The Small Lakes of Sammamish

A Report on Water Quality Monitoring Results
for Water Year 2012 at Pine and Beaver Lakes

Pine Lake - 2007

Prepared for the City of Sammamish
by the King County Lakes and Streams Monitoring Group
Science and Technical Support Section,
Water and Land Resources Division
King County Department of Natural Resources and Parks

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King County

OVERVIEW

The King County Lakes and Streams Monitoring group and its predecessor the Lake Stewardship Program have worked with volunteer monitors for more than 19 years on Pine Lake and the two basins of Beaver Lake within the City of Sammamish. The water quality data indicate that in general, Pine Lake and Beaver-2 are low to moderate in primary productivity with good water quality, while Beaver-1 has been and continues to be highly productive, indicative of the input from the nearby wetland to the north that constitutes its major surface water source. A deteriorating wetland that delivered large amounts of nutrients to Pine Lake was diverted in the 1990s, which was effective in curbing phosphorus inputs to the lake and resulted in an increase in water quality.

Both Beaver Lake and Pine Lake have public access boat launches and parks with beach front, where members of the public are able to access the lakes. At present, no invasive noxious aquatic weeds have been reported for either lake aside from fragrant water lily. However, residents should keep a watch on aquatic plants growing submersed or near shore to catch early infestations of Eurasian milfoil, Brazilian elodea, or other noxious weeds.

This report refers to two common measures used to predict water quality in lakes. The Trophic State Index or TSI (Carlson 1977) is a method of calculating indicators from collected data that allows comparison between different parameters and predicts the volume of algae that could be produced in the lake. A second measure is the nitrogen-to-phosphorus ratio (N:P), which is used to predict what groups of algae may become dominant in the lake during certain periods. Both the TSI and N:P ratios have been calculated using data collected through the volunteer monitoring program.

The discussion in this report focuses on the 2012 water year. 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://www.metrokc.gov/dnrp/wlr/water-resources/small-lakes/data/default.aspx.

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

BEAVER LAKE

In the mid-nineties, residents at both basins of Beaver Lake (Figure 1: smaller north basin referred to as Beaver-1 and large main basin referred to as Beaver-2) began monitoring water quality through participation in the King County Lake Stewardship Program (KCLSP). Volunteer monitoring efforts have continued through 2012. Physical and chemical data collected through the years of monitoring indicate that this lake in the City of Sammamish over time has remained moderate (Beaver-2) to high (Beaver-1) in primary algal productivity (mesotrophic and eutrophic, respectively), with fair to very good water quality.

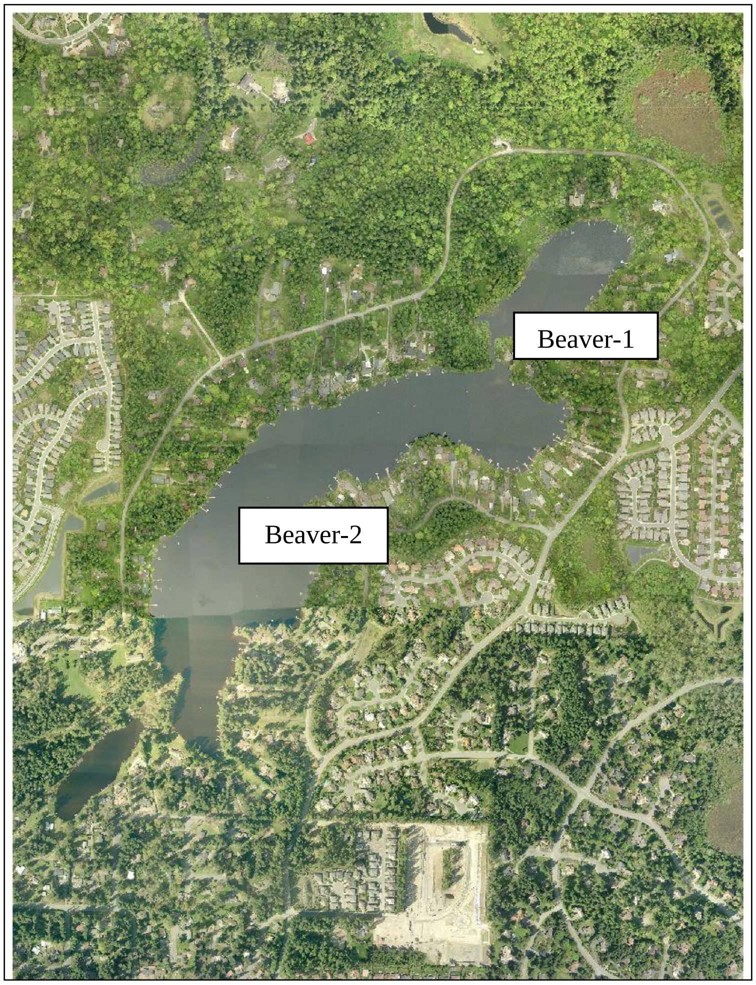

Figure 1. Aerial photo of Beaver Lake showing both lake basins. A third small basin that contains the lake outlet is located in the bottom left of the figure.

Physical Parameters

Excellent precipitation and water level records were kept for the main basin (Beaver-2) from late December 2011 through September 2012 by a volunteer monitor new to the program.

Water levels in Beaver-2 increased in response to storm events (Figure 2). Although lake level measurements began in late December 2011 rather than in October with the beginning of the water year, it is likely that a pattern similar to previous years and characteristic of the regional pattern of early autumn lows, followed by lake level increase with the onset of winter rain. The record does support the relationship between rain events and a short-lived positive response in lake level. Typically, the highest lake levels do not usually persist longer than a few days to a week when the outlet is flowing freely, but there have been instances in the past when the outlet weir has been clogged with debris and when beaver activity has plugged the outlet channel, leaving lake levels high for longer periods. The winter high water levels decrease slowly through the summer months, leading to the minimum water level at the end of water year 2012.

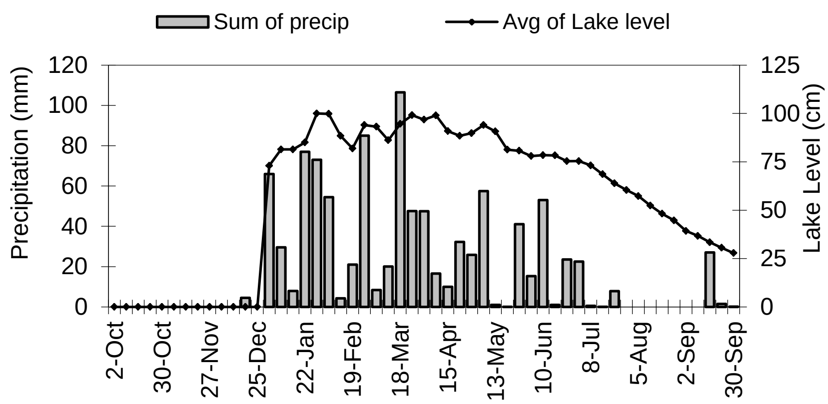

Figure 2. WY 2012 Beaver-2 Lake Level and Precipitation

Residents on Beaver-1 did not collect daily precipitation or lake level information, but the channel between the two lakes rarely shows perceptible flow between the water bodies. Continuous lake level measurements made by the King County hydrology group for the Beaver Lake Management District have shown that water levels are generally equivalent between the two basins (unpublished data).

Beaver-2 Level I volunteers collected weekly temperature and Secchi transparency data throughout the year, while Level II volunteers made temperature and Secchi measurements from late May through October as they collected water samples. Secchi transparency measured by the Level I volunteer from December through September ranged between 1.4 m and 3.5 m, with an average of 2.4 m (Figure 3). The Secchi data from the Level II volunteer, measuring from May through October only, ranged from 2.2 to 3.4 m, with a summer average of 2.6 m.

The closely related data shows that the water transparency did not fluctuate very much in 2012, even between two different observers, who may vary in how they read the endpoint of the Secchi test, depending on their ability to differentiate subtle changes, as well as how their vision reacts to glare off the water surface, the type of boat they are using, and how close to the water surface they can safely view the disk.

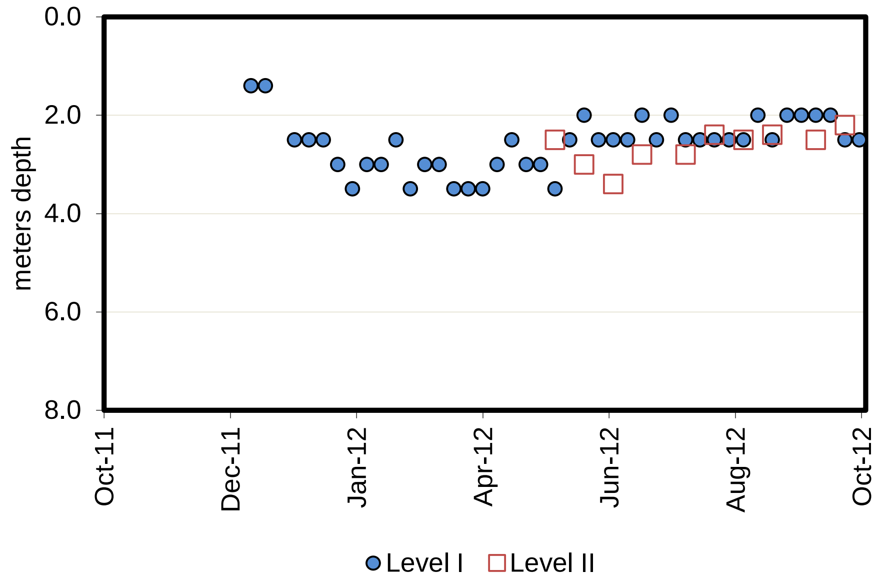

Figure 3. 2012 Beaver-2 Lake Secchi Transparency. (Note inverted Y-axis)

Surface water temperatures ranged between 5.0 to 26.0 degrees Celsius between December and September of water year 2012 with partial year average of 13.6 and a May – October average of 19.0 degrees Celsius measured by the weekly volunteer and 19.6 degrees Celsius average of the water quality monitor's readings (Figure 4). The extended period without rain in summer 2012 is reflected by the higher shallow water temperatures achieved in the lake.

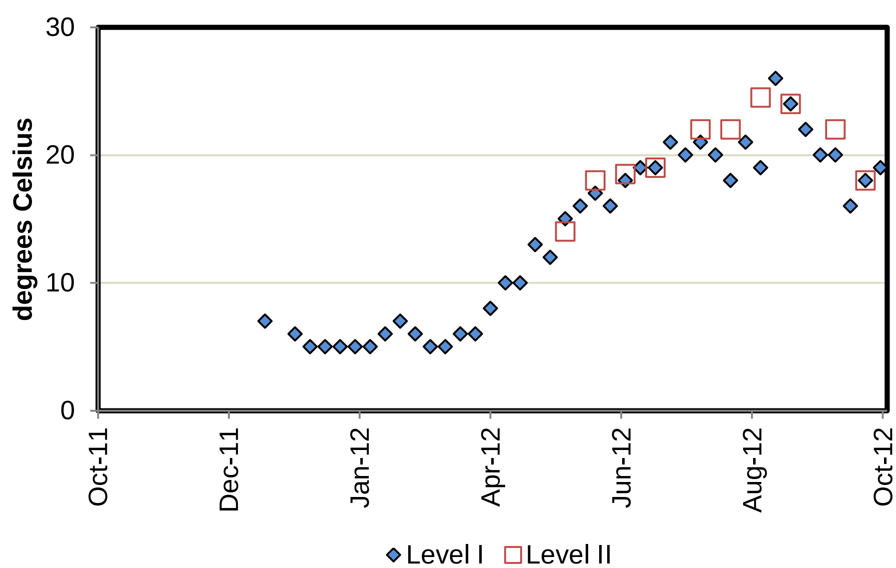

Figure 4. 2012 Beaver-2 Lake Water Temperatures

The north basin (Beaver-1) was monitored for Secchi transparency and water temperature by the Level II monitor from early May to the end of October 2012. **Transparency** remained remarkably steady, ranging from 1.1 m to 1.5 m with an average of 1.3 m (Figure 5). Beaver-1 was at the lower end of clarity for the lakes monitored by the KCLSP in 2012 due to the tea-colored water coming from wetland ELS 21 that drains directly into the basin. The large bloom of *Anabaena planctonica* in summer 2011 that created a high degree of turbidity was not repeated in 2012.

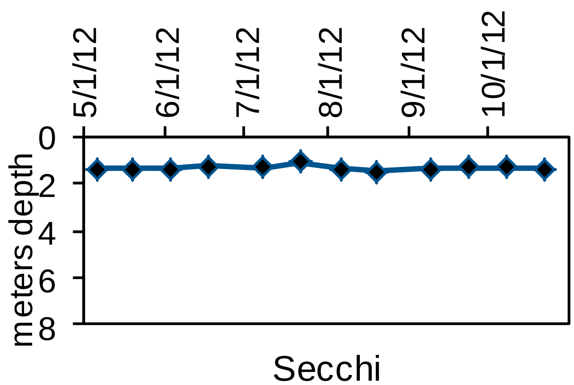

Figure 5. 2012 Beaver-1 Secchi Transparency

Temperatures for Beaver-1 ranged from 11.0 degrees Celsius to 23.5 degrees Celsius with an average of 18.0 degrees Celsius (Figure 7) that places the north basin of Beaver Lake among the cooler lakes measured during the 2012 sampling season.

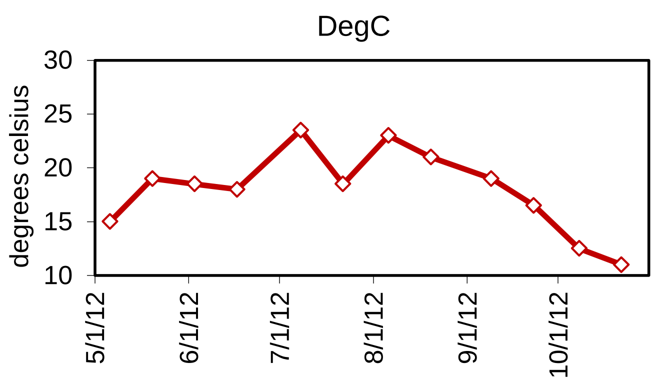

Figure 7. 2011 Beaver-1 Lake Water Temperatures

Comparison for Secchi transparency and 1m temperatures can be made between the two basins for the May – October monitoring program (Level II). Beaver-2 has consistently greater water clarity than Beaver-1 throughout the entire sampling season (Figure 8). However, neither lake showed a great deal of variation in 2012.

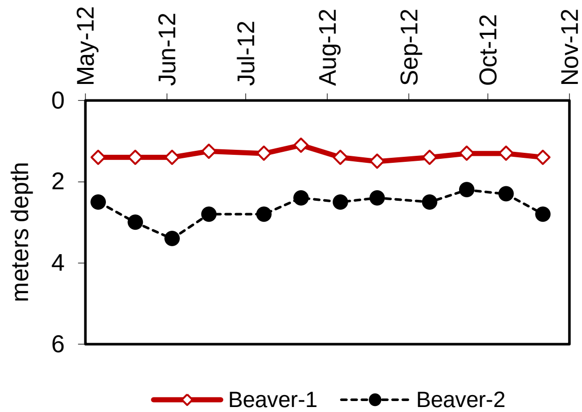

Figure 8. Secchi measurements for Beaver-1 and Beaver-2

Water temperatures showed an interesting relationship, with both lakes warming at a similar rate in the spring through early summer when the weather was unusually wet, but diverging by late summer during the extended dry, sunny period. The warmer temperature achieved by Beaver-2 may be a function of the greater surface area of the lake relative to its mean depth than is present in the basin of Beaver-1, which has a similar maximum depth but a much smaller surface area.

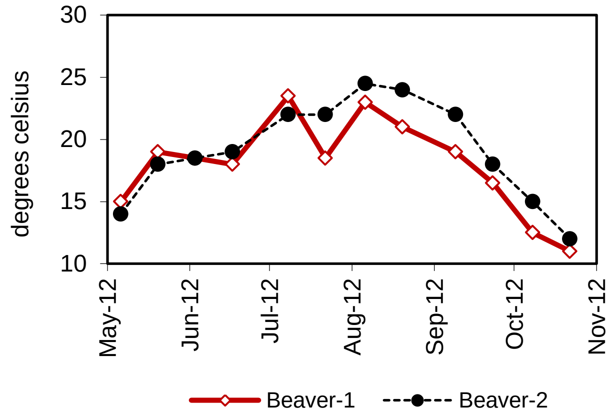

Figure 9. 1m water temperatures for Beaver-1 and Beaver-2

Mean summer water temperatures during the time period that Beaver Lake has been monitored have varied from year to year, but show no overall trend toward change. The two basins do not track each precisely, but in most years are fairly close in value.

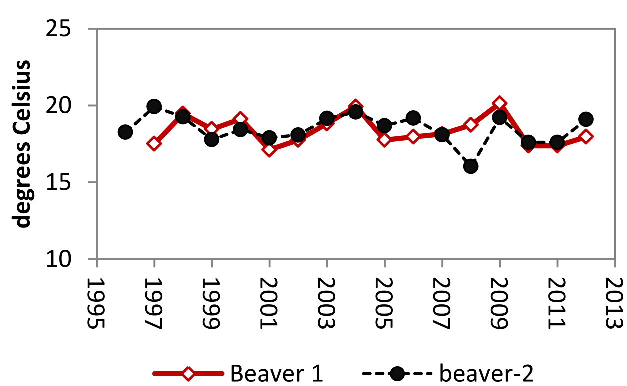

Figure 10. Mean May – October 1m water temperatures for Beaver-1 and Beaver-2

Nutrient and Chlorophyll Analysis

Nutrients

Phosphorus and nitrogen are naturally occurring elements that are necessary in small amounts for both plants and animals. However, many actions associated with residential development can increase concentrations of these nutrients beyond natural levels. In lakes of the Puget Sound lowlands, phosphorus is often the nutrient in least supply, meaning that biological productivity is often limited by the amount of available phosphorus. Increases in phosphorus concentrations 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 species that can produce toxins. Samples collected by volunteers at approximately biweekly intervals are analyzed for total phosphorus (TP) and total nitrogen (TN) concentrations at one meter depth.

During the monitoring period, Beaver-2 both TN and TP values remained extremely steady throughout the season with only a slight decrease in spring and a very minor increase in TN again in October (Figure 11). These variations are so small they may be within the accuracy of the sampling and analytical methods.

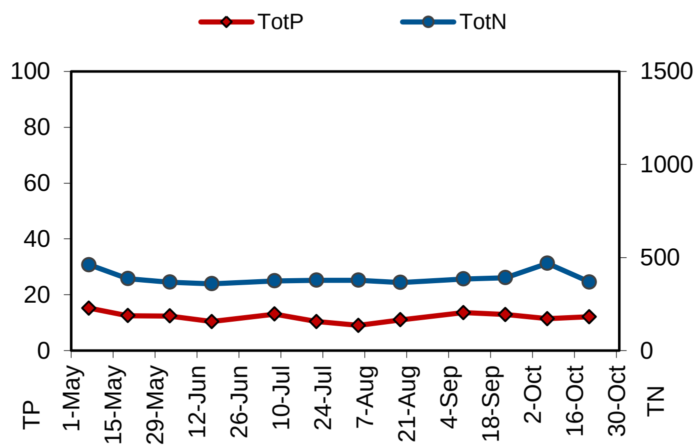

Figure 11. 2012 Beaver-2 Total Phosphorus and Total Nitrogen in ug/L.

Beaver-1 had higher levels of TP than Beaver-2, but approximately equivalent levels of TN (Figure 12), unlike 2011 when the nitrogen-fixing bloom of *Anabaena* caused the TN levels in Beaver-1 to skyrocket (see 2011 annual report for discussion). TN increased drastically in early August through early September and then gradually decreased from late September to October. This was concurrent with the *Anabaena* bloom mentioned in the section on Secchi transparency. Interestingly, TP did not echo this increase and was mostly stable throughout the sampling season.

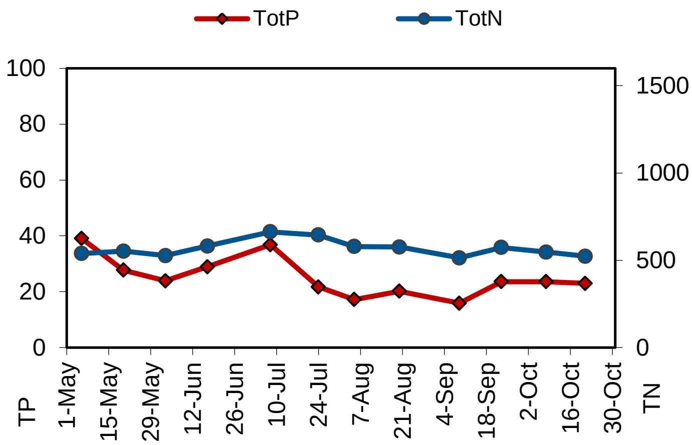

Figure 12. 2012 Beaver-1 Total Phosphorus and Total Nitrogen in ug/L.

N : P ratios

The ratio of nitrogen to phosphorus (N:P) can be used to determine if nutrient conditions are favorable for the growth of cyanobacteria (bluegreen algae) that can impact beneficial uses of the lake. When N:P ratios are near or below 20 - 25, cyanobacteria often dominate the algal community due to their ability to take nitrogen from the air and therefore not being limited by nitrogen availability. However, if phosphorus is also limited, cyanobacteria will be less successful because they are relatively poor competitors for phosphorus.

In Beaver-2, the N:P ratio ranged from 28.3 to 42.0 (Figure 13), with no values below 20 and an average of 33.0, which suggests that nutrient conditions in the larger basin were generally not favorable for nuisance bluegreen growth in 2012.

The N:P ratio in Beaver-1 ranged from 13.8 to 33.7 with an average of 24.0 (Figure 13). The N:P ratios from May through July were below or near 20, which suggested that the spring provided nutrient conditions that were favorable for nuisance bluegreen algae growth, but as summer progressed the conditions became less suitable for producing a cyanobacterial bloom in the lake.

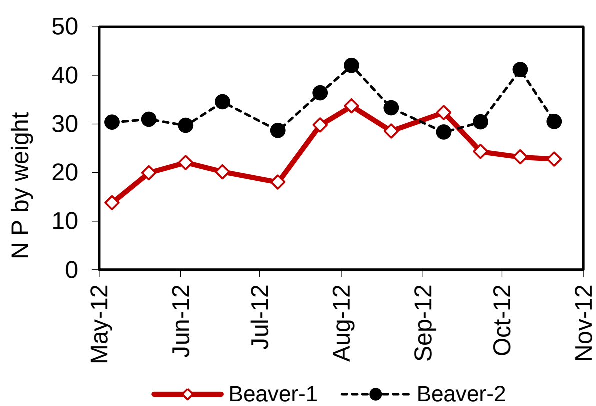

Figure 13. Nitrogen to Phosphorus ratios for 1m water in Beaver-1 and Beaver-2 during 2012.

Chlorophyll a

Chlorophyll concentrations relate to the amount of algae present in lake water. All algae must have chlorophyll in order to fix energy from sunlight, so higher amounts of chlorophyll indicate more abundant algae. However, some cyanobacteria (bluegreen algae) also use other pigments to capture light, so the chlorophyll per cell volume may be smaller than for other groups of algae. Pheophytin is a degradation product of chlorophyll, and large amounts present in a sample can indicate the presence of sediment detritus or a source of old chlorophyll, in addition to that contained in living algae. Some of these additions can be caused by wind and rain storms, sediment disturbance, bank erosion, or wash-in from watershed activities.

Chlorophyll *a* concentrations in Beaver-2 were around 5 ug/L through most of the season, which is a moderate level, climbing to a peak of approximately 10 ug/L peak in fall. Pheophytin (degraded chlorophyll) levels were slightly above detection levels, but remained low with the exception of the first date in May (Figure 14).

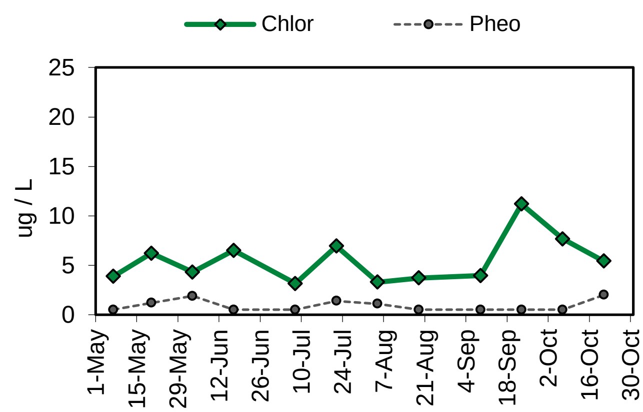

Figure 14. WY 2012 Beaver-2 Chlorophyll *a* and Pheophytin concentrations

In Beaver-1, chlorophyll *a* concentrations were higher than in Beaver-2 (note Y-axis scale change) though they started at a lower level in May (Figure 15). While there were distinct highs and lows throughout the season, there was a general increase through the season with the maximum value recorded on the last sampling date. While *Anabaena planctonica* was present in the lake in 2012, it did not make a large bloom similar to 2011. The majority of the pheophytin levels were below detection levels throughout the period.

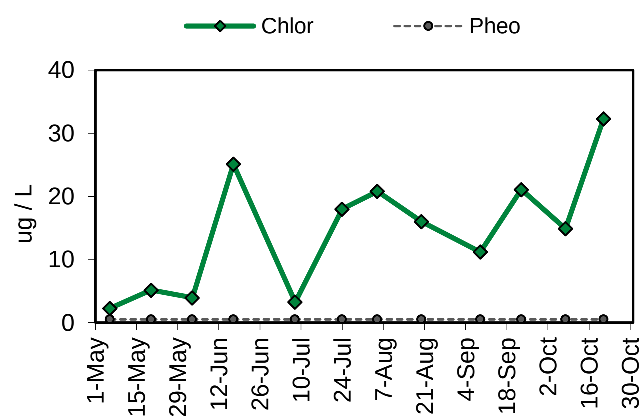

Figure 15. WY 2012 Beaver-1 Chlorophyll *a* and Pheophytin concentrations

Water column profiles

Profile data on Beaver-2 indicates that thermal stratification was present from early summer and persisted through late summer (Table 1). Slightly higher concentrations of total phosphorus were found in deep water in May, but much more so by August, suggesting that anoxia could have triggered a release of phosphorus from the sediments in late summer. The phosphate (OPO4) values in deep water in August are consistent with this idea. Ammonia (NH3) concentration, which is another indicator of low oxygen conditions in the deep water, was not very high in May but was also elevated in August, indicating that anoxia in the deep water had increased through the summer.

Chlorophyll *a* profile data indicated that higher concentrations of phytoplankton were in the shallow water in both May and August. However, both dates have moderately low chlorophyll concentrations overall, suggesting the lake did not support an abundance of phytoplankton and had moderate primary productivity.

Table 1. Beaver-2 Profile Sample Analysis Results. Secchi and Depth in meters. Temperature in degrees Celsius. Chlorophyll and Pheophytin in ug/L. Nitrogen, phosphorus, and alkalinity in mg /L. UV254 is in absorption units. Sample values below minimum detection level are marked in bold, red with the MDL value.

Lake name	Date	Secchi	Depth	DegC	Chlor-a	Pheo	Total N	NH3	Total P	OPO4	UV254	Total Alk
Beaver-2	5/20/12	3.0	1	18.0	6.21	1.2	0.387	**0.005**	0.0125	**0.002**	0.235	13.9
Beaver-2			7	7.0	2.07	1.8	0.489		0.0127			
Beaver-2			14	7.0			0.549	0.007	0.0222	0.0059		
Beaver-2	8/19/12	2.4	1	24.0	3.72	**0.5**	0.366	0.006	0.0110	**0.002**	0.187	15.2
Beaver-2			7	9.3	1.3	1.9	0.393		0.0175			
Beaver-2			13	7.5			0.618	0.041	0.0621	0.0094		

The UV254 value shows that some tea coloration is present in the water of Beaver-2 and represents a moderate level of dissolved organic carbon, while the total alkalinity indicates soft water that is not well buffered against pH change.

Profiles from Beaver-1 (Table 2) showed that thermal stratification set up in the lake in early spring and lasted through late summer. TP and TN levels were elevated at the deeper sample in May and were accompanied by significant ammonia (NH3) and orthophosphate (OPO4) concentrations, suggesting that oxygen was already depleted in the deepest part of the lake. That was confirmed in the August profile with the same parameters showing an even greater difference than in May.

Chlorophyll *a* data suggest the most algae were found in the surface water. The chlorophyll levels were particularly high in August in the 1 m sample, but were lower overall than in 2011 when there was a large *Anabaena* bloom.

Table 2. Beaver-1 Profile Sample Analysis Results. Secchi and Depth in meters. Temperature in degrees Celsius. Chlorophyll and Pheophytin in ug/L. Nitrogen, phosphorus, and alkalinity in mg /L. UV254 is in absorption units. Sample values below minimum detection level are marked in bold, red with the MDL value.

Lake name	Date	Secchi	Depth	DegC	Chlor-a	Pheo	Total N	NH3	Total P	OPO4	UV254	Total Alk
Beaver-1	5/20/12	1.4	1	19.0	5.17	1.3	0.552	**0.005**	0.0277	**0.002**	0.453	10.6
Beaver-1			7	6.0	**0.5**	1.2	0.531		0.0175			
Beaver-1			14	5.0			0.771	0.148	0.0947	0.0517		
Beaver-1	8/20/12	1.5	1	21.0	16	**0.5**	0.576	**0.005**	0.0202	**0.002**	0.446	13.0
Beaver-1			7	5.5	2.84		0.519		0.0258			
Beaver-1			14	5.0			1.060	0.575	0.2650	0.178		

The high UV254 values are indicative of the marked tea color of the water produced by dissolved organic carbon molecules leached from the upstream wetland, and are approximately double that of Beaver-2. The low alkalinity value shows that the lake water is very soft and quite poorly buffered against pH change.

TSI Ratings

A common method of tracking water quality trends in lakes is by calculating the "trophic state index" (TSI), developed by Robert Carlson in 1977. TSI indicators predict the biological productivity of the lake based on water clarity (Secchi) and concentrations of TP and chlorophyll *a*. A value of 50 or higher indicates eutrophy, or a highly productive lake in terms of algae, while values below 40 indicate oligotrophy, or low rates of productivity. Values between 40 and 50 are considered moderate or mesotrophic.

The 2012 Beaver-2 TSI indicators for chlorophyll *a* and Secchi were again very close to each other in the medium range of mesotrophy (Figure 16), down from the values in 2009 when there was an *Anabaena* bloom similar to the bloom in Beaver-1 last year. The TSI-TP indicator was lower than the other two indicators near the threshold between mesotrophic and oligotrophic. The trend over the series appears stable since 1998, and Beaver-2 remains in the mid mesotrophic range.

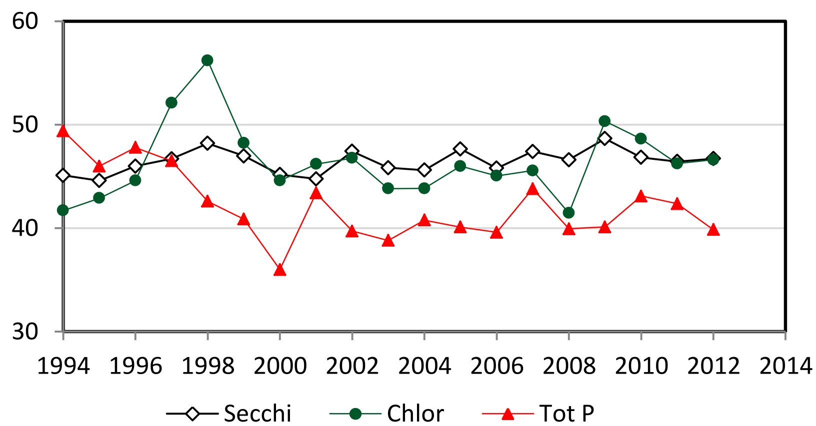

Figure 16. Beaver-2 Trophic State Indicators through 2012.

In 2012, the TSI indicators for chlorophyll a and Secchi in Beaver-1 were close to each other in the mid-range for the productivity classification of eutrophic, and the TSI-phosphorus indicator was on the threshold between eutrophic and mesotrophic (Figure 17). The high chlorophyll and Secchi TSI in 2011 was not repeated in 2012. Phosphorus has been stable since 2005. If a trend line is drawn through the average of the 3 indicators, there is no significant change over time. However, a slight, but steady increase in phosphorus has been seen in this basin since 2002, and a close watch should be kept on this as development proceeds in the upper watershed, particularly any activity that might impact the high quality wetland to the north of Beaver-1.

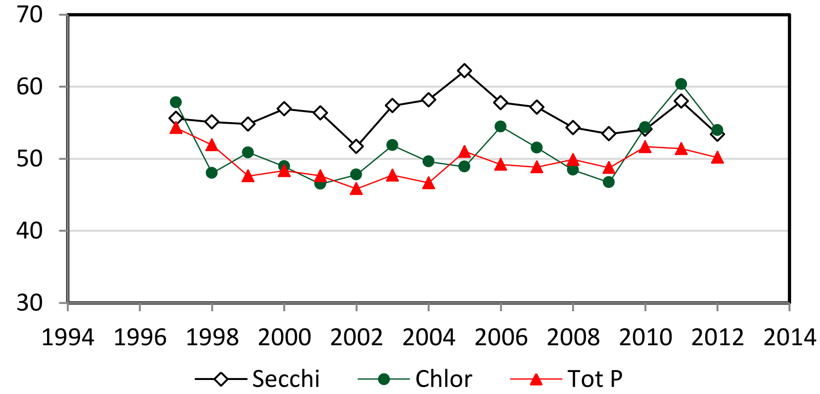

Figure 17. Beaver-1 Trophic State Indicators through 2012.

A trend line run through the TSI-TP indicator values since 1998 shows a significant increasing trend over time (Figure 18). The correlation coefficient of 0.527 indicates that 53% of the variability can be explained by the upward trend. This suggests that increased nutrients are entering the lake over time, perhaps from changes occurring in the high quality wetland adjacent to the lake or from the stormwater ponds that drain to the main inlet.

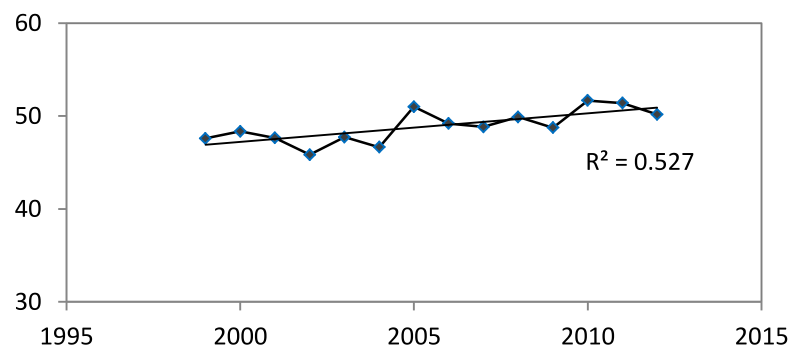

Figure 17. Annual average Beaver-1 TSI-TP. R^2 is the correlation coefficient of the regression line drawn through the points.

Conclusions and Recommendations

Based on monitoring data, water quality in Beaver-2 has remained stable over recent years, and the average N:P ratio does not promote bluegreen algae blooms, although the *Anabaena* bloom in 2009 shows that cyanobacterial blooms can still occur on occasion.

In Beaver-1, there is a slight, but steadily increasing trend in phosphorus TSI values since 2002. The cyanobacterial summer bloom of 2011 was not repeated in 2012. A close eye should be kept on the lake over the next few years to see if this trend continues. Continued monitoring of both nutrient and chlorophyll concentrations should be done to insure recreational safety and to assess water quality conditions into the future as development in the watershed proceeds.

PINE LAKE

Physical Parameters

Excellent precipitation and water level records for Pine Lake were compiled by the volunteer monitor for the 2012 water year. Water levels in the lake responded to winter storm events and increased through January, but then remained relatively steady until late June when the water level began to slowly decrease over the remainder of the water year. Precipitation and lake level data collected since 1995 suggest the lake rises with the onset of autumn rains and remains somewhat elevated through the winter and into spring. However, the highest lake levels do not usually persist longer than a week or two (Figure 1).

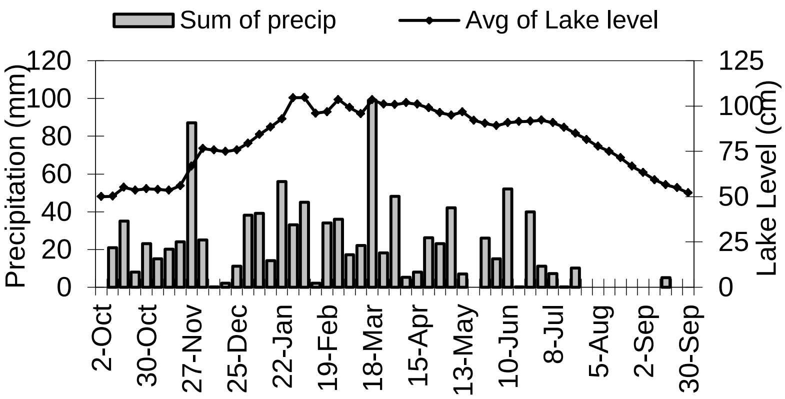

Figure 1. WY 2012 Pine Lake Level and Precipitation

Pine Lake volunteers collected weekly temperature and Secchi transparency data throughout the 2012 water year in addition to values collected during the "Level 2" monitoring season from early May through late October. Secchi transparency ranged through the year between 2.3 and 6.8 m (Figure 2). The annual average was 4.6 m, while the summer average was 4.9 m, which placed it in the higher range of clarity for monitored small lakes in 2012. The lowest transparency values were recorded in October, possibly from a fall algae bloom as the lake waters cooled and mixed.

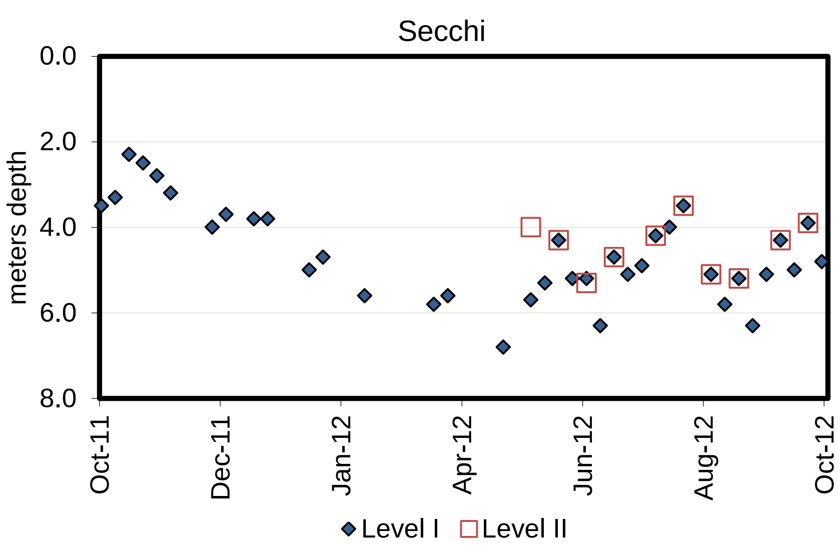

Figure 2. 2012 Pine Lake Secchi Transparency

Surface water temperatures ranged between 5.0 to 25.0 degrees Celsius in 2012, with an annual average of 16.6 and a summer average of 21.1 degrees Celsius, which was warmer than in 2011 (Figure 3).

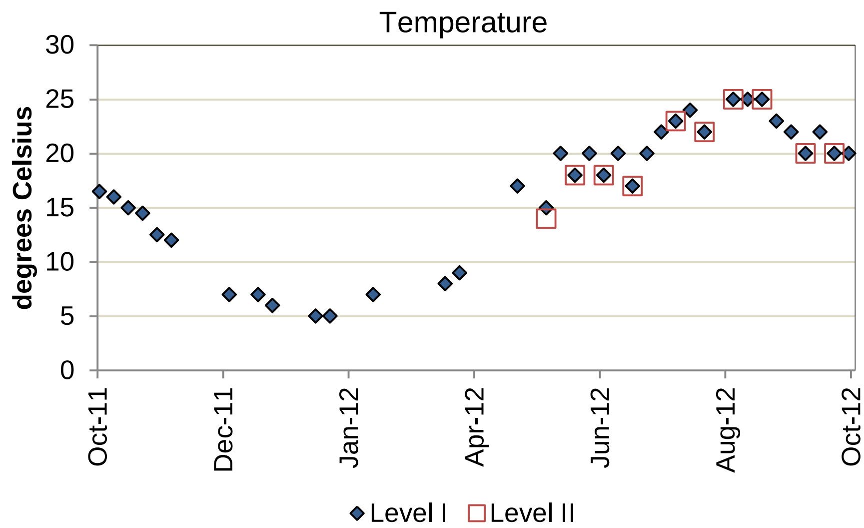

Figure 3. 2012 Pine Lake Water Temperatures

Mean summer water temperatures during the time period that Pine Lake has been monitored have varied from year to year, but show no overall trend toward change over time (Figure 4).

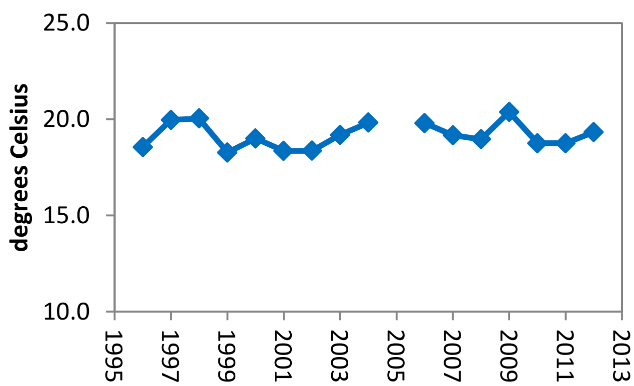

Figure 4. Mean May – October 1m water temperatures for Pine Lake

Nutrient and Chlorophyll Analysis

Phosphorus and nitrogen are naturally occurring elements that are necessary in small amounts for both plants and animals. However, many actions associated with residential development can increase concentrations of these nutrients beyond natural levels. In lakes of the Puget Sound lowlands, phosphorus is generally the nutrient in least supply, meaning that biological productivity is most often limited by the amount of available phosphorus. Increases in phosphorus concentrations 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 species that can produce toxins. Samples collected by volunteers are analyzed for total phosphorus (TP) and total nitrogen (TN) concentrations at one meter depth.

During the monitoring period for Pine Lake, TN and TP values remained relatively constant throughout the sampling season, with little variation over time (Figure 5). There was a slight decrease in both parameters from the initial values in spring, followed by a minor increase in TN near the end of July and then in both parameters in fall.

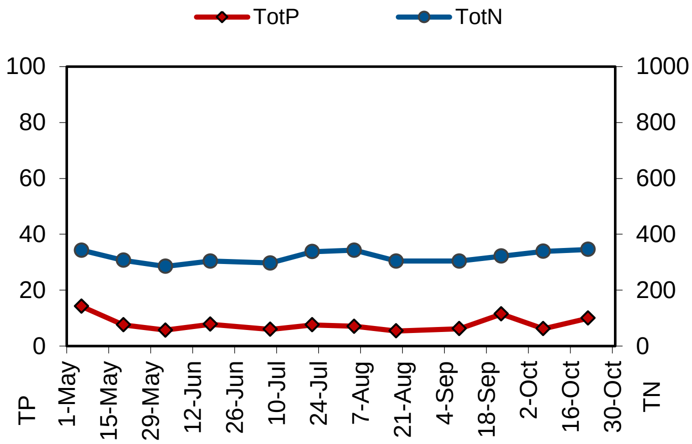

Figure 5. 2012 Pine Lake Total Phosphorus and Total Nitrogen Concentrations in µg/L.

The ratio of nitrogen to phosphorus (N:P) can be used to determine if nutrient conditions are favorable for the growth of cyanobacteria (bluegreen algae) that can impact beneficial uses of the lake. When N:P ratios are near or below 20-25, cyanobacteria often dominate the algal community due to their ability to take nitrogen from the air. In Pine Lake, total phosphorus and total nitrogen remained in relatively constant proportion to each other through the sampling period, ranging from 24 to 56 with an average of 43 (Figure 6), which suggests that nutrient conditions in the lake were generally not favorable for nuisance bluegreen blooms during the monitoring season.

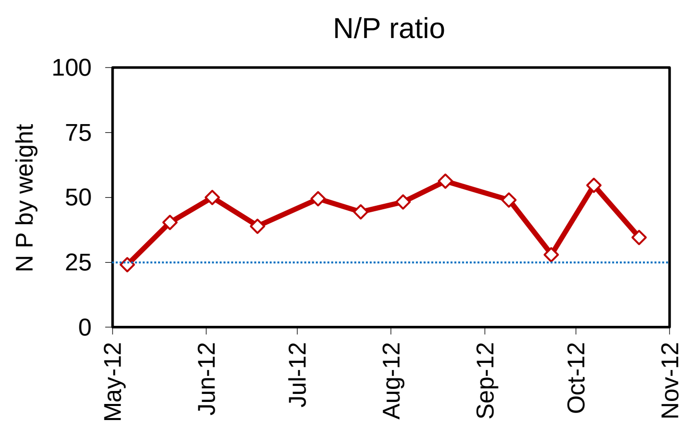

Figure 6. 2012 N/P ratio by weight

Chlorophyll a

Chlorophyll concentrations relate to the amount of algae present in lake water. All algae must have chlorophyll in order to fix energy from sunlight, so higher amounts of chlorophyll denote more abundant algae. However, some of the cyanobacteria (bluegreen algae) also use other pigments to capture light, so their relative amounts of chlorophyll may be smaller than for other groups of algae. Pheophytin is a degradation product of chlorophyll, and large amounts present in a sample can indicate that the presence of sediment or other detritus containing old chlorophyll in addition to that contained in vibrant, living algae. Sources include inputs from wind and rain storms, sediment disturbance, bank erosion or wash-in from watershed activities.

Chlorophyll *a* concentrations in Pine Lake also remained low throughout most of the sampling season, increasing on the last sampling date (Figure 7). Pheophytin (degraded chlorophyll) levels remained below detection levels throughout the season.

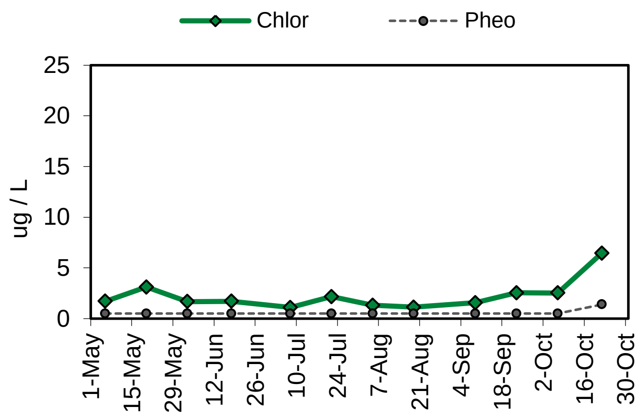

Figure 7. 2012 Pine Lake Chlorophyll *a* and Pheophytin concentrations

Profile samples

Temperature data from the profile sampling on Pine Lake indicates that thermal stratification was present in early summer and persisted through late summer (Table 1). Higher concentrations of phosphorus were found in deep water in May and in August, suggesting that some phosphorus was released from bottom sediments. However, ammonia (NH3) remained low on both dates, indicating that oxygen depletion may have been minimal. Ortho phosphate (OPO4) values remained fairly low, as did chlorophyll values, suggesting that any phosphorus recycling from the sediments was minor and not having a significant effect on phytoplankton abundance.

Table 1. Pine Lake Profile Sample Analysis Results. Secchi and Depth in meters. Temperature in degrees Celsius. Chlorophyll and Pheophytin in ug/L. Nitrogen, phosphorus, and alkalinity in mg /L. UV254 is in absorption units. Sample values below minimum detection level are marked in bold, red with the MDL value.

Lake name	Date	Secchi	Depth	DegC	Chlor-a	Pheo	Total N	NH3	Total P	OPO4	UV254	Total Alk
Pine	5/20/12	4.3	1	18.0	3.11	**0.5**	0.307	**0.005**	0.0076	**0.002**	0.0735	21.7
Pine			5	14.0	6.12	**0.5**	0.284		0.0086			
Pine			10	8.0			0.339	0.012	0.0173	0.0028		
Pine	8/19/12	5.2	1	25.0	1.13	**0.5**	0.304	**0.005**	0.0054	**0.002**	0.043	24.5
Pine			5	25.0	1.66	**0.5**	0.303		0.0057			
Pine			10	10.0			0.652	**0.005**	0.0649	**0.002**		

Both profile dates have similar chlorophyll concentrations at both shallow and mid-depths, showing that the lake had limited phytoplankton in the zone that sunlight penetrates, with generally low biological productivity.

The UV254 values were indicative of clear water with little dissolved organic carbon, unlike the tea color of the water in Beaver Lake that impacts water clarity. The alkalinity value, while still low, is higher than found in Beaver Lake. This may relate to the higher degree of development and soil disturbance in the Pine Lake watershed. However, Pine Lake water still has fairly soft water that is poorly buffered against pH change.

TSI Ratings

A common method of tracking water quality trends in lakes is by calculating the "trophic state index" (TSI), developed by Robert Carlson in 1977. TSI indicators predict the biological productivity of the lake based on water clarity (Secchi) and concentrations of TP and chlorophyll *a*. A TSI value of 50 or higher indicates eutrophy, or a highly productive lake in terms of algae populations, while values below 40 indicate oligotrophy, or low rates of productivity. Values between 40 and 50 are considered moderate or mesotrophic.

The 2012 Pine Lake TSI indicators for chlorophyll *a* and Secchi were fairly close to each other on either side of the threshold between oligotrophy and mesotrophy, while the TSI–TP indicator was in the lower end of the oligotrophic range and was significantly lower than the other two values (Figure 8). The average of all three TSI indicators in 2012 has been fairly constant since 2003, suggesting that conditions in Pine Lake have stabilized in the upper ranges of oligotrophy. There may be a slight decreasing trend in TSI-TP over the period of monitoring but more years should be collected to test for robust statistical significance in the trend.

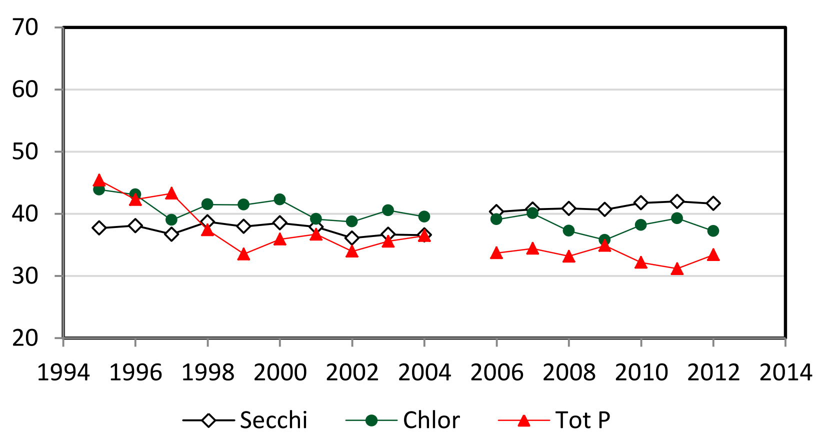

Figure 8. Pine Lake Trophic State Indicators through 2012

A trend line run through the TSI-TP indicator values since 1998 shows a decreasing trend over time (Figure 9). An R^2 value of 0.4868 indicates that 49% of the variability over time can be explained by the trend. This supports the success that the diversion in the 1990s of the inlet coming into Pine lake from a degraded wetland has had in controlling nutrient inputs to the lake, as well as the more stringent stormwater controls connected to new residential development.

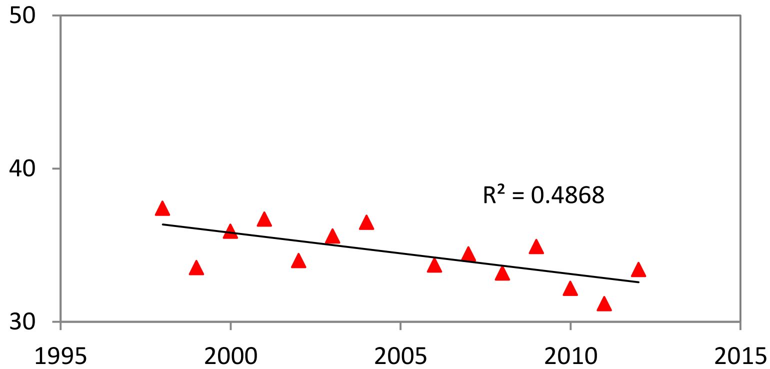

Figure 8. Annual mean TSI-TP since 1998. R^2 is the correlation coefficient of the regression line drawn through the points.

Conclusions and Recommendations

Based on monitoring data, overall water quality in Pine Lake appears to have stabilized during the period measured, with a low rate of productivity during summer months. High average N:P ratios could indicate nutrient conditions are usually not favorable for nuisance bluegreen algae blooms during the recreational season. Continued monitoring of nutrient and chlorophyll concentrations will assess future conditions and track changes, as well as providing additional data to assess the statistical significance of the apparent decline in TP over time.