

# LAKE CRABAPPLE EXPANDED MONITORING STUDY

## INTRODUCTION

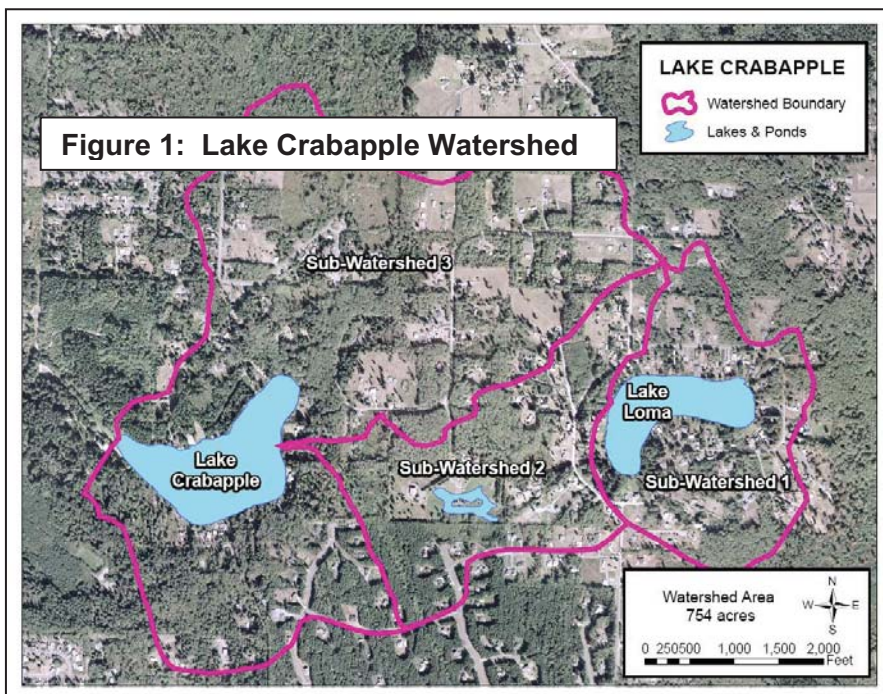
Snohomish County Surface Water Management (SWM) has been monitoring summer water quality conditions in Lake Crabapple with the help of lake resident volunteers since 1992. In recent years, residents of Lake Crabapple have become concerned about the overall health of the lake and the impacts of increasing development in the watershed. In October 2005, the residents of Lake Crabapple formed a group to fund additional monitoring of the lake to address these concerns. SWM agreed to assist the residents in developing the larger scale monitoring plan and assessing the results. The goal of the expanded monitoring was to provide data for a more thorough analysis of lake conditions, particularly to help determine the sources of water and nutrients flowing into and out of the lake. This information will help to assess the potential impacts of future development, as well as provide more complete baseline data to track the future health of the lake. The original findings of this study were developed into a report in 2008. The report was updated in 2011 to include additional future scenarios of watershed development for Lake Crabapple.

## EXPANDED MONITORING PLAN

The Lake Crabapple expanded monitoring plan included year-round monitoring of the hydrologic and chemical characteristics of Lake Crabapple. This report is based on the results from October 2005 through September 2007. To understand the lake hydrology, volunteers recorded the water level of the lake daily and took frequent readings of the inlet and outlet stream levels when they were flowing. SWM staff also took monthly measurements of the discharge or volume of water flowing at

the inlet and outlets.

Volunteers also conducted year-round bi-weekly monitoring of Lake Crabapple. The basic monitoring included water clarity, water temperature, dissolved oxygen concentrations, and general lake observations (algae levels, water color, etc). The volunteers also collected water samples for chemical analysis. From November through March (when the lake was mixed) samples were



# Lake Crabapple Expanded Monitoring Study

collected monthly from a depth of one meter. From Apr-Oct (when the lake was stratified), samples were collected twice a month from 1, 6, and 12 meters deep. All samples were analyzed for total phosphorus (the main nutrient feeding algae growth). The one-meter samples were also analyzed for chlorophyll *a* (a measure of algae concentration) and intermittently for alkalinity and nitrate/nitrite. Finally total phosphorus samples were taken on a monthly basis from the main inlet stream when flowing.

## LAKE HYDROLOGY

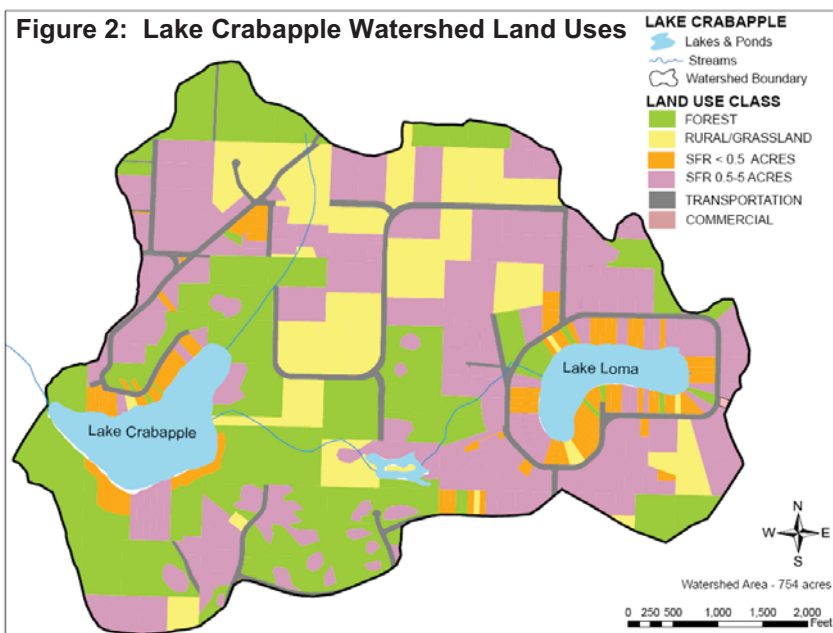
### Lake Description

Lake Crabapple is a 37.6 acre lake located north of the Tulalip Reservation in the Seven Lakes area. It is the second in a four-lake chain that begins at Lake Loma and ultimately drains into Tulalip Bay. Lake Crabapple has a maximum depth of 14.9 meters and a mean depth of 5.5 meters. The lake volume is approximately 630 acre-feet. The lake lies in a protected bowl, which contributes to its strong stratification into warm upper waters and cold bottom waters during the summer months. There is only one identifiable inlet to Lake Crabapple, located on the eastern shore of the lake. There may be additional unidentified inlets that enter the lake via underground pipes or small ditches.

### Watershed Characteristics

A watershed is all of the surrounding area that drains into the lake. Its characteristics determine the concentration of nutrients, sediments, and other potential pollutants entering the lake. The Lake Crabapple watershed covers 754 acres and can be divided into three sub-watersheds (Figure 1). The first sub-watershed includes Lake Loma and covers 134 acres. The second sub-watershed is 144 acres in size and includes the tributary stream from Lake Loma to Lake Crabapple. The third sub-watershed covers 476 acres and includes the remainder of the area.

The immediate watershed (not including the Lake Loma sub-watershed) is 16.5 times the size of the lake, while the total watershed is over 20 times the size of the lake. This is a higher lake-to-watershed ratio than many other lakes and indicates



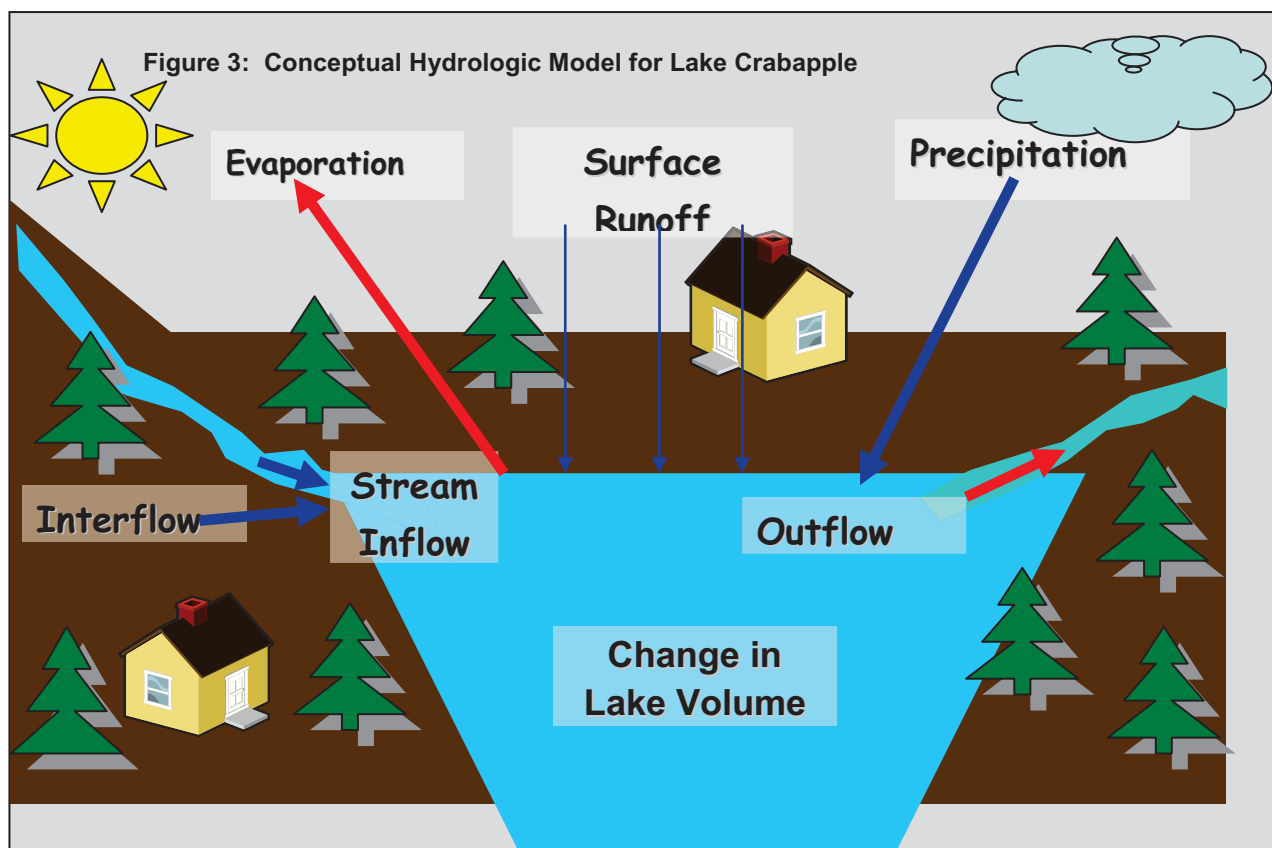
## Lake Crabapple Expanded Monitoring Study

that Crabapple may be more susceptible to impacts from pollution coming from the surrounding lands.

In 1973, only 2% of the watershed was developed with residential uses, and the rest of the watershed was undeveloped. By 1995, over 100 new homes had been added to the immediate watershed, bringing the developed percentage of the watershed to about 20%. Using 2003 aerial photos, the watershed was classified into 6 different land use categories (Figure 2). Single family residential (SFR) was the highest class of land use, consisting of 39% lower density SFR (between 0.5 and five acres) and 17% high density (less than 0.5 acre lots). Forest was also a major land use class covering 33% of the watershed, followed by rural/grassland at 21%. The remaining watershed was composed of transportation (6%) and other uses (2%).

### Water Budget

A water budget is a mass balance model that accounts for all of the lake inflows and outflows over a specified period of time. It helps determine the primary sources of inflow into the lake and provides a foundation for understanding the nutrient loading into the lake. The difference between the inflows and outflows should equal the change in lake volume over time. The major inflows into Lake Crabapple are direct precipitation onto the lake surface, inflow from inlet streams, interflow (water within the upper pervious soil layers), and surface runoff (Figure 3). Outflows include the outlet

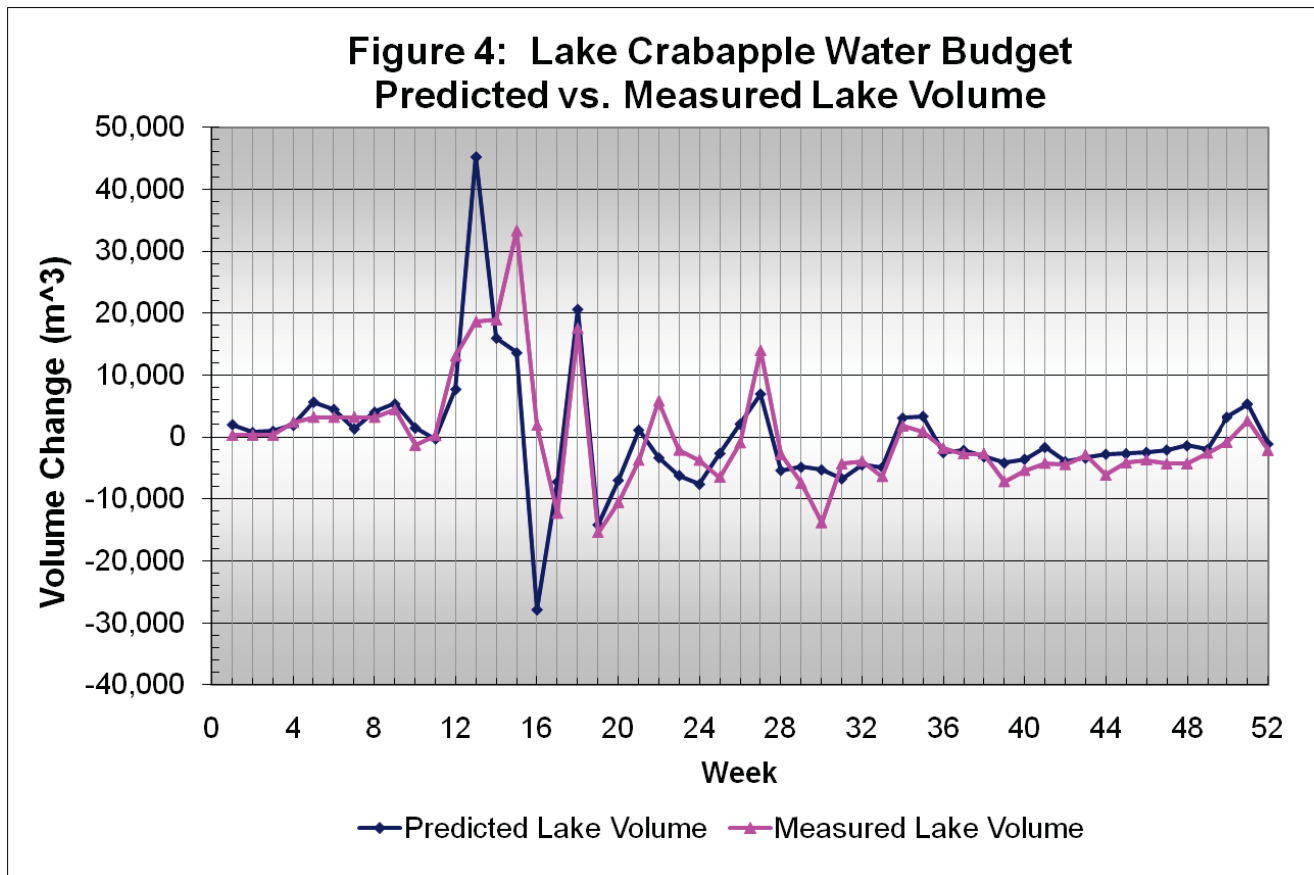


# Lake Crabapple Expanded Monitoring Study

stream and evaporation. Deep groundwater could also be an inflow or an outflow from the lake depending on the season. However, deep groundwater is difficult to measure, so for the purposes of this study, the groundwater contributions were not addressed.

Each of the inflows and outflows was characterized for the 2005 water year (October 2005 – September 2006). Precipitation and evaporation were derived from local weather station sources. Inlet and outlet flow and changes in lake volume were determined from the expanded monitoring data.

Surface runoff and interflow could not be measured directly. Instead, a runoff model was developed using the SCS (Soil Conservation Service) Curve Number model developed by the Natural Resource Conservation Service (NRCS, 2004). The model uses the current land uses in the watershed together with the soil type data to assign a number to each portion of the watershed. This information was then combined with daily precipitation data, seasonal adjustments for vegetation cover, and antecedent moisture conditions to predict surface runoff directly into the lake and into the stream. Baseflow (the interflow combined with the base flow of the stream) was subsequently determined by comparing the runoff estimates with the measured inlet flows.



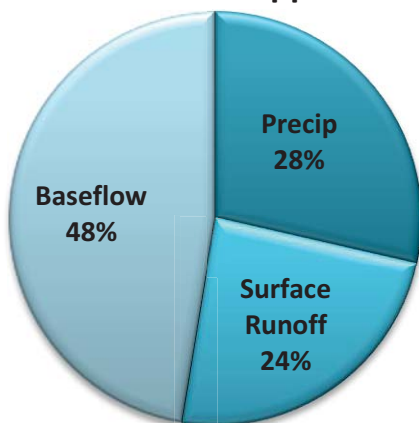
## Lake Crabapple Expanded Monitoring Study

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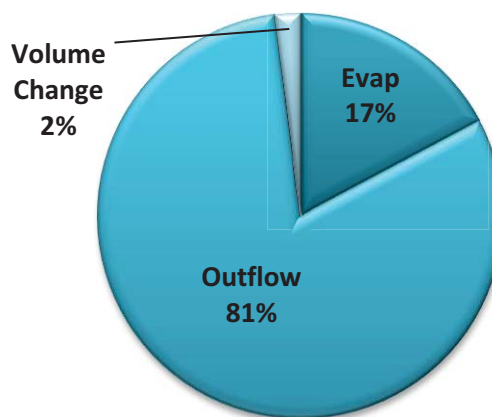
To calibrate the model, the weekly predicted changes in lake level were compared to the actual weekly changes in lake level. The model was calibrated so that each week there would be an error of no more than +/- 20% of the maximum actual change in lake level during the model period. The final model was able to achieve this goal 86% of the time (Figure 4).

The results of the water budget model show that the largest inflow to Lake Crabapple is from baseflow, accounting for 47% of inflow. Direct precipitation on the lake (28%) and surface runoff (23%) accounted for the remainder of inflows (Figure 5). Flow out of the outlet accounts for the major loss of water from the lake (81%), while evaporation was responsible for 17% (Figure 6). In 2005 – 2006, the volume of water remaining in the lake was slightly lower at the end of the water year (Sept), accounting for the remaining 2% of water loss.

**Figure 5: Lake Crabapple Inflows**



**Figure 6: Lake Crabapple Outflows**



## LAKE WATER QUALITY

### Temperature

Temperature profiles show that the lake was strongly thermally stratified during the entire May through October period in both 2006 and 2007 (Figures 7-10). This means that the warm upper waters and the cool bottom waters did not mix. During the stratified periods, warmer water extends from the surface to about 3 or 4 meters down. The upper waters warm up beginning in March, reaching a peak in late July, and then cool down until November. At the same time, bottom water temperatures change only a little. This strong stratification is essential for keeping the phosphorus that is released from the bottom sediments during periods of low dissolved oxygen from migrating upward and becoming available for algae growth in the lake.

## Lake Crabapple Expanded Monitoring Study

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By November, the surface waters had cooled considerably so that temperatures were almost equal from top to bottom. The lake water turned over (or mixed) as the stratification weakened. The lake stayed mixed during the winter until March, when the upper waters began to warm slightly.

### Dissolved Oxygen

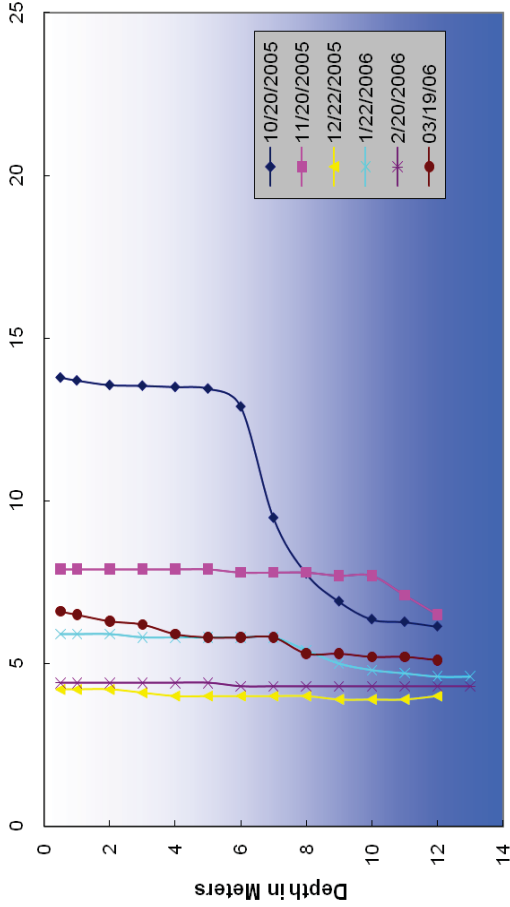
The depth profiles of dissolved oxygen measured in 2005-2007 largely correspond to the temperature profiles seen during that time period (Figures 11-14, laid out in pairs beside the temperature profiles). Oxygen levels increased in the winter and declined in the bottom layers of the lake through the summer. There was essentially no oxygen in the water at 6 meters and below by late July in 2006 and by early July in 2007. During the stratified summer period, oxygen in the lower waters is consumed by the decomposition of organic material within the lake. Since the lake is strongly stratified, the oxygen is not replenished by the overlying oxygen-rich upper waters or the atmosphere.

Several times during the summers of 2006 and 2007, dissolved oxygen levels at 3 and 4 meters increased sharply. This was likely due to vigorous algae growth at the interface between the upper and lower waters. Algae often thrive in this zone because there is available light in the upper waters and higher nutrients available in the lower waters. The high chlorophyll *a* values observed during these time periods support this explanation.

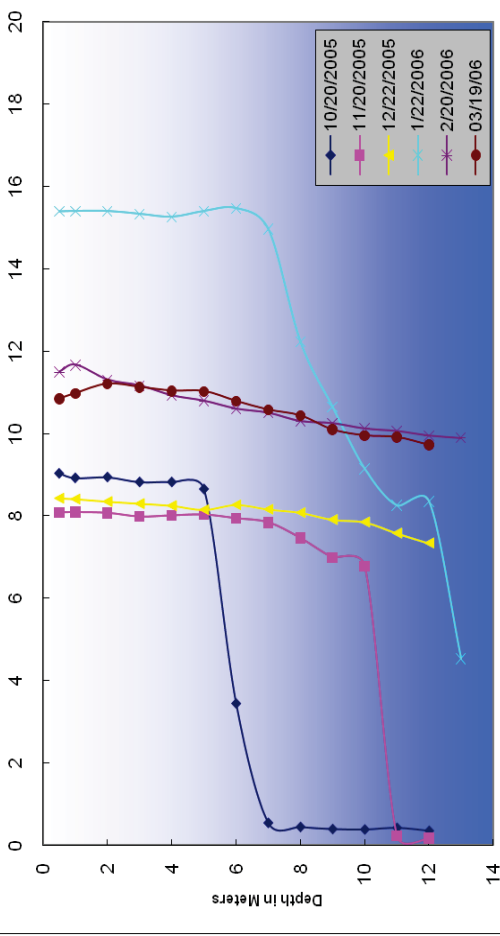
By November in both years, when the upper waters cool, the dissolved oxygen was still near zero below approximately 10 meters, meaning that the lake had not completely mixed. By December the lake was usually mixed, with uniform temperature and dissolved oxygen throughout the water column. The lake remained mixed until March when the upper waters began to warm and dissolved oxygen began to decline again in the bottom waters.

# LAKE CRABAPPLE EXPANDED MONITORING STUDY

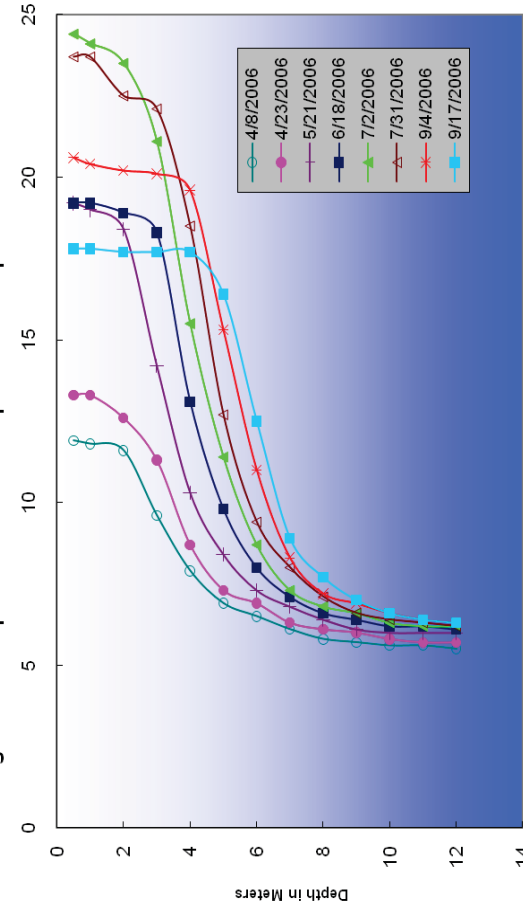
**Figure 7: Temperature Profile: October 2005 - March 2006**



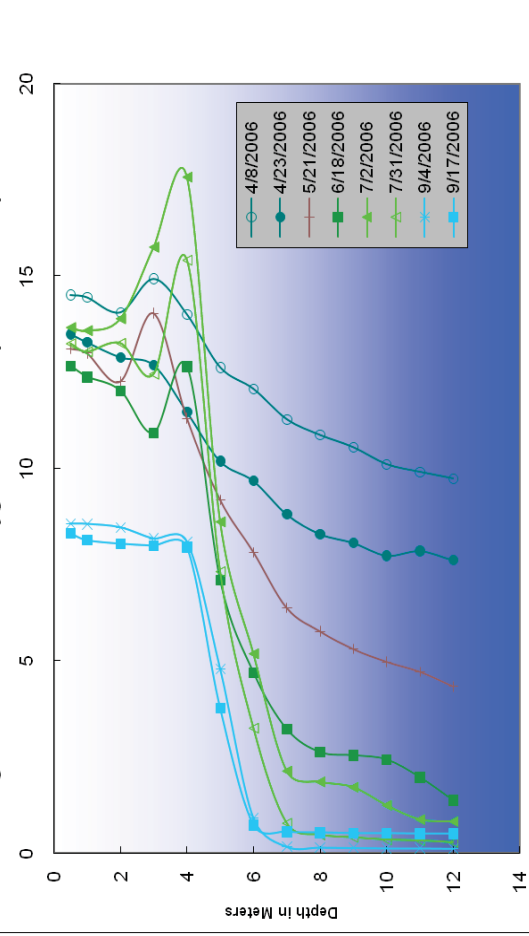
**Figure 11: Dissolved Oxygen Profile October 2005- March 2006**



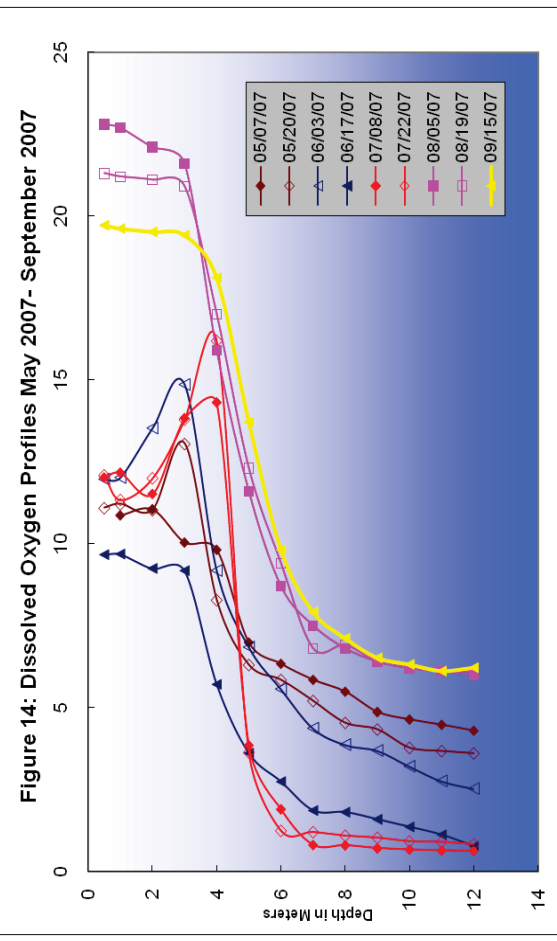
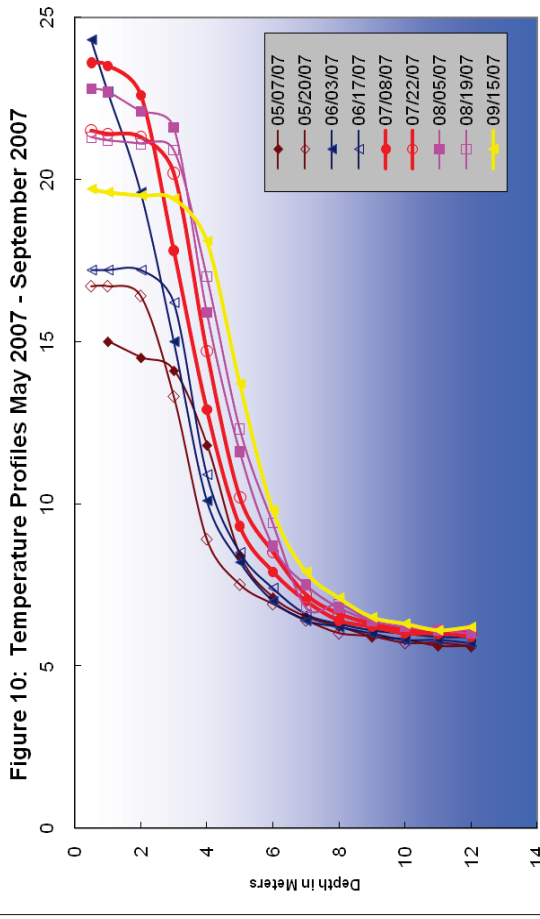
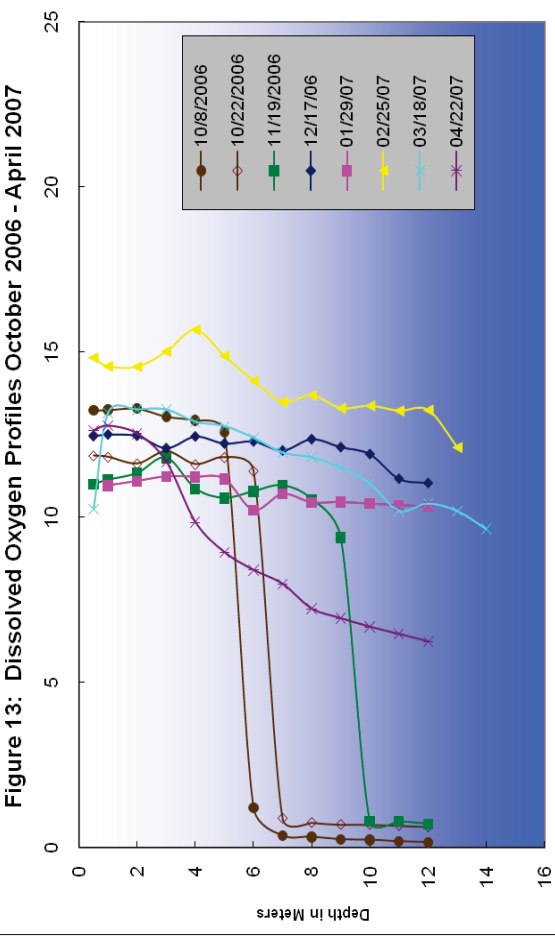
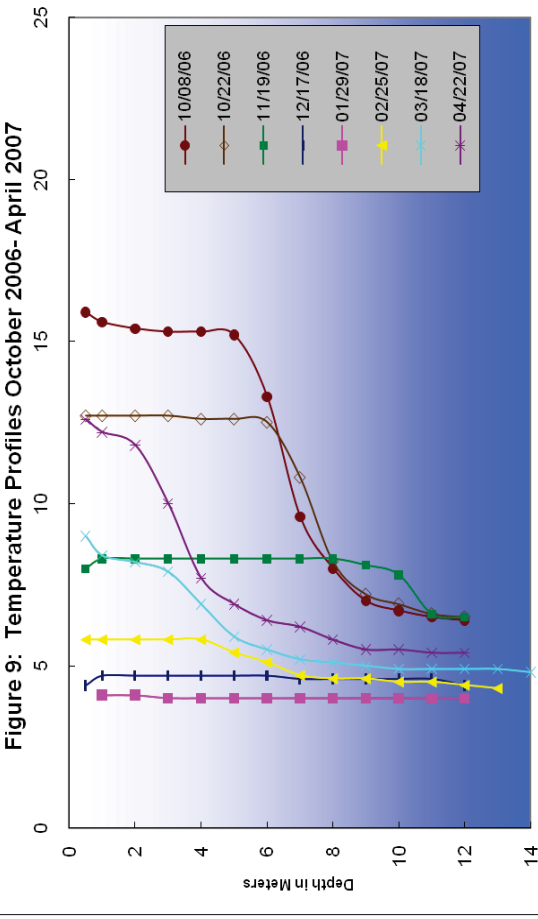
**Figure 8: Temperature Profiles April 2006 - September 2006**



**Figure 12: Dissolved Oxygen Profiles April 2006 - Sep 2006**



# Lake Crabapple Expanded Monitoring Study

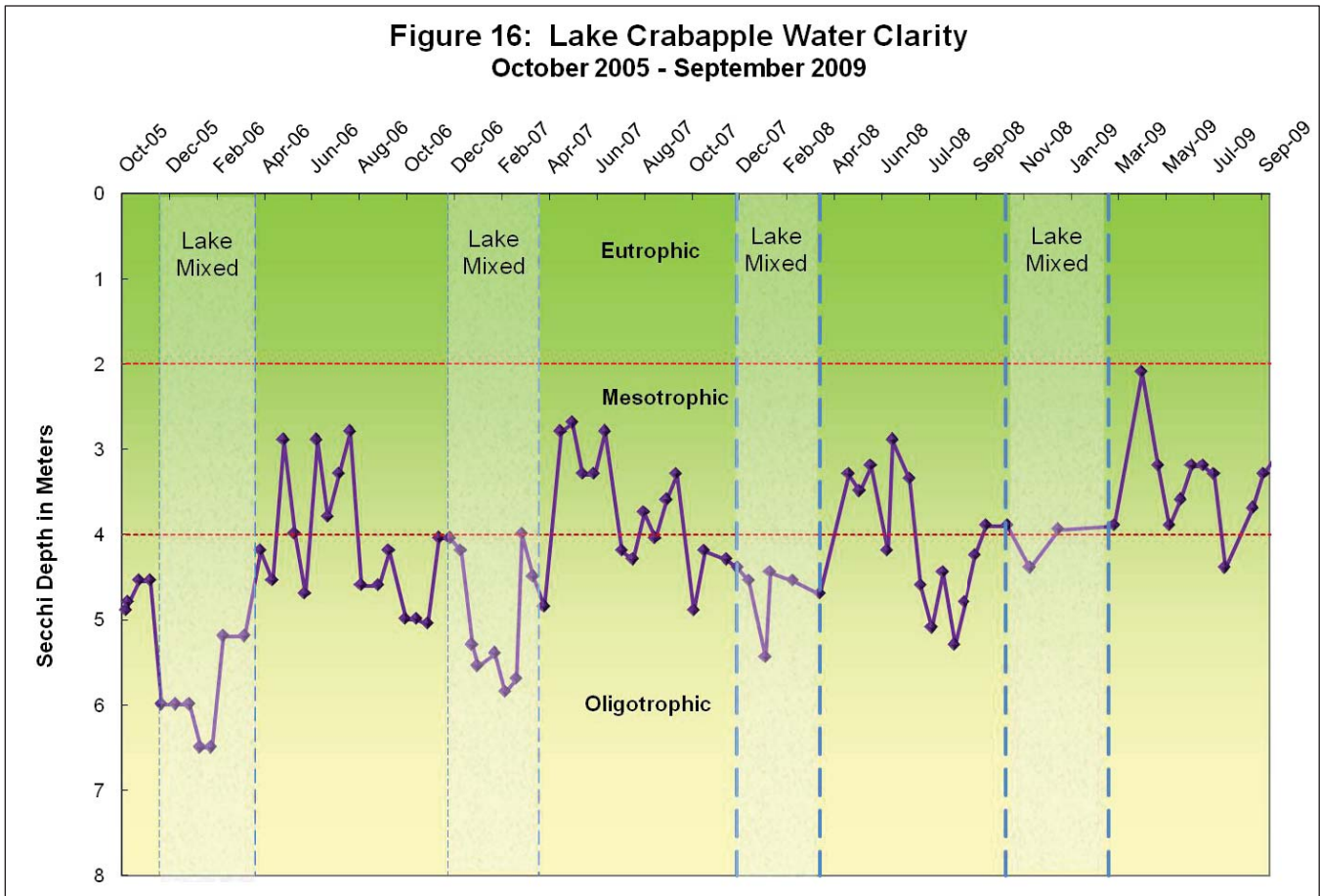
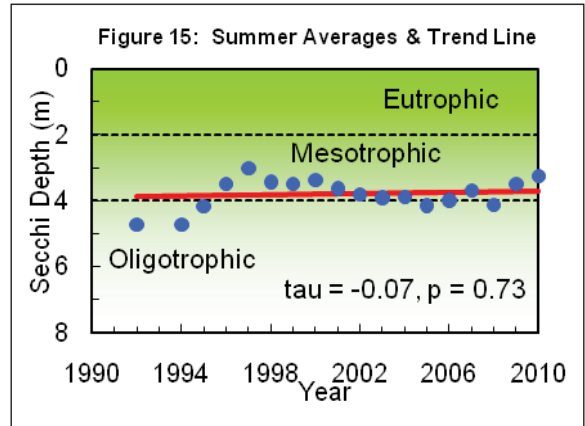


# LAKE CRABAPPLE EXPANDED MONITORING STUDY

## Water Clarity

Water clarity in Lake Crabapple is moderate, with a long-term summer average of 3.8 meters (Figure 15). Although there was a period between 1994 and 1997 when summer water clarity was steadily declining, in recent years the clarity has been relatively stable. Overall, from 1992 to 2010, there has been no significant statistical change in summertime water clarity in Lake Crabapple.

Water clarity values during the winter months (Nov to April) of 2005-2009 ranged between 4 and 6.5 meters, which is greater than water clarity during the summer (Figure 16). This mainly reflects the lower level of algae growth during the winter. However, just as in the summer, there are some periods with lower clarity in winter. This can likely be explained by increased particulate matter entering the lake via stormwater runoff during periods of high precipitation. However, it also may indicate higher levels of algae growth especially in the spring when there have been documented blooms of algae.



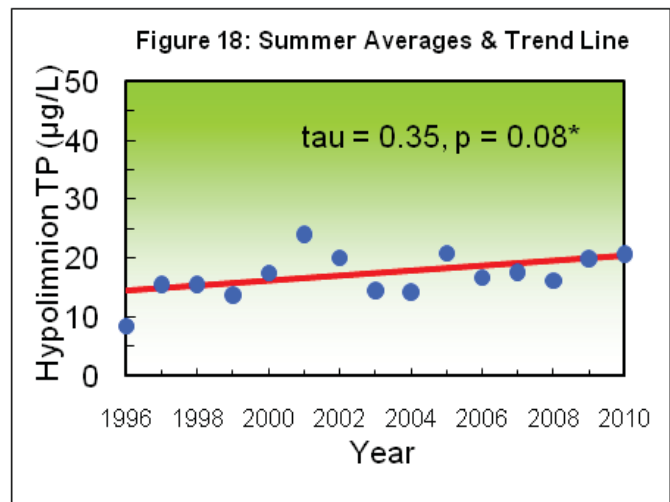
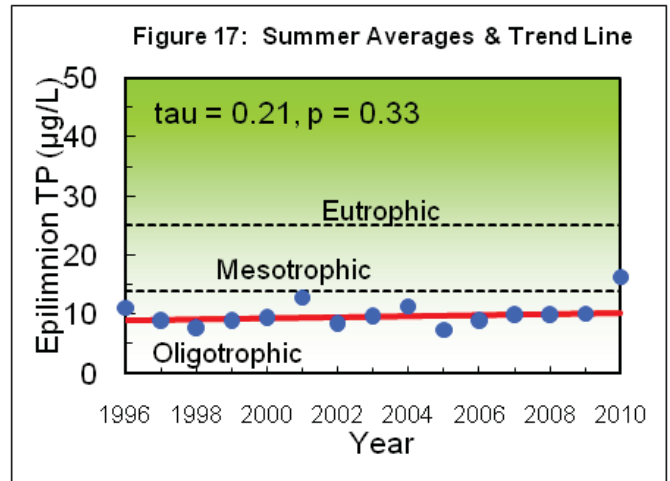
Total Phosphorus (key nutrient for algae)

Phosphorus is the main nutrient that feeds excess algae growth in lakes. It is also usually the nutrient in shortest supply, so the addition of a little phosphorus results in lots of algae growth. And, it does not take much phosphorus to impact a lake. The amount of phosphorus in lake water is measured in parts per billion or  $\mu\text{g/l}$ . High phosphorus levels can cause problems such as reduced water clarity, excessive plant and algae growth, or potentially toxic algae blooms.

Total phosphorus concentrations in Lake Crabapple are moderate to low (Figure 17). The long-term 1996-2010 summer average for the epilimnion (upper waters) is  $10 \mu\text{g/l}$ . There has been little variation year-to-year and no significant trends between 1996 and 2010. The 2010 average was the highest recorded.

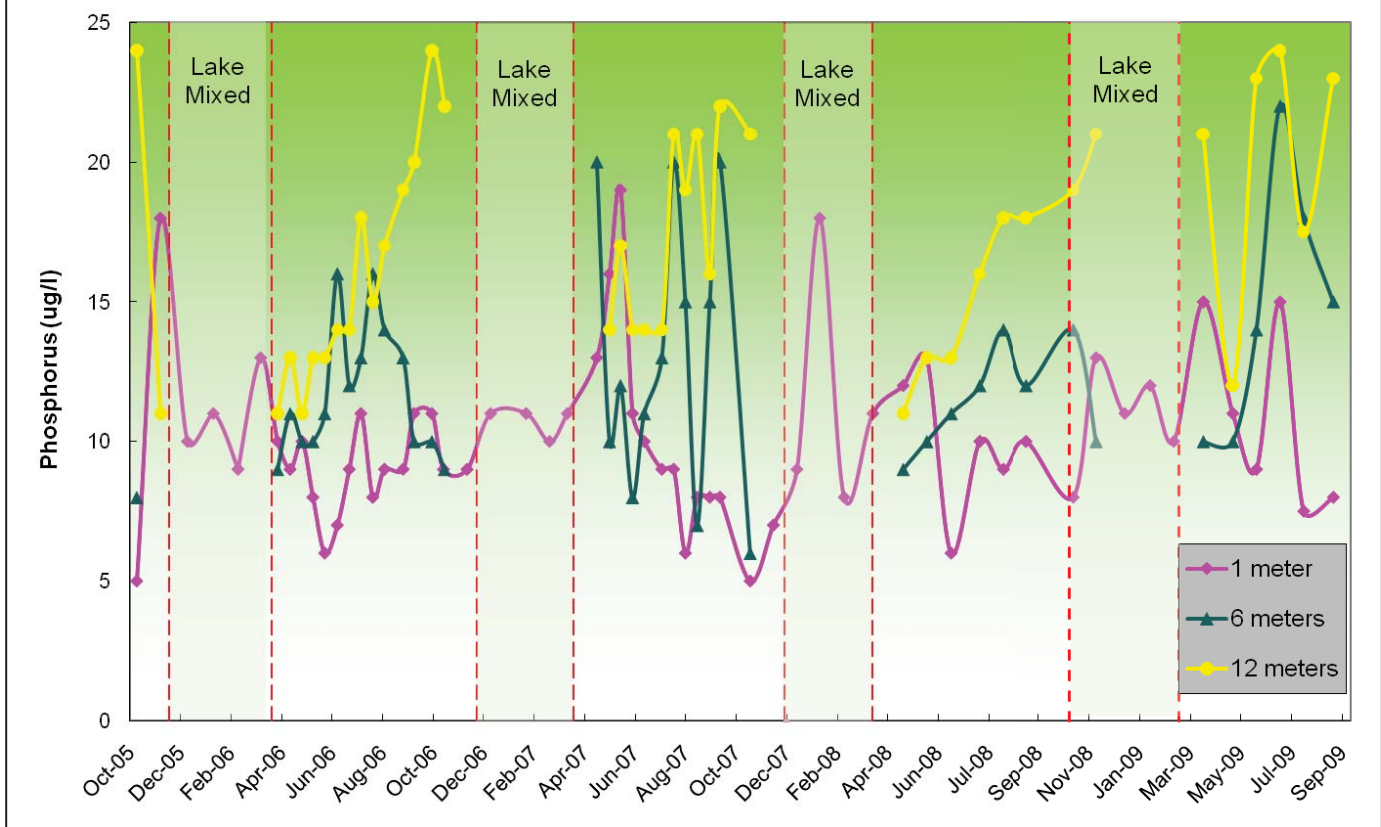
The long-term summertime phosphorus average in the hypolimnion (bottom waters) is  $17 \mu\text{g/l}$  (Figure 18). Phosphorus levels in the hypolimnion have been increasing since 1996. Between 1996 and 2010, there has been a statistically significant trend toward higher phosphorus. More phosphorus in the bottom waters may eventually lead to more algae growth in the lake.

Year round phosphorus concentrations for Lake Crabapple are shown in Figure 19 for the epilimnion, the metalimnion (the middle of the lake or 6 meter depth), and the hypolimnion. Overall phosphorus concentrations are lower in the winter than they are in the summer. During the summer, the concentrations vary by depth in the lake. The phosphorus levels in the bottom waters climb steadily throughout the summer peaking in September. Phosphorus concentrations in the upper waters are more variable throughout the summer, but are consistently lower than the hypolimnion. When lake mixing occurs, the hypolimnion concentration decreases and the epilimnion concentration increases as the built-up phosphorus is redistributed throughout the lake. The metalimnion (6 meter) values more closely align with the epilimnion values very early in the spring. As the summer progresses, they become closer to the hypolimnion values. By late summer, the warmer water extends down below 6 meters, so the 6-meter results again match the epilimnion values more closely.



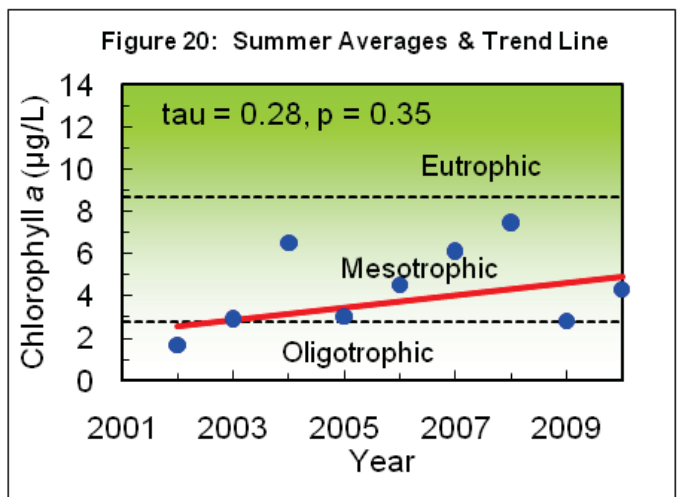
# Lake Crabapple Expanded Monitoring Study

**Figure 19: Lake Crabapple Total Phosphorus Throughout Water Column**  
October 2005 - September 2009



## Chlorophyll a (Algae)

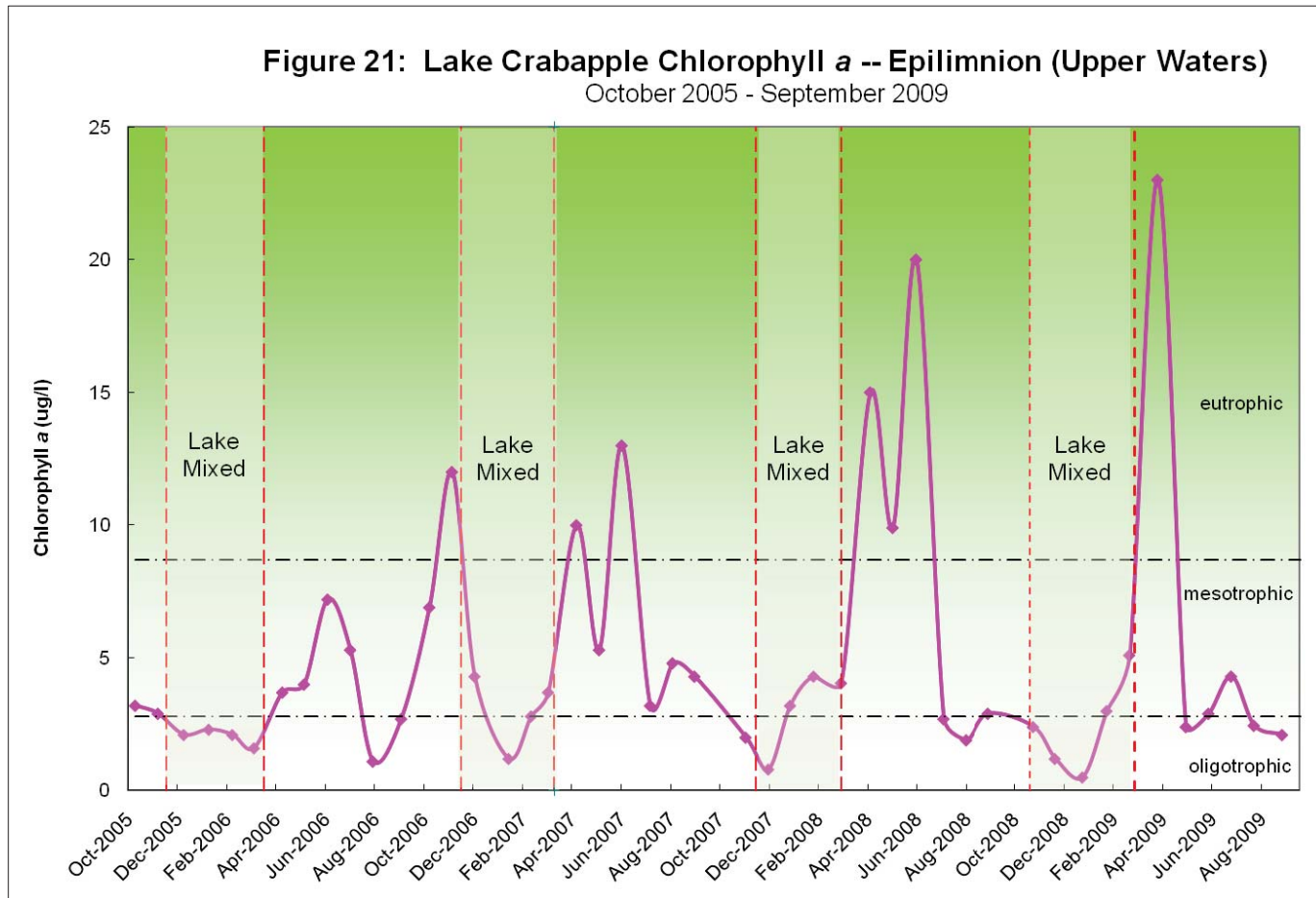
Chlorophyll *a* is a measure of the amount of algae in the lake water. Chlorophyll *a* values in Lake Crabapple showed moderate algae levels in the summers of 2003 - 2010 with a long-term average of 4.4 µg/l (Figure 20). However, there was a severe algae bloom in the lake in the spring of 2005 that turned the lake brown and drastically reduced water clarity. The bloom was *Uroglenopsis*, a type of golden-brown algae that was reported to be blooming at several other lakes in the region. A similar brown algae bloom occurred in the spring and early summer of 2008.



Chlorophyll *a* monitoring was conducted monthly year-round from Oct 2005 through September 2009 (Figure 21). The year-round monitoring showed spikes in algae growth each year. The pattern of spring

## Lake Crabapple Expanded Monitoring Study

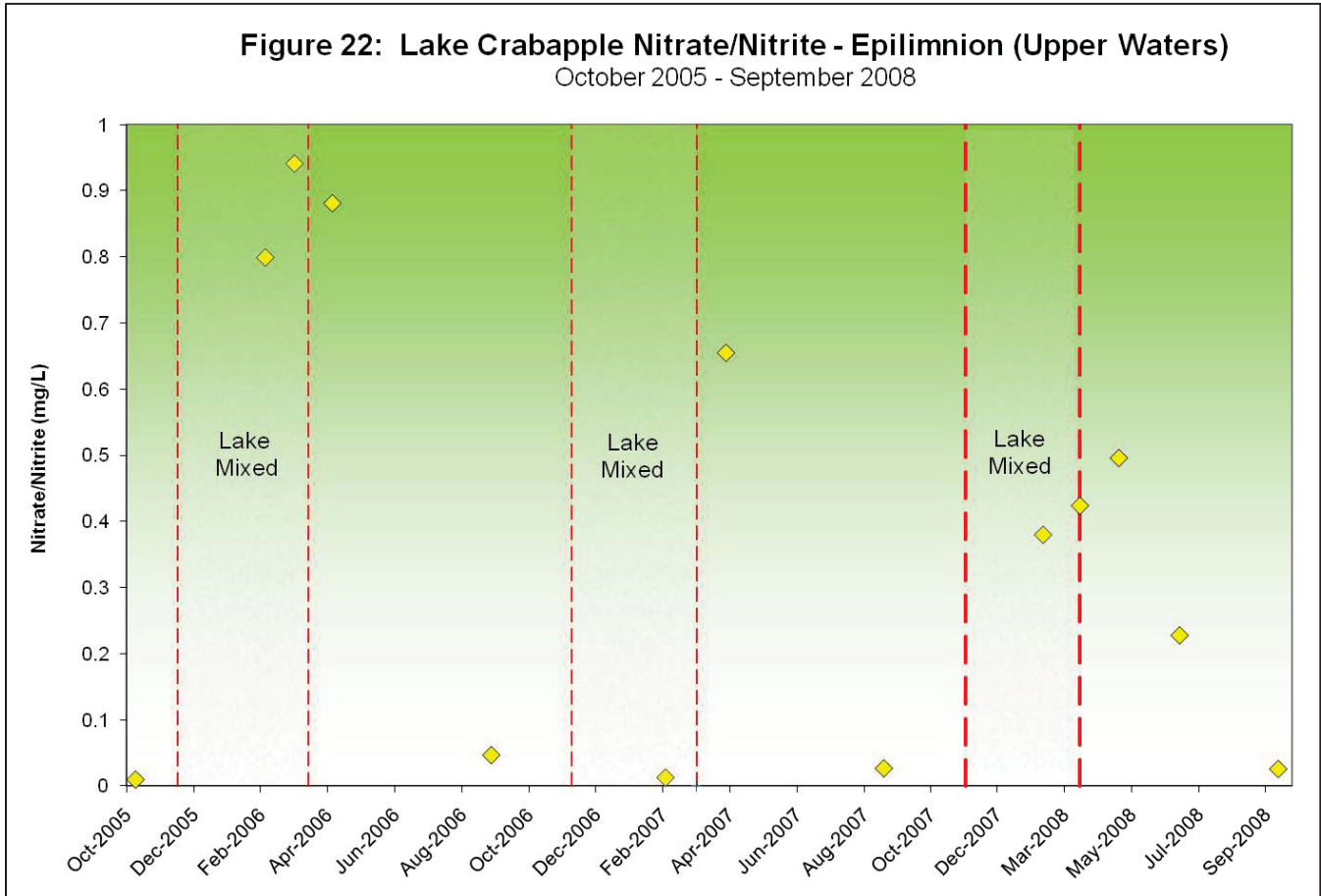
spikes in algae is likely from influxes of excess phosphorus washed into the lake via stormwater runoff during early spring rain events. In 2008, these algae blooms lasted into the summer. There was also a bloom in November 2006, likely in response to the nutrient rich bottom waters being mixed with the upper waters during lake turnover.



### Nitrogen

Nitrate is a form of nitrogen that is necessary and readily available for plant and algae growth. In 2005-2007, nitrate values averaged 421  $\mu\text{g/L}$  which is relatively high (Figure 22). However, the measurements were highly variable and ranged from 10 to 941  $\mu\text{g/L}$ . The lower values observed during October 2005 and September 2006 corresponded to high productivity as indicated by the chlorophyll *a* and Secchi data, indicating that algae growth was using up most of the available nitrogen. Overall, the nitrate/nitrite values confirm that there is plenty of nitrogen available for algae growth and that phosphorus is the nutrient limiting the productivity of the lake for most of the year.

# LAKE CRABAPPLE EXPANDED MONITORING STUDY

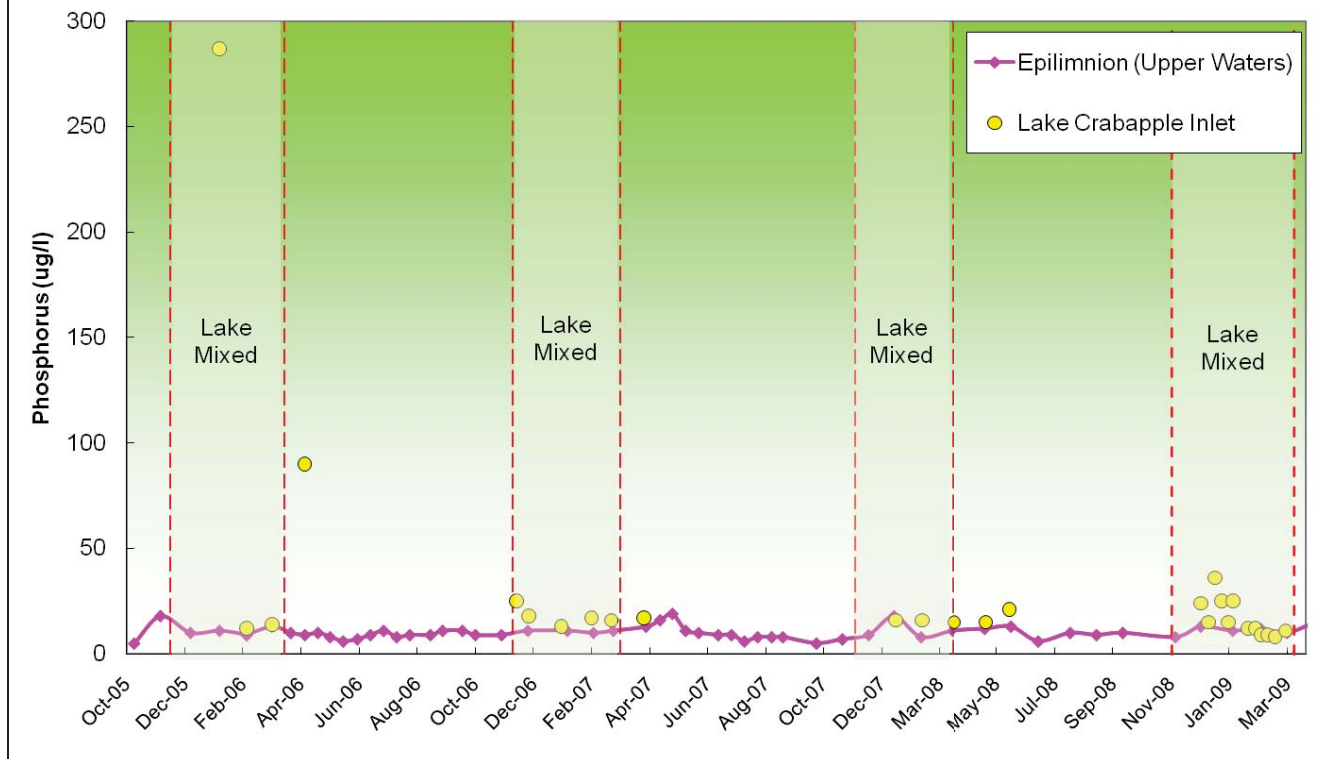


## Inflowing Nutrients

An unnamed seasonal stream from Lake Loma is the main surface flow that feeds Lake Crabapple. Phosphorus concentrations in the inlet were measured each winter from January 2006 through March 2009. Phosphorus concentrations in the inlet ranged from 12  $\mu\text{g/l}$  to 287  $\mu\text{g/l}$ , although most values were below 25  $\mu\text{g/l}$  (Figure 23). In January and April 2006, phosphorus concentrations spiked dramatically at 287  $\mu\text{g/l}$  and 90  $\mu\text{g/l}$  respectively. With the exception of the few peaks, phosphorus levels in the stream were similar to in-lake measurements. However, assuming that those two high values represented flows that lasted for a number of days, a large proportion of the phosphorus loading to the lake for that year may have come during those times of surface runoff.

# Lake Crabapple Expanded Monitoring Study

**Figure 23: Lake Crabapple Phosphorus -- Inlet and Epilimnion (Upper Waters)**  
October 2005 - March 2009



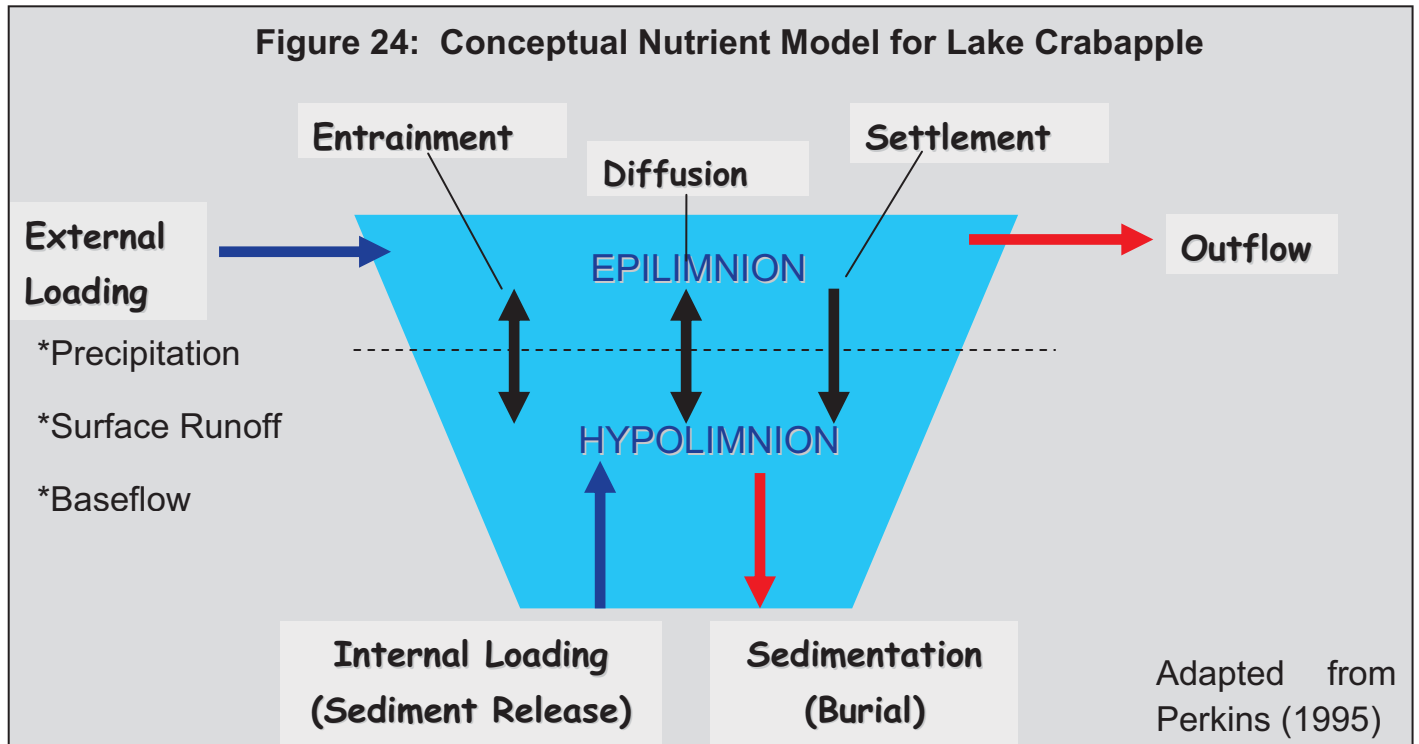
## NUTRIENT BUDGET

A nutrient budget is a model that accounts for all of the inflows and outflows of nutrients to the lake. More nutrients will result in higher algae and plant production. While lake monitoring provides an understanding of the changes in lake nutrients over time, a nutrient budget can clarify the sources of nutrients. The model can then be adapted to help predict the impacts of changes in the watershed on nutrients in the lake.

### Model Development

A nutrient budget, focused on the limiting nutrient phosphorus, was developed for Lake Crabapple for the 2005 through 2006 water year. The budget is based on a two layer mass balance model of the lake (Figure 24) originally used to examine Onondaga Lake in New York (Auer et al., 1997) and later adapted for Lake Sammamish, Washington (Perkins et al., 1997). In a mass balance model, all inputs of phosphorus into the lake minus all phosphorus outputs from the lake should equal the change in phosphorus concentration within the lake over the year. Additional guidance was provided for model development from work in Pine Lake, WA (City of Sammamish, 2006) and Cottage Lake, WA (Ecology, 2004).

## Lake Crabapple Expanded Monitoring Study



The external sources of phosphorus for Lake Crabapple include direct precipitation onto the lake surface, surface runoff directly into the lake and streams, and baseflow (shallow interflow and base stream flows). The internal loading source stems from phosphorus release from the sediments that occurs when the hypolimnion, or bottom waters, become devoid of oxygen in the summer months. Phosphorus can leave the lake directly via the outlet and through sedimentation (or burial) of phosphorus into the lake bottom. Phosphorus may also cycle between the upper and lower layers during the stratified period via the processes of diffusion and entrainment. Diffusion typically entails the movement of phosphorus from the nutrient rich hypolimnion to the less-rich epilimnion. Entrainment is the capture of phosphorus in the epilimnion from the nutrient rich bottom waters that occurs as the depth of lake stratification descends during the fall prior to lake mixing.

The external phosphorus contributors were determined based on the inputs of water from each source derived from the water budget and estimated or measured phosphorus concentrations for each source. The phosphorus concentration of precipitation was assigned a value of 17 ug/L based on previous measurements of phosphorus concentrations in rainwater conducted for Pine Lake in King County, WA (City of Sammamish, 2006). Baseflow concentrations were determined by the average of all measured stream inflow concentrations from 2005-2007 with the exception of the two elevated readings in January and April 2006. Finally, surface runoff was estimated by taking the two-year average of all inflow measurements, including the two elevated readings. The surface runoff values had a higher uncertainty than the other parameters because inlet water samples were not specifically taken during storm events when phosphorus concentrations would likely be elevated.

## Lake Crabapple Expanded Monitoring Study

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The internal processes of entrainment and diffusion were determined based on data from the temperature profiles of the lake as well as phosphorus concentrations in the upper and lower waters. The conceptual model used to estimate internal cycling was derived from the Pine Lake study (City of Sammamish, 2006 and the Cottage Lake TMDL (Ecology, 2004).

The amount of phosphorus released from the sediments could not be measured directly. Sediment release typically occurs when oxygen profiles indicate that the lower waters are anoxic (near zero oxygen), and is only expected to occur during the stratified period. The amount of sediment release is based on a sediment release rate (SRR) in kg/week. Previous sediment core studies have been performed to assess the approximate rate of sediment releases at other lakes (Auer et al, 1997, Perkins et. al., 1997). From these studies, an initial SRR and an acceptable range were assigned throughout the year.

Similarly, the amount of sedimentation of phosphorus buried in the lake bottom was not directly measured. To determine the sedimentation, a phosphorus settling rate (m/week) is multiplied by the surface area over which settling is occurring and the concentration of phosphorus in the water. Settling rates may vary seasonally and within layers (during the stratified period) depending on the type of phosphorus entering the lake (dissolved or particulate). The settling rate is expected to be lower when the phosphorus is in a dissolved state and not adhered to particles. For this model, an initial settling rate and appropriate range derived from previous studies were assigned to each of four periods throughout the year for the respective layers of water.

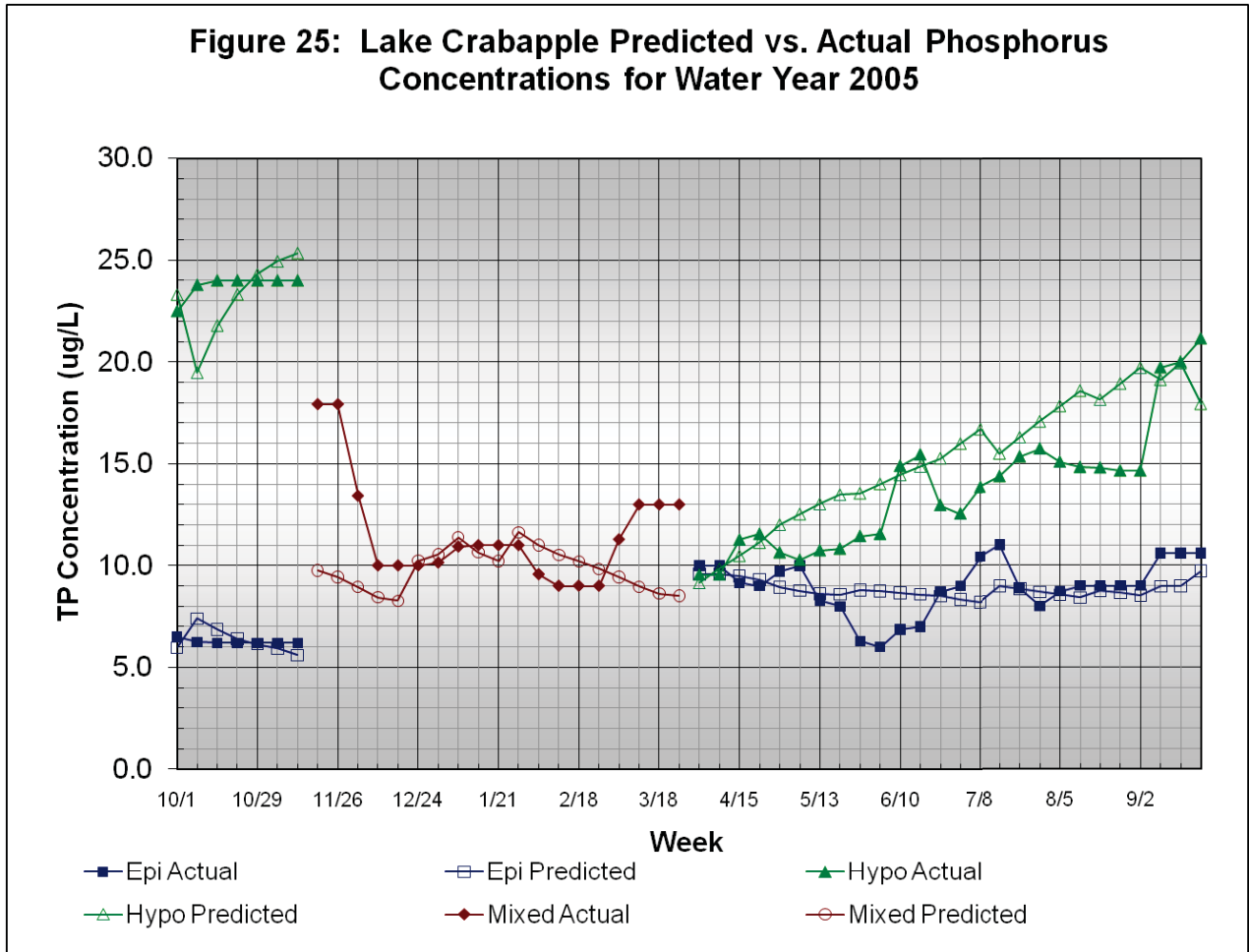
### Model Calibration

Once all of the inflows and outflows of phosphorus are accounted for, the model should predict a weekly phosphorus concentration in the upper and lower lake waters. The model-predicted phosphorus concentrations can then be compared to the measured concentrations in the lake to calibrate the model to improve its accuracy. The Lake Crabapple model was calibrated primarily by changing the three variables with the greatest uncertainty: the sediment release rate, the settling rate of the epilimnion during the stratified and the mixed periods, and the settling rate of the hypolimnion. A sensitivity analysis was conducted for each of the variables to determine their impact on the model. The range of the sensitivity analysis was constrained to previous study values. Each variable was adjusted and the results assessed by maximizing the Nash Sutcliffe Efficiency (NSE) coefficient (Nash and Sutcliffe, 1970). The NSE coefficient is an indicator of how closely the model is able to predict the observed data and can range from one to negative infinity. An NSE value of 1 would indicate that predicted values would exactly match the observed values with decreasing values indicating less predictive power.

The final model output (Figure 25) shows the model-predicted and the actual phosphorus concentrations in the epilimnion (Epi) and the hypolimnion (Hypo) during stratification and in the whole lake for the mixed period. The Lake Crabapple model achieved an overall NSE coefficient of

# Lake Crabapple Expanded Monitoring Study

0.77. The model was most effective at predicting the changes in phosphorus concentration in the hypolimnion and the epilimnion during the stratified period. The predicted value for the average summer epilimnion concentration was 8.7 compared to an actual concentration of 8.8  $\mu\text{g/l}$ . The predicted hypolimnion value was 16.3  $\mu\text{g/l}$  compared to the measured 14.5  $\mu\text{g/l}$ . The model did not perform as well during the mixed period, particularly during the weeks just after and just before lake stratification (Figure 25). The predicted whole-lake winter concentration was 9.8  $\mu\text{g/l}$  compared to the measured value of 11.6  $\mu\text{g/l}$ . The larger discrepancy in concentrations near the beginning and the end of the mixed period can, in part, be explained by the uncertainty of the concentration of surface runoff and the timing of stratification. Overall, the model is also not as sensitive in showing the minor fluctuations in phosphorus concentrations throughout the summer in the upper waters. However, the model does provide a reasonable overall picture of the trends in each layer over the entire modeling period. Furthermore, it will help to assess any changes in the average summer concentrations of the epilimnion and hypolimnion with changes in the lake watershed.

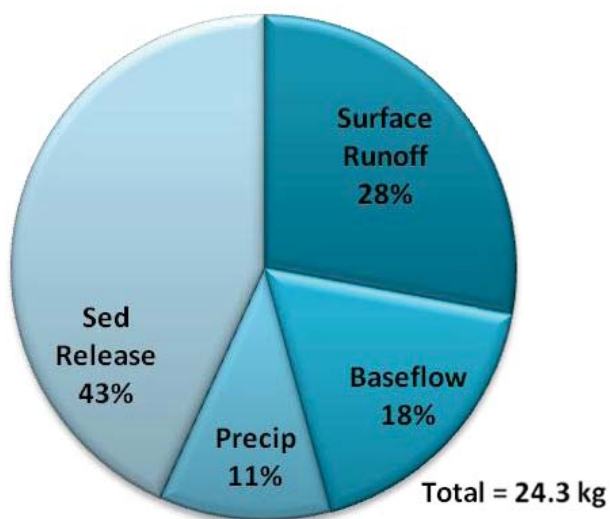


# Lake Crabapple Expanded Monitoring Study

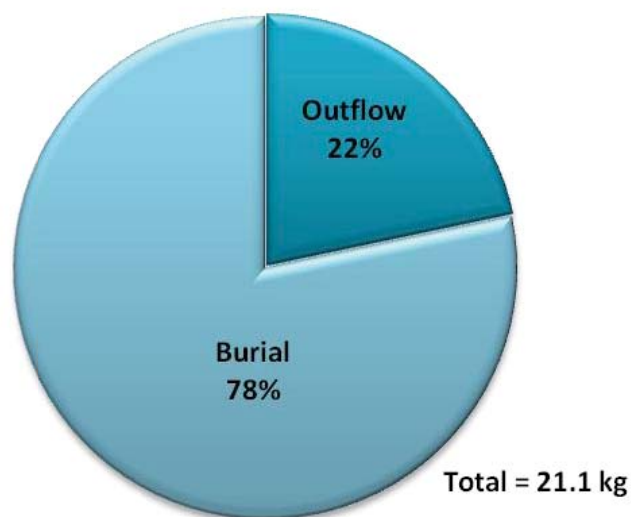
## Nutrient Budget Results

The 2005-2006 water year results reveal that internal loading is the primary sources of phosphorus to Lake Crabapple, accounting for 43% (10.5 kg) of all inputs (Figure 26). Surface water runoff (6.8 kg/year or 28%) and baseflow (18%, 4.3 kg/year) are the next highest contributors. Precipitation accounts for the remaining 11% (2.7 kg) of annual phosphorus inputs. Phosphorus was removed from the water column primarily via sedimentation (burial), which accounted for 16.5 kg (78%) (Figure 27). The remaining phosphorus was lost through direct outflow (4.6 kg, 18%). Over the course of the water year, there was also a net increase in phosphorus in the lake of 3.2 kg.

**Figure 26: Lake Crabapple  
Nutrient Inputs**



**Figure 27: Lake Crabapple  
Nutrient Outputs**



The first important finding from the model is that internal loading is a significant contributor of phosphorus into the system. Internal loading is the result of a build-up of phosphorus in the lake sediments over time, which is then released back into the water under low oxygen conditions. Internal loading can be particularly problematic because, with increased external inputs, a positive feedback loop is created. Higher amounts of phosphorus coming into the lake and settling to the bottom lead to higher levels of nutrients being available for internal loading. At this time, Lake Crabapple still has relatively good water quality, even with a large proportion of internal loading. However, between 1996 and 2010, there has been a statistically significant trend toward higher phosphorus levels in the bottom waters, so more sediment release may be expected in the future. Fortunately, the strong stratification helps to protect the water quality of the lake because the phosphorus released during the summer months primarily stays in the hypolimnion. However, the lake is susceptible to high whole-lake phosphorus concentrations in the fall when the lake mixes. More fall and winter algae blooms

## Lake Crabapple Expanded Monitoring Study

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may be the result of long-term increases in internal loading. Once internal loading becomes problematic, it is difficult to control without costly lake treatments.

The second important finding is that surface runoff contributions are the next highest contributor of phosphorus to the lake. The runoff concentrations relate directly to the land uses and the types of activities being conducted in the watershed. The watershed of Lake Crabapple is still mostly undeveloped, with much of the forest area still intact. The runoff concentrations in the watershed are relatively low compared to similar lakes with more developed watersheds in the County. However, if poor land owner practices and substantial new development occur, this will create more surface runoff and more nutrient sources and may lead to increases of nutrients reaching the lake that can cause excess algae and accelerated eutrophication.

### **MODELING FUTURE WATERSHED LAND USE CHANGE SCENARIOS**

The nutrient model developed for Lake Crabapple can serve as a valuable tool to assess the impacts of increases in watershed development on nutrient (phosphorus) loading to the lake. High phosphorus levels can cause problems such as reduced water clarity, excessive plant and algae growth, impaired aquatic habitat, and potentially toxic algae blooms. The Lake Crabapple watershed is still largely undeveloped, with 80% of the watershed consisting of forest, grasslands, or low density residential. The low level of development is one of the factors that have helped Lake Crabapple maintain good water quality. However, an increase in development in the watershed has a high potential to negatively impact the water quality of the lake because nutrient loading typically increases with development.

Increased development has a two-fold impact on nutrient inputs into the lake that must be accounted for when modeling development scenarios. First, the amount of water entering the lake through stormwater runoff will increase with development unless aggressive measures are taken to limit runoff. Additional buildings, driveways, and roads increase the total amount of impervious surfaces in the watershed, thereby decreasing the amount of water that can infiltrate into soils. There usually is an increase in runoff (typically higher in nutrients) and a corresponding decrease in baseflow (typically lower in nutrients) after development occurs.

Second, increased development is typically associated with increases in the primary sources of nutrients that can potentially flow into the lake via runoff. The major sources of external nutrients to the lake include fertilizers, pet and animal wastes, runoff from roofs and driveways, erosion from construction and land clearing, and poorly maintained septic systems. All of these sources will increase with increased development in the absence of additional stormwater controls.

# Lake Crabapple Expanded Monitoring Study

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## *Modeling Assumptions*

The model could be used in the future to identify the potential impacts of a specific proposed development, assuming the development is relatively large. In the absence of such a proposal, a series of scenarios were developed to assess a general increase in watershed development. Depending on the level of stormwater controls implemented during development activities (such as detention ponds, rain gardens, etc.), there may be different impacts on the level of phosphorus in the runoff. In addition, actions of current and future landowners in the watershed can influence runoff concentrations. The following section describes the modeling assumptions made for each of the scenarios.

## *Land Use Change Scenarios*

To show the full spectrum of potential land use changes, three development scenarios were entered into the model showing development increases of 10%, 30% and 50% over current land uses. "Development" was defined as the conversion of forests, grasslands, or low density residential housing (parcels between 0.5 and 5 acres) to medium density residential development (parcels between 0.15 and 0.5 acres). The overall increase in development was applied equally across all existing land use/soil type combinations, except for land already in medium to high density residential development. A small portion (6%) of the total land converted under each of these scenarios was assumed to be converted to infrastructure (streets, roads, ditches).

## *Runoff TP Concentration Conditions*

Four different phosphorus concentration conditions that could be associated with any of the levels of new development were selected to illustrate the potential impacts of increased development on runoff and baseflow phosphorus concentrations (Table 1). Well-planned development that serves to slow or reduce stormwater runoff will result in the lowest phosphorus runoff concentrations. Traditional development with low or no stormwater controls will result in higher conditions of phosphorus concentrations. To determine the potential future conditions, the model uses runoff phosphorus concentrations from Crystal Lake, which has been monitored for inlet flow during the 2007-2008 water year. Crystal Lake's watershed is similar to Lake Crabapple, as there are significant tracts of forested land and a protected lake system. However, Crystal Lake has a higher degree of residential and commercial development in its watershed. Furthermore, Crystal Lake has a mid-range of runoff values when compared to known historical data at other Snohomish County lakes, including Blackmans Lake, Martha Lake, Lake Stevens, and Lake Roesiger. On average Crystal Lake's inlet concentrations taken during the 2007-2008 water year were 32 µg/l during baseflow and 93 µg/l during stormwater runoff. Using these averages, four conditions were established, with Crystal Lake's current runoff concentrations set as a mid-condition value or "Condition 2" (Table 1). Condition 1 was set at 25% below the existing Crystal Lake runoff, and Conditions 3 and 4 represent a 25% and 55% increase over Crystal Lake runoff.

# Lake Crabapple Expanded Monitoring Study

**TABLE 1: STORMWATER RUNOFF PHOSPHORUS CONCENTRATION CONDITIONS**

Runoff Nutrient Conditions	Stormwater Runoff Controls	Baseflow Phosphorus Concentration (ug/l)	Runoff Phosphorus Concentration (ug/l)
2006-07 Crabapple	NA	16.5	50.9
Future Condition 1	High	24.0	69.8
Future Condition 2	Moderate	32.0	93.0
Future Condition 3	Low	40	116.3
Future Condition 4	None	49.6	144.5

### *Short Term Land Use Change Impacts*

The Lake Crabapple nutrient model was then run multiple times using the various land use scenarios and the future runoff concentration conditions. Table 2 shows the results of the modeling runs, with the amounts of nutrients coming from various sources and the predicted phosphorus concentrations in the epilimnion (upper waters) and hypolimnion (bottom waters). The average in-lake phosphorus concentrations measured in 2009-2010 were used as the starting point for the model runs because phosphorus levels were somewhat higher than during the 2005-2006 base year. In other words, the lake is already showing evidence of more nutrient inputs.

As expected, the model runs show that each incremental increase in land use change or higher runoff nutrient condition leads to successively higher phosphorus loads entering the lake and subsequently higher phosphorus concentrations in the epilimnion and hypolimnion of the lake (Table 2). In general, it appears that increases in nutrient loading are more pronounced with changes in nutrient runoff conditions as compared to increases in development percentage alone. For example, a 50% increase in land development with a Nutrient Condition 1 leads to a 3 µg/l increase in the summer epilimnion phosphorus concentration and a 5 µg/l increase in hypolimnion phosphorus. However, a 10% increase in development with Nutrient Condition 4 leads to a 10 µg/l increase in the epilimnion and a 17 µg/l increase in the hypolimnion. The more realistic future combinations would be a lower level of development being paired with a lower nutrient condition and higher levels of development being paired with higher nutrient conditions. For example, a 30% increase in watershed development under

## Lake Crabapple Expanded Monitoring Study

Nutrient Condition 2 would lead to an increase of 5 µg/l in the epilimnion and an increase of 8 µg/l in the hypolimnion.

**TABLE 2: NUTRIENT LOADING AND RESULTANT PHOSPHORUS CONCENTRATIONS FOR DEVELOPMENT SCENARIOS**

Development Scenerios with Ranges of Inflowing TP Concentrations							
	Nutrient Range	Runoff Loading (kg)	Baseflow Loading (kg)	Internal Loading (kg)	Total Inputs (kg)	Epi TP Conc. (ug/l)	Hypo TP Conc. (ug/l)
0%	Current	6.8	4.3	10.5	24.2	9	16
10%	1	9.7	2.7	10.5	29.1	9	17
	2	12.9	8.3	10.5	34.4	14	24
	3	16.2	10.4	10.5	39.7	16	28
	4	20.0	12.9	10.5	46.1	19	33
30%	1	10.6	6.2	10.5	29.9	11	21
	2	14.2	8.2	10.5	35.5	14	24
	3	17.7	10.3	10.5	41.1	17	29
	4	21.9	12.7	10.5	47.8	20	34
50%	1	11.7	6.1	10.5	30.9	12	21
	2	15.6	8.1	10.5	36.8	15	26
	3	19.5	10.1	10.5	42.8	17	30
	4	24.1	12.6	10.5	49.9	21	35

\*Current conditions were set to the in-lake phosphorus concentrations measured in 2009 and 2010

To put the modeling results in context, the resultant phosphorus concentrations can be looked at in terms of the trophic status of the lake. As discussed previously, Lake Crabapple’s current phosphorus concentrations in the epilimnion are considered to be in the low or oligotrophic range. Concentrations from 14 to 25 µg/l are considered mid-range, or mesotrophic. Lakes with high levels of nutrients (exceeding 25 ug/l) are considered eutrophic and typically have low water clarity and high levels of aquatic plant and algae growth. Although some lakes are naturally in the eutrophic range, it is abnormal to see lakes rapidly change from one trophic state to the next.

Under development scenarios where a high degree of stormwater controls are implemented (Nutrient Conditions 1 or 2), the epilimnion concentrations at Lake Crabapple continue to be in the oligotrophic range (Table 2). However with fewer stormwater controls, the epilimnion concentrations begin to exceed 14 µg/l and would largely be in the mesotrophic range. In the poorly managed runoff scenarios, the epilimnion concentrations begin to exceed 20 µg/l. Lakes that have epilimnion TP concentrations exceeding 20 µg/l are considered to be impaired and may be included in the

## Lake Crabapple Expanded Monitoring Study

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Washington State list of impaired waterbodies known as the 303d list (WAC 173-201A-230). “Impaired” means that the phosphorus concentrations are high enough to affect beneficial uses of the waterbody.

Any near-term impacts from increases in phosphorus on lake recreation will likely be most visible at Lake Crabapple in the spring and fall. The lake already exhibits frequent spring algae blooms that correspond with the input of nutrients during periods of high runoff. These blooms would likely be more common and persistent if runoff increases in quantity and nutrient concentration. Lake Crabapple, however, does have the benefit of strong summer stratification. This means that the higher concentrations in the hypolimnion, in particular, will be sequestered during the summer months and be largely unavailable for algae growth. However, at lake turnover in the fall, the higher levels of nutrients in the hypolimnion will become available and will also likely lead to more common winter and spring blooms.

### *Long-Term Land Use Change Impacts*

The Lake Crabapple model provides a conservative estimate of the nutrient changes with higher levels of development. That means that the model is only designed to show the short-term impact of nutrient loading on the lake from external nutrients. The internal loading in this model is held at a constant (Table 2). It does not take into account the increased build-up of phosphorus in the lake bottom over a period of years that would result from higher nutrient concentrations in the lake. In a real world scenario, as the amount of phosphorus in the lake sediments increases over time, the internal loading each year would also likely increase. Through the years, this increasing internal loading would also lead to even higher concentrations in the epilimnion. These findings underscore the importance of having phosphorus control methods in place as development occurs around Lake Crabapple.

## **LAKE CRABAPPLE MANAGEMENT RECOMMENDATIONS**

Overall, Lake Crabapple can currently be classified as mesotrophic, with moderate water clarity, relatively low phosphorus concentrations, and low to moderate productivity of plants and algae. The nutrient model shows that internal loading of phosphorus is the primary contributor to phosphorus concentrations in the lake. At the time of the original expanded monitoring project, there were no trends in water clarity or in total phosphorus levels. This means that the lake is meeting the water quality targets set forth in the 2003 State of the Lakes Report to maintain stable water clarity and total phosphorus levels in the epilimnion. However, as of 2010, there is now a trend towards increasing phosphorus in the hypolimnion at Lake Crabapple. Furthermore, the nutrient model shows that the lake is at risk of future water quality declines if changes in the watershed increase surface runoff and nutrient inputs.

## Lake Crabapple Expanded Monitoring Study

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In order to protect the condition of the lake, measures to control nutrients in the watershed should be taken. As the model shows, the lake can remain in its current state if future development is designed with effective stormwater controls that limit nutrient runoff. It is also critical that current and future residents take actions on their properties to minimize nutrient runoff into the lake. A few simple actions can help protect the lake:

- ✓ Keep (or plant) a buffer of native plants adjacent to the lake – or let vegetation grow longer.
- ✓ Avoid the use of fertilizers at all near the lake. If needed, use phosphorus-free fertilizers for your lawn and slow release organic fertilizers for vegetable and flower gardens.
- ✓ Pick up pet waste, bag it and throw it in the trash.
- ✓ Maintain septic systems by inspecting every 1-3 years and pump them as needed.
- ✓ Pipe runoff from roofs, driveways, and porches into your yard away from the lake. Do not pipe them directly into the lake (or into the septic drainfield).
- ✓ Prevent soil from eroding and running into the lake during landscaping or construction projects.

To find out more about the causes and problems of elevated lake nutrient levels and tips to improve lake water quality visit [www.lakes.surfacewater.info](http://www.lakes.surfacewater.info).

## LAKE CRABAPPLE EXPANDED MONITORING STUDY

DATA SUMMARY FOR LAKE CRABAPPLE					
Source	Date	Water Clarity (Secchi depth in meters)	Total Phosphorus (ug/l)		Chlorophyll a (ug/l)
			Surface	Bottom	Epilimnion
McConnell, et al, 1976	Summer 1973	2.3 - 5.5 (3.6) n = 3	10 - 18 (14) n = 3	14 - 15 (15) n = 3	1.4 - 2.0 (1.7) n = 3
Entranco, 1986	1983	2.9 - 4.4 (3.7) n = 4	<5 - 7 (6) n = 5	8 - 33 (15) n = 5	1.8 - 4.6 (3.1) n = 5
Volunteer	1992	4.6 - 4.9 (4.7) n = 2	-	-	-
SWM Staff or Volunteer	1994	3.8 - 6.0 (4.7) n = 12	-	-	1.8 - 3.8 (2.8) n = 2
SWM Staff or Volunteer	1995	3.3 - 5.0 (4.2) n = 9	-	-	8.1
Volunteer	1996	2.7 - 4.1 (3.5) n = 10	9 - 13 (11) n = 2	8 - 9 (9) n = 2	-
SWM Staff or Volunteer	1997	2.5 - 3.5 (3.0) n = 9	6 - 12 (9) n = 2	14 - 17 (16) n = 2	-
Volunteer	1998	3.0 - 4.5 (3.4) n = 10	6 - 10 (8) n = 4	15 - 16 (16) n = 4	-
Volunteer	1999	2.7 - 4.0 (3.5) n = 10	8 - 11 (9) n = 4	12 - 16 (14) n = 4	-
SWM Staff or Volunteer	2000	2.8 - 4.1 (3.4) n = 10	7 - 12 (10) n = 4	16 - 19 (18) n = 4	-
SWM Staff or Volunteer	2001	2.6 - 4.8 (3.6) n = 10	12 - 14 (13) n = 4	18 - 29 (24) n = 4	
SWM Staff or Volunteer	2002	2.6 - 5.0 (3.8) n = 10	7 - 11 (9) n = 4	15 - 29 (20) n = 4	1.1 - 2.7 (1.7) n = 4
SWM Staff or Volunteer	2003	2.6 - 5.5 (3.9) n = 13	7 - 12 (10) n = 4	14 - 15 (15) n = 4	1.6 - 6.4 (2.9) n = 4
SWM Staff or Volunteer	2004	1.8 - 5.4 (3.9) n = 12	6 - 19 (11) n = 4	13 - 16 (14) n = 4	1.1 - 21 (6.5) n = 4
SWM Staff or Volunteer	2005	2.4 - 4.9 (4.1) n = 12	5 - 10 (7) n = 5	14 - 33 (21) n = 5	2.1 - 4.8 (3.0) n = 5
SWM Staff or Volunteer	2006	2.8 - 5.0 (4.0) n = 12	6 - 11 (9) n = 12	11 - 24 (17) n = 12	1.1 - 7.2 (4.5) n = 6
SWM Staff or Volunteer	2007	2.7 - 4.9 (3.7) n = 12	5 - 19 (10) n = 11	14 - 22 (18) n = 11	3.2 - 13 (6.1) n = 5

## Lake Crabapple Expanded Monitoring Study

DATA SUMMARY FOR LAKE CRABAPPLE					
Source	Date	Water Clarity (Secchi depth in meters)	Total Phosphorus (ug/l)		Chlorophyll a (ug/l)
			Surface	Bottom	Epilimnion
Volunteer	<b>2008</b>	2.9 - 5.3 (4.1) <i>n</i> = 12	6 - 13 (10) <i>n</i> = 6	13 - 19 (16) <i>n</i> = 6	1.9 - 20 (7.5) <i>n</i> = 5
SWM Staff or Volunteer	<b>2009</b>	3.1 - 4.4 (3.5) <i>n</i> = 10	8 - 15 (10) <i>n</i> = 5	12 - 24 (20) <i>n</i> = 5	2.1 - 4.3 (2.8) <i>n</i> = 5
SWM Staff or Volunteer	<b>2010</b>	2.4 - 3.9 (3.2) <i>n</i> = 11	7 - 35 (16) <i>n</i> = 4	19 - 24 (21) <i>n</i> = 3	2.4 - 5.9 (4.3) <i>n</i> = 4
<b>Long Term Avg</b>		<b>3.8</b> (1992-2010)	<b>10</b> (1996-2010)	<b>17</b> (1996-2010)	<b>4.4</b> (2002-2010)
<b>TRENDS</b>		<b>None</b>	<b>None</b>	<b>Increasing</b>	<b>None</b>

### NOTES

- Table includes summer (May-Oct) data only.
- Each box shows the range on top, followed by summer average in ( ) and number of samples (*n*).
- Total phosphorus data are from samples taken at discrete depths only.
- "Surface" samples are from 1 meter depth and "bottom" samples are from 1-2 meters above the bottom.

## LAKE CRABAPPLE EXPANDED MONITORING STUDY

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