# Lake Sawyer Water Quality:
## Water Quality Monitoring Results for Water Year 2014

July 2015

King County

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## Water Quality Monitoring Results for Water Year 2014

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# OVERVIEW

The King County Lakes and Streams Monitoring Group and its predecessor, the Lake Stewardship Program, collaborated with citizen volunteers to monitor Lake Sawyer between 1993 and 2004. In 2006, the City of Black Diamond began working with King County to continue monitoring efforts. Water quality data to-date indicate that the lake has good water quality, and currently exhibits moderate-to-low algal productivity (low mesotrophy).

There is a public park at the southern end of Lake Sawyer that offers opportunities for fishing and recreation. Additionally, there is a public boat launch along the northwestern shoreline. The lake is known to host the non-native aquatic plants Eurasian watermilfoil (*Myriophyllum spicatum*), fragrant water lily (*Nymphaea odorata*), Japanese knotweed (*Polygonum cuspidatum*), and yellow flag iris (*Iris pseudacorus*). Care should be taken to clean both boats and trailers when transporting water craft from Lake Sawyer to other lakes, in order to avoid contamination of other water bodies.

The discussion in this report focuses on the 2014 water year. The specific data used to generate the charts in this report, and a map of the lake showing the sampling location 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 online 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 briefly discussed in this section to introduce the parameters and to 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.

Level I volunteers measure Secchi depth and water temperature at a station in the middle of the lake weekly throughout the year. Level II volunteers measure 12 times 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

Precipitation and water level records were compiled for the 2014 water year by the Level I volunteer (Figure 1). Points not connected on the chart indicate omitted or missed collection periods. Water levels peaked in February, were relatively stable until May, and then slowly decreased through the rest of the water year.

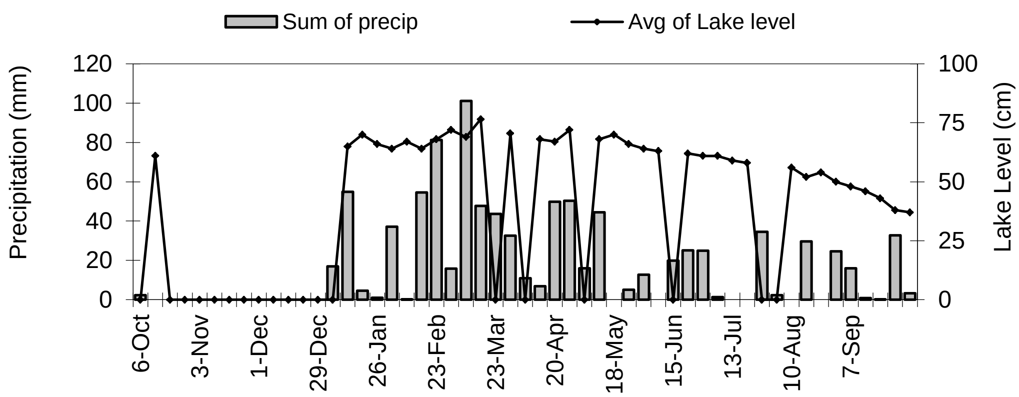


**Figure 1. Lake Sawyer water level and precipitation for water year 2014.**

Secchi depth ranged from 3.3 to 5.7 meters (Figure 2). The summer average transparency was 4.5 m for the Level I data taken weekly and 3.8 m for the Level II data taken biweekly May - October, placing Lake Sawyer in the upper third for water clarity out of 34 small lakes monitored in 2014. The Level I annual average was 4.3 m. Water clarity was the least in March and July and most in September, indicating a period of exceptional clarity just before the shallow and deep layer of the lake began mixing with the onset of cooler fall weather.

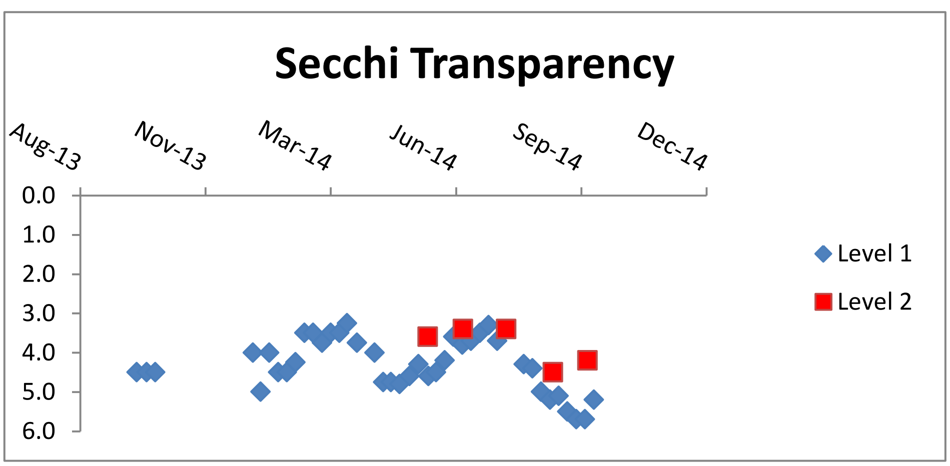


**Figure 2. Lake Sawyer Secchi transparency 2014**

Water temperatures at 1 m depth ranged between 4.0 and 25.0 degrees Celsius over the year, with an annual average of 14.0 °C (Figure 3). The temperature pattern of water at the

1 m depth exhibited in 2014 was similar to that of 2013 (with the same annual average as 2013). Lake Sawyer had its lowest temperature recorded in February and the highest temperatures recorded during the July and August months (at 1 meter).

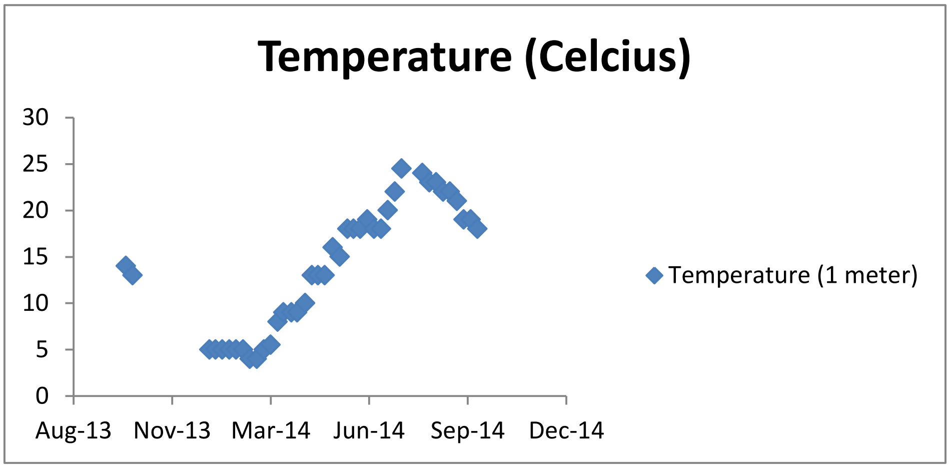


**Figure 3. Lake Sawyer temperature 2014.**

The average May – October temperature in 2014 was slightly cooler than that of the 2013 summer average (Figure 4). This is similar to many of the other lakes sampled during 2014, the majority of which exhibited decreases in average temperature compared to 2013. While there is no directional trend detected in the summer water temperatures to-date, continued monitoring will ensure that if a trend does emerge it will be detected.

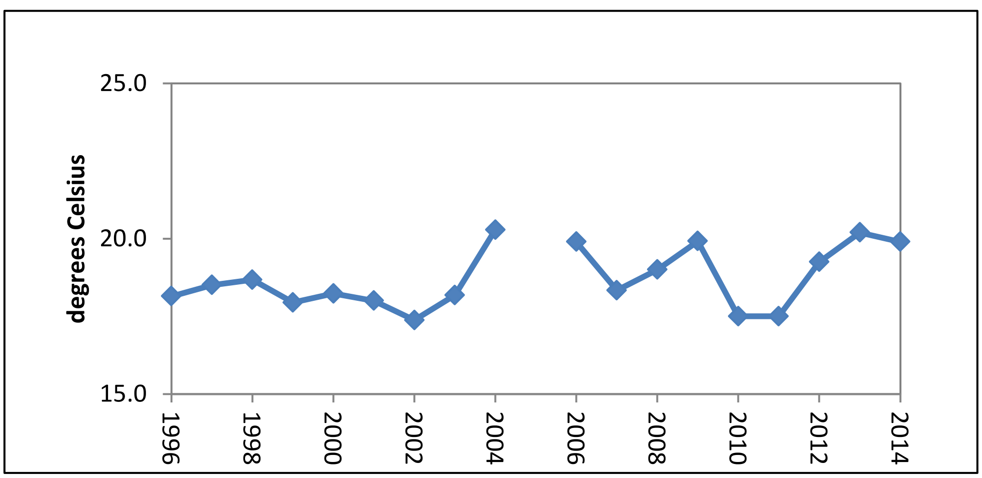


**Figure 4. Average summer temperature for Lake Sawyer, 1996-2014**

# 3.0 NUTRIENT AND CHLOROPHYLL ANALYSIS

## 3.1 Nutrients

Samples for total phosphorus (TP) and total nitrogen (TN) analyses were collected at a depth of one meter at approximately one month intervals between May and October. Samples from additional depths were collected on two sampling dates: one in May and another in late August.

Total phosphorus concentrations remained fairly stable throughout the sample season (Figure 5). Total nitrogen decreased from the beginning of the sample season through August, and increased in September and October. Both the concentration levels and patterns exhibited by total nitrogen and total phosphorus were similar to those observed in 2013.

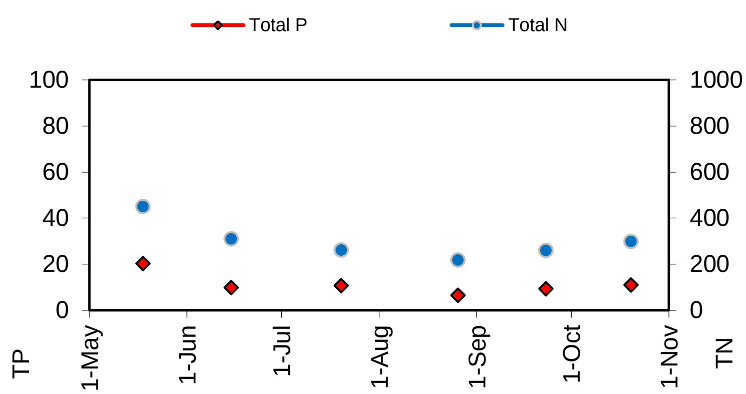


**Figure 5. Lake Sawyer Total P (TP) and Total N (TN) in µg/L, summer 2014.**

In 2014, Lake Sawyer N:P ratios ranged from 22.2 to 33.4, with an average of 27.9 (Figure 6). Ratios were variable across the sampling season with the lowest ratios occurring in May and the highest in August. N:P levels hovered around the threshold at which nitrogen may become a limiting nutrient, giving cyanobacteria an opportunity to out-compete other algal species. The range of N:P ratios was slightly higher than last year, indicating that Lake Sawyer may be moving towards more phosphorus limitation.

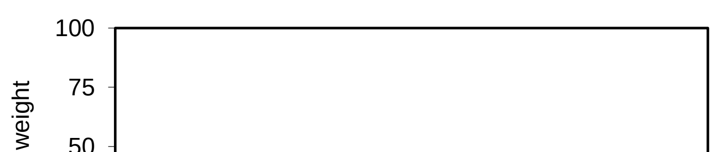

**Figure 6. Lake Sawyer N:P ratios. Values below the red line indicate a potential nutrient advantage for cyanobacteria.**

The average N:P ratio between May and October in 2014 was similar to those of 2009 – 2013 . However, the average ratio appears to be increasing slightly every year starting in 2009 (Figure 7). Previous to 2009, the values appear to have generally higher, although there was one low average value in 2001 that was similar to more recent years. No significant trend can be derived from the data up to this point in time.

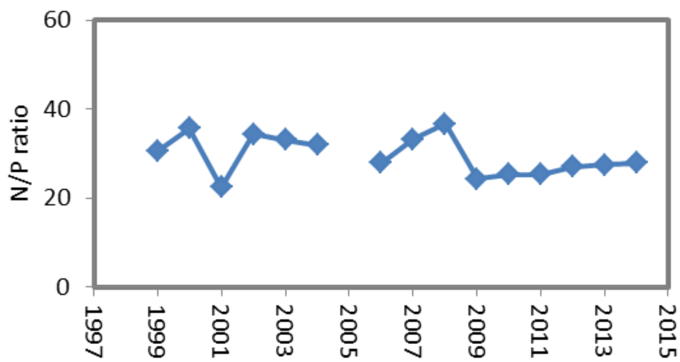


**Figure 7. Lake Sawyer summer average N:P ratios over time.**

## 3.2 Chlorophyll

Chlorophyll concentrations in Lake Sawyer ranged from 1.5-4.8 µg/L, with an average of 3.13 µg/L (Figure 8). Chlorophyll levels decreased from late May through late August and then increased through October, with the beginning and ending concentrations very similar to each other. The fall increase in chlorophyll may be the result of an increasing population of cyanobacteria and is typical of a pattern commonly observed in local lakes. Pheophytin, a degradation product of chlorophyll, was at very low levels throughout the season, without a single value above the detection limit.

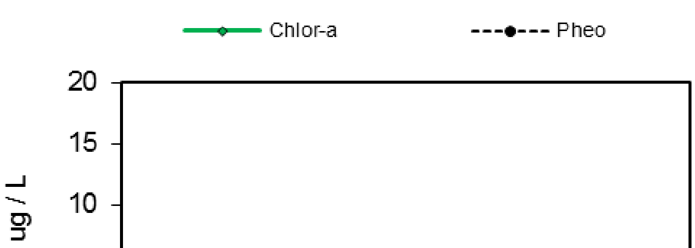

**Figure 8. Chlorophyll and pheophytin concentrations for Lake Sawyer, May-October 2014.**

# 4.0 WATER COLUMN PROFILES

Profile samples collected in Lake Sawyer in 2014 indicate that thermal stratification (temperature layering) was present by May and persisted through the second profile sampling in late August (Table 1).

The deeper water exhibited somewhat lower total phosphorus levels in the May sample when compared to 2013. Higher phosphorus levels in the hypolimnion (deep lake water below the temperature change) that indicate anoxia (lack of oxygen) are typical in Lake Sawyer ,but were not as dramatic in 2014 as they were in 2013. Anoxia in water facilitates the release of phosphorus from sediments, resulting in higher total phosphorus and orthophosphate (OPO4) values.

Total nitrogen was moderately stable through the water, though lower in August than in May. The lack of increase in deep water ammonia indicates that this year may have not had the degree of anoxia in the hypolimnion that has been seen in the past in Lake Sawyer.

**Table 1. Lake Sawyer profile 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 (MDL) are marked in bold, red font with the MDL value.**

| Lake name | Date | Secchi | Depth | DegC | Chlor-a | Pheo | Total N | NH4 | Total P | OPO4 | UV254 | Total Alk |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sawyer | 05/18/14 | 3.6 | 1 | 19 | 3.46 | <MDL | 0.450 | 0.014 | 0.0203 | 0.001 | 0.094 | 56.9 |
| | | | 8 | 7 | 1.72 | <MDL | 0.532 | | 0.0078 | | | |
| | | | 16 | 6 | | | 0.526 | 0.012 | 0.0158 | 0.004 | | |
| Sawyer | 8/26/14 | 4.5 | 1 | 24 | 1.5 | <MDL | 0.217 | 0.004 | 0.0065 | 0.001 | 0.0597 | 56.1 |
| | | | 8 | 20 | 1.56 | <MDL | 0.233 | | 0.0079 | | | |
| | | | 16 | 13 | | | 0.352 | 0.014 | 0.0102 | 0.003 | | |

Chlorophyll profile data indicate that some algae were present below the thermocline as well as in the shallow water, since the mid-depth sample was significantly cooler than the shallow sample on both profiling dates. In May, higher concentrations of algae occurred close to the surface, while in August the mid-depth sample contained more chlorophyll. In August, algal species that can adapt to lower light conditions may have been able to take advantage of the higher nutrient concentrations beneath the thermocline. These conditions are very similar to those seen in the 2013 profile samples

UV254 is the wavelength at which most organic compounds absorb light, and is used to measure the amount of dissolved organic compounds that add color to lake water. The low values for UV254 indicate that the water of the lake is relatively clear, with a very small amount of coloration from dissolved organic substances.

Total alkalinity values indicate that the lake is less soft than many other regional lakes, and therefore has more buffering capacity against changes in pH. This may be due to the type of the rock in the watershed, which has supported coal production in the past.

# 5.0 TROPHIC STATE INDEX RATINGS

In 2014, Lake Sawyer TSI values indicate that the lake remains in the mesotrophic-oligotrophic range for productivity (Figure 9). The Secchi TSI was in the low mesotrophic range, very similar to the majority of values since 2006. The chlorophyll TSI was on the border between oligotrophy and mesotrophy, and the total phosphorus TSI was in the upper oligotrophic range, which it has been since 2007. The consistently lower TSI value for phosphorus than for the other two indicators may be related to the species of algae found in the phytoplankton of Lake Sawyer.

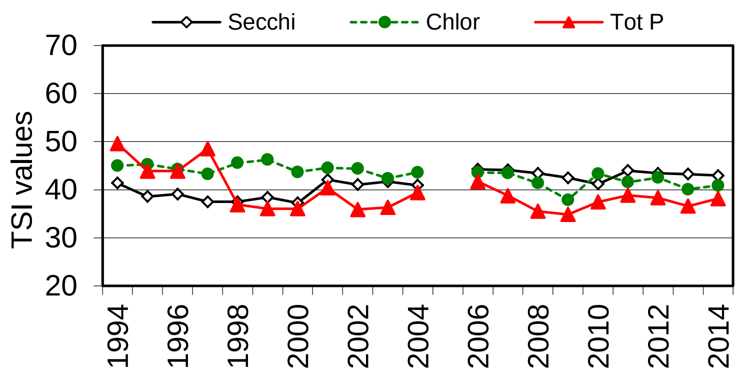


**Figure 9. Lake Sawyer Trophic State Indicators over time. Chlor = Chlorophyll-*a* and Tot P = total phosphorus.**

There is a substantial drop in phosphorus values between 1997 and 1998, which is very likely an artifact of the change in analytical methods by the King County environmental lab. Therefore, when evaluating trends, the data before 1998 that include phosphorus cannot be compared with later data (Figure 10). When a linear regression trend line is applied to the TSI value average over time, a very slight decrease in TSI is detected (Figure 10). Similar tests applied to the individual TSI values show the same minimal directional change.

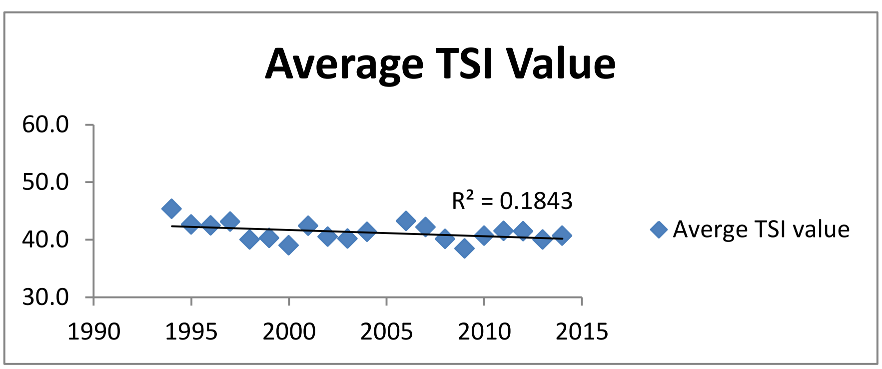


**Figure 10. Averages of TSI values for phosphorus, Secchi transparency, and chlorophyll-*a* over time for Lake Sawyer.**

# 6.0 TMDL FOR PHOSPHORUS

The Total Maximum Daily Load for Lake Sawyer set by the Washington Department of Ecology in 1993 defined a goal of an average of 16 ug/L total phosphorus concentration for the lake, but did not include the time period or water depth for which this was to be calculated (annual vs summer; epilimnion vs. whole lake). A wasteload allocation of zero was set in accordance with the removal of the Black Diamond wastewater treatment plant discharge to the wetlands feeding Rock Creek. A total annual influx of 715 kg phosphorus from the inlets was estimated to meet the 16 µg/L average concentration target. Load allocations for tributary input was set at 511 kg/yr and internal loading input at 124 kg/yr, with 80 kg/yr allowed for other sources such as direct runoff and dust fall.

Onwumere (WDOE publication 02-02-054 December 2002) found that Lake Sawyer appeared to be meeting the TMDL target as a long term average, but noted that it might not be meeting a maximum in-lake mean summer target if calculated separately for each month over the period. The Lake Sawyer Water Quality Implementation Plan (WDOE June 2009) noted that significant urban growth was scheduled for the area and that such development had the potential for impacting water quality in the lake.

The long term data set collected by King County and trained volunteer monitors begins in 1985 and continues to date, with a one year gap in 2005. However, it is important to note that there was a change in laboratory methods between 1997 and 1998 that may have affected the comparability of the data from before to values after the change.

Average June–September 1 m values (Figure 11) show that there were a number of years around the time of the decommissioning of the sewage treatment plant when summer average phosphorus concentrations were higher than in previous years and were generally above the TMDL goal. However, since 1998 the values have been similar to the late 1980s and have shown no cause to believe that the lake has not been meeting the standard set in the TMDL. There were small increases each year between 2007 and 2011, but a decrease in 2012 and a slight uptick in 2014 may signal that the change in values from year to year values are due to variability rather than a trend.

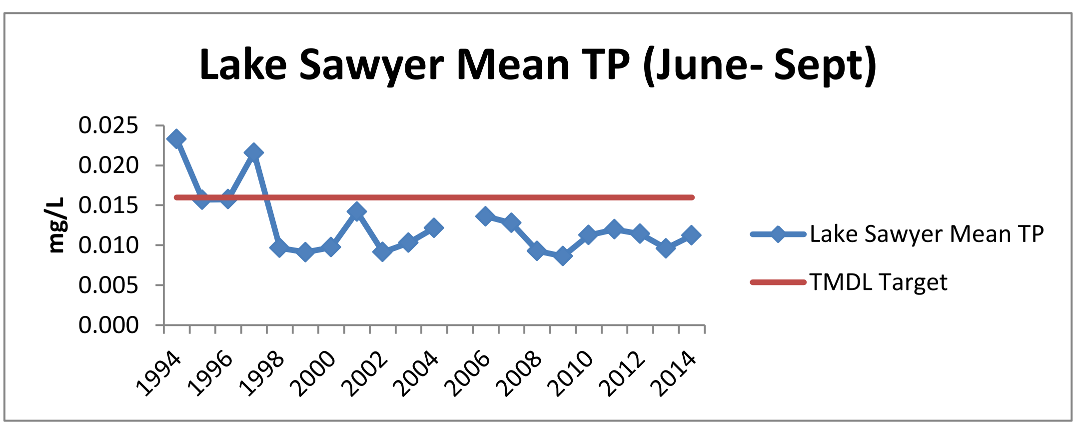


**Figure 11. Summer average total phosphorus at 1m depth at Lake Sawyer. The red line represents the TMDL target of 16 ug/L.**

The data continue to be encouraging, suggesting that Lake Sawyer continues to meet the TMDL and has been doing so for many consecutive years, depending on how the ambiguous TMDL requirement is interpreted. . However, because significant land development in the watershed is expected to occur in the near future, it is important to continue monitoring to look for changes as it proceeds, as well as for some time afterwards, in order to be sure that the stormwater controls are effective in meeting water quality goals and targets.

# 7.0 INLET WATER QUALITY

A second monitoring effort that began in 2006 has focused on the water quality of the major streams flowing into Lake Sawyer during the wet season: Rock Creek (station LSIN1) and Ravensdale Creek (station LSIN9). The program consists of sampling once a month by either volunteers or city staff at stations near the creek mouths flowing into the lake during the wet season (generally November through May) when both creeks are flowing heavily. At the same time, water flowing from the lake at the outlet weir is also sampled (LSIN10).

Volunteers were trained and city staff available to take the routine samples at 3 sites and were provided with prepared sample bottles and equipment. Samples were submitted to the King County Environmental Laboratory for analysis. Parameters measured included specific conductivity and total alkalinity as indicators of development, total phosphorus and orthophosphate for TMDL monitoring, total suspended solids, temperature and water stage for flow calculations.

An additional goal of sampling one to two storms a year at an expanded list of sites was also planned, but this has not been accomplished in all years, as target criteria were set for one inch of rainfall following an antecedent dry period of at least 24 hours, and these conditions sometimes could not be met during periods when the King County laboratory was staffed for receiving and processing water samples. For storms, oil and grease are added to the routine data collection for the 3 main stations, and 5 more stations are sampled in addition.

## 7.1 Total Alkalinity and Specific Conductivity

Specific conductivity measures the amount of dissolved salts in water by measuring the current-carrying capacity of the sample at 25 degrees Celsius. Total alkalinity, also known as “acid-neutralizing capacity,” measures the amount of calcium carbonate equivalents in the water that act as a buffer, thus moderating pH changes. It is closely related to the common term “hardness” of the water.

In general, both specific conductivity and total alkalinity are tied to the soil types and rocks found in the drainage basin. Both parameters generally increase in surface waters as a basin is developed because of soil profile disturbance, as well as concrete emplacement and the importing of foreign fill soils (often sub-soils with more mineral salt content than native top soils). Because of this, both parameters can be used as indicators of development over time.

Both parameters are sensitive to the amount of base flow relative to surface runoff in creeks at the time of sampling. Baseflows will have higher conductivity and total alkalinity because of the increased contact time that the water has had with soils or subsurface features. Thus values must be judged against the rate of discharge when making comparisons. Because neither creek is currently monitored for flow, this kind of comparison is currently not feasible. However, consistent patterns between the two creeks and the lake can be examined.

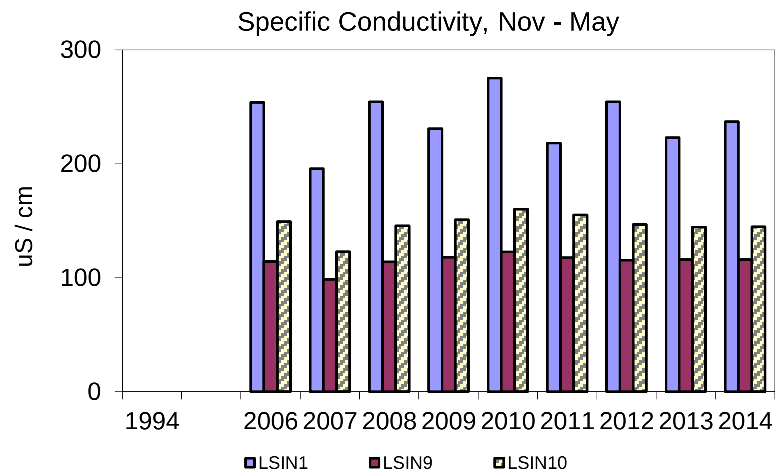


**Figure 12. November - May average of specific conductivity for Lake Sawyer and inlets.**

Rock Creek (LSIN1) is much higher in specific conductivity than Ravensdale Creek over time and varies considerably from year to year, while the values in Ravensdale are quite conservative over time (Figure 12). The outlet from Lake Sawyer appears to be midway between the two, but is closer to Ravensdale in value.

The hydrological model constructed in the 1990s for the Lake Management Plan assigned more inflow to Lake Sawyer from Ravensdale Creek than from Rock Creek, based on the hydrological measurements taken in 1993-1994. Therefore, if the model is correct, the water from Ravensdale with lower specific conductivity would have a significant dilution effect on the water coming into the lake from Rock Creek.

This is consistent with present land use in the two basins; in particular it should be noted that Rock Creek drains a currently inactive coal mining site that includes bare soils and rock outcroppings. In the future Rock Creek will also receive surface water flows from several large planned developments in the watershed. Unfortunately, specific conductivity and total alkalinity were not measured before 2006, so a long-term comparison cannot be made to the time period before or during the operation of the experimental sewage treatment plant.

Total alkalinity, which is a measurement of the acid buffering capacity of the water, follows the same general pattern as specific conductivity (Figure 13). Alkalinity in the lake is higher than in Ravensdale Creek, but significantly lower than Rock Creek, very similar to the pattern shown by specific conductivity. Alkalinity values can be impacted by development of forested land due to factors such as soil horizon disturbances, emplacement of foreign materials as fill to contour landscapes, and ongoing leaching of concrete structures. As development proceeds in the watershed, monitoring total alkalinity in the two creeks and lake will document changes reflecting the increased development, as well as other activities in the basin.

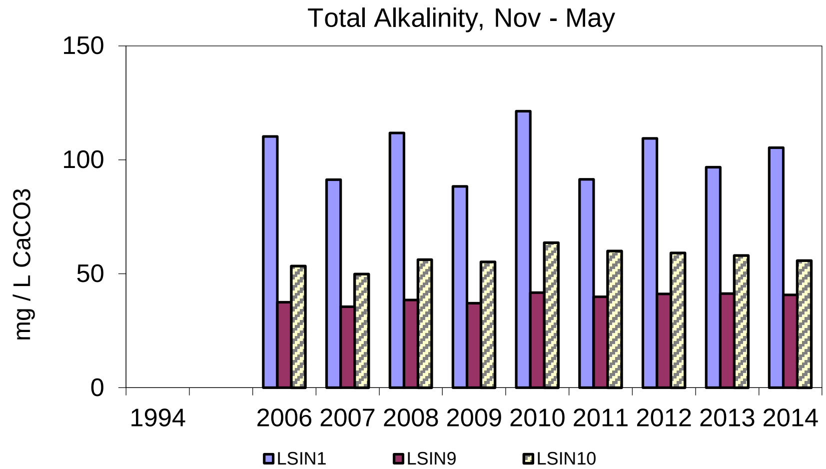


**Figure 13. November - May average of total alkalinity for Lake Sawyer and inlets.**

## 7.2 Phosphorus and Total Suspended Solids

Inputs of both total phosphorus and orthophosphate were routinely measured on a monthly basis from November through May. Total phosphorus is a measure of all phosphorus in a water sample including both dissolved and particulate forms, while orthophosphate is comprised of dissolved, inorganic phosphate that is readily available for immediate uptake as a nutrient for algae and aquatic plants.

Theoretically most phosphorus could be available for biological growth over time if it were all converted to orthophosphate on entering the lake; in reality a certain amount entering in particulate form is likely to be buried in the sediments and never be in the water column in an available form. In addition both particulate and dissolved forms of phosphorus flow out of the lake with water leaving through the outlet, particularly in winter when the lake outflow volume is large and residence time in the lake is short.

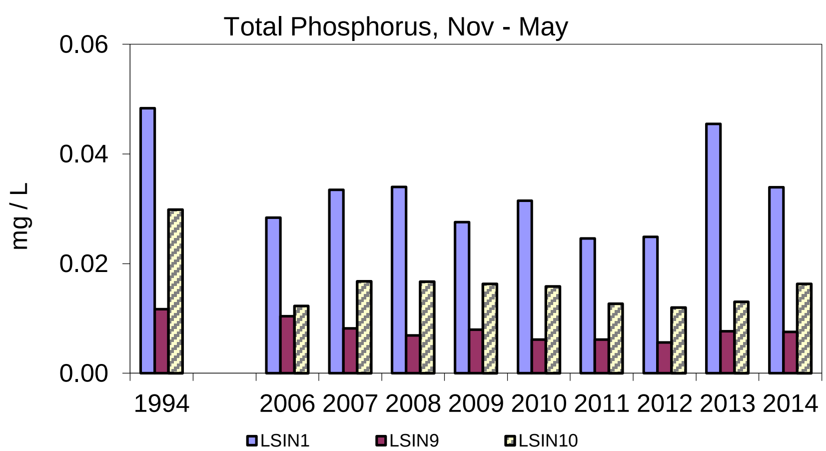


**Figure 14. November - May average of total phosphorus values for Lake Sawyer and inlets**

Total phosphorus in 2014 was lower at all sites when compared to the 1994 water year (Figure 14), but the Rock Creek (LSIN01) average was only slightly lower than it was in 2013 and more typical of levels seen in the late 2000's, while Ravensdale and the lake outlet appeared to be more stable over time. The elevated 2013 and 2014 phosphorus values may be a short-lived variation due to rain patterns in the basin relative to sampling dates, but should be watched, as the planned developments are currently under construction and more development is expected over the next few years.

There is a well-documented relationship between winter phosphorus concentrations in temperate lakes and spring/summer algae production, such that winter P values may be used to predict algae production the next growing season. There is a lag time in most Pacific Northwest lakes between when the most phosphorus enters lakes (winter) and when it is utilized (summer). The seasonal pattern in climate delivers most inflow to water bodies during the winter, while inflows in summer deliver little water to lakes, and subsequently also cause little outflow as well. The result is that summer nutrient inputs may actually be very small, even though the nutrient concentrations of inlet waters may be high due to groundwater influence. Thus, the past decrease in winter phosphorus concentrations has been a good indicator for Lake Sawyer, suggesting that summer algae may also be reduced.

In 2014 orthophosphate concentrations were slightly lower than in 2013 (OPO4, Figure 15). Variation between years can be expected based on local precipitation patterns, resulting flows, and their relationship to sampling dates. In 2014, the OPO4 average was slightly lower than 2012 and as low as it has been since 2007 for Rock Creek. The outlet from Lake Sawyer also lower than 2013, but higher than 2006 and 2012. The Ravensdale values were the lowest seen over the entire period measured.

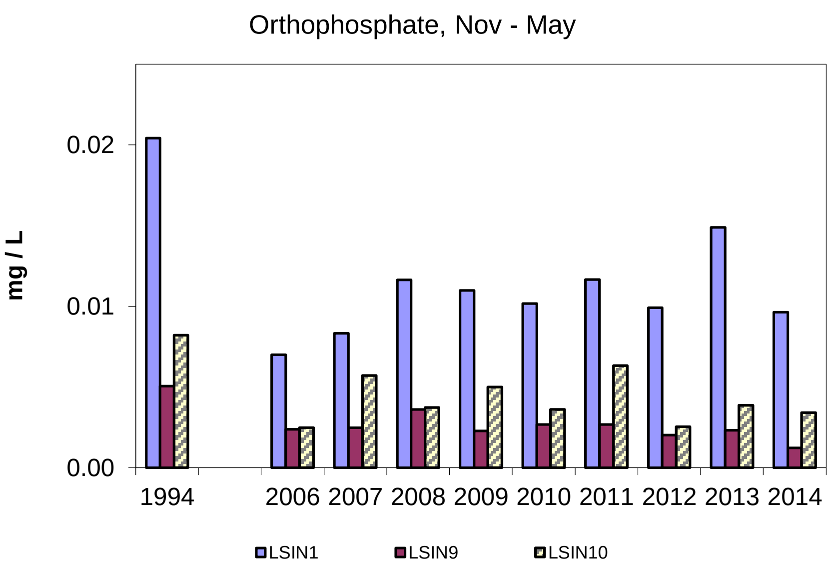


**Figure 15. November - May average of orthophosphate for Lake Sawyer and inlets.**

Total Suspended Solids measure the amount of particulate material, both organic and inorganic, being carried by creek flows into the lake or by outflow away from the lake. This is measured by collecting through filtration all materials larger than a certain diameter, generally 0.45 µm.

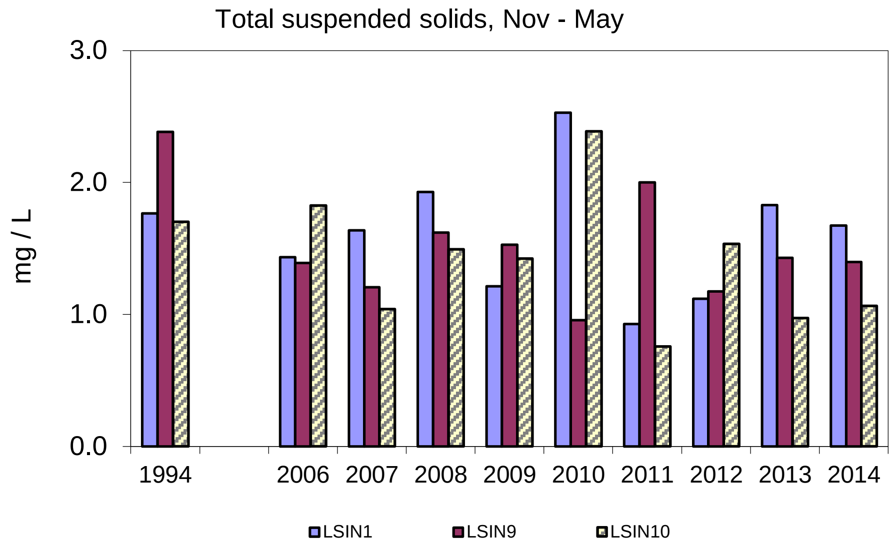


**Figure 16. November - May average of total suspended solids for Lake Sawyer and inlets.**

The TSS values collected in 2014 were very similar to those collected in 2013, but the pattern found between the creeks and the lake outflow for other parameters do not hold for suspended solids. Ravensdale is not always lower than Rock Creek in any given year, and the lake water can be higher than both creeks. It should be noted that particles in the lake water may represent algae blooms from the lake or may be erosion from nearby shoreline banks along the outlet channel.

## 7.3 Trends

Trends generally cannot be reliably calculated until a minimum of 8 consecutive years of data have been collected; There have been 9 years of data collected since 2006, so an effort can made to evaluate trends for the parameters that have been measured in the inflow and outflow streams during the wet season.

Directional changes were evaluated for all measured parameters and stations. Most parameters showed no change over time or showed a best-fit change that had a low correlation coefficient indicating that the relationship was not robust, based on the values to-date. However, four directional changes were validated by relatively high correlations (Table 2).

**Table 2. Statistically robust trends calculated for stream parameters from 2006 – 2014.**

| Sample Site | Parameter | Direction | $R^2 > 0.3$ |
|---|---|---|---|
| Ravensdale | Total P | (Slight) Down | 0.3019 |
| Ravensdale | Ortho P | (Slight) Down | 0.3215 |
| Rock | Ortho P | Up | 0.3116 |
| Ravensdale | Alkalinity | (Slight) Up | 0.6276 |

Ravensdale Creek shows a fairly slow, but steady decrease in phosphorus concentrations over time. Ortho P is following the same trend on Ravensdale Creek with a slight decrease since 2006. The alkalinity in Ravensdale Creek has been increasing slowly since 2006, and the trend has a strong correlation.

Rock Creek appears to be increasing in orthophosphate, which could relate to disturbance of soils in the watershed, changes in the wetlands through which it flows, or daily activities of people living in the basin. It is interesting that this increase is not accompanied by concurrent changes in total alkalinity or conductivity, which might be expected if development is partially responsible for the increasing trend. Sampling above and below the wetland complex through which the creek flows before entering the lake could produce pertinent information on factors affecting the trend.

## 7.4 Storm Water Samples

The technical services contract between Black Diamond and King County calls for sampling 1–2 storm events each year during November–May, but in the past it has sometimes proved difficult to match periods when storm criteria are met with volunteer availability and the operational hours of the King County Environmental Laboratory.

Beginning in 2010, staff from the City of Black Diamond agreed to sample stream sites if a precipitation event met the storm criteria, and this resulted in 8 storm events sampled since then at seven sites (Figure 17). Storm samples were taken by collecting a single grab sample from each site as soon as possible after the criterion of approximately 1' of rain in 24 hours had been met and the creeks are flowing freely.

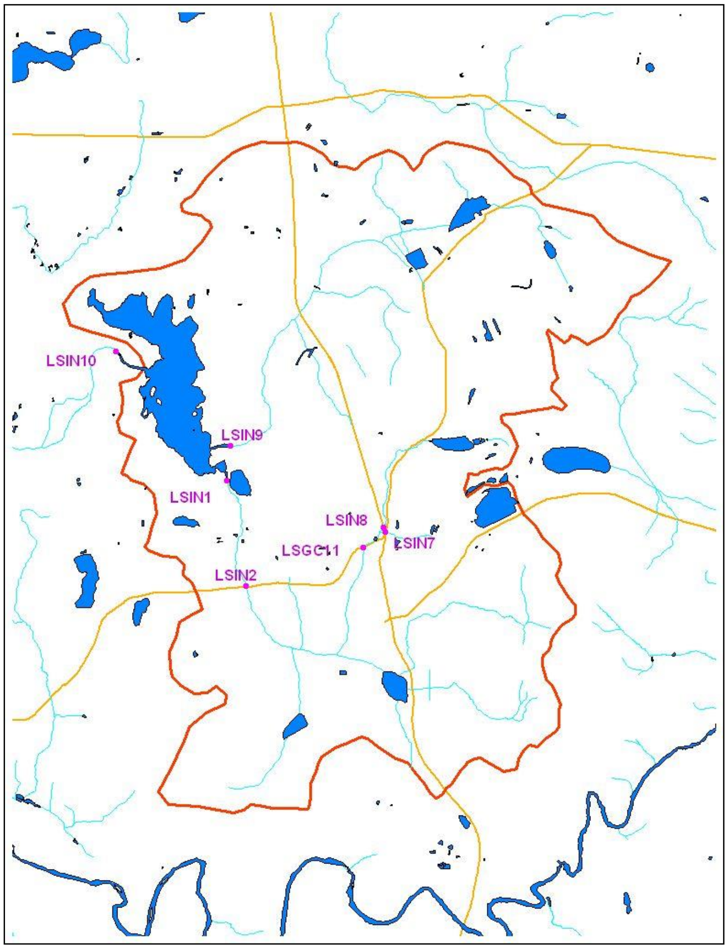


**Figure 17. Location of storm sample sites on Ginder Creek, Rock Creek, Ravensdale Creek and the Lake Sawyer outlet**

The measured parameters were the same as for the routine sampling, with the addition of "HEM: oil and grease" measurements (HEM stands for hexane extractable materials) at 3 stations: LSIN1 (mouth of Rock Creek), LSIN9 (mouth of Ravensdale Creek), and LSIN10 (outlet of Lake Sawyer). Sample values for HEM from all three sites have been below or just barely above the minimum detection level for all events sampled. This suggests that there have been no extraordinary sources of oil and grease to the surface water during the storm events measured to date. At present, there are no state water quality standards for oil and grease concentrations.

The following discussion includes the data from 8 storm events, sampled between 2006 and the end of 2014.

NOTE: in Figure 18 below and all subsequent figures representing storm samples, the dark blue bar represents the outlet from Lake Sawyer, while light blue is the station at the mouth of Ravensdale Creek flowing into the lake. The yellow, orange, and brown bars represent tributaries and stations along Rock Creek's path from upstream down to the mouth, beginning at the Ginder Creek crossing under Highway 169 (site LSIN8 and tributary LSIN7 just before it enters Ginder), downstream to the crossing under Roberts Drive (LSCG11) flowing south. Rock Creek site (LSIN2) is at the crossing under Roberts Drive, flowing north to Lake Sawyer through a series of wetlands, while LSIN1 is the routine monitoring site at the mouth just before Rock Creek empties into Lake Sawyer. See the map in Figure 17 for locations.

## 7.5 Total Alkalinity and Specific Conductivity

Comparing values among stations for alkalinity or specific conductivity can point to a particular stretch of waterway where inputs are entering the stream from increased development or soil disturbance. A jump in value for either of these parameters can also occur in stormwater collecting over surfaces in developed areas before running off or flowing through exposed soils and subsoils.

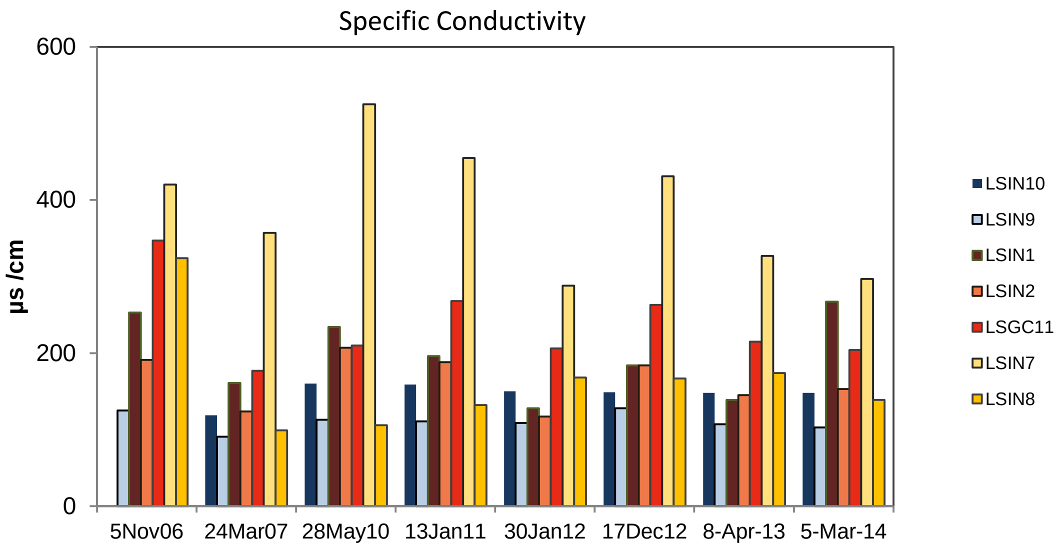


**Figure 18. Specific Conductivity at 7 sites for 8 storm events in the Lake Sawyer watershed.**

There is a distinct pattern reflected in all of the storm events, even though sampling storms by taking single grab samples can be notoriously variable in results (Figure 18). LSIN7 consistently has the highest value in each event, which likely relates to soil exposure on the area around the mine site that it drains. When this combines with water with lower specific conductivity in Ginder Creek (LSIN8) , the resulting water is between the two upper stations in value (LSGC11), but generally still higher than LSIN2 (downstream at Roberts Drive), which includes water from three other tributaries that dilute the Ginder Creek input. In the first 5 storms, there was an increase in conductivity between LSIN2 and LSIN1, and this could be related to the creek flowing through a large gravel operations site between the two sampling stations. During the last storm LSIN1 had higher values than LSIN2 which has not typically been the case. Ravensdale Creek water consistently had the least specific conductivity of all the storm sampling sites.

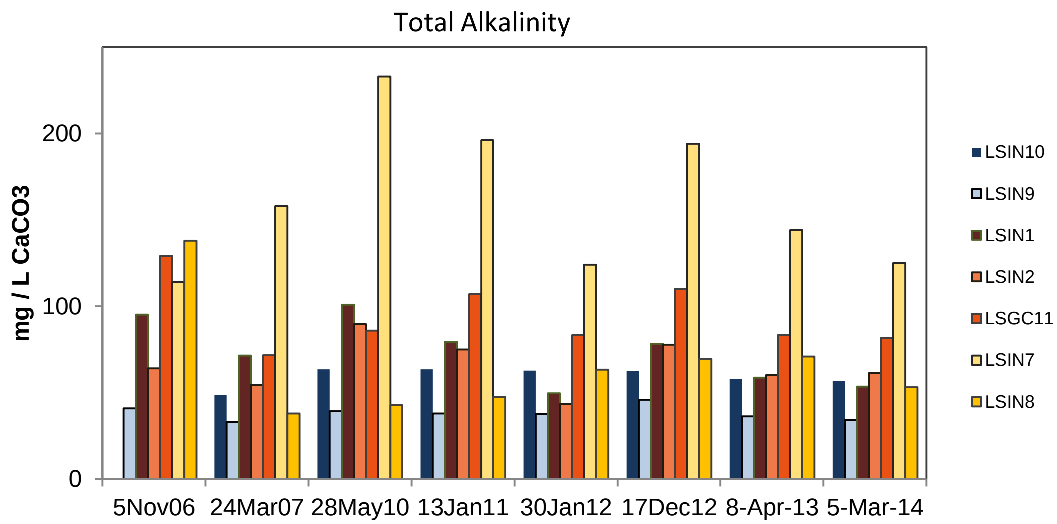


**Figure 19. Total Alkalinity at 7 sites for 8 storm events in the Lake Sawyer watershed.**

Total alkalinity (also called "acid neutralizing capacity") tells a generally similar story (Figure 19), with the difference that in the 2006 event, higher alkalinity was measured in the upper Ginder Creek sample (LSIN8) than the mine site tributary (LSIN7). However, in subsequent storms upper Ginder was consistently quite low in alkalinity. This unusual event has been discussed in previous annual reports. In general, the relationship between LSIN1 and LSIN2 is the same for total alkalinity as for specific conductivity.

## 7.6 Total Suspended Solids

Measuring total suspended solids indicates the amount of particulate material carried in the water. It can be especially high during storm events through erosion of banks or side channels by increased flows, as well as through excess runoff flowing over the surface instead of infiltrating soils, and picking up particles as it moves. Increases in nutrients carried by streams during storms are often attributable to the content of suspended solids in the water. Wetlands and stormwater facilities are generally designed with the idea of detaining water long enough to allow the suspended solids load to settle out of the water before flowing out of the facility downstream, thus removing a portion of the nutrient load before the water enters a lake or other receiving body of water.

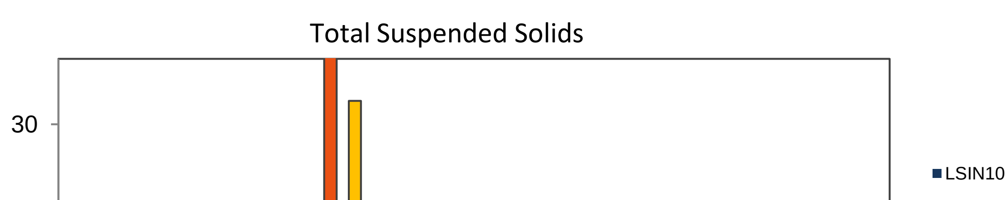

**Figure 20. Total suspended solids at 7 sites for 8 storm events in the Lake Sawyer watershed.**

Data from storm events in the Lake Sawyer watershed (Figure 20) are consistent with these processes. While there is a wide range in the amount of suspended solids in the creeks during storm events, the samples from stations along Ginder Creek in the upper watershed consistently carry a higher sediment load than samples from the Rock Creek stations located in the flat, wetland-dominated lower portion of the creek close to entering the lake. Either the other inlets are diluting the heavily laden waters of Ginder Creek before reaching the LSIN2 station or the wetlands are serving the function of detaining water long enough for sediment to fall out of suspension, thus reducing the input to Lake Sawyer. The small tributary to Ginder Creek (LSIN7) had the highest TSS values of the sampling event with a value that was considerably higher than in the past samples.

## 7.7 Phosphorus

Both total phosphorus and orthophosphate were measured for storm events. In general, for storm samples the amount of total phosphorus varies in relationship with the amount of total suspended solids in the water. Orthophosphate is essentially independent of suspended materials and should vary less with storm-induced erosion, although it will vary to some degree with water source: surface runoff, direct precipitation and groundwater.

While all of the Ginder and Rock Creek samples are higher in phosphorus than the Ravensdale Creek samples (Figure 21), the pattern between stations along the Rock Creek drainage is not as consistent as it was for total suspended solids for the entire period.

This may be related to the intensity of the storms, or it is possible that there may be a change in make-up of the sediments between the stations, with some upper stations carrying more large inorganic particles than the lower stations in the watershed, because of differences in rates of settling. Fine organic particles are often lighter and do not settle as quickly as mineral or rock fragments when water velocities decrease. However, this cannot be determined without measuring total organic carbon for each sample, which was not done.

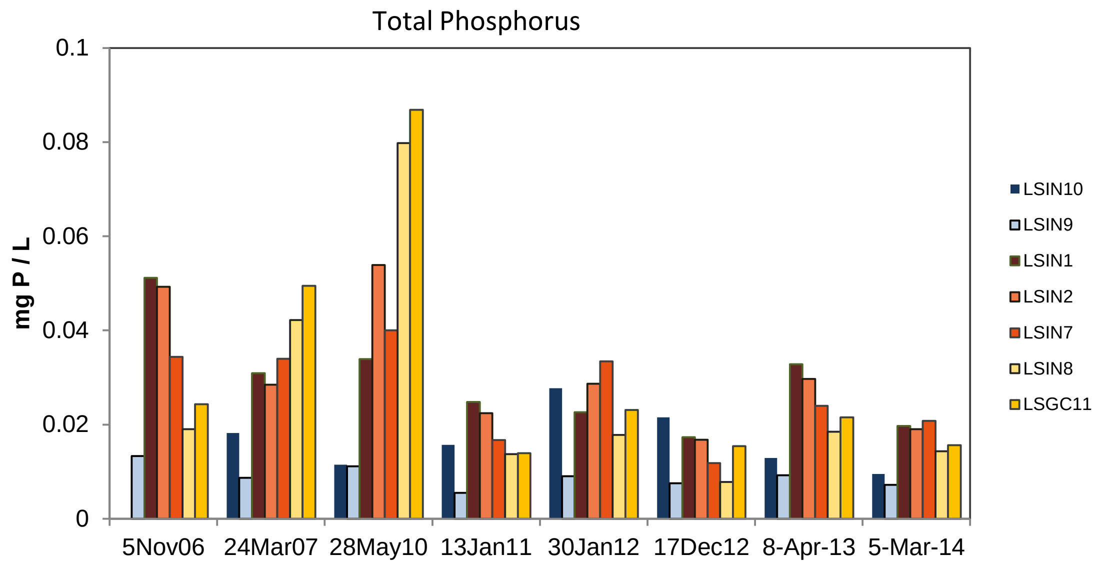


**Figure 21. Total phosphorus at 7 sites for 7 storm events in the Lake Sawyer watershed.**

It is interesting to note that the 2006 and the 2011-13storms show a pattern of increase as the samples move from the upper to lower reaches of the Rock Creek system, while the reverse is shown for 2007 and 2010. The 2014 samples show very similar values for both streams as the water moves down the system. There could be some relationship to the timing of the grab samples in relationship to the storm hydrograph or that a pulse of peak erosion was captured by the sampling. There could also be some relationship to soil disturbances going on in the sub-basins. All of the storms sampled after 2010 have had lower phosphorus concentrations overall, and this could be compared to the amount of precipitation for each event to see if it is a function of storm size or whether it might be related to decreased erosion along the creeks. All sites collected during the 2014 storm event contained less total phosphorus than the samples taken in 2013.

## 7.8 Orthophosphate

Orthophosphate concentrations should be lower and more conservative than total phosphorus, because it represents a dissolved constituent rather than particles from bank or water shed erosion (Figure 22). Phosphorus was lower in concentration in water from the Ginder Creek stations than in the downstream Rock Creek stations, so it is possible that the wetlands may be releasing some orthophosphate to the creek that increases concentrations. The high phosphate values in the lake outlet in the January and December samples are characteristic of water from lakes in mid-winter when there are small numbers of algae present and the lake is thermally mixed.

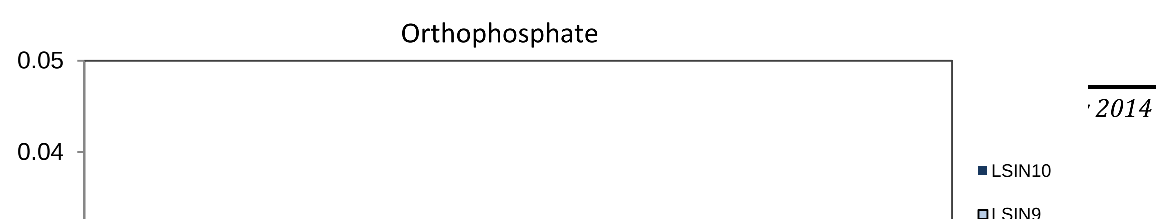

**Figure 22. Orthophosphate at 7 sites for 7 storm events in the lake Sawyer watershed.**

# 8.0 CONCLUSIONS AND RECOMMENDATIONS

Based on May–October water quality data, summer water quality in Lake Sawyer has continued to be relatively stable over the last decade. The nutrients in the lake varied by only a small amount over the sampling season, and the N:P ratios were generally around 27.9 in 2014, which indicated that nutrient conditions in the lake could have been favorable for bluegreen algae blooms, but the overall low concentrations of phosphorus may have kept major blooms from forming. Chlorophyll remained in the low range, with the average value being 3.13 µg/L and no values above 4.8 µg/L during the entire sampling season

The inlets have showed a general decline in phosphorus since the 1990s, but there was a significant decrease in the amount of total phosphorus in Rock Creek as compared to 2013. The year 2014 marked the 9$^{th}$ year of monitoring the inlets from November – May, and trend lines were calculated for all parameters and stations. After 9 years, 4 trends were validated by correlation coefficients higher than 0.3: a slight decline in total phosphorus and ortho phosphorus in Ravensdale Creek; an increase in ortho phosphorus in Rock Creek; and small increases in total alkalinity in and Ravensdale Creek. These may change over time as development proceeds in the Lake Sawyer watershed.

One storm was sampled in 2014 and was added to the data for storms since 2005, but did not change the conclusions arising from storms measured to-date. More erosion is taking place during storms in the upper watershed of Ginder Creek than in the lower portion of Rock Creek, particularly from the tributary flowing from the mine site property. More bioavailable orthophosphate may be released from the wetlands than from the upstream portions of the watershed.

It appears from four recent storm samples that hexane-extractable oil and grease may not be a concern at this time in the inlets at sites close to the lake and at the outlet from the lake.

Beginning in late 2014, King County added both Rock and Ravensdale Creeks to their program of routine monitoring, as well as targeting several storms a year for basin characterization monitoring. This addition will generate routine data once a month year round, as well as storm data, and will replace the need for the City of Black Diamond to fund volunteer monitoring of the inlet streams, allowing for the lake monitoring program to become the same as for other cities across the county.