Introduction
Algae blooms can happen in lakes dependent on a number of factors being favorable for them to occur. These include nutrients, temperature, sunlight, water flow/movement, and water chemistry (oxygen, pH, conductivity, etc..). When all of these are right, a bloom can happen. As lake residents we all know this is the case and typically we see a bloom in the spring and again in the fall. Whether they are toxic or not is another topic, and for now let's just focus on the algae bloom occurrences.

The primary nutrients of concern are phosphorous and nitrogen, with phosphorous typically the one the runs out first in the bloom, with nitrogen left over. This is called a phosphorous-limited reaction. Once the phosphorous is used up, the bloom stops. Phosphorous and nitrogen enters the lake from the basalt rock it sits on, sediment at the bottom of the lake, atmospheric dust, lawn/garden fertilizer, geese, forestry fertilizer, rain driven run-off, and failing septic systems. Generally, Summit Lake has very low nutrient levels but not always. More on this later.

The water temperature and sunlight levels are better for blooms from later spring, through summer, into early fall.

Interestingly still water is also a contributor to the blooms, so please don't complain about the wind, especially in the spring and fall, it stirs up the lake water and limits the blooms. Maybe we should install some giant fans at the Boy Scout camp. ☺

A couple of definitions before we get into the science of it all…

Definitions
ppb – parts per billion, similar to micrograms per liter (µg/L). There are one billion micrograms of water in a liter, so for example if there are 12 parts of phosphate in a billion parts of water, its 12 ppb or 12 µg/L. (*ppm* is parts per million, similar descriptions, a ppm is 1000X a ppb))

Trophic state – a classification system which rates bodies of water on purity, clarity, and amount of biological activity. For our purposes of controlling the trophic state we are most interested in the phosphate levels. See Table 1 below for specifics.

Lake Trophic Class	Phosphate levels (ppb)	Description
Oligotrophic	0-12	Having the least amount of biological productivity, "good" water quality. Low algal production, and consequently, often have very clear waters, with high drinking-water quality.
Mesotrophic	12-24	Having a moderate level of biological activity, "fair" water quality. Commonly clear water lakes and ponds with beds of submerged aquatic plants and medium levels of nutrients.
Eutrophic	24-96	Having a high amount of biological activity, "poor" water quality. High biological productivity. Due to excessive nutrients, especially nitrogen and phosphorus, these water bodies are able to support an abundance of aquatic plants.
Hypereutrophic	96 and up	Having the highest amount of biological activity, "poor" water quality. Frequent and severe nuisance algal blooms and low transparency
Source: Wikipedia – Trophic state index		

Table 1) Lake Trophic Classes and associated phosphate levels

Lake Physics

Warm water rises, cold water sinks. So, particularly in the fall, the lake "turns over" when these temperatures change. The lake is fairly cool in the early summer as anyone who swims before the 4th of July will agree to. As the sun warms the surface of the lake through our lovely summers the swimming gets better, but the deep water stays cool. The warmer water at the top stays at the top and the cold water stays low. The lake stratifies.

Look at Figure 1. The county has some reasonable data on water info vs depth, but sadly just May through October, we really would like to see the yearly picture to better and fully understand the phenomena. Figure 1 can be a bit overwhelming, so let's walk through it. Six graphs, each one a month; May thru October. The Y axis (or vertical axis) on each graph is depth. The top of the graph is the top of the lake and going lower in the graph is heading towards the lake bottom. There are four parameters on each graph; Temperature, pH, DO (dissolved oxygen), and conductivity. For our review, we can ignore pH and conductivity. So focus on the red squares (temperature) and the blue circles (dissolved oxygen). Their values are along the top X axis (or horizontal axis). To the right is warmer and more oxygen, to the left is colder and less oxygen.

Now look just at May… the water temperature at the top of the lake is about 15C or 59F. The red squares show it gets colder as it gets deeper down to about 7C or 45F. The dissolved oxygen (DO) shows the lake surface is at about 11 ppm and the bottom about 8 ppm. These top and bottom values, being similar, show the lake is fairly well mixed, top to bottom.

Now look at the temperature (red squares) in each of the 6 months. The bottom stays consistently around 7C or 45F. The surface warms each month all the way up to 21C (70F) in August and then cools off to 16C (61F) by October. No surprises there. What is very interesting is to look at the DO levels (blue circles). You can see that at the bottom, the DO levels are dropping as the summer goes on. The lake is NOT mixing top to bottom and the oxygen down low is getting used up. The lake is stratifying. Now look again at the temperatures, particularly the shape of the red curves between August and October. By September you can see a very sharp change at about 12 meters. That's the thermocline. There are two very different bodies of water, above and below this level. This is where the lake has stratified.

Unfortunately, the counties data is very limited and we don't have the rest of the year. But we know can make some suggestions at what November's graph would look like. It will be much more like May's, with reasonably consistent values at all depths. Why? Because sometime around mid-October as the weather cools the top of the lake it becomes cool enough that the cooler water goes to the bottom and the lake bottom water goes to the top. The lake experiences a "turn-over". This event mixes everything and is what triggers the fall bloom.

None of this is abnormal or bad, and occurs in all deep lakes, but an understanding of this is important to understand the Summit Lake phosphorous cycle which is discussed later.

Something similar happens in the spring, but sadly we don't have any data to help paint the picture. We might expect some turnover in the transition to spring, as the winter has cooled the water enough to cause its buoyancy to again stir the pot. Unfortunately, the county has no resources to increase their monitoring plans.

Note that the other years data is similar to that shown here for 2011, this data set chosen as it was good for walking thru the discussion.

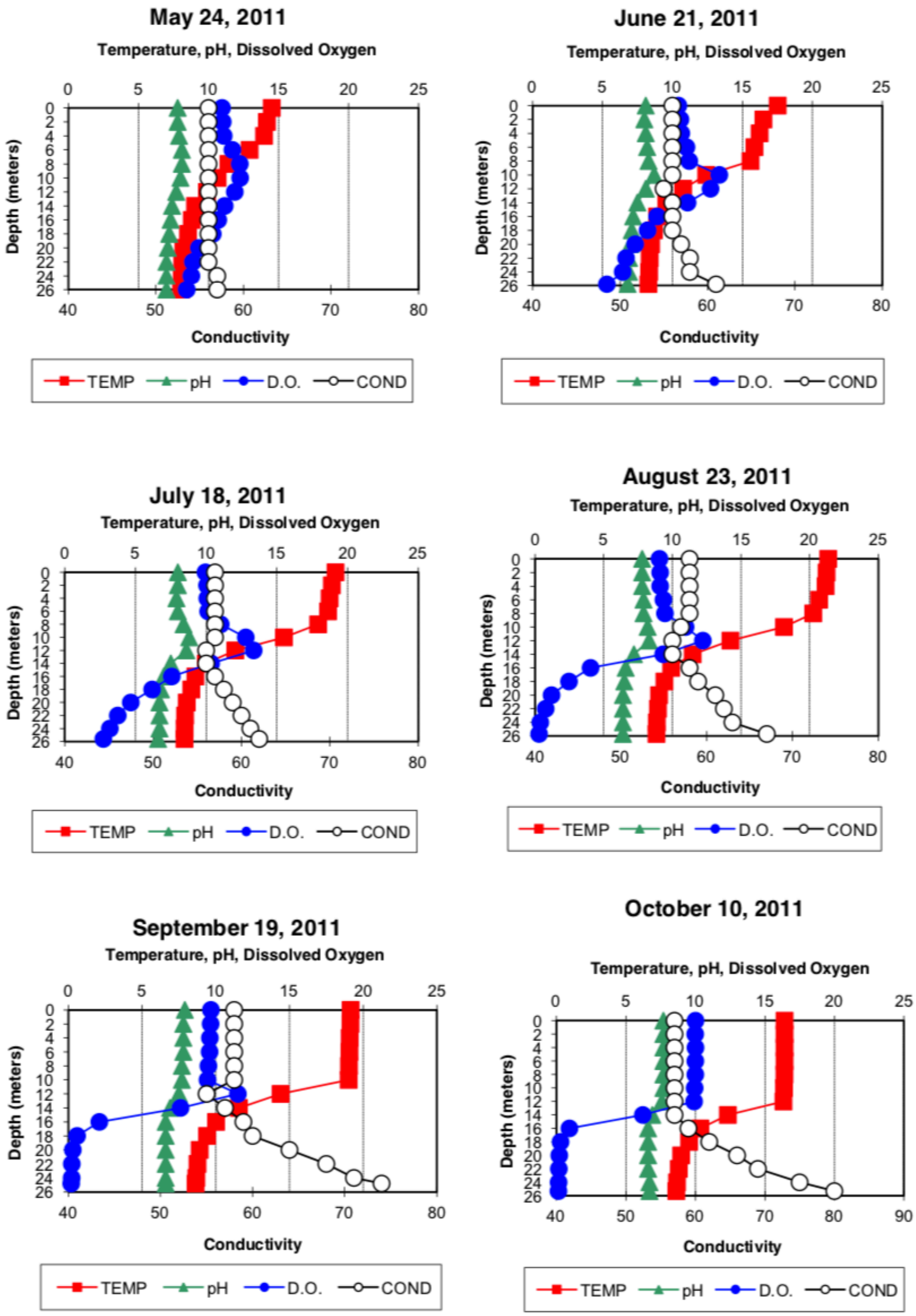

Figure 1) Summit Lake water monitoring by month at varying depths – Credit: *Thurston County Public Health and Social Services – Environmental Health water data web site.*

Lake Chemistry

With the basics of lake turnovers and seasonal water mixing in mind, we can now turn to the nutrients. Again, the county has some limited data for water chemistry but its spotty, summer-only focused, and sampling is reduced each time there is an algae bloom because the budget gets spent on measuring bloom toxicity instead of water quality.

That said, some of the data does help tell a story. Recall that phosphorous levels are closely related to water quality and less than 12ppb shows an oligotrophic (very clean) lake. Figure 2, below, shows the data (blue circles) from May through October for phosphorous at the surface of the lake. Pretty darn good numbers, even cleaning up as the summer goes along. This would seem to tell us there is nothing to worry about and nothing to do.

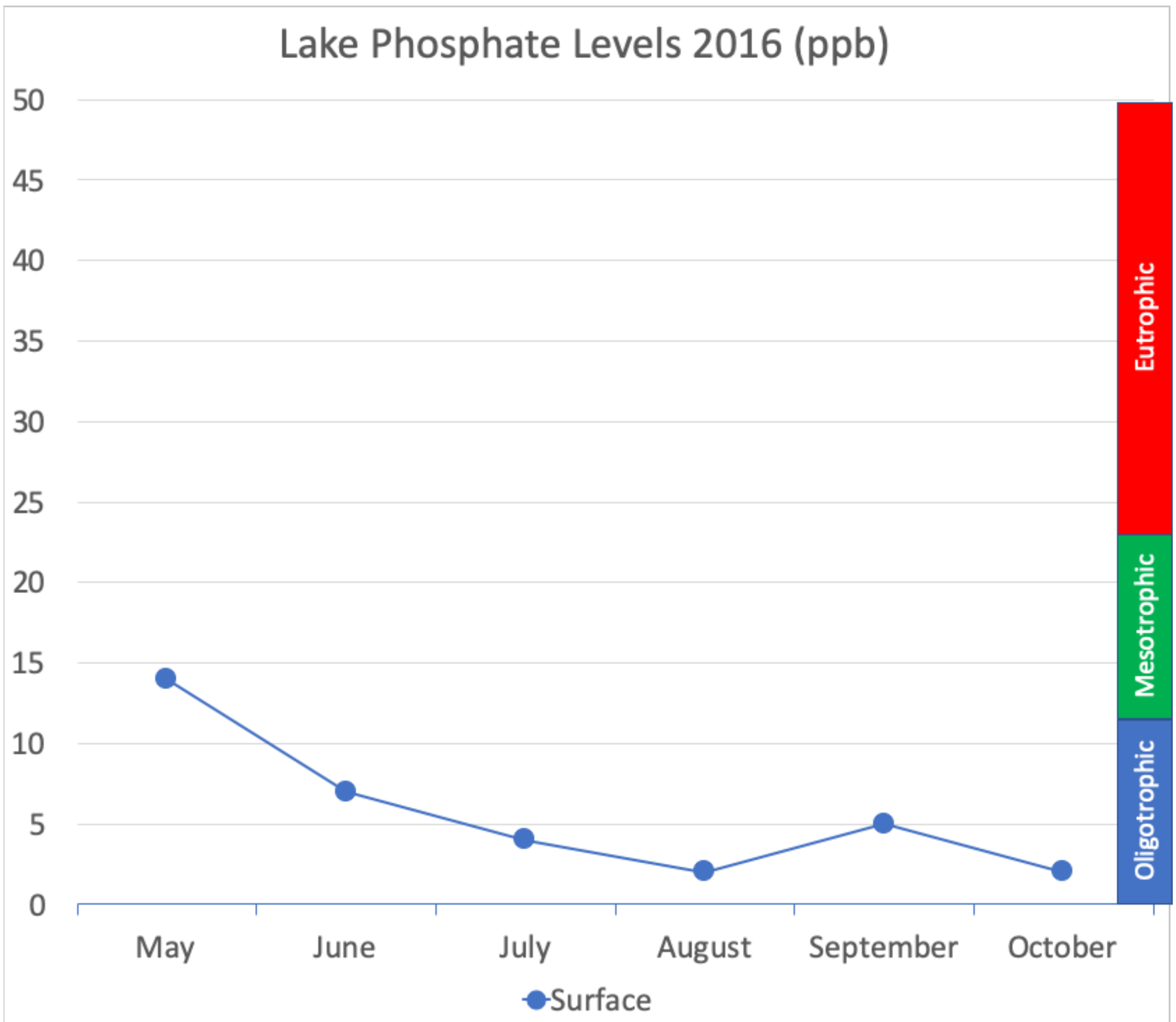

Figure 2 Summit Lake Phosphate levels by month at the lake surface – data from: *Thurston County Water Resources Annual Report - 2016*

Figure 3 adds the levels (orange squares) at the bottom of the lake. In the above section discussing lake physics, we saw the lake is pretty well mixed from top to bottom in May and June, but then we saw the lake stratified thru the summer and into the fall. The phosphate levels in Figure 3 confirm this is going on. The surface and bottom P values are identical in May and June, but start creeping up in July with a peak in September, with a bottom P value nearly 10X the surface P value.

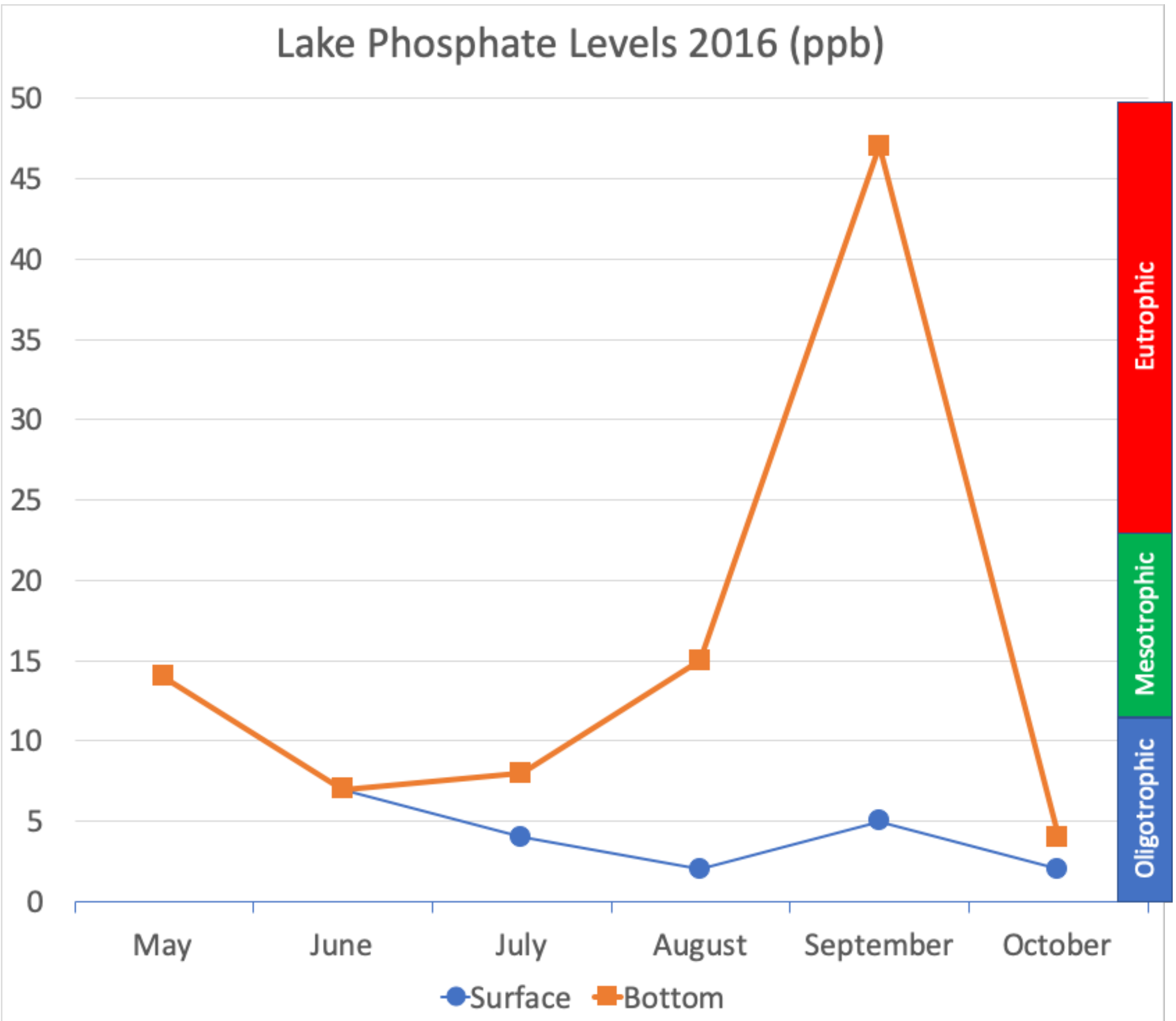

Figure 3 Summit Lake Phosphate levels by month at the lake surface and the lake bottom – data from: *Thurston County Water Resources Annual Report - 2016*

Septembers P value was 47 ppb. This is well into the Eutrophic level (24-96 ppb). Recall that this is characterized by: *Having a high amount of biological activity, "poor" water quality.* Of course there is no bloom at the bottom of the lake because there is very little sunlight, no oxygen, and very cool temperatures.

We can also see that October data is after the lake turnover and the fall bloom. Somewhere between the September and October data collection days, the lake turned over, all the bottom water and it's phosphorous was mixed with the warmer, oxygenated water from the top of the lake and now on the surface is exposed to sunlight, and the bloom occurs. Once the bloom consumes the P, and/or the lake cools off, and/or our clouds return, the cyanobacteria return to their less active state, waiting for the next time all the conditions are right for a bloom.

That next period will be in the spring, but again, we don't have the data to fingerprint the one (spring bloom vs fall) that has caused us more problems.

2016 was chosen as a typical year with a reasonably complete data set, other years data shows similar patterns.

<u>The Summit Lake Phosphorous Cycle</u>
In summary we are beginning to see the workings of the lake's cycles and why it does what it does.

There is a source of phosphorous that enters the lake, this occurs all summer long while the lake is stratifying and "storing" the P below the thermocline. When the fall turnover happens, all of the nutrients at the bottom are then mixed with warmer water with enough oxygen and sunlight to allow the cyanobacteria to bloom. This bloom continues until either the nutrients are used up, the lake gets cold, or the sun goes away for the winter. We see in figure 3 above October water quality is very good at the surface and the bottom and would NOT sustain a bloom (2-4 ppb = very Oligotrophic) while a good bit of the lake (everything below 12 meters) in September (47 ppb firmly in the Eutrophic range) was a significant nutrient source once the turnover occurred.

Our next task should be getting enough information to put the cycle together for the rest of the calendar year; November through April. This is the time leading to the spring bloom which seems to be more important than the May through October glimpse that we have.

<u>Conclusions</u>
No claims are made here as to the source of phosphorous, they all contribute some. But if we can find out which contributes most and then can control it, we can limit the extent of the blooms. Lake turnovers, algae blooms, etc… are all very much a part of nature and we won't change that. We should only worry about the parts we can control, and that's increased nutrients into the lake. Unfortunately, right now all we have are each person's different opinion about where its coming from. We also are in desperate need of more and better data from the lake. The county data is limited and while we were able to piece together a typical fall portion of the phosphorous cycle, that's only a small piece of the puzzle. The spring blooms have seemed to be the larger generator of toxicity and we are blind there with no lake water data. Better and more frequent data would also help us track any improvements or degradation we see in P levels in the lake as time progresses.

One of the conclusions from the U of Washington meetings a few years back was that we really needed to identify which species of cyanobacteria we had that was causing the toxins. There are over 2000 species of cyanobacteria; it would be a very useful first step to test the next several blooms for what we have. Perhaps the species has certain attributes that we can use to help our future plans. The county certainly has no resources to accomplish this, nor anyone actively tracking our lake water as their Job#1. The old adage of "you can't manage what you don't measure" certainly rings true here. Our next steps must be better, more extensive, more frequent data about the lake cycles, the cyanobacteria, and the sources of the nutrients that feed it all.

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