
Green			6	17.5	2.3	1.9	0.475	0.049	0.0220	**0.0020**		
Green	8/26/13	1.2	1	22.0	3.3	**2.09**	0.372	0.017	0.0191	**0.0006**	0.049	45.0
Green			3	22.0	2.7	**2.65**	0.367		0.0166			
Green			6	22.0	3.3	0.5	0.438	0.025	0.0232	0.0009		

Nitrogen is often found in lakes in the form of ammonia (NH3) in deep water when oxygen becomes depleted during periods of thermal stratification. Thus if present, it can be used as an indicator of low oxygen concentrations when oxygen cannot be measured directly because of lack of equipment or resources. In Green Lake, no substantial increases in ammonia (NH3) were found in the deep water on either date, suggesting that anoxia never became established in the bottom water. Total nitrogen remained roughly equivalent from top to bottom in the lake on both dates.

Concentrations of phosphorus in deeper water also remained roughly equivalent to shallow depths, showing that any small amount of phosphorus potentially released from the sediments under oxygenated conditions was either taken up by algae or mixed quickly through the entire water column.

Chlorophyll-*a* profile data indicate that algae are present throughout the water column in approximately equal concentrations. This is consistent with the lack of a developed thermocline in summer, so that algae are constantly being mixed through the entire water column.

The low values for UV254 indicate that the water of the lake contains little in the way of dissolved organic substances and the Secchi transparency is probably not affected by water color.

The total alkalinity values show that the water in the lake is less soft than many regional lakes and thus the lake has more buffering capacity against pH change. This may be related to the amount of development in the watershed, but could also be due to underlying geology in the area.

6.0 TROPHIC STATE INDEX RATINGS

In 2013 all three TSI indicators were in the lower range of mesotrophy, up a little from 2012 (Figure 12). While the TSI-Secchi has remained remarkably stable since the alum treatment in 2004, both the TSI values for phosphorus and chlorophyll have varied over time.

Values used for calculating the TSI values for the years 1995 – 1996 and 2000 were provided by Kevin Stoops of the Seattle Parks Department and Rob Zisette of Herrera Environmental consultants. It should be noted that while 1995 – 1996 were sampled throughout the summer, values for 2000 were based on 3 sample dates from May through July of that year. While this makes direct comparability somewhat problematic, May – July are typically months that have good conditions for algae growth and are also a time in which much recreational activity is occurring.

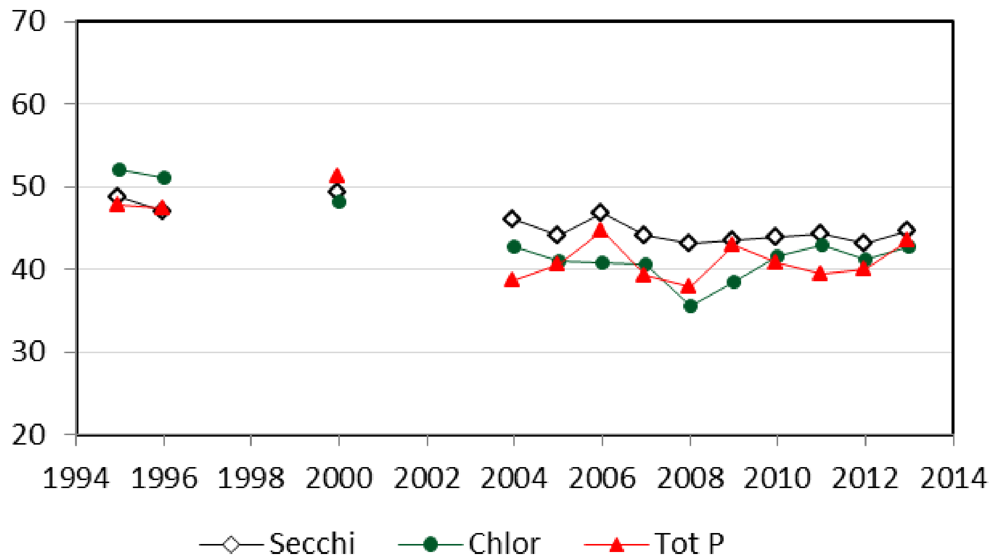

Figure 12. Green Lake-1 Trophic State Indicators over time.

Because 10 consecutive years of data have been collected, including both data collected by Seattle during the year of alum treatment in 2004 and nine further years of collection by King County, the TSI indicators were tested for directional trends over time. Both TSI-TP and TSI-chlorophyll lines were flat, with low correlation coefficients of 0.040 and 0.022 respectively, showing no directionality either up or down. The TSI-Secchi had a slight downward trend that was accompanied by a correlation coefficient of 0.242, suggesting that only about a quarter of the variability over time was explained by the trend. Note that a download trend for Secchi implies that the water is increasing in clarity over time.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Based on monitoring data, water quality in Green Lake has been relatively stable over the period measured since the alum treatment in 2004. The success of the 2004 alum treatment, coupled with diversion of storm water away from the lake, has probably had much to do with the stability of phosphorus in the lake over the last ten summers. There is no upward trend in summer phosphorus concentrations over time, which makes it difficult to predict the longevity of the effect of the last alum treatment.

The low N:P ratios in 2013 indicate that nutrient conditions were favorable for cyanobacterial (bluegreen algae) growth, beginning in mid to late summer. To date, the overall low levels of available phosphorus have likely kept major blooms from forming, but at times nitrogen could be limiting as well. It is of note that total nitrogen values have been rising over time in a relatively well validated trend, while total phosphorus values have been remaining relatively steady. Monitoring of both nutrient and chlorophyll concentrations could be continued to assess future conditions and to document the longevity of the 2004 alum treatment effectiveness for phosphorus control.

Cyanobacterial accumulations have been observed at places other than the monitored swimming beaches during summer, even though overall nutrient concentrations are relatively low in the lake. These scums should continue to be sampled and submitted to the Washington State Department of Ecology's Toxic Algae Monitoring Program to determine whether or not the cyanobacteria present in the lake are producing toxins. This will allow officials to identify health and safety hazards, thus allowing Seattle Parks and Seattle King County Public Health to take protective actions to safeguard the public.